THESIS.

MAINTENANCE OF WAY OF RAILROADS.

A.N. Talbot, Class of '81.
Maintenance of Way of Railroads.

In the last few years, the management and operation of railroads has grown to be of surprising importance. Not the least important among the divisions of railroad management is the matter of Maintenance of Way. In this is generally included the ordinary repairs and renewals of track, bridges and buildings, the improvement of the line, grade, roadbed, and materials of the track, and the construction of all permanent structures which may be made after the road is in operation. A thorough treatment of the subject would fill a large volume. In the following article, only a cursory treatment has been attempted, many important items not being mentioned, or at least only with passing notice. All that is claimed for the paper is a notation of some of the ideas.
of the writer derived from observation and experience in the work.

Maintenance of way may be under the exclusive control of an engineer; the work may be divided among the engineering department, general roadmasters, and superintendents of bridges and buildings; or it may be under the management of a superintendent experienced only in traffic and in station service. The best arrangement is that in which an engineer, with special training for the department, has the management of maintenance of way, subject of course to the general instructions of superior officers. On roads with a considerable mileage, divisions of 400 or 500 miles may have division engineers in charge. The roadmasters or supervisors in charge of 80 to 150 miles of track each, and the general foremen of bridges and buildings should be under the immediate charge of this engineer. This arrangement has the advantage that the
engineer, with a training fitting him for the varied duties of this office—superintendence, executive ability and clerical work—can manage the affairs economically, intelligently, and satisfactorily, while the subordinates may be men with only the so-called practical knowledge.

The whole matter of maintenance of way is a mass of details, which must be not only mastered, but also carefully carried out; for the road will be good, bad or indifferent, according as these details are attended to. With the class of labor employed, it is necessary, not only to give orders, but also to see that they are personally carried out.

Track.—The most important item in maintenance of way is that of track. The relative value of this department is not usually recognized, for its supervision is too often left to ignorant and incapable men, or the superintendent of the road or of the division, believing...
that track work requires no special training will assume indifferent charge of it, when the salary of a competent engineer or roadmaster would be many times saved by economy in repairs, by the absence of looseness in some directions, and by the superior condition of the track. Too much importance cannot be attached to the employment of capable and efficient men from roadmaster down to section foremen, and to this end a suitable salary should be paid. A roadmaster should have considerable executive ability, much tact in handling men and affairs, be wide-awake and faithful, and be thoroughly versed in all branches of track work. He is generally deficient in clerical ability. In case there is no engineer over him more qualifications should be required. A supervisor under a roadmaster or engineer may be selected for his practical knowledge of the affairs of the division. Track labor is generally regarded as the lowest form of labor,
and it is assumed that track work requires little skill. But experienced track laborers will do double the work accomplished by new men, and these sections will be the best, under similar circumstances, which keep the same gang for years. The road should be divided up into sections, the lengths of which will depend upon the amount of switches, condition of roadbed and track, and amount of outside work generally required of a section gang. For usual traffic on ordinary lines, from four to seven miles of single track will be proper. Branch feeders and lines with small traffic, where excellence of track is not expected, often have sections twelve miles in length. Sections are generally counted as one half their length in main track. The number of men required on track work varies. A usual rule for ordinary track repairs is that of one man to the mile. Extra work, as putting in new ties, replacing iron with steel, will require more. In cases of necessary
The track force may be cut very much, provided that the reduction is made at the right season of the year. Among the requisites of good track are: 1st Line, 2nd Surface 3rd Gauge.

