General Specifications

FOR

Concrete and Reinforced Concrete

INCLUDING

FINISHING AND WATERPROOFING

BY

JEROME COCHRAN, B. S., C. E., M. C. E.

Author of "Cement Specifications," "Inspection of Concrete Construction,"
"Principles of Municipal Refuse Collection and Disposal,"
"Inspection of Sewer Construction," "Principles
of Camp Sanitation," and Numerous
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PREFACE

CONSIDERABLE advance has been made in the past ten years in the design and construction of works involving concrete and reinforced concrete and the framing of specifications for that part of the work. Aside from the personal study and efforts of individual engineers, Special Committees from several national organizations have been appointed for the purpose of investigating current practice and providing definite information concerning the properties of concrete and reinforced concrete and to recommend necessary factors and formulas required in the design of structures in which these materials are used.

The American Railway Engineering Association appointed a Committee on Masonry on July 20, 1899, with instructions, as a part of its duties to prepare specifications for concrete masonry. A preliminary set of specifications for Portland cement concrete was reported to and adopted by the Association on March 19, 1903. At the meeting of the Executive Committee of the American Society for Testing Materials, held on December 5, 1903, a special committee on "Reinforced Concrete" was appointed. A Special Committee on Concrete and Steel-Concrete was appointed by the Board of Direction of the American Society of Civil Engineers on May 31, 1904. At the Annual Meeting, held on January 18, 1905, the title of this Special Committee was, at the request of the Committee, changed to "Special Committee on Concrete and Reinforced Concrete." At the first meeting of the Committee on June 17, 1904, it was decided to co-operate with similar committees which had been appointed by the American Railway Engineering Association and the American Society for Testing Materials through the organization of a Joint Committee on Concrete and Reinforced Concrete. The Joint Committee, at its first meeting on June 17, 1904, invited the Association of American Portland Cement Manufacturers to join in its deliberations through a committee appointed for the purpose. The National Association of Cement Users and other organizations have also been working along the same lines as the Joint Committee.

Two meetings of the Joint Committee were held in 1904, five in 1905, two in 1906, five in 1907, two in 1908, and one each in 1911 and 1912. In 1908 the "Special Committee on Concrete and Reinforced Concrete" of the American Society of Civil Engineers began the preparation of the Progress Report which was submitted to the Society in January, 1909. In the spring of 1911 the work of revising the 1909 Progress Report was taken up, and a number of meetings were held. The discussions submitted to the American Society of Civil Engineers and subsequent papers relating to the same subject were carefully considered, and the differences of opinion between members of the Committee were threshed out. Through the co-operation of the four societies represented on the Joint Committee, the report was again put in type, and the necessary editions were printed for the use of the members of the Committee, the last bearing the date of August 1, 1911. In the form thus reached, the report remained until November 20, 1912, when the Joint Committee again met and gave the final review needed to bring it into the shape in which it is now presented in the Proc. Am. Soc. C. E., vol. 39, pp. 117–168, February, 1913.

Under these circumstances it might be thought that there is no longer any pressing need for the continuance of individual efforts in this field, and it has been with some hesitation that the author has undertaken the publication of these "General Specifications for Concrete and Reinforced Concrete." Without venturing to criticize the work done by the above organizations, as well as others, it has seemed to the author that there is yet room for individual work in this field, if for no other reason than that there still remain quite divergent views not only as to the substance, but as to the form, scope and phraseology of specifications, and contributions based upon some knowledge and experience in concrete and reinforced concrete design and construction may not be without value in reaching final conclusions.

In the preparation of this book the endeavor has been to observe a logical order and a due proportion between different parts. Great care has been taken in classifying and arranging the matter. It will be helpful to the reader to notice that the book is divided successively into chapters, articles, sections and paragraphs. The constant aim has been to present the subject clearly and concisely. Every precaution has been taken to produce the work in a form for convenient use and ready reference. The table of contents shows the general scope of the book; and a very full index makes everything in the book easy of access. The preparation of this book has involved an immense amount of labor and the author hopes that its value to those engaged in preparing specifications for the design and construction of works involving the use of concrete and reinforced concrete may be in some slight degree commensurate to the labor involved.

Numerous but carefully selected references to articles in engineering periodicals and transactions containing specifications for concrete construction are made a prominent feature of this work. The main object in giving these references is to enable the student or young engineer to study the methods employed by others in drawing up concrete specifications.

Where it is possible to say so much, it is not easy to tell when to stop or when one has stopped short of saying all he should, and the author will not be surprised to find that he has erred at times in both respects. If those of his readers who discover such errors will tell him of them, the author will see that they are corrected. In fact, the author will be pleased to hear from any reader regarding any error, typographical or otherwise, found in this work, or any idea or suggestion that may be useful in a future edition; address the author, care of the publishers. By working together in this manner it will be possible to produce a set of specifications which will be of increasing influence toward good concrete construction, and this is the sole purpose of the author's work.

JEROME COCHRAN, C. E.

DETROIT, MICH., *August* 1, 1913.

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INTRODUCTION

THIS introduction is merely an elementary outline of the essential elements in concrete construction. The forming of concrete structures is essentially a manufacturing operation, and requires more close attention to detail both in the design and the building than most other classes of construction. In the following chapters the various divisions of the subject are treated in detail.

CONCRETE MATERIALS

Concrete is formed by a mixture of cement or lime mortar with any aggregate such as gravel, broken stone, cinders or broken brick, the whole forming a solid conglomerate mass of stone. Ordinary concrete is composed of cement, sand, gravel or crushed stone, or both, and water. In the specifications given in this book, in speaking of concrete, that formed from natural, Portland or Puzzolan cement will be understood unless otherwise stated in the immediate paragraph. In the chapter on concrete design Portland cement concrete will of course be understood.

Selection of Materials. — The selection of cement, sand, gravel or broken stone and water is largely dependent upon local conditions, and therefore no unalterable rule can be laid down in regard to it, but the following general conditions may serve as a rough guide.

Cement. — For ordinary masonry above ground subjected only to the influence of the weather and to moderate pressures, where the cement acts principally as a binding material, the same grade is not evidently required as for a high masonry dam where impermeability and resistance to crushing are the main requirements, or for a floor or sidewalk covering where hardness is the principal consideration, or for sewer and harbor works where impermeability and ability to resist the chemical action of sewage and sea water are of paramount importance. In other words, the exposure of the work to the weather or its protection from external conditions by position in the interior of piers or foundations or in rock or deep excavations under constant conditions of temperature, moisture, etc., will be prominent in deciding what specifications to adopt for the cement to be used.

For external work the conditions of variation in temperature, drainage, possibility of shocks, blows, vibrations, abrasions, appearance, etc., determine the grade of Portland cement to be used. In fact, it is a wise rule to use Portland cement for nearly all classes of concrete. It is the only cement that can be used for all kinds of concrete work.

In reinforced concrete, fireproofing or other combination structures, where the joint action of concrete with other materials is essential, other qualities than the tensile or compressive strength may make the decision.

The rate of setting is frequently a prime factor in making the decision, especially in sidewalks, curbs and facing work, and in structures under water.

Natural cement may be used in massive masonry where weight rather than strength is the essential feature, such as dry unexposed foundations with moderate compression. It may be used for sub-pavements of streets and for sewer foundations, for use in mortar for ordinary brickwork, and for ordinary stone masonry where the chief requisite is weight or mass. It should *not* be used in work under water, in marine construction, in columns, beams, floors, or other members subjected to severe or suddenly applied stresses.

Where economy is the governing factor, a comparison may be made between the use of natural cement and a leaner mixture of Portland cement that will develop the same strength.

Puzzolan or slag cement is not nearly as strong, uniform, or reliable as Portland or natural cement, is not used extensively, and is never used in important work. It is usually limited to use in sea water, generally to structures constantly exposed to moisture, such as foundations of buildings, sewers and drains, and underground works generally, and in the interior of heavy masonry or concrete. It is unfit for use when subjected to mechanical wear, abrasion, or blows, and should *never* be used where it may be exposed to the action of dry air for long periods. Under such conditions it will turn white and disintegrate, owing to the oxidation of its sulphides to the surface. The low strength, variable compositions, and certain properties of slag cement renders it undesirable for reinforced concrete structures.

Except for unimportant structures, the cement should be sampled and tested in a laboratory. It is generally safe to select in the open market a brand of Portland cement of American manufacture which has a first-class reputation, and to use it without testing, for ordinary structures. For important concrete construction, such as reinforced concrete buildings, etc., complete specifications should be prepared before purchasing the cement, and laboratory tests conducted to determine whether it is fulfilling the requirements. At any rate, even if the cement is not tested, it should always be purchased with the requirement that it must pass the specifications of the American Society for Testing Materials or those of the United States Government.

Cement may be had in cloth sacks, paper bags or wooden barrels. More commonly it is shipped in cloth sacks with an allowed rebate for the return of empty bags in good condition. Each bag of Portland cement weighs 94 pounds net and four bags constitute a barrel of 376 pounds. One bag of loose cement is practically equivalent to one cubic foot. On account of its sensitiveness to moisture, Portland cement must be carefully protected from dampness at all times, even when piled at the site of the work.

Sand. — The usual specification for sand requires that it be clean, coarse, free from loam, clay or organic matter. An idea of the cleanliness of sand may be obtained by placing it in the palm of one hand and rubbing it with the fingers of the other. If the sand is dirty, it will badly discolor the palm. Tests of sand for use in concrete work are as necessary as tests of the cement. Even a small amount of vegetable matter is detrimental. Sand containing it shows up irregularly. Such sand should prove satisfactory by tests before using. A practical test may be made by placing a four-inch depth of sand in a fruit-jar, and by adding water until the jar is within one inch of full and by shaking the contents vigorously. If, after the water has again become clear, there is a layer of mud more than one-fourth inch in thickness, the sand should not be used without first washing. Other methods of testing sand are described in the author's Treatise on the Inspection of Concrete Construction published by the Myron C. Clark Pub. Co., Chicago, 1913.

Sand for concrete should be clean and hard and should have grains grading in size from $\frac{1}{4}$ inch down. Pit and stream sands are generally of good quality, but drift sand is usually too fine of grain to make good concrete.

Washed sand may be less desirable than unwashed. Washing removes the fine particles as well as the foreign material. The fine grains, if not in excess, are needed to fill the voids of the larger. The only safe way to decide whether sand ought to be washed would be to test it under both conditions.

Fine sand, even if free from vegetable matter, makes a weaker concrete than coarse sand. A coarse sand, however, may show up poorly if there are too few fine particles to fill the voids. The best graded sand is one in which the grains held on a uniform series of sieves are so arranged that the voids in one lot are filled, and not overfilled, by the grains in the next smaller size, and so on. If a larger proportion of the grains is less than $\frac{1}{32}$ inch in diameter, nearly double the amount of cement will be required than with an equally clean sand having a uniform graduation up to $\frac{1}{4}$ inch, in order to obtain equal strength. Preference should therefore be given to sand containing a mixture of coarse and fine grains, with the coarse grains predominating.

Coarse Aggregate. — Either gravel or broken stone, or both, may be used for the coarse material of the aggregate. The maximum size of the coarse aggregate should be such that the concrete may be readily placed around the steel reinforcement and into the corners of the forms. The maximum size for reinforced concrete building construction is generally specified to be one and one-quarter inches.

The strength of the concrete is dependent on the strength of the stone, therefore only good hard dense stone should be used. Crushed trap rock or granite gives the best results. Broken dolomite and limestone are frequently used and give good results. Soft stone should be avoided in important structures. The broken stone should be clean and free from quarry refuse, stone dust, etc. If the broken stone contains dust, it should be uniformly distributed throughout the stone, and the proportion smaller than ¼ inch should be determined by test and considered as sand when proportioning. The use of shale, slate, and very soft limestones and sandstones should be avoided. The crushed rock should be screened only sufficiently to remove the fine dust.

The gravel should be of a hard dense rock and should be free from impurities, such as a coating of vegetable matter or clay, etc. If the gravel is dirty it should be washed with a hose before it is shoveled on to the mixing platform. In using gravel the proportions of stone and sand should continue uniform. Gravel which has been graded down from the largest stone to pebble size gives the most compact concrete. Bank-run gravel, just as dug from the pit or taken from the stream bed, seldom runs even and rarely has the proper proportions of sand and pebbles for making the best concrete. An ideal pit gravel is 40 per cent sand. Since there is generally too much sand in proportion to the pebbles, it is advisable and economical to screen the sand from the pebbles and then to remix them in the correct proportions. As a general rule, pebbles larger than one and one-quarter inches in diameter are discarded, especially in reinforced concrete building construction; all material smaller than ¼ inch is considered sand. Gravel should contain no rotten stone and should be clean.

Blast-furnace slag has been used to some extent for concrete, but owing to its porous nature, however, it takes about 30 per cent more cement and mortar than either sand or broken stone. Owing to the extreme variations in slags from different furnaces, the slag should by all means be investigated by a good testing laboratory. Some slags contain chemicals which are injurious to steel.

For fireproofing and for various other purposes requiring low stresses, cinder concrete is often used. The cinder should consist of hard, clean, vitreous clinker free from sulphides, unburned coal and ashes. A clean cinder will not discolor the palms of the hands when rubbed between them.

PROPORTIONS

Various proportions of cement, sand and broken stone or gravel are used, depending upon the use to which the concrete is put. Some engineers and contractors have a preference for one proportion and some for another, and it is foreign to the purpose of this introduction to argue as to the relative merits of the different mixtures, for the reason that the mixture in which all the spaces (voids) between the stone or gravel are filled with sand and all the spaces between the sand are filled with cement is the ideal mixture. This mixture is rarely obtained, as the voids in each load of gravel and sand vary slightly, and in order to be absolutely safe a little more sand and a little more cement than will just fill the voids are used. Any mixture of concrete may be strong provided the materials are uniformly distributed throughout the mass and it is so well tamped that all the stone and sand can be cemented together by the cement.

MIXING

After the materials are selected, the next step is to mix them properly and with dispatch. All concrete should be machine mixed, using a batch mixer. The materials should first be thoroughly mixed dry, after which plenty of clean water is added, so that the resultant mixture becomes what is known as a wet or mushy mixture. All mixing should continue until the concrete is uniform. The water should be measured, and when the proper consistency has been found use practically the same amount for each batch.

PLACING CONCRETE

After the concrete is properly mixed it should be placed at once. Concrete may be handled and placed by any means which will not cause the materials to separate. Concrete should be deposited in layers about 6 inches thick unless otherwise specified. Before placing a fresh layer upon work which has set, the surface must be cleaned of foreign matter and thoroughly wet.

Spading and joggling the sides of forms is necessary to obtain neat appearing surfaces.

Concrete after it has been poured must not be disturbed by walking or wheeling over same till it has thoroughly set.

The placing of concrete is discussed very fully in Chapter V, page 97.

FORMS

Forms must be true and rigid, properly braced and of sufficient strength to carry the dead weight of the construction as a liquid without deflection.

All joints must be tight enough to prevent mortar floating away and thereby leaving stone pockets. Cracks in the forms may be covered with sheet metal. The use of paper should be avoided.

Forms need but few nails unless they are built so that the pressure tends to separate them from the cleats. The skillful foreman may be recognized by the scarcity of nails he uses. Column boxes should be securely clamped and beam boxes so framed that the floor joists practically hold the sides without nailing.

Forms supporting reinforced concrete members must be left in place until the concrete rings sound and is of sufficient strength to carry its own weight together with whatever live load is liable to come on the construction. Care must be exercised in removing forms during freezing weather.

REINFORCING STEEL

All steel should be free from loose scales, but a thin film of rust is not considered objectionable. Bars covered with loose or scaley rust may be cleaned with a stiff wire brush.

Steel must be properly placed, wired and otherwise held in exact position called for on plans. This is of vital importance and should be looked after with the utmost care and checked over just before pouring the concrete.

All ordinary bending should be done cold and the bending force applied gradually and evenly and not with a jerk. A jerky action, especially on large bars, is likely to snap or crack the best steel.

FINISHES FOR CONCRETE SURFACES

Concrete as a structural material, either in mass work or in blocks, or as a surface layer or coating, permits of surface finishes which are pleasing to the eye and distinctive to concrete alone. Where attempt at imitation is a minimum, the main objects of surface finish are to remove discolorations, surplus cement, hair cracks, or blemishes, and to provide a uniform surface more or less decorative in nature. The problem met with early in the use of concrete was to do away with the effect of variation in color between different layers, to remove blemishes from the surface and to provide something which would offset that dull-colored, monotonous surface which seemed so objectionable to many. Concrete workers in general have gradually added information regarding treatment of concrete surfaces, until the artistic prejudice has been largely overcome.

If the reader has condemned concrete on account of its color, its monotonous or uninteresting appearances, or its lack of artistic possibilities, it is hoped that the methods of treatment specified in Chapter VI, page 135, may serve to change his point of view, and also to stimulate an interest among workers in concrete in discovering other methods whereby this valuable building material may receive just treatment from the public at large.

WATERPROOFING CONCRETE WORK

Specifications for waterproofing given in Chapter VII, page 149, are quite general in their nature and will very likely require changing to suit the conditions surrounding a particular job. There is a distinction between damp-proofing and waterproofing. Where dampness only is to be contended with, it is needless expense to install a waterproofing system. For damp-proofing purposes, oftentimes a good "wash" will answer the purpose, and in some cases carefully mixed concrete is sufficiently impervious to withstand dampness. On the other hand, waterproofing results can never be obtained by damp-proofing methods. Waterproofing will answer for damp-proofing, but damp-proofing will not answer for waterproofing.

Integral Method. — Theoretically, the introduction of foreign ingredients, i.e., the mixture of some compound with the concrete itself, to make concrete impervious to water, should bring good results, but in practice the doubtful effect which these compounds have upon the cement, the liability of destroying the bonding properties of the concrete, introduce an element of danger and uncertainty which is most unsatisfactory for the engineer to consider.

Assuming a proper compound or mixture could be devised and selected, there is always the possibility of a slight settling and consequent cracking of the concrete. No matter how slight this settling is, water under pressure needs only the smallest crack to start a formidable opening.

Coating Surfaces. — Waterproof cement mortar coatings and washes applied to the inner surface of the concrete necessarily afford the advantage of easy repairs, but they afford the disadvantage of allowing the structure to become completely saturated up to the waterproof layer. The reinforcement is also subjected to unnecessary contact with water, causing rust. Likewise, if the protecting layer, that is, on the inside surface, be injured, water is directly back of it, ready to percolate through to the inside of the structure.

All efficient waterproofing is dependent, to a large extent, upon the quality of workmanship in its application. To withstand water pressure, the use of a mortar coating requires a perfect bond between the protecting layer and the concrete. To effect this, the surface of the concrete must be very carefully prepared. The chance of error is greater in this case than in a method where the waterproofing is accomplished by the membrane method, i.e., by means of fabrics lapped and cemented in successive layers. In the first case careless workmanship may be responsible for the lack of a perfect bond and the protecting layer of plaster or wash scaling off offers a weak point in the defense against water pressure.

Membrane Method. — The elastic membrane placed outside the foundations successfully meets every waterproofing requirement. The elastic membrane is composed of felt and cementing compound permanently elastic, built up by successive layers; the number varying according to the water pressure. The elastic limit and tensile strength should of course be such that shocks and the tension due to foundations settling can be taken care of without the cracking or tearing of the membrane.

Generally speaking, the elastic membrane method is the most expensive of all; — the most expensive compared with other waterproofing methods, but all waterproofing methods are infinitesimal in cost compared with the total cost of the structure which they are designed to protect.

The durability of the elastic membrane depends upon the fabric used, upon the number of layers, upon the compound with which the various layers are fastened together, and upon the care exercised in application. Great care should, therefore, be used in the choice of the felts and compounds which compose the membrane. The number of layers of felt required depends entirely upon the water pressure and the conditions of the work.

DESIGN OF REINFORCED CONCRETE

For reinforced concrete work, such as beams, floors, light walls, roofs, bridges, arches, etc., an engineer should be called upon to design the dimensions and reinforcement.

The general theory is the same for all systems of reinforced concrete construction, namely, that all transverse or lateral strains affect the material the same as such strains affect a beam; that is, by placing the fibers or material on the side from which the force is acting under compression and on the opposite side under tension.

As the concrete is an exceptionally good material for compression it needs no reinforcing upon the compression side, but as it is a poor material for tension, metal tension members are inserted upon the tension side. The systems of reinforced concrete may be divided into three classes, first, those that use expanded metal, second, those that use wire mesh and third, those that use iron or steel bars in some one of the various forms. Of the third class, nearly every conceivable shaped bar is used — flat, round, square, twisted and special rolled shapes or deformed bars.

More detailed information concerning the design of reinforced concrete structures will be found in Chapter VIII, page 164.

SCOPE OF THE SPECIFICATIONS

The following " General Specifications for Concrete and Reinforced Concrete " are intended as outlines to aid in the construction of specifications for individual cases. It is not expected that these specifications will be followed in detail or without elaboration for all classes of work, but they are presented with the hope that in their proper use consulting engineers, architects and others called upon to get out specifications containing concrete requirements may be relieved of some of the petty details accompanying such work, though important, is too often neglected on account of its tediousness and the time it consumes.

It is not intended to present to the student forms which he is to copy, but so to direct him that he may be able to intelligently prepare a specification adapted to work on which he may later be engaged. In this, as in all other parts of his work, he must study not only his own work but the methods of others.

Though it is expected that these specifications will be found sufficiently full and explicit for most requirements, yet in some instances a careful study must be made, for reasons which will suggest themselves, of the surrounding conditions and limitations and the specifications modified in accordance therewith.

CONCRETE AND REINFORCED CONCRETE

CHAPTER I

CONCRETE MATERIALS

Art. 1. Cement

The matter contained in this article has been taken largely from the author's book on "Cement Specifications," published by D. Van Nostrand Company, N. Y. City, 1912.

1. General Requirements

1. **In General.** — The cement shall be a first-class Portland cement (unless otherwise specified) of a standard brand made by a manufacturer of established reputation, and shall meet the following requirements.

2. **Brand to be Approved.** — Before any cement will be allowed to be used, the brand and name of the maker must be submitted to and receive the approval of the Engineer, and no cement will be permitted to be used that is not in all respects satisfactory to him. It is understood that such approval merely covers the selection of the brand; that the cement itself may be rejected if it fails to meet the requirements herein specified.

3. **Use Limited to One Brand.** — Only one brand of cement shall be allowed upon the works, except by special permission of the Engineer.

4. **Packages.** — The cement shall be packed in strong cloth or canvas sacks which shall be plainly marked with the brand and name of the manufacturer and shall in all cases be in original packages. The cement shall be furnished in unbroken packages; it must show no signs of damage from moisture or other causes, such as caking, lumpiness or other defects. Packages received in broken or damaged condition may be rejected or accepted as fractional packages, at the option of the Engineer.

5. **Weight.** — Each bag shall contain not less than 94 pounds, net, of cement, four sacks of Portland or three sacks of Natural cement being equivalent to one barrel. The weights of the separate packages shall be uniform.

6. **Storing.** — In order to allow ample time for the inspection and testing of cement, it shall be stored in a suitable house or houses provided by the Contractor for that purpose. The houses shall be sufficiently large so

that the different lots of cement can be kept separate and readily accessible. The floor shall be raised above the ground so as to keep the cement dry, and the sides and roof shall be water-tight to protect the cement from rain or the injurious effects of the elements. The cement shall be stored in such manner as to permit easy access for proper inspection, sampling and identification of each shipment. No cement shall be used that has not been in the storehouse for at least two weeks.

7. **Inspection and Tests.** — All cement used on the work shall be subject to inspection and such rigorous tests as shall be ordered by the Engineer, and the Contractor shall provide every facility to assist in the inspection and sampling of the cement for testing, repeated as many times as are deemed necessary by the Engineer.

Tests may be made both at the place of manufacture or storage, and at the site of the work if the Engineer deems wise, and he shall have the liberty at all times to inspect the materials, process of manufacture and daily laboratory records of analyses and tests at the cement works.

8. **Rejection of Cement.** — When used in the work, the cement shall be free from lumps and partially or wholly set cement, and in all respects satisfactory to the Engineer. Cement found at any time to be unsatisfactory — before, during or after its placing in the work — shall be subject to rejection, even to the extent of taking down masonry or other work in which unsatisfactory cement may have been used. Cement rejected on the work shall be immediately removed from the site.

2. Test Requirements

9. **In General.** — All tests shall be made in accordance with the methods proposed by the Special Committee on Uniform Tests of Cement of the American Society of Civil Engineers, presented to the Society on January 17, 1912, with all subsequent amendments thereto. The acceptance or rejection shall be based on the requirements named below.

(a) *Portland Cement*

10. **Definition.** — Portland cement shall be defined as the finely pulverized product, resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials, and to which no addition of other material greater than three per cent (3%) has been added subsequently to calcination.* No slag puzzolan, sand or mixed cements will be accepted under this classification.

11. **Fineness of Grinding.** — All cement shall be finely ground, so that 100 per cent shall be passed through a sieve of 20 by 20 meshes per square inch.

* Portland cement has a definite chemical composition varying within comparatively narrow limits.

At least 99 per cent shall pass through a sieve of 50 by 50 meshes per square inch.

At least 92 per cent shall pass through a sieve of 100 by 100 meshes per square inch.

At least 75 per cent shall pass through a sieve of 200 by 200 meshes per square inch.

12. Specific Gravity. — The specific gravity of the cement, thoroughly dried at 100° C., shall not be less than three and ten one-hundredths (3.10).

Should the test of cement as received fall below this requirement, a second test may be made on a sample ignited at a low red heat. The loss in weight of the ignited cement shall not exceed 4 per cent.

13. Time of Setting. — The time of setting shall be determined with neat cement paste of normal consistency by the Vicat needle. The setting shall not commence before thirty (30) minutes, nor terminate in less than one (1) hour nor more than ten (10) hours.

14. Tensile Strength. — Briquettes one (1) square inch in cross-section, made of normal consistency and kept twenty-four (24) hours in moist air and the remaining time in water at normal temperature, 70° F., shall show at least the following strength as determined from an average of five specimens:

(*a*) *Neat Cement.*

Age.	*Strength.**
24 hours in moist air	175 lbs.
7 days (1 day in moist air, 6 days in water)	450 lbs.
28 days (1 day in moist air, 27 days in water)	550 lbs.

(*b*) *One Part Cement, Three Parts Sand.*

Age.	*Strength.*
7 days (1 day in moist air, 6 days in water)	150 lbs.
28 days (1 day in moist air, 27 days in water)	250 lbs.

(*c*) *One Part Cement, Three Parts Sand.*

Age.	*Strength.*
7 days (1 day in moist air, 6 days in water)	110 lbs.
28 days (1 day in moist air, 27 days in water)	180 lbs.

The sand for test (*b*) shall be standard Ottawa sand,† which shall pass a 20 by 20-mesh sieve and be retained on a 30 by 30-mesh sieve.

* The American Society for Testing Materials gives the minimum requirements as follows: Neat cement — 24 hours, 150–200 lbs.; 7 days, 450–550 lbs.; 28 days, 550–650 lbs. 1:3 mortar — 7 days, 150–200 lbs.; 28 days, 200–300 lbs.; the exact values to be fixed in each case by the consumer. If no minimum strength is specified the mean of these values is to be taken as the minimum strength required.

† A natural sand obtained at Ottawa, Ill., passing a screen having 20 meshes and retained on a screen having 30 meshes per lin. in.; prepared and furnished by the Ottawa Silica Company, for 2 cents per lb., f.o.b. cars, Ottawa, Ill., under the direction of the Special Committee on Uniform Tests of Cement of the American Society of Civil Engineers.

The sand for test (*c*) shall be taken by the Engineer from that used on the work and is intended as a test of the mortar.

15. Failure of Briquettes to Pass Tests. — Should the briquettes from a slow-setting cement fail, by a slight amount, to pass the twenty-four (24) hour or seven (7) day requirements for neat cement only, the lot in question will be held awaiting the results of the twenty-eight (28) day briquettes. Should the results of the seven (7) day tests on both neat and mortar briquettes fall below the requirements stated herein, the shipment will be rejected. If the strength of the twenty-eight (28) day mortar briquettes on a lot held awaiting the results of the twenty-eight (28) day neat briquettes does not show at least a ten per cent (10%) increase over the strength shown by the seven (7) day mortar briquettes, the lot will be rejected, even if the briquettes show a strength as herein required.

16. Constancy of Volume or Soundness. — Circular pats of neat cement paste, three (3) inches in diameter, one-half (½) inch thick at the center and tapering to a thin edge, shall be kept in moist air for twenty-four (24) hours.

(*a*) A pat shall be kept in air at normal temperature for twenty-eight (28) days.

(*b*) Another pat shall be kept in water maintained as near 70° F. as practicable for twenty-eight (28) days.

(*c*) A third pat shall be exposed to steam above boiling water in a loosely closed vessel for five (5) hours.

To pass the requirements, these pats shall remain firm and hard, and show no signs of distortion, checking, cracking or discoloration or disintegration.

17. Failure of Pats to Pass Tests for Soundness. — In case the pats exposed to steam, on a lot of cement otherwise satisfactory, show signs of failure, two more pats shall be made. If one of the extra pats fails after exposure to steam the lot will be held for twenty-eight (28) days and resampled. If both of the additional pats are sound the lot may be accepted. In case a lot is held for resampling at the end of twenty-eight (28) days because of failure of the steam pats, the lot must pass every requirement on the second sampling or it will be immediately rejected.

In case the normal pats on a lot of cement held awaiting the results of the twenty-eight (28) day briquettes show signs of disintegration, the lot will be rejected, even if it passes the other requirements.

18. Chemical Composition. — The cement shall not contain more than one and seventy-five one-hundredths per cent (1.75%) of sulphuric anhydride or anhydrous sulphuric acid (SO_3), nor more than four per cent (4%) of magnesia (MgO). It shall contain no adulteration nor excess of ingredients, which, in the opinion of the Engineer, shall render it unfit for use in the work.

The chemical composition of the cement shall also be within the following limits:

Silica	21 to 24 per cent
Alumina	5 to 10 per cent
Iron oxide	2 to 4 per cent
Lime	60 to 65 per cent
Alkalies	not more than 3 per cent

But in certain cases where such amounts of these substances are objectionable the Engineer may specify lower percentages.

The cement shall not contain an excess of free lime.

19. **Microscopic Test.** — The cement shall show no signs of the presence of a detrimental amount of uncombined magnesia as indicated by the microscopic test.

20. **Color.** — The color shall be a uniform bluish gray, free from yellow or brown particles.

(*b*) *Natural Cement*

21. **Definition.** — Natural rock cement shall be defined as the finely pulverized product resulting from the calcination of an argillaceous lime stone at a temperature only sufficient to drive off the carbonic acid gas.* No slag, puzzolana, nor sand cement will be accepted under this classification.

22. **Fineness of Grinding.** — Cement shall be finely ground, so that not more than ten per cent (10%) by weight shall remain on a sieve of 100 meshes per lineal inch, made of No. 40 wire, Stubb's gauge, and thirty per cent (30%) on a sieve of 200 meshes per lineal inch.

23. **Specific Gravity.** — The specific gravity of the cement, thoroughly dried at 100° C., shall not be less than two and eight-tenths (2.8).

24. **Time of Setting.** — The time of "initial set" shall not occur in less than ten (10) minutes, and it shall reach its "final or hard set" in not less than thirty (30) minutes, or in more than three (3) hours. The time of setting shall be determined by means of the Vicat needle from pastes of neat cement of normal consistency, the temperature being between 60° and 70° F.

25. **Tensile Strength.** — Briquettes of cement, with one (1) square inch of cross-section, shall develop the following ultimate tensile strength as determined from an average of five specimens:

Age. *Neat Cement.*	*Strength.*†
24 hours in moist air	75 lbs.
7 days (1 day in moist air, 6 days in water)	150 lbs.
28 days (1 day in moist air, 27 days in water)	250 lbs.

* Although the limestone must have a certain composition, this composition may vary within much wider limits than in the case of Portland cement. Natural cement does not develop its strength as quickly, nor is it as uniform in composition, as Portland cement.

† See footnote on page 6.

Age.	One Part Cement, Two Parts Standard Sand.	Strength.
7 days	(1 day in moist air, 6 days in water)	120 lbs.
28 days	(1 day in moist air, 27 days in water)	175 lbs.

Age.	One Part Cement, Three Parts Standard Sand.	Strength.*
7 days	(1 day in moist air, 6 days in water)	50 lbs.
28 days	(1 day in moist air, 27 days in water)	110 lbs.

For all tests with sand, standard Ottawa sand, which will pass a No. 20 sieve and remain on a No. 30 sieve, shall be used.

26. Constancy of Volume or Soundness. — Circular pats of neat cement paste three (3) inches in diameter, one-half (½) inch thick at the center and tapering to a thin edge, shall be kept in moist air for twenty-four (24) hours.

(*a*) A pat shall be kept in air at normal temperature for twenty-eight (28) days.

(*b*) Another pat shall be kept in water maintained as near 70° F. as practicable for twenty-eight (28) days.

These pats shall remain firm and hard, and show no signs of distortion, checking, cracking, discoloration or disintegration after twenty-eight (28) days in either air or water.

27. Boiling Test. — A boiling test may also, at the option of the Engineer be required, to be made by mixing pats as above, placing them at once in cold water, raising the temperature of the water to boiling in about an hour, continuing boiling for three hours, then examining for checking and softening.

(*c*) *Puzzolan or Slag Cement*

28. Definition. — This term shall be applied to the finely pulverized product made by grinding together without subsequent calcination granulated blast-furnace slag with hydrated lime. Although often sold under the name of Portland cement and available for many of the same processes, it is not a true Portland cement according to the accepted definitions given.

29. Fineness of Grinding. — Cement must be finely ground, so that at least ninety-seven per cent (97%) shall pass through a sieve of 100 by 100 meshes per square inch made of No. 40 wire, Stubb's gauge.

30. Specific Gravity. — The specific gravity of the cement, thoroughly dried at 100° C., shall be between 2.7 and 2.8.

31. Time of Setting. — The time of "initial set" shall not occur in less than forty-five (45) minutes, and shall acquire its "final set" in ten (10) hours. The time of setting shall be determined by means of the Vicat

* The American Society for Testing Materials gives minimum requirements as follows: Neat cement — 24 hours, 50–100 lbs.; 7 days, 100–200 lbs.; 28 days, 200–300 lbs. 1 : 3 mortar — 7 days, 25–75 lbs.; 28 days, 75–150 lbs.; the exact values to be fixed in each case by the consumer. If no minimum strength is specified the mean of these values is to be taken as the minimum strength required.

needle from pastes of neat cement of normal consistency, the temperature being between 60 and 70° F.

32. **Tensile Strength.** — Briquettes of cement, with one (1) square inch of cross-section, shall develop the following ultimate tensile strength as determined from an average of five specimens:

Neat Cement.

Age.	*Strength.*
7 days (1 day in moist air, 6 days in water)	350 lbs.
28 days (1 day in moist air, 27 days in water)	500 lbs.

One Part Cement, Three Parts Standard Sand.

Age.	*Strength.*
7 days (1 day in moist air, 6 days in water)	130 lbs.
28 days (1 day in moist air, 27 days in water)	220 lbs.

For all tests with sand, standard Ottawa sand, which will pass a No. 20 sieve and remain on a No. 30 sieve, shall be used.

33. **Constancy of Volume or Soundness.** — Circular pats of neat cement paste three (3) inches in diameter, one-half (½) inch thick at the center and tapering to a thin edge, placed on a glass plate, shall not show any signs of warping or cracking after twenty-eight (28) days in water.

34. **Weight.** — The average weight per barrel shall not be less than 330 pounds net. Four sacks shall contain one barrel of puzzolan cement.

Art. 2. Sand, Broken Stone and Gravel

1. General Requirements

35. **Selection of Aggregates.** — Concrete will, in general, consist of a matrix of cement mortar and an aggregate of broken stone or gravel, or a combination of broken stone and gravel. Every possible precaution shall be used in the selection of materials which go into the concrete. While the selection is ordinarily governed by the materials obtainable in the locality, careful consideration shall be given to the character of the work and the desired qualities in the finished construction. Local materials shall be carefully tested and not employed if found unsuitable, unless their inferior quality is taken into account in designing the structure. The materials used shall give uniform character and color to any structure or group of structures.

36. **Specifications for Aggregates.** — Specifications for aggregates shall stipulate the kind, the mineral nature of the particles, the size and shape of the particles, the cleanliness, the amount of voids and whether or not it shall be screened. The aggregate should vary in size as much as possible between the limits of size allowed for the work.

37. **Excavated Materials for Aggregates.** — Aggregate material may be obtained from the foundation and by wash excavation. In regards to the

use of materials from the foundation and by wash excavations, the Contractor will understand that the intention is to carefully utilize all local material so far as the same may be found available when the excavations are fully opened up. The uncertainty as to just how the excavated material will work renders it impossible to decide in advance the proportion of concrete that may be used in the work.

Sand obtained from the excavation will not be accepted unless permission in writing is given by the Engineer.

38. **Screens.** — The Contractor shall provide screens for ascertaining the proportion of materials of various sizes produced by the crusher, in order to enable the Engineer to determine the necessary proportion of sand in the concrete, and he shall at intervals, when required, make such tests as may be necessary for this purpose without extra charge.

39. **Screening Material from the Run of the Crusher or Bank.** — In screening the material, three screens shall be used (unless otherwise specified), namely, one with 2-inch mesh clear opening, one with $\frac{3}{4}$-inch mesh, and one sand screen, the size of mesh to be satisfactory to the Engineer. All material not passing the 2-inch screen will be rejected. All passing the 2-inch and retained on the $\frac{3}{4}$-inch screen will be used if suitable in other respects. All material passing the $\frac{3}{4}$-inch screen and retained on the sand screen to be used when and where ordered by the Engineer. The material passing the sand screen may be used for sand if considered suitable by the Engineer.

It is expected that practically the entire run of the crusher will be used in the concrete work, but if the stone is of such a character as to give too great a proportion of either size as above outlined, the Contractor may be required to change the crusher jaws or method of separation of the sizes to accomplish this result.

40. **Use of Material without Screening.** — If it is suitable for the purpose, material direct from the crusher or bank may be used without screening and subsequent mixing, but only with the permission of the Engineer.

41. **Impure Sand or Gravel.** — Impure sand or gravel may be used provided the impurities be removed by washing, to the satisfaction of the Engineer. The right is reserved, however, to reject any loads of which any part may not be up to the requirements.

42. **Washing Sand or Gravel.** — Sand or gravel for small jobs may be washed in almost any type of batch concrete mixer by simply revolving the mixer and letting the hose play inside without stopping. When the mixer overflows the water will carry off the foreign matter. For large jobs of sand or gravel washing other arrangements shall be made subject to the approval of the Engineer.

43. **Platforms.** — Platforms shall be provided upon which all sand, gravel and broken stone shall be placed when brought upon the line of

the work, and kept there until used, and any not so placed will be rejected.*

44. **Protecting Material.** — No travel or vehicles of any kind, other than the Contractor's, must be allowed to pass over any broken stone, sand or gravel, otherwise it will be rejected, and must be removed.

45. **Samples of Aggregate.** — Samples of the sand, broken stone and gravel proposed to be furnished shall be submitted with each bid and retained in the office of the Engineer as a standard for comparison during the progress of the work. Such samples are to indicate the arrangement the bidder proposes to use, by one of the poorest quality and one of the best in each class, with the understanding that the material furnished is to run between the two so that the average of the material furnished will be practically the average of the samples. All samples shall be plainly and neatly labeled with place from which taken, where proposed to be used, date and name of collector.

46. **Owner Furnishing Sand and Gravel.** — The Owner or City has made a contract for the gravel and sand needed for the concrete construction and the same will be charged to the Contractor at cost. A copy of the contract is appended to this specification showing the assortments.

2. Sand, Crushed Stone and Gravel Screenings

47. **In General.** — Fine aggregates shall consist of sand, crushed stone or gravel screenings. Good sand and screenings being an important element in the making of a good concrete, the following characteristics shall be required. *Fine aggregates shall always be tested.*

48. **Quality.** — The sand should consist of grains of any moderately hard rock that is perfectly sound. Any sand showing any indications of chemical decay shall be unconditionally rejected.

49. **Quartz Sand.** — Preference will in all cases be given to quartz sand. Sand formed from other stone than quartz may be used only by special permission when quartz sand is not available.

50. **Sea Sand.** — Sea sand, if used, should be freed from salt, or the concrete will effloresce. † When sea sand is used for plastering or any work where the salt is liable to come to the surface and show, it shall be thoroughly washed.

51. **Selection between Round and Angular Grains.** — In the event of selection between round or angular grains, preference shall be given to the round-grained sand, as it packs more closely, affords no opportunity for bridging and gives minimum percentage of voids.

52. **Size of Grains.** — The sand shall be well graded from coarse to fine so that when mixed with the cement required will produce a dense and

* Specifications, especially for street pavements, should contain this requirement and it should be enforced. When sand, broken stone or gravel are deposited directly upon the earth, it is difficult to avoid taking up earth and mud with the materials, especially when the street is wet and muddy.

† In Marine reinforced concrete construction this objection does not apply, and sea sand is almost invariably used. Salt does not affect the strength.

compact mortar. That is to say, the sand shall consist of a mixture of coarse and fine grains with the coarse grains predominating. The largest grains shall pass when dry a screen of ¼-inch mesh, and in such proportion that the voids, as determined by saturation, shall not exceed 33 per cent of the entire volume. Not more than 6 per cent of fine aggregate shall pass a sieve having 100 meshes per lineal inch.

Fine sand shall be avoided (it is difficult to mix evenly and this generally leads to poor results). Sand shall not contain an unreasonable amount of coarse particles. The ideal rule in proportioning the sand is that the coarser grains shall be twice the fine including the cement.

53. **Foreign Matter.** — The sand shall be free from quick sand, clay, loam, mica, sticks, organic matter and other impurities. The sand may be moist but not wet. Under no circumstances shall sand contain more than three (3) per cent of perishable matter, nor enough clay or loam to render it unsuitable, in the opinion of the Engineer. The sand may contain occasional pieces of small gravel. Sand containing mica shall be rejected. No sand shall be used for the outside finish of any concrete which contains small particles of coal or lignite, although sand of this character may be accepted for foundation concrete, or for the interior portion of heavy pieces of concrete work.

Note. — Some engineers require that sand shall not contain clay or loam to the extent of more than one-half (½%) per cent when used for reinforced concrete work and shall be absolutely free from any other foreign matter. An addition of clay and (so-called) loam to sand, however, has been found in many instances to produce an actual increase in strength. The supposition is that it is because of the voids being more perfectly filled than if the sand was clean and sharp.

54. **Mesh Composition of Sand.** — The mesh composition of sand shall be such that at least sixty (60) per cent by weight shall pass a twenty- (20) mesh screen, nor more than eighty-five (85) per cent shall pass a fifty- (50) mesh screen, and not more than fifteen (15) per cent shall pass an eighty- (80) mesh screen.

55. **Mesh Composition of Crusher Dust.** — If crusher dust be used, its physical qualities and mesh composition shall conform to the same requirements as prescribed for sand.

56. **Color.** — All sand used in concrete that will be exposed to view shall be of a bright uniform color and satisfactory, in this as in all other respects, to the Engineer.

57. **Screenings as a Substitute for Sand.** — Screenings from crushed stone containing all the dust of fracture shall not be used as a substitute for sand, without the permission of the Engineer.

58. **Crusher Dust or Screenings.** — Crusher dust, passing a ¼-inch screen, from broken stone or gravel, may be substituted for a part or all of the sand provided the product thus obtained passes the prescribed require-

ments for natural sand. If the product of the crusher is delivered to the mixer so regularly that the amount of dust (as determined by frequently screening samples) is uniform, the screening may be omitted and the average percentage of dust allowed for in measuring the sand.

59. **Tensile Strength.*** — Mortars composed of one (1) part of Portland cement and three (3) parts of fine aggregate by weight when made into briquettes should show a tensile strength of at least 70 per cent of the strength of 1 : 3 mortar of the same consistency made with the same cement and standard Ottawa sand. To insure uniformity, these tests should be continued at intervals of 7 days, 28 days, and three months both in the natural state and after washing the sand. If the natural sand gives higher tensile strength, washing can be dispensed with.

60. **Samples.** — The Contractor shall, before placing any orders for sand, crushed stone or gravel screenings, submit samples of what he proposes to use to the Engineer, who will test such samples; and if they pass the requirements as noted above, orders may be placed. Samples of sand, of about one quart, shall be submitted in glass jars with stoppers.

On all large and important structures it is absolutely essential that samples of sand be submitted to the Engineer for test before same is used in the work. (See Par. 45.)

61. **Testing Sand.** — Sand shall be tested for foreign matter, for adhesion of cement, for crushing resistance and also for fire resistance when used in building construction. In sampling the sand, care shall be used to obtain an average sample.

62. **Storage.** — The approved sand, crushed stone or gravel screenings when brought to the job must be stored on a board platform or in bins in such a way that it will be clean and free from foreign matter when ready for use. The sand or screenings shall be delivered and stored where directed by the Engineer. (See Pars. 43 and 44.)

63. **Washing.** — If the sand delivered on the works does not at all times conform to the degree of cleanliness required, namely less than 3 per cent of loam or clay, it shall be washed for such length of time as may be necessary to render it acceptable.† (See Par. 42.)

64. **Screening Sand.** — When used for mortar, the sand shall be screened of all particles inconsistent with the character of the work.

65. **Rejection.** — In all cases the Engineer shall decide as to whether any sand offered by the Contractor shall be used on the work. At any time, however, if the sand, crushed stone or gravel screenings delivered does not fully meet the requirements as stated above, it will be rejected. Any sand or screenings showing signs of disintegration shall be unconditionally

* The value of a sand cannot always be judged from its appearance, and tension tests, of the mortar prepared with the cement and the sand proposed, should always be made for reinforced concrete structures.

† Washing does not always improve sand, as the finer particles which may be of value to the compactness and solidity of the mortar are carried away in the process. Washing is, however, often necessary to properly clean the sand from objectionable impurities.

rejected. The presence of any clay whatsoever will be sufficient ground for rejection. Sand containing over (5) per cent of mica or laminated particles may be rejected at the discretion of the Engineer.

66. **Additional Sand.** — Sand required in addition to the run of the crusher, or such substitute as the Engineer may adopt, shall be furnished by the Contractor.

3. Broken Stone and Gravel

67. **In General.** — Coarse aggregate shall consist of inert material, such as broken stone or gravel. In some cases gravel is preferable to broken stone as so many stones have a flaky cleavage and the rounded pebbles make a more even and sounder concrete than these flaky pieces, owing to the ease with which the sand and cement can fill the voids.

68. **Quality of Broken Stone.** — The crushed or broken stone shall consist of pieces of hard and durable rock, such as trap, limestone, granite, or conglomerate, and must be quarried from ledges and have a specific gravity of not less than 2.60.

Aggregates containing soft, flat or elongated particles shall be excluded from important structures. Stone must be broken in cubical forms with angular fracture. That is to say, the stone shall be of such a character as to break in fragments approximately cubical in shape, not flat or elongated, and not having incipient cracks, but suitable in every respect for first-class concrete.

69. **Granite.** — All granite must be equal to the best grade of Maine granite. It must be fine and uniform in grain and color, perfectly sound and free from sap, seams, dries, cracks and defects of any kind calculated to impair its strength, durability or appearance.

70. **Limestone.** — All limestone must be of the best quality of gray limestone, capable of standing without failure a pressure of at least 1200 pounds per square inch. It must be perfectly sound and free from sap, seams, dries, cracks or defects of any kind calculated to impair its strength or durability. All soft, white limestone must be excluded. When considerable fire resistance is essential (i.e., reinforced concrete buildings), limestone and like materials liable to disintegrate or become calcined under the action of fire must not be used.

71. **Sandstone.** — Sandstone must be in strength, quality and freedom from defects fully equal to the limestone specified above.

72. **Use of Either Broken Stone or Gravel.** — Either gravel or broken stone or both may be used for the aggregate of the concrete. Whichever material is used shall be hard enough and sound enough, in the judgment of the Engineer, to be suitable for the work.

73. **Sizes of Broken Stone or Gravel.** — The size of broken stone or gravel shall be proportioned to the sizes of the members in which the concrete is to be placed. In columns, slabs and small beams the maximum

size of the stone or gravel shall not run over $\frac{3}{4}$ inch, and the minimum size shall be approximately $\frac{1}{4}$ inch. In members of larger proportions $1\frac{1}{4}$ inches broken stone or gravel may be used and in massive work 2 inches (or sometimes $2\frac{1}{2}$ inches) broken stone or gravel may be used and where permitted by the Engineer, rubble stone may be embedded in the concrete.

A graduation of sizes of the particles shall be insisted upon. The maximum size of the coarse aggregate shall be such that it will not separate from the mortar in laying and will not prevent the concrete fully surrounding the reinforcement or filling all parts of the forms.* Broken stone or gravel must conform with the specifications in regard to size.

74. **Mesh Composition for $2\frac{1}{2}$-inch Broken Stone.** — For concrete in which the broken stone does not exceed two and one-half ($2\frac{1}{2}$) inches in its major dimensions, two-thirds of the stone shall be broken to pass a two- (2) inch screen, and be rejected by a one and one-quarter- ($1\frac{1}{4}$) inch screen; the other one-third ($\frac{1}{3}$) shall pass a one and one-quarter- ($1\frac{1}{4}$) inch screen and be rejected by a one-quarter- ($\frac{1}{4}$) inch screen.

75. **Mesh Composition for $1\frac{1}{4}$-inch Broken Stone.** — For concrete in which the broken stone does not exceed one and one-quarter ($1\frac{1}{4}$) inches in its major dimensions, two-thirds ($\frac{2}{3}$) of the stone shall be broken to pass a one and one-quarter- ($1\frac{1}{4}$) inch screen, and be rejected by a seven-eighths- ($\frac{7}{8}$) inch screen; the other one-third ($\frac{1}{3}$) shall pass a seven-eighths- ($\frac{7}{8}$) inch screen, and be rejected by a one-eighth- ($\frac{1}{8}$) inch screen.

76. **Mesh Composition for Gravel.** — If gravel shall be substituted for broken stone, it must conform to the same physical conditions and mesh composition as required for broken stone of the different kinds of concrete.

77. **Cleanliness of Broken Stone.** — Broken stone shall be clean and free from dust, dirt and other foreign matter, but may consist in part of fine screenings and medium-sized pieces, the intention being to take all of the product of the crusher except fine dust. Disintegrated stone or broken stone containing mica shall be rejected. When it is desired to use screenings with the crushed stone the proper proportion of sand to be used shall be determined by analysis (see page 28).

78. **Cleanliness of Gravel.** — The gravel shall be clean and free from dust, dirt and other foreign substances, and washing of same will be required when considered necessary by the Engineer, in order to render it sufficiently clean. That is to say, the gravel shall be composed of clean pebbles free from sticks and other foreign matter and containing no clay or other material adhering to the pebbles in such quantity that it cannot be lightly brushed off with the hand or removed by dipping in water. When containing sand in any considerable quantity the amount per unit of volume of gravel shall be determined accurately to admit of the proper proportion

* The size of the coarse aggregate may be increased for concrete in large masses, as a large aggregate produces a stronger concrete than a fine one, although it should be noted that the danger of separation from the mortar becomes greater as the size of the coarse aggregate increases.

of sand being maintained in the concrete mixture (see page 28). The gravel shall be entirely clean and ready to mix into concrete when unloaded from the wagons. If the gravel is mixed with dirt it must not be used.

79. **Mixed Aggregate.** — A mixture of gravel and broken stone may be used. Gravel, when specified to be mixed with broken stone, shall be mixed with the broken stone in the proportion not exceeding fifty per cent; but this mixed aggregate should not be used in any reinforced concrete work.

80. **Name of Gravel Pit.** — Gravel shall be from pits of established reputation and the Contractor will be required to give the name of the pit from which gravel is to be furnished.

81. **Natural Mixture of Bank Sand and Gravel.** — Great care shall be exercised in using a natural mixture of bank sand and gravel without screening, owing to the likelihood of there being far too much sand for the gravel. Frequent tests shall be made to see that the proportions of the coarse and fine grains are correct.

82. **Preparing Broken Stone Before Delivery.** — Broken stone must be crushed and screened before being brought upon the work as crushing or screening will not be allowed upon the work, unless by the written consent of the Engineer.

83. **Testing.** — Broken stone or gravel shall be tested for adhesion to cement, crushing resistance and also for fire resistance when used in building construction.

84. **Samples.** — Samples of broken stone or gravel must be furnished to the Engineer for approval, before the Contractor places any orders for same, and after such samples have been found to fulfill the requirements as noted above, orders may be placed. Sea washed gravel must in all cases be approved by the Engineer. Samples of broken stone or gravel, of not less than one (1) cubic foot, shall be submitted in suitable boxes or other receptacles. (See Par. 45.)

85. **Screening Sand from Gravel.** — Sand shall be screened out of gravel when required by the Engineer, but may be mixed with it in the proper proportions, if of the specified quality. That is to say, unless the mixture runs evenly throughout the bank, and is found to be made up of the proper proportions of sand and gravel, the sand shall be screened out of the gravel and the materials prepared in the usual way.

86. **Delivery of Broken Stone or Gravel.** — The broken stone or gravel shall be delivered on the work as ordered by the Engineer. The quarries selling broken stone, sometimes attempt to dispose of broken stone mixed with quarry refuse, stone, dust, etc., and each carload shall be carefully inspected, and rejected if the material is not perfectly satisfactory and of such quality as will give first-class results when mixed in concrete.

87. **Storage.** — The approved broken stone or gravel when delivered to the job must be stored in such a manner that it will be free from dirt or

foreign matter of any kind when ready for use. The broken stone or gravel shall be delivered and stored where directed by the Engineer.

88. **Rejection.** — At any time, however, if the broken stone or gravel delivered does not fully meet the requirements as stated above it will be rejected. Piles or heaps having any admixture of dirt or stones of a larger size than specified shall be unconditionally rejected. Any stone which shows a tendency to break into flat, thin pieces will be rejected. No soapstone or rotten stone will be allowed.

89. **Removal of Unsuitable or Inferior Material.** — All dirty or unsuitable material shall be removed from the site of the work as soon as ordered by the Engineer or Inspector in charge. In the event of any inferior broken stone or gravel not fully up to the requirements set forth in the preceding clauses (and of which the Engineer shall be the sole judge) being brought upon the said works or street, or detected in any load or lot, the whole load or lot will be condemned, and must be at once removed by the Contractor, otherwise the Engineer shall cause its removal and the Contractor will be charged with all expenses incurred, including handling, cartage, storage and any other costs involved, which expenses and costs will be deducted from any moneys due the Contractor, and will be retained by the Owner or City.

90. **Screening stone from the Run of the Crusher.** — The run of the crusher may be used. The rock must be clean when delivered at the crusher. It shall be broken by machine and screened in a rotary screen which will remove all the dust and fragments that will pass through a hole $\frac{3}{8}$ inch in diameter and all pieces which will not pass through a hole $1\frac{1}{2}$ inches in diameter; all fragments between these limits will be retained. The sand screened from the stone will be used when considered suitable by the Engineer.

If the crushed dust and fine fragments be not screened out, the stone must be so handled that the fine material will be evenly distributed through the mass when it reaches the concrete platform or mixer.

91. **" One Man " Stone (Rubble Stone).** — In massive concrete " One man " stone or large blocks may be used when called for by the plans, or authorized in writing by the Engineer. When rubble stone is permitted in concrete, such stones shall be hard boulders or stone blocks.

92. **Niggerheads or Boulders.** — Niggerheads or boulders shall be clean, hard, rough and free from cracks or other unsoundness. In volume they shall not exceed 20 per cent of the masonry containing them. No rotten or soft stones or rock shall be used, nor those which are partly rotten or soft. (See Par. 615, page 108.)

Art. 3. Miscellaneous Materials

93. **Slag.** — Only the best quality of hot pot slag, free from dust and foreign matter, shall be used. For concrete, it shall be broken so as to

pass in any direction through a $2\frac{1}{2}$-inch ring; for other purposes, so as to pass in any direction through a 3-inch ring, but in all cases to be broken before being brought on the site. Slag for concrete work shall be nearly free from sulphur or other injurious agents and must be hard and not spongy.*

93a. **Substituting Slag for Broken Stone or Gravel.** — Crushed furnace slag conforming to the specifications for size and of a quality which will develop under test a crushing and transverse strength equal to that of the stone herein specified (Art. 2, Sec. 3, page 12) may be substituted for broken stone in all concrete except where additional specifications or notes on plans specifically call for broken stone or gravel. Should, however, the percentage of voids in the slag prove to be excessive, a reduction in the proportions of slag may be required without additional compensation to the Contractor.

93b. **Twice Burned Slag.** — Furnace slag broken to the specified size and then burned in heaps to free it from sulphur shall afterwards be well washed and weathered in the open air.

94. **Cinders.** — Cinder concrete shall not be used for reinforced concrete structures. It may be allowable in mass for very light loads or for fire-protection purposes.

The cinders shall be composed of hard, clean, vitreous clinker, free from sulphides, unburned coal, or ashes. Those used for fire-protection purposes shall be a good quality of steam cinders containing not more than 15 per cent of unconsumed coal.

95. **Burned Clay.** — Hard burned clay shall be made from suitable clay, free from sand or silt, burned hard and thoroughly. Absorption of water shall not exceed 15 per cent.

96. **Crushed Slate or Shale.** — Crushed slate or shale shall not be used in reinforced concrete construction.

97. **Water.** — Only fresh, clean water free from ashes and other impurities shall be used. The water used in mixing concrete shall also be free from oil, acid, strong alkalies or organic matter. Water carrying in suspension considerable quantities of mineral or vegetable matter shall be unconditionally rejected. It must also be free from iron or other impurities that tend to discolor the concrete. Water shall be free from mineral salts which are detrimental to cement work.

98. **Sea Water.** — Sea water should not be used for mixing concrete. In case it becomes necessary to use sea water, where pure water cannot be obtained, the latter may be used, but careful tests must be made at all times.

99. **Lime Water.** — The use of water strongly impregnated with lime weakens the strength of the concrete and should be avoided.

* Judging a slag from the analysis of a small sample is not safe, because its composition varies with changes in the operation of the furnace or in the nature of the materials being smelted. A slag some months old is preferable, as aeration has had opportunity to remove the sulphur.

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CHAPTER II

PROPORTIONING AND MIXING CONCRETE

Art. 5. Proportioning of Concrete

1. GENERAL REQUIREMENTS

100. In General. — The concrete shall be composed of cement, sand and broken stone or gravel mixed with clean water in the proportions hereinafter specified. These proportions are intended to produce a concrete in which the mortar will fill all the voids, and the proportions shall be so adjusted that when rammed in place, free mortar will flush to the surface. A good concrete worker can tell when the first batch of concrete is rammed in place if the proportions of mortar and aggregate are such that the concrete will ram well and all the voids will be filled solid.

101. Relation of Fine and Coarse Aggregates. — The fine and coarse aggregate shall be used in such relative proportions as will insure maximum density. In unimportant work it is sufficient to do this by individual judgment, using correspondingly higher proportions of cement; for important work these proportions shall be carefully determined by density experiments (see Sec. 2, page 28), and the sizing of the fine and coarse aggregates shall be uniformly maintained, or the proportions changed to meet the varying sizes.

Gravel of equal proportion can be substituted for broken stone where the sand is added separately. If the gravel is used without screening, it shall be examined from time to time, and in case its composition is not such as to give the required proportions, sand or broken stone shall be added as may be necessary. Where the sand and gravel are supplied already mixed use a quantity 10 per cent greater than the proportion of stone indicated in Sec. 3, page 31.

During construction, the aggregate shall be frequently examined as described below (see Sec. 2, page 28) to determine the relative proportions of the particles of varying sizes.

102. Relation of Cement and Aggregates. — The proportions of cement to sand and stone shall be chosen after a very careful study of the local conditions and the available materials.

For reinforced concrete construction a density proportion based on 1 : 6 should generally be used, i.e., 1 part of cement to a total of 6 parts of fine and coarse aggregates measured separately. For columns richer mixtures are usually preferable, and in massive masonry or rubble concrete a mixture of 1 : 9 or even 1 : 12 may be used.*

103. Determination of Amount of Cement to be Used with Aggregates. — A theoretical correct concrete should consist of sand and gravel or crushed stone or a combination of them, containing any amount of cement equal to the voids in such combination. In other words, interstices shall be filled with mortar. To state this in another way, if the concrete is made up of sand and gravel, such proportion of cement shall be used with the sand as is equal to the voids in the sand, and such quantity of this resulting mortar of sand and cement shall be used with the crushed stone or gravel as will fill all the voids in the crushed stone or gravel.

Restating this in a few words, the cement shall fill the voids in the sand and the resulting mortar shall fill the voids in the aggregate.

104. Definition of Voids. — The space existing between particles of sand, crushed stone or materials of which an aggregate is composed. In other words, by voids in a mass of materials is meant the space that is occupied by air. These air spaces, or voids, are usually referred to as a percentage of the whole volume.

105. Proportions by Volume. — All concrete proportions shall be by volume (see Sec. 4, Measuring Ingredients, page 33).

106. Proportion of Sand to Stone or Gravel. — As a rule, the proportion of sand to stone or gravel shall be 1 : 2, depending upon the character of material used, and the exact proportion shall be found before concreting by making a small test beam.

107. Proportions of Concrete. — For the information of the Contractor in the way of computing the cost of concrete of the quality herein required, it may be stated that ordinarily the per cent of mortar will be about (say) 40 per cent of the measured volume of the aggregate. In case of the use of a certain proportion of gravel or tailings in the aggregate, the proportion of mortar may be reduced to somewhat less than (say) 35 per cent.

108. Accurate Proportioning. — The Inspector shall make certain that the specified proportions are accurately and uniformly adhered to. Any variation from these proportions must be with the written consent of the Engineer.

109. Dispute Regarding Quantities of Aggregates. — Should there be any dispute in regard to the quantities of aggregate to be used for each bag of cement, it shall be decided by a test.

110. Cost of Concrete Governed by Amount of Cement Used. — Portland cement concrete shall contain on an average (say) one and one-half barrels of Portland cement per cubic yard in place. In no case will a greater proportion of sand than — parts sand to one part cement be per-

* These proportions should be determined by the strength or the wearing qualities required in the construction at the critical period of its use. The best guide as to the proper proportions for any particular case is by experienced judgment based on individual observation and tests of similar conditions in similar localities.

mitted to be used. In case the number of barrels in any piece of masonry falls below the average stated above, then the price per cubic yard shall be reduced in proportion to the reduction in amount of cement used. Prices of concrete will not be increased if greater quantities of cement than specified above per cubic yard are used.

111. Description of Proportions for 1 : 2 : 4 Concrete. — Concrete of 1 : 2 : 4 proportions shall consist of 1.57 barrels of cement containing 3.8 cu. ft. per barrel, 44/100 cu. yds. loose sand and 88/100 cu. yds. loose stone.

112. Changing Proportions of Concrete. — The proportions will be established from time to time and will not be changed during any period of twenty-four hours, unless the Contractor desires to use materials of widely varying characteristics, and the proportions determined at any one time shall continue to be used, until the next determination is made and the Contractor ordered to change the previous proportions.

113. Additional Cement. — In any of the mixtures hereinafter stated the Engineer may increase the proportions of cement for special reasons in particular places. If the Engineer insists on more cement, the Contractor shall be paid cost and 10 per cent extra.

114. Less Cement. — If cement is used less than the specified proportion, the Contractor shall credit the Owner or City for such difference at the price he is paying for cement.

2. Experimenting for Voids

115. In General. — In these provisions for the concrete it is the intention to take advantage of balanced sand, gravel or broken stone, i.e., to use varying sizes for the purpose of decreasing the voids and using less cement to secure the best results. It will probably be necessary therefore to experiment with different proportions of varying sizes of sand and gravel or broken stone in order to ascertain the best mixture of the available materials at hand to secure the desired ends.*

116. Gravel Containing Sand. — When gravel containing considerable quantities of sand is used, several trials shall be made to determine the proportion of sand it contains that will pass through a No. 4 screen and a corresponding deduction shall be made from the sand used in making the mortar, so that the final proportions of the cement and sand in the complete mixture shall be as specified for mortar. Only the gravel remaining after screening out the sand shall be treated as aggregate during the experimenting for voids referred to later.

117. Aggregate Composed of Broken Stone and Gravel. — When the aggregate is composed of both broken stone and gravel they shall be mixed

* On large work, and where the determination of the exactly correct proportions is expedient, the voids in the sand and stone are determined by saturation with water or by specific gravity as described in the author's book on Inspection of Concrete Construction, published by the Myron C. Clark Pub. Co., Chicago, 1913. With the proportion of voids thus carefully ascertained, there is generally used an excess of 5 to 10 per cent of cement over the voids in the sand and a 5 per cent excess of sand over the voids in the stone.

in such proportions (to be determined by experiment) as will give the least per cent of voids when mixed.

118. Amount of Mortar Mixed with Aggregate. — In general, the amount of mortar mixed with the aggregate shall be at least 10 per cent more than the voids in the loose aggregate, which shall be determined by experiment.

119. Measuring Ingredients. — When the cement is packed in barrels the barrel shall be the basis of measure for the sand and also for the aggregate. But when cement is packed in sacks, 3½ cu. ft. shall be considered a barrel of sand or aggregate.

In experimenting for voids, where possible, the method of weights shall be used, assuming the weight of dry gravel and broken stone to be 165 lbs. per solid cubic foot, and excluding from the aggregate the sand which occurs in the gravel.

120. Proportions of Cement and Sand in Mortar. — The amount of mortar made by a given amount of cement and sand shall be determined by experiment, but in the absence of such experiments for special cases the following may be used as an approximation, the units of cement being a barrel of 380 lbs. net for Portland and 265 lbs. net for natural cement.

