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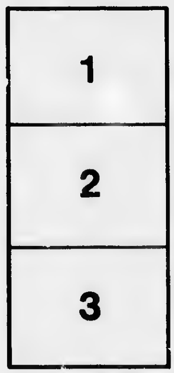

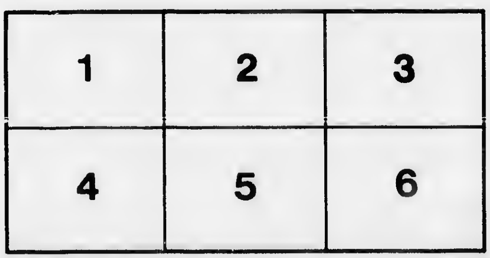

Institution of Mechanical Engineers.

ON THE CONSTRUCTION OF CANADIAN LOCOMOTIVES.

By Mr. FRANCIS R. F. BROWN, of Montreal.

In the present paper the writer purposes dealing more particularly with those classes of Locomotives which have been built from his designs and under his personal supervision at the shops of the Canadian Pacific Railway, Montreal. A few preliminary remarks are desirable, in order to present the subject on a fairer basis for comparison with English practice.

The permanent way in Canada consists generally of flat-bottomed rails, weighing from 56 lbs. to 72 lbs. per yard according to class of service and age of road. The rails are spiked to flattened ties or sleepers at about 2 feet centres, or closer if necessary. Either common or angle fish-plates are used; and brace castings are placed against the outside rails at curves as required.

Grades are usually expressed in percentage, or in ft. per mile; and curvature in degrees of the angle subtended by a 100-ft. chord on the curve; thus a curve of 1° has a radius of 5,730 feet, and a curve of 6° has a radius of $\frac{5730}{6} = 955$ feet. The maximum grades on main lines are commonly 1 per cent. or 52·8 feet per mile, and the maximum curvature 6° or 955 feet radius; these limits of course do not apply to mountain sections.

The classes of service comprise:—way or stopping freight, that is, goods trains; through or fast freight; mixed, that is, one or more passenger coaches attached to freight trains for local country service; local passenger; and express. All these have to run on single track, and are operated by telegraph from the "train despatcher's" office. In order to get the traffic through, it is considered of more importance that the engines should haul the largest possible loads with such economy as can be obtained, than that they should haul smaller loads at a cheaper rate per ton in regard to fuel.

The passenger service on main lines is more often a combination of express and local than either one of these chiefly. Thus the majority of through express trains have to stop at nearly all stations either by time-table or by signal. Special care is therefore required in designing the engines so as to combine free running with the quickest possible starting power; and a continuous brake is also rendered necessary as well as expedient for economising time in stopping.

In all classes of service the dead or non-paying weight hauled forms a much greater percentage of the total train than on an English railway. This is partly due to the fact of the freight cars having to be protected against the climate, and to the employment of specially designed refrigerator cars and ventilated cars for the carriage over long distances of perishable goods, such as fresh meat, fish, butter, cheese, &c. It is also partly owing to the strength of the passenger coaches being greatly increased with a view to the safety and comfort of the passengers; for it must be borne in mind that a through transcontinental train in Canada carries with it all the conveniences of a first-class hotel. The through trains on the Canadian Pacific Railway from the Atlantic to the Pacific ocean carry parlour, sleeping, dining and buffet coaches, with sofas, easy chairs, state rooms, smoking room, bath room, lavatories, &c.; all of which accessories to comfort necessarily add to the dead weight per passenger.

A portion of the traffic is worked by wood-burning engines, which require a special form of grate, and arrangements of wire-netting for the ash-pan and chimney in order to prevent setting fire to the surrounding country. For coal-burning engines the quality of the fuel is very variable; some of the coal is of such a kind as to necessitate rocking grates with dumping arrangements, sharp blast, and netting for arresting sparks; all of these appliances have to be used for maintaining efficiency, but they are somewhat detrimental to economy, inasmuch as to some extent they react upon each other.

In England the express engines, some of them burning the best Welsh coal, have a very different array of circumstances to contend with: which is usually overlooked when comparing the relative performances of the two types of locomotives.

The general designs of the engines which form the subject of this paper are of the American type, as being the best adapted for overcoming climatic difficulties, giving as it does a flexible wheel-base to suit the road when disturbed by frost and thaw, affording easy access to all parts of the mechanism, and enabling necessary repairs to be effected with the greatest facility: all of which points are of great moment for enabling the traffic to be carried on without stoppage for repairs.

S.A. Light Engines for Freight and Mixed traffic.—The lightest class of engine which the writer will describe is designated S.A.; of which a longitudinal section and plan, one quarter full size, are shown in Figs. 1 and 2, and cross sections, half full size, in Figs. 3 and 4. This class was specially designed by himself with a view to condense the stock of patterns, and at the same time to give the best and most satisfactory results, whether working on the Atlantic or Pacific coast or on the prairie or rocky sections intervening, with all the extreme variations in class of coal from anthracite to almost lignite, and of water from lime to alkali, which are encountered in operating a railway across 3,000 miles of country: so that a locomotive of this class might be transferred to any portion of the line and give equal satisfaction. This system also reduces to a minimum the stock of duplicates for repairs; and enables the repairs to be effected without loss of time, and at a low cost.

For obtaining the requisite adhesion with this class of wheel-base —consisting of a four-wheeled lateral-motion truck in front, and four coupled drivers behind—and for economising weight, great care has been exercised to reduce the weight of the front end of the engine without impairing its strength, or diminishing the protection in case of collision; and the maximum weight obtainable has been placed on the driving wheels. Equalising bars are placed between each pair of truck wheels and also between each pair of driving wheels, in order to minimise all disturbance from inequalities of road and to equalise the wear on the tires as much as possible. This system virtually carries the rigid portions of this engine on three points, namely the centre of truck and the centre of each equaliser between the driving wheels, thus giving the most stable form of support that can be attained.

The S.A. class of engine has 17 × 24 ins. cylinders and 5 ft. 2 ins. driving wheels. The weight of the engine in working order, that is with two gauges of water (*i.e.* above the second try-cock) and with fire in the fire-box, is distributed as follows:—on truck 30,900 lbs., on drivers 53,900 lbs.; total weight 84,800 lbs. = 37·85 tons. According to the usual formula the tractive force is nearly 112 lbs. per lb. of average steam-pressure in the cylinders.

S.C. Light Passenger Engines.—For light passenger service a similar engine is built, classed as S. C., but having driving wheels of 5 ft. 9 ins. diameter; and a casting is inserted above the truck centre to raise the front end correspondingly. The distribution of weight is as follows:—on truck 31,600 lbs., on drivers 58,100 lbs.; total weight 89,700 lbs. = 40·04 tons. The tractive force is 100½ lbs. per lb. of average steam-pressure in the cylinders.

The capacity of tender for both these classes is 2,800 gallons of water and 10 tons of coal if required. The water supply along the line is stored in frost-proof tanks, which have a capacity of about 40,000 gallons, and are distributed at intervals varying from 10 to 25 miles and averaging about 16 miles. The tender capacity is sufficient to carry water enough for running two of these intervals, in case the supply at any tank should be stopped from external causes. As the railways are worked in divisions of about 110 to 140 miles, the coal capacity of the tender allows of carrying enough to serve for a round trip, wherever the exigencies of the coal supply render this advisable.