The alignment of a track is generally considered of primary importance. Deviations from a regular line either straight or curved cause the train to be thrown from side to side and consequently an oscillation of the car on the springs. This is probably productive of the most of the annoyance of rough-riding roads. Long swings in the track are offensive to the eye, though they make no difference in the riding properties. Curves should be carefully lined, and the frequent use of an instrument in replacing centers is advised. Rails must be carefully bent to the required curvature by means of a rail-bender. The method of dropping the rail or of curving with the sledge should not be allowed. Steel rails, spiked straight and
Then lined into a curve, will gradually regain their original line and leave the track a succession of tangents. Too much care cannot be taken to have the rails properly curved. Ordinates furnished to the foremen for middle and quarter points of rails will aid in getting correct curvature. Easement curves, by which the curvature is gradually increased from the tangent to the main curve, are very useful, though the intelligence of the average track hand cannot be relied on either to lay them out or to retain their alignment. In sand or rock ballast it is necessary that the ballast extend six inches beyond the end of the tie so that the line will not be deranged so easily. Stakes 200 feet apart, or 50 feet apart on curves sharper than 20' with tacks set in with a transit are of great benefit and can not be too highly recommended. Points of curve should be referenced so that the old alignment may be easily found. It is the practice of
trackmen to use one rail as the "line side," and to
gauge the other rail by that one.
The surface of the track is of far more
importance than is generally supposed. While most
of the irregularities in the line of the rails will have
no effect on the riding qualities of the track—because
the narrower gauge of the wheels will naturally avoid
many of the crooks and turns—the weight of the car
will cause it to follow the inequalities of the vertical
alignment. The effect of this is greatly augmented
when one rail is lower than the other, as when one
side of the track thaws first and so settles unevenly.
In this case the wheel on the grade rail will act as the
center of the movement of the car and the portion of the
car which is directly above this rail will be thrown to
the other side of the track, proportionally as the other
rail is lower, causing the car to rock and tilt badly.
Part of this motion may be taken up by the springs but their action is liable to aggravate the case. When one rail rises and the other falls from the true grade, the effect is largely increased. Another effect of this is that the consequent blow of the flange against the lower rail soon gets the rail out of line and all the conditions are soon aggravated. Trackmen use their level too little. A well-lined track shows off to good advantage and brings praise from the roadmaster or from those who view the road from the rear end of a train; and in trying to gain this praise too little attention is paid to surface. In surfacing, the level should be used at least once every rail length. Another chance of error is the usual poor quality of the level furnished; and the roadmaster should watch that this tool is sensitive and in adjustment. Low joints, caused by the deficiency in strength of the rail fastenings, are very common defects and a great cause of
unpleasantness to passengers. They are the most liable to be found after heavy rains or when the ground is "breaking up." This defect is partially remedied by a strong angle splice and larger ties for joints placed closer together than are the other ties. In this way the weakest point in track is greatly improved.

The gauge of the track should be regular. Wide gauge gives too much play to the wheels, and blows from side vibrations soon derange the line. If the increased width between the rails is too much, the track will easily spread and the train be derailed. Narrow gauge will be pushed out by wheels of greater gauge, and the track thus made loose and irregular. Care must be taken that the gauges used are of proper length. The instrument should be tested and securely fastened before being sent to the foreman. It is also well to compare all gauges with a standard at short intervals. On curves the gauge
should be wider than on straight lines in order to allow the flanges of rigid wheel bases to pass through without binding. The adjacent diagram shows the position of the exterior wheels of a consolidation engine, the portion at the end of the axles representing the lap or distance from a point under the axle to the point where the flange first touches the rail. By an inspection of the diagram, it will be seen that the necessary increase of gauge will be the difference between KD and IC, IC or BM being true gauge, and this difference is the same as the difference between the ordinates DC and 1K. The rigid wheel base of a consolidation engine is about 14 ft. 9 in. = BE = b and the lap AB about 15½ in. = l. Then by the approximate formula for
calculating ordinates, \( m = \frac{c^2}{8R} \left( \frac{(b+2d)^2}{R} - \frac{(b-2d)^2}{R} \right) \).

On the A.T. & S.F.R.R. this amount is doubled to allow for irregularities in track, increased curvature in track as lined by trackmen &c. Considering that the wheel gauge is generally less than 4 ft. 8 1/2 in., I believe that the amount given by this formula is sufficient. The gauge of a 7° 30' turnout should be 4 ft. 8 1/2 in. from the fixed end of the slide rail to the heel of the main frogs, and the main track should have the same gauge for that distance. The Railway Gazette recently criticised the usage of widening gauge — seemingly on the supposition that the object of the increase was to stop the flange wear on the outer rail, whereas the extremely long wheel base with broad wheel gauge is the condition which compels its notice.
The common formula for elevation of rail on curves is deduced from the law of centrifugal force. A considerable difference of practice is found on different roads, depending on the speed of trains used in the calculation. It is usual to take a mean velocity, less than the fast passenger trains and greater than the slow freight trains. Other influences affect the tendency to climb the outer rail, as the amount of coning in the wheels, the amount of play between the rails and the wheels, the stiffness of the trucks, the position of the line of draught, and the regularity of the track curve, so that the common formula is not accurate. Careful experiments are needed in this matter. Too often each track foreman gives the amount of elevation which he is pleased to think right, and light curves are often found with two or three times the necessary elevation. A good rule to follow on standard gauge track with ordinary speeds...
is to make a difference in the elevation of the two rails of one half inch per degree, putting one half this amount on the outer rail above the grade line and one half on the inner rail below the grade line. This difference in elevation should be at its full amount at the beginning and at the end of the curve. The track should be brought to a level on the tangent, making an easement or run-off of ten feet per degree of curve. This length of run-off has been determined by experiment to give the best riding qualities. Curves sharper than 10° should have no more than 5 in. elevation, as the rate of speed on such will be much lower than on curves of greater radius.