	Cement.					
	Portland.			Natural.		
Proportions	1:1	1:2	1:3	1:1	1:1.5	1:2
Cement, barrel	1	1	1	1	1	1
Sand, cubic feet	3.5	7	10.5	3.5	5.25	7.0
Resulting mortar, cubic feet	6.0	8.0	10.7	5.7	6.9	7.8

121. Determination of Voids. — To determine the voids in the sand or the material to be used as an aggregate, what is known as the "Water test" shall be employed. In preparing for this test, the sand or gravel shall be perfectly dry. Sand has a greater volume when wet.

A receptacle holding a known amount, such as a quart jar, shall be filled with the material to be tested, sand, for example, and into this receptacle shall be poured as much water as the sand or other material will absorb. The water shall be measured. The amount of water absorbed indicates the voids, and also indicates the exact amount of cement which is necessary to use in order to produce a solid concrete. In introducing the water into the vessel containing the aggregate, care must be taken to prevent entrapping air. The water should be applied at one point along the side of the vessel.

122. Determination of Voids on a Larger Scale. — The following elaborate method of determining voids in materials is that given by Ernest McCullough in his book on "Engineering Work in Towns and Small Cities," page 137:

"Use a box containing about five cubic feet and fill it flush with the stone, or largest sized aggregate. Pour in water gently in order that no air will be trapped and measure the water as it goes in. The amount of water used determines the amount of finer material necessary to exactly fill the voids.

"Empty the box on a platform and spread the material in a thin layer, allowing the water to run off. Then cover it with the next smaller size aggregates as determined by the amount of water used to fill the voids and turn the whole mass over with shovels until well mixed. Then shovel it into the box, tamping it so the whole amount will go in. Should it more than fill the box screen the remainder to separate the sizes and remove from the box enough of the smaller size material to permit the surplus of the screened larger material to go in. In this way all the coarser material will be in the box and enough of the smaller material to pack the voids.

"Fill the box again with water. This amount of water represents the amount of the next smaller sized material necessary. Take for example that stone, gravel and sand are being used. The first aggregate tested for voids was the stone. The second test was the stone and gravel. The third test is for stone, gravel and sand.

"The material necessary to fill the voids, after screening surplus, must be placed on a memorandum. The amount was found by using water, but when placing in the box it will be found that on account of the sizes of the smaller sized aggregate some will not pack in like sand or cement.

"Having filled the box again with water empty on the platform and spread the aggregates. Cover them with the amount of sand indicated by the water test and turn over thoroughly until mixed. Then place in the box in small amounts and tamp into place.

"Having filled the box, after screening surplus as above directed, and ascertained the amount of stone, sand and gravel, pour in a measured quantity of water again until the box is filled. This last amount of water represents the amount of cement paste necessary to finally fill all the voids.

"By proceeding in the above manner with graded sizes of materials the voids can be reduced as low as 7 per cent.

"In drawing up specifications the amount of each size of aggregates used can then be specified and the mixing will do the rest."

123. **Definite Proportions.** — In all cases the proportions shall be reduced to such a basis that they can be stated as follows in terms of the actual materials as delivered on the ground for use.

One bbl. cement to .... cu. ft. sand to ...... cu. ft. gravel to .... cu. ft. broken stone.

124. **Description of Experiments, Approval, etc.** — The proportions so stated, together with descriptions of all experiments leading thereto, shall be submitted to the Engineer for approval, and after approval shall be

followed in measuring the materials until there is reason to change them through change in condition of materials received. The necessity for such change shall be determined by the Inspector and approved by the Engineer.

125. **Adjusting Proportions of Aggregate.** — The relative proportions of sand and coarse aggregate shall be adjusted periodically, based on determination of the voids in the materials used in mixing the concrete.

126. **Cost of Work Governed by Proportioning Concrete.** — If the proportions as herein stated are not suitable for the crushed stone furnished, the Engineer will determine the proper proportion. If the change in proportion alters the cost of the concrete, the difference shall be paid for or deducted as the case may be.

127. **Tests of Voids as Work Progresses.** — Tests of the voids in the aggregate will be made from time to time under the direction of the Engineer and instructions given as to the per cent of mortar of the specified composition to be used. No extra allowance will be made to the Contractor for such tests.

3. Proportions for Different Classes of Work

128. **In General.** — The concrete shall consist of one part cement, from 2 to 4 parts of sand, and from 4 to 10 parts of broken stone or gravel measured by loose volume. (The proportions must vary to suit the character of the work and the requirements which the concrete must meet.) For reinforced and damp-proof concrete that proportion is desirable which produces the densest concrete possible. Under other conditions only sufficient cement is used to develop the strength required of the concrete. For reinforced and damp-proof concrete, a 1 : 2 : 4 mix is commonly used. Where compressive strength alone is a requisite, the concrete is often proportioned 1 : 2½ : 5. For massive foundations, a 1 : 3 : 6 concrete may be used. In such proportions, the first term refers to the parts of cement (usually Portland), the second to the parts of sand and the third to the parts of broken stone or crushed rock, screened gravel, or other coarse aggregate. The proportions are based on the measurements by volume in which a bag of cement is considered one cubic foot. If pit or lake gravel is used, although the saving in cement will usually more than compensate the cost of screening and remixing, similar proportions are adopted in which the second or sand term is dropped. Such proportions then read 1 : 4, 1 : 4½, 1 : 5, 1 : 6 and so on.

The following list is presented to be used as a rough guide to the selection of proportions for different classes of work. The relative proportions of fine to coarse aggregate must be varied to suit the materials. The proportions shall be determined by the strength or wearing qualities required in the different classes of construction.

Gravel of equal proportion may be substituted for broken stone where the sand is added separately. Where the sand and gravel are supplied already mixed use a quantity 10 per cent greater than the proportion of stone indicated; for example, in a standard mixture use 1 part Portland cement and 4.4 parts of gravel. Do not add together the proportions of stone and sand as the sand in the ordinary mix only fills the voids and does not increase the volume of the stone.

129. **Rich Mixture.** — In columns and other structural parts subjected to high stresses or requiring exceptional water-tightness, rich mixtures shall be used in the proportion of 1 : 4½, i.e., 1 part of Portland cement to 1½ parts of sand to 3 parts of coarse aggregate measured separately.

130. **Standard Mixture.** — In reinforced concrete floors, beams, girders and columns, in arches, in reinforced engine or machine foundations subject to vibrations, in tanks, sewers, conduits or other water-tight work, standard mixtures shall be used in the proportion of 1 : 6, i.e., 1 part of Portland cement to 2 parts of sand to 4 parts of coarse aggregate measured separately. (This mixture may be considered as good, strong concrete as practically need be used for any piece of Portland cement concrete of appreciable bulk.)

131. **Medium Mixture.** — In ordinary machine foundations, retaining walls, abutments, piers, thin foundation walls, building walls, ordinary floors, sidewalks and pavements, and sewers with heavy walls, medium mixtures shall be used in the proportion of 1 : 7½, i.e., 1 part of Portland cement to 2½ parts of sand to 5 parts of coarse aggregate measured separately. (This mixture may be considered as giving a concrete of sufficient strength, when of proper dimensions, for any ordinary masonry construction, and, at many times and places, ample for very heavy work.)

132. **Lean Mixture.** — In unimportant work in masses, in heavy walls, in large foundations supporting a stationary load, and in backing for stone masonry, lean mixtures shall be used in proportion of 1 : 9, i.e., 1 part of Portland cement to 3 parts of sand to 6 parts of coarse aggregate measured separately. (This mixture may be considered as giving a concrete of sufficient strength, when of proper dimensions, for much ordinary plain work in favorable positions.)

133. **Proportions for Natural Cement Concrete.** — For natural hydraulic cement concrete a good mixture of 1 part cement, 1 part sand and 2 parts broken stone or gravel may be considered as good, strong concrete, as practically can be made with natural cement; and 1 to 2 to 4 or 4½ may be considered as poor and weak concrete, as practically should be made with natural cement, to be used in any work to be classed as durable and sufficient for loads usually placed upon masonry of ordinary dimensions.

134. **Usual Proportions.** — The usual proportions unless otherwise particularly shown upon the drawings, or called for by the specifications applying to the particular piece of work shall be:

Plain or Massive Concrete.
One (1) part Cement.
Two and a half (2½) parts Sand.
Five (5) parts Broken Stone or Gravel.

Reinforced Concrete.
One (1) part Portland Cement.
Two (2) parts Sand.
Four (4) parts Broken Stone or Gravel.

When an aggregate of mixed sand and stone or gravel is used there shall be not less than one part Portland cement and 4½ parts of such aggregate for concrete to be used in walls, beams, girders and floors and not less than 1 part cement to 3¼ parts of such aggregate for concrete to be used in columns. Such aggregate must not be used unless it leaves a residue of gravel or crushed stone upon a one-quarter inch sieve amounting to not less than 75 per cent nor more than 95 per cent of the original volume. Mixed aggregate which does not fulfill these requirements may be used if crushed stone, gravel or sand is added to produce the proper proportions.

135. **Cinder Concrete.** — Cinder concrete shall be composed of 100 lbs. cement, 2 cu. ft. gravel or coarse sand, and 6 cu. ft. of cinders.*

136. **Slag Concrete.** — Slag concrete may be composed of 100 lbs. cement, 2 cu. ft. gravel or coarse sand, and 6 cu. ft. of slag. In substituting slag for broken stone experiments shall be made to determine exactly what proportion should be used.

4. Measuring Ingredients

137. **In General.** — Methods of measurements of the proportions of the various ingredients, including the water, shall be used, which will secure separate uniform measurements at all times. The proper amount of the several kinds of material shall be measured in some way which is entirely satisfactory to the Engineer or Inspector in charge of the work, so that they may be satisfied that the requisite proportions of each kind of material are delivered for each batch of concrete.

138. **Approximate Method.** — The Engineer shall not permit an approximate method of measuring to be used which may yield an excess of sand and broken stone over cement. If an approximate method is used, same must provide for not less than the proper proportion of cement with the possibility that this proportion will overrun. By this is meant that if the barrows of sand and broken stone or gravel are heaping the proper amount of cement will be used. The usual course of providing a struck barrow of cement and heaping barrows of sand and broken stone or gravel will not be permitted.

* Cinder concrete is usually made in the proportion 1 part cement to 2½ parts sand to 5 parts cinder.

139. **Measurement of Materials.** — The measurement of materials will be by weight and volume. Concrete shall, as a rule, be proportioned by weights. The materials shall be measured loose in a uniform manner, easy to control either by workmen or superintendent, without likelihood of frequent error. Fine and coarse aggregate shall be measured separately as loosely thrown into the measuring receptacle.

140. **Measuring Receptacles.** — The measurement of materials will be by bottomless boxes in which the materials may be cast and leveled off; by a properly constructed double gate in a bin chute; or by the use of suitable carts or barrows having square or cylindrical bodies expressly designed for this purpose.

141. **Unit of Measure.** — The unit of measure shall be the cubic foot. The unit of measurement for cement shall be the bag as received from the manufacturer, having a net weight of not less than 94 lbs. (for Portland or natural cement). Such a packed bag shall be considered as being equal to one (1) cubic foot of cement. Cement lighter than above must be counted of proportionately less volume. One volume of sand or broken stone shall be taken as 3½ cu. ft. shaken down.

142. **Measuring Cement.** — Cement shall be measured in the original packages and the packages counted, instead of weighing on scales, since bags or barrels of cement have standard weights. If bags received from the manufacturer contain less than 94 lbs. net of Portland (or natural) cement the Contractor shall bring up the weight with additional cement. If the bags weigh uniformly more than is here called for the Contractor shall be allowed to remove the excess cement provided each bag thus altered is altered by weight.

The Inspector shall weigh one bag in forty as the cement is received, in order to check weights. Every facility must be given to the Inspector to properly supervise the process of weighing.

If the cement is turned out of the bags or barrels for the purpose of storing, it shall be weighed again as rebagged or packed, and each bag or barrel must contain no less weight of cement than the above mentioned unit.

143. **Measuring Sand, Broken Stone or Gravel.** — The sand and broken stone or gravel must be actually measured in bulk. The measurement of sand and broken stone or gravel in the ordinary shallow round bottom wheelbarrow will not be considered satisfactory, and shall not be permitted. The use of barrels or boxes without heads and bottoms, into which the sand and broken stone or gravel may be cast, the containing vessel then being removed, will be deemed satisfactory, or preferably the use of square and uniform sized wheelbarrows built specially for this service. No counting of shovelfuls or other approximations will be allowed.

In measuring sand and screenings, proper allowances shall be made for variations in moisture, and the Contractor shall make such moisture tests and allowances in measurement as directed.

144. Proportioning by Volumes. — The proportioning may, however, also be done by volumes, using approved boxes or other receptacles and when not packed more closely than by throwing them in the usual way into a barrel or box.* Proper measuring boxes specially constructed for the purpose shall be provided by the Contractor as directed by the Engineer. Care must be taken at all times to keep the cement box perfectly clean and dry. Each of these boxes shall when filled and struck level contain the prescribed proportions by weight, which shall be proved by a reliable scale.

If other methods of measurement are permitted, the measurements shall be based on the measurement of the cement in the original package, and not after being removed therefrom.

145. Sizes of Gage Boxes. — The following sizes of gage boxes, without bottoms, will be found convenient:

Kind of concrete mixture.	Sand box.		Stone box.	
	Size.	Vol., cu. ft.	Size.	Vol., cu. ft.
1–2½–4	2′ 9″×2′×1′ 8″	9.25	5′×4′ 5¼″	14.80
1–3–6	2′ 9″×2′×2′ 0″	11.10	5′×6′ 8″	22.20
1–2–5	2′ 9″×2′×1′ 4″	7.40	5′×6′ 6⅝″	18.50
1–2½–6½	2′ 9″×2′×1′ 8″	9.25	5′×7′ 2½″	24.05

The sizes of measuring boxes are dependent upon the amount of concrete to be mixed in each batch. For work of moderate magnitude, measuring boxes of convenient size are specified in the following table showing quantities of materials and approximate resulting amount of concrete for two-bag batch, using sand and stone.

Kind of concrete mixture.	Proportions by parts.			Two-bag batch.						
				Materials.				Size of measuring boxes, inside measurement.		Water in gallons for medium wet mixture.
	Cement.	Sand.	Stone or gravel.	Cement.	Sand.	Stone or gravel.	Concrete.	Sand.	Stone or gravel.	
				Bags.	Cu. ft.	Cu. ft.	Cu. ft.			Gallons.
1:2:4	1	2	4	2	3¼	7½	8½	2′×2′ 11½″	2′×4′ 11½″	10
1:2½:5	1	2½	5	2	4¾	9½	10	2′×2½′ 11½″	2′×5′ 11½″	12½
1:3:6	1	3	6	2	5¾	11½	12	2′×3′ 11½″	2′×6′ 11½″	13½

* In making a batch of concrete the amount of each material required should be actually measured by volume, otherwise concrete entirely homogeneous in texture and appearance cannot well be produced. Since a bag of Portland or natural cement (loose) is equivalent to one cubic foot, for convenience all measurements should be based on the cubic foot as the unit as mentioned in Par. 141.

146. **Measuring in Wheelbarrows.** — The contents for each batch shall be carefully mixed in a measuring box until the workmen have become accustomed to filling their wheelbarrows in the required manner, and the Superintendent may require all material to be measured in boxes if, in his judgment, the measuring in barrows is not sufficiently accurate.

Where barrows are used, they shall be of the straight top type and shall all be of one size or the size shall be plainly marked if more than one size is used. The measure of the size shall be the cubic contents of the barrow "struck flat" with a straight edge. No heaping will be allowed.

147. **Heaping Wheelbarrow Loads (Alternate Clause).** — The use of iron barrows may (with the Engineer's consent) be permitted for measuring the broken stone and sand, provided they are so constructed as to contain, when heaped to their utmost capacity, exactly the correct proportions as determined from time to time by the Engineer. When such measurement is permitted, no allowance will be made for material which may fall from the barrows in conveying the same to the place of mixing.

148. **Size of Batches.** — Batches shall be of such size that they can be proportioned without using fractions of measures. If compelled to use fractions of bags, said fractions shall be weighed upon the assumption that the neat cement weighs not less than 94 lbs. per cubic foot. The amount of water to be used shall be accurately measured for each batch.

149. **Measuring Water.** — The Contractor shall provide suitable means for controlling and accurately measuring water for mixing concrete.

150. **Verification of Measures.** — The accuracy of the measuring boxes, hoppers, etc., shall be verified to make sure that each holds the amount intended. This may be done by using a known measure to fill the measuring box, etc., employed, or the volume of the measuring box, etc., may be computed mathematically. Tests shall be made by the Contractor with the carriers — whether wheelbarrows, boxes or cars — used by him so that the required proportion of concrete may be maintained as nearly as possible; and the Engineer will supervise these tests and fix said proportions for the kind of carrier used at each piece of work. No extra allowance will be made to the Contractor for such tests.

151. **Accurate Measuring.** — Accurate measurements are of the greatest importance, and shall require (1) that definite measuring units be employed; (2) that the accuracy of the measuring boxes, etc., be verified as stated above; (3) that the filling of the measuring boxes, hoppers, etc., be exact and (4) that, when two or more boxes or hopperfuls, etc., go to make up a batch, the exact number is employed for each and every batch.

The operations of measuring shall follow a regular routine or sequence which shall not be varied from and a double check system shall be used by which both the cement man and the mixer operator check the number of measures.

152. **Measuring Materials for Reinforced Concrete Work.** — No chances which vigilance and caution can avoid shall be taken in measuring and charging the cement content of concrete for reinforced concrete work. The measuring and feeding of the cement shall be done under the direction of a Superintendent, Inspector or Foreman, having at least two years' experience in handling reinforced concrete. They shall be made to understand that safety to life and property depends on the accuracy of their work. The method of measuring the ingredients of the concrete must be subject to the approval of the Engineer.

153. **Automatic Measuring Devices.** — When automatic measuring devices are used to proportion the concrete, it shall be required (1) that they are regulated to give the proper proportions; (2) that the materials do not clog, choke or arch in the feed hoppers; (3) that the feed hoppers are kept amply supplied with materials.

Art. 6. Mixing of Concrete

1. General Requirements

154. **In General.** — Concrete may be mixed either by machines or by hand, depending upon the volume of concrete to be mixed. In either case the methods and manner of mixing must be satisfactory to the Engineer and subject at all stages to his approval. The mixing of the concrete shall be done as rapidly as possible. Concrete shall not be mixed in larger quantities than is required for immediate use. The Contractor shall exercise great care with the mixing of concrete and see that it is thoroughly mixed and not allowed to look raw when deposited in the forms.

The test for the degree of mixing or turning will be that all the fragments of stone are fully covered with mortar.*

Concrete must not be mixed on completed sections of the work.

155. **Inspector's Supervision.** — Concrete must always be mixed in the presence of an Inspector and the Contractor shall in advance notify the Engineer when mixing is to be done. Concrete mixed in the absence of the Inspector shall be subject to rejection at the will of the Engineer. Anytime the Inspector sees any of it slighted he shall reject it at once, or have it mixed over. The Inspector shall satisfy himself that the proper proportions of cement, sand and broken stone or gravel are used, checking from day to day or from time to time with the total amount of each which is received and used. If any difference of opinion should arise on any matter between the Contractor and Inspector, the work must be stopped until the Engineer's decision can be obtained.

156. **Engineer's Directions.** — The greatest care must be taken to thoroughly mix all mortar and concrete so as to obtain the very best results.

* It is essential that the mixing should occupy a definite period of time as it is difficult to determine, by visual inspection, whether the concrete is uniformly mixed, especially where limestone or aggregates having the color of cement are used. The minimum time will depend on whether the mixing is done by machine or hand.

The Engineer's directions must be implicitly followed at all times in this respect, and the Engineer is at liberty to vary his directions from time to time as the work progresses, so as to insure the accomplishment of this object, and the Contractor must forthwith cause such instructions to be obeyed.

157. Consistency of Reinforced Concrete. — The materials must be mixed wet enough to produce a concrete of such a consistency as will flow into the forms and about the metal reinforcement, and which, on the other hand, can be conveyed from the mixer to the forms without separation of the coarse aggregate from the mortar. In other words, the consistency of the concrete shall be soft and wet without being sloppy, and in general shall be such that after dumping the concrete in the forms it may be consolidated and worked into place with spades or shovels and a slight quaking secured with little or no tamping. A good concrete worker can tell whether the concrete allows of easy tamping and runs freely around the steel bars.

The mixture shall be moderately wet, and no very wet or very dry concrete shall be used without especial permission. Care must be taken that the concrete is not too wet, so that the stone and sand settle under the water during its transportation to the forms, although what is usually known as a wet mixture shall be used for all reinforced work.

158. Consistency of Concrete for Various Structures. — (*a*) A medium or quaking mixture of a tenacious, jelly-like consistency, which quakes on ramming, shall be used for ordinary mass concrete, such as foundations, heavy walls, large arches, piers and abutments.

(*b*) Wet or mushy concrete, so soft that it will flow when agitated, but not so wet as to produce a separation of the materials in transferring to the work, shall be used for rubble concrete, and for reinforced concrete, such as thin building walls, columns, floors, conduits and tanks. The concrete must be so mixed that it must be handled quickly or it will run off the shovel; or so that it will assume a level surface when dumped into a wheelbarrow and wheeled about 25 ft. Concrete shall not be mixed too wet and the cement drowned out. The mixture must not be so thin that it will seep through the joints in the forms.

159. "Dry" and "Wet" Concrete. — Concrete will be used "wet" wherever practicable and "dry" only when the nature of the work renders such use unavoidable. The consistency of the concrete shall be as required by the Engineer.*

* The amount of water necessary to a batch of concrete is dependent upon the character and condition of the aggregate and the consistency required of the concrete for the purpose and for the manner in which it is to be used. When possible, and especially for reinforced construction, it is advisable to use that consistency commonly known as wet or mushy as specified in Par. 158, in which state the concrete is sufficiently wet that, when being transported from the mixer to the work in buckets or in wheelbarrows, its surface naturally becomes smooth and level. With all things equal, wet or mushy concrete is most dependable for completely filling all space in the forms, for securing a perfect bond with the steel reinforcement, and for producing a very dense concrete.

For certain effective surface treatments and for detailed ornamental castings a dry concrete is often used. The amount of moisture required is a variable quantity. At least sufficient water should be used to give the material the plasticity common to molding sand. For massive work dry concrete should be wet enough to flush mortar slightly to the surface under heavy tamping. Dry concrete attains a working strength more quickly than wet concrete, and the forms may be removed sooner, but ultimately the wet mix surpasses it in strength.

160. Wetting Stone and Gravel. — The aggregate shall be wet, if required, before being mixed. Stone and gravel used in the concrete must not be drenched in the vehicles used to deliver it upon the platform or to the mixer, unless proper arrangements are made to drain the receptacles, but shall be wetted before they are placed therein. Stone and gravel shall contain no loose water in the heap when added to the mortar in the proper proportion. In other words, the stone and gravel shall be thoroughly wetted a sufficient time before being placed in the concrete to allow any surplus water to drain away, but shall remain moist when it reaches the concrete platform or mixer.

161. Failure to Mix Concrete Properly. — Failure to mix concrete to the required consistency shall be sufficient cause for immediate stopping of all the work pertaining to the operation in question.

162. Quantity to be Mixed. — Concrete shall not be mixed in larger quantities than is required for immediate use (generally one barrel of cement at a time). It shall not be allowed to lay, and then remixed with water and used.

163. Dirt to be Kept out of Concrete. — At all stages of the work, concrete and mortar must be kept entirely free from dirt of all kinds, and if unavoidably mixed with dirt, shall be removed and replaced to the satisfaction of the Engineer.

164. Mixing Coloring Matter. — In using coloring matter with concrete (see Art. 30, Sec. 2, page 138), the color shall always be mixed with the cement dry, before any sand or water is added. This mixing shall be thorough, so that the mixture is uniform in color. After this mixing the combination shall be treated in the same manner as ordinary cement.

165. Amount or Quantity of Water.* — The concrete, except where required by the Engineer to be deposited dry, shall be mixed with a quantity of water which will produce a mixture of satisfactory consistency of the wetness required.

The amount of water used in making the concrete shall be approved by the Engineer. The amount of water per batch shall be determined in consultation with the Superintendent, and when so determined the Contractor shall keep the consistency unvarying. In other words, the water shall be measured, and when the proper consistency has been found the exact same amount for each batch shall be used.

An excess of water, causing the materials to separate, shall be avoided, no more being used than necessary to unite the materials. No water shall be put by means of a hose.

The proper amount of water can be determined only by experience, and must be varied from time to time to suit the conditions of the weather and

* There is much difference of opinion as to the quantity of water that should be used. It is customary for some contractors to mix very dry, and trust that ramming will make a homogeneous concrete and a thoroughly protective coating on the reinforcement if any, while others use a fairly wet mixture, as less ramming is required.

the nature of the work. It is very important that Portland cement shall have sufficient water for its complete hydration. Natural cement requires less water for hydration than Portland. In all cases, however, a sufficient quantity to thoroughly hydrate all the cement must be used.

166. **Remixing.** — When the concrete has to be transported a long distance in cars, and the water has separated from the solid matter, the concrete shall be remixed before being placed in the forms. That is to say, concrete which may become compacted or segregated during transportation shall be satisfactorily remixed before being placed in the forms.

167. **Retempering.** — Mortar, grout or concrete which has been allowed to stand until initial set has taken place shall not be used; retempering, i.e., remixing with water, will not be allowed for partially set concrete unless by special permission of the Engineer who may, at his discretion, require additional cement to be used in retempering.

168. **Failure to Place Concrete before Setting.** — No concrete shall be used after it has begun to set; when setting commences, the material thus injured shall be immediately wasted. If in the opinion of the Engineer the Contractor fails to take due precaution against such injury, he will charge to the Contractor and deduct from the estimate the value of the cement in the wasted material.

169. **Freezing Weather.** — Concrete shall not be mixed at a freezing temperature, unless special precautions are taken to avoid the use of materials containing frost. The amount of water should be decreased when the weather is cool or freezing (see Art. 22, page 122).

170. **Wet Weather.** — Concrete shall not be made when rain is falling on it.

171. **Approval of Concrete.** — A competent foreman shall be in constant attendance to give his approval of every batch of concrete before it is used.

172. **Hot Weather.** — In hot weather the sand and gravel, or broken stone, must be kept wet in order to reduce the time of initial set to as near the normal as possible. If necessary, the sand and broken stone or gravel piles shall be protected from the sun. In very hot weather the sand and gravel or broken stone when exposed to the sun often becomes so heated at times as to cause certain kinds of cement to set almost immediately. This has been known to occur in the mixer causing concrete to cake and stick to the mixer to such an extent as to interfere with its proper working. The remedy is to wet the aggregate.

2. Machine Mixing

173. **In General.** — Wherever the amount of work to be done is sufficient to justify it, and for all work exceeding 750 cu. yds., approved mixing machines, either cubical steel or iron boxes, sometimes called malaxators, measuring (say) five feet on the edge, and capable of mixing (say) two-

barrel batches of concrete at one time, or continuous rotary mixers of approved design, shall be used.

Machine mixing of concrete will be preferred, provided the machine used secures equal accuracy in the ratios of materials and equally as good mixing as prescribed in Sec. 3 (page 44) for hand-mixing.*

174. **Type of Mixer, Approval.** — The Contractor shall notify the Engineer of the style of mixer proposed to be used, and the Engineer's approval of same shall be obtained before mixing is begun. That is to say, the type of mixer to be used must be approved by the Owner or City or its Engineer, who shall also control as to the method of feeding materials to the machine. The mixer shall be erected and operated in such a manner that the charging, mixing, discharging and regulation of the materials is uniform, efficient and certain. It shall feed the ingredients in their proper proportions at all times. If at any time the mixer fails to perform the mixing in a satisfactory manner, it must be repaired or removed and another machine substituted.

175. **Batch Mixer.** — A batch mixer in which the materials are charged, mixed and discharged in batch units shall be given preference at all times for reinforced concrete work. The machinery shall consist in part of a box or receptacle in which a definite volume of water, cement, sand and broken stone or gravel not exceeding a total of (say) 2 cu. yds. in any one batch shall be placed and there mixed by stirring or revolving for an indefinite length of time. The process of charging the machine and mixing the concrete shall be conducted in accordance with instructions of the Engineer.

176. **Testing Batch Mixer.** — The mixer shall be tested, and the batch of concrete, of the size that will give the best results, will be used.

177. **Charging Batch Mixer.** — The ingredients shall be placed in the machine in a dry state and in the volumes specified, after which clean water shall be added and the mixing continued until the wet mixture is thorough and the mass uniform, every particle of stone or gravel being completely coated with mortar. The proper measures of ingredients shall be emptied into the charging box in the following order: 1st, sand; 2nd, cement; 3rd, broken stone or gravel; 4th, water, the proportion of water being so regulated that the concrete can be thoroughly compacted and will show merely a thin film of moisture upon the surface.

Care shall be taken to run each batch till it is thoroughly mixed dry before beginning to wet up.

Water must be measured so that exactly the same amount is used for each batch. Water shall not be put into the mixer with a hose, as this invariably results in a lack of uniformity in the fluidity of the mix. Care

* When a machine mixer is used the inspector should be required to acquaint himself with the theory and principle of operation of that particular type of mixer and be able to detect any change in the proportions or uniformity of the mixture at any time.

shall be exercised in adding water to obtain the proper consistency. Water shall at all times be added by measure.

A thorough system must be employed for insuring beyond doubt that not less than the specified amount of cement goes into each batch.

178. **Charging Batch Mixer (Alternate Method).** — In mixing, the broken stone or gravel must be placed in the mixer first, thoroughly wet. The cement and sand shall then be dropped into the mixer in alternate layers and mixed thoroughly until an amalgamated concrete is obtained, in which the broken stone or gravel is suspended in a thick paste of mortar.

179. **Charging Batch Mixers without Automatic Measuring Devices.** — Proper precautions shall be taken to see that the requisite proportions of the different ingredients are used. If machines are used which are not provided with devices to deliver each of them, the process of making the concrete shall generally be as follows: The proper amount of sand, cement and broken stone or gravel for a batch not to exceed one yard of concrete shall be delivered on the platform and roughly mixed together so that when the dry mass is cut down and delivered to the mixer by means of shovels proper amounts of each of the ingredients are handled in each shovelful.

It will not be regarded as a satisfactory process to deliver broken stone or gravel, sand and cement at random to the mixer without taking some special means, as above described, to insure the delivery of the proper quantities of each ingredient as nearly as may be simultaneously.

Before starting work, the Inspector will mark lines on the wheelbarrows, above which sand and broken stone or gravel shall not be filled.

180. **Number of Turns.** — The requisite number of turns for batch mixers shall be determined by trial mixing of a few batches and when once determined that number shall be set as the minimum allowable. The product is improved by longer mixing, and all the time less than the period required for initial set, available between delivers required at the forms, should be utilized for extra turns to the mixer. Some mark shall be placed on the mixer so that the number of turns of the mixer can be counted. The time required for each operation shall also be checked, in order to obtain uniform results. No particular number of turns will be held sufficient unless the result desired be accomplished.*

The mixing should continue for a minimum time of at least one minute after all the ingredients are assembled in the mixer.

181. **Discharging Batch Mixer.** — The color of each batch shall be carefully noted as it comes from the mixer. Uniformity of color shall be insisted upon. The concrete leaving the mixer must be uniform in appearance and the mixing process must be carried on until this condition is obtained. The entire batch shall be discharged each time.

* The concrete should receive at least four complete turns of the drum before being discharged and if, in the opinion of the inspector, a greater amount of mixing is required, this number of turns should be increased until a thoroughly mixed concrete is secured.

182. **Checking Operations at the Mixer.** — The operations of placing the materials in the mixer shall be carefully checked and an Inspector shall be especially detailed for this work.

183. **Batch Record Cards.** — An accurate account shall be kept of the number of batches mixed, the same to be recorded on a printed card which will be furnished by the Engineer for that purpose. These batch record cards shall be preserved and filed for future reference.

184. **Discharging with a Drop.** — Concrete, in discharging the mixer, shall not drop or fall for any considerable distance.

185. **Cleaning Mixer Platform.** — At least once every twenty minutes the mixer shall be stopped and the platform upon which the concrete is being fed shall be entirely cleared, so that no concrete shall remain long enough to attain its initial set.

186. **Attendance at the Mixer.** — A competent foreman or inspector must be in constant attendance at the mixer to give his approval of every batch which leaves the machine. He shall be responsible for speed in feeding the mixer, speed in removing concrete, for accuracy of measurements, amount of water used, cement used, etc. The laborers placing the materials in the mixer shall be selected for their intelligence and ability to understand the directions given them. They shall also be of sufficient intelligence to understand the responsibility of their work, and must be made to realize that a single batch of concrete not containing the proper amount of cement may endanger life and property.

187. **Continuous Mixers.** — Continuous mixers in which the materials are charged, mixed and discharged in a continuous stream, are to be used only under special conditions, and then only on mass work, like retaining walls, foundations and dams. A continuous mixer in the operation of which the proportions of the ingredients depend upon the shovelers shall be subject to the special approval of the Engineer.

188. **Charging Continuous Mixers.** — Materials shall be fed evenly into the mixer in the proper proportions. If the mixer has an automatic measuring device, it shall be kept amply full and the material shall not clog in the mixing drum. If the mixer is fed by shoveling, it shall be done from properly proportioned piles of cement, sand and aggregate, and each shovelful shall contain a proper mixture of materials.* Shoveling shall be done at a uniform rate as it is essential to good results from a continuous mixer. (The chief fault of continuous mixers is the difficulty of charging them properly.)

189. **Testing Continuous Mixers.** — A batch of concrete shall be measured out in the desired proportions and run through the machine to see if it feeds correctly. After the concrete comes through it shall be examined

* The materials must be placed in properly proportioned piles, not containing more than 10 cu. yds. in the case of sand, broken stone or gravel, and the machine must exhaust all materials simultaneously. Should it be impossible to obtain these results, due to improper piling of material, the engineer should require the use of measuring boxes for proportioning the charge for the mixer. It is preferable not to depend for the securing of the proper proportions on the accuracy of machine gaging or the proportion of shovelers used.

to see if it is thoroughly mixed and if too wet or dry. If not mixed right, it shall be run through again or mixed by hand. The Inspector will check the run of the mixer with measured wheelbarrows from time to time as he desires. This shall be done at least once during each day's work and at times unexpected by the foreman. Measured quantities of cement, sand and broken stone or gravel in the required proportions shall be fed into their respective hoppers. If the mixer is gaged properly and feeding freely the measured quantities of materials will be exhausted simultaneously. Should some cement be retained in the cement hopper after the sand and stone are exhausted, it is sufficient indication that the mixer is either improperly gaged or that the cement feed is clogged. Whatever the trouble it must be corrected before the mixer is allowed to continue.

190. **Gravity Mixers.** — If the portable gravity concrete mixer is used, the manufacturer's instructions for its use must be adhered to, unless otherwise directed by the Engineer.

191. **Care of Mixers.** — Concrete mixers must be kept clean. Before stopping at the noon hour, the mixer must be thoroughly washed out and again at night, care being taken that no old concrete is left in it. Bearings must be kept in good condition, and where grease cups are used they should be screwed down once every two hours.

3. Hand Mixing

192. **In General.** — When the Engineer considers it impracticable to mix concrete by machine, it may be mixed by hand, in the specified proportions. The mixing shall be performed as expeditiously as possible and with the use of a sufficient number of skilled men. The Contractor will be allowed to use his own method of mixing, provided it gives the desired results. Mixing on the ground will not be permitted.

193. **Hand Mixing Subject to Approval.** — When from any cause resort to hand mixing is necessary, this shall be done thoroughly and to the satisfaction of the Engineer. Concrete mixed by hand can be used only by special permission of the Engineer.

194. **Hand Mixing for Reinforced Concrete.** — Hand mixing should be avoided for reinforced concrete work if possible, but when allowed in an emergency the inspection shall be rigid in order that the work be done deliberately and carefully. Hand mixing as done for ordinary mass concrete work will not do for reinforced concrete work. To secure good results the mixing must be thorough.

195. **Mixing Platform.** — A suitable platform shall be provided on which to do the mixing. The planking shall be tight enough to prevent leakage of water carrying cement. The platform shall be of sufficient size to accommodate men and materials for the progressive and rapid mixing of at least two batches of concrete at the same time. Batches shall not exceed

one cubic yard each. The mixing platform should be boarded off to prevent the wind blowing the cement away while it is being turned dry.

196. Proportioning Materials. — All material for concrete shall be accurately measured in suitable boxes. No counting by shovels or other approximation will be allowed. To determine the proper proportions, a barrel of cement weighing not less than 400 lbs. gross shall be taken as measuring 3½ cu. ft.

197. Method of Hand Mixing. — A correct proportion of gravel or broken stone shall be evenly spread upon the mixing platform, and in no case more than 8 ins. deep. In a suitable box, the correct proportion of sand and cement shall be mixed dry until the whole mass is one even color. The gravel or broken stone shall then be wetted and the mixture of dry sand and cement shall be evenly spread over it. Commencing at the corners, the men shall, with shovels, turn the mass over away from the center, and coming back, turn it to the center. In addition to the thorough wetting of the stones, if, in the judgment of the Engineer, it will be necessary, sufficient water shall be added to the mass by a rose-head sprinkler to enable the material to become thoroughly incorporated, and the process of mixing shall be continued until the surface of each stone is well covered with mortar.

Sand and cement must never be mixed up in advance, because the natural moisture which all sands contain will make the cement set and cake.

198. Hand Mixing: Alternate Method. — The sand shall first be spread in a thin layer on the platform, and the cement spread over this and the whole turned until homogeneous in appearance and color. The water necessary to mix a thin mortar shall then be added and the mortar spread again. The broken stone or gravel, which shall have been previously wet, shall then be added to the mortar and the whole turned until all the particles are coated with cement and the mixture is of uniform consistency. Or, at the option of the Engineer, the coarse aggregate may be added before, instead of after, adding the water.*

If the Contractor desires to use some other method, he shall submit it for approval.

199. Water for Mixing. — Water shall be moderately sprinkled on the material from a sprinkler nozzle, care being taken not to wash out the cement or to put on at any time an excess of water and to leave the concrete too dry rather than too wet. Water must not be dashed or thrown upon the mass in buckets or large quantities, or by means of a jet. Concrete should be wet to that degree that after thorough ramming the mortar will flush to the surface.

200. Natural Mixture of Sand and Gravel. — When a natural mixture of sand and gravel is used, the material shall be handled the same as sand,

* The method described in Par. 197 produces better concrete with less expenditure of labor than here described, and is to be preferred.

that is, it shall be spread evenly and, after the addition of cement, mixed dry and then wet.

201. Care in Mixing. — Mixing must be done on a clean mixing board. Special care shall be taken to prevent the incorporation of any dirt or foreign matter into the concrete. Care shall also be taken to keep the sand and broken stone or gravel in distinct and separate bins or piles. That is to say, the shovelers shall always maintain a clear space between piles. The mixing shall be conducted in a manner which will not permit of the loss of cement through the running off of surplus water.

202. Size of Batch in Hand Mixing. — The quantity of concrete in each batch shall not be greater than the quantity that, under the conditions, can be mixed and deposited in permanent position in the work before the cement begins to set. Batches shall not exceed one cubic yard, and smaller batches are preferable, based upon a multiple of the number of sacks to the barrel.

203. Number of Turns. — The number of times concrete should be turned over will depend upon the method of handling it, the nature of the sand and broken stone or gravel, also the amount of water added. Merely shoveling the material from one part of the platform to another will not be considered a proper method of mixing. The whole mass should be turned over with shovels at least three times (not counting the shoveling off the board), until thoroughly incorporated. With experienced laborers, the concrete should be well mixed after three such turnings; but if it shows streaky or dry spots, it must be turned again. The Engineer may prescribe the number of times the mixture shall be turned over, dry and wet, if he considers it necessary.* No particular number of turns will be held sufficient unless the result desired be accomplished.

204. Order of Turning Materials. — The order of turning must be so regulated that the last turn made will place the material in a single pile at or near the center of the board, preparatory to its removal to the place for it in the work.

205. Removal of Concrete from Platform. — In removing the concrete from the platform, care must be taken to preserve the incorporation, which can best be done by shoveling it from the base at the edges of the pile toward the center of it, and at the same time cutting down the apex of the pile with a hoe or shovel, in such manner as to avoid an accumulation of loose stones.

206. Cleaning Platform. — At night the mixing platform shall be left clean and if any mortar or concrete is not used it shall be thrown out to prevent it from being remixed again in the morning.

207. Tools for Hand Mixing. — In mixing by hand the men shall be provided with long-handled, square-bladed shovels, as they can reach the

* Specifications are most likely to be ambiguous concerning the number of turns required, and as to what constitutes a turn. There should, therefore, be a definite understanding on these points.

center of the pile better and will not tire themselves as with a short-handled shovel. The use of a rake or hoe will be permitted in mixing sand and cement but not after stone has been added.

208. Mixture of Mortar Having an Excess of Water. — Any mixture of mortar having an excess of water (of which the Engineer or Inspector shall be the judge) will be rejected, and must be removed from the platform and evenly spread on top of the finished concrete, where and as directed, or if, in the judgment of the Inspector, it may be used in the concrete, it shall be his duty to see that at least two or more measures of broken stone or gravel are omitted from the batch.

209. Removal of Mortar from Platform. — If any mortar is removed from the platform for any purpose, the Inspector's duty is to see that at least one or more measures of broken stone or gravel are omitted from the batch. Mortar required for other purposes should be prepared separately, as each batch of concrete must have its full proportion of cement.

Art. 7. Bibliography of Specifications for Proportioning and Mixing Concrete

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CHAPTER III

FORMS AND CENTERING
(Falsework)

Art. 8. Design of Forms and Centers

1. Design of Forms

210. In General. — Forms shall be so designed that the concrete will conform to the proper dimensions and shapes. They shall be simple of construction, and easy of erection, maintenance and removal; and shall be so designed as to be safely removable without the removal of their supports and must be of sufficient strength to support the material until firmly set.

211. Rules for Designing Forms. — Rules for designing concrete forms are difficult to deduce as every structure has its own peculiarities; the amount of concrete deposited in the form, if wet, or dry, if deposited by hand mixing or machine mixing from a board or from dump buckets, all influence the design. Forms have been built which were perfectly safe with a dry mixture shoveled off a board, but which needed rebracing when the concrete was wet and was dumped from buckets.

212. Proportioning Forms. — All forms shall be so designed and constructed so as to carry four times the dead load of the concrete and steel reinforcement.

All forms and supports for forms shall be designed to carry safely the following loads:

213. Dead Load. — The dead load shall consist of the calculated weight of the forms and the concrete, the liquid concrete being assumed to weigh 150 lbs. per cubic foot.

214. Live Load. — The live load on forms shall be taken at 75 lbs. per square foot upon slabs and 50 lbs. per square foot in figuring beam and girder forms, and struts.

215. Wind Pressure. — Forms shall be designed to withstand safely a wind pressure of 20 lbs. per square foot upon all surfaces exposed to the wind.

216. Pressure of Concrete on Forms. — In proportioning forms, concrete will be treated as a liquid of its full weight for vertical loads and one-half its weight for horizontal pressures.

217. Unit Stresses. — The allowable compression in timber struts shall be from 600 to 1200 lbs. per square inch, varying with the ratio of the size of the strut to its length. Extreme transverse fibre stress in timber beams shall be assumed at 750 lbs. per square inch.

218. Size of Forms. — The forms shall be designed in as large sections as can be conveniently handled.

219. Removal of Forms. — All forms must be designed so that they may be removed with as little injury as possible to the concrete or to the forms.

220. Deflection of Beams and Girders. — Beam and girder forms must be stiff enough so that their deflection as the weight increases will not cause partial rupture of the concrete or sagging of the beam. The maximum deflection allowable is $\frac{1}{8}$ inch.

221. Design and Location of Shores. — Forms shall be so designed as to permit the shores to remain in place while and after removing forms on columns, beams, girders and slabs. The design and location of shores shall be as carefully executed as the rest of the form work. Shores shall be located at mid-span, one-third span, quarter-span, etc., points. Shores in each story shall come directly over shores in the story below. At the top of the shores or struts, provision shall be made against crushing of the wood plank or cross-piece. Brackets or hard-wood cleats shall be used where the compression exceeds 700 lbs. per square inch across the grain of the strut.

All supports shall be calculated as to their safe carrying capacity and no support less than three (3) inches thick on its smallest dimension will be allowed.

222. Approval of Form Details. — Complete drawings of the forms showing the manner of supporting and bracing with a description of the various materials to be used shall be submitted by the Contractor to the Engineer, free of cost to the Owner, and no work shall be done on the construction of the said forms until said drawings have been approved by the Engineer. The approval of these drawings or sketches shall not be final or place any responsibility upon the Owner, and in case the Engineer deems it advisable, the manner of supporting and bracing can be changed if the manner first approved has been tried and found defective.

2. Design of Arch Centers

223. In General. — Arch centers shall be so designed that the arch will conform to the proper dimensions and shape.

224. Pine. — Merchantable long-leaf pine lumber shall be used throughout, unless otherwise noted.

225. White Oak. — Sills, corbels, wedges and all other lumber subjected to side pressure shall be of white oak. The wedges shall be of straight grain oak only.

226. Grade. — (See Par. 237, page 53.)

227. Unit Stresses. — Unit stresses in all material for the centers will be computed on the basis of one-fifth of the breaking strain of the material used, in accordance with the tables of Messrs. Kidwell & Moore for wooden beams and columns, 1899.

228. Deflections. — In the design of the center care shall be taken so that the center will be stiff. The joists, caps and bows shall not have a deflection exceeding $\frac{1}{4}$ inch under the full load of the arch, or the partial load of the arch, the concrete being figured as a liquid having a weight of 150 lbs. per cubic foot. Lagging shall have a deflection under the full load of the arch of not more than $\frac{1}{8}$ inch.

229. Joints. — No dependence will be placed in nails, except for fastening the lagging, for securing the wedges and for minor details, and then only upon the approval of the Engineer.

230. Settlement. — The settlement of the center under full load shall not be greater than $\frac{3}{4}$ inch for each 30 ft. in vertical height.

231. Foundations. — The foundations for the centers shall be of concrete of the same kind and according to the specifications hereinbefore specified for the permanent work. They shall be of such size as will not permit of a settlement greater than $\frac{1}{4}$ inch under the maximum loads they are designed to carry.

232. Bows. — The Contractor will not be allowed to use centers having trussed spaces greater than 20 ft., but must carry posts down from the bow to suitable foundation. Bows in no case shall exceed 6 ft. 6 ins. on centers. They shall be stiffly sway-braced, both transversely and longitudinally.

233. Preventing Distortion of the Arch. — The tendency of the centers to rise at the crown as they are loaded at the haunches must be provided for in the design, or if not the centers must be temporarily loaded at the crown and the load so regulated as to prevent distortion of the arch as the work progresses.

234. Wedges. — When wedges are at the tops of posts, they shall be placed at right angles to the length of the cap. Wedges at or near the top shall not be loaded with more than 15 short tons per wedge. At the bottom they shall not be loaded to more than 20 short tons. Wedges shall be of hard oak with a bevel of 1 : 5 to 1 : 10, preferably the former.

235. Sand Boxes. — If the Contractor wishes to use sand boxes to lower the centers, he shall submit details of the same for the approval of the Engineer.

236. Approval of Centering Details. — Complete drawings of the centers with complete description of the various materials to be used shall be submitted by the Contractor to the Engineer for his approval. This approval, however, will not relieve the Contractor from any risks or responsibility for accidents attending faulty design or construction of such centers.

Art. 9. Fabrication and Erection of Forms and Centers

1. Lumber for Forms and Centers

237. **Grade.** — The lumber for forms or centers shall be of such quality, size and finish that there is absolute stability and perfect work at all times. It shall be adopted to the structure and to the kind of surface required on the concrete. That is to say, lumber used for forms shall be adopted to the kind of service required of the concrete.

238. **Quality of Lumber.** — The lumber shall be free from decay, splits, wind-shakes, sawed true and out of wind, and square-edged, full-sized, free from large or loose knots or any other defects which would seriously impair its strength or durability. The lumber shall not be so dry that when soaked by the concrete it will swell so as to bulge and distort the forms, not so green that it will shrink so as to leave open joints. No warping or splintered lumber shall be used. All lumber shall be subject to the approval of the Engineer.

239. **Kind of Lumber.** — White pine, yellow pine, spruce, Oregon pine and redwood are suitable for forms. White pine should be used for ornamental work. Hemlock is unreliable and should be used only when absolutely necessary.* Oak is hard to nail, expensive and imprints grain marks on the concrete even when the form is well wetted.

240. **Size of Lumber.** — The size of the lumber shall be such that it will not deflect, bulge or warp under the loads imposed upon it. Forms shall in general be composed of tongue and grooved sheeting, if $\frac{7}{8}$-inch sheeting is used, or carefully matched stuff if heavier sheeting be used. Lumber shall be straight and true and of even thickness. Wide boards shall not be used for sheathing for the reason that they curl and split badly.

241. **Exposed Surfaces or Facework.** — The form boards used on all exposed surfaces shall be of dressed lumber and closely fitted in order to secure the best results in appearance and surface of the finished work. The lumber for facework shall be surfaced on one side and two edges and dressed on the face side to even thickness.

242. **Undressed Lumber.** — For backings and other rough work undressed lumber may be used. Undressed lumber shall be used where the concrete is to be plastered. In other words, forms for non-exposed surfaces may be rough lumber, but shall be water-tight.

243. **Use of Old Form Lumber.** — Form lumber which has been previously used shall be cleaned before the lumber is again built into forms, and, if necessary, the sides and ends shall be freshly jointed so as to make a perfectly smooth finish to the concrete.

244. **Inspection and Rejection.** — The lumber shall be inspected when received, and any lumber unfit for use in forms shall be rejected immediately,

* It is best not to use hemlock in any case. Hemlock when exposed to the weather for even a short time becomes absolutely unreliable.

2. General Requirements

245. **In General.** — The Contractor will be required to furnish all plank timber, braces and tie rods, or other material required in construction of forms for concrete work, for which no allowance will be made, nor for any scaffolding, nor centering on arches (except when necessary to use trusses), nor other timber used in concrete construction, except such as is necessarily left in the work, the cost of all such material being included in the contract price per cubic yard of completed work.

All forms for work under this contract shall be provided under the items requiring the placing of concrete.

246. **Type of Forms.** — The Contractor may use such type of forms as he may desire, if in the opinion of the Engineer the proper results will be obtained, but if it is apparent to the Engineer that the forms are not properly constructed so as to give the desired results, the Contractor shall make such changes as the Engineer shall deem necessary to give satisfactory results.

247. **Steel Forms.** — Steel forms shall be of acceptable design. They shall be so rigid as to permit making the faces practically true planes in conformity with the plans, with a variation of not more than ¼ inch.

248. **Old Forms.** — Although new forms are not required for this work, the Engineer shall, however, have the privilege of rejecting any forms which are not deemed in proper condition to be used.

249. **Economy in Form Construction.** — Forms shall be constructed with a view to economy in taking down rather than cheapness in erecting or in first cost. Greater economy will result in using forms over and over again, than in using poor lumber which rips to pieces when taken down.

250. **Workmanship.** — Forms shall be constructed by experienced and capable workmen only, and must be of first-class workmanship throughout. All forms shall be made, put up and removed in a manner satisfactory to the Engineer. In other words, all forms shall be approved by the Engineer before concrete is cast and must be put up to his entire satisfaction and under his direction.

251. **Loads on Forms.** — All forms shall have ample strength to support properly the loads they are called upon to carry. Loads on forms shall be restricted to those for which the forms are designed. These loads shall comprise the weight of the concrete and such necessary construction loads as the weight of workmen, runways, wheelbarrows, etc. Storage of construction materials for future use on the forms shall not be permitted under any circumstances.

252. **Massive Concrete Forms.** — In constructing all forms of concrete masonry, the casings or molds shall be substantially built of planks sufficiently heavy (in general 2 ins. thick) to hold the concrete. These planks

must be surfaced on two edges and one side so as to be of uniform thickness. They must be neatly fitted together so that the mortar face shall be as smooth as possible, without showing the ends or edges of the planks.

In order that the faces of the masonry may be true, the sides of the forms must be firmly braced and secured by rods or wire extending through the concrete. On the removal of the forms, all such wire and tie rods must be cut off at least 1 in. beneath the surface, and the holes neatly filled with mortar.

253. **Fabrication of Forms.** — All measurements shall be accurate, the lines true and square, the joints close, and the finish shall be done in a neat and workmanlike manner. A maximum variation of $\frac{1}{4}$ inch only shall be permitted from the sizes shown on the drawings. Forms shall be finished to the exact height on top. Particular attention shall be given to the piecing out of beam boxes, the alteration of column forms, etc. All forms shall be arranged so as to be taken down in proper order without injuring the concrete.

254. **Exposed Surfaces (Use of Sheet Metal).** — Forms shall present to the concrete on the surface afterwards exposed to sight a perfectly smooth surface, to be obtained by covering such portions of the forms with sheet metal, or by carefully planing the wood.

255. **Water-tight Joints.** — All joints in forms shall be fairly tight, being close enough to prevent leakage of the liquid mass which will bleed the concrete of any material portion of its contents. In other words, the forms shall be built as nearly water-tight as practicable, to prevent the escape of mortar.*

256. **Covering Cracks in Forms.** — Cracks in forms may be covered with sheet iron, but the use of paper will not be permitted.

257. **Improving Edges in Joints of Forms.** — In all cases where it is evident to the Engineer the joints between the individual boards of the forms will provide an excessive roughness, or unsightly board marks, in the exposed concrete, the edges of said joints of the forms are to be removed and be replaced or otherwise improved and repaired satisfactory to him before concreting. In case two or more end joints in adjacent planks are in the same vertical plane, special precautions shall be taken to prevent a lip or fin on the concrete.

The edges of the plank should be dressed with slight bevel, so that the planed surface is the widest; this is done to insure a tight form.

258. **Exposed Concrete for Particular Work (Smooth Forms).** — All exposed concrete (unless otherwise specified) shall be made the subject of extra care; the forms are to be made of new dressed T & G lumber free from knots and split edges with all joints driven tight and securely nailed

* The joints in form construction should be close — especially where a wet mixture of concrete is used, though the best results are not always obtained by using matched boards. The moisture sometimes causes the wood to swell, and when they are driven up tight there is a tendency to buckle which sometimes results in poor work.

and all imperfect pieces removed or properly repaired. Joints shall be made perfectly flush after they are built in place by planing off any unevenness or projections that occur, and any openings at joints or corners, or any knot holes or other voids, shall be plugged flush with some stiff plastic substance such as clay mixed with plaster of Paris or sand. No tin patching will be permitted. All face boards shall start horizontally and be kept horizontal by drawing the boards down with a wedge, and each board shall be securely nailed to every stud.

In other words, all forms for concrete surfaces that will be exposed to view, from the outside, shall be of planed new lumber, and shall be renewed as often as necessary to secure smooth, finished surfaces for the concrete, special attention being given to the joints and edges of the plants where they are in contact.

259. **Lagging and Studs.** — Studs shall be of sufficient size and so spaced as to prevent the lagging from springing between studs. The lagging shall be surfaced, of uniform thickness and suitable width, and of selected material, and the edges surfaced so as to form tight joints when put in place, the object being to obtain concrete structures with even surfaces and true alignment. All lagging shall be tongued and grooved, unless otherwise specified, and the studding for all the work shall be dressed or sawed to an even thickness in order that the alignment may be perfect.

If $\frac{7}{8}$-in. lagging is used the studs shall not exceed 18 ins. on centers, and if 2 by 8-in. studs are used the wales shall not be less than 8 by 8 ins. These wales on a basis of 2 by 8-in. studs shall not be further apart than 8 ft., nor shall the bolts which hold them and which will have dimensions of $\frac{3}{4}$ in. be further apart than 8 ft.

The planking forming the lining of the forms shall invariably be fastened to the studding in perfectly horizontal lines, the ends of these planks shall be neatly butted against each other, and the inner surface of the form shall be as nearly as possible perfectly smooth, without crevices or offsets between the sides or ends of adjacent planks.

260. **Bolts and Sleeve Nuts.** — All forms, except by the consent of the Engineer, shall be held in place by means of bolts, so made that the outer 3 ins. of the bolts can be removed after the forms are taken down, and the remaining holes shall be filled with 1 : 3 mortar. This may be accomplished by sleeve-nut connections which will permit the removal of the projecting ends of bolts or rods, etc., leaving only small holes in the concrete which can be stopped with mortar in the above proportions.

Washers shall be used under all bolt heads and nuts, and before proceeding with the concrete work forms shall be brought true to line and grade and all bolts shall be taut.

261. **Use of Spikes and Nails.** — Spikes and nails shall be used sparingly. Generally the forms are to be securely held together by the use of clamps and braces. The forms shall be built so that they will draw free without

the use of long levers and sledges. Nails should be driven only part of their full length, so that they can be freely gripped and pulled.

262. **Wire Ties.** — Wire ties shall be used freely to secure forms against pulling apart.

263. **Steel Clamps.** — Adjustable steel clamps for clamping and adjusting forms shall be built on practically indestructible lines, giving rapid readjustment in all classes of forms. Clamps shall be removed without the use of crowbars, hammers or other tools. Heavy C clamps shall be used freely to secure forms against pulling apart.

264. **Bracing of Forms.** — All forms shall be securely braced to withstand the loads that come upon them and to preserve their alignment. Braces shall be firmly fixed at the foot and top, and as many braces and supports shall be used as may be necessary to prevent deflection from the working of the concrete. That is to say, the posts and braces shall be of sufficient strength to make a practically unyielding support to the sheathing. All form work, centering and supports must be properly braced and cross-braced in two directions. Ample bracing must be provided against danger from severe storms. In other words, all uprights must be braced in such a manner as to constitute a stiff frame work capable of resisting the action of the wind.

265. **Methods of Bracing Forms.** — Several optional methods of bracing forms for heavy concrete work will be considered such as the Contractor has previously used.

1. With outside inclined braces, leaving the interior of the form unobstructed.
2. Tie rods across the interior of the form connecting opposite posts at frequent intervals.
3. Each post trussed vertically and tied across at top and bottom only.
4. Horizontal trussed wales outside of posts, spaced from four to five feet apart in the vertical and tied across at the ends.

266. **Inclined Braces.** — If thin braces are employed, they shall be in pairs, one on either side of the vertical post, and made to act together by cross-pieces nailed to the two planks.

267. **Bracing Forms with Cross Ties.** — Another method of bracing forms is to construct them with cross ties between the front and back, these ties to be placed at frequent intervals above the lower portion of the form and to be removed as the concrete is built up, the studding out of which the forms are constructed being sufficiently long to extend above the top of the finished masonry, and at least one set of ties being used above this level.

268. **Arrangement of Building Forms.** — The arrangement of forms and centering shall be such that the slab centering and sides of beams, girders and column forms can be removed first, and then allow the bottoms of beams and girders to be supported for a longer time. (See Secs. 4 and 5.)

269. Swelling of Forms. — Forms shall be so framed that swelling will not fracture the concrete or prevent easy removal. Care must be taken to prevent work from being thrown out of plumb by swelling of lumber in forms.

270. Construction of Forms. — Forms shall be so constructed that they can be removed without injury to the concrete, and that they can be erected accurately. Construction which necessitates the use of heavy crowbars or hand sledging to take the forms apart shall not be permitted. In other words, the forms shall be so secured at all parts as to permit their removal without danger of injuring the concrete in any way.

All forms shall be so constructed as to be readily accessible for inspection at all places and at all times and can be easily cleaned. Openings shall be provided in the forms at the proper places so as to permit of the ready inspection and cleaning of the spaces to be filled with concrete. All open joints shall be effectually stopped to prevent the escape of water so far as practicable.

The forms shall be so constructed, in all cases, as to leave, proper niches, grooves, openings and brackets in the concrete, for supporting the ends of the beams, edges of floors and ends of walls, etc.

Forms shall be substantial and unyielding, so that the concrete shall conform to the designed dimensions and contours.

271. Beveled Corners. — Corners of forms shall be beveled whenever possible, in order to facilitate their removal, and to improve the appearance of corners in the concrete. Beveled or rounded corners shall be made on all exposed angles by introducing the proper triangular strips or round-corner moulding pieces within the forms. All exposed corners shall be beveled unless otherwise required. The forms shall be so made that all corners of the concrete will be chamfered as directed by the Superintendent. In other words, wherever there is no conflict with specific details, salient angles will be filleted and reëntrant angles chamfered.

272. Square Corners (Alternate Clause).—Exterior angles shall be made square.

273. Water Drips. — Water drips on projecting ledges of abutment copings, window sills, etc., shall be formed by nailing a small half-round to the upper surface of the form a short distance back from the projecting face.

274. Expansion Joints.—Beveled strips of wood shall be inserted vertically (or horizontally as the case may be) at every expansion joint, leaving a notch 1½ ins. wide and ¾ in. deep, thus avoiding irregular and saggy contact.

275. Openings in Forms. — Cores must be provided in forms for wiring, pipe and for any other purposes, as directed by the Engineer.

All openings for conduits, wiring, piping, etc., to be provided for in placing the forms for the reinforced concrete work, as shown on drawings and as directed.

276. Forms Exposed to the Weather. — After the forms are built they shall not be allowed to stand long in the sun or be exposed to the weather before being filled with concrete. Forms likely to be exposed to the weather for some time shall be kept wet in order to prevent the form work from being twisted out of shape.

277. Alignment of Forms. — All forms shall be erected in exact alignment, both vertically and horizontally. Column and wall forms shall be plumb. Girder boxes and wall forms shall be without winds or twists and floor slab centers shall be level, etc. If the forms stand any considerable time between erection and time of depositing the concrete, the alignment shall be checked just before placing the concrete. The alignment shall also be checked after storms and high winds. The alignment shall be maintained during the placing of the concrete. In other words, the lines of all forms must be checked by the Contractor and be brought to the correct lines, immediately before concreting. Forms shall be provided with jacks or other suitable device to permit realignment during the progress of the work. Any extra expense incurred by faulty alignment or undue irregularities must be paid by the Contractor.*

278. Rigidity of Forms. — Forms shall be thoroughly braced or tied together so that the pressure of the concrete, or the movement of men, machinery or materials, shall not throw them out of place. Wherever, in the opinion of the Engineer, forms are not sufficiently stayed and braced or of sufficient strength in any way, the Contractor shall make such additions and changes as the Engineer may direct at the Contractor's expense. In other words, forms shall be amply strong to resist the pressure which will be brought upon them, namely, the ramming of concrete against their faces and the static pressure of the semi-fluid mass in the case of concrete laid wet.

279. Removing Forms for Finishing. — Where the surface is to be finished by scrubbing or other process requiring the concrete to be still green, proper provision shall be made, in the construction of the forms, for laying bare the concrete as fast as it reaches the required hardness.

280. Supply of Forms. — Sufficient forms shall be furnished by the Contractor to permit of pushing the work rapidly; and, if at any time the proper rate of progress is retarded by lack of forms, additional forms shall be provided. In other words, no delays caused by waiting for concrete to harden before removing forms will be permitted, and sufficient form material must be provided to allow the concrete work to progress without interruption.

281. Caulking of Forms. — If necessary to obtain a tight form, caulking with oakum, or other suitable material, may be required for which the Contractor shall provide suitable tools and materials. Caulking of ¼-in. Manilla

* Nothing can look worse than brackets, mutuals or pilaster caps which, while otherwise well wrought, are placed out of plumb due to carelessness in placing the forms and in supporting them.

twine may be used to make forms tight at joints if preferred by the Contractor or a plain joint may be made.

282. Fitness of Forms. — The Engineer shall be the judge of the fitness of the forms for use at all places and at all times, and his orders respecting the bracing, supporting and wiring, as well as the cleaning, soaping, redressing or replacing of the forms, shall be strictly followed. Deformed, broken, defective or otherwise imperfect centers or forms shall be repaired and made satisfactory or shall be removed from the work, as ordered by the Engineer.

282a. Inspection of Forms and Centers. — The Engineer shall, at all reasonable times, have access to the shop or other place where forms and centers are being made and shall be furnished with every facility for inspecting the same.

The inspection of forms by the Engineer during or after the process of construction or any suggestion of assistance furnished by the Engineer shall not be construed as relieving the Contractor of the entire or any part of the responsibility for the accuracy or sufficiency of any of said forms or for the satisfactory completion of the masonry to any extent dependent thereon.

283. Plumbing and Leveling of Forms. — All plumbing and leveling of forms shall be attended to by competent men.

284. Forms Left in Place. — Any forms left in place by direction of the Engineer shall be paid for by the thousand (1000) feet, board measure, of the completed form measured in the work.

285. Forms for Winter Concrete. — If concrete is done in freezing temperature the forms must have a light sheathing outside of the main vertical or horizontal beams or wales, or must be otherwise so arranged as to permit heating the main sheathing to a temperature of at least 35° F., and maintaining this temperature until the forms are removed and the finish completed.

286. Metal Covering for Forms. — Covering wooden forms with metal should not be permitted, as the metal readily breaks and tears when removing, and if the form is strained in the handling the metal covering makes it harder to put back in shape. If metal is necessary to permit easy removal or to give the concrete surface a smooth finish, a complete metal form should be specified.

287. Approval of Form Details. — The Contractor will be held to have carefully estimated on good and sufficient form work. All details for forms shall be submitted to the Engineer for his approval before starting the work, but such approval will not release the Contractor from any responsibility for the safety of his work and the work of other Contractors.

288. Protection of Form Work. — The Contractor will be required in all cases to use proper care and diligence in building his forms, and in keeping same plumb, straight and true and in bracing and securing all parts of the work against wind, storm and frost, in as much as they may interfere with the stability and perfection of the work; also in all cases to judge as to the amount of diligence and care required for the same.

289. **Removal of Forms.** — Contractor shall not remove forms for concrete work until the concrete has set up to the satisfaction of the Engineer. (See Art. 10, page 69.)

290. **Rejection of Forms.** — Should the forms lose their proper shapes and dimensions or should the surfaces become unduly roughened or dented, satisfactory forms shall be substituted. In other words, forms or centers shall be replaced by new ones when they lose their proper dimensions or shape, deformed or defective forms being removed from the work.

