UNIVERSITY OF ILLINOIS BULLETIN

ISSUED WEEKLY

VOL. XIV SEPTEMBER 18, 1916 NO. 3

[Entered as second-class matter Dec. 11, 1912, at Urbana, Ill., under the Act of August 24, 1912.]

THE TRACTIVE RESISTANCE ON CURVES OF A 28-TON ELECTRIC CAR

BY

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BULLETIN NO. 92

ENGINEERING EXPERIMENT STATION

PUBLISHED BY THE UNIVERSITY OF ILLINOIS, URBANA

PRICE: TWENTY-FIVE CENTS

EUROPEAN AGENT

CHAPMAN AND HALL, LTD., LONDON

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and

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THE TRACTIVE RESISTANCE ON CURVES OF A 28-TON ELECTRIC CAR

I. Introduction

The tractive resistance of cars running on curved track is greater than their resistance on straight track of like grade and construction. This excess is generally termed curve resistance or resistance due to curvature. A knowledge of its magnitude is needed in many problems which present themselves in connection with steam and electric railway design and operation. While these problems are more important and more numerous on steam roads, they are not unimportant nor infrequent on electric roads. Nearly all the existing information regarding curve resistance has arisen from tests and experience with trains on steam railways, and it is doubtful whether the values of curve resistance thus derived are valid for the single self-propelled cars used on electric lines. Such considerations led the Railway Engineering Department of the University of Illinois to make the tests, the results of which are presented in this bulletin.

The tests were undertaken to measure the curve resistance of a 28-ton electric car, owned by the department, with the view of determining its value at various speeds and on as great a variety of curves as were available on the lines of the Illinois Traction System, upon which the experiments were conducted. The results established for this car the relations between curve resistance and speed and between curve resistance and rate of curvature.

The test conditions, test methods, and final results are presented in the body of the bulletin, while the details concerning the apparatus, test data, methods of calculation, and intermediate results are given in the appendixes. Throughout the bulletin the term "curve resistance" or "resistance due to track curvature" means the tractive force needed by the car on curves in excess of the force needed to move it over straight track. This tractive force is the force required at the wheel rims to keep the car moving at uniform speed on level track and in still air. It is expressed in pounds per ton of car weight.

Acknowledgment is gratefully made of the interest and coöperation of the officers of The Illinois Traction System, which rendered it possible to conduct the tests on that road; and to Mr. D. C. Faber, formerly a Fellow in the Department of Railway Engineering, who was in charge of the test car during some of the tests and who made some of the preliminary calculations.

II. Summary

At the expense of some duplication there is presented at this point a summarized statement of the conditions, methods, and results of the tests, which may serve to provide a general view of the work and to facilitate an understanding of the more detailed explanations which follow.

1. *The Car, Track, and Equipment.*—The tests were made with a car such as is commonly used on interurban electric roads; it has a body 45 feet long of the double-end type with round vestibules. This body is carried on four-wheeled trucks which are spaced 23 feet 3 inches from center to center and which have a wheel base of 6 feet 4 inches. The car is equipped with four 50-horsepower motors and weighs approximately 28 tons.

The tractive resistance of this car was determined when running upon each of seven curves whose curvature varied from 2 to 14½ degrees, and also when running upon adjacent tangent track. The superelevation of the outer rail on the curves varied from 0.75 inches on the 2-degree curve to 5.9 inches on the 14½-degree curve. The track was laid with 70-pound rails on ties spaced about 24 inches between centers in gravel or cinder ballast. Judged by the standards which prevail on electric interurban roads built for moderate speed, the track was well constructed and well maintained. It was surveyed especially for the purposes of the tests. With a few exceptions the tests were made on dry rail in fair weather. The average air temperature varied during the tests from 25 to 65 degrees F. and the maximum average wind velocity was 18 miles per hour.

2. *Methods.*—In making a test, the test car was run first in one direction and then in the other over one of the curves and its adjacent tangent. During each such pair of runs the car speed was maintained as nearly constant as possible. Similar pairs of runs were then made at other speeds, until sufficient data had been accumulated to define the resistance at various speeds on the curve and on its corresponding tangent. Under this procedure each pair of runs results in two values of resistance: one with such wind as prevailed helping the car, the other with the wind opposing it. From the final curves which define the mean between these values, the influence of the wind is, therefore, nearly, if not quite, eliminated, and the results relate to movement in still air. The results of the tests provide mean values of resistance on each curve and on its tangent. The difference between these values of resistance is the desired resistance due to track curvature.

3. *Results.*—The tests demonstrate that for the car in question curve resistance varies directly with both track curvature and speed. For a particular speed, the curve resistance increases as the curvature increases and in direct ratio with the curvature, as shown in Fig. 16. This implies that at a particular speed the curve resistance, when expressed in pounds per ton per degree of curve, is a constant for all curvatures; a relation which is in accord with the results of previous experiments. On the other hand, the value of curve resistance expressed in pounds per ton per degree is shown to be different at each different speed, and it varies in such a way that for a curve of a particular curvature the curve resistance increases in direct ratio with the speed, as shown in Fig. 17. The concurrent relations between curve resistance, track curvature, and speed are shown in Fig. 18, and they are defined by the formula:

$$R_c = 0.058\ S\ C,$$

in which R_c is the curve resistance expressed in pounds per ton, S is the speed in miles per hour, and C is the degree of curve. Values derived by means of this equation appear in Table 4.

III. Means Employed in Conducting the Tests

4. *The Test Car.*—The car used for the tests is owned by the Railway Engineering Department of the University. It is a standard 45-foot car similar to those commonly used on interurban roads built for moderate speed. Its general design is shown in Figs. 1 and 2.

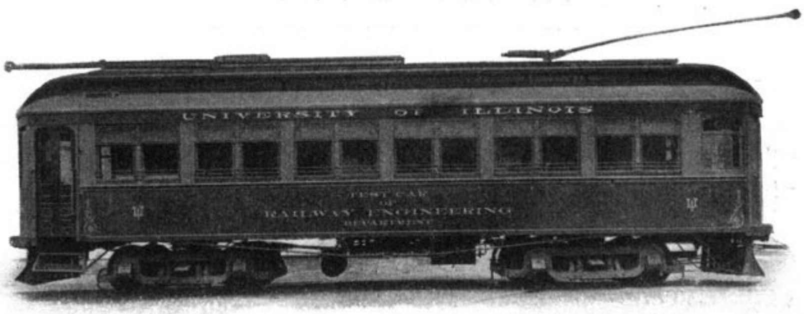

Fig. 1. The Test Car

The car weighs 55,150 pounds, although during the tests this weight was subject to certain corrections due to changes in equipment and in the number of passengers. The sectional area of the car body and trucks is 90 square feet.

The trucks are of the standard Motor Truck Company's C-60 type and weigh 7,824 pounds each, without the motors. The truck journals are $4\frac{1}{4}$ by 8 inches, the wheel diameter is 33 inches, and the

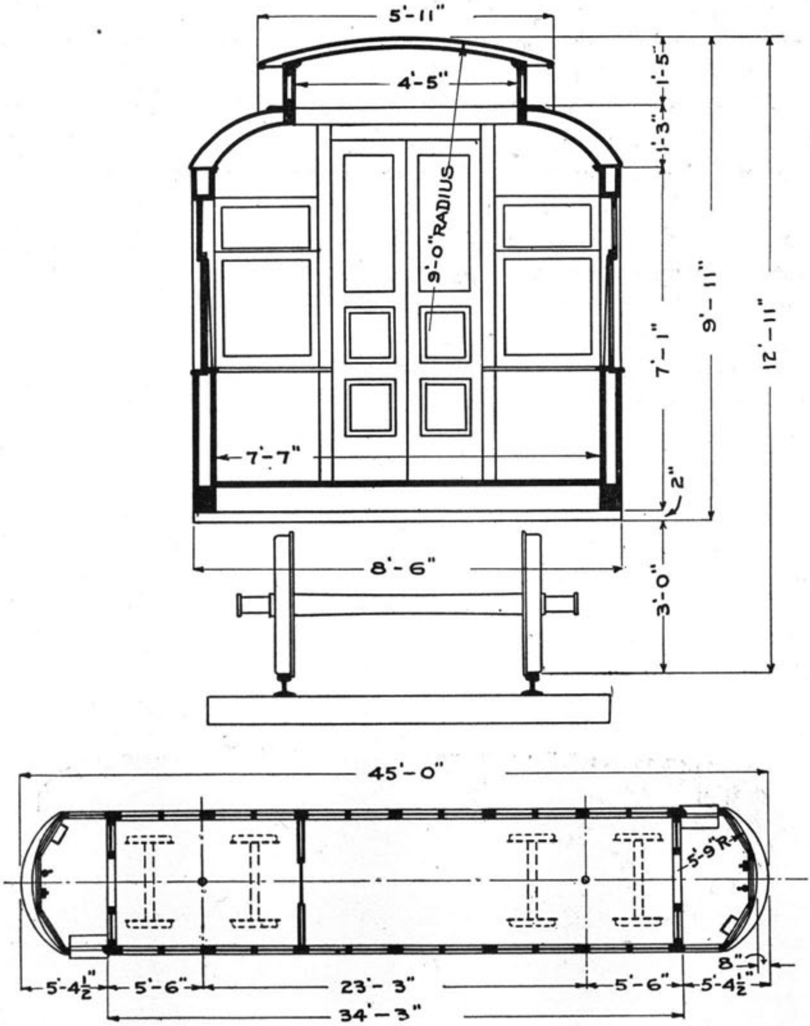

FIG. 2. PLAN AND CROSS SECTION OF THE TEST CAR

truck wheel base is 6 feet 4 inches. One of the trucks is equipped with rolled steel wheels and the other with chilled cast iron wheels, all of which have standard Master Car Builders' tread and flange contours. During these tests the car was equipped with ball-bearing center plates. Each truck is provided with two Westinghouse 101-D, 500-volt, direct current motors, which have a commercial rating of 50 horsepower each. The motors are mounted on the axles and geared to them in the ratio of 22 to 62. They are controlled by the Westinghouse unit switch system of multiple control.

An especially designed recording apparatus within the car offers a means for measuring and recording the current consumed, the voltage, speed, time, distance traversed, location on the road, and brake cylinder pressure. Continuous graphical records of these data are drawn upon a chart which is made to travel at a rate proportional either to time or to the distance traveled by the car. A more complete description of the car and of this recording apparatus appears in Bulletin 74 of the University of Illinois Engineering Experiment Station. In addition to the data above enumerated, there were recorded for each run the average wind velocity and direction, air temperature, rail condition, and the gross car weight.

5. *The Track.*—The tests were made on the lines of the Illinois Traction System between Danville, Urbana, Champaign, Decatur, and Springfield. The oldest portions of this track were laid in 1903, the latest in 1907. Judged by the standards which prevail on interurban electric roads built for moderate speed, the track was well constructed and well maintained. On both the curves and the tangents used in the tests, the track was laid with 70-pound A. S. C. E. section rails carried on hard-wood ties spaced about 24 inches between centers. The ballast was either gravel or cinders.

The curves chosen were seven in number varying in curvature from 2 to 14½ degrees, as great a range in curvature as was presented by the track available for test purposes. The gauge on all but the 8-degree and the 14½-degree curves was 4 feet 8½ inches, while on these two curves it was 4 feet 9 inches. A summary of the facts relating to the seven curves is given in Table 1. All the track used for

TABLE 1
DATA RELATING TO THE SEVEN CURVES

Average Curvature	Length of Track Section	Superelevation			Grade	Weight of Rail
		Average	Maximum	Minimum	Difference in Elevation	
Degrees	Feet	Inches	Inches	Inches	Feet	Lb. per Yd.
2°–0′	500	0.7	1.2	0.0	1.47	70
2°–50′	1737	3.0	4.1	1.3	8.52	70
3°–40′	1125	1.9	3.3	0.2	4.81	70
5°–0′	714	2.8	3.8	0.4	0.15	70
6°–30′	365	4.5	5.4	2.2	3.22	70
8°–0′	176	5.3	5.5	5.0	0.65	70
14°–30′	276	5.9	6.9	5.0	0.17	70

the tests was surveyed especially for the test purposes, and the results of these surveys are presented in Appendix I, together with further details.

IV. Test Conditions and Test Methods

6. *Test Conditions.* — The tests were all made in moderate weather. The lowest air temperature recorded during any test was 15 degrees F., and the lowest average temperature throughout the duration of any test was 25 degrees. The corresponding highest temperatures were 70 degrees and 65 degrees, respectively. With five exceptions the tests were made on dry rails. The highest average velocity of the wind prevailing during any of the tests was 18 miles per hour, whereas the maximum component of this velocity parallel

Table 2

A Summary of Test Conditions on the Curves and on Their Corresponding Tangents

1	2	3	4	5	6	7
Curve or Tangent	Test Number	Degree of Curve	Weight of Car and Load	Approx. Average Air Temp.	Rail Condition	Average Wind Velocity
			Pounds	Deg. F.		M.P.H.
Curve	117–118	2°–0′	56200	25	Wet	12.0
	123–124	2°–0′	56750	30	Dry	4.0
Tangent W	117–118		56200	25	Wet	12.0
	123–124		56750	30	Dry	4.0
Curve	119–120	2°–50′	56750	45	Dry	3.5
	121–122	2°–50′	56750	30	Dry	3.0
Tangent S	119–120		56750	45	Dry	3.5
	121–122		56750	30	Dry	3.0
Curve	125–126	3°–40′	57350	35	Dry	15.0
	127–128	3°–40′	57500	25	Wet	0.0
	129-130	3°–40′	57350	65	Dry	15.0
Tangent R	125–126		57350	35	Dry	15.0
	127–128		57500	25	Wet	0.0
	129–130		57350	65	Dry	15.0
	141–142		57800	40	Dry	3.8
	153–154		57900	60	Dry	0.0
Curve	125–126	5°–0′	57350	35	Dry	15.0
	127–128	5°–0′	57500	25	Wet	0.0
	129–130	5°–0′	57350	65	Dry	15.0
Tangent R	*					
Curve	133–134	6°–30′	57300	35	Wet	7.5
Tangent D	109–110		56950	55	Wet	18.0
	111–112		56350	55	Wet	18.0
	113–114		56200	55	Dry	10.0
Curve	141–142	8°–0′	57800	40	Dry	3.8
	153–154	8°–0′	57900	60	Dry	0.0
Tangent R	*					
Curve	141–142	14°–30′	57800	40	Dry	3.8
	153–154	14°–30′	57900	60	Dry	0.0
Tangent R	*					

* Same tangent as for 3°–40′ Curve

to the tangent track or to a chord connecting the ends of the curve was 15 miles per hour. The wind velocity and direction were obtained by means of a portable wind vane and an anemometer set up beside the test track. A summary of the conditions for each test is given in Table 2.

7. *The Selection of the Track.*—The primary consideration in the selection of the curves was to have them include as great a variety and range in degree of curvature as the circumstances would permit. When available, those curves were chosen which had at either end a long and comparatively level stretch of straight track, in order that the resistance on the curve and on the tangent might be measured simultaneously and, therefore, under like conditions of wind and weather. In three out of the seven cases, however, the straight track adjacent to the curve was, by reason of its construction or maintenance, or by virtue of the operating conditions which there prevailed, unsuitable for the purposes of the tests, and in these instances the tangent track was chosen elsewhere. In such cases the determination of tangent resistance was made as far as possible under conditions similar to those which obtained during the tests on the related curve. The curves chosen were fairly regular in curvature, and all the track on both the curves and the tangent sections was well ballasted.

8. *General Methods.*—By means of the data which were recorded during each run and which have been enumerated in Chapter III, it is possible to calculate the gross resistance offered to the motion of the car over a given track section. This gross resistance is composed of the resistance due to grade, that due to acceleration, that due to wind,* the net resistance on level straight track at uniform speed, and, on the curved track, the resistance due to curvature. The purposes of the tests require the elimination of the first three of these five elements of gross resistance. The grade and acceleration resistances may be easily eliminated by calculation, but the wind resistance is neither controllable nor to be eliminated by calculation from the data at hand. The elimination of wind resistance may, however, be accomplished by the method of making the tests, and with this end in view the following method of test was used.