It is customary to give curves on sidings one half the elevation that is used on main track. Turnouts as far as the frog should be made level. A peculiar level board, made with half inch notches at one end, so that the one of these that corresponds to the right degree of curve
can be placed on the outer rail, is of value in securing proper elevation.

In wet and low districts, drainage is of primary importance, since without it good track cannot be maintained. The slopes of the roadbed, both in excavation and in embankment should be made to conform to a standard, a good form of which is shown in Fig. 1. Drains must be cut from low places to such depth as will give a sufficient fall. Ditches should be parallel to track and well and neatly made. Boxes and culverts must be kept clean, and it is well to have a certain time set aside for seeing that all outlets of this kind are clear of drift, weeds etc. Surface ditches at some distance from the roadbed are of great value, especially in places where, with no established channel or waterway, the heavy and sudden rainfalls, with little vegetation and no cultivation to detain the flow, are carried down to the track in a
great sheet, often a half mile wide. A ditch with a width of base of eight or ten feet and a depth of three or four feet, and with the excavated material forming a dyke on the lower side, will conduct this flood of water to the bridge opening without damage to the track. Ditches should be large enough to carry the greatest amount of water that the heaviest rainfall will bring.

Above the finished surface of construction called the subgrade and below the ties is placed from six inches to a foot of ballast. The materials used are broken stone, gravel, furnace slag, cinders, and earth. The qualities required are: good drainage, firmness under pressure so that surface and line will be maintained, wearing qualities, and freedom from dust. Broken stone is usually regarded as the best ballast. It should be evenly broken, should not crumble easily, should contain no matter that would pass through a screen with a 5/8 in. mesh, and no
stone that will pass through a 2 1/2 in. ring. Rock ballast has perfect drainage, is not apt to freeze up, is thus to a great extent free from the heaving after thawing, and can be worked in wet as well as in dry weather. The drawbacks to rock are: cost of material, greater requirements in foremen, inability to make a raise of a half inch or an inch, difficulty of surfacing, and increased cost of repairs of track, putting in a new tie requiring the track to be torn to pieces. When rock ballast is used, the track should be all renewed and must be sorted so as to bring those of a uniform size together. When a general renewal is required, all the ties should be taken out, the best of which may be again used on sidings and branches. This plan avoids frequent tearing up of the track. Besides, with ties of different age adjacent, the weight of the traffic will force the rough stone into the ties unequally, and the resulting poor surface cannot be remedied in rock with the
ease that a similar difficulty in gravel could be attended to. A ballast combining most of the advantages of rock with the fewer difficulties of gravel would be a bed of 8 in. or 9 in. of rock, and 5 in. of gravel on top of this. Gravel must be free from boulders, large stone, and lumps of dirt, and should not contain more than 25% of sand or particles that will pass through a screen with the meshes 1/4 in. in the clear. Rock ballast will cost one dollar a cubic yard, or more, delivered on the spot, and gravel about 45 cents. The items for ballasting a mile of track are about as follows: material $800; labor of filling, raising, surfacing and lining $500; preparation—taking out center, widening banks, taking out sags, replacing ties + $500; raising bridges and miscellaneous expenses $200 — or $2000 in all. Rock ballast would increase the estimate by $1000 for material and $200 for labor of putting in, or $3200 in all. An excellent cross section for gravel ballast is found in Fig. 1.
and one for rock ballast is found in Fig. 2. Cinders make excellent ballast, especially in yards. Furnace slag is also to be recommended. In many places in the west, where the climate is dry and the little rain falls in sudden showers and does not soak into the ground, earth makes as good a ballast as is needed. Ties last well in it and track will keep in good condition with one surfacing a year. The cost of handling track is very much reduced in such regions. With earth ballast, drainage is very important for water soaked earth soon becomes soft and mushy so that it is impossible to keep up track in it.

