Tracking Characteristics of Great Northern Electric Locomotives on a 10-Deg Curve

I. INTRODUCTION

An unusual amount of maintenance needed on the sharper curves of the electrified section of the Great Northern Railway appeared to coincide with the use of two new electric locomotives of large power and size. At the request of the engineering department of the railroad tests were made of the lateral and vertical loads imposed on the track by these locomotives and others.

1. Acknowledgement

The tests were carried out by the research staff of the Engineering Division of the Association of American Railroads. G. M. Magee, director of engineering research, was in general charge of the program and Randon Ferguson, electrical engineer, was in direct charge of the tests, assisted by M. F. Smucker, assistant electrical engineer. Mr. Ferguson also prepared the report. The railway company's chief engineer, H. J. Seyton, was represented by W. J. Cruse, engineer of track, who assisted in all phases of the program. W. M. Keller, director of mechanical research of the Association aided in the planning of the tests and gave helpful suggestions regarding mechanical matters. J. L. Robson, general superintendent of motive power, was represented on the tests by J. H. Heron, superintendent of motive power, who actively assisted in all mechanical matters. The data were reduced and plotted by G. Wanschura, mechanical assistant of the railroad, and other members of the engineering and mechanical staff.*

2. Purpose of Tests

Certain difficulties with the track in the electrified section of the railroad where the curvature was sharp appeared to be coincidental with the acquisition of two unusually large, powerful and long electric locomotives. These two locomotives were acquired in 1946, and shortly thereafter the low rail on the sharper curves began showing a larger than normal flow of metal and it became increasingly difficult to keep these curves in line and gage, with the rail tending to tilt outward with respect to the center of the track. This action would appear to indicate larger than normal lateral forces and unusually heavy vertical loads on the low rail. It was stated that the rails needed to be transposed after about one year's service and replaced after about another year. The annual gross tonnage was about 12 million tons.

A new rail laying program being in prospect in this territory, it was thought desirable to make such measurements as necessary to determine the lateral and vertical forces with a view to possible changes that might be made in the track or locomotives to promote improvements in maintenance, stability, or possibly safety. The engineering department of the railway accordingly requested the research staff of the Association to work out the program and make the necessary measurements. Since the measurements were similar to those made for a previous test project, the equipment could be assembled with little or no delay and the tests were started Dec. 5, 1952, and finished in 2 weeks.

* The Great Northern Railway assumed the cost of the tests and very kindly agreed to the publication of this condensation of the full report for the benefit of AREA members.

II. THE TRACK, LOCOMOTIVES AND INSTRUMENTATION

1. The Track

A test location was selected about two rail lengths east of the Foss River bridge (Bridge 418). A general view of this location and the test house is shown in Fig. A–a.* The rail was 115 RE section, which had been laid October 1951, and had been transposed in November 1952. The outer rail showed considerable flow which had taken place in its original inner position. Sections of the rail heads at several locations on the curve are shown in Fig. B. The tie plates were 8½ in by 13 in, double shoulder, with 2 hold down spikes for the plate and ⅜-in eccentricity. Ties were 7 in by 9 in by 8 ft 6 in, and the ballast was processed gravel. The track was on a high fill on the approach to the bridge and was on 2.2 percent grade downward, westbound. The curve was compound, being nominally 10 deg, 0 deg 30 min, 10 deg, 4 deg, 10 deg, 4 deg 38 min. The curvature was nominally 10 deg at the point where measurements were taken, but varied from about 8½ deg to 11½ deg as measured by a 62-ft chord. The elevation of the outer rail was nominally 3 in, corresponding to a balanced speed of 21 mph. The actual elevations are given in Fig. C. The speed limitation on the curve was 20 mph because of the bridge and some previous difficulty at this location. At the location where the lateral and vertical forces were measured the curvature was between 9 deg and 10 deg. A plan of the track is shown in Fig. C, and a view of the test house and test location in Fig. A–a. The track was recently gaged to 56½ in, and was close to that amount at the actual test location.

2. The Locomotives

The test locomotive was No. 5019 of Class W–1, but the other similar locomotive (No. 5018) was also used in the tests. Diagrams of the test locomotive and certain others for which records were taken are shown in Fig. D, and a view of the locomotive on the test location in Fig. A–b. Views of these locomotives are shown in Fig. F and G. The wheel arrangement and nominal loads are shown in the locomotive diagrams. The test locomotive is rated at 5000 hp continuously available at the rail, which is equivalent to a 6000 hp rating as customarily applied to diesel-electric locomotives. All axles are motorized and separate field exciter generators give flexible control in motoring and regenerating for various conditions of load and voltage. Pantographs collect the current from a 11,000-v, 25-cycle trolley supply. The overall length between couplers is 101 ft, and the cab is a single continuous structure the full length of the locomotive. The longest rigid wheel base is 16 ft 9 in. All wheels are the same diameter—42 in. The speed is restricted to a maximum of 55 mph.

A single-frame unit runs from the front of the locomotive over the guiding truck and the four following drivers to the mallet hinge at the middle. The front end of this frame rests on a center plate at the mid-length of the front truck and then on the various following driver springs. The four driver group is equalized straight through and dead ended at each end. The two end wheels of this group have coil springs between the leaf springs of the equalizers and the journal box, and the two inner wheels have rubber sandwich pads in the same relative position. These rubber pads act to resist lateral movement by developing shearing resistance in the pad, but the relation of this resistance to the movement is not known.

The cab of the locomotive is supported at three points—on a center plate on the frame 9 ft 9 in back of the truck center plate; on four spring pads at the ends of the

* Only a selected group of the figures contained in the full report are reproduced with this abstract, but the figures shown retain the same figure numbers as the complete report.

frames at the middle of the locomotive length; and at the center plate back of the truck at the other end. The spring pads at the mid-length bear against the plate on the cab and each carries a nominal load of 25,000 lb.

A rocker and spring arrangement between the front truck and the frame is an antiswivel device to stabilize rotation of the truck about the center plate. This sort of device is generally assumed necessary for stabilization under high-speed conditions on tangent track. A view of this device is shown in Fig. A–e. This restraint was released on both trucks for one set of tests. A similar doubled arrangement is placed between the two ends of the frames at the middle and termed a hobble. This hobble is intended to restrain relative movement of the ends of the frames in the hinge linkage. It was also disconnected to provide unrestricted movement for some runs. A view of the hobble and mallet hinge is shown in Fig. A–f.

The guiding trucks at each end are equipped with a double rocker arrangement that requires a certain lateral force to start it to moving laterally, and a certain lateral force to move it further, the magnitude of each force being determined by the dimensions of the linkage. Originally this initial force was set at 24 percent of the vertical load, with a 13.1 percent constant force required for further movement. Modification of the linkage at present in use makes these forces 18 percent initial and 10 percent constant. This change was made in one locomotive shortly after it was received, but not in the second locomotive until October 1952.

Originally the lateral play in the two outer drivers of each group of four was $\frac{3}{16}$ in, and $1\frac{3}{16}$ in. in the two inner drivers. As presently used, the play has been increased on the two drivers next to the trucks to $1\frac{3}{16}$ in. The others remain the same. The lateral play was modified for one series in the tests by increasing the play in the two wheels next to the middle coupling (Nos. 6 and 7 from the front) to $1\frac{3}{16}$ in, and decreasing that in the adjacent ones (5 and 8) to $\frac{3}{16}$ in. One trial was also made of decreasing the lateral in No. 3 wheel by $\frac{1}{2}$ in. The values quoted are per wheel and the total lateral or change of lateral will be double the value given.

3. Test Apparatus and Procedure

The instrumental requirements of this project were similar to those developed for a recent program of tests on steam locomotives to determine the effect of lateral resistance in leading and trailing trucks. The lateral forces were measured by dynamometer members in a tie plate that supports the rail on rollers free to move transversely of the track. Stresses were measured in the two dynamometer members by two wire resistance gages, and two gages were arranged in an electrical bridge so that lateral thrust in one direction was indicated by the output of one gage, and in the other direction by the gage on the other side of the rail, both being recorded by a single galvanometer. A more detailed description of this and other apparatus is given in the report of previous tests.*

Four of these lateral load measuring tie plates were installed under the inner and outer rails at consecutive ties. A view of the installation is shown in Fig. A–c. The lateral movement of rail head (inner and outer rails) was also measured relative to the ties. A cable with one end fixed with reference to the rail head was wrapped around a pulley on the end of a potentiometer shaft and held taut by a spring attached to a bracket. The potentiometer was connected electrically to a galvanometer so the change of resistance from the rotation of the potentiometer and galvanometer current was proportional to the rail movement.

* Lateral Forces Exerted by Locomotives on Curved Track, American Railway Engineering Association Bulletin 488, for June–July 1950.

It had previously been found that the vertical loads on the rail could be estimated with good accuracy, regardless of eccentricity of bearing of the wheel on the rail, by measuring vertical stresses in the rail web on the two sides just below the upper fillet. The relation of the summation of these stresses to the total weight of the locomotives gives a factor which may be used to calculate individual wheel loads. Conversely, the ratio of the stresses on the two sides may be used to estimate the position of the centroid of the bearing pressure on the head of the rail. Simultaneous values of the stresses on the two sides of the rail directly under the wheel must be used. These stresses were measured by wire resistance gages of ¼-in gage length cemented to the web of the rail.