S.A. Light Engines.— *Boiler.*—The first point which attracts attention is the "wagon-top," as it is called, which is 8½ inches high above the top line of the barrel, Fig. 1. The object of this construction is primarily to obtain by increased height of firebox a sufficient area in the firebox tube-plate for inserting such a number of tubes as will give the most efficient proportion of heating surface in the tubes. The size of tube which is almost universally adopted is 2 inches outside diameter. A smaller diameter causes a diminution of efficiency at the front end of the tube, owing to the comparative absence of flame from the class of coal used; and on account of sagging it is unwise to attempt to use smaller tubes, unless the barrel of the boiler is short. Moreover the adoption of a single size for general use facilitates repairs, and reduces the number of tools necessary to be kept, as well as the stock of tubes kept in the stores. For a given diameter of boiler the number of tubes, and therefore the efficient tube surface, is much increased by the height of the wagon-top. Other very important advantages are also gained by the wagon-top. As the dome must be placed on the wagon-top, the regulator can thus be elevated by that amount above the surface of the water, thereby assisting to avoid priming, which is most troublesome with some kinds of water. This arrangement concentrates the heavier portions of the boiler over the driving wheels, and thereby adds largely to the adhesive weight. Moreover the barrel of the boiler is kept from being unnecessarily large, and the average water-level approaches very nearly to filling the barrel. One advantage of this is that, when driving hard into a snow bank (or "snow bucking," as it is called), it is almost impossible for the water to leave the top of the firebox uncovered, since the barrel requires but a small quantity to fill its vacant space; and the same remark applies when the engine is going down an incline.

Firebox.—As the upper portion of the firebox is wider than the shell between the frames, Fig. 3, this necessitates putting in the inside box in a special manner. The writer's practice is to put it in from the front, before riveting in the throat sheet or front plate of the shell, which is put in afterwards, the connection being made between barrel and firebox by a double-riveted joint; this practice gives entire satisfaction. The foundation ring is $2\frac{1}{2}$ inches deep, and 3 inches wide at sides and back, and $3\frac{1}{2}$ inches wide at front; it is single-riveted all round, with $\frac{1}{4}$ inch projection below the plates to allow for solid caulking. It is forged from scrap-iron, and welded together at the centre of each end. It is then machined all round, inside and outside; and the corners are tapered for the scarfing on the plates. The outer plates are scarfed very carefully to extend about $2\frac{1}{2}$ to 3 inches beyond the edge of the plate, sufficient material being left on the edge of the plate to give this length of scarf. This allows of three rivets for holding the plates close to the outer corner of the ring, and effectually prevents the plates at the corner from being sprung away by the caulking. The inside corners of the firebox tube and back plates have $\frac{7}{8}$ inch internal radius, and the scarfing on the side plates is brought well round the outside of the tube and back plates. There has not been a single instance of one of these corners giving trouble by leaking.

The fire-hole is elliptic in form, 16 inches long by 14 inches high, Fig. 1. It is formed by flanging the two back plates outwards, and a welded sleeve of Yorkshire iron, $5\frac{5}{16}$ inches wide by $\frac{3}{8}$ inch thick, is inserted between them, which is riveted to the inside box before the box is put in place. The flange of the outer plate extends beyond the sleeve, to form a backing for caulking the sleeve, and to allow the fire-door to fit against it. This form of fire-hole gives no trouble by leaking; and its flexibility allows the inside box perfect freedom for vertical expansion and contraction.

The firebox crown is not quite flat, Fig. 3, having $\frac{1}{2}$ inch rise in the centre from each side for preventing deposit of scale from occurring through deflection of the roof-plate in the centre, which sometimes happens with flat tops. The front portion is supported by ten lateral crown-bars or roof-girders; and the after portion by five rows of direct stays, with ten in each row. The crown-bars BB consist of two wrought-iron plates, 5 inches × $\frac{5}{8}$ inch, set 1 inch apart; and have cast-iron blocks between the ends, forming feet to fit the curve of the crown-plate and to rest on the top edge of the side-plates of the firebox. Each crown-bar is secured to the roof-plate by ten bolts of $\frac{7}{8}$-inch diameter with taper fit, driven upwards through the crown-plate, and having a fluted head below, with a copper washer between the head and the plate; the head is fluted round the bolt for the purpose of leaving room for any burr on the edge of the plate, and for enabling the annular face of the head to fit up solidly against the plate and make a perfect joint with the copper washer. The head is of the snap or cup form, in order to give as little projection for deposit as possible. The crown-bar is $2\frac{1}{2}$ inches above the plate, giving ample water-space between, in which are placed cast-iron ferrules on each bolt, having the bottom face of the same diameter as the bolt-head below the plate, while the upper face is made large enough to give the crown-bar a solid bearing on it. The washer on the top of the crown-bar has its edges bent down at front and back, so as to clip the two plates of the bar and keep them from any tendency to spread. These bars are spaced equally with the rows of direct stays, at a uniform pitch of $4\frac{5}{16}$ inches longitudinally, leaving $2\frac{1}{2}$ inches between the lap of the joint and the front row. The bars are hung in pairs from the external shell by a series of braces on each side, which are connected by a stirrup and pin to the crown-bars and to brackets on the boiler; three brackets are riveted in the dome on each side, and two on the shell on each side; those riveted to the dome assist materially in preventing any deformation of the shell owing to the large size of the hole cut in the shell plate. Allowance is made in all the braces for upward expansion of the firebox. The direct stays are $1\frac{1}{8}$ inch diameter, screwed with eleven threads per inch, and riveted over the plates on the outside of the shell and on the inside of the firebox, excepting only the outer row on each side, which are not tapped through the shell, but are screwed into hangers in pairs; the hangers are secured by pins to brackets on the shell, similar to those which carry the crown-bars; the brackets are all of mild cast-steel, and of light pattern. The hangers have allowance for upward expansion of the side-plates of the firebox.

This system of staying presents advantages. Crown-bars are preferable to direct stays for the forward part of the roof-plate, inasmuch as they allow considerable movement of the firebox while firing up, and the grip of the roof bolts prevents the roof from buckling, which invariably occurs from the direct contact of flame. This does not apply to the back end of the crown, where there is very little flame contact; and the absence of crown-bars on this portion materially assists in keeping the crown of the box free from deposit, and in removing it when formed.

The back plate of the shell and the smoke-box tube-plate are supported by gusset-stays attached to the top of the shell and barrel. Those on the back plate have the angle-irons continued down to relieve the strain on the top row of stays to the inside box. The taper plate of the wagon top is prevented from extending by four braces from the line of the bottom joint of the taper to the gusset-stays on the back plate, as shown in Fig 1.

A row of cross stays 1⅛ inch diameter, screwed eleven threads per inch, are tapped into the shell from side to side between each crown-bar and each row of crown-stays, and are placed 2½ inches clear above the crown. These cross stays prevent the flat sides of the wagon top from bulging out, and relieve the top row of side stays from undue strain, thus avoiding trouble from broken stays. Three cross stays are placed for the same purpose in the taper course above the back end of the tubes, each being connected by pins to a pair of stiffening angle-irons which are riveted to the oval sides of this course.

All side, front, and back stays for the firebox are ⅞ inch diameter, screwed eleven threads per inch, and riveted outside and inside. The tube-plate is stayed to the barrel below the tubes by four barrel-stays with studs through the tube-plate.

Dome.—The dome is 2 feet 4 inches diameter outside by 2 feet 6 inches high to joint. It is flanged out to the shell, and double-riveted; and the shell is strengthened by an extra thickness of plate which also takes the dome rivets; this plate and the shell project inside the dome far enough for a row of rivets, thus reducing the hole in the shell to 2 feet ½ inch diameter, and tending to prevent priming from being started by splashing. The top ring of the dome is of cast-iron, and has a cast-iron cover studded on with ground or copper-wire joint. Provision is made in the dome cover for whistle and safety-valve connections.