The question of cross ties involves many considerations and deserves especial attention. The kind of ballast, drainage, climate, size of rail, weight of locomotives and amount of traffic govern the life of a tie and should, with the price in the locality, indicate the kind and the distance apart. Light rails require more ties, both to shorten the
distance spanned by the rail and to give a greater bearing surface for the weight. The increasing cost of ties and their probable scarcity in the future make the selection of ties an important economical question. Every effort should be made in the way of drainage etc. to prolong the life of a tie. An old tie should be left in the track until it commences to crush or becomes broken—unless of course there is a general renewal, when the cost of labor would determine its being replaced at the same time as the rotten ones. With good ties near to hold the track to gauge, an old tie which is well bedded and tamped will bear its part of the load. For any considerable amount of traffic, 17 ties to a 30 feet rail or 2 992 to the mile, should be used. Branches and roads with little traffic may use 16 or even 15 to the rail length, and on side tracks 15 is sufficient. Ties must be sorted so that those of the same length, breadth and depth will come together, and the different woods should not be
mixed. With different lengths and breadths, the unequal bearing on the ballast will soon give a poor surface to the track. Difference in depth causes unequal results from moisture, poor drainage and frost. Crooked and irregular ties should be rejected. No bark should be allowed to remain on the tie. The usual length required is 8 feet, though it is better to have them 8½ or even 9 feet. A depth of at least 6 inches and a breadth of from 8 to 10 inches should be specified. Hewn ties are preferable. Their greater length of life is probably due to the fact that the process of hewing tends to close the pores of the wood, while the surface of the sawed tie is rough and retains moisture. Besides, the quality of hewn ties can be easily determined, while the appearance of a sawed tie may be deceiving. Of the many varieties, oak is by far the most valuable, both on account of its wear under the rail and its length of life. It will last 8 to 12 years under
heavy traffic. Pine under light service is very durable, in dry regions, and with good drainage its life is from 6 to 12 years and under favorable circumstances may be even longer. Rock ballast cuts into pine badly. Cedar ties do not rot easily, but are too soft to stand the pressure of the rail. The method of prolonging the life of a tie by means of "treating" is being used, principally experimentally, and will come in to general use in the future. Hitherto it has been cheaper to let the ties rot and then renew them than to give a costly preparation. The probable proximate exhaustion of our forests will make wood preservation a necessity. Several processes prove to be successful, and the selection depends upon the individual circumstances, use, exposure and value of timber. Ryanizing, the method by which the timber is steeped in a solution of corrosive sublimate, is excellent for bridge trestles and ties. The cost is about $1.60 per thousand feet B. M.
In Burnettizing, the process which is considered the best for ties, the timber is subjected to a bath of steam and hot water under pressure, and then the moisture is thoroughly expelled by the use of a partial vacuum (about 10 lbs. pressure) — afterward the solution chloride of zinc, under a pressure of 100 lbs., all the work being performed in a closed cylinder. A modification of this process finishes the treatment by forcing a solution of tannin into the surface of the wood, which prevents the other solution from being washed out. It is expected that in the new works of the A., T. and S.F.R.R. at Las Vegas, N.M. the cost per tie of treating will be about 10 cents. The life of a tie treated in this way is supposed to be double that of the natural wood. Samples of hemlock and maple in use 15 years and of oak in use 17 years show that this process is satisfactory. Burnettized timber is apt to check and split in the sun, and
consequently is not desirable for bridge ties. Other processes are used with less success in economy.

In Europe, and especially in Germany, iron and steel ties are superseding wood. The general form of cross section is \(\square\) or \(\triangle\). The cost is given at \$1.50 per tie.

Perfect drainage is required to prevent rusting. In laying ties the ends should project equally beyond the rails. With suspended and opposite joints, it is best to use larger ties and place them as close together as will allow tamping. The middle of ties should not be tamped so hard as under the rails and at the ends of the tie, in order to avoid the danger of the tie breaking in two upon the settling of the track under the pressure of traffic.

Since the early days of railroads, rails have undergone a complete transformation in form and material. The \(L\) pattern, the cast-iron "fish-belly," the strap rail fastened to longitudinal stringers, the "doublehead," and the
old pear-shaped rail differ greatly from the modern shape shown in Fig. 3. The wear of wheel and rail is most economical on this form and the material is well distributed — the base gives as broad a bearing as possible on the tie, the web gives the requisite amount of stiffness, and the head fits the shape of the rail — while the approach to squareness on the upper and lower parts of the web allows a more secure fastening. Owing to the decreased cost and the many advantages, steel rails are coming into general use. Rails should be carefully inspected and all defective ones rejected. Care should be taken that there are no surface or side kinks, especially at the ends where the splice will come. Defects of this latter kind will cause a "lip" when the rails are put in track. For standard gauge, 48 to 56 lbs. per yard iron rail and 52 to 80 lbs. per yard steel rail are used. In the east the average weight of steel rail is considerable more than 60 lbs.
while in the west and south the average will fall below that amount. Heavy traffic requires heavy rails. Stiffness and strength, and hence more permanent surface, line and good joints, increase much more rapidly with increased weight of rail than does the cost. Amount of traffic, ballast, cost of ties etc. will govern the desirable weight of rail. Rails unfit for main track may be used on branches and sidings. Patterned rails may be cut off in regular lengths and used again on branches and sidings. Steel rails must be carefully handled — the practice of throwing them from a car should not be allowed. The rails should be "full spiked" and spikes should be driven straight, with care taken that the last blow is not too heavy. The corresponding spikes on the ends of a tie should be on the same side of the tie, that the tie may not slew from its position at right angles to the track and thus decrease the gauge.
There is much diversity in the practice of joints, whether alternate or opposite, supported or suspended. Opposite joints have for the past few years been held by the best railroads as being the least objectionable. In poorly-kept track, they are undoubtedly the best. A recent writer seeks to prove that on any but very poor track broken joints are desirable. He claims that with them there is no regular and normal tendency to continue or cumulate oscillations; that the effect of the rattle and noise is materially diminished; that the dancing of the car due to the joints is materially reduced; that the lateral stiffness of the track is much increased; and that the other defects of track and rolling stock—bad level, bad gauge, bad line, bad wheels &c.—are far more important in the aggregate effect on the riding of cars than any difference in the disposition of joints. More information is needed on this important subject.
which forms a prominent item in the effort to avoid low joints and in the cost of keeping good track. An advantage of the opposite joint is that it gives a chance for two joint ties which may be larger and placed closer together than are the others—thus greatly reducing the amount of low joints.