Over each track section the car was run in one direction at a predetermined speed which was maintained as nearly uniform as possible. It was then immediately run over the same section at the same speed, but in the reverse direction. Where curved and tangent track

*Throughout the bulletin wind resistance is distinguished from the resistance due to still air, the latter being an inseparable part of inherent or net resistance.

were adjacent they were both included in each of these runs. This process was repeated at various speeds until enough data had been accumulated to define for this track section the relation between resistance and speed up to the maximum speed of operation. The whole group of these pairs of runs constitutes what is designated in the report as a test.

The wind in one case opposes and in the other helps the motion of the car, and each pair of such runs results, when grade and acceleration resistance have been eliminated, in two values of resistance; one value equal to net resistance* plus such resistance as was offered by the wind, the other equal to net resistance minus the resistance offered by the wind. In runs in which the direction of the wind was parallel to the direction of motion of the car, a properly determined mean between these two values is the net resistance itself with the influence of wind entirely eliminated. In runs in which the direction of the wind made an angle with the direction of motion of the car, only that portion of wind resistance due to the component of wind velocity parallel to the track would disappear from the mean value of resistance, and there would remain embodied in this mean† a certain resistance due to the increased wheel-flange friction caused by that component of wind velocity which is normal to the direction of motion of the car. All the resistance curves resulting directly from the tests represent the mean between paired values determined in the way just described. The curves themselves, therefore, define values of resistance in which there remains only that effect of the wind produced by its velocity component normal to the track; that is, they are in error by only a slight excess in flange friction. Under the low wind velocities which prevailed this error is small, and doubtless much less than the casual variations which occur in inherent resistance itself. These conclusions apply to the immediate results of the tests; that is, to the resistance-speed curves shown in Figs. 3 to 13, inclusive. For reasons stated in the next paragraph the error referred to does not, however, appear in the final results.

The simultaneous operation of the car over the curve and its adjacent tangent ensures that the resistances on the curve and on the tangent were obtained under practically identical wind conditions. Whatever error or excess in mean resistance arises from the normal component of wind velocity is, consequently, likewise identical on the

*As used in this connection the term net resistance is assumed to include on the curves the resistance due to curvature.

†The method of determining this mean is explained in Appendix II.

curve and on the tangent. Since, however, the final result sought, the resistance due to curvature, is the difference between the total resistance on the curve and the resistance on the tangent, this error, by the process of subtraction, disappears from the final results of the tests. In those cases in which tangent resistance had to be measured on track not adjacent to the corresponding curve, the wind conditions were nearly the same as during tests on the curve, and the same conclusion, therefore, holds in these instances also.

From the data recorded in the test car the gross resistance was first determined for each run over each track section. This was then corrected for acceleration by means of data provided by the car records, and next for grade resistance by reference to the track profiles. The methods of making these calculations are stated in Appendix II, together with further details concerning the car records and the test methods.

V. The Immediate Results of the Tests

The calculations made for each run result, for the track section under consideration, in a value of car resistance at a particular speed. For all the runs these resistance values, together with the corresponding speeds, are set forth in the tables given in Appendix III. Using these values as coördinates, the points shown in Figs. 3 to 13 have been plotted; each point defines the resistance-speed relation during one run, and the whole group of points in each figure characterizes this relation for a particular track section. By a method which is explained in Appendix II, a line has been drawn among the points of each of these figures which represents the mean resistance discussed in Chapter IV, and which in each case has been accepted as defining the relation existing between resistance and speed for the track section in question. Figs. 3 to 13, inclusive, constitute the immediate results of all the tests.

The points indicated by circles in these figures pertain to runs in which the wind opposed the motion of the car, while those represented as black dots pertain to runs in which the wind helped the car motion. The few cases in which there was no wind are represented by circles half filled in. Under the test procedure previously outlined, there should appear in each figure equal numbers of circles and dots. This condition, however, is not exactly met in any of these figures, because during the process of calculation a few points were rejected on account of discrepancies or inadequacy in the record. In general, however, the balance implied by the test procedure is substantially realized.

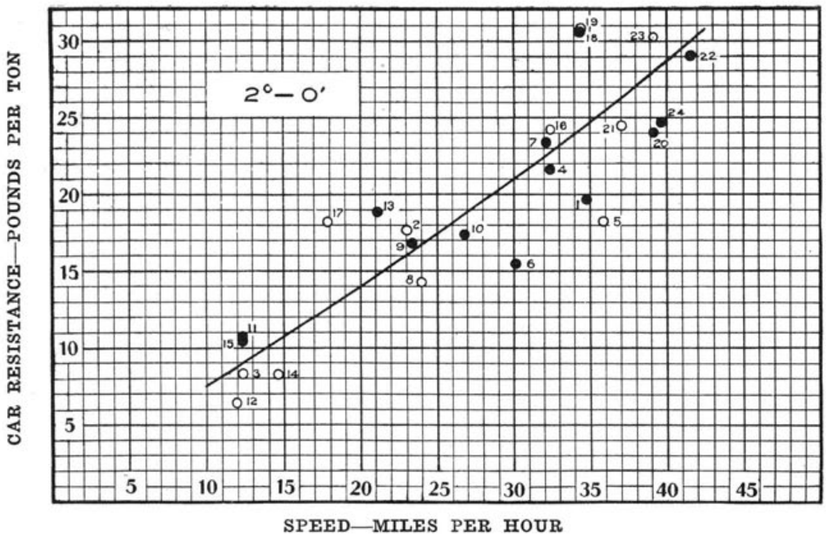

FIG. 3. THE RELATION OF RESISTANCE TO SPEED ON THE 2°–0′ CURVE

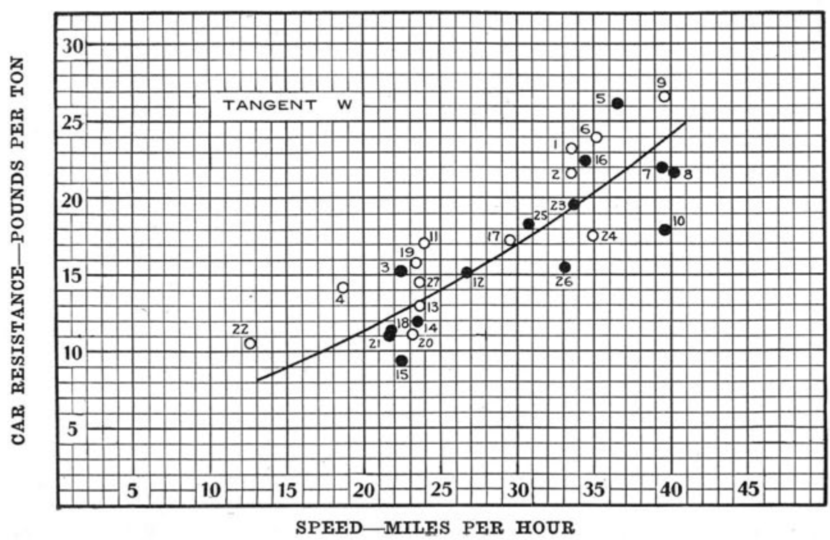

FIG. 4. THE RELATION OF RESISTANCE TO SPEED ON TANGENT W, WHICH PERTAINS TO THE 2°–0′ CURVE

There is considerable variation among the points in these figures and also a considerable variation from the mean defined by the curves. Some of this is due to the influence of wind, but even among the points

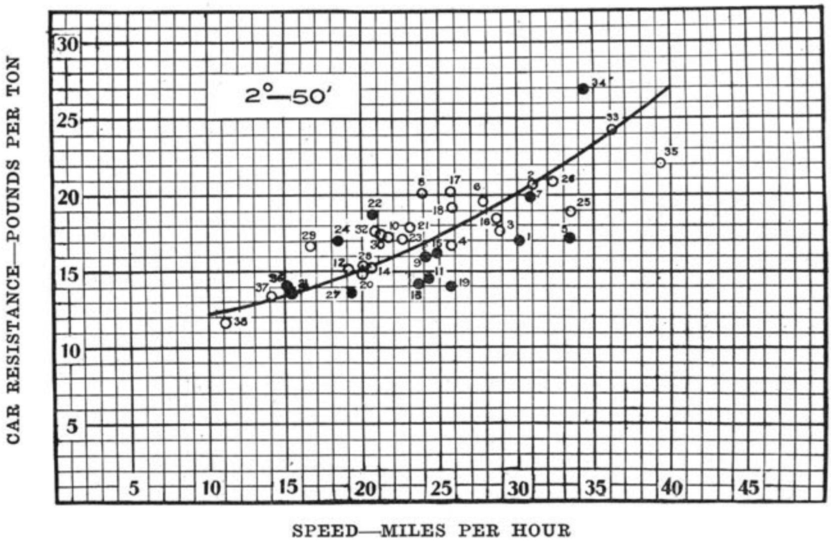

FIG. 5. THE RELATION OF RESISTANCE TO SPEED ON THE 2°–50′ CURVE

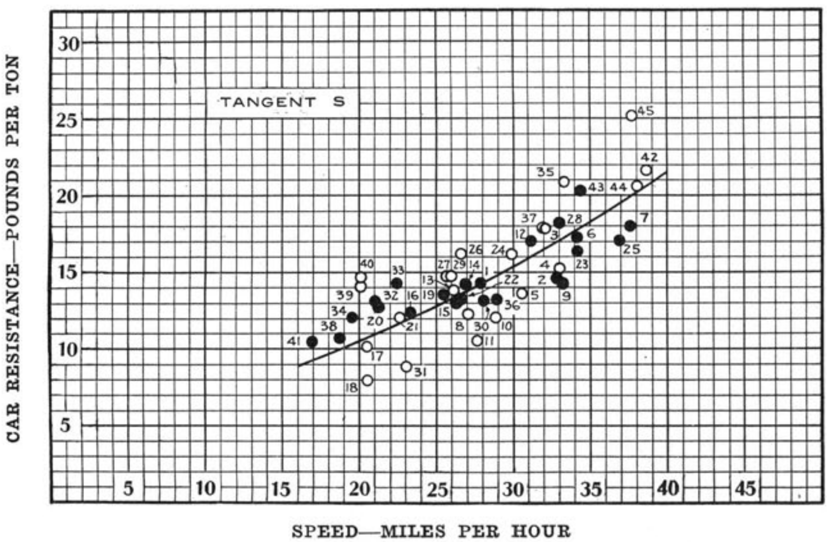

FIG. 6. THE RELATION OF RESISTANCE TO SPEED ON TANGENT S, WHICH PERTAINS TO THE 2°–50′ CURVE

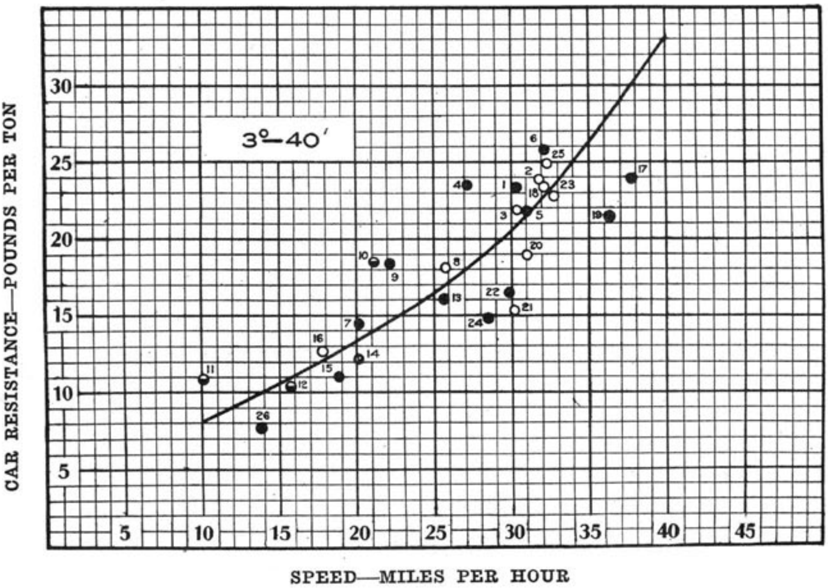

FIG. 7. THE RELATION OF RESISTANCE TO SPEED ON THE 3°–40′ CURVE

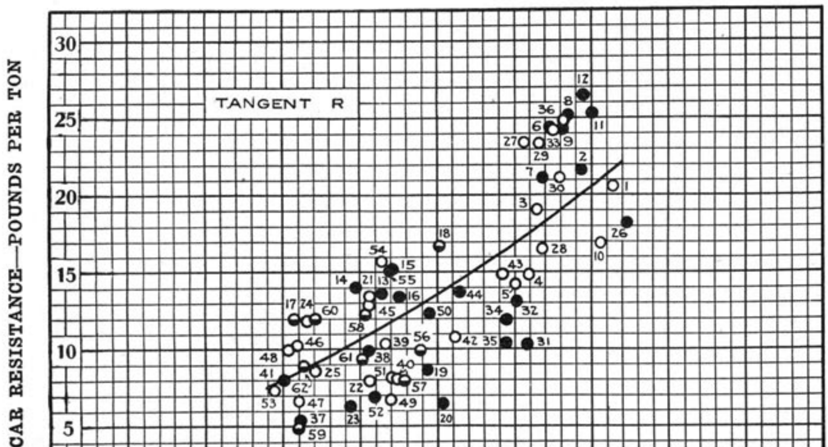

FIG. 8. THE RELATION OF RESISTANCE TO SPEED ON TANGENT R. WHICH PERTAINS TO THE 3°–40′, THE 5°–0′, THE 8°–0′, AND THE 14°–30′ CURVES

relating to like wind conditions there is similar disagreement. Part of this variation may be due to accumulated errors in instruments or in the calculations; but, since every precaution was taken to avoid such errors, they are undoubtedly rare and small in amount. The reasons for the differences referred to must be sought chiefly in the casual changes which occur in such elements of inherent resistance as flange friction, journal friction, and gear friction, and perhaps also in instantaneous changes in wind velocity and direction. The discordance shown is not greater than that usually encountered in measurements of car or train resistance.

