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LOCOMOTIVE DESIGN

By GEO. L. FOWLER and CARL J. MELLIN

Part IV

SPRINGS, TRUCKS, CAB, AND TENDER

SECOND EDITION

CONTENTS

49-55 Lafayette Street, New York City

CHAPTER I

SPRING RIGGING AND EQUALIZERS*†

The proper distribution of the weights on the wheels should be considered as soon as the type of engine and the service which it is to perform have been decided upon. The weight that can be placed upon each wheel is limited by the rail, the bridges on the line and the general features of the track construction. In this distribution of the weight the method of spring suspension and equalization plays an important role, and it must be so designed that a safe load, or one that will hold the truck wheels down on the rails under all conditions of speed and track curvature, is put on them, while that on the driving wheels must be sufficient to give them the proper adhesion for the development of the required power.

It may be stated that in a general way the number and size of the driving wheels are chosen in connection with the allowable weights on the same according to the service performed, while the size of the cylinders is determined by the weights and dimensions chosen. The cylinder dimensions and boiler pressures are so proportioned that the power exerted at the rail, which is expressed by the following formula, shall fall between 22 and 23 per cent of the total load on the driving wheels:

$$T = \frac{d^2 \times 0.85\, p\, S}{D} \qquad (1)$$

in which

T = the tractive power,
d = diameter of cylinders,
p = the boiler pressure,
S = stroke of piston in inches,
D = diameter of driving wheels in inches.

When these figures have been decided upon, a skeleton drawing of the engine is prepared by which the weight and its distribution is outlined, and here the locomotive designer's judgment and experience are called into play. The layout is afterward carefully checked by a calculation of the weights of the various parts and their moments with reference to the center of the truck when a four-wheeled bogie is used; otherwise they are taken from the center of the cylinder.

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* The present number of MACHINERY'S Reference Series is the fourth part of a treatise on complete Locomotive Design, covered by Nos. 27, 28, 29, and 30 of the Series, and originally published in RAILWAY MACHINERY (the railway edition of MACHINERY). Each of the four parts of the complete work treats separately on one, or more, special features of locomotive design; and while the four parts make one homogeneous treatise on the whole subject, each part is complete by itself. In order to give concrete form to the examples and theoretical considerations, it is assumed that a consolidation freight locomotive and an Atlantic type passenger engine are being designed. It is further assumed that these locomotives are designed for a division 150 miles long, laid with rails weighing 75 pounds per yard, and with a ruling grade of one per cent ten miles in length.

† MACHINERY, Railway Edition, August, 1906.

When the desired weight of engine has been obtained, the wheels should be so arranged that they form two groups or systems of supports. The one at the front should be cross equalized so that the center of support falls in the center line of the engine. This is very readily accomplished where a four-wheeled truck is used at the front and takes care of the front system. All of the remaining wheels are then included in the system for the rear. When these can be equalized on each side so as to form three points of suspension, ideal conditions have been obtained. This can be readily accomplished in the case of eight- or ten-wheeled engines.

When the rear system is entirely composed of driving wheels, as in the case of the engines just mentioned, the momentum of the load falls along the line of the center of gravity of the axle support. But, when trailing wheels, carrying a lighter burden, as in the case of the Atlantic engine, are used, it falls along a resultant line of these several centers. It is then necessary to so adjust the wheel base that the weight is carried on a line coinciding with the resultant axle centers of gravity.

In the case of mogul or consolidation locomotives where a two-wheeled truck is used at the front, one or two pairs of the forward drivers are equalized with it. The common supporting point of the system is brought to the center of the engine by a transverse equalizer, usually placed on a line with the front end of the forward driver springs, and this coincides in its longitudinal center, as it crosses the engine, with the center of gravity of that portion of the machine and load that it is proposed to carry on the forward system of suspension. The center of the load of the rear system falls, as in the previous case, in the center of its wheel base if the wheel spreads are equal; otherwise in the center of gravity of its respective axle supports.

With these points known, as well as the distance between them, together with the weight of the engine above the axles, the design should be modified by the shifting of the boiler and other parts, so as to bring the load on the proper centers in a way to secure the desired distribution on the axles. The weights of the several parts should be calculated with all possible accuracy, especially where this data regarding the parts of an earlier engine are not available for comparison; and for this work no short-cut rule can be given.

The weight on the axles having been determined, the next point is to ascertain the size of the springs to carry the load, which is equal to that on the axles, less the weight of the driving boxes, spring saddles, and the springs themselves. This is found by means of the following formula:

$$P = \frac{S\,b\,h^2\,n}{6\,l} \qquad (2)$$

in which

P = load on one end of the spring,
S = allowable fiber stress in the steel, usually put at 80,000 pounds,
b = width of spring leaves,
h = thickness of spring leaves,

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n = number of spring leaves,

l = length of spring from edge of spring band to point of spring hanger bearing, as indicated by Fig. 1.

In this P is, of course, equal to one-half the total load on the spring.

For ease of riding, the leaves should be made as broad as possible, and experience shows that a length of from 36 inches to 42 inches from one point of suspension to the other is that best adapted to locomotive work, though this is, of course, to be governed by circumstances and the conditions surrounding the design, which may involve the use of either a longer or shorter spring. As for the thickness of the leaves, that varies from 3/8 inch to 7/16 inch.

The spring when first made must have a certain amount of free height or set, so that, when the load has been applied, it will deflect to a point best adapted to the carrying of the load. This deflection may be found by the formula:

$$F = \frac{6\,P\,l^3}{E\,b\,h^3\,n} \qquad (3)$$

in which

F = the deflection,

E = modulus of elasticity of the steel, which may be put at 31,500,000.

The other symbols have the same significance as in the case of Formula (2).

For the helical springs that are frequently used at the extremities of the spring suspension, the total carrying capacity is calculated by the formula:

$$P = \frac{S\,\pi\,d^3}{8\,D} \qquad (4)$$

in which

d = diameter of steel of which the spring is made,

D = diameter of coil to center of steel.

The other symbols are the same as in Formula (2).

The diameter of the steel to be used thus becomes:

$$d = \sqrt[3]{\frac{8\,P\,D}{\pi\,S}}$$

The deflection of the helical springs will be

$$F = \frac{8\,P\,D^3}{\pi\,G\,d^4} \qquad (5)$$

in which G is the modulus of elasticity for torsion, and may be put at 12,000,000, or

$$F = \frac{D\,S\,l}{d\,G} \qquad (6)$$

Finally the length of the wire between end coils will be found by the formula:

$$L = \frac{F\,G\,\pi\,d^4}{8\,P\,D^2}, \text{ or } \frac{F\,d\,G}{D\,S} \qquad (7)$$

in which the significance of the symbols remains as before.

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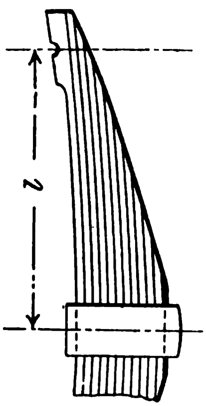

Fig. 1. Diagram for Use with Formula (2)

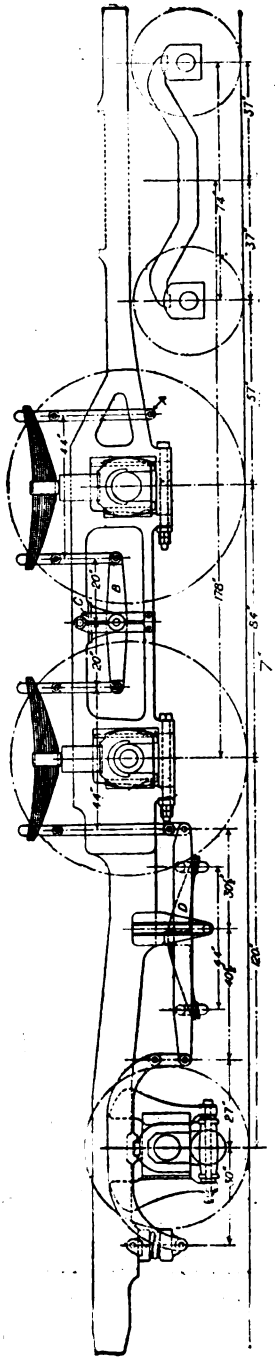

Fig. 2. Spring Rigging for Atlantic Type Passenger Locomotive

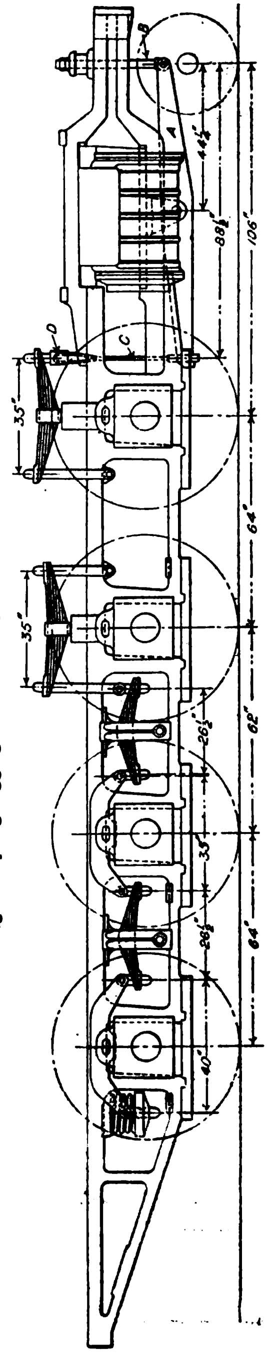

Fig. 3. Spring Rigging for Consolidation Type Freight Locomotive

Figs. 2 and 3 illustrate the manner in which the principles that have thus been laid down have been followed in the case of the two engines, the designing of which we are here following. On the Atlantic locomotive (Fig. 2) there are two systems of equalization: One at the front cared for by the four-wheeled truck, and which is not shown in detail, as the load is carried on the center plate and needs no further explanation. In the rear system, there are four points of support for the frame. Starting at the front, the forward spring hanger carries the frame at the point *A* and transmits the load sustained at that point to the semi-elliptic spring set on the axle box. A hanger dropping down from the rear of this spring takes hold of the equalizer *B*, which is pivoted at its central point on the fulcrum *C* and serves to sustain its portion of the load.

In the same way the stresses are transmitted to and through the spring over the rear driver and down to the equalizer *D*, which forms the connection between the rear driver and the trailing truck wheel. At this point the overhang of the firebox makes it impossible to place the semi-elliptic springs above the frame, so the equalizer is made of two bars, and a spring shorter than the distance between the supporting hangers is used. This is also done in order that the spring may not be of excessive weight and length. The rear axle box is fitted with a yoke, at the back end of which the helical spring for supporting the rear frame is placed. In this suspension every point of support is a pivot, and there are no rigid connections. Hence there can be no variation from the proportioned distribution of the weights.

For example, it is evident that the load carried by the forward spring hanger at *A* must be equal to that on the rear hanger of the same spring, otherwise the spring would be tipped down toward the hanger with the greatest load upon it. This would extend back through the whole system of suspension. If such a tilting should occur toward the front, for example, that action would then tilt the intermediate equalizer *B*, which would put an additional stress upon the forward hanger of the rear driver spring. Such an additional load would be transmitted on to the helical spring at the back, which would at once resist further compression by adding to the weight it was normally lifting and thus check any tendency of the whole system to tilt by sending forward to the point *A* a greater lifting power, and thus, by increasing the stresses on the forward hanger, equalize the system and distribute the proper proportion of load among all of the points of support.

In order to perform the supposititious work of this engine, as stated in the foot-note on page 3, one weighing 167,000 pounds, with 23,000 pounds on each driving wheel, would have to be offered. This leaves 75,000 pounds to be distributed between the trailing wheel and the front truck. In proportioning the rear equalizer, the two arms have been so designed that a load of 18,500 pounds is put upon each of the trailing wheels, leaving 38,000 pounds to be carried by the front truck. These weights include those of the wheels, so that the actual load on the springs will be less by the amount of the weights of the wheels, axles, boxes and springs. As the total of these weights will amount to about 13,000 pounds for the driving wheels, with their axles and boxes, and 9000 pounds for the trailing wheels, with the same connections, the springs with the arrangement shown must provide for sustaining a total load of 107,000 pounds. As part of the load is carried twice, so to speak, due to the equalizing arrangement, the various springs will be loaded as follows:

Driver box springs, each	19,750 pounds
Intermediate driver and trailing truck equalizer spring	17,275 pounds
Trailing truck helical spring	6,600 pounds

In these weights the total load on both ends of the spring is given, so that in the calculation of the same, the figures must be divided by two as already stated.

