A MAINTENANCE-OF-WAY DEPARTMENT RAILROAD TESTING PLANT.*

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SOME time ago the writer, whose experience has been chiefly with railway motive power, was asked to assist a maintenance-of-way engineer in the investigation of a problem which involved a study of track design and the stresses imposed upon its various members.

Consultation with several men of recognized experience and authority, as well as an investigation of all experimental work performed in this connection, and a search through the literature of the subject, revealed the fact that dependable data upon which to base definite conclusions upon various points raised were lacking.

This same revelation was made by Mr. O. E. Selby, Bridge Engineer of the Cleveland, Cincinnati, Chicago & St. Louis Railway, in writing an admirable paper, entitled "A Study of the Stresses Existing in Track Superstructure and Rational Design Based Thereon," which was published in Bulletin No. 80, American Railway Engineering and Maintenance-of-Way Association, October, 1906. This paper contained several paragraphs elaborating upon the statement that "railroad track has grown in strength as heavier loads have made increased strength necessary, but such growth has been entirely along empirical lines, and not one single detail of track superstructure bears marks of engineering design."

Mr. Selby, after careful consideration of such factors as rail loading and stress therein, tie bending, bearing of tie upon the ballast, depth of ballast and its bearing upon the subgrade, developed the track design shown in Fig. 1. The sizes on the drawing are for 60,000-pound axle loads. The principal sizes for 50,000-pound loads, using various weights of rail, are given in Table I.

* Communicated by the author.

TABLE I.

Rail.....	80 pounds	90 pounds	100 pounds	Rail with Sec. Mod. 20
Axle load.....	50,000	50,000	50,000	60,000
Size of ties.....	7" x 8" x 8½"	7" x 8" x 8½"	7" x 8" x 8½"	7" x 9" x 8½"
Spacing of ties....	16½"	18"	20"	20"
No. of ties 33-foot rail.....	24	22	20	20
Depth of ballast...	14" stone	16" stone	18" stone	{ 12" stone 12" gravel
Width of roadbed..	21'	21'	22'	24'

From this table it is at once seen that the number of ties per 33-foot rail, as well as the depth of ballast, is much greater than that found in standard track to-day, and, since the figures

FIG. I.

Track superstructure for 60,000 lb. axle loads.

in the table are the result of a careful consideration of the strength of the materials involved, it is not surprising that the question of strengthening our present standard tracks is becoming such a live one, especially with our heavier trunk lines.

The depth of ballast, computed by Mr. Selby, was obtained from formulæ for the thickness of ballast necessary to produce equal distribution of axle loads on the surface of subgrade beneath the ballast, for which Mr. Thomas H. Johnson, Consulting Engineer of the Pennsylvania Lines West of Pittsburgh, was responsible. Mr. Johnson deduced these formulæ after studying a report, made by Railroad Director Schubert, of Berlin, in 1899, of observations extending over a period of over three years, on the action of ties actually in track. This report was translated and published by Mr. W. C. Cushing, Chief

Engineer, Maintenance-of-Way, Pennsylvania Lines, and appeared in Bulletin No. 76 of the American Engineering and Maintenance-of-Way Association, June, 1906.

In Mr. Johnson's formulæ the two following premises are made:

1. "That the width of distribution of the load is equal, for stone ballast, to the width of the tie plus the depth of the ballast, and, for gravel ballast, to the width of the tie plus half the depth of the ballast."

FIG. 2.

From Fig. 2 this premise may algebraically be expressed thus:

$$\text{For gravel, } x = b' + \frac{1}{2} d' \dots \dots \dots (1)$$

$$\text{For stone, } x = b' + d' \dots \dots \dots (2)$$

where x is the width of ballast pyramid carrying the load.

2. "That the intensities of pressure within that width are proportional to ordinates to an arc of a circle whose radius and chord are each equal to the width of distribution of the load."

The deduction of the formulæ is as follows:

If the circular arcs be considered as approximate parabolas, the intensities of pressure may be assumed to be proportional to

the ordinates of the curves. The area of the parabolic segment $= \frac{2}{3}xy$, hence the mean ordinate $= \frac{2}{3}y$, or the mean pressure $= \frac{2}{3}$ the maximum.

