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Staff Study, HRS-11

16. Abstract

This research study involved the load testing and structural analysis of eight typical State Highway Department inlet grates; six roadway and two median grates. Other grate variables were: steel or cast iron, shape of grate members, and flat or sloped installed grate surface. The objectives of the study were: (1) to determine the structural behavior of the selected grates under static and dynamic wheel loads, (2) to develop criteria for designing inlet grates on the basis of structural strength and behavior, and (3) to make recommendations for possible revision of Federal Specification RR-F-621b (dated 9/14/67), "Frames, Covers, Gratings, Steps, Sump and Catch Basin, Manhole", which may be used for acceptance of inlet grates.

The inlet grates were subjected to incremental static wheel loads up to 10,000 pounds and 6000-pound rolling and impact dynamic wheel loads. Each grate was also subjected to flat plate load tests to determine the ultimate load capacity and mode of failure. Computer analyses were made to determine whether the behavior of the subject grates under static wheel loads could be predicted.

This report contains the results of the static and dynamic loading tests, and recommended criteria for the structural design of inlet grates.

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ACKNOWLEDGEMENTS

The research study described herein was suggested by the Federal Highway Administration Office of Engineering. The Region 15 Demonstration Projects Committee assisted in the selection of inlet grates. The California, Colorado, Delaware, Idaho, Kansas, Maine, and Virginia State Highway Departments supplied two sets of each of the selected inlet grates and frames. Many other State Highway Departments expressed strong interest in this project, and offered grates for study.

The authors express appreciation to the personnel of the State Highway Departments and Federal Highway Administration region and division offices who have assisted in obtaining inlet grate plans and the grates which were evaluated in this study. Thanks are also expressed to the Federal Aviation Administration personnel at Dulles International Airport for their permission to construct the field test site on an airport access road, and for their assistance during the field tests.

The assistance of Federal Highway Administration Region 15 personnel in the design and construction of the field test site, and in conducting the field tests is acknowledged. Special appreciation is expressed for the assistance of Messrs. Ronald Nelson, Harry Laatz, Richard Nay, and other members of the Bridge Structures Group, Structures and Applied Mechanics Division, Office of Research, in all phases of this study.

Form FHWA 121 (Rev. 5-73)

UNITED STATES GOVERNMENT

Memorandum

DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

DATE: July 10, 1974

In reply refer to: HRS-11

SUBJECT: Transmittal of Research Report No. FHWA-RD-73-90 "Evaluation of the Structural Behavior of Typical Highway Inlet Grates, with Recommended Structural Design Criteria"

FROM: Director
Office of Research
Washington, D.C. 20590

TO: Regional Federal Highway Administrators
Regions 1, 3-10 and Regional Engineer, Region 15

Distributed with this memorandum is the subject report which contains information of interest to structural and hydraulic engineers responsible for the design or selection of highway inlet grates. Sufficient copies of this report are being distributed to provide two copies for each Regional Office, one copy for each Division Office and the standard number of copies for each State Highway or Transportation Department.

In general, the optimum design of inlet grates must include considerations of the following factors: (1) hydraulic efficiency, (2) vehicle safety, (3) protection against vandalism, and (4) structural adequacy. This report is addressed primarily to the latter consideration. The FHWA Office of Development, Implementation Division, is currently requesting proposals for a contract to develop a "Manual for the Design of Safe and Effective Storm Sewer Inlet Grates."

This report describes the load testing and structural analysis of eight typical State Highway Department inlet grates; six roadway and two median grates. The grate specimens were provided by State Highway Departments and the Region 15 Demonstration Projects Division assisted with the field test portion of the research. Grate variables were: steel or cast iron, shape of grate members, and flat or sloped installed grate surface. The objectives of the study were: (1) to determine the structural behavior of the selected grates under static and dynamic wheel loads, (2) to develop criteria for designing inlet grates on the basis of structural strength and behavior, and (3) to make recommendations for possible revision of Federal Specification RR-F-621b (dated 9/14/67), "Frames, Covers, Gratings, Steps, Sump and Catch Basin, Manhole," which might be used for acceptance of inlet grates.

A limited number of additional copies of this report are available for official use from the Bridge Structures Group (HRS-11), Structures and Applied Mechanics Division, Office of Research. Additional copies for the public are available from the National Technical Information Service (NTIS), Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22151. A small charge will be imposed for each copy ordered from the NTIS.

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1. INTRODUCTION

At the request of the Federal Highway Administration Office of Engineering, the Structures and Applied Mechanics Division has conducted a structural research study on typical highway inlet grates. This was the result of a survey which was taken by the Office of Engineering which indicated the following: (1) Most of the inlet grates in service throughout the United States are very heavy; often requiring two men and lifting devices to place them. (2) Very few State Highway Departments have "modern" criteria for designing inlet grates on a structural basis. Some grates are designed for hydraulic capacity. (3) Some State Highway Departments fabricate grates and then proof test them in accordance with Federal Specification RR-F-621b (described in Section 3.3 of this report). However, this is not a requirement for Federal Aid construction. (4) Many State Highway Departments do not have standard designs for inlet grates. In at least one State over 100 different sizes and shapes of inlet grates are used.

As a result of the above survey, the need for a structural research study on highway inlet grates was recognized. Subsequently the State Highway Departments were requested to supply the Office of Engineering with copies of the plans for their most typical inlet grates. These plans were reviewed, and eight styles of inlet grates from seven States were selected for study. The Highway Departments of those States supplied two duplicate sets of the grates and frames for testing. These grates provided the following variables for evaluation: location used - roadway and median; material - steel and cast iron; shape of structural members - plate, I-beam, double-extra strong pipe, variable sections; surface position - flat and inclined.

In general, the optimum design of inlet grates must include consideration of the following factors; (1) hydraulic efficiency, (2) vehicle safety, (3) protection against vandalism, and (4) structural adequacy. This study is addressed primarily to the latter consideration.

2. EXPERIMENTAL STUDY

2.1. Objectives.

The objectives of this study were as follows.

1. To determine the structural behavior of the selected inlet grates under static and dynamic wheel loading conditions.

2. To develop criteria for designing inlet grates on the basis of structural strength and behavior.

3. To make recommendations for revising the existing Federal Specification pertaining to inlet grates (RR-F-621b), if that is desirable.

2.2. Scope.

The subject research study involved the following four phases of work.

In the laboratory each of the roadway grates was subjected to incremental static wheel loading tests, up to 10,000 lbs., to determine their structural response characteristics. Although the highest level of loading was above normal service load conditions it did provide data to evaluate extreme conditions. Measurements were taken to determine the strain and deflection distribution among each of the individual bars of each grate.

At a field installation each of the inlet grates was subjected to 6000-lb. rolling and impact truck wheel loading tests, to determine their response to typical dynamic (in-service) loading conditions. The truck speed for these tests ranged from crawl speed (about 1 mph.) to 50 mph. Impact loadings were achieved by running the truck off a 2-1/4-in. high ramp, positioned so that the 6000-lb. wheel would land on the center of the grate. Measurements were taken to determine the midspan strain distribution in each member of the grate and the deflection at the centerpoint of the grate.

In the structural laboratory the second specimen of each grate type was statically loaded to failure. The loads were applied on a 9- by 9- in. square steel plate, in accordance with Federal Specification RR-F-621b. Although this specification is essentially a proof test, which evaluates the acceptability of grates at a 25,000-lb. load level, the loadings were increased until the grates either fractured or the ultimate load capacity of the grate was reached. The data from these tests were also used to evaluate the test method itself, by comparing them against the data from the static wheel loading tests.

In addition to the above structural tests the "theoretical" structural behavior of each of the roadway grates was calculated by using an electronic computer and a program for a structural analysis for grid systems. The results of these calculations were compared to the results of the static wheel load tests, to determine whether conventional methods of structural analysis can be used to design inlet grates.

3. METHODS OF TEST AND COMPUTER STRUCTURAL ANALYSIS

3.1. Static Wheel Load Tests.

The object of this phase of the study was to determine the behavior of the inlet grates under incremental static loads applied by a typical truck wheel. Figure 1 shows a general view of the test arrangement.

The inlet grates were subjected to incremental loading up to 10,000 lbs., through an 11.00-20, 12 ply, triple tread truck tire, which was inflated to 85 psi. As a personnel safety precaution 90 percent of the tire volume was filled with water, prior to inflation with air. The tire and tube was mounted on a 3-piece flat rim with an axle making the wheel assembly.

The inlet grate frame was cast into a reinforced concrete box, which served as a mounting fixture for the inlet grate. A thin layer of plaster grout was placed on the seating edge of the frame prior to setting the grate, to eliminate irregularities in the contact surfaces and to assure an even bearing.

The loading assembly consisted of two parallel, triangular, structural steel frames which were connected at the apexes by 3/4-in. diameter rods. The upper frame held the wheel assembly, which was centered at the centroid of the triangle; and the lower frame supported the inlet grate box. The load was applied by drawing the frames together by turning the nuts on the connecting rods, thereby forcing the wheel down on the inlet grate. The grate was oriented so that the longitudinal grate bars were parallel with the longitudinal axis of the wheel, as the grates were installed in the field. The wheel loads were adjusted by monitoring full-bridge SR-4 strain gages on each of the rods. Each of the rods was essentially a load cell, for which load/strain curves were established by calibrating them in a universal testing machine.

Deflection and bending strain of each grate bar was measured at the midspan of the grate. Deflections were read to the nearest 0.0001 in. on Ames dials. Strain gages were bonded to the underside of each grate bar, at their midspan centerline, to obtain bending strains.

3.2. Dynamic Wheel Load Tests.

The object of this phase of the study was to determine the behavior of the inlet grates under "typical" service load conditions. Figure 2 shows several pictures which were taken during this test series.

For these tests the right rear dual wheels of a dump truck were removed, and replaced with the single 11.00-20 tire and wheel which was used for the laboratory tests. The truck was loaded with sand to

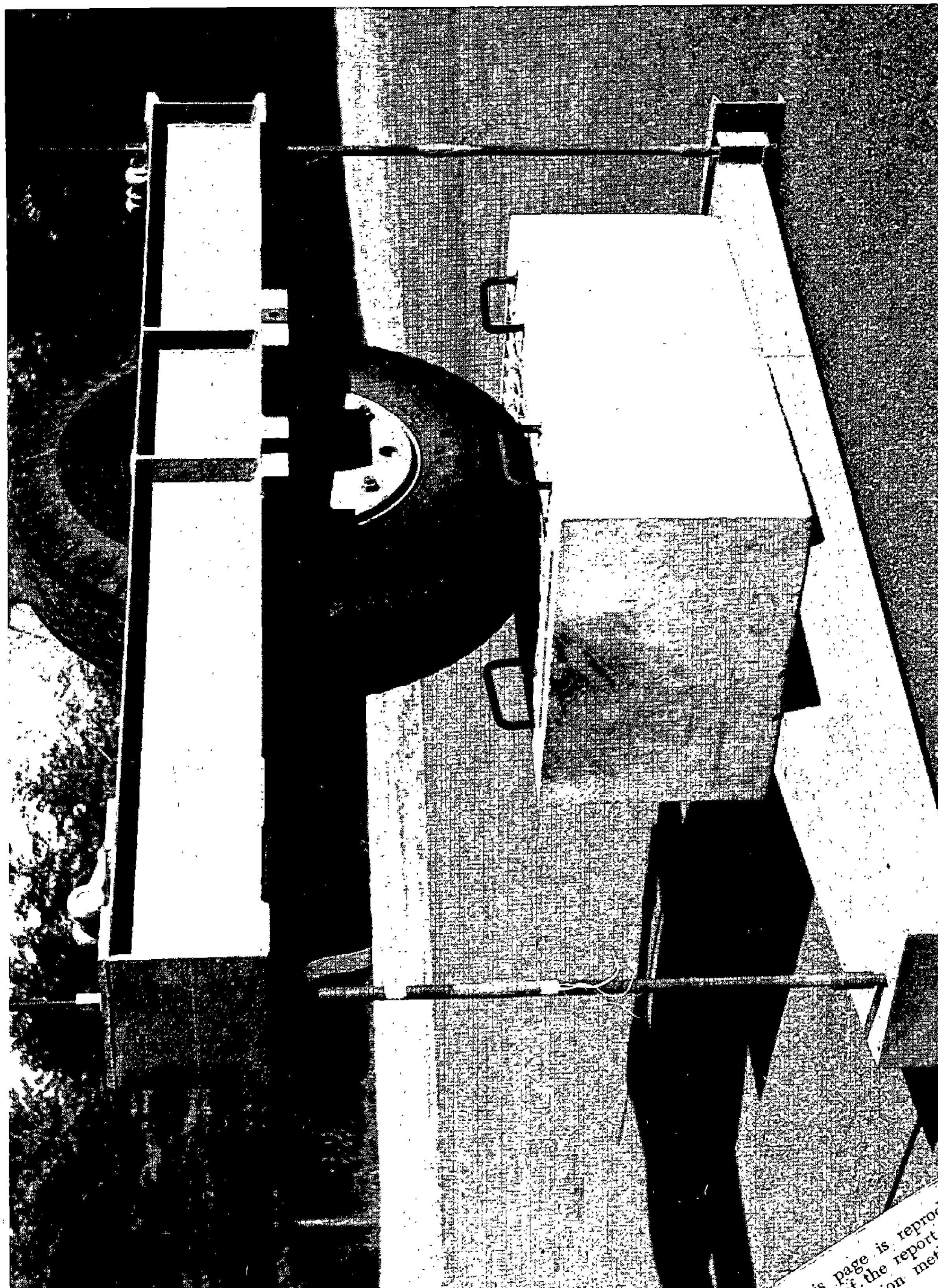

Figure 1. Static Wheel Load Test Arrangement

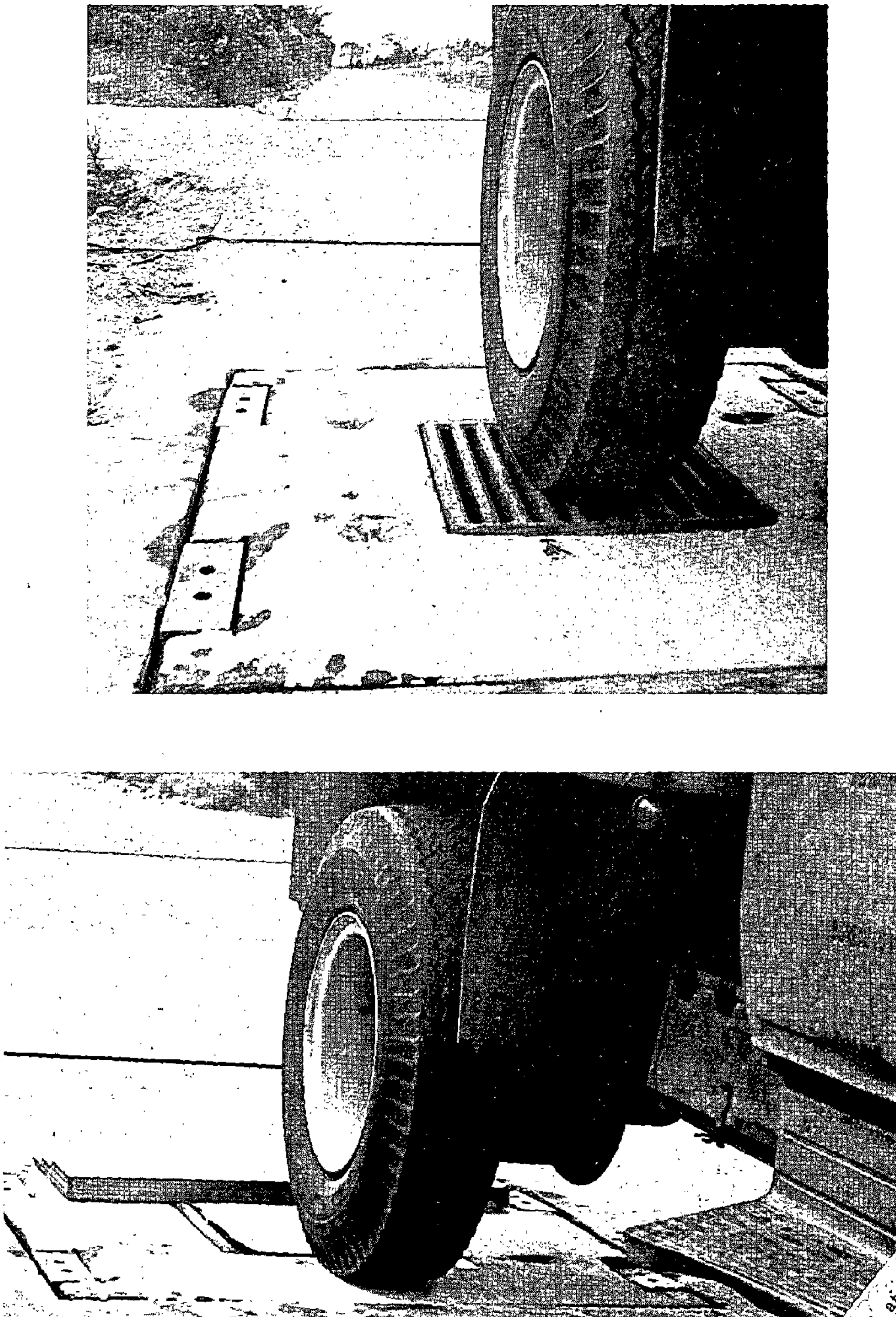

Figure 2. General View of Field Test Site

provide a 6,000-lb. load on the test wheel; which simulated an AASHO H-15-44 truck loading. Rolling and impact wheel loads were applied to each of the grates at speeds which ranged from 1 to 50 mph. Impact loads were applied by driving the truck over a 2-1/4-in. high ramp, as shown on Figure 2. The lateral position of the wheel loads were "recorded" on heavy brown paper which was taped over the grate.

For the field tests a special facility was constructed on a little used service road at Dulles International Airport, in Northern Virginia. In the surface treated road a 45- by 14-ft. by 7-in. thick reinforced concrete slab was cast on a 10-in. thick crushed stone base course to provide a strong and smooth platform to hold the inlet grates and to permit smooth truck passages. A 5- by 5- by 1-1/2-ft. deep, reinforced concrete box was cast into the right wheel-path in the pavement slab, to provide a universal holder for each of the inlet grates. The frame for each inlet grate was cast into reinforced concrete sections which were inserted into the universal box in the roadway slab. Each frame insert was adjusted so that the grate was level with the top surface of the roadway slab, and set into a rapid setting, high-strength mortar to provide uniform bearing. For the sloping grates, their edge nearest the center of the road was made level with the roadway and the grate sloped upward towards the edge of the road. A cold-mix asphalt ramp was placed on the roadway slab to permit a smooth truck passage over these grates.

Deflection of the centerpoint of the grate and bending strain at the midspan of each grate bar was recorded on an oscillograph. The deflection was recorded from a cantilever beam deflection gage which was placed on the bottom of the concrete box, and connected to the grate centerpoint.