The indications from the above apparatus and gages were measured and recorded by the two 12-channel amplifier and oscillograph units. The amplifiers increase the gage outputs sufficiently and in an accurately known manner to drive magnetic galvanometers in the oscillographs. The indications were recorded photographically as the locomotives passed over the test section. A dark room was set up in the test house and all records developed and dried soon after being taken. This practice enabled the results to be quickly known and the test procedure could be modified accordingly. A view of the apparatus in the test house is shown in Fig. A–d.

Speeds of 5, 20 and 30 mph were run as representing the slowest operating condition, the speed limitation, and approximately 3-in unbalanced elevation, respectively. Operation eastbound was normally pulling and westbound regenerating, and this was simulated in the test runs. Handling a tonnage train at the various speeds was found to be impracticable because of the time required by a set of runs, so the other locomotive of the same class, 5018, was used to load the test locomotive by having it regenerate up grade and push the test locomotive regenerating down grade. The load could be adjusted to the various speeds by the electrical controls in the locomotives. A car was placed between the two locomotives. This method of operation had been used in other electric locomotive tests and greatly expedited the test program.

The test locomotive (5019) was tested in the normal condition, with the hobble released, and with both the hobble and antiswivel device released. Lateral play in some of the axles was also changed, as previously described.

Normal operation on the curve quite often requires sanding because of the grade and weather conditions. The sand prevents the curve oilers from being effective and the locomotives do not negotiate the curve as readily as they would if the sand were not present.

III. LATERAL FORCES AND VERTICAL WHEEL AND AXLE LOADS ON THE 10-DEG CURVE WITH TEST LOCOMOTIVE 5019

1. Normal Condition—Motoring and Regenerating

The lateral forces for the various test runs with two test conditions for the test locomotive are given in Figs. 1, 1a, 5, and 5a. The values plotted are the average of the four ties on each rail. This force, as previously stated, is the tie reaction to the force exerted by the locomotive driver as it passes the given tie position. It has been previously found that three ties will take the total lateral reaction of the track developed by the force applied by a locomotive wheel. The amount taken by the ties adjacent to the tie at which the force is applied will depend on the relative play at the several locations and the lateral stiffness of the track. The previous test mentioned had indicated that the total lateral applied force could be approximated for the larger values by multiplying the tie reaction at the wheel by 1.70. However, a check of the records for the test here reported indicates that a factor of 2.00 would be more nearly correct for these tests. It was also found in the previous test that it was satisfactory to use the tie reaction at a single tie as a wheel passed it for comparative purposes, and these are the values plotted in the above-mentioned diagrams. The values from the four ties on a rail are averaged. The use of this value instead of the total applied force eliminates the necessity of making simultaneous readings on the records with respect to time on three different traces to obtain a single value.

Fig. 1 shows the lateral tie reactions developed by the 12 drivers of the test locomotive in its normal condition motoring up grade at speeds of 5 mph, 20 mph, and 30 mph. It is quite evident that the first wheel (No. 1) and the leading wheel of the second frame (No. 7) are doing most of the turning of the locomotive on the curve. An average force of almost 15,000 lb was developed at 30 mph at No. 7, with a single maximum (shown by the pip on top of the average value) of about 17,000 lb. Use of the factor 2.00 given above would indicate a force applied by the wheel of 34,000 lb. The amount at the front wheel is smaller but still of considerable magnitude. The forces at these wheels are seen to be less at the lower speeds, indicating that part of the force is due to the increased centrifugal force of the higher speeds. The distribution of the forces shown indicates that the two frames of the locomotive act somewhat as individual units, with the end wheels pressing against the outer rail and the middle wheels against inner rail in much the same manner as the steam locomotives tested previously. However, the action is less severe, and there is not the tendency to develop extreme lateral and vertical loads on one of the intermediate drivers on the low rail at low speed that was found with the larger steam locomotives. The vertical loads for this locomotive are shown in Fig. 1–a, and it should be pointed out that the axle loads, and in most cases the wheel loads, are highest at the end wheels. This load distribution is probably due to the "bridging" of the long cab along the length of the curve so that some of the cab weight is lifted off the center supports and more rests on the trucks and end drivers. The lateral action of the rockers in the trucks also lifts the supports somewhat when they move laterally.

The lateral force of 15,000 lb on No. 7 driver may be compared with a force of about 23,000 found on a 4–8–4 steam locomotive (maximum value of 29,000), which was found on the third inner driver at 5 mph. This very high lateral was accompanied by a vertical load of 67,000 lb in the steam locomotive. The highest vertical load on the electric locomotive was about 53,000 lb. (Fig. 1–a).

The test locomotive was run westbound in regeneration. The lateral forces were highest at the same wheels but all values were lower, indicating that regeneration is a less severe condition in this respect than motoring. The vertical loads were essentially the same for the two conditions of operation.

2. Hobble Restraint Released

The hobble that provides restraints for keeping the end of the frames in alinement was released and a set of runs made. The release of the two ends of the frame from this restraint caused increased lateral force on the wheels that were already highest, except the lateral on No. 10 on the inner rail was reduced somewhat. The maximum vertical loads were not appreciably changed. Runs were eastbound (up-grade). Since reduction of this restraint made conditions worse, it seems logical that increase in the restraint might help reduce the critical lateral forces.

3. Hobble and Antiswivel Restraints Released

The antiswivel devices are intended to restrain rotation of the end trucks and it was thought that perhaps releasing them would make the locomotive more flexible in adapting itself to the curvature. The main function of the antiswivel device is to promote stability on tangent track at the higher speeds, and since the speed of this locomotive is restricted to 55 mph, it is probably not essential. The principal effect on the lateral forces of this change was to reduce the force at the No. 1 wheel to about the value for the normal operating condition, and the vertical loads remained about the same as for the normal condition. It is apparent that these changes either did not help much or made the condition worse. Runs were eastbound (up-grade).

4. Effect of Variation of Lateral Play

Lateral forces are inherent in the passing of locomotives around curves and their magnitude is dependent partially on the stiffness and length of the locomotive and the relation between the various parts. One method of reducing high values of lateral forces in steam locomotives has been to divide the forces between several wheels instead of having one wheel take all the force. Since wheel No. 7 developed high lateral in all cases, and it was one that had small lateral play, it seemed reasonable that it could be made to share the force with No. 8 by giving it more play and decreasing that in No. 8 which had a large amount. Similar changes were made in Nos. 5 and 6 on the assumption they would act in a manner similar to Nos. 7 and 8 when operating in the reverse direction. Results of tests made with this condition are plotted in Figs. 5 and 5–a. The maximum speed was 20 mph, and the runs were eastbound (up grade).

It is apparent that these changes effected considerable improvement in the lateral forces and some in the vertical loading of the wheels that had had high vertical loads. The highest average lateral has dropped from approximately 15,000 lb to 10,000 lb, and some of the vertical loads were also decreased appreciably. Only two wheels are over 40,000 lb, and they are about 45,000 lb. This method of attack appears promising.

Since wheel No. 1 had taken a considerable lateral force (though not as high as No. 7) it was reasoned that possibly this force could be shared by No. 3 (and possibly No. 2) if the play in No. 3 was decreased from the $1\frac{3}{16}$ in. Accordingly, $\frac{1}{2}$-in shims were placed in each end of the axle to reduce the play by 1 in. This change did not effect any improvement at the outer rail and increased the lateral at No. 3 wheel on the inner rail to almost 15,000 lb. Apparently, the clearance is needed at that point to provide a lateral for the rigid wheel base. The maximum speed run for this condition was 15 mph.

Locomotive 5018, the other one of the same class as 5019, was recorded eastbound (up grade) at the head end on a freight train at 15 mph, and on eastbound passenger trains at 20 mph and 30 mph. The results were quite similar to those for 5019 in the normal condition with wheels Nos. 1 and 7 having the highest laterals and the vertical loads higher at the ends on the truck wheels.

IV. MISCELLANEOUS DATA ON TEST LOCOMOTIVE

Measurements were made of the lateral movement of the rail head with respect to the ties. These measurements are not plotted for this report as their principal value is of a qualitative and corroboratory nature. However, it can be stated in general that the larger movements were found at the wheels where the lateral forces were greatest and in the same direction, and the greatest magnitude of the deflection was about 0.50 in.

Previous tests have indicated that the ratio of the vertical web stresses near the upper fillet used to calculate the wheel and axle loads can be used to estimate the position of the centroid of bearing pressure of the wheel on the rail. A diagram showing this relation given in the previously mentioned report on "Lateral Forces Exerted on Curved Track by Locomotives" was used to determine the positions of the bearing pressures for the test locomotive in the normal condition at speeds of 5 mph, 20 mph and 30 mph. These are plotted in Fig. L. It is seen that Nos. 1 and 7 wheels, which develop the highest laterals on the outer rail, are bearing well toward the gage side. Wheel No. 3 on the inner rail, which gives high lateral on the inner rail at low speeds, is also bearing at the inner edge of the rail, as is No. 10 on the other end. The pattern in this figure will be helpful in determining how to distribute the lateral play for reduction of the lateral forces.

Moving pictures were taken of the wheels of the locomotive on the inner rail by a camera between the rails so as to show the relative position of the flange with respect to the rail head. Most of the wheels ride with the flange close to the rail (inner) for the 5 and 20-mph speeds, but at 30 mph most of the flanges are away from the rail. There was little lateral force on the inner rail at 30 mph.