Boiler shell.—The boiler is built entirely of Siemens-Martin mild-steel plate imported from Scotland. The barrel is 52½ inches diameter outside at the smallest course, and 11 feet 4¼ inches long, the plates being $\frac{7}{16}$ inch thick. The firebox shell is 6 feet $7\frac{5}{8}$ inches long by 3 feet $6\frac{1}{2}$ inches wide outside between the frames; and inside 5 feet $11\frac{5}{16}$ inches long by 2 feet 11 inches wide at bottom and 3 feet $6\frac{1}{2}$ inches at top. The depth below the centre line of the boiler is 4 feet 8 inches to edge of plate, and the height above the centre line is 11 inches at sides and $11\frac{1}{4}$ inches at centre. The thicknesses of plates are as follows:—front and back tube-plates $\frac{1}{2}$ inch; back and side plates inside $\frac{5}{16}$ inch; back plate and top of shell $\frac{1}{2}$ inch; sides of shell $\frac{7}{16}$ inch; top of inside box $\frac{3}{8}$ inch; dome $\frac{7}{16}$ inch; smoke-box $\frac{3}{8}$ inch. Cleaning plugs are inserted as follows:—one in each corner at bottom of box; two in each side in accessible positions; one in front of shell at bottom, and one close under the barrel; five across the back plate just above line of crown; six in front tube-plate, namely two above tubes, two at sides, and two at bottom. Two hand-holes $2\frac{1}{4}$ inches diameter are placed on the taper plate, to afford access to the back end of the tubes, and to wash the deposit down into the leg of the firebox.

The boiler work is all sheared, punched, and riveted by hydraulic machinery on Tweddell's plan, the rivets being all of very mild Siemens-Martin steel: except in the foundation ring and where hand-riveting is necessary, in which case Lowmoor rivets are used. The crown stay-bolts and all screwed stays are of the same quality of steel as the rivets. The flanging is done by hand on special blocks, and the plates are heated in a furnace, and annealed after flanging whenever they have been locally heated. The edges of all plates are planed to an angle of 75° before being put together. The longitudinal seams are double-riveted zigzag with lap joints; and the circumferential seams are single-riveted, except the connection between fire-box and barrel which is double-riveted. The tubes are wrought-iron lap-welded, of German or American make, 185 in number, 2 inches outside diameter, No. 12 B.W.G. thick (0·110 inch), 11 ft. $8\frac{1}{4}$ ins. long between tube-plates; and are arranged in vertical rows, all being kept clear of the $\frac{7}{8}$-inch internal radius of fire-box tube-plate. The smoke-box tube-plate is drilled $\frac{1}{16}$ inch larger than the tubes, and the fire-box tube-plate to net size; the tubes are swaged down at the back end through about an inch length, sufficiently to receive a copper ferrule 2 inches outside diameter and No. 18 B.W.G. thick (0·050 inch), which is driven on, and the tubes are then inserted in place, and rolled tight at both ends with a Dudgeon expander, and beaded at the back end only.

Smoke-box.—The smoke-box is formed by a continuation of the barrel, the front tube-plate being circular, Fig. 4, and flanged forward to fit inside the front barrel course, which is also riveted to the smoke-box barrel. The front end of the smoke-box is stiffened by an angle-iron ring, to which is bolted the circular door-frame or front of cast iron; this is fitted with a round cast-iron door, which is hinged at the side and secured by three tapped bolts, and makes a conical joint with the frame. The conical joint makes a much tighter door than the flat joint, as the door is less easily sprung out of shape while being machined. The door has a number-plate bolted on in the centre.

The boiler is rigidly secured at the front end only, where the saddle and cylinders are cast to shape and chipped to fit, Fig. 4; and the smoke-box is secured by turned driving bolts, with a thickening plate on the inside of the box. The firebox end is provided with four angle-iron supports to slide on the top of the frame, and with four strap-brackets to clip the top bar of frame, which have liners sufficiently thick to allow of only $\frac{1}{16}$ inch lateral play on each side, as shown in Fig. 1. Four clips are placed on the sides of the box, to slide on the bottom bar of the frame and prevent twisting of the frame. As the fulcrum of the spring equaliser or compensating lever is bolted to the centre of the top bar of the frame, the weight of the firebox is transferred almost directly to the centre of the equaliser. No other connection is made between boiler and frame, so that the boiler is perfectly free to expand and contract.

Heating Surface.—The heating surface is as follows:—tubes (external) 1132 square feet; fire-box 112·5; total 1244·5 square feet. The grate area is 17·3 square feet.

Testing.—These boilers are built to carry a pressure of 150 lbs. per square inch, and are tested with steam to 165 lbs. The hydraulic test is not generally used by the writer, as it is considered by some engineers that the structure is damaged to some extent by the excessive pressure. Hydraulic pressure has however been applied up to 220 lbs. per square inch, in order to test the soundness of the design; and the result was very satisfactory.

Regulator and Steam Pipes.—The regulator, Fig. 1, is of the common balanced double-seat type and is of cast-iron, as is also the valve-box, both being designed so as to reduce the strains of expansion and contraction, and to enable the valve to be kept tight without attention. It will be noticed that the seats form very sharp cones, and are very wide compared with English practice; they are found to give the best results for durability and tightness. The regulator rod slides in the stuffing-box, being actuated by a horizontal lever provided with a sector, similar to a reversing lever. The driver sits on the right-hand side; and all handles are brought close to him, so as to be worked easily and quickly without losing sight of the track.

The regulator pipe is carried in the dome by a wrought-iron strap; and has a drooping flange or collar cast on near the top, to prevent water from creeping up the pipe and causing priming to start. The main steam-pipe S is of wrought-iron lap-welded, $5\frac{1}{2}$ inches diameter inside, and $\frac{1}{4}$ inch thick; it has a cast-iron sleeve riveted on at each end, with a copper joint for caulking. The joints at each end are ball shaped and ground tight; the back face of the front sleeve forms a ball joint to the tube-plate, and the T pipe studs make the two joints at this end. The joints between the branch pipes and the T pipe are made with a brass ring, having a ball joint at one side and a flat joint at the other, and both joints are ground. Similar joints are made between the branch pipes and the cylinder casting, which projects inside the smoke-box for convenience, Figs. 1 and 4. These joints are all painted with black varnish before being finally put together. The branch pipes are $4\frac{1}{2}$ inches diameter at each end, and the centre portion is made of oval section so as to leave the space in front of the tubes as open as possible.

Exhaust and Petticoat Pipes.—The exhaust pipes are in one casting, Figs. 1 and 4, so made as to get the exit as low as possible; each exit is on the top of the pipe, and forms a semi-ellipse divided by a web of metal; on this face is bolted the nozzle N, which is 7 inches high, and the tip is $3\frac{3}{4}$ inches diameter, being very slightly larger than the exit from each pipe. Thus the nozzle does not contract the steam passage, and therefore avoids "blowing over" into the other cylinder; but it serves to convey the jet of steam to the centre of the petticoat pipe and chimney, thus producing the maximum effect as an ejector. The petticoat pipe P is in effect a continuation downwards of the chimney, the two acting similarly to a Friedman injector with two admissions, one above the petticoat and the other below it. The petticoat pipe is smaller in diameter than the chimney, being about 13 inches diameter; it has a cone-shaped bottom M spreading out to about 17 inches diameter and an extension sleeve X at the top; it is held in place by a cross stay in the middle and a pair of stays at the top to prevent vibration. Thus the areas of the openings at top and bottom are both adjustable, so that the smoke-box can be kept clear of cinders, and the draught in the tubes can be equalised top and bottom, to obtain the best results.

Chimney.—The chimney or stack for coal burning is 16½ inches diameter inside, and has the base casting made in two parts, Fig. 4, one bolted permanently to the smoke-box, and the other riveted to the barrel of the stack, with a turned joint between them. This admits of the stack being readily changed for repairs, or for wood burning if required. The stack is of the "diamond" type, that is, it has a double-cone top of cast iron to admit a sheet of steel-wire netting for spark arresting, the netting being inserted in the joint between the two portions of the cone. This netting is 3½ × 3½ meshes per square inch with wire No. 12 B.W.G. thick (0·110 inch), and is protected in the centre by a cast-iron cone with curved faces to deflect the sparks aside, the cone being held by three vertical stays from the barrel of the stack. The barrel is of Bessemer steel No. 12 B.W.G. thick (0·110 inch), and is parallel in form.

The wood-burning chimney is made somewhat similar, except that it is all of steel No. 12 B.W.G. thick (0·110 inch); and the netting is made in the form of a flattened ⌓ in section, and is dropped in from the top to rest on a ring riveted to the inside of the stack; it is protected by a cone, as in the former case. The netting used is much finer, being 11 × 11 meshes per square inch, and made of steel wire No. 19 B.W.G. thick (0·040 inch).