The suspension for the consolidation locomotive is shown in Fig. 3. Starting with the forward driver, equalization is accomplished by means of the equalizer *A* with a bearing on the bottom of the saddle casting on the center line of the engine. At the front this equalizer is suspended and pulls down upon a bolt *B* whose upper end rests upon a spring cap that is carried by the truck. At the rear it pulls down on the hanger *C*, that is attached to the center of the cross-equalizer *D*, whose outer ends are carried by the hangers coming down from the front ends of the springs. The balance of the equalization of this system is clearly shown by the engraving.

As for the rear system, which includes the three pairs of drivers, it resembles that of the Atlantic engine, except that the springs are of a sufficient length to reach from one driver box yoke to the other, thus taking the place of an intermediate equalizer. In this engine the weight on the drivers may be given as 19,500 pounds each. With the proportions of the forward equalizer shown in Fig. 3, the weight on the two truck wheels would be about 21,000 pounds, so that the total weight of the engine would be 176,000 pounds. By making the same reduction as before for the wheels, axles, and boxes, the weight to be carried by each of the springs becomes 16,300 pounds and they may be calculated accordingly.

The spring strengths are not the only calculations that have to be made in the work of the suspension. This also involves that of the equalizers and hangers. The former can be calculated from the formula for beams supported at the ends and loaded in the middle as follows:

$$b\,d^2 = \frac{18\,P\,L}{S} \tag{8}$$

in which

b = the thickness of the bar,

d = the depth of the bar,

L = distance between hanger connections in feet,

S = safe fiber stress = 8000 pounds for steel castings and 14,000 pounds for wrought iron.

P = load to be carried.

Fig. 4 gives the general proportions for these parts for the Atlantic engine. It is necesasry, however, in the designing of these parts to make them of ample strength to withstand the shocks to which they will be subjected, hence the low fiber stress that has been specified in the schedule for Formula (8).

The spring hangers must also be designed of ample strength; these are not only subjected to a tensile stress that may be applied with more or less suddenness but one which is also constantly varying when the engine is in motion. In this, too, the fiber stress should not be

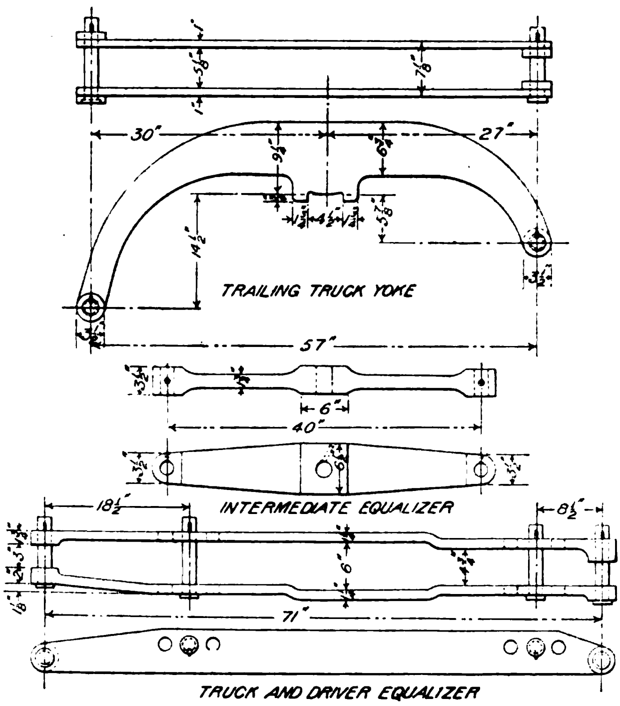

Fig. 4. Yoke for Truck Box and Equalizers, Atlantic Type Locomotive

allowed to exceed 8000 pounds for the static load. Exactly what it will amount to when the engine is in motion is not known, but it is apt to be as much as 50 per cent in excess of the calculated load. Fig. 5 shows a number of types of spring hangers that are used on consolidation and mogul locomotives, including noc only those that are to be found upon the engine under consideration, but some others as well.

In the whole of the spring suspension, as in other parts of American cars and locomotives, nothing is fastened down, but dependence is placed upon the weight to hold the parts in position. The hangers, therefore, rest upon the ends of the springs through the intervention of the hanger gibs, some of the forms of which are shown in Fig. 6. For these no calculation is to be made. They are subjected to a shearing stress only

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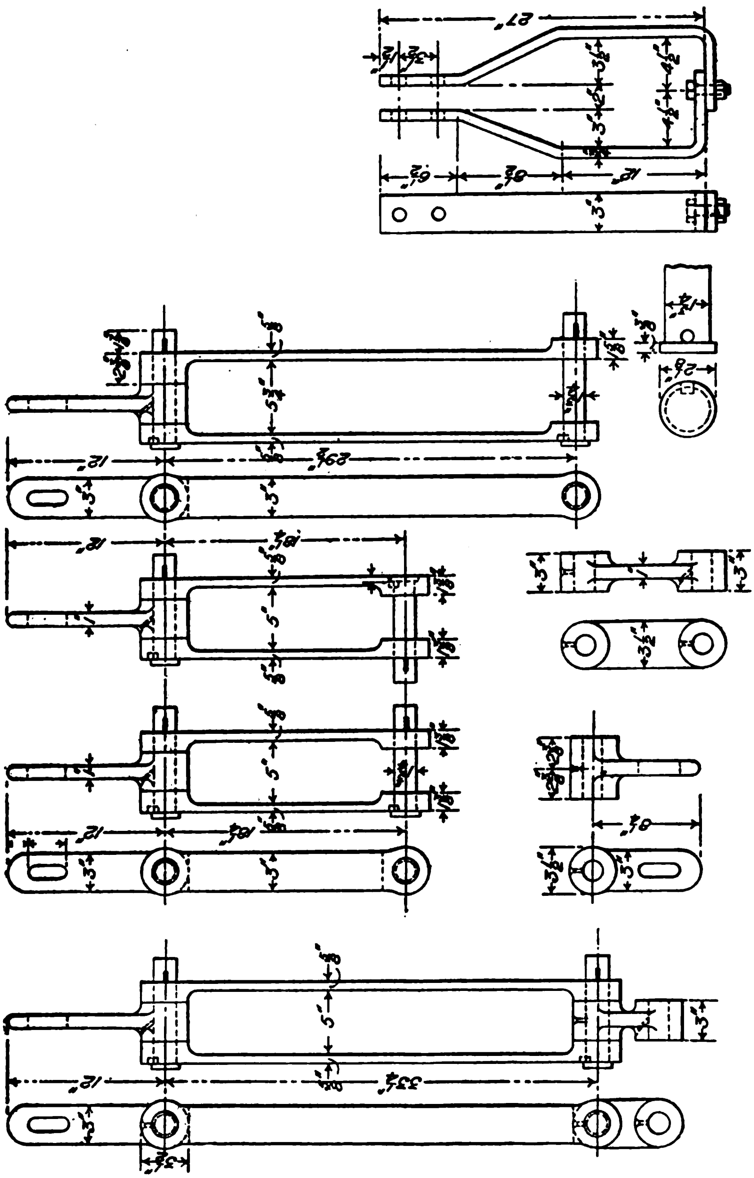

Fig. 5. Spring Hangers for Consolidation Locomotive

and must be made heavy enough to withstand this and allow for a large amount of wear as well. As the latter is the larger item of the two, the actual stress that it put upon the gibs when the engine is new and everything up to its original dimensions, is very small.

It will thus be seen that for a proper adjustment of the spring suspension, great care must be taken so that the center of gravity of the portion that is to be carried by the front or back system of suspension should fall in the proper place. In the case of the Atlantic engine, we have the two driving wheels located 84 inches apart and each carrying 23,000 pounds. The trailing wheel is 120 inches behind them and carries 18,500 pounds. The center of gravity of these three weights falls 0.4 inch back of the rear driver, and that is the point at which the center of gravity of the weight to be carried should be arranged to fall. The same care should be taken in the case of the consolidation locomotive that the center of gravity of the weight carried by the rear system should fall in a line with the next to the rear pair of drivers when these are spaced equal distances apart.

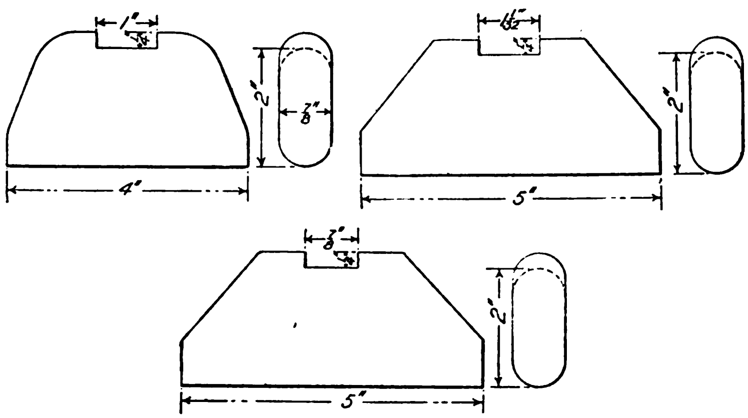

Fig. 6. Spring Hanger Gibs

When these precautions are taken, the engine will not only be easy riding, but there will be far less trouble with the parts of the spring suspension in the way of breakages than where these precautions are ignored.

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CHAPTER II

THE TRUCKS*

The truck is an essentially American characteristic of the locomotive. For many years European locomotives, especially those used in freight service, were built without any truck, and the guiding of the engine was done by the flanges of the front pair of wheels. In this country, however, the truck has always been used upon road engines and has been considered an essential detail in their safe and satisfactory operation.

Broadly speaking, the engine truck proper, or the one located at the front end, may be divided into two classes, the two- and four-wheeled types. The four-wheeled truck is the one that has been universally used on locomotives intended for passenger service, while the two-wheeled has been applied to freight engines, or those that are used, for the most part, in freight service, with an occasional assignment to passenger work. The exclusion of the two-wheeled truck from engines designed for passenger service has been due to the necessity of using a large boiler and so increasing the total weight of the engine beyond the requirements of adhesion represented by the tractive power that it was desired to develop. Under these circumstances the extra weight, beyond that needed for adhesion, could be carried on four wheels to better advantage than on two. As for safety, there is no difference of opinion that the two-wheeled truck is quite up to all the demands of the most exacting service.

In the designing of the trucks there is little else to be done than to secure ample strength to carry the load imposed and arrange for axles and boxes of sufficient bearing surface to do the work required without heating. At the same time care must be taken that sufficient weight is put upon the truck to hold it down and cause it to keep the rails upon the sharpest curves to be encountered, and thus prevent the flanges of the wheels from climbing the rail and causing a derailment when called upon to guide the direction of motion of the machine from a straight line to a curve and through the latter. In the case of the consolidation engine under consideration, as well as upon those of the mogul class, the two-wheeled pony or Bissel truck is used.

The plan of framing this type of truck is shown in Fig. 7, and the details of the working parts in Fig. 8. From these drawings, as well as from a comparison with Fig. 3, it will be seen that the truck is pivoted at the center between the wheels. As this would not hold them in place on the rails, but would allow them to swing into a position approximately longitudinal to the track, if any obstruction were to check the motion of one, a radius bar, *A*, is added that reaches to a point beneath the engine, where it is pivoted on the center point. This

* MACHINERY, Railway Edition, November, 1906.