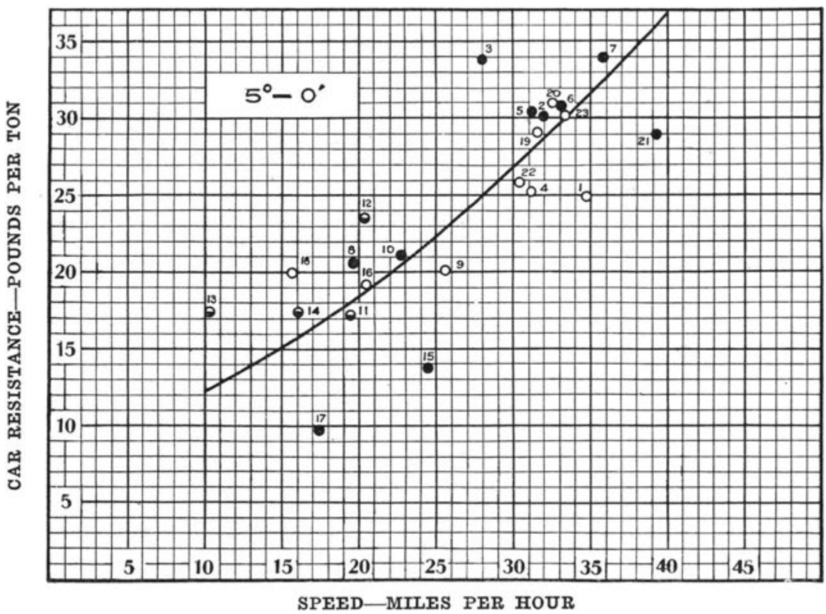

FIG. 9. THE RELATION OF RESISTANCE TO SPEED ON THE 5°–0′ CURVE

All the figures show a continuous increase of resistance with speed, except Fig. 13, applying to the 14°–30′ curve. In this case the resistance decreases until a speed of about 12½ miles per hour is reached and then increases as the speed is increased beyond this point. This peculiarity, which showed itself during the earliest runs on this curve, led to repetitions of the tests, but always with the same result, and Fig. 13 must be accepted as representing the facts in the case. The superelevation on this curve is 5.9 inches, and the component of car weight parallel to the plane of the rails amounts to about 5,800 pounds. It was assumed that perhaps this component, up to the

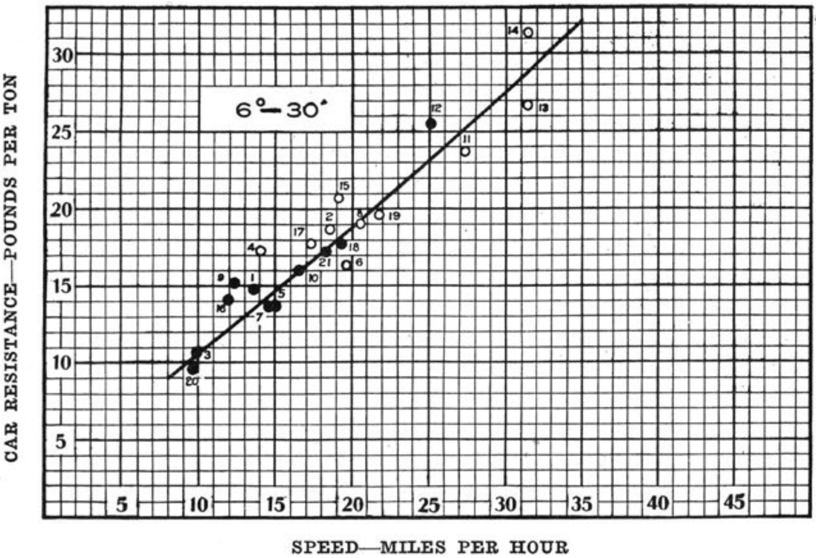

FIG. 10. THE RELATION OF RESISTANCE TO SPEED ON THE 6°–30′ CURVE

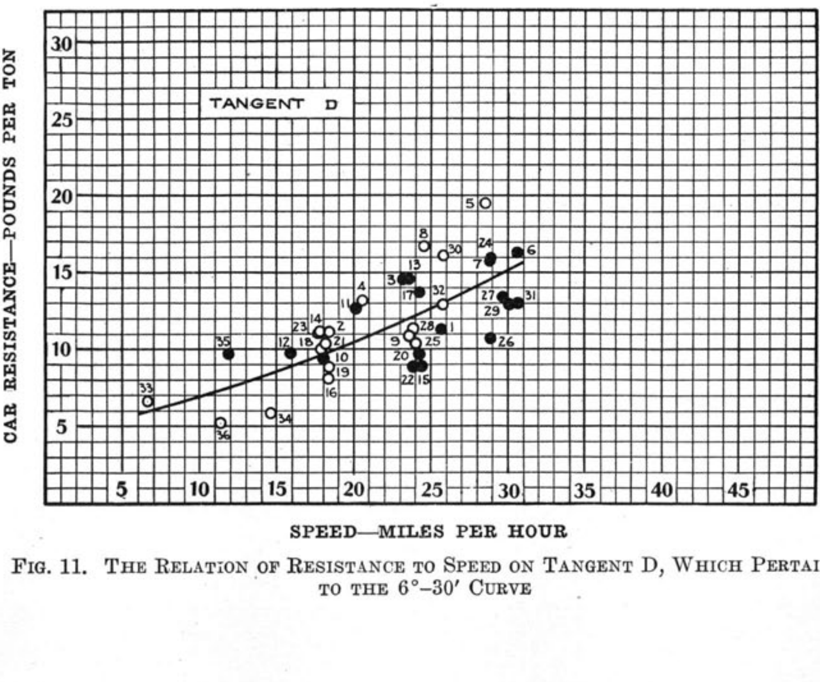

FIG. 11. THE RELATION OF RESISTANCE TO SPEED ON TANGENT D, WHICH PERTAINS TO THE 6°–30′ CURVE

speed of minimum resistance, had produced an excessive flange friction on the inner rail and had bound the trucks by keeping the inner side bearings in continuous contact. Since this component is opposed by the centrifugal force developed by the car in rounding the curve, these effects should continuously diminish as the centrifugal force increases up to the speed where this component of car weight equals the centrifugal force. Here the point of minimum resistance would

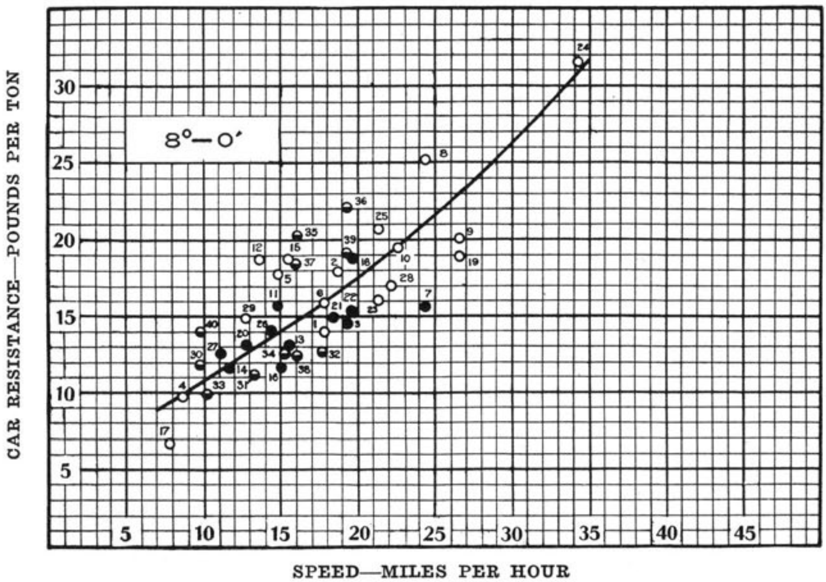

FIG. 12. THE RELATION OF RESISTANCE TO SPEED ON THE 8°–0′ CURVE

be expected to occur. Calculations for this case, however, show this speed to be at 16 instead of at 12½ miles per hour. This discrepancy is not in itself enough to discredit the assumption; but investigation of the other curves shows that this speed, at which the centrifugal force and the weight component are in balance, occurs at from 23 to 26 miles per hour, and, if the assumption were valid, similar minimum points should occur at these speeds in the resistance curves for these cases. No such minimum points occur, however, in any of the other figures, and the explanation on these grounds must consequently be abandoned. The condition presented in Fig. 13 is accepted as unexplained by the information at hand.

From the results shown in Figs. 3 to 13, grade and acceleration resistance have been eliminated, and, as previously explained, the effect of the component of wind velocity parallel to the track has also been eliminated; the influence of the normal component of wind velocity, on the other hand, is still embodied in these results. The resistance defined by the line drawn in Fig. 3, for example, which relates to the 2-degree curve, consequently comprises net resistance on level track at uniform speed, resistance due to the component of wind velocity normal to the track, and the resistance due to curvature. The resistance defined by the line in Fig. 4, which relates to the tan-

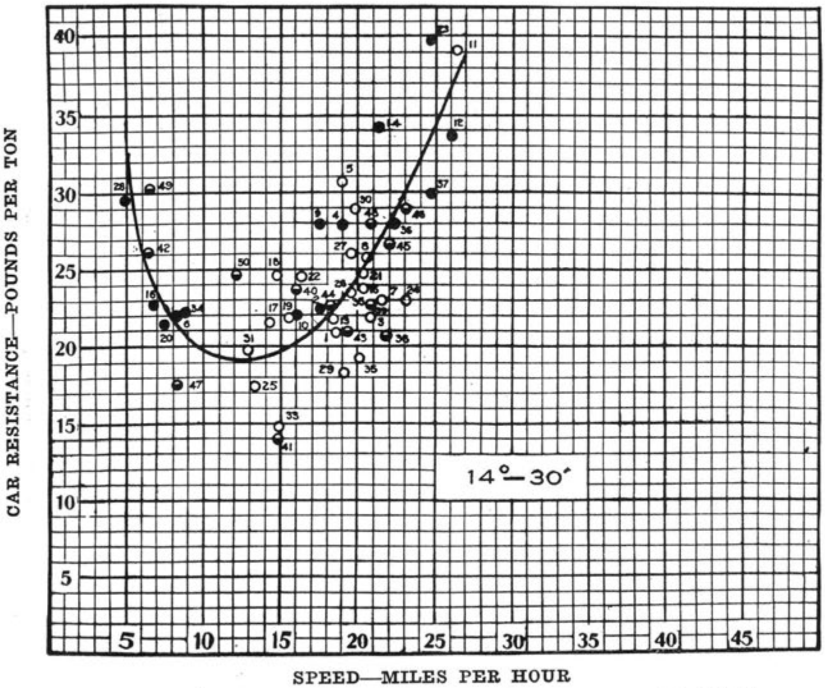

FIG. 13. THE RELATION OF RESISTANCE TO SPEED ON THE 14°–30′ CURVE

gent adjoining the 2-degree curve, comprises net resistance on level track at uniform speed and the resistance due to the normal component of wind velocity. The ordinates of the curves in these two corresponding figures, therefore, differ only by an amount equal to the resistance due to curvature on the 2-degree curve. Similar statements apply to the curves in Figs. 5 to 13.

In the further consideration of Figs. 3 to 13 it will be convenient to keep in mind their relationship. The 2°–0′, 2°–50′, 3°–40′, and 6°–30′ curves (Figs. 3, 5, 7, 10) have each their own tangent (Figs. 4, 6, 8, 11), the diagram for which immediately follows the diagram for the corresponding curve. The 5°–0′, 8°–0′, and 14°–30′ curves (Figs.

9, 12, 13) have all the same tangent as the 3°–40′ curve. The relation between these figures is as follows:

Fig. 3, the 2°–0′ curve, is used with Fig. 4, Tangent W.
Fig. 5, the 2°–50′ curve, is used with Fig. 6, Tangent S.
Fig. 7, the 3°–40′ curve, is used with Fig. 8, Tangent R.
Fig. 9, the 5°–0′ curve, is used with Fig. 8, Tangent R.
Fig. 10, the 6°–30′ curve, is used with Fig. 11, Tangent D.
Fig. 12, the 8°–0′ curve, is used with Fig. 8, Tangent R.
Fig. 13, the 14°–30′ curve, is used with Fig. 8, Tangent R.

VI. The Final Results of the Tests

9. *The Resistance Due to Curvature.*—The resistance-speed curves of Figs. 3 to 13, properly paired, are all brought together in Fig. 14 in which seven pairs of lines appear, one for each of the seven curves. The first pair of lines in Fig. 14 relates to the 2-degree curve, the upper line marked *C* shows the relation between resistance and speed on the curve, while the lower line marked *T* shows this relation on the adjacent tangent. These lines are reproduced from Figs. 3 and 4, respectively. Fig. 14 presents also six additional pairs of curves similarly marked pertaining to the six remaining curves, and all reproduced from Figs. 5 to 13.

As has been stated in Chapter V the difference between the ordinates of these pairs of lines at any speed is the value of curve resistance at that speed for the curve in question. For example, for the 2-degree curve (see Fig. 14) the resistance on the curve at 20 miles per hour is 14.0 pounds per ton, and the resistance on the tangent is 11.3 pounds per ton. The difference between these values, 2.7 pounds per ton, is the curve resistance at 20 miles per hour on the 2-degree curve. At speeds varying from 10 to 40 miles per hour the values of resistance on the curve, resistance on the tangent, and curve resistance have been thus determined for each of the seven curves and set forth in Table 3. This table summarizes, therefore, the direct results of the tests as presented in Figs. 3 to 14, inclusive, and it presents also the derived values of curve resistance whose determination was the immediate purpose of the tests. The values of curve resistance given in the table are accepted as the average values at the various speeds. As has been previously explained these values are nearly, if not quite, freed from any effect of wind.

10. *The Relation of Curve Resistance to Curvature.*—For each of the speeds in Table 3 there appears for each of the seven curves a

TABLE 3

VALUES OF RESISTANCE ON THE CURVE, RESISTANCE ON THE TANGENT, AND RESISTANCE DUE TO CURVATURE FOR EACH OF THE SEVEN CURVES AND AT VARIOUS SPEEDS. THESE VALUES ARE DERIVED DIRECTLY FROM FIGURES 3 TO 13 INCLUSIVE. THEY ARE EXPRESSED IN POUNDS PER TON

Curve	Speed—M.P.H.							
	10	15	20	25	30	35	40	
2°–0′	7.50	10.78	14.00	17.45	21.00	24.70	28.70	Res. on Curve
	6.95	9.00	11.30	13.93	16.88	20.25	24.15	" " Tang.
	0.55	1.78	2.70	3.52	4.12	4.45	4.55	Curve Res.
2°–50′	12.20	13.40	15.05	17.30	20.00	23.25	27.00	Res. on Curve
	6.95	8.55	10.44	12.75	15.30	18.21	21.50	" " Tang.
	5.25	4.85	4.61	4.55	4.70	5.04	5.50	Curve Res.
3°–40′	8.00	10.50	13.25	16.40	20.50	26.20	33.00	Res. on Curve
	5.80	8.02	10.60	13.45	16.70	20.47	24.50	" " Tang.
	2.20	2.48	2.65	2.95	3.80	5.73	8.50	Curve Res.
5°–0′	12.25	15.00	18.38	22.30	26.83	31.62	36.70	Res. on Curve
	5.80	8.02	10.60	13.45	16.70	20.47	24.50	" " Tang.
	6.45	6.98	7.78	8.85	10.13	11.15	12.20	Curve Res.
6°–30′	10.60	14.65	18.75	23.00	27.50	32.05	36.55	Res. on Curve
	6.87	8.62	10.55	12.65	15.00	17.80	20.95	" " Tang.
	3.73	6.03	8.20	10.35	12.50	14.25	15.60	Curve Res.
8°–0′	10.80	14.05	17.55	21.60	26.25	31.75		Res. on Curve
	5.80	8.02	10.60	13.45	16.70	20.47		" " Tang.
	5.00	6.03	6.95	8.15	9.55	11.28		Curve Res.
14°–30′		19.70	24.60	34.45				Res. on Curve
		8.02	10.60	13.45				" " Tang.
		11.68	14.00	21.00				Curve Res.

value of curve resistance. At 15 miles per hour, for example, there are given in the third column of the table seven values of curve resistance: 1.78 pounds per ton on the 2-degree curve, 4.85 pounds per ton on the 2°–50′ curve, and so on. These values are plotted in the second diagram of Fig. 15 as seven points which show the relations existing during the tests between curve resistance and curvature at the speed of 15 miles per hour. Using the remaining values from Table 3, similar groups of points have been plotted in Fig. 15 which show this relation at the other speeds.

An inspection of the points in Fig. 15 discloses at all speeds a fairly regular relationship between curve resistance and curvature. With perhaps the exception of the first, pertaining to 10 miles per hour, these diagrams show for each speed an increase in curve resistance which is approximately directly proportional to the increase in curvature. There have been drawn among the points in these diagrams straight lines which have been accepted as defining the average of the relations between curve resistance and curvature represented by the points derived from the individual tests. For obvious reasons these lines are all made to pass through the origin of coördinates.