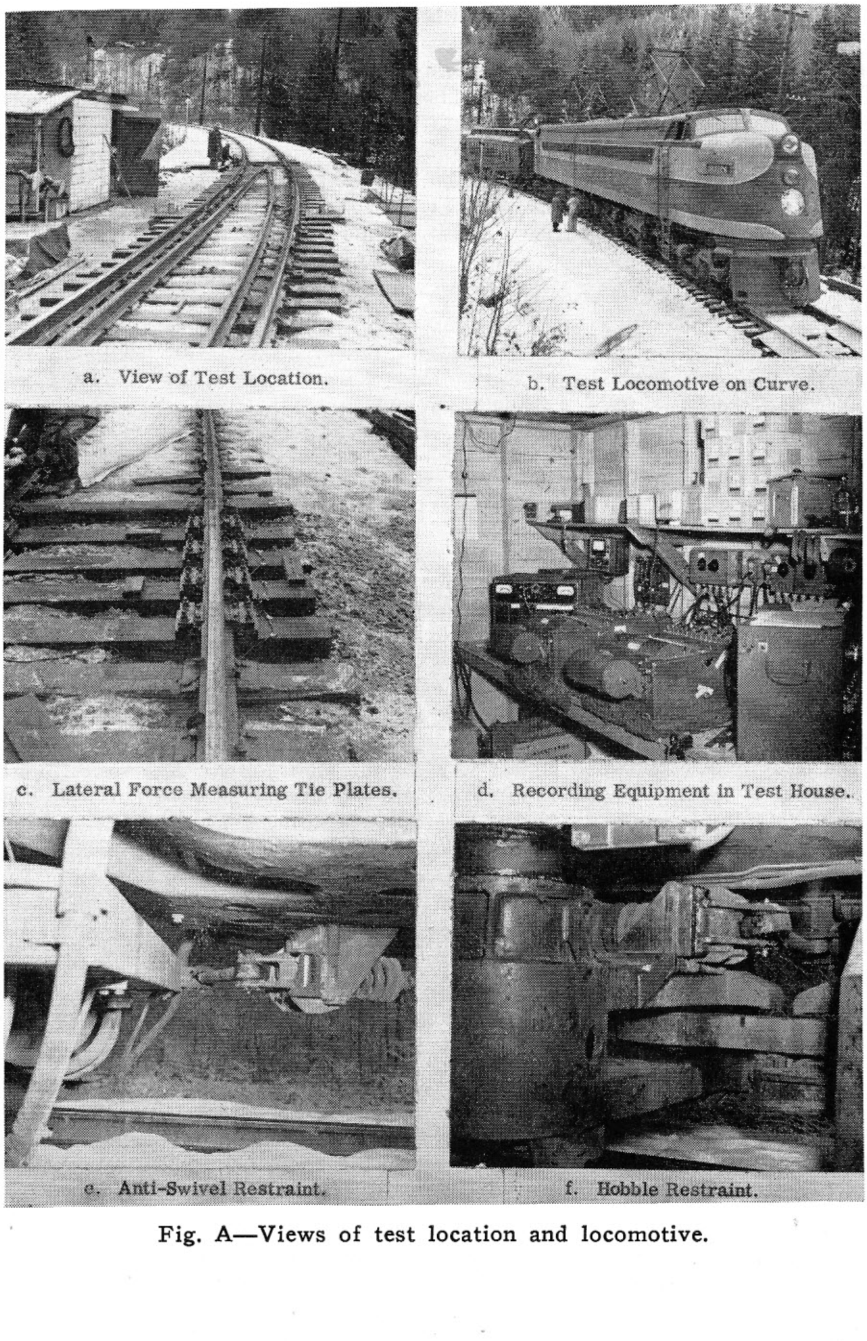
V. LATERAL FORCES AND VERTICAL WHEEL AND AXLE LOADS FOR OTHER LOCOMOTIVES

A three-unit diesel-electric locomotive was made available and the runs were made with it as a matter of general interest and for comparison with the electrics. Previous tests on other roads had shown the diesel-electric locomotives to be very easy on sharp curves compared to similar size steam power. The results for diesel-electric No. 308 ABC are shown in Figs. 10 and 10–a, eastbound on the test train (up grade, pulling). The lateral forces are quite low, hardly any being over 5000 lb, and the vertical wheel loads quite uniform for a given speed. Of course, there is a transfer from inner to outer rail as the speed increases, but only a few wheels are over 40,000 lb, and those only slightly. The loads at any one wheel have a stair step variation for the three speeds, being ascending to the right for the outer rail and the opposite for the inner rail, indicating the changes were largely due to variation of the centrifugal force only. Visual and auditory observations at the test location confirmed these results in that the diesel-electric passed around the curve without appreciable squealing or grinding or twisting of the rail, all of which were very evident with the electrics as they traveled around the curve. Similar results are shown for diesel-electrics in the previously mentioned report on lateral forces in steam locomotives.

Records were also taken with Great Northern diesel-electric No. 410 ABCD, a four-unit helper in an eastbound freight at 14 mph (Figs. 20 and 20–a). This locomotive developed even lower lateral and vertical loads than the No. 308. Fig. D gives the wheel spacing and other data for this locomotive.

The stresses and lateral forces under other types of electric locomotives were recorded as they passed by in regular traffic during the time of the tests on the regular test locomotive. It was found that under certain conditions one of these other classes of locomotives developed lateral and vertical loads similar to those found with the test locomotive.

(The figures referred to in this report are presented on the immediately following pages.)



a. View of Test Location.

b. Test Locomotive on Curve.

c. Lateral Force Measuring Tie Plates.

d. Recording Equipment in Test House.

e. Anti-Swivel Restraint.

f. Hobble Restraint.

Fig. A—Views of test location and locomotive.

