SECT. II.—OTHER SELECTED PAPERS.

(Paper No. 2284.)

“Tramway Permanent Way.”

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THE utility of tramways, as a means of reducing the tractive resistance in moving a loaded vehicle, has been recognized since the seventeenth century, when rails of oak were employed. This primitive track has progressively developed into the substantial structure of to-day.

First, to lessen the wear, wrought-iron bars were spiked to the upper surface of the timbers, then cast-iron plates were used in the same manner, and latterly wrought-iron rails, rolled in different sections, were fixed in a variety of ways to the top of the oak beam, or, as it is now called, the longitudinal sleeper. This last system, with longitudinal timbers and rolled-iron or steel flat or box-rails, was almost invariably adopted till about the year 1870. By that time a great variety of systems had been introduced, having a substructure of cast-iron or a combination of cast- and wrought-iron, in the forms of sleepers and chairs, the rails used being of rolled steel of different sections, but generally of the box or web pattern. Then followed the rolled-steel flange rail similar to a railway flat-bottomed rail, but with a groove in the head like other tramway sections. The usual weight was from 40 lbs. to 60 lbs. per lineal yard, and for a foundation, some were bolted to plates 12 inches broad, some to longitudinal, and others to cross trough-sleepers of rolled iron or steel. Occasionally this rail was also used with ordinary timber cross-sleepers. Last came the girder-rail, and this is the rail most largely used at the present time. It is a flat-bottomed rail with deep web rolled to sections of from 60 lbs. to 100 lbs. per yard, having a flange from 6 inches to $7\frac{1}{2}$ inches broad to take the place of the longitudinal wooden sleeper before referred to.

Having thus roughly traced the development of tramway permanent way, the Author will now discuss the merits and demerits of a few of the principal systems at present in use. Most of the defects to be noted have been proved by the Author experimentally. Of some of the more complicated systems he has no acquaintance;

in such cases he will only refer to such obvious objections as present themselves to his judgment. With the exception of the timber longitudinal-sleeper and box-rail systems, which were never satisfactory even with horse-traction, he has judged all the later systems by the standard of their suitability for steam-traction. A great many of the cast-iron chair and sleeper systems have been tolerably successful with horses, but have failed when a locomotive was run over them. Nearly all new companies now apply to Parliament for powers to use steam, and the Author thinks this standard of stability is not unreasonable, especially as a line may now be laid with girder-rails, which will carry a locomotive fairly well at as little, or less, cost as that of the built-up systems.

LONGITUDINAL-TIMBER SYSTEMS.

In the earlier lines laid upon longitudinal-sleepers, the rail was merely a flat bar, not intended to have any material vertical stability; but, relying for this on the sleeper, it was simply

intended to supply a durable wearing-surface (*Fig. 1*). Here the mode of fastening by vertical holding-down bolts was the main deficiency; the rail, being so weak, deflected under the load. In front and behind the points of contact there was a corresponding rise or lifting of the rail from the sleeper. This, with a rolling load, of course gave rise to a series of concussions between the rail and sleeper, which in a short time loosened the fastenings, and wore the top of the sleeper to such an extent that ultimately the rail lay loose, and only bore on the sleeper while a load was passing over it. Hence resulted a vertical and lateral rocking motion, during the passage of any vehicle, which

soon caused the destruction of the bearing-surface of the sleeper, distortion of the rail, and loosening and crushing of the grouting at the sides. In wet weather the surface water found its way down the joint between the setts and the rail, and so under the sleeper and paving, carrying away with it the pulverized particles and bedding of the paving. The vertical weakness of this rail also caused great tractive resistance to a moving car, through deflection as the wheels passed over it; and, indeed, in this respect, some of the old lines laid on this system are little, if at all, better than a good macadamized road.

To obviate the vertical deflection, by stiffening the rails to some extent, they were afterwards rolled with vertical flanges at both edges in the form of a channel-bar. This form of rail is now called a box-rail (*Fig. 2*). The holding-down bolts having been found useless, to prevent the lateral rocking-motion, another variety of fastening, in the form of dogs or staples, was tried; with some success, but not sufficient to save the system from failure. The rail was not yet stiff enough, and still admitted of too much deflection during the passage of heavy traffic, and the vertical concussion soon loosened all the "dogs." The loosening process set up was similar to that employed by carpenters and scaffolders for releasing "dogs," where the blows applied to the outside of the dog effected the same purpose as the vibratory action and shocks caused by the traffic on the rail.

In the box-rail system it was usual to have a liner, or joint-plate, 8 inches to 12 inches long, and about $\frac{3}{8}$ -inch thick, under the joints of the rails; but the Author thinks its failure might have been easily foreseen. It was merely a loose plate, subject to movement under a load, thereby greatly increasing the vibration at the joint, and the probability of water finding its way about the substructure. This box-rail has not been a success for horse-tramways, and when a locomotive has been put on it, the results in several cases have been disastrous. On the lines referred to, it is common enough to see the ends of the rails rise about an inch, before and after the engine has passed over the joint. This system, however, is obsolete, and forms merely a stage in the history of tramway development.

CAST-IRON CHAIR SYSTEMS.

These systems were designed presumably to overcome the unfortunate results of the wear on the top of timber sleepers, and the consequent loosening of the rails; and at the same time to form a more durable connection between the rails and the substructure.

The majority, however, showed more mechanical ingenuity than practical success, not fulfilling the necessary conditions of rigidity of rolling-surface, and durability of connection between the rail and the substructure, owing to the absence of means of periodically tightening the fastenings of the great number of separate parts. In the Author's opinion, other things being equal, the system with the fewest parts per yard is generally preferable to others. Close attention to the fastenings of a tramway is out of the question, as the paving would have to be lifted at every bolt or cotter, which, in the systems under consideration, would mean almost every yard. In fact, this kind of maintenance on a tramway is never anticipated, and seldom attempted, except when the paving needs repair. In a permanent way, while, to have a great number of bolts is bad, to have cotters is worse so far as

Fig. 3.

LIVESEY'S.

Fig. 4.

COCKBURN MUIR'S.

loosening is concerned, though cotters seem to be more popular. In some of these systems provision is made for tightening-up, by using vertical holding-down bolts, with slotted heads countersunk in the groove of the rail; but with this head it is impossible to get the bolt screwed up to any useful degree of tightness, owing to the feebleness of the hold on the head.