Notwithstanding the wonderful improvement in rail fastening in the past few years, no perfect splice has been devised. The joint is the only great obstacle to perfect track. It will always be weaker and of different elasticity from the rest of the track. The angle bar is the most efficient connection. Fig. 4 shows its general form. With this a supported joint can be used and a bearing of two ties obtained. The reinforcing in the center of the bar gives increased strength. At the best, the bars will frequently break, generally from the top, a result of the sinking of the rail under weight of drivers on each side of
the joint, and the consequent strain in an opposite direction from that for which the bar is planned. An important feature in the angle bar is the presence of slots in the flange of the angle, in which spikes are driven. This prevents the very objectionable action of the rails creeping, while the rail is left free to contract or expand. Not enough care is taken to have the bars fit the rails and to have the bottom of the flanges flush with the bottom of the rail to give an increased and even bearing on the tie. A recent modification makes the splice long enough to cover three ties, making a supported joint.

Another novelty is the use of rails cut at an angle of 45° or 60°. The Fisher joint, which is in effect a chair reaching over two ties is highly praised, but has several objectionable features.

The bolts and nuts used to fasten the splices to the rail, being of poor quality and having consequently poor
threads, the blows of the train and the movements of the track soon loosen the nuts, and as the angle bars are not then held firmly in place, the strength of the joint becomes materially diminished; the joint settle, the ends of the rails become bent, and the resulting noise and unpleasant riding is a bad advertisement for the road. It is therefore essential that the bolts be kept tight. Numerous nut-locks have been devised with more or less success. It is said that an Irishman with a wrench is the best nut-lock. Any mechanical device must be simple, durable and permanent, as there will be 1400 bolts in a mile of track and the labor employed in looking after them is not skilled mechanical labor. Favor seems to be divided between the Verona nut-lock and the Pratt washer. The Verona nut-lock, which has a very large part of the patronage of railroads is shown full size in Fig. 5. It consists of a tempered steel ring cut obliquely at one point.
It is quite efficient, but on a second tightening of the nut it is apt to lose its elasticity. The cost is less than 2 cents apiece. The Pratt washer is a rubber washer enclosed in a malleable iron case. At first it is efficient and especially serviceable in stopping the rattling, but hot weather often ends its term of service. The cost is about 5 cents apiece. The vulcanized-fiber washer is widely used, but soon decays and hardens by exposure. A very efficient lock is the Harvey, shown in Fig. 6. It consists of a nut having the same pitch but a different form of thread from the bolt, so that by the act of screwing up the distortion of both threads produces a tight fit. When the nut is screwed up, the bolt is locked securely.