3.3. Static Plate Load Tests.

The primary objective of this phase of the study was to determine the behavior of the inlet grates under the plate loading conditions cited in Federal Specification RR-F-621b (dated September 14, 1967), "Frames, Covers, Gratings, Steps, Sump and Catch Basin, Manhole." (1)[1/] In addition, the loading was increased beyond the specified 25,000-lb. load criteria until the grate either fractured or the ultimate load capacity of the grate was reached.

The Federal Specification provides a proof load test which may be used for acceptance of highway inlet grates, but there is some indication that few highway departments use this specification. It is not a requirement for Federal Aid construction. The following is excerpted from the specification.

1/ Numbers in parentheses identify references shown in Section 8 of the report

"Proof-load test. The frames and covers or gratings selected shall show no permanent deformation when the proof-load (25,000 lb.) is concentrated on a 9- by 9-inch area placed on the cover or grate (through a rubber pad). The specified load shall be applied by a suitable testing machine and held for a period of one minute. Upon removal of the load, the cover or grating and frame shall be examined for cracks, or permanent deformation, such as buckling. Any cracks or permanent deformation, shall be cause for rejection."

For these tests the loads were applied to the grates in the reinforced concrete boxes which were used for the static wheel load tests. The loads were applied through a 9- by 9- by 1-1/2-in. thick steel plate and a 1/2-in. thick, 60-durometer hardness rubber pad. To apply vertical loads to the sloped surface grates an additional trapezoidal, high-strength mortar block was used. These tests were conducted in a universal testing machine.

As with the dynamic wheel load tests, deflection of the centerpoint of the grate and bending strain at the midspan of each grate member was recorded on an oscillograph. In addition, the mode of failure and the location of yield hinges were recorded.

3.4. Computer Analysis.

A structural analysis of the grates, subjected to static wheel loads, was made by using the computer program "Analysis of Two-Dimensional Grid Structures." (2) This provided computed valued for flexural and tosional moments, shear, and deflection for each position of the wheel on the grates for the selected load increments. Midspan strain in the longitudinal and transverse grate members were subsequently calculated from bending moments, assuming a linear strain distribution. Loading for the computer analysis assumes that the effective width of tire tread contact is equal to the grate member width. Analyses were based on the tireprint data discussed in Section 5.1. of this report and measured lengths of tire contact on each grate member.

4. DESCRIPTION OF INLET GRATE TEST SPECIMENS

4.1. Inlet Grate "A".

This is a galvanized, nine bar welded steel roadway grate, with no transverse stiffeners. External dimensions of the grate are 3 ft. 4 in. by 1 ft. 5-5/8 in. The longitudinal bars and end plates have a 3-1/2- by 1/2-in. cross section. The weight of the grate (excluding the frame) is 191 lb. A fabrication drawing of this grate is shown on Figure 3.

4.2. Inlet Grate "B".

This is a galvanized, ten bar welded steel roadway grate, with eight transverse stiffener rods. The cross rods and the bearing bars are electroforged into a one-piece construction. The numerous cross rods are provided as protection against bicycle and motorcycle accidents. The external dimensions of the grate are 3 ft. 4 in. by 1 ft. 5-5/8 in. The longitudinal bearing bars and the end plates have a 3-1/2- by 1/2-in. cross section. The smooth cross rods are 3/8 in.-diameter. The weight of the grate (excluding the frame) is 109 lb. A fabrication drawing is shown on Figure 4.

4.3. Inlet Grate "C".

This is a galvanized, six bar welded steel, sloped surface roadway grate, with two transverse rods on the bottom of the bearing bars. The external dimensions of this grate are 2 ft. 5 in. by 1 ft. 5-1/8 in. The bearing bars have a cross section of 3 by 5/8 in. The 5/8-in. thick end plates vary in height from 4-5/16 in. to 6-1/2 in. The smooth transverse rods have a diameter of 1/2 in. The weight of this grate (excluding the frame) is 168 lb. A fabrication drawing of this grate is shown on Figure 5.

4.4. Inlet Grate "D".

This is a nine bar welded steel, sloped surface roadway grate, with no transverse stiffeners. The external dimensions of this grate are 2 ft. 4-3/4 in. by 1 ft. 4-1/2 in. The longitudinal bearing bars and end bars have cross sections of 3 by 5/8 in. and 3 by 3/8 in., respectively. The weight of this grate (excluding the frame) is 144 lb. A fabrication drawing of this grate is shown on Figure 6.

4.5. Inlet Grate "E".

This is a nine bar, cast-iron roadway grate, with one transverse bar at the midspan. The external dimensions of the grate are 36 by 20 in. The longitudinal, transverse midspan, and end bars have a cross section of 2 by 1 in. The weight of this grate (excluding the frame) is 165 lb. A fabrication drawing of this grate is shown on Figure 7.

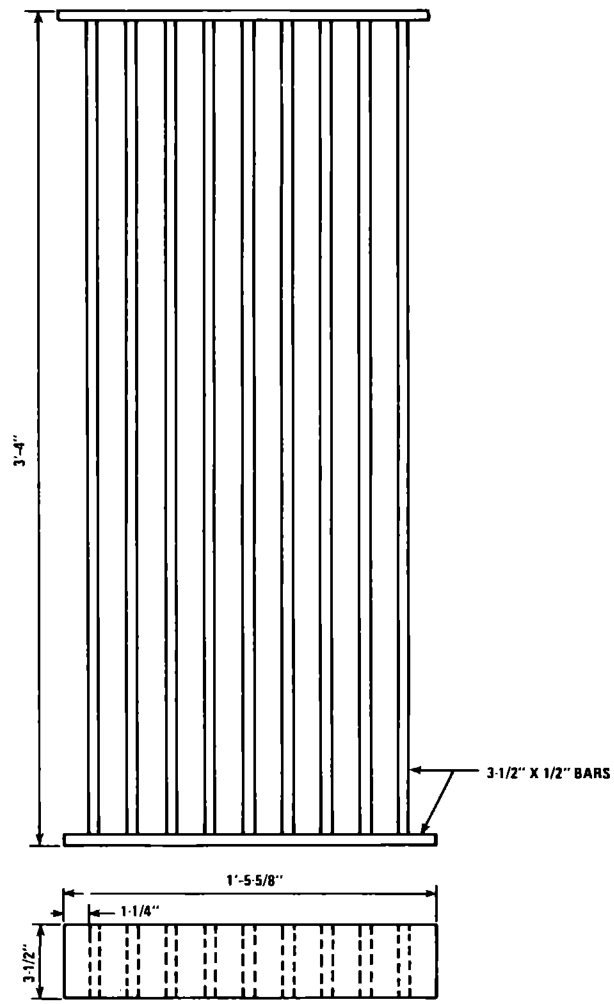

Figure 3. Inlet Grate "A"

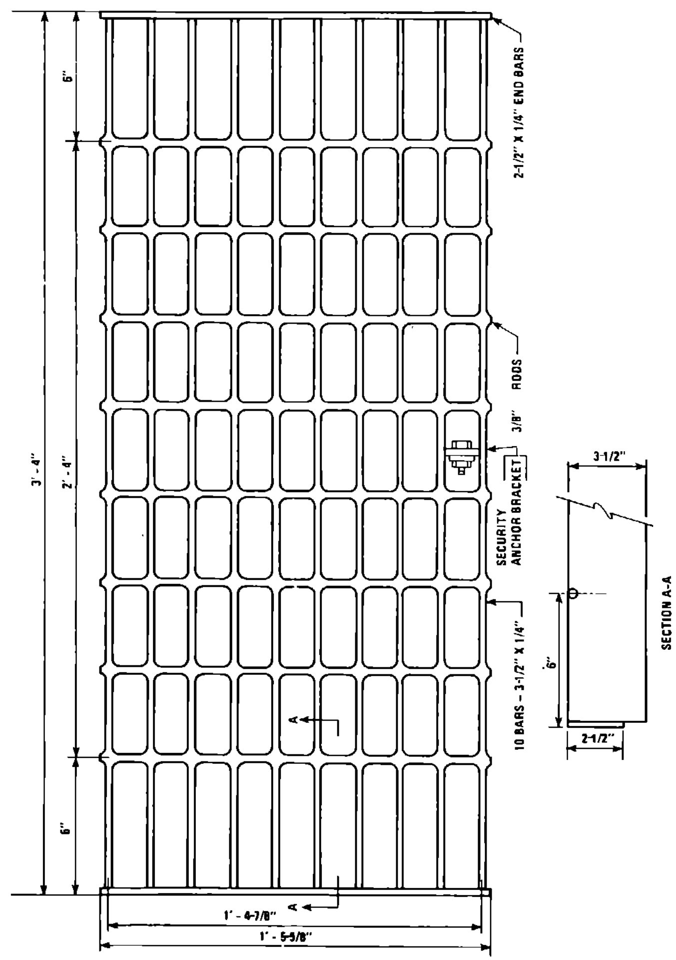

Figure 4. Inlet Grate "B"

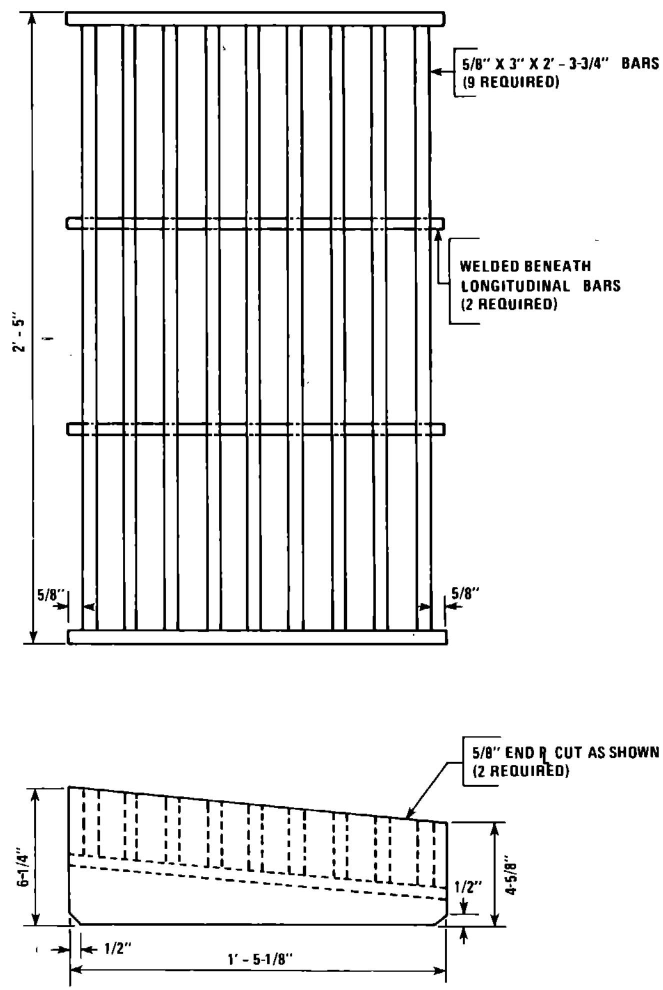

Figure 5. Inlet Grate "C"

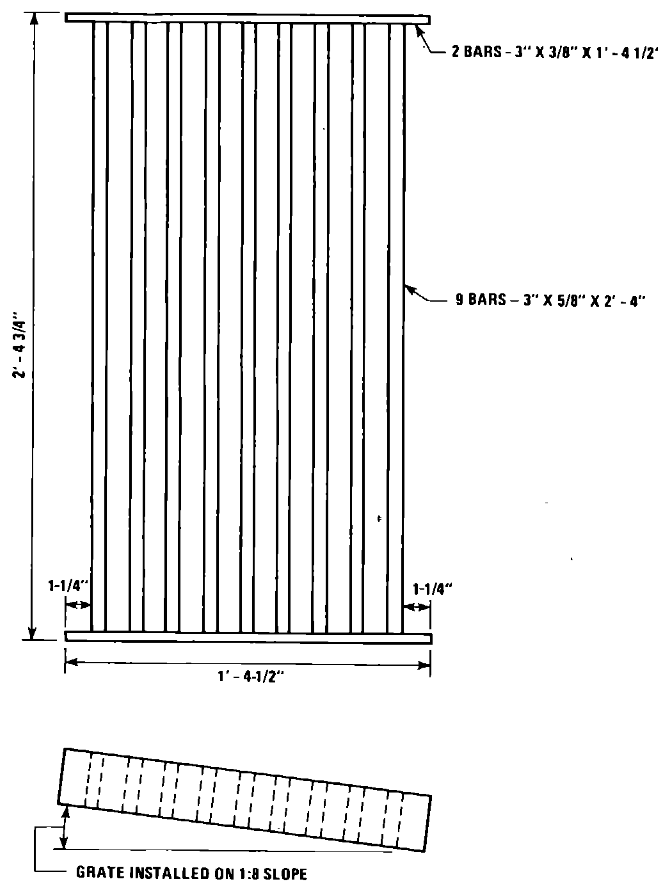

Figure 6. Inlet Grate "D"

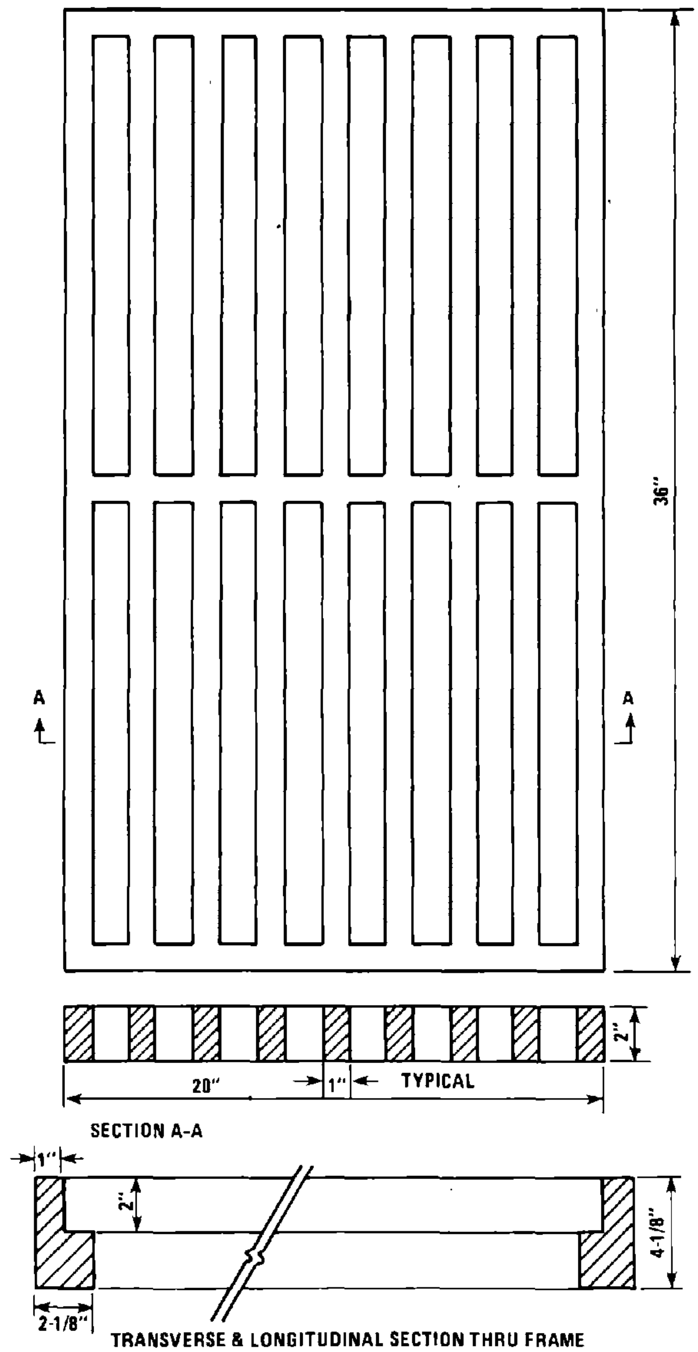

Figure 7. Inlet Grate "E"

4.6. Inlet Grate "F".

This is a cast-iron roadway grate, comprised of nine longitudinal bars enclosed in a box-shaped rim, with no transverse stiffeners. This square grate has external side dimensions of 23-7/8 in. All of the interior grate bars have a trapezoidal-shaped cross section and a bowed (underside) longitudinal profile, which varies in depth from 2 in. to 4-1/8 in. The weight of this grate (excluding the frame) is 224 lb. A fabrication drawing of this grate is shown on Figure 8.

4.7. Inlet Grate "G".

This is a galvanized, welded steel median grate, comprised of four (7.7 lb./ft.) I-beams connected at each end by two 3-1/2 by 1/4 in. plates. The external dimensions of this grate are 3 ft. 4-1/2 in. by 2 ft. 2-5/8 in. The weight of this grate (excluding the frame) is 131 lb. A fabrication drawing of this grate is shown on Figure 9.

4.8. Inlet Grate "H".

This is a galvanized, welded steel median grate, comprised of seven 1-1/2-in. diameter, double-extra strong pipes (6.41 lb./ft.), connected at each end with 2- by 2- by 3/8-in. angles. The external dimensions of this grate are 3 ft. 5 in. by 3 ft. The weight of this grate (excluding the frame) is 272 lb. A fabrication drawing of this grate is shown on Figure 10.