The Author will now briefly describe a few of the more generally used systems with cast-iron chairs.

Livesey System, Fig. 3.—This was largely used until recently in Buenos Ayres. The rail, which is a good specimen of the "Box" pattern, is fixed to the chair by a steel or wrought-iron key or cotter, driven between the chair seat and the inside of the webs. The chairs are bolted to a wrought-iron trough-shaped base-plate, and are tied by wrought-iron tie-bars fixed with a cotter.

Cockburn-Muir System, Fig. 4.—In this system there is a heavy anvil-like chair, bedded on concrete, carrying a light T-shaped rail, which is fixed to it by a cast-iron dove-tail key under the

tread. A wrought-iron bar fixed with a cotter ties the chairs together.

Kincaid's Systems, Figs. 5, 6 and 7.—These three systems are similar in so far that the chairs are all of pyramidal form of extra depth, and anchored or imbedded in a concrete foundation, dispensing with the use of tie-bars. The rails differ in each type, and of course also their fastening to the chairs.

These types have done good service in several towns in this country.

KINCAID'S.

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KINCAID'S.

VIGNOLES'.

Vignoles' System, Fig. 8.—This has been in use in North Staffordshire under locomotives for many years, and differs in a marked degree from most other chair-systems.

The rail is of a good section, of tee-shape, 5 inches deep. It is hung on a single shoulder of the chair, which shoulder is on the outside of the rail-web, and on the inside there is a fish-plate of peculiar form. The fish-plate, web of rail and chair are bolted firmly together, and the chairs are spiked to cross-timber sleepers, which are imbedded in concrete.

Barker's System, Fig. 9.—It perhaps is hardly correct to class this with cast-iron chair systems. The so-called chairs are about 3 feet long with only $\frac{1}{2}$ inch of space between their ends, and,

Fig. 9.

BARKER'S.

as the rail has a bearing or bed on them to the full extent of their length (and so is practically continuous), they are more correctly termed "cast-iron longitudinal sleepers."

The system has been used to a considerable extent in important towns in this country.

The rail is tee-shaped and is fixed on the sleepers by a cotter passing through the sleeper or chair and the web of rail. The sleeper or chair is of good section as to rail-bed, and it has flanges 12 inches broad, affording a large bearing on the concrete foundations. Tie-bars are not generally used unless the line is to be laid without paving.

Beloe's Systems, Figs. 10 and 11.—Here a double rail is provided on each side of the track similar to the check rail on a railway curve, from which it differs in so far that the car-wheels having

Fig. 10.

BELOE'S.

Fig. 11.

BELOE'S.

a central flange with a tread on both sides bearing on both rails, the space between the two rails acts as a groove.

As will be seen, *Figs. 10 and 11* are similar except in the mode of fixing the rails to the chairs. These chairs are spiked to cross-timber sleepers, which are imbedded in concrete as usual. It has been used, the Author understands, in several towns in this country.

CROSS-SLEEPER SYSTEMS.

Contemporaneous with the last-mentioned types were the cross-sleeper systems, of timber and steel, where an ordinary flat-bottomed rail was rolled with a planed groove in the head, and otherwise like an ordinary railway rail. The head of the rail was first rolled in the solid, and the groove planed out, which was an expensive operation, and prevented the rail being a commercial success till a means of rolling the groove was found. The advent of this rail, as applied to tramways, marked an important era. It was first rolled in sections of from 40 lbs. to 60 lbs. per yard, and was laid on sleepers like a railway, but without chairs, and was merely fastened to the sleepers with dog-spikes (*Fig. 12*). The rails were joined by fish-plates and bolts in the usual manner. This track is easily laid, and, with macadam inside and outside of the rails, makes an excellent permanent way, using, say, a 60-lb. rail; and even with paving, where pitch grouting is used and the traffic is light, it stands very well. The rails in many car-depots are so laid. But the spikes are liable in course of time to draw slightly under traffic, and consequently the rail to rock laterally. To overcome this tendency it is now customary to use steel cross-sleepers, with a riveted and bolted clip to fix the rail to the sleeper, the riveted clip being on the outside of the rail. If the sleepers are properly packed up with concrete,

Fig. 12.

CROSS-TIMBER.

Fig. 13.

STEEL CROSS-SLEEPER.

Fig. 14.

STEEL CROSS-SLEEPER.

or, better still, beaten down on it till they are entirely bedded, this makes an excellent line. In the Author's opinion it is the best system for a foreign line where economy in construction is the first consideration. There are two sections of steel sleepers in use (*Figs. 13 and 14*), of which the former represents the one used in

the Alford and Sutton line in Lincolnshire, and in the Barbadoes line. Of the two the Author prefers the latter, as being stiffer, and having a much better bearing on the concrete, although not so easily packed with concrete. When the Author has had occasion to use those sleepers, he has beaten them well down on plastic concrete till they took a complete bearing. This is superior to packing.

LONGITUDINAL STEEL-SLEEPER SYSTEMS.

The Winby-Levick System, Fig. 15, is a further development of the flat-bottomed rail system, in combination with a steel or wrought-iron longitudinal sleeper, or base-plate. The rail weighs about 60 lbs. per yard, has an ordinary fish-joint, and a longitudinal base-plate or sleeper 12 inches broad by $\frac{3}{8}$ inch thick (*Fig. 15*). The rail is secured to this plate by cotter-bolts, and the whole is laid on a bed of concrete. The principal fault is the want of transverse stiffness in the base-plate, which sinks in the centre

Fig. 15.

WINBY-LEVICK.

Fig. 16.

WINBY-LEVICK.

where the rail bears (*Fig. 16*), thus raising the edges when a load passes over, and loosening the setts adjoining the rails.