At speeds up to 25 miles per hour the points in Fig. 15 which relate to the 2°–50′ and to the 5-degree curves lie above the mean values represented by the lines, while at higher speeds they correspond closely with the mean. At speeds up to 25 miles per hour the points for the 3°–40′ and for the 8-degree curves correspond well with the mean, but

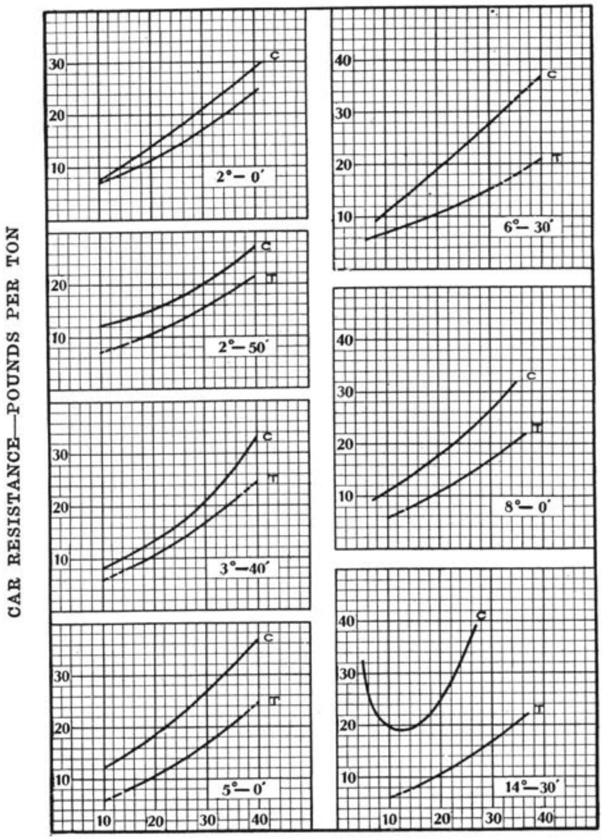

FIG. 14. THE RELATION OF RESISTANCE TO SPEED ON ALL THE CURVES AND ON THEIR CORRESPONDING TANGENTS

lie below it at higher speeds. The test data offer a probable explanation of these variations only in the case of the 5-degree curve, whose poorer construction might be assumed partially to account for its high resistance. In the other cases, however, no such explanation is available. In drawing the lines in Fig. 15 due consideration was given to the relative weight of the points there plotted; that is, to the number of tests represented by the various points.

The lines drawn in Fig. 15 are brought together and reproduced to a larger scale in Fig. 16, in which, as before, each line defines for a particular speed the average or general relation between curve resistance and curvature. The whole group defines this relation for the

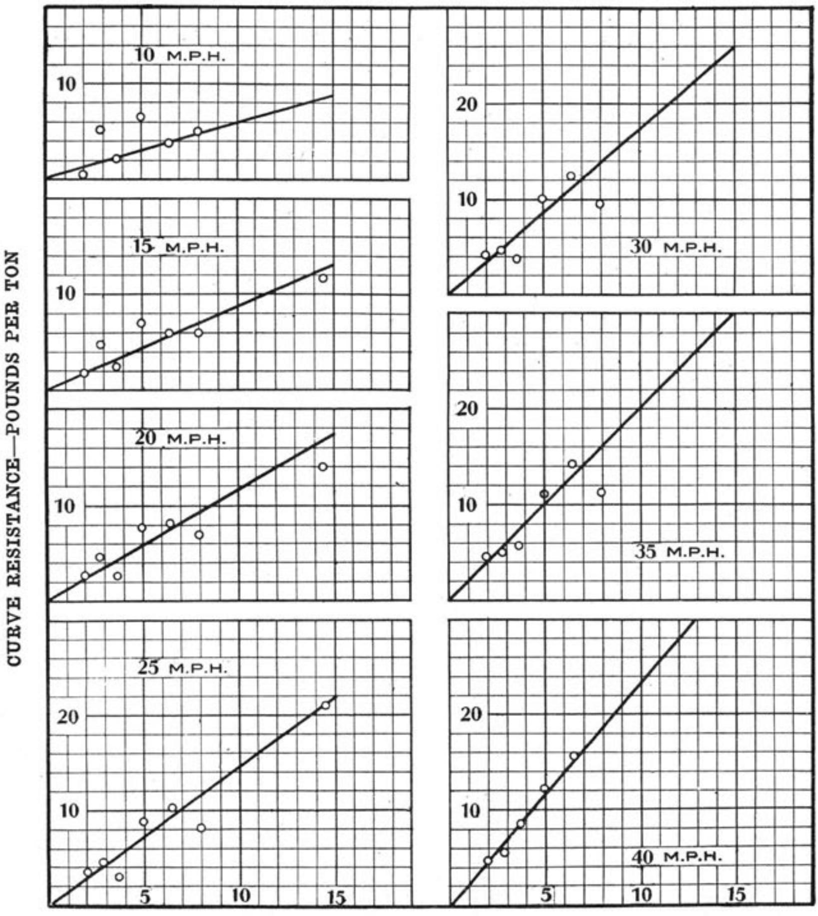

FIG. 15. THE RELATION BETWEEN CURVE RESISTANCE AND CURVATURE AT VARIOUS SPEEDS

entire series of tests. For each speed curve resistance increases in direct proportion with the curvature. At 15 miles per hour, for example, the curve resistance expressed in pounds per ton is 4.35, 8.70, and 13.05, for curves of 5, 10, and 15 degrees, respectively. This implies at this speed a constant curve resistance of 0.87 pounds, when expressed in pounds per ton *per degree*. The direct proportionality between curve resistance and curvature exhibited in Fig. 16 is in accord with the results of previous experiments and with current practice.

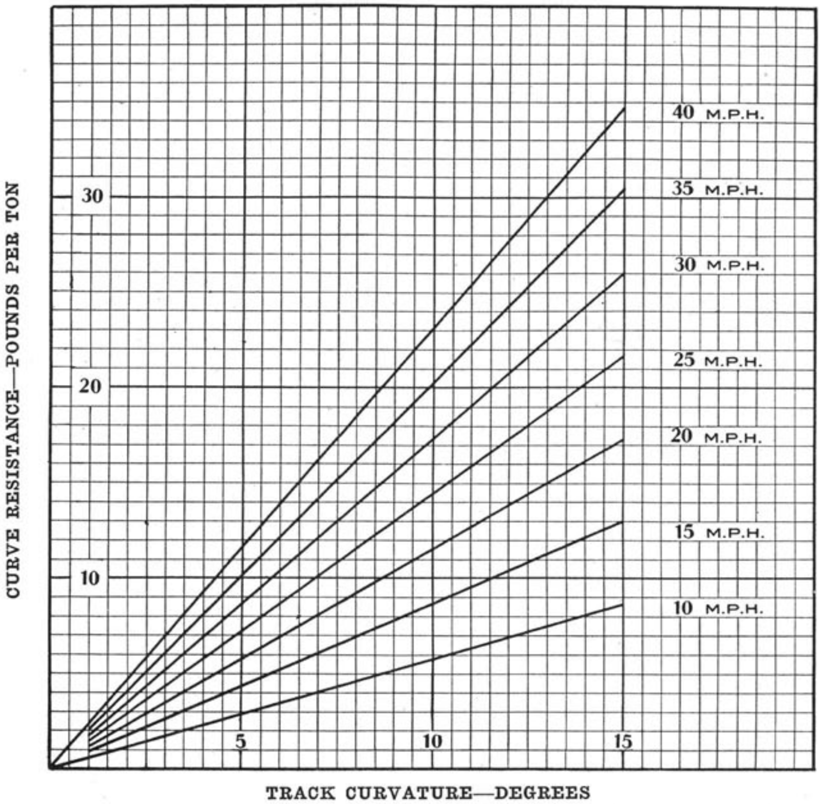

FIG. 16.—THE RELATION BETWEEN CURVE RESISTANCE AND CURVATURE, AT VARIOUS SPEEDS. THE LINES SHOWN ARE ASSEMBLED FROM FIG. 15

11. *The Relation of Curve Resistance to Speed.*—The lines of Fig. 16 present values of curve resistance for seven speeds which cover the speed range of the experiments. The figure offers, therefore, a means of determining the general relation between curve resistance and speed. If in Fig. 16 the ordinates of the seven lines are measured at a curvature of 5 degrees, seven values of curve resistance are obtained: 2.90, 4.35, 5.80, 7.25, 8.70, 10.15, and 11.60 pounds per ton, which correspond respectively to speeds of 10, 15, 20, 25, 30, 35, and 40 miles per hour. These corresponding values of resistance and speed are plotted in Fig. 17 as the seven points there shown for a curvature of 5 degrees. These points are found to lie on a straight line as shown

in the figure. The two other straight lines corresponding to 10 degrees and 15 degrees curvature were obtained by a like process. That the lines connecting the points in Fig. 17 are straight is due, of course, to the relation which exists between the lines in Figs. 15 and 16; that is, to their relative slope. It is proper to explain that the lines originally drawn in Figs. 15 and 16 did not precisely satisfy this condition in the derived lines of Fig. 17. They did so so nearly, however, that, for the sake of the resulting simplicity, it seemed justifiable to modify them, and the slopes of a few of the lines in Fig. 15

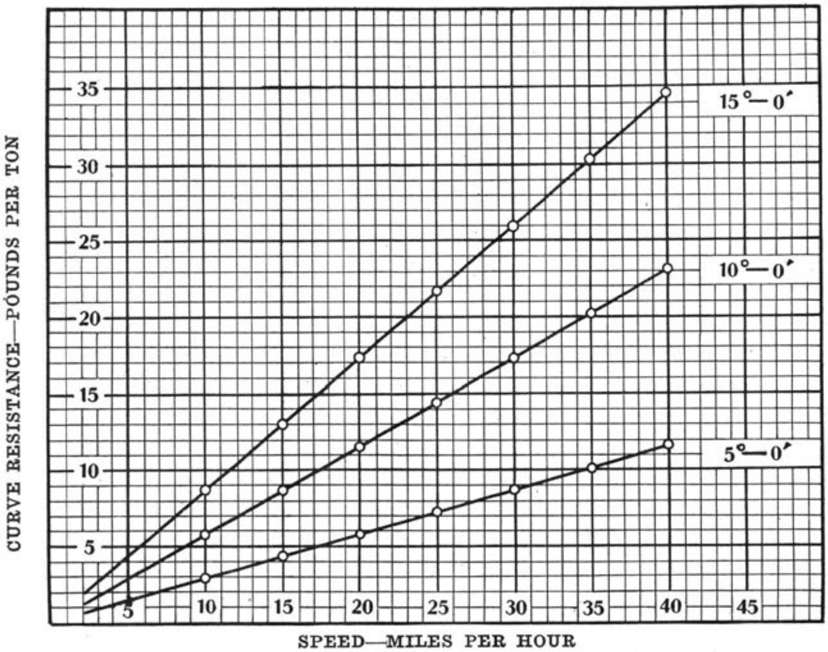

FIG. 17.—THE RELATION BETWEEN CURVE RESISTANCE AND SPEED FOR CURVES OF VARIOUS CURVATURES

were adjusted so that the lines connecting the derived points in Fig. 17 would be straight. An inspection of Fig. 15 shows, it is believed, that this adjustment has done no violence to the experimental data. It has, on the other hand, resulted in a simplicity of the relations shown in Fig. 17 and of the formula given beyond, which seems amply to warrant it.

The lines drawn in Fig. 17 apply to curvatures of 5, 10, and 15 degrees, and by the process above explained similar lines for other rates of curvature might have been included. Fig. 17 is derived directly from Fig. 16 and, like it, presents the average results of the whole research. From Fig. 17 it is obvious that for constant curvature, curve resistance was directly proportional to speed; that is, on any given curve the resistance due to curvature varied in these experiments directly with the speed. On the 5-degree curve, for example, its average value at 10 miles per hour was 2.90 pounds per ton, and at 30 miles per hour 8.70 pounds per ton, three times as much. In previous experiments there has been occasional evidence that curve resistance might be greater at high than at low speeds, although in some discussions of the subject the contrary is held to be true. Neither opinion has had definite or adequate support, and there has hitherto been no conclusive experimental evidence of any definite relation be-

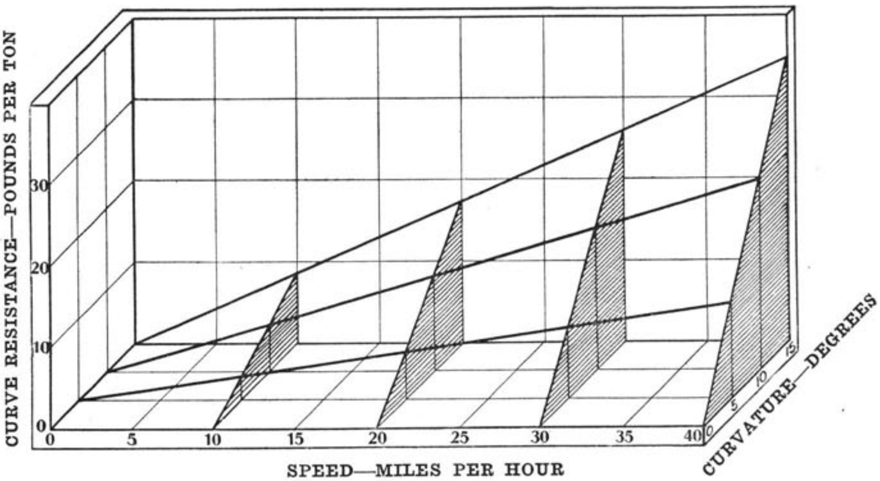

FIG. 18. THE CONCURRENT RELATIONS BETWEEN CURVE RESISTANCE, SPEED, AND CURVATURE

tween curve resistance and speed. In practice the influence of speed has been generally ignored.

12. *The Concurrent Relations of Curve Resistance, Curvature, and Speed.*—For the car used in the tests curve resistance varies directly with both curvature and speed, the rate of variation in each case being as shown in Figs. 16 and 17. These two figures have been combined in the diagram of Fig. 18, which exhibits the concurrent relations of the three variables. These relations are also defined by the equation:

$$R_c = 0.058\ S\ C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

in which R_c is the curve resistance on level track at uniform speed expressed in pounds per ton, S is the speed in miles per hour, and C is the degree of curve. This formula represents exactly the mean relations between curve resistance, speed, and curvature, which are defined by the lines drawn in Figs. 15, 16, and 17, and it embodies, consequently, the generalized results of all the tests.

By means of Formula 1 there have been calculated the values of curve resistance which are presented in Table 4. The values are given for curves varying from 1 to 15 degrees and for speeds ranging from 10 to 40 miles per hour, corresponding approximately to the range in curvature and in speed during the tests. Inspection of Table 4 shows curve resistance to vary from 0.58 pounds per ton on a 1-

TABLE 4

VALUES OF CURVE RESISTANCE AT VARIOUS RATES OF CURVATURE AND AT VARIOUS SPEEDS. THESE VALUES ARE DERIVED FROM FORMULA 1 AND REPRESENT THE FINAL RESULTS OF THE TESTS

Curvature Degrees	Curve Resistance — Pounds Per Ton							Curvature Degrees
	Column Headings Indicate Speed in Miles Per Hour							
	10	15	20	25	30	35	40	
1	0.58	0.87	1.16	1.45	1.74	2.03	2.32	1
2	1.16	1.74	2.32	2.90	3.48	4.06	4.64	2
3	1.74	2.61	3.48	4.35	5.22	6.09	6.96	3
4	2.32	3.48	4.64	5.80	6.96	8.12	9.28	4
5	2.90	4.35	5.80	7.25	8.70	10.15	11.60	5
6	3.48	5.22	6.96	8.70	10.44	12.18	13.92	6
7	4.06	6.09	8.12	10.15	12.18	14.21	16.24	7
8	4.64	6.96	9.28	11.60	13.92	16.24	18.56	8
9	5.22	7.83	10.44	13.05	15.66	18.27	20.88	9
10	5.80	8.70	11.60	14.50	17.40	20.30	23.20	10
11	6.38	9.57	12.76	15.95	19.14	22.33	25.52	11
12	6.96	10.44	13.92	17.40	20.88	24.36	27.84	12
13	7.54	11.31	15.08	18.85	22.62	26.39	30.16	13
14	8.12	12.18	16.24	20.30	24.36	28.42	32.48	14
15	8.70	13.05	17.40	21.75	26.10	30.45	34.80	15

degree curve at 10 miles per hour to 34.8 pounds per ton on a 15-degree curve at 40 miles per hour. Expressed in pounds per ton *per degree of curve,* curve resistance varies from 0.58 at 10 miles per hour to 2.32 at 40 miles per hour. Although for the sake of exact correspondence between the table and Formula 1 and Figs. 16 and 17 the tabular values are given to the second decimal place, it should not be assumed that the last figures are significant.