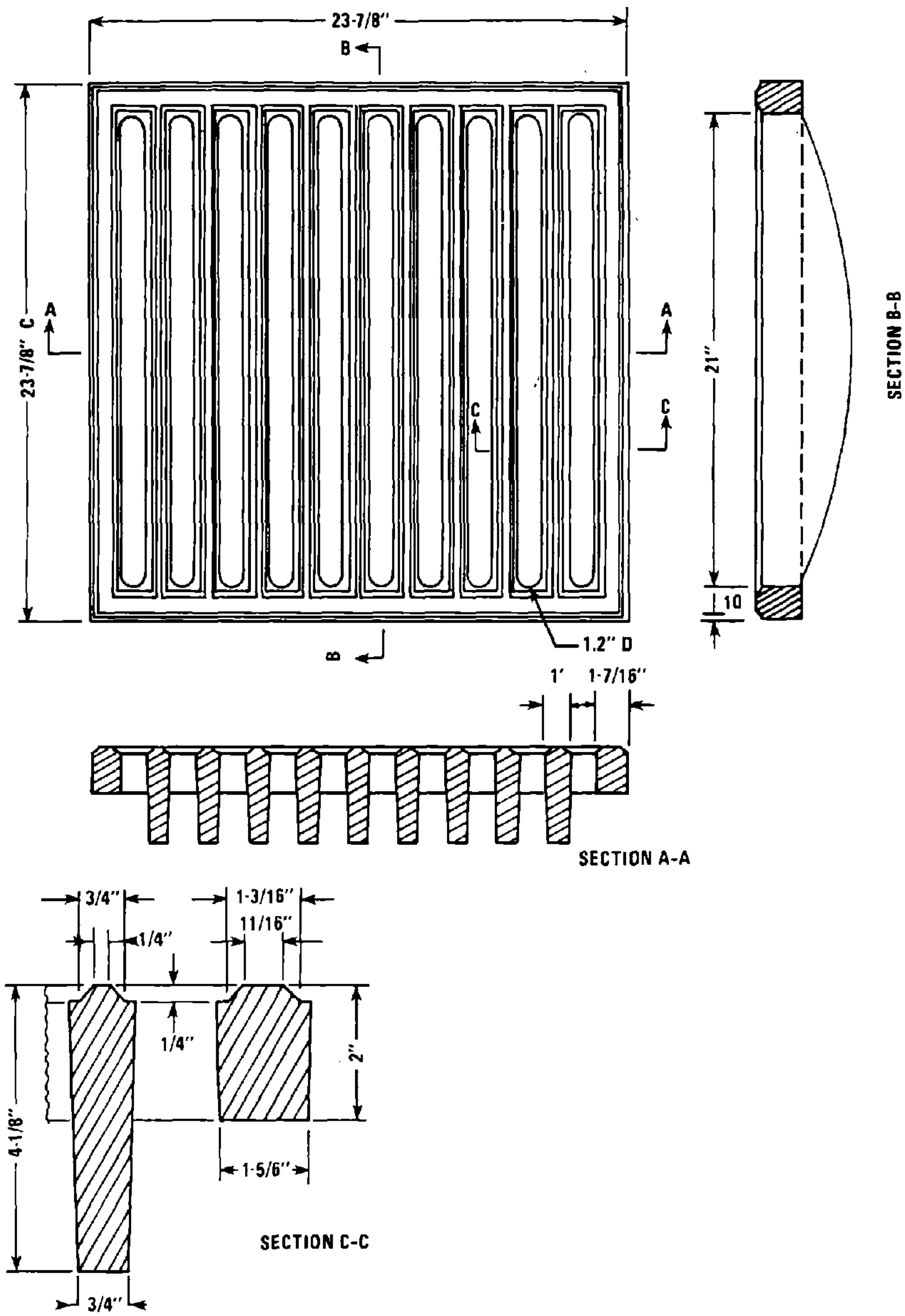

Figure 8. Inlet Grate "F"

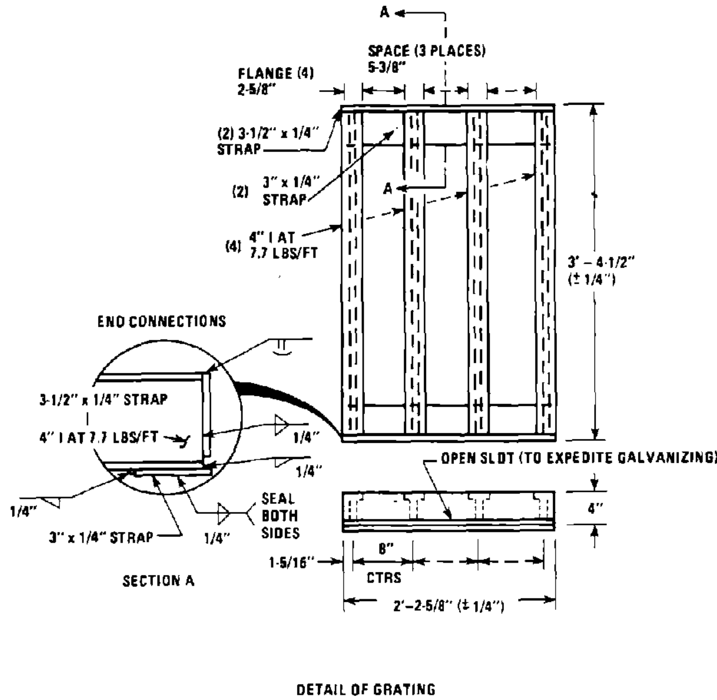

Figure 9. Inlet Grate "G"

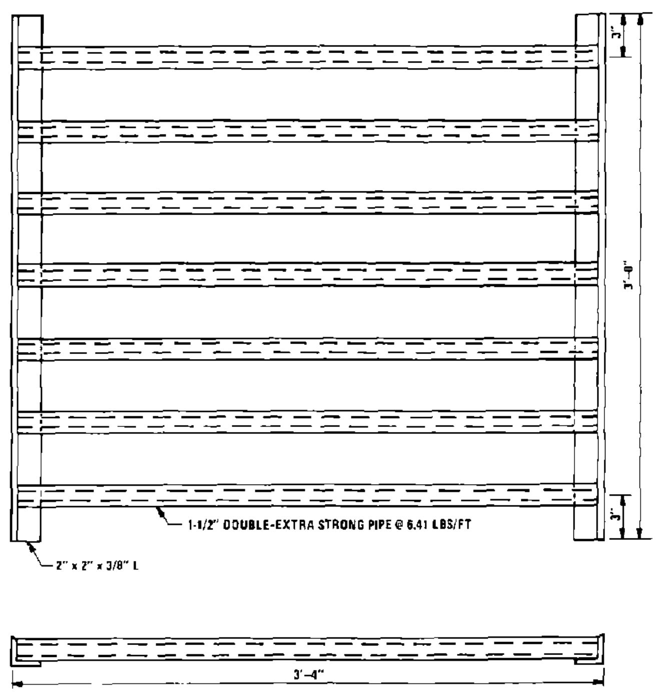

Figure 10. Inlet Grate "H"

5. DISCUSSION OF TEST RESULTS

5.1. Tire Contact Area Tests.

In order to make a computer analysis for the expected structural behavior of the inlet grates subjected to static tire loads it was necessary to develop tire contact area and contact length data at various load levels. The tire manufacturer did provide one tireprint, which was made at the 11.00-20 tire's rated load of 5920 lb (Figure 11). It may be seen that the print also shows measured pressure intensities over the contact area. By averaging the values of the pressure points over longitudinal strips of the tireprint the variation of unit tread pressure versus distance from the longitudinal centerline of the tire was calculated (Figure 12).

To develop a relationship between load and tire contact area additional tireprints were made at 2,500-, 7,500-, and 10,000-lb. loads. These tireprints were obtained by placing a piece of vellum paper on a 1/4-in. thick flat steel plate, on top of one of the concrete grate boxes. Tireprint impressions were obtained by coating the tire tread contact area with black paint and loading the tire on the vellum paper to the selected load level. The actual (net) tire contact area was calculated by subtracting the inscribed area of the tire grooves from the gross contact area. The relationship between net tire contact area and applied load is shown on Figure 13. It may be seen that this is not a linear relationship; which is most likely due to the stiffness of the tire sidewalls. Also shown on this figure is the relationship between average unit tire pressure and the applied load.

The above relationships described behavior of the truck tire on a flat plate surface, which does not directly apply to the behavior of a tire on a grate surface. Obviously the effect of the intermittent bar supports must be offset by an increase in the length of tread contact over that measured on a flat plate. Therefore, it was necessary to develop a relationship between tread contact length and applied load for each of the inlet grates. This was done by actually measuring the length of tread contact on each grate bar. Figure 14 shows a comparison between tread contact length versus load curves for a typical flat roadway grate (Grate "A") and a flat plate. The flat plate curves represent a superposition of bar spacing and area on the flat plate tireprints. This figure also shows the variation in tread contact length for tests in which the tire was applied to four and five grate bars.

The above relationships, represented by figures 12-14, apply only to the six flat grates which were tested in this study. As noted previously, two of the grates studied are either fabricated or installed with a sloping surface. Therefore, it was necessary to derive similar information for sloping grates. Figure 15 shows the derived variation

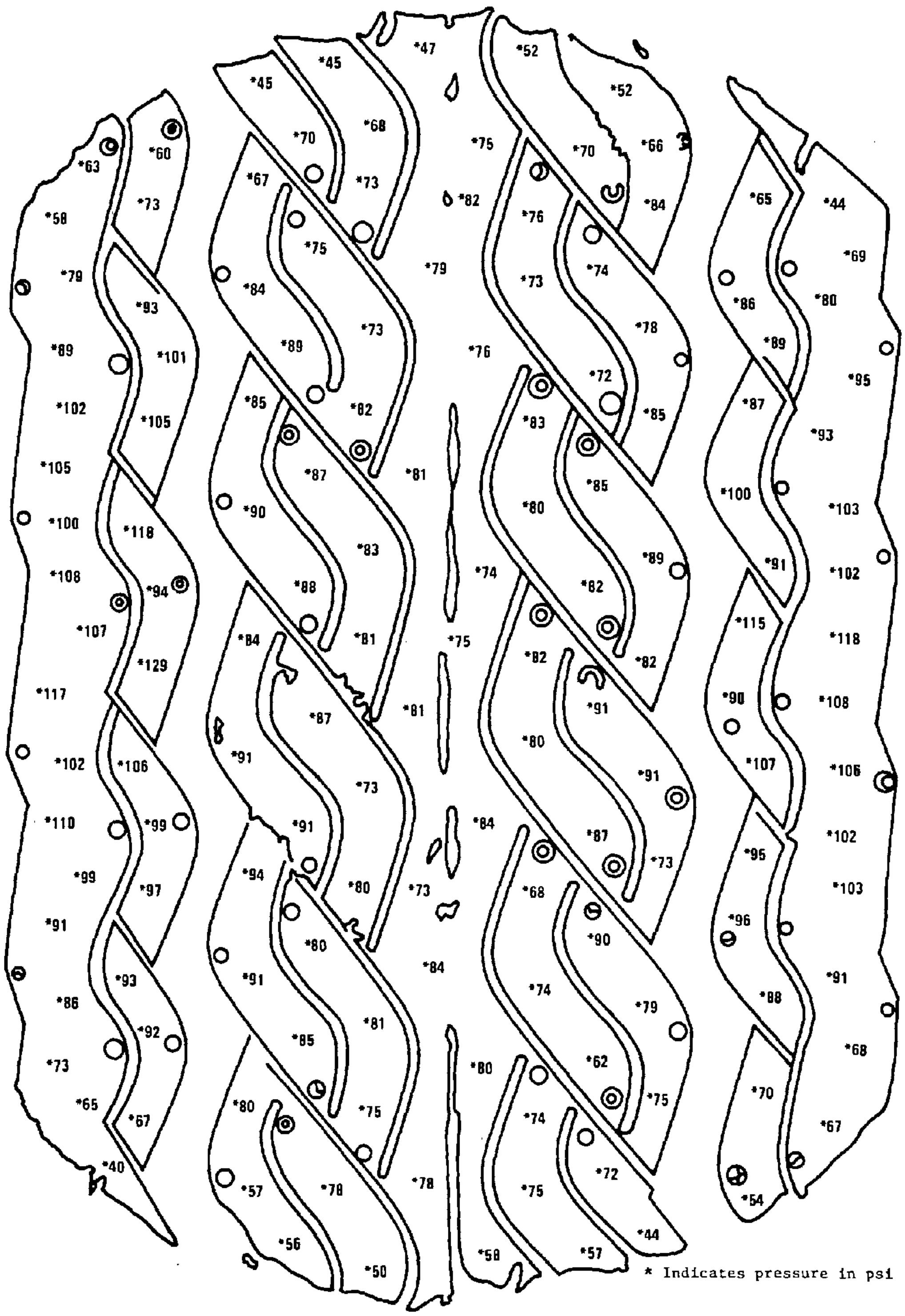

Figure 11. Test Tire Print and Pressure Distribution at 5,920 lb. Load

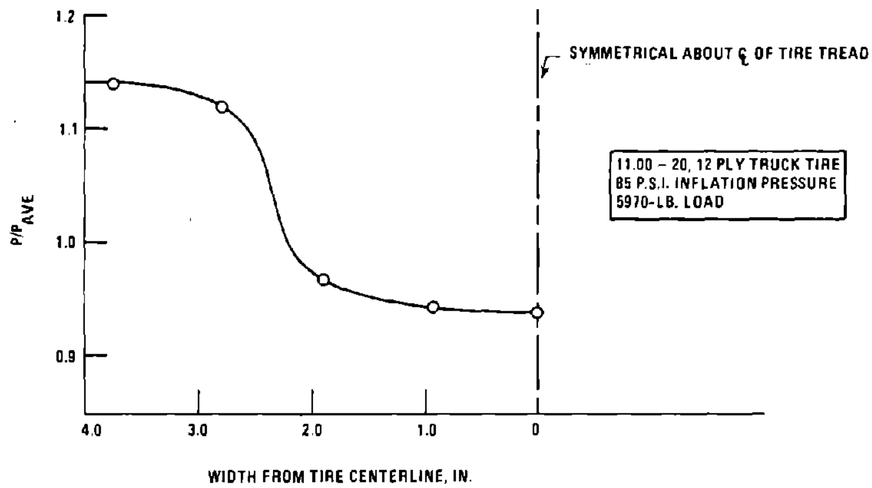

Figure 12. Derived Variation in Unit Tread Pressure for Flat Grates

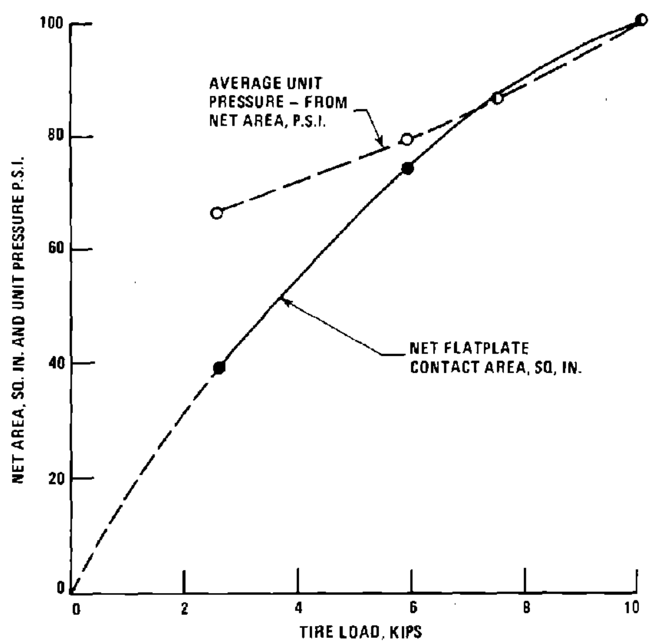

Figure 13. Tire Contact Area & Pressure vs. Load

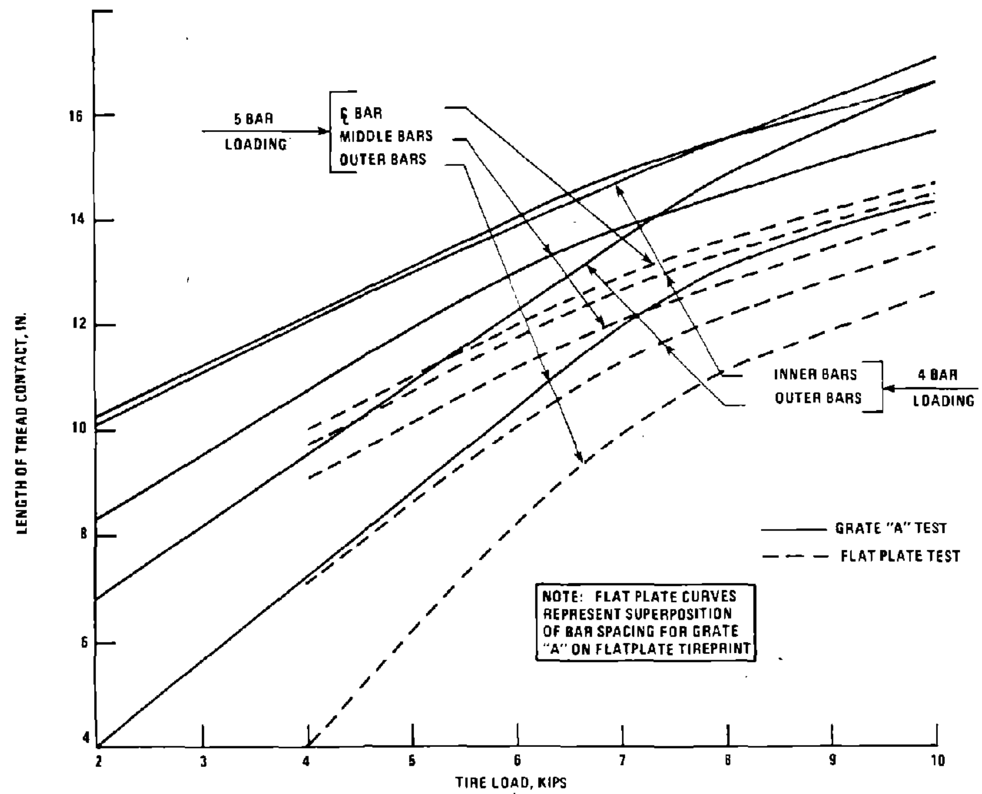

Figure 14. Comparison of Tread Contact Length vs. Load, for a Flat Plate and a Grate Contact Surface

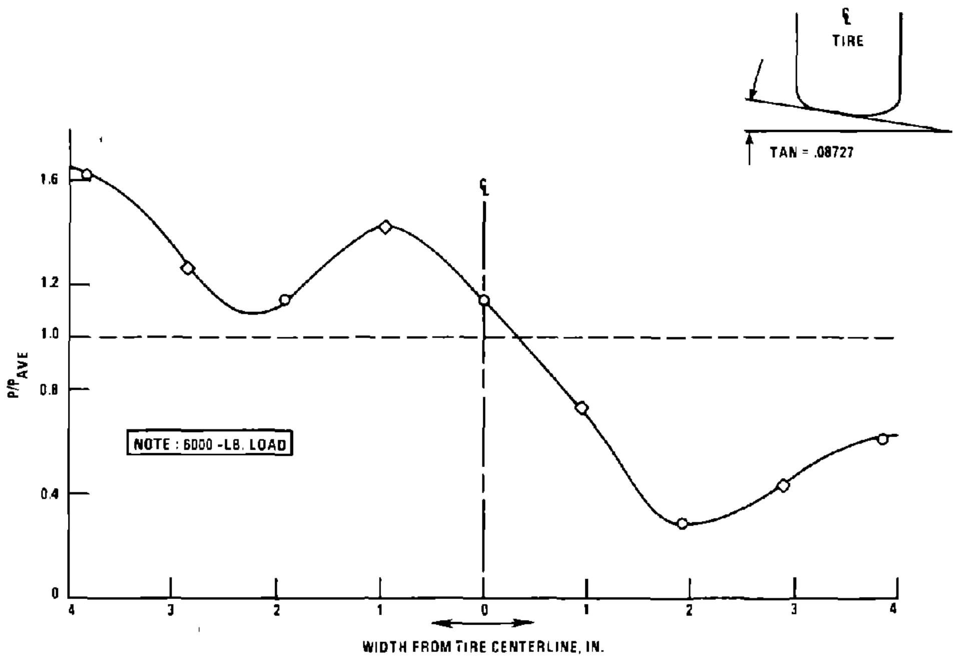

Figure 15. Derived Variation in Unit Tread Pressure for Sloped Grates

in unit tread pressure over the tire contact surface for a sloped grate. Figures 16 and 17 show the relationship between applied load and the tread length in contact with the bars of a sloped grate, for the tire in contact with four and five grate bars, respectively.