291. **Inclusive Price.** — The price bid for concrete construction shall include the furnishing of all form and bracing lumber, unless otherwise specified.

291a. **Carpenter Foreman.** — The Contractor shall place in charge of the erection of forms and centers a man who has had extensive and responsible charge of other work of this class and who can give references, as to ability and experience, satisfactory to the Engineer. No foreman lacking the required experience in this line, on high-grade work, shall be allowed upon the work.

3. Wall Forms

292. **Fabrication of Wall Forms.** —The forms for all walls shall be of lumber planed on one side and double edged. One edge shall be slightly beveled. This beveled edge shall be placed against the straight edge of the next plank and driven to form a tight joint with an even surface. All forms shall be studded carefully to avoid bending of boards between studs. For certain parts of the work below ground the faces of the forms or moulds may be of rough or unplaned timber. The arrangement of edges and corners of walls which are to be exposed upon completion shall be carefully maintained.

292a. **Tongued Joints.** — Wherever shown on the plans, or permitted by the specifications, or directed by the Engineer, the ends of walls abutting against one another shall be finished against proper forms, built so as to form a tongued and grooved joint.

293. **Erection of Wall Forms.** — Wall forms should be made and erected in units. Wall ties, either bolts, wire or steel shall be put through at right angles, or square with the wall, otherwise the forms will be " skewed " and shall be of an approved design such that no ironwork is left exposed on completion of the wall.

294. **Interior Support of Wall Forms.** — Wooden struts, concrete struts or wiring shall be used for supporting wall forms from the interior while filling, and shall be so spaced as to prevent distortion. The struts must always be placed where the sheathing is supported by a stud and the wire

should loop the stud, then by twisting the wire with a short bar the forms can be drawn and held rigidly in place during filling. When the concrete has been placed to the level of the strut, it can be removed and the weight of the concrete will then hold the forms apart.

On removal of the forms the wires shall be cut close to the concrete, the edges stove in with a punch and the surface smoothed over.

295. Exterior Bracing of Wall Forms. — The forms, in addition to the interior bracing, must be braced on the outside. This will generally be accomplished by bracing to the earth or to adjoining structures. The exterior bracing must be relied on for holding the forms to alignment.

Care must be exercised to prevent forms from lifting during filling. In a wall section which has considerable batter, a hook made of reinforcing steel, imbedded in the foundation, may be used to tie the forms, the tie being made with No. 8 wire.

In trench work where there is sufficient depth the upward or side movement of forms shall be cared for by bracing to the sides of the trench.

296. Wire Ties and Spacers. — All wire ties for wall forms shall be in place and made taut so as to pull the sides close against the spacers. All spacers shall be removed from the forms as soon as the concreting reaches them. The projecting ends of all wire ties used to hold together the sides of wall forms and left embedded in the concrete shall be cut off deep enough to keep rust spots from showing on the face of the wall. No. 8 wire will fulfill the requirements of most work.

297. Concrete Wall Spacers. — When the space between forms is so narrow that the removal of struts becomes a troublesome task, concrete struts may be substituted. Concrete struts shall be placed in the same manner as wooden and shall be broken with a tamper when the concrete is placed to the proper level, or if they have been cast with a water stop, they will be permitted to remain in the wall. Care shall be taken to prevent a void immediately under the strut. If required by the Engineer, struts shall be broken in order to prevent this possibility. Care must be exercised to avoid a water channel along the side of the strut.

298. Concrete Spacers for Important Walls. — Where the appearance of exterior surfaces on the walls is of great importance, concrete spacers shall be used, composed of the same quality of concrete as the rest of the wall. These spacers shall be about 2 ins. by 2 ins. by thickness of wall with a longitudinal hole $\frac{1}{8}$ inch larger than the bolt to be used.

299. Bolt Ties and Spacers. — Bolts shall be tightened against spacers set between the two sides of the forms inside. Bolts shall preferably be enveloped inside the forms with sleeves or thoroughly greased, otherwise the bolt will stick and can be drawn out only by wrenching and injuring the concrete. Care shall be taken to construct forms in such a way that tie-rods will not come closer than 4 ins. to a projecting corner or other detail or the concrete may be spalled off in pulling them.

300. **Projecting Ends of Wire Wall Ties, etc.** — All projecting wires, bolts or other devices used for securing wall forms and that pass through the concrete shall be cut off at least one (1) inch beneath the finished surface and the ends covered with cement.

301. **Removal of Tie Rods.** — When it is desired to withdraw bolts or rods used to support thin wall forms, they shall be thoroughly greased or wrapped with stiff paper before the concrete is placed.

302. **Tie Rods Left in the Concrete.** — When specified that tie rods are to be left in the concrete wall, they shall be provided with sleave nuts near the end, which, when unscrewed, will leave the end of the rod within the wall not less than two inches from the face. The hole left by the nut shall be carefully filled with 1 : 3 mortar after the forms are removed.

303. **Interchangeable Panel Forms.** — Interchangeable panel forms shall not be used for any wall forms where finished work will be exposed on interior, or above grade on exterior. Such forms may be used elsewhere only with the express permission of the Engineer.

304. **Outriggers.** — Outriggers for staging on which to handle curtain walls shall be of at least 2 in. by 10 in.-planking, placed on edge.

305. **Foundation Walls.** — Forms shall be constructed for foundation walls in case the earth shall not stand plumb in the excavation.

306. **Alignment of Wall Forms.** — The alignment of edges, corners and sides of walls shall be carefully preserved by frequent tying and bracing the forms and by the use of heavy stringers or rangers. (See Sec. 2, page 59.)

306a. **Sloped Wing Walls.** — Where wing walls are called for which have slopes corresponding to the angle of repose of earth embankment, these slopes shall be finished in straight lines and surfaces, the form for such wing walls and slope being constructed with its top at the proper slope, so that the concrete work on the slope may be finished in short sections, say from three to four feet in length, and bonded into the concrete of the horizontal sections before the same shall be set, each short section of sloped surface being grooved with a cross line separating it from the adjacent sections. The Contractor will not be permitted to finish the top surface of such sloped walls by plastering fresh concrete upon the top of concrete which has already set, but the finished work must be made each day as the horizontal layers are carried up, to accomplish which the form must be constructed complete at the outset, or if the wing wall is very high, short sections of the form, including the form for slopes, must be completed as the horizontal planking is put in place.

4. Column Forms and Braces

307. **In General.** — Column forms shall be so constructed as to permit of their removal without disturbing the beam or slab forms. All forms are to be held together by bolts or strong wire, so spaced as to prevent any distortion. They are to be held apart with separators which can be easily

removed as the work progresses, or which may be incorporated in the concrete without injury to it.

308. **Opening at Bottom of Forms.** — An opening shall be left at the bottom of all column forms for cleaning and for adjusting the steel reinforcement. This opening shall not be closed until all is in readiness for pouring the columns.

309. **Fabrication of Column Forms.** — Column forms shall be made up with plank not less than 1½ ins. thick and stayed at intervals of not more than 18 ins. vertically between bands or straps and shall fit closely at the corner joints. Outside dimensions given on column schedule must be adhered to.

310. **Beveled Strips.** — All column forms shall have diagonal or bevel strips in the corners, unless the corners of columns are protected by metal strips, otherwise they are likely to be chipped off. It is also difficult to so tamp the concrete as to make the corners perfect.

311. **Spacing and Squaring Column Forms.** — All column forms shall be accurately spaced in all directions and shall be set square with the lines laid down on the plans. Great care must be taken in starting the erection of a new set of forms to keep the column spacing perfect and centered over construction below.

312. **Alignment of Column Forms.** — Rigid care must be exercised in seeing that all columns are plumb and true, and thoroughly cross braced to keep them so. (See Sec. 2, Par. 277, page 59.)

5. Beam and Slab Forms

313. **Beam and Girder Forms.** — All beam and girder bottoms shall not be less than two-(2) inch stock, sized, and shall be supported at close intervals to prevent deflection and to obtain a perfectly true lower surface.

The sides of beam and girder forms shall be splayed slightly in order that they may be readily removed and shall be held tightly together by wedges or clamps, to prevent the pressure of the concrete springing them away from the bottom boards.

314. **Diagonal or Bevel Strips.** — All beam and girder forms shall have diagonal or bevel strips in the corners. Triangular strips shall be tacked along the corners of the forms as a fillet to cut off the corner by a plane making equal angles with the adjacent faces.

315. **Camber of Beam Forms.** — All beam and girder boxes shall be given a camber of ½ inch for every 10 feet of span in order to provide for settlement under load. The bottoms of all beam and girder forms must taper off uniformly to each end and they must be rigidly to this line.

316. **Slab Forms.** — All slab forms shall be well braced to prevent any sagging. Joists for slab forms shall be not less than 2 ins. by 8 ins., 24 ins. on centers held up with a line of supports down center line. Where joists

abut on beam forms, wedges shall be used. Tight fitting except by the use of wedges shall not be resorted to. No spliced joists shall be allowed at any point.

317. **Bracing Floor Forms.** — The shores shall be stayed along the line of the joist at the top and longitudinally and transversely midway for stories ten to twelve feet in height.

318. **Removal of Sides of Beam Forms.** — Beam and girder forms shall be so constructed as to permit of the removal of the sides before the bottom is disturbed in order that the condition of the concrete can be examined.

319. **Placing of Shores.** — Shores shall be set up and do their duty without hard driving, which is sure to injure the setting concrete under them.

320. **Extra Shores.** — Additional shoring shall be provided when necessary in order to prevent sagging of forms when receiving concrete.

321. **Length of Shores.** — Shores shall be cut to proper length for the work, the length being such that the cap and footing pieces can be placed and the double wedges can be started and tightened.

322. **Square Ends on Shores.** — The ends of all shores shall be sawed off square so as to have uniform bearing on wedges.

323. **Wedges.** — Wedges shall be used to obtain the correct adjustment of shores and shall be loosened and removed without producing undue strains in the floor system. Wedges should preferably be on the floor at the bottom of the uprights, where they will be accessible when adjustments are necessary. After leveling up forms, the wedges shall be nailed so that there will be no slipping.

All wedges shall be so constructed that the outside surfaces of any two wedges will be parallel.

324. **Footings for Shores.** — If the concrete floor is comparatively green, the load must be distributed by blocking, preferably of hardwood. No shoring shall be erected over soft ground or concrete less than a week old, without a footing block of ample size to properly distribute the load.

325. **Caps for Shores.** — The shores shall be properly capped with plank or scantling to distribute the pressure.

326. **Covering Slab Forms with Paper.** — Forms under floor slabs may be covered with rosin-sized sheathing paper lapped one inch at joints and tacked in place.

327. **Openings in Girder Forms.** — Leave a pocket in the bottom of girders and where necessary to clean out chips, etc., after the columns are poured.

327a. **Wire Hangers.** — Wire hangers may be used for centering for concrete floors that are laid between structural floor beams and girders. They may be used to attach to metal furring for wire lathing. Holes should be bored in the slab forms $\frac{1}{8}$ in. larger than the wires, in order to take down forms without injuring them.

6. Arch Centers

328. **In General.** — Suitable forms shall be constructed to hold in place sections of arch ring being concreted. If the concreting is done in longitudinal sections, the forms shall be set vertical and parallel with the face of the arch. If the concreting is done in transverse sections, the forms shall be set in radial planes and straight across the arch at right angles to the faces.

329. **Settlement.** — The crowns of the centers shall be raised above the intended height of the finished arches to allow for settling when the centers are being loaded and when struck. An allowance for settlement should be made equal to $\frac{3}{4}$ in. for each 30 ft. vertical height.

330. **Rigidity of Arch Centers.** — Arch centers shall be perfectly rigid so that the arch will not be stressed in the slightest degree before the concrete attains a perfect set. That is to say, the centering must be rigid during the construction of the arch and stiff enough to prevent its distortion from the unsupported weight of the concrete before the keying of the arch.

331. **Striking Arch Centers.** — Suitable means shall be provided for striking or lowering the center without injuring the surface of the concrete and without straining the arch. The centers may be provided with striking wedges or sand boxes so that the lowering of the center may be effected slowly. Jack-screws also may answer the same purposes as wedges or sand boxes. Centers in all cases must be dropped away from the arch readily.

332. **Bolting Centers.** — In constructing centers for arches of more than 30 ft. span, no reliance shall be placed upon spiking, but all main members must be bolted together at joints.

333. **Lagging.** — Lagging shall be of an even thickness and made smooth to give a good surface to the soffit of the arch. The lagging for the center may be in two or more thicknesses if the Contractor so desires; but the top layer shall be tongued-and-grooved lumber, and the lower layers shall be dressed to match the top surface when in place. With thin lagging care shall be taken to prevent deflection.

334. **Wedges.** — All wedges shall be so constructed that the outside surfaces of any two wedges will be parallel. Wedges shall have a slope or batter of 1 to 10, and the pressure on the same shall not exceed 300 lbs. per square inch. The grain of same shall run with the slope and their contact faces shall be planned true and smooth for their entire width and length, and if so ordered by the Engineer, they shall be lubricated to facilitate the striking of the centers without unnecessary jar.

335. **Sand Boxes.** — Sand boxes shall be waterproof and the sand used in the same shall be thoroughly washed to remove all silt and thoroughly dried before using. Care must be taken to keep the sand dry during the entire construction. The sand in these boxes must be thoroughly packed

to prevent settlement of the concrete before setting. The sand may be readily removed by letting it out through a hole in the box.

336. **Foundations.** — Substantial foundations shall be provided for the center.

337. **Workmanship.** — All carpentry work shall be the best class of heavy timber work. Care shall be taken to see that all saw cuts are true, and surfaces of abutting timbers shall be adzed off to make a snug fit.

338. **Shimming Joints.** — Just before the centering is loaded it shall be inspected and all joints which have opened up shall be shimmed tight, using shingles or thin wedges. During the construction of the arch similar wedging shall be done, as the settlement of the falsework may open joints.

339. **Payment.** — The centering shall not be paid for directly, but the payment of the same shall be included in the price for the arch concrete in accordance with the schedule of prices hereinafter to be determined upon.

7. Ornamental Molds

340. **Construction of Molds.** — Iron molds for concrete newels, finials, rails, balusters, spindles, balls, cap and bases for piers, etc., shall be so constructed as to be easily operated with perfect results without the use of unusual skill. They shall be so constructed as to be removable piece by piece without injuring the casing.

341. **Workmanship.** — Molds shall follow out the absolute perfection of architectural lines and artistic appearance.

342. **Sectional Molds.** — All molds made in sections shall be carefully fitted and shall be equipped with locking and squaring devices, which will accurately bring all molds into perfect alignment.

343. **Rigidity of Molds.** — Molds shall have ample strength and rigidity to withstand tamping and other strains without distortion.

8. Miscellaneous Forms

344. **Forms for Dams.** — On upstream face of dam, forms need be only smooth enough to give good substantial work, free from voids. On crest and downstream face, forms must have planed surfaces, so as to leave the finished work smooth.

345. **Conduit Forms.** — In order to prevent the rolling of conduit forms, care shall be taken in filling to keep a uniform level on both sides of the barrel.

346. **Anchoring Batter Forms.** — Forms for retaining walls shall be firmly anchored down to resist the up-thrust or floating effect of the semi-liquid concrete.

346a. **Sidewalk Forms.** — Forms shall be placed in the manner necessary to outline both external edges of the walk accurately, the top of the frames being located to coincide with the established grade of the walk. The forms must be well staked to the established lines and grades and be free from warp and of sufficient strength to resist springing out of shape, i.e., 2 ins. thick by about 5 ins. wide.

At each slab division, cross-forms shall be put in the full width of the walk and at right angles to the side forms. They should be made of ⅛ inch metal with stiffeners of the same thickness on the ends and top.

9. Cleaning and Wetting of Forms

347. **Cleaning Forms.** — Forms shall be carefully cleaned of all sawdust, dirt, chips, ice and other foreign matter before placing concrete, and whenever necessary, forms shall be cleaned out by steam jet or equally effective means. The cleaning shall be done just previous to placing the concrete. Adequate measures shall be taken to prevent the adhesion of mortar to the forms. Especial care must be taken to prevent sawdust from lodging in the beam boxes and in the column boxes.*

348. **Previous Use of Forms.** — All forms having been previously used shall be thoroughly cleaned and prepared before being used again.

349. **Wetting of Forms.** — All forms, if not coated with some oil, shall be thoroughly wetted before the concrete is poured. The water shall be thoroughly applied to the boards until they take up no more moisture.† In freezing weather steam must be used in place of water to drench the forms, immediately before placing the concrete.

350. **Coating of Oil, Soap, Limewash, etc.** — Forms shall be covered with a coating of oil, soap, limewash or other substance to prevent the concrete from adhering to the surface.

351. **Oil for Forms.** — The oil to be used in oiling forms shall be thick and heavy enough to act as a filler for the forms. The quality of oil known as "sludge" at the oil refineries, or its equal, is recommended. The oil shall be thin enough to flow and fill the grain of the wood. A slight oiling of forms will result in great economy in saving of forming lumber. An excess of oil must not be used.‡

352. **Use of Boiled Linseed Oil.** — All forms which are to be used repeatedly shall be given on the surface next the concrete three good coats of pure boiled linseed oil, applied with a brush, and each coat allowed to dry before the forms are used. If at any time the forms become rough, and there is, in the opinion of the Engineer, danger of injury to the smoothness or appearance of the concrete, they shall be cleaned, redressed and again given three coats of boiled linseed oil as above specified, or new and satis-

* It is of the utmost importance that the bottom of floor forms when in place shall be clean of all shavings, sawdust and chips before the concrete is placed, and the same precaution must be used with reference to column and wall forms. In winter time all form work must of course be clear of ice and snow before the concrete is placed.

† In summer time, or hot weather, forms should be kept well wetted in order that the lumber may not shrink and leave large cracks through which a wet mixture of concrete will run, and by which unsightly fins or markings are left upon the concrete.

‡ An excess of oil is apt to leave the concrete discolored and stained on the outside. It is also likely to cause trouble where the concrete is plastered on the inside, by the oil coming out in the finished plaster work.

factory forms shall be provided. Provision must be made to prevent the splashing or spilling of oil on a concrete surface to which fresh concrete is to be added.

353. **Cold-water Paint.** — Forms may be coated, after thoroughly cleaning, with cold-water paint, and, after they have been erected, shall receive another coat.

354. **Oiling Forms Under First Floor.** — Oiling of forms shall not be done on this work, except for the forms under the first floor. There the Contractor may oil the forms with a quality of oil known as " Paraffine" or a similar product.

355. **Use of Paraffine Oil.** — The use of paraffine oil upon the form lumber will be allowed if properly used.

356. **Soap Coating for Forms.** — Forms for surfaces that are to be whitewashed, grouted or plastered shall be treated with a cheap soap boiled and applied hot, instead of oil or grease, as the oil or grease is apt to discolor the whitewashing or plastering.

Art. 10. Removal of Forms and Centers

It is safe to say that the majority of failures of reinforced concrete structures has been due to the premature removal of "forms." It is not sufficient for an architect or engineer to state in his specifications that the forms shall not be removed until the concrete has hardened sufficiently to permit of their removal with safety. The time which should elapse before removal should be stated.

1. General Requirements

357. **In General.** — Forms shall not be removed until the concrete shall have become hard enough to be unquestionably self-supporting.

No forms shall be removed except in the presence of the Inspector.

358. **Notification of Form Removal.** — No forms whatever shall be removed at any time without first notifying the Engineer in charge. But such notification shall not be considered to relieve the Contractor of responsibility for the construction and removal of such forms.

359. **Contractor's Risk.** — Forms are removed from the concrete at the Contractor's risk at any time, and should any of the concrete give way by such removal or become permanently injured, the Contractor shall remedy same at his own expense. The Contractor shall be expected by suitable observations to know when the concrete in any section of the work is sufficiently hardened to bear its own dead load plus additional load as may be imposed by the work of installation and shall not be relieved of responsibility for premature removal of centers. The Engineer, however, may, when he deems advisable, order the centering to remain for a longer time. The Engineer's acquiescence in permitting removal of forms shall not relieve the Contractor of responsibility for same.

360. Time of Removing Forms. — Under no circumstances shall forms be removed until the concrete has attained sufficient strength to resist accidental thrusts and permanent strains which may come upon it.

Forms supporting reinforced members shall be left in place until the concrete rings sound and is readily chipped by a blow from a pick.* Much care shall be given to this portion of the work, which is fraught with danger under incompetent direction.

No exact time for the removal of forms can be safely prescribed because of the varying character of the work, the variations in the setting of different cements and the influence of atmospheric conditions. Forms shall, however, remain longer under beams and arches than around columns or walls, and longer under beams and arches of long spans than of short spans.†

The directions of the Engineer as to the time for removing the forms, molds, and centers shall be strictly followed.

361. City Ordinances. — Removal of forms shall comply with the City ordinances and they shall not be removed until the approval of the Engineer is obtained.

362. Foreman to be in Charge. — A competent and experienced foreman shall be in charge of the removal of forms at all times. At no time are more men to be engaged in the striking of forms than the foreman can fully direct and supervise. No foreman lacking the required experience in this line, on high-grade work, shall be allowed upon the work.

363. Test Concrete Beams. — As an aid to judging when forms and supports may be removed safely, and when the concrete work may be used safely to carry extraneous weights and loads, the Engineer may, if he so desires, test concrete beams about 4 ins. by 6 ins. by 3 ft. in length, made of concrete taken from batches which are being placed in the portions of the structure under consideration.

364. Forms Not Supporting Loads. — Forms which do not support loads may be removed as soon as the concrete has taken its final set.

365. Minimum Time Limits for Form Removal. — (*a*) The minimum time for the removal of forms (not the supporting shores) shall be as follows:‡

For walls in mass work 2 days.
For thin walls 3 days.
For sides of lintels, girders and beams 3 days.

* When the concrete gives a distinctive ring under the blow of a hammer, it is generally an indication that it has hardened sufficiently to permit the removal of the forms with safety. If, however, the temperature is such that there is any possibility that the concrete is frozen, this test is not a safe reliance, as frozen concrete may appear to be very hard.

† It may be stated in a general way that forms should remain in place longer for reinforced concrete than for plain or massive concrete, and that forms for floors, beams, and similar horizontal structures should remain in place much longer than for vertical walls.

‡ The time for removal of forms is one of the most important steps in the erection of a structure of concrete or reinforced concrete. Care should be taken to invariably inspect the concrete and ascertain its hardness before removing the forms. So many conditions affect the hardening of concrete that the proper time for the removal of the forms should be decided by some competent and responsible person, especially where the atmospheric conditions are unfavorable.

For bottom of slabs 4 days, for spans of 6 ft. or less, plus 1 day extra for each additional foot of span.

For columns 2 days.

(*b*) The minimum time for the removal of shores shall be as follows:

For bottoms of beams and girders 14 days for spans of ordinary length.

(*c*) Should frost occur before the concrete has attained sufficient strength to enable the removal of the centering, the counting of time for this removal shall start after the influence of frost has been entirely eliminated.

366. **Freezing Weather.** — When the necessary precautions are taken during freezing weather, the forms may be taken down at the usual time, if, in the judgment of the Engineer, the test prisms made under the same conditions as the concrete has attained sufficient strength. As a general thing, the forms must remain in place much longer than in warm weather.

367. **Forms to be Easily Removed.** — Forms shall be removed gently without chipping or jarring the concrete. Prying with bars or striking with a sledge shall not be allowed as all jar and vibration shall be avoided.

368. **Manner of Removing Forms.** — Forms when being taken down shall not be dropped onto floors and knocked against columns and walls. The forms should always be eased down by a cable or other similar method. A regular procedure shall be followed in removing forms, and the work shall be done by regular gangs so that the men become trained in the requirements and methods of the work. Care shall be exercised and precaution taken to prevent large masses of forms from falling on floors. In other words, the work of removing the forms, molds, and centering shall be done with great care so as to avoid injury to the concrete.

369. **Cleaning and Piling Forms.** — The forms upon removal shall be thoroughly cleaned of all cement and any necessary repairs shall be made and the forms piled in some convenient place.

370. **Superimposed Loads upon Forms When Being Removed.** — When forms are being removed, there shall be no load upon the portion of the concrete affected in excess of one-sixth of the live load for which the portion affected was designed, unless temporary shores are left in to take care of such load.

2. Column Forms

371. **In General.** — Column forms, if removed first, shall be so removed as not to disturb the beam and girder forms.

372. **Time of Removal.** — Column forms shall not be removed in less than two (2) days, in summer, in cold weather, four (4) days, provided girders are shored to prevent appreciable weight reaching columns.

3. Slab, Beam and Girder Forms

373. Floor Slabs and Sides of Beams. — Forms shall not be removed from floor and roof slabs of ordinary spans in less than seven (7) days. Sides of beams and girders shall not be removed in less than three (3) days. The bottom of beam and girder forms shall remain in place until after the side forms have been removed so as to inspect the sides of the beam without lessening the support of the beam against collapse.

In all cases leave at least one line of shores in center of floor slabs when removing floor forms.

374. Beam and Girder Supports. — The original supports for all beams and girders must remain in place at least fourteen (14) days, but all beams and girders having more than 30 ft. span from center to center of support shall be considered as special cases and be subject to inspection of the Building Department before removal of supports.

375. Freezing Weather. — The time at which props or shores may safely be removed from under beams and girders will vary with the condition of the weather, additional time, however, shall be allowed for each and every day that the thermometer registers any time during the day or night below 35° F.

376. Removal of Shores. — Before removing the shores under any beam or girder, the column supporting it shall be striped, so that the columns may be examined on all sides, and at least one side of each beam and girder form shall be removed in order to expose the concrete to view, so as to give evidence of the soundness and hardness of the concrete.

The shoring underneath principal girders and beams shall be the last to be removed.

377. Method of Removing Shores. — Shores shall be removed without jarring the structure by properly pulling the double wedges at the bottom. Shores shall be lowered gently and not allowed to drop heavily onto floors and thrown against columns. When shores are finally removed, they shall be taken out for a beam or a panel at a time and under no circumstances shall all shores under a floor be knocked down at haphazard or in rapid succession.

378. Removing Shores before Forms. — While it is customary practice to some extent to remove shores one at a time and then put them back again in order to permit the removal of bottom boards of beam forms, etc., this practice shall not be permitted.

379. Precautions to be Observed in Removing Floor Forms. — In removing forms the falsework shall be lowered to such extent as to permit the form to drop away an inch or two from the slab, in which position it is to remain for twenty-four (24) hours.

While the wedges are being loosened the concrete must be carefully inspected.

379a. Wire Hangers. — Wire hangers used for centering for concrete floors that are laid between structural floor beams and girders must be cut off very close to the concrete after the removal of the centering.

4. Wall Forms

380. Massive Walls. — Forms for massive concrete walls shall not be removed in less than one (1) day, or when the concrete will bear pressure of the thumb without indentation.

381. Thin Walls. — Forms for thin concrete walls shall not be removed in less than two (2) days for ordinary conditions; in cold weather, five (5) days.

5. Arch Centers

382. Striking Centers. — The centers shall be struck when directed by the Engineer, which direction will not be given until the masonry above them has been completed up to the level of the bottom of the coping. When centers are removed, all supports between abutments and piers must be removed to the bed of the stream or to the surface of the ground.

382a. Removal of Forms. — Forms which do not support loads may be removed as soon as the concrete has taken its final set. Lagging should be removed from spandrels, copings and railings as early as possible.

383. Time of Removing Centers. — Centers for arches of small size shall not be removed in less than one (1) week and for large arches with heavy dead load not less than one (1) month. The time of removal must be determined by the design of the arch and the weather.

384. Method of Removing Centers. — Arch centers shall be removed without shock or jar to the arch ring. Centers shall be lowered evenly and gradually, so that the ring can settle uniformly. For very long spans the Engineer will provide special instructions for striking centers.

6. Miscellaneous Forms

385. Conduits or Sewers. — Forms for conduits may be removed within from two to three days, provided there is not a heavy fill upon the conduits.

No center shall be slackened until the back fill has been carried to such height, not less than one (1) foot nor more than two (2) feet above the top of the arch, as the Engineer may approve.

385a. Sidewalk Forms. — Forms for concrete sidewalks shall be left in place until the concrete or mortar has set.

385b. Ornamental Molds. — Ornamental work should have the forms removed as soon as possible, so that defects can be plastered up and so that swelling of the wood will have less time to act.

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CHAPTER IV

STEEL REINFORCEMENT

Art. 12. General Requirements

1. Design of Reinforcement Fixed by Engineer

386. In General. — Where reinforced concrete work is shown by the drawings, the same shall be reinforced with steel bars furnished in place by the Contractor. The steel bars shall be distributed, spaced and lapped, and of the sizes indicated by these drawings.

The sizes and locations of the steel reinforcing bars, as shown on the plans, are tentative only, and subject to changes, additions, or omissions, as may be found desirable by the Engineer during the construction of the work.

387. Square Sections. — The sizes marked on plans, unless otherwise noted, refer to square sections of reinforcing steel. If the bars used by the Contractor are not square in section they shall have an area equal to the area of the square bars indicated by the drawing.

388. Medium Steel. — All reinforcing shall be of medium steel of ultimate tensile strength from 55,000 to 70,000 lbs. per square inch, an elastic limit of not less than one-half the ultimate strength and a minimum elongation in eight inches of 1,400,000 divided by the ultimate strength per cent.

Medium steel for reinforcement shall be made from new billets and shall conform to the requirements of the Standard Specifications for Concrete Reinforcement Bars adopted by the Association of American Steel Manufacturers, 1910. (See Art. 13, page 82.)

389. High-carbon Steel (Alternate Clause). — High-carbon steel shall have an ultimate strength of 90,000 lbs. per square inch and a yield point of at least 50,000 lbs. These rods shall bend cold around a radius equal to three times their diameter to an angle of 90° without breaking. Cold twisted steel bars shall have a yield point of 50,000 lbs. and an ultimate strength of about 85,000 lbs. per square inch.

390. Substituting Mild Steel for High-carbon Steel. — Should, in case of contingency, the Contractor be compelled to use mild steel bars in lieu of high-carbon bars, he shall increase the sectional area in slabs by 10 per cent and in girders by 20 per cent; in columns, either mild steel or high-carbon bars may be used.*

* There is considerable diversity of opinion among engineers as to the best kind of steel to use for reinforcing bars. The high carbon steel gives the greater tensile resistance and also a greater elastic limit, but it is also less ductile and can be bent with less surety than the medium or low carbon steel.

391. Type of Reinforcement: Approval. — The steel reinforcement shall be of the Ransome twisted bar type or some equivalent deformed shape, in which the minimum cross-sections at any point will be equal to the area of the square bar specified. When the bars are deformed or corrugated by means other than twisting, the character of the bars used shall be satisfactory to and subject to the approval of the Engineer.

392. Length of Bars. — All bars to be secured from rolling mills in length called for in details; no splicing or welding will be permitted. In other words, wherever possible, lapping of bars to secure sufficient length should be avoided.

Bars for long span in beams or girders shall be furnished in one length. In general, bars of single length shall be used in all beams.

393. Lap of Bars and Other Reinforcing Details. — Before ordering steel reinforcement, the Contractor shall get the Engineer's instructions regarding all such details as amount of lap of bars, method of joining, etc., where such details are not explicitly shown on drawings.

394. Lapping. — Where bars necessary for the construction of walls and floors would be too long to be secured in single lengths, several shorter lengths may be used by welding them together, or by laying them with a lap not less than indicated in the following table. In special cases the Engineer reserves the right to indicate which method is preferred; otherwise the Contractor may choose the method most satisfactory to him:

Size of Square Bar.	Length of Lap.
$\frac{1}{4}$ inch	8 ins.
$\frac{3}{8}$ inch	12 ins.
$\frac{1}{2}$ inch	16 ins.
$\frac{5}{8}$ inch	21 ins.
$\frac{3}{4}$ inch	25 ins.
$\frac{7}{8}$ inch	28 ins.
1 inch	33 ins.

395. Steel Corner Bars. — Concrete curbs, steps, columns, etc., will preferably have metal reinforcement at the corners such as provided by the Wainwright galvanized-steel corner bar, consisting of a round nose with a lug extending back into the concrete and firmly anchoring it in place, or equally efficient protection.

396. Expanded Metal. — Expanded metal for reinforcing concrete shall be made by cutting staggered slits in sheets of medium steel with an elastic limit of not less than 35,000 lbs. per square inch and expanding it cold into diamond or other shaped meshes. Only the best quality of medium steel shall be used and no rods or bars should be required for cross bonding. The material shall be shipped in flat sheets and of a size easily handled.

The staggered slits shall be accurately spaced and the cross members formed from the same shall provide perfect reinforcement against temperature and shrinkage strains as well as tensile stresses.

397. **Wire Mesh.** — Either triangular or square mesh may be employed, but the joints of the fabric shall be firmly fastened by tying or welding; the style of fabric shall be submitted to the Engineer for his approval.

397a. **Calculation of Weights.** — The weight of the bars shall be determined by calculation from the specified dimensions, assuming the weight of the steel to be 0.283 lb. per cubic inch, and basing the calculations on the neat lengths of each line of rods from end to end, as built in the work, with no allowance for laps, when laps are used.

2. Design or Type of Reinforcement Left to Bidders

398. **In General.** — The reinforcing steel shall be of the forms, dimensions and spacing shown or of any other forms, dimensions and spacing of rods or fabric offering an equivalent area of reinforcing metal and satisfactory to the Engineer. That is to say, should the Contractor desire to use another method of reinforcing, it shall have the same net area per foot of section.

399. **Drawings.** — The Contractor shall submit with his bid, drawings clearly showing in detail the size of the several bars proposed to be used by him for reinforcement, the amount, position, lap and all other data which will be necessary to make his intentions clear. All steel shall be properly fastened into place and the manner for so doing must be indicated on the drawings. No change will be allowed in the plans except with the approval of the Engineer.

400. **System of Reinforcement.** — No system of reinforcement will be accepted that does not make proper and sufficient provision for the shear as well as bending in beams, girders, etc.

401. **Tensile Stresses.** — All tensile stresses, theoretical and practical, that may occur in the structure and any of its parts shall be fully and properly provided for by steel reinforcement. The reinforcement shall be calculated to provide for all horizontal and diagonal tension, vertical shear and compression where there is not sufficient concrete for that purpose. In general the reinforcement shall run as continuously as possible throughout the structure, and full development of every piece provided by suitable end-anchorage and lapping.

402. **Diagonal Tension.** — Diagonal tension in beams and girders to be cared for completely by diagonal reinforcement, either a part of or rigidly attached to the main reinforcement. In the slabs, these stresses and the negative stresses shall be cared for, simultaneously with the positive stresses, by elevating a sufficient number of the bars across the supports, providing in effect a catenary curve reinforcement.

403. **Vertical Shear.** — Vertical tension to be cared for by vertical loops of steel passing around the lower horizontal bars and extending well up into the compression flange in which they shall be well anchored. These loops or stirrups shall be spaced not further apart than the effective depth of the member and at progressively diminishing intervals towards the supports. In case of T-beams, vertical stirrups are necessary to guard against possible separation of the rib from the slab along the plane of junction and to insure the full and proper development of the T-action.

404. **Location of Reinforcement.** — The reinforcing metal shall be located at the distances from concrete faces shown or on amplified working drawings, but no part of the metal shall be nearer than one (1) inch to a concrete face, except for slabs which may be one-half (½) inch, and generally the distance shall be much greater than one inch.

405. **Square Bars.** — The design for the reinforced concrete structure is based on the use of medium steel square bars for taking tension and shear stresses. The elastic limit of bars shall be at least thirty-six thousand pounds per square inch. If the Contractor so desires, he may substitute for the reinforcement shown on the plans a standard patented steel reinforcement. If the bars used are not square in section they shall have an area equal to the area of the square bars indicated by the drawings.

406. **Net Section.** — The smallest net section allowable for the various size bars as marked on plans shall be as follows:

⅜-in. bars	0.14 sq. in.
½-in. bars	c.25 sq. in.
⅝-in. bars	0.39 sq. in.
¾-in. bars	0.56 sq. in.
⅞-in. bars	0.77 sq. in.
1-in. bars	1.00 sq. in.
1⅛-in. bars	1.27 sq. in.
1¼-in. bars	1.56 sq. in.

407. **Deformed Bars.** — There being some advantage in the use of bars which afford a mechanical bond, such bars will be permitted. The Contractor shall state clearly in his bid whether he proposes to use the plain bars or bars with a mechanical bond. If he proposes to use bars giving a mechanical bond, it must be of a type and design approved by the Engineer. Bars shall be especially deformed for reinforced concrete work, so that their efficiency will not depend upon the adhesion of the concrete to the surface of the metal. They shall be uniform, as to deformation, from end to end of each bar, and twisted bars shall show an increase in elastic limit of at least 50 per cent, and in ultimate strength of at least 25 per cent above the strength obtained prior to twisting.

408. **Substituting Deformed Bars for Plain Bars.** — In order that the Contractor may know how to compare the prices of mechanical bond bars

with the plain bars, he shall assume twenty-five per cent less metal required in beams and slabs than plans show for the plain bars of medium steel. Unit stress shall not exceed 20,000 lbs. per square inch.

409. **Turns of Twisted Bars.** — If twisted bars are used, they shall have not less than the following number of turns:

$\frac{1}{2}$-in. bar	one complete turn in $2\frac{3}{16}$ ins.
$\frac{5}{8}$-in. bar	one complete turn in 3 ins.
$\frac{3}{4}$-in. bar	one complete turn in $4\frac{3}{8}$ ins.
$\frac{7}{8}$-in. bar	one complete turn in 6 ins.
1-in. bar	one complete turn in $8\frac{1}{2}$ ins.
$1\frac{1}{4}$-in. bar	one complete turn in 12 ins.

Twisted bars shall be twisted cold, and the number of complete turns per foot of length shall be subject to the approval of the Engineer.

410. **Royalty.** — If the Contractor uses any patented bar, the cost bid shall cover the cost of all royalties and engineering advice.

411. **Shape or Cross-section of Deformed Bars.** — Steel used in reinforcement must be so shaped or deformed as to prevent slipping in the concrete. Rods or bars shall be of a cross-section that will permit the concrete to flow up under the lower side of the rod or bar with the least resistance, and with no deformation on the rod or bar that will tend to pocket or confine the air in such a manner as to prevent the concrete from completely surrounding and attaching itself by adhesion to the rods and thereby insuring prevention of rust and adequate fire protection.

412. **Wedging Action.** — Preference shall be given to rods with a cross-section that will give the least wedging action to the concrete fireproofing underneath the rod when the beam is subjected simultaneously to a load overhead and a fire underneath.

413. **High-carbon Steel.** — If steel of higher elastic limit than medium steel is to be used, it must be of first-class quality and subjected to special tests even if used at the same working stress as mild steel.

High-carbon steel shall be made entirely from new billets, having (1) a desired ultimate strength of 88,000 lbs. per square inch with an allowable range of 8000 lbs. from the ultimate strength; (2) an elongation in per cent in eight (8) inches of 1,200,000 divided by the ultimate strength; (3) capable of cold bending 180° around four (4) diameters without fracture.

414. **Trussed Bars or Assembled Units.** — Trussed bars or assembled units shall consist of a main horizontal tension member, to which the necessary shear members shall form the rigidly connected diagonals, making a unit of main bar and developing the full strength of the shear members. Each bar shall be accurately supplied with the required shear members so that the only labor necessary in the field shall be the bending of the shear members to the proper angle, which must be easily done by hand.

415. **Wire Cloth.** — Woven wire cloth made from various gages of wire may be used for floor slab reinforcing and for plastering, subject to the acceptance of the Engineer.

416. **Expanded Metal, Ribbed Metal, etc.** — The Contractor may use expanded metal, ribbed metal or other type of fabric for the floor reinforcement, if such substitu ion allows of cheaper cons ruc ion, and at the same time gives equivalent strength. Such substituted reinforcement material shall have equivalent area of the rods given and must be first approved by the Engineer.

417. **Mechanical Bond.** — Shrinking of wire bands or other material around plain bars will not be held to constitute a mechanical bond.

418. **Samples.** — The Contractor shall submit samples of bars to be used before beginning the work.

3. Delivery and Storage of Steel

419. **In General.** — The steel shall be delivered in such quantities and at such times as may be required by the work.

The steel must be sorted, bundled and labeled when delivered.

420. **Time of Delivery.** — The Contractor shall have at least thirty days' notice of the date when the steel will be required, and when the requirements are greater than (say) 100,000 lbs. in any one calendar month, fifty days' notice shall be given. The delivery of more than (say) 300,000 lbs. in any one calendar month shall not be required, except where the excess over 300,000 lbs. results from delinquency of delivery under prior requirements.

421. **Notices.** — All notices for delivery of steel should express quantities in carload lots.

422. **Delivery of Steel for Concrete Building.** — All reinforcing steel shall be delivered at the building site in the following manner:

All loose bars for floor slabs, etc., are to be bundled and tagged, showing their respective sizes and lengths. All bars for girders, beams, etc., whether loose or built up, are to be delivered in a similar manner.

All column bars are to be bundled and tagged separately for each section of column. All hooping for columns is to be tagged with column number and section.

All wire mesh reinforcing shall be shipped flat and cut to the required widths and lengths.*

423. **Bending of Steel.** — As far as possible all bars are to be delivered at the site bent in accordance with their requirements, but the Contractor shall provide such facilities and labor as may be necessary to complete the bending of bars in the field to complete the work. (See Pars. 475 and 478.)

424. **Condition of Delivery.** — All steel to be free from heavy rust or scale.

* Expanded metal is furnished in gauges from 4 to 18, in sheets 6, 8, and 12 feet in length, and in widths of from 1 to 6 feet. The usual way of shipping expanded metal is in flat bundles containing five or six sheets wired together.

425. **Checking and Assorting Steel.** — As soon as the steel is received at the site, it shall be checked, assorted and stored in such a manner that it can be readily inspected.*

426. **Storage of Steel.** — All steel on arrival at the site shall not be laid on the ground but placed in suitable racks under cover. The steel shall be so stored that those portions needed first may be reached without disturbing the remainder.

427. **Protection of Steel.** — The steel shall be protected from rust, dirt, oil, paint, etc. That is to say, bars shall be protected from the weather, but must not be oiled or painted.

4. Field Tests and Inspection

427a. **In General.** — The Contractor shall furnish to the Engineer satisfactory evidence that the material offered for use on the work is of the character and grade specified, either by affidavits from the makers of the steel, copies of the mill tests of the material used, or otherwise, as may be required.

428. **Number of Tests.** — Test by a competent inspector shall be made of each carload of reinforcing material used in the work; at least, one sample of each size cross-section of the various styles of reinforcing material contained in each car shall be subjected to one tensile test and to one bending test.

429. **Report of Tests.** — A report of the above tests showing the elastic limit, ultimate strength and elongation in eight (8) inches of each specimen shall be submitted to the Engineer.

430. **Deficient Material.** — If the results of any of these tests are deficient, either the deficient material shall be rejected or the amount of reinforcement, where such deficient material is used, shall be increased in such proper proportion as to secure a section in which the stresses induced shall not exceed by over ten per cent (10%) the limit allowable.

431. **Physical Tests (Alternate Clause).** — The Engineer's representative shall take a specimen of each size bar for each twenty tons, or more if desirable, for full physical tests, same to be at the rate of (say) $2.50 for each test.

432. **Claims for Delays.** — The Contractor shall not be allowed any claim for delay due to the taking of the above tests.

433. **Net Area.** — The net area of cross-section of finished steel reinforcement shall not be less than 95 per cent of the area shown in the approved design.

* In any construction work annoyance and loss of time are saved by exercising care in the disposal of the materials, and the manner of taking care of steel reinforcement is not an exception to this rule. The steel, upon delivery, should be sorted out with reference to the position it occupies in the building or other structure, and with regard to sizes. In a very large operation of concrete buildings or other structures the steel should be placed in racks and checked off as used. If some system is not adopted in taking care of the steel reinforcement, it will be found that some of the longer bars will be used in places for which shorter bars were ordered, and that the short bars left over will not meet the requirements of the conditions for which the longer bars were needed.

434. **Fracture.** — All broken test pieces of steel reinforcement must show a silky fracture of uniform color.

435. **Excess Weight.** — The Contractor will not be paid for any excess of weight due to the steel reinforcement having been rolled thicker than specified or shown on the drawings, but should the weights fall below a correct estimate made from the drawings, either a deduction will be made from the contract amount equivalent to the deficiency or the steel will be rejected, at the option of the Engineer.

436. **Costs of Tests.** — The cost of all tests and analysis shall be borne by the Contractor, unless otherwise specified.

437. **Bending Test for Steel Reinforcement.** — The reinforcement shall be subject to a bending test and no steel which fails to pass this bending test shall be used under any circumstances. The bending test is as follows: Test specimens for bending shall be bent cold to the following angles without fracture on the outside of the bent portion:

Around twice their diameter.	Around their own diameter.
Specimens 1 inch thick, 80°.	Specimens $\frac{1}{4}$ inch thick, 130°.
Specimens $\frac{3}{4}$ inch thick, 90°.	Specimens $\frac{3}{16}$ inch thick, 140°.
Specimens $\frac{1}{2}$ inch thick, 110°.	Specimens $\frac{1}{8}$ inch thick, 180°.

Art. 13. Requirements for Tests of Concrete Reinforcing Bars

438. **In General.** — All tests and inspection shall be made at the place of manufacture prior to shipment.

439. **Process of Manufacture.** — Steel may be made either by the open-hearth or Bessemer process. Bars shall be rolled from billets. No material from old rails, scrap, etc., will be accepted.

440. **Chemical and Physical Properties.*** — The chemical and physical properties shall conform to the following limits:

Properties considered.	Structural steel grade.	
	Plain bars.	Deformed bars.
Phosphorus, maximum:		
Bessemer	.10	.10
Open-hearth	.06	.06
Ultimate tensile strength, lbs. per sq. in	55,000–70,000	55,000–70,000
Yield point, minimum, lbs. per sq. in.	33,000	33,000
Elongation, per cent in 8 ins., minimum	1,400,000 / T. S.†	1,250,000 / T. S.
Cold bend without fracture:		
Bars under $\frac{3}{4}$ in. in diameter or thickness	180° d.=1 t.	180° d.=1 t.
Bars $\frac{3}{4}$ in. in diameter or thickness and over	180° d.=1 t.	180° d.=2 t.

* As adopted by The Association of American Steel Manufacturers, 1910.
† T.S. = tensile strength.

Properties considered.	Hard grade.		
	Plain bars.	Deformed bars.	Cold-twisted bars.
Phosphorus, maximum:			
Bessemer	.10	.10	.10
Open-hearth	.06	.06	.06
Ultimate tensile strength, lbs. per sq. in.	80,000 min.	80,000 min.	Recorded only
Yield point, minimum, lbs. per sq. in.	50,000	50,000	55,000
Elongation, per cent in 8 ins., minimum	$\frac{1,200,000}{\text{T.S.}}$	$\frac{1,000,000}{\text{T.S.}}$	5%
Cold bend without fracture:			
Bars under ¾ in. in diam. or thickness	180° d.=3 t.	180° d.=4 t.	180° d.=2 t.
Bars ¾ in. in diam. or thickness and over	90° d.=3 t.	90° d.=4 t.	180° d.=3 t.

441. **Allowable Variations.** — If the ultimate strength of structural steel varies more than 4000 lbs. from that desired, a retest shall be made on the same gage, which, to be acceptable, shall be within 5000 lbs. of the desired ultimate. If the ultimate strength of hard-grade or high-carbon steel varies more than 6000 lbs., a retest shall be made on the same gage, which, to be acceptable, shall be within 8000 lbs. of the desired ultimate.

442. **Chemical Determinations.** — In order to determine if the material conforms to the chemical limitations prescribed in Par. 440 above, analysis shall be made by the manufacturer from a test ingot taken at the time of the pouring of each melt or blow of steel, and a correct copy of such analysis shall be furnished to the Engineer or his inspector.

443. **Yield Point.** — For the purpose of these specifications, the yield point shall be determined by careful observation of the drop of the beam of the testing machine, or by other equally accurate method.

444. **Form of Specimens: Deformed Bars.** — Tensile and bending test specimens may be cut from the bars as rolled, but tensile and bending test specimens of deformed bars may be planed or turned for a length of at least 9 ins. if deemed necessary by the manufacturer in order to obtain uniform cross-section.

445. **Cold-twisted Bars.** — Tensile and bending test specimens of cold-twisted bars shall be cut from the bars after twisting, and shall be tested in full size without further treatment, unless otherwise specified as in Par. 444, in which case the conditions therein stipulated shall govern.

446. **Hot-twisted Bars.** — If it is desired that the testing and acceptance for cold-twisted bars be made upon the hot-twisted bars before being twisted, the hot-rolled bars shall meet the requirements of the structural grade for plain bars shown in Par. 440.*

447. **Number of Tests.** — At least one tensile and one bending test shall be made from each melt of open-hearth steel rolled, and from each blow or lot of ten tons of Bessemer steel rolled. In case bars differing ⅜ in. and

* Square reinforcing bars are frequently designated as "cold-twisted" or "hot-twisted," these terms being applied to square twisted bars which have been deformed by being twisted cold or hot respectively.

more in diameter or thickness are rolled from one melt or blow, a test shall be made from the thickest and thinnest material rolled. Should either of these test specimens develop flaws, or should the tensile test specimen break outside of the middle third of its gaged length, it may be discarded and another test specimen substituted therefor. In case a tensile test specimen does not meet the specifications, an additional test shall be made.

448. **Bending Test.** — The bending test may be made by pressure or by light blows.

449. **Modifications in Elongations for Thin and Thick Material.** — For bars less than $\frac{7}{16}$ in. and more than $\frac{3}{4}$ in. nominal diameter or thickness, the following modifications shall be made in the requirements for elongation.

(*a*) For each increase of $\frac{1}{8}$ in. in diameter or thickness above $\frac{3}{4}$ in. a deduction of 1 shall be made from the specified percentage of elongation.

(*b*) For each decrease of $\frac{1}{16}$ in. a deduction of 1 shall be made from the specified percentage of elongation.

(*c*) The above modifications in elongation shall not apply to cold-twisted bars.

450. **Number of Twists.** — Cold-twisted bars shall be twisted cold with one complete twist in a length equal to not more than 12 times the thickness of the bar.

451. **Finish.** — Material must be free from injurious seams, flaws or cracks, and have a workmanlike finish.

452. **Variation in Weight.** — Bars for reinforcement will be subject to rejection if the actual weight of any lot varies more than 5 per cent over or under the theoretical weight of that lot.

453. **Defective Material.** — Material which, subsequent to the above tests at the mills, and its acceptance there, develops weak spots, brittleness, cracks or other imperfections, or is found to have injurious defects, will be rejected at the shop and shall be replaced by the manufacturer at his own cost.

Art. 14. Placing Steel Reinforcement

1. General Requirements

454. **Handling Reinforcement.** — An metal which has been bent or otherwise injured in handling or in transit shall be carefully repaired by the Contractor before being used. Reinforcing bars must be straight and free from flaws in any degree calculated to impair their strength.

455. **Replacing Broken Bars.** — Should any bar be broken it must be laid aside and another bar of same length and cross-section procured without delay.

456. **Cleanliness of Steel.** — The steel reinforcement, before being placed in forms, shall be thoroughly cleaned from loose, scaly rust, dirt, oil, paint or coating that may be detrimental to the positive adhesion of the concrete to the steel. A slight film of red rust, which facilitates the forming of a

hard film or coat of ferro calcite, and increases the adhesion of the concrete, shall not be considered objectionable, but any bar on which rust scales have begun to form will be rejected, unless such scales are thoroughly removed with wire brushes or by other means. Concrete which has lodged on the steel reinforcement and hardened during previous work shall be entirely removed before the reinforcement is finally concreted in.

457. **Painting or Oiling Bars.** — No steel reinforcement shall be painted or oiled. (Some engineers have required that all reinforcement be dipped in a bath of cement grout before being installed in the forms, but, by careful manipulation during the placing of the concrete, this extra handling and cost is unnecessary and may be done away with.)

458. **Methods of Cleaning Reinforcement.** — All heavy rust and mill scale must be removed from the reinforcing metal by hammering, steel scrappers or brushes, pickling in a weak solution of hydrochloric acid, or by some other equally efficient means of cleaning the metal, before being covered by the concrete.

459. **Use of Pickling Bath.** — If the steel bars have more than a thin film of rust upon its surface, they may be cleaned before being placed in the concrete by pickling in a bath consisting of one part commercial sulphuric acid to six parts water, or other proportions, depending upon the amount of rust on the bars, as the Engineer may direct. Bars must be washed thoroughly in clean water after the bath and before placing in the concrete.

460. **Supervision.** — Reinforcement shall be placed under the direction of the Engineer (or Inspector) and all such erection and placing shall be in charge of a competent foreman who shall be familiar with the drawings.

461. **Cleaning Forms.** — No steel shall be placed until the forms have been thoroughly cleaned and inspected. Forms must be cleaned of all dirt and shavings and care must be taken to prevent new dirt and shavings from coming into the forms. (See Art. 9, Sec. 9, page 68.)

462. **Assembling of Reinforcement.** — The steel reinforcement shall be so assembled that the exact number, size, form, spacing and location of bars, stirrups, ties, spacers, etc., called for by the Engineer's plans is adhered to in every member.

Should any discrepancy be noted in regard to the reinforcement of similar members, it shall be brought to the immediate attention of the Engineer.

463. **Inspection of Reinforcement.** — All steel reinforcement shall be as per plans and details and shall be placed and inspected by the Engineer before any concrete is put in place, and to admit of this inspection, steel for a day's work shall be placed in advance of the concrete.

464. **Carelessness in Placing Reinforcement.** — The Engineer will insist upon the reinforcement being accurately placed, and any carelessness on the part of the Contractor in this will be sufficient grounds for the Engineer to require the removal of the work and the replacing of it correctly.

465. Embedment of Reinforcement. — Steel reinforcement shall be embedded to a depth of at least one (1) inch from any surface, unless otherwise specified. Care shall be taken to keep all bars at such distance as the Engineer directs from the nearest exposed face. The bars shall be thoroughly embedded in the concrete, care being taken to compact the concrete closely against and around the bars.

466. Thickness of Concrete Covering. — The minimum exposed concrete covering of all faces for steel reinforcement shall be as follows:

$\frac{3}{4}$ in. for slabs.
$1\frac{1}{4}$ ins. for beams and girders.
$1\frac{1}{4}$ ins. for columns and walls.
2 ins. for foundations.

However, in case of direct permanent exposure to the elements, this minimum covering shall be uniformly 2 ins.

467. Distance between Reinforcing Bars. — The clear spacing between parallel reinforcement in beams and girders shall not be less than $1\frac{1}{4}$ ins. No reinforcing bars to be closer together than $2\frac{3}{4}$ diameters, center to center.

468. Placing Reinforcement in Proper Position. — Before placing concrete, the steel reinforcement must be placed the proper distance from the bottom and sides of forms and in the position required in the finished structure, and each piece or member so firmly fixed as to positively prevent any subsequent displacement. Especial care shall be taken in placing steel in proper position.

The Inspector shall insist that the reinforcing steel be so fixed and held in place in the forms that it will not be displaced from its proper position and spacing during the placing and compacting of the concrete.

When the reinforcement is arranged in several layers, each layer shall be packed separately in concrete.

469. "Loose-bar" Method. — Particular attention shall be given to loose-bar reinforcement that it is accurately and properly supported in position, so that all parts shall remain in true relation and alignment until locked in the setting concrete. Such device or devices shall be used as will absolutely prevent the bars from approaching the forms beyond the limits specified for protection, and at the same time maintain a uniform and accurate spacing of the bars throughout the length of the members.

470. "Assembled Unit" System. — Care shall be taken in handling unit systems that the lower units are not bent out of shape by the weight of those above.

471. Spacing "Chairs." — Spacing "chairs" and clips for separate bar reinforcement shall be made of heavy weight and good quality of sheet steel. They shall have ample strength against crushing down under such loads as are likely to come on the reinforcement. The bottom edges of the chair shall be bent to form flat feet and prevent cutting into the form boards when used to support floor reinforcement. For wall and column reinforcement, the bending of the bottom edge of the chair to form feet may be omitted, and for spiral hooping the slots for the spiral rods must be cut to pitch so that the chairs set straight with the vertical bars.

472. **Support of Metal Separators.** — All metal separators used to keep the reinforcement at the right distance from the forms shall rest on a piece of galvanized iron, or else a rust spot will show on the under surface.

473. **Supply of Supports.** — Ample supports shall be furnished so as to prevent sagging of the reinforcement.

474. **Wooden Blocks.** — Wooden blocks shall not be used unless absolutely necessary, for the reason that, remaining in the concrete, as they are liable to do, a weak spot will be developed.

475. **Bending of Bars.** — All reinforcing bars shall be bent before they are placed in position. The bending of all bars shall be done in such a manner that they will not break or crack at the bend. The bending force shall be applied gradually and not with a jerk.* Bending must be done with absolute accuracy in accordance with the detail sheets for the various portions of the structure. The bends shall be accurate in line and plane.

476. **Cold Bending.** — All ordinary bending shall be done cold. It is very important, especially in bending large bars, that the bending force be applied gradually and evenly and not with a jerk.

477. **Hot Bending.** — Bending shall preferably be done cold. If the bars are heated and blacksmith work is done, care must be exercised that the steel is not burned in the operation, otherwise it will be condemned by the Engineer. Warming up to a low cherry red shall be the highest heat permitted.

478. **Bar Benders.** — All reinforcing bars for the entire job shall be accurately bent in a bending machine in accordance with the dimensions and forms shown on the drawings. Bending machines shall be required to bend any kind of a steel bar up to an inch and a quarter ($1\frac{1}{4}$) in diameter to any angle required.

479. **Splicing of Bars.** — The splicing of bars shall be done exactly according to the Engineer's plans. No splices will be permitted except at points shown on plans. Various forms of splices are in use and if not definitely instructed by the plans and specifications the Contractor shall learn from the Engineer what form or forms will be acceptable.

The length of lap required for splicing of reinforcing bars in tension shall be determined on the basis of the safe bond stress and the stress in the bar at the point of splice; or a connection shall be made between the bars of sufficient strength to carry the stress. Splices at points of maximum stress should be avoided. Joints in bar work shall be lapped at least 18 inches.

* While the ordinary steel reinforcement will stand a great amount of rough handling, yet it is best not to attempt to bend suddenly or otherwise subject the steel to severe shocks, especially where high carbon steel is being used, as sometimes the steel bars will be broken off. Accidents of this kind are more likely to occur in cold weather.

480. **Welding of Bars.** — No welding of reinforcement except in column hoops will be permitted without special permission from the Engineer.

481. **Protruding Ends of Bars.** — The ends of bars which are left protruding for splicing shall be, if they are likely not to be connected up for some little time, painted with cement paint to diminish rusting and guarded against being bent or loosened. Throughout the work care must be exercised to prevent disturbing bars, portions of which are embedded in fresh concrete.

482. **Fastening Reinforcement.** — All reinforcement shall be securely fastened to preserve spacing, location, alignment, etc. Braces, blocks, suspenders, spacers, ties, etc., shall be used in ample number to make certain of this feature. All temporary fastenings shall be removed as fast as the concreting reaches them.

Whenever practicable all the reinforcing metal shall be put in place in the forms and securely fastened in correct positions by wiring or otherwise before the placing of the concrete is begun.

483. **Wiring Reinforcement.** — The wiring of reinforcement at intersections shall be done carefully and strongly, using No. 16 or No. 18 B. & S. gage soft black wire. Reinforcing material shall be wired together at laps and intersections, where directed.*

484. **Fastenings for Reinforcement.** — All wiring, straps, braces and templates required for the proper holding of the reinforcement in place must be furnished by the Contractor in a manner entirely satisfactory to the Engineer.

485. **Tagging Reinforcing Bars.** — When the bars are cut and bent to proper shape, each individual bar in every beam and girder, or group of bars in columns, slabs, walls, footings, etc., shall be tagged with a cloth tag and wired securely to the bars (for beams and girders), or each bundle of bars, and marked with the proper number of the structural member, and the tags must be left on after the bars are placed in proper position in the forms.

486. **Removing Tags.** — The Engineer or his Inspector will examine the bars after they have been placed, personally remove the tags, after which the concrete may be placed.

487. **Placing Concrete.** — The Contractor is to take the greatest care in the erection of the reinforcement, keeping a constant eye on it at the point where the concrete is being placed, to see that all the bars are in their proper location. Concrete shall not be deposited in any portion of the work until all the reinforcement for that section of work is in position and has been

* For fastening reinforcing rods and bars together, and for securing the stirrups, as well as for fastening cross-bars in wall reinforcement, and slab rods, no better method has been found than that of wiring them together. This, of course, can be done with pliers, but where there is much to do the device known as the "Curry Tyer" has been used successfully, and with a resultant saving in time. By the use of this tool the wire is given a uniform number of twists, and the rods or bars are secured much more positively than can be done with an ordinary plier. It is also claimed that much time is saved in cold weather by the use of this device, as with ordinary pliers the work is necessarily slow from the fact that the workmen's hands become numb.

checked over to see that it agrees with the drawings. The steel work must be kept sufficiently ahead of the concrete work to give ample time for inspection.

488. **Additional Reinforcement.** — Should the Contractor deem it necessary to increase the reinforcement over and above that called for on the schedules, in order to take the responsibility for the work, he shall increase the same without cost to the Owner.

488a. **Bonding.** — In all form work which will join other work to be built later, the ends of the bars in the work first put in shall project through the forms at the proper places to bond into the work to be built subsequently, to the distances indicated by the drawings, or as directed by the Engineer.

488b. **Compensation.** — The compensation to be paid for the steel bars to be used for reinforcement for concrete work shall be at a price per ton of 2000 lbs., weights being calculated as specified in Par. 397a.

488c. **Inclusive Prices.** — The prices named by the Contractor shall include the cost of the steel bars, the cost of the privilege of using them, the cost of transportation, delivery, handling, cutting, welding, placing and building them into the concrete work complete, and shall take into account and provide compensation for the loss due to laps, waste ends, shortening arising from deformation, and all other conditions affecting the cost of placing the steel bars in final position in the work.

2. Slab and Beam Reinforcement

489. **Concrete Spacing Blocks.** — Notched concrete spacing blocks composed of the best concrete shall be used, unless otherwise specified, for beam, girder and slab reinforcement. The notches shall be properly spaced so as to separate the bars from each other and from the sides of the forms, and the blocks shall be of the proper thickness to hold the bars at the required height above the bottoms of the beams, girders and slabs.

490. **Spacing Chairs.** — Spacing chairs or heavy wire supports may be substituted for the concrete spacing blocks, subject to the approval of the Engineer.

491. **"N" Shaped Saddles.** — Saddles made of No. 20 gauge metal strips $\frac{3}{4}$ in. wide shall be bent "N" shape and nailed to forms and then the slab rods laid on saddle and wired thereto.

492. **Washers for Supporting Slab Bars.** — Washers are to be threaded over the system of bars lying next to the forms so as to hold them off the forms, giving a space for the fireproofing of bars.

493. **Sagging of Reinforcement.** — Ample supports shall be furnished so as to prevent sagging of the floor reinforcement.

494. **Bending Beam Reinforcement.** — In bending the girder and beam bars, care must be taken that the depth of the bent bars is not greater than given in the drawings, as otherwise the bars might project above the concrete floor.

495. **Beam Stirrups.** — Sufficient stirrups shall be provided in beams and girders to take up with the bent bars all the diagonal shearing strains.

Stirrups shall never be spaced farther apart than the effective depth of the structural member and must always pass under main tension bars. Care shall be taken to properly space stirrups and to keep them in place.

496. **Fastening U-Bars or Stirrups.** — U-bars shall be accurately bent, with 6-in. wing resting on form work. Under each wing shall be placed one $\frac{1}{4}$-in. or $\frac{5}{16}$-in. rod to which each U-bar must be wired and to assist in holding up bent-up floor steel and to which floor steel must be wired. Where no floor slab occurs on one or two sides of a beam, bend wing of the U-bars into the beam, fastened to side of beam with staples.

497. **Tagging Beam and Girder Bars.** — When the bars are cut and bent to proper shape, each individual bar in every beam and girder shall be tagged with a cloth tag, wired securely to the bars and marked with the number of beam and girder, and the tags must be left on after the bars are placed in proper position in the forms.

498. **Beam Spacing Bars.** — Over each beam or girder shall be placed (say) one $\frac{3}{8}$ in. spacing bar, to which all slab bars shall be tied with No. 14 wire.

499. **Assembled Units for Beams and Girders.** — All beam and girder bars including stirrups are to be assembled into units. Loose bars in beams and girders will not be permitted. The steel reinforcement shall be assembled, either on the ground or before shipment, so that all the members constituting the reinforcement of a beam or girder are held rigidly in place in the forms and the members maintained the proper distance apart during the concreting.

500. **Marking Centering for Placing Beam Reinforcement.** — When the forms are ready for the steel, the Contractor shall go over the floors with the blue prints and a piece of crayon or keel, and letter the beams and girders to correspond with the plans, in large figures on the decking beside the beams and shall specify the bars required, i.e. —

Beam B12.
Two — 1-in. Rounds, Bent.
Two — $1\frac{1}{4}$-in. Rounds, Straight.

501. **Placing of Beam Reinforcement.** — The stirrups shall first be placed in all beam and girder forms as shown on drawings, then the straight bars, and afterwards the bent bars. The bars shall be placed symmetrical with the axis of the beam, the bars shall be held the required height above the bottom of the beam (generally an inch and a half), and the proper space shall be maintained between the reinforcement and the sides of the beam. They shall overlap equally at both ends. The required connections shall also be made at the ends of beam or girder with the column bars or

the reinforcement of abutting beams or walls. All planes and lines shall be true and parts of the reinforcement tied with No. 14 wire or otherwise held firmly in position.