13. *Conclusion.*—The final results of the tests are summarized in Formula 1 and in Table 4, which present mean or average values of curve resistance at various rates of curvature and at various speeds. They apply to the particular car tested under conditions of weather and track which have been fully defined. They are useful for predicting the curve resistance to be expected from similar cars running under like conditions, but if they are so used these conditions should be borne in mind. It is probable that the formula applies to cars

whose weight varies considerably from the weight of the test car; but if the truck wheel base is materially different, the formula should be used with caution. Its use should probably not be extended to speeds much in excess of 40 miles per hour. How far the formula is applicable beyond a curvature of 15 degrees cannot be stated, but it is significant that it represents the actual test results on the 14½-degree curve with considerably greater accuracy than on some of the curves of lower curvature. Whether the results apply closely to other than self-propelled cars is open to question.

Formula 1 and Table 4, as well as Figs. 16 and 17, are generalizations which define only average values of curve resistance. They are derived by processes which preclude their precise agreement even with all the test values themselves, as is disclosed by an examination of Fig. 15. Consequently, in an individual case their use in predicting curve resistance cannot reasonably be expected to give results which correspond with the actual resistance any more exactly than do the averages upon which these generalizations rest correspond with the results of the individual tests; no closer correspondence, that is, should be expected than exists between the mean curves and the points of Figs. 3 to 13 which are fundamental to the whole process. Such limitations are common to all generalizations of train or car resistance and do not seriously impair their usefulness for the purposes for which they are generally employed.

Bulletin 74 of the Enginering Experiment Station gives the results of experiments in which the resistance of this car was determined when running on level tangent track at uniform speed. This resistance is given by the formula:

$$R_t = 4 + 0.222S + 0.00181\frac{A}{W}S^2 \quad \ldots\ldots\ldots\ldots\ldots (2)$$

By combining this equation with Formula 1 above, we obtain for this car the following formula which gives its total resistance when running on a level curve at uniform speed.

$$R = R_t + R_c = 4 + 0.222S + 0.00181\frac{A}{W}S^2 + 0.058\ SC \ldots\ldots (3)$$

In Formula 3, R is the total resistance expressed in pounds per ton, S the speed in miles per hour, C the curvature in degrees, A the cross-sectional area of the car in square feet, and W its weight in tons. If the car is on a grade and its speed changing, the usual corrections for grade and acceleration must be applied to Formula 3.

APPENDIX I

The Track

Information regarding the track has been given in Chapter III. This appendix is intended to supplement Chapter III by the presentation of further details concerning the track on the curves.

The results of the track surveys are presented in Figs. 19 to 25, inclusive, in which are given for each curve the profile on each rail, elevations having been taken every 100 feet; the superelevation of the outer rail, also at 100-foot intervals; and the degree of curvature. For the 2°–0′, 2°–50′, 3°–40′, and 5°–0′ curves the curvature was determined at 50-foot intervals by measuring mid-ordinates, for the 6°–30′ curve it was determined at 50-foot intervals by measuring deflection angles, and for the 8°–0′ and 14°–30′ curves by measuring deflection angles at intervals of 25 feet. Each curve has been designated by the average of these values of curvature. Distances are shown in the figures by means of stations which were 100 feet apart. In the tables given in Appendix III the section limits are defined by trolley line pole numbers. The location of each pole is indicated on the alignment diagrams of Figs. 19 to 25 by means of a short dash beside which is recorded its distance in feet from the preceding station. For example, Pole 20, Fig. 19, is located 80 feet from Station 23.

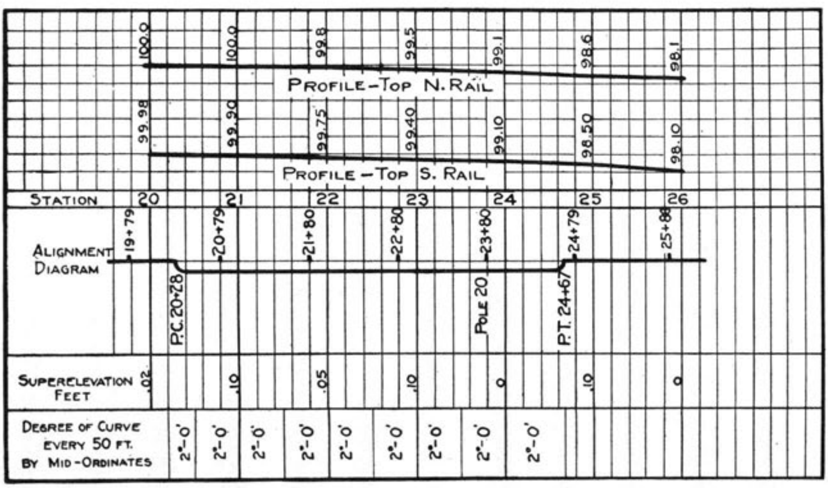

Fig. 19. Profile and Alignment Diagram of the Track on the 2°–0′ Curve

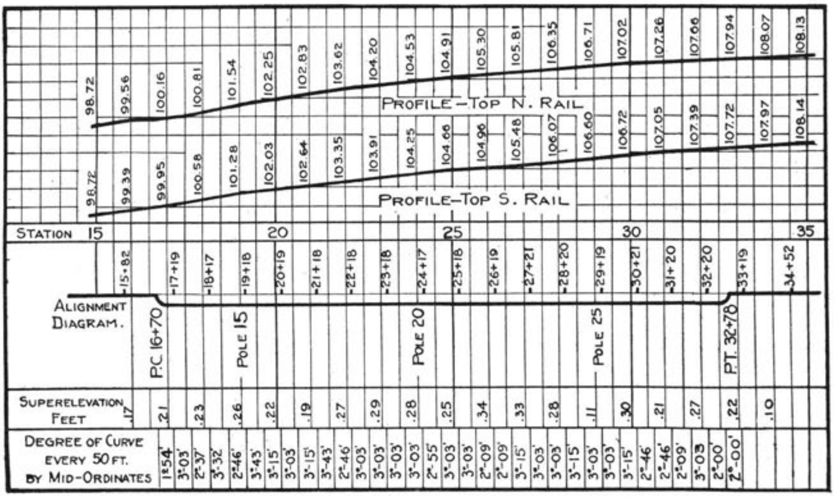

FIG. 20. PROFILE AND ALIGNMENT DIAGRAM OF THE TRACK ON THE 2°–50′ CURVE

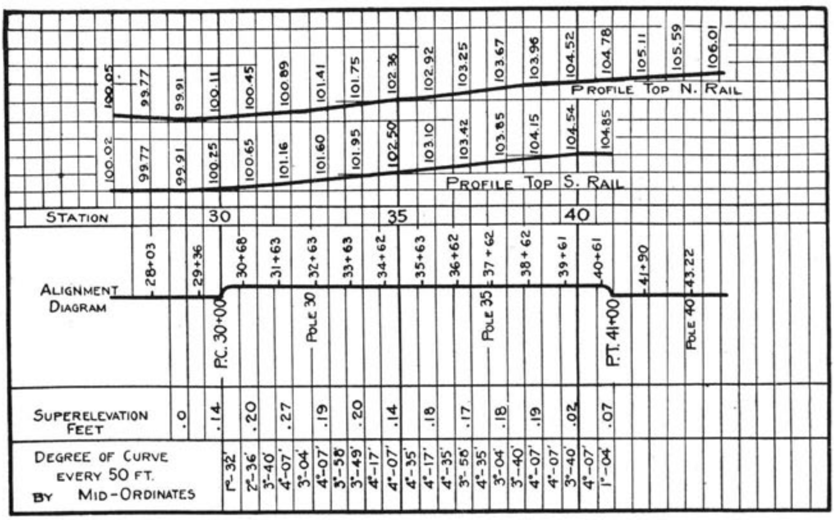

FIG. 21. PROFILE AND ALIGNMENT DIAGRAM OF THE TRACK ON THE 3°–40′ CURVE

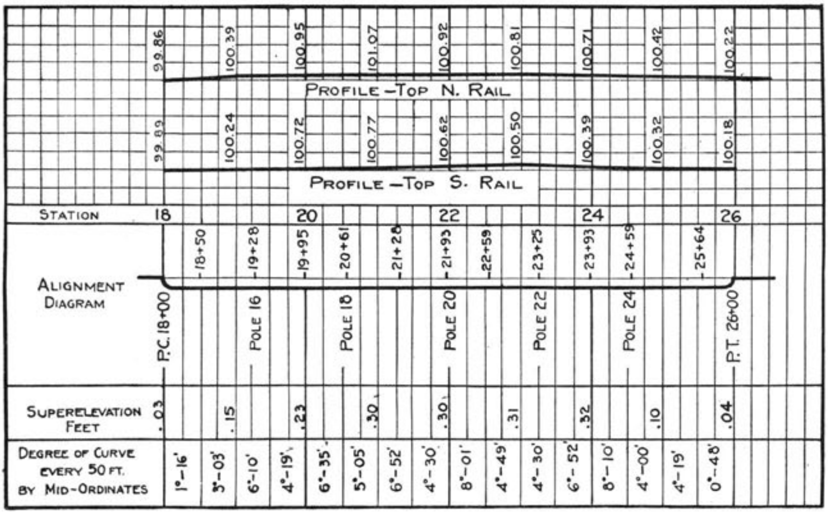

FIG. 22. PROFILE AND ALIGNMENT DIAGRAM OF THE TRACK ON THE 5°–0′ CURVE

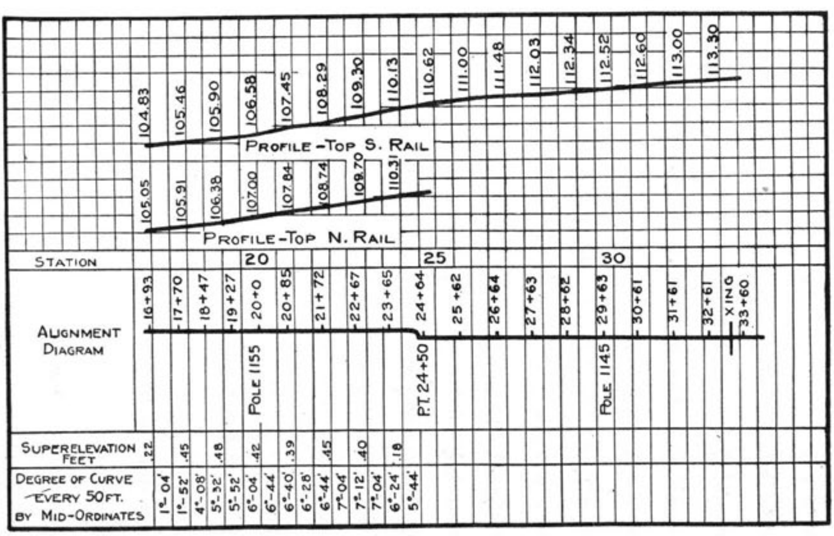

FIG. 23. PROFILE AND ALIGNMENT DIAGRAM OF THE TRACK ON THE 6°–30′ CURVE

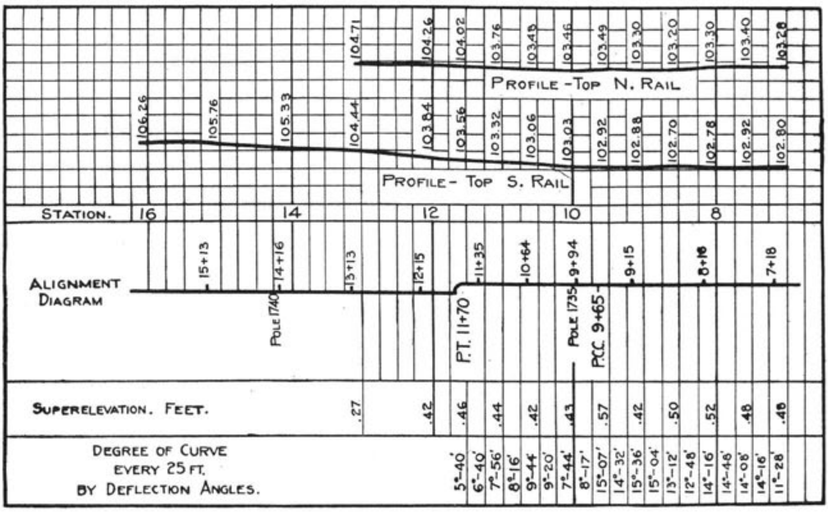

FIG. 24. PROFILE AND ALIGNMENT DIAGRAM OF THE TRACK ON THE 8°–0′ CURVE

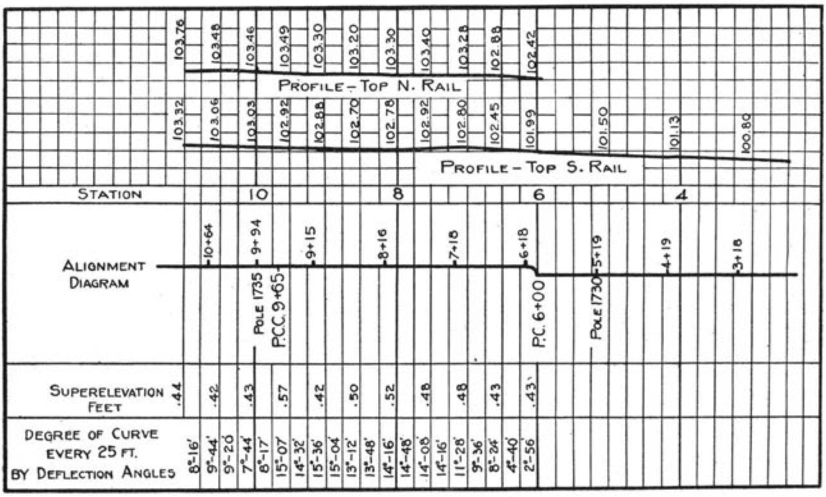

FIG. 25. PROFILE AND ALIGNMENT DIAGRAM OF THE TRACK ON THE 14°–30′ CURVE

APPENDIX II

Test Methods and Methods of Calculation

This appendix is intended to supplement what has been stated in Chapter IV concerning the test methods and to present also certain details concerning the methods used in calculating the values of resistance and speed which constitute the immediate results of the tests.

Methods Used in Producing the Curves of Figs. 3 to 13.—As has been previously explained, the points in Figs. 3 to 13 occur in pairs, one point in each pair relating to a run in which the wind helped the car, the other to a run in which the wind opposed the car. The curves drawn in the figures define the mean of the values represented by these points. If wind resistance varied directly with speed, an arithmetical mean or average of the values represented by the points would define a point on this curve. Since wind resistance varies, however, about as the square of the speed, a mere arithmetical mean of these values does not serve exactly to define the mean curve; but this mean must be established by another and somewhat more elaborate process. Such a process has been set forth on page 34 of Bulletin 74 of the University of Illinois Engineering Experiment Station. When the wind velocities are low, the difference between the curves defined by taking an arithmetical mean and by this more exact process is negligible. During these tests the wind velocities were generally low, and the points representing runs with and against the wind are generally closely interwoven. For this reason the mean curves in Figs. 3 to 13 were all produced by taking the arithmetical mean of the resistance values represented by the points in the figures. Preliminary to drawing these curves, the average coördinates of various groups of points in each figure were determined, and these average coördinates were then plotted as auxiliary points through which the curve was passed as nearly as possible.

Methods of Calculation.—The data recorded during these tests are enumerated in Chapter III. All the data which pertained directly to car operation were graphically recorded upon the test car charts. A portion of the chart obtained during Test 121 is reproduced as Fig. 26, upon which the section limits and certain explanatory lettering have been added.