5.2. Data and Analysis for Grate "A".

Under the static test series this grate was subjected to four increments of load (2497 lb., 5989 lb., 7412 lb., and 9953 lb.) in the following two tire positions on the grate.

(1) Midspan loading symmetrical about the centerline of the grate, with five bars loaded.

(2) Midspan loading symmetrical about the midline between No. 3 and No. 4 grate bars, with four bars loaded.

The data from these tests are shown as transverse midspan strain profiles for each of the longitudinal bars. (Figures 18 and 19) It may be seen from these figures that the applied load is carried essentially by the loaded bars, with little strain being transferred into the adjacent bars by torsion through the end plates. The saw-tooth nature of the curve for the 9953-lb. load is attributed to the effect of tire sidewall stiffness and minor variations in the load distribution from that shown in figure 12.

The results of the computer analysis of this grate, for the various levels of applied load are also shown on figures 18 and 19. The results of the computer analysis are quite close to those measured during the static tests.

The results of the field rolling load dynamic tests are shown on Figure 20, as transverse midspan strain profiles. Also shown on this figure (for reference) are the static load curves for the 5989-lb. tests. Considering only maximum values, this data indicates a rolling load dynamic factor of 1.11.

The results of the field dynamic impact load tests are shown on Figure 21; as well as the static load curves for the 5989-lb. tests. It may be seen that there is a moderate increase in midspan strains for these tests. Considering only maximum values, this data indicates an impact factor of 1.37.

Results from the static plate load tests are shown on Figures 22 and 23. Figure 22 shows a comparison between the transverse strain profile curves for the plate and static tire tests, at the 10,000-lb. load level. It may be seen that these curves are very close; and therefore, it may be concluded that the results of a plate load test would represent the results of an actual tire test (at least up to this

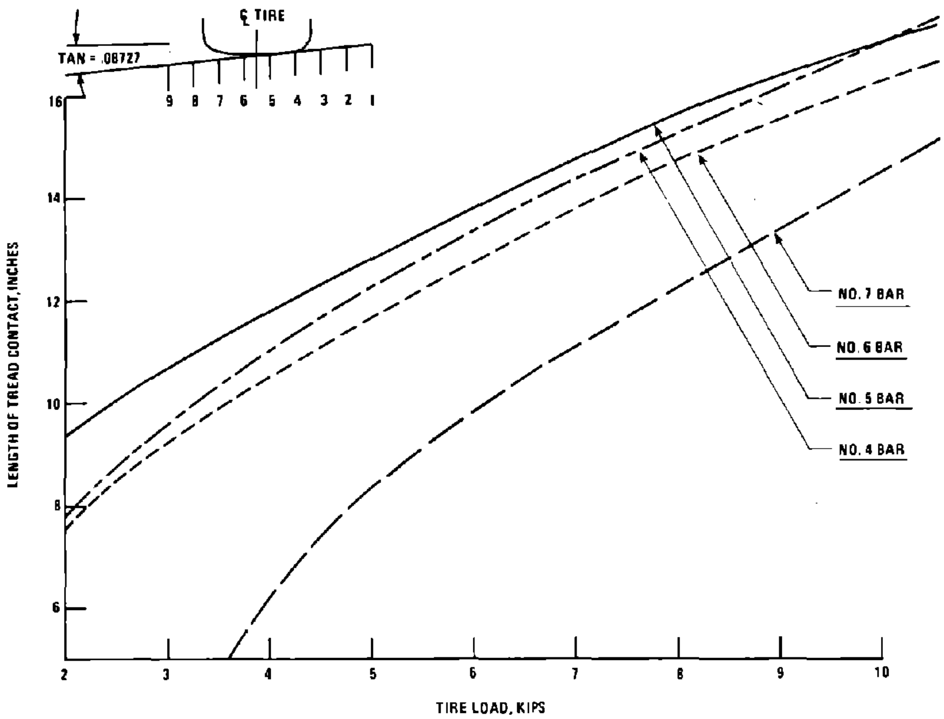

Figure 16. Tread Contact Length vs. Load for Sloped Grates (4 Bar Loading)

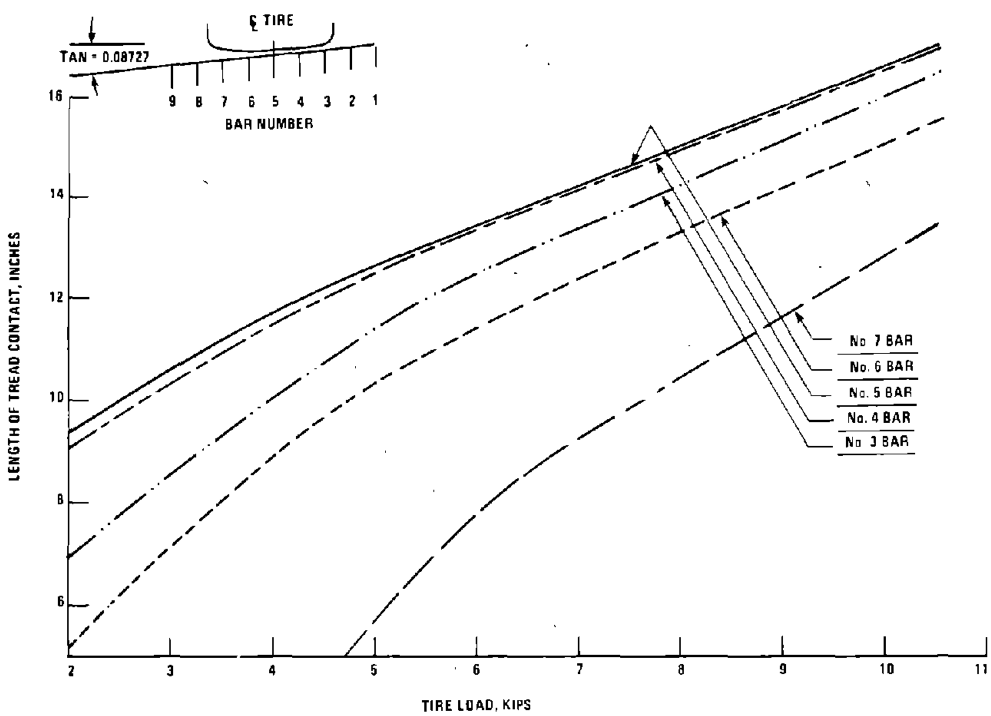

Figure 17. Tread Contact Length vs. Load for Sloped Grates (5 Bar Loading)

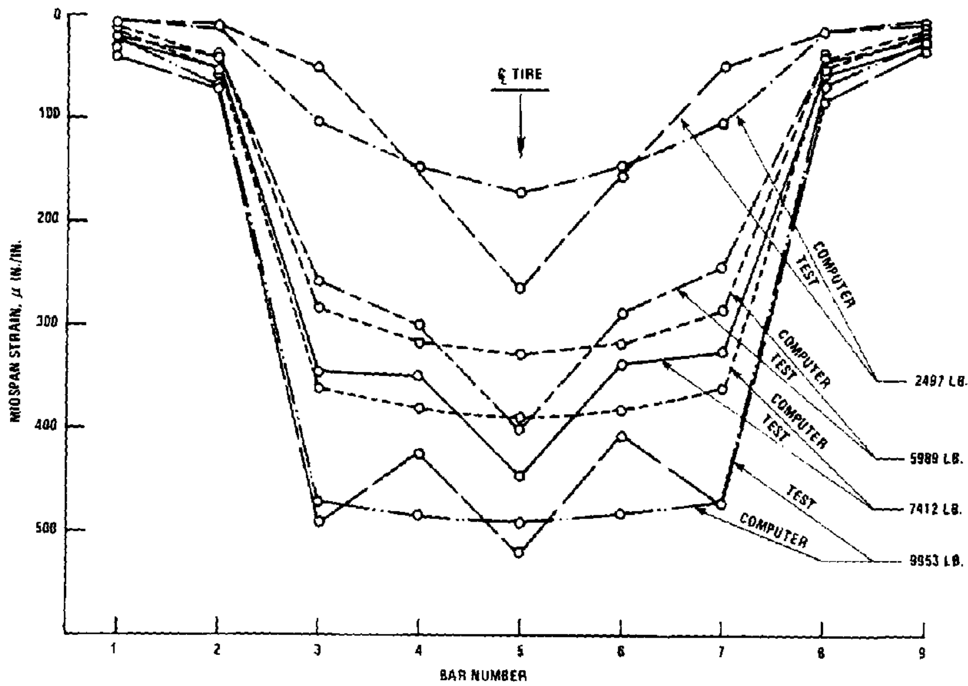

Figure 18. Grate A - Static Wheel Load Strains on Transverse Centerline (5 Bar Loading)

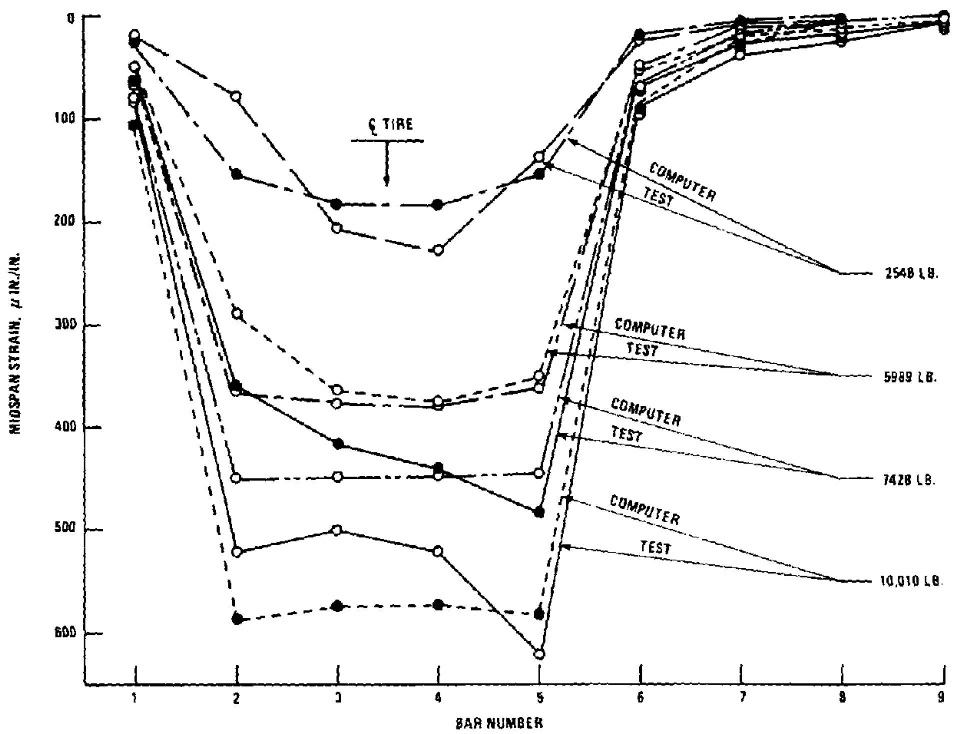

Figure 19. Grate A - Offcenter Static Wheel Load Strains on Transverse Centerline (4 Bar Loading)

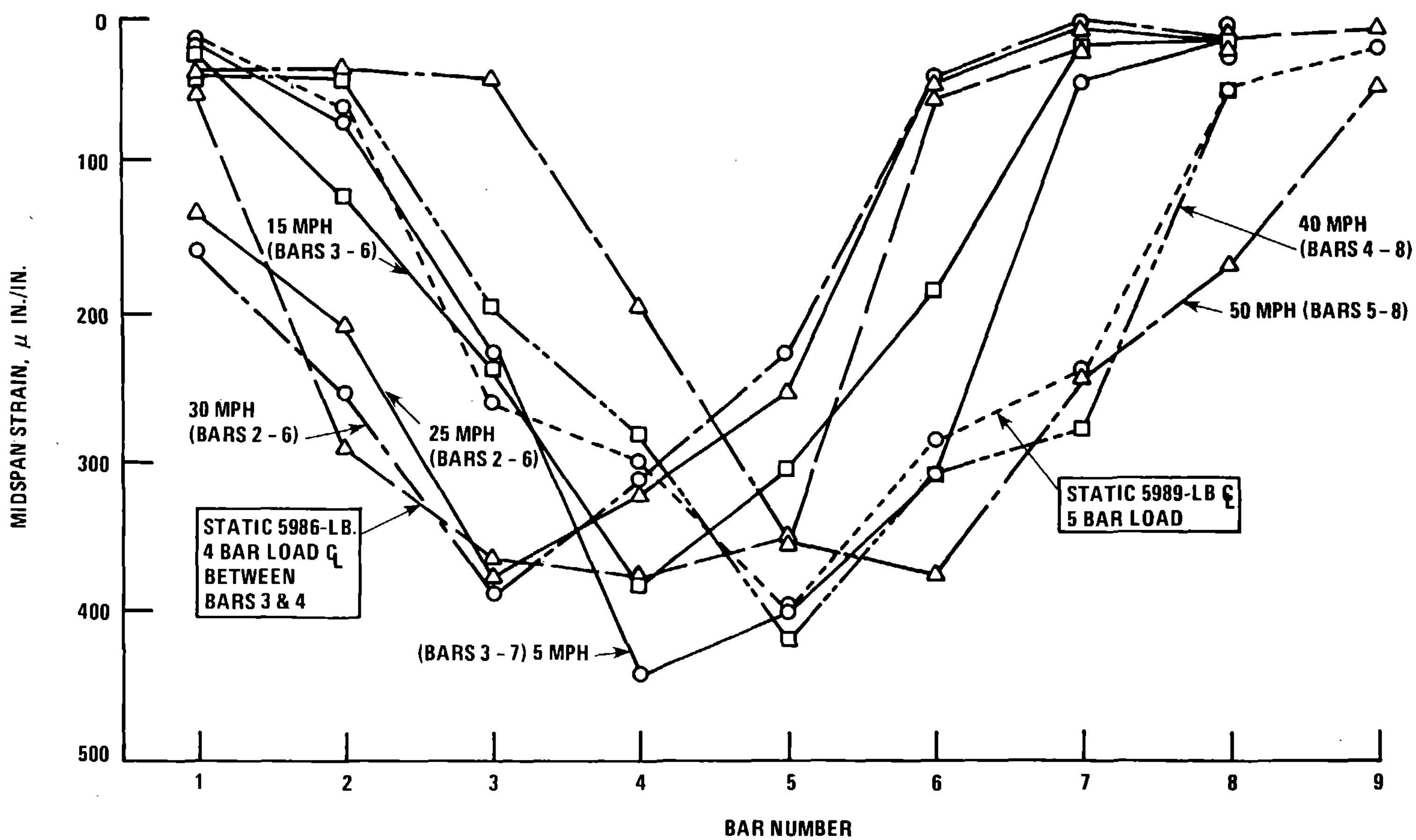

Figure 20. Grate A - Rolling Load Strains on Transverse Centerline

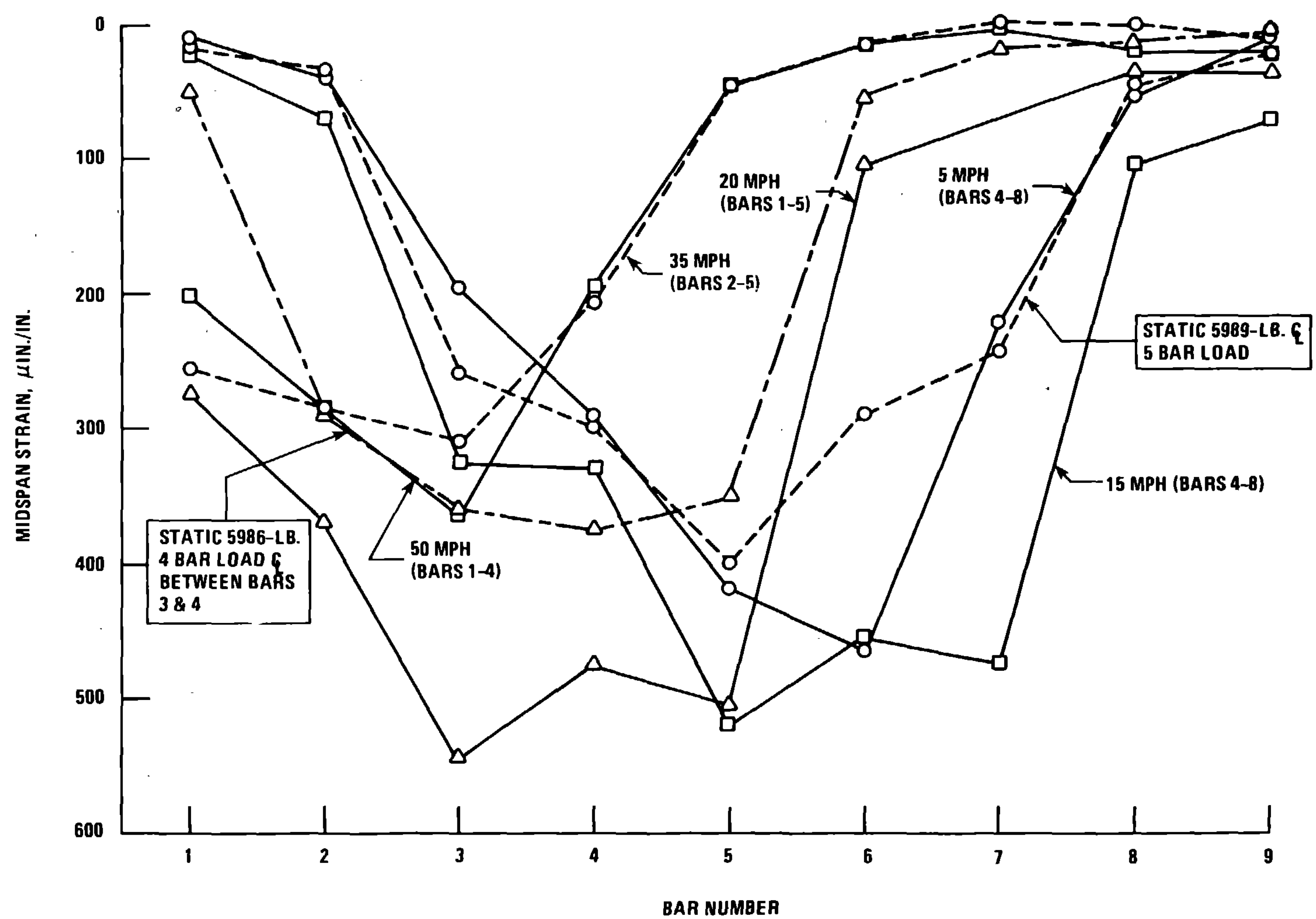

Figure 21. Grate A - Impact Load Strains on Transverse Centerline

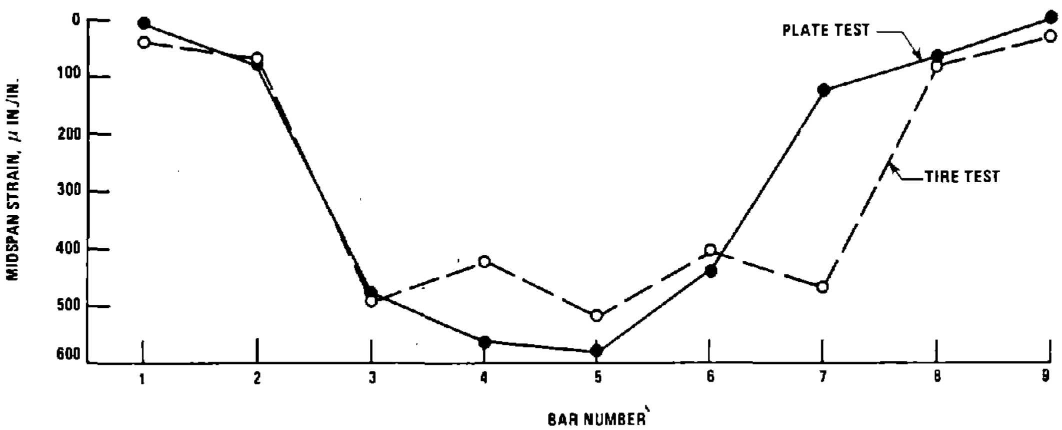

Figure 22. Grate A - Comparison of Static Tire and Plate Load Test Results (Strains at Transverse Centerline for 10,000-lb. Load)