502. Placing Slab Reinforcement. — The slab bars shall be placed after the girder bars, and shall be wired at two points to keep their place. It will be insisted that they are placed in their exact position during the wiring; a variation of 1 in. shall be permitted if during concreting the bars are shifted. The Contractor shall supply his men with a sufficient number of hooks, to be used to raise the bars ¾ in. (or the specified distance) above the floor during concreting. Constant attention shall be given to the reinforcement to see that the slab bars are in their proper location over the beams, and are perfectly straight throughout their length.

Both expanded metal and woven wire fabrics must be handled intelligently in the field. In using expanded metal the long diagonal of the mesh must always be parallel with the span of the slab, as otherwise the full tensile strength of the material is not obtained. Expanded metal should be lapped on the ends at least 6 inches, and such laps should occur over points of support.

503. Wiring Slab Bars. — Slab steel shall be securely wired together so as to form a strong network.

504. Use of Staples. — Slab reinforcement shall be secured in place by staples driven into the forms, the ends of the staples being clipped off, after the forms are removed.

505. Tagging Slab Bars. — All slab bars shall be wired in bundles and properly tagged; the tag for each bundle to be left attached to one of the ends after being placed in the forms.

506. Floor Slabs Reinforced in More Than One Direction. — Floor slabs having reinforcement in more than one direction shall have intersecting rods tied with wire at least twice in each span.

507. Extra Beam or Girder Bars. — The extra bars over the beams or girders shall be placed immediately after the slab is concreted over the beams, and pressed into the concrete.

508. Provision for Shafting Hangers. — Provisions for shafting hangers shall be made before the concrete is poured. Hangers shall extend well above the lower reinforcement in beams and girders.

509. Exposed Reinforcement on Bottom of Floors. — Should reinforcing metal be exposed on the bottom of floor construction that section of the floor shall be removed and replaced as the plastering over same with cement mortar will not be permitted.

510. Placing Steel in Mushroom System. — Special attention shall be given to placing the bars in belts of the width of the mushroom frame and fairly uniform spacing shall govern, though this is of less importance than keeping to the general distribution throughout the full width of the belts of reinforcement.

In placing the floor slab bars, those running from column to column directly in one direction shall preferably be placed, then those running at right angles and following up later with the diagonal belts of bars.

Bars shall be wired together to hold them in the position as shown on the plans. It is desirable to use No. 18 soft annealed wire, taking a piece (say) a yard long and fastening an intersection, then carry the wire diagonally to the next intersection, taking a half hitch and proceed until this piece is used up and making the end fast. Then start with a new piece and proceed as before.

Two lines of ties, crossing and normal to the intersecting belts at the center, will hold these bars in position very nicely. A similar tie across the parallel belts and a suitable number of fastenings around the mushroom head are required to hold the bars in position.

510a. Bedding Laps. — Where laps are used in floors, the lapped bars shall be bedded in and surrounded with Portland cement mortar, mixed 1 part cement to 2 parts sand, care being taken to work the mortar closely against the bars and to trowel and pat it to expel the air.

3. Column Reinforcement

511. "Assembled Unit" Method.—All reinforcing bars for columns shall be assembled together before being placed in the forms. Hooping shall be securely tied to each of the upright bars. No free end of hoops shall be bent out of line of the hoops, and the hoops shall be tight and regularly spaced. All hoops shall preferably have both ends turned and clinched around the vertical steel.

512. Spacing Column Bars. — Templates shall be used at bottom and top of column to insure accurate spacing of bars. This is necessary to insure that the bars of successive columns will fit when spliced.

Where bars are bent at top to form connections with column above, another template must be used to be sure that the connections will fit.

513. Tying Column Bars. — Wire ties or hoops holding the vertical bars shall be taut, and they shall fit exactly. The vertical spacing of the hoop shall be exact and according to the Engineer's plans. Hoops and verticals must be fastened together as shown on drawings.

514. Welding Column Hoops. — Hoops for columns shall be welded to develop the full strength of the section, if so required by the Engineer.

515. Spiral Reinforcement (Shop Fabrication). — Spiral reinforcement called for in columns must be shop fabricated on machines designed for that purpose and absolutely true to diameter and pitch called for. All hooping must be so designed that the spiral is rigidly attached to the vertical bars and no splices shall be allowed in the spirals, except at floor levels.

516. Shipment of Column Spirals. — Column spirals shall arrive on the work either collapsed or extended, but in any case must be fitted up with at least two diametrically spaced $\frac{1}{4}$-in. by 1-in. spacing rods, to which the spirals shall be firmly clamped at each crossing. All spirals shall be tagged as to their location.

517. **Tagging Column Units.** — When the bars are cut and bent to proper shape, each set of bars in every column shall be tagged with a cloth tag, wired securely to the bars and marked with the number of column, and the tags must be left on after the bars are placed in proper position in the forms.

518. **Fabricating Column Spirals.** — Particular care shall be taken in forming the spirals for columns and in properly fastening them to the longitudinal spacing bars so that the pitch of the spiral will be accurately maintained. Spirals shall be bent to a true curve.

519. **Placing Spiral Reinforcement.** — The spiral hooping shall be wired to each vertical bar at frequent intervals so that the two sets of reinforcement form a strong network. That is to say, the column bars shall be rigidly wired to the coils, so that they retain their desired spacing in handling and concreting. After placing the column spirals and properly tying the longitudinal bars into their proper positions, no more reinforcement is to be erected until the column forms have been filled with concrete.

520. **Splicing Column Bars.** — Column bars shall be spliced as follows:

(*a*) In a butt joint the ends shall be square, the bearing uniform and the joint be held to line by sleeves or splice bars.

(*b*) If lap joints are allowed, the wire wrappings, cable splices, etc., shall be made taut and secure.

Large bars shall be properly butted and spliced. Small bars may be lap jointed.

521. **Butt Joints for Column Bars.** — Column bars shall have full perfect bearing at each joint, and such joints shall occur at floors or other points of lateral support and a tight fitting pipe sleeve shall be provided at all joints of column bars. Column bars which do not fall exactly under those of the story above shall be heated and carefully bent before being hooped together, so as to be perfectly in line vertically.

522. **Lap Joints for Column Bars.** — Lower column bars shall be carried into the upper column sufficiently to develop the full strength of the upper bars and shall be wired to the latter with three No. 10 wire hoops having 1 in. pitch.

523. **Structural Shapes.** — Where structural shapes of more than 2 ins. width are used, they shall be wired (hooped) with No. 10 annealed wire 2 ins. pitch.

524. **Bearing Plates.** — At foundations, steel bearing plates shall be provided for large bars or structural shapes. No reinforcement shall be put into the column forms until the bearing plates at the bottom are properly grouted in place. These plates are to come $\frac{3}{4}$ in. below the top of footings.

525. **Placing Column Reinforcement.** — The reinforcing frame for the column shall be placed plumb, concentric with that of the column below

and braced in two directions. No part of the steel shall touch the wall of the form and the space between the steel and form shall be uniform. Column bars shall be held in a sufficiently rigid manner to maintain their accurate positions.

526. **Bending Column Bars.** — Before placing column reinforcement, the Contractor shall make sure that all bends required in same, at points where they extend into smaller columns on floors above, are made.

527. **Column Footings.** — In case of column footings, a 2-in., or sometimes 4-in., layer of concrete shall be spread on the ground before the footing bars are placed. Each bar shall be tied at two points by No. 16 wire.

All footings are to have (say) four dowels extending 2 ft. 0 in. into columns as shown.

4. Wall Reinforcement

528. **Spacing Curtain Wall Reinforcement.** — Concrete curtain walls must be reinforced in both directions. The maximum spacing of reinforcement shall be 18 ins. between centers, reinforcement in both faces of the wall being considered, thus making them staggered throughout the height and length of the whole wall 9 inches on centers.

529. **Placing Wall Reinforcement.** — The reinforcement shall be placed the required distance from the faces of the wall and in the exact planes laid down in the Engineer's plans. The stipulated spacing of the bars shall be accurately followed and the bars shall be straight and true to line.

529a. **Headers.** — In all walls in which the work is laid up in sections the full height of the wall, finishing against headers to form tongued and grooved joints, the horizontal bars shall be carried through the joint continuously without break, and no lap shall be permitted at such places.

530. **Use of Staples.** — Wall reinforcement should be attached to the outer forms, wherever possible, with galvanized staples if necessary.

531. **Wiring Wall Reinforcement.** — Horizontal wall bars shall be wired to vertical bars at least every four feet, and proper provision shall be made to keep them the proper distance from the face of the wall. Bars must be strongly wired together at not less than one-half of the intersections, if required by the Engineer.

532. **Removal of Staples or Wire Ties.** — Staples or wire ties used to hold the reinforcement in place and left embedded in the concrete shall be cut off deep enough to keep rust spots from showing on the face of the wall.

533. **Tagging Wall Reinforcement.** — All wall bars shall be wired in bundles and properly tagged; the tag for each bundle to be left attached to one of the ends after being placed in the forms.

534. **Wall Footings.** — In case of wall footings, a 2-in., or sometimes 4-in., layer of concrete shall be spread on the ground before the bars are placed. Bars in wall footings do not need to be wired.

5. Miscellaneous Reinforcement

535. Circular Tank Reinforcement. — Spacing of bars shall be accurate and in exact accordance with the plans. The reinforcement shall be concentric with the vertical axis and all splices shall be made with particular care and as directed by the Engineer.

536. Conduit Reinforcement. — Spacing of bars for conduit reinforcement shall be in exact accordance with the plans. The planes of the circumferential bars shall be perpendicular to the axis of the conduit and the alignment of the longitudinal bars shall be parallel to the axis of the conduit. The reinforcement shall be concentric with the axis of the conduit and conform exactly to the required circumferential curve.

Art. 15. Bibliography of Specifications for Steel Reinforcement

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CHAPTER V

TRANSPORTING AND PLACING OF CONCRETE

Art. 16. Transporting Concrete

1. Runways, Towers and Conveyors

537. **Contractor's Plant.** — The Contractor shall provide suitable hoist and all other tools and implements for handling the concrete with the greatest dispatch possible. The arrangement for handling the concrete shall be such that it will be under perfect control at all times.

538. **Transporting Concrete.** — Provision shall be made for rapid transportation of the fresh concrete to the forms in tight carriers and in such a manner as not to separate in any degree the component parts. Concrete shall be conveyed from mixer to place with buckets, cars or wheelbarrows. Chutes may be used with the approval of the Engineer only if they can be so arranged as to deliver the concrete in a thoroughly mixed condition (see Art. 23, page 127). Other forms of continuous conveyors shall not be used without the express permission of the Engineer. No concrete must be wheeled over 150 ft. from mixer to point where it is to be deposited. No wheeling will be allowed on the centering or green concrete. The wheelbarrows shall not be filled so full as to permit mortar to slop out.

539. **Capacity of Concrete Plant.** — The concrete plant must be of such capacity as to handle not less than (say) one hundred and seventy-five (175) cubic yards of concrete in a working day of eight hours, or the Contractor shall install a plant capable of placing not less than   cubic yards per hour.

540. **Runways.** — Good runways for wheelbarrows or other means must be provided to convey the concrete to place without displacing forms or reinforcing. Running barrows directly across reinforcing rods will not be allowed. In other words, forms and reinforcement must be protected from injury from the wheelbarrows or carts by use of substantial runways.

Concrete spilled along runways shall not be deposited in the structure. Runways must be kept free from dirt and in good condition.

541. **Construction of Runways.** — Runways, built double widtn or in double sets, shall be constructed to mixers and from mixers to forms where concrete is to be used. Proper cleats shall be provided underneath the planks to hold them together. Runways shall be so constructed as to avoid unnecessary jolting of the concrete in transit. Ends of boards form-

ing runways must butt together to avoid jarring of wheelbarrows or carts.

Runways should be at least 36 ins. wide for two-wheel carts.

542. **Arrangement of Runways.** — Runways shall be so arranged that workmen travel out by one route and return by another.

Runways must not rest directly on the steel reinforcement, but shall be well supported by horses or trestles that permit proper clearance of the steel and concrete. That is to say, runways must be well above centering for the transportation of concrete or materials.

543. **Support of Hoisting Machinery and Runways.** — All hoisting machinery and runways must be supported independently of the forms, so that the concrete shall not be subjected to vibrations.

544. **Concrete Bucket Towers.** — Concrete bucket or elevating towers shall be well constructed according to plans and specifications, submitted by the Contractor and approved by the Engineer. A double ladder should be made on this tower with rungs 12 ins. top to top.

545. **Concrete Hoppers.** — Storage hoppers for concrete should be made large enough to hold at least two full batches of concrete. Great care must be taken to see that the hopper discharges uniformly and that mixed concrete does not accumulate and lie in the hopper until it has set. In hot weather this needs special attention.

546. **Concrete Cars.** — Concrete cars shall be of simple construction, easily cleaned, dumping at both sides or both ends as desired, and without moving parts, which will become clogged with concrete. The size of car or bucket to be used will depend somewhat on the character of the work.

Art. 17. Precautions to be Taken Before Concreting

547. **In General.** — Erection of forms shall proceed well in advance of the concreting, and ample opportunity shall be given the Engineer to thoroughly inspect them before any concrete is placed therein. Before placing the concrete, care shall be taken to see that the forms are substantial and thoroughly oiled or otherwise treated to insure smooth surfaces and the place to be occupied by the concrete is free from débris and the reinforcing steel has been placed and firmly secured by wiring or other methods to prevent displacement. All shavings, sawdust and other rubbish of this kind must be removed from the forms just before placing concrete and the bottoms of all column forms flushed perfectly clean.

548. **Engineer's Approval.** — When the forms are ready to be filled with the concrete, the Engineer shall be notified and no concrete shall be deposited in the forms until he has inspected the arrangement of the steel and the various fastenings of the reinforcement, and given his approval of the work. The Engineer will then give due notice to proceed with the concrete.

549. **Fastenings, etc.** — Before commencing to pour concrete on floors or walls, the Contractor shall ascertain whether proper provision has been made for location of hangers for shafting, sprinklers, lights and the passage of wires, pipes, shafting, belts, etc., through floors and walls. In other words, the Contractor shall inform himself in advance of what is needed in every piece of work, and have the same on hand in advance of beginning of the concrete work.

550. **Steel Reinforcement.** — Special care shall be used to see that each piece of reinforcement is in its proper position before pouring, and is not moved in placing the concrete. All steel shall be securely fastened in position while concreting is being done, this fastening in no case to be of wood.

551. **Notifying Engineer.** — To avoid delays, the Engineer shall be notified one day in advance when the steel and forms will be ready for inspection.

552. **Preventing Adhesion of Concrete to Forms (Smearing Forms).** — Special care shall be taken to prevent wooden forms or other absorbent materials (such as porous tiles, etc.) which will come in contact with the fresh concrete from absorbing its water, by insuring that the surfaces of such materials exposed to the concrete have been rendered non-absorbent by being thoroughly wetted, just before the placing of concrete or in any other suitable manner. The oil or grease shall be thin enough to flow and fill the grain of the wood. That is to say, before placing concrete upon wood faced forms, the centers shall be smeared over with soft soap, crude oil, or other material, satisfactory to the Engineer, to prevent the adhesion of the concrete to the forms.

553. **Removing Lumps of Concrete from Different Receptacles.** — No lumps of concrete shall be permitted to lie in any of the cars, hoppers, troughs, wheelbarrows or other receptacles which are used for conveying it from the mixer to the forms. Each receptacle shall be cleaned at the cessation of work.

554. **Resumal of Work.** — Before depositing any concrete after work has been discontinued for over one hour, the forms shall be cleaned of any concrete adhering to them, and all fins or broken pieces on the top of the concrete removed; and the forms and upper surfaces of the concrete shall be thoroughly wetted.

555. **Removal of Unfinished or Unsafe Panels.** — All unfinished and unsafe panels or sections shall be removed before starting a new one, and any batches or remnants of materials, containing cement, not used on the first set, shall be condemned and removed whether in the wall or floor, or in the vicinity of the work.

556. **Inspecting Concrete Before Placing in Forms.** — No concrete shall be laid except in the presence of an Inspector. The Inspector shall carefully note the uniformity of the mixture delivered to the forms and shall see that it contains no foreign substances, such as wooden blocks, chips, etc. He

shall carefully note whether the color apparently indicates the proper mixture and in case of doubt must verify from the mixer the proportions of the batch.

557. **Plumbing and Leveling of Forms.** — Before the pouring of concrete, there shall be workmen assigned to keep watch of all forms and correct any displacement or looseness of forms or reinforcement.

558. **Removing Lumps of Concrete from Forms and Reinforcement.** — Any concrete, which may be spilled on the forms or reinforcement and is set and dry in advance of completed work, must be swept up and removed, and forms and reinforcing must be washed clean before fresh concrete is deposited.

559. **Excess Water in Forms.** — Excess water in forms shall be drawn off by boring holes with an auger before placing concrete. By thus drawing the water off the top before closing a day's work and taking care that no water accumulates, laitance may be avoided. If the water is allowed to stand and to evaporate, very fine impurities, finer than pass a 200 mesh, will be deposited on the surface.

560. **Rock Surfaces or Foundations.** — Rock shall be cleaned and washed with wire brooms, roughened if required, and covered with a thick neat cement grout before placing the concrete or the surfaces thoroughly wetted. Especial care shall be taken to see that all loose or broken chips of rock and dust are removed before concrete is placed either on or against the rock. Steel bars shall be used to anchor concrete to rock, if required.

561. **Earth Surfaces.** — Earth surfaces shall be wetted and compacted by ramming immediately before depositing concrete thereon. (See Art. 18, Sec. 2, page 109.) Any considerable amount of dust or loose earth must be removed.

562. **Proper Arrangements to be Made for Concreting.** — Concrete shall not be started in a form until everything is in readiness to proceed without interruption.

563. **Dry Weather.** — In dry weather or whenever so required by the Engineer, the forms shall be thoroughly wet with water just before placing the concrete within them.

564. **Freezing Weather.** — In freezing weather steam must be used in place of water to drench the forms, immediately before placing the concrete. The frost must be removed from the ground by fires, the use of pavement heaters, or other suitable method. (See also Art. 22, page 122.)

565. **Turning Over Concrete in Wheelbarrows.** — When the water rises to the surface in wheeling concrete from the place where mixed to the place of deposit, the concrete shall be turned over in the barrow with a shovel before it is deposited in the forms.

566. **Bonding New to Old Concrete.** — In case it should become necessary to join fresh concrete to a surface already set, where a bond is desired, such surface shall be treated as specified in Art. 20, page 118.

567. Bracing of Falsework. — Before pouring concrete the bracing and supports shall be carefully inspected and, if necessary, wedges shall be tightened up. All bracing shall be firmly secured and perfectly rigid, so that the moulds, forms or centers will be true to the lines and grades as given by the Engineer.

Art. 18. Placing, Puddling and Ramming Concrete

1. General Requirements

568. Handling Concrete. — Concrete, after the addition of water to the mix, shall be handled rapidly, and in as small masses as is practicable, from the place of mixing to the place of final deposit, and under no circumstances shall concrete be used that has partially set before final placing (see page 40). A slow setting cement shall be used when a long time is likely to occur between mixing and final placing.

When concrete is properly made the whole mass becomes one stone when it has set, and it is very important that the placing of concrete shall be continuous. The Contractor may at times be required to complete the section of work then going on without stopping, even if working overtime is resorted to. It is of vital importance that no stop be made in placing the concrete in any portion of the work until the depth or thickness called for is in place.

Concrete shall be kept in motion until deposited in place.

Only workmen accustomed to handling concrete shall be employed on the work.

569. Dumping Concrete. — Concrete shall be dumped from receiving box or car, or shoveled directly into place, use of slides and chutes being forbidden. The concrete shall be dumped as nearly as possible in the place it is to occupy in the work. Concrete must either be dumped slowly or shoveled out and shall not be dropped from too great a height or thrown from too great a distance when being placed upon the work. It should not be dropped further than 6 ft. The Contractor shall furnish suitable appliances when necessary to deposit concrete without allowing it an excessive free fall. It shall be so deposited as not to injure the forms or the concrete already placed.

570. Separation of Aggregates. — Great care must be used in dropping the concrete. Otherwise the concrete will fall in a cone-shaped pile and separate the stone from the mortar, which will pile up. Concrete must be deposited in such a manner that there will be no separation of coarse from fine material. Excess of water causing materials to separate must be avoided. Concrete may be handled and placed in any way, best suited to the nature of the work, provided the materials do not separate in placing.

571. Depositing in Buckets. — Buckets shall just clear the work when discharged, as when the materials are allowed to drop they are liable to jar the forms and displace the reinforcement and at the same time produce separation of the stone from the mortar. Buckets shall not leak and spill concrete over the work.

572. **Forms for Concrete Construction.** — All concrete shall be deposited in forms of substantial character. (See Chapter III, page 50.)

573. **Time of Placing.** — The time elapsing between mixing and pouring the concrete shall be well within the time set of the cement. As a rule the elapsed time shall not exceed 30 to 60 minutes between wetting the cement and the undisturbed concrete in final place. (Some specifications restrict it to 10 minutes.) The Engineer will be guided by the tests in establishing a limit of time beyond which any concrete once mixed shall not be used in the work.

574. **Preventing Concrete from Setting Too Rapidly.** — Care shall be taken not to allow the first concrete placed to appreciably stiffen or set before the remaining concrete is placed. The remedy for this is to occasionally, as often as is necessary, add a little more concrete to that already placed over all exposed surfaces.

575. **Rehandling Concrete.** — Concrete shall be so placed as to avoid rehandling within the forms as no tempering or unnecessary rehandling of concrete will be permitted.

576. **Depositing in Wheelbarrows.** — Wheelbarrows must not strike the floor in dumping.

577. **Pouring Concrete.** — The concrete shall generally be placed in small masses and in thin horizontal layers of about 4 ins. to 6 ins. in thickness; but where satisfactory to the Engineer and when satisfactory arrangements are made to insure the placing of the concrete in approximately horizontal layers without the separation of its ingredients, and to insure the complete filling of the forms, the concrete may be "poured."

578. **Method of Pouring.** — Wet or liquid concrete must be deposited so that it will not flow along the forms or sweep the reinforcement out of place. All concrete shall be poured in the most approved manner. That is to say, liquid concrete shall be so deposited as to maintain a nearly level top surface and so avoid flowing along the forms.

579. **Placing Concrete Under Water.** — No concrete shall be laid in water except under the instructions of the Engineer and with special permission for each case. (See Art. 24, page 128.)

580. **Rock Faces.** — Special care shall be taken in placing concrete against a rock face where a bond is desired.

581. **Order of Placing Concrete.** — Concrete shall be placed in the positions as directed by the Engineer, and the order of placing shall in all cases be as directed by the Engineer.

582. **Work Divided into Sections.** — The work shall be carried up in sections of convenient height and length, and the sections completed without

intermission as far as practicable. In no case shall work on a section stop within eighteen (18) inches of the top, or any face.

583. **Placing Concrete in Straight Lines.** — In placing concrete, the work should be, if possible, carried along in a straight line on the section of the structure which is being concreted.

584. **Manipulation of Concrete: Compacting.** — The concrete shall be deposited in such a manner as will permit the most thorough compacting, such as can be obtained by working with a straight shovel or slicing tool kept moving up and down until all the ingredients have settled in their proper place by gravity and the surplus water has been forced to the surface by ramming or otherwise compacted so as to make a dense and compact mass. The manner and extent of the compacting shall be satisfactory to the Engineer. When placing the concrete there must always be one man detailed, or more if the Engineer so orders, whose duty it will be to do tamping exclusively, following up the shovelers or dumpers as they place the concrete. In general, the methods shall be such as to give a compact, dense and impervious concrete.

Special care shall be exercised to prevent the formation of laitance, which hardens very slowly and forms a poor surface on which to deposit fresh concrete. All laitance shall be removed.

585. **Placing Concrete in Layers.** — Excepting in arch work, all concrete must be deposited in horizontal layers of uniform thickness. Layers of concrete must not be tapered off in wedged-shaped solids, but must be built with square ends, temporary planking being placed at ends of partial layers, so that none shall run out to a thin edge. Each layer shall be deposited before the "initial" set of the previously deposited layer and shall be left somewhat rough to insure bonding with the next layer above, and shall be of such thickness that it can be incorporated with the one previously laid. The surface of the top layers shall be leveled with a straight edge, or in other suitable manner. In other words, the layers shall be kept, in general, as nearly horizontal as may be during the process of placing, unless otherwise ordered by the Engineer, one layer being completed before another is started, and layers of concrete must not be run out to a thin edge.

Tops of horizontal layers of concrete shall be properly cleaned before other concrete is placed on them. (See Art. 20, page 119.)

586. **Staggering Layers of Concrete.** — Layers shall not be tapered off, but be built with square ends, and when, from any cause, it becomes impracticable to complete a layer, a plank of convenient width shall be secured to the form against which the concrete shall be rammed, thus making a vertical joint. Should it become necessary to start a second layer at once, it should stop short of the first plank at least 12 ins., when a second plank must be secured in the same manner as the first, and the concrete rammed against it, the layers being carried up full thickness to the board, and left

rough. No loose stones or porous places shall be left on the surface of any layer, but such places must be filled with mortar, and the ramming repeated until wet mortar flushes to the surface. The ends, where a full layer cannot be laid at the time, shall be squared off in every case by vertical temporary planking.

587. **Pouring Concrete at Several Points.** — Concrete shall be poured at several points over the area to be filled so as to reduce flowing and spreading to a minimum.

588. **Thickness of Layers.** — The concrete shall be deposited in layers of the thickness required, but one layer shall quickly follow another, so as to give monolithic and homogeneous work. Layers of a medium wet (plastic) mixture shall not exceed 6 ins. after ramming, unless otherwise directed by the Engineer, and shall be truly horizontal. The concrete shall generally be placed in thin horizontal layers of about 4 ins. to 6 ins. in thickness.

The thickness of layers will depend upon the character of the work in hand, of which the Engineer shall be the judge.

589. **Thickness of Layers on Steep Slopes.** — In special cases where the concrete must be placed on steep slopes, a dry mixture in 4-in. layers may be used.

590. **Thickness of Layers for Massive Concrete.** — The concrete will be moderately rammed in 12-in. layers or less, as may be directed by the Engineer.

591. **Thickness of Layers for Dry Mixtures.** — Dry mixtures, when specified, shall be deposited in even layers not exceeding 6 to 8 ins. in thickness.

592. **Puddling with Full Forms.** — Filling the forms completely and puddling afterward will not be permitted.

593. **Placing Concrete Around Reinforcing Steel.** — In filling in concrete around reinforcing steel, the concrete must be worked continuously with suitable tools, as it is put in place. Care must be taken to avoid displacing the reinforcement. Bars shall be lightly tapped to assist the settlement of concrete under and around them and shall be entirely incased in concrete, care being taken to insure the coating of the reinforcing metal with mortar and the thorough compacting of the concrete around the bars.

594. **Puddling or Churning Wet Concrete.** — Puddling shall be thoroughly done so as to work out air bubbles and pockets and bring the concrete into close contact with the reinforcement at every point. This shall be done by thoroughly churning the concrete after it has been deposited in the forms. Forks, spades or other suitable instruments shall be used for this purpose. These implements shall be small enough to enter well into the spaces between and around the reinforcement, and shall be pushed along all faces of the walls.

The Inspector shall insist upon the concrete being well spaded, for only by thorough spading can air bubbles be worked out. The stones shall be carefully but judiciously spaded away from the face; too much and unskillful spading will permit an upward flow which will wash the cement from the concrete at the face.

595. **Obtaining Smooth Face for Exposed Surfaces by Spading.** — Faces exposed to view shall be made smooth by thrusting a spade or fork through the concrete close to the form to force back the large stones and prevent stone "pockets." Care shall be taken in removing the large stones from the face to prevent an upward flow which will wash the cement from the concrete at the face. The finer mixture must be flushed against the forms. No separate facing and no plastering will be allowed, and when the forms are removed, a smooth surface, free from voids, will be required, and pointing of holes in the face must be reduced to a minimum by the above method.

In the case of a dry mixture, "spading" must be done with greatest care by experienced hands to get uniform results. Such special rammers and forks shall be used as near the face as may be required to give the desired finish.

596. **Facing.** — Facing may be accompanied in one of two ways: (1) The material next the face may be spaded back with a flat shovel or flat fork, to permit the mortar to flow to the face; (2) about one inch of mortar (not grout) of the same proportions as used in the concrete, but without the stone or gravel, shall be placed next the forms immediately in advance of the concrete. Either method may be used at the option of the Engineer, the Contractor being permitted to use the least costly method that gives a satisfactory result.

Care must be taken to remove from the form the dried mortar which splatters against them, in order to secure a perfect face.

597. **Obtaining Smooth Surfaces with Rich Mortar.** — Smooth surfaces may be obtained by spreading a thin layer of rich mortar (1 cement to 2 or 3 sand), about 1 inch thick, over a section of the area to be concreted ahead of the regular mixture. The thickness of mortar facings shall not exceed 1½ ins., nor be less than ¾ in.

598. **Placing Mortar Facing and Backing.** — The mortar facing and backing must go on simultaneously in the same horizontal layers. In order to gage the thickness of the mortar facing accurately, a light board or diaphragm of thin metal with convenient handles shall be set on edge parallel to and 1 or 1½ ins. from the front wall of the forms (see page 136). The facing material shall be deposited in the space between this board and the form. The concrete of the backing shall then be deposited and spread against the back of this board, which may then be withdrawn and the whole mass thoroughly rammed so as to bond the mortar facing and backing by destroying the surface demarcation between them, but no stone must be forced nearer to the front wall of the form than ¾ in. Necessary devia-

tions from this method may be adopted on the approval of the Engineer. Care must be taken to remove from the forms the dried mortar which spatters against them, in order to secure a perfect face.

By using the metal diaphragm or light board in the manner above described the face of each layer may be made exactly the right amount of mortar, and the proper thickness of the layer may be accurately determined. The intention is that the facing and the backing shall be rammed and set together. In no case is one to be put in advance of the other, so that either may set before the other.

The facing shall show a smooth dense surface without pits or irregularities. This is most likely to be secured by thorough and systematic ramming. The facing mortar shall be of the same composition as the mortar used in the concrete back of same.

Plastering the face after removing the forms will not be permitted unless otherwise provided (see page 144).

599. Mortar Face for Arches. — In places where the above method cannot be used, as the under surface of arches, the same end shall be attained by methods satisfactory to the Engineer.

600. Refinishing Mortar Facing. — In no case shall any work be finished by plastering mortar on concrete which has set, but should it become necessary at any time to refinish a surface which has set, it shall be picked off so that at least 3 ins. of mortar can be added, and the surface of the old concrete shall be roughened and thoroughly wet before new material is added, such new material being mortar as specified for facing.

601. Ramming and Compacting of Concrete. — After being placed, each layer must at once be thoroughly rammed and consolidated so that no void spaces are left. The Contractor shall insist upon the thorough ramming and compacting of all concrete, as the value of the work largely depends upon the completeness with which this highly important part of the work is done. The bottoms of tamping tools shall be kept clear of hardened mortar so as to pack the concrete with flat surfaces. No mortar that has been prepared for the purpose of forming a new batch of concrete shall be taken to plaster any rough or improperly tamped places that may appear in the work, as ramming or tamping must be the only means employed to obtain a smooth and regular surface. When a dry mixture is used it shall be tamped until water flushes to the surface.

Concrete shall be laid and rammed in layers, as far as practicable, normal to the direction of the pressure it carries.

Care shall be taken in the ramming not to displace any braces, ties, forms, pipes or other embedded fixtures.

602. Ramming to be Completed as Work Progresses. — The ramming must be completed as the work progresses. In no case shall concrete be permitted to remain in the work if it has begun to set before the ramming is completed.

603. Light Ramming of Concrete. — It is not expected that much ramming will be necessary, but the Contractor shall resort to light ramming as required by the Engineer to secure good results by causing the water to flush to the surface. As soon as water flushes to the surface tamping shall be stopped.

604. Rammers or Tampers. — Twelve-pound metal rammers shall as a rule be used, and such other rammers or pneumatic machines as may be required by the Engineer to secure thorough work in different places. Special shaped tampers will be required for places where ordinary tampers would not be effective. In all cases, tampers shall be of such form and material as the Engineer may approve. The tamping tools shall be at least six inches square at the bottom and shall not exceed twenty square inches. Unless written order is given by the Engineer to the contrary, the tamping shall be done with iron tampers six inches square.

605. Wooden Tampers or Rammers. — Tampers or rammers shall be made of an oak stick eighteen (18) inches long, 4 by 4 inches at the top, and 3 by 3 inches at the bottom fixed to a handle at the top.

606. Force of Rammers and Shovelers. — For distributing and ramming the concrete in place after delivery, a sufficient force of rammers and shovelers shall be maintained for each mixer in operation to handle the concrete rapidly and ram it thoroughly before another batch is dumped within the forms; and when this labor is specially severe the Contractor shall require the changing of men so employed in order that this part of the work may be thoroughly performed. The labor necessary to spread and compact the concrete must be other than that required to mix it.

607. Concrete to be Free from Voids. — The concrete must be so thoroughly compact that there shall be no pores or open spaces between the stone of which it consists that are not thoroughly filled with mortar, and every effort shall be made to secure the greatest possible density of the mass.

608. Time Required for Ramming Concrete. — The length of time ramming should be continued and the vigor with which it should be done depend largely on the degree of plasticity of the concrete. If the concrete is made of such a consistency that when struck a smart blow with the back of a shovel a film of moisture will just show on the surface, it shall receive vigorous ramming to insure a compact mass. A flushing of water to the surface shall serve as an indication when to cease tamping.

609. Removal of Defective Layers. — Any portion of any layer of concrete which has been left long enough to have any appearance of setting shall be taken up and relaid before the next layer is put on, if so required by the Engineer or may be treated as follows:

610. Fresh Layer on One Which has Set or Partially Set. — When a fresh layer is to be put on one which has set or partially set, the entire surface must be thoroughly swept with metal brooms or brushes. The skin or film usually forming on the surface of the concrete must be completely scrubbed or steamed away. All surfaces and pockets must be cleaned of all sawdust, shavings or other matter, and when completely cleaned, it shall be thoroughly wetted before the new layer of concrete is placed. (See also Art. 20, page 118.)

611. Tapping Forms to Produce Smooth Surfaces. — In addition to tamping, the forms of all concrete work, beams, girders, etc., shall be lightly and continuously tapped with a suitable maul, as may be directed by the Engineer to provide smooth and perfect surfaces. The outside of the forms shall be pounded with wooden mauls or mallets immediately after receiving the concrete, to assist in shaking down and consolidating the concrete.

612. Removal of Defective Concrete. — Any concrete work indicating that it has not been thoroughly mixed in the required proportion shall be dug out and replaced as directed by the Engineer.

613. Wetting Concrete. — When a deficiency of moisture is indicated after ramming is completed, it shall be supplied by sprinkling with a fine spray of clean water. After ramming, surface of concrete shall be kept moist until it fully sets by sprinkling at short intervals. For this purpose not less than one large watering pot for each mixer shall be kept in constant service, and as many more as may be required.

614. No Walking on Fresh Layers. — When in place, all wheeling, working or walking on the concrete must be prevented, until at least twelve hours after being deposited or until it has set for a sufficient length of time, to be determined by the Engineer. (See also Art. 21, page 120.)

615. Rubble Concrete.* — The incorporation into the concrete of clean, hard, sound stones, and of all sizes that may be conveniently handled over 50 lbs. weight, will be permitted for mass concrete (generally without reinforcement), provided the stones be separated by a minimum thickness of 4 inches, and be thoroughly embedded in the concrete on every side. Such stones must be thoroughly scrubbed clean before being placed in the work and shall be wetted immediately before setting in position. These stones shall be set in the concrete as the layers are being rammed, in a manner satisfactory to the Engineer, and so placed that each stone is completely and perfectly embedded. No stone shall come within four (4) inches of any exposed face. In cases where large stones are placed in layers of concrete which are likely to set before subsequent layers are placed thereon, they shall be laid with one-half their surface exposed. If a dry concrete is used, the concrete shall be thoroughly tamped around each large stone.

616. Night Work. — At times it may become necessary to continue the work into the night in order that a suitable stopping point may be reached by continuous work in placing concrete. Night work shall not be done

* Where the concrete is to be deposited in massive work its value may be improved and its cost materially reduced by the use of clean stones (sometimes called "bulk-swellers," "plumbs," "oneman stones," "niggerheads," "boulders," "packing," "displacement stones," "puddling stones," or "cobblestones") thoroughly embedded in the concrete as near together as is possible and still entirely surrounded by concrete.

except in cases of emergency. During the progress of night work, it is necessary to be extremely careful that the work is carried on in exact accordance with the specifications. No night work will be permitted unless suitable arrangements are made for the lighting of the work. Night work shall be carried on with as small a gang as will insure the placing of fresh concrete before that beneath it has set. In other words, pouring at night shall be avoided, but if unavoidable, suitable light acceptable to the Engineer shall be furnished by the Contractor.

617. **Inclusive Price.** — The price bid per cubic yard in place shall include all lumber, timber, bolts and materials used in the forms for the concrete and all work on the same, and no allowance shall be made for cofferdams, pumping or bailing, or for any materials or labor necessary on account of water.

618. **Measurement.** — All concrete shall be measured in accordance with the dimensions shown on plans, and no allowance will be made for quantities in excess of the measurements so indicated, unless such excess quantities shall have been placed by written order of the Engineer.

619. **Payment.** — Payment for all concrete will be made at a unit price per cubic yard for each class of concrete, and this payment will cover (except where otherwise stated) the cost of all incidental material, labor, tools, etc., necessary for the completion of the work, and the maintenance of the same in good condition until the acceptance thereof.

620. **Extra Concrete.** — Extra concrete will not be paid for unless the changes provided for are made, and then only for such work as is done under written orders from the Engineer.

Payment for extra concrete will be made at the rate of   dollars per cubic yard in place. This price will cover all forms and incidental work.

620a. **Concrete Foreman.** — The Contractor shall place in charge of the placing of the concrete a man who has had extensive and responsible charge of other work of this class and who can give references, as to ability and experience, satisfactory to the Engineer. No foreman lacking the required experience in this line, on high-grade work, shall be allowed upon the work. The Engineer shall have the right to discharge at any time, without consultation with the Contractor, the Concrete Foreman, when he is of the opinion that the man is incompetent, inexperienced or unfaithful, or refuses to carry out the instructions relating to his work as given by the Engineer, or is in any way careless or negligent in his method of handling the work.

2. Placing Concrete in Excavations and Foundations

621. **In General.** — Concrete shall be placed in excavations by means of chutes (see page 127) or other appliances to prevent an excessive free fall. The Contractor is expressly prohibited from using methods that will cause separation of the aggregate and matrix unless with special permission

of the Engineer, and in such cases, the concrete must be thoroughly remixed before being placed.

When used for foundations concrete shall, when practicable, be deposited and rammed against the sides of the excavation.

621a. Foundations Below Water Level. — Where concrete is to be put into a foundation below water level, all water shall as far as possible be removed from the excavation. If it is impossible by means of the ordinary pumping facilities to control the flow of water, the excavation may be taken out in sections, and the concrete may be placed in the foundation, section by section. Special care must be taken to ram thoroughly the bottom layer of concrete, and to remove all mud and clay from the vertical face of each section of concrete, as additional sections are excavated and prepared for additional concrete work.

Where the foundation is soft, as for example where piles are used, either fine or coarse broken stone may be spread over the bottom of the excavation and thoroughly rammed into the earth before putting in any concrete.

In no case shall a dry mixture of sand, cement and crushed stone be put into a foundation. The concrete may be mixed with a less proportion of water, but must not be placed in the foundation without thorough mixing.

Where strata of gravel and sand permit the entrance of water into the foundation with such freedom that small sections of the same cannot be excavated and pumped out for concreting, a grout of pure cement or of a mixture of cement and one or two parts of sand may be injected through a pipe into the loose gravel and sand in the bottom of the foundation, this work being done while the excavation is filled with water. The pipe through which this grout is passed should be pushed a few inches below the surface of the gravel, and a bucketful or more of grout should be poured down through the pipe, the pipe being then moved one or two feet, and the operation repeated, distributing the grout over the whole area of the bottom to be thus cemented, and the work then should be allowed to stand for twenty-four to thirty-six hours. It will generally be found that the sand and gravel will be converted into a watertight concrete, permitting the pumping of the excavation.

621b. Foundation Concrete. — Foundation concrete may be put into excavations without the use of forms, provided the sides of the excavation are reasonably true and the material is sufficiently firm, so that the concrete may be rammed thoroughly without yielding of the adjacent earth. Foundation concrete, if put into excavations which are not protected by forms, need not have any special attention given to the finish of the concrete against the earth around it.

Where it is necessary to use forms in the construction of foundation work, the finer material of the concrete shall be worked to the outer portion of the mass against the forms, so as to insure the filling with mortar of all pores or open spaces between the concrete stone. Where a cheaper kind of concrete is used for foundation work, the top of the same shall be finished smooth and level, the corners and edges being thoroughly rammed and compacted, and the whole surface filled full of mortar. It will not be satisfactory to leave a honey-combed surface or one on which loose concrete stone is left scattered about. If necessary, the Inspector shall have the Contractor make batches of mortar, consisting of one part of cement to three parts of sand, the same being thoroughly mixed, and shall cover the whole surface of the foundation concrete with enough of this mortar to flush full all such open, porous places.

It is not expected that the surface of such foundation shall be accurately leveled unless cut stone masonry is to be built upon it, but the Inspector must insist that that portion of such foundation concrete which projects outside of the masonry which is to be built upon the foundation must be thoroughly rammed and compacted, and must have a finished surface.

622. Pouring Concrete in Trenches. — Concrete must be lowered into trenches (over 6 ft. deep) in boxes or buckets, and will in no case be allowed to be cast in by shovels from the surface. The Engineer may require that the concrete be dumped in inclined chutes, instead of buckets, the angle of the incline to be determined by him.

623. Wetting Trenches. — Before the first layer of concrete is put into the trench, the bottom of the trench must be thoroughly sprinkled with water from a hose, so that the water in the concrete may not be absorbed.

624. Footings. — Footings shall be cast at one operation where practicable. All footing concrete shall be deposited in layers not exceeding nine (9) inches in thickness, and each layer shall be thoroughly rammed.

3. Placing Concrete in Columns and Walls

625. Pouring Columns. — Columns shall be poured well ahead of the beams, one day being preferable.* In filling columns the concrete shall be poured in small batches, preferably by dumping the barrows on the floor, and shoveling the concrete into the column. The operation shall preferably be continuous from the base to the underside of supported beam or girder, but if stopped short of completion, the unfinished surface must be left level.

When laying concrete in columns, a continuous spading shall be kept up during the operation so as to work it thoroughly in and around the reinforcing steel. It is absolutely necessary to expel bubbles of air by constantly puddling or joggling the concrete with a rod heavy enough to sink into the concrete with ease.

* There are important reasons for filling column forms considerably in advance of the beams or girders attaching to them, and this instruction must not be disregarded.

Filling the columns completely and puddling afterwards shall not be allowed.

626. **Mortar at Base of Column.** — Before the regular column mixture is poured, there shall be at least 2 or 3 ins. of mortar of proportions 1 to 1 placed in the bottom of column forms.

627. **Preventing "Honeycombing" in Columns.** — The lower 1 ft. of each column shall be filled with a concrete containing more sand and less stone than the regular mix, under the instructions of the Engineer, in order to avoid any "honeycombing" at this point. The balance of the column shall be filled with concrete mixed as herein specified for columns.

628. **Tamping Column with One Rammer.** — At least one man shall continuously tamp a column, during the process of concreting, by means of a stick of lumber 1 in. by 2 ins. (or 2 ins. by 2 ins.), or with thin tampers that will go in and around the reinforcement at all four sides simultaneously. During the operation, the concrete in the column shall be constantly churned in order to prevent arching in the interior of the column, by being freed from air bubbles.

629. **Use of Two Rammers to a Column.** — In pouring concrete in column forms, the Contractor shall provide long slender poles with flat steel ends for puddling the concrete. At least two of these rammers shall be constantly used in each column during the pouring.

630. **Hammering Sides of Column Forms.** — The outside of column forms must be hammered with mallets, during the process of pouring, so as to exclude air bubbles and make a smooth surface.

631. **Columns Over 12 Feet in Height.** — All columns more than twelve feet (12 ft.) in height shall be filled from the sides and top as directed by the Engineer. The concrete in the columns shall be deposited continuously through tremies, if so required by the Engineer, in order that the stone and the mortar shall not be separated or the bottom part of the column shall be poured through an opening left in the side which can be closed when the concrete reaches that point.

632. **Excess of Water in Columns and Walls.** — Particular care must be given to the filling of columns and walls not to have an excess of water, the whole must be uniform from bottom to top. If water accumulates on the concrete, churning or working shall cease until additional drier concrete is placed to prevent the washing out of cement.

633. **Minimum Time for Filling Long Columns.** — In all cases where columns are of an unsupported length of more than twelve (12) times the least diameter, the filling shall be done gradually and to every foot of height there should not be less than ten (10) minutes time used to insure minimum amount of contraction, due to the setting up of the mixture.

634. **Cement Grout at Base of Column.** — Before beginning to fill the forms of columns, the bottom or bearing surface must each time be thoroughly slushed with a neat cement grout.

635. **Column Reinforcement.** — Care must be taken that the column bars keep their place while concreting the columns, and for this purpose the tops of the bars must be steadied by wires or boards.

636. **Placing Concrete in the Mushroom System.** — In pouring, the column and mushroom head shall be filled first completely, then proceed to pour the concrete in the slab.

637. **Spiral Columns.** — In columns having spiral or circumferential reinforcement the concrete shall preferably be introduced by means of a tremie or tube, in order to prevent the ingredients from sorting in layers.

638. **Pouring Walls.** — Walls shall be blocked off into convenient lengths and the whole work brought up uniformly along this section to prevent long, wedge-shaped layers of concrete. Upon stopping, the concrete shall be brought up to a uniform level. The concrete in walls shall be laid in layers, not less than four (4) inches, nor more than nine (9) inches in thickness. No rods to hold the forms will be allowed to pass through the walls, except on the written permission of the Engineer.

Soupy concrete should be used for thin walls, but not so wet that the mortar is watery. The concrete should be puddled rather than rammed, the object being to prevent stones from collecting in any one place, and causing noticeable voids on the surface.

4. Placing Concrete in Slabs and Beams

639. **Pouring Slabs.** — In making slabs, the full thickness shall be poured in one continuous operation. If possible slab and beam shall be made monolithic. During the pouring of floors there shall be at least two workmen assigned to giving their undivided attention to this work. Care must be taken to raise slab reinforcement the proper distance above centering as concreting progresses.

640. **Insuring Proper Thickness of Floors.** — When concreting floor slabs, stakes shall be placed from place to place showing the thickness of the floor in order to insure a level floor.

641. **Concreting Floors in Units.** — The units of construction as indicated on the drawings shall be rigidly observed, and each unit completed at one time. The floor slabs may be made in sections, provided that the ends of all sections coincide with the center of beams.

642. **Hollow Tile Construction.** — In hollow tile floor construction, the concrete on top of the tile must be poured at the same time as the concrete in the joists.

643. **Shoring Forms.** — During the process of concreting, the Contractor shall see that a careful workman is stationed underneath slabs, beams, girders, etc., to watch for any deflection in the forms and do any necessary wedging up. A workman is to be employed at all times watching centering while concreting is being done. This workman to stretch wires

from column to column to guard against deflection, and to see to immediate strengthening of centering where necessary.

644. **Pouring Beams in One Operation.** — Beams shall be poured in one continuous operation from bottom to top, the concrete worked closely around the reinforcement by puddling, and the stone worked back from the sides by spading. If possible, beam and slab shall be poured in one continuous operation. At least one man, but generally two men, will be required to tamp each beam, during the process of concreting, by means of special spades, and the Contractor shall supply a sufficient number of crowbars and heavy hooks for shaking and eventually lifting the reinforcement.

645. **Pouring Beams in Two Operations.** — In beams and girders, the concrete is first to be carried up to the tops of the bottom bars, and immediately after being thoroughly damped or churned by striking the bars with the tamping tools, the beams and girders are to be completely filled and carried over the slab in one operation.

646. **Pouring T-Beams.** — When beam and slab are designed to act together as a T-beam, both shall be poured in one operation. No portion of the work must be started unless it can be pushed to completion, except by special permission of the Engineer.

647. **Pouring Extra Long Beams.** — No stops shall be allowed on extra long beams or girder spans and special arrangements shall be made to do the entire work in one operation.

648. **Spading and Churning Beams.** — Spading and churning the sides of beams and girders is necessary to obtain neat appearing surfaces.

649. **Beam Stirrups.** — Care shall be taken that the stirrups remain in their places and are held up tight against the under side of beam tension bars while concrete is being placed.

650. **Shrinkage Cracks on Surface of Slabs.** — Any preliminary shrinkage cracks which occur on the surface of the slab due to too rapid drying shall be immediately filled with liquid cement grout.

5. Placing Concrete in Arches

651. **In General.** — In concreting arches, the arch ring shall be divided into sections of such size that the pouring of each can be made a continuous operation. Transverse and longitudinal arch blocks shall be cast continuously and the Contractor shall not start such work unless provided with sufficient plant and material to insure the finish of such a section continuously.

No work shall be started on arch rings until piers and abutments have been examined and permission given by the Engineer.

652. **Concreting in Longitudinal Sections.** — In longitudinal sections, the concrete shall be begun simultaneously at both skewbacks and continued uniformly and continuously to the crown. That is to say, the

construction of the arch ring must proceed continuously and without interruption from the time it is started until completed, work being begun at both abutments simultaneously, and carried at a uniform rate of progress therefrom until joined in completion at the crown of the arch.

653. **Concreting in Transverse Sections.** — Where the sections are transverse or across the arch, the better practice is to concrete the crown section first and work towards both skewbacks a pair of sections, one each side, at a time.

654. **Placing Layers of Concrete.** — The thickness of the layers and the degree of ramming shall be such as specified for other work (see Sec. 1, page 106), but the layers must be placed as near radially as practicable, and the ramming done in a direction as nearly at right angles thereto as possible. In the abutments of arches the layers shall be sloped as nearly as possible normal to the direction of the line of thrust of the arch.

655. **Rising of Centering at Crown.** — While the arches and spandrel walls are being concreted, the centering shall be watched closely, and if it shows any tendency to rise at the crown, it shall be loaded with concrete materials until such tendency is overcome.

656. **Division of Arch into Parallel Rings.** — Should the size of the arch be such as to make it impracticable to construct the entire ring in one day it may be divided vertically into a series of parallel rings of such width that one ring can be constructed continuously. The width of such ring shall however in no case be less than five feet. One side of this sub-ring shall be formed against the ring previously constructed, and the other side against a substantial vertical partition which must be removed immediately before commencing the next ring. This could be removed in a day or two, when the concrete would still be green enough for the next ring to adhere fairly well. In order to form a substantial bond between the adjacent parallel rings, cleats shall be fastened to the partitions in such locations and of such shape and dimensions as shall be directed by the Engineer. Sections of the arch along the axis are to be limited to such length as to permit of the concrete being deposited continuously between springing lines.

657. **Bonding New to Old Rings.** — In constructing new rings against old ones, the vertical surface of the old ring shall first be thoroughly cleaned and scrubbed with coarse brushes and water and then flushed with cement grout immediately before placing of the new concrete. (See also Art. 20, page 118.)

657a. **Spandrel or Face Walls.** — The spandrel or face walls may be carried up at the same time as the arch ring is laid, or may be connected with it later by leaving short lengths of steel projecting radially from the concrete of the arch. Some specifications require that arch centering shall be lowered sufficiently to allow the arch ring to assume its permanent set before parapet walls are placed.

658. Layer of Granolithic for Tunnels, etc. — Where concrete is placed on top of sheathing, as in the roofs of tunnels, culverts, sewers, etc., a layer of granolithic shall first be placed, in order to insure a smooth finish to the interior, and the concrete above shall then be thoroughly tamped into it.

659. Groined Arches. — Vaulted roofs shall be laid in alternate squares, the lines of division being through the crown of the groined arches.

Art. 19. Joints Due to Stopping of Work

660. In General. — All concrete work shall be constructed along proper structural lines and when a section or panel of reinforced concrete or any trussed concrete member is started, it shall be finished in its entirety before shutting down, but when this is not possible, the resulting joint shall be formed where it will least impair the strength and appearance of the structure. Joints shall be made only at such points as may be approved by the Engineer.

661. Joints Between Day's Work. — The Inspector's directions shall be followed as to the location of joints between day's work. Joints between day's work shall be at some feature line, or be made truly straight and level.

662. Horizontal and Vertical Joints. — Layers of concrete shall be kept truly horizontal, and if, for any reason, it is necessary to stop work for an indefinite period, it shall be the duty of the Inspector and of the Contractor to see that the top surface of the concrete is properly finished, so that nothing but a horizontal line shall show on the face of the concrete, as the joint between portions of the work constructed before and after such period of delay. If, for any reason, it is impossible to complete an entire layer, the end of the layer shall be made square and true by the use of a temporary plank partition. No irregular, wavy or sloping lines shall be permitted to show on the face of the work at different periods, and none but horizontal or vertical lines shall be permitted in such cases.

The top layers of concrete at the end of a day's work shall be left roughened up or grooved out along their center line in order to form a positive and water-tight bond with subsequent work.

663. Precautions Regarding Horizontal Joints. — Every time a day's work is finished and a horizontal joint is thereby required, the concrete shall either stop 6 ins. below a wale, wiring or rodding, or 6 ins. above. If stopped 6 ins. below, the wires or rods can be tightened and the face boards made to hug the previous day's work, thus avoiding an unsightly lip and a saggy contact which will deform an otherwise good surface. If stopped 6 ins. above the wires or rods, the weight of the concrete will tighten the wire and draw the wale close to the studs and thus bring the boards tight tc face. Should the above precautions be neglected, the Contractor must shim the boards away from the studs with shims, and not just drive them out with a hammer. Unless the boards are shimmed, the wet concrete will force them back against the studs and the result will be an ugly finish.

664. **Joints in Footings.** — Footings shall be cast to their full depth at one operation. Where it is necessary to make joints between different portions of the same footing, the surfaces are to be roughened after tamping so as to provide a suitable clinch for adjoining concrete to be placed later and be scrubbed with cement grout with a broom before placing other concrete. (See Art. 20, page 118.)

665. **Joints in Slabs.** — In slabs, the concrete shall be stopped in a vertical plane at right angles to the span either (a) at midspan, or (b) over the center of the supporting beam or girder.* No horizontal joints will be allowed in slabs. Panels having girders supporting but one beam shall have no stops parallel to beams. For such panels all stops shall be parallel to girders and preferably at the center of beams.

666. **Joints in Tile Floor Slabs.** — The concrete for a tile floor slab with concrete over the top of the tile must all be poured at the same time.

667. **Joints in Beams and Girders.** — Girders or beams shall never be constructed over freshly formed columns without allowing a period of at least two hours to elapse to permit settlement in the columns. Before resuming work the top of the column shall be thoroughly cleansed of foreign matter and laitance.

In beams or girders, the concrete shall be stopped in a vertical plane at right angles to the length of the beam either (a) at midspan, or (b) over the center of the supporting column.* Should a beam intersect a girder at a point midway between supports, the joint should be offset a distance equal to twice the width of the beam. Any concrete which may run pass the bulkheads must be cleaned up before the concreting of the next section is started. In no event shall work be terminated in beams or girders where future shearing action becomes great, as at their ends or directly under a heavy concentrated load.

Where brackets are used, the brackets shall be considered as part of the beam or girder.

668. **Joints in Deep Beams.** — As a rule, deep beams should be constructed somewhat in advance of the slab, but no concrete is to be placed in the beam, and allowed to become so dry as not to properly bond with the balance of the work.

669. **Joints in T-Beams.** — Whenever joints occur in a direction normal to the span of secondary beams, sufficient reinforcement shall be provided for in the slabs across the main girders if the design of such girders has been based on a T-section.

670. **Joints in Columns.** — Joints shall be made in the columns flush with the lower side of the girders, and shall be at right angles to their sur-

* In no case shall work be terminated on beams or floor slabs in any other places than indicated above without special permission from the engineer in charge of the work.

faces. In other words, the pouring of concrete for a column must be a continuous operation to the bottom of the beams or girders.

671. **Joints in Wall.** — Walls shall be stopped in vertical planes across the wall; if practicable the stoppage shall occur where an expansion joint is to come. When the day's work must stop elsewhere than at an expansion joint, it must be essentially on a vertical line with a key or other positive form of bond provided for the connection of the subsequent work. This vertical stop-line shall be stepped back at least one foot for other and subsequent day's work.

672. **Mushroom System.** — In stopping in all cases, the column and mushroom head shall be cast and the splice or joint made up against a vertical plank in the center of a panel, the splice being in a vertical plane.

673. **Grooves for Joining Future Work.** — When the placing of the concrete is suspended, all necessary grooves for joining future work shall be made before the concrete has had time to set. This shall, at the discretion of the Engineer, be accomplished by embedding pieces of plank in the top of the horizontal and vertical layers of concrete, to be removed after the concrete has set, leaving depressions. Beveling the edges of these planks will facilitate their removal. This method, or other methods approved by the Engineer, shall be used whenever it is necessary to leave work unfinished over night or for a longer time. At such points special care shall be taken to tamp the concrete thoroughly, in order that it may be as dense and compact as at other places.

674. **Reinforcing Beam and Girder Joints.** — Steps in successive stages of concreting made parallel to beams shall be vertical and in the center of girders. At such stops place two $\frac{3}{4}$-in. square bars, 3 ft. long, in each girder, projecting 18 ins. into new work.

Stops parallel to girders shall be vertical and at the center of beams, giving each beam two $\frac{1}{2}$-in. square bars, 2 ft. long, projecting 12 ins. into new work.

Note. — The above clauses may be used when it is feared that the bond between old and new concrete will be questionable. The reinforcement above specified is for average spans under ordinary conditions and will suffice for most cases.

Art. 20. Bonding New to Old Concrete

675. **In General.** — Should the continuous laying of concrete be interrupted for any reason, means satisfactory to the Engineer must be taken to clean and roughen the concrete which has set and to secure a good and efficient bond between the older concrete and the fresh concrete placed above and upon it.

Where required, stone or metal binders shall be used between courses or such provision shall be made for binding adjacent portions of the work as the Engineer may approve.

676. **Partly Set Surfaces.** — In joining new work to that which is partly set, such precautions of cleaning, wetting and bonding shall be observed as the Engineer directs.

677. **Preparing Surface.** — When a course of fresh concrete is to be laid on a surface of concrete already set, the surface shall be thoroughly cleaned of all foreign material and laitance or scum, and drenched with water (preferably under pressure), so as to make a firm bond between the two layers. The surface of the set concrete shall be rubbed with a stiff wire or willow broom.

Special care must be taken to remove all loose inert or foreign material from the old concrete before any attempt at bonding the new work is made. If laitance has collected, it must be carefully and completely removed before the new material is added.

The surface of the hardened concrete may be treated with an acid wash, such as "Ransomite." The acid wash shall be thoroughly removed by washing with pure water.

678. **Mortar Joints.** — If required by the Engineer, the surface of the set concrete shall be roughened with a pick and a bed of mortar ½ in. thick spread before laying the fresh concrete. The mortar shall not be leaner than one part Portland cement to two parts sand.

679. **Cement Grout.** — A grout of neat cement may be substituted for the mortar, at the option of the Engineer. In joining new and old layers together, too much care cannot be taken to have them well grouted as refilling proceeds; too much grout, however, should not be used, or the bedding will not be so good. The cement grout shall be thoroughly brushed and tamped in with an ordinary broom, after which the new concrete may be placed.

680. **Failure of Concrete to Bond or Set.** — Any concrete that fails to show proper bond, or that fails to set after, in the opinion of the Engineer, it has been allowed sufficient time, shall be taken up and replaced by the Contractor at his own expense with new concrete of proper quality.

681. **Thin Edges of Mortar.** — Thin edges of mortar that have run out over the centering or bottom of forms shall be broken up into small pieces and allowed to become embedded in new work.

682. **Asphalt Bond.** — When two or more sections completed on different days join, a hot asphalt or other bond approved by the Engineer shall be used between adjacent sections.

683. **Layer of Broken Stone or Strips of Wood.** — The surface of the concrete which is to be bonded to other concrete shall be left in a rough condition, either by spreading a layer of broken stone or gravel over the same, ramming half the depth of the stone into the green concrete and

leaving the upper half of the stone protruding, or by setting in strips of wood which, when removed, will form a groove and assist in making a good bond.

684. **Expansion Joints.** — Where expansion joints occur the faces of the old concrete, after being cleaned dry, shall be given a heavy coat of crude oil satisfactory to the Engineer, which shall have at least one day's drying before fresh concrete is laid against it. Compensation for this work, including the furnishing of oil, shall be included in the unit prices bid for the concrete.

685. **Ramming Layers of New Concrete.** — Care must be taken to especially and vigorously ram the first new layer of concrete and the ramming continued so that a dense concrete will result with perfect bonding between the several layers. These layers must be made with great care and in a manner satisfactory to the Engineer.

Art. 21. Protection of Concrete after Placing

686. **In General.** — Concrete should not be disturbed more than absolutely necessary after being put in place.

Until sufficient hardening of the concrete has occurred, the structural parts shall be protected against the effect of freezing and premature drying as well as against vibrations and loads. Concrete shall not be exposed to the action of water until thoroughly set. Freshly deposited concrete shall be protected from the direct rays of the sun and wind by boards or tarpaulins. When work is delayed for any reason the upper exposed surface shall be protected by a canvas cover until the work proceeds.

687. **Concrete Deposited in Wet Places.** — Concrete required to be deposited in wet places shall be thoroughly protected so that the cement shall not be washed out. (See Art. 24, page 128.)

688. **Wheeling or Handling Material.** — In placing the concrete, the work shall be so laid out that partly set concrete will not be subjected to shocks from men wheeling or handling material over it. Concrete shall be allowed to set for 24 hours, or more if so directed, before any work shall be laid upon it or any walking allowed upon it. Workmen who persist in walking on green concrete shall be discharged.

689. **Sprinkling Concrete.** — All exposed surfaces of finished and unfinished concrete shall be kept constantly moist by sprinkling with clean water at short intervals, unless otherwise directed during cold weather, or by covering with moistened burlap, or by such other means as shall be approved, and this moistening shall continue until the permanent covering is in place or until, in the opinion of the Engineer, the concrete has sufficiently hardened. Wetting shall commence as soon as the surface of the concrete has set.

690. **Concrete Exposed to Premature Drying.** — The faces of concrete exposed to premature drying shall be kept wet for a period of at least seven days. This shall be done by a covering of wet sand, burlap or by continuous sprinkling, or by some other method equally effective in the opinion of the Engineer.

691. **Concrete Placed in Warm Weather.** — Concrete laid in warm weather shall be drenched with water twice daily, Sunday included, during the first week after being put in place. The aggregate shall be thoroughly wetted, more water used in the mixing, and, if necessary, the work shall be covered with planks or tarpaulins. Throughout the work care shall be taken to prevent the rapid drying of the concrete by the sun.*

Note. — Some specifications require that concrete be well sprinkled in hot weather every two hours of the first day and at longer intervals during the several succeeding days.

692. **Plumbing and Leveling of Forms.** — No work shall be done upon forms nor are they to be moved in any way after the concrete is in place, except to correct or secure them.

693. **Protection from Blasting.** — Sufficient canvas or timber covering shall be provided to protect freshly laid work from blasting.

694. **Protection from Traffic.** — Where traffic is unavoidable over green concrete, the surface shall be covered with three inches of sand for protection, or the Contractor may provide suitable boards for the purpose of distributing the weights.

695. **Protection from Frost.** — When considered advisable by the Engineer, fresh concrete shall be covered to protect it from danger of injury by frost.

696. **Time to Set (Heavy Loads).** — Time must be given for concrete to become firm before masonry foundation or other mass work is commenced upon it, usually as much as twenty-four hours, as heavy pressure tends to retard the setting. In the case of quick setting natural cements, however, twelve hours may be sufficient. No water shall be allowed to stand on, or to flow over, fresh concrete work, until the work has had such time to set as may be prescribed by the Engineer.

696a. **Protection of Finished Work.** — Details of ornamentation must be carefully shielded until the entire structure is completed. Sharp corners can be protected from chipping and spalling by placing wooden pieces as buffers on each side. Ornaments cast as independent units must not be set until the latest time permissible. Such ornaments, as well as those cast in place, should be crated and enclosed with canvas to protect them from falling débris and sticky mortar.

* Intense heat of the sun in midsummer and high, dry winds tend to evaporate water from the surface of green concrete and thus injure its appearance. This is easily prevented by such means as enclosing and shading the concrete with planks or tarpaulins. Freshly placed concrete, even though protected, should be sprinkled with water as soon as this can be done without pitting the surface. It may then be covered with sand, if expedient, and thereafter wet as often as necessary. When possible, the exposed surface of concrete should be safeguarded from sun and wind until the concrete has attained an age of thirty-six hours.

Art. 22. Concreting in Freezing Weather

1. General Requirements

697. In General. — When it is necessary to make concrete in freezing weather only Portland cement shall be used, and the materials shall be heated by steam or otherwise, and hot water used in the mixing. Natural cements should not be used in freezing weather, as they will not stand freezing.

Placing of concrete in freezing weather shall be carried on continuously to insure a perfect monolithic mass.

The chuting of concrete in winter shall not be permitted.

698. Prohibiting Concreting in Freezing Weather. — To prohibit placing of concrete when the temperature is near or below freezing, as is frequently done in specifications, causes unnecessary delays and imposes an unjust hardship upon the Contractor. If concrete work is properly handled it may be successfully carried on irrespective of weather conditions. The cold weather clause in specifications instead of prohibiting should be so written as to permit of construction during freezing weather, provided proper precautions, such as specified below, are taken.

699. Precautions to be Observed. — No concrete shall be laid in freezing weather unless precautions satisfactory to the Engineer be taken to prevent injury to the concrete. Thoroughly effective means shall be taken in every case to prevent the wet mixture from chilling or freezing and the Contractor shall make such special preparations as may be required to secure as good work as is done at other times. The mixer shall be housed.