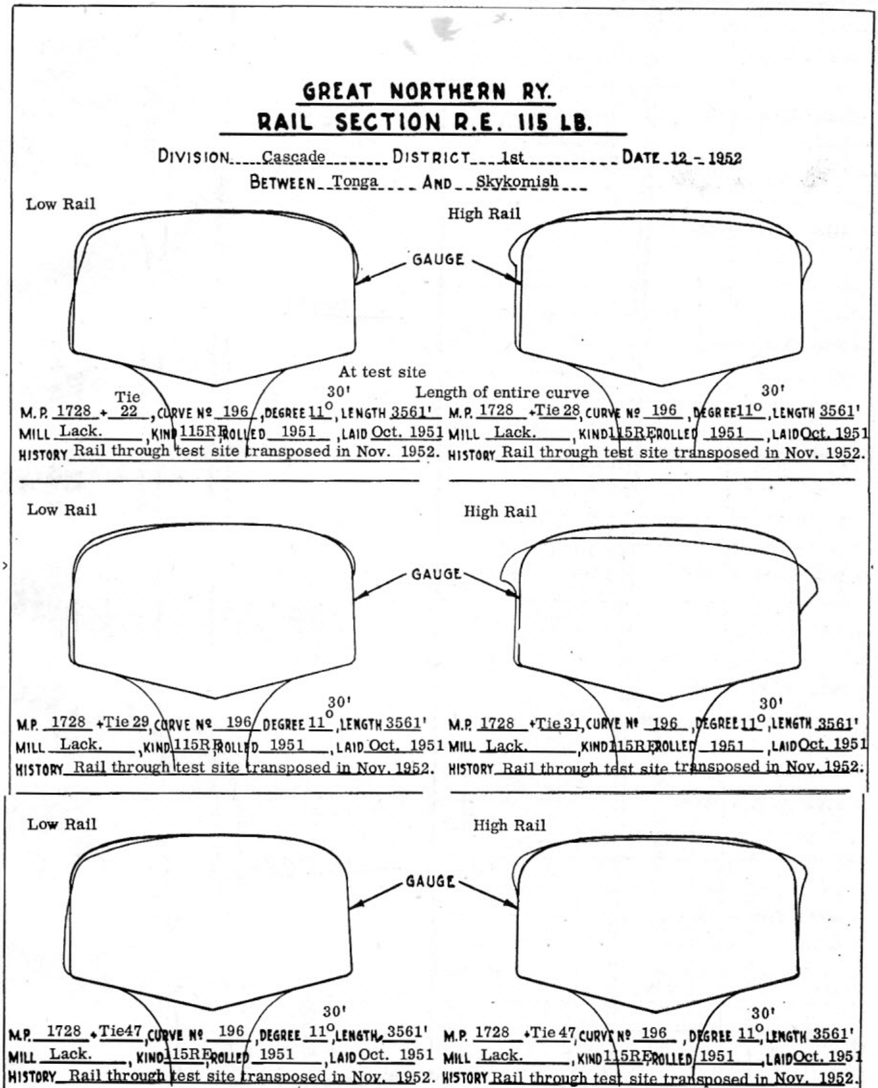


Fig. B. Sections of Rail Heads

A

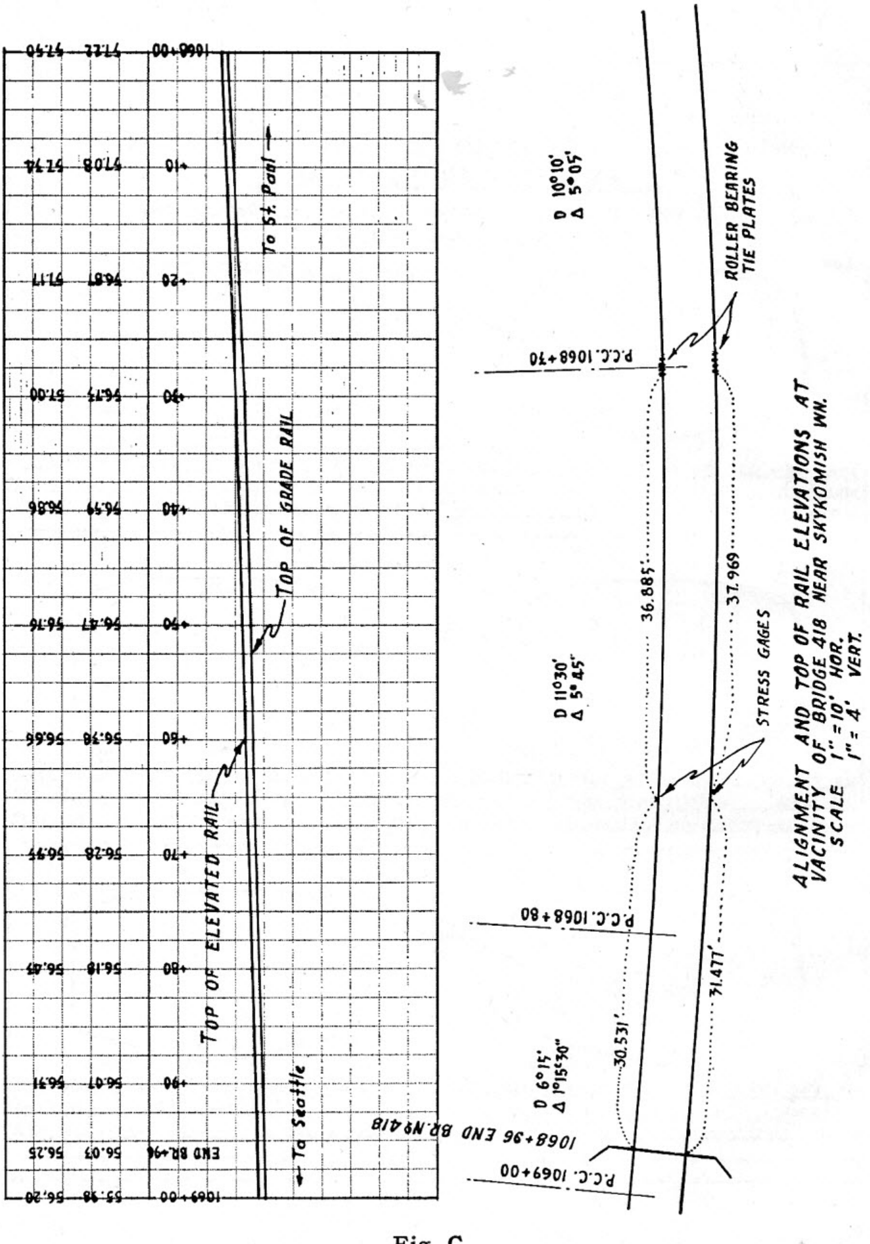
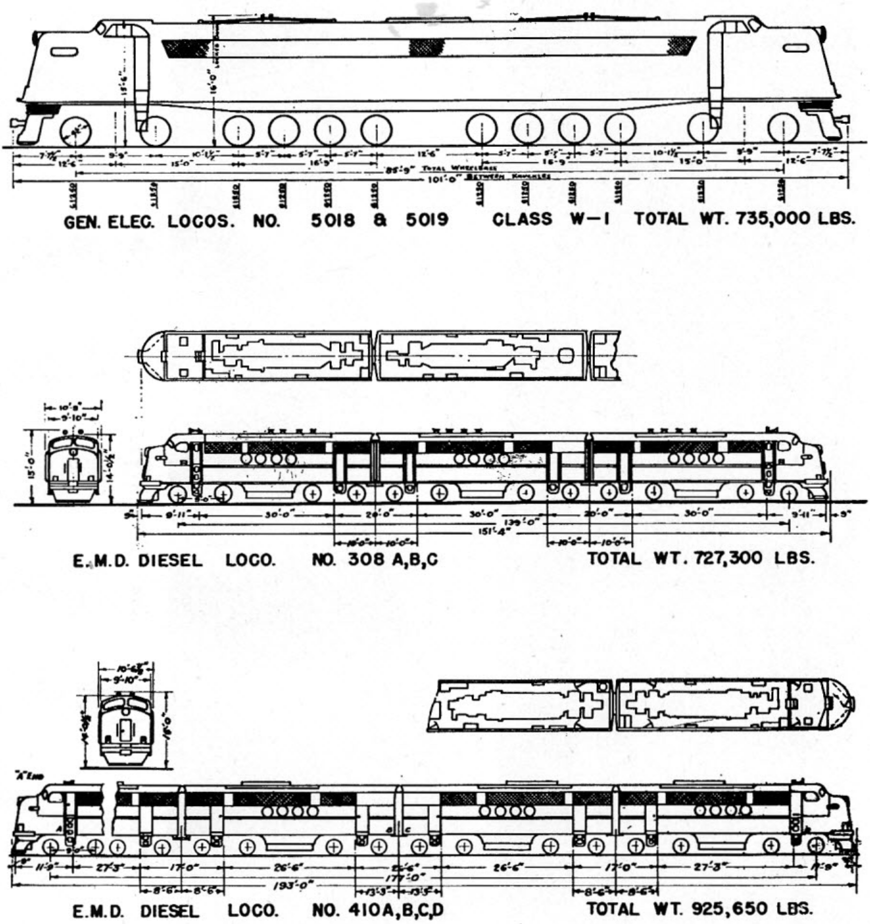


Fig. C.



AXLE LOADS & WHEEL SPACING OF LOCOMOTIVES

Fig. D.

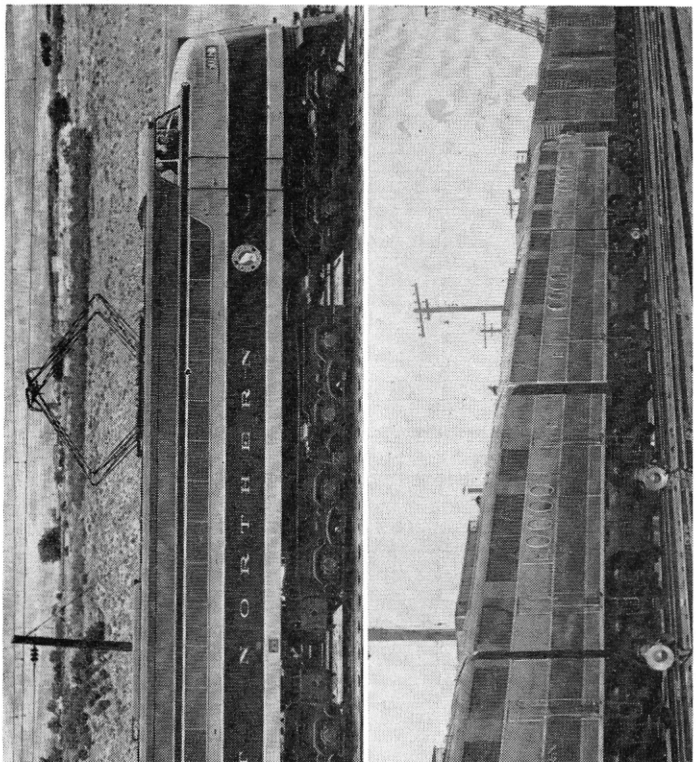


Fig. F—Views of test locomotive (Class W–1) and four-unit diesel.