When the track sections were surveyed, markers were placed beside the track at the ends of the curves and tangents, and during a test the positions of these numbered markers were recorded upon the chart. In this way the chart made during a run over the test track was divided into two or more sections as illustrated by Fig. 26. That

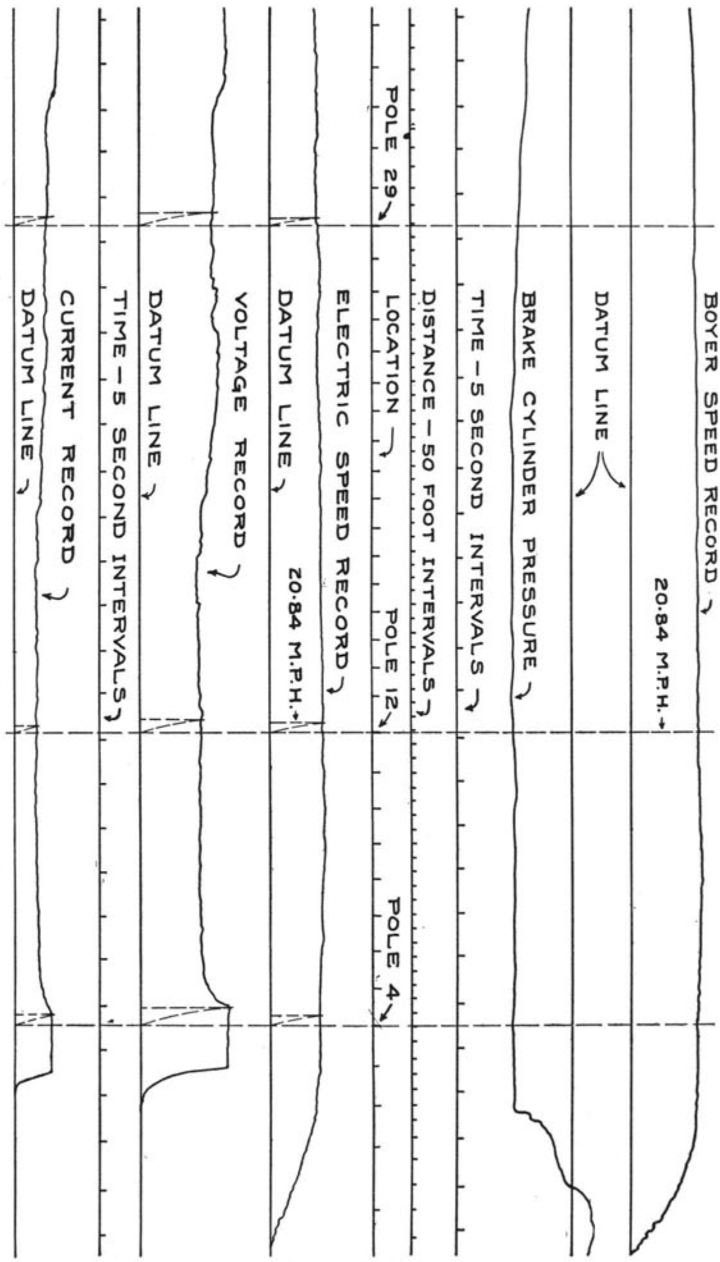

FIG. 26. REPRODUCED FROM A PORTION OF ONE OF THE TEST CAR CHARTS

part of the chart lying between the poles numbered 12 and 29 was produced during a run over a section of curved track, while that portion lying between the poles numbered 4 and 12 was made during a run over a section of tangent track. In making the calculations only those chart sections were considered over which there were no brake applications, no large variation of the current or voltage from the average value, and no large difference in the speed of the car. It has been found desirable to choose both track and chart sections so that the energy consumed by grade and acceleration will be as small as possible, and the errors in their calculation will have slight effect on the accuracy of the values of average net car resistance. When the variation in speed is large the energy required to produce acceleration is alone frequently greater than that required to overcome all other resistances combined. In all the tests reported in this bulletin the variations in speed in passing the track sections have exceeded 2 miles per hour in only 11 per cent of the total number of resistance determinations, and in only 3 cases out of 392 has this speed variation exceded 5 miles per hour. The maximum variation over any section was less than 10 miles per hour.

The result desired from each chart section is a value of average net car resistance. These values are given in Column 18 of Tables 5 to 11 in Appendix III. Full explanations of the significance of the various items in these tables and of the methods by which they were derived are presented in Appendix II of Bulletin 74 of the Engineering Experiment Station.

APPENDIX III

The Immediate Results of the Tests

This appendix presents in tabular form the fundamental data, some of the intermediate results, and the final values of car resistance and speed for each of the curves. The corresponding data for tangents D, W, S, and R, are given in Tables 9, 10, 11, and 12, respectively, of Bulletin 74 of the Engineering Experiment Station. The items in these tables have all been derived by the processes explained in Appendix II. The points in Fig. 3 to 13 were plotted by using as coördinates the values of resistance and speed which appear in Columns 18 and 19 of these tables.

TABLE 5

THE IMMEDIATE RESULTS OF THE TESTS ON THE 2°–0′ CURVE, GIVING THE RESULTS OF RESISTANCE AND SPEED USED IN PRODUCING FIG. 3

1	2	3	4	5	6	7	8	9
				Grade			Motor Data	
Item No.	Test No.	Wind Opposing or Helping	Section Limits Trolley Line Pole Numbers	Rise or Fall Over Section +Up —Down	Length of Track Section	Time to Run Over Section	Number in Use and Connection *	Efficiency of Motors and Gears
		O or H		Feet	Feet	Sec.		Per cent
1	124	H	16–21	—1.47	500	9.8	4M	73.1
2	123	O	21–16	+ "	"	14.8	4S	73.0
3	123	O	21–16	+ "	"	27.6	"	70.0
4	124	H	16–21	— "	"	10.5	4M	72.2
5	123	O	21–16	+ "	"	9.5	"	81.4
6	124	H	16–21	— "	"	11.3	"	77.6
7	124	H	16–21	— "	"	10.6	"	69.8
8	123	O	21–16	+ "	"	14.2	4S	71.5
9	124	H	16–21	— "	"	14.6	"	67.1
10	117	H	21–16	+ "	"	12.7	"	77.9
11	124	H	16–21	— "	"	27.6	"	64.7
12	123	O	21–16	+ "	"	28.6	"	66.5
13	124	H	16–21	— "	"	16.1	"	72.7
14	123	O	21–16	+ "	"	23.3	"	68.4
15	124	H	16–21	— "	"	27.6	"	63.8
16	118	O	16–21	— "	"	10.5	4M	83.2
17	118	O	16–21	— "	"	19.1	4S	76.7
18	117	H	21–16	+ "	"	9.9	4M	85.2
19	118	O	16–21	— "	"	9.9	"	85.7
20	117	H	21–16	+ "	"	8.7	"	85.0
21	118	O	16–21	— "	"	9.2	"	85.6
22	117	H	21–16	+ "	"	8.2	"	84.3
23	118	O	16–21	— "	"	8.7	"	84.4
24	117	H	21–16	+ "	"	8.6	"	84.5

*S = Series-Multiple. M = Multiple.

TABLE 5 (Continued)

THE IMMEDIATE RESULTS OF THE TESTS ON THE 2°–0′ CURVE, GIVING THE RESULTS OF RESISTANCE AND SPEED USED IN PRODUCING FIG. 3

10	11	12	13	14	15	16	17	18	19
	Speed				Energy Imparted to the Car				
Item No.	At Entrance to the Section	At Exit from the Section	Average Voltage	Average Current	By the Current	By the Change in Kinetic Energy	By the Grade	Net Car Resistance	Average Speed Over the Section
	M.P.H.	M.P.H.	Volts	Amp.	Ft. Lb.	Ft. Lb.	Ft. Lb.	Lb. per Ton	M.P.H.
1	33.84	33.84	358	103.0	194820	0	+83420	19.61	34.79
2	23.40	22.50	270	57.6	247840	+84690	— "	17.56	23.03
3	10.80	11.34	142	55.7	225410	—24510	— "	8.28	12.35
4	32.94	32.76	354	100.0	197920	+24240	+ "	21.54	32.47
5	33.66	33.66	445	134.8	342130	0	— "	18.23	35.88
6	29.70	30.96	378	119.6	292370	—156690	+ "	15.44	30.17
7	32.94	32.40	342	94.3	175980	+72330	+ "	23.38	32.16
8	23.58	22.86	268	53.9	216320	+68550	— "	14.20	24.01
9	23.04	23.04	229	46.8	154830	0	+ "	16.79	23.35
10	27.00	26.10	592	53.0	228960	+97010	—82610	17.32	26.84
11	11.16	12.78	121	46.6	148550	—79510	+83420	10.75	12.35
12	11.34	11.34	126	49.4	174630	0	— "	6.43	11.92
13	19.98	20.70	245	57.6	243600	—60040	+ "	18.82	21.17
14	14.40	14.22	157	51.1	188650	+10560	— "	8.16	14.64
15	10.80	12.42	122	45.4	143890	—77110	+ "	10.59	12.35
16	32.04	33.48	470	148.4	449390	—191530	+82610	24.23	32.47
17	18.18	19.08	405	55.1	241150	—68070	+ "	18.20	17.85
18	35.82	36.18	541	168.4	566700	—52620	— "	30.71	34.43
19	34.02	36.00	552	182.8	631350	—281440	+ "	30.78	34.43
20	40.14	40.68	592	157.4	508190	—88590	— "	23.99	39.18
21	36.36	38.34	573	168.5	560760	—300250	+ "	24.42	37.05
22	42.48	42.12	586	143.6	429000	+61830	— "	29.05	41.57
23	39.60	40.32	562	150.8	458950	—116810	+ "	30.23	39.18
24	39.96	40.14	565	151.4	458440	—29270	— "	24.67	39.64

TABLE 6

THE IMMEDIATE RESULTS OF THE TESTS ON THE 2°–50′ CURVE, GIVING THE RESULTS OF RESISTANCE AND SPEED USED IN PRODUCING FIG. 5

1	2	3	4	5	6	7	8	9
							Motor Data	
Item No.	Test No.	Wind Opposing or Helping	Section Limits — Trolley Line Pole Numbers	Grade — Rise or Fall Over Section — +Up —Down	Length of Track Section	Time to Run Over Section	Number in Use and Connection *	Efficiency of Motors and Gears
		O or H		Feet	Feet	Sec.		Per cent
1	119	H	29–12	—8.52	1737	39.2	4M	77.4
2	120	O	12–29	+ "	"	38.1	4M	83.7
3	120	O	12–29	+ "	"	41.0	4M	78.4
4	120	O	12–29	+ "	"	46.0	4M	78.9
5	119	H	29–12	— "	"	35.4	4M	67.8
6	120	O	12–29	+ "	"	42.6	4M	82.5
7	119	H	29–12	— "	"	38.3	2M	77.6
8	120	O	12–29	+ "	"	49.4	2M	85.3
9	119	H	29–12	— "	"	49.2	2M	78.2
10	120	O	12–29	+ "	"	54.5	2M	83.1
11	119	H	29–12	— "	"	48.8	4 S	67.5
12	120	O	12–29	+ "	"	61.9	4 S	82.1
13	119	H	29–12	— "	"	50.1	4 S	69.7
14	120	O	12–29	+ "	"	57.7	4 S	82.0
15	119	H	29–12	— "	"	47.7	4 S	72.4
16	120	O	12–29	+ "	"	41.3	4M	80.3
17	120	O	12–29	+ "	"	46.0	2M	85.7
18	120	O	12–29	+ "	"	45.9	2M	85.5
19	119	H	29–12	— "	"	46.0	4 S	71.2
20	120	O	12–29	+ "	"	59.2	4 S	80.7
21	121	O	29–12	— "	"	51.3	4 S	62.8
22	122	H	12–29	+ "	"	57.2	4 S	77.9
23	121	O	29–12	— "	"	52.5	4 S	61.6
24	122	H	12–29	+ "	"	64.3	4 S	76.8
25	121	O	29–12	— "	"	35.3	4M	65.1
26	121	O	29–12	— "	"	36.6	4M	72.0
27	122	H	12–29	+ "	"	61.2	4Sw	76.0
28	121	O	29–12	— "	"	59.0	4Sw	55.6
29	121	O	29–12	— "	"	71.3	2M	73.4
30	121	O	29–12	— "	"	56.0	4 S	64.9
31	122	H	12–29	+ "	"	77.2	4 S	75.1
32	121	O	29–12	— "	"	56.9	4 S	64.1
33	121	O	29–12	— "	"	32.7	4M	77.7
34	122	H	12–29	+ "	"	34.4	4M	83.8
35	121	O	29–12	— "	"	30.1	4M	73.8
36	122	H	12–29	+ "	"	78.2	4 S	75.4
37	121	O	29–12	— "	"	83.9	C	—
38	121	O	29–12	— "	"	106.5	C	—

*S = Series-Multiple. M = Multiple. Sw = Switching. C = Coasting.

TABLE 6 (Continued)

THE IMMEDIATE RESULTS OF THE TESTS ON THE 2°–50′ CURVE, GIVING THE RESULTS OF RESISTANCE AND SPEED USED IN PRODUCING FIG. 5

10	11	12	13	14	15	16	17	18	19
	Speed				Energy Imparted to the Car				
Item No.	At Entrance to the Section	At Exit from the Section	Average Voltage	Average Current	By the Current	By the Change in Kinetic Energy	By the Grade	Net Car Resistance	Average Speed Over the Section
	M.P.H.	M.P.H.	Volts	Amp.	Ft. Lb.	Ft. Lb.	Ft. Lb.	Lb. per Ton	M.P.H.
1	26.96	32.18	358	123.2	987020	—632860	+483510	17.00	30.21
2	30.38	31.46	436	159.9	1639720	—136910	— "	20.68	31.08
3	31.10	29.12	365	127.8	1105890	+244430	— "	17.59	28.89
4	26.42	26.06	340	139.2	1266870	+ 38730	— "	16.68	25.75
5	31.82	33.08	330	90.1	526250	—167640	+ "	17.09	33.46
6	26.78	27.86	397	152.3	1567090	—120970	— "	19.53	27.80
7	31.10	31.10	380	59.5	495590	0	+ "	19.87	30.92
8	23.90	24.62	417	119.2	1544830	— 71620	— "	20.08	23.97
9	22.46	25.88	325	69.3	639000	—338910	+ "	15.90	24.07
10	22.46	21.02	355	101.5	1203440	+128350	— "	17.21	21.73
11	23.54	25.52	425	41.7	430480	—199130	+ "	14.50	24.27
12	19.58	19.76	488	67.8	1240200	— 14520	— "	15.06	19.13
13	22.10	24.98	438	43.5	490600	—277960	+ "	14.13	23.64
14	21.92	21.38	516	65.9	1186400	+ 47930	— "	15.24	20.53
15	23.72	26.06	472	46.1	554210	—238790	+ "	16.22	24.83
16	30.02	29.12	378	138.9	1284060	+109110	— "	18.46	28.68
17	24.98	26.24	458	121.1	1612430	—132300	— "	20.22	25.75
18	25.16	25.52	443	114.3	1465370	— 37400	— "	19.16	25.80
19	23.54	26.60	482	44.5	518120	—314530	+ "	13.94	25.75
20	21.38	19.76	488	62.7	1078150	+136630	— "	14.84	20.01
21	22.10	22.10	196	42.4	394880	0	+ "	17.82	23.09
22	20.84	20.48	278	75.3	1375940	+ 30490	— "	18.72	20.70
23	21.56	21.74	189	41.4	373260	— 15980	+ "	17.06	22.56
24	18.86	18.50	239	74.3	1293620	+ 27570	— "	17.00	18.42
25	33.26	33.08	288	86.5	422170	+ 24480	+ "	18.87	33.55
26	31.64	32.54	327	104.3	662910	+118410	+ "	20.86	32.36
27	18.50	17.78	223	71.8	1098370	+ 53550	— "	13.56	19.35
28	19.76	19.94	160	37.2	287900	+ 14650	+ "	15.36	20.07
29	14.90	17.06	203	61.3	480140	—141520	+ "	16.68	16.61
30	19.58	20.84	200	44.6	478180	—104400	+ "	17.39	21.15
31	15.08	15.62	200	69.5	1188680	— 33980	— "	13.62	15.34
32	19.58	20.48	194	43.8	457010	— 73910	+ "	17.58	20.81
33	35.24	36.50	420	113.8	895690	—185300	+ "	24.22	36.22
34	34.34	32.72	479	155.7	1585580	+222710	— "	26.88	34.43
35	38.30	38.66	407	98.9	659400	— 56800	+ "	22.04	39.35
36	12.74	14.18	203	71.1	1255410	— 79470	— "	14.05	15.14
37	16.34	13.46	..	..	0	+175940	+ "	13.38	14.12
38	13.10	11.30	..	..	0	+ 90040	+ "	11.64	11.12