The proper precautions necessary to insure satisfactory results with concrete during freezing weather depend very much upon the class of construction, large plain mass work, such as retaining walls and abutments, not requiring the same care and protection as thin walls, columns, beams and floor slabs.

In addition to the precautions herein stated, the Contractor shall take such other precautions as may be found necessary to secure first-class work in every respect, including the character of the finish of all exposed faces.

700. Engineer's Permission. — In case it becomes necessary to do work in the winter weather, no concrete shall be mixed, nor placed, nor any other operation performed, likely to be interfered with by cold during any of the months of December, January, February and March and thereafter until the frost is out of the ground, unless permission be obtained from the Engineer. If, however, the Engineer is of the opinion that any operation can be satisfactorily performed during these months, he may give the Contractor a special written permit, which permit shall define the work and the conditions under which such work may be done and such conditions shall be faithfully followed.

701. **Contractor's Responsibility.** — The Contractor shall be responsible for all defects in the work done during the above months which may arise from the action of the elements, not withstanding such permit, and additional precautions taken. He shall make good such work, and shall make good any work destroyed or damaged by the frost, even though built at any season of the year.

702. **Starting Work After Prolonged Freezing Weather.** — After prolonged freezing weather the work shall not be taken up again with the warmer weather until the approval of the Engineer has been obtained.

703. **Minimum Temperature for Concreting.** — No concrete shall be made or placed when the weather is, or is predicted to be by the United States Weather Bureau within twelve hours, as low as twenty degrees.

704. **Inspection of Winter Work.** — The Engineer will insist upon the careful inspection of winter work before removing the forms, owing to the close resemblance between frozen and thoroughly hardened concrete in appearance. Frozen concrete frequently shows a fracture through the aggregate.

705. **Diminishing Area of Concreting.** — In the winter time, the area of concrete work shall be cut down by the use of bulkheads, so as to decrease the time of exposure of a single layer, which will result in running the work up to a greater height for a day's work.

706. **Concreting Thin Walls.** — On thin walls, the time of concreting shall be limited to 28° F. on a rising thermometer and 32° F. on a falling thermometer.

707. **Accumulation of Surplus Water on Concrete.** — In general, less water shall be used for mixing in cold than in warm weather, and in no case shall a surplus of water be allowed to accumulate and freeze on top of a layer of concrete and then be covered up with more concrete before thawing out. If too much water is used in the concrete, the expansion of the water in freezing may disintegrate the concrete by the mechanical action of the ice in forming.

708. **Removal of Defective Work.** — Whenever any cement work freezes before it has become thoroughly set the entire mass shall be removed and replaced by the Contractor at his own expense.

709. **Suspension of Work.** — The Engineer shall, however, when he deems it best, stop all concreting when the weather is at or below the freezing point. In other words, the Engineer may prohibit the laying of concrete at any time when, in his judgment, the conditions are unsuitable or the proper precautions are not being taken, whatever the weather may be, in any season. Care shall be taken that each day's work is finished off to a horizontal or level line, so that the work may, if necessary, be left in proper shape for an indefinite period.

710. **Removal of Frozen Concrete Surfaces.** — Portions of surface concrete which have frozen shall be removed before laying fresh concrete

upon them and the Contractor shall make certain that all frost and ice on the surface has been removed. No sudden removal of same by using hot water or steam will be permitted, but must be removed by use of cold water. The use of fires for the removal of frozen concrete surfaces should be prohibited.

2. Heating Materials

711. In General. — Special precautions shall be taken to avoid the use of materials containing frost or covered with ice crystals during freezing weather.

Where it is possible to obtain sand and broken stone or gravel that is dry and free from frost these materials will not be required to be heated, but if not, the Contractor shall provide the necessary means for, and shall heat the gravel or stone, sand and water.* Artificial heat to prevent concrete from freezing shall be subject to the approval of the Engineer. The Contractor must provide ample steaming capacity.

If reinforcing steel is used, the steel must also be heated to the same temperature as the concrete.

712. Temperature of Concrete When Placing. — The concrete shall be placed in the work at a temperature of at least 60° F., regardless of the temperature of the surrounding atmosphere.

713. Frozen Aggregates. — The use of frozen, lumpy sand or stone depending on hot water used in mixing to thaw it out will not be permitted.

714. Ordinary Heating of Aggregates. — For weather not too severe and the amount of aggregate to be used not too large (say fifty (50) yards per day), the materials may be heated by building wood fires near the supply piles, that is, both sand and gravel or stone.

715. Amount of Heat Required. — The amount of heat required depends upon the temperature of the air and the rapidity with which the work can be done after heating stops. The water shall be warmed, but not boiled, the sand and other aggregates shall be heated, but not hot enough to blister the skin of the hand. Some specifications require that all sand, stone, gravel and water used in mixing the concrete in freezing weather shall be heated to a temperature of not less than 150° F., and the concrete placed while yet steaming. There is some danger in killing the cement with such boiling hot water. The temperature of the water should not exceed 130° F. at the most, preferably to 120° F.†

716. Steam Coils. — Aggregates may be heated by means of a steam coil placed near the cars that are being unloaded by simply throwing the material on the steam coil and allowing the sand and gravel or stone to remain a sufficient length of time to absorb the necessary amount of heat.

* As the coarse aggregate forms the greater portion of the concrete, it is particularly important that this material be heated to well above the freezing point.

† The materials must never be heated to a temperature of over 130 degrees, as the strength of the concrete will be weakened.

717. Salamander for Heating Aggregates. — Another method of heating the aggregates is by means of a large salamander. This may be accomplished by providing a double bottom of sheet metal to a supply hopper of sufficient capacity to store at least a day's run. The heat from the salamander is thus led into the air space directly under the aggregates and the necessary draft is supplied by chimneys passing through the aggregates. (This method will be found very effective in extremely cold weather.)

718. Use of Boiling Water. — When the temperature is below freezing and above 20° F., the concreting may be carried on by using boiling water for mixing (tests shall, however, be made to determine whether the hot water does not injure that particular brand of cement, in regard to strength), and by pouring boiling water on the forms, and especially the reinforcement, so that not a particle of ice or snow remains. No concreting in cool weather shall be commenced unless all preparations for boiling water are made. When so required by the Engineer, in addition to using hot water, a pint of salt per bag of cement shall be added to the mixture.

719. Method of Heating the Water. — For heating water the common practice of relying upon a steam pipe placed in an ordinary barrel will not be allowed by the Engineer as the water is generally used too fast to permit of its being properly heated by this method. A suitable tank shall be provided, and the water heated by means of a coil supplied with steam from the boiler supplying the mixer engine or when this is inadequate one shall be erected for this purpose. The size of the tank shall be governed by the amount of water needed and the time required for heating it.

720. Mixing Concrete with Boiling Water. — The Contractor is hereby cautioned in mixing concrete against killing the cement with boiling hot water. The sand and broken stone or gravel shall first be mixed with boiling hot water in order to take the frost out of the aggregate and warm it up and reduce the temperature of the water down to 120 or 130° F., which will not injure the cement.

3. Use of Common Salt

721. Lowering the Freezing Point of Concrete. — Only those substances that have no effect on the strength and durability of the concrete shall be used to reduce its freezing point. The excessive use of salt for this purpose will not be permitted.

722. Sodium Chloride (Common Salt). — When the weather is at freezing or a few degrees below, the concreting may be continued by using sodium chloride (common salt) in mixing water as directed by the Engineer. When salt is added to prevent freezing, the amount shall not exceed ten (10) per cent* of the weight of the water. The salt shall be thoroughly dissolved in the water before mixing the concrete — approximately one pound of

* A 5 per cent solution of common salt is ordinarily used and is not detrimental to the strength of the concrete when so used.

salt to every 18 gallons of water when the thermometer is at 32° F., and one additional ounce of salt for every further degree below 32.

The difference in temperature between freezing point and the temperature likely to be encountered before the concrete sets shall be the amount of salt, expressed in percentage of the amount of water by weight, to be used. In other words, approximately one per cent by weight of salt to the weight of the water shall be required for each degree Fahrenheit below freezing, but not more than 10 per cent shall be permitted under any circumstances and this amount will not be considered effective for temperatures lower than 22° F.

723. **Calcium Chloride.*** — Calcium chloride shall not be added in quantities exceeding 2 per cent of the weight of the cement when used as an agent for lowering the freezing point of the concrete. In other words, dissolve in the water needed to properly mix the concrete two pounds of calcium chloride for each bag of cement used. The use of chloride of calcium in concrete shall be used by special arrangement and under supervision of the Engineer.

4. Protection of Concrete

724. **In General.** — Any concrete liable to be exposed to rain, frost or snow, before it has attained its permanent set, shall be temporarily protected by planks and tarpaulins or other methods approved by the Engineer. No concreting in cool weather shall be commenced unless the required quantity of tarpaulins are at the site. (See Art. 21, page 120.)

Heated concrete shall be protected by suitable covering to insure the concrete setting before it has cooled to a freezing temperature. The concrete work must be covered before stopping work at night, even though it is warm during the daytime.

Work to be placed upon concrete laid in freezing weather shall be delayed until the setting of the cement makes the mass sufficiently stable to carry the weight.

In no case shall alternate freezing and thawing of the concrete be allowed.

725. **Temperature above Freezing.** — All reinforced concrete shall be kept at a temperature above freezing for at least 48 hours after being put in place.

726. **Use of Manure.** — The use of manure shall not be allowed for the covering of concrete as it causes disintegration, unless the concrete is well and sufficiently covered so as to be waterproof against the drainage therefrom. If stable manure can be kept in place in sufficient quantities to keep its fermentation it is the most efficient material for covering. In no case shall fresh manure be placed over very green concrete to protect it from freezing, as it will spoil the surface of the concrete.

* Calcium chloride has an advantage over common salt in that it reduces the freezing to a lower point.

727. **Use of Straw or Hay.** — A covering of straw or hay will be allowed only on certain conditions.

728. **Heating Forms.** — The forms shall be specially constructed to protect all parts of the concrete from injury by frost, and radiators or live steam shall be used within the form sufficient to keep the temperature above 35° F. during, and for at least two days after, the placing of concrete.

729. **Mortar Finish.** — For a spaded or mortar finish, extreme care shall be taken to protect the work, preferably by covering the outside of the forms with a layer of tar paper. Care shall be taken to tack this paper on securely.

730. **Cutting Sides of Forms to Expose Mortar Face.** — When concreting at low temperature, particularly with a mortar facing, blocks of the lagging (say) 4 by 12 ins., at different points of the most exposed sides of the work, shall be cut out, in order to note whether or not the mortar facing is being affected by frost.

731. **Surface Finish for Important Structures.** — Structures in which the surface finish is important must not be permitted to freeze until the concrete is well set.

732. **Protection of North and West Side of Structure.** — Special pains shall be taken to protect the north and west side of the structure.

5. Removal of Forms

733. **In General.** — All forms under concrete placed in freezing weather shall remain until the season has advanced beyond the probability of a frost. If the Engineer permits earlier removal of forms, they shall remain until all evidences of frost are absent from the concrete and the natural hardening of the concrete has proceeded to the point of safety. Forms for such work shall be kept in place at least two weeks longer than customary. Special care must be taken in removing centering when the concreting has been done in cold weather.

Falsework shall never be removed while the concrete is frozen. If necessary, artificial heat shall be employed to thaw the whole mass and the set and hardness determined before removing falsework.

Art. 23. Depositing Concrete Through Chutes

1. General Requirements

734. **In General.** — The concrete shall be deposited in place by gravity through movable pipes, troughs or chutes, provided with elevator, hoists, etc., as may be required.

735. **Segregation.** — Segregation — separating the stone from the finer material — shall be avoided in depositing concrete through chutes.

736. **Consistency of Mixture.** — In chuting concrete a mixture shall be used which is just as wet as it can be and at the same time hold together. A rich mixture will flow better than a lean mixture, and a mixture which has been thoroughly worked in the mixer flows better than one which has not. The Contractor shall determine the wetness of mixture to be employed by making a few trials with mixtures of different consistencies.

737. **Cleaning Chutes.** — Cleaning of chutes is essential at the end of the day's work and in beginning work again the chute shall be drenched with water to lubricate it so as to avoid trouble in handling the first few batches of concrete.

2. Construction of Chutes

738. **Sagging.** — Chutes must have ample strength against bending or sagging between supports. If the supports are far apart the chute shall be stiffened by truss rods or some similar means.

739. **Slope of Chutes.** — A slope of 1 to 8 is about as flat as concrete will flow without help, even when the travel is short. The inside of chutes, particularly if its slope is flat, must be as smooth as practicable. A wet concrete will flow quite readily on a slope of 1 to 4.

740. **Elbow Connections.** — If the chute changes direction, say, from a 45-degree slope to a vertical drop into the forms, the elbow connection shall be firmly anchored against the shock of the flowing mass due to its change of direction.

741. **Canvas Sleeve.** — If the chute has a long steep straight run, some arrangement shall be made to prevent scattering when the stream discharges. A canvas sleeve extending from the chute or a short vertical elbow will ordinarily accomplish the result.

742. **Wear.** — The wear from fast moving batches of concrete is considerable and where a chute will have long use, provision shall be made for wear. A removable steel lining may be used to take the wear.

743. **Platforms.** — Chutes shall be built on substantial platforms, high enough in the air to give proper fall to remotest chutes.

Art. 24. Depositing Concrete Under Water

744. **In General.** — Concrete shall not be placed in water, unless unavoidable. Where concrete must be placed under water, the structure should be encased with a cofferdam or unusual care must be taken to prevent the cement from being floated away. This usually can be accomplished in still water by placing the concrete through a large pipe or tremie, and in large work by means of a bucket provided with a bottom dump.

No concrete shall be laid in running water unless proper precautions are taken subject to the approval of the Engineer. The concrete shall be preferably deposited by means of a bucket or dredge having a bottom dump; where this method is impracticable a box chute may be used, provided it is kept filled with concrete.

In large structures it may be necessary to divide the mass of concrete into several small compartments or units, filling one at a time. With proper care it is possible in this manner to obtain as good results under water as in the air.

745. **Running Water.** — When the concrete must be deposited in running water it may be done by placing the concrete in bags and depositing the bags in place, or by other means equally satisfactory to the Engineer. Instead of bags for placing concrete, the Engineer may require that substantial forms be used, so built as to prevent currents of water flowing through them when using tremies or buckets.

746. **Depositing Dry Concrete Under Water.** — Dry concrete, i.e., a mixture of aggregates and cement without water, shall not be employed in laying concrete under water.

747. **Instructions for Concreting Under Water.** — The Engineer will issue special instructions for concrete which is to be deposited under water where so indicated on the plans, or where authorized in writing by him. When such method is authorized the concrete shall be deposited with the greatest care by means of the tremie, drop-bottom buckets or other methods approved by the Engineer. In every case, where concrete is to be placed under water, special directions regarding its composition and method of placing shall first be obtained from the Engineer.

748. **Coarse Aggregate.** — Broken stone or gravel for concrete deposited under water shall range in size from $\frac{1}{16}$ in. to $\frac{3}{4}$ in. in diameter.*

749. **Minimum Depth for Depositing Concrete Under Water.** — The Contractor will be allowed to deposit concrete under water up to an elevation of 1 ft. below mean low water by use of a tremie, or other method satisfactory to the Engineer. No concrete above an elevation of 1 ft. below mean low water shall be deposited under water. Water shall be excluded from the forms until the concrete has been in place three hours.

750. **Depositing and Spreading Concrete Under Water.** — Placing concrete through water shall be carried on continuously to insure a perfect monolithic mass.

The concrete shall not be dropped from any height over six inches, but shall be deposited and spread gently without ramming to the satisfaction of the Engineer, so as to prevent the separation of the ingredients and thus secure a homogeneous mass. Under no circumstances will it be permitted to deposit concrete by dropping it freely into water, and allowing it to settle to the bottom.

Care shall be taken to keep the surface of the concrete approximately

* The coarse aggregate should be smaller than ordinarily used, and never more than 1 in. in diameter. The use of gravel facilitates mixing and assists the flow of concrete through the tremie.

level by means of a rake or other suitable tool immediately after being deposited. The Engineer will insist upon the concrete being deposited in the allotted place in a compact mass and in a good and workmanlike manner. The concrete must not be rammed.

751. **Tremies.** — If tremies are used, they shall consist of a long tube reaching from the place where the concrete is to be deposited to the surface of the water, its upper end being provided with a hopper for receiving the mixture. They shall be constructed of steel, handled by power, so as to be easily adjusted in moving from place to place, and designed so as to give a slow uniform movement of the mass in passing from the hopper to the point of deposit.*

Where necessary in passing under and around certain objects, curved adjustable lengths shall be provided at the bottom of the tremie for depositing the concrete in places that would be otherwise inaccessible.

The concrete shall be mixed very wet (more so than is ordinarily permissible) so that it will flow readily through the tremie and into the place with practically a level surface.

752. **Charging the Tremie at the Beginning of an Operation.** — A wadding (say) of cement sacks shall be placed in the tremie on top of the water to prevent the concrete from dropping through while filling the pipe. Concrete shall be discharged into the tremie hopper and on top of the wadding. When the hopper is about half filled, the tremie and hopper shall be raised a trifle, thereby permitting the water in the tremie to escape at the bottom as the weight of the concrete pushes the wadding downwards through the pipe. Meanwhile fresh batches of concrete shall be dumped into the tremie hopper. In this manner the tremie shall be filled with concrete until the wadding reaches the bottom and the concrete commences to run out of the pipe.

Note. — In most cases, one or two dry batches of concrete will serve the same purpose as the wadding of cement bags and may be used instead for charging the tremie at the beginning of an operation.

753. **Charging the Tremie While Concreting.** — The concrete shall be so mixed that it will readily flow in the tremie, and the flow shall be controlled by keeping the mouth of the tremie at all times buried in the concrete at a sufficient depth, in order to prevent the water from rushing in from the outside by forming a seal. As fast as the concrete escapes at the lower end of the tremie it shall be replenished at the upper end, thus forming a continuous stream, which must be maintained during the process of concreting.

If the stream shows a tendency to run out too fast, the tremie shall be lowered and thus choke off the flow; if, on the other hand, the concrete

* The use of tremies, properly designed and operated, is a satisfactory method of placing concrete under water. The tremie should be suspended so that it can be lowered quickly when it is necessary to choke off or prevent too rapid flow; the lateral flow should preferably be not more than 15 ft.

does not flow fast enough, the tremie shall be raised until the concrete flows more rapidly.

754. **Depositing Concrete from Tremie.** — By charging the tremie in the above manner the only point where there is danger of washing away of the cement from the aggregate is in the adjusting of the concrete from the bottom of the tremie to its final position. Care shall be taken that the concrete has no fall through the water, but oozes out so as to cause a minimum disturbance of the material. The flow shall be continuous, in order to produce a monolithic mass and prevent the formation of laitance in the interior.

755. **Depositing in Drop-bottom Buckets.** — Where drop-bottom buckets are used, they shall be filled on the mixing platforms and the tops closed and latched, so as to prevent the washing away of the cement in passing through the water, and lowered vertically to the bottom as rapidly as practicable. They shall not be dumped until the bucket is close to the point of deposit, so that the concrete will not fall through the water. Care must be taken to keep the deposited concrete as nearly horizontal as possible over the area to be covered. The placing of isolated piles of concrete will not be permitted.

756. **Depositing Concrete in Bags.** — Where bags are used, the concrete shall be placed therein on the mixing platforms and lowered to the diver, who shall pack them closely into position, so that the cement oozing through the mesh of the bags of gunnysack or other porous cloth will bind the entire mass together. If the concrete be enclosed in paper bags or other soluble envelopes, it shall be placed in the desired position under water in such a manner that the bag or envelope is not ruptured until after or at the time it is in place.

Porous cloth bags shall be lowered rapidly through the water into place to reduce the time of wash. No delay shall occur in the process of depositing which will permit concrete in place to become set before succeeding bagfuls are deposited. The delay between mixing the concrete and filling and depositing the bags shall not be long enough to permit the concrete to have set.

757. **Choice of Methods.** — The proper one of the three above methods shall be adopted, with the approval of the Engineer, to best fit conditions as they arise.

Art. 25. Contraction Joints

758. **In General.** — Temperature changes and shrinkage during setting necessitates joints at frequent intervals or else effective reinforcement, depending upon the range in temperature and the design of the structure. To provide against unsightly cracks, due to unequal settlement, a joint shall be made at sharp angles. In all cases joints shall be at right angles

to their surfaces, and shall be constructed exactly according to the Engineer's plans.*

759. **Location.** — Expansion joints must be provided at all points where temperature changes would otherwise cause unsightly cracks. The frequency of these joints will depend, first, on the range of temperature to which the concrete will be subjected, and second, on the quantity and position of the reinforcement. These joints should be determined, and provided for in the design.

760. **Massive Concrete Walls, Etc.** — In massive work, such as retaining walls, abutments, etc., built without reinforcement, joints shall be provided approximately every 30 feet throughout the length of the structure. To provide against the structure being thrown out of line by unequal settlement, each section of the wall may be tongued and grooved into the adjoining section. Each section shall be finished from the footing course to the top before the adjoining section is started, and no attempt shall be made to make the sections adhere to each other, so that when cold contracts the structure it will open up slightly in these vertical joints, and not in an irregular crack. In reinforced concrete the length of these sections may be materially increased at the option of the Engineer.

761. **Reinforced Concrete Walls.** — In reinforced concrete walls the expansion joints shall be spaced fifty (50) feet apart unless otherwise called for or shown by the plans.

762. **Forming Ordinary Joints.** — In ordinary short walls the joint may be made by setting up a temporary vertical form or partition of plank and completing the section behind as though it were the end of the structure. The partition will be removed when the next section is begun and the new concrete placed against the old without mortar flushing.

763. **Forming Tongue and Groove Joints.** — A plank shall be spiked vertically to the face of the partition against which the concrete is to be rammed, so that a depression will be formed in the end of the section, giving the effect of tongue and groove joints in the finished wall. †

764. **Asphalt or Coal Tar Pitch Joints.** — Unless otherwise specified or shown by the plans, the bond at the expansion joints shall be broken by a heavy coat of asphalt or coal tar pitch, applied hot to the surface of the section of concrete which was first placed. All joints shall be vertical.

765. **Columns.** — Girders shall never be constructed over freshly formed columns without allowing a period of at least two hours to elapse to permit settlement in the columns.

* Shrinkage and contraction joints should be lubricated by either an application of petroleum residuum oil or a similar material, so as to permit a free movement at the joint when the concrete expands or contracts.

The insertion of a sheet of copper or zinc, or even tarred paper, will be found advantageous in securing expansion and contraction at the joint.

† This will prevent the structure being thrown out of line by unequal settlement. A groove should be formed in the surface of the concrete at vertical joints in walls or abutments.

Art. 26. Pointing and Making Good Defects in Concrete

766. **In General.** — After the forms are removed, no patching or plastering shall be done until all surfaces have been inspected and permission given. Grouting of concrete after it has been laid or the application of neat mortar to the surface and the sweeping of the surface with street brooms to make it smooth or to cover up defects will not be permitted.

767. **Defective Work.** — Should voids be discovered when the forms are taken down, the defective work shall be removed and the space refilled with one to one (or two) cement mortar. In other words, the defective work shall be cut and the space refilled with suitable material in a proper manner. If bolts are used for securing the forms of the ends of which are removed, leaving small holes, all such holes shall be neatly pointed or stopped with mortar in the above proportions. Concrete made of fine stone in the stated proportions of mixture may be used for leveling up depressions.

768. **Repairing Broken Corners.** — Broken corners shall be carefully repaired by thoroughly cleaning the surface, wetting the patch down well, then if possible, driving 20d nails or railroad spikes into the concrete, putting up a form and grouting the broken place.

769. **Frozen Concrete.** — Any concrete which has been frozen or frost bitten shall be promptly removed and repaired as directed by the Engineer. (See Art. 22, page 122.)

Art. 27. Bibliography of Specifications for Placing Concrete

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CHAPTER VI.

FINISHING CONCRETE SURFACES

Art. 28. General Requirements

770. **In General.** — The finishing of the surface shall be determined before the concrete is placed and the work conducted so as to make possible the finish desired.

771. **Workmanship.** — All finishing shall be done in a first-class manner by competent concrete finishers.

772. **Protection.** — All finished surfaces shall be properly protected by canvas covers or other suitable arrangements.

Art. 29. Plain, Spaded, Mortar and Troweled Finishes

773. **Ordinary Surface.** — It is expected that the surfaces of the concrete will be so smooth and dense that special treatment further than care in placing the concrete to avoid noticeable voids or stone pockets need be done, and any such work must be executed at the Contractor's expense.

Faces which will show in the finished work shall be true to the form intended, and shall be smooth and free from cavities due to shortage of mortar.

774. **Spaded Finish.** — Faces exposed to view shall be made smooth by thrusting a spade or chisel through the concrete close to the form to force back the large stones and prevent stone pockets, care being taken to obtain a uniform mix and texture at the face. Spading is best done with a special flat-bladed spade, having the blade perforated with holes or slots, which will screen back the stones and allow the mortar to pass.

The forms shall be thoroughly wet or greased with crude oil before placing the concrete against them. On removal of the forms, surfaces shall be (state kind of finish desired, see Arts. 31 and 32).* Noticeable voids or stone pockets discovered when the forms are removed shall be filled immediately with mortar mixed in the same proportions as the mortar in the concrete.

Compensation for all labor and material required in such finishing, including the mortar filling when required, shall be included in the price per cubic yard for concrete work.

* For many forms of construction the natural surface of the concrete is unobjectionable, but frequently the marks of the boards and the flat dead surface are displeasing, making some special treatment desirable.

775. **Mortar Face Finish.** — If a mortar (or a granolithic) finish be specified, it shall be obtained by placing the facing mortar and concrete backing at the same time and tamping them together. The tamping shall not be so hard as to force pieces of stone through the facing, but hard enough to bond thoroughly the facing mortar and backing.

The mortar (or granolithic) finish must be maintained between the concrete and the face form in a thickness of about 1 inch, care being taken that the concrete is rammed into and perfectly united with it. If iron or wooden mold boards are used to retain the mortar against the face while placing the concrete, care must be taken that the board is not permitted to remain until initial set takes place, but be frequently jarred and raised slightly at short intervals to prevent the formation of shuts and seams and air spaces between mortar and the concrete.

To expose the aggregate the film of mortar that flushes to the surface next to the forms must be removed. This shall be accomplished either by brushing or washing the surface before it has hardened (see Art. 31, Secs. 1, 2 and 3, pages 138, 140 and 141), or by tooling and blasting it after thoroughly hardening. (See Art. 31, Sec. 4, page 142.)

776. **Moldings, Cornices, etc.** — Moldings, cornices and other ornaments requiring mortar surface shall be formed by spreading plastic mortar upon the interior of finely constructed molds, just as the concrete is being laid.

777. **Metal Facing Form or Mold.** — The metal facing form or mold for placing the facing material on vertical surfaces shall consist of short lengths of iron plates 8 ins. or 10 ins. wide and about 6 ft. long with three angle irons riveted to each plate, the size of the angle depending upon the thickness of the facing material specified (generally 1 in. or 1½ ins.). An angle shall be placed at the center and one about 6 ins. from each end of the plate, one edge of which shall be provided with handles and slightly flared to assist in depositing the material. The metal facing form shall be placed against the wall form with the handles up and the angles tight against the form. The space between it and the back of the wall shall be filled with ordinary concrete backing of the specified proportions and the space between the metal form and the face form shall be filled with facing material of the proportions stated below.

778. **Proportions for Mortar Facing.** — The facing mixture shall not be of too rich proportions. Mortar facing shall be composed of one part of cement to three parts of sand or screenings, unless otherwise specified. Mortar richer than a 1 : 2 mixture should not be used.

Crushed marble screenings shall be used if obtainable. These screenings or sand must not be too fine and shall not exceed ¼ inch. Limestone, granite or other stone screenings, different colored gravels and sand may be substituted for the marble chips with the approval of the Engineer.

779. **Proportions for Granolithic Finish.** — If a granolithic finish or surface is specified it shall be made by placing against the face forms in advance of the body concrete a fine granolithic or facing concrete composed of one (1) part of Portland cement, one and one-half ($1\frac{1}{2}$) parts of coarse sand and two and one-half ($2\frac{1}{2}$) parts of pebbles or crushed granite or other approved stone as may be selected, screened to pass $\frac{1}{2}$ in. and be retained on $\frac{1}{4}$-in. screen, thoroughly mixed and soft enough for full flushing. (For manner of placing this granolithic, see Par. 775 above on Mortar Face Finish.)

Note. — Where both fine and coarse aggregates are used in the mixture for the facing material a 1 : $1\frac{1}{2}$: 3, or 1 : 2 : 3, or even a 1 : 2 : 4 concrete with Portland cement, sand or stone screenings and crushed stone or screened gravel may be used.

780. **Thickness for Cement or Mortar Finish.** — Cement finish when applied to a concrete base must be laid at the same time as the concrete and shall not be less than $\frac{1}{2}$ in. thick for floors. The minimum thickness of mortar (or granolithic) finish for walls shall not be less than 1 in., and where both fine and coarse aggregates are used in the mixture for the facing material, not less than twice the maximum dimension of the large aggregate.

781. **Spaded and Troweled Finish.** — The coarse aggregate shall be well pulled back from the face of the form to allow the mortar to flush to the surface. The forms shall be stripped while the concrete is still green enough to be worked down with a trowel.

Art. 30. Introduction of Various Ingredients into Mortar or Concrete

1. Different Sized and Colored Aggregates

782. **In General.** — If a permanent colored concrete surface be specified, it shall be obtained by properly finishing a surface faced with a mixture composed of Portland cement and an aggregate of the proper size and color. The surface must be sand blasted or otherwise treated, so as to expose these aggregates.

783. **White Sand or Marble Dust.** — White sand or marble dust used in making concrete gives the finished work a lighter color than is obtained by using ordinary sand.

783a. **White Cement and Aggregates.** — A white concrete surface may be obtained by mixing 1 part white Portland cement with 2 or 3 parts coarse white sand or marble screenings, and applying the mixture as a finishing coat or mortar facing. After the coating or mortar facing has set hard, it shall be washed off with dilute sulphuric acid, 1 part acid to 5 parts water. This acid shall be applied by painting on with a brush two or three successive coats and then the surface shall be washed with plenty of clean water.

2. Coloring Matter

784. In General. — When aggregates of the required color are not available, or for any reason it is not possible to obtain a surface of the desired color in this manner, mineral coloring matter shall be added to the facing mortar.

785. Coloring Matter. — For stucco or mass work, dry mineral color shall be added to the Portland cement before mixing. Only those coloring materials shall be employed which consist of the oxide of the various elements, since the salts are liable to disintegrate.

The quantity and quality of the coloring shall be such as not to impair the strength of the concrete.

786. Samples of Colored Mortar. — All colors for the various concrete surfaces shall be as hereafter selected or as directed by the Engineer. Sample specimens containing different proportions of the coloring matter and of Portland cement shall be made and allowed to become quite dry before being submitted to the Engineer for approval.

787. Proportioning Pigments. — The following proportions are suggested, the amounts named being added to 100 pounds of Portland cement: *

Black, 2 pounds Excelsior carbon black.

Blue or green, 5 to 6 pounds ultramarine.

Brown, 6 pounds roasted iron oxide.

Gray, 8 ounces of lampblack.

Red, 6 to 10 pounds raw iron oxide.

Yellow or buff, 6 to 10 pounds yellow ocher.

788. Mixing Colored Facing Mortar. — Sand for the colored facing mortar must be perfectly dry and the cement, sand and coloring matter shall be mixed dry before the water is added. In mixing the ingredients, the greatest care and exactitude are essential. If improperly mixed, the surfaces are apt to be spotty. The coloring of the mixture when freshly made must be deeper than that actually required in the finished surface as the colors will bleach considerably on drying out. The coloring matter shall be thoroughly mixed with the cement mortar in such a manner as to produce a uniform and even shade satisfactory to the Engineer.

Art. 31. Removal of Surface in Various Ways

1. Scrubbed or Brushed Finish

789. Preliminary Preparations. — Great care shall be taken in successive casting to prevent marks showing (after scrubbing or brushing) where the new and old work join. When it is proposed to scrub or brush the surface of the concrete before it is more than twenty-four hours old, the forms

* By increasing or decreasing the proportion of coloring matter, various hues may be obtained.

shall be designed with the idea of being promptly removed without damage to the rest of the structure. Forms are to be built in sections and so arranged that each section can be taken down at the proper time, to give access to the face of the concrete.

790. **Scrubbed or Brushed Finish.** — Forms are to be taken down in twenty-four hours during warm, dry weather; otherwise, to remain as much longer as conditions require, which will be determined according to the temperature of the weather and the setting quality of the cement. The surface is then to be brushed with ordinary fiber (or wire) brushes and water until all of the surface cement has been washed off, leaving the gravel or stones exposed and in good relief. If necessary, a small amount of muriatic acid should be added to the water. The concrete surface shall be scrubbed until the surface film is removed and the aggregate is exposed to a uniform degree, and then rinsed off with water and kept moist for several days. (For Acid Wash Finish, see Sec. 3, page 141.) A vigorous use of water is advisable.

791. **Precautions.** — Care must be taken that the pebbles are not dislodged. The time for doing the scrubbing is when the concrete is still green, but if the concrete is too soft to permit scrubbing, the work must be delayed a sufficient length of time. The brushing or scrubbing shall be started just as soon as it is possible to do so without removing particles of aggregate.

792. **Flushing Cement Particles.** — Cement particles removed by the brush shall be thoroughly flushed off the surface by clean water, else they will adhere in patches and form rough blotches.

793. **Pebble-dash Facing.** — The concrete shall be composed of gravel and rounded stone not exceeding 1 in. in its smallest diameter. When the forms are removed the cement and sand must be brushed from around the face of the gravel with steel brushes, leaving approximately half of the gravel exposed. Brushing should commence within twenty-four hours after the concrete has set.

794. **Cut Stone.** — A method similar to the one used in obtaining a "Pebble-dash" shall be employed in giving to concrete the appearance of cut stone. In this case crushed rock shall be substituted for the gravel, the character of the rock depending upon the color and texture desired in the finish. After the removal of the forms the cement and sand shall be brushed from around the face of the stone next the face exposed to view, followed by clean water.

795. **Fiber and Wire Brushes.** — For scrubbing the surface ordinary scrubbing brushes with stiff palmetto or other fiber bristles with a light stream of water from hose or can will generally be sufficient if the concrete has not set too hard. If set is harder wire brushes followed by fiber brushes and rinsing may be used. Fine and coarse brushes should be used. A brush about four inches wide, made by clamping together a sufficient number

of sheets of wire cloth, will generally be found more effective than the ordinary wire brush for brushing green concrete surfaces.

796. Sand-Blasting. — If for any reason a portion of the face form cannot be or fails to be removed before the concrete has become too hard for removing the surface film by scrubbing, the hard face shall be treated by sand-blasting or tool-dressing, to a texture matching the scrubbed portion. (See Sec. 4, page 142.)

797. Protection of Corners. — In scrubbing concrete surfaces, care must always be taken to avoid roughening or blunting corners of the work, and to maintain all edges sharp.

798. Patching Defective Work. — If any void spaces appear, or if spalls are broken off, the defects shall be patched with similar mix immediately after the scrubbing, using the hand or a wooden float — not a steel trowel — for applying and smoothing the patches. After they are sufficiently set — say within from 5 to 24 hours — all patches must be scrubbed to the same texture as the general surface and be rinsed clean and kept moist for several days.

2. Rubbed Finish

799. Ordinary Rubbed Finish. — A rubbed finish shall be obtained by rubbing the concrete surfaces with a piece of sandstone, concrete, emery or carborundum, about the size of a brick, which shall grind down the surface of the concrete sufficiently to remove all impressions of the timber or other irregularities. In no case on an exposed surface of the concrete shall the joints of any component pieces of the forms, nor the grain of the wood, be visible.

800. Fine Sandy Finish. — A fine sandy finish shall be obtained after the concrete has set by rubbing with a block of carborundum about 3 by 4 by 1½ inches.

801. Rubbed Mortar Surface. — After the forms are removed, the concrete shall be thoroughly wet with a brush and then rubbed with a coarse carborundum stone (No. 16), bringing the surface to a lather. After this stone has been used sufficiently to take off the rough projections, the lather shall be washed off with a brush and the concrete again wet, and then dusted with a mixture of dry sand and cement, the proportion being one part Portland cement to two parts of sand. This shall be rubbed into the surface with the coarse (No. 16) stone. Care shall be taken not to allow any of the mortar to remain on the surface. To give the final finish, a (No. 30) carborundum stone shall be used and the whole surface well rubbed.

Note. — This finish gives a lighter surface than troweling, fills any voids that may be in the cement coating, and leaves the concrete more waterproof than it would be originally.

802. Alternate Method of Applying Mortar Surface. — After the concrete has been thoroughly rubbed with a piece of sandstone or carborundum, a cement wash composed of one part Portland cement to two parts of fine sand shall then be applied with a brush and the surface immediately rubbed with the sandstone or carborundum, and the work afterwards washed down with clean water. The grout will be used simply to fill surface imperfections and shall not remain as a film on the surface.

3. Acid Wash Finish

803. **In General.** — By applying dilute hydrochloric and sulphuric acid to concrete surfaces and rubbing this with a steel brush, the cement can be dissolved away from the particles of aggregate and the various shades of browns and reds of gravel brought out. After the scrubbing is completed great care shall be used to remove all traces of acid, otherwise the acid will continue to etch out the cement in places and give a permanent discoloration of the surface.

The concrete work should be deposited in a fairly dry mixture, and care taken not to use materials which are disintegrated or affected by the acid.

804. **Washing Brushed Surface with Acid.** — After the entire surface has been scrubbed or brushed (see Sec. 1, page 138), it shall be washed with a diluted solution of acid applied with a brush. While wet with acid, the surface shall be quickly worked over with an ordinary scrubbing brush and the acid immediately removed with clean water applied through a hose. It is important that the surface be thoroughly washed after the acid treatment, as otherwise it will have a mottled, streaky appearance.

805. **Amount of Dilution.** — The amount of dilution for hydrochloric and sulphuric acid shall be determined by experiment as it varies with the age of the concrete. The older the concrete the stronger shall the solution be.

For concrete which is about two weeks old ordinary commercial acid shall be diluted with three parts of water. When but a few days old a dilution of one part acid to five or six parts of water shall be used. A mixture of the two acids will produce a stronger action than the use of one alone.

806. **Acid Solutions for Different Facing Materials.** — A solution of 1 part commercial muriatic acid to 2 or 3 parts of clean water shall be used on surfaces in which standard Portland cement is used, and a sulphuric acid solution of the same strength when white Portland cement and white aggregates are used in the facing mixture.

807. **Rewashing Surfaces Composed of Selected Aggregates with Acid.** — Should the surface become stained after being scrubbed and washed (see Sec. 1, page 138) by placing course upon course as the wall is erected, the wall shall be washed off with water played on the surface by means of a hose each night as the day's work is completed, and after the water is completed to the top, the whole surface shall be gone over with 1 part commercial muriatic acid and 4 to 6 parts water, the solution of muriatic acid being applied with an ordinary whitewash brush, having very little exposed metal. The acid shall be left on the walls from fifteen to thirty minutes,

after which it shall be washed off with a hose, and in places where the stains are most noticeable the surface shall be scrubbed with an ordinary scrubbing brush.

808. **Removal of Efflorescence.** — Efflorescence, a white deposit on the surface of concrete, shall be removed by using a weak solution of hydrochloric (muriatic) acid, one part of acid to six or ten of water. The wash shall be well rubbed into the pores of the concrete with a brush and shall be rinsed off with clean water as soon as the efflorescence has disappeared.

809. **Removal of Efflorescence (Alternate Clause).** — Efflorescence shall be removed by the application of soap and alum washes on the surface.

4. Tooled and Sand-blasted Surfaces

810. **Tooling Concrete.** — A tool surface shall be obtained by dressing the concrete surface with pneumatic hammers or such other tools as are ordinarily used for dressing stone surfaces. When the concrete is to be tooled, from 30 to 60 days must elapse before the concrete is hard enough to give a good, clean, tool cut. In every case, the concrete must be well hardened before tooling.

811. **Dressed Finish or Hammered Surface.** — A dressed finish shall be obtained by dressing the concrete surface with a sharp brush hammer and washing with muriatic acid diluted about one-half and carefully washed off. This shall be done after the concrete has thoroughly set. For fine detail work and for finished concrete block, and necessarily for imitations of natural stones, this form of dressing shall be used. Brush hammering may be done either by hand or with a pneumatic tool. The hammer used for this purpose should be light in weight, and have but few points.

812. **Picking.** — The concrete must not be too green or the pick will loosen the stones, while if set very hard the labor is unnecessarily great. The size of stone in the concrete should be limited to about $\frac{3}{4}$ in. to 1 in.

813. **Sand-blasting.** — All necessary sand-blasting shall be done without delay as soon as the forms are removed. A good surface may be obtained in a short time with air at 50 to 75 lbs.* The concrete should be from ten to fourteen days old, preferably longer. The nozzle shall not be over $\frac{1}{4}$ in. diameter and must be held within a few inches of the surface to be cut.

814. **Samples of Sand-blasting.** — Samples of sand-blasting shall be submitted to the Engineer for his approval before any sand-blasting is commenced.

815. **Protection of Corners.** — In sand-blasting, or tool-dressing, care must always be taken to avoid roughening or blunting corners of the work, and to maintain all edges sharp. When sand-blasting near the intersection of two surfaces a board shall be held against one in such a manner as to protect the angle or edge, as the case may be.

* Correct nozzle pressure is a variable quantity. Usually for concrete thirty days old, a working pressure of 60 pounds is adequate. Older concrete may require as much as 80 pounds pressure.

816. Size of Aggregate for Tooled Surfaces. — Where the surface is to be tooled, the facing material shall be composed of comparatively small-sized aggregate, as it is hard to dress and obtain uniform results on surfaces where large angular hard stone is encountered.

817. Construction of Forms. — It is not necessary to construct the forms so they may be taken down in sections as required for scrubbed or brushed surfaces (see Art. 31, Sec. 1, page 138), for the concrete shall be thoroughly hardened before tooling, especially if sharp edges and surfaces of a fine uniform texture are desired.

818. Preparing Surface for Sand-blasting. — Any pronounced ridges or irregularities in surface formed by cracks or open joints in the forms shall be removed by tooling and any pointing that may be necessary shall be done several days before the surface is sand-blasted.

819. Sand-blasting Molding, Joints and Courses. — Strips nailed to the forms to make molding, joints and courses shall be left in place while the surface is being sand-blasted. Otherwise the sharp angles and edges will be rounded off in a rough and unsightly manner. The area protected by the strips shall be left unfinished, unless otherwise specified.

820. Material for Sand-blasting. — A clean, sharp, thoroughly dried silica sand or crushed quartz shall be used for sand-blasting, and for use with a ¼-in. nozzle the sand shall be screened through a No. 8 screen, and through a No. 12 when a ⅛-in. nozzle is used.

Art. 32. Coating Surfaces in Various Ways

1. Grout Washes

821. Preparation of Surfaces. — All exposed surfaces must present a smooth, uniform surface of cement mortar, and all disfigurements must be effaced, and if there are any open, porous places, they must be neatly filled with mortar. Any ridges due to cracks or joints in the forms shall be rubbed down smooth and hard with a float and the rubbing continued until the marks of the forms are entirely effaced.

822. Washed or Grout Finish. — A washed finish shall be obtained by removing the forms within 10 to 12 hours after the concrete has been deposited, under ordinary temperature, and finishing with a thin mortar grout rubbed into the concrete with either a wooden float or a piece of sacking and then brushing over with a wet plasterer's brush. The grout shall be mixed in the proportions of one part Portland cement to one part of coarse sand and shall have the consistency of whitewash. The grout shall not leave a scale on the work, the object being only to fill the surface imperfections.

The grout may be applied in any other manner provided a uniform appearance is produced. If applied with a trowel, the grout shall be stiff and applied in a very thin coat and troweled or rubbed so that only the pores are filled and no body of the mortar left on the surface.

823. **Additional Washes.** — No plaster (except as provided for on plans) shall be placed upon the surface of any concrete, after the forms are removed, to produce a finish, but one or more additional brushings of the above wash shall be applied if necessary in any case to produce a proper finish.

824. **Skim Coat of Plaster.** — Care shall be taken to see that the men do not get a coat of the grout on similar to a skim coat of plaster, as that will peel in cold weather.

825. **Plaster of Paris Wash.** — Immediately upon the removal of forms, the concrete surface shall be thoroughly cleaned from any oil or grease that may have come from the forms, and a very thin wash, composed of equal parts of Portland cement and plaster of Paris shall be applied with a whitewash brush. This gives a very light gray finish, and should a trifle darker shade be required, one part plaster of Paris to three parts cement shall be used.

826. **Grouting Machine.** — A compressed-air spraying machine shall be used where there is a large amount of grouting of surfaces to be done.

2. Plastered Surfaces

827. **In General.** — Plastering as a method of finishing concrete surfaces should not be employed, as it is practically impossible to apply mortar in thin layers and make it adhere for any length of time. In case a mortar face is called for, the concrete surface to be plastered shall be specially treated to receive the plaster coat. To obtain a good bond between the plaster and the concrete the following means shall be employed:

828. **Metal Lath and Furring.** — The metal lath shall be of sufficient rigidity to readily take mortar when supported by furring spaced 16 ins. center to center. The lath shall be wired to the furring angles or channels every 8 ins. with No. 18 annealed galvanized steel wire. Care shall be taken to have a sufficient lap in the lathing. The lath shall be tied together and also to the furring so that there can be no settlement or sagging of the lath or the furring to which the lath is attached.

The furring shall leave sufficient space for the mortar to push through the mesh and clinch without interference from the backing to which the furring is attached. Furring and laths shall be such as to leave an air space of at least $\frac{3}{4}$ in. For exterior walls, it shall be protected from rusting by being entirely galvanized or treated by any other equally efficient process.

829. **Use of Nails as Furring.** — At frequent intervals wire nails shall be driven in the forms on the inside so that the pointed ends project about 2 inches outside of the rough concrete after the forms have been removed. Before applying the plaster a small iron nut shall be put on each projecting

nail, the concrete work being then covered with a wire lath of 2½ meshes to the inch and No. 20 wire, and the nails bent over it with the blow of a hammer. The nuts shall serve to keep the wire lath a distance of about ¼ in. from the old concrete. The nails should be about 3 ins. long with a bend of ¾ in. at one end. The nuts may be either square or hexagonal, about ¼ in. high.

830. **Preparation of Base to Obtain a Bond.** — The texture shall be as rough as possible with recesses in the surface which will support and key on a coating when applied, and this surface shall be free from dust and dirt which would prevent the bond of union. Before coating the surface the base shall be thoroughly saturated with water so as to avoid suction of moisture from the covering coat which would impair its strength and durability. Care must be taken to apply the plaster at once, and before the surface has an opportunity to dry.

831. **Metal Lath and Wooden Furring.** — Concrete walls shall be provided with 1¼ ins. by 3 ins. thoroughly dry and seasoned furring strips 18 ins. apart, to which shall be fastened substantial metal lath and this shall be plastered with lime mortar.

832. **Guaranteeing Plaster Finish.** — Best well seasoned lime plaster with hair shall be used and guaranteed against defects from unslacked lumps of lime or unsuitable material of all kinds for one year.

833. **Proportioning, Mixing and Placing Plaster.** — All plastering shall be three-coat work. The mixing shall be thoroughly done. The lime mortar shall be mixed four days before using, and the cement shall not be added until the mortar is ready to be used, and shall be mixed in small quantities as the work progresses.

The first or scratch coat shall be composed of one part Portland cement, three parts sand and one-half part hair putty. This hair putty shall consist of long cattle hair or fiber, thoroughly worked into good lime putty. The face of the first coat must be well scratched to make a key for the second coat, and shall be thoroughly dry and surface cracks appear before the second coat is applied.

The second coat shall be composed of one part Portland cement, two and one-half parts of sand and with not over 5 per cent lime putty, and the cow-hair omitted. The scratch coat will be dampened before the second coat is applied.

The third or finishing coat shall consist of one part Portland cement to two parts of sand or screenings, with not more than 5 per cent of lime putty: (crushed marble screenings will be preferred for facing mortar and unless otherwise specified this shall be used. To this finishing coat may also be added pebbles or other non-combustible material as may be desired to obtain a variation in the finished appearance). Screenings or sand must not be too fine but should be from ¼ inch diameter down.

Where a total thickness of not more than one inch is required, it is practicable to apply it in two coats, i.e., omitting the second coat above specified.

In all cases, one coat shall follow the previous one as soon as it has sufficiently set to allow of so doing.

Plaster should never be applied when the temperature is below freezing.

834. **Joints.** — Joints shall be allowed at intervals and made as inconspicuous as possible.

835. **Thick Plaster Finish.** — If a thick plaster (say) one-half inch or over is necessary, the surface must be carefully roughened, wet and coated with a neat cement grout, preferably spread on very thin with a wire brush, and then immediately followed with two coats of one to three mortar, the lower coat scratched and the top coat wood floated to a sand finish: (or a single coat of plaster of the desired thickness shall immediately follow the grout wash).

836. **Pebble-dash Finish.** — A pebble-dash finish shall be made by throwing on mortar and leaving it regular but rough. The cement and lime paste shall be mixed to the consistency of thick cream and washed pebbles added in the proportion of 5 parts plaster to 1 part pebbles by volume.

836a. **Pebble-dash Finish (Alternate Method).** — A pebble-dash surface shall be obtained by applying the finishing coat of plaster fairly wet, and then throwing clean pebbles into the fresh plaster. The pebbles shall be about $\frac{1}{2}$ in. in diameter and shall run uniformly. The pebbles must be wet just before throwing them on the fresh plaster. The work shall be started at the top and the pebbles thrown with a sweeping motion such as is used in sowing seed. The pebbles must be distributed uniformly over the surface and must be thrown with sufficient force to embed them securely. Care must be taken not to disturb the cement after it has started to set, and in order to avoid this the surface must be covered with the pebbles immediately after the fresh plaster is applied. Particular care must be taken to shape the whole surface continuous; that is, one patch of plaster must not be allowed to dry before the adjoining space is covered.

3. Painted Surfaces

837. **Preparation of Surfaces for Oil Paints.** — The concrete surface shall be thoroughly washed with 7 to 8 per cent solution of muriatic acid and followed by a good wash of clean water. After the treated surface has thoroughly dried, the paint shall be applied, using enough turpentine in the priming coat to make it almost flat and increasing the amount of oil each succeeding coat. The concrete shall have thoroughly dried out before painting is attempted.

838. **Printed Directions to be Followed.** — Where specially prepared paints are used the Contractor shall follow the manufacturer's printed directions for applying same. That is to say, where special preparations

are used in coloring surfaces, care shall be taken to follow closely the directions of the manufacturer of the preparation.

839. **Spraying Machines.** — If, in the opinion of the Engineer, such use is necessary or desirable, compressed-air spraying machines shall be used for whitewashing or cold-water painting concrete surfaces.

Art. 33. Other Methods of Exterior Finish

840. **In General.** — Other methods of exterior finish may be used providing same are specified in the contract or agreed upon between the Contractor and the Engineer; or if so agreed upon the exterior finish may be omitted entirely.

41. **Cut-stone Finish.** — Strips of wood shall be nailed into the forms to give the effect of cut stone to the surface when the forms are removed.

842. **Clapboard Finish.** — Exterior forms shall be arranged by letting the outside boards 1 in. thick lap over each other, the exposed width being about 10 ins., to give the effect of clapboard finish. The concrete shall be left as it comes from the forms and no rubbing will be required. The thickness of the wall with this finish will be taken as the minimum thickness, and the average thickness will be about $\frac{1}{2}$ in. greater.

843. **Optional Method.** — An optional method of exterior finish will be considered such as the Contractor has previously used and of which he can show representative work done.

843a. **Inserted Patterns.** — Surfaces may be treated by inserting pattern figures of colored clay, colored tile, or mosaics in the concrete.

Art. 34. Bibliography of Specifications for Finishing Concrete Surfaces

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15. Surface Finish: Progress Report of Special Committee on Concrete and Reinforced Concrete. Trans., Am. Soc. C.E., vol. 66, p. 445, Mar., 1910.

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18. Specifications for Scrubbed Concrete Surface. Written by Henry H. Quimby and adopted at the Natl. Assoc. Cement Users in Dec., 1910. Eng. News, vol. 64, p. 700, Dec. 22, 1910; Concrete, vol. 11, p. 76, Jan., 1911.

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20. Inspection of Surface Finishes for Concrete Work, by Jerome Cochran. Engng. and Contr., vol. 37, p. 322 (14,000 words), March 20, 1912.

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CHAPTER VII

WATERPROOFING CONCRETE WORK

Art. 35. General Conditions

844. **Intent.** — It is the intent of these specifications to obtain a structure that will be entirely free from dampness and the percolation of ground or outside water, and to that end the Contractor shall supply the material and perform the work in accordance with the plans and the following specifications.

845. **Expansion Joints.** — Expansion joints shall be waterproofed, preferably by keys of asphalt in the case of walls, or by lead covers and filling of asphalt, or by covering carefully with felt layers if the membrane system be used (see Art. 39, page 157).

846. **Price.** — A lump sum price for the waterproofing complete as shown on plans and described in specifications shall be given, also a price per square foot for any extra work which may be required.

847. **Other Materials, etc.** — Other waterproofing compounds, felts, etc., may be bid upon, and, if they are bid upon, the fact should be stated in the bid and a full and detailed description or specification of the material and method of use must be submitted to the Engineer who will decide as to what material or method shall be used. All materials of this nature shall be used in the manner prescribed by the manufacturers in their standard specifications for such work.

848. **Guarantee.** — The Contractor shall be required to furnish a written guarantee that all his work will be water and moisture proof and that he will be responsible for and will promptly repair any leaks which appear in his waterproofing which cannot be attributed to indisputable settlement or other defects in masonry upon which his waterproofing is applied, provided such masonry has not been constructed by the waterproofing contractor.

849. **Defective Masonry.** — It is the intention that all concrete shall be water-tight, and where this result has not been obtained, the defective masonry must be cut out and replaced by concrete, to the approval of the Engineer, and at the cost of the Contractor, and the price bid shall include such necessary repair work.

Art. 36. Proportioning and Laying Concrete for Water-tight Work

850. **In General.** — Where concrete is to be made water-tight without additional treatment or introduction of waterproofing compounds, the

aggregate shall be so selected as to have a minimum of voids. A dense even mixture of concrete shall be the primary expedient to secure water-tight concrete.*

851. **Use of 1 : 2 : 4 Concrete.** — The water-tightness of the wall shall be secured by the proper proportioning, mixing and placing of 1:2:4 concrete and the walls when finished must show a smooth water-tight surface.

852. **Proportioning Materials.** — The proportion of sand should not exceed two parts by weight to one cement and in the highest class of work equal parts of cement and sand shall be used.

853. **Mixing Concrete.** — A rather wet mixture should be used in preparing concrete when water-tightness is desired. The concrete shall be so mixed that it will just carry the man ramming, and which when walked or tamped on by him will cause it to " quake."

854. **Making Good Defects.** — Any places showing rough or any points where leakage occurs shall be plastered with a coat of 2 to 1 cement mortar in which shall be mixed waterproofing material approved by the Engineer and leave the walls in a water-tight condition.

Art. 37. Special Treatment of Surface. Coating Surface

1. Preparation of Surface

855. **Condition of Surfaces.** — All surfaces, before the application of the waterproof coating, shall be prepared by chipping off their entire skin, so that an entirely new surface is produced. The concrete surface shall be thoroughly chipped not more than two days prior to application of the coating.

856. **Facilitating Chipping of Surfaces.** — The chipping of surfaces may be facilitated by a previous application of muriatic acid of (say) 1 : 10 solution or a bonding compound, the strength of the solution depending upon the age of the wall; or the use of the bonding material may be deferred until the chipping has been completed. Allow the acid to remain until it has exhausted itself, which will require at least ten minutes. A second liberal coat of acid solution shall be applied before removing the first. A third coat shall be supplied if the two applications have not satisfactorily exposed the aggregate and entirely removed the shin of hardened cement.

857. **Removal of Unspent Acid.** — In case acid or bonding powders have been employed, all unspent acid shall be removed by rigid application of the hose, immediately after the acid treatment has reached a satisfactory stage. No other than clear, clean water shall be employed for

* In the case of subways, long retaining walls and reservoirs, provided the concrete itself is impervious, cracks may be so reduced by horizontal and vertical reinforcement properly proportioned and located that they are too minute to permit leakage, or are soon closed by infiltration of silt.

cleaning surfaces, and the slushing shall be continued until the salts are removed.

858. **Brushing of the Chipped Surfaces.** — The dust, dirt and loosened material shall be completely removed from the chipped surfaces, either by scrubbing with stiff wire brushes, water nozzle under good pressure, steam jet, or other suitable means. An absolutely clean surface shall be obtained, not further ahead of the coating work than twenty-four hours.

859. **Filling Voids.** — All holes shall be filled up, large holes with the waterproof concrete, and small holes with waterproof mortar. A perfect bond must at all points be secured with the underlying concrete.

2. Waterproof Cement Mortar Coating

860. **In General.** — Water-tightness shall be secured by surfacing with an unbroken continuous coat of cement mortar to which an approved waterproofing compound has been added. The compound, as manufactured by , or its equal may be used for waterproofing the cement or imparting to the later its water-repelling properties. The waterproof cement mortar coating shall be prepared as follows:

861. **Preparation of the Coating.** — A high-grade Portland cement passing all the usual requirements as to strength, soundness, etc. (see Art. 1, Sec. 1, page 1), shall be used. To each bag of cement there shall be added dry the waterproof compound called for above, exact proportion or percentage being as directed by the manufacturer. The cement and compound must be manipulated until a homogeneous mixture in every respect is obtained.

The cement thus waterproofed shall be in the proportion of one part cement to two parts of sand. The sand shall be absolutely clean, containing no loam or foreign matter, and well graded from coarse to fine. The sand need not be sharp. The sand is to be moistened, waterproof cement spread over it, and the whole manipulated until a homogeneous waterproof coating mortar is obtained. This material is to be made in small quantities and used fresh.

Under no circumstances must the compound be added after the cement has partially set or has been mixed with sand.

862. **Drenching Surfaces.** — Just before the main mortar coating is to be applied, the chipped and wire broomed walls shall be thoroughly drenched and soaked to its full absorbing capacity.

863. **Slush Coating.** — Before the wall shows marked signs of drying a "slush coating" shall be applied. To prepare this, some of the mixed, ready-for-use coating shall be thinned with water to the consistency of cream. It shall be applied with a palmetto, or an equally strong-fibered scrubbing brush, with a scouring effect, care to be exercised to fully cover, in this manner, the inner surfaces of all crevices and holes.

864. Scratch Coat. — Before the slush coating has dried, the first application of the regularly mixed coating shall be applied as a scratch coat, from one-fourth to three-eighths inch thick, and pressure brought on the trowel to push the coating on, to form a uniform bearing.

The scratch coat shall be troweled to a fairly good surface and scratched before hardening.

865. Finishing Coat. — Upon the scratch coat, before its final setting, the finishing coat of sufficient thickness to obtain a total thickness of (say) five-eighths inch shall be applied. This shall be pushed on hard and uniformly troweled and floated to a true surface, free from pits, pin holes, sagging cracks, projections or other defects. The floating of the finished surface shall be done from the bottom of the wall up. Special care must be exercised to apply this finish coat before the first coat has reached its final set.

The composition of the finished coating shall be one part of waterproofed cement to two parts of sand, well graded and previously moistened.

866. Applying Finishing Coat After Scratch Coat has Set. — Should there be causes at any time to prevent applying the finishing coat before the scratch coat has already set, then the latter shall be thoroughly rinsed and slush-coated before finishing coat is applied.

867. Removing Coating Which has Become Set. — Any portion of the coating which shall become set before it has been properly floated and finished shall be entirely removed by chipping, and replaced with freshly-mixed coating.

868. Joining One Day's Work to Another. — The joining of one day's work to a previously applied and hard set coating shall be to straight edges, cut at the time when the older work is being finished. To make the joining, the edge shall first be scraped with the edge of a trowel or scraper; slush coating shall then be scrubbed into this edge, and fresh, regularly mixed coating shall be hard rubbed, back and forth, under the nose of a pointed trowel, into the preceding slush coat. This point shall again be well packed when the floating and the finish troweling takes place. In all cases a continuous seal must be obtained.

869. Testing for Soundness. — When the work has thoroughly hardened (three to five days being allowed therefor), sounding with a light hammer over the wall shall be resorted to by the Engineer, to discover any loose or hollow portions. Any hollow or shelly places thus revealed shall be entirely cut out with sharp steel points and replaced in the same manner as above specified. The bond of the coating to floor or wall shall at every point of contact be firm and sound.

870. Protection of Finishing Coat. — The finishing coat shall be kept moist by spraying or otherwise, and protected from frost and sun while it is in the process of setting.

3. Alum and Soap Solution: Sylvester Process *

871. **In General.**— The application of alternate coatings of soap and alum solutions shall be applied to the surface of walls intended to be waterproof.

872. **Proportions.** — The process shall consist in applying first a solution of three-quarters (¾) of a pound of soap to one (1) gallon of water, followed, after twenty-four hours, by the application of a solution containing two (2) ounces of alum to one (1) gallon of water. The soap and alum shall each be perfectly dissolved before using. These proportions may be varied if better results are thereby secured.

873. **Application of Coatings.** — Both solutions shall be applied with a flat brush, the soap solution boiling hot, and the alum solution at 60° to 70° F. The first coat shall remain on twenty-four hours, or until it is dry and hard. Alum solution, second coat to be applied thoroughly over the first coat. Second coat shall remain twenty-four hours before third coat (soap solution) is put on. These washes shall be applied with a soft brush.

874. **Number of Washes.** — Two or more washes of each solution shall be applied, depending upon exposure, pressure and other local conditions.

875. **Frothing.** — Care shall be taken to avoid frothing in applying the soap wash.

876. **Temperature of Air.** — Temperature of air shall not be less than 50° F. at the time of application of the washes.

877. **Condition of Surface.** — The surfaces shall be clean and dry before applying any of the washes.

4. Paraffine Process

(Cold Process)

878. **Manufacturer's Directions.** — The Contractor shall obtain explicit directions from the manufacturer and follow them.

879. **Condition of Surface.** — Surface to be treated shall be smooth and freed from all projections. Holes shall be filled up. Surface to be clean and thoroughly dry, not only on surface but all the way in.

880. **Application of Coating.** — Paraffine shall be applied thoroughly; well rubbed in, filling all corners, recesses, etc.

881. **Number of Coats.** — At least two coats shall be applied. In severely exposed locations, three coats are advisable.

882. **Protection.** — Fire shall be kept away from the material during application.

(Hot Process)

883. **Application of Coating.** — Paraffine shall be applied to the surface hot with a brush, or if required by the Engineer, the surface shall first be treated with artificial heat and when sufficiently warm, melted, hot paraffine wax shall be thoroughly rubbed in.

* This process has been principally employed and is mainly adapted to coating the surfaces of tanks, conduits, and other water-carrying structures, to render them tight.

Care shall be taken to avoid an excessive use of paraffine which would give a glossy, oily appearance to the surface.

884. **Experienced Workmen.** — The hot paraffine shall be applied by those specially equipped for and experienced in the work. The workmen shall at all times be under intelligent supervision.

5. Asphalt Coating: Bituminous Process

885. **In General.** — Waterproofing shall be obtained by means of covering the concrete with a waterproof coat of asphalt. All asphalt shall be brought to the job in original packages.*

886. **Manufacturer's Directions.** — The Contractor shall obtain directions from the manufacturer and follow them.

887. **Composition of Asphalt.** — All asphalt shall be of the best grade, free from coal tar or coal-tar products. It must not volatilize more than one-half of one per cent under a temperature of 300° F. for 10 hours. It must not be affected by 20 per cent solution of ammonia; 35 per cent solution of hydrochloric acid; 25 per cent solution of sulphuric acid, nor by a saturated solution of sodium chloride. It shall show no hydrolithic decomposition when subjected for a period of ten hours, to hourly immersions in water with alternate drying by warm air currents.

888. **Range of Temperature.** — (*a*) For metallic structures, exposed to the direct rays of the sun, the asphalt must not flow under 212° F., nor become brittle at 0° F., when spread thin on glass.

(*b*) For structures under ground, a flow point of 185° F., and a brittle point of 0° F. shall be required.

(*c*) A mastic made from either grade of asphalt by mixing it with sand must not perceptibly indent when at a temperature of 130° F. under a load of 20 pounds per square inch. It must also remain pliable at a temperature of 0° F.

889. **Condition of Surface.** — All surfaces to be waterproofed must be in a condition fit to receive the same, namely, clean and dry.

890. **Preparing Metal Surface.** — Before applying asphalt to a metal surface, the metal shall be cleaned of all rust, loose scale and dirt, and if previously coated with oil must be burned off with benzine, or other suitable means. The metal surface must be warm to enable the asphalt to adhere to it, and the warming is best accomplished by covering it with heated sand, which shall be swept back as the hot asphalt is applied.

891. **Preparing Concrete Surface.** — If the concrete surface cannot be made dry and warm, it shall be first coated with asphalt reduced with naphtha or with some other asphalt paint applied cold. This is particularly necessary for vertical surfaces. It is difficult to make either cold or hot asphalt adhere to the surface of concrete or mortar when the latter is covered

* Coal-tar preparations, applied as a mastic, are used for waterproofing, and should be proof against injury by liquids or gases. For retaining and similar walls in direct contact with the earth, the application of one or two coatings of hot coal-tar pitch to the thoroughly dried surface of concrete is an efficient method of preventing the penetration of moisture from the earth.

with a thin film of cement. To overcome this the surface should be covered with a finishing coat of mortar composed of one (1) part of Portland cement to one or two parts of sand. If this is not permissible the surface should be cleaned by chipping or with a sand-blast.