Ashpan.—This is constructed with dampers at each end, which are worked from the foot-plate; and the bottom is slightly curved up at each end, Fig. 1, to hold water if required. It is carried by studs tapped into the foundation ring, and is secured by cotters for easy removal. Ashpans for wood-burning engines have a fine netting screen inserted inside each damper, to prevent the ashes from being blown out.

Grate.—For coal-burning the grate consists of cast-iron crossbars, which are pivoted at each end on side bearers carried by studs in the foundation ring. The crossbars have a series of alternate fingers at each side, placed so that the fingers of one bar extend between those of the next, and leave $\frac{5}{8}$ inch air-space all round; the body of the bar is also perforated with air-spaces. The bars have levers below, connected with a coupling-rod R, which is worked by a lever L from the footplate, so that they can be rocked on their bearings to break up all clinkers which may be forming, shake down the ashes, and clear the fire. The two front bars are replaced by a dump, where required, so that any clinkers which may be formed can be dropped into the ashpan without dropping the fire; the dump is also worked from the footplate.

The wood-burning grate is formed by two rectangular shelves running round the firebox, the upper about 10 inches wide and the lower about 6 inches, each sloping down towards the centre, and open in the centre; a third similar shelf below is closed in the centre, forming a sort of tray which is the bottom of the grate. A vertical space of 3 inches for admission of air separates each. The two lower are each carried from the one above, and the top one by side bearers in the firebox.

Boiler Mountings.—Two Richardson "pop" safety-valves V, $2\frac{1}{4}$ inches diameter, are secured to the dome cover; one or both are locked so that they cannot be tampered with. Both are set to blow off at 150 lbs. pressure, and will do so within $\frac{1}{2}$ lb., thus effectually preventing any increase above that pressure. When carefully adjusted they will close as soon as the pressure drops $\frac{1}{2}$ lb. below the blowing-off pressure; they therefore prevent any waste of steam.

The whistle is screwed on a stem fixed in the centre of the dome cover. It is of the low-toned class, the bell being $5\frac{3}{8}$ inches diameter and 8 inches long outside; it is worked by a horizontal lever under the cab roof above the driver's hand.

A globe mounting is placed on the top of the fire-box inside the cab; the joint to the boiler is made with a loose ring, forming a ball joint to the plate and a flat joint to the mounting; both are ground joints, and are secured by three studs. This globe supplies steam to injectors, blower, heater, Westinghouse pump when used, and steam-gauge; the various cocks are screwed in symmetrically round the globe. A main stop-valve is placed inside the globe, so that the steam can be shut off from all of these, and any temporary repairs effected at once. This mounting also holds the steam-gauge and its lamp.

Tallow cups or lubricators are fixed on each side of the fire-box with blow-through valves; and are connected to the steam-chest by copper tubes carried along the inside of the boiler clothing, for the purpose of lubricating the cylinders and valves.

On the back of the fire-box are fixed a glass water-gauge and lamp, and a set of three try-cocks; the latter suffice to ascertain the water-level if the glass gauge should get broken or stopped by dirt. All these cocks are of the compression type, that is, having a screw spindle with conical end to screw down tight on the seat; and the glass-gauge cocks are designed so that they can be closed and the glass removed, and the whole space round their stems can be cleaned out, while steam is in the boiler. These gauges and the tallow cups are all screwed into the fire-box shell, no mountings being put on with flat joints and studs. All mountings are provided with wooden handles. A cast-iron plate is fixed above the fire-door, to hold oil cans &c. while running. Two handles are placed in convenient positions on the back of the fire-box, which are connected with the feed-cocks between the tender and the injector or pump.

The fire-door is of the Stirling type, secured by a hinge bracket on the back of the fire-box, and fastened by a latch; the centre of the door has a swinging panel, which is adjustable to admit air. Steel castings are now being used for this door by the writer, in place of forgings.

A blow-off cock is placed centrally at the bottom of the back plate, and is worked by a handle from the foot-plate.

Cylinders and Saddle.—The saddle D, Fig. 4, between the frames is an independent casting, bolted to the smoke-box and fitting the frames, with flanges on inside and on top. Each cylinder is fitted to the outside face of the frame, and is bolted with driving bolts, which also secure the inside flange of the saddle. The cylinders fit between lugs on the top of the frame and on the top flange of the saddle; and the cylinders and saddle are keyed in position. The cylinder casting has an extension, forming the steam and exhaust passages, and connecting the cylinders with the smoke-box; this extension is securely bolted to the smoke-box and the saddle. This plan admits of either cylinder being taken off for repair or renewal, without interfering with the saddle or frame, enabling the work to be done in the shortest possible time and at the lowest cost.

The steam-chests are placed on the top of the cylinders, Fig. 4, and are removable, so that refacing or repairs to the valve-seats can be done rapidly and conveniently. The joints at top and bottom are made with copper wire; and the studs which hold the cover also secure the chest in place. The steam passage being cast in the cylinder enters the chest at the bottom, behind the valve-seat. The chests are placed as close in as the smoke-box will admit, to afford protection. The steam ports are $16 \times 1\frac{1}{4}$ inch, and the exhaust port $16 \times 2\frac{5}{8}$ inches. The valves are of the Allen type with $\frac{7}{16}$ inch supplementary port in four sections; the lap is $\frac{15}{16}$ inch, and the lead $\frac{1}{8}$ inch bare. The travel in full gear is $5\frac{1}{8}$ inches, the throw of the eccentrics being 5 inches. Very satisfactory results are being obtained for economy, efficiency, and speed. All the valves are of cast-iron of the same quality as the cylinders; and no scraping is done on the faces, because the surfaces, when care is taken at first, become quite polished and hardened, showing that valves of this metal run with a very small amount of friction or wear.

The cylinders and steam-chests are lagged with wood over a sheet of asbestos cloth, and are sheeted with stiff Russia iron, Fig. 4. The cylinder and steam-chest covers have casings of cast-iron.

Frames.—Fig. 1. These are forged from selected scrap-iron under a 30-cwt. Davy hammer; and are each made in two parts, the splice being placed in front of the driving axle and secured with keys and driving bolts. The mode of manufacture of the main frame is to forge the top bar in one piece from end to end, then weld on the horns or pedestals with a split scarf, the welding being done under a 12-cwt. hammer; the bottom bar is then veed in, and the inclined bar at the back end is dabbed on at the top and veed in at the bottom; the lower jaw of the splice is forged, together with a portion of the pedestal. The front end or extension frame is made as straight as possible, to obtain economy in forging and machining; and is provided with lugs on the top only, to receive the saddle-flange and the cylinder.

Across the front end of the frame, and behind the buffer beam, a heavy plate F, 8 inches wide and $\frac{3}{4}$ inch thick, is secured by being checked into the frame and riveted with angle-irons to the buffer-beam plate and to the front foot-plate. This gives protection to the cylinders in case of accident, and has proved to be of great service. Stays are placed to connect the smoke-box with the front end of the frame, so as to add vertical stiffness to the latter.

The back end of the frame is secured by a heavy cast-iron foot-plate, which is accurately planed and well bolted in place. This casting carries a wedge arrangement, for taking up all slack motion in the coupling between engine and tender. Side brackets are bolted to the frame and foot-plate, for supporting the back end of the running boards and cab.

Motion.—The pistons are of the built-up class with two packing-rings, bull ring, and junk ring, all of cast-iron. The advantage of this plan is that the packing rings can be examined and replaced without disconnecting the piston-rod from the crosshead. The piston-head is put on the rod with a taper of 1 in 16, and is made sufficiently tight to shrink on, and is then secured by a fine-threaded nut. The piston-rods and slide-bars are forged of mild Bessemer steel.

"United States" metallic packing-rings are used for the piston-rods and valve-stems, and give full satisfaction; the rods continue in first-class condition, and a set of packing-rings lasts about twelve months.