John Kerr's System, Figs. 17 and 18.—The rail is about $5\frac{1}{2}$ inches deep, and weighs about 60 lbs. per yard where paving is to be used; but, where there is no paving, a section of less depth and of about 40 lbs. per yard can be substituted. This rail is fastened to longitudinal trough-sleepers of wrought-iron or steel. Two different kinds of fastenings are employed. The first is similar to that on the Winby-Levick system, namely, cotter-bolts, and the second is a pair of clips, one riveted on the outside, and one bolted on the inside of the rail. The rails are joined by fish-plates, and the rail and sleeper break joint to the extent of 3 feet 6 inches. The fastenings are 3 feet 6 inches apart, the cotter-bolts being on alternate sides of the rail. The Author prefers the clips, as the

holes for the cotter-bolts weaken the flange of the rail, and render it liable to break under the crow-bar or when bending is required. Also the clips admit of more play, and allow the rail to be bent to easy curves without affecting the sleeper. With these rails the Author has found it possible to get a versed sine of 2 inches in a 24-foot length, without bending the sleeper. When the curves are smaller, the sleeper may be curved by making several cross-cuts with cold sates, on the convex side of the curve, from the rail-flange to the edge of the sleeper. The smaller the radius the greater the number of cuts required, and a versed sine of 8 inches in a 24-foot rail may thus be obtained, which is about equivalent to a curve of 110 feet radius. For curves smaller than this the sleepers are supplied in lengths of about 3 feet 4 inches.

Fig. 17.

Fig. 18.

KERR.

In laying this system, after the ground has been excavated to the required depth, two ridges of fine concrete (the stone or macadam to pass through a 1-inch ring) are placed in the track of the rails. The rails, fixed to the sleepers, are put on the top of these ridges, and should then be about 6 inches above their finished level (*Fig. 17*). The sleepers and rails are now beaten down to their proper level, and the surplus concrete escapes under the sleepers (*Fig. 18*). During the beating the rails are held to gauge by temporary tie-rods dropped over their heads. The spaces between the metals and in the margins are now filled in, and floated to the level of the top of the sleepers with concrete, which, being allowed to set, the line is ready for paving. This system has been laid without tie-bars, which are unnecessary after the concrete is thoroughly set; but it has been found difficult to beat or ram the paving in the centre without spreading the gauge, the concrete being rarely properly set before this is done. The Author therefore prefers to use tie-rods.

Of the advantages of this system, the first, and most important, is the large and solid bearing on the concrete, which is boxed in, and the fact that it is almost impossible for water to find its way under the sleeper. There is no appreciable wear between rail and sleeper, and, as they break joint, a rail-joint rarely works loose, even when heavy locomotives are employed, because the rail has a continuous solid bearing on the sleeper at the joint, and for 3 feet 6 inches beyond it. The rails can be readily renewed without disturbing the sleepers, and, being of a light section with a narrow flange, are easily raised with the crow-bar. This can be done without any tendency to twist, as is common with the heavier sections having broad flanges.

GIRDER-RAILS.

The girder-rail system of tramway permanent way is the most modern, and, excepting the last-mentioned, the only one in the Author's knowledge that has given practically successful results where locomotives have been used. The girder-rail is now rolled in sections varying from 35 lbs. to 105 lbs. per lineal yard. The lighter sections are usually laid with a substructure of timber, iron, or steel sleepers, on a foundation of ballast or concrete. The heavier sections, however, are mostly laid on a bed of concrete, their flanges (from 5 to 7 inches wide) being relied on for a base or footing. This is in most cases sufficient, provided the rails have a thorough bearing throughout the entire width of flange, and the concrete is made with good Portland cement. Lias-lime concrete is not advisable.

Besides varying in weight, the rails differ considerably in form. *Figs. 19 to 34* represent some of the sections used in this country, on the Continent, and in the Colonies. *Figs. 19 to 24*, weighing from 40 lbs. to 68 lbs. per yard, show sections adopted in conjunction with longitudinal or cross-sleepers of wood or steel; while *Figs. 25 to 35*, weighing from 68 lbs. to 100 lbs. per yard, are usually laid on a bed of concrete.

All these rails are put together with fish-joints; but, with the exception of those used on rails under 5 inches in height, the fish-plates have been much too light. Some of these rails, moreover, are rolled to such a section as to greatly decrease the efficiency of even a heavy fish-plate. This will be understood by reference to *Figs. 30, 31, and 33*. These sections have the angle between the shoulders of the head and the web of rail too great, and

there is consequently no effective fish-bed. This is a most serious defect, as the head of the rail acts as a wedge which is driven down between the fish-plates each time a load passes over the joint, overcoming all the spring or vertical camber in the fish-plates.

In the majority of loose joints, the Author has found most of the fish-plates flat, with no camber, or with the camber reversed, and

Fig. 19. *Fig. 20.* *Fig. 21.* *Fig. 22.* *Fig. 23.* *Fig. 24.* *Fig. 25.* *Fig. 26.* *Fig. 27.* *Fig. 28.* *Fig. 29.* *Fig. 30.* *Fig. 31.* *Fig. 32.* *Fig. 33.* *Fig. 34.* *Fig. 35.*

dangling loose, only hung by the bolts as in B, *Fig. 36*. With such sections, it has been customary to use fish-plates only $\frac{7}{16}$ inch in thickness, which is out of proportion to their height even if they had a good bed.¹

To overcome this weakness, a fish-plate with flanges has been adopted similar to that shown at A, *Fig. 37*. If the weakness had

been lateral the flanges would have been of some use, but, without an increase in thickness they are no stiffer vertically. They seem to increase the liability of the fish-plate to slip on its bed. With this type where $\frac{1}{8}$ -inch camber was on the plate, the Author has screwed up the bolts ($\frac{7}{8}$ inch in diameter) till the spring was overcome, and the plates both touched the web of the rail (B, *Fig. 37*).

Another defect, in an exaggerated form, possessed by these last three sections, results from the tread of the rail being outside the centre of the web, and consequently the weight being carried down the outside of the web. This induces a tendency in the rail to cant or tilt to the outer side, and thereby to loosen the joints of the paving next the rail.

Figs. 34 and 35 are in use on the Continent. Under ordinary circumstances they have no point in their favour, as compared with a common girder-rail, and many points against them. In the Author's experience a fatal and almost invariable defect is in the lightness of the fish-plates, and this defect is, in most modern sections of girder-rails, intensified by the large angle of the shoulders, which, in many cases, affords no bed whatever under the rail-heads.