The total length and distance apart of sidings will depend upon the amount of traffic of the road. They should be distributed as evenly as possible. A siding should be long enough to hold the longest train, and an even
greater length will enable trains to pass each other without coming to a dead stop. 2000 feet between headblocks is a desirable length. When there is plenty of room, it is best to place sidings not nearer than 15 feet apart center to center. In large yards in cities where space is valuable 11 feet center to center is common and even 10 feet is used. Old and short rails may be worked in on side tracks to good advantage. The plan of a yard at division points will require considerable ability and study to secure convenience and dispatch in making up trains. Usage in the curvature of turnouts is as diversified as are many other parts of a railroad. A standard should be adopted, and only two sizes of frogs used except in unusual cases. The 7°30' curves used on the A.T. & S.F. R. R., though sharper than the turnouts of most roads, give good satisfaction. It is usual to calculate the curves for turnouts to a parallel track as reversing
at a point half way between; but with frogs made straight from the point to the heel, as they always are, it would seem advisable to make a tangent between frog points. For the stub switch—the device in which a pair of rails spiked firmly back of the point of curve are swung to connect as in ordinary track with the lead rails—the throw at the toe of switch is usually taken at 5 inches for standard gauge. The length of switch is the distance from the point of curve to the end of the switch rail. The toe of the switch rests on a heavy timber called the headblock. The distance from the head block or end of moving rail to the point of frog is called the lead. The switch rods used to hold the unspiked part of the switch rail in place should be strong, of accurate gauge and should fit the rails so there will be no chance for play or for breakage. In fact the main points in any switch are, that the parts should fit
accurately, that they should be strong, not easily tampered with and not liable to be jolted off, and that the switch work easily and faithfully. The head chair or fitting on the head block for the switch rail and other rails to rest on may be of cast, malleable, or wrought iron. Wrought iron chairs are the most serviceable. A good chair—one on which a good joint may be maintained—rests on two ties with the connecting rod working in a groove between them. The revolving switch stand when well made is more desirable than the one with swinging target. There should be no play anywhere and no lip should be allowed at the top of switch. To avoid this, care must be taken that all parts are in order. Another matter that must be watched is that the switch rail does not expand or creep until its contact with the lead rails will not allow it to slide. Though the stub switch is simple and cheap and in
freight yards unobjectionable, the liability to misplace-
ment and derailment on main lines where trains pass at
a high rate of speed makes it a source of danger.
The point switch is in use in various forms. In
this one rail of the main track and one of the side
track are broken, a sharpened rail being used, which
when thrown fits against the rail next it and forms an
unbroken line. Most styles have a safety spring, by
which a train may run through a switch when set for
the other track, without breaking the tie rods. The objection
to this is that a pebble or block may so obstruct the
rails that the spring will allow the target to be set
for the side track when the point has not moved.
The Wharton switch, although the homeliest and the most
expensive, is the most efficient yet invented. For out-
of-the-way sidings and places where high speed is
necessary on main track it has great advantages.
With it the rails on the main track are entirely unbroken. The device for entering the turnout carries the wheel up an inclined rail until it is high enough for the flange to clear, when the main rail is crossed. It is also a safety switch, for when set for side track a train coming on the main track from the opposite direction will move a guard rail which rests against the main track rail and thus revolve the rod which throws the switch back to place; and a train coming from the side track when switch is not thrown will run on an inclined plate, while a guard rail will gradually guide the wheel to one side until the flange crosses the main track rail and the wheels take the main track. This switch is clumsy and expensive, the switch fixtures alone for a single throw costing nearly $250. A new device which will prove to be desirable in large yards when tracks are close together and space valuable is the slip switch, an idea
of which can be obtained from the diagram in Fig. 7.
So much jar and wear comes on switches that it is necessary that great care be taken in their construction and maintenance. Particular care should be paid to drainage and ballast. A full set of the best switch ties of uniform thickness should be laid on a good bed of ballast. With such a foundation less trouble will be encountered in maintaining the switches. In laying, after putting down the frog and establishing the headblock, the lead rails from the frog to the headblock should be spiked to line and the opposite rails spiked to gauge from this. Guard rails should be placed 2 1/2 inches from gauge and in double turnouts it is best that the guard rail extend from opposite the toe of frog, to opposite the heel of the other. The several distances in a turnout from a straight track are generally used in turnouts and crossovers from curved tracks. The degree
of curve of the turnout is increased or decreased by the
degree of curve of the main track, according as the
turnout is on the inside or outside of the curve, and the
reversing curve of the turnout is changed in opposite
manner. This practice allows the same frogs and with
the same length of track brings the turnout at the same
distance from the main track, as was calculated for
turnouts from straight track, the error being very slight
and the convenience considerable.

In the construction of a new railroad,
considerations of economy, time, and lack of knowledge of
the amount of traffic which the road will control, as well
as an ignorance of the physical features of the country,
usually require that the road be built as cheaply as
possible. With increased resources, the road should be
improved into a more permanent form. In the meantime
a careful study of the requirements of the road and the
most necessary points of betterment should be made. On
the judgment and ability displayed in this depends most
of the economical value of the improvements, for the carrying
out of the instructions is a matter easily accomplished.
The points where water from streams or from overflow
will require a higher grade, the localities where surface
ditches will be more efficient than high embankments.
the places where sags on the grade cause its frequently
break in two or allow too uneven speed, the parts of
the alignment which are too faulty to be allowed to
remain, the necessary water way for bridges and culverts
and many other items of a similar nature may be
decided more wisely after a period of observation than
would be possible at the time of construction. Notes
should be taken and plans made for all desirable
improvements to be used whenever the financial condition
of the road will allow the expenditures.
In raising grade, team work is much more economical in supplying earth than is the work train, the cost of material furnished by the latter being from two to four times as much as that by the former. The height which the track may be raised at one lift depends upon the frequency of trains and the size of the gang. 10 inches is generally the best amount. Trains must not be allowed to run over the track until it is well tamped. Especially with steel must this care be exercised. The cost of track labor in raising and finishing track, when earth is deposited at the ends of the tied by the contractor is 9 to 15 cents per cubic yard of increased embankment. Track should be put to proper grade before ballast or other improvements of that nature are made. A marked feature in the appearance of a railroad is the attention which has been given to clearing up all old material and storing it at convenient points.
Neatness in dressing banks and ditches, clearance of weeds and rubbish and in fact all the details which go to make up the general appearance of the road make a desirable impression on the observer.