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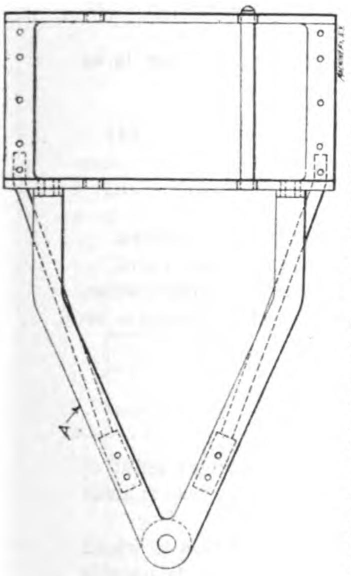
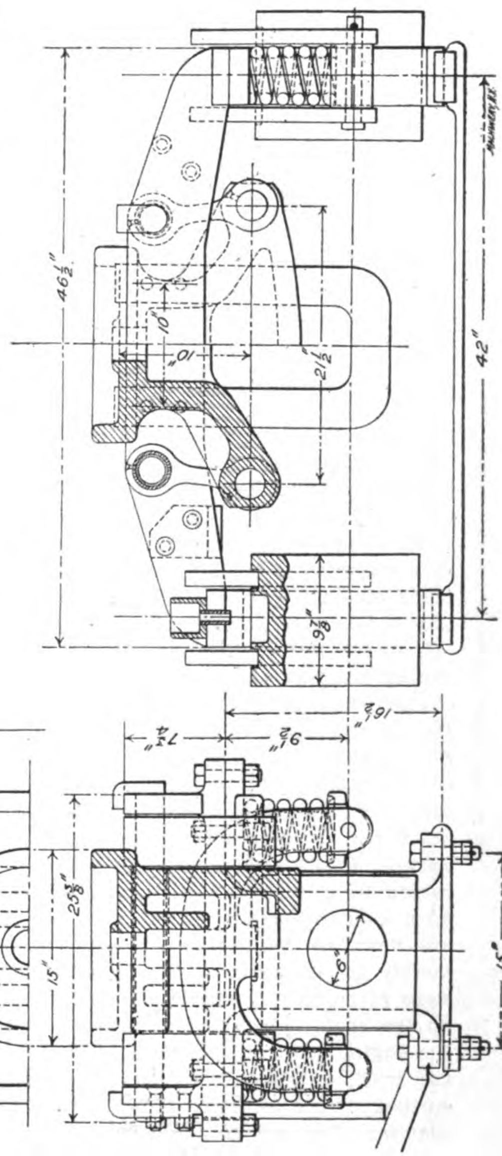


Fig. 7. Outline Plan of Pony Truck Frame for Consolidation Locomotive



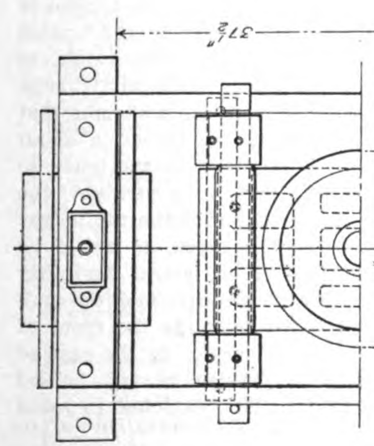


Fig. 8. Pony Truck Frame or Consolidation Locomotive

point is carried back far enough to insure stability of the wheels upon the rails, and at the same time, permit of sufficient side motion to allow the truck to swing out of line with the center of the engine when entering and passing over a curve.

The formula used for calculating the length of the radius bar is as follows:

$$R = \frac{A \times B}{A + B} \times 0.85 \qquad (9)$$

in which

R = the length of the radius bar,

A = the total wheel-base for consolidation and mogul locomotives,

B = the distance from the front driving wheel to the truck wheel.

In the case of the consolidation locomotive under consideration, $A = 314$ inches and $B = 124$ inches. Formula (9) therefore becomes:

$$R = \frac{38{,}936}{438} \times 0.85 = 75.56 \text{ inches.}$$

This, then, may be taken as the distance from the pivotal point of the radius bar to the center of the truck axle, which in this case is made 6 feet 3½ inches.

As the radius bar has no load to sustain and the only stress to which it is subjected is that of holding the wheels on the track, it is usually made of a flat bar of steel about 5 inches by 1¼ inch laid flat and stiffened by round braces rising diagonally from the foot of the pedestals and bolted to the horizontal portion of the bar itself at a convenient distance back of the truck frame.

The design of frame, as shown in Fig. 8, may be taken as typical of that in use upon mogul and consolidation locomotives in the United States, and is of an exceedingly simple construction. The weight of the front end of the engine is carried on the center plate, and this in turn is suspended by the center plate hangers from the transoms that reach across from side to side. These hangers are spread a small amount at the bottom so as to increase the tendency of the truck to return to the central position when coming back to a straight line from a curve. As the center plate and the pivot pin of the radius bar are normally located in the center line of the truck, it would be merely an extension of the rigid wheel base if no lateral flexibility were given to the wheels. It is this lateral flexibility, and the pull on the center plate by the hangers that tends to guide the front of the engine out of a straight line and around a curve. In the case of the truck under consideration, the frame is carried by two helical springs at each side, and these, in turn, rest on seats attached to yokes that set on top of the axle boxes.

We have already noted that the weight on the truck of this engine is to be about 21,000 pounds, or 10,500 pounds on each wheel. In order to carry this load an axle 6 inches in diameter is provided with a journal 9⅞ inches long. This gives a load of about 177 pounds per

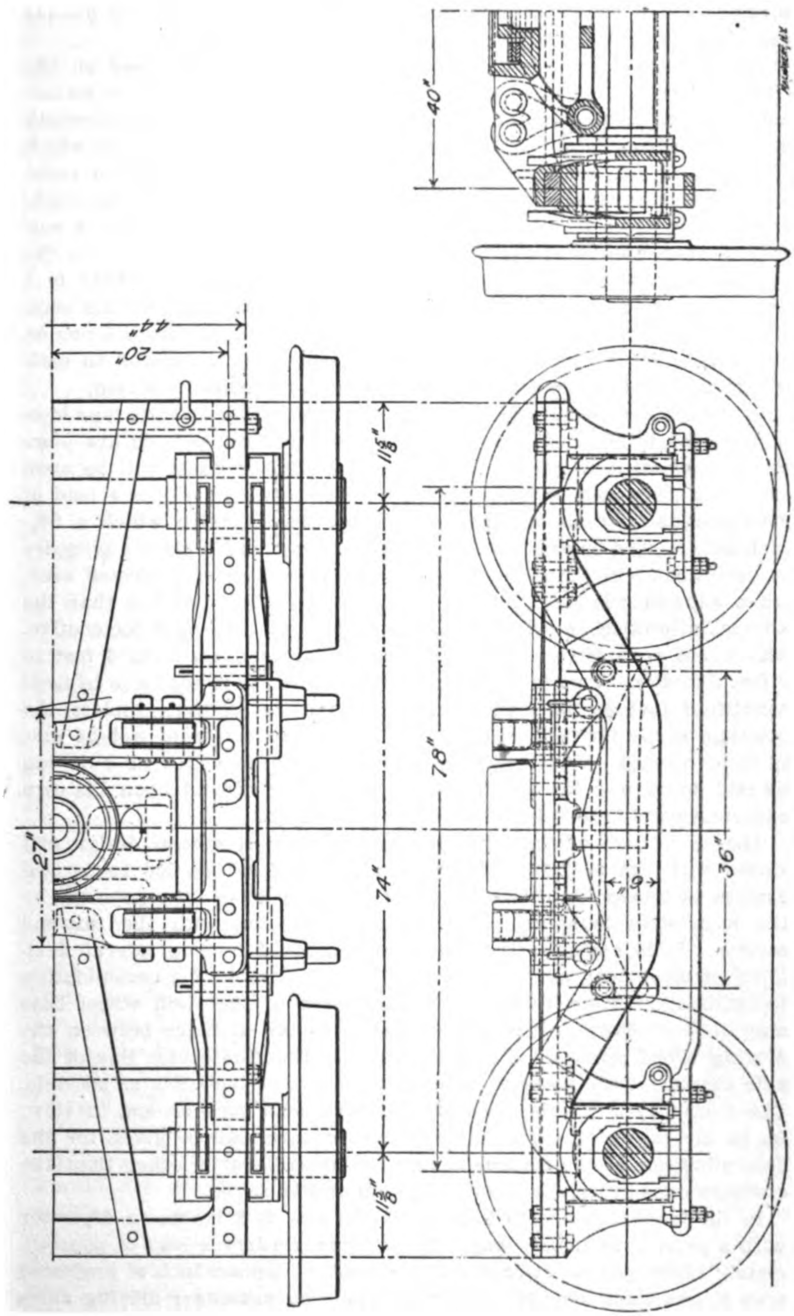


Fig. 9. Four-wheeled Forward Truck for Atlantic Locomotive

square inch of projected area, or somewhat less than the 180 pounds usually allowed for the driving axles of freight locomotives.

The ordinary four-wheeled front truck of locomotives used on the eight-wheeled, ten-wheeled and Atlantic types calls for little or no calculation that is of value other than the determination of the strength of the equalizing bars from which the semi-elliptic springs, upon which the frame rests, are suspended. The front end of the engine rests, through a center plate on the saddle, upon the center plate of the truck. In the particular truck illustrated in Fig. 9, the center plate is suspended from the transoms by hangers in the same manner as in the case of the pony truck for the consolidation locomotive. There is a difference in the form of the hangers, however, in that, in this case, the hangers have two bearings at the top, arranged so that the two on either side act as inclined hangers, and yet remain parallel to each other; this tends to keep the center plate in a horizontal position.

In the calculations of the weight to be given to this Atlantic type locomotive, the total is 167,000 pounds, of which 92,000 pounds are upon the driving wheels. Of the balance, about 38,000 pounds will be upon the front truck and 37,000 pounds upon the rear. This puts a load of 9500 pounds on each of the four forward wheels, with which a 5¾-inch axle is used having journals 12 inches long. This gives a pressure of somewhat less than 140 pounds per square inch of projected area, when allowance is made for the weight of the wheels, or less than the amount allowable on the driving journals of a passenger locomotive. The wheel base of these four-wheeled trucks averages from 6 feet to 6 feet 6 inches. This is a matter that is subject to change due to local conditions such as the diameter and arrangement of the cylinders, the position of the forward pair of drivers, the proportion of weight that is to be carried on the truck, and other items for which no rule can be laid down, and for which the designer must depend upon his own experience and knowledge of the fitness of things.

The rear truck of the Atlantic locomotive is of special design and varies with the builder. This type of locomotive has led to several designs of trucks for this point, most of which have been patented by the locomotive builders or individuals connected with the railroad service. It is essential that the wheels should have a lateral flexibility of movement, as in the case of the pony truck of a consolidation locomotive, in order that the virtual length of the rigid wheel base may be kept down to the actual length, or the distance between the driving wheel centers. It is also desirable that the center line of the axle should remain as near radial to the curve of the track as possible. The trucks used in this place are designed with such an end in view. As in the case of the other trucks, no formulas can be given for the determination of the dimensions of the several parts, other than the ordinary ones in use for beams and similar structures.

In the truck, illustrated in Fig. 10, the axle is 8 inches in diameter with a journal 14 inches long. As this has to carry a load of approximately 18,500 pounds at each end, the load per square inch of projected area is less than the 170 pounds allowable on passenger driving axles when due allowance is made for the weight of the wheels.

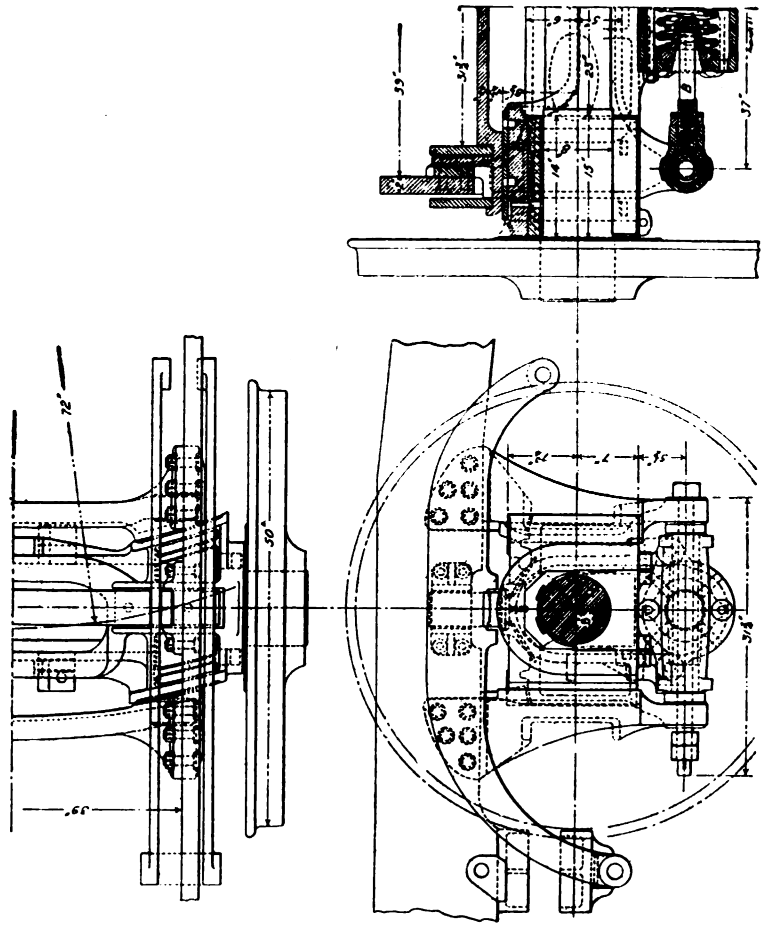


Fig. 10. Radial Trailing Truck for Atlantic Locomotive

The axle is, of course, straight; but the boxes, instead of having their wearing surfaces parallel to its center line, are set in pedestal jaws that are cut at an angle and on a radius of 6 feet. Hence, the transverse movement of the wheels is the same as though they were swinging through the arc of a circle whose center is at the center of curvature of the faces of the pedestals. Owing to this, the wheels are held approximately in a true radial position. The swing of the overhang of the engine beyond the rigid wheel base throws these wheels out of center, and the return of the frame to its central position on a straight track would restore the normal condition of things, but assistance is rendered in overcoming the resistance of the boxes to this movement by a centering spring placed beneath the axle. The pedestals are, of course, rigid transversely with the main frame of the engine and carry the push bars *B*, which bear against followers that are set in castings that move laterally with the boxes. Any movement of the latter, in either direction, compresses the intermediate spring, which thus has a constant tendency to restore the truck to its central position.