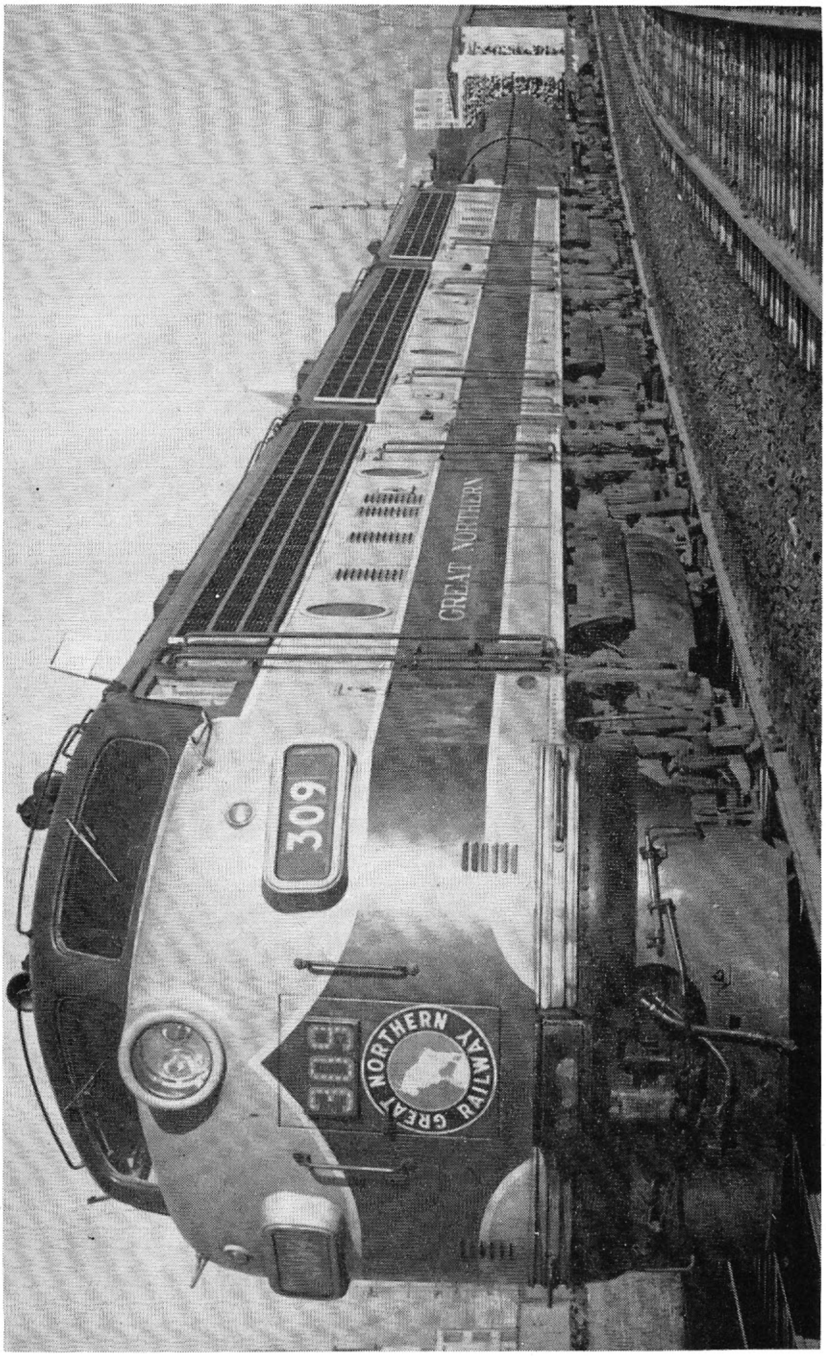
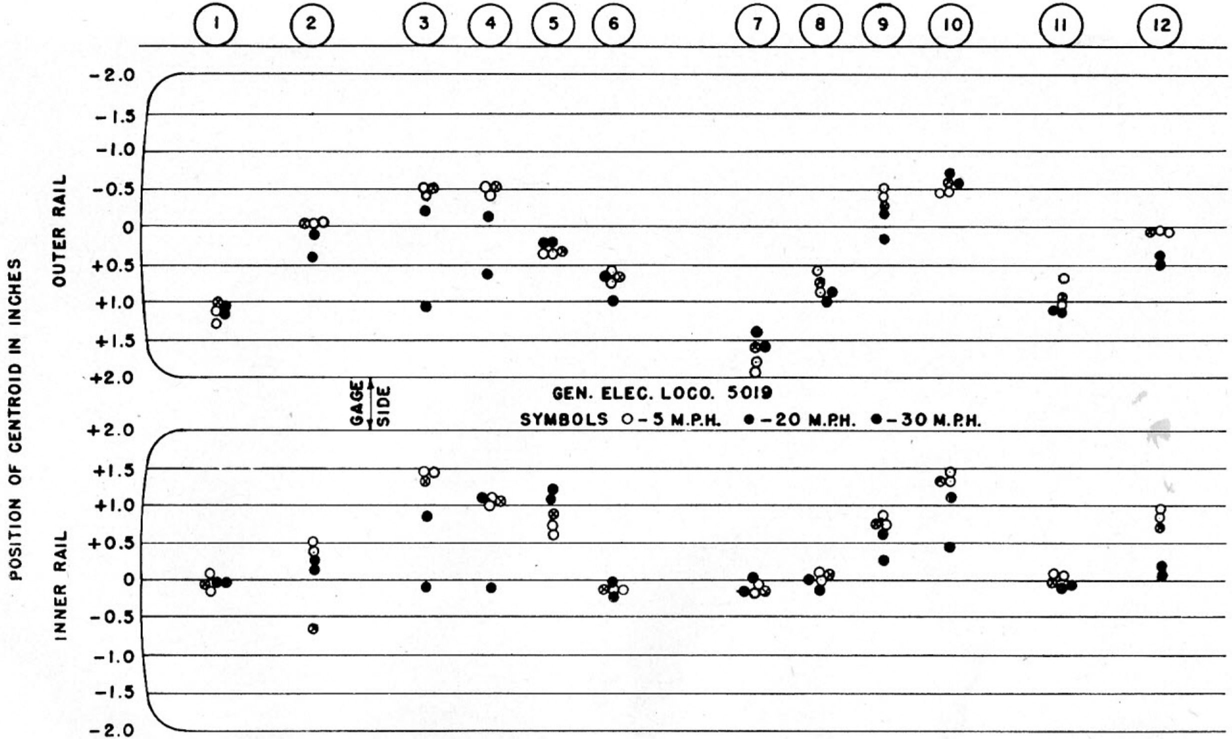


Fig. G—View of three-unit diesel.



POSITION OF CENTROID OF WHEEL BEARINGS ON 115 LB. RE RAIL HEADS AS DERIVED FROM VERTICAL RAIL WEB STRESSES ON 10° CURVE AT FOSS RIVER BRIDGE.

SERIES NO. 1 – RUNS 11 & 13, 15 & 17, 21 & 25.

Fig. L.

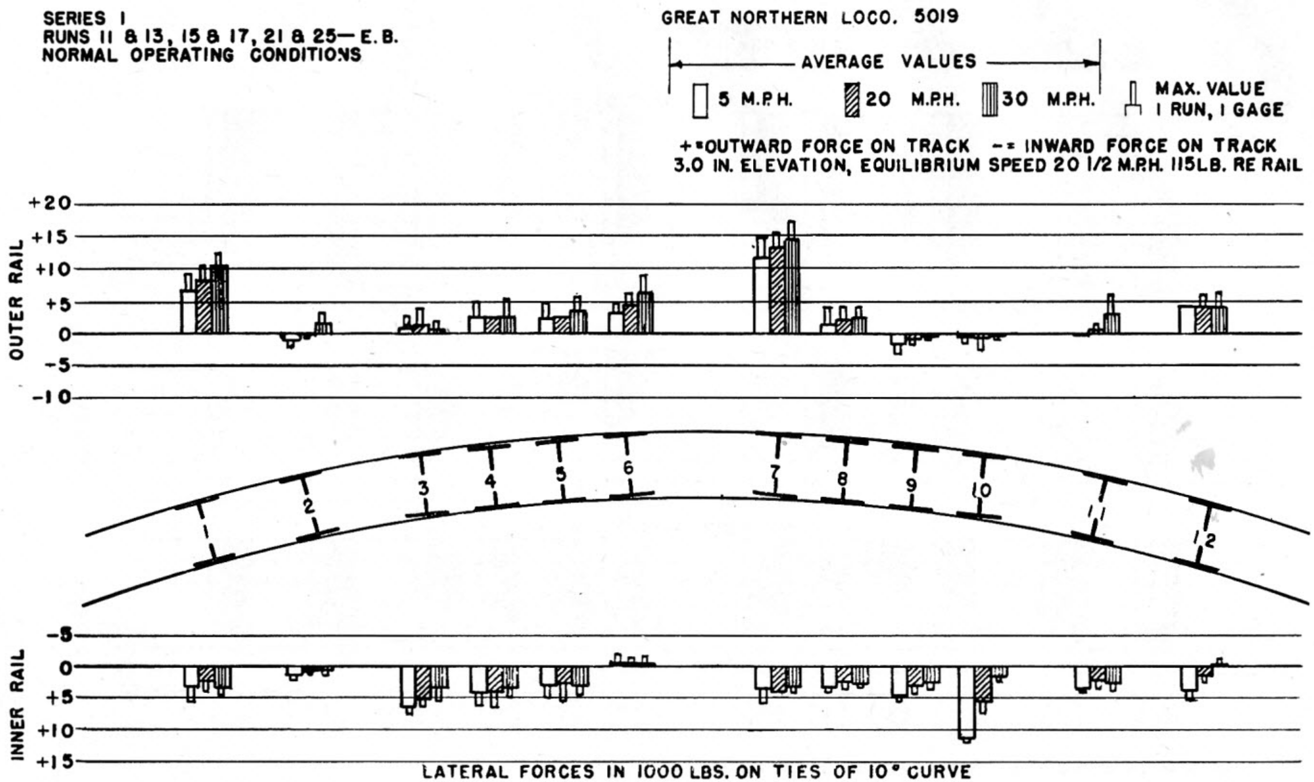


FIG. 1 — MEASURED LATERAL FORCES APPLIED TO THE TIES BY LOCOMOTIVE WHEELS.