892. **Preparing Asphalt.** — The asphalt shall be heated in a suitable kettle to a temperature not exceeding 450° F. If this is exceeded it may result in "pitching" the asphalt. Before the "pitching" point is reached the vapor from the kettle is of a bluish tinge, which changes to a yellowish tinge after the danger point is past. If this occurs the material shall be tempered by the addition of fresh asphalt. The asphalt has been coked sufficiently when a piece of wood can be put in and withdrawn, the asphalt clinging to it. Care should always be taken not to prolong the heat to such an extent as to "pitch" the asphalt; should it become necessary to hold the kettle for any length of time, bank or draw the fire and introduce into the kettle a quantity of fresh asphalt to reduce the temperature.

893. **Application of Asphalt.** — (*a*) The first coat shall consist of a thin layer of hot asphalt thoroughly mopped over the prepared surface.

(*b*) The second coat shall consist of a mixture of clean sand or limestone screenings, free from earthy admixtures, previously heated and dried, and asphalt, in the proportion of one (1) part asphalt to three (3) parts of sand or screenings by volume. This coat shall be thoroughly mixed in the kettle and then spread on the surface with warm smoothing irons, such as are used in laying asphalt streets, and thoroughly tamped and pressed into place. The irons should not be hot enough to burn the asphalt.

(*c*) The finishing coat shall consist of pure hot asphalt spread thinly and evenly over the entire surface, and sprinkled with washed roofing gravel, torpedo sand or stone screenings, to harden the top, when the coating is to be covered with earth or broken stone, so the asphalt coating will not be damaged.

(*d*) The entire coating shall not be less than ¾ in. thick at the thinnest place. The thickness of the coating will depend upon the character of the work and may vary from ¾ in. to 2 ins. in thickness.

(*e*) The first coat shall be allowed to set up before the second coat is applied. Coating shall be well rubbed in in corners and recesses and continuous throughout.

Art. 38. Introduction of Foreign Ingredients. Integral Method

1. Waterproofing Compounds

894. **In General.** — Concrete may be waterproofed by mixing with the cement some form of waterproofing compound of proved efficiency and now obtainable from manufacturers.*

* A concrete of dry consistency is more or less pervious to water, and compounds of various kinds have been mixed with the concrete for the purpose of making it water-tight. Many of these compounds are of but temporary value, and in time lose their power of imparting impermeability to the concrete.

895. Waterproofing Paste. — Water-tightness shall be secured by the addition of   Waterproofing Paste, as manufactured by   , to all water used to temper the dry mixture of cement and aggregate in proportions and mixed as directed below. (See Sec. 2, page 156.)

896. Waterproofing Powder. — Water-tightness shall be secured by proportioning the ingredients of the concrete so that the voids in the same shall be reduced to the minimum as far as practicable in accordance with the foregoing specifications, and by the addition to the cement of a dry powdered paraffinated waterproofing compound.

2. Proportioning, Mixing and Placing Concrete

897. Proportions for Concrete. — The concrete composing the main body of the structure shall consist of one (1) part cement, two (2) parts of sand, and four (4) parts of stone, each to meet the following requirements:

898. Ingredients for Concrete. — (*a*) The cement shall be a high-grade Portland, which has been carefully tested and found to satisfactorily pass the requirements given in Art. 1, Sec. 2, page 2, and preferably ground so that eighty per cent (80%) shall pass a standard two hundred- (200) mesh sieve.

(*b*) The sand shall consist of spherical grains of any hard rock that is practically free from clay, absolutely free from organic matter, and uniformly graded in size from coarse to fine.

(*c*) The stone shall be screened from gravel, and shall for sixty per cent (60%) of its bulk be uniformly graded between diameters of one (1) and one and one-half (1½) inches, and for forty per cent (40%) of its bulk be uniformly graded between diameters of one-quarter (¼) and one (1) inch. A hard crushed trap rock may be substituted for gravel if screened to meet the requirements indicated.

899. Mixing Paste. — The dry mixture of cement, sand and stone in the above proportions shall be tempered to a medium wet consistency with water to which one (1) part of waterproofing paste has been added as directed by the manufacturers, for every   (   ) parts of water.

900. Mixing Powder. — The proportion of the waterproofing compound in the concrete shall be not less than 4 lbs. of compound to each barrel of cement employed for making this concrete.

The waterproofing compound must be added dry to the cement and the two thoroughly mixed until a uniform mixture is obtained. Under no circumstances must the compound be added after the cement has partially set or has been mixed with sand. The sand shall be slightly moistened before mixing with the cement.

901. Placing. — All the concrete shall be placed in one continuous operation, each pouring being thoroughly spaded to insure uniform density.

Great care shall be taken in placing the concrete so that maximum density will be secured.

902. **Uniting Old and New Concrete Surfaces.** — In cases where joints are absolutely unavoidable, very special care shall be taken to clean and roughen the old surface and have it thoroughly wet and slush-coated immediately before placing additional concrete. If so required by the Engineer, the surfaces of concrete already set shall be thoroughly washed with material prepared for such purposes. This washing shall then be followed by washing with water. Upon the surface thus prepared, the new concrete shall be laid.

Art. 39. Layers of Waterproofing Material. Membrane Method

1. General Requirements

903. **Skilled Labor.** — Necessary working room must be provided for the proper execution of the work and none but men skilled in this work shall be employed. In other words, the waterproofing shall be done only by experienced and expert laborers or waterproofers. Unless skilled workers are employed, materials may be wasted and be of no benefit.

904. **Applying Waterproofing Against Sheeting.** — In places where permanent sheeting is placed at the waterproofing line, the waterproofing, if permitted by the Engineer, may be applied against the sheeting.

905. **Additional Waterproofing Material.** — Should felt undipped in asphalt be used in special situations, to overcome difficulty in placing waterproofing materials, such will be estimated as additional waterproofing at the price for felt and asphalt waterproofing as provided in the proposal.

906. **Freezing Weather.** — No waterproofing shall be done when the temperature is below 25° F. Good work cannot be done in very cold weather as the air chills the bitumen too quickly.

907. **Storage of Felt.** — The rolls of felt shall be stored on end and not laid on the side.

2. Preparation of Surface

908. **Condition of Surfaces.** — All surfaces to be waterproofed shall be as smooth as possible and shall be dry. All dirt and foreign matter shall be removed before waterproofing is applied. Concrete must be allowed to thoroughly set and all uneven surfaces leveled up with a coat of cement mortar. The surface shall be smoothed off with a trowel, if too rough.

909. **Approval of Surfaces by Engineer.** — All surfaces upon or against which waterproofing is to be placed must be dry and approved by the Engineer before waterproofing is applied.

910. **Application of Heat for Drying Surfaces.** — In particular situations where special difficulty is encountered in securing dryness on surfaces to

be waterproofed, apparatus for local application of heat shall be used if necessary to expedite drying of the surfaces, or as otherwise permitted by the Engineer. The method to be pursued shall be in accordance with most approved usage as applicable to the materials prescribed.

911. **Minimum Time for Drying Surfaces.** — In all cases every available piece of apparatus shall be used as may assist in securing dryness on all surfaces to which waterproofing is to be applied, but not until the concrete has had at least 48 hours to set.

912. **Drainage System.** — It is a difficult thing to place the material on a wall reeking with water and an adequate drainage system must be installed and maintained and the wall shall be dry when the waterproofing is applied. If this is not done, the material is liable to be pressed off the wall before the supporting masonry is placed. In the floor where necessary, sump with drainage channels shall be provided, so that water may be removed by pumping in advance of the waterproofing.

913. **Additional Layer of Felt.** — If for any reason it is impracticable to have the concrete dry, then a layer of felt or treated fabric in addition to those called for in the specifications shall first be laid against the surface, and on the upper surface of the felt or treated fabric shall be spread the first layer of pitch or asphaltum; the said layer of felt or fabric shall not be counted as one of the required layers or plys.

(Some specifications require that asphalt cut with naphtha shall first be applied cold.)

914. **Roughening Surface.** — In case the concrete is covered with a fine skin of cement, it shall be roughened up to insure sticking of material.

915. **Metal Surfaces.** — Metal surfaces shall be dry and clean, free from rust, loose scale and dirt. If previously coated with oil, same shall be removed with benzine or other suitable means.

3. Composition of Materials

916. **Pitch.** — Pitch shall consist of either coal-tar or natural asphalt as the Engineer may direct.

917. **Coal-tar Pitch.** — The coal-tar pitch shall be straight-run pitch which will soften at 70° F. and melt at 100° F., being a grade in which distillate oils, distilled therefrom, shall have a specific gravity of 1.105.

918. **Grade of Asphalt.** — The asphalt used shall be the best grade of Bermuda, Alcatraz or lake asphalt, of equal quality, and shall comply with the following requirements.

919. **Composition of Asphalt.** — The asphalt shall be a natural asphalt or a mixture of natural asphalts, containing in its refined state not less than ninety-five (95) per cent of natural bitumen soluble in rectified carbon bisulphide or in chloroform. The remaining ingredients shall be such as not to exert an injurious effect on the work. Not less than two-thirds of the total bitumen shall be soluble in petroleum naphtha of seventy (70)

degrees Baumé or in acetone. The asphalt shall not lose more than four per cent of its weight when maintained for ten hours at a temperature of three hundred degrees.

920. **Artificial Asphalts, etc.** — The use of coal-tar, so-called artificial asphalts, or other products susceptible to injury from the action of water will not be permitted on any portion of the work, or in any mixtures to be used.

921. **Felt.** — The felt used in waterproofing such parts of the structure as is below ground water level shall be composed of asbestos or other equally non-perishable material dipped in asphalt and weighing not less than fifteen (15) pounds to the square of one hundred (100) feet.

The felt used in other parts of the structure shall be the same as the above, or of the best quality of coal-tar felt weighing not less than fifteen (15) pounds to the square of one hundred (100), except, that if the latter be used, one layer more will be required than of the former. All felt shall be subject to the inspection and approval of the Engineer.

922. **Treatment of Fabric.** — The fabric to be used, with the pitch or asphaltum for waterproofing, shall have been treated with pitch or asphaltum or other suitable material before being brought on the work. The fabric and the material used in its treatment shall be approved by the Engineer.

4. Laying Waterproofing Material

923. **In General.** — The waterproof sheet shall be applied continuously over the whole surface to be treated as shown on the plans. All surfaces to which waterproofing is to be applied shall be made as smooth as possible; on these surfaces there shall be spread either hot melted pitch or asphaltum (or other cementing material) in a thick layer of uniform thickness; on this layer of pitch or asphaltum shall be laid a fabric of such material as may be approved by the Engineer; this process shall be repeated until such number of layers as may be required by the Engineer have been placed, and a final coat of pitch or asphaltum shall then be applied.

924. **Joints.** — The layers of felt shall not be laid independently but shingled on consecutively. All joints shall be broken properly at least 4 ins. on cross joints and 12 ins. on longitudinal, and at least 12 ins. lap left at corners to form good connections with adjoining sections. Special care shall be taken that all joints are well broken and cemented together.

925. **Joints Due to Stopping Work.** — Where it is necessary to stop work, laps of at least 12 ins. shall be provided for joining on new work.

926. **Spreading Pitch or Asphalt.** — Each layer of pitch or asphalt fluxed as directed by the Engineer must completely and entirely cover the surface on which it is spread without cracks or blowholes or other imperfections. The compound shall not be spread on more than nine square feet of surface at a time, — i.e., not more than three feet in front of a roll of felt

which is 36 ins. wide. The mopping of the materials should be done quickly, uniformly and thoroughly, while it is of the proper temperature.

927. **Laying Fabric.** — On the prepared surface shall be laid a uniform layer of the melted pitch or asphaltum. Then the first layer of the fabric shall be rolled out into the pitch or asphaltum while the latter is still hot, and pressed against it so as to insure its being completely stuck over its entire surface, and shall be free from all blowholes, pin holes or other imperfections. Ahead of each roll as it is unfolded, the hot pitch or asphaltum shall be swabbed upon the prepared surface with a mop so that the fabric is spread directly upon the hot material. As soon as the first roll of fabric is started, the second shall be placed overlapping the first a width depending upon the number of layers to be placed. The third roll shall then be started lapping both of the previous two and so on the entire width of the surface to be covered. In no part of the work shall fabric touch fabric, but be cemented with pitch or asphaltum.

The sheets shall be applied vertically to the wall surfaces and these sheets shall not be longer than can conveniently be handled.

928. **Side Wall and Floor Connections.** — In connecting side wall with floor work, the layers of fabric on the sides shall be carried down on the outside of the ends of the floor layer and a lap of at least 12 ins. shall be allowed for same. Especial care must be taken with this detail.

929. **Side Wall and Roof Connections.** — In connecting side wall and roof work, the layers of fabric of the roof shall be carried on the outside of the side wall layers and shall lap at least 12 inches. Especial care must be taken with this detail.

929a. **Corners.** — All corners shall be reinforced with two extra pieces of felt snugly fitted into it, one between the second and third layer and one on top.

930. **Carrying Waterproofing Against Sheet Piling.** — In case tongue and grooved sheet piling is used for making and protecting the excavation and this piling has been treated with an efficient wood preservative satisfactory to the Engineer, the waterproofing may be carried up against the sheet piling. The sheet piling shall be given a thorough coat of hot pitch or asphaltum and all points thoroughly filled before the first layer of fabric is placed thereon. Coppered carbolineum or other wood preservative satisfactory to the Engineer may be used for protecting the sheet piling.

931. **Connecting New to Old Work.** — Where it is necessary to stop work, a lap of at least 12 inches shall be provided for connecting on the adjacent portion of the work. Before new work is added to old, the old surface shall be cleaned of all foreign matter, such as cement, mortar, or other substance which finds its way thereon. After cleaning the laps, they shall be well covered with a second layer of Irish hot pitch or asphaltum as before, and these operations continued until the requisite number have been placed, the last layer of felt being covered with a final coat of hot

pitch or asphaltum. The new fabric shall be made to stick smoothly and evenly over entire joint area.

931a. **Final Coating.** — The whole waterproofed surface shall be given a thorough coating of compound.

5. Protection of Waterproofing

932. **In General.** — After the waterproofing has been put into place, it shall be properly protected against injury from any cause whatever, i.e.,

(*a*) Backfilling with earth.
(*b*) Depositing concrete against same.
(*c*) Laying brickwork or rubble against same.
(*d*) Bulging of waterproofing from wall.
(*e*) Cracking of same due to bulging.
(*f*) Running of material due to heat.
(*g*) Injury due to frost.
(*h*) Throwing tools, bricks or other débris thereon.
(*i*) Passing of men or wheelbarrows thereover.

933. **Safety Coat of Mortar.** — The waterproofing herein described shall be protected from injury by a layer of cement mortar (generally 1 in. thick) mixed in the proportion of 1 part Portland cement to 2 parts sand, which shall be placed as soon as possible after the laying of the waterproofing, not exceeding 12 to 24 hours, or sooner if the Engineer shall so direct. Special care shall be taken in laying the mortar not to break, tear or in any way injure the membrane.

934. **Failure Due to Improper Safety Coat.** — Should the waterproofing be injured, owing to failure of placing the protective coat of cement mortar, which injury is caused by exposure to weather, bulging from masonry surface or puncturing from any cause, the Contractor shall remedy the same at his own expense.

935. **Placing Masonry Against Waterproofing.** — When the safety coat is omitted, and backing of earth or concrete, brick or stone masonry is to be laid immediately against the waterproofing, the greatest care shall be exercised that the sheet is not punctured by sharp corners of brick or stones. In other words, care shall be taken not to break, tear or injure in any way the outer surface of the pitch or asphaltum.

936. **Placing Brick Against Waterproofing.** — When brickwork is placed against waterproofing on vertical walls, a slight space shall be left for slushing in with mortar to avoid puncturing the outer surface of the pitch or asphaltum. The bricks shall not be rammed up against the waterproofing sheet.

937. **Water Pressure.** — The work shall be free from water pressure during the laying of the waterproofing, being relieved by draining and pumping if necessary. An emergency pump shall be provided if ordered by the Engineer.

938. **Backfilling with Earth.** — Protection of the waterproofing shall not stop with placing the backfilling on same. Tamping against it shall be absolutely forbidden.

939. **Openings or Incisions in Waterproofing.** — When openings or incisions in the sheet are necessary, the Contractor shall see that such places are repaired in the most thorough manner.

940. **Passages for Pipes, etc.** — All pipe passages shall be pocketed and connections thoroughly made. Such places shall not be covered up until the work has been examined by the Engineer and found properly executed.

941. **Repairing Waterproofing.** — Any masonry that is found to leak at any time prior to the completion of this work shall be cut out and the leak stopped, if ordered by the Engineer.

941a. **Gas.** — Care should be taken to prevent gas from coming in contact with waterproofing mixture. Asphaltic compounds have been seriously injured by gas escaping from the mains in the street.

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By the Use of Coal Tar and Felt, p. 242.

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CHAPTER VIII

DESIGN OF REINFORCED CONCRETE

Art. 41. General Assumptions

942. **In General.** — All reinforced concrete work shall be designed in accordance with standard engineering practice, and the following assumptions: *

943. **Working Stresses and Safe Loads.** — Calculations shall be made with reference to working stresses (Art. 44, page 170) and safe loads (Art. 42, page 165) rather than with reference to ultimate strength and ultimate loads.

944. **A Plane Section Before and After Bending.** — A section plane before bending remains plane after bending.

945. **Modulus of Elasticity.** — The modulus of elasticity of concrete in compression is constant within the usual limits of working stresses.

946. **Stress-strain Curve.** — The stress-strain curve of concrete in compression will be assumed to be a straight line. The strain in any fiber is directly proportionate to the distance of that fiber from the neutral axis. That is to say, the stresses on the concrete vary directly from zero at the neutral axis to maximum at the extreme fiber; thus the variation of stress in the section above the neutral axis is indicated by a triangle.

947. **Ratio of Moduli of Elasticity.** — The ratio of the modulus of elasticity of steel (E_s) to the modulus of elasticity of concrete (E_c) shall be taken at 15 for stone and gravel and slag concrete and 30 for cinder concrete, or $E_s \div E_c = 15$ for normal concrete, or $E_s \div E_c = 30$ for cinder concrete, except as modified in Par. 997.

948. **Tensile Stresses.** — In calculating the moment of resistance of slabs, beams or girders the tensile stresses in the concrete shall be neglected. In other words, all tensile stresses will be considered to be resisted entirely by the steel reinforcing, no allowance whatever being made for concrete in tension.

949. **Adhesion or Bond.** — The adhesion or bond between the concrete and the steel is assumed to be sufficient to make the two materials act together as a homogeneous solid. Under compressive stresses the two materials are therefore stressed in proportion to their moduli of elasticity and their distance from the neutral axis.

* It is recognized that some of the assumptions given herein are not entirely borne out by experimental data. They are given in the interest of simplicity and uniformity; and variations from exact conditions are taken into account in the selection of working stresses in Art. 44 and formulas in Appendix A, p. 247.

950. Neutral Axis. — The neutral axis of any homogeneous section passes through the center of gravity of the section.

951. Elastic Limit. — The elastic limit of the material is not exceeded.

952. Initial Stresses. — Initial stresses shall be neglected. That is to say, initial stress in the reinforcement due to contraction or expansion in the concrete shall be neglected.

952a. Deflections. — The deflection of beams is affected by the tensile strength developed throughout the length of the beam. For calculations of deflections, a value of 8 for the ratio of the moduli will give results corresponding approximately with the actual conditions.

953. General Dimensions. — The following dimensions shall first be calculated or assumed.

954. Length of Slabs. — The span length for slabs, supported at ends, shall be taken as the clear opening plus thickness of slab.

955. Length of Continuous Slabs. — The span length for slabs, continuous, shall be taken as the distance from center to center of supports but generally need not exceed the clear span plus the depth of the slab.

956. Length of Beams. — The span length for beams shall be taken as the distance from center to center of supports, but need not be taken to exceed the clean span plus the depth of the beam. Brackets shall not be considered as reducing the clear span.

957. Length of Columns. — Length of columns shall be taken as the maximum unsupported length.

Art. 42. Loads

1. Dead Load

958. In General. — The dead load shall include the weight of the structure and all fixed loads and forces.

959. Weight of Concrete. — The weight of concrete shall be assumed to be per cubic foot, 150 lbs. for reinforced (stone or gravel) concrete; 130 lbs. for average slag concrete; 95 lbs. for cinder concrete, unless the exact weight of the concrete to be used be determined by weighing.

2. Live Load

960. In General. — The live load shall include all loads and forces which are variable.

961 Minimum Loads. — The minimum live load on any floor shall be 50 lbs. per square foot. Minimum live load on roofs shall be 30 lbs. per square foot. The minimum live load for floors and roofs shall be as provided by building codes.

962. Floor Loads. — In addition to the dead load all floors shall be proportioned to carry the following live loads unless otherwise specified.

	Lbs. per Sq. Ft.
Apartment houses	50
Churches	75 to 100
Dancing halls	150
Department stores	100 to 200
Office buildings	75 to 100
School buildings	75 to 100
Theaters	75 to 100
Warehouses, light	100 to 200
Warehouses, heavy	200 to 400

For buildings for light and heavy manufacturing purposes, extra heavy warehouses, etc., the loads to be provided for will be specified by the Engineer.

962a. Roof Loads. — In reinforced concrete buildings of considerable size it is sometimes considered essential, in designing the roofs, to make allowance for snow and wind loads. Generally in the design of smaller buildings, which classification would include dwellings, even pretentious types, it is usual to combine the snow and wind loads, and to use a superimposed load on the roof of from 25 to 30 pounds per square foot. This load added to the weight of the roof construction gives the total roof load per square foot.

In climates comparatively temperate the load of 25 to 30 pounds could be reduced to from 15 to 20 pounds unless it was proposed to use the roof as a promenade, when it would be safer to use a somewhat heavier superimposed load. Roofs that are very steep have, of course, little snowload, but on the other hand the wind pressure increases.

963. Impact. — An impact allowance shall be added to the computed maximum live load stresses, as follows:

(*a*) For floors of armories, churches, dancing halls, public halls, schools, theaters and factories . . . . $\text{Impact} = S\left(\frac{100}{L+300}\right)$,

(*b*) For floors carrying moving machinery for crane girders and posts; for highway bridges . . . . $\text{Impact} = S\left(\frac{200}{L+300}\right)$,

(*c*) For railroad bridges . . . . $\text{Impact} = S\left(\frac{300}{L+300}\right)$,

where S = computed maximum live load stress, moment or shear,
L = length of span in feet, or loaded length of span, whichever gives a maximum.

No impact allowance shall be added to stresses produced by centrifugal, traction and wind forces.

964. Wind Pressure. — All structures shall be designed to withstand a wind pressure of 30 lbs. per square foot on any exposed surface.

3. Reduction of Loads

965. **Floor Slabs.** — The full loads shall be used in figuring floor slabs.

966. **Beams.** — The full live load shall be considered as carried into all beams.

967. **Girders.** — A reduction of 15 per cent full live loads may be allowed in figuring girders, except in buildings used for storage purposes.

968. **Columns.** — The above live loads (Par. 962) may be reduced for columns as follows:

Columns supporting roof and top floor, no reduction.
Columns supporting next ten floors, a cumulative reduction of 5 per cent for each succeeding floor.
Columns supporting remaining floors, a total reduction of 50 per cent.

In other words, a reduction of 5 per cent of full live load coming to the columns supporting the second floor below the roof may be allowed and a further reduction of 5 per cent of the full live loads of each story below until the total reduction shall amount to 50 per cent of the full live load of any floor, after which all loads shall be figured net to the foundations, but no live load less than 50 lbs. per square foot, including reduction, shall be allowed.

This reduction shall not apply to live load on columns of warehouses and similar buildings which are likely to be fully loaded on all floors at the same time.

In assuming the load coming to the columns all beams and girders shall be considered as carrying a net load consisting of 100 per cent each of the live and dead load, subject to the above reductions.

Art. 43. Bending Moments

969. **In General.** — Bending moments must be selected for individual conditions. The bending moments shall be computed as follows:

970. **Simple Slabs.** — Slabs, reinforced in one direction only and uniformly loaded and supported at both ends,

$$M = 1.5\,wl^2, \text{ at center} = 0 \text{ at ends,}$$

where M = bending moment in inch-pounds;
w = dead or live load in pounds per linear foot;
l = length of span in feet. (See Par. 954.)

971. **Partially Restrained Slabs.** — For slabs supported at one end and continuous at the other, $M = 1.2\,wl^2$, at center, and $M = 0$ at one end and $M = -1.2\,wl^2$ at the other.

In the case of slabs continuous over two spans only, reductions of the values as herein given shall be made in accordance with the best engineering practice.

972. Continuous Slabs. — For slabs continuous or fixed at both ends, $M = wl^2$, at center and $M = - wl^2$ at ends.

973. Slabs Reinforced in Both Directions. — For slabs whose length does not exceed 1½ times their width and which are reinforced in both directions and supported on four sides and fully reinforced over the supports (the reinforcement passing into the adjoining slabs) may be figured on the basis of bending moments equivalent to $\frac{wl^2}{F}$ for load in each direction. For simple spans, $F = 8$; when partially continuous, $F = 10$; when continuous or fixed over both supports, $F = 12$. The distribution of the loads may be determined by the formula:*

$$r = \frac{l^4}{l^4 + b^4},$$

where r = proportion of load carried by the transverse reinforcement;
l = length of span;
b = breadth of slab.

974. Simple Beams. — Where beams are freely supported at both ends the moment must be figured as of simple beams, i.e., $\frac{wl^2}{8}$ for uniform load.†

* The exact distribution of load on square and rectangular slabs, supported on four sides and reinforced in both directions, cannot readily be determined. The above method of calculation is recognized as faulty, but is offered as a tentative method by the Joint Committee of the Am. Soc. C.E., Am. Soc. for Testing Materials, Am. Ry. Eng. Assoc. and the Assoc. of Am. Portland Cement Mfgrs., which will give results on the safe side.

For various ratios of $\frac{l}{b}$ the values of r are as follows:

	r
1	0.50
1.1	0.59
1.2	0.67
1.3	0.75
1.4	0.80
1.5	0.83

Using the values above specified, each set of reinforcement is to be calculated in the same manner as slabs having supports on two sides only, but the total amount of reinforcement thus determined may be reduced 25 per cent, by gradually increasing the rod spacing from the third point to the edge of the slab.

† The greatest bending moment on any simple beam may be determined by finding the algebraic sum of the moments about the point at which the greatest bending moment occurs.

For convenience it is customary to use simple formulas, arranged in terms of the weight and span, for finding the bending moment on beams loaded with a uniformly distributed load, a load concentrated at the center, or at triangular shaped load such as the weight of brickwork on a lintel over an opening.

In the following tabulation a simple beam is considered as one supported at both ends, while a cantilever is a projecting beam or one supported at one end only. In the formulas the bending moment, M, is determined in inch-pounds; the weight, W_2, is taken in pounds, and the span in feet or inches as designated L or l, respectively.

FORMULAS FOR BENDING MOMENTS

Simple Beam, Uniform Load	$M = \frac{Wl}{8}$ or $1.5\ WL$.
Simple Beam, Load Concentrated at the Center	$M = \frac{Wl}{4}$ or $3\ WL$.
Simple Beam, Triangular Load, Apex at the Center	$M = \frac{Wl}{6}$ or $2\ WL$.
Simple Beam, Uniform Load; Ends of Beam Fixed	$M = \frac{Wl}{10}$ or $1.2\ WL$.
Cantilever Beam, Uniform Load	$M = \frac{Wl}{2}$ or $6\ WL$.
Cantilever Beam, Load Concentrated at End	$M = Wl$ or $12\ WL$.

975. **Partially Restrained Beams.** — Beams supported at one end and continuous at the other to be figured with a bending moment of eight-tenths (0.8) that of a simple beam.

In the case of beams and girders continuous over two spans only, reductions of the values as herein given shall be made in accordance with the best engineering practice.*

976. **Continuous Beams.** — In beams or girders where continuous action can be obtained a bending moment of two-thirds ($\frac{2}{3}$) that of a simple beam may be assumed, unless the concrete at the bottom of the beam at the support shall by this assumption receive excessive compression.†

976a. **Concentrated Loads.** — Special consideration and provision shall be given and made in case of concentrated loads.

976b. **Flat Slab Floors.** — (*a*) Girderless flat slab floors reinforced in either two or four directions and supported by enlarged column capitals may be constructed according to the following principles: —

W = total dead and live load per square foot.

L = length of one side of panel if square, or if rectangular it is the longer dimensions measured from center to center of columns.

B = shorter dimensions of rectangular panel measured from center of columns.

l = side of square having same diagonal as rectangle BL, or in a square panel it equals L.

D = diameter of column capital at a point where it is at least $1\frac{1}{2}$ ins. thick.

K = bending moment coefficient having the values hereinafter defined.

D must not be less than .225 L and the sides of the column capital must not slope at an angle with the perpendicular of more than forty-five degrees.

L must not be more than 1.2 B.

(*b*) *Slabs reinforced in four directions.* The steel in the center of the panel shall be designed to resist a bending moment of one twenty-fifth Wl^3 for interior and one twenty-second Wl^3 for exterior panels. The steel so determined shall be divided equally among two diagonal and two cross bands for square panels and in the case of rectangular panels one-half of this steel shall be equally divided between the diagonal bands and the remainder between the cross bands in proportions to the cubes of their lengths.

The negative bending moment in 180° around the column capital, that is, the negative moment resisted by two diagonal and two cross bands at the supports shall be taken as one-fifteenth Wl^3.

* In the case of beams and slabs continuous for two spans only, the bending moment at the central support should be taken as $\frac{wl^2}{8}$ and near the middle of the span as $\frac{wl^2}{10}$.

† At the ends of continuous beams, the amount of negative moment which will be developed will depend on the condition of restraint or fixedness, and this will depend on the form of construction used. There will usually be some restraint, and there is likely to be considerable. Provision must be made for the negative bending moment, but, as its amount will depend on the form of construction, the coefficient cannot be specified here, and must be left to the judgment of the designer.

To compute the concrete stress at the column capital a negative bending moment of one twenty-fifth Wl^3 shall be assumed to be resisted by a band of concrete not wider than D plus six times the slab in thickness, nor wider than the sunken panel or drop if such is used, nor wider than .4 L.

(*c*) *Slabs reinforced in two directions only.*

The bending moments in each direction shall be calculated by dividing the slab into eight (8) equal strips, starting from the center line of two columns. Each strip shall be regarded as a continuous beam having a positive bending moment at the center and a negative bending moment at the line of supports. The bending moment at each of these points shall be Wl^3 divided by $8\,K$ for square panels and for rectangular panels $\frac{WL^2B}{8\,K}$ in the direction of L and $\frac{WB^2L}{8\,K}$ in the direction of B. The values of K shall be taken for interior panels as follows, starting at the center line of columns:

	At line of supports.	At center.
First strip	−13	+26
Second strip	−19	+38
Third and fourth strips, each	−58	+58

For exterior panels these values are to be decreased 20 per cent. Compressive stresses in concrete are to be calculated by assuming that the entire width of each strip resists the bending moment assigned to it.

(*d*) When the slab near the column is increased in thickness so as to form a sunken (or raised) panel or drop the dimensions of this drop shall be not less than .375 times the panel length in the same direction.

Art. 44. Working Stresses

Before applying the following working stresses in proportioning parts of a structure, proper allowances for vibration and impact should be added to live loads where necessary to produce an equivalent static load.

In selecting the permissible working stress to be allowed on concrete, the working stresses usually allowed for other materials of construction should be used as a guide, so that all structures of the same class, but composed of different materials, may have approximately the same degree of safety.

The contractor is not particularly interested in the ultimate strength of concrete, but he is interested in the allowable unit working stresses. These allowable unit stresses are different in the several cities, and are fixed by the building laws. Outside of the jurisdiction of the cities the judgment of the designer is the governing factor in deciding upon these values.

977. Normal Concrete. — The following working stresses for concrete are based on concrete composed of one (1) part Portland cement, two (2) of sand, and four (4) of stone or gravel; or the proportions may be such that the resistance of the concrete to crushing shall develop an average compressive strength of 2000 lbs. per square inch after hardening for twenty-eight (28) days,* when tested in cylinders 8 ins. in diameter and 16 ins. long. The tests to determine this value must be made under laboratory conditions of manufacture and storage, using the same consistency as is used in the field.

TABLE OF STRENGTHS OF DIFFERENT MIXTURES OF CONCRETE.
(In Pounds per Square Inch.)

Aggregate.	1:1:2	1:1½:3	1:2:4	1:2½:5	1:3:6
Granite, trap rock	3300	2800	2200	1800	1400
Gravel, hard limestone and hard sandstone	3000	2500	2000	1600	1300
Soft limestone and sandstone	2200	1800	1500	1200	1000
Cinders	800	700	600	500	400

978. Tensile Stresses: Concrete. — The tensile strength of concrete shall not be considered, but the steel shall take all of the tensile stresses.

979. Tensile Stresses: Reinforcement. — The allowable unit stress in steel reinforcement in tension shall not exceed, for soft steel, 14,000 lbs. per square inch; for medium steel, 16,000 lbs. per square inch; and for high steel, that is, steel containing a high percentage of carbon, and having an elastic limit of at least 40,000 lbs. per square inch, with adequate mechanical bond, 20,000 lbs. per square inch.

980. Extreme Fiber Stress in Concrete.† — All members subject to flexure shall be designed for an extreme fiber stress of not greater than 750 lbs. per square inch for stone or gravel concrete; for slag concrete, 650 lbs. per square inch; and for cinder concrete, 400 lbs. per square inch.‡ For all calculations the straight line formula must be used, which assumes that the stress-strain curve of concrete in compression is a straight line, for the above unit stresses have been determined by this formula in ac-

* The allowable working stresses given in footnotes on this and succeeding pages are those recommended by the Joint Committee in its latest report on Concrete and Reinforced Concrete, published in the Proceedings of the Am. Soc. of Civil Engrs., vol. 39, pp. 117–168, Feb., 1913. These allowable stresses are given in the form of percentages of the ultimate strength of the particular concrete which is to be used; this ultimate strength is to be that developed in cylinders 8 ins. in diameter and 16 ins. long, of a wet consistency, made and stored under laboratory conditions, at an age of 28 days. In the absence of definite knowledge, in advance of construction, as to just what strength may be expected, the Committee submits the following values as those which should be obtained with materials and workmanship.

Although occasional tests may show higher results than those here given, the Committee recommends that these values should be the maximum used in design.

† The extreme fiber stress of a beam, calculated on the assumption of a constant modulus of elasticity for concrete under working stresses, may be allowed to reach 32.5 per cent of the compressive strength. Adjacent to the support of continuous beams stresses 15 per cent higher may be used. — Joint Committee, Dec., 1912.

‡ Cinder concrete should not be used in the main members of the structure, such as girders, beams, columns and footings, owing to its variation in strength and the difficulty of securing material of uniform quality. In floor slabs and floor arches, where the compressive strain on the concrete is low, cinder concrete may be used.

cordance with the requirements of Art. 41. A unit stress of 750 lbs. per square inch is equivalent to 630 lbs. when determined by the parabolic formula.

981. **Shearing Stress on Concrete.** — Shear on concrete beams having no reinforcement shall not exceed 40 lbs. per square inch. Shear on reinforced concrete beams shall not exceed 60 lbs. per square inch on the net sections.* When the vertical shear exceeds this figure steel must be provided and so placed as to take care of any shear in excess of the 60 lbs. specified above. But in no case shall the combined shear on steel and concrete exceed 140 lbs. per square inch.

The allowable units bearing stress upon concrete subject to punching shear shall be one hundred (100) pounds per square inch.

982. **Shear on Steel.** — The shear on steel (any grade) shall not exceed 10,000 lbs. per square inch.

983. **Bearing.** — Bearing on concrete surfaces larger than loaded area shall not exceed 600 lbs. per square inch.†

For beams and girders built into pockets in concrete walls, the bearing shall not exceed 500 lbs. per square inch.

984. **Direct Compression (Massive Concrete).** — The direct compressive stress to be applied to massive concrete shall not exceed 500 lbs. per square inch, nor 400 lbs. for 1–3–6 concrete or equivalent.

The allowable compressive unit stress on 1–2–4 natural cement concrete shall not exceed 200 lbs. per square inch.

985. **Plain Columns.** — The allowable unit stress upon concrete in direct compression in columns without hoops or vertical reinforcement whose length does not exceed 12 times the diameter or least side, shall not exceed 500 lbs. per square inch and for columns whose length does not exceed 18 times the diameter or least side, 400 lbs. per square inch.‡

986. **Columns with Vertical Reinforcement Only.** — The allowable unit stress upon concrete in direct compression in columns without hoops but with vertical reinforcement shall be the same as for the unit stresses in

* In calculations on beams in which the maximum shearing stress in a section is used as the means of measuring the resistance to diagonal tension stresses, the following allowable values for the maximum vertical shearing stress are recommended by the Joint Committee, Dec., 1912:

(*a*) For beams with horizontal bars only and without web reinforcement calculated by the method given in the Appendix, Formula (22), p. 251; 2% of the compressive strength.

(*b*) For beams thoroughly reinforced with web reinforcement: the value of the shearing stress calculated as for *a* (that is, using the total external vertical shear in Formula (22) for shearing unit stress) must not exceed 6% of the compressive strength. The web reinforcement, exclusive of bent-up bars, in this case, shall be proportioned to resist two-thirds of the external vertical shear in the formulas given in the Appendix, Formulas (24) or (25), p. 251.

(*c*) For beams in which part of the longitudinal reinforcement is used in the form of bent-up bars distributed over a portion of the beam in a way covering the requirements for this type of web reinforcement: the limit of maximum vertical shearing stress (the stress calculated as for *a*), 3% of the compressive strength.

(*d*) Where punching shear occurs, that is, shearing stress uncombined with compression normal to the shearing surface, and with all tension normal to the shearing plane provided for by reinforcement: a shearing stress of 6% of the compressive strength may be allowed.

† When compression is applied to a surface of concrete of at least twice the loaded area, a stress of 32.5 percent of the compressive strength may be allowed. — Joint Committee, Dec., 1912.

‡ For concentric compression on a plain concrete column or pier, the length of which does not exceed 12 diameters, 22.5 per cent of the compressive strength may be allowed. — Joint Committee, Dec., 1912.

plain columns. (Par. 985.) The maximum compressive stress in the vertical reinforcement shall not exceed 6,750 pounds per square inch.*

987. **Interior Columns with Vertical Rods and Wire Stays.** — Columns reinforced with vertical rods and wire stays placed 12 ins. center to center must not exceed the following stresses:

For interior columns 10 ins. by 10 ins. the stress on concrete shall not exceed 350 lbs. per square inch.

For interior columns 12 ins. by 12 ins. to 21 ins. by 21 ins. inclusive the stress must not exceed 500 lbs. per square inch.

For interior columns 22 ins. by 22 ins. and over the stress on concrete must not exceed 600 lbs. per square inch.

The unsupported lengths of columns 18 ins. and under in diameter shall not exceed twelve (12) times the diameter or least side. Columns 19 ins. and over shall not exceed in length fifteen (15) times the least diameter.

988. **Wall and Eccentrically Loaded Columns.** — Wall columns reinforced by vertical rods and wire stays 12 ins. center to center shall not be less than 12 ins. in diameter. Columns loaded unsymmetrically, and especially corner columns, shall be figured with lower unit stresses than for interior columns. The allowable compression on concrete shall not exceed 400 lbs. for columns from 12 ins. to 18 ins. least diameter and 500 lbs. for columns 19 ins. or over.

989. **Hooped or Spiral Columns.** — The unsupported length of circular hooped columns should not exceed fifteen (15) times the diameter for interior columns or twelve (12) times the diameter for wall columns and for all other columns eccentrically loaded.†

The allowable unit stress on the core for interior columns shall not exceed the following:

	Lbs. per Sq. In.
Columns 10 ins. in diameter	800
Columns 11 ins. in diameter	850
Columns 12 ins. to 15 ins. in diameter	900
Columns 16 ins. to 22 ins. in diameter	1000
Columns 23 ins. and larger in diameter	1100

These sizes refer to core diameter. The over-all diameter shall be at least 3 ins. greater than the core diameter.

* Columns with longitudinal reinforcement only, to the extent of not less than 1 per cent and not more than 4 per cent: the unit stress should not exceed 22.5 per cent of the compressive strength. It is also recommended that the ratio of unsupported length of column to its least width be limited to 15. — Joint Committee, Dec., 1912.

† Columns with reinforcement of bands, hoops, or spirals, as hereinafter specified: the unit stress should not exceed 27% of the compressive strength of the concrete, provided the ratio of the unsupported length of the column to the diameter of the hooped core is not more than 8.

Columns reinforced with not less than 1% and not more than 4% of longitudinal bars, and with bands, hoops, or spirals, as hereinafter specified: the unit stress should not exceed 32.5% of the compressive strength of the concrete, provided the ratio of the unsupported length of the column to the diameter of the hooped core is not more than 8.

Where hooping is used, the total amount of such reinforcement shall be not less than 1% of the volume of the column enclosed. The clear spacing of such hooping shall be not greater than one-sixth of the diameter of the enclosed column, and preferably not greater than one-tenth, and in no case more than 2½. Hooping is to be circular, and the ends of bands must be united in such a way as to develop their full strength. — Joint Committee, Dec., 1912.

For wall or eccentrically loaded columns reduce the above loads ten per cent (10%).

According to some building codes, columns reinforced with longitudinal steel with spirally wound hooping, the safe load shall be computed as follows:

Safe load (in pounds) = $650 [Ac + 15 (As + 2.4 Ah)]$.

Ac = net cross-section of concrete inclosed in hooping.

As = net cross-section of longitudinal reinforcement.

$Ah = \frac{3.14 da}{p}$ where p = pitch of hoop in inches and a = cross-sectional area of the wire or rod forming the hoop in square inches, provided that Ah shall be not less than one-half ($\frac{1}{2}$) of one per cent nor more than $1\frac{1}{2}$ per cent of Ac.

990. **Vertical Reinforcement.** — The vertical steel must never be figured as carrying more than twenty-five per cent (25%) of the total load. The unit stress on vertical steel must be figured at fifteen (15) times the unit stress on concrete.

991. **Columns with Structural Steel Shapes.** — The allowable unit stress upon concrete in direct compression in columns reinforced with structural steel shapes thoroughly encasing the concrete whose length does not exceed twelve (12) times the diameter or least side shall not exceed 750 lbs. per square inch, and for columns whose length does not exceed eighteen (18) times the diameter or least side, 650 lbs. per square inch.

992. **Bond.** — The allowable bond between concrete and plain reinforcing bars shall not exceed 80 lbs. per square inch of surface of bar for stone or gravel concrete, 50 lbs. per square inch for slag concrete, and 30 lbs. per square inch for cinder concrete.* Where adequate mechanical bond is provided between concrete and deformed bars, the adhesive stress shall not exceed 160 lbs. per square inch of surface of bar for stone or gravel concrete. When deformed bars are used in slag or cinder concrete the values given above may be doubled.

993. **Steel in Compression.** — Compression in steel shall not exceed the maximum coexisting stress in the contiguous concrete multiplied by the ration of the modulus of elasticity of the steel to that of the concrete, i.e., 11,250 lbs. per square inch when the stress in the concrete is 750 lbs. per square inch.

994. **Other Concretes.** — The above working stresses shall be proportionally increased or decreased, depending upon the proportion and quality of the aggregate. For concretes, differing in strength or proportion of aggregates from normal concrete (Par. 977), substitute their ultimate strength in twenty-eight (28) days in proportion to the increase or decrease

* The bond stress between concrete and plain reinforcing bars may be assumed at 4% of the compressive strength, or 2% in the case of drawn wire. — Joint Committee, Dec., 1912.

in compressive strength; the maximum increase over the above working stresses shall not exceed twenty-five per cent (25%).

995. **Other Steels.** — For steels, differing in strength from those given above, substitute for tensile values given above (Par. 979) 40 per cent of their strength at the yield point, as determined by tests.

996. **Shrinkage and Temperature Stresses.** — Shrinkage of concrete, due to hardening and contraction from temperature changes, causes cracks the size of which depends on the extent of the mass.*

The resulting stresses are important in monolithic construction, and shall be considered carefully by the designer.

Large cracks, produced by quick hardening or wide ranges of temperature, can be broken up to some extent into small cracks by placing well distributed reinforcement (in amount generally not less than one-third of 1 per cent) of a form which will develop a high bond resistance near the exposed surface of the concrete; in long continuous lengths of concrete it is better to provide shrinkage joints at points in the structure where they will do little or no harm (see Arts. 25 and 60). Reinforcement is of assistance and permits longer distances between shrinkage joints than when no reinforcement is used.

Temperature stresses shall be calculated, where the structure cannot expand and contract freely, for a variation of not less than 50° F.

997. **Maximum Stresses.** — When combining the temperature stresses with stresses due to all other causes, the specified working stresses given above may be increased ten per cent (10%), provided that this combination gives a greater sectional area.

998. **Modulus of Elasticity.** — The value of the modulus of elasticity of concrete has a wide range, depending on the materials used, the age, the range of stresses between which it is considered, as well as other conditions. It is recommended by the Joint Committee (Progress Report of Special Committee on Concrete and Reinforced Concrete, Proc., Am. Soc. C.E., vol. 39, page 157, Feb., 1913) that in computations for the position of the neutral axis and for the resisting moment of beams and for the compression of concrete in columns it be assumed as:

(a) One-fifteenth of that of steel, when the strength of the concrete is taken as 2,200 lbs. per square inch or less.

(b) One-twelfth of that of steel, when the strength of the concrete is taken as greater than 2,200 lbs. per square inch, or less than 2,900 lbs. per square inch, and

(c) One-tenth of that of steel, when the strength of the concrete is taken as greater than 2,900 lbs. per square inch.

Although not rigorously accurate, these assumptions will give safe results.

* The distance apart of the cracks, and consequently their size, will be directly proportional to the diameter of the reinforcement and to the tensile strength of the concrete, and inversely proportional to the percentage of reinforcement and also to its bond resistance per unit of surface area.

For the deflection of beams which are free to move longitudinally at the supports, in using formulas for deflection which do not take into account the tensile strength developed in the concrete, a modulus one-eighth of that of steel is recommended by the above committee.

Art. 45. Reinforced Concrete Framework of Buildings

1. General Requirements

1000. **Definition of Reinforced Concrete.** — By reinforced concrete is meant approved concrete in which steel is embedded in such a position that it will resist all tensile stresses and assist in the resistance to shear along proper structural lines so that the stresses in the combination can be ascertained by computation and verified by tests.

1001. **Class of Buildings.** — Reinforced concrete may be used for all classes of buildings if the design is in accordance with good engineering practice and stresses are figured as given in Art. 44, page 170.

1002. **Height of Buildings.** — There shall be no limit upon the height of buildings of reinforced concrete except as limited by the requirements given in Art. 44, page 170.

1003. **Figured Dimensions.** — Dimensions of beams, columns, slabs and other parts of the construction indicated on the drawings shall be considered a minimum.

2. Slabs, Beams and Girders

1004. **Thickness of Slabs.** — The total thickness of a slab shall not be less than one thirty-sixth ($\frac{1}{36}$) of the slab span in the direction of the principal reinforcement. Slabs spanning over two (2) feet shall have a minimum thickness of three (3) inches.

1005. **Bearing of Slabs.** — Where floor slabs are supported by a brick or stone wall, they must have at least four (4) inches bearing, and the floor steel must run in the full four inches and should be hooked.

1006. **Finish of Slabs.** — Where concrete floors are to be used without being covered with some wearing surface, a cement finish of at least one (1) part Portland cement to two (2) parts sand and at least one-half ($\frac{1}{2}$) of an inch thick must be firmly bonded to the structural concrete, and in no case shall this finish be considered a part of the structural thickness of the floor slab, but must be allowed entirely for wearing surface.

1007. **Bars in Floor Slabs.** — Bars for floor slabs framing between concrete beams should be ordered about one or two inches less than the center to center distances of beams, depending on width of beams. If framing between structural steel work, allow about one inch clearance between faces of steel work. Allow a bearing of at least four (4) inches for the bars on walls. Only in extreme cases should reinforcing bars for slabs exceed five-eighths ($\frac{5}{8}$) of an inch in diameter.

1008. Expansion Bars in Floor Slabs. — In all solid slab construction expansion bars must always be used. Unless otherwise specified by the Engineer use $\frac{7}{32}$-in. round bars spaced 18 ins. center to center. Where larger sections are used spacing may be farther apart. Some specifications require that for solid slabs reinforced for strength in one direction only shall be reinforced in the other direction, to prevent shrinkage cracks, by rods not less than $\frac{3}{8}$ in. in diameter, placed above the main reinforcement and spaced not more than 2 ft. center to center.

1009. Continuous Slabs. — Where continuity of spans are depended upon and allowed for in determining the bending moment at center, the slab must be properly reinforced over the supports to resist the negative moment. All continuity steel must extend to at least the fifth points of the clear span in slabs. The continuity steel must be sufficient both in section and length to prevent excessive strain or fracture at the point of support.

1010. Concentrated Loads. — Solid slabs reinforced for strength in one direction only and carrying concentrated loads shall be reinforced perpendicular to the main reinforcement by rods $\frac{3}{8}$ in. in diameter, spaced not more than 1 ft. center to center to distribute such loading.

1011. Spacing of Slab Bars. — Slab steel shall not be spaced more than two and one-half ($2\frac{1}{2}$) times the thickness of the slab, except in the end quarters of the spans each way in slabs reinforced in both directions. In the end quarter of the spans each way, the spacing of the bars may be two (2) times that for the middle half of the span.

The minimum spacing of parallel bars shall not be less than three (3) inches.

Two layers of bars perpendicular to each other shall be in contact, the bars forming the main reinforcement being in all cases placed undermost. That is to say, the reinforcement spanning the shortest direction shall be below the reinforcement spanning the longer direction.

1012. Minimum Protection: Slab Bars. — The minimum protection for reinforcing steel which shall be taken as the distance from the surface of the steel bar to the nearest concrete surface shall be one-half ($\frac{1}{2}$) inch for slab bars.

1012a. Multiple-way Reinforcement. — Slabs with multiple-way reinforcement shall be figured direct from satisfactory certified test data of similar and proportional construction.*

* At present a considerable difference of opinion exists among engineers as to the formulas and constants which should be used for continuous flat slabs with multiple-way reinforcement, but experience and tests are accumulating data which it is hoped will in the near future permit the formulation of the principles of design for this form of construction which has recognized advantages for special conditions, as in the case of warehouses with large, open, floor space.

1013. Tile and Joist Construction. — Where tile and concrete are used together the joists between the tile should not be less than four (4) inches wide and the ratio of minimum depth to clear span of joist shall not be greater than one to eighteen.

Wherever a portion of the slab above the tile joist shall be considered as acting as a T-beam section, the slab portion must be cast at the same time as that for the joist and must have a minimum thickness of at least two (2) inches.

1014. Roofs. — Roofs subject to extraordinary changes of temperature in their several parts shall receive careful design of their reinforcement, especially when the slabs are treated as the flanges of long-span roof beams.

1015. Reinforcement of Beams. — All beams and girders shall be reinforced with steel against diagonal tension and shear; other reactions if necessary shall likewise be reinforced against. Neither the reinforcing metal nor concrete shall be subjected to combined stresses so as to exceed in combination the stresses allowable separately.*

Where vertical stirrups are used without being secured to the longitudinal reinforcement, the force transmitted between longitudinal bar and stirrup must not be greater than can be taken through the concrete, and care must be taken to provide for the larger bond stress developed in the longitudinal bars with this construction than exists in the absence of stirrups.

Sufficient bond resistance between the concrete and the stirrups or diagonals must be provided.

Where the longitudinal bars are bent up, the points of bending of the several bars shall be distributed along a portion of the length of the beam in such a way as to give efficient web reinforcement over the portion of the length of the beam in which it is needed.

Proper connection must always be made between stirrups or other web reinforcement and the longitudinal tension reinforcement, whether the latter is on the lower side of the beam or on its upper side. Where negative moment exists, as is the case near the supports in a continuous beam, web reinforcement, to be effective, must be looped over, or wrapped around, or be connected with, the longitudinal tension reinforcing bars at the top of the beam, in the same way as is necessary at the bottom of the beam at sections where the bending moment is positive and the tension reinforcing bars are at the bottom of the beam.

1015a. Rectangular Beams (Reinforcement). — In rectangular beams the tensile reinforcement must not exceed one per cent of the area of the concrete above the steel.

* From experiments with beams, it is concluded that it is safe practice to use only two-thirds (⅔) of the external vertical shear in making calculations of the stresses that come on stirrups, diagonal web pieces, and bent-up bars, and it is here recommended for calculations in designing that two-thirds of the external vertical shear be taken as producing stresses in web reinforcement. — Joint Committee, Dec., 1912.

1016. Limits to Width and Depth of Rectangular Beams. — In isolated beams the width must not be less than $\frac{1}{24}$ of the clear span and the depth not less than $\frac{1}{15}$ of the clear span.*

1017. Tee Beams. — Where slabs and beams are cast together a portion of the slab may be considered as part of the beam forming a Tee section. This increases the available compression area and permits the use of a larger percentage of steel than that allowed in rectangular beams (Par. 1015a). In the design of Tee beams and girders acting as continuous beams, due consideration must be given to the compressive stresses at the support at the bottom of the beam. Stirrups should be used for the purpose of bonding the flange and stem.

A Tee beam must be deep enough to prevent overstressing concrete in the flange.

1018. Width of Tee Beams. — The width of Tee or tributary part of the slab must not exceed the following limitations: †

1. The maximum width of the Tee shall not be greater than one-third ($\frac{1}{3}$) of the clear span.

2. No Tee shall be considered as projecting more than five (5) times the thickness of the slab on either side of the stem.

3. The width of the Tee shall not exceed five (5) times the width of stem.

1019. Neutral Axis of Tee Beams in Stem. — In Tee beams where the neutral axis falls below the slab, the resistance of the stem shall be neglected.

1020. Limits to Width and Depth of Tee Beams. — The depth of Tee beams and girders shall not be less than $\frac{1}{15}$ of the clear span. In Tee beams and girders the depth of the portion below the slab shall not be greater than twice its width.

1021. Reinforcement Parallel to Tee Girder. — In the case of a floor system consisting of slabs, beams and girders, where the slab reinforcement runs parallel to the girder, the portion of the slab as noted above (Par. 1018) cannot be figured as part of the compression flange unless rein-

* There are three factors which regulate the width of beams and girders of reinforced concrete: (1) The minimum space into which reinforcing bars or rods can be placed and into which concrete may be poured and spaded or tamped.

(2) The minimum width that will allow the steel to be sufficiently fireproofed.

(3) The minimum amount of concrete around the reinforcing bars or rods that will develop their resistance.

It is seldom practicable to make reinforced concrete beams less than 6 inches in width, and they may be as much wider as is needed to meet the requirements stated above, or as may be necessary for architectural appearances.

It is customary in designing beams and girders to confine the minimum depth of the beam or girder, counting from the under side of the three-fifths slab to the bottom of the member, as $\frac{3}{8}$ of an inch for each foot in span.

† The Joint Committee (see p. 168) recommends that the effective width shall be determined by the following rules:

(*a*) It shall not exceed one-fourth of the span length of the beam;

(*b*) Its overhanging width on either side of the web or stem shall not exceed four times the thickness of the slab.

Beams in which the tee form is used only for the purpose of providing additional compression area of concrete should preferably have a width of flange not more than three times the width of the stem and a thickness of flange not less than one-third of the depth of the beam. Both in this form and in the beam and slab form, the web stresses and the limitations in placing and spacing the longitudinal reinforcement will probably be controlling factors in design.

forcement be placed in the slab at right angles to the girder to insure that the two act together. In other words, when the principal slab reinforcement is parallel to the beam or girder, transverse reinforcement shall be used, extending over the beam and well into the slab.

1022. Compression Steel in Beams. — All members must be carefully investigated for compression. Wherever the extreme compressive fiber stress on concrete exceeds 750 lbs. per square inch sufficient compression steel must be provided in the top of the beam to reduce the stress to this figure. The compressive stress allowed on such steel shall not exceed fifteen (15) times the computed compressive stress in the concrete at the same distance from the neutral axis.

It is customary to figure the steel as taking a portion of the compression equal to the net area multiplied by fifteen times the compression stress on concrete at a point two (2) inches below the top of the beam. The steel must be located so that its center of gravity coincides with this point.

The effect of placing steel in the compression side of a beam is to raise the neutral axis. This change is so slight, however, that it is only necessary to take it into consideration when the quantity of steel is very large, in which case it is usually advisable to increase the depth of beams, thereby reducing the amount of compression steel in the beam.

In no case should the total area of steel in compression exceed 75% of that in tension.

1023. Spacing of Beam Reinforcement. — Unless otherwise specified there must be at least one and one-half inches of concrete between the side of the beam or girder and the edge of the first bar. The minimum distance center to center of any bar in the same layer shall be 2½ diameters for round bars and 3 diameters for square bars, and not less than 2 diameters between centers of bars in different layers. It is preferable that at least 1½ ins. be allowed between the bars to permit the concrete to flow properly between them.*

1024. Spacing of Stirrups. — The longitudinal spacing of U-stirrups or bent rods, where used, shall not exceed three-fourths (¾) of the depth of the beam.†

* The use of more than two layers is to be discouraged, unless the layers are tied together by adequate metal connections, particularly at and near points where bars are bent up or bent down.

† There are various formulas by which the number of stirrups can be figured, but designing engineers do not, as a rule, apply them in practice, especially in concrete building construction where the loads are light. A very excellent rule, and one which is used almost universally by designing engineers of considerable experience, is to place in the beam or girder stirrups equal in number to the span in feet. As the stirrups are primarily shear members, and as the shear increases toward the points of support and is zero at the center of the span of a beam uniformly loaded, it is customary to place the stirrups close together at the abutments, and farther apart toward the center of the span. A very good rule is to space the stirrups at the abutments according to the following tabulation:

First three stirrups at 4 in. *c* to *c*.
Next two stirrups at 6 in. *c* to *c*.
Next stirrup at 12 in. *c* to *c*.
Next stirrup at 18 in. *c* to *c*.

The maximum distance for stirrups should not be over three feet apart at the center of the span.

1025. Minimum Protection. — The minimum protection (or fireproofing) for reinforcing steel which shall be taken as the distance from the surface of the steel bar to the nearest concrete surface shall be one and one-half (1½) inches for beams and girders.

1026. Bearing of Beam Bars. — All bars in beams and girders should bear at least six (6) inches on their support. Where beams and girders are of about equal depth so that the steel in the beams rest on or near the steel in the girder, stirrups should be placed to carry the ends of the bars and to distribute their bearing.

Steel in beams framing into girders or columns should be ordered to extend to within ½ in. of the centers of the girder.

Steel in beams framing into wall columns, wall girders or girders around openings must be ordered to extend to within two (2) inches of the outside face of the columns or girders.

1027. Continuity Bars in Beams. — All continuity steel must extend to at least the fifth (5th) points of the clear span in beams and girders. The continuity steel shall be sufficient both in section and length to prevent excessive strain or fracture at the point of support.

1027a. Bond Strength. — Ends of reinforcing bars must be secured against slipping, either by depending upon the bond, in which case the length of the free end of plain bars shall be not less than 48 diameters of the rod, or by bending the free end through 180 degrees to a radius of 4 diameters of rod, or by an anchorage consisting of the free end being upset and provided with a nut and a washer.

Adequate bond strength throughout the length of a bar is preferable to end anchorage, but, as an additional safeguard, such anchorage may properly be used in special cases. Anchorage furnished by short bends at a right angle is less effective than hooks consisting of turns through 180 degrees to a radius of 4 diameters of rod.*

In case of anchorage of bars, an additional length of bar must be provided beyond that found on the assumption of uniform bond stress, for the reason that, before the bond resistance at the end of the bar can be developed, the bar may have begun to slip at another point, and "running" resistance is less than the resistance before slip begins.†

* The formula given in Appendix *A*, p. 247, for bond stresses in beams is for straight longitudinal bars. In beams in which a portion of the reinforcement is bent up near the end, the bond stress at places in both the straight bars and the bent bars will be considerably greater than for all the bars straight, and the stress at some point may be several times as much as that found by considering the stress to be uniformly distributed along the bar, according to the Joint Committee. (Progress Report of Special Committee on Concrete and Reinforced Concrete, Proc., Am. Soc. C. E., vol. 39, pp. 149–150, Feb., 1913.) In restrained and cantilever beams, full tensile stress exists in the reinforcing bars at the point of support, and the bars must be anchored in the support sufficiently to develop this stress.

† Where high bond resistance is required, the deformed bar is a suitable means of supplying the necessary strength; but it should be recognized that, even with a deformed bar, initial slip occurs at early loads, and that the ultimate loads obtained in the usual tests for bond resistance may be misleading. — Joint Committee, Dec., 1912.

3. Columns

1028. Bending Stresses. — Bending stresses due to eccentric loads and lateral forces must be provided for by increasing the section until the maximum stress does not exceed the values specified in Art. 44; and, where tension is possible in the longitudinal bars, adequate connection between the ends of the bars must be provided to take this tension.

In columns with concentric loading, buckling need not be considered if the ratio of the effective length to the effective diameter does not exceed 12; the effective diameter to correspond to the assumed theoretical area.

1028a. Minimum Size of Columns. — No columns shall be less than ten (10) inches in diameter.

1029. Number of Vertical Bars. — Columns with vertical reinforcement must contain at least four (4) vertical bars, placed one in each corner. Where columns are greater than eighteen (18) inches in diameter, a greater number of bars should be used so that their spacing on the edge of the column will not be greater apart than fourteen (14) inches. The longitudinal rods or bars in columns are not, as a rule, decided upon with regard to their number and area by any fixed formula. The general practice is to put in enough steel to equal in area 1 to $1\frac{1}{2}$ per cent of the effective sectional area of the concrete.

1030. Staying of Steel in Compression. — Steel bars in compression shall be stayed against buckling by means of ties or hoops, never spaced farther apart than the effective diameter of the member under compression. Unless otherwise specified, the vertical bars shall be tied together with $\frac{1}{4}$-in. wire stays at intervals of not more than twelve (12) inches, or spirally-wound steel may be used. The wire stays or hoops must be firmly fastened to the bars by wiring or other means, and the ends of hoops must project into the columns at least four (4) inches.

Where more than four (4) bars occur in a column, the additional bars must be hooped similar to the corner hoops and spaced not further apart than twelve (12) inches on centers.

Where spiral hooping is used, the total amount of such reinforcement shall be not less than 1 per cent of the volume of the column enclosed.

Hooping is to be circular, and the ends of bands must be united in such a way as to develop their full strength.

Adequate means must be provided to hold bands or stays in place so as to form a column, the core of which shall be straight and well centered.

1031. Minimum Reinforcement. — In all cases, reinforced columns must contain at least one (1) per cent of vertical reinforcement, and must in all cases have a positive means of confining the concrete and steel either by spiral reinforcement or wire stays encasing the vertical bars. In columns with longitudinal reinforcement only, at least two (2) per cent of the effective area shall be vertical bars.

1032. Ratio of Length to Diameter. — In reinforced concrete columns, the ratio of length to least side or diameter shall not exceed fifteen (15).*

1033. Splicing Column Bars. — When vertical reinforcement is used in columns, such as rods, they shall either have full perfect bearing at each joint, and such joints shall occur at floors or other points of lateral support, and a tight fitting pipe sleeve shall be provided at all joints of vertical reinforcement rods, or the lower rods shall be carried into the upper column sufficiently to develop the full strength of the upper rods.†

1034. Lap Joints. — All splices must be at the floor lines. The bars must lap eighteen (18) inches.

1035. Distance Between Spirals. — The clear distance between spirals shall not exceed one-sixth ($\frac{1}{6}$) the diameter of the enclosed column or core, and preferably not greater than one-tenth ($\frac{1}{10}$), and in no case more than 3 ins.

1036. Minimum Protection. — The minimum protection (or fireproofing) for reinforcing steel which shall be taken as the distance from the surface of the steel bar to the nearest concrete surface shall be one and one-half ($1\frac{1}{2}$) inches for columns. For columns having no reinforcement, the minimum thickness of a fire-retarding coating shall be two (2) inches.

In stores, warehouses or other buildings where combustible materials are likely to be stored, the concrete covering over the metal reinforcement should be increased to 2 or 3 ins.

1036a. Effective Area. — In figuring the strength of reinforced concrete columns, only the area within the limits of the ties, bands, hooping, spirals or wrapping shall be considered as effective area. In plain concrete columns, the concrete considered as protective covering shall not be included in the effective section.

4. Curtain Walls

1037. Thickness of Walls. — The thickness of slab and amount of reinforcement necessary for a curtain wall, or a vertical wall which is to bear no weight, shall be determined by figuring it as a flat slab supported at all four sides, and carrying a uniformly distributed load of at least 30 lbs. per square foot due to wind pressure.‡

* The strength of hooped columns depends very much on the ratio of length to diameter of hooped core, and the strength due to hooping decreases rapidly as this ratio increases beyond five. The working stresses recommended by the Joint Committee (see Par. 989) are for hooped columns with a length of not more than eight diameters of the hooped core.

† In columns bars more than $\frac{3}{4}$ in. in diameter, not subject to tension, should be properly squared and butted in a suitable sleeve; smaller bars may be lap-spliced, the length of lap being determined on the basis of the safe bond stress, the stress in the bar, and the shearing resistance of the concrete at the point of splice, or the stress may be cared for by embedment in large masses of concrete. — Joint Committee, Dec., 1912.