It will thus be seen that but very little of a definite guiding nature can be said regarding the designing of the trucks that are to be used under American locomotives. The general design of the pony and the four-wheeled truck has been established by such long usage that it is no longer a subject for discussion. Details are being constantly varied to meet the changing demands of weight, proportions and service, but with no essential change in the main features of the designs.

With the rear truck of the Atlantic, Pacific and Prairie types of locomotives, the case is somewhat different. These locomotives have hardly been in service long enough to have settled down to an established basis of construction in detail and it will probably be a number of years before this will be done. Meanwhile the general principle of the freedom of lateral movement for the wheels, with the approximation to the maintenance of a radial position for the axle has been accepted and acted upon, but beyond this the truck may be said to be in a process of development, though the engines to which it is applicable may be considered as among the standards of American railroad practice.

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CHAPTER III

CAB, CAB FITTINGS, AND ACCESSORIES*

As the cab contains all of the various means that are required for the operation of the engine, the greatest care is exercised to so place them that they are all of easy access to the operator. No absolute rule can be laid down for the arrangement of these several fittings, except to say that, in a general way, the planning is to be done for the convenience of operation and the comfort of the men in the cab. It therefore becomes largely a matter of good judgment on the part of the designer or of the choice of the purchaser, and is further dependent, to a great extent, upon the space available and other conditions appertaining to the form and construction of the appliances that are to be used. These include the injectors, lubricators, engineer's brake valve, gages, etc., which are usually bought from manufacturers who make a specialty of such supplies.

Formerly the cab was invariably built of wood, strongly braced, and so constructed that it could be lifted from its place and set aside for painting and repairs while the engine itself was in the repair shop. The advantages claimed for the wooden cab were that it was warmer in winter, cooler in summer, cheaper in first cost, and more easily repaired in case of accidental damage. Whether the claims could be substantiated or not, the fact is that now the steel cab is used generally upon new work. The cab is usually made of plates about ⅛ inch thick, and is strongly braced with angles and tees. In the case of the two engines that have been under consideration, there is but little difference in the size of their cabs. Some of these differences are due to the character of the engine and some to the preferences of the user. In the case of the consolidation locomotive, the cab has a body length of 7 feet, with a rear roof projection of 3 feet 6 inches. These are approximately the standard dimensions of the modern cab, and allow it to set over the boiler for a sufficient distance to house the cab attachments and levers, and still leave ample room at the back for the footplate accommodations for the fireman. This projection of the boiler back into the cab is usually from 48 to 50 inches at the top. In the case of the consolidation locomotive, it is 49 inches. Where the back head of the boiler is sloping, as it is in the Atlantic locomotive, it is sometimes necessary to place the bottom of the firebox farther back in the cab, in order to have room on the top for the necessary attachments. This was the case in this instance, and the cab in consequence is 6 inches longer than that of the consolidation.

The corners, bottom edge, carlines and plates are made of angles riveted to the sheets, and it is common, though not universal, practice

* Machinery, Railway Edition, December, 1907.

to countersink the heads on the outside so as to obtain a smooth surface. At the front there is usually a door upon each side giving access to the running board, though sometimes this is replaced, on the right-hand side, by a drop window. The sides are invariably provided with windows running the whole length of the cab and arranged to suit the user. The sashes are made to slide past each other so that the actual point of opening can be varied. The side opening in the consolidation locomotive cab that is here illustrated is divided into two parts. The front space, which is 23½ inches wide in the clear, is filled by a fixed sash, while two sliding sashes are placed in the space at the rear. These move past each other and make it possible to have the double space clear. In the Atlantic engine, the more common arrangement of one fixed and one sliding sash is used. The fixed sash is placed at the front and the sliding sash moves across inside of it. This gives one wide opening for the engineer to lean out of.

Cab Roof

The roof is arched from eave to eave and is carried by carlines made of angles. It is of sheet metal, as in the case of the consolidation, or of wood as in the Atlantic engine. Wood is preferable for the roof on account of its freedom from the annoyance of sweating or moisture in cold weather. The roof is exposed on the inside to the steam that occasionally rises from the boiler and its attachments, and when becoming cold, this steam is apt to be condensed on the lower surface of the roof and falls back in large drops, to the annoyance of the crew.

With the boiler projecting back into the cab for a distance of 4 feet or more, it occupies so much of the cubic contents of the latter that it would heat the air to an uncomfortable extent were the cab roof not provided with a ventilator. This is, therefore, always done at present. It consists of a trap that opens upward on a hinge at its front end, or of a sliding hatch. The trap is to be preferred because its position is such that, when the engine is in motion, it not only deflects such cinders as may strike the roof from the stack, but it has a tendency to assist in drawing the hot air out of the cab. The cab is supported by heavy brackets attached to the frames, and is entirely self-contained.

Throttle and Reverse Lever

Within the cab there are but two attachments that belong to the locomotive itself and are so necessary for its operation that they are included in the basic design for the engine. These are the reverse and throttle levers. The reverse lever is usually pivoted in a bracket bolted to the frame, and works in or beside a quadrant notched to receive its latch. As the point of cut-off is varied by the movement of the reverse lever to and fro, it is desirable that the notches in the quadrant shall be as close together as possible so as to permit of small variations in the point of cut-off. For this reason they are frequently cut to resemble a straight-tooth gear and the lever latch is made with a number of teeth to mesh with them.

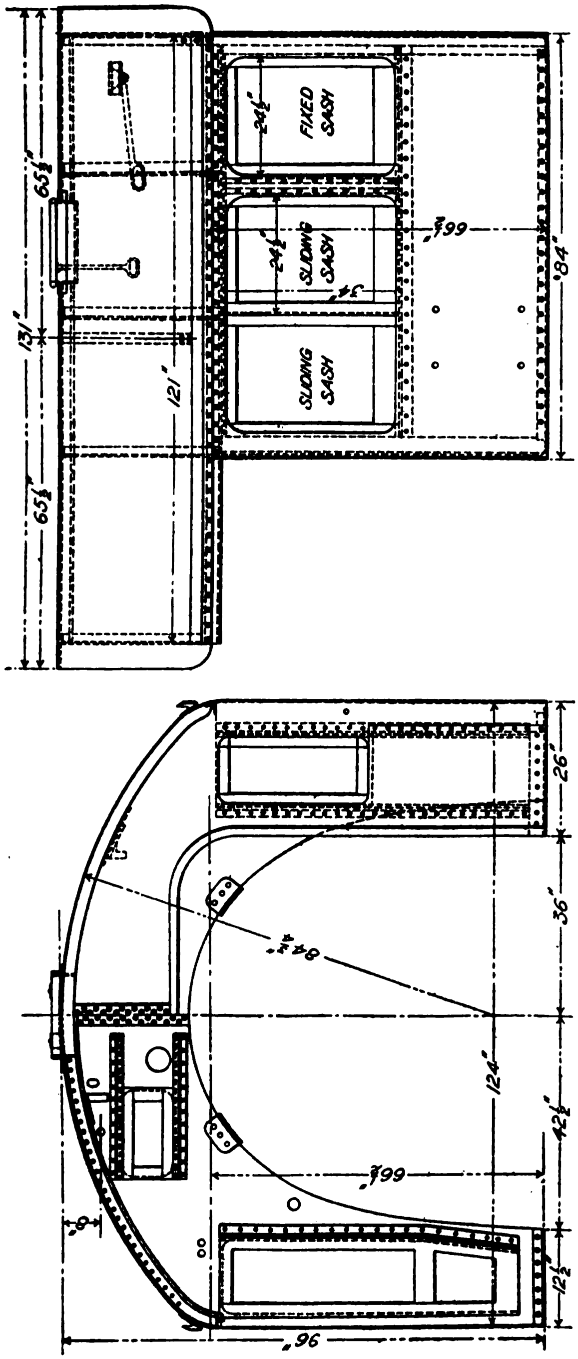

Fig. 11. Steel Cab for Consolidation Locomotive

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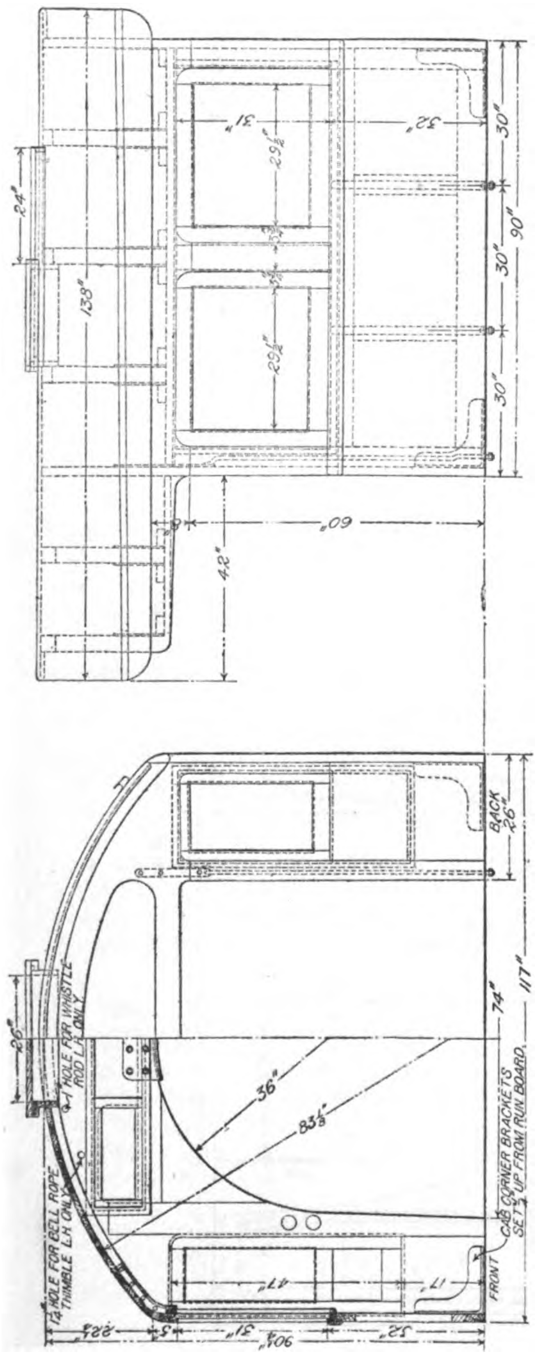

Fig. 12. Steel Cab for Atlantic Type Locomotive

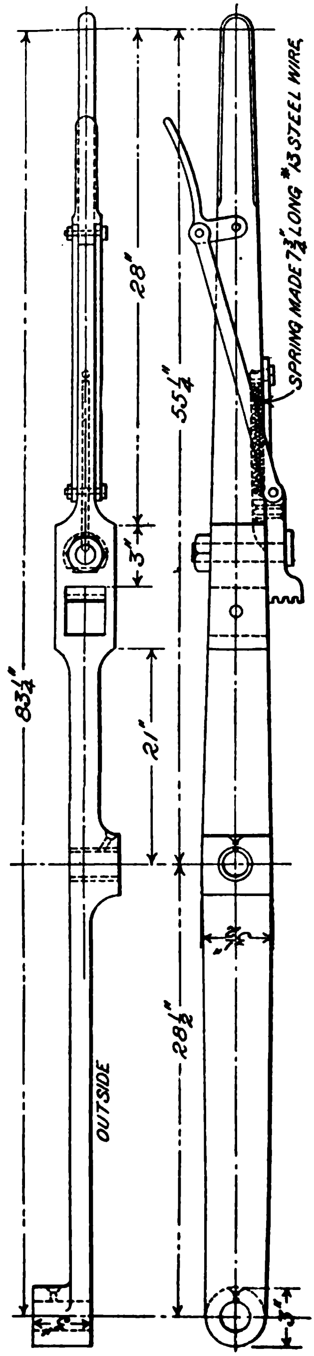

Fig. 13. Design of the Reverse Lever

It is essential in designing the reverse lever that it should be made of a strength sufficient to resist the jars and jerks to which it will be subjected, and also have a length sufficient to enable the engineer to move it, and thus shift the point of cut-off when the engine is in motion. The eccentric straps of a locomotive have been likened to a pair of prony brakes having a constant tendency to throw the links down into the position of full forward gear. So, as there is nothing to resist this tendency when the latch is lifted from the quadrant, but the pull of the man on the lever, the leverage should be sufficient to enable him to do it without danger of having it jerked from his grasp, or of being pulled forward himself. A leverage of about three to one, as in the lever illustrated, will usually be found to be sufficient for this purpose.