SERIES I
RUNS 11 & 13, 15, 21 & 25 – E.B.
NORMAL OPERATING CONDITIONS

GREAT NORTHERN LOCO. 5019

AVERAGE VALUES: 5 M.P.H. | 20 M.P.H. | 30 M.P.H. — MAX. VALUE 1 RUN, 1 GAGE

3.0 IN. ELEVATION, EQUILIBRIUM SPEED 20 1/2 M.P.H. 115 LB. RE RAIL

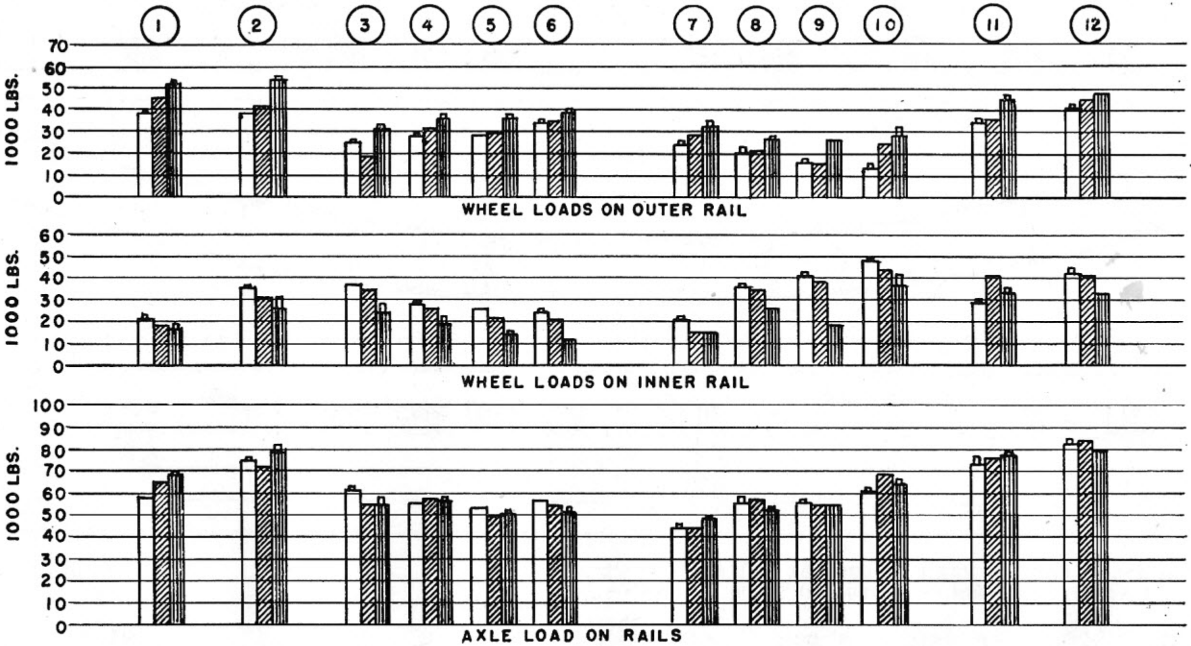


FIG. 1a – VERTICAL WHEEL AND AXLE LOADS DERIVED FROM DIRECT RAIL WEB STRESS ON THE 10-DEG. CURVE AT FOSS RIVER BRIDGE.

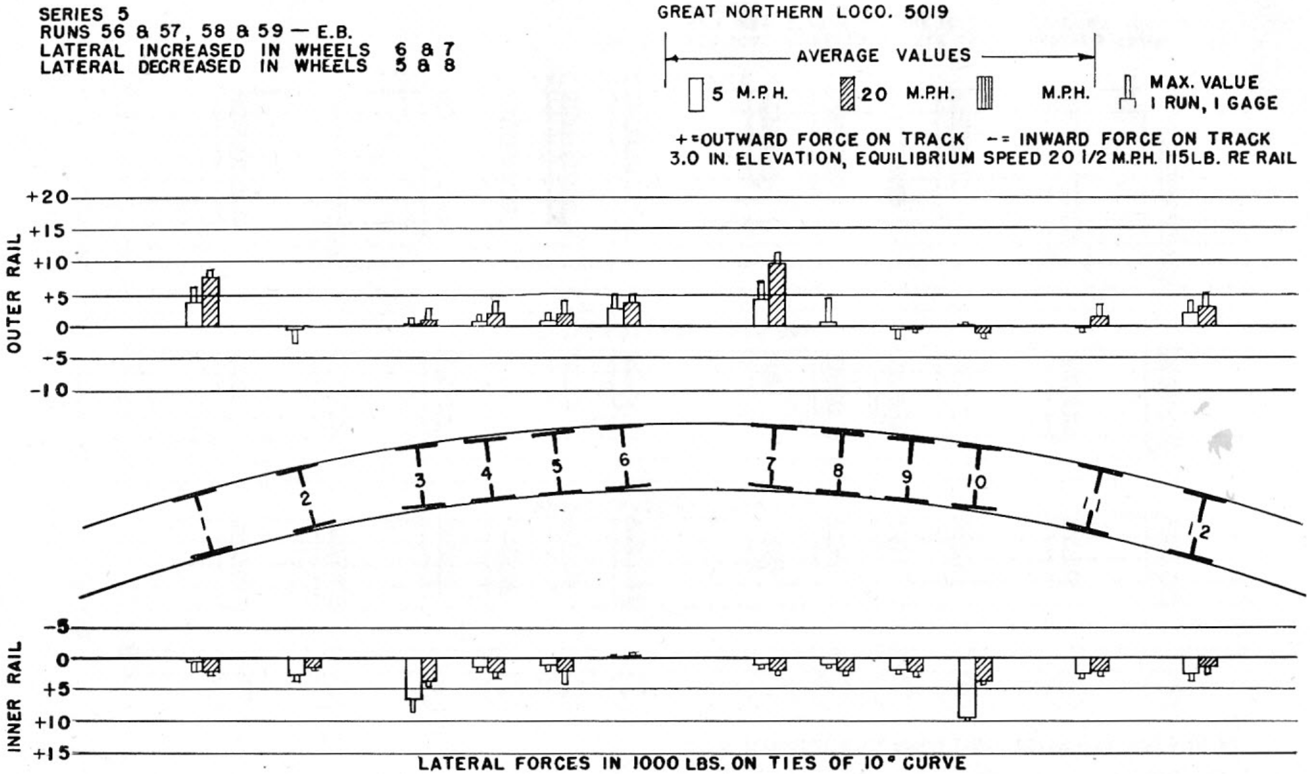


FIG. 5 — MEASURED LATERAL FORCES APPLIED TO THE TIES BY LOCOMOTIVE WHEELS.

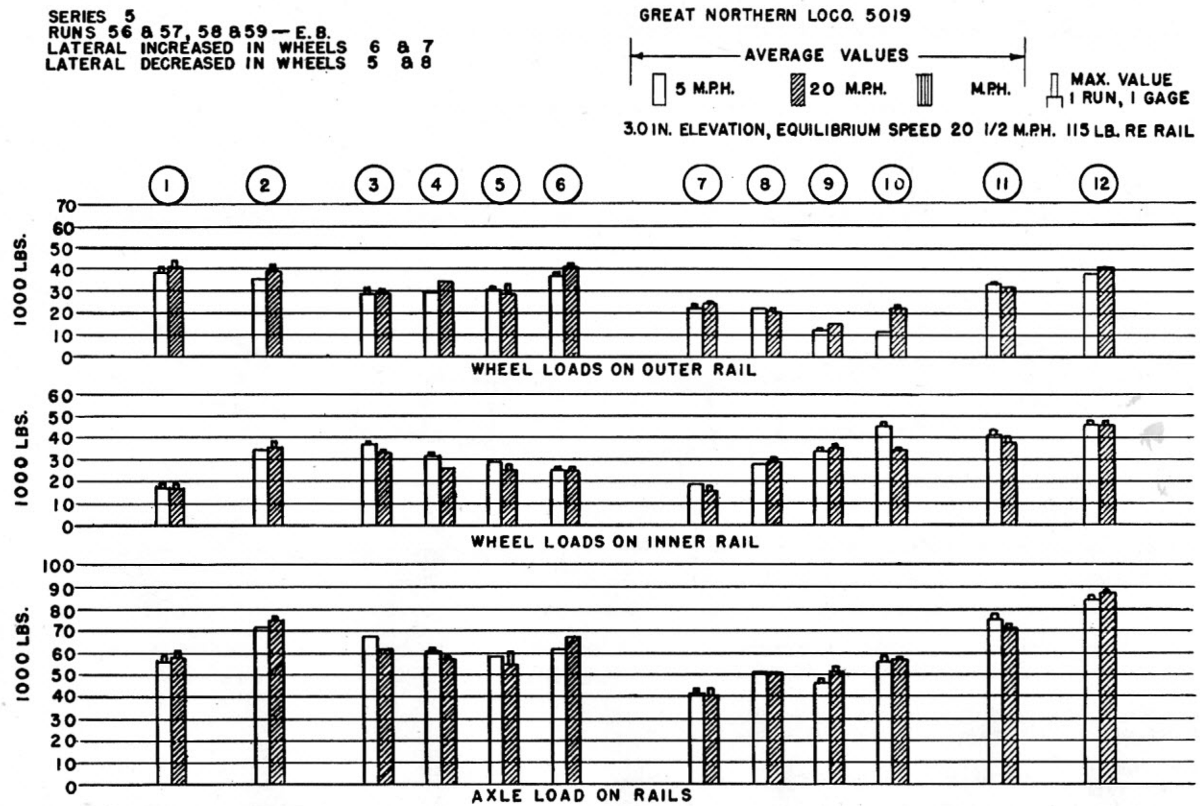


FIG. 5a— VERTICAL WHEEL AND AXLE LOADS DERIVED FROM DIRECT RAIL WEB STRESS ON THE 10-DEG. CURVE AT FOSS RIVER BRIDGE.