Figs. 38 and 39, two sections suggested by the Author, avoid, to a great extent, this large angle at the shoulder, and provide a bed with a square thrust for about one-half the thickness of the fish-plates. The latter are better proportioned in their depth and thickness, and are sufficiently rigid to prevent buckling, and secured with bolts of relative strength. *Fig. 38*, a section of a rail about 56 lbs. per yard, is to be used with longitudinal or cross-sleepers, for a country or foreign line, where macadam, 4-inch cubes, or shallow random paving is to be put down. It is $4\frac{1}{2}$ inches deep and has a 4-inch flange. The web is $\frac{3}{8}$ inch thick, the fish-plates are $\frac{3}{4}$ inch thick, fastened with $\frac{7}{8}$ -inch bolts, with rounded heads, square necks and nuts. *Fig. 39*, the section of a girder-rail of about 86 lbs. per yard, is intended for a first-class line, laid on a bed of concrete. It is 6 inches deep, has a 7-inch

flange, and is $\frac{7}{8}$ inch thick in the web. The advantage of a 7-inch flange is doubtful, as the great width is apt to cause the rail to twist under the crowbar, but it is generally considered that the extra bearing on the concrete outweighs the facility of crowing with a flange only 6 inches broad. The fish-plates are 1 inch thick, and the bolts are similar to those shown in *Fig. 38*, but 1 inch in diameter instead of $\frac{7}{8}$ inch.

In both these sections, there are square fish-beds, under the heads and on the flanges, and the tread of the rail extends to the inside of the web, the entire thickness (or horizontal area) of which thus carries the weight.

POINTS.

As regards the material for a tramway point, the hardest is the best if, at the same time, it has sufficient toughness to withstand the blows to which it is subjected. Chilled iron is generally used, and, if the chill is deep enough, this is certainly the hardest of all the different forms of iron; but this very quality is inseparably combined with brittleness. Consequently, the lips forming the inside of the groove, and the fine tailing out of the tongue or frog, in the open points, are soon subject to fracture where locomotives are employed. Owing to this brittleness, it is hardly possible to have a fish-joint with a chilled-iron point, as, it being necessary to cast the point to the section of the rail so that the fish-plates may fit, it reduces the sectional area too much for chilled cast-iron. To overcome this difficulty, in the Rochdale tramway, the half-length of the fish-plates were cast into the heel and toe of the point. This caused considerable extra labour in fitting and fishing the rails, the fish-plates being slightly out of position. The objection to this, however, was in the extra amount of work necessary to replace a point. The whole rail fished to the toe of the point, and the paving on each side of the rails and point had to be lifted for a distance of about 34 feet; then the point, after the running-in rail was lifted, had to be driven out towards the toe until the fish-plates at the heel were clear of the rail. The fitting in of the new point was a still more tedious process. However, it involved only about one-half the cost of renewing a crossing. On the tramway mentioned, between thirty and forty chilled-iron points and crossings have had thus to be replaced, owing to fracture of the frog or lip, and the company is now substituting cast-steel points in their place.

Cast-steel annealed is extensively used on steam tramways. It is softer than chilled iron, but is also considerably tougher; and the Author has never known a sound cast-steel point to be fractured under traffic, even when of the true section of the rail, and joined to it by an ordinary fish-joint. This desirable quality of toughness generally carries with it the disadvantage of softness, though this has varied greatly in degree. According to the Author's experience, even among points in the same consignment from the same foundry, some will cut like lead under the chisel, and others chip like cast metal. Assuming it possible to rely on the hardness being equal, there is great uncertainty as to the result of the annealing process, as it is almost impossible to prevent the points from warping or twisting. This also occurs, to a certain extent, in cooling after casting.

In built-up points, made from the rolled Bessemer-steel rail, the steel is generally uniform in temper, and harder than annealed cast-steel, unless it has been manufactured purposely to undergo the unnecessary test of a falling weight. The Author has never known a rail to be fractured at the lip or elsewhere, after having been laid, though a very few have failed under crowing, when weakened by punched holes in the flange, which has ordinarily been a narrow one. He considers this material more durable than chilled cast-iron, or annealed cast-steel. Where open points are used, built-up points are superior to all others; but built-up loose tongue or drop-points would be too costly.

In a line where the turn-outs have a straight run-in, and horse traction is used, open points are the best, as they are safe and do not shake the cars like drop-points. Besides, built-up points can easily be made with the turn-out side curved, thus practically overcoming the angle between the running-out line of the point, and the single line. They have ordinary fish-joints like the rails, and, at the heel ends, the two rails may be made to break-joint; thereby greatly lessening the tendency to rock.

For steam tramways, it is necessary, for safety, to have either a drop or an automatic point, in each pair of rails. The full-sided fixed, or dummy point, now known as the drop-point, *Figs. 40*, was the first used, and up to this time is by far the most general. It may be briefly described as an ordinary open point, with the running-out groove gradually sloping up to nearly the level of the rolling surface of the point, and the running-in groove the full depth throughout. This point, when new, acts very well; but with a frequent service, worked by heavy locomotives, the Author has known of many cast-steel points, and some of chilled iron, which

have worn out in six months, and become ordinary open points, through the running-out groove wearing to the depth of the wheel flanges. This is a serious objection; but another, not less so as regards cost, consists in the injury to the locomotives and cars caused by the simultaneous lateral and vertical blows to which the wheels are subjected on leaving a turn-out. The only way of lessening the lateral blow is to have the running-out groove of the point curved, so as to make a true tangent of the straight run-in; but this is seldom done.

To avoid the vertical drop, several automatic points have been

designed. The first of any practical importance was designed by Mr. C. E. Winby, *Figs. 41*. It has a tongue which forms the bottom of the running-out groove, and which has a vertical motion. The tongue is kept up to the level of the rolling surface, either by the spring of the tongue itself, or by a spiral spring under it. This point is made as a left-hand one, so that, when the locomotive or car is running into the turn-out, the tongue is inside the flange of the left-hand wheels, and is therefore less likely to be disturbed by the wheels in running in. In its normal state, this point appears like a drop-point; but, when the engine runs out of the turn-out, the flanges of the wheels press down the vertical tongue, and the tread of the wheels remains on the rolling surface of the point. Thus the desired object of avoiding a drop is gained.

Chapman's point, *Figs. 42*, is the same as the last in principle; but, instead of a spring, a weighted lever keeps the tongue in its normal position.

The drawback to these two varieties of automatic points is the probability of the flanges of the wheels, in entering the turn-out, pressing down the tongue by mere friction, and so sending the engine on the wrong line. This is more likely to happen with the

locomotive-wheels than with those of the car, as with the former there is more lateral motion. Indeed, in several cases, where the turn-outs had a straight run-in, with a drop-point only partially worn, the Author has known the engine to take the wrong road, while the car has remained on the right one.

On the Rochdale steam-tramways, the Chapman point has been abandoned, and an old-fashioned type adopted; namely, an ordinary

Figs. 41.