Bridges and Buildings. — Time and space will allow only a cursory view of some of the needs of the bridge and building department. The organization is much like that of the track department. The best arrangement is that in which an engineer has direct control of all operations in that department. For every sub-division of 200 or 400 miles, there should be a general foreman of bridges and buildings. Under him are the gangs of carpenters, headed by a sub-foreman, who make the repairs and renewals on wooden structures. Besides, he should have immediate control of iron erection gangs and of all other men employed in repairs and renewals of bridges and buildings.
The use of pile bridges is quite general, and for all small openings for streams whose water-way and location do not require a long span they are probably the most economical structures to put in at the time of building a road. Before they will need to be renewed, water courses will assume a more determined character and the proper size for a permanent structure may be determined, while the material for the work may be transported more easily. On the Mexican Central R.R., where permanent structures were put in at the first much expense and delay were found in building the bridges. Pile bridges consist of bents, generally 15 or 16 feet apart and having three or four piles to each bent driven firmly into the ground, with caps of timber, and when extending far out of the ground securely braced with timbers. On this foundation is placed the stringers and the ties above that. Stringers notched at the end will split.
and fail sooner than others. A suitable guard rail of timber should be placed outside the rails and one made of old rail on the inside of the track. The cost of driving piles depends greatly on the amount of interference by passing trains. Care should be taken that as little time is lost through being "laid out" as possible. Oak piles in Colorado last from 10 to 12 years, pine piles not over five or six. Caps and stringers pine—last from 8 to 10 years. Oak ties, sawed, have about the same length of life. Pile bridges should have a careful inspection by a competent bridge man at least once a month besides the daily watch of section men. The bridge gang should go over the bridges twice a year to surface, line &c., in addition to the ordinary renewals. The cost of repairs on a pile bridge, not counting renewals, will be about $15 per span of 75 feet. The original cost is about $120 per span of 75 feet.
or 88 per lineal foot. In places where the nature of the channel and stream will not allow the use of pile bridges, wooden and combination (lower chord and rods of iron) trusses of the Howe type are much used, though the first cost and the expense of keeping up are much greater than with the former. Not enough care is taken in the maintenance of wooden trusses. The painting will need renewing every three years. The timbers should be frequently inspected for deterioration and watch should be kept that the iron connections do not rust out. The wooden chords should be protected from the weather by a covering of some metal—preferably corrugated iron—placed so as to insure proper ventilation over the chord. The rods need adjusting at least twice a year. The expense of ordinary repairs on a Howe truss will probably amount to a dollar a lineal foot a year. By far the most economical and best bridges are those with substructure of masonry and
superstructure of iron. Up to spans of 20 feet, girders formed by I beams placed side by side are to be recommended. For spans from 20 to 75 feet plate girders are the best. For greater lengths pin-connected trusses of the Pratt or similar forms are usually the most suitable. From \( \frac{1}{10} \) to \( \frac{1}{12} \) of the span will be required for the depth of the plate girders, and the weight of the girders will run from 10 to 15 pounds per linear foot, varying according to the length and design. These as well as the trusses should be designed and proportioned by a competent engineer according to specifications which are too long to be inserted here. A careful inspection of the iron should be made at the shops and another after erection. One great fault in putting up iron bridges is that the riveting is so poorly done that the rivets soon become loose and the consequent wear greatly weakens the bridge. Every part of an iron bridge should be
painted every three years. It is desirable that the ties be of treated material. Guard rails and timbers are of great importance in the safety of a bridge. The ordinary repairs on an iron bridge will not exceed 25 cents per running foot a year. More care should be taken in the adjustment of rods than in a wooden truss.
The substructure for an iron bridge should be of a permanent and substantial character. Borings should be made to determine the nature of the underlying earth. Where rock or coarse gravel cannot be reached at a reasonable depth and the weight on the foundation is more than a ton to the square foot, it is best to drive piles in rows not more than 2 1/2 feet apart, cap them, and fasten a grillage of timbers at least a foot thick on top of that. Precautions should be taken to prevent scour around the abutment. Among the requirements for masonry for ordinary spans are: minimum of 12
inches courses and minimum bed of 18 inches, joints not over 3/4 inch, no opening over 50 square inches to be filled with spalls, good bond, dressed coping stones, best cement mortar, joints scraped out and pointed with Portland cement mortar &c. Whenever the inspection shows cracked masonry, or such condition that the weather will injure the masonry, it should be pointed and repaired. For smaller openings, both box and arch culverts are used. Arch culverts are generally built with a semi-circular arch with the springing line placed a distance above the paving equal to the radius of the arch. Arches of from 6 to 10 feet span are very effective. The paving should be well put in, and often a "sunk wall" at the ends should extend some distance below the foundation. The cost of arches and boxes is greatly increased on high embankments. The question of the method of determining the requisite
amount of water way has not been very satisfactorily answered. Probably the best plan is to have the section men at every flood mark the height of high water on all bridges and culverts and to have an engineer take notes on these every year. A ten years record would give valuable data for determining the necessary water way, and permanent structures can be put in accordingly. For calculating water way for a small known drainage area, Myers' formula \( A = c V N T \) is often used. In this \( N \) is drainage area in acres, \( A \) is the area of required opening in square feet, and \( c \) is a coefficient depending upon the slope, vegetation, cultivation, rainfall etc. of the country. For ordinary rolling prairie \( 1/2 \) is an average value for this coefficient, but for mountainous places it must be raised to 4 or 5. This is based on a rainfall of 2 inches per hour. For large streams high water mark may be obtained from
residents or from appearance of driftwood. Cross sections should be taken at points a mile or two apart and the slope of the channel obtained. Then the velocity of the stream may be calculated by the formula $V = cNRS$ in which $V =$ velocity in feet per second, $R =$ mean hydraulic depth, $S =$ slope or inclination, and $c$ is an arbitrary coefficient which may be taken as 90 for a large value of $R$ and as 80 for a small value. With velocity and area of section, volume of discharge is found; and with the average velocity and average volume of discharge of the several sections, the mean area required at the bridge may be obtained. Allowance must be made for obstruction of piers &c.