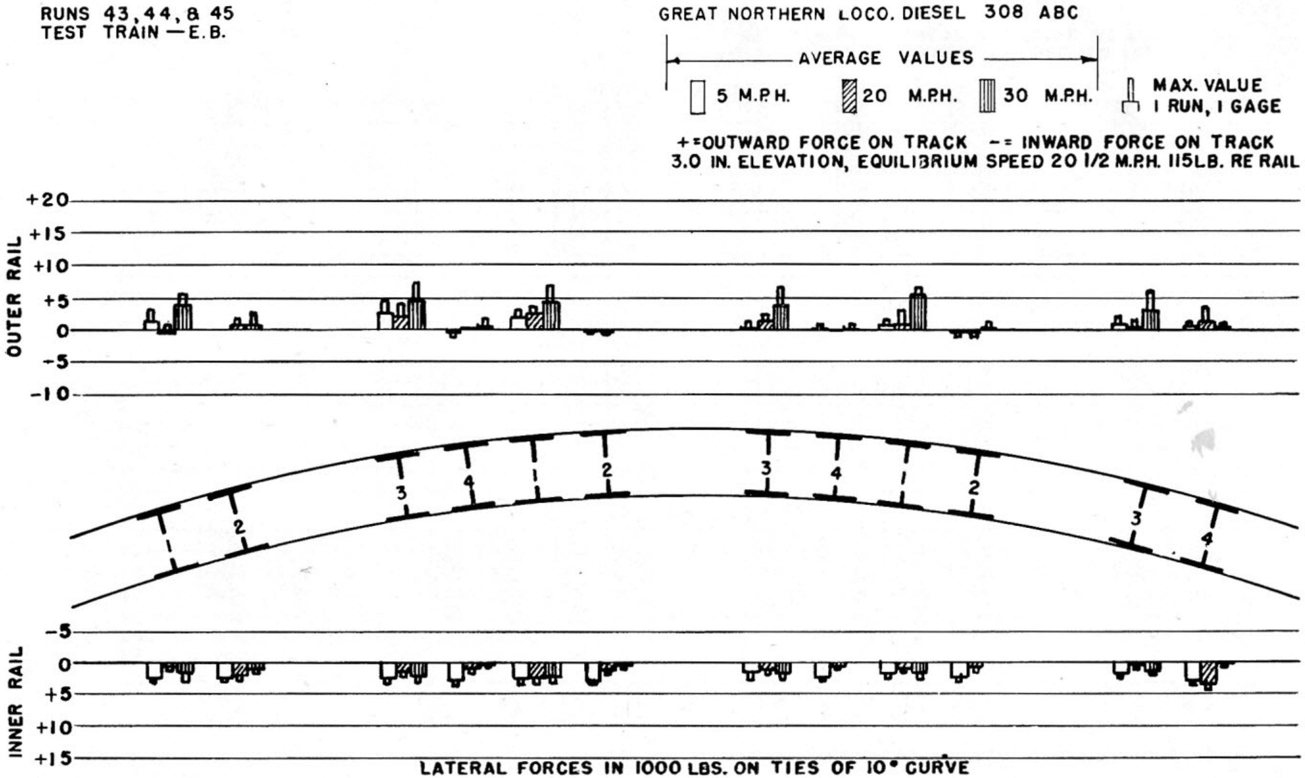


FIG. 10 — MEASURED LATERAL FORCES APPLIED TO THE TIES BY LOCOMOTIVE WHEELS.

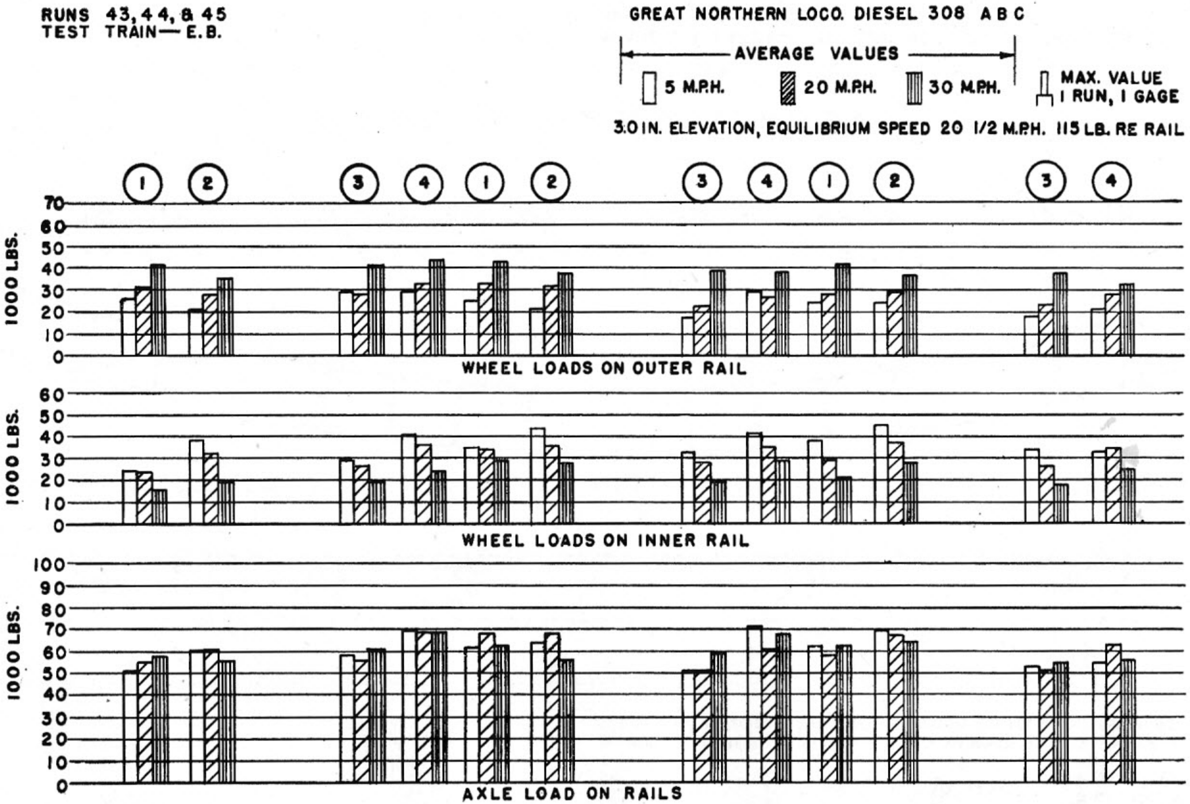


FIG. 10a— VERTICAL WHEEL AND AXLE LOADS DERIVED FROM DIRECT RAIL WEB STRESS ON THE 10-DEG. CURVE AT FOSS RIVER BRIDGE.

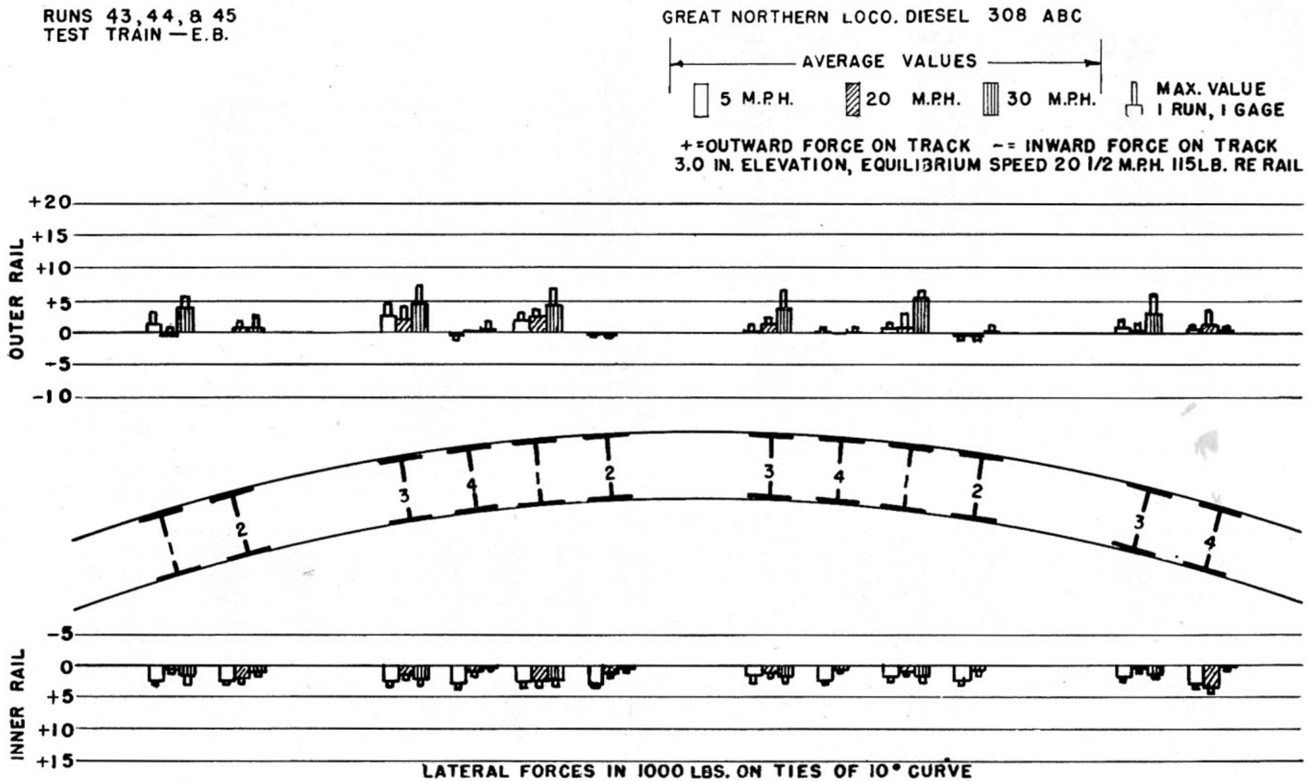


FIG. 10 — MEASURED LATERAL FORCES APPLIED TO THE TIES BY LOCOMOTIVE WHEELS.