The pressure at b is 0, hence, to obtain an approximately uniform distribution of pressure over the surface of the subgrade, the tie-spacing S must be such that the curves overlap and have a common ordinate y' equal to $\frac{1}{2}y$. This will obtain when $db = \frac{1}{4}cb$; $eb = \frac{1}{4}ab$ or $mo = \frac{3}{4}mn$.

Hence, the tie-spacing $S = \frac{3}{4}x$.

Therefore, from (1), for gravel,

$$S = \frac{3}{4}(b' + \frac{1}{2}d')$$

and from (2), for stone,

$$S = \frac{3}{4}(b' + d')$$

from which the required ballast depths d' are obtained by transposition:

$$\text{For gravel, } d' = \frac{4}{3}(S - \frac{3}{4}b')$$

$$\text{For stone, } d' = \frac{4}{3}(S - \frac{3}{4}b')$$

both of which give values of d' much greater than exist in practice.

The question whether, in order to strengthen our tracks for the increased loads imposed, the number of ties or the depth of ballast, or both, should be increased, is one upon which opinions vary widely among those concerned. The following is here presented in this connection:

Fig. 3 shows a diagrammatic section of the ordinary standard main line track, in which 7-inch by 8-inch ties are spaced 22 inches apart, or 18 per 33-foot rail, and laid upon 6 inches of ballast. The slopes of the ballast pyramids, transmitting the load from bottom of tie to subgrade, are determined in accordance with Mr. Johnson's premises for the distribution of pressure at the bottom of stone ballast. It will be noted that the width of the base of the ballast pyramid under each tie is 14 inches and the width of the strip of subgrade unloaded and lying between adjacent ties is 8 inches. As shown by Director Schubert's experiments, and in line with the experience of all trackmen, the subgrade line, originally straight, will be disturbed, as AB in

Fig. 4, the amount of disturbance being proportional to the weakness of the subgrade and to the ratio of the area of subgrade

between the loaded ballast pyramids and that of subgrade beneath the ballast through which the load is transmitted.

By changing the tie-spacing to 20 inches, or 20 per 33-foot rail, as shown dotted in Fig. 3, the ratio of loaded to unloaded

width of subgrade at the 6-inch depth of ballast becomes $14/6$ instead of $14/8$, an increase of $33\frac{1}{3}$ per cent. The subgrade is more nearly confined, a condition which, of course, materially

FIG. 5.

Sketch of track plan.
7" x 8" x 8' 6" ties spaced; 22" or 18" per 33' rail. Showing outlines and areas of loaded sections of subgrade with 6", 8", 14" and 21 1/2" of ballast under the ties.

increases its carrying capacity. Maintaining the 22-inch tie-spacing and increasing the depth of ballast from 6 inches to 8 inches changes the ratio of loaded to unloaded width of sub-

grade from $14/8$ to $16/6$, an increase of approximately $52\frac{1}{2}$ per cent.; while the combination of the decreased tie-spacing and increased ballast depth increases the original ratio from $14/8$ to $16/4$, or approximately 128.6 per cent.

In the diagrammatic plan of track shown in Fig. 5 it is assumed that the rail load is spread by the tie 18 inches on each side of the rail centres, or, for an 8-inch tie, over an area of $36 \times 8 = 288$ square inches of the lower face of the tie under each rail, and over somewhat less than the $36 + 6 \times 8 + 6$, or 588 square inches of the subgrade. The corresponding area of unloaded subgrade is 42×8 , or 336 square inches, and the ratio of loaded to unloaded subgrade areas is $588/336$. Decreasing the tie-spacing to 20 inches will increase this ratio to $558/252$, or $33\frac{1}{3}$ per cent., while combining with this decrease, an increase of ballast depth of 2 inches, will increase the ratio to $588/168$, or 100 per cent.

Fig. 5 also shows that with 18 ties per 33-foot rail the unloaded area of subgrade between adjacent ties becomes zero when the depth of ballast is increased from 6 inches to 14 inches, while with 20 ties per 33-foot rail it becomes zero with a ballast depth of 12 inches.