Buildings should be convenient, substantial and tasty. It is well to carefully plan a standard for each class of buildings on the road, paying attention to every detail. Such a course will insure uniform
serviceability. On most roads the buildings are poor, even considering the amount of money spent on them. Engine houses should be of stone and carefully constructed. 80 feet between chords and 58 stalls to the circle makes a desirable house. That angle between stalls allows a No. 9 frog to be used. Turntables should be of iron with suitable masonry. Patent coal chutes save much time over the old derrick and bucket. Oil houses, sand houses, offices, shops, depots and other buildings all require planning and supervision with greater or less degree of ability. All wooden buildings should be painted once in three years.

Water Service. — The supply of water for locomotives is often in a department by itself and should be under the charge of the same engineer who has charge of maintenance of way. The interval between tanks depends upon the grade and upon the style of
Locomotives used. For grades of more than 2 per cent 10 miles should be the maximum distance; for grades of 1 per cent, 15 to 20 miles; for light grades 20 to 30 miles. Whenever possible springs should be utilized to furnish a gravity supply. Pipes even laid several miles will prove an economical investment. Wind may be utilized for a pumping power. When these sources fail, water may be pumped into a tank by a steam engine. Tanks should be well built and of 50,000 gallons capacity. A locomotive will hold from 2000 to 3000 gallons of water. The average cost of pumping 1000 gallons on the A. T. and S. F. R. R. is less than 5 cents.

Ripraping.—In places where the current of a stream runs strongly against the embankment or bridge abutment, a protection of riprap should be used. It is usual to lay the stones into a dry
wall. Even where the slope is made very light some part of the wall, generally the bottom, will wash away, letting the remainder fall and soon spoiling the riprap. When there is such a probability, stones thrown in loosely, making a pile thick enough and with the proper slope, will insure greater stability. This requires much more stone, but as fast as any may wash away, those above settle to take the place. To divert the current, dikes or breakwaters are made, preferably at right angles to the current. These may consist of a row of piles four or five feet apart, capped with a piece of old bridge timber and planked down to the water line, with a heavy body of riprap on each side of this up to high water line; or there may be two rows of piles five or six feet apart with planked sides forming a crib, which should be well supplied with rock to protect from
The management of maintenance of way is a growing field for the engineer. The old belief that an engineer's services were not needed after the completion of the construction of the road is passing away. This branch of railroading utilizes the technical knowledge, the powers of observation and the judgment of the engineer and is not so easily learned as are the other departments. Roads like the Pennsylvania R.R. are continuing their engineers in the control of track, bridges, and buildings, and, believing that the discipline and judgment acquired here fit them to more easily learn the other work, are promoting them to superintend other departments as well. Executive ability becomes characteristic of the engineer. With these many advantages maintenance of way in the future must be managed by the engineering department.
Fig. 1.
CROSS SECTION OF ROADBED BALLASTED WITH GRAVEL.

Fig. 2.
CROSS SECTION OF ROADBED BALLASTED WITH ROCK.
Fig 3.

SECTION OF 61 LB. RAIL.
Fig. 4.

Fig. 5.

Fig. 6.