The cross-heads are of the four-bar type, and are of mild cast-steel, fitted with cast-iron gibs of cylinder metal.

The connecting-rods are of Siemens-Martin mild steel, with the oil cups forged solid on the straps. The coupling-rods are forged from best selected scrap-iron, without welding, and with solid eyes and oil cups forged on. Half-brasses and cotters are used in all these rods, on account of extreme cold in winter.

The motion proper is of the indirect kind, in the American style, for allowing free access to the steam-chest. The eccentric straps, expansion links, lifting links, reversing handle, and rocker arms, are all of mild cast-steel of English manufacture. All pins work in bushed ends where required. The weight of the motion is counterbalanced by a semi-elliptic spring, Fig. 2, bearing in front of the motion plate, and coupled to a short lever on the reversing shaft. The motion plate is of rolled mild steel, and the valve-rods are of forged mild steel.

Axles and Crank-Pins.—All axles are of Siemens-Martin mild steel, and are parallel, except in the centre between eccentrics &c. The crank-pins are of Lowmoor or Bowling hammered bars, and are case-hardened on the journals; the wheels are heated, and the crank-pins being turned parallel are driven in with a large tup and riveted over on the inside. The crank-pins have to be of the best material and extra strong, to withstand the effect of frost in winter, as cases have been known where all four have broken off suddenly when the engine was left standing long.

Wheels.—The driving wheels are of strong cast-iron, Fig. 3, with hollow spokes of egg-shaped section and hollow rim. The counterbalance weight is cast in solid, the rim being cut at each end of the weight in order to prevent damaging the wheel by contraction. The counterbalance is calculated to balance the total revolving weights and one half of the reciprocating weights. The wheels are pressed on the axles with a hydraulic pressure of 80 tons, and then keyed tightly.

The tires are of crucible steel 3 inches thick, and are secured on the centres by shrinkage only; no other attachments are necessary to secure them, and they can be safely worn down to

$1\frac{1}{2}$ inch thickness in winter and $1\frac{1}{4}$ inch in summer, without becoming loose or breaking.

The axle-boxes are of cast-iron with brass bearings babbitted. The back horn-block is wedge-shaped, with setting-up and locking bolts.

Truck.—The frame of the truck, shown half full size in Fig. 5, consists of a cast-iron plate or saddle D, strongly ribbed and resting on the top bars of the side frames F; it has a lateral space in the centre, to allow the swinging casting G to move sideways on four links L hung on pins through the saddle. The swinging casting is free to revolve on a centre bolted to the underside of the saddle between the cylinders, thus forming the sole support for the front end of the engine.

Each side-frame F of the truck consists of two straight wrought-iron bars, connected at each end by a pair of horn-blocks or pedestals. The springs S, one on each side of the truck, are placed in the interstices of the frame in an inverted position, so that the weight is transferred direct from the centre of the top frame to the spring buckle, thus relieving the side-frame of the truck from any strain due to weight. The ends of the springs are connected to equalising bars H, one on either side of each spring, which rest on the tops of the axle-boxes.

The axle-boxes are of cast-iron, with loose brass bearings babbitted; so that by removing the sponge box and lifting the truck about half an inch the bearing can be removed with the fingers and a new one substituted. The collars on the axles are loose, to permit of this being done.

The axles have journals 5 inches diameter by 8 inches long. The wheels are Krupp wrought-iron coiled discs, 30 inches diameter, with $2\frac{1}{2}$ inch crucible-steel tires and Mansell clip-rings. They are put on the axles with a hydraulic pressure of 40 tons.

Cab.—The cab is of ash, open at the back in the centre, and having doors in front to pass out on the running boards. There are two windows on each side, one sliding and one fixed. The roof is double, and extends back over the front of the tender. Seats are placed on each side, the right-hand being the driver's. The central opening at back is provided with thick canvas curtains for winter use only.

Pilot or Cow-catcher.—This is of oak, strongly bound with iron, and bolted on the front of the buffer beam, as shown in Figs. 1 and 2. The point is supported by rods from the push casting C on the buffer beam, and by stays from the bottom back beam to the saddle between the cylinders; so that it cannot be broken down by the weight of an animal encountered on the line.

Clothing and Furniture.—The boiler is lagged with wood, so as to leave an air space of about an inch; and is then covered with heavy Russia iron, with bands of the same. The dome is similarly covered, with the addition of cast-iron base and cap.

The sand-box H has $9\frac{1}{2}$ cubic feet capacity, and is placed on the top of the boiler for dryness, with a brass pipe at each side to the driving wheels; both valves are worked by one handle from the cab. It is finished in Russia iron, with castings for base and cap, similar to those on the dome.

A bell is placed on all engines, to be rung at crossings and on entering stations, in conformity with the law.

A pump is placed on the left-hand side of the engine, and a No. 8 non-lifting injector of Gresham pattern on the right-hand.

A gong is fixed in the roof of the cab, with a cord running the full length of train, for signalling stops by the conductor, or in cases of necessity or alarm.

These engines are occasionally equipped with Westinghouse pump and reservoir, for extra service as passenger engines.

Tender.—The tank has a capacity of 2,800 gallons of water and 10 tons of coal. It is mounted upon a wooden frame of white oak, which is strongly braced longitudinally and laterally, and is carried on two four-wheeled rigid-centre trucks. The two springs on the front truck are placed laterally on the cross frame, and of the four springs on the back truck two are placed longitudinally on the side frames and two laterally on the cross frame; thus the tender is carried on three points, and rides very steadily in consequence. The cross frames of the two trucks are of I beams, 10 inches deep by 5 inches wide and weighing about 40 lbs. per foot, secured at the ends by wrought-iron plates and to the side frames by driving bolts. The side frames are of two flat bars $3 \times 1\frac{1}{4}$ inch and one 3 × 1 inch; the second 3 × 1¼ inch bar is gibbed at the ends to form a truss with the top bar, all three bars being secured to the axle-boxes at the ends. The axle-boxes are the standard freight-car boxes with removable bearings, so that duplication is carried as far as possible. The axles are of Siemens-Martin steel and are duplicates of those used under coaches and freight cars. The wheels are 33 inches diameter, of cast-iron with chilled treads. Hand-brakes are applied to both trucks, so as to equalise the brake power on all the wheels.

Painting.—The writer's practice is to paint the engines black, without stripe or ornament of any sort. The letters and figures are put on in gold leaf for passenger engines, and in yellow paint for freight engines. Extra large figures are put on the tender for the convenience of the traffic and operating departments.

S.C. Light Passenger Engines.—The foregoing S.A. class of freight engines are equipped as S.C. engines for light passenger service by substituting driving wheels of 5 ft. 9 ins. diameter, and adding Westinghouse automatic brake equipment complete, with improved brakes on the driving wheels, arranged to compress each wheel between two shoes, as shown in Fig. 7, so as to neutralise the thrust on the axle. Extra care was taken in calculating and placing the counterbalance weights in the wheels, and a corresponding satisfactory result in steadiness has been obtained. The tender has also the automatic brake, arranged to admit of being worked by hand if necessary; and instead of cast-iron wheels, Krupp wrought-iron coiled disc-wheels of 33 inches diameter are used, with Martin-steel tires 2½ inches thick. The feed water is supplied by two No. 8 injectors, one non-lifting on the left-hand side, and the other lifting on the right-hand side.

S.B. Heavy Passenger Engines.—These are built on similar lines to the preceding classes, as regards type of wheel-base and general features. They are especially designed for working very heavy and fast trains, up to ten coaches weighing 60,000 to 80,000 lbs. each, and at speeds of 45 miles per hour between stations. Their weight in working order with a double supply of water and with fire in the firebox is distributed as follows:—on truck 31,000 lbs., on drivers 64,800 lbs.; total weight 95,800 lbs. = 42·77 tons.

The cylinders are 19 inches diameter and 22 inches stroke, and the driving wheels are 5 ft. 9 ins. diameter. The tractive force is thus 115 lbs. per lb. of average steam-pressure in the cylinders.