‡ Plain concrete walls, if made of concrete which will develop an average compressive strength of at least 1500 lbs. per square inch after 28 days, may be of the same thickness as brick walls laid in cement mortar. If properly reinforced in both directions, the thickness may be reduced to two-thirds of that of brick walls. Spandrel and curtain walls of steel construction shall have a minimum thickness of 8 ins. if reinforced with not less than $\frac{3}{4}$ lb. of steel per square foot of wall. Partitions, if constructed of reinforced concrete, shall have a minimum thickness of 3 ins., and shall be reinforced with not less than $\frac{1}{4}$-in. rods on 12-in. centers, running both vertically and horizontally. The filling of panels of the skeleton frames of sheds or mill buildings shall not be less than 4 ins.— General Specifications for Structural Work of Buildings, by C. C. Schneider, p. 35, May, 1910.

1038. Reinforcement. — The reinforcement in such walls shall consist of lateral rods, wires, expanded metal or wire fabric. Bars must be laid in vertical and horizontal rows at least one and one-half ($1\frac{1}{2}$) inches from either face. In all cases the reinforcement shall be proportioned to the span and the height.

1039. Openings in Walls. — Openings in concrete curtain walls shall be thoroughly reinforced to prevent formation of cracks from one to another. Over openings the bars must be spaced close enough together to form a perfect and strong lintel to carry the weight of the structure above.

1040. Lap of Bars. — Where bars come together, end to end, they must lap not less than fourteen (14) inches.

5. Footings

All columns shall be supported by footings of proper design, depth and area to safely transmit the loads to the soil, and proper bearing plates or reinforcement shall be provided under the footing of the columns to properly distribute the loads on the footings.*

1041. Bending in Footings. — The maximum compression at the top of reinforced concrete footings due to the direct load from the columns combined with the compressive stress due to bending in the footing shall not exceed the allowable working stress for concrete in compression due to bending (Par. 980).

1042. Shear on Footings. — Footings must be deep enough to take care of the entire load from the columns through shear on the concrete without reliance upon the steel reinforcing of the footings for assisting in such resistance to shear.

1043. Spacing of Bars. — Bars must be so spaced as to properly transmit the load carried by the column uniformly into the foundation.

1044. Dowels. — Dowels must be placed in the footing to which the column bars must be wired.

Art. 46. Reinforced Concrete Trusses

1045. Tensile and Compressive Stresses. — Reinforced concrete trusses shall be designed in such a manner that the tensile stresses will be entirely resisted by the steel and the compressive stresses by the concrete.

1046. Eccentric Connections. — Eccentric connections in reinforced concrete trusses shall be avoided as far as possible, and the tension bars shall be anchored at the connections in such a way as to develop their full stress without producing bending moment about the joints, otherwise such moments shall be thoroughly investigated and provided for.

* At foundations bearing plates should be provided for supporting the column bars, or the bars may be carried into the footing a sufficient distance to transmit the stress of the steel to the concrete by means of the bearing and bond resistance; in no case shall the ends of the bars be permitted merely to rest on concrete. — Joint Committee, Dec., 1912.

1047. Stress Diagrams. — Complete stress diagrams giving all sizes of material and all stresses in reinforced concrete trusses must be submitted by the Contractor.

Art. 47. Reinforced Steel Construction

1048. Reinforced Steel Buildings. — Reinforced steel buildings composed of articulated steel frames for columns, beams and girders shall be so designed that these frames may be erected independently of the encasing concrete and shall be capable of carrying, independently, a definite portion of the load.

Composite columns, beams and girders of structural steel and concrete in which the steel forms a member by itself shall be designed with caution. To classify this type of construction as a concrete member reinforced with structural steel is hardly permissible, as the steel will generally take the greater part of the load. When this type of construction is used, the concrete shall not be relied on to tie the steel units together or to transmit stresses from one unit to another. The units shall be adequately tied together by tie-plates or lattice bars, which, together with other details, such as splices, etc., shall be designed in conformity with standard practice for structural steel.

1049. Bending Moments. — In addition to its portion of the specified loads, the steel frame shall be proportioned to provide for all bending stresses due to the negative bending moment, in the case of partially continuous construction, or the bending moments due to eccentric loads.

1050. Tensile Stresses. — The steel shall also be sufficient to resist all tensile stresses due to the full load at stresses not exceeding 16,000 lbs. per square inch.

1051. Additional Resistance. — All reinforced steel beams, girders and columns must have sufficient concrete to provide the necessary resistance to all stresses caused by live loads, or balance of the load.*

1052. Simple Beams. — All reinforced steel beams and girders shall be computed as simple beams, unless special provision is made to develop continuity.

Art. 48. Reinforced Concrete Unit Construction

1053. In General. —

1054. Testing Units. — When slabs, beams, girders or other parts are made in units and erected to place similar to structural steel members, they shall be subject to testing under the direction of the Engineer and at the Contractor's expense. The number of such tests and manner of testing will be agreed upon between the Engineer and the Contractor.

* The concrete may exert a beneficial effect in restraining the steel from lateral deflection, and also in increasing the carrying capacity of beams, girders and columns. The proportion of load to be carried by the concrete will depend on the form of the member and the method of construction. Generally, for high percentages of steel, the concrete will develop relatively low unit stresses, and caution must be used in placing dependence on the concrete.

Art. 49. Arch Bridges

1. Classification by Use

1055. In General. — Concrete arch bridges will be divided according to use into the following classes:

Class No. 1. — Heavy Railroad Bridges.
Class No. 2. — Light Railroad Bridges.
Class No. 3. — Heavy Electric Railway Bridges.
Class No. 4. — Light Electric Railway Bridges.
Class No. 5. — City Bridges carrying Electric Railway Tracks.
Class No. 6. — City Bridges without Electric Railway Tracks.
Class No. 7. — Highway Bridges carrying Electric Railway Tracks.
Class No. 8. — Highway Bridges without Electric Railway Tracks.
Class No. 9. — Light Highway Bridges.
Class No. 10. — Foot Bridges.

2. Classification by Loadings

1056. Loadings for Arch Bridges. — Concrete arch bridges must be designed to safely carry the heaviest load likely to come upon them.

In short span bridges, the concentrated loads are the determining factors in the design — uniformly distributed loads usually specified (100 to 150 pounds per square foot) causing smaller stresses.

1057. Class No. 1. — Heavy railway specification answering the purposes of all railroads carrying heavy traffic, hauled by locomotive power, where the heaviest loading may be taken as Cooper's E 60.

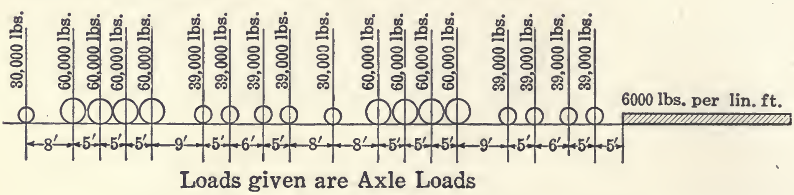

Fig. 1. — Cooper's Standard E 60 Loading. — Class 1.

1058. Class No. 2. — Light railway specification answering the purposes of all railroads carrying light traffic, hauled by locomotive power, where the heaviest loading may be taken as Cooper's E 40.

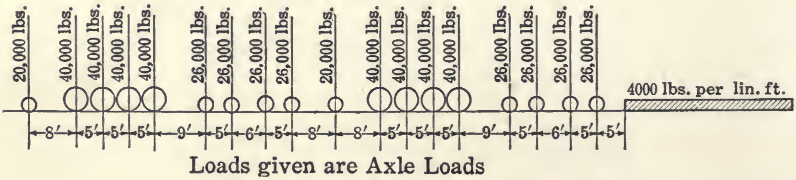

Fig. 2. — Cooper's Standard E 40 Loading. — Class 2.

1059. **Class No. 3.** — Heavy electric railway specification answering the purposes of all electric railways carrying very heavy traffic, where the heaviest loading may be taken as two 100-ton (200,000 lbs.) cars entrain; wheel base, 6 ft. 0 in.; center to center trucks, 30 ft. 0 in.

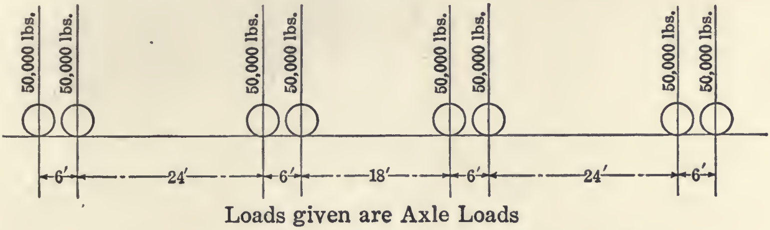

FIG. 3. — Standard 100-ton Electric Car Loading. — Class 3.

1060. **Class No. 4.** — Light electric railway specification answering the purposes of all electric railways carrying light traffic, where the heaviest loading may be taken as two 40-ton (80,000 lbs.) cars entrain; wheel base, 5 ft. 0 in.; center to center trucks, 24 ft. 0 in.

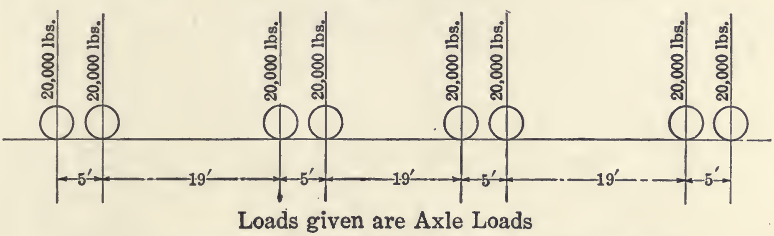

FIG. 4. — Standard 40-ton Electric Car Loading. — Classes 4 and 7.

1061. **Class No. 5.** — City highway bridge specification answering the purposes of all city work, where heavy concentrated loads and large interurban cars may be taken as (*a*) a concentrated live load of twenty-one tons (42,000 lbs.) on two axles, eleven (11) foot centers; four (4) foot gauge for front wheel and seven (7) foot gauge for rear wheels; (*b*) a uniformly distributed load of one hundred and fifty (150) lbs. per square foot on all roadways and footwalks; (*c*) two 60-ton (120,000 lbs.) electric cars entrain; wheel base 5 ft. 0 in.; center to center trucks, 30 ft. 0 in.

1062. **Class No. 6.** — City highway bridges without electric railway tracks will be designed to carry the concentrated and uniformly distributed live loads as given for Class No. 5.

1063. **Class No. 7.** — Highway or suburban bridges carrying electric railway tracks will be designed to carry (*a*) a concentrated live load of twenty-one (21) tons on two axles, eleven (11) foot centers; four (4) foot gauge for front wheel and seven foot gauge for rear wheels, two-thirds of the total load being assumed on the rear wheels; (*b*) a uniformly distributed load of one hundred and twenty-five (125) lbs. per square foot on all roadways and footwalks; (*c*) two 40-ton (80,000 lbs.) electric cars en-train; wheel base, 5 ft. 0 in.; trucks, 24 ft., 0 in.

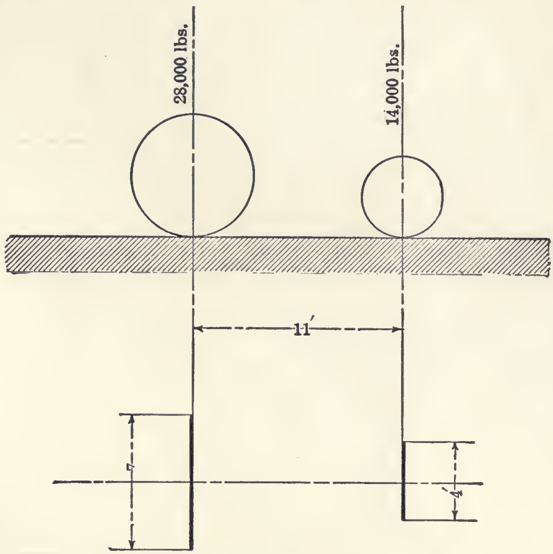

FIG. 5. — Standard 21-ton Road Roller Loading. — Classes 5, 6, 7 and 8.

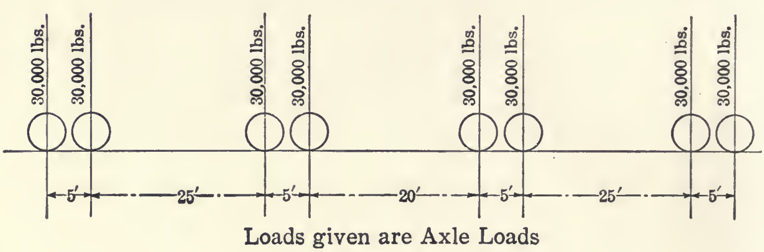

FIG. 6. — Standard 60-ton Electric Car Loading. — Class 5.

1064. Class No. 8. — Highway or suburban bridges without electric railway tracks will be designed to carry the concentrated and uniformly distributed live loads as given for Class No. 7.

1065. Class No. 9. — Light highway specification answering the purposes of ordinary country traffic where the heaviest load may be taken as a twelve-ton road roller (24,000 lbs.) and a uniformly distributed live load of one hundred (100) lbs. per square foot arranged as for Class No. 7.

1066. Class No. 10. — Foot bridges will be designed for a uniformly distributed live load of seventy-five (75) lbs. per square foot.

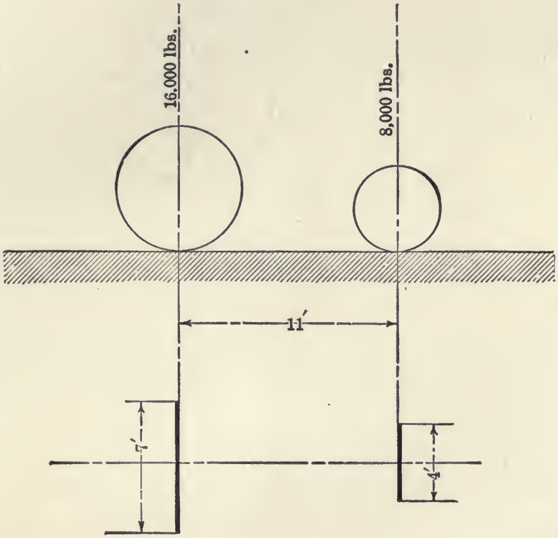

FIG. 7. — Standard 12-ton Road Roller Loading. — Class 9.

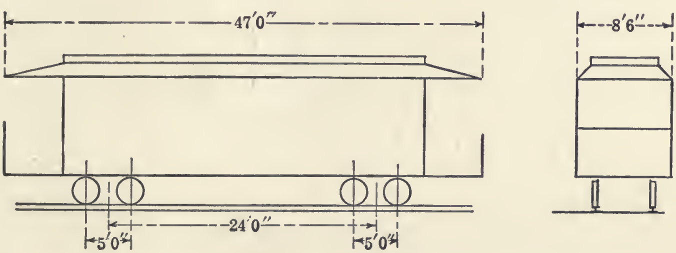

FIG. 8. — Standard Car, Class No. 2 — 40 tons on eight wheels.

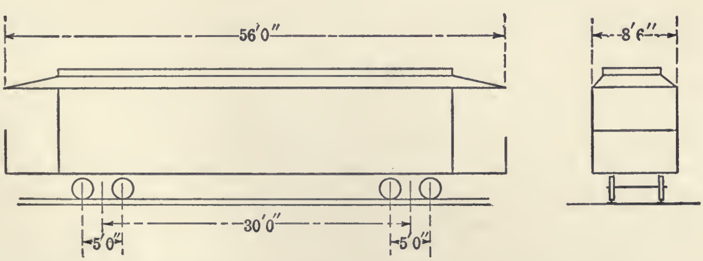

FIG. 9. — Standard Car, Class No. 3 — 60 tons on eight wheels.

3. Load Diagrams

1067. In General. — The above diagrams represent the loadings adopted in the above classifications to be used in the design of arch bridges. (See Figs. 1, 2, 3, 4, 5, 6, 7, 8 and 9.)

4. Dead and Live Loads

1068. Loads. — The structure shall be proportioned for the following loads:

a. The dead load.
b. The live load.
c. The wind load.

1069. Dead Load. — The dead load shall include the weight of the bridge and the weight of that part of the fill supported by the bridge including the paving or track system.

1070. Live Loads. — (See Sec. 3, above.)

1071. Impact. — The stresses due to the dynamic effect or impact of the live load shall be added to the maximum computed live load stresses and shall be determined in the following manner:

For Classes 1 and 2,

$$I = S\frac{300}{L + 300},$$

For Classes 3 and 4,

$$I = S\frac{200}{L + 300},$$

For all other classes,

$$I = S\frac{150}{L + 300},$$

in which

I = impact or dynamic increment to be added to live load stresses;
S = computed maximum live load static stress;
L = loaded length of track or distance in feet producing the maximum live stress in the member.

Impact shall not be added to strains produced by centrifugal and lateral or wind forces.

1072. Centrifugal Force. — When the structure is on a curve, there shall be added to the above lateral forces a moving lateral force, for all classes carrying tracks of three (3) per cent of the specified train load for each degree of curvature up to a maximum of five (5) degrees. This percentage shall be reduced by 0.001 for every degree of curvature above five (5) degrees.

1073. Wind Load. — The wind load shall consist of a moving load equal to fifty (50) pounds per square foot on the exposed surface of the unloaded structure, or thirty (30) pounds per square foot on the loaded structure plus a moving load of three hundred (300) pounds per lineal foot on the loaded chord.

5. METHODS OF DESIGN

1074. **Unit Stresses.** — Every section of the arch must be of such dimensions or with such reinforcement that the safe working stresses in the concrete shall not be exceeded. For highway bridges the maximum compression in the concrete of the ring shall not exceed 500 lbs. per square inch due to live and dead loads, nor more than 600 lbs. per square inch due to live and dead loads, temperature and rib shortening combined. For railroad bridges three-fourths of the above values shall be used.

1075. **Reinforcement.** — Reinforced concrete arches shall have not less than three-fourths of one per cent of the crown section for the reinforcing steel. The reinforcement should not exceed one and one-quarter per cent of the ring at the crown, the exact quantity to use being selected by judgment and then tested by the computation and revised if necessary. This reinforcement must extend below the springing plane a sufficient distance to develop the full strength of the bar by adhesion.

1076. **Spandrel Walls.** — The spandrel walls shall be securely anchored to the arch rings by means of proper dowels.

1077. **Waterproofing.** — All arches shall be waterproofed. (See Chapter VII, page 149.)

1078. **Range of Temperature.** — All concrete arches with filled spandrels shall be assumed to be subject to a range of temperature equal to plus or minus 20° F. from that at which the concrete is laid. For arches with open spandrels the range in temperature of the concrete is somewhat less than that of the surrounding air. For example, in the latter case with a range of temperature of the air from − 20° to + 100° F., the range for arch computation shall be taken at least 40 degrees on each side of the mean temperature.

1079. **Design of Abutment.** — In the design of the foundation of an arch bridge, the following forces shall be considered to act on the foundation: (1) the thrust of the arch; (2) the weight of the foundation; (3) the weight of the earth above it; and (4) the lateral earth pressure.

Art. 50. Flat Slab and Girder Bridges

1. CLASSIFICATION BY LOADINGS

1080. **Loadings for Highway Bridges.** — Highway bridges must be designed to safely carry the heaviest load likely to come upon them. The author has adopted the three standard classifications by loadings as given on page 79 (Bulletin No. 3) for Highway Bridges and Culverts, prepared by the Corrugated Bar Co., Buffalo, N. Y.

In short span bridges, the concentrated loads are the determining factors in the design — the uniformly distributed loads usually specified (100 to 150 lbs. per square foot) causing smaller stresses.

1081. Class No. 1. — Light highway specification answering the purposes of ordinary county traffic where the heaviest load may be taken as a twelve-ton road roller. Uniformly distributed load, 100 lbs. per square foot.

1082. Class No. 2. — Heavy highway specification, designed for localities where heavy road rollers, up to twenty tons, and electric cars of a maximum weight of forty tons must be provided for. Uniformly distributed load, 125 lbs. per square foot.

1083. Class No. 3. — City highway specification, designed for heavy concentrated loads and large interurban cars. This classification should be adopted for all city work; the weight of the maximum car has been taken as sixty tons. Uniformly distributed load, 150 lbs. per square foot.

2. Load Diagrams

1084. In General. — The following diagrams represent the loadings adopted in the above classifications and used in the design of flat slab bridges, box culverts and girder bridges shown in Bulletin No. 3 Designing Methods, prepared by the Corrugated Bar Co.

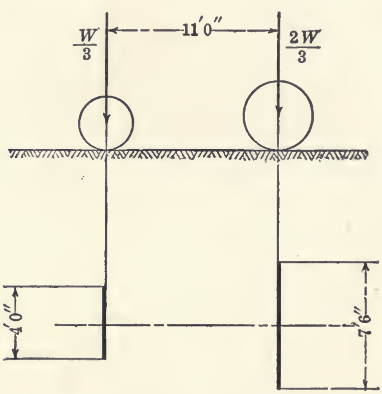

Fig. 10. — Road Roller Loading Diagram, Class 2.

The concentrations due to a steam roller will be taken as indicated by Fig. 10, two-thirds of the total load being assumed on the rear wheels.

3. Dead and Live Loads

1085. Dead Load. — The dead load shall include the weight of the bridge and the weight of that part of the fill supported by the bridge including the paving or track system.

1086. Uniformly Distributed Load. — A uniformly distributed load shall be considered as causing the specified pressure per square foot on the bridge regardless of depth of fill.

1087. Minimum Fill. — A minimum fill of twelve (12) inches is required on all bridges.

1088. Wheel Concentrations. — Wheel or road roller concentrations shall be considered as acting on a line whose length equals the out to out tread of the wheels.

1089. Loads on Car Tracks. — Loads on car tracks shall be considered as uniformly distributed over a width of roadway equal to the length of the ties and in the direction of the track for a distance of two feet on both sides of single wheels and for a distance of the wheel base plus two feet for trucks.

The above distribution of load is at the level of the roadway. The following methods of finding the loads on the bridge itself are suggested in the above bulletin.

1090. Wheel Loads on Roadway. — Assume distribution of load by fill to be only in the direction of the roadway and to be carried down on a slope of $\frac{1}{2}$ to 1. The following diagram, Fig. 11, showing the distribution of road roller concentrations, illustrates their method.

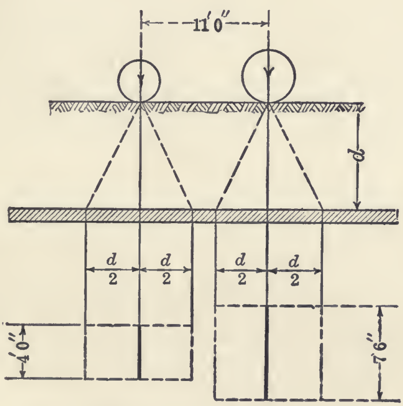

FIG. 11. — Showing Distribution of Loads due to Road Roller.

With this arbitrary distribution of loading it will be noted that for a strip, the width of the front wheel, the loaded areas overlap when the depth of fill is greater than the distance between axles. In this case, consider the load as uniformly distributed over an area of slab 7 ft. 6 ins. wide by (d + 11 ft. 0 in.) long.

1091. Wheel Loads on Tracks. — See distribution by track system (Par. 1089). These loads will be considered as distributed in a manner similar to that adopted for wheel loads on the roadway, excepting that the distribution will be assumed to be in both directions. It should, however, be borne in mind that on double track slab bridges the width of slab considered as supporting one track cannot be taken as greater than the distance center to center of tracks.

The following diagram (Fig. 12) shows the assumed distribution of standard truck load, 40-ton car.

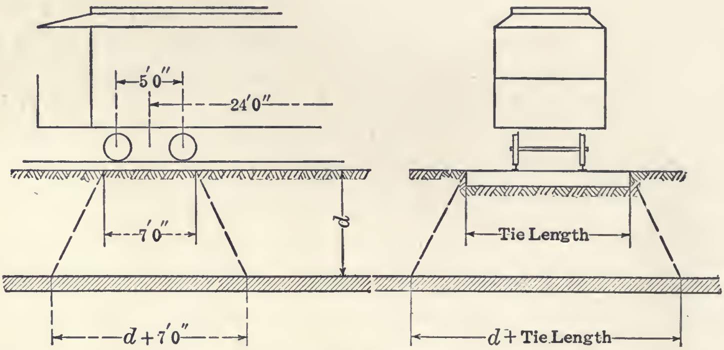

FIG. 12.—Load Distribution, 40-ton Car.

1092. Treatment of Loads for Girder Bridges.—The distribution of loads through the fill will be as above outlined; in this type of bridge, however, the girders must be so located as to properly take care of the track loads, the girders under the tracks being assumed to carry the full load.

1093. Abutments and Side Walls.—For the design of abutments and side walls the horizontal component of the earth pressure shall be taken as one-third of the vertical pressure at that depth, assuming the resultant to act at a distance one-third the height above the base. The intensity of the horizontal pressure due to live load shall also be taken equal to one-third of the vertical intensity at any depth, assuming that the planes of zero pressure bounding the supporting prism of earth to have a slope of one-half to one.

1094. Weights and Dimensions of Electric Cars.—If it is desired to make a special design the following data on electric cars taken from bulletin No. 3 may be of use. The values given must be taken as approximate averages. The weights given are for the loaded car and include the weight of the trucks.

Small cars, such as are used in small towns, four wheels on two axles, seating twenty-eight persons. Car body, 20 ft. 0 in. by 8 ft. 3 ins.; over-all length, 29 ft. 0 in.; distance center to center axles, 8 ft. 0 in.; weight, 11 tons.

City car for heavy service, seating fifty-two persons. Car body, 34 ft. 0 in. by 8 ft. 6 ins.; over-all length, 47 ft. 0 in.; wheel base, 4 ft. 0 in. to 6 ft. 0 in.; center to center trucks, 24 ft. 0 in.; weight, 15 tons.

Large interurban cars, seating 72 persons. Car body, 50 ft. 0 in. by 8 ft. 6 ins.; over-all length, 56 ft. 0 in.; wheel base, 6 ft. 3 ins.; center to center trucks, 30 ft. 0 in.; weight, 42 tons.

1095. **Impact.** — When the fill is less than five feet add 25 per cent for impact for rapid moving loads.

4. Methods of Design

1096. **Bending Moments.** — Having found the loads on the bridge by the methods above outlined, the bending moments and shears shall be obtained by the ordinary principles of mechanics. All bridges of single span shall be considered as beams freely supported at the ends and the bending moments must be figured on this assumption. For bridges with two or more spans the girders shall be figured as continuous beams and provision made for reverse moment over the supports.

1097. **Shearing Provisions in Flat Slab Bridges.** — In flat slab bridges it will not be necessary to make other provision for shearing stresses than by bending up part of the main reinforcing bars as required.

1098. **Shearing Provisions in Girder Bridges.** — In girder bridges, however, special provision must be made against failure by diagonal tensile stresses, as the girders carry all the shear. The concrete may be assumed to carry safely fifty pounds of vertical shear per square inch or rectangular cross-section. In girders some of the reinforcing bars shall be bent up near the ends of the beam and stirrups put in as required.

1099. **Waterproofing and Drainage.** — Some form of waterproofing should be used and the top surface of the slab arranged for drainage. (See Chap. VII, page 149.)

1100. **Bearing on Abutments: Slab Bridges.** — All concrete bridges resting on abutments shall have at least twelve (12) inches bearing; a maximum pressure of fifty pounds per square inch will be allowed for slab bridges.

1101. **Transverse Reinforcement: Slab Bridges.** — To properly distribute concentrated loads and to tie the bridge in the transverse direction ½-in. rounds should be placed (over the main reinforcing bars) crosswise of the bridge, and 12 ins. on centers.

1102. **Bearing of Girder Bridge on Abutments.** — In order to properly distribute the load and provide for sufficient bearing area the bridge should be made solid for the full depth of the girders, where it rests on the abutment. This construction is desirable on all girder bridges, owing to the rigidity and general stiffness given by the solid end.

Art. 51. Box Culverts

1103. **Reverse Moments.** — Box culverts will be built monolithic and reinforced against reverse moment at the corners.

1104. **Design of Top Slab.** — For the designing moment, use eight-tenths of the moment that would be developed if the ends were free. For reinforcement at the corners use one-half the amount of steel required in slab and fillet the corners.

1105. **Bottom Slab.** — The bottom slab should be made the same as top slab.

1106. **Transverse Reinforcement.** — To properly distribute concentrated loads and to tie the box culvert in the transverse direction, reinforcement shall be placed (over the main reinforcing bars) crosswise of the culvert.

1107. **Side Walls.** — In addition to supporting the top slab the side walls shall be capable of resisting the horizontal pressure of the earth. This moment will be of opposite sign to that produced in the side walls owing to the rigid connection with the top and bottom slabs. The designing moment shall be taken as eight-tenths of that which would be produced in a beam free at the ends.

1108. **Lateral Pressure.** — The horizontal intensity of earth pressure shall be taken as one-third of the vertical intensity.

1109. **Aprons.** — Box culverts shall be provided with aprons to prevent scour and the wing walls shall be figured as retaining walls.

Art. 52. Retaining Walls

1110. **Lateral Pressure.** — A uniformly distributed load covering the entire surface of the fill shall be assumed to exert a uniform horizontal or lateral pressure, the intensity of which shall be assumed to act at one-third ($\frac{1}{3}$) the height of the wall, regardless of the depth, and to be equal in amount to the weight of the material included by a plane bisecting the angle of the plane of repose of the material measured from the vertical at the wall and the upper surface of the back filling material.

1111. **Hydraulic Pressure.** — Whenever the material back of a retaining wall is liable to be saturated with water, the wall must be designed to resist the full theoretical hydraulic pressure.

1112. **Overturning.** — Reinforced concrete retaining walls shall be so designed that the stability against overturning will be at least as great as that of a solid masonry wall the base of which is $\frac{4}{10}$ of the height. For ordinary fills (horizontal surface), where the material is not likely to become saturated, the design may be based on an active horizontal pressure, the intensity of which at any point is $\frac{1}{3}$ of the vertical intensity at that point. A wall designed on this basis will have a slightly greater factor of stability than the gravity section referred to.

1113. **Maximum Soil Pressure.** — The maximum soil pressure at the toe of the retaining wall shall be computed in all cases, as it is very often the determining factor in the design of the base.

1114. **Drainage.** — In the design of retaining walls, provision shall be made for adequate drainage. This is an important feature as the development of an hydraulic head back of the wall might result in its failure.

1115. **Stability against Sliding.** — The earth fill in front of the wall assists to a slight extent in resisting sliding, but its action is not positive, and shall not be included in the design. A projection extending into the soil shall be provided in all cases.

1116. **Shrinkage or Temperature Cracks.** — Provision shall be made in all retaining wall work against the development of shrinkage or temperature cracks. On account of the small sections required in a reinforced concrete design, it is practicable to prevent the development of such cracks by the use of longitudinal reinforcement. Some longitudinal reinforcement shall be used even if expansion joints are provided.

About $\frac{5}{10}$ per cent of reinforcement will be sufficient to prevent cracks.

1117. **Type of Retaining Walls.** — Retaining walls of the cantilever type will generally be found economical up to heights of eighteen (18) feet; for higher walls the buttress type should be used.

1118. **Anchorage of Vertical Bars.** — It is necessary in all cantilever designs to investigate the anchorage of the vertical bars in the base. If the length of imbedment is not sufficient the bars may pull out, due to the shearing of the concrete around them.

1119. **Design of Cantilever Base.** — That part of the base back of the wall shall be made sufficiently strong to lift the fill resting upon it in addition to its own weight. It is desirable to fillet the corners, where the face wall joins the base, sufficient reinforcement being provided in the rear fillet to carry the bending moment. That is to say, diagonal reinforcement shall be placed in the rear fillet in sufficient amount to carry the bending moment at that point.

1120. **Design of Face Wall of Buttress Type.** — The face wall should be designed as a continuous horizontal beam, and reinforcing bars placed near the rear face at the abutments and extending to the fifth points of the clear span of buttresses.

1121. **Design of Base of Buttress Type.** — That part of the base back of the face wall shall be designed as a continuous horizontal beam, and made strong enough to lift the earth resting upon it as well as its own weight. It must also be designed to resist the upward reaction of the earth when this exceeds the weight of the materials above the section considered.

1122. **Design of Buttresses.** — The buttresses act as vertical beams attached to the base by the inclined reinforcing bars. The total stress in the steel necessary to anchor the buttress shall be obtained by dividing the overturning moment due to the thrust of the earth by the lever arm of the steel. It is necessary to have some vertical reinforcement to transfer the load from the base plate to the buttress.

The face wall shall also be tied to the buttress by means of horizontal bars. These bars shall have sufficient area to transfer the horizontal thrust to the buttress without assistance from the concrete, and shall be hooked over the horizontal bars in the face wall.

Art. 53. Piers and Abutments

1. Concrete Piers

1123. Massive Concrete. — Massive concrete should be used for piers that are liable to be submerged in water, in order to obtain the greatest possible weight.

1124. Ice Pressure. — Ice pressure against concrete piers shall be taken as equal to the water line on the exposed side into the maximum depth of ice for that latitude and multiplied by 900 lbs. per square foot.

1125. Impact. — Concrete piers shall be proportioned to withstand impact from floating débris such as logs, etc., to which they are likely to be subjected.

1126. Hydraulic Uplift. — In the design of piers, provision shall be made for the hydraulic uplift of water penetrating underneath the footings of piers. This is an important feature as the development of an hydraulic uplift underneath the footing of the pier might result in its failure.

1127. Batter. — Piers shall be given a batter of three-quarters of an inch to the foot, unless otherwise shown on the plans.

2. Concrete Abutments

1128. Massive and Reinforced Concrete. — Concrete abutments will preferably be constructed of massive concrete for all cases requiring a heavy mass, and where a heavy mass is not required, reinforced concrete should be employed.

1129. Types of Abutments. — The three principal types of abutments are the wing abutment, the U-abutment and the T-abutment. The type of abutment will be indicated on the plans.

1130. Overturning. — Abutments must be designed so as to be stable against overturning by revolving on the line formed by the intersection of the front face and the footing.

1131. Crushing. — Abutments shall be safe against crushing on the line formed by the intersection of the front face and the footing.

1132. Sliding. — Abutments must be designed to resist sliding, either by the abutment sliding on the footing or the footing sliding upon the foundation bed.

1133. Maximum Soil Pressure. — The maximum soil pressure at the toe of the abutment shall be computed in all cases, as it is very often the determining factor in the design of the footing. The pressure of the toe of the footing upon the foundation shall not be excessive.

1134. **Drainage.** — In the design of abutments, provision shall be made for adequate drainage, or if not possible to do this, they must be proportioned to resist the action of fluid pressure due to the back fill. This is an important feature as the development of an hydraulic head back of the abutment might result in its failure.

1135. **Batter.** — The faces of abutments should be given a batter of three-quarters of an inch to the foot. Back walls for abutments for steel bridges must have a thickness at the base of at least one-half their height or else be reinforced.

Art. 54. Reservoirs

1. Vertical Walls

1136. **Types of Reservoirs.** — Reservoirs of rectangular shape will be divided into three classes: first, those with vertical side walls; second, those with sloping exterior walls; third, those structures in which the reinforced concrete construction merely acts as a lining for the earth embankment. The following discussion applies only to the first type of reinforced concrete reservoirs, i.e., Vertical Walls.

1137. **Lateral Pressure.** — Reservoir walls when banked with earth must be designed to resist the maximum thrust that the fill may exert, assuming the reservoir empty. It is possible, however, that at times the earth may not exert any active pressure on the wall, and may even shrink away from the back face. In fact, when the fill is mainly clay it may shrink away from the back of the wall. (Such materials as sand or other granular substances without cohesion between the particles will, of course, exert an active pressure.) The walls shall, therefore, be designed as retaining walls to hold back the earth when the reservoir is empty, and shall also be figured for the water pressure neglecting such horizontal earth pressure as may exist.

1138. **Stability against Sliding.** — All designs shall be investigated for frictional stability against sliding as reservoir walls have failed by moving bodily forward while preserving their perpendicular position. Adequate provision shall be made against failure by sliding on the foundation and a projection or toe extending into the soil shall be used in all cases.

1139. **Draining Reservoir Site.** — The reservoir site shall be drained, not only to preserve the bearing power of the soil but also to prevent the development of an hydraulic head outside of the reservoir which might destroy the floor when the reservoir is empty.

1140. **Maximum Soil Pressure.** — The maximum soil pressure shall be computed in all cases, as it is often the controlling factor in the design of the base.

1141. **Intensity of Horizontal Pressure.** — The intensity of the horizontal pressure exerted by the earth against the wall at any point shall be equal to one-third of the vertical pressure at that point; also that the resultant horizontal pressure acts at a point one-third of the height above the base of the wall.

1142. **Design of Base.** — That part of the base back of the face wall shall be designed as a continuous horizontal beam between buttresses, and shall be made strong enough to lift the earth resting upon it in addition to its own weight. It must also be designed to resist the upward reaction of the earth should this exceed the weight of the material above the section considered.

1143. **Face Wall.** — The face wall shall be designed as a continuous horizontal beam, bending moments being computed by the formula $M = \frac{1}{12} wl^2$.

1144. **Buttresses.** — The buttresses act as vertical beams attached to the base by the inclined reinforcing bars. The total stress in the steel necessary to anchor the buttress shall be obtained by dividing the overturning moment by the lever arm of the steel. The face wall shall be tied to the buttress by means of horizontal bars. These bars shall have sufficient area to transfer the horizontal thrust to the buttress without assistance from the concrete, and shall be hooked over the horizontal bars in the face wall. Vertical reinforcement shall be used to transfer the load from the base plate to the buttress.

1145. **Longitudinal Reinforcement.** — Longitudinal reinforcement shall be provided in all walls, even if expansion joints are introduced. With thin walls from $\frac{3}{10}$ to $\frac{5}{10}$ of 1 per cent of reinforcement will generally be sufficient.

1146. **Division Wall.** — The division wall shall be designed to withstand water pressure on either side and shall be symmetrical about a vertical center line. The base shall be made strong enough to lift the water resting upon it in addition to its own weight.

1147. **Floor.** — The floor of the reservoir shall consist of a concrete slab of a minimum thickness of six inches and separated into blocks about 8 ft. 0 in. by 8 ft. 0 in., by a joint extending the full depth. Joints should be about $\frac{1}{2}$ in. wide and shall be filled with an asphalt filler.

1148. **Waterproofing.** — The reservoir walls should be backed with at least twelve inches of clay puddle. The division wall may be given a surface treatment if found desirable. (For Waterproofing, see Chap. VII, page 149.)

1149. **Drainage.** — The site shall be drained and trenches containing drain tile and filled with large broken stone well compacted shall be provided.

Art. 55. Conduits and Sewers

1150. **Circular or Curved Sewer Sections.** — The stresses developed by vertical loads on circular or curved sewer sections are to a certain extent indeterminate, as the pressures that may be exerted by the surrounding earth cannot be accurately predicted either in direction or amount.

1151. **Rectangular Sections.** — In the case of rectangular sections the above conditions do not exist and the action may be designed with reasonable accuracy.

1152. **Oblique or Unequal Pressures.** — The design shall provide for such stresses as might be developed from oblique or unequal pressure during construction.

1153. **Closed Rectangular Conduits.** — Closed rectangular conduits working under head shall be designed for the internal pressure in addition to the external loads. No reliance shall be placed on any possible restraining action due to the lateral pressure of the surrounding earth. For conducting water under pressure the circular type of conduit will be found preferable, excepting in special cases. Closed rectangular culverts are box culverts and their design is discussed in Art. 52, page 196.

1154. **Pressure Pipes.** — The steel reinforcing bans shall be figured to carry all the tensile stresses due to the pressure of the water, the concrete being considered as a filling-in material. Low-unit stresses shall be used in determining the amount of hooping required in these circular conduits and a sufficient amount of longitudinal reinforcement shall be used to take care of temperature and shrinkage stresses. The main reinforcement may be put in as spirally wound bars or individual hoops. The spiral method is to be preferred. If individual hoops are used, the bars shall lap at least 30 diameters and stagger around the circumference of the pipe.

Art. 56. Detailing Reinforced Concrete Structures

The matter contained in this article has been taken largely from the author's article on "Detailing Reinforced Concrete," published in the *Engineering News*, Vol. 67, pp. 626-632, April 4, 1912.

The graphic representation of reinforced-concrete design is not uniform or standardized as it is in structural steel. There are nearly as many methods of preparing drawings as there are practitioners, which obviously is a condition that demands remedy. The specifications given below are an attempt by the author to outline rules for detailing reinforced-concrete structures which will help toward more uniform practice.

The drafting offices of many of our large reinforced-concrete companies have become so extensive that it is important to use uniform methods as far as possible. The actual rules in use at each particular concern will vary more or less to suit the practice and facilities of that concern. The following are drawn up as a general guide, and may be modified more or less, to suit particular cases. The author hopes that the hints herein given will be useful not only to the draftsmen employed with reinforced-concrete companies, but also to engineering students. Rules for making drawings are mainly valuable in giving greater uniformity.

1. Drafting-room Standards and Organization

1155. Standards. — The drafting room of every reinforced-concrete concern should be provided with a set of the firm's standards, which have all the instructions and regulations intended to apply to the design and execution of all work in the drafting room. These instructions in regard to the drafting room should be made as complete as possible and with the idea that all men are beginners. A strange draftsman entering a new office is generally ignorant of the principles of that firm's system of reinforced concrete. It is one great fault of persons compiling instructions and regulations that they leave their work 50 per cent completed. More time spent in the preparation of these standards will greatly increase the efficiency of the drafting force, especially the beginners. No variation should be permitted from these drafting-room instructions without special permission from the head of the department.

1156. Organization. — The drafting room is generally divided in the grades of designers or squad bosses, draftsmen and tracers. Usually there is a chief draftsman or head of the department who has general supervision of all work and assigns the work to the various men under him, whom he considers best fitted to get out the drawings for it.

1157. Designers or Squad Bosses. — To ensure the proper handling of the work in the drafting room, all the information and data connected with each new contract should be handed to a designer, or squad boss, who is expected to familiarize himself with the estimate and correspondence relating thereto and the conditions of the contract affecting the design. He will be expected to see that all orders, drawings and details required in his jobs are properly executed and checked. It will be his duty to see that all orders are placed in sufficient time for shipment according to contract, that all details are complete and so clear the contractor can make no mistake in placing the steel.

The designer or squad boss will also be expected to see that all slabs and girders are designed as economically as possible. As the work progresses he must at all times keep himself informed in regard to the relation between shipped and estimated tonnage. Care must be exercised to keep the design within the estimate. If this is found to be impossible the fact should be immediately reported to the head of the department and such a report must include the reason for the same.

Specifications must be carefully read and all paragraphs which affect the design must be marked with a colored pencil. Under no circumstances will the designer or squad boss be allowed to make any reductions in the live and dead loads, or to use higher stresses than those specified in the specifications without special permission from the head of the department.

A record-card file is kept in the office to which access can always be had. In this file will be found the contract number, the instructions with regards to shipping dates, fabrication and kinds of material included in the contract.

The designer or squad boss will be expected to keep notes covering the various features of the job, such as special instructions from engineers and architects, and the cause for overrunning an estimate. He will be expected to see that the calculations on the job are kept carefully and in such form that they can readily be referred to. He will also be expected to inform the head of the department of any failure of the design or estimate that may seem questionable.

1158. **Draftsman's Equipment.** — Each draftsman should be supplied with a sketch book by the company, in which he should make all his notes, calculations and data referring to his work, and under no circumstances should notes of value be made on loose sheets. Many figures which a draftsman makes, however, will be on scratch paper, but all figures which may be needed for future reference and for consultation when the changes made by the checker are gone over, should be kept in a permanent and methodical form. Every entry should invariably be commenced with the subject and date, and full notes made of data on which the calculations were based and the results clearly stated. It cannot be too strongly insisted that intelligible notes be kept of all calculations of design and of any important points which it may be desirable to preserve. The computations should include all minor details, which are sometimes of the utmost importance. These notes as stated above should always be headed with the date, the name of the work to which the notes apply, and the name of the draftsman or designer. These books should remain the property of the company.

The draftsman must have a ready knowledge not only of the principles of drawing, but of the conventional methods of detailing reinforced concrete, and any device or system that will lessen the cost and difficulty of construction as regards the arrangement of the reinforcement without sacrificing strength is desirable. When the tracing is complete, the draftsman should look over it carefully, trying to detect any errors, as all such count against him. In fact, a reputation for making mistakes is perhaps the worst a draftsman can make for himself.

The draftsman should be familiar with the use of the slide rule, and should use it to calculate the area of steel required in beams, slabs, etc., and the compressive stress in the concrete, etc.

A draftsman should have at hand reference books in order that he may look up any point in theory with which he is not familiar. A few may be mentioned here, but, of course, for structures out of the ordinary special works should be consulted. The most useful are:

Brayton's "Standards — A Pocket Companion for the Uniform Design of Reinforced Concrete"; Brook's "Reinforced Concrete: Mechanics and Elementary Design"; Buel's "Reinforced Concrete"; Corrugated Bar Co.'s "Designing Methods" (a series of bulletins on designing methods for reinforced-concrete construction); Dodge's "Diagrams for Designing Reinforced Concrete Structures"; Gillete & Hill's "Concrete Construction"; Hawkesworth's "Graphical Handbook for Reinforced Concrete Design"; Heidenreich's "Engineers' Pocketbook of Reinforced Concrete"; Hool's "Reinforced Concrete Construction"; Mensch's "Architect's and Engineer's Handbook of Reinforced Concrete Construction"; Pittsburg Steel Products Co.'s "Blue Book" (containing information and tables relative to the use of Pittsburg standardized reinforcement for concrete); Reid's "Concrete and Reinforced Construction"; Reuterdahl's "Theory and Design of Reinforced Concrete Arches"; Taylor & Thompson's "A Treatise on Concrete, Plain and Reinforced"; Trussed Concrete Steel Co.'s "Kahn System Standards" (a handbook of practical calculation and application of reinforced concrete); Turneaure & Maurer's "Principles of Reinforced Concrete Construction"; Warren's "Handbook on Reinforced Concrete." Access to *Engineering News*, *Engineering Record*, and other engineering journals will be valuable. An individual card index should be kept in order that any subject may be looked up when occasion requires.

It would be well if all of the above books might be found in every drafting room; but if the expense prevents that, the ambitious draftsman should at least make himself acquainted with their contents. These works will also be found of great value to designers and estimators.

2. General Requirements

1159. Data. — Before starting on the drawings for any particular structure a draftsman should make himself perfectly familiar with all data (contract, estimate, general plans, specifications, etc.) in the company's possession. Examine these data carefully with the view of referring any discrepancy, doubtful or ambiguous point to the head of the department at the earliest opportunity, and avoiding any unnecessary delay. Time spent in a general preliminary consideration and plan of action is generally well spent. If further information is required, it should be asked for at once. A draftsman should never be ashamed to ask intelligent questions.

1160. Tracings and Sketch Sheets. — All working drawings liable to repetition must be traced and blueprinted. All temporary details, requiring only one copy, may be made on sketch sheets and press-copied.

1161. Size of Drawings. — Drawings may be made 12 × 24 ins., 15 × 30 ins., 18 × 36 ins., 24 × 36 ins., 24 × 42 ins., or any convenient size between trimming lines.

1162. Border Lines. — Border lines will consist of a single heavy line, leaving a ½-in. margin inside of the trimming line. The thickness of the border lines should match the work in hand, together with the size of the sheet. It is the first thing to be drawn in a pencil drawing, and the last thing in an inked drawing.

1163. **Appearance of Drawings.** — A drawing should have a workmanlike appearance or it will not inspire confidence in its correctness. The general arrangement and the lettering are the main features so far as appearance is concerned.

3. Scale, Lettering and Working Lines

1164. **Scales.** — The selection of a scale for a drawing depends upon the size of the work. The scale used must be large enough to show the details clearly. In general, plans should be made to a scale of $\frac{1}{4}$ in. = 1 ft. for ordinary work, and for very complicated work even larger scales should be used. Plans for very straight work may generally be made $\frac{1}{8}$-in. scale. Do not make drawings larger than necessary. The scale should be noted on the drawings.

Sections should be $\frac{1}{2}$-in. scale or larger, if necessary. This applies to detail sections. General sections through a building are exceptions and may be made to a smaller scale.

1165. **Lettering.** — The general appearance of drawings depends to a certain extent upon having the lettering, titles, etc., neat, legible, appropriate in character and uniform in style. In fact, there is no part of a drawing so important as the lettering. A good drawing may be ruined in appearance by lettering done carelessly. The lettering must be plain, neat and easily legible; however, time should not be wasted in making fancy letters. The letters and figures should be made as carefully as is consistent with rapidity. Plain block letters and figures written vertically are most easily read. All letters must be neat and large enough to show up well on the blueprint, but they should not be more conspicuous than the drawings.

1166. **Stenciling.** — Stencil letters may be used to bring out important parts of the drawing, such as beams and section marks. A stiff, short stencil brush should be used. Care must be taken not to have too much ink on the brush or the stencil work will be smeared or blurred.

1167. **Working Lines.** — Drawings should be made with the fewest lines possible consistent with clearness. Fairly heavy lines should be used for drafting so as to give a good, clear blueprint. The lines must be bold and clearly defined in proportion to the scale. Fine lines should be avoided except for dimension lines. In other words, wherever the size of scale will permit, lines should be made firm and heavy. For smaller scales the lines must be lighter and greater care must be used to show the details clearly.

1168. **Dimension Lines.** — Dimension lines should be made in very fine black lines, either dotted or continuous. Red does not print well and should be avoided. It is necessary, however, to have such lines very fine and uniform, as otherwise they may be confused with the drawing itself. A suitable blank space should be left for the dimension proper.

4. Figures and Dimensions

1169. **Term "Dimension."** — By the term "dimension" is meant the figure, the notation marks, the line and the arrowheads.

1170. **Requirements of Dimensions.** — Every dimension should indicate with unmistakable clearness two things: (1) the points of surfaces between which measurement is to be made; (2) the distance to be measured. These are the chief requirements. There is nothing on the whole drawing so important as the dimensions.

1171. **Figures.** — All figured dimensions on drawings should be plain round vertical figures, formed by a line of uniform width and sufficiently heavy to insure printing well. The figures must be entirely free from ornamental or superfluous features, so that they may be both easy to read and easy to write. Their shapes should be such that it is practically impossible to mistake one figure for another. No thin or doubtful figures will be tolerated.

If sloping lettering is used on the drawing, sloping figures should also be used.

The size of the figures should be suited to the other parts of the dimension, and should be chosen with discretion. A suitable size for ordinary work is $\frac{3}{16}$ in. Figures must not be less than $\frac{1}{8}$ in.

1172. **Notation Marks.** — It is preferable to have the notation marks for the foot and inch slope in the opposite direction to the figures and thereby avoiding the likelihood of being confused with the figure 1, especially in connection with the numerator of a fraction. The reversing of the notation marks gives additional character to a dimension.

1173. **Arrowheads.** — A dimension arrowhead should never be placed so that it is interfered with by any other line. Arrowheads should always be in black and made with great care, their points just touching the line to be measured.

1174. **Fraction Line.** — No diagonal-barred fractions should be used. The horizontal fraction line is better than the sloping one, not only because it is less likely to be scribbled, but because it makes a neater looking and more compact fraction.

1175. **Dimensioning.** — Dimensions should always indicate the finished size of the member or structure, without any reference to the scale of the drawing. A dimension not agreeing with the scaled distance, or which has been changed after the drawing has been made, should be heavily underscored. The dimensions should be placed so as to be the most convenient for the workman in the field and not scattered over the entire drawing. Dimensions should be clearly given in some one view, and not repeated in other views. Dimensions must never be crowded so as to impair clearness. Extension lines should not touch the outline. A dimension should never be placed on a center line. Dimensions should read from the bottom and right side of the sheet, no matter what part of the sheet they are on.

1176. **Main Dimensions.** — Only such dimensions as are necessary for laying out the work in the field or as assist materially in checking the plan should be noted on drawings. Main dimensions which are necessary for checking, such as center to center distances, over-all dimensions, story-heights, etc., should be repeated from drawing to drawing. Unnecessary repetition of dimensions must be avoided. All drawings must give general dimensions. In other words, the essential dimensions must be present, but the nonessential ones should be left off, for too many dimensions are just as undesirable as an insufficient number. Always give an over-all dimension and place it outside of detail dimensions. Never require the workman to add or subtract figures.

1177. **Referencing Dimensions.** — All dimensions should be referenced to some definite base line and working point, as the center line or track of the center line of the structure and their intersection.

1178. **Fractional Dimensions.** — Dimensions of reinforced-concrete structures should not be given closer than to quarters of an inch, except where unavoidable.

1179. **Expressing Dimensions.** — All dimensions on drawings, when 1 ft. and over, should be in feet and inches, thus 16 ins. would be marked "1′ 4″"; when under 1 ft. use inches, i.e., seven and one-half inches write "$7\frac{1}{2}$″." Width and depth of beams and dimensions of columns should always be expressed in inches in their respective schedules or on the elevations, plans or sections. Thus "12″ × 26″ beam," or "22″ × 22″ column." The breadth of beams should always be given first and then the depth, even if the beam be a very shallow one.

1180. **Footings.** — All corners of footing courses and neatwork lines on footings should be definitely located. All intersections of planes should be definitely located.

1181. **Distance from Base of Rail.** — Elevations and distances from base of rail of all important points in concrete bridges, piers, abutments, etc., should be given on plans.

1182. **Batter.** — Exact batters on inclined faces, as well as determining dimensions, should be given.

1183. **Piles.** — Piles should be located in rows, the spacing being perpendicular and parallel to the rows, and the end pile in each row being definitely located.

5. Arrangement of Drawings

1184. **Laying Out Work.** — If the design be a simple one, the estimate sketches may be all the laying out that is necessary, and draftsmen can proceed to make working drawings from these sketches. In any case it is very important to have the drawing started right with the structure arranged as it should be. There is a best place to begin on a structure and a most logical order in which to work it up, not only each drawing, but every detail. If this is followed very little erasing will have to be done. It is generally easier to redraw a sheet, however, than to make the necessary corrections to one that has been wrongly laid out. There is an advantage in compactness, but clearness should be the first consideration. Arrange the details and plan so as to well fill the sheet.

1185. **Scheme of the Design.** — Drawings should tell at a glance the general scheme of the design. They should show clearly the quantity and exact position of all reinforcement; the method of its anchorage, where continuity or extra bonding are required; detailed size of all the concrete work; and in short all details affecting strength or appearance. Drawings should show clearly general arrangements and details of parts. Care must be taken to make them plain and complete, and as simple as possible, so that the unskilled workmen in the field can understand them. Each drawing should be made complete in itself. In other words, make the drawing so plain that it will explain itself and that only gross negligence on the part of the contractor will allow a mistake to be made in using it.

1186. **Views.** — The number of views is determined by that judgment which serves common sense. As many views should be given as will show the construction of every piece of masonry. Cloth and paper are cheaper than men's time, and it is better to use a little more of this material in drawing extra views than to have any confusion in the erection of the structure. The selection of a view or views which shows the piece of masonry in the most comprehensive manner should always be made. Do not give views, or parts of views, which are unnecessary. In structures which consist of several parts, a diagram should be added showing the relative location and elevation of the different parts.

1187. **Explanatory Notes.** — Notes may be used when they will save considerable drafting, but should generally be avoided. Making the drawing complete will guard against mistakes in the office and the field. Use uniform methods, putting explanatory or general notes in the same part of all drawings. Do not change existing customs without exceptionally good reasons. Uniformity of drawings not only saves much time when looking for information in the field, but also much liability of mistake from oversight. A note should be so worded that its meaning cannot possibly be mistaken or misunderstood. Notes must not be too abbreviated. All notes must be in short sentences, explicit and concise. It is not permissible to refer to a reference; the drawing referred to should give full information.

1188. **Title.** — A title is an essential part of any drawing, and an invariable place on the drawing must always be provided for it. The title should be arranged uniformly for each job near the lower right-hand corner of the drawing (for convenience in referring to the drawings after they have been filed), printed in plain vertical or sloping letters. The title lettering on a drawing should be the most prominent lettering. The title should be lettered freehand in single-stroke capitals, either upright or inclined, but never both styles in the same title. The initial letter of every word, excepting prepositions, should be taller than others and all letters in a word should be close together, but at the same time sufficiently separated for clearness. A title generally looks better without lines drawn underneath. This is entirely optional however; if lines are put under they should not be too close to the letters. The wording of titles should be submitted to the head of the department for approval. All lines in the title must be arranged symmetrically with reference to a center line.

Every drafting room has its own standard form for titles. In large offices this is often printed in type on the tracing cloth. Sometimes the title is put on with a rubber stamp, and inked over while wet. Printing is the most satisfactory method when the number of drawings turned out is large.

Adjacent to the title the following information should be placed in the extreme lower right-hand corner of all drawings: Contract number; number of sheet; total number of sheets in the job; name or initials of the draftsman and the checker; date and scale. Above this may be placed the name of the reinforced concrete concern. The contract number should be put in large figures so it will strike the eye at once. The initials or name of the designer should also appear on each drawing. The date and the name or initials of the persons responsible for the drawing should be in very small letters.

Drawings requiring the approval of officers should have proper place provided for that purpose, preferably near the title.

1189. **Numbering Drawings.** — When there are several sheets to one set of plans, they should be numbered by different letters, such as 78-A, 78-B, etc. Each distinct piece of work should have a separate job number.

1190. **Referencing.** — Any number of drawings may be referred to the first drawing, but the first drawing should have a note stating what drawings have been referred to it.

6. Sections, Elevations, Etc.

1191. **Proper Position.** — Show all elevations, sections and views in their proper position — looking toward the member. Place the top view directly above and the bottom view below the elevation.

1192. **General Sections.** — If a certain work requires more than one drawing, show general sections on the first drawing only, but place notes on each drawing showing clearly where general sections are to be found. In a sectional view the portion of the object which is cut away and nearest the view is removed, and what is left is shown in the sectional view.

1193. **Complete Detailed Sections.** — If there is any doubt as to the make-up of a section, a cross-section should be shown giving on this the make-up of the section and important dimensions. Show complete detailed sections of any "out-of-the-ordinary" parts of the work, such as cantilevers, connections to structural steel, heavy concentrated loads framing with beams, eccentric connections, etc.

1194. **Location of Sections.** — Sectional views can be placed, if convenience demands it, at any place on the sheet, but always indicate where the section is taken by noting carefully below section. The direction in which a section is taken should be indicated by arrows on the line representing the cutting plane

1195. **Concrete Sections.** — Concrete sections may be indicated by blackening the reverse side of the tracing with pencil. A blue crayon pencil should never be used for this purpose when a print is to be taken from the tracing, as it will not show up.

Concrete sections may also be indicated by stippling with triangular marks in the following manner: Stones are first placed at random with a single continuous stroke and varying pressure of the pen, followed by heavy irregular-shaped dots placed sparingly between the stones. The tint of the whole should be finally finished by placing judiciously small dots, indicating particles of cement, which will give the necessary finish to the section, and make it resemble very closely real concrete. In "gravel concrete" the gravel should receive rounded outlines instead of irregular shaped figures. For the placing of the heavy black dots in "cinder concrete" a heavy lettering pen may be used, each dot being made by a single application.

The above conventional methods of representing concrete sections may give rise to some confusion when the sections are to indicate the positions of reinforcing steel, especially when the reinforcement is shown by circular or square black sections. Unless the stippling with triangular marks to represent concrete is carefully done, the black sections representing the reinforcing steel may be taken for part of the concrete. In order to avoid this confusion, the concrete may be represented by light, broken, diagonal lines.

Any one of the three methods mentioned above will be acceptable for showing concrete in section, provided it is properly executed. Blackening the reverse side of the tracing with pencil to indicate concrete sections will require less time. Care, however, must be taken not to darken the section too heavily or the reinforcement will not show up clearly.

7. Steel Reinforcement

1196. **Economy of Arrangement.** — In the design and arrangement of reinforcement, due regard should be given to the cost and difficulty of construction. Simplicity and duplication in the reinforcement will result usually in a large saving.

1197. **Indicating Reinforcing Steel.** — Plans and details of reinforced concrete structures should show the size, length and exact location of all reinforcing material, and should provide for proper connections between the component parts, so that they cannot be displaced. The detailer should always remember that though the contractor may be an engineer and have the reputation of doing good work, yet he is relying on the drawings to give him all the necessary information to properly place the reinforcing steel.

In general, the sizes and lengths should be shown on the elevations and the spacings on the cross-sections. In highly reinforced work the concrete dimensions and the reinforcement details should be shown on separate views. Large-scale cross-sections and diagrams should be added where the bar arrangement is complicated.

In side elevations the reinforcing system or skeleton of rods and wires should be shown by fairly heavy, short, double or single dashes, and by solid black sections, giving circular or square shape of such wires or rods, where this reinforcement appears in cross-sections. The reinforcement is thus allowed to stand out bold and clear.

1198. **Type of Bars.** — Reduce to a minimum the number of different types of bars on each job.

1199. **Bearing of Bars.** — All reinforcing steel must have a full bearing on the adjacent supports.

1200. **Length of Bars.** — Bars should be called for in lengths which can be cut from stock lengths with minimum waste. Bars should be called for in even feet, if possible, and where other lengths are necessary try to vary the lengths by multiples of 3 ins. As few different lengths as possible should be used. Avoid ordering bars in ½-in. lengths.

1201. **Length of Short Bars.** — In arriving at the length of bars under 5 ft. long, such as dowels, etc., where a variation of a few inches will not make any difference, the scheme of marking " ± 3″ " after the length of bar required may be adopted. This enables the shop to use scrap material without re-shearing. For examples, " 4–⅝″ Squares, 4′ 6″ ± 3″ " means that the bars may vary from 4 ft. 3 ins. to 4 ft. 9 ins. in length.

1202. **Bends in Bars.** — Unnecessary bends, bends in heavy bars, and many bends in the same bar should be avoided wherever possible. In other words, reduce to a minimum the number of bends in each bar and the number of types of bent bars required on each job. The fewer bends in bars the better. Small sized bars of low elastic limit should be used for stirrups and for reinforcement which must be bent to a small radius.

1203. **Bending Hooks on Small Bars.** — For cold bent hooks it is generally necessary to have at least 6 ins. of length in the hook on base size material for the machine to grip. The bars should be marked ± (plus or minus), which means that the dimension so marked is not absolutely accurate, but may vary as much as 3 ins. in order to allow for any difference caused by the bending. Cold bent hooks are generally bent around a 3-in. pin so that the radius should not be indicated unless it has to be more or less than 1½ ins.

Right-angle bends must be hot bends if not enough material is allowed for machine grip.

If the length of the hook is absolutely fixed it must be so noted on the detail.

1204. **Use of Sign ±.** — The plus or minus sign should be placed on one dimension on each bar when the bending is complicated, and on one dimension of each bar that is to be hooked.

1205. **Bending Diagrams or Sketches.** — Bending diagrams or sketches should be shown for all bent bars. The lengths of bars should be measured along the center line. The dimensions on bends should always be from out to out except in the case of stirrups, column hooks and column spirals. Do not attempt to combine many pieces in one sketch if by so doing too many notes are required.

1206. **Shop Marks on Bent Bars.** — All bent bars should be given some reference mark. There is much variation in reference to the marking of bent bars. These marks should consist of capital letters and numerals, or numerals only. No small letters should be used. The following scheme is suggested: For the first $\frac{3}{8}$-in. bent bar mark it 300, the second 301, and so on; mark the first $\frac{1}{2}$-in. bent bar 400, the second 401, and so on. For $\frac{5}{8}$-in. bent bars use 500, $\frac{3}{4}$-in. use 600, and so on. The hundredth figure will indicate at once whether the bar is a $\frac{3}{8}$-in. bar or a $\frac{7}{8}$-in. bar; thus 704 would indicate that $\frac{7}{8}$-in. bars are to be bent and probably it is the fifth in the series of $\frac{7}{8}$-in. bars having different bends. The word "marked" in abbreviated form may be used in front of the shop marks: thus, "14–$\frac{3}{4}''$ Rounds 26′ 3″ lg. Mk. 609."

1207. **Bills of Material.** — A complete bill of material should appear on *each* drawing. It should be placed directly above the title; and it is a good plan to block out a space for it immediately after the title has been allowed for. Every piece of reinforcing steel shown on the drawing should be accounted for on the bill of material, so that any clerk in the office can order from it independently of anything else. The material bill on each drawing also shows to the contractor the exact amount of steel called for by that drawing, without having to figure it out.

In the table of the bill of material the first column should contain the number wanted. The second column should contain the size and type of bar, i.e., round or square. The third column should contain the length of the bar, expressed in feet and inches. The fourth column should state whether the bar is a bent one. The fifth or last column should contain an identifying or shop mark which is exactly the same as the one placed on the piece of reinforcement shown on the drawing, and may be a letter or a number as stated above. If there are no bent bars shown on the drawing, the last two columns will, of course, be omitted.

List the smallest sizes and shortest lengths first, keeping the round and square bars separate.

The following form is suggested:

BILL OF MATERIAL

Number.	Size.	Length.	Bent.	Mark.
24	⅜″φ	8′ 9″	Bent	300
11	⅜″φ	9′ 3″	Bent	301
43	½″φ	14′ 6″	Bent	400
38	½″φ	21′ 0″	......	...
15	⅜″Φ	12′ 3″	Bent	310
27	⅜″Φ	16′ 0″	Bent	311
33	½″Φ	10′ 9″	Bent	423

8. Foundation Plans

1208. **Size of Footings, etc.** — On this plan should be shown the size of all footings, the quantity of steel in them and their elevation referred to some fixed line, such as the nearest floor line.

1209. **Dowels.** — All dowels are anchors and their connection in this portion of the structure should be clearly shown.

1210. **Working Lines.** — Footings should be shown in full lines as if the floor and the soil covering them had been removed.

1211. **Footing Schedule.** — The following form of footing schedule is suggested:

(1) FOOTING SCHEDULE

Footing, numbers.	Number of footings.	Steel.					Dowels.		
		No.	Size.	Length.	Shear.	Mark.	No.	Size.	Length.
3, 4, 5, 6	4	32	¾″×2″	8′ 9″	C–30	61	6	¾″	4′ 6″
12, 21, 22	3	26	1½″×2¼″	9′ 3″	C–30	150	6	¾″	4′ 6″
		14	1¾″×¾2″	14′ 6″	S–30	190	..	..	....
		13	1½″×¼2″	21′ 0″	C–30	151	8	¾″	4′ 6″
9, 10, 23, 24. See detail	2	10	½″ φ	12′ 3″	....	..	..	..	....
		6	1⅛″ φ	16′ 0″	....	..	6	¾″	4′ 6″
		5	1⅛″ φ	9′ 0″	....	..	..	..	....