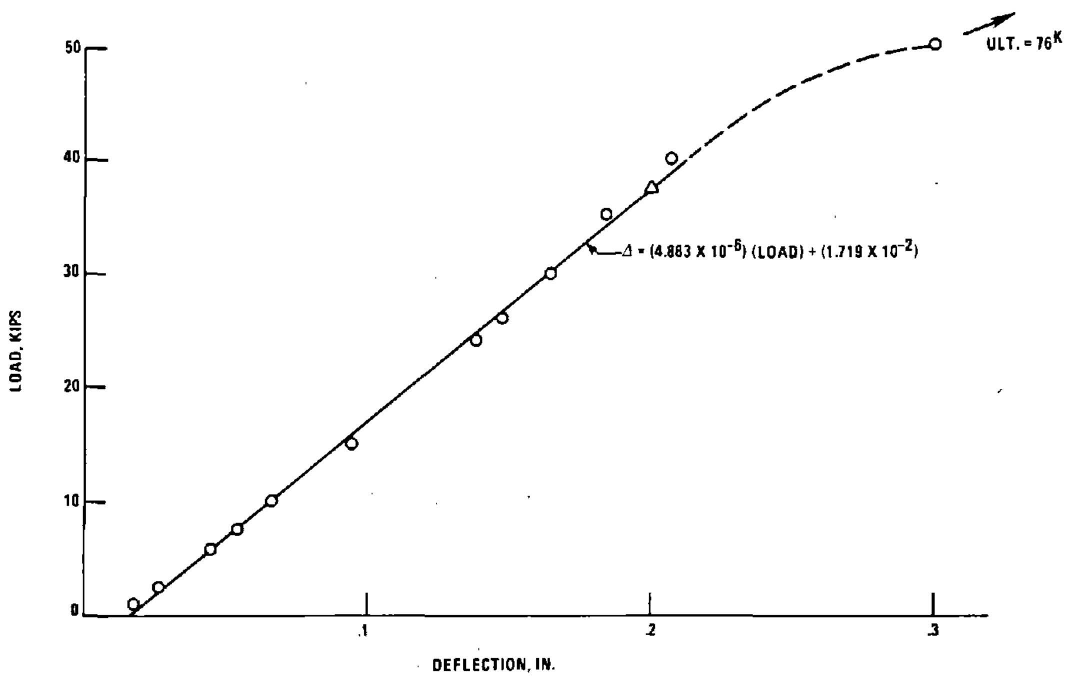

Figure 23. Grate A - Centerpoint Deflection under Plate Load Test

load level). Figure 23 shows a plot of deflection versus load, up to 50,000 lb. This grate had an ultimate load of 76,000 lb. Failure was by yield of the loaded five central bars and yield of the end plates between the next adjacent bars in torsion. From this curve, it may be estimated that yield (i.e. permanent deformation) of the grate occured at about 40,000 lb. This may be compared to the Federal Specification minimum requirement of 25,000 lb.

5.3. Data and Analysis for Grate "B".

This grate was subjected to four increments of static load (2500 lb., 5920 lb., 7500 lb., and 10,000 lb.) in the following two tire positions.

(1) Midspan loading symmetrical about the centerline of the grate, with four bars loaded.

(2) Midspan loading symmetrical about grate bar No. 7, with five bars loaded.

The data from these tests are shown as transverse midspan strain profiles for each of the longitudinal bars. (Figures 24 and 25) It may be seen from the curves on Figure 24 that this grate acts as a grid system, with load distribution (strain development) in the next two adjacent bars on each side of the four loaded bars. This is also noticeable on Figure 25, for the off-center static tire loading.

The results of one computer computation (at 5920 lb.) is shown on Figure 24. Comparing these results with those from the static tire test, it appears that the correlation in only fair. However, it is believed that most of the discrepancy is due to the fact that the input data for the computer analysis assumed that the tire loads were applied only to the four longitudinal bars. However, the tire actually also applied load to several of the cross rods which are welded into the longitudinal bars. Also, some of the difference may be due to the problem of modeling the stiffness of the numerous welded connections. It is felt that the results of the computer analysis are reasonably close to the actual measured behavior of this grate.

The results of the field rolling load dynamic tests are shown on Figure 26, with the curves from the 5920-lb. static tire tests for comparison. Considering only maximum values this data indicates a rolling load dynamic factor of 1.04.

The results of the field dynamic impact load tests are shown on Figure 27, with the 5920-lb. static tire test curves for reference. It may be seen that there is a very small increase in midspan strains over those measured in the static tests, except for the data from the 35 mph. impact test. The oscillograph records for this run have been checked, but no errors can be detected. However, since this data seems

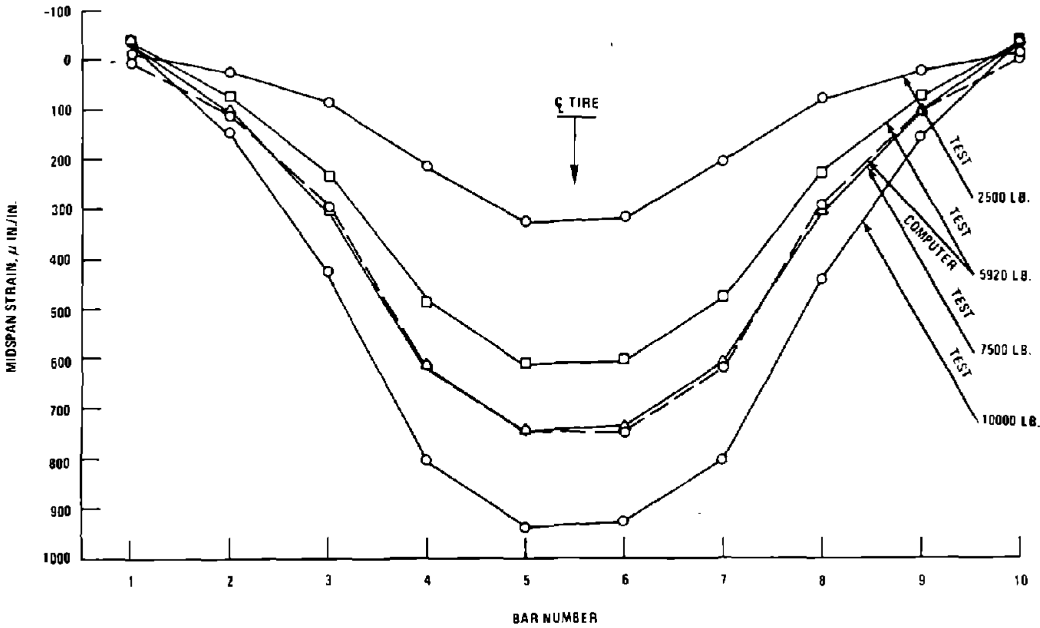

Figure 24. Grate B - Static Wheel Load Strains on Transverse Centerline (4 Bar Loading)

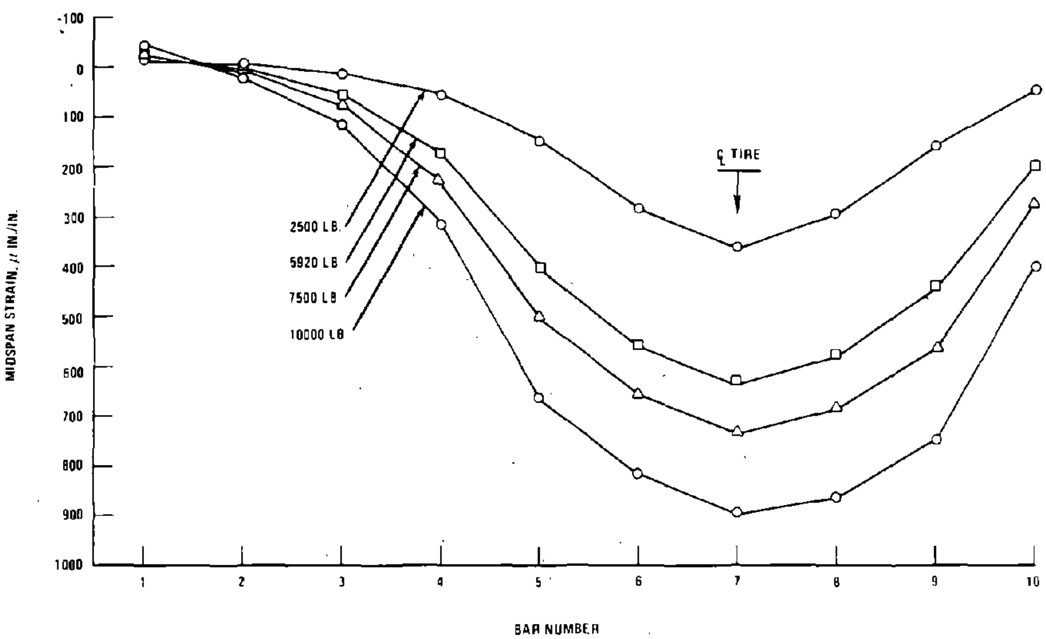

Figure 25. Grate B - Offcenter Static Wheel Load Strains on Transverse Centerline (5 Bar Loading)

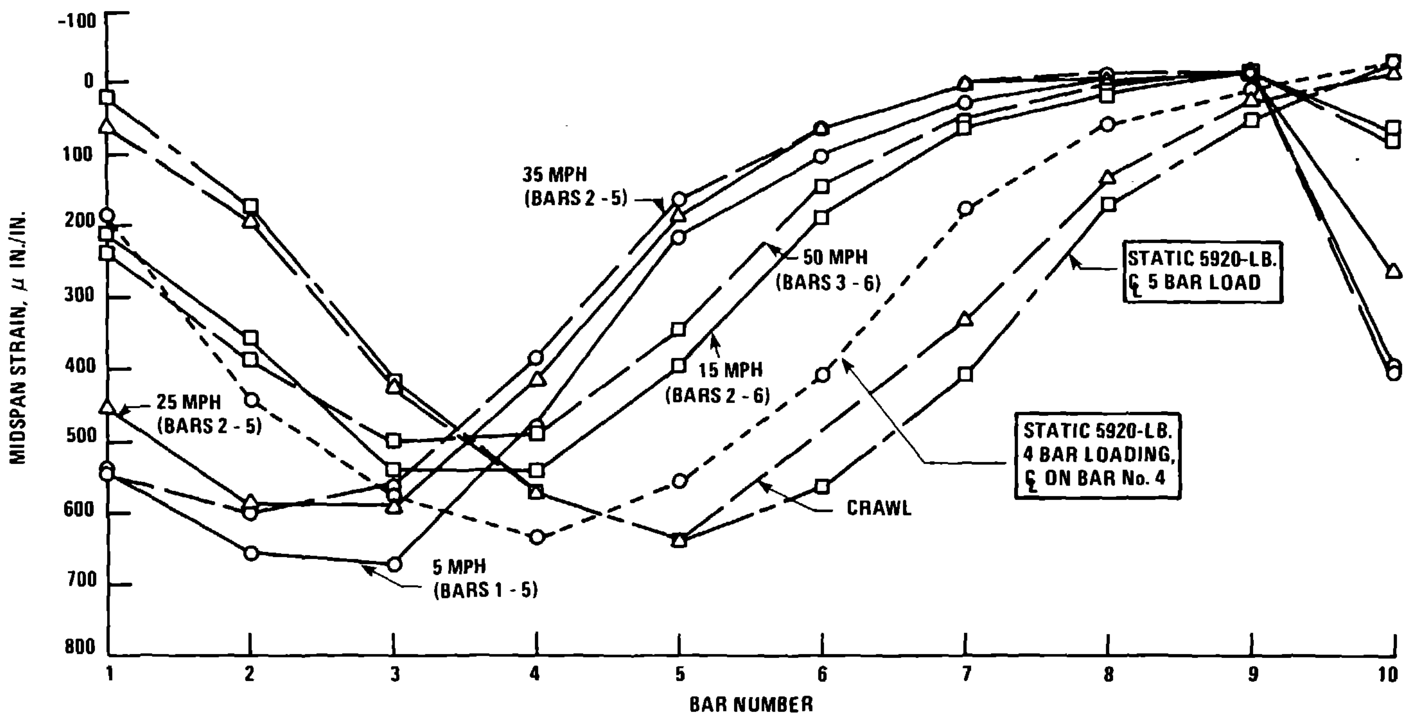

Figure 26. Grate B - Rolling Load Strains on Transverse Centerline

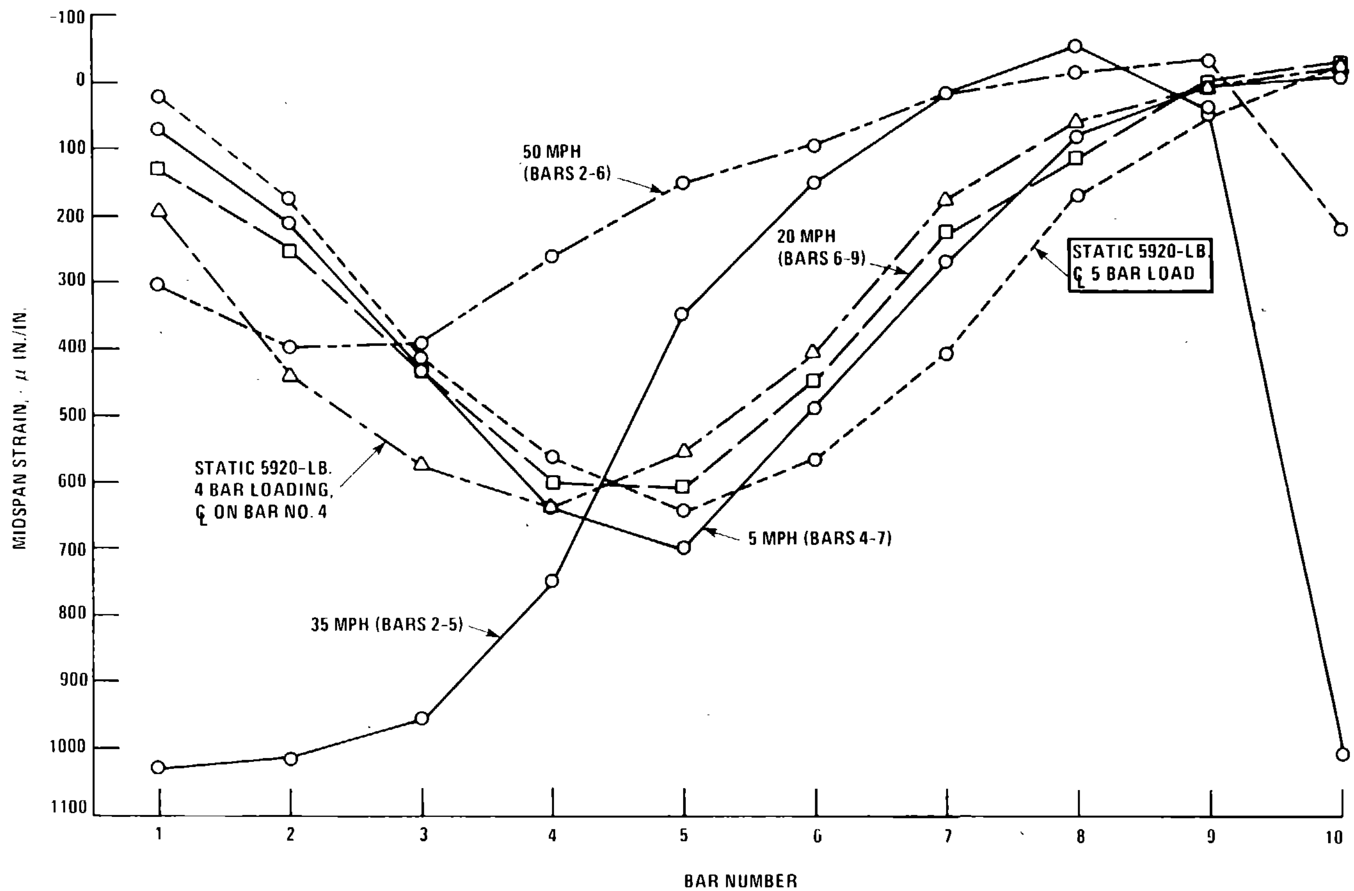

Figure 27. Grate B - Impact Load Strains on Transverse Centerline

to be very different from that from all other impact tests this curve has been disregarded in the evaluation of this grate. Comparing maximum values for the impact and static tire tests, this data indicates a dynamic impact factor of 1.09.

Results from the static plate load tests are shown on Figures 28 and 29. Figure 28 shows a comparison of the transverse strain profiles for the plate load and static tire tests, at the 10,000-lb. load level. It may be seen that these two curves are very close, which (again) indicates that the plate test might be used to predict the behavior of this grate under static tire load conditions. Figure 29 shows a plot of deflection versus load, up to 30,000 lb. This grate had an ultimate plate load of 40,000 lb. Failure of this grate was by yield of the four loaded bars (Numbers 4-7) and the next adjacent bars (Numbers 3 and 8). From this curve, it is estimated that yield (permanent deflection) occured at about 18,000 lb., which is less than that permitted by the Federal Specification. A picture of this grate after the plate load test is shown on Figure 30.