Especial attention must also be paid to the latch. It must be cut square and fit the quadrant with little or no sloping sides, to prevent it

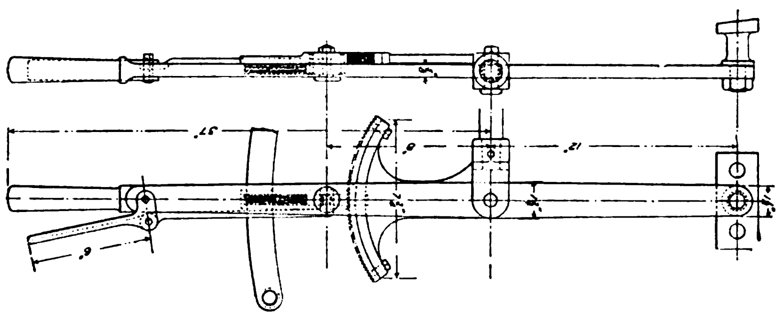

Fig. 14. Throttle Lever for Consolidation Locomotive

jarring out. The spring that holds it down in place must be stiff, and there must be such ample leverage on the latch lifter that it will be easily operated. When the engine is working, there is a constant and severe jarring of the lever as the pull of the links tends to throw it forward, and unless it is rigid in itself, and the latch is held down firmly by the spring, it is likely to work itself free, and in its movement forward may inflict severe injury upon the engineman or the machinery.

The throttle lever should be carefully designed so that it will hold the valve in any desired position. Strength is required in order that it may be able to hold the valve firmly down upon its seat, and not because it is otherwise subjected to any severe stresses. When the valve is open, the load upon the lever sinks to insignificance; and, as the valve is usually balanced, the leverage required for manipulation is not great. It should, however, be provided with a latch that admits of fine adjustment and will hold it secure when the valve is shut. The quadrant had best be made of wrought iron, case-hardened and cut with teeth of fine pitch. Good results can be obtained if there are about six to the inch. It will be noted that, in the design illustrated, which is the one in common use, the quadrant moves with the throttle stem, so that the effect is to make the possible adjustment even less than that corresponding to the pitch of the notches. The length of leverage indicated not only gives the engineer a very delicate and sensitive control of the valve, but is, in part, necessitated by the fact that the throttle stem is in line with a vertical plane passing through the center of the boiler, and it is necessary to bring the handle out on one side to be within easy reach.

Running-boards

The running-boards are closely allied to the cab, and frequently extend back into it, forming the foot-boards. They are of simple design; as shown in the cut, Fig. 16, they are made of steel plate about 3/16 inch thick, and are stiffened at the edges, usually by a 2 × 2-inch

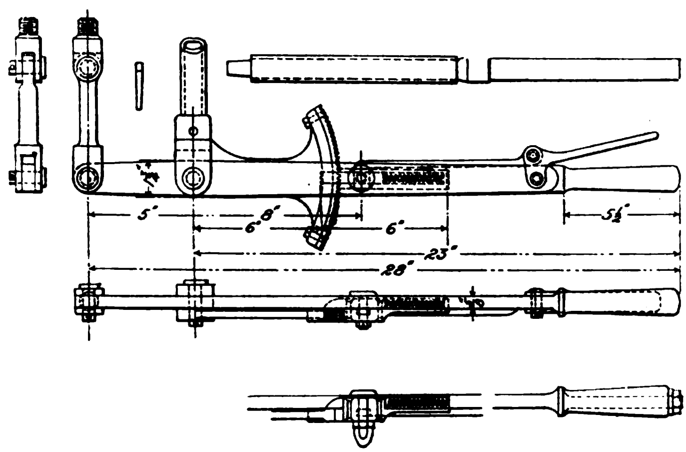

Fig. 15. Throttle Lever for Atlantic Type Locomotive

angle. They must be cut away where necessary to allow for the placing of pipes, air-pump, and other fixtures. As the load on them rarely exceeds the weight of a few men, they are readily carried by simple brackets of flat iron riveted to the boiler. They should reach from the cab to the steam chest or the front end.

Cab Fittings and Accessories

While the designer of a locomotive must be familiar with, and provide for, the various cab fittings and accessories that are to be applied to the machine, he has nothing to do with their designing, and frequently is not even consulted regarding the selection of fittings from those that are upon the market. The manufacturing of these parts is in the hands of specialists, and the purchaser usually selects what he pleases and orders them put upon the engine. The part played by the designer in the matter is that of so locating them that they may be readily manipulated and their indications easily seen by the engineer and fireman.

These parts consist of the injector, engineer's valve, water gages, steam gage, whistle, lubricator, injector cock, cylinder cocks, blow-off

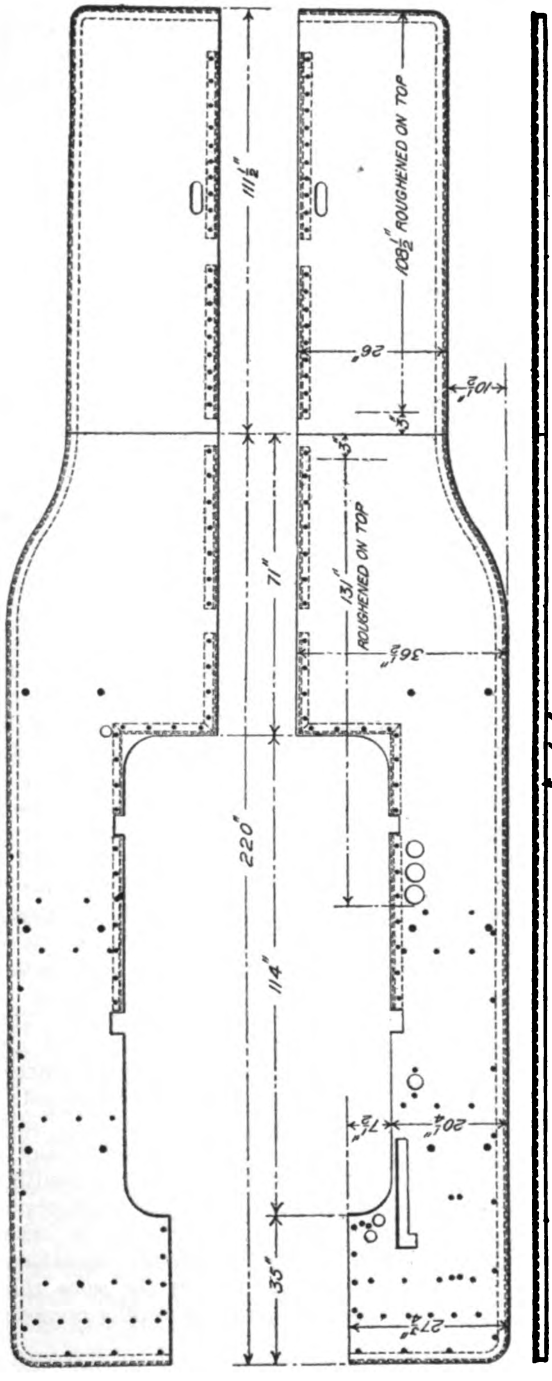

Fig. 16. Design of Running-boards

cock, headlight, air-pump, and sander. It is essential that some of these should be so placed as to afford the maximum of convenience to the engineer in the running of the engine. The reverse and throttle levers are the essential features of the engine itself, and near them must be located the handle for the working of the injector and the engineer's valve. One is needed in order to control the supply of water to the boiler, and the other for the manipulation of the air-brakes, for very few locomotives are now built that are not equipped with such brakes. With these handles easy of access, the engineer can control his train with safety, and the time expended in making the various movements is reduced to a minimum. Next to the injector and the engineer's valve come the whistle and water gages. The whistle lever is usually so located that it can be worked by reaching up and grasping either the lever itself or a cord attached to it that is near the roof; and the gage cocks are close at hand on the left, often near the engineer's valve. Owing to the introduction of the water glass, many engineers have come to depend upon it entirely for water level indications, with the result that it often happens that the gage cocks are placed out of reach. This should never be done, for they should always be close at hand.

The steam and air gages are usually placed upon the top of the boiler and face directly to the rear. The air gage indicates the amount of air carried in the reservoir and train pipe, and should often be consulted by the engineer, especially after an application of the brakes in order to note whether the pressures have been unduly reduced. So with the steam gage, he watches it when the pressure is low rather than when it is high, but for the fireman its visibility is of the first importance, and it should be so placed that it can be read from all points on the foot-plate and the tender, as well as from the seat upon the left-hand side. As these attachments are in constant use, and as it is upon them that the safe running of the train depends, the greatest pains should be exercised that they be so placed as to afford the utmost of convenience to the men. Of secondary importance are the handles for operating the cylinder cocks and sander. Usually it is necessary for the engineman to reach forward to the front of the cab or down to the floor to grasp them. Of the two, the sand lever should be the more easy of access.

Within the cab there are a number of other attachments. The lubricator for oiling the valves and cylinders is usually placed upon the top of the boiler. As it works continuously after being started, it is never allowed to crowd more important parts out of desirable places. Under present conditions the lubricator should have at least three points of feeding, one for each steam chest and cylinder, and one for the air-pump. Sometimes a lubricator is used with a multiple feed with pipes leading to the several axle journals. The same requirement holds true for the location of the valves controlling the steam heat and operating the blower. They are only manipulated occasionally and so need not be in prominent positions; but, at the same time, care should be taken to put them where they will be readily accessible, and not tuck them away where there is a likelihood of burning the hand when an attempt is made to reach them.

For fixtures that are applied outside the cab, the designer should see that they are properly located. The injector check, for example, should be placed somewhat back from the front tube-sheet, though there is by no means an agreement as to exactly where this should be. Practice varies in this respect from 10 inches to 5 feet back of the sheet and the probability is that 3 feet would be a good safe average location. This refers to the usual practice of placing the check on the side of the boiler and about on a line with its center. When this is done there should be an ample space of not less than 6 inches left between the opening and the first tube opposite it. When the injector check is placed in the back head, there should be a pipe leading from the inside opening forward, beneath the water line to a point within 3 feet or 4 feet of the front tube-sheet.

The headlight must be of such a size and so located that it will not interfere with the draft of the stack. The top of the stack is usually the highest point on the engine, so that ordinarily there is no trouble. Occasionally, however, the top of the ventilator of the headlight has been brought up flush with, or raised slightly above, the top of the stack. In these cases, when steam is shut off and the engine is drifting, an eddy is formed over the top of the headlight that turns down into the stack and drives the smoke and gases out into the cab.

All oil cups that are not forged solid with the parts that they are intended to serve should be of the strongest and most substantial construction; else they will become loosened and lost or broken by the jarring of the engine or the movement of the parts.

As already stated, the designer has little to say regarding the details of the cab fixtures that are to be used. A certain standard has been adopted by the customer or user, and this is specified. If the designing is done by the engineering department of the road that is to use the locomotive, it naturally follows that the regular standards will be applied. This applies not only to those items mentioned above but to other details as well, such as lagging for boiler and cylinders, the material for castings, the finish of the running-board, the type of air-brake and pump, the size of the air reservoir, the arrangement of the air-pump exhaust, the whistle signal, gong, turret or combination fitting on the back end of the boiler, washout plugs, feed hose connections, lazy cocks, safety valves, vacuum valves, gage lamps, signal flags and lanterns, oil cans, jacks and engine tools, the color and method of painting, and frequently the material used. In all this the designer is merely a passive instrument who must place each individual piece in its proper position, see that provision is made for fastening it securely, and that it is readily accessible for manipulation and repairs. This last item is of the utmost importance and it cannot be emphasized too strongly. While a locomotive is intended for service on the road and nothing should be sacrificed to make it as efficient as possible, it must always be borne in mind that the working parts will wear out and will eventually need to be repaired. For that reason all parts should, as far as possible, be so constructed and placed that they can be readily removed and replaced. Neglect of this precaution will result in that minor and general repairs will be far more expensive than they would have been had the parts been more accessible. This accessibility is also of the first importance in the matter of inspection. Where inspection is easy, it is much more apt to be thorough than where it is difficult, and neglect along these lines finds its direct reflection in the cost for repairs. Finally, strength and security should invariably occupy the first place in the mind of the designer, and cheapnes of first cost should not blind him to the requisites of strength and durability. And as he takes particular pains that the frames, boiler and cylinders are rigidly fastened in position, so he should see to it that all of the accessories should be secure, using flanges for all larger boiler connections instead of screw connections, for it will be upon the detailed attention that has been paid to these seemingly minor matters that the successful operation of the locomotive may depend.