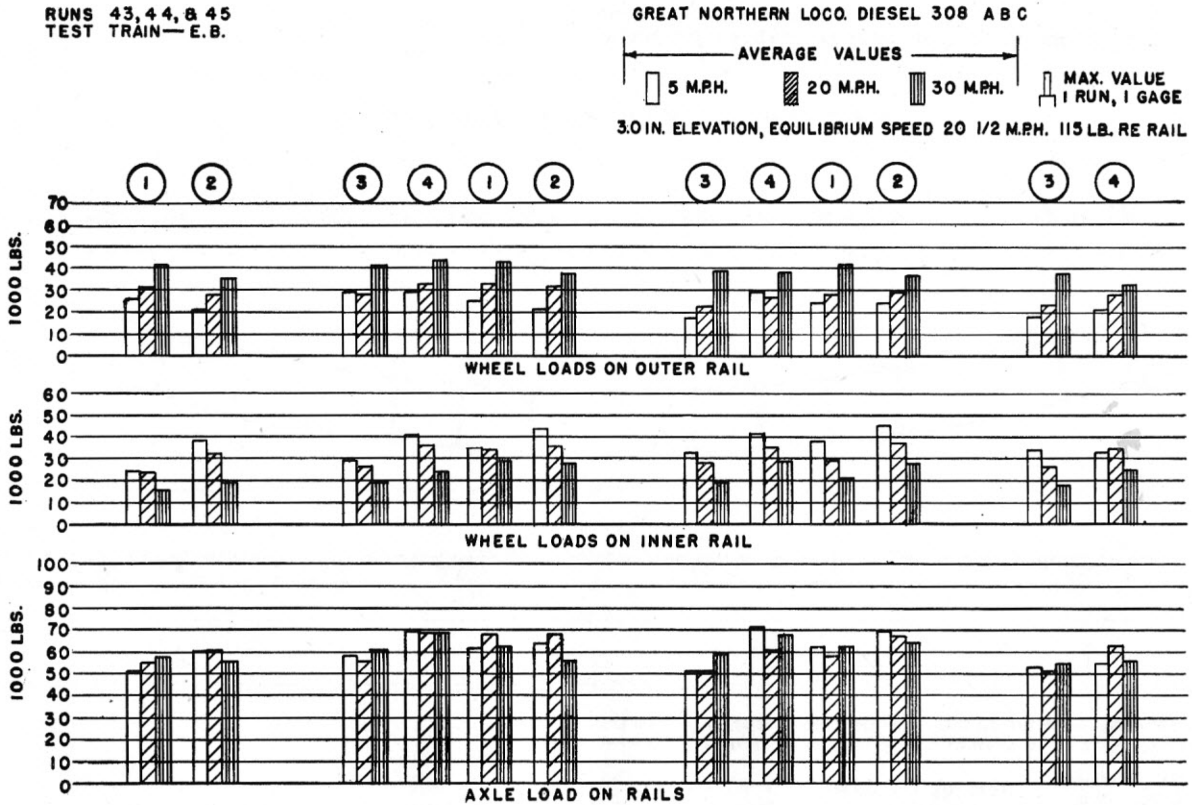


FIG. 10a— VERTICAL WHEEL AND AXLE LOADS DERIVED FROM DIRECT RAIL WEB STRESS ON THE 10-DEG. CURVE AT FOSS RIVER BRIDGE.

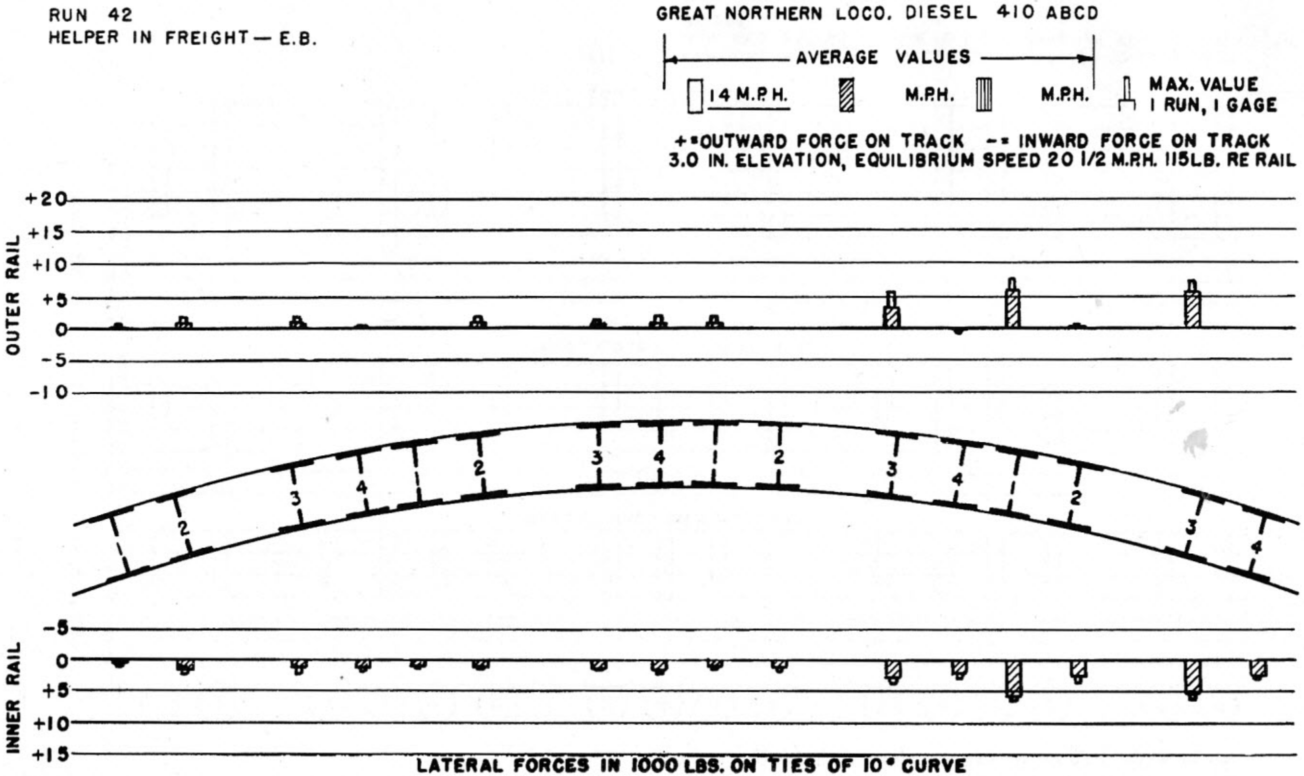


FIG. 20 —MEASURED LATERAL FORCES APPLIED TO THE TIES BY LOCOMOTIVE WHEELS.

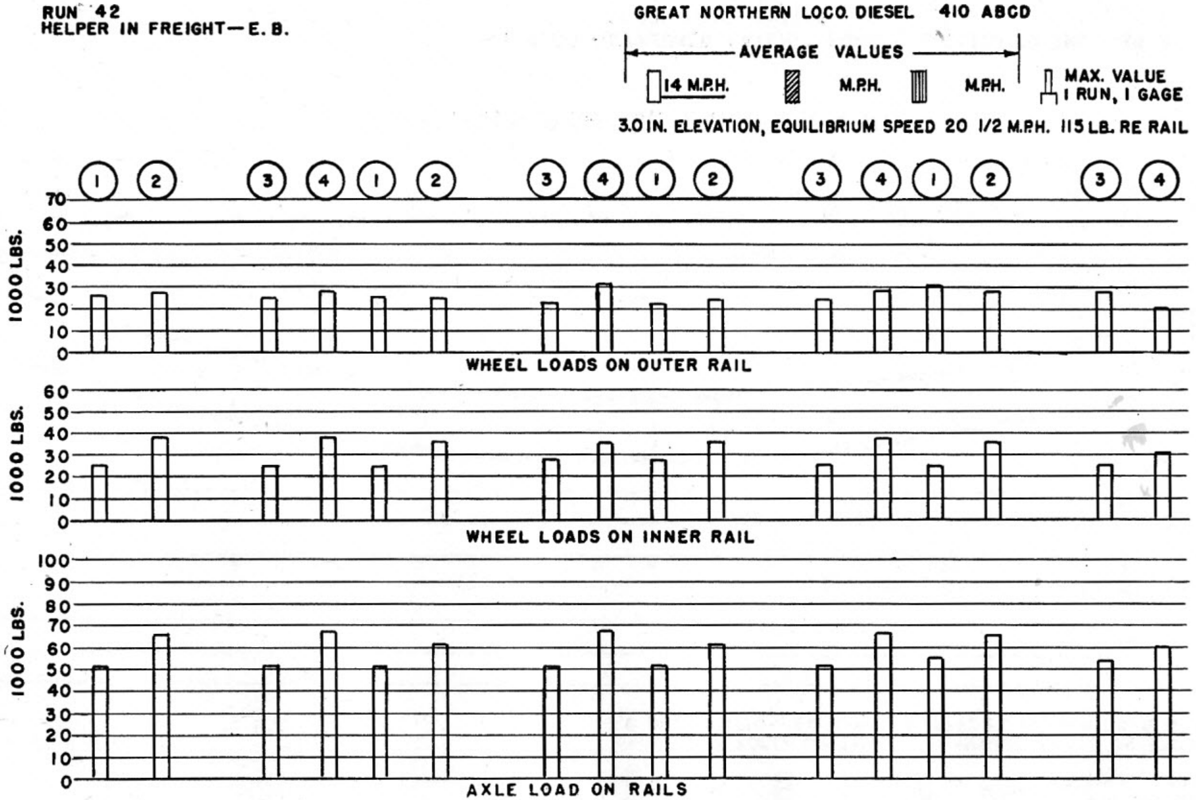


FIG. 20a VERTICAL WHEEL AND AXLE LOADS DERIVED FROM DIRECT RAIL WEB STRESS ON THE 10-DEG. CURVE AT FOSS RIVER BRIDGE.

PROCEEDINGS

OF THE

FIFTY-THIRD ANNUAL CONVENTION

OF THE

American Railway Engineering Association

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