5.4. Data and Analysis for Grate "C".

This grate was subjected to four increments of static load (2500 lb., 6000 lb., 7500 lb., and 10,000 lb.) in the following three tire positions.

(1) Midspan loading symmetrical about the centerline of the grate, with four bars loaded.

(2) Midspan loading symmetrical about the centerline of the grate, with five bars loaded:

(3) Midspan loading symmetrical about grate bar No. 7, with five bars loaded.

The data from these tests are shown on Figures 31 to 33, as transverse strain profiles. It should be noted that this grate had a sloped surface, and the strain profiles are not symmetrical about the centerline of the load. The tire load was applied vertically, rather than normal to the sloped surface. From these curves it may be seen that this grate acts as a grid system, with some load being transferred to the bars adjacent to those loaded by the tire.

In order to make computer analyses for the behavior of this grate it was necessary to use some of the data from the actual static tire tests. As indicated previously it was necessary to derive the variation in unit tire pressure over a sloped grate surface (Figure 15). Figures 16 and 17 show the curved relationship between load and tire contact length on the grate bars. Although the data is not reported herein, strain gages were also applied to the trapezoidal shaped end

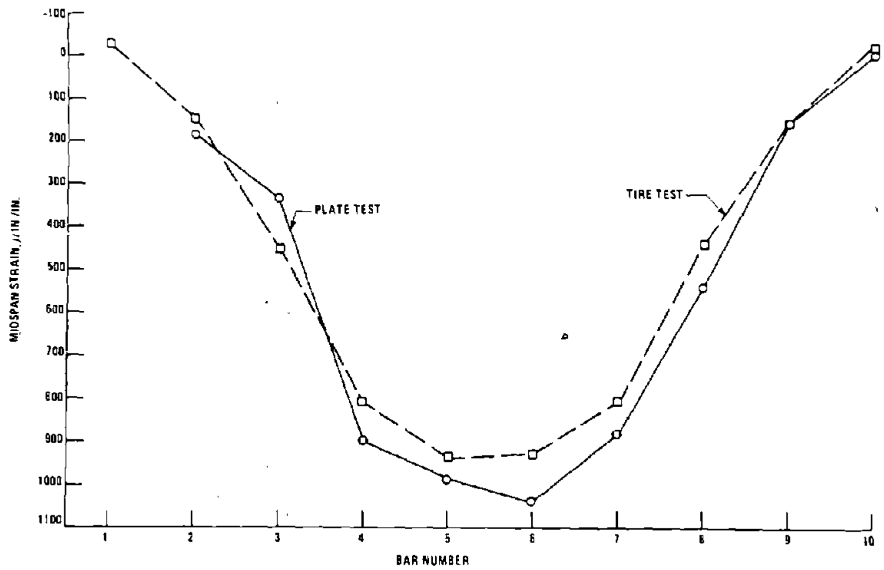

Figure 28. Grate B - Comparison of Static Tire and Plate Load Test Results (Strains at Transverse Centerline for 10,000-lb. Load)

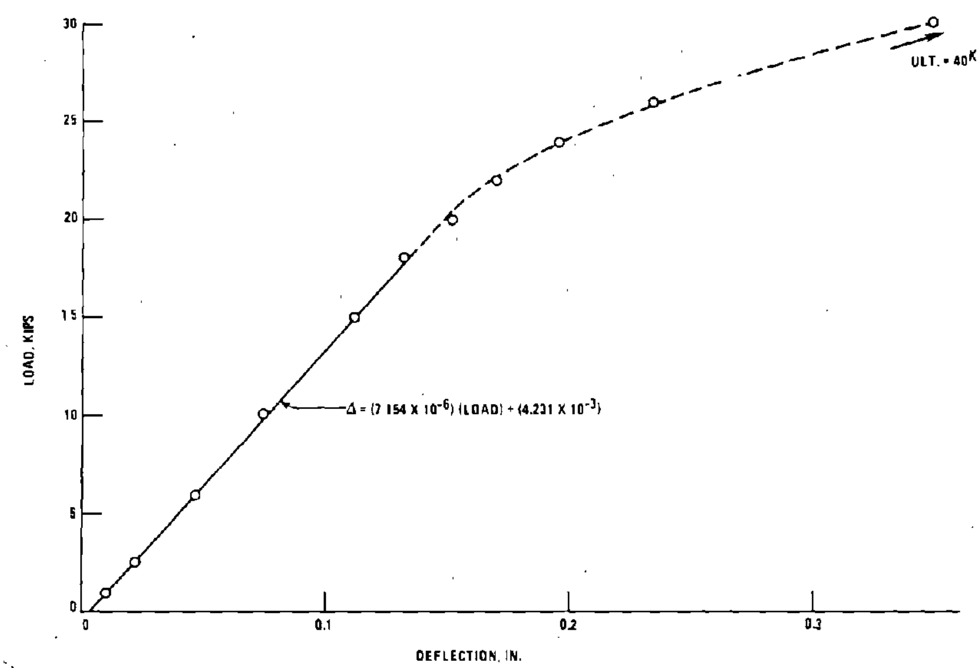

Figure 29. Grate B - Centerpoint Deflection under Plate Load Test

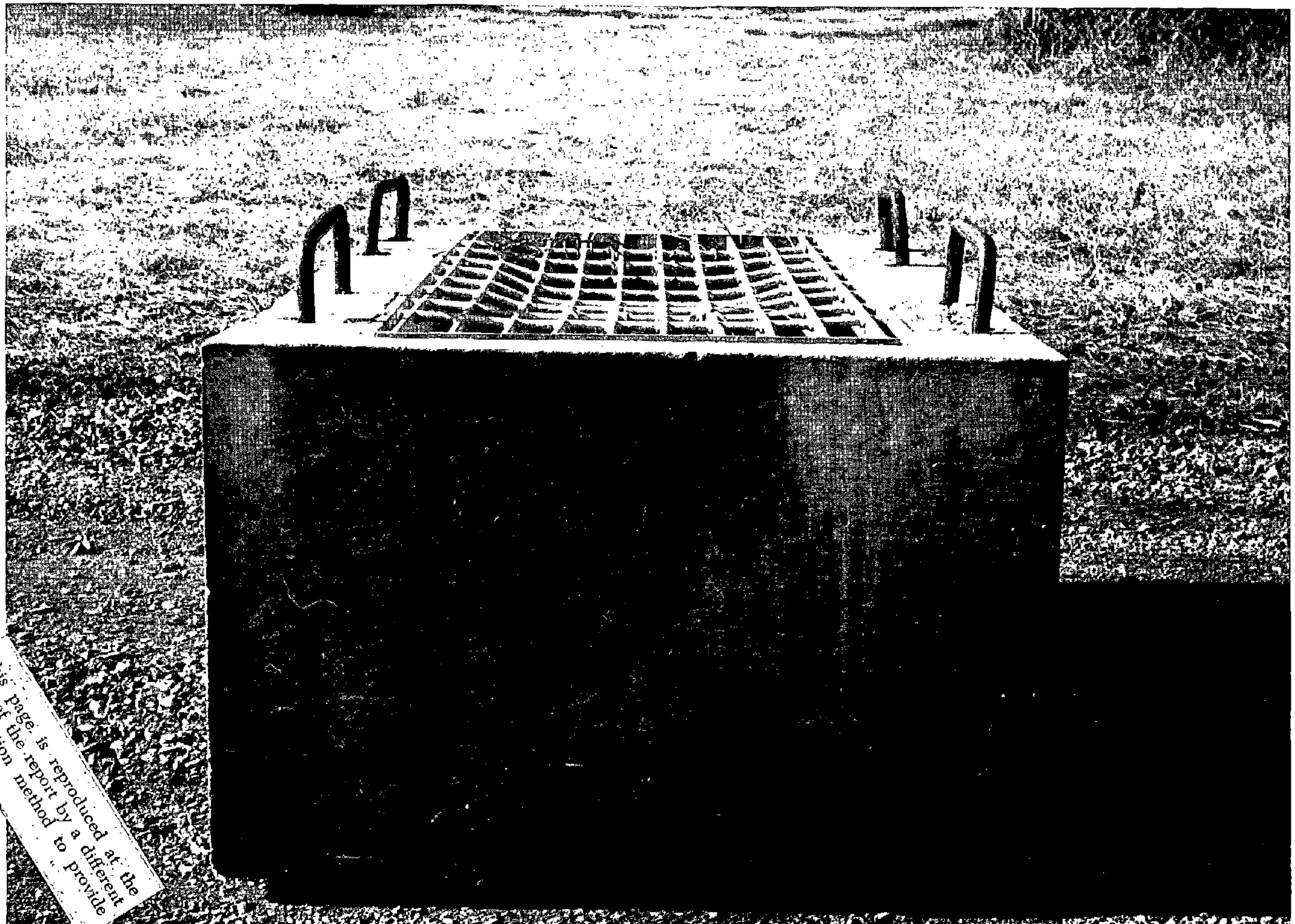

Figure 30. Grate B - After Plate Load Test to Failure

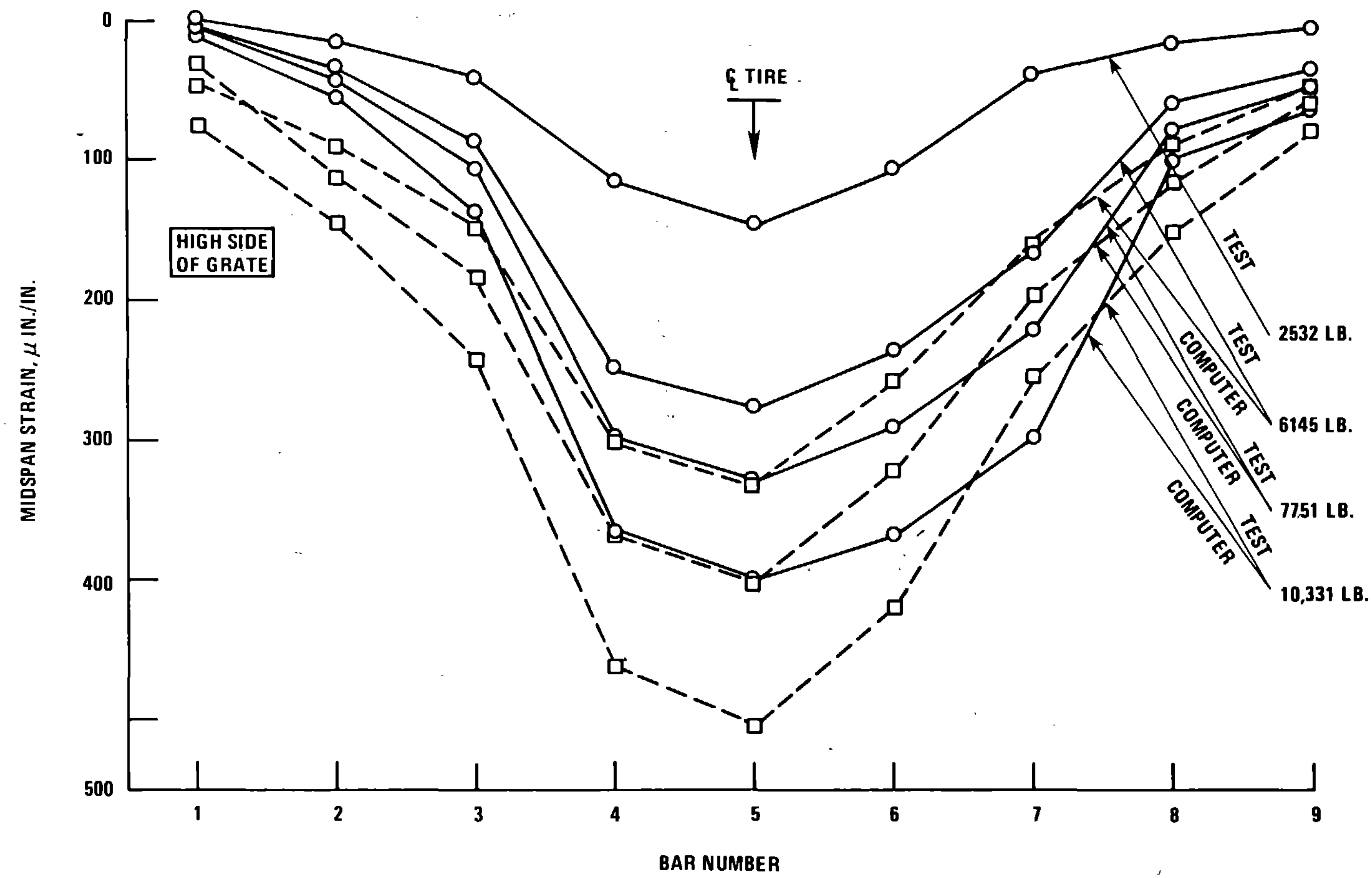

Figure 31. Grate C - Static Wheel Load Strains on Transverse Centerline (4 Bar Loading)

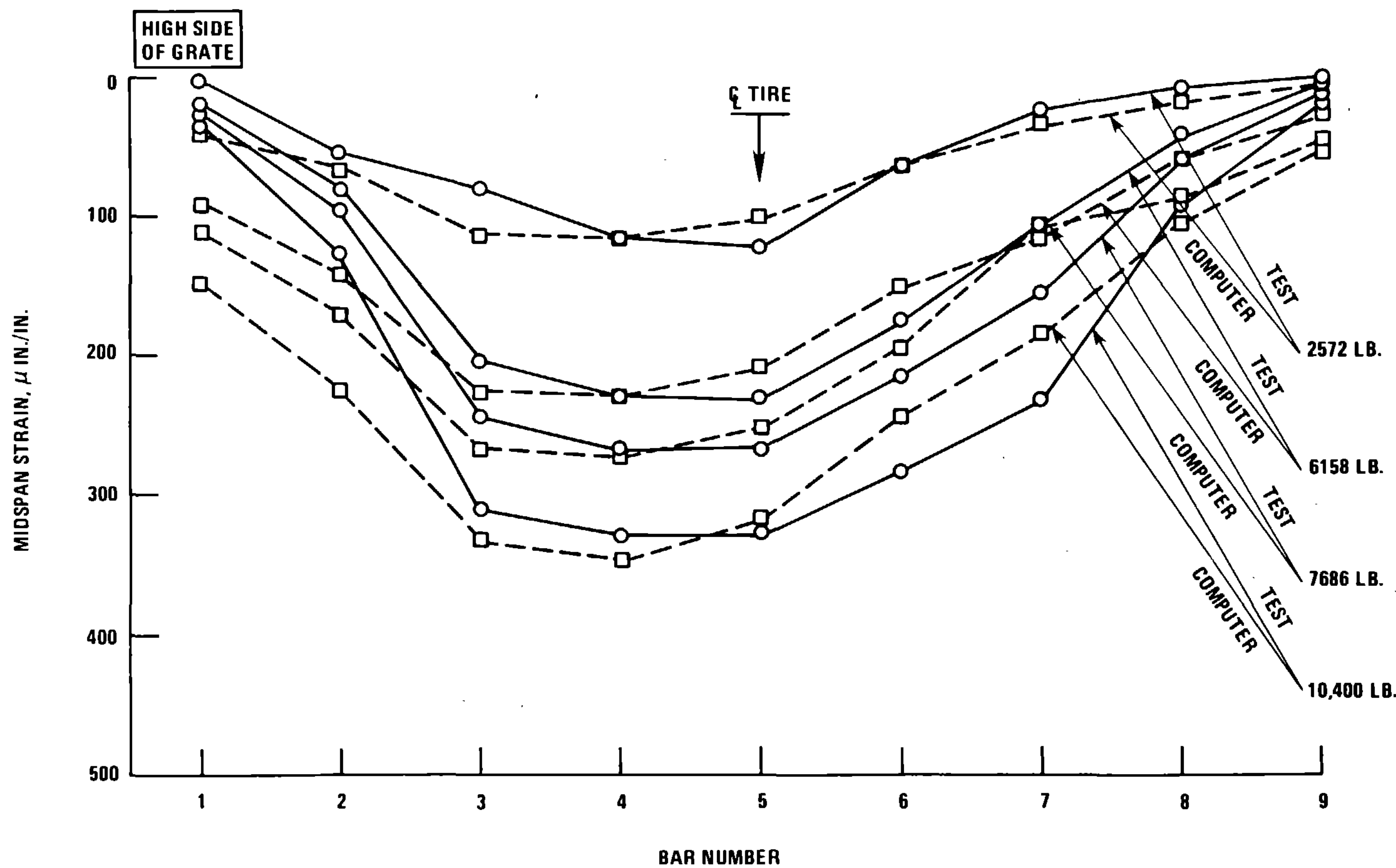

Figure 32. Grate C - Static Wheel Load Strains on Transverse Centerline (5 Bar Loading)

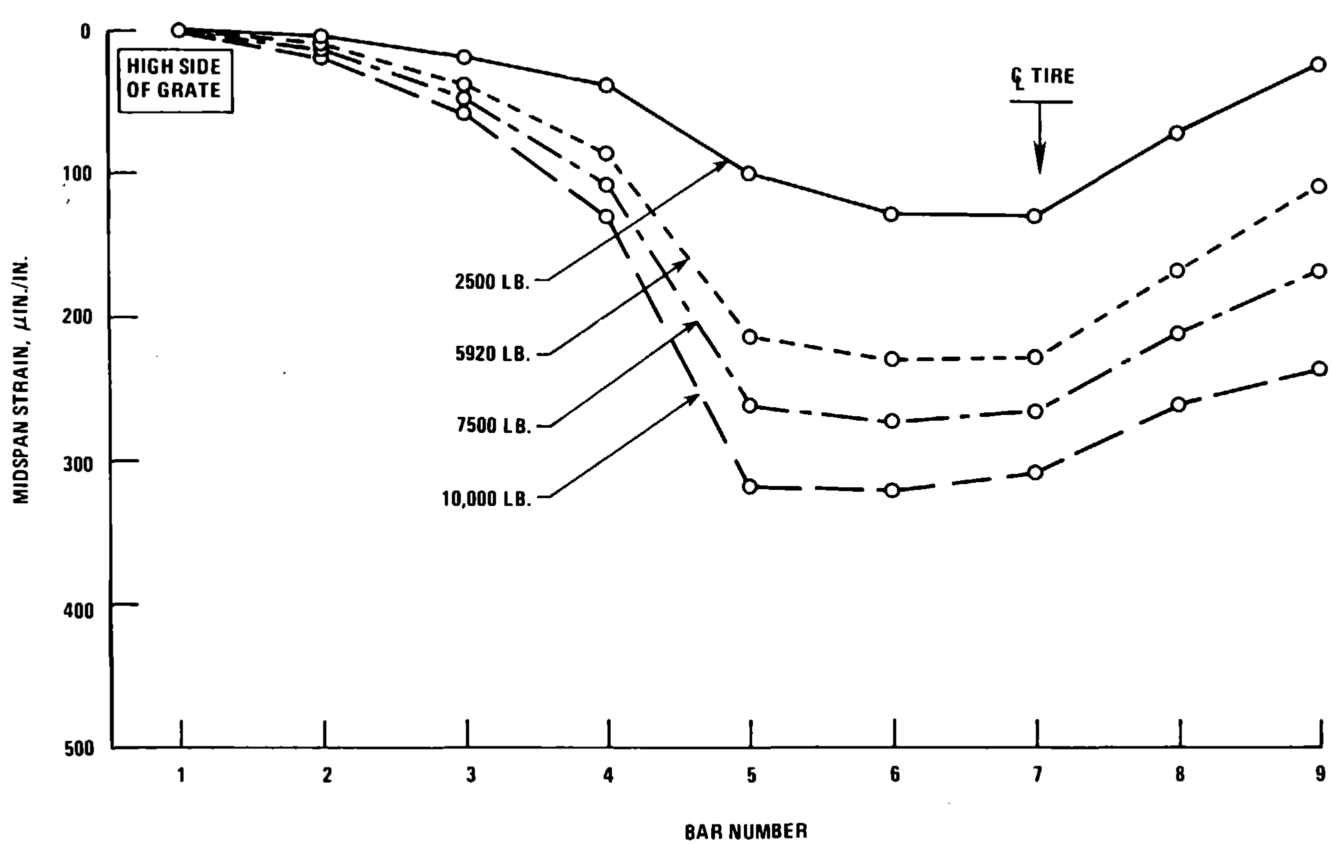

Figure 33. Grate C - Offcenter Static Wheel Load Strains on Transverse Centerline (5 Bar Loading)

plates to measure their effectiveness in transferring shear and moment. The results of the computer analyses are plotted on Figures 31 and 32. Considering the problems in modeling the influence of the sloped grate configuration and the trapezoidal end plates it is felt that the results of the computer analyses are in reasonable agreement with the measured behavior of this grate.