WINBY'S POINT.

loose-tongued point, with the tongue kept to the right by a spiral spring. The left-hand road is thus always open except when a car is running out of the turn-out. In that case, the flange of the wheel wedges over the tongue against the spring, which throws the tongue back into its original position as soon as the wheel clears the toe of the point. The substitution of this spring for the piece of rubber generally used by stablemen has earned for this point the name of Marshall's Patent, *Figs. 43*. The action is simple and

effective; but it is doubtful whether the rubber is not preferable, as being cheaper, more easily replaced, and perhaps more reliable than the spring.

The most useful and effective automatic point, in the Author's

Figs. 42.

CHAPMAN'S POINT.

PART PLAN.

HORIZONTAL SECTION.

LONGITUDINAL SECTION.

Figs. 43.

MARSHALL'S POINT.

PLAN.

SECTION A.B.

opinion, is that of Mr. Joseph Kincaid, M. Inst. C.E., *Figs. 44*. It combines all the advantages of an automatic point, with those of an ordinary loose-tongue point. The tongue is 7 inches deep at the toe, where it is thinnest; and instead of having a vertical or lateral movement, it is arranged so as to rock or tilt, as the car

passes out of the turn-out. When at rest, the tongue completely closes the running-out line, and it is impossible, under ordinary circumstances, for the engine or car to take the wrong road. The right-hand, or running-out road, can be opened by a small lever carried on the car which fits into a socket in the counterbalance in the switch-box. It acts like, but more easily than, an ordinary switch-lever, as it has merely to tilt the deep tongue, instead of moving it over bodily. The space between the sides of the point-box and the tongue is wider at the bottom, so that loose stones are not liable to get jammed therein. The bottom of the box is also inclined towards the toe of the tongue to facilitate stones rolling that way into the switch-box. In running out of the turn-out, the

Figs. 44.

flanges of the wheels open the point by tilting the tongue into the running-in groove with the least possible friction. Mr. Kincaid has recently improved the design of this joint, whereby it can be used, 1st, as an automatic point closing the right-hand road; 2nd, as an automatic point closing the left-hand road; 3rd, as a facing point closing either road.

All crossings, whether on a steam or horse tramway, should be built of the rail used on the line, and should have the running-through rail 10 to 12 feet long, and the crossing rail 8 to 10 feet, so as to break-joint (*Fig. 45*). They should have a $\frac{1}{4}$ -inch base-plate under, and extending 2 feet on each side of, the crossing. The flanges of the rails should be riveted to this, and roughened

cast-iron or steel filling-pieces bolted in the angles of the rails. This type of crossing has been used extensively, and the Author

Fig. 45.

has never known one to be loosened, even where locomotives have been running over it for three or four years.

PASSING-PLACES.

A matter of considerable importance in laying a single line of tramway is the form of the turn-outs or passing-places, which, until recently, did not receive much attention on the part of engineers.

The first turn-out was symmetrical, similar to *Fig. 46*, and was used on tramways worked by horses; the points were open,

Fig. 46.

and the run-in exactly bisected the angle of the points. The half-angle being so small, it was easy to take either road, by causing the horses to pull slightly in the required direction. The drawback of this form of turn-out is the uncertainty always present as to which road the car will take, even when pulled over by the horses. When the car is heavily loaded, and, if one rail is lower than the other, the car inclines towards the low side and takes that road. To overcome this uncertainty it became necessary to give the car a straight run into the proper road, and this was first done by laying the turn-outs as shown by *Fig. 47*. This reduced

Fig. 47.

the chances of the car taking the wrong road to a minimum, but it has serious faults. Thus it involves an S curve on the single line,

just before it joins the points, which was necessary, because the single line has to be brought from the centre, to allow the double line of turn-out to be also in the centre of the road. Moreover a car running out of the turn-out, as shown by the arrow (*Fig. 47*) is transgressing the rule of the road, to the great danger of any vehicle going in an opposite direction, especially at night, when the rails cannot be seen. A lesser defect is the great wear of the rolling-stock caused by running round the small curves in leaving the turn-outs, and then back on the single line to the centre of the road. In the best form of turn-out (*Fig. 48*), the points are laid so that there is a straight run in to the proper road, and the turn-out is practically symmetrical so far as the curves are con-

Fig. 43.

cerned. The whole angle of the points is certainly thrown on the running-out road, but this is unavoidable with a straight run in. The single line running into the centre of the turn-out necessitates an S curve on both the running-in and running-out line, but they are easy curves compared with those of *Fig. 47*. The most important advantage, however, is that the car is never on the wrong side of the road.

TIE-BARS.

All systems of tramway permanent way need tie-bars, if only to prevent spreading of gauge while paving and ramming. Of these there are several kinds. Perhaps the oldest is that which ties the rails from the centre of the web as in *Fig. 49*. They are usually of $1\frac{1}{2}$ -inch by $\frac{1}{2}$ -inch bar-iron, drawn to a $\frac{3}{4}$ -inch bolt at each end, with two nuts, and are fixed on edge so as to come between two courses of setts. The advantage of these ties is cheapness, but they are a source of inconvenience in paving, as at every tie-bar there is a closing course to put in, and consequently a variation in the width of the joints; or, a whole course of setts to cut as closers. Then again the joints enclosing the tie-bars are always wider than the others. The inconvenience with the paving is increased in curves and turn-outs, the difficulty being to get the paving to radiate in courses exactly to suit the tie-bars. There are also a

great many holes to drill or punch in the web of the rail, and with this tie-bar it is possible for the rail to cant so that the web is off the plumb, and, consequently, the whole of the rolling surface of the rail not in use. A more expensive, but perhaps better, tie-bar (*Fig. 50*), is fixed under the flange of the rail; but this must be a comparatively rigid bar, and the Author prefers a small channel-bar with clips. For the Rochdale steam tramways

Fig. 49. *Fig. 50.*

Mr. J. W. Newton used a similar bar; but instead of channel-bar, he adopted 2-inch angle-bar, with a steel liner riveted to it underneath the flange of the rail. This type of bar facilitates paving, and lessens the liability of the rail to cant, provided the clip bolts are thoroughly screwed up. The objection to this tie-bar, besides expense, is that, unless special care be taken to bed the setts properly over the clips and bolts, they are apt to work loose and rock.