According to Johnson's formula for stone ballast, uniform distribution of subgrade loading will be obtained with $21\frac{1}{3}$ inches of ballast for 18 ties per 33-foot rail and with $18\frac{2}{3}$ inches of ballast for 20 ties per 33-foot rail.

Any consideration of the relief to be expected from decreasing the tie-spacing, increasing the depth of ballast or otherwise, should take into account the cost, and in this connection Table II is presented on page 214.

From this table it is seen that a reduction of tie-spacing from 22 inches to 20 inches increases the ratio of width of loaded to unloaded subgrade by $33\frac{1}{3}$ per cent. at a cost of \$464, \$928, and \$1856 per mile for single, double, and four-track lines respectively, while an increase of ballast depth of two inches (from 6 inches to 8 inches) increases this ratio by $52\frac{1}{2}$ per cent. at the respective cost of \$256.90, \$507.23, and \$1006.51 per inch additional ballast, or \$513.80, \$1014.46, and \$2013.02 for the two inches of additional ballast. Whether the first or the second or a combination of both is best is therefore somewhat of an open question.

Some individuals and committees have recently recommended a ballast depth greatly in excess of previously existing standards and still greater than the ballast depths actually obtaining even on our densely travelled lines, without qualification dependent upon either the subgrades or the characteristics of the imposed loads.

TABLE II.

STATEMENT SHOWING COMPARATIVE COST OF INCREASING NUMBER OF TIES PER RAIL LENGTH (33 FEET) FROM 18 TO 20 AND COST PER INCH DEPTH OF PUTTING ADDITIONAL BALLAST UNDER STANDARD TRACK OF ONE OF OUR LARGER LINES.

Ties per mile spaced	Single track	Double-track	4-track
18 per rail length.....	2,880	5,760	11,520
20 per rail length.....	3,200	6,400	12,800
Additional ties.....	320	640	1,280
Cost per tie:			
1 tie.....	\$0.90	Volume of 1 tie, 3.3 cubic feet. Cost of ballast, 75 cents per cubic yard. Cost of laying ballast, 40 cents per cubic yard. Total cost of ballast in track, \$1.15 per cubic yard.	
2 plates.....	.28		
8 spikes.....	.11		
	<u>\$1.29</u>		
Credit account ballast displaced.....	.14		
Net cost per tie.....	<u>\$1.15</u>		
Labor, placing tie in track..	.30		
Cost per tie in track.....	<u>\$1.45</u>		
Cost of additional ties in track.....	\$464*	\$928*	\$1,856*
Full width of ballast base.....	164½"	324½"	644½"
Cubic yards per square inch section per mile equals 1.35			
Cubic yards ballast required.....	223.39	441.07	875.23
Cost of required ballast in track, at \$1.15.....	\$256.9	\$507.23	\$1006.51

*Does not include labor cost of respacing present ties to make the insertion of additional ties possible, nor the cost of distributing the ties and ballast to point where placed in track.

To the writer it appears that the design of railroad track must be approached in the same way as the design of any mechanical parts. As a foundation it should be treated like any other foundation, and a study of its requirements, purposes, construction, and maintenance should be made. It must be designed to carry loads of certain individual magnitude, density and speed, etc., and must do this upon subgrade of given condi-

tions. With a sufficient amount of the right kind of data, it should be possible to combine the knowledge of the loads to be imposed with that of the subgrade conditions, and prescribe the most efficient and economical track construction, which, if it cannot be immediately provided, can be approached from year to year in connection with regular track maintenance work. Subgrade conditions vary materially within short distances, but with these conditions properly charted it should be a very easy matter, in bringing the condition of the track up to a desired standard, to concentrate effort upon those sections which are farthest from that standard and which will be located from tabulated or charted data or from the frequency of service failure.

Opinions of maintenance men vary greatly upon a majority of questions relating to track and track superstructure design, and practically none of these opinions is supported by such conclusive test or experience as will make early agreement or reconciliation possible. In the maintenance-of-way department dependable data are not being collected as in the motive power department, in which department much money has been, and is continually being, profitably spent to settle questions pertaining to the design and operation of both locomotives and cars, many of which questions are of less importance than some of those relating to track construction.