The wheel-base is 23 ft. 6½ ins., and the distance between the driving wheels 8 ft. 9 ins. The coupling-rods are made of **I** section, for the sake of lightness and stiffness. The distance from the centre of the driving axle to the centre of the cylinders is 11 ft. 8 ins.

The springs are underhung, instead of overhead as in the preceding classes, thereby enabling the boiler centre to be placed lower; and the riding qualities are very satisfactory.

The boiler is 54 inches diameter outside the barrel, which is all in one sheet from the taper course to the front end, where it is connected with a solid wrought-iron ring, 10½ inches wide and ½ inch thick, in which the front tube plate is riveted, thus dispensing with a longitudinal joint crossing the tube-plate flange. The barrel is 11 ft. 0¾ inch long, and 11 ft. 4¾ ins. between the tube-plates. The firebox is 7 ft. by 3 ft. 6½ ins. outside, 5 ft. 4½ ins. deep from centre line, and 11¾ ins. above centre line at sides, to 12¼ ins. above at centre. The details of construction are otherwise exactly the same as in the preceding classes, except that the longitudinal seams of the barrel are here double-welted butt-joints, with the inside welt narrow and the outside one wide, the latter being double-riveted with wider pitch in the outer row of rivets. The tubes are exactly the same as in the preceding classes, except for length; and are 204 in number. The working pressure is 160 lbs. per square inch. The heating surface is as follows:—tubes (external) 1,235 square feet, firebox 134·8; total 1369·8 square feet. The grate surface is 18·4 square feet.

The main steam-pipe is 7½ inches diameter inside and $\frac{5}{16}$ inch thick, and the branch pipes are 6 inches diameter. The steam ports are 18 × 1⅝ inch, and the exhaust port 18 × 3¼ inches. Allen valves are used, with the Morse balancing arrangement; the latter consists of four cast-iron strips set on the back of the valve, jointed at the corners, and held up by springs against the inner face of the steam-chest cover, which is planed; a small hole in the back of the valve communicates with the exhaust. The average travel of the valve is 5 $\frac{11}{16}$ inches; the lap is $\frac{15}{16}$ inch, and the lead $\frac{3}{32}$ inch. The steam-chest cover is hollow for the steam to pass to the front end of the valve.

The truck has a wrought-iron frame, and the cross frame carrying the weight is of a truss form; the whole being rather lighter and stronger than in the preceding classes. The wheels are 36 inches diameter, of Krupp make, namely a wrought-iron coiled disc with steel tire; the axles, axle-boxes, and hornblocks are duplicates of those in the preceding classes.

The outside finish is considerably different, in consequence of the running boards being placed lower down, in a line with the top of the tender frame and foot-plate; a box splasher and sand box are put on the driving wheels. The feed-water is supplied by two No. 9 injectors, one non-lifting on the left hand and one lifting on the right hand; in Fig. 6 is shown, three times full size, the way in which the lifting injector is worked, which being more rapid and simple in action is considered preferable to the ordinary style. The engines are equipped with Westinghouse automatic brakes, similarly to the S.C. class; and also with a double sight-feed lubricator.

The tender has a capacity of 2,800 gallons and 10 tons of coal, and is built in a similar manner to the preceding, except in having 40-inch Krupp wrought-iron coiled disc-wheels with Martin-steel tires.

S. D. Consolidation Engines. — The term "consolidation" is simply used to denote that the engine has four pairs of driving wheels coupled and a two-wheeled truck or bogey in front. These engines have been designed for special service on the north shore of Lake Superior, where the grades and curves are frequent and heavy, and the service is almost entirely composed of through trains. They are intended to haul freight in summer, and passenger trains in winter when bad weather or the exigencies of traffic render this necessary; they thus require to possess the qualities of rapid steaming and steady free running, with a minimum internal friction and wear and tear from the high number of revolutions per minute. Their weight in working order is about 104,000 lbs. or 46½ tons.

Boiler.—The boiler barrel, as shown in Fig. 8, is 54 inches diameter by 11 ft. 10½ ins. long, and is similar in design to that of the S.B. class of heavy passenger engines (page 21); but the longitudinal seams are all double-riveted lap-joints. The firebox is made from the same class of bending blocks, but its shape is shallow and wide, so as to spread over the top of the frames; the boiler centre being 7 ft. 3 ins. high gives a depth of 3 ft. 9 ins. from centre to bottom of firebox, or about 1 ft. 5 ins. depth of leg below the barrel. The firebox is 8 ft. 9 ins. long by 4 ft. 2¼ ins. wide outside, and the thicknesses of plates and width of water spaces are similar to those in the former classes; but the top of the box slopes down from 12¼ inches above the centre line at the front to 4¼ inches at the back, in order to avoid burning the firebox crown on descending grades. The system of staying &c. is the same as that in the former classes. The firebox is carried on top of the frames by four cast-steel slippers secured to the foundation ring and having lips to prevent side play, Fig. 8. Two strong Lowmoor iron plates are secured to the outside of the box near the front end, and are bent under the frame and bolted; and at back end two heavy Low Moor iron links connect the box with the frame, so that it is perfectly free to expand and contract but is allowed no other movement. The boiler is fixed only by being bolted at the front end to the cylinders; the motion plate, though having an extension to fit the underside, is not fixed to it. The tubes are 208 in number, 2 inches outside diameter, and No. 12 B.W.G. thick (0·110 inch). The pressure is set at 160 lbs.

Smoke-box.—This is of the "extension" type, as shown in Fig. 8, with high exhaust-pipe and straight stack. In it is fitted a horizontal plate F, extending from the tube-plate to the front of the exhaust-pipe, above the line of the top tubes and below the tip of the exhaust, and fitted closely round all pipes; to the underside of this horizontal plate, and in front of the exhaust, is riveted a vertical baffle-plate E, with an extension piece at bottom which is capable of adjustment to regulate the draught through the tubes. From the front end of the horizontal plate a netting extends to the front of the smoke-box, and is made secure all round. The netting is similar to that in use for diamond stacks. The deposit of cinders in the extension of the smoke-box is dropped through a hopper P attached to the underside, the hopper being made air-tight when not in operation. The exhaust nozzle N is single; and the dividing partition inside the pipe is carried up as high as possible, to prevent "blowing over." This arrangement gives very free steaming qualities, with a decreased back-pressure in the cylinders.

Heating Surface.—The heating surface is as follows:—tubes (external) 1329·5 square feet; firebox 118·7 square feet; total 1448·2 square feet. The grate area is 28·7 square feet.

Regulator and Steam Pipes.—These are similar to those used on the S.B. engines; but the length of firebox does not admit of the regulator being worked from the back of box. The rod is therefore carried through a stuffing-box attached to the back of dome and projecting inside the cab front. The handle is fixed horizontally as before, but is longer for convenience.

Chimney.—Figs. 8 and 9. The chimney is smallest about 6 inches above the top of the smoke-box, being $16\frac{1}{2}$ inches diameter at that point and increasing to $18\frac{1}{2}$ inches diameter at top. It is made of Bessemer steel plate, with cast-iron top and bottom rings; and has a light outer barrel cased with Russian iron, the space between having ventilating holes at top and bottom. The chimney base is a separate casting, as in the former classes.

Grate.—The grate consists of ten rocking bars and dump arrangement. The bars are made to rock in two sections of five bars each, so as to lighten as much as possible the work of rocking them.

Ashpan.—This is made in three sections, to admit of being taken down easily for repairs. It has two sliding doors in the bottom, to permit of ashes being dropped if necessary; and is provided with front and back dampers.

Boiler Mountings.—These are similar to those used on the former classes of engines.