In the newer sections of the Glasgow tramways, Messrs. Johnstone and Rankine use sawn timber sleepers, which act principally as tie-bars, the concrete being thoroughly packed under the rail flanges between the sleepers, so that the rail has a continuous bearing alternately on the concrete and on the sleepers. This is a successful system with horse traction, but more expensive than the last, there being only half the number of bars, as their purpose is to tie the rails only. Cross-timber sleepers, in conjunction with girder-rails, were used in 1879 by Mr. Thomas Floyd in the construction of the Croydon and the Northampton tramways.

PAVING.

In the construction of a first-class tramway in this country, the paving is a most important consideration. The first element is the kind of stone to be adopted. The qualities most desirable are those that combine the maximum durability with the minimum of slipperiness. An endeavour will be made to estimate the qualities of a few of the commonest varieties of stone used for paving setts, commencing with the hardest.

Some varieties of whinstone may be considered, the hardest of the stones in common use, though others are softer than any granite, except, perhaps, Dalbeattie. Whinstone is of a dark greenish colour, much closer grained than granite, very heavy, and dresses very well. The chief objection to whinstone setts is their slipperiness in dry weather. Owing to their fine, close grain, they become glazed, or superficially engrained, with the iron from horses' shoes and wheel tires, and in dry weather the setts are dangerously slippery. In wet, the iron is probably partially oxidized, and washed off, when the surface of the stone again "bites." Thus whinstone affords a bad foothold for horses in dry weather.

Guernsey granite varies in grain, some of it being almost as fine or close as whinstone. It is a bluish grey stone, so durable that it is now commanding a preference over all other granites where the traffic is severe. It is not so slippery as whinstone, still it does not afford so good a foothold as some of the coarse-grained granites. It dresses almost as well as whinstone, and is not so heavy. Leicestershire bastard granite is not quite so close in grain as whinstone, but assimilates more to the finest Guernsey in this respect. It is of a reddish brown colour, is about equal to Guernsey granite in durability, but is, perhaps, rather more slippery. Like Guernsey granite and whinstone, it is readily dressed, and is of about the same specific gravity as the latter. These close-grained, bastard granites, are generally heavier than the coarse-grained ones, but are more easily dressed. Leicestershire coarse-grained granite is similar in grain to Peterhead and other true granites, and is of a pink colour. It is not quite so lasting as the coarser-grained Guernsey granite, is about the same as regards slipperiness, and is somewhat lighter.

Aberdeen granite is of close grain and grey colour, and, like the last mentioned, is very durable; but Aberdeen is superior to Leicestershire, or any other durable granite, for a good foothold, and is, if anything, not so heavy. This is an excellent stone for the streets of towns.

Pwllheli is a Welsh granite, with similar grain to Leicestershire, and of a light greenish colour. It is probably not so durable as Aberdeen granite, but makes an excellent paving for the less busy streets of a city or town, as it never becomes slippery. It is also a comparatively light stone.

Dalbeattie is, perhaps, the softest of all granites, very coarse-grained, of a crumbly appearance, and of a light grey colour. It is not slippery, and makes good paving for a suburban road where there is not much heavy traffic.

Millstone grit is found in the Chorley district of Lancashire. It is a coarse-grained bastard sandstone, the outside and top rock being of a yellowish colour, while the inside is blue and more homogeneous. This stone is softer than Dalbeattie granite; but, as it affords the best of all footholds for horses, it makes excellent paving for a country line.

Blue Lonkey stone is quarried in the Whitworth, Facit, and other districts in Lancashire. It resembles York stone in character, but is harder and occurs in thicker strata. It is a durable material for a country line, and is second only to millstone grit for a good foothold. Blue Lonkey is suitable for suburban lines between the rails, with granite setts in the margins.

Close-grained granites and Lonkey stone can generally be squared with a few strokes of the hammer; but true granites and millstone grit require a certain amount of "nidging" after such squaring, as they do not break so cleanly. Even after this "nidging," setts of these stones are delivered with the top surface tolerably square, but with "bellies," or bulging sides.

It is necessary now to refer to the sizes of setts used in paving work in connection with tramway permanent way. The depth of rail to be laid of course rules that of the setts, which latter should be quite an inch less, but the breadth remains to be determined. This, so far as the harder setts are concerned, is either 4 inches, or 3 inches, other breadths being uncommon. Setts of the latter size afford a better foothold, from the fact of the joints being more numerous. The Author, however, has found 4-inch setts quite as safe, making better work, and needing less repair. Probably this arises from their being better dressed with much fuller bottoms. They are also more suitable for wide joints in the paving. Lonkey and millstone grit setts may be used up to 5 inches or 6 inches wide.

There ought to be very little "camber" in paving between the rails, $\frac{3}{4}$ -inch in a line of 4 feet 8 $\frac{1}{2}$ inches gauge being sufficient. For this gauge a width of 18 inches of paving outside the rails is enough; but for a line of 3 feet 6 inches gauge on a macadam road, there should be a margin of 2 feet 3 inches of paving outside the rails; since, if merely an 18-inch margin is laid, it has to carry all the traffic on the outermost joint of the setts, which is the weakest part of the paving.

It is a common practice, where the roads are macadam, to tooth or quoin the outer edges of marginal paving. But this, in the Author's opinion, is a mistake, as it is more difficult to keep the macadam up to the level of the paving, and the wheels of

ordinary vehicles consequently drop from each long tooth on to the next, thereby tending to loosen the setts.

GROUTING.

This is done with pitch and oil, Portland cement, or blue-lias lime. For a tramway, the first is the best if properly run, just under boiling-point, at the correct temper in dry weather. The joints should first be racked, or filled with pea-gravel which has passed through a $\frac{1}{2}$ -inch riddle, and stopped at a $\frac{1}{4}$ -inch. The paving should then be beaten or rammed, and the tempered pitch run in hot, to within $\frac{1}{2}$ inch of the top of the setts. It ought not to be "topped" up, but covered over $\frac{1}{2}$ inch thick, with sandy pea-gravel, which lessens the chance of the grouting melting during hot weather. The haunches of the rails should not be plastered with cement, but should be allowed to fill with the pitch as it is run into the paving. In hot weather the pitch should be tempered very soft, or it may become brittle in frost and pulverized with the traffic. Where, for economy, cement or lime grouting is used, it is better to pave with coarse-grained setts, as with these the cement has a rougher surface to hold, and has a greater chance of remaining tight. Such cement, or lime grouting, should be in the proportion of not less than 1 part of cement or lime to 2 parts of clean sharp sand.