(2) FOOTING SCHEDULE

Column numbers.	Base.	Cap reinf.	Size of cap.	Rect. reinf.	Diagonal reinf.	Dowels.
1	8′ 3″×8′ 3″×24″		none	5–¾″ φ–8′ 0″ each way	2–¾″ φ–11′ 0″ 4–¾″ φ– 9′ 9″ 4–¾″ φ– 8′ 6″	12–⅞″ φ 3′ 0″ lg.
2–2a	12′×10′×32″	Col. No. 2 cap 3′ 8″×5′ 8″×16″ Col. No. 2a cap 3′ 4″×4′ 10″×16″		11–⅞″ φ–11′ 6″ 13–⅞″ φ– 9′ 6″	none	20–1″ φ–3′ 0″ 16–⅞″ φ–3′ 0″
3, 4, 5 11, 21	11′×9′ 6″×32″ Slope to 12″		5′ 8″×3′ 9″ 16″ deep	6–¾″ φ– 9′ 0″ 6–¾″ φ–10′ 6″	4–¾″ φ–11′ 0″ 4–¾″ φ–12′ 3″ 4–¾″ φ–13′ 6″	26–1¼″ φ 3′ 0″ lg.

1211a. Bill of Material. — A list of material as it is to be ordered should be placed upon each foundation plan. This includes all the steel that will be required to install that portion of the work as shown on the drawing. The following form is suggested:

BILL OF MATERIAL

No.	Size.	Length.
128	$\frac{3}{8}'' \phi$	5′ 0″
172	$\frac{1}{2}'' \phi$	11′ 3″
30	$\frac{5}{8}'' \phi$	5′ 6″

9. Column Drawing or Schedule

1212. Completeness of Details. — This drawing should give all the necessary information to permit the proper placing of all material required in the columns. As the columns represent the most vital part of a building, since the failure of one may cause the fall of the entire structure, the detail must be so complete that the contractor cannot possibly omit any of the steel or fail to get it in its proper location.

1213. Numbering Columns. — Number all columns consecutively 1, 2, 3, 4, etc., no matter if all columns have the same load and contributary floor area.

1214. Cross-section. — The column detail should include a cross-section of the column with the dimensions placed thereon, including all recesses or keyways for bonding the curtain walls. The section should show the location of the vertical reinforcement and the hoops or stays.

1215. Special Connections and Anchors. — The drawings must also contain sufficient details to show all special connections and anchors between the columns and the rest of the structure.

1216. Splicing Column Bars. — Column bars should be spliced at floor levels, where beams and slabs give lateral supports. Vertical column bars, unless otherwise specified, should extend above the floor level the following distances: $\frac{1}{2}$-in. to $\frac{7}{8}$-in. bars, 18 ins.; 1-in. and $1\frac{1}{8}$-in. bars, 21 ins.; $1\frac{1}{4}$-in. and other bars, 24 ins. Drawing should indicate clearly that the bars are to be wrapped with wire.

1217. Fireproofing. — The minimum thickness of a fire-retarding coating covering the reinforcement for columns should not be less than $1\frac{1}{2}$ diameters or $1\frac{1}{2}$ ins.

1218. Shop-fabricated Spirals. — When shop-fabricated spirals are used the spiral should be stopped 2 ins. above the bottom of the lowest beam unless otherwise specified.

1219. **Bending Sketches.** — The following bending sketches are suggested for column reinforcement. Fig. 13 is for column bars. The ordinary column hoop or stay is shown in Fig. 14, while special column hoops are shown in Fig. 15. Spiral details are shown in Fig. 16.

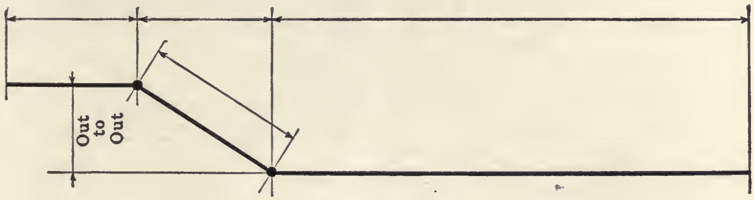

FIG. 13. — Bending Sketch for Column Bars.

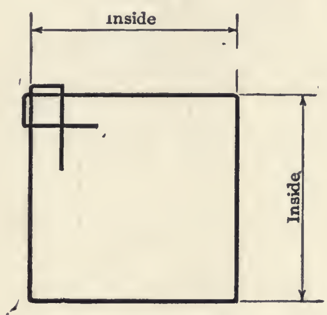

FIG. 14. — Column Hoops or Stays.

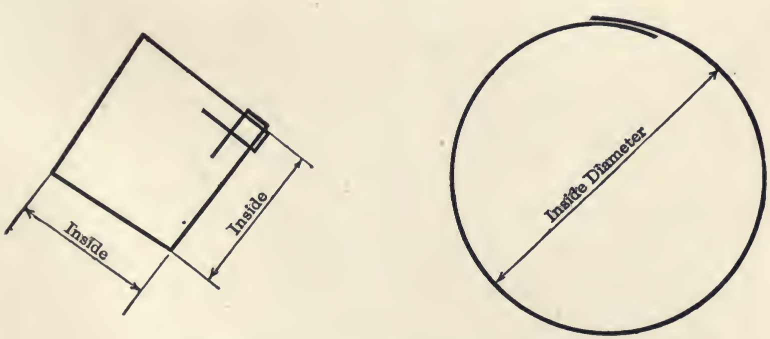

FIG. 15. — Special Column Hoops or Stays.

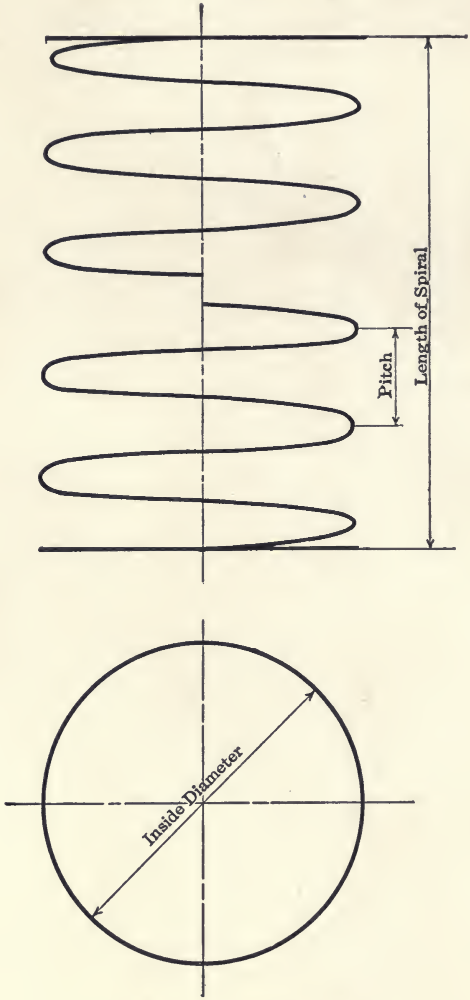

FIG. 16. — Spiral Hooping.

1220. Column Schedule. — A column schedule should be placed upon the drawing. The following forms of column schedules are suggested:

(1) COLUMN SCHEDULE

Col. numbers...	1, 11, 3, 13, 4, 14, 6, 16	2, 12, 5, 15	7, 17
No. of cols......	8	4	2
Supporting attic floor.	12″×16″ 4–$\frac{3}{4}$″ ϕ–13′ 3″ 12–$\frac{1}{4}$″ ϕ stays 4′ 8″	12″×16″ 4–$\frac{3}{4}$″ ϕ–13′ 3″ 12–$\frac{1}{4}$″ ϕ stays 4′ 8″	
Second floor....	12″×16″ 4–$\frac{3}{4}$″ ϕ–15′ 0″ 13–$\frac{1}{4}$″ ϕ stays 4′ 8″	12″×16″ 4–$\frac{3}{4}$″ ϕ–15′ 0″ 13–$\frac{1}{4}$″ ϕ stays 4′ 8″	12″×16″ 4–$\frac{3}{4}$″ ϕ–13′ 3″ 13–$\frac{1}{4}$″ ϕ stays 4′ 8″
First floor......	12″×20″ 4–$\frac{3}{4}$″ ϕ–12′ 0″ 12–$\frac{1}{4}$″ ϕ stays 5′ 4″	12″×26″ 6–$\frac{7}{8}$″ ϕ–12′ 0″ 12–$\frac{1}{4}$″ ϕ stays 6′ 4″	12″×20″ 4–$\frac{3}{4}$″ ϕ–12′ 0″ 12–$\frac{1}{4}$″ ϕ stays 5′ 4″
Caps...........	2′ 0″×2′ 8″×1′ 0″	2′ 0″×3′ 2″×1′ 0″	2′ 0″×2′ 8″×1′ 0″
Footings........	5′ 3″×5′ 3″×1′ 4″	6′ 0″×6′ 0″×1′ 4″	5′ 3″×5′ 3″×1′ 4″
Dowels.........	4–$\frac{3}{4}$″ ϕ–3′ 6″	6–$\frac{3}{4}$″ ϕ–3′ 6″	4–$\frac{3}{4}$″ ϕ–3′ 6″
Footing steel	10–$\frac{1}{2}$″ ϕ–5′ 0″ 8–$\frac{1}{2}$″ ϕ–5′ 9″ 6–$\frac{1}{2}$″ ϕ–6′ 9″	10–$\frac{1}{2}$″ ϕ–5′ 9″ 8–$\frac{1}{2}$″ ϕ–6′ 3″ 6–$\frac{1}{2}$″ ϕ–7′ 6″	10–$\frac{1}{2}$″ ϕ–5′ 0″ 8–$\frac{1}{2}$″ ϕ–5′ 9″ 6–$\frac{1}{2}$″ ϕ–6′ 9″

(2) COLUMN SCHEDULE

Total number of columns	1			5		
Columns	2			3, 4, 5, 6, 7		
Story	Concrete	Vertical bars	Hooping or ties	Concrete	Vertical bars	Hooping or tires
Roof *H* 7th floor	28″×13″	6–$\frac{3}{4}$″ ϕ 12′ 0″	No. 0 12″ cts.	12″×12″	4–$\frac{5}{8}$″ ϕ 12′ 0″	No. 0 12″ cts.
B 1st floor	28″×28″	8–1″ ϕ 17′ 10″	No. 0 12″ cts.	28″ Oct. 25″ core	6–$\frac{7}{8}$″ ϕ 17′ 10″	4/0@ 2″ pitch
A Basement	38″×38″	10′ 1$\frac{1}{8}$″ ϕ 13′ 0″	No. 0 12″ cts.	30″ Oct. 27″ core	8–$\frac{7}{8}$″ ϕ 13′ 0″	4/0 @ 1$\frac{1}{2}$″ pitch

(3) COLUMNS SUPPORTING SECOND FLOOR

Nos.	Size.	Longitudinal reinforcement.	Ties.
1, 3, 8, 10, 11, 20	10×20	4–$\frac{3}{4}$″ φ–16′ 6″/g	$\frac{5}{16}$″ φ–12″%
13, 18	14×14	4–$\frac{3}{4}$″ φ–16′ 6″/g	$\frac{5}{16}$″ φ–12″%
21, 22	10×10	4–$\frac{5}{8}$″ φ–14′ 6″	$\frac{5}{16}$″ φ–12″%

(4) COLUMN SCHEDULE

Column mark		1 to 6	9, 10
Number		6	2
Supporting roof	Size	12″×12″	14″×14″
	Steel	4–$\frac{1}{2}$″ R. B.–12′ 3″ 12–$\frac{1}{4}$″ φ stays 4′ 0″ lg.	4–$\frac{3}{4}$″φ 12′ 9″ 12–$\frac{1}{4}$″φ stays 4′ 8″ lg.
Supporting third floor	Size	16″×16″	18″×18″
	Steel	4–$\frac{3}{4}$″ φ–18′ 9″ 14–$\frac{1}{4}$″ φ stays 5′ 4″ lg.	4–1″ φ–16′ 3″ 14–$\frac{1}{4}$″ φ stays 6′ 0″ lg.

1221. Bill of Material. — A list of material as it is to be ordered shall be placed upon the column drawing or schedule. This includes all the steel that will be required to install that portion of the work as shown on the drawing.

10. Floor and Roof Plans

1222. Layout. — The layout of beams, girders and floor slabs should be made as simple as possible.

1223. Working Lines. — The more important structural elements, such as beams and columns, should stand out in bold relief. The location of every column should be clearly shown, either by cross-hatching or otherwise. Beams should be indicated by heavy broken lines, bars in floor slab by fine full lines.

1224. Arrangement of Steel Reinforcement. — Floor and roof plans must be drawn in such a way that every piece of steel required in the portion of the structure which the plan represents shall have its location clearly shown. On the plan itself should be shown slab steel, continuity bars over columns, girders or bearing walls, anchor bars or any other steel required in the slab or in the top of the beams and girders.

1225. **Reinforced-concrete Connections.** — As the connections between reinforced-concrete members are frequently a source of weakness, drawings must include complete details of all such connections.

1226. **Structural-steel Connections.** — All details must be carefully executed, particularly where concrete construction is used in connection with structural steel. In this class of construction the anchorage between the two classes of material must be carefully considered.

1227. **Indicating Slab Bars.** — In ordinary straight work it is not necessary to indicate every bar in the slab. A few lines to indicate the general arrangement are sufficient.

1228. **Bearing of Bars.** — All bars in beams and girders should bear at least 6 ins. on their supports. Where beams and girders are of about equal depth so that the steel in beams rest on or near the steel in the girder, stirrups should be placed to carry the ends of the bars and to distribute their bearing. Steel in beams should rest at least 7 ins. on brick walls, and even more for important beams and girders, depending on the design. Slab steel should have a bearing of at least 4 ins.

1229. **Spacing of Bars.** — The minimum spacing of parallel bars in slabs should not be less than 3 ins. Two layers of bars perpendicular to each other should be in contact, the bars forming the main reinforcement being in all cases placed undermost.

The minimum distance from the center of any bar to the edge of beam or girder should be two diameters, or $1\frac{1}{2}$ ins. The minimum distances center to center of any bar in the same layer should be $2\frac{1}{2}$ diameters for round bars and 3 diameters for square bars, and not less than 2 diameters between centers of bars in different layers. The spacing between two layers of bars should never be less than $\frac{1}{2}$ in. in any case. The longitudinal spacing of stirrups or bent rods should not exceed three-fourths of the depth of the beam.

1230. **Length of Bars.** — If framing between concrete beams, bars in floor slab should be ordered about 1 or 2 ins. less than the center to center distances of beams, depending on width of beams. (Some offices require that all straight bars in slabs are to lap 3 ins. beyond center of beam at each end, making a 6-in. lap.) If framing between structural steel work, allow about 1 in. clearance between faces of steel work, or when bars are specified to be hooked over I-beams, allow 3 ins. for the hook on each end beyond the flange of the I-beam.

Steel in beams framing into girders or columns should be ordered to extend to within $\frac{1}{2}$ in. of the centers of the girder. (Some offices require that all straight bars in beams are to extend 42 ins. beyond the center line at each end, thus giving a 9-in. lap.) Steel in beams framing into wall columns, wall girders, or girders around openings should be ordered to extend to within 2 ins. of the outside face of the columns or girders.

Never order bars in $\frac{1}{2}$ in. lengths.

1231. **Fireproofing.** — The minimum thickness of a fire-retarding coating covering the reinforcement should be for slabs not less than $1\frac{1}{2}$ diameters, or $\frac{3}{4}$ in., and for beams and girders not less than $1\frac{1}{2}$ diameters or $1\frac{1}{2}$ ins.

1232. **Dimensions of Beam.** — The size of the beam is the full width of the beam and the height is the distance from top of slab to bottom of beam. No beam is to be less than 7 ins. wide unless the span is under 10 ft.

1233. **Lettering Beams and Girders.** — All beams and girders must be marked by letters or numbers. Stencil letters may be used to bring out the beams and girders. The first-floor beams may be marked "A-1" or "101," etc., and the second-floor beams "B-1" or "201," etc., prefixing the roof in all cases with the letter "R." The beams on the first floor may also be marked A, B, C, etc., through the alphabet and then start with 1, 2, 3, etc., the other floors being treated in a similar manner. It is not necessary to give similar beams on different floors the same mark.

1234. **Location of Structural Members.** — Column centers and numbers, size and location of openings, size and location of beams and girders, thickness of slabs, etc., must be given on each plan.

1235. **Reference Line.** — Some fixed reference line should be assumed on each floor or roof plan to which all dimensions must be given. This line must appear on all drawings. The face of the concrete construction, the building line, the face of the pilasters, or any other line that may be easily identified on the engineer's or architect's plans may be assumed as this reference line. If this line is not a part of the concrete construction it should be shown as a dot and dash line and notes must be placed on the plan to show its meaning.

1236. **Indicating Bearing Walls.** — Drawings should be laid out to show concrete construction only. Walls should not be shown unless they are required for bearing. Where such walls are entirely covered by the concrete construction, they must be indicated by dotted lines. If the outside walls are used to carry concrete beams or slabs and if these beams or slabs do not extend to the outside edge, full lines must be drawn to indicate both the outside face of the walls and the outside edge of the concrete construction. The inside face of the wall must be shown by a dotted line and the amount of bearing must be shown for beams, slabs and girders by figures.

1237. **Beam and Girder Schedule.** — A beam and girder schedule should be placed upon each drawing. It is not necessary to show the steel in beams and girders on the floor or roof plan, as this can be done better in the schedule itself. Continuity bars over columns, girders or bearing walls, however, should not be shown in this schedule, but must be clearly shown on the plan.

The following forms are suggested:

(1) BEAM SCHEDULE FOR 3d, 4th AND 5th FLOORS

Beam.	No	*B.*	*D*	Tee	Reinforcement.	Bar mark.					↕	*h*	Stirrups.	Remarks.
					2–$\frac{7}{8}$″–18′ 3″	....	..	..	......	..	..	..	4–$\frac{1}{4}$″ ϕ	....
301	..	12	16	34	1–$\frac{3}{4}$″–22′ 0″	600	14	26	12′ 6″	26″	48″	13	4 loop	....
					1–$\frac{7}{8}$″–18′ 0″	700	26	26	10′ 6″	26″	12	13	each end	....
					2–$\frac{3}{4}$″–14′ 0″	....	..	..	....	..	..	..	4–$\frac{1}{4}$″ ϕ	....
302	..	12	16	23	1–$\frac{5}{8}$″–20′ 6″	500	46	26	8′ 6″	26	46	13	4 loop	....
					1–$\frac{5}{8}$″–14′ 9″	501	12	26	8′ 5″	26	12	13	each end	....
					2–$\frac{1}{2}$″–14′ 0″	....	..	..	....	..	..	..	4–$\frac{1}{4}$″ ϕ	....
303	..	8	18	..	1–$\frac{5}{8}$″–20′ 9″	502	48	30	7′ 9″	30	48	15	4 loop	....
					1–$\frac{5}{8}$″–20′ 9″	503	60	30	5′ 9″	30	60	15	each end	....
					1–$\frac{5}{8}$″–14′ 0″	comp. bar in top of beam								

(2) BEAM SCHEDULE

Concrete.				Reinforcement.				
Beam.	Size.	Tee.	No.	No.	Size.	Length.	Shear.	Mark.
				2	1$\frac{1}{2}$×2$\frac{1}{4}$	19′ 0″	Std. 30	154
A	12/26	24″	2	2	$\frac{3}{4}$″ ϕ	18′ 10″	Bent	600
				1	$\frac{7}{8}$″ ϕ	19′ 0″	Straight	....
				1	$\frac{7}{8}$″ ϕ	8′ 4″	Bent	700
				2	1$\frac{3}{4}$×2$\frac{3}{4}$	19′ 0″	Std. 30	190
B	12/26	30″	15	1	$\frac{5}{8}$″ ϕ	20′ 4″	Bent	500
				1	$\frac{3}{4}$″ ϕ	20′ 4″	Bent	601
C	8/16	None	2	2	$\frac{1}{2}$×1$\frac{1}{2}$	12′ 0″	Std. 12	13
				1	$\frac{1}{2}$″ ϕ	8′ 0″	....	....

1238. **Tile and Joist Construction.** — Where beams carry tile and concrete-joist construction, the size of the Tee must be clearly shown. It is not sufficient to only note the size in the beam schedule. Tees should be shown by sections on the drawing or by dash lines on the plan indicating the point where the tile should stop. Too much emphasis cannot be placed upon this very important point and should always receive the most careful attention.

1239. **Special Details.** — Any other steel that cannot be clearly indicated either on the plan or in the beam and girder schedule must be shown by special details.

1240. **Bending Diagrams.** — Diagrams must be made for all bent bars in beams, girders or slabs. Start to bend bars at the quarter point of center to center dimensions of beams. If more than two bars are bent in a beam, the bends should not all start at the same point. For example, if three bars are to be bent, one bar should start to bend at the quarter point and the other two at about the fifth point.

The following bending sketches are suggested for floor and roof reinforcement. Fig. 17 illustrates the method of bending the ordinary "U" stirrup. Fig. 18 illustrates the method of bending beam and girder reinforcement either for shear or continuity as the case may be.

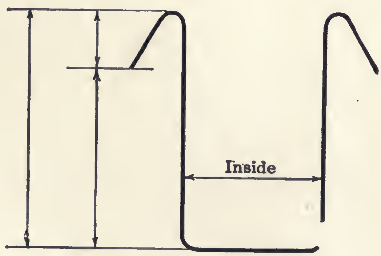

FIG. 17. — Beam or Girder Stirrups.

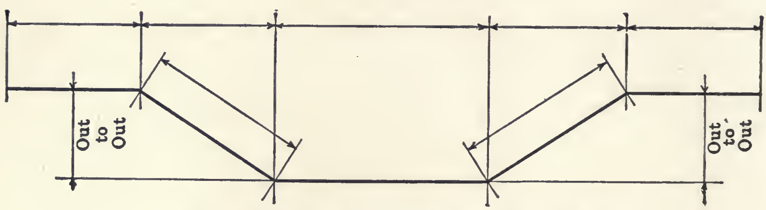

FIG. 18. — Bending Sketch for Beam or Girder Bars.

SCHEDULE OF BENT BARS

No.	Size.	Mark.	Length.						
6	$\frac{3}{8}''$ ϕ	300	8′ 6″	6″	24″	3′ 6″	24″	6″	8″
11	$\frac{1}{2}''$ ϕ	400	17′ 0″	8″	32″	10′ 4″	32″	8″	8″
23	$\frac{1}{2}''$ ϕ	401	16′ 8″	8″	32″	10′ 0″	32″	8″	8″
14	$\frac{5}{8}''$ ϕ	500	19′ 9″	..	..	13′ 1″	32″	4″	8″

1241. **Bill of Material.** — A list of material as it is to be ordered should be placed upon each floor or roof plan. This includes all the steel that will be required to install that portion of the work. If several floors are shown upon one drawing, list the material for each floor separately. Never include more than one floor in the bill of material. Since no useful purpose would be served by delivering all of the steel for, say, a six- or 10-story building, on the site at the beginning of the work, thereby entailing large storage capacity and much time on the part of the material clerk, the steel is sent to the job floor by floor.

BILL OF MATERIAL

No.	Size.	Length.	Shear.	Mark.
	Kahn Bars.			
33	$\frac{1}{2}\times1\frac{1}{2}$	17′ 4″	Std. 12	1
5	$\frac{1}{2}\times1\frac{1}{2}$	13′ 6″	Ctr. 6	2
12	$\frac{3}{4}\times2$	22′ 0″	Std. 24	66
42	$\frac{3}{4}\times2$	12′ 9″	Ctr. 18	75
38	$1\frac{1}{2}\times2\frac{1}{4}$	10′ 0″	Ctr. 24	153
14	$1\frac{3}{4}\times2\frac{3}{4}$	20′ 0″	Std. 30	191
	Rib Bars.			
81	$\frac{3}{8}$″	5′ 6″	....	...
64	$\frac{3}{8}$″	21′ 9″	Bent	300
6	$\frac{1}{2}$″	11′ 0″	......	...
175	$\frac{1}{2}$″	26′ 6″	Bent	400
48	$\frac{1}{2}$″	29′ 3″	Bent	401
52	$\frac{5}{8}$″	19′ 10″	Bent	500
15	$\frac{3}{4}$″	18′ 6″	Bent	600
2	$\frac{3}{4}$″	33′ 9″	Bent	601

11. Walls

1242. **Wall Corners.** — Use ample steel to tie together joining walls at corners.

1243. **Belt Courses, Cornices, Etc.** — Use ample reinforcement in belt courses, cornices, etc., to connect them to main walls. In general, more reinforcement is needed to prevent cracking at changes of thickness than in walls.

1244. **Bill of Materials.** — A list of material as it is to be ordered should be placed upon the drawing showing there inforcement in curtain or retaining walls. This includes all the steel that will be required to install that portion of the work as shown on the drawing.

12. Checking and Correcting Drawings

1245. **Checking Drawings.** — The amount of checking required will depend entirely on the care with which the work has been laid out and the drawing made. If laid out by an experienced draftsman that knows his business, very little checking will be required. It is false economy to think that the cost of making reinforced-concrete details will be decreased by employing cheap and inexperienced men. The drawings made by such men usually cost in actual wages paid out for making them about twice as much as though they had been made by higher-priced draftsmen who know their business.

The checker should take nothing for granted, but should check and investigate everything. It is a great help in checking drawings to outline first a standard method of doing the work, jotting down special mistakes which are likely to occur, etc. It will probably be necessary to make changes in and additions to the outline, but when it is perfected it will undoubtedly add greatly to the speed and effectiveness of checking. In checking drawings the check list given below will be found convenient. It may be reviewed to see if all matters have been considered.

CHECK LIST

- Anchors
- Arrangement of drawings
- Bar spacing
- Beams and girders:
  - area of steel
  - bent bars
  - bearing
  - bill of material
  - brackets
  - compressive steel
  - continuity steel
  - dimensions
  - fireproofing
  - length of beam
  - length of steel
  - lettering of
  - schedule
  - shear
  - spacing of steel
  - stirrups
  - tee section
  - web reinforcement
- Bearing of bars
- Bearing walls
- Bending diagrams
- Bending schedules
- Bill of material
- Bond of reinforcement
- Clearness of details
- Columns:
  - area of steel
  - bill of material
  - compression
  - dimensions
  - fireproofing
  - future connections
  - height of
  - hooping
  - lap of bars
- Columns:
  - location
  - number of stays
  - numbering of
  - schedule
  - spirals
- Continuity bars
- Contract number
- Cross-sections
- Dimensions
- Drawing number
- Elevations
- Explanatory notes
- Footings:
  - bill of material
  - dimensions
  - dowels
  - elevation
  - length of bars
  - number of bars
  - schedule
  - spacing of bars
- Girders, *see* Beams
- Lap of bars
- Length of bars
- Lettering
- Openings
- Reinforcement
- Schedules
- Sections
- Shear on concrete
- Shop marks on bent bars
- Size of bars
- Slabs:
  - area of steel
  - nachor bars
  - bearing
  - bent bars
  - bill of material

Slabs:
- continuity steel
- fireproofing
- length of bars
- spacing of bars
- temperature bars
- thickness

Spacing of:
- beams
- columns
- reinforcement
- stirrups

Special reinforcement
Splicing of reinforcement
Structural steel connections
Tee beams, *see* Beams
Temperature bars
Tile and joint construction:
- *see also*, Beams
- size of tiles
- spacing of joists
- thickness of concrete covering
- thickness of floor

Title of drawing
Views
Walls:
- bill of material
- height
- length of bars
- spacing of bars
- thickness

Width of Tee beams
Working stresses

1246. **Correcting Drawings.** — All drawings after being checked must be corrected at once, in preference to any other work. Look into all corrections carefully before doing any erasing. Do not erase the checker's marks. The draftsman must not simply take the checker's word for the proposed changes, but he must himself investigate the changes, and before any such changes are made the two must mutually agree. If changed without the draftsman's consent, then the drawing is really not checked at all. The proposed changes should be marked on the drawing with a blue pencil. This color will not print, is easily seen and is easily cleaned off afterward with a spongy rubber or benzine if placed on tracing cloth. Proposed new figures should be placed far enough away from the existing ones, that the new figures will not be effaced when erasing the ink ones. The draftsman must leave all blue marks on the tracing, and return the same to the checker for his final approval.

1247. **Alterations.** — When tracings are altered in any way, the date of revision and the initials of the draftsman are to be marked on the tracing, thus: "Rev. 7/21/11. ERS."

13. Handling Orders

1248. **Ordering Material.** — As soon as a contract has been secured and entered, complete data relating to the construction are turned over to the drafting department. Material should be ordered as soon as possible after the receipt of a job, using a few sizes and different lengths as practicable. The first thing to be done after the drawing has been checked is to prepare a list of the reinforcing material required, which is called a "material or order bill." The draftsman to whom this is entrusted should carefully take off the quantities from the drawing. Shipments to be made in accordance with the terms of the customer's order or contract.

1249. **Material Bills.** — It is very important that all material be billed correctly on material bills, as all material is charged against the customer according to the material bills and all shipping is done according to these bills. The importance of avoiding errors and omissions in the material bills is apparent, since they may cause serious delay to the entire work. Care should, therefore, be taken to include everything in the material bill that will be required to properly reinforce the structure, unless upon inquiry from the squad boss that certain reinforcing steel may be ordered later.

It is usual to make material bills on printed forms, prepared just for this purpose. The forms are generally printed on thin strong paper that will admit of blueprinting. Sometimes the lists are written with a copying pencil or with hektograph ink.

The material bill should indicate the kind of material (medium or high carbon) and the specifications governing its quality and inspection.

1250. **Separation of Shipments.** — For a contract of any magnitude the material bills should be gotten out in sections; those parts which will be needed first should be gotten out first. Orders should be placed with respect to floors, and *each floor* separated; frequently it is necessary to split orders for shipment, and failing to place orders properly means delay.

In large structures, such as viaducts, long retaining walls, warehouses, factory buildings, etc., which are generally subdivided into shipments of suitable size, both straight and fabricated material bills must be made up separately for each shipment.

1251. **Number of Copies.** — Make bills of material in duplicate. The original copy to be sent to the sales department and duplicate to be kept in the drafting room. Specifications for quality of steel must be noted on the first sheet of each order.

1252. **Straight Material Bills.** — All material which is not fabricated should be listed on material bills marked "Straight Bars — No Fabrication," or words to like effect. List the smallest bars and shortest lengths first, keeping the rounds and squares separated.

1253. **Fabricated Material Bills.** — All material which is to be fabricated should be listed on sheets marked "Bars for Fabrication." All fabricated material bills must have on them the company's shop mark and where so required, the customer's mark.

One set of blueprints or copy must be made of all fabricated-material details and sent to the sales department. If necessary, other sets of prints may be made as required.

1254. **Numbering Bills of Material.** — All bills should be numbered consecutively, whether straight or fabricated, and should show the number of the drawing to which they refer.

Where material bills are canceled, give revised material bills a new number.

14. Miscellaneous

1255. Care of Drawings. — Drawings at all times should be kept neat and orderly. They should be protected from chance of injury, both during the day and night. All tracings should be covered before leaving work with a heavy cloth or a piece of table oilcloth. This applies to drawings actually being worked upon and all tracings used in connection with the work. Never fold a drawing or tracing.

It is absolutely essential that the drafting room be kept in business-like order. All architect's and engineer's drawings should be filed when no longer needed. Do not allow old drawings to accumulate around the room.

1256. Cost of Drawing. — There is always a noticeable decrease in the cost of the details or working drawings when the plans for the reinforcement are made and designed by an engineer, either independently or associated with the architect, and separated from the general architectural plans. In comparing the cost of designing the reinforcement and making the drawings from the engineer's or architect's plans, the cost of the former is on an average of about 25 per cent higher than the latter. Where the architect's plans are made with no dimensions, with only the outline and sections given, it being necessary to refer to the general plans for the location and dimensions, there is no saving of time, and the detailing runs as high as on the architect's plans.

The cost of reinforced-concrete details depends on so many things that it is hard to set any fixed rule for determining what this cost is. The type of the building is the first consideration; then the architect and engineer, their methods of drawing up their plans; and finally the detailing drafting force one is obliged to depend upon.

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NOTE. — For additional References to Reinforced Concrete Building Construction, see Art. 62, p. 244.

CHAPTER IX

REINFORCED CONCRETE BUILDING CONSTRUCTION

Art. 58. System of Reinforced Concrete Left to Bidders

1. General Requirements

1257. **In General.** — The drawings and specifications show the general arrangement of the reinforced concrete work, i.e., scope and general character of design, and all bidders without exception shall submit their proposals based upon same.

Before work is commenced complete plans shall be prepared, accompanied by specifications, stress computations, and descriptions showing the general arrangements and all details.

1258. **Recalculations.** — The drawings show the minimum dimensions intended for concrete and steel, but the entire concrete job must be recalculated in accordance with the requirements for loading, allowable working stresses, assumed weights, etc., as given herein, and anything omitted or short of these requirements, or short of the best engineering practice, must be rectified or furnished in accordance therewith, even if not mentioned in the specifications or shown on the drawings, so as to make the entire job first-class and substantial when completed.

1259. **Proposals.** — Proposals will be received on any recognized system of reinforced concrete subject to the conditions specified herein. No system of reinforced concrete will be considered which is not of recognized standing, and which has not been used successfully for five years on important work.

1260. **Experience of Engineer Specialists.** — Only firms employing engineer specialists of at least five (5) years' experience in reinforced concrete work shall be allowed to submit a bid on this work.*

1261. **System of Construction Illustrated by Sketches.** — The system of construction which the Contractor intends to use, shall be stated in the proposal, and the method proposed for applying it to this work shall be illustrated by general sketches showing the disposition of the reinforcement in typical members of the construction. No proposition will be considered without such calculations and sketches. In all cases the system employed must give the results called for by sketches. These sketches

* The design of reinforced concrete structures should receive at least the same careful consideration as those of steel, and only engineers with sufficient experience and good judgment should be entrusted with such work.

shall be filed at the Engineer's office by the bidder or the engineering firm employed by them on or before the time set for the opening of the bids.

1262. **Approval of System by Engineer.** — It shall be understood that no system shall be finally accepted until details of system proposed are submitted to the Engineer and his approval in writing obtained therefor.

1263. **Approval of System by Building Department.** — It must be understood furthermore that no system of reinforcement will be considered which has not been approved by the building departments of all the principal cities of the United States who have studied reinforcement in concrete construction and have embodied conditions governing its use in their Building Code, i.e., New York, Chicago, Philadelphia, Washington, Cleveland and St. Louis.

1264. **Approval of System by State or City Official.** — Plans and specifications for all public structures shall be approved by a legally authorized state or city official, and copies of such plans and specifications placed on file in his office.

1265. **Conditions Under Which Design May be Varied.** — If the Contractor desires to use a system not covered by or varying from the conditions stipulated herein as to design, he shall present to the Commissioner of Buildings plans and specifications, giving in details the construction and formulas he uses in his design, and to be such that they can be checked properly and kept on record by the Commissioner. The Contractor shall then make a destruction test, or present evidence satisfactory to the Commissioner of Buildings that such test has been made, with full particulars of the results of said test. If said test shows that, based on the specifications submitted, the construction has a factor of safety of four (4) on the total dead and live load, the said system may be used in accordance with said specifications.

1266. **Bond.** — If any system is approved, the Contractor shall furnish the Owner a Surety Company Idemnity Bond for the full amount of the cost of said system, protecting said Owner from any loss or damage of whatsoever nature due to faulty work or material, inadequate strength of construction, premature removal of forms, or from any other cause affecting its strength or character.

1267. **Infringements.** — The Contractor shall be held responsible for any and all infringements upon any patented systems which may be used.

1268. **Sacrifice of Perfect Stability.** — All designs must be of the highest class and type of reinforced concrete, and should any design be submitted which indicates a sacrifice of perfect stability in order to reduce first cost, it will be rejected.

1269. **Arrangement of Reinforcement.** — Whatever system of reinforcing is employed, it must be strongly tied together and braced in a firm and secure manner, so that when the concrete is dumped into the forms it will not displace the steel nor get same out of position or alignment.

1270. **Mushroom or Flat Slab System.** — The design of the multiple way or patented reinforcing system shall be subject strictly in every way to the Engineer's approval. The Engineer reserves the right to cause any part of the design to be made stronger if he shall in his judgment deem it so advisable and his decision shall be final. Such a system must be approved by the Engineer before any contract is entered into with the Contractor.

In the case of the so-called mushroom system, or other systems which are not subject to rigid stress analysis, the design will be accepted only subject to the tests upon the completed structure and the Engineer reserves the right to dictate the test loads and manner of carrying on tests for such special cases.

1271. **Plain Concrete.** — No plain or unarmored concrete shall be used unless plainly called for in the specifications.

2. Working Drawings

1272. **In General.** — The successful Contractor shall submit for Engineer's approval drawings showing sizes and arrangement of reinforcement. These drawings shall be accurate and clear as regards construction and dimensions, to obviate trouble in interpreting them.

1273. **Drawings by Whom Furnished.** — The party furnishing the reinforcing system shall prepare the working reinforcing plans subject to the approval of the Engineer, and shall also keep in close touch with the work in the field to insure that the steel is placed in accordance with the drawings.

1274. **Scope of Working Drawings.** — The drawings shall cover the plans, elevations and sections of all reinforced members with the dimensions and sizes of all important features, fully descriptive in every particular of the system of reinforcement proposed. This shall also include the static computations, designating the loads assumed separately, such as dead and live, together with resulting stresses.

The working drawings shall also show clearly the size and position of all reinforcement, and the design shall provide for proper connections between the component parts, so that they cannot be displaced. In other words, the plans shall show the size, length, dimensions for points of bending, and exact position of all reinforcement, including stirrups, ties, hooping and splicing.

1275. **Marking Live Loads.** — The live loads in pounds per square foot shall be marked upon every floor plan of the drawings submitted.

1276. **Modifying or Changing Drawings.** — Working drawings shall be open to such suggestions and comments as in the opinion of the Owner and Engineer, may be deemed necessary in the interest of the work and in the event of the proposed outline or any feature thereof being insufficient to accomplish the results intended, may be disapproved, whereupon a different method and plan shall be submitted.

1277. Approval of Drawings. — When the plans, etc., for the system of reinforcement are satisfactory they will be approved by the Owner and Engineer and when approved shall be a part of the general plans and specifications as if originally incorporated therein.

1278. Contractor's Responsibility. — The approval of the plans for the system of reinforcement shall not relieve the Contractor from the responsibility of the sufficiency and efficiency for this part of the construction.

1279. Number of Drawings. — The Engineer shall be furnished with two complete sets of all constructional drawings for approval also two corrected approved sets for office.

3. Specifications

1280. In General. — The specifications shall state the qualities of the materials to be used for making the concrete, and the manner in which they are to be proportioned.

The strength which the concrete is expected to attain after a definite period shall be stated in the specifications.

The specifications shall be signed by the Engineer and the Contractor.

4. Computations

1281. In General. — The computations shall give the loads assumed separately, such as dead and live loads, wind, and impact, if any, and the resulting stresses. The computations shall also include all minor details, which are sometimes of the utmost importance. As the connections between reinforced concrete members are frequently a source of weakness, the design shall include a detailed study of such connections, accompanied by computations to prove their strength.

Art. 59. Responsibility and Supervision

1282. Contractor's Responsibility. — The Contractor shall make a careful survey of all drawings and thoroughly familiarize himself with the extent of the work under his contract. He shall assume responsibilities and obligations set forth in the specifications pertaining to the General Contractor.

1283. Engineer's Supervision. — Inspection during construction shall be made by competent inspectors employed by and under the supervision of the Engineer, and shall cover the following:

1. The concrete materials. (See Chap. I, page 1.)
2. The proportioning and mixing of concrete. (See Chap. II, page 26.)
3. The form work. (See Chap. III, page 50.)
4. The steel reinforcement. (See Chap. IV, page 75.)
5. The placing of concrete. (See Chap. V, page 97.)
6. The character of the workmanship.

1284. **Contractor's Supervision.** — The Contractor must have in charge of the reinforced concrete at all times during time of construction a thoroughly competent Superintendent, one with large experience in this form of construction. Under him there shall be men in charge of centering; one in charge of mixing the concrete; one in charge of placing steel reinforcement; one in charge of pouring concrete; and one in charge of striking centering; all to be experienced in their particular branches, and satisfactory to the Superintendent. Any one not deemed capable by the Superintendent shall be replaced immediately upon his request by some one more satisfactory. The different foremen shall be actually present where the work is being done.

1285. **Records.** — Records of falsework, concrete pouring, and steel inspection, signed by the Contractor's Superintendent, and the concrete foreman, shall be kept and signed on printed forms provided for this purpose. These must be kept accurately and filed daily with the Engineer.

Failure to comply with this requirement shall be considered sufficient cause to warrant the dismissal of the neglectful employes.

1286. **Adherence to Plans.** — No change in dimensions of structural members shall be made without the Engineer's permission and approval, and no changes will be permitted that interfere with the labor or material of other branches of work except at the expense of the Contractor making the changes, and in all cases the strength of the construction must be maintained. In other words, the Contractor shall adhere strictly to the plans, as the strength of the finished structure depends upon this. The Inspector will not be allowed to make any changes in the plans without the written consent of the Engineer.

1287. **Relations to Other Contractors.** — The Contractor must arrange his work in harmony with other mechanics on the building and must assist in securing and setting all work embedded in, attached to or passing through the reinforced concrete.

1288. **Dating all Forms.** — The Contractor shall nail tags on the forms, giving the exact date when the concrete was poured in them.

1289. **Cutting Holes in the Concrete.** — Cutting holes in the concrete will not be permitted except by the permission in writing of the Engineer. The location of each cut must be clearly indicated.

No drilling into or cutting of the fireproofing or of the steel reinforcing spirals, hoops, stirrups or rods in any columns or beams for the purpose of attaching fixtures, hangers or for any purpose which will in any way injure the concrete or reinforcing in same, is to be permitted.

Beams must not be cut under any consideration.

When holes have to be cut through the slabs the cutting shall commence from the bottom. Light hammers and chisels should be used in preference to heavy tools.

1290. **Carrying Capacity of Floors.** — Upon the completion of the building, the Contractor shall obtain from the Engineer, under the approval of the Building Department, signed certificates, to be posted on each floor of the building stating the safe carrying capacity per square foot.

Art. 60. Details of Construction

1. Bolts, Sockets, Wall Ties, Pipe Sleeves, Etc.

1291. **Bolts.** — The Contractor shall furnish and place anchor bolts for the steel work and bolts for attaching buffer log, and any other bolts, necessary for attaching rolling steel doors, their guides and any other work.

1292. **Expansion Bolts.** — Expansion bolts shall become firmer and firmer the more the strain is increased. Style to be used will vary according to size and weight of materials to be fastened.

1293. **Concrete Sockets.** — Furnish and build into soffits of beams and underside of floor and roof construction where directed adjustable concrete sockets. Sockets are to be accurately placed in proper alignment as directed and nailed or bolted to forms as may be required to secure them in position until concrete is placed, and all nails to be removed when forms are taken down.

1294. **Anchors for Gas-pipe Railings.** — Build in all anchors around stairs, area ways, etc., for gas-pipe railings.

1295. **Angles Over Windows and Doors.** — Build in steel angles specified for support of brickwork over windows and doors.

1296. **Wall Ties.** — The Contractor shall build into the outer face of beams and girders located in the outside walls, necessary wire ties for trying the face brickwork. Care must be taken to embed a sufficient number of wire ties, so that brickwork will be thoroughly tied to the concrete. One tie to each brick, every five courses, shall be used unless otherwise specified.

The wire ties shall be at least $\frac{1}{8}$ in. in diameter, with bent ends. One end of the tie is to be placed in the concrete before it has set. Upon the removal of forms, the projecting end of the tie shall be bent at right angles and embedded in the mortar between the bricks.

1297. **Service Pipes.** — Conduits or pipes for conveying electricity, air or gas may be embedded in the concrete except in columns, provided they are of such size and so placed as not to weaken the structure or its fireproofing in any way.

1298. **Pipes Conveying Liquids.** — Pipes conveying liquids in any form are not to be embedded in any part of the structural concrete except as may be necessary to pass through floors and walls.

1299. **Pipe Sleeves.** — Build in all necessary sleeves for piping, conduits, outlet boxes and ducts provided under mechanical equipment. The plumber, heating contractor, electrician and sprinkling contractor will furnish their own pipe sleeves and will set same, but the concrete Contractor is to bore all holes and do all cutting of form work necessary for their installation in their proper position under their direction and is to take every precaution to prevent their being displaced during concreting. The cement must be neatly finished around the pipe sleeves.

1300. **Door Guards, etc.** — Build in steel door guards, sills, thresholds, wheel guards, etc., furnished by the Steel Contractor. Angle nosings for all elevator floor openings are to be concreted in.

2. Concrete Floors and Wearing Surfaces

1301. **Basement Floors.** — Basement floors shall be laid on a bed of cinders or gravel or sand carefully compacted and at least six (6) inches in thickness.

A concrete base composed of one part Portland cement to three parts of sand to five parts of broken stone or gravel shall be placed upon the subbase of cinders, gravel, etc. The thickness of this base should be at least 3½ inches thick.

Care should be taken to maintain rectangular slabs of uniform thickness.

1302. **Granolithic Finish.** — A granolithic finish of at least ½ in. of cement mortar, composed of one part Portland cement to two parts of sand or crushed rock, preferably trap or granite, shall be applied immediately following the placing of the under concrete.*

In placing the finish, great care must be taken to get a proper bond between the concrete and the granolithic finish. The concrete must be thoroughly cleaned, and just before the finish is ready to be applied, a neat cement paste should be rubbed into the concrete with a steel brush.

The floor should be kept moist for not less than two weeks.

The finish must conform to the specifications and the drawings.

1303. **Hollow Tile and Joist Construction.** — Tile and joist construction shall consist of reinforced concrete joists with hard burned hollow tile filling between of sizes marked on the plans and the whole covered with concrete on top to thicknesses called for on schedule, this being poured with the joists and considered as a part of the construction.

Where hollow tile is used with the floor system, it shall be of the best quality, vitrified clay, and having walls and webs not less than ¾ in. thick. The exterior surface of tiles shall be scored to give greater adhesion.

The bottom of the tile should in no case be broken, but a slight break in the upper part is not objectionable, provided that the concrete is allowed to flow into the same.

* The granolithic or cement finish can be placed directly upon the concrete slab at the time it is put in place, or, if this is not practical, the slab can be swept clean, washed with dilute muriatic acid, the acid thoroughly removed by washing with water, and the top coat worked on. This method is successful when care is used in the application and workmanship of the top finish. Usually the finish is 1 inch in thickness, and sometimes in house work brass sockets are inserted at or near the corners of rooms so that the rugs may be secured in place.

The tile must be placed regularly at equal distances apart, and absolutely straight and true for the reception of sleepers, etc., and at such distances as shown on drawings. The tile is generally spaced, four or five inches apart. A wooden strip of the proper width should be laid between the lines of tile when a new line is being laid to serve as a spacer, and also to get the proper alignment. When the line of tile has been spaced, the spaces can be removed and used on the adjacent line. Under no conditions should the joist between two rows of tile be made crooked or with non-parallel sides. It is advisable, in placing the tile, that the long lengths be placed in the center of the span and the joints be made to alternate in the adjoining rows.

Care must be taken in placing the concrete between the tile, so that at least a full inch is filled in over the entire bottom before the steel is placed in position. Care must be taken to form T-shaped beams by stopping the rows of tile back from the edge of the beams as shown on drawings, and covering the ends of tile with tin to prevent the concrete from flowing into same.

The tile must be thoroughly wet before placing the concrete, especially in warm weather.

Concrete on top of tile floor construction must be placed at the same time as concrete grout is poured.

Even where concrete is not specified to go on top of the tile the Contractor shall allow enough concrete in the joist to flow over the whole top surface of the tile for a thickness of about ¼ in.

*Wood Top Flooring**

1304. **Base.** — The concrete floor shall be brought up to within two inches of its ultimate thickness.

1305. **Nailing Strips or Sleepers.** — Two-inch by three-inch beveled-edge planed nailing strips shall then be accurately placed in parallel lines 18 ins. apart and running at right angles to the girders.

1306. **Cinder Concrete Filler.** — Cinder concrete, composed of one part Portland cement to eight parts of cinders, shall then be poured between the wood sleepers, using them as screeds in leveling the top surface. The cinder fill shall be thoroughly tamped and brought to a true level flush with the top of sleepers, or just below their top, as may be directed by the Engineer. Care must be used not to move the sleepers from their true level, and where they are so moved, they must be restored to their level or otherwise leveled up. Care must also be taken to see that the

* When a wood floor is desired, and this would ordinarily be in house construction, two-inch by three-inch sleepers may be laid, 18 inches center to center. Sometimes nails are driven in the side of the sleeper and the space between is filled with cinder concrete, this being made level with the top of the sleepers. Either a rough floor to receive a fine hardwood floor, or the finished floor, is laid directly upon the sleepers. It would be better in house construction, if the finished floor is to be laid directly upon the sleepers, to paint the back of the flooring, so that any moisture that may remain in the sleepers or in the cinder concrete will not warp and twist the flooring.

sleepers are thoroughly embedded in the cinder concrete without any voids.

1307. **Plank Sub-Floor.** — On top of the sleepers and at right angles to them shall be spiked square edged plank planed on one side and both edges, 3 ins. thick and 7 to 10 ins. wide. These planks shall run across the building, tightly drawn up and nailed with two 4-in. wire nails at each bearing. These planks shall not exceed three different widths in the entire lot and not over 10 ins. wide. The ends of the planks shall meet halfway between the sleepers.

Note: This sub-flooring should be omitted for office buildings and the top flooring laid directly upon the sleepers.

1308. **Maple Top Flooring.** — The finished flooring shall be of clear stock maple, 1 in. thick before planing, thoroughly air and kiln-dried and not over 4 ins. wide. The flooring shall be planed on one side to an even thickness the edges and ends squared, making each board the same width the entire length, and the under-side double-channeled or plowed. All ends must be matched.

1309. **Laying Maple Flooring.** — Finished floor shall be laid at right angles to the sub-floor and each board neatly fitted at the ends, breaking joints at random for every course of boards.

This flooring shall not be taken into the building or laid until the walls and sub-floor plank are thoroughly dried out.

1310. **Nailing.** — The finished floor shall be nailed with ten-penny or 3-in. wire floor nails in diagonal rows 14 ins. across the boards with two nailings in each row in every board. All nails shall be set and all standing joints shall be finished off perfectly smooth on completion.

3. Concrete Roofs and Gravel Roofing

1311. **Expansion Joints.** — The surface of the reinforced concrete roof shall be divided into blocks in setting from 10 to 15 ft. in either dimension by a thin $\frac{3}{8}$-in. wood strip resting on the reinforcement. The strip to be removed when the concrete has set and later, the slot shall be cleaned out and filled with special selected asphaltic compound.

The same sort of a joint may be carried around skylights and scuttle curbs.

1312. **Saddles for Roofs (Cinder Concrete).** — All saddles or slopes necessary to properly drain the roof to the outlet boxes and which are not provided by the slopes of the reinforced concrete and the roof shall be made with cinder concrete fill, thoroughly tamped, brought to even surfaces and finished with a $\frac{1}{2}$-in. finish ready for the roofing.

1313. **Float Finish.** — The concrete roof shall receive a float finish before applying the tar and gravel roofing. The cement finish shall be composed of (1) part Portland cement to (2) parts sand put on while the concrete is green and thoroughly troweled to form a hard, durable finish for roofing. The float finish shall be $\frac{1}{2}$ in. thick.

Slag or Gravel Roofing

1314. **Construction.** — The best grades of slag or gravel roofing will consist of four or five plies or thicknesses of heavy tarred roofing felt laid on a roof and thoroughly mopped between each sheet with a good even coat of straight-run coal tar pitch, and on top another good coat of pitch which while hot is covered with clean screened hard slag or gravel.*

1315. **Definite Specification.** — The engineer or architect should give a full, definite specification for slag or gravel roofing, giving in detail the amount of felt to be used and the number of plies, the amount of pitch and slag or gravel to be used per square of roofing.

1316. **Weight of Composition Roofing.** — The felt shall weigh at least 14 lbs. per 100 sq. ft. for each ply and from 100 to 120 lbs. of pitch shall invariably be used for each square of roofing and about 300 lbs. of slag or 400 lbs. of gravel shall be required per square.

1317. **Fastening Felt.** — If the roof is laid over concrete the concrete shall be thoroughly coated with pitch and the felt then laid; if laid over sheathing boards, the felt shall be carefully secured with round tin disks and substantial barded wire nails.

4. Stairs, Partitions, Etc.

1318. **Stairs.** — Stairs are to be constructed according to details and each run or flight shall be made a unit.

The forms for faces of risers to be lined with sheet metal bent to form rounded nosing as directed.

The treads and landings are to be finished with ½-in. coat of 1 to 2 Portland cement mortar put on while the concrete is still green and smoothly troweled.

Treads are to have slight outward pitch.

5. Sidewalk Lights

1319. **In General.** — The sidewalk lights shall be constructed of reinforced concrete and no metal shall be exposed in the construction. The construction shall consist of a flat or slab portion with ribs on under side between every two rows of glass in one direction.

1320. **Thickness of Glass.** — The glass shall not be less than one inch thick and always of full thickness of slab. In reflecting prisms, the reflecting part shall be entirely below the level of bottom of slab.

1321. **Ribs.** — The ribs shall not be less than 3½ inches deep, and shall run in the direction in which the light is to be thrown.

* In placing a prepared roofing or a 4- or 5-ply slag and gravel roof it is the usual practice to smooth over the top of the cinder concrete forming the slope of the roof with cement mortar, so as not to have any projecting stones or edges of aggregates, which are likely to cut through the felt. The first layer of felt is well secured to the concrete with hot pitch. This has always been sufficient to hold the roofing in place. Gussets should be built up around all the parapet walls, and the felt run up and under some form of coping tile, or else in cheaper work, fastened under a cleat which is secured to nailing strips left in the concrete.

1322. **Reinforcement.** — The main reinforcement shall be held in the center of each rib by wire yokes, one for each glass. The reinforcement perpendicular to the ribs shall be $\frac{3}{16}$-inch rods between each two rows of glass.

1323. **Proportion of Concrete.** — The concrete shall consist of one part of first-class Portland cement and one and one-half parts of coarse, clean sand.

1324. **Expansion Joints.** — The paving shall be divided into suitable sections or panels, and these shall have copper expansion joints between the sections to enable them to expand and contract without danger of leakage or strain.

1325. **Carrying Capacity.** — The pavement shall be able to carry 300 lbs. per square foot of uniform load without permanent injury to the paving.

1326. **Guarantee.** — This work shall be guaranteed against leakage and against defects of workmanship or material for three (3) years.

Art. 61. Test Pieces and Loading Tests

1327. **Test Pieces.** — A test cube, in the case of slabs 6 by 6 by 6 ins. and in the case of beams 12 by 12 by 12 ins. shall be made each day. Each cube shall be dated. These cubes will be poured in boxes and will be used to approximately determine the condition of the work before the forms are removed. Care shall be used to see that each cube is exposed to conditions approximating the exposure of the portion of the work to which it refers.

1328. **Test Pieces (Alternate Clause).** — Samples of concrete shall be taken from the wheelbarrows as it is being transported to the forms and tested in 8-in. cylinders, 16 ins. long, to ascertain the crushing strength, as directed by the Engineer.

1329. **Tests of Finished Work.** — The Contractor will be required to make load tests on any unit area of the reinforced concrete construction sixty (60) days after the completion of the building. Such tests shall be made as directed by the Engineer.*

1330.. **Number of Tests.** — These loading tests will not generally exceed one for each floor, although the Engineer reserves the right to repeat tests as often as may be deemed necessary.

1331. **Loading.** — Single panels shall be loaded to twice the specified live load plus one-half the dead load of the finished area.†

1332. **Deflections.** — The deflection under the above loading shall not exceed $\frac{1}{400}$ part of the span or length of member tested. Deflectometers are to be used.

* Load tests on portions of the finished structure should invariably be made where there is reasonable suspicion that the work has not been properly performed, or that, through influences of some kind, the strength has been impaired.

† Loading shall be carried to such a point that one and three-quarters times the calculated working stresses in critical parts are reached, and such loads shall cause no injurious permanent deformations. — Joint Committee, Dec., 1912.

1333. **Signs of Failure.** — The floor shall sustain the above loading for at least twenty-four (24) hours without cracking or other evident signs of failure. In other words, there shall be no perceptible cracking of the under side of the concrete. The floor must return to its normal position after removal of load.

1334. **Costs of Tests.** — The above tests are to be made at the Contractor's expense.

1335. **Failure of Structure Under Test Loading.** — Should any portion of the construction fail to meet the above tests through defective workmanship or material in concrete, the Contractor will be required to remove such defect and provide construction adequate for proper fulfillment of this service for which this structure is intended at his own sole cost and expense, and without cost to the Owner.

1336. **Commissioner of Public Buildings.** — If loading tests are considered necessary by the Commissioner of Public Buildings, they shall be made in accordance with his instructions.

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NOTE: — For additional References to Reinforced Concrete Building Construction and Design, see Art. 57, page 227.

APPENDIX A

SUGGESTED FORMULAS FOR REINFORCED CONCRETE CONSTRUCTION

These formulas are based on the assumptions and principles given in Chapter VII, Arts. 41, 43, 44 and 45, and are taken from the Progress Report of Special Committee on Concrete and Reinforced Concrete, Proc., Am. Soc. of C. E., vol. 29, pp. 163–168, Feb., 1913.

(a) *Standard Notation*

1. *Rectangular Beams.*

The following notation is recommended:

f_s = tensile unit stress in steel.
f_c = compressive unit stress in concrete,
E_s = modulus of elasticity of steel,
E_c = modulus of elasticity of concrete,
$n = \frac{E_s}{E_c}$,
M = moment of resistance, or bending moment in general,
A = steel area,
b = breadth of beam,
d = depth of beam to center of steel,
k = ratio of depth of neutral axis to effective depth d,
z = depth of resultant compression below top,
j = ratio of lever arm of resisting couple to depth d,
$jd = d - z$ = arm of resisting couple,
p = steel ratio (not percentage).

2. *T-Beams.*

b = width of flange,
b' = width of stem,
t = thickness of flange.

3. *Beams Reinforced for Compression.*

A' = area of compressive steel,
p' = steel ratio for compressive steel,
f_s' = compressive unit stress in steel,
C = total compressive stress in concrete,

C' = total compressive stress in steel,
d' = depth to center of compressive steel,
z = depth to resultant of C and C'.

4. *Shear and Bond.*
V = total shear,
v = shearing unit stress,
u = bond stress per unit area of bar,
o = circumference or perimeter of bar,
Σ_0 = sum of the perimeters of all bars.

5. *Columns.*
A = total net area,
A_s = area of longitudinal steel,
A_c = area of concrete,
P = total safe load.

(*b*) *Formulas*

1. *Rectangular Beams.*

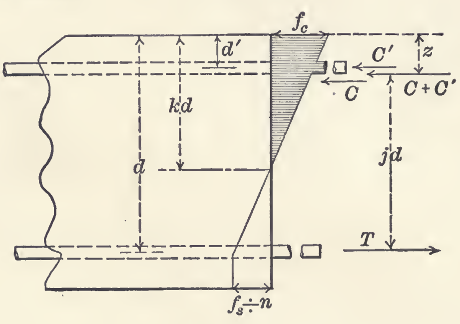

Fig. 1.

Position of neutral axis,

$$k = \sqrt{2\,pn + (pn)^2} - pn. \quad (1)$$

Arm of resisting couple,

$$j = 1 - \tfrac{1}{3}k. \quad (2)$$

(For f_s = 15,000 to 16,000, and f_c = 600 to 650, k may be taken at $\tfrac{3}{8}$.)

Fiber stresses,

$$f_s = \frac{M}{Ajd} = \frac{M}{pjbd^2}. \quad (3)$$

$$f_c = \frac{2\,M}{jkbd^2} = \frac{2\,pf_s}{k}. \quad (4)$$

Steel ratio, for balanced reinforcement,

$$p = \frac{1}{2} \frac{1}{\frac{f_s}{f_c}\left(\frac{f_s}{nf_c} + 1\right)}. \quad (5)$$

2. *T-Beams.*

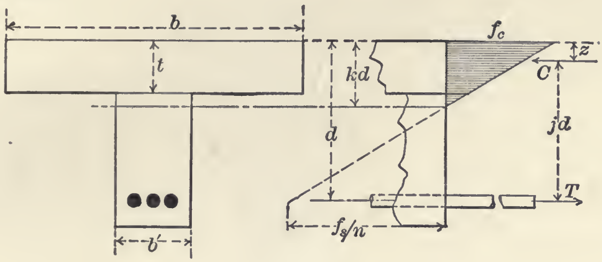

FIG. 2.

Case I. When the neutral axis lies in the flange.
Use the formulas for rectangular beams.

Case II. When the neutral axis lies in the stem.
The following formulas neglect the compression in the stem:
Position of neutral axis,

$$kd = \frac{2\,ndA + bt^2}{2\,nA + 2\,bt}. \qquad (6)$$

Position of resultant compression,

$$z = \frac{3\,kd - 2\,t}{2\,kd - t}\,\frac{t}{3}. \qquad (7)$$

Arm of resisting couple,

$$jd = d - z. \qquad (8)$$

Fiber stresses,

$$f_s = \frac{M}{Ajd}. \qquad (9)$$

$$f_c = \frac{Mkd}{bt\,(kd - \frac{1}{2}t)\,jd} = \frac{f_s}{n}\,\frac{k}{1-k}. \qquad (10)$$

(For approximate results, the formulas for rectangular beams may be used.)

The following formulas take into account the compression in the stem; they are recommended when the flange is small compared with the stem:
Position of neutral axis,

$$kd = \sqrt{\frac{2\,nd\,A + (b - b')\,t^2}{b'} + \left(\frac{nA + (b - b')t}{b'}\right)^2} - \frac{nA + (b - b')t}{b'}. \qquad (11)$$

Position of resultant compression,

$$z = \frac{(kdt^2 - \frac{2}{3}\,t^3)\,b + [(kd - t)^2\,(t + \frac{1}{3}\,(kd - t))]\,b'}{t(2\,kd - t)\,b + (kd - t)^2\,b'}. \qquad (12)$$

Arm of resisting couple,

$$jd = d - z. \qquad (13)$$

Fiber stresses,

$$f_s = \frac{M}{Ajd}. \quad (14)$$

$$f_c = \frac{2\,Mkd}{[(2\,kd - t)\,bt + (kd - t)^2\,b']\,jd}. \quad (15)$$

3. *Beams Reinforced for Compression.*

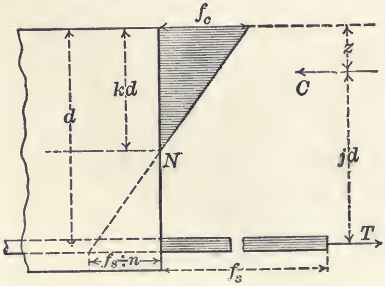

FIG. 3.

Position of neutral axis.

$$k = \sqrt{2\,n\left(p + p'\frac{d'}{d}\right) + n^2\,(p + p')^2} - n\,(p + p'). \quad (16)$$

Position of resultant compression,

$$z = \frac{\frac{1}{3}\,k^3d + 2\,p'nd'\left(k - \frac{d'}{d}\right)}{k^2 + 2\,p'n\left(k - \frac{d'}{d}\right)}. \quad (17)$$

Arm of resisting couple,

$$jd = d - z. \quad (18)$$

Fiber stresses,

$$f_c = \frac{6\,M}{bd^2\left[3\,k - k^2 + \frac{6\,p'n}{k}\left(k - \frac{d'}{d}\right)\left(1 - \frac{d'}{d}\right)\right]}. \quad (19)$$

$$f_s = \frac{M}{pjbd^2} = nf_c\frac{1 - k}{k}. \quad (20)$$

$$f_s' = nf_c\frac{k - \frac{d'}{d}}{k}. \quad (21)$$

4. *Shear, Bond, and Web Reinforcement.*

In the following formulas, Σ_0 refers only to the bars constituting the tension reinforcement at the section in question, and jd is the lever arm of the resisting couple at the section.

For rectangular beams,

$$v = \frac{V}{bjd}. \qquad (22)$$

$$u = \frac{V}{jd\,\Sigma_0}. \qquad (23)$$

(For approximate results, j may be taken at $\frac{7}{8}$.)

The stresses in web reinforcement may be estimated by the following formulas:

Vertical web reinforcement,

$$P = \frac{Vs}{jd}. \qquad (24)$$

Web reinforcement inclined at 45° (not bent-up bars),

$$P = 0.7\frac{Vs}{jd}. \qquad (25)$$

in which P = stress in single reinforcing member, V = amount of total shear assumed as carried by the reinforcement, and s = horizontal spacing of the reinforcing members.

The same formulas apply to beams reinforced for compression as regards shear and bond stress for tensile steel.

For T-beams,

$$v = \frac{V}{b'jd}. \qquad (26)$$

$$u = \frac{V}{jd\Sigma_0}. \qquad (27)$$

(For approximate results, j may be taken at $\frac{7}{8}$.)

5. *Columns.*

Total safe load,

$$P = f_c(A_c + nA_s) = f_cA(1 + (n - 1)p). \qquad (28)$$

Unit stresses,

$$f_c = \frac{P}{A\,(1 + (n - 1)p)}. \qquad (29)$$

$$f_s = nf_c. \qquad (30)$$

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