The writers upon maintenance-of-way subjects will have served a useful purpose if they succeed in focusing attention upon the comparative deficiency of experimental work in this field, for as soon as this deficiency is realized then work will be inaugurated which will, in a few years, elevate the science of track construction to its proper level. The condition of our tracks is now lagging behind requirements, and we cannot consistently hope for a better state of affairs unless some move along scientific lines is soon inaugurated. In the meantime, locomotive and car designers must "mark time," so far as increased loads and speeds are concerned.

While some investigations should necessarily be made under regular service, many can, nevertheless, be (and a few have been) carried out upon an experimental track of significant proportions. An experimental track was constructed a comparatively short time ago by the Prussian State Railroads at Oranienburg, Germany, and is being used to determine experimentally

the best construction. Dr. H. K. Hatt, of Purdue University, who visited this installation a few years ago, reported:

"It consists of an oval track two miles in circumference over which runs a train consisting of electric locomotive and cars. At about every fifty feet two vertical rail ends were sunk in the ground on each side of the track and clips riveted onto them to serve as a reference line, for measurement of track deformation. The service is considered as severe in one year as eight years on the main line. The cost of the roadbed and equipment is stated to have been \$40,000.

"About a year before my visit the first track had become worn out and a new track consisting mainly of steel and beech ties had been set under service.

"Some of the elements which were being experimented with at Oranienburg may be listed as follows: Prussian standard steel ties with side ribs have been down one year in different forms of ballast. The evidences of derailment of cars were visible, but the steel ties were not sprung. The modern double steel tie was used at the joints.

"Various forms of anchorage of rails to ties were under experimentation. These anchors are found more necessary in steel ties than in the case of wood. The various forms of anchors seemed all to be effective, although the track as a whole had not been down long enough to give final results.

"The scarf joint appeared to be unsuccessful, inasmuch as the inner edge of the scarf sheared off at the edge, due to the wave motion in the rail.

"The records of traffic passing over this experimental track show that in 369 working days the number of kilometre tons was about six million. In the months of January, February, March, and April, in 1909, there were nearly seven million kilometre tons. The locomotive weighed $59\frac{1}{2}$ tons and would pull a train of from 240 to 375 tons. The speed of the train was 60 kilometres per hour.

"At the time of my visit the plant was not in operation.

"The above notes were jotted down from conversation with one of the officials in charge at the time of the visit, and were not submitted to the railway authorities for confirmation. They should serve, therefore, to illustrate the programme of work rather than to present official conclusions."

The loads imposed upon this experimental track are insignificant in comparison with those which, for the results obtained to be of service, would have to be placed upon such a track in this country.

The writer would suggest that an experimental track be designed and constructed in the form of a figure 8, so that one loop could be operated while the other was being prepared for test. On this track, properly enclosed by fencing, etc., a motor, hauling any desired combination of cars, loaded with any desired axle loads, could be controlled from the office of an engineer of maintenance-of-way tests located in the centre of either of the loops, and in this way any combination of rails, fastenings, ties, joints, ballast, frogs, switches, signals, and safety devices could be tested.

The value of an ability, by this method, to rapidly test rails of different steels, under more scientific conditions, must be apparent when the amount of work done in settling rail questions during the last ten years is considered.

Such a plant, with its so general benefits, could be very properly be jointly constructed by interested railroads, perhaps under the direction of the American Railway Engineering Association, and tests on it carried out by some one of our educational institutions interested, in much the same way that motive-power department tests of various equipment furnished by different railroads, directly or indirectly through the Master Car Builders and Master Mechanics' Association, have for some years been conducted at Purdue University, Lafayette, Ind.

Panama-Pacific International Exposition, San Francisco, February 20-December 4, 1915.—The Department of Liberal Arts, of which Theodore Hardee has recently been appointed chief, announces that special efforts will be made to obtain a complete collection of exhibits of architecture, its allied arts and engineering. It will comprise drawings, models, and photographs of architecture and engineering in their various branches; plans followed in the improvement of rivers and harbors, water-works and sanitation; irrigation and roadmaking methods; specimens of artificial stone and kindred building material; processes used in testing structural materials, and special contrivances for safety, comfort and convenience in buildings. Detailed information may be had by addressing the Exposition.