WOOD PAVING.

In many provisional orders, it is stipulated that tramways shall be paved with wood in front of churches, schools, halls, &c., extending beyond the frontage for about 50 lineal yards on each side. Of the woods in common use, none is more suitable for tramway paving than seasoned beech. This should be thoroughly creosoted, and grouted to within $\frac{1}{4}$ inch of the top of the setts with properly-tempered pitch grouting. After the grouting has set, the paving should be covered $\frac{1}{2}$ inch deep with sandy gravel, which has passed through a $\frac{1}{2}$ -inch screen. The wood setts should be creosoted; not necessarily for the antiseptic properties of the creosote, but to prevent, as far as possible, the wood from swelling after laying, by making it comparatively watertight. It also promotes the adhesion of the pitch grouting to the wood blocks, making the joints tighter and more impervious to surface water.

With cement grouting the creosote prevents the cement from getting the slight hold of the wood which it would otherwise take. The Author considers pitch far superior to cement for grouting, as the joints, besides being tighter, are more elastic and yielding, if the setts should swell in wet weather. This swelling, though not common with creosoted beech paving, is unavoidable with ordinary deal blocks. In one instance, creosoted deal blocks were used, grouted with cement. The gauge of the line was 4 feet 7½ inches, the rail a 75-lb. girder one, with 1½-inch by ¾-inch tie-rods 9 feet apart. After two or three days' rain the paving became saturated, burst all the tie-rods, and spread the gauge of the line to 4 feet 9 inches. It is doubtful whether pitch grouting could, with spongy deal blocks, have prevented such results, but probably it might have lessened them.

DESIGNING A LINE.

The first point to consider is whether the line should be double, or single, with turn-outs or sidings. In the majority of cases of course the single line would be the cheaper, but there are some instances where it would not. The Tramways Act of 1870 enacts that all lines shall be laid in the centre of the road, and that the rails shall not, for a distance of over 30 feet, be within 9 feet 6 inches of the face of the curb-stone. When these conditions cannot be complied with, owing to the road being too narrow, such narrow places are to be described and marked on the Parliamentary plans when applying for a provisional order. In almost all schemes there are such narrow parts of the road, and, where the ordinary traffic is not great, the company is generally allowed to lay one rail 9 feet 6 inches from one curb, and leave the distance of the other rail from the opposite curb, whatever the width of the road will allow. In other cases, the line has been laid with one rail within 2 feet of one curb, to allow a greater distance than 9 feet 6 inches between the other rail and the opposite curb. This is not advisable, as the line has to be laid to the level of the existing road, which in all cases should have a crown, or cross camber; and, in most narrow roads, this lowers the rail nearest to the curb so much under the other that it is dangerous, from the liability of the car to slip off into the channel. The Author has known cases where there was a difference in level of from 3 to 5 inches between the two rails in a gauge of 4 feet 8½ inches. If a single line be laid along the side of a road, the cars must necessarily be, while going in one direction, on the

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wrong side, thus jeopardizing all other vehicles. Where the wheel traffic is great, it is usual to compel a company to lay a double line of rails at all narrow parts of the road, to lessen this inconvenience. From the foregoing, it will be understood, that where a tramway has to be laid along roads on which the traffic is considerable, and there are long stretches of road under the required breadth, it may be more economical to lay a double line throughout.

The next consideration is the gauge, and it may be here remarked that, in some instances, by adopting a narrower gauge than 4 feet 8½ inches, the first cost of line may be reduced, by avoiding, where the road is narrow, a great amount of double line. For instance, say a road was so narrow that, with a gauge of 4 feet 8½ inches, one rail was the statutory 9 feet 6 inches from the curb, and the other rail only 8 feet 3½ inches from the opposite one; it would still be practicable with a gauge of 3 feet 6 inches to get the clear space of 9 feet 6 inches between the rail and the curb on both sides. In fact, a gauge of 3 feet 6 inches decreases the necessary minimum width of road for a single line by the difference in gauge, namely 1 foot 2½ inches.

Besides reducing the cost in this way, a narrow gauge admits of curves of a less radius, which often means a considerable saving in the purchase of land, or the moving of footpaths. A further saving is effected in material and labour.

One disadvantage of a narrow-gauge tramway is that it costs more to maintain than a line of 4 feet 8½ inches, all conditions being similar. Wherever a tramway is laid, the greater number of drivers prefer to run their vehicles on the metals if possible. The heavier the load, the greater the inducement for a driver to get his wheels or wheel on the rail. On a gauge of 4 feet 8½ inches, most vehicles will track properly on the rails with both wheels, and not much damage is done to the paving, beyond a little wear where the setts are higher than the rails. But with a gauge of 3 feet 6 inches, where a driver cannot get both wheels of his vehicle on the rails, he will, if possible, have one wheel. Consequently, while one wheel is on the rail, the other is running along the outside course of setts in the paving of the opposite margin, which is the weakest part if the road is a macadam one, and the margins are paved only 18 inches beyond the rails. Where the road is paved to the channels, the paving is worn into a rut; and where the road is macadam and the margins only are paved, besides being rutted the grouting is generally broken and the paving loosened. Another objection to the narrow gauge is that the cars have very little margin of stability when they carry

outside passengers; they have to take curves of small radius, and the danger is often aggravated by overcrowding on the top. The chance of capsizing is greater with steam than with horse traction, because the locomotive is taken round curves at greater speed, and overcrowding is more tolerated on a steam than on a horse tramway. Considering these drawbacks, the Author prefers a gauge of 4 feet 8½ inches, believing it to be cheaper ultimately. Narrow-gauge lines, however, may be suitable where the ordinary traffic is not great, or where outside cars are not generally used on account of the climate.

CONSTRUCTION.

The Author will now endeavour to describe the systems of construction which, in his opinion, are the most suitable, and the most likely to give good results for town and for country lines.