The results of the field rolling load dynamic tests are shown on Figure 34, with the curve from the 6158-lb. static tire test for comparison. Considering only maximum values, this data indicates a rolling load dynamic factor of 1.13.

The results of the field dynamic impact load tests are shown on Figure 35, with the 6158-lb. static tire test for comparison. Considering only maximum values, this data indicates a dynamic impact factor of 1.49.

Results of the static plate load tests are shown on Figures 36 and 37. Figure 36 shows a comparison between the transverse strain profiles for the plate load and static tire tests, at the 10,000-lb. load level. It may be seen that the two curves are in reasonable agreement, especially considering the effect of the sloped surface of the grate. Figure 37 shows a plot of deflection versus load, up to 56,000 lb. This grate had an ultimate load of 98,500 lb. Failure was by yield of the five loaded bars. From this curve it is estimated that yield (permanent deflection) occured at about 42,500 lb., which is considerably over the 25,000 lb. minimum of the Federal Specification. A picture of this grate after the plate load test is shown on Figure 38.

5.5. Data and Analysis for Grate "D".

This grate was subjected to four increments of load (2500 lb., 6000 lb., 7500 lb., and 10,000 lb.) in the following two tire positions.

(1) Midspan loading symmetrical about the centerline of the grate.

(2) Midspan loading symmetrical about the midline between grate bars No. 5 and 6.

The data from these tests are shown on Figures 39 and 40. It should be noted that this grate had a sloped surface, and the strain profiles are not symmetrical about the centerline of the load. For these tests the tire load was applied vertically, rather than normal to the sloped surface of the grate. As noted on these figures, the number of grate bars contacted by the tire varied as the load was increased.

The results of the field rolling load dynamic tests are shown on Figure 41, with the 6000-lb. static tire test strain profile for

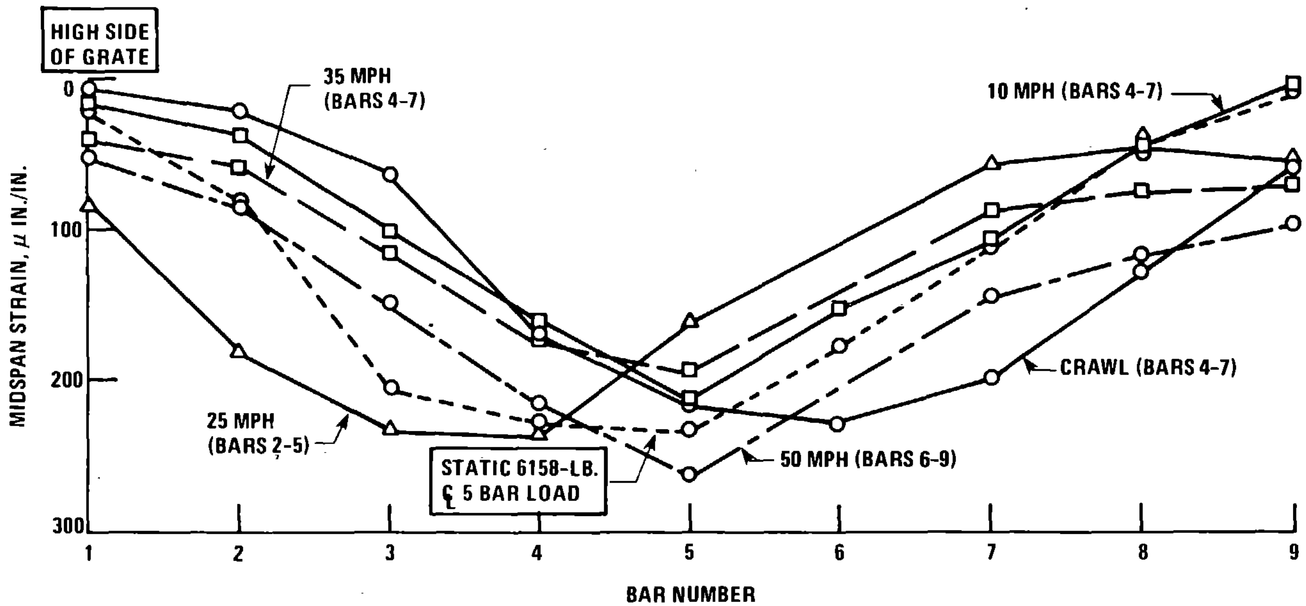

Figure 34. Grate C - Rolling Load Strains on Transverse Centerline

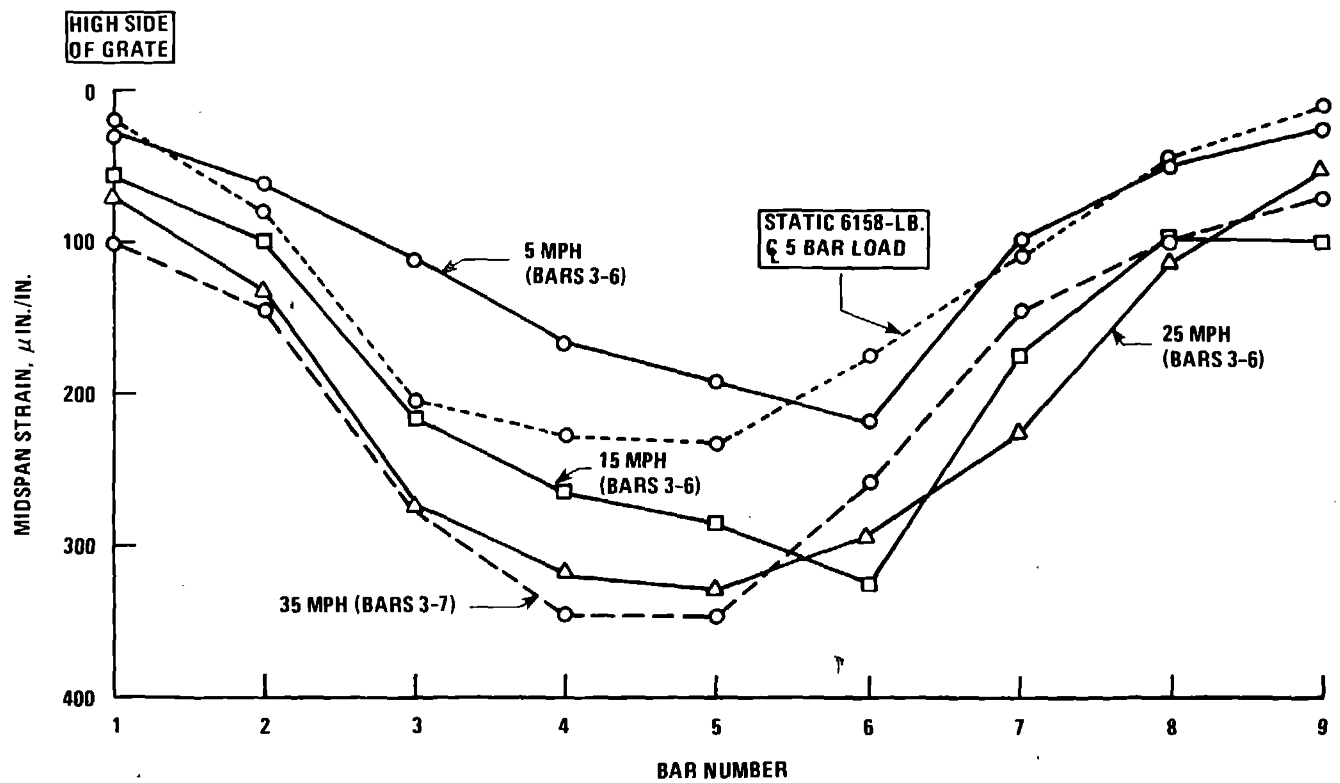

Figure 35. Grate C - Impact Load Strains on Transverse Centerline

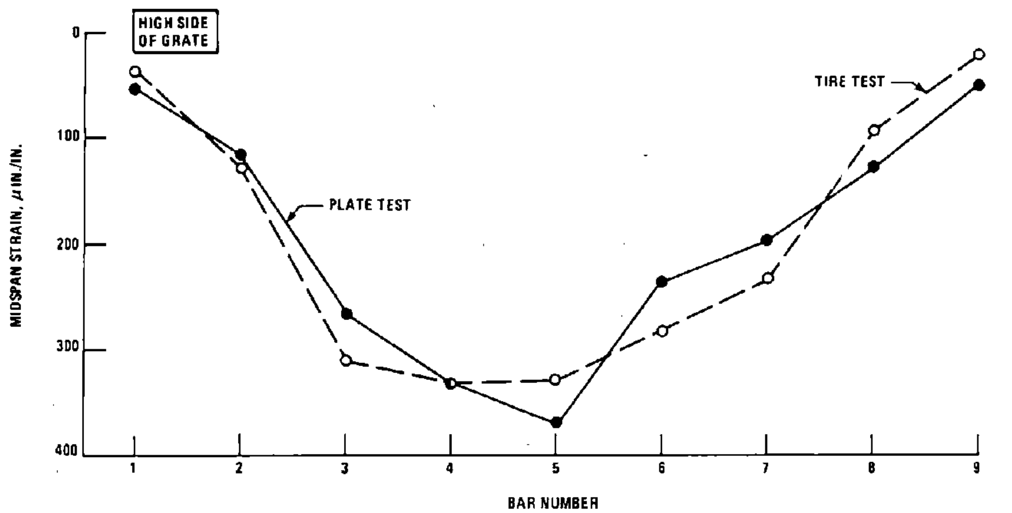

Figure 36. Grate C - Comparison of Static Tire and Plate Load Test Results (Strains at Transverse Centerline for 10,000-lb. Load)

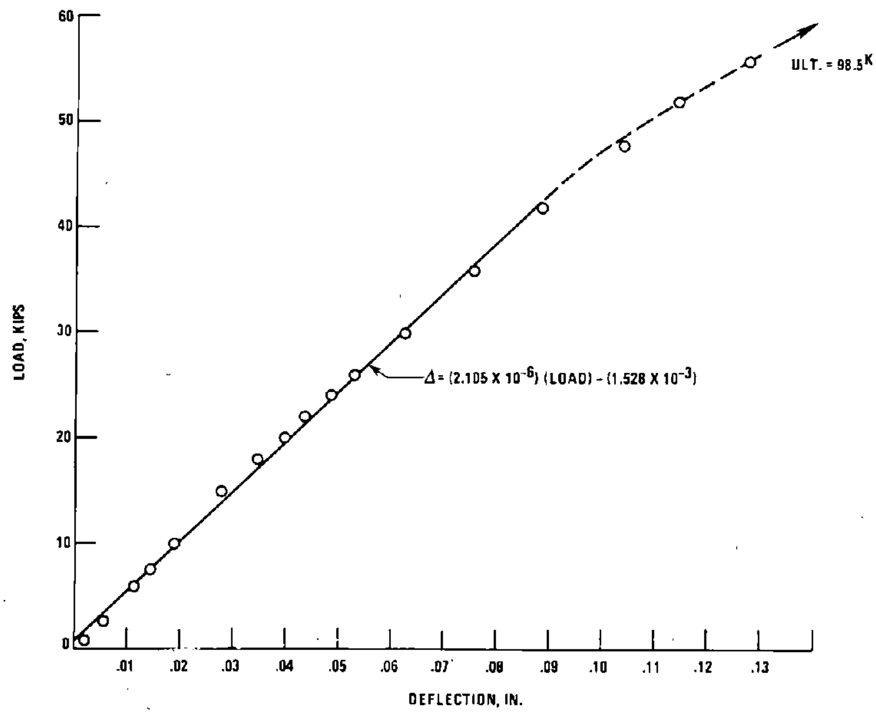

Figure 37. Grate C - Centerpoint Deflection under Plate Load Test

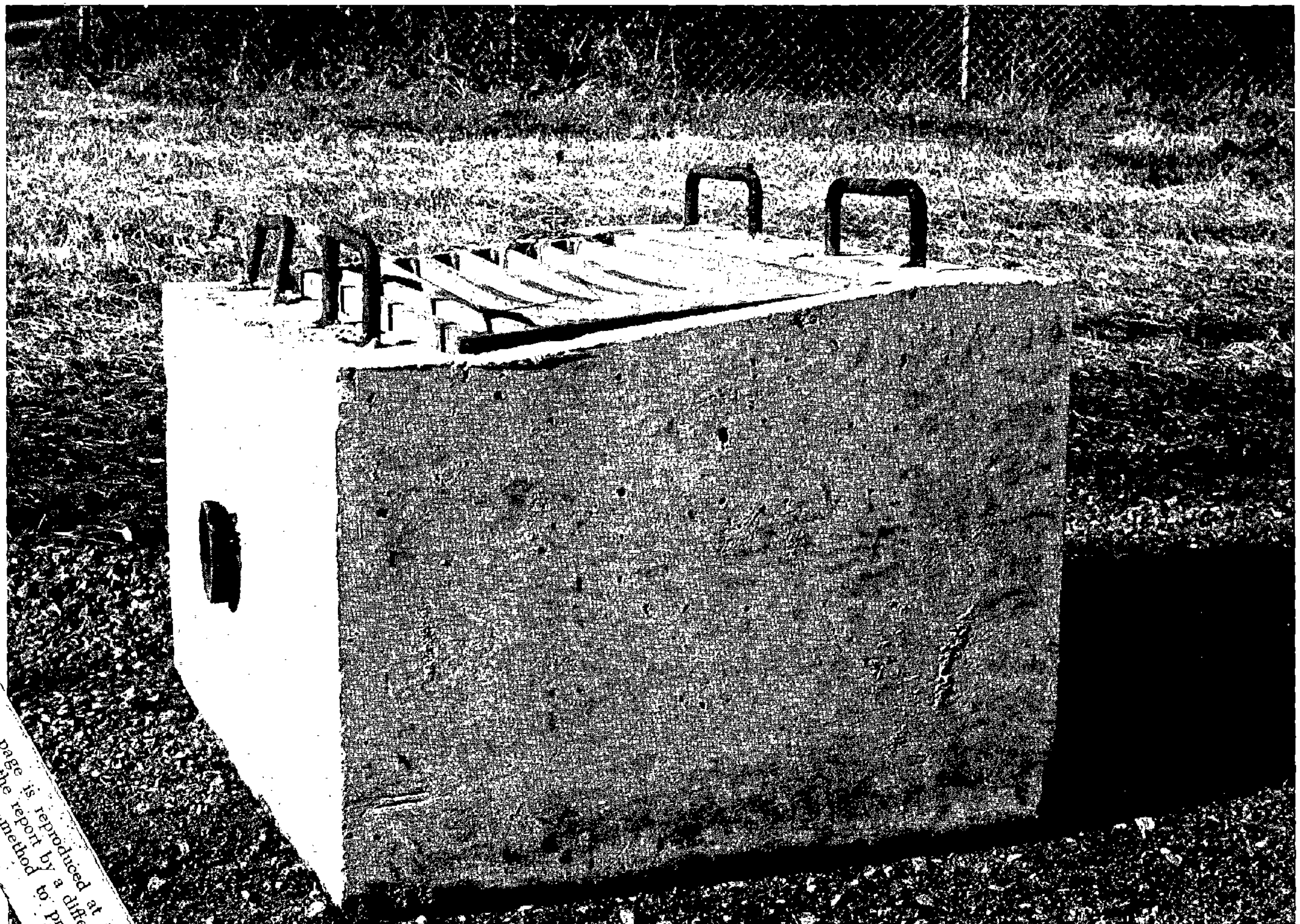

Figure 38. Grate C - After Plate Load Test to Failure

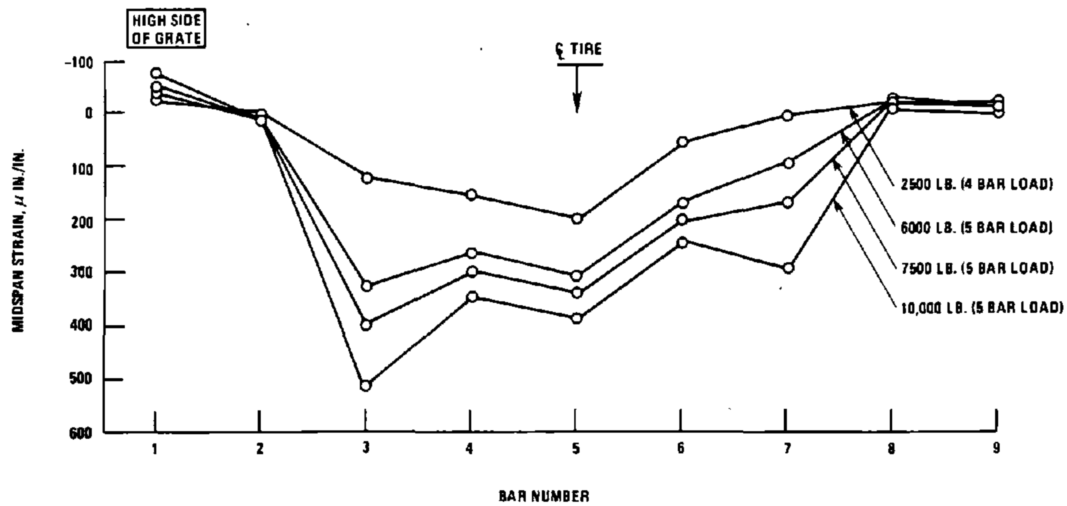

Figure 39. Grate D - Static Wheel Load Strains on Transverse Centerline

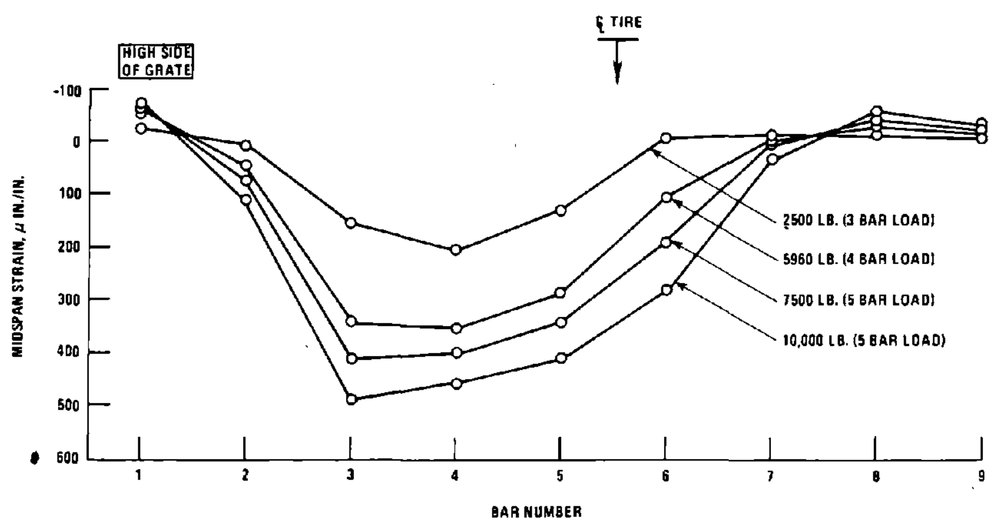

Figure 40. Grate D - Offcenter Static Wheel Load Strains on Transverse Centerline