TABLE 7

THE IMMEDIATE RESULTS OF THE TESTS ON THE 3°–40′ CURVE, GIVING THE RESULTS OF RESISTANCE AND SPEED USED IN PRODUCING FIG. 7

1	2	3	4	5	6	7	8	9
							Motor Data	
Item No.	Test No.	Wind Opposing or Helping	Section Limits / Trolley Line Pole Numbers	Grade Rise or Fall Over Section / +Up —Down	Length of Track Section	Time to Run Over Section	Number in Use and Connection *	Efficiency of Motors and Gears
		O or H		Feet	Feet	Sec.		Per cent
1	126	H	27–38	+4.81	1125	25.3	4M	78.0
2	125	O	38–27	— ”	”	24.1	”	66.6
3	125	O	38–27	— ”	”	25.2	”	71.0
4	126	H	27–38	+ ”	”	28.2	”	79.8
5	126	H	27–38	+ ”	”	24.7	”	83.5
6	126	H	27–38	+ ”	”	23.8	”	84.2
7	126	H	27–38	+ ”	”	38.0	4S	75.5
8	125	O	38–27	— ”	”	29.7	”	71.5
9	126	H	27–38	+ ”	”	34.6	”	75.7
10	128	..	27–38	+ ”	”	36.2	4M	78.1
11	127	..	38–27	— ”	”	75.6	”	23.5
12	128	..	27–38	+ ”	”	48.7	4S	71.7
13	129	H	38–27	— ”	”	29.9	”	48.7
14	130	O	27–38	+ ”	”	38.1	”	75.3
15	129	H	38–27	— ”	”	40.8	”	35.0
16	130	O	27–38	+ ”	”	43.1	”	74.2
17	129	H	38–27	— ”	”	20.3	4M	63.3
18	130	O	27–38	+ ”	”	23.9	”	82.3
19	129	H	38–27	— ”	”	21.1	”	26.7
20	130	O	27–38	+ ”	”	24.7	”	78.1
21	130	O	27–38	+ ”	”	25.4	”	78.2
22	129	H	38–27	— ”	”	25.7	”	30.5
23	130	O	27–38	+ ”	”	23.4	”	83.7
24	129	H	38–27	— ”	”	26.9	”	64.2
25	130	O	27–38	+ ”	”	23.7	”	80.6
26	129	H	38–27	— ”	”	55.6	4S	53.3

*S=Series-Multiple. M=Multiple.

TABLE 7 (Continued)

THE IMMEDIATE RESULTS OF THE TESTS ON THE 3°–40′ CURVE, GIVING THE RESULTS OF RESISTANCE AND SPEED USED IN PRODUCING FIG. 7

10	11	12	13	14	15	16	17	18	19
	Speed				Energy Imparted to the Car				
Item No.	At Entrance to the Section	At Exit from the Section	Average Voltage	Average Current	By the Current	By the Change in Kinetic Energy	By the Grade	Net Car Resistance	Average Speed Over the Section
	M.P.H.	M.P.H.	Volts	Amp.	Ft. Lb.	Ft. Lb.	Ft. Lb.	Lb. per Ton	M.P.H.
1	32.56	29.68	344	131.1	656380	+371050	—275850	23.30	30.32
2	33.64	32.20	275	90.7	295220	+196260	+ "	23.79	31.83
3	30.58	30.40	294	104.8	406550	+22720	+ "	21.86	30.44
4	28.42	26.62	340	147.0	829490	+205080	— "	23.52	27.20
5	31.84	32.02	407	162.0	1002830	—23790	— "	21.80	31.05
6	32.56	32.56	449	166.9	1107550	0	— "	25.78	32.23
7	21.04	20.32	239	67.5	682800	+61640	— "	14.52	20.19
8	25.18	26.44	262	54.0	443210	—134640	+ "	18.12	25.83
9	23.02	20.86	264	66.2	675120	+196200	— "	18.46	22.17
10	20.28	20.46	280	152.4	889700	—15220	—276580	18.49	21.19
11	9.66	8.94	91.8	40.4	48610	+27790	+ "	10.91	10.15
12	17.94	16.68	173	58.4	520450	+90510	— "	10.34	15.75
13	26.28	25.02	155	33.1	110180	+133800	+275850	16.12	25.65
14	20.52	20.52	236	66.9	668180	0	— "	12.16	20.13
15	18.54	18.18	93.6	26.5	52240	+27360	+ "	11.02	18.80
16	18.90	18.18	207	64.4	628790	+55260	— "	12.65	17.80
17	39.24	37.62	304	81.8	235690	+257740	+ "	23.85	37.79
18	32.04	30.78	395	151.0	865310	+163850	— "	23.35	32.09
19	38.52	36.00	151	43.3	27170	+388730	+ "	21.44	36.35
20	33.30	31.50	344	132.0	646040	+241440	— "	18.96	31.05
21	30.24	28.98	270	156.3	618180	+154460	— "	15.40	30.20
22	30.24	28.44	140	47.1	38100	+218640	+ "	16.51	29.85
23	32.58	32.58	436	160.4	1010100	0	— "	22.76	32.78
24	28.80	29.16	222	86.8	245430	—43190	+ "	14.82	28.51
25	34.74	32.40	383	139.9	754830	+325210	— "	24.93	32.36
26	11.16	14.76	103	36.5	164350	—193160	+ "	7.66	13.80

TABLE 8

THE IMMEDIATE RESULTS OF THE TESTS ON THE 5°–0′ CURVE, GIVING THE RESULTS OF RESISTANCE AND SPEED USED IN PRODUCING FIG. 9

1	2	3	4	5	6	7	8	9
				Grade			Motor Data	
Item No.	Test No.	Wind Opposing or Helping	Section Limits — Trolley Line Pole Numbers	Rise or Fall Over Section — +Up —Down	Length of Track Section	Time to Run Over Section	Number in Use and Connection *	Efficiency of Motors and Gears
		O or H		Feet	Feet	Sec.		Per cent
1	125	O	24–14	—0.15	714	14.0	4M	82.9
2	126	H	14–24	+ ″	″	15.2	4M	80.5
3	126	H	14–24	+ ″	″	17.4	4M	83.1
4	125	O	24–14	— ″	″	15.6	4M	77.3
5	126	H	14–24	+ ″	″	15.6	4M	85.3
6	126	H	14–24	+ ″	″	14.7	4M	83.4
7	126	H	14–24	+ ″	″	13.6	4M	85.8
8	126	H	14–24	+ ″	″	24.8	4S	76.5
9	125	O	24–14	— ″	″	19.0	4S	70.3
10	126	H	14–24	+ ″	″	21.4	4S	76.3
11	127	..	24–14	— ″	″	25.0	4M	74.9
12	128	..	14–24	+ ″	″	23.9	4M	75.8
13	127	..	24–14	— ″	″	47.3	4S	70.8
14	128	..	14–24	+ ″	″	30.4	4S	73.4
15	129	H	24–14	— ″	″	19.9	4S	68.7
16	130	O	14–24	+ ″	″	23.7	4S	74.6
17	129	H	24–14	— ″	″	27.9	4S	69.9
18	130	O	14–24	+ ″	″	31.0	4S	75.0
19	130	O	14–24	+ ″	″	15.4	4M	85.5
20	130	O	14–24	+ ″	″	14.9	4M	79.0
21	129	H	24–14	— ″	″	12.4	4M	83.4
22	130	O	14–24	+ ″	″	16.0	4M	85.1
23	130	O	14–24	+ ″	″	14.6	4M	82.8

*S=Series-Multiple. M=Multiple.

TABLE 8 (Continued)

THE IMMEDIATE RESULTS OF THE TESTS ON THE 5°–0′ CURVE, GIVING THE RESULTS OF RESISTANCE AND SPEED USED IN PRODUCING FIG. 9

10	11	12	13	14	15	16	17	18	19
	Speed				Energy Imparted to the Car				
Item No.	At Entrance to the Section	At Exit from the Section	Average Voltage	Average Current	By the Current	By the Change in Kinetic Energy	By the Grade	Net Car Resistance	Average Speed Over the Section
	M.P.H.	M.P.H.	Volts	Amp.	Ft. Lb.	Ft. Lb.	Ft. Lb.	Lb. per Ton	M.P.H.
1	34.72	35.26	462	146.7	580160	—78220	+8600	24.93	34.77
2	33.10	32.02	383	138.6	479000	+145580	— ”	30.09	32.03
3	28.42	28.24	387	164.6	679280	+21110	— ”	33.79	27.98
4	32.74	31.84	354	123.2	387840	+120310	+ ”	25.24	31.21
5	30.22	32.20	460	196.4	886580	—255830	— ”	30.39	31.21
6	32.74	32.56	436	155.8	614200	+24330	— ”	30.77	33.12
7	33.82	35.08	524	195.9	883380	—179700	— ”	33.95	35.80
8	19.60	20.32	243	71.9	488880	—59500	— ”	20.55	19.63
9	26.26	24.82	245	51.8	250010	+152260	+ ”	20.07	25.62
10	22.30	22.30	268	68.1	439530	O	— ”	21.05	22.75
11	18.84	19.56	221	131.9	402550	—57370	+8630	17.23	19.47
12	20.10	19.56	245	136.5	446780	+44440	— ”	23.51	20.37
13	10.74	10.92	121	59.8	357380	—8090	+ ”	17.44	10.29
14	16.32	16.68	189	62.7	390010	—24650	— ”	17.38	16.01
15	24.30	23.76	220	49.3	218690	+53720	+ ”	13.73	24.46
16	19.98	19.80	230	64.3	385700	+14820	—8600	19.14	20.54
17	17.64	18.54	166	54.0	257880	—67400	+ ”	9.72	17.45
18	16.02	16.74	194	69.9	465020	—48830	— ”	19.91	15.70
19	30.06	32.58	480	199.6	930380	—326760	— ”	29.06	31.61
20	33.48	31.86	380	128.4	423550	+219110	— ”	30.97	32.67
21	39.06	38.88	482	150.6	553640	+29040	+ ”	28.88	39.26
22	27.54	30.24	441	194.1	859580	—322930	— ”	25.79	30.43
23	34.02	33.66	431	150.0	576390	+50440	— ”	30.20	33.34

TABLE 9

THE IMMEDIATE RESULTS OF THE TESTS ON THE 6°–30′ CURVE, GIVING THE RESULTS OF RESISTANCE AND SPEED USED IN PRODUCING FIG. 10

1	2	3	4	5	6	7	8	9
				Grade			Motor Data	
Item No.	Test No.	Wind Opposing or Helping	Section Limits — Trolley Line Pole Numbers	Rise or Fall Over Section — +Up —Down	Length of Track Section	Time to Run Over Section	Number in Use and Connection *	Efficiency of Motors and Gears
		O or H		Feet	Feet	Sec.		Per cent
1	133	H	1155–1151	+3.22	365	18.3	4S	73.1
2	134	O	1151–1155	— "	"	13.4	"	38.0
3	133	H	1155–1151	+ "	"	25.1	"	74.5
4	134	O	1151–1155	— "	"	17.7	"	49.8
5	133	H	1155–1151	+ "	"	16.5	"	74.5
6	134	O	1151–1155	— "	"	12.7	"	45.1
7	133	H	1155–1151	+ "	"	17.0	"	75.9
8	134	O	1151–1155	— "	"	12.1	"	49.3
9	133	H	1155–1151	+ "	"	20.2	"	75.6
10	133	H	1155–1151	+ "	"	15.0	"	78.3
11	134	O	1151–1155	— "	"	9.1	4M	57.0
12	133	H	1155–1151	+ "	"	9.9	"	83.5
13	134	O	1151–1155	— "	"	7.9	"	54.1
14	134	O	1151–1155	— "	"	7.9	"	76.3
15	134	O	1151–1155	— "	"	13.0	4S	53.7
16	133	H	1155–1151	+ "	"	20.9	"	75.6
17	134	O	1151–1155	— "	"	14.4	"	62.2
18	133	H	1155–1151	+ "	"	12.9	"	78.4
19	134	O	1151–1155	— "	"	11.4	"	50.9
20	133	H	1155–1151	+ "	"	25.7	"	75.2
21	133	H	1155–1151	+ "	"	13.6	"	77.4

*S=Series-Multiple. M=Multiple.

TABLE 9 (Continued)

THE IMMEDIATE RESULTS OF THE TESTS ON THE 6°–30′ CURVE, GIVING THE RESULTS OF RESISTANCE AND SPEED USED IN PRODUCING FIG. 10

10	11	12	13	14	15	16	17	18	19
	Speed				Energy Imparted to the Car				
Item No.	At Entrance to the Section	At Exit from the Section	Average Voltage	Average Current	By the Current	By the Change in Kinetic Energy	By the Grade	Net Car Resistance	Average Speed Over the Section
	M.P.H.	M.P.H.	Volts	Amp.	Ft. Lb.	Ft. Lb.	Ft. Lb.	Lb. per Ton	M.P.H.
1	14.59	12.38	173	63.2	215730	+123080	—184510	14.75	13.60
2	18.84	18.84	106	13.2	10510	0	+ "	18.65	18.57
3	9.49	10.00	146	78.4	315710	—20530	— "	10.58	9.91
4	13.23	14.08	97.2	34.6	43730	—47940	+ "	17.24	14.06
5	15.61	14.25	202	66.3	242830	+83860	— "	13.60	15.08
6	18.84	19.52	149	31.4	39530	—53870	+ "	16.27	19.60
7	14.93	14.25	202	74.4	286030	+40980	— "	13.63	14.64
8	19.69	20.03	140	33.7	41510	—27890	+ "	18.95	20.57
9	12.04	11.53	182	77.5	317720	+24820	— "	15.11	12.32
10	16.29	16.46	248	84.5	363020	—11500	— "	15.97	16.59
11	27.17	27.17	225	73.8	63500	0	+ "	23.71	27.35
12	24.45	24.11	380	180.0	417000	+34090	— "	25.49	25.14
13	31.76	31.42	230	69.8	50600	+44360	+ "	26.72	31.50
14	31.59	31.93	365	115.8	187890	—44600	+ "	31.35	31.50
15	18.84	19.18	158	35.9	58400	—26690	+ "	20.68	19.14
16	11.19	11.19	184	77.2	331060	0	— "	14.01	11.91
17	16.12	17.48	169	42.4	94670	—94360	+ "	17.68	17.28
18	19.69	19.18	282	77.9	327710	+40940	— "	17.61	19.29
19	20.71	21.05	169	34.1	49320	—29320	+ "	19.56	21.83
20	9.49	11.53	157	83.4	373260	—88550	— "	9.58	9.68
21	18.67	17.82	256	75.6	300490	+64050	— "	17.21	18.30

TABLE 10

THE IMMEDIATE RESULTS OF THE TESTS ON THE 8°–0′ CURVE, GIVING THE RESULTS OF RESISTANCE AND SPEED USED IN PRODUCING FIG. 12

1	2	3	4	5	6	7	8	9
							Motor Data	
Item No.	Test No.	Wind Opposing or Helping	Section Limits — Trolley Line Pole Numbers	Grade — Rise or Fall Over Section — +Up —Down	Length of Track Section	Time to Run Over Section	Number in Use and Connection *	Efficiency of Motors and Gears
		O or H		Feet	Feet	Sec.		Per cent
1	142	O	1735 –1737.5	+0.65	176	6.7	4S	80.3
2	142	O	1735 –1737.5	+ "	"	6.4	"	66.8
3	141	H	1737.5–1735	— "	"	6.2	"	41.2
4	142	O	1735 –1737.5	+ "	"	13.9	"	73.3
5	142	O	1735 –1737.5	+ "	"	8.1	"	64.8
6	142	O	1735 –1737.5	+ "	"	6.7	"	78.0
7	141	H	1737.5–1735	— "	"	4.9	4M	21.5
8	142	O	1735 –1737.5	+ "	"	4.9	"	65.4
9	142	O	1735 –1737.5	+ "	"	4.5	"	72.3
10	142	O	1735 –1737.5	+ "	"	5.3	"	73.9
11	141	H	1737.5–1735	— "	"	8.1	4S	33.0
12	142	O	1735 –1737.5	+ "	"	8.8	4M	74.0
13	141	H	1737.5–1735	— "	"	7.7	4S	28.2
14	141	H	1737.5–1735	— "	"	10.3	"	21.2
15	142	O	1735 –1737.5	+ "	"	7.7	4M	75.9
16	141	H	1737.5–1735	— "	"	7.95	4S	49.6
17	142	O	1735 –1737.5	+ "	"	15.3	"	70.1
18	141	H	1737.5–1735	— "	"	6.1	"	52.8
19	142	O	1735 –1737.5	+ "	"	4.5	4M	85.2
20	141	H	1737.5–1735	— "	"	9.4	4S	56.4
21	141	H	1737.5–1735	— "	"	6.5	"	59.1
22	141	H	1737.5–1735	— "	"	6.1	"	62.5
23	142	O	1735 –1737.5	+ "	"	5.6	4M	69.7
24	142	O	1735 –1737.5	+ "	"	3.5	"	86.1
25	142	O	1735 –1737.5	+ "	"	5.6	"	74.6
26	141	H	1737.5–1735	— "	"	8.3	4S	59.7
27	141	H	1737.5–1735	— "	"	10.7	C	
28	142	O	1737.5–1735	+ "	"	5.4	4M	69.6
29	142	O	1735 –1737.5	+ "	"	9.4	"	73.4
30	153	..	1737.5–1735	— "	"	12.2	4S	28.5
31	153	..	1737.5–1735	— "	"	9.0	"	43.8
32	154	..	1735 –1737.5	+ "	"	6.8	"	74.0
33	154	..	1735 –1737.5	+ "	"	11.7	"	74.7
34	153	..	1737.5–1735	— "	"	7.8	"	66.8
35	153	..	1737.5–1735	— "	"	7.4	"	40.4
36	153	..	1737.5–1735	— "	"	6.2	"	51.5
37	154	..	1735 –1737.5	+ "	"	7.5	"	76.1
38	153	..	1737.5–1735	— "	"	7.46	"	37.3
39	153	..	1737.5–1735	— "	"	6.2	"	54.8
40	153	..	1737.5–1735	— "	"	12.2	"	46.7

*S=Series-Multiple. M=Multiple. C=Coasting.