In the case of a first-class line, to be laid through the principal streets of any large industrial centre, a substantial permanent way is wanted—one that will withstand the shocks of the heaviest wheel traffic without loosening at the joints. For such a line it is a mistake to reduce the first cost, knowingly at the expense of longevity or stability; for municipal authorities, as a rule, are assiduous in exercising their powers to compel tramway companies to repair their lines. To withstand the shocks to which such a line is liable, it is necessary to have a rail of some considerable weight beyond that required for rigidity, and the Author thinks 80 lbs. to 100 lbs. per yard is not too heavy under certain circumstances. He suggests the section, *Fig. 39*, with heavy fish-plates, fastened with four fish-bolts 1 inch in diameter. In his opinion, no increase of stiffness is gained at the joints by using six bolts to each plate as is sometimes done. The tie-bars should be about 9 feet apart, and be either those bolted to the flange, or those bolted through the web. Their merits and demerits are about equally balanced; the latter are the cheaper. The concrete should be at least 6 inches deep, and composed of old macadam and Portland cement in the proportion of 6 or 7 parts of macadam to 1 part of cement. If old macadam cannot be had, broken stones and clean sharp sand should be used in the proportions of (respectively) 4 and 2 parts to 1 part of cement. After the excavation is made, a layer of concrete 4 inches thick should be put in the bottom with its surface left rough. When the concrete has set the rails should be laid to their proper line and level 6 inches above formation level. This will leave 2 inches between the bottom of the flange of the rail and

the surface of the first layer of concrete, which space should be thoroughly packed with rather fine concrete from each side of the rail with beater picks. The concrete between the rails and in the margins should then be made up 2 inches, to the correct camber, thoroughly floated, and brought to a smooth surface; and, when set, the line should be paved with bedding 1 inch thick. Less is insufficient, on account of the inequalities in the depths of the best dressed setts. The fine material from old macadam, put through a $\frac{1}{2}$ -inch screen, makes an excellent bed. Perhaps the only material superior to it is fine-screened engine ashes. Both are better than sand, which never binds, and is liable to be washed out, if surface water gets under the paving during repair, or at a loose joint or sett.

As to the best kind of sett to use, some engineers prefer the hardest, though they become very slippery in time. In the busiest streets the Author would use Aberdeen, Guernsey, or Leicestershire granite. Whinstone is harder, but wears very slippery in a few months under constant traffic. For streets in towns with only a medium amount of traffic, Pwllheli or similar granite is most suitable. For a suburban line whinstone setts answer very well where the traffic is light, and not constant enough to glaze it. Another granite suitable for such a locality is Dalbeattie. If economy is of importance, Blue Lonkey or millstone grit may be used between the rails and the whinstone in the margins. In this combination, the slipperiness of the whinstone is not material, as the horses get their footing on the soft setts between the rails.

In ordinary circumstances, the Author would not use granite setts less than 4 inches in width, and 5 inches as a maximum for Lonkey or millstone grit. If the line is to be worked by steam, pitch-grouting should be employed; but if by horses, cement may be adopted for the suburban districts. Pitch-grouting should always be used in a town. It stands traffic better, the paving can be repaired more quickly and thoroughly, and it is ready for traffic in an hour after the grouting is run—an important matter in repairing paving in a busy street. Whether the grouting be pitch or cement, the paving should be covered with sandy pea-gravel. Cement-grouting should be allowed to set before opening the tramway for traffic.

COUNTRY OR COLONIAL LINES.

For such lines cheapness is commonly the first consideration. Consequently, many are of narrow gauge, not paved, but made up

to the rail-level with macadam. This reduces the first cost of a tramway line by nearly 40 per cent. in this country; and as macadam has been used with success, both at home and abroad, this is a strong argument in its favour. Indeed, in many instances, its adoption makes a scheme feasible which, with paving, would be too expensive. Still, for a home line, the Author would suggest that it should, if possible, be paved with Dalbeattie granite, Blue Lonkey, or millstone-grit setts, using lias-lime grouting.

A rail, similar in section to *Fig. 38*, would be suitable with steel cross-sleepers (*Fig. 14*) every 3 feet, or, alternatively, with timber cross-sleepers 9 inches by 4 inches. Steel sleepers should be beaten down on a layer of concrete about 4 inches thick under each sleeper. With timber sleepers, old macadam is good enough for packing.

For a colonial line, where the road is to be made up with macadam without paving, the rail need not be so deep. Sections such as *Figs. 25* and *26* have been used satisfactorily, both with timber and with steel sleepers.

If a line has to be worked by horse-power, open-built points are the most suitable for turn-outs, with a straight run in; but if locomotives are to be used, the Author prefers Kincaid's automatic right-hand point, with a left-hand open point of cast-steel; and he would have all crossings built of the rail used.

CABLE TRAMWAYS.

It may not be out of place just to mention the system of cable-traction tramways, which seems likely to be the system of the future. It has lately made remarkable progress in this country, in the way of overcoming public prejudice; and, besides the line at Highgate, there are now important lines in Edinburgh and in Birmingham, and in both towns extensions have recently (1890) been carried out.

The Edinburgh Northern Cable line is of 4 feet 8½ inches gauge. The construction is somewhat similar to that of Highgate, the tube-frames being of cast-iron, and having only the slot rails bolted to them when laid. After the concreting is done, the track rails are laid and fastened to the tube-frames by tie-bars on each side. The Birmingham line is similar to the Chicago lines, with a rolled tee-bar tube-frame or yoke, having both slot and track rails bolted to it. The gauge is 3 feet 6 inches.

The permanent way, apart from the special arrangement or construction of the cable tube, is the same as for an ordinary

tramway. As the cars are heavier than horse-cars, though less than one-half the weight of an ordinary locomotive, the traffic is more severe than on a horse line, but not nearly so much so as on a steam line. On the above-mentioned lines girder-rails are used, the Birmingham rail being about 95 lbs. per yard, and the Edinburgh 75 lbs. When ordinary points are adopted in conjunction with a slot point, they must be curved on the turn-off line to suit accurately the radius of the slot curve. The paving being divided into such narrow strips by slot and track rails, the setts should be in shorter lengths than usual, according to the gauge of the line. For a 4 feet $8\frac{1}{2}$ inches gauge, setts varying from 6 to 9 inches long will do; but for a gauge of 3 feet 6 inches, they should not be so long. Consideration of this will save much labour in cutting.

The remarks already made, regarding construction of permanent way, apply equally to cable lines; but the arguments in favour of pitch grouting are, in relation to them, considerably more forcible, the additional vibration of the slot rails making it almost a *sine quâ non*.

The Paper is accompanied by numerous diagrams, from which the figures in the text have been prepared. *Figs. 1 to 39* inclusive are to the scale of $\frac{1}{8}$, or $1\frac{1}{2}$ inch = 1 foot.