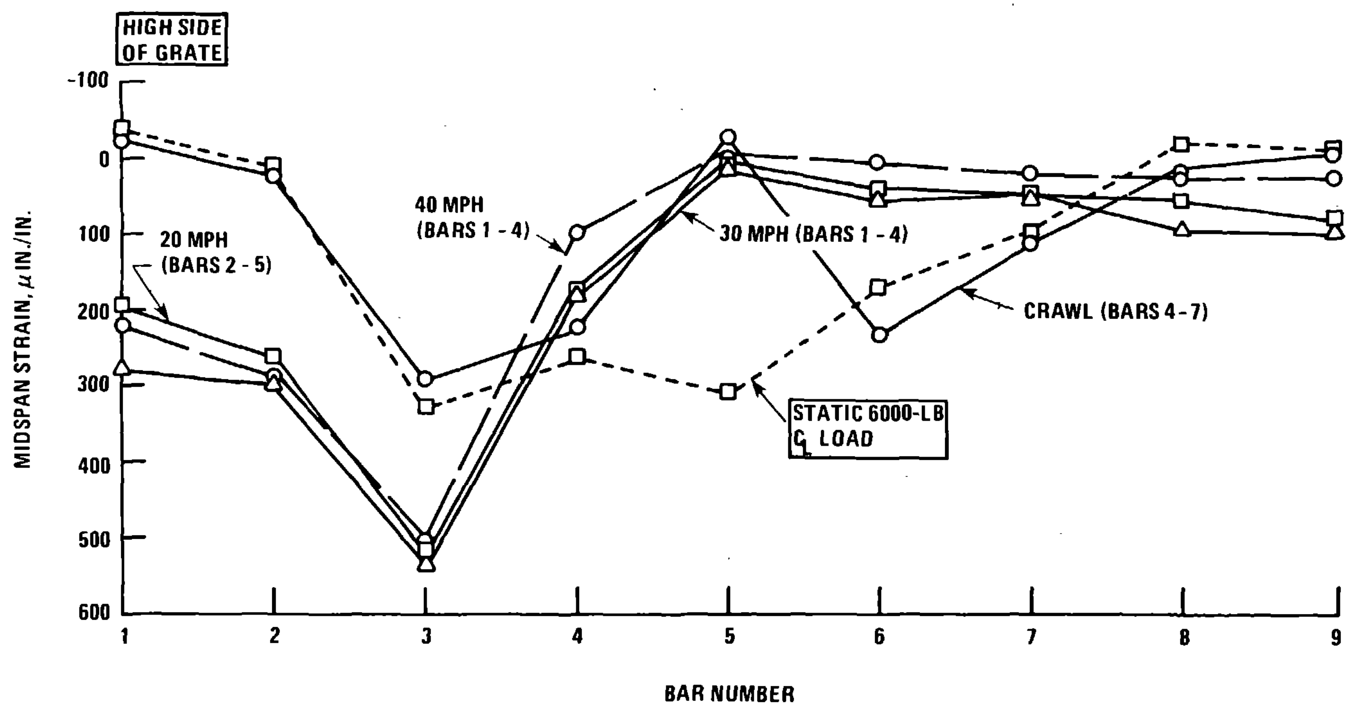

Figure 41. Grate D - Rolling Load Strains on Transverse Centerline

comparison. Considering only maximum values, this data indicates a rolling load dynamic factor of 1.65.

The results of the field dynamic impact load tests are shown on Figure 42, with the 6000-lb. static tire test strain profile for comparison. Considering only maximum values, this data indicates a a rolling load dynamic factor of 1.65.

The results of the field dynamic impact load tests are shown on Figure 42, with the 6000-lb. static tire test strain profile for comparison. Considering only maximum values, this data indicates a dynamic impact factor of 2.10.

Results of the static plate load tests are shown on Figures 43 and 44. Figure 42 shows a comparison between the transverse strain profiles for the plate load and static tire tests, at the 10,000-lb. load level. It may be seen that there are some differences between the two curves, which are probably due to variations in the tire load distribution over the sloped surface versus the uniform plate loading. Considering this, the curves are reasonably close. Figure 44 shows a plot of deflection versus load, up to 52,000 lb. This grate had an ultimate load of 109,300 lb. Failure was by yield of the longitudinal grate bars. From this curve it appears that yield of this grate occured at about 30,000 lb. However, considering the ultimate load of 109,300 lb., this seems unreasonable. Regardless, the yield (permanent deflection) of this grate was greater than the 25,000 lb. minimum of the Federal Specification. A picture of this grate after the plate load test is shown on Figure 45.

5.6. Data and Analysis for Grate "E".

This grate was subjected to five increments of static load (2465 lb., 3960 lb., 6068 lb., 7555 lb., and 10,024 lb.) with the tire positioned at the centerpoint of the grate. The data from these tests are shown on Figures 46 and 47. As shown on Figure 7, this is a heavy cast iron grate, with a substantial transverse member at midspan. However, as shown on Figure 48, both grates which were received for this study contained large voids in the castings, at the center of the grate on the underside (tensile) surface. This prevented placement of strain gages at the midspan of two of the longitudinal bars, but at a 3.25-in. offset. To obtain biaxial strain data 90° rosette gages were applied at the midspan of the other longitudinal bars. Figure 46 shows the strain profile in the longitudinal direction, and Figure 47 shows the strain profile in the transverse direction. Although it has not been done, to assess the maximum strains at the transverse centerline the transverse and longitudinal strains would have to be combined. The voids at the center of the grate precluded measurement of the maximum strains at the center of the grate.

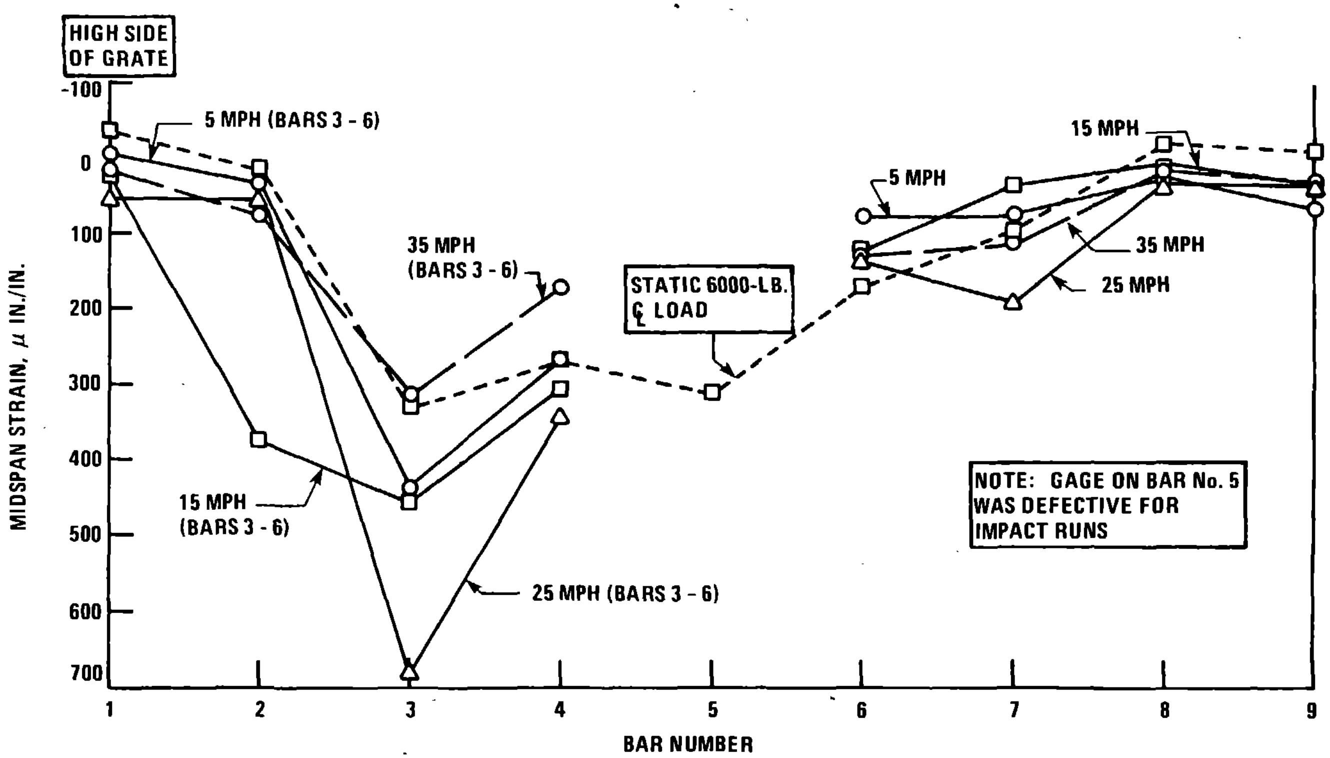

Figure 42. Grate D - Impact Load Strains on Transverse Centerline

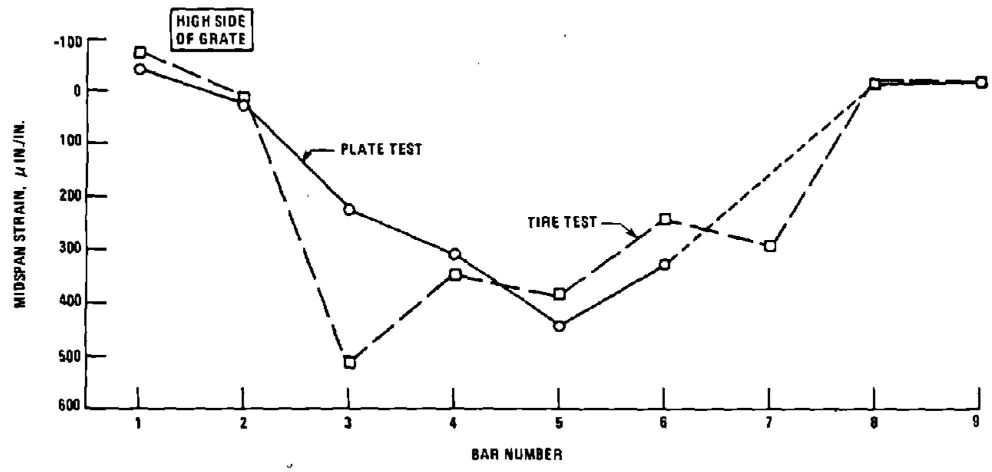

Figure 43. Grate D - Comparison of Static Tire and Plate Load Test Results (Strains at Transverse Centerline for 10,000-lb. Load)

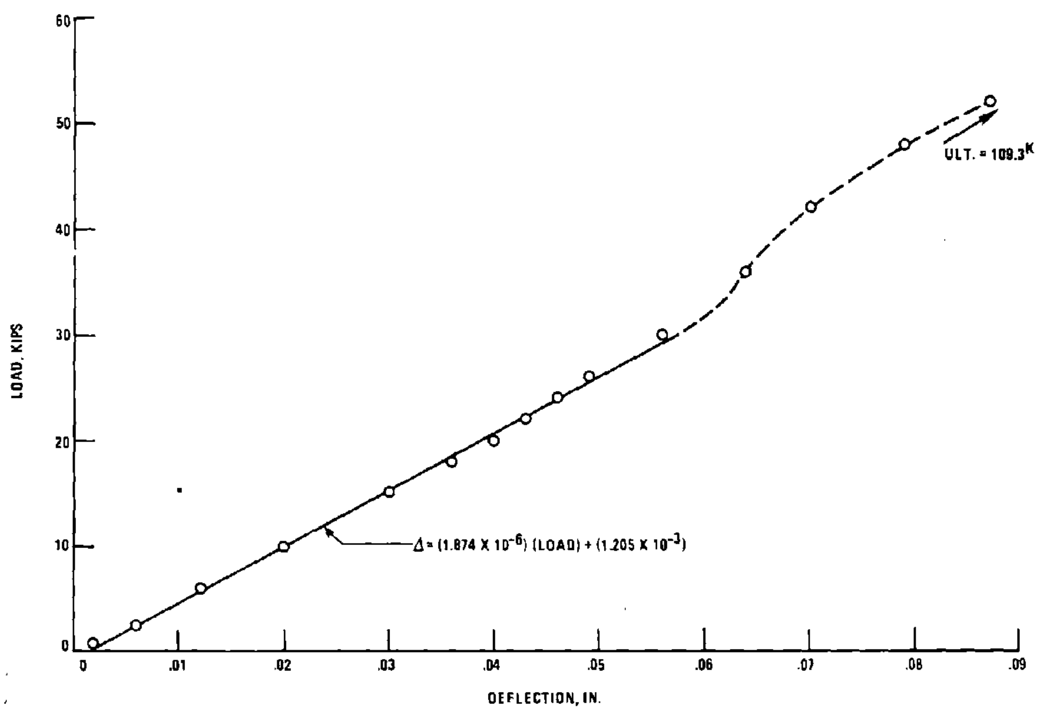

Figure 44. Grate D - Centerpoint Deflection under Plate Load Test

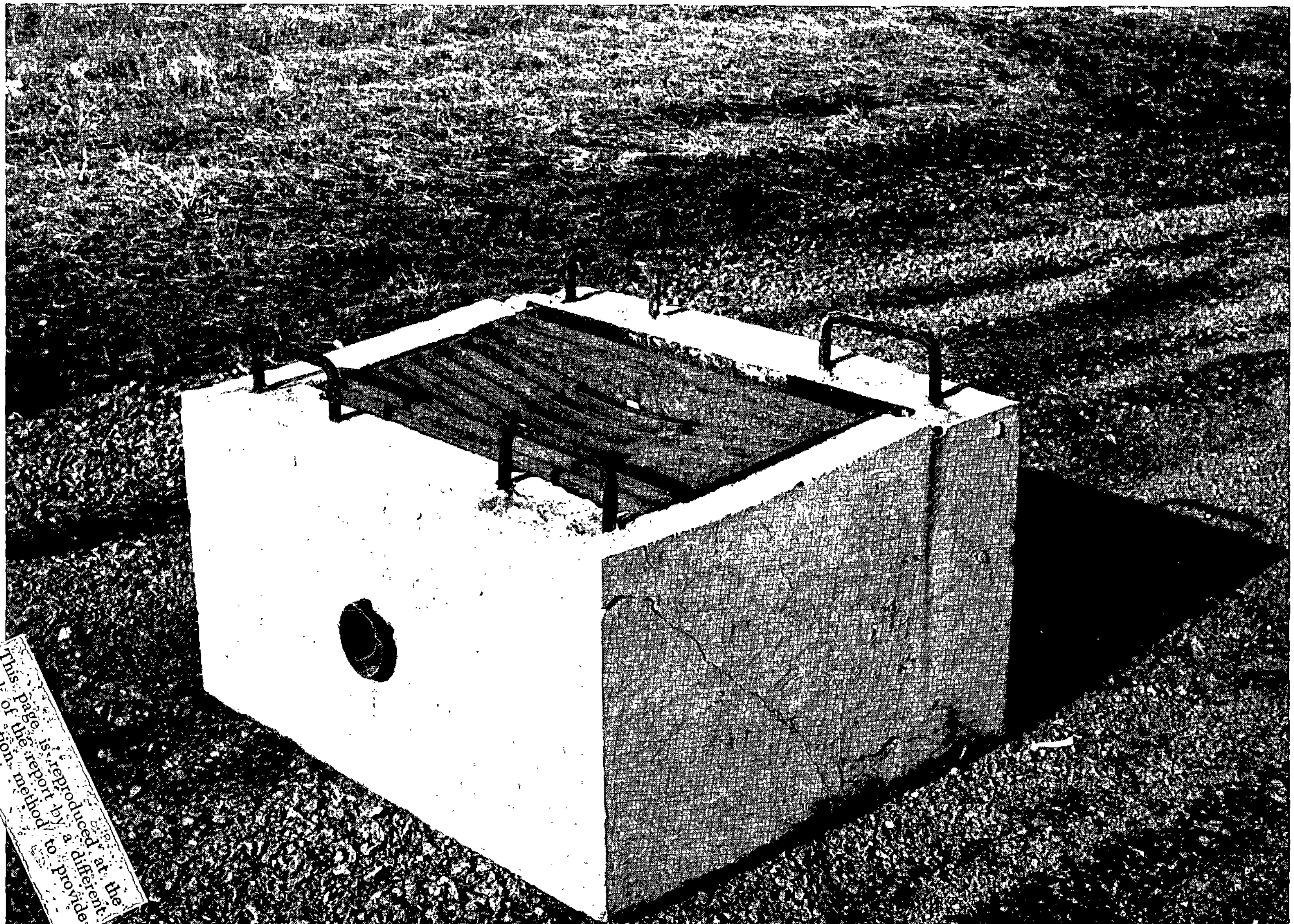

Figure 45. Grate D - After Plate Load Test to Failure