CHAPTER IV

THE TENDER*

The locomotive having been designed for the service for which it is intended, it remains to provide it with a suitable tender for carrying the supply of fuel and water. In American practice this tender, until recently, almost invariably consisted of a U-shaped tank carried on a metal framework, though wood is still occasionally used on the smaller engines for this purpose. The tank, in turn, is mounted upon two four-wheeled bogie trucks. The fuel is carried between the legs of the U of the tank.

Tank Capacity

The first point to be settled in the design is the capacity of the tank. This will depend not only upon the size of the engine and the work which it is to do, as governing its steam consumption, but also upon the location of the water tanks and the distances that will have to be run between stops. Where the tender is to be fitted with a water scoop for taking water from track tanks, and these are located at frequent intervals, obviously the tender can be of less capacity than where long runs must be made. Further, a variation in tank capacity will be called for between a mountain and level division with the same distance between water stops, because of the greater steam consumption upon adverse grades when compared with the level. As a matter of fact, however, no actual distinction is made in this respect between engines on the same system. Provision is made for a sufficient water supply for the heaviest work that is to be done on any part of the line; and, then, if the engine is transferred to lighter work, there is simply an excess. The one thing needful is that the tank should hold enough water to do a little more than supply the engine, when working at full capacity over the severest section of the line.

Tank Construction

There are two general types of tank construction that are used in the United States, known as the plain U-tank and the water bottom type. The latter type varies somewhat and generally has no water legs, but in their stead a slope from the back end of the coal space, extending down toward the front and reaching across the tank, and then turning horizontally to form a water space beneath the floor. It is used where the foot-board of the engine is high, so as to raise the tank floor up to the same level for the convenience of the fireman.

Figs. 17 and 18 illustrate the tank designed for use on the consolidation and Atlantic locomotives, respectively. The tank for the consolidation locomotive has a capacity of 6000 gallons and is without a water bottom. It consists of a U-shaped tank, with a sharp incline at the

* MACHINERY, Railway Edition, January, 1908.

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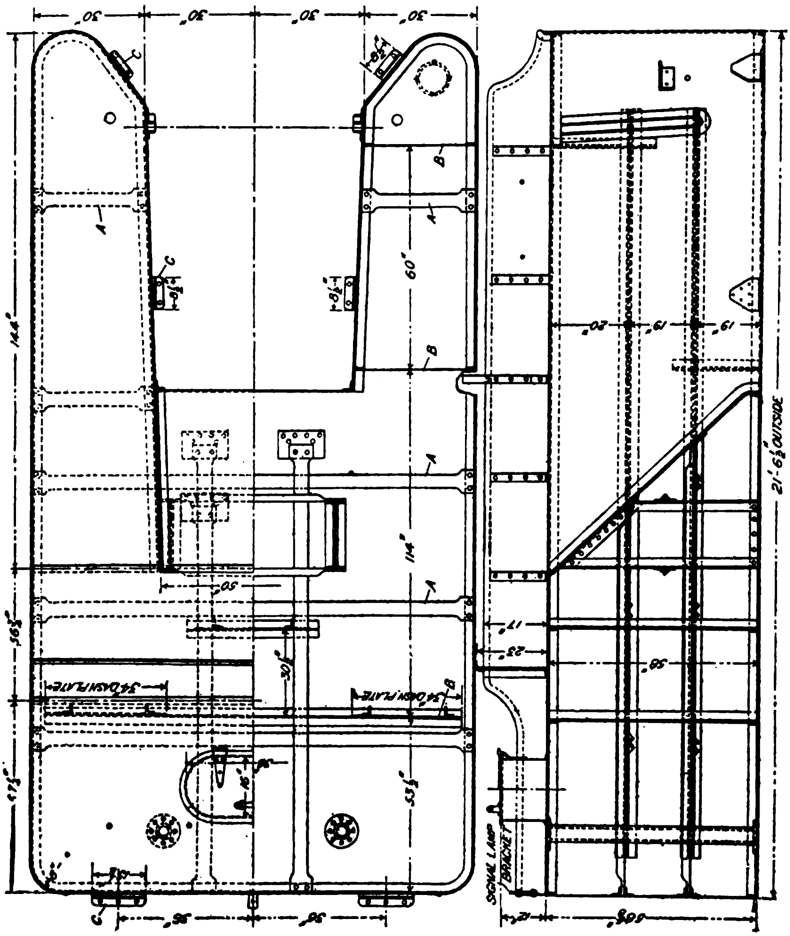

Fig. 17. Tank of 6,000 Gallons Capacity for Consolidation Locomotive

back of the coal space, and is bolted to the tender frame, upon which it rests. The outsides are vertical and are made of 3/16-inch to 1/4-inch steel. The framing for the tank is on angles, usually 2½ inches by 2½ inches, arranged on the inside, and it is to them that the plates are riveted. Ordinarily, ½-inch rivets are used, spaced 1½ inch between centers. In the construction of the tank it is unnecessary to calk the seams, as in the case of a boiler, because there is no internal pressure other than that due to the weight of the water. For that reason the joint between the plate and the angle is laid with a strip of heavy paper (usually tarred), so that, when the rivets are driven, the plate and the angle are drawn together to form a water-tight joint. While there are no pressures against the sides that can cause trouble, the tank itself, as a whole, is subjected to heavy strains, and it must be braced accordingly. These strains arise from the surging of the contained water due to the varying motions of the tender. Whenever the brakes are applied, the water rushes to the front and banks up in the legs, and then flows back to the rear. In addition to this, there is a constant surge to and fro laterally as the frame rolls on the trucks. When it is taken into consideration that the water in a half-empty tank weighs from 24,000 to 32,000 pounds, it will readily be understood that the effect of the wave action of this weight, as it moves about, may be very severe. There is a two-fold tendency in this action. One is to shift the tank upon the frame, and the other is to cause the sides to bulge. The surging effect is lessened by the interposition of splash plates in the legs and body, by which the space through which the water must flow is greatly contracted, and the effects of a high momentum destroyed. For the protection of the side plates against bulging, they are stayed with internal transverse, vertical and horizontal bracings of plates and angles riveted to the sheets so as to effect the most uniform distribution of the stresses possible, and so prevent any deformation of the tank.

The splash or dash plates are riveted to the vertical angles as shown at *B* in Fig. 17. In spite of these precautions the splashing effect of the water longitudinally is still very severe, so that the grill of internal stiffening angles should be such that the openings should not be more than from 18 inches to 24 inches across. The tank, as a whole, must be so firmly fastened to the frame that there is no possible danger of displacement because of the surging of the water or the shocks to which it will be subjected in service. This fastening is usually effected by means of heavy angle lugs having one leg riveted to the vertical plates and the other bolted to the framing. Although it is the side or vertical portion of the tank that is called upon to withstand the heaviest shocks due to the movement of the water, the top and bottom sheets, by presenting the larger surfaces to coal and the weather, are more exposed to wear and corrosion, and are, therefore, generally made from ¼ inch to 5/16 inch thick. It is especially desirable that the face of the coal space should be as smooth as possible, so as to afford no lodging place for coal or dirt, as such accumulations are apt to promote corrosion.

At the front end of the coal space, vertical angles are riveted to the legs to hold the coal boards, and wherever holes are cut for pipe or other connections the sheet should be stiffened by a plate of ample thickness and size, usually in the form of a flange riveted over the place. It is impossible to give any formula for calculating the stresses to which a tender tank may be subjected, because they are so varied in character and so irregular in application that it is not known what they are. For that reason it would be well to follow the general features that have been set forth in the designing of the tank, both as to method of construction and the dimensions of the material, although with the consideration that a reasonable increase may be made in the case of tanks of enlarged capacity.

In addition to the arrangements that have to be made to enable the tank to carry its load sucessfully, there are other attachments, to the location of which careful attention should be paid. This refers to such items as a shield that is placed across the top of the tank, back of the coal space, to protect the tank opening from flying pieces of coal and debris; it is made of wood or steel plates from 20 inches to 36 inches in height. The tank opening may be either round or oblong, and if oblong, the long diameter usually extends across the tank, as shown in the cuts Figs. 17 and 18. Sometimes, however, it extends lengthwise. The effect is the same in either case—the elongated opening avoiding the necessity for a close spotting at water stops.

There are handholes, or grab irons, to be placed near the steps at the front end, or in accordance with the legal requirements governing safety appliances. The lantern brackets at the rear are usually mere hooks located to suit the requirements of the purchaser. The same thing holds true regarding the tool-boxes. Usually there is a box on top of the forward end of each leg of the tank, provided with locks and keys, and in which the lighter engine supplies are kept, such as oil, waste, and hand tools; while, at the rear, either on top of the tank or behind it on the frame, there is another, extending across the engine, in which heavy supplies, such as chain, jacks, extra coupler knuckles and the like, are stored. These boxes are heavy and are made of wood, and must be securely bolted in position.

The other form of tank, that with a water bottom extending forward beneath the floor space, is shown in the engraving of the tank of the Atlantic locomotive. In this case it is given a capacity of 8000 gallons, and is correspondingly longer and deeper than the one of a smaller capacity used with the consolidation engine. In other respects it resembles in construction the one already described. There are, of course, some variations in detail, as, for example, the ladder at the back, which is required because of the great depth (68 inches), making the top so high that a man cannot readily raise himself up to it, as is possible in the case of the smaller tank. It will be noticed, too, that cupboards with doors are placed in the forward end of each leg. These are points that the designer must be prepared to think of and provide, if they are called for in the specifications.

In these large tanks the apron for holding the coal in place is usually made vertical and flush with the side, instead of being flared, as is the practice on the older and smaller tenders, and is only carried back as far as the manhole shield, the space about the hole being protected by a low railing. The top edge of the apron is always stiffened, usually by a bar of half-round iron riveted on the upper edge. These are minor, but somewhat important, details to which a designer should pay close attention, that the effect may be satisfactory not only to the eye, but in the service which is to be rendered.

Tender Frame Construction

The frame upon which the tank rests was formerly made of wood, but present construction is usually of steel. This frame is usually a short rectangular structure built of rolled sections firmly bolted and riveted together, and so braced diagonally that it cannot be twisted or

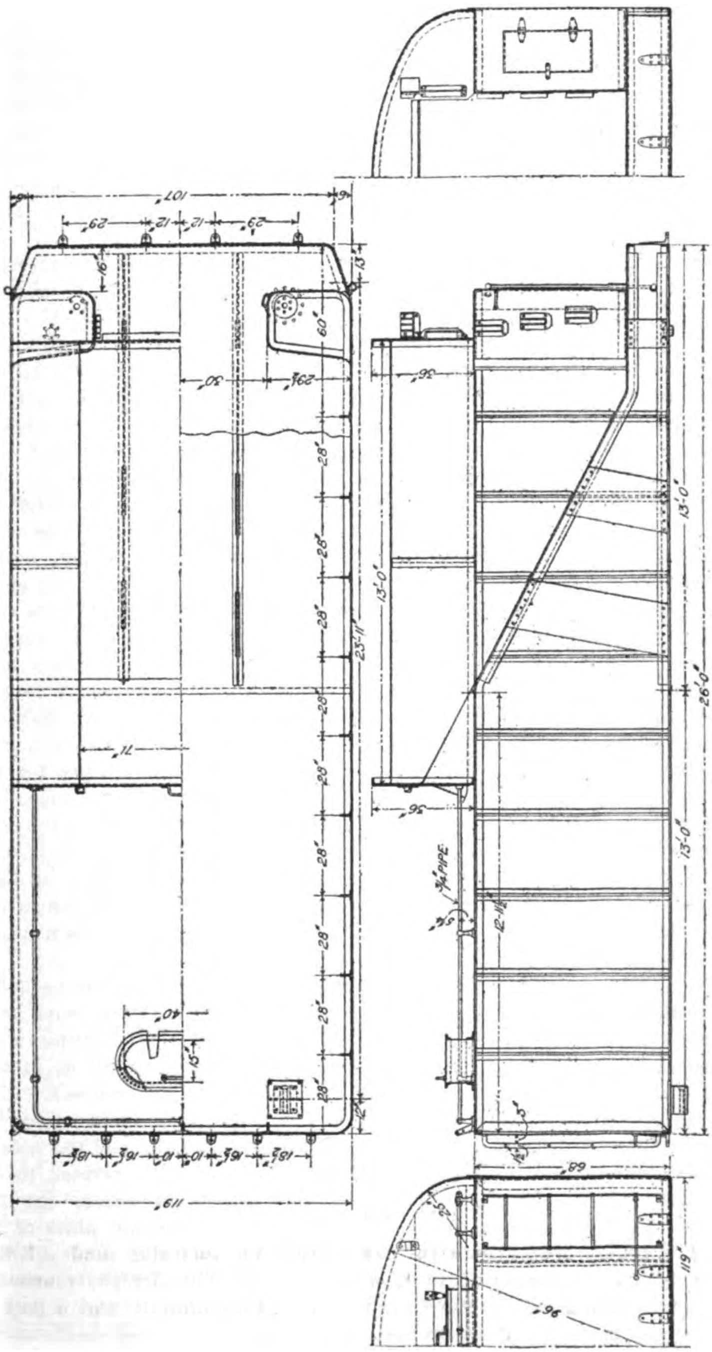

Fig. 18. Tank of 8,000 Gallons Capacity for Atlantic Type Locomotive

distorted by any of the ordinary stresses to which it may be subjected. The load imposed is always uniformly distributed over the whole length. In this connection, the under frame should be of ample strength to carry the whole load, as the water and coal rest fully on the lower frame and are supported to only a slight extent by the vertical walls of the tank. However, the distance between points of support of the frame is short, running from 10 feet to 12 or 13 feet, which is the distance between truck centers.