Cylinders.—As shown in Fig. 9, half full size, these are of the "half-saddle" type, and are bolted together in the centre, the top forming the seat for the smoke-box. They are secured to the frames by being placed between the upper and lower bars, and bolted by four vertical bolts driven through both frame-bars and cylinders, and by three horizontal bolts through the lower frame-bar. They are also keyed in position between lugs on the frame-bars. The steam passage S in the saddle divides, and enters the steam-chest at the bottom at both ends. The exhaust passages E are brought as near to the centre as possible, where they enter the smoke-box; and are semicircular, to suit a circular exhaust-pipe. The cylinders are 19 inches diameter by 22 inches stroke, so as to reduce the piston-speed. The steam ports are 18 × $1\frac{5}{8}$ inch, and the exhaust ports 18 × $3\frac{1}{4}$ inches. The valves are of the Allen type with $\frac{9}{16}$ inch supplementary port; the lap is $\frac{15}{16}$ inch, and the lead $\frac{3}{32}$ inch full. The travel in full gear is $5\frac{3}{4}$ inches, the throw of the eccentrics being $5\frac{1}{2}$ inches. A bracket B is fixed on the underside of the saddle, to connect with the equalising lever of the truck, and so carry the front end of the engine.

Frames.—Fig. 8. These are forged from selected scrap iron, and are each made in three pieces. The main frame extends from the back end to the front of the first driving wheels, and has extension arms to which the upper and lower bars at the front end are keyed and bolted. These bars carry the cylinder between them, and project to the back of the buffer-beam, being there keyed and bolted together. Cast-iron brackets are inserted between them, to carry the cross-bars for the truck bearing-centre and sleeve. The lower bar also carries the cross-bar for the truck radial centre R. The front end is constructed similarly to that of the former engines, except that the angle-irons connecting the buffer-beam and heavy horizontal cross-plate are boxed to fit against the frames, and are bolted to them. This is necessary for hauling heavy loads backwards when required. The back end of the frame is formed of two heavy cross-bars, checked for the frame, and checked into the frame above and below, the upper one being extended to carry the back casting of the cab, and the lower one brought up to form a truss; and they are bolted together at the outer end by the footstep rod. The drag-box D is bolted between these bars, and the pin hole is placed in front of them. The wedge block is bolted on the top of the upper bar, which is considerably the stronger; and the whole arrangement is made to suit any of the standard tenders for freight engines. A heavy cross-stay A is bolted to the back of the trailing horns; and behind the main drivers the upper bars and lower bars are connected by two cross-stays T, which have a stiff plate bolted on them; this arrangement entirely prevents any twisting movement in the frame from the weight of the boiler above. The motion plate M is secured to the top of the frames by brackets, and is placed between the first and second drivers; it has a stay-plate bolted on and extended to fit against the underside of the boiler barrel, with an angle-iron under the barrel but not fixed to it, thus preventing any upward deflection of the frame. A cross-stay on the top of the frames between the second and third drivers serves to carry the spring for counterbalancing the weight of the motion. A heavy wrought-iron strut is placed between the upper and lower bars of the frame between the first and second drivers, where the spring equaliser is placed below. The horn stays, plates, and wedges are all duplicates of those in the S.A. class.

Motion.—The motion is constructed in a similar manner to those of the former classes, the rough steel castings being duplicates of them in nearly all cases. The piston-head is solid, with split cast-iron rings sprung in, and is secured to the rod as in the former classes. The crossheads, as shown 1½ times full size in Fig. 10, are of cast steel, and are of the Laird type, that is, their sides D extend upwards and are bolted on the sides of a cast-iron slide-block B, which works between two bars R, both secured above the piston-rod, so that the lower bar passes through the crosshead and forms the lateral guide, while the upper bar is wider and covers the whole slide-block, thus giving extra bearing surface, besides acting as a cover to protect the lower bar; the whole arrangement is thus raised out of the way of dirt from the ballast. The connecting-rods are similar to those of the S.B. class; but are longer, so as to connect on the third pair of drivers. The side-rods are forged from best selected scrap iron, and the first and fourth ends are duplicates of those in the S.A. class.

Axles and Crank-Pins.—These are of similar material to those in the former classes; the rough axles and the axle-boxes complete are duplicates of those in the S.A. class.

Driving Wheels.—The driving wheels, shown in section in Fig. 9, half full size, are of cast iron, with hollow spokes and rim, and are all from one pattern, with changeable crank-pin hubs, the balance-weight being cast partially solid in the first and fourth pairs, while the second and third pairs are cast hollow and filled with lead. As a result these engines run remarkably steadily and quietly. The wheels are 51 inches diameter with 3-inch tires, and the two centre pairs have bald or plain tires 6 inches wide, the first and fourth being flanged and 5½ inches wide.

Truck.—Fig. 11, half full size. The frame D of the truck is a wrought-iron forging, with two vertical cross-bars welded in the form of a rectangle upon two horizontal bars, which latter carry the horns bolted to the underside. A swinging casting G in the centre of this frame is connected with it by inclined links and pins L, and supports a hollow cast-iron pillar, working in a guide-sleeve which is carried by cross-bars C secured to the frame of the engine between the cylinders and the buffer-beam. A strong bolt in the inside of the pillar is fitted to it with a ball joint at the top, and has an eye at the bottom, to carry one end of an equaliser L pivoted in a casting placed under the cylinder-saddle, as previously described; the other end of the equaliser is connected with the driving springs, and thus the equaliser carries the front end of the engine. The radial frame E of the truck is V shaped, the two ends being bolted at the front to the main frame D of the truck, and the centre is bored and bushed for a centre pin R, which is carried by a cross-bar on the lower frame-splice, as previously mentioned, and also by a stay from the cylinder-saddle. The axle and boxes are duplicates of those in the S.A. class, and the wheels are duplicates of those in the S.B. class. The springs S are double spiral, two to each box, placed under the corners of the truck frame, and connected fore and aft by a pair of equalisers Q, shaped like a horse-shoe hung upon the top of the box.

Driving Spring-Gear.—As shown in Fig. 8, the spring-gear is arranged in such a way as virtually to support the engine on three points. The weight on the third and fourth drivers on each side is carried by three springs inserted in the interior spaces of the frame; one heavy spring is in an inverted position in the centre, with the buckle bearing against the underside of the top bar of the frame, and each end is connected by hangers to a pair of equalisers resting on each axle-box, alongside of the frame; the other end of each pair of equalisers is connected to the buckle of a smaller spring, the ends of which rest in cast-iron shoes fixed to the underside of the top bar of the frame.

The first and second pairs of driving wheels have springs over the top of the frame, which are connected by hangers to an equaliser placed below the frame. The front ends of the first pair of springs are connected by a lateral equaliser, the centre of which is connected by a hanger to the back end of the truck equaliser, as previously mentioned.

Cab.—The cab is similar to former ones, but larger, being made wide enough to permit the driver and fireman to stand alongside the firebox.

Clothing and Furniture.—The boiler is covered with a layer of thick woven asbestos felting of fine quality, and then lagged with wood and covered with Russian iron in the usual way. The clothing is continued inside the cab to the back corner of the firebox, as a protection for the driver and fireman.

The sand-box H on the top of the boiler serves for forward running only. For backing, two hind boxes are placed under the running boards below the cab.

The feed-water is supplied by two lifting injectors, one No. 8 on the right-hand side, and one No. 9 on the left-hand.

The remainder of the attachments are similar to those on the other engines.

These engines are equipped with Westinghouse pump, reservoir, and driver brakes between the first and second pairs of drivers; also with the American steam-brake between the third and fourth pairs of drivers.

Tender.—The tank has a capacity of 3000 gallons of water and 10 tons of coal. It is mounted and carried in exactly the same way as in the former classes. The tender brakes are arranged to work either with the Westinghouse air-brake or with the American steam-brake or by hand. The weight of the tender when empty is 35,000 lbs., and when fully loaded 85,000 lbs.

S. G. Mogul Engines.—The term "Mogul" is applied to such engines as have a two-wheeled truck in front of the cylinders and three pairs of coupled drivers behind. The author is now engaged in working out the details of a class of Mogul engines with 19 × 24 inch cylinders, as shown in outline in Fig. 12, designed for fast freight service in summer on the heavier sections of the road, and for heavy fast passenger service in severe winter weather. The lines of the S. D. class (page 22) have been followed to a great extent, in order to obtain the requisite boiler power; and duplication of parts of former classes is also closely adhered to, not a single new pattern being required.