TABLE 10 (Continued)

THE IMMEDIATE RESULTS OF THE TESTS ON THE 8°–0′ CURVE, GIVING THE RESULTS OF RESISTANCE AND SPEED USED IN PRODUCING FIG. 12

10	11	12	13	14	15	16	17	18	19
	Speed				Energy Imparted to the Car				
Item No.	At Entrance to the Section	At Exit from the Section	Average Voltage	Average Current	By the Current	By the Change in Kinetic Energy	By the Grade	Net Car Resistance	Average Speed Over the Section
	M.P.H.	M.P.H.	Volts	Amp.	Ft. Lb.	Ft. Lb.	Ft. Lb.	Lb. per Ton	M.P.H.
1	17.52	18.96	290	94.9	218390	—109530	—37570	14.02	17.91
2	18.78	17.88	203	46.7	59780	+ 68790	— ''	17.89	18.75
3	19.32	19.32	401	24.1	36420	0	+ ''	14.55	19.35
4	7.62	9.06	128	71.4	137360	— 50080	— ''	9.77	8.63
5	16.26	15.18	162	45.5	57060	+ 70800	— ''	17.75	14.81
6	17.88	18.42	260	79.3	158950	— 40870	— ''	15.83	17.91
7	25.26	24.90	117	43.1	3920	+ 37650	+ ''	15.56	24.49
8	26.34	25.26	236	89.2	49750	+116190	— ''	25.24	24.49
9	27.06	26.52	301	109.7	79230	+ 60330	— ''	20.05	26.67
10	21.12	20.58	258	120.3	89660	+ 46950	— ''	19.47	22.64
11	14.82	14.28	86	27.7	9440	+ 32760	+ ''	15.68	14.81
12	13.92	13.56	171	136.4	112000	+ 20630	— ''	18.69	13.64
13	16.08	15.72	59	26.2	4980	+ 23870	+ ''	13.06	15.58
14	11.76	11.40	56	22.6	4060	+ 17380	+ ''	11.60	11.65
15	15.54	15.54	212	145.3	132750	0	— ''	18.71	15.58
16	15.90	15.90	110	34.3	21960	0	+ ''	11.70	15.09
17	7.26	8.16	108	58.8	100460	— 28940	— ''	6.67	7.84
18	20.40	20.04	166	35.3	27840	+ 30350	+ ''	18.83	19.67
19	25.26	26.34	432	204.6	249930	—116190	— ''	18.91	26.67
20	13.02	13.02	97	38.9	29560	0	+ ''	13.20	12.77
21	19.68	19.68	169	39.8	38110	0	+ ''	14.88	18.46
22	20.04	20.04	169	42.7	40570	0	+ ''	15.36	19.67
23	22.74	22.20	236	101.3	68830	+ 50600	— ''	16.09	21.43
24	34.08	34.44	539	208.3	249520	— 51430	— ''	31.56	34.29
25	21.48	20.94	243	126.7	94860	+ 47760	— ''	20.65	21.43
26	14.28	14.28	112	41.2	33730	0	+ ''	14.02	14.46
27	11.94	11.40	0	0	0	+ 26280	+ ''	12.55	11.21
28	23.10	22.56	262	100.0	72620	+ 51410	— ''	17.00	22.22
29	12.66	12.66	171	130.0	113120	0	— ''	14.85	12.77
30	10.04	9.68	57	26.3	7690	+ 14800	+37640	11.80	9.84
31	13.64	13.64	107	31.6	19650	0	+ ''	11.24	13.33
32	17.42	17.42	220	62.5	102060	0	— ''	12.64	17.65
33	10.22	11.66	153	78.1	154050	— 65690	— ''	9.96	10.26
34	15.08	15.62	165	48.1	60980	— 34570	+ ''	12.57	15.38
35	16.52	15.80	130	29.9	17130	+ 48520	+ ''	20.27	16.22
36	20.66	20.12	179	34.3	28920	+ 45910	+ ''	22.07	19.35
37	15.62	15.62	207	75.4	131410	0	— ''	18.40	16.00
38	16.16	15.98	116	28.9	13750	+ 12060	+ ''	12.45	16.09
39	20.12	19.76	165	36.6	30270	+ 29930	+ ''	19.20	19.35
40	9.86	9.50	68	33.5	19160	+ 14530	+ ''	14.00	9.84

TABLE 11

THE IMMEDIATE RESULTS OF THE TESTS ON THE 14°–30′ CURVE, GIVING THE RESULTS OF RESISTANCE AND SPEED USED IN PRODUCING FIG. 13

1	2	3	4	5	6	7	8	9
				Grade			Motor Data	
Item No.	Test No.	Wind Opposing or Helping	Section Limits — Trolley Line Pole Numbers	Rise or Fall Over Section — +Up —Down	Length of Track Section	Time to Run Over Section	Number in Use and Connection *	Efficiency of Motors and Gears
		O or H		Feet	Feet	Sec.		Per cent
1	141	O	1735–1732	— 0.17	276	10.1	4 S	74.2
2	142	H	1732–1735	+ ,,	,,	10.7	,,	72.9
3	141	O	1735–1732	— ,,	,,	9.0	,,	60.7
4	142	H	1732–1735	+ ,,	,,	9.9	,,	78.4
5	141	O	1735–1732	— ,,	,,	9.9	,,	61.7
6	142	H	1732–1735	+ ,,	,,	22.7	,,	72.4
7	141	O	1735–1732	— ,,	,,	8.7	,,	74.4
8	141	O	1735–1732	— ,,	,,	9.1	,,	60.0
9	142	H	1732–1735	+ ,,	,,	10.7	,,	75.0
10	142	H	1732–1735	+ ,,	,,	11.6	,,	77.2
11	141	O	1735–1732	— ,,	,,	7.1	4M	84.2
12	142	H	1732–1735	+ ,,	,,	7.2	,,	83.0
13	141	O	1735–1732	— ,,	,,	10.2	4 S	72.0
14	142	H	1732–1735	+ ,,	,,	8.8	4M	80.0
15	141	O	1735–1732	— ,,	,,	9.2	4 S	76.8
16	142	H	1732–1735	+ ,,	,,	27.5	,,	72.2
17	141	O	1735–1732	— ,,	,,	13.2	,,	70.3
18	141	O	1735–1732	— ,,	,,	12.7	,,	60.6
19	141	O	1735–1732	— ,,	,,	12.0	,,	69.3
20	142	H	1732–1735	+ ,,	,,	25.0	,,	72.9
21	141	O	1735–1732	— ,,	,,	9.2	,,	75.7
22	141	O	1735–1732	— ,,	,,	11.5	,,	76.8
23	142	H	1732–1735	+ ,,	,,	7.6	4M	78.2
24	141	O	1735–1732	— ,,	,,	8.1	4 S	73.8
25	141	O	1735–1732	— ,,	,,	14.1	,,	69.2
26	141	O	1735–1732	— ,,	,,	9.6	,,	73.9
27	141	O	1735–1732	— ,,	,,	9.6	,,	75.0
28	142	H	1732–1735	+ ,,	,,	38.1	,,	71.7
29	141	O	1735–1732	— ,,	,,	9.8	,,	72.9
30	141	O	1735–1732	— ,,	,,	9.5	,,	77.7
31	141	O	1735–1732	— ,,	,,	14.5	,,	66.5
32	142	H	1782–1735	+ ,,	,,	5.6	4M	86.1
33	141	O	1735–1732	— ,,	,,	12.6	4 S	68.7
34	142	H	1732–1735	+ ,,	,,	21.1	,,	75.2
35	141	O	1735–1732	— ,,	,,	9.3	,,	74.7
36	142	H	1732–1735	+ ,,	,,	8.4	4M	83.8
37	142	H	1732–1735	+ ,,	,,	7.6	,,	79.9
38	153	..	1735–1732	— ,,	,,	8.6	4 S	74.5
39	154	..	1732–1735	+ ,,	,,	9.0	,,	77.4
40	153	..	1735–1732	— ,,	,,	11.7	,,	63.2
41	153	..	1735–1732	— ,,	,,	12.6	,,	75.1
42	153	..	1735–1732	— ,,	,,	29.0	,,	67.7
43	153	..	1735–1732	— ,,	,,	9.7	,,	71.6
44	153	..	1735–1732	— ,,	,,	10.3	,,	70.8
45	153	..	1735–1732	— ,,	,,	8.5	,,	67.7
46	153	..	1735–1732	— ,,	,,	8.1	,,	77.0
47	153	..	1735–1732	— ,,	,,	22.3	,,	68.2
48	153	..	1735–1732	— ,,	,,	9.0	,,	75.9
49	153	..	1735–1732	— ,,	,,	28.9	,,	48.9
50	153	..	1735–1732	— ,,	,,	15.4	,,	64.7

*S = Series-Multiple. M = Multiple.

TABLE 11 (Continued)

THE IMMEDIATE RESULTS OF THE TESTS ON THE 14°–30′ CURVE, GIVING THE RESULTS OF RESISTANCE AND SPEED USED IN PRODUCING FIG. 13

10	11	12	13	14	15	16	17	18	19
	Speed				Energy Imparted to the Car				
Item No.	At Entrance to the Section	At Exit from the Section	Average Voltage	Average Current	By the Current	By the Change in Kinetic Energy	By the Grade	Net Car Resistance	Average Speed Over the Section
	M.P.H.	M.P.H.	Volts	Amp.	Ft. Lb.	Ft. Lb.	Ft. Lb.	Lb. per Ton	M.P.H.
1	18.96	18.96	224	63.2	156470	0	+9830	20.85	18.63
2	18.24	17.52	194	60.1	134150	+ 53680	— "	22.32	17.59
3	21.48	20.22	167	41.1	55320	+109550	+ "	21.90	20.91
4	18.60	18.78	260	82.4	245280	— 14030	— "	27.76	19.01
5	19.32	18.06	420	35.9	135870	+ 98200	+ "	30.58	19.01
6	7.62	7.62	112	67.9	184360	0	— "	21.88	8.29
7	21.66	21.48	268	61.2	156580	+ 16190	+ "	22.89	21.63
8	21.12	19.50	178	40.3	57780	+137200	+ "	25.68	20.68
9	18.60	17.88	225	66.4	176840	+ 54760	— "	27.80	17.59
10	14.28	15.18	227	80.2	240470	— 55280	— "	21.98	16.22
11	26.16	26.52	383	202.7	342260	— 39540	+ "	39.18	26.50
12	26.34	26.34	383	164.5	277660	0	— "	33.58	26.14
13	19.32	18.78	193	57.5	120240	+ 42900	+ "	21.69	18.45
14	21.30	21.12	312	164.3	266140	+ 15920	— "	34.13	21.38
15	19.86	20.04	260	71.6	194000	— 14970	+ "	23.68	20.45
16	5.82	5.82	91.8	70.9	190650	0	— "	22.67	6.84
17	14.28	13.38	142	56.4	109640	+ 51900	+ "	21.48	14.26
18	15.72	13.56	113	42.0	53860	+131870	+ "	24.52	14.82
19	15.90	15.00	164	52.7	106040	+ 57980	+ "	21.80	15.68
20	6.00	7.26	106	75.4	214790	— 34840	— "	21.33	7.53
21	20.04	19.86	247	67.8	172010	+ 14970	+ "	24.67	20.45
22	16.98	17.52	220	78.3	224390	— 38840	+ "	24.49	16.36
23	26.52	25.26	290	150.0	190670	+136030	— "	39.72	24.76
24	22.74	22.38	264	59.8	139180	+ 33870	+ "	22.93	23.23
25	13.02	12.66	140	54.0	108800	+ 19280	+ "	17.29	13.35
26	19.68	19.32	230	61.4	147760	+ 29270	+ "	23.43	19.60
27	19.68	19.32	243	65.2	168270	+ 29270	+ "	26.00	19.60
28	3.48	4.02	93.6	67.2	253450	— 8440	— "	29.48	4.94
29	19.14	19.14	218	59.0	135510	0	+ "	18.22	19.20
30	20.04	20.04	264	76.7	220480	0	+ "	28.87	19.81
31	13.38	12.30	128	49.2	89600	+ 57830	+ "	19.72	12.98
32	33.90	34.08	573	194.7	396700	— 25510	— "	45.30	33.60
33	14.28	14.28	164	51.4	107630	0	+ "	14.73	14.93
34	6.18	9.96	151	88.6	313150	—127200	— "	22.08	8.92
35	20.22	20.40	243	63.8	158880	— 15240	+ "	19.24	20.23
36	21.48	23.10	370	199.1	382450	—150580	— "	27.84	22.40
37	24.00	23.64	318	149.1	212320	+ 35760	— "	29.87	24.76
38	21.56	21.56	266	61.6	154840	0	+9840	20.61	21.88
39	21.56	21.74	279	72.3	207240	— 16250	— "	22.67	20.91
40	17.06	15.44	144	44.1	69260	+109780	+ "	23.64	16.08
41	13.82	15.26	189	71.8	189400	— 87310	+ "	14.01	14.93
42	8.06	5.18	75	54.7	118880	+ 79500	+ "	26.06	6.49
43	20.12	19.76	226	55.0	127340	+ 29930	+ "	20.92	19.40
44	18.86	18.32	223	53.5	128320	+ 41860	+ "	22.53	18.27
45	22.46	21.20	217	47.7	87850	+114700	+ "	26.58	22.14
46	22.10	21.74	300	68.0	187670	+ 32910	+ "	28.83	23.23
47	8.96	8.60	96	54.2	116760	+ 13180	+ "	17.49	8.44
48	20.66	20.30	272	66.5	182270	+ 30740	+ "	27.89	20.91
49	9.68	0.00	49.5	34.8	35960	+195370	+ "	30.18	6.51
50	13.64	11.66	120	46.5	82010	+104450	+ "	24.57	12.22

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