At the point of support the bolsters should be of ample strength and of great stiffness. Any flexibility or limberness will be sure to manifest itself in the imposition of an excessive weight on the side bearings and a racking of the structure as a whole. Therefore, the body bolsters should be so designed that twice the maximum load can be sustained on the center-plate, with an ample margin to spare in the way of a factor of safety. It is not known exactly what the actual stresses imposed upon tender bolsters may be, other than that they are, at times, at least 50 per cent in excess of the static loads.

The frame illustrated in Fig. 19 is that intended for use under the short 6000-gallon tank for the consolidation locomotive. The coal, water, accessories, and tank will weigh, approximately, 80,000 pounds, to which is added the weight of the frame, which will run the static load on the bolsters up to about 90,000 pounds, or 45,000 pounds on each one. Therefore, each bolster should be of ample strength to sustain at least 68,000 pounds. In this case, four 10-inch channels are used as the sills, and the span between center-plates is 11 feet 8 inches, with an overhang of something less than half the amount. Each of these channels is capable of supporting a uniformly distributed load of about 19,450 pounds for the span given, or 77,800 pounds for the four sills, with a fiber stress of 16,000 pounds per square inch. As this span is but 55 per cent of the total length of the frame, the load actually imposed will be about 49,500 pounds, which, as compared with the 77,800 pounds, cuts down the fiber stress correspondingly; so that, as far as the longitudinal members of the structure are concerned, there is ample strength to carry the load and keep well within allowable fiber stresses.

The perfect uniformity of the loading makes it possible to determine the probable distribution of the same on the bolsters more accurately than is possible on cars, where eccentric and local loading is apt to occur. Where it is intended that the side bearings shall be in contact and carry a due proportion of the load, it is not necessary that the bolster shall be as stiff as where the whole load is to be on the center-plate. In this case, the former condition prevails and the bolster consists essentially of two broad plates 28 inches wide riveted to the top and bottom flanges of the sills, and extending across the full width of the frame. They are ½ inch thick. A diagonal plate of the same width is placed between the center and side sills, and a filling piece is inserted above the side bearings. In this way the plates are protected from bending due to the load on the side sill, and a portion of the load is carried down to the center-plate.

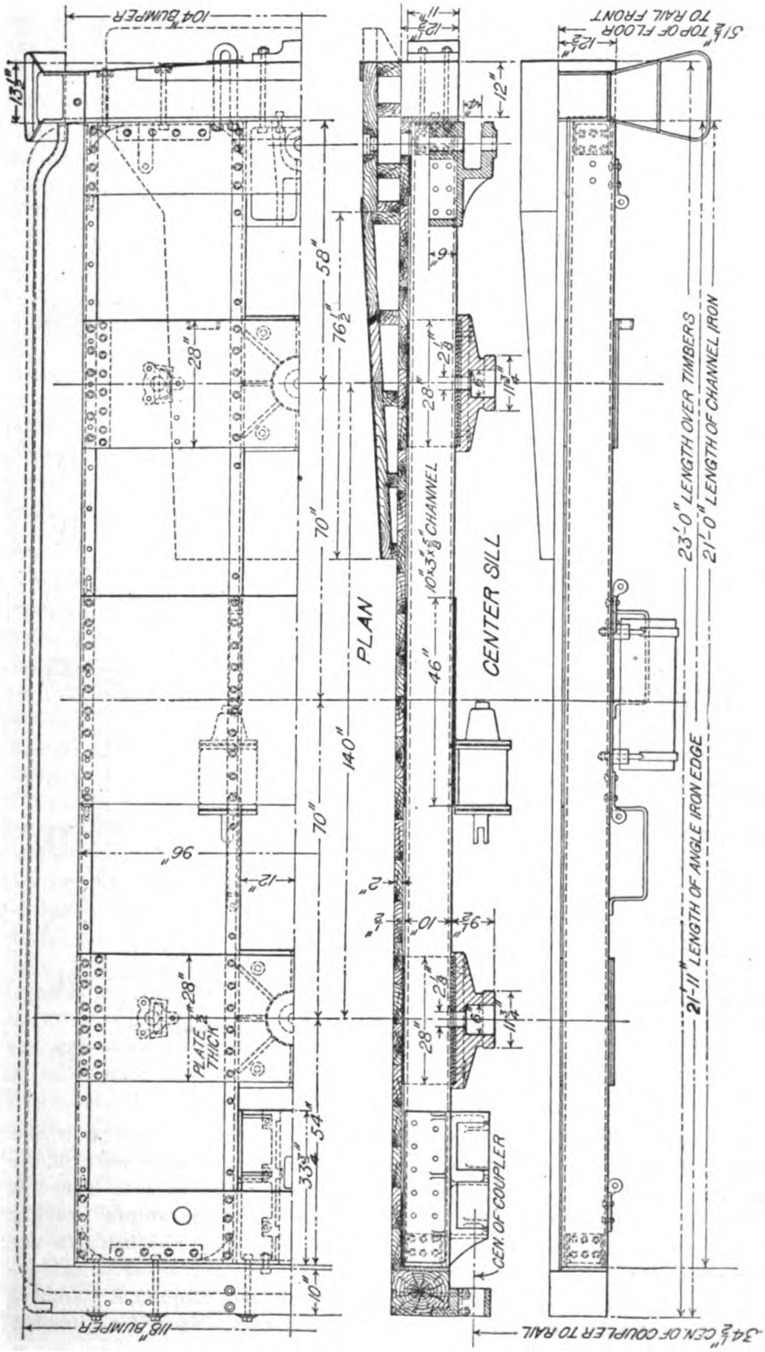

Fig. 19. Tender Frame for Consolidation Type Locomotive

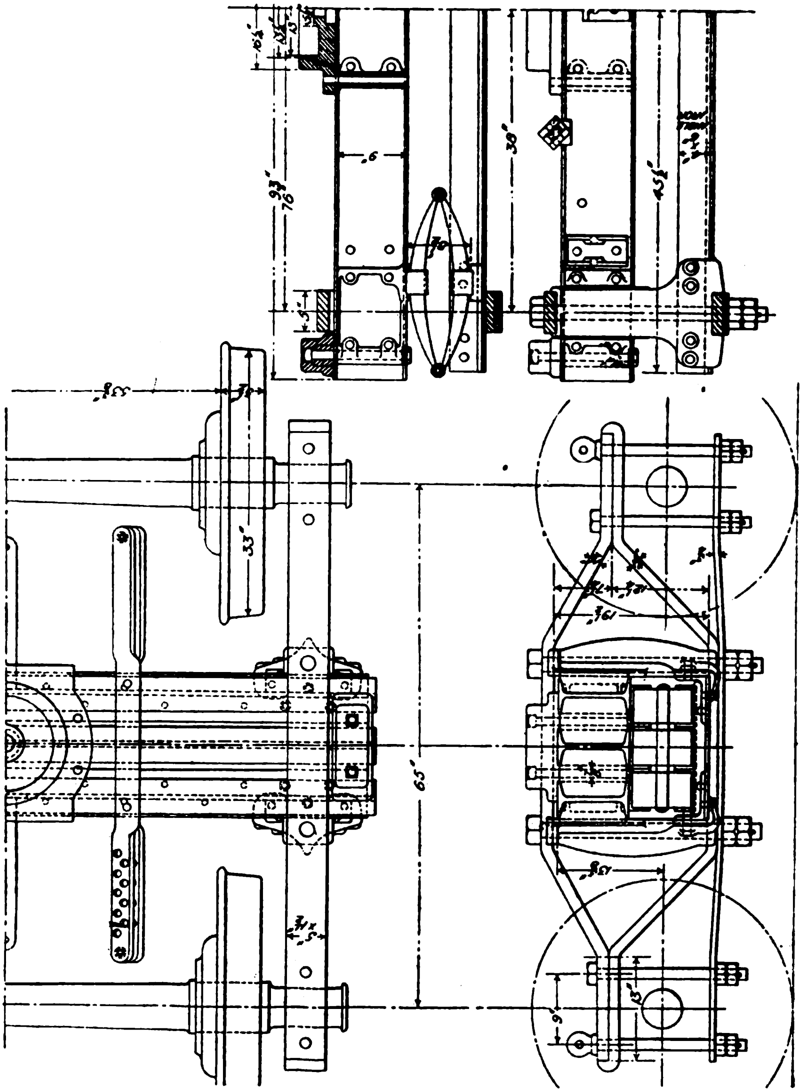

Fig. 20. Atlantic Locomotive Tender Truck for Tank of 8,000 Gallons Capacity

The center-plate should have an ample bearing surface to carry the load, and should have sufficient depth to receive the male portion, so that derailment or excessive shocks should not be able to cause a separation of the parts. As to what constitutes an ample bearing surface, there is no agreement of practice or opinion. The loads in use vary from 300 pounds to 3,000 pounds per square inch of area, in contact. In 1903 the Master Car Builders Association adopted a standard form of center-plate having 100 square inches area. This, for a loaded car, would give a pressure of about 650 pounds per square inch. In the center-plate of the tender under consideration, the area of contact is 80.16 square inches, and this, with a load of 45,000 pounds, has an imposed pressure of something more than 560 pounds per square inch, which is well within the limits of the Master Car Builders recommendations. The form of the center-plate depends upon the adjoining parts, but in any case it should be heavy and strongly ribbed to avoid deflection, and is usually made of cast iron.

Ranking close in importance with the elements forming the frame are the castings at the front and back to which the draft and buffing rigging is attached. These castings are of cast iron or steel, and are of heavy sections, securely riveted between the center sills. There is no rule for the calculation of the stresses to which they may be subjected, as the tractive effort of the engine is often many times exceeded. The draw-pin, at the forward end, should be at least 3 inches in diameter, and the casting must be of such proportions as to resist the full shearing strength of such a pin. The end plates may be 1 inch thick, riveted across the ends of the sills and held in place by suitable angles.

Tender Trucks

The trucks used under tenders are of a great variety of form. Many of these forms are patented or are the objects of special manufacture. When such a truck is to be used, the engine designer has merely to specify the weights that are to be carried, and then provide for connection to the form and dimensions offered. No attempt will be made to describe a variety of trucks, but attention will be confined to the one using an ordinary diamond side frame, like that extensively used under freight cars. As the duties of a tender are similar to those of a freight car carrying heavy bulk freight, it is quite necessary that the trucks used should be similar. Accordingly, the wheel-base is from 5 feet to about 5 feet 6 inches. The side frames, too, are identical in construction with those used under freight cars, the bars being proportioned to the load to be carried, with an allowance for extra heavy service due to the location of the tender immediately behind the engine.