The boiler is similar to that of the S. D. class, the same flange blocks being used; it is somewhat shorter in the barrel, but its centre is the same height above the rails, namely 7 ft. 3 ins., though the wheels are increased from 51 ins. to 62 ins. diameter. The bottom of the firebox is made shallower at the back end, to clear the trailing axle-boxes; while the front end is kept to the full depth, to allow sufficient depth of fire below the bottom tubes. The frame is similar to that of the S. D. class, but with three pairs of horns; between the driving and trailing wheels it is forged down to suit the firebox, thereby enabling the boiler centre to be kept to 7 ft. 3 ins. height, although driving wheels of 11 ins. greater diameter are used. The cylinders are made from the S. D. pattern, but lengthened in stroke to 24 ins., and made shallower in the boiler seat. Other duplicates of the S. D. class are the truck, buffer-beam, pilot, crosshead, crank-pins, spring saddles, details of spring gear, side-rod brasses, motion plate, back beams, drag box, cab, details of grate and shaker, chimney, exhaust and steam pipes, regulator and handle, steam-chest cover and hopper.

Duplicates of the S. B. class are the connecting-rod, piston and rod, valve buckle, eccentrics and straps, details of motion, rocker box, smoke-box front and door.

Duplicates of the S.A. class are the wheel centres, tires, axles, boxes, horns and wedges, horn stays, and reversing handle.

Boiler mountings, brass fittings, fire-door, bell, and a number of minor details, are standard, and common to all classes. The tender duplicates with the S. D. class. The Westinghouse brake will form part of the equipment; and Delancey's balanced valve will be used, as shown full size in Fig. 13.

The weight of this class will be about 100,000 lbs. or 44½ tons, of which about 86,000 lbs. or 38½ tons will be on the driving wheels. The boiler will be set to carry 170 lbs. pressure.

Cost of Production.—A batch of five engines of the S.A. class which the writer has recently completed cost, without extras, $5,205 each, or about £1,071; or 2·44 pence per lb. for the finished engine and tender. The cost of an English engine, built in the shops of the London Brighton and South Coast Railway, has recently been given by Mr. Stroudley at 5·57 pence per lb.* The cost here given by the writer, being less than half that of the English engine, may be regarded with some surprise; and a few leading details will therefore be added. This cost includes all the coal used in the forge, blacksmith's, boiler and other shops, as well as all small tools and supplies used in the construction of the engines, such as brooms, brushes, candles, chisels, files, hammers, handles for tools, hemp, oil, waste, sand paper, tallow, wrenches, &c.; and also a complete set of tools of all sorts, lamps, oil cans, jacks, dogs and wedges, fire-irons, &c., for the equipment of the engine in running order. But it does not include the salaries of foremen, draughtsmen, and clerks; repairs to machinery; maintenance of buildings; water or coal used in the stationary boilers required for running the shop engine. These are not included, for the reason that on some railways such expenses are charged in a lump sum, varying from 5 to 15 per cent., which is added to the cost of the finished engine. In the main shops of the Canadian Pacific Railway these expenses are about 5 per cent.; but in order to put these shops on such a basis as will compare with any

* Institution of Civil Engineers, Proceedings, March 1885, vol. lxxxi, page 149.

other establishment, it is the practice to add 15 per cent. to the cost of both labour and material of the manufactured goods. Hence, by omitting this charge altogether in the cost above given, a comparison can be more easily made according to the varying practice of other railway shops and manufactories.

Detailed Costs.—With regard to the detailed cost of certain portions of finished work for these engines, the forged frames cost 2 pence per lb., including scrap (charged out at market value) and all coal; when planed, drilled, and slotted all ready for erecting, the frames cost $2\frac{2}{3}$ pence per lb. The finished boiler ready to go into the frames costs 4 pence per lb., the steel plates having to be imported from Scotland, and freight and duty paid. The total cost of cylinders, fitted with covers, studded, and ready for erecting, is $2\frac{3}{4}$ pence per lb.; and as the shops do not include a foundry, 2 pence per lb. has to be paid for the cylinder castings. The cast-iron driving-wheel centres cost $1\frac{1}{3}$ penny per lb., including cost of freight for over 400 miles. Connecting-rods and side-rods, fitted up with brasses, cotters, &c., all ready for use, cost $7\frac{1}{2}$ pence per lb.

The writer has lately built ten engines of the S.A. class and eight of the S.C. class, all of which are sent across the continent and are running between the Rocky Mountains and the terminus on the Pacific Ocean.

Appended is a specification of the tests prescribed for materials used in the construction of locomotives built outside the Montreal shops of the Canadian Pacific Railway.

Appendix.—Tests of Materials.

All materials used in the construction of the locomotive must be of the best quality of their respective kinds, carefully inspected, and subjected to the following tests. Notwithstanding these tests, should any defects be developed in working, the corresponding part will be rejected.

Boiler Iron.—All boiler iron to be best quality Lowmoor, Bowling, or Krupp. A careful examination to be made of every sheet, and none to be accepted that show mechanical defects. In every boiler one sheet to be ordered 3 inches longer than the size required, from which a strip is to be cut and tested. The piece so tested must have an ultimate tensile strength with the grain of not less than 50,000 lbs. per square inch, an ultimate tensile strength across the grain of not less than 45,000 lbs., and must show a ductility, measured by elongation or reduction of area, of not less than 20 per cent. Should any of the test pieces fail to fulfil the above requirements, the entire boiler may be rejected. Should any plates develop defects in working, they must be rejected. Each plate must be stamped with the maker's name.

Boiler and Fire-box Steel.—A careful examination to be made of every sheet, and none to be accepted that show mechanical defects. A test strip from each sheet, taken lengthwise of the sheet and without annealing, should have a tensile strength of 55,000 lbs. per square inch, and an elongation of 30 per cent. in an original length of 2 inches. Sheets are not to be accepted if the test shows a tensile strength less than 50,000 lbs. or greater than 65,000 lbs. per square inch, nor if the elongation falls below 25 per cent. Should any sheets develop defects in working, they must be rejected.

Iron and Steel Stay-Bolts and Boiler Braces.—Iron or steel for stay-bolts and braces must have an ultimate tensile strength of not more than 60,000 lbs. nor less than 48,000 lbs. per square inch, with an elongation of not less than 20 per cent., and a reduction of area of fractured section of not more than 35 per cent. It must also withstand the following test. A piece of the iron or steel from 18 inches to 24 inches in length is to have one end fastened in a vice; over the other end a piece of pipe is to be passed to within 6 inches of the vice. By means of the pipe the sample must be bent until the end is at right angles to the portion in the vice, and then bent back to its original position. This must be repeated not less than twelve times without showing fracture, the bending being each time in the opposite direction to that previous.

Boiler Tubes of Steel or Iron.—All boiler tubes must be carefully inspected and be free from pit-holes or other imperfections. They must be rolled accurately to the gauge required. They must be expanded in the boiler without crack or flaw. When tested, iron or steel tubes must show a tensile strength of not less than 55,000 lbs. per square inch, and a ductility of not less than 15 per cent.

Tubes of Brass or Copper; Brass and Copper Pipes.—Tubes of brass or copper to be of uniform circumferential thickness and solid drawn; to be perfectly round. A piece 30 inches long, annealed and filled with rosin, must withstand being doubled until the extremities touch each other without showing defects. A piece 30 inches long, not annealed, filled with rosin, and placed on supports 20 inches apart, must withstand bending to a deflection of 3 inches without showing defects.

Bar Iron.—All bar iron (flats, rounds, and squares) must be capable of sustaining an ultimate tensile stress of 50,000 lbs. per square inch, with an elastic limit of 25,000 lbs., and a minimum ductility, measured by elongation or reduction of area, of 20 per cent.