The simplicity of the form of the diamond truck would render the stresses, due to vertical load, as they fall upon the arch bars, easy of analysis, were it not for the blows and horizontal thrusts to which they are subjected. Take the truck for the consolidation locomotive, for example; it is calculated to carry a maximum load of about 49,000 pounds. Of this, one-half, or 24,500 pounds, is upon each side frame. The bolts are called upon to sustain but comparatively little in tensional stress, but must be able to withstand the shear put upon them in giving rigidity to the truss which is formed by the various tension and compression members of which it is composed. By plotting the frame and solving by a simple parallelogram of forces, it will be found that the lower arch bar would have to carry a tension stress of about 28,000 pounds, while the stress on the upper one would be that of compression and be about 27,700 pounds, provided the bars were straight between the points of support. Owing to the requirements of construction, the bars have two bends between the points of support, throwing them out of a direct line, and introducing a bending moment that will be likely to crack the lower bar at the upper face of the lower bend. For this reason the bars must be made considerably stronger than would be required were there no such bending effect. The amount of this will depend upon the distance of the center of the bend from the point of support, and the angle at which the bar stands in the frame. The fiber stress set up by these conditions can be approximately determined by the use of the same methods as those suggested for the determination of the general stresses set up in the frame by the vertical loading. In addition to the vertical loads and the stresses resulting therefrom, there are severe lateral stresses set up by the lurching of the tender from side to side and the effect of centrifugal force on curves. These last are calculable by the regular formula for centrifugal action, but for the other stresses, due to the unevenness of the track, cramping of the wheels, high speed and derailments, there are no data available, and recourse must be had to the experience of the past.

Turning to the two trucks shown, that for the consolidation locomotive, Fig. 21, has been given a lower arch bar of 1⅜ inch thickness and an upper one of 1½ inch, and a tie bar of ¾ inch, all having a width of 4½ inches, based upon the considerations given above. The lower bars act in tension and the upper in compression. The bolster is of cast steel, and the axles are those adopted as the standard by the Master Car Builders Association for cars of 80,000 pounds capacity.

In the truck for the tender of the Atlantic locomotive, Fig. 20, the wheel-base is greater. The heavier loads and harder service which the high speed entails, put greater stresses on the frames, which must, therefore, be made heavier, and with this an increased diameter of column bolts are used, which are made 1¾ inch diameter. This calls for a correspondingly larger hole, so that the width of the bars is made 5 inches, and this is in accordance with the greater width of the journal, which is that of the Master Car Builders standard for cars of 100,000 pounds capacity. The top arch-bar has, in this case, a thickness of 1½ inch, as before, while that of the lower one, owing to its greater width, is made 1¼ inch, while the bottom or tie bar is ¾ inch thick.

The bolster of the Atlantic engine consists of three 9-inch I-beams held by suitable separating pieces to the columns and frames.

With this, the most important points involved in the designing of a locomotive have been treated, although there are numerous details that have been left untouched, since they belong to the class of detail work or of special manufacture. The object of this work is merely to present a guide to the general work, for it will be readily appreciated, that anyone, to undertake the designing of a locomotive, must first have had considerable drawing office experience, to whom the filling out of the parts omitted in this work will be comparatively simple. The result of what has been done is shown in Figs. 22 and 23.

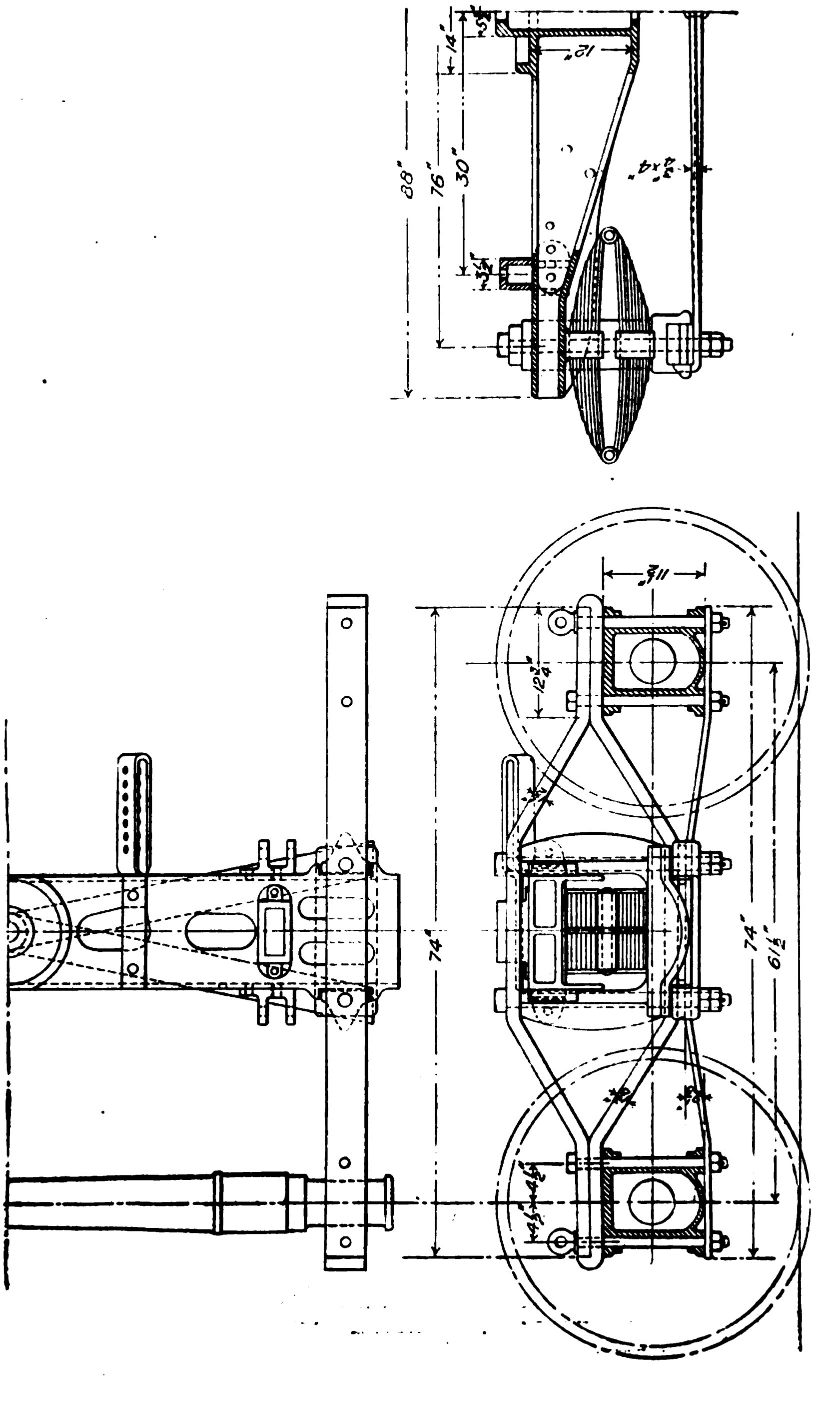

Fig. 21. Consolidation Locomotive Tender Truck for Tank of 6,000 Gallons Capacity

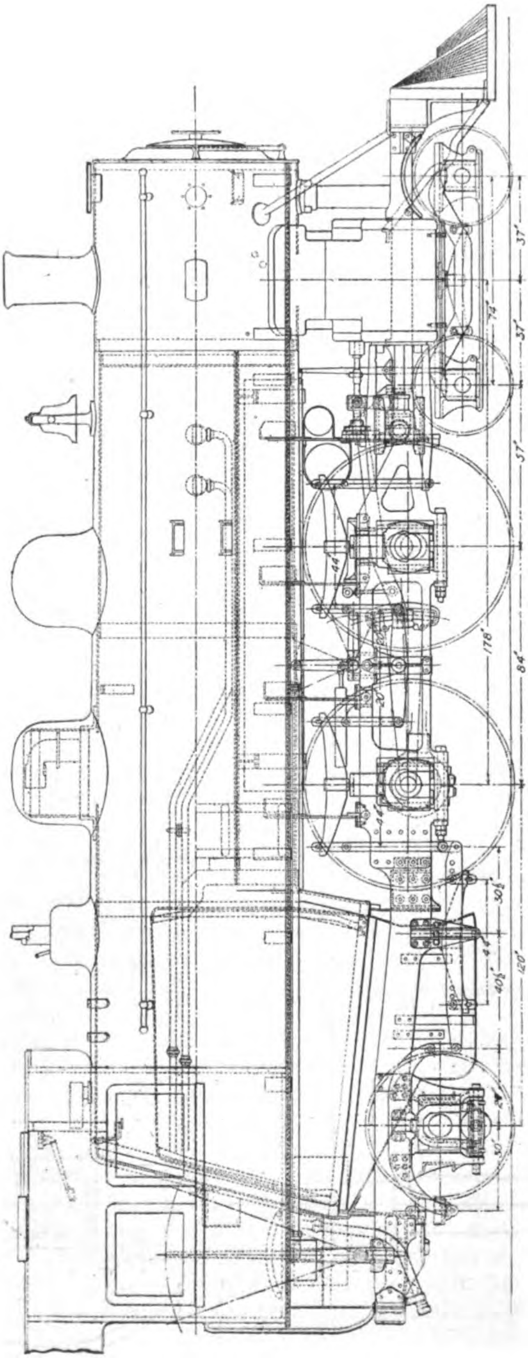

Fig. 22. Locomotive of the Atlantic Type

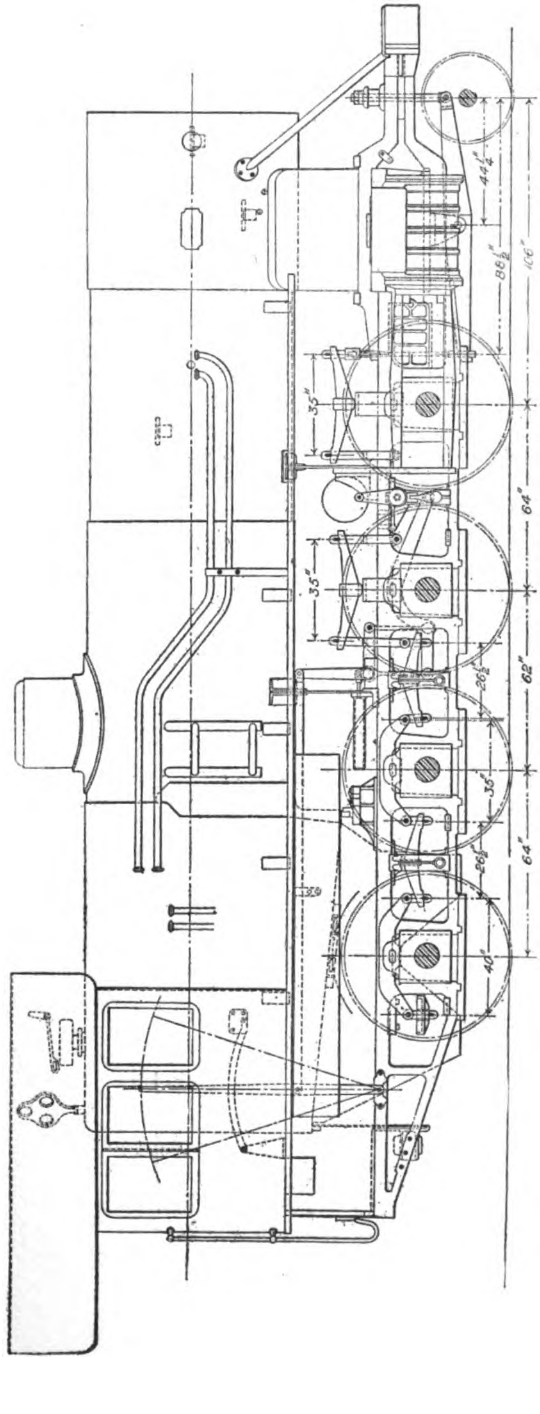

Fig. 23. Locomotive of the Consolidation Type

In conclusion, there are a few suggestions that should be constantly kept in mind during the whole progress of the work, whether it be that of designing a locomotive, a stationary engine or any other piece of machinery, and that is to bring the three elements of utility, simplicity and beauty into one harmonious whole. They are the three important factors entering into the composition, and no one of them should ever be disregarded, for they can always be combined without additional expense, and this combination should be made to enter into every detail of the work.

A successful designer must, therefore, be not only a master capable of solving the technical problems involved in a manner to obtain the highest degree of efficiency, but he must have that practical knowledge gained from experience, from which he will be able to choose the simplest methods of construction, and to this should be added an inborn instinct as to the fitness of things, which should have been cultivated by practice and study, whereby the results, though, perhaps, not falling quite within the recognized realms of art, should still be of such a character that they are pleasing to the eye, and as such claim the attention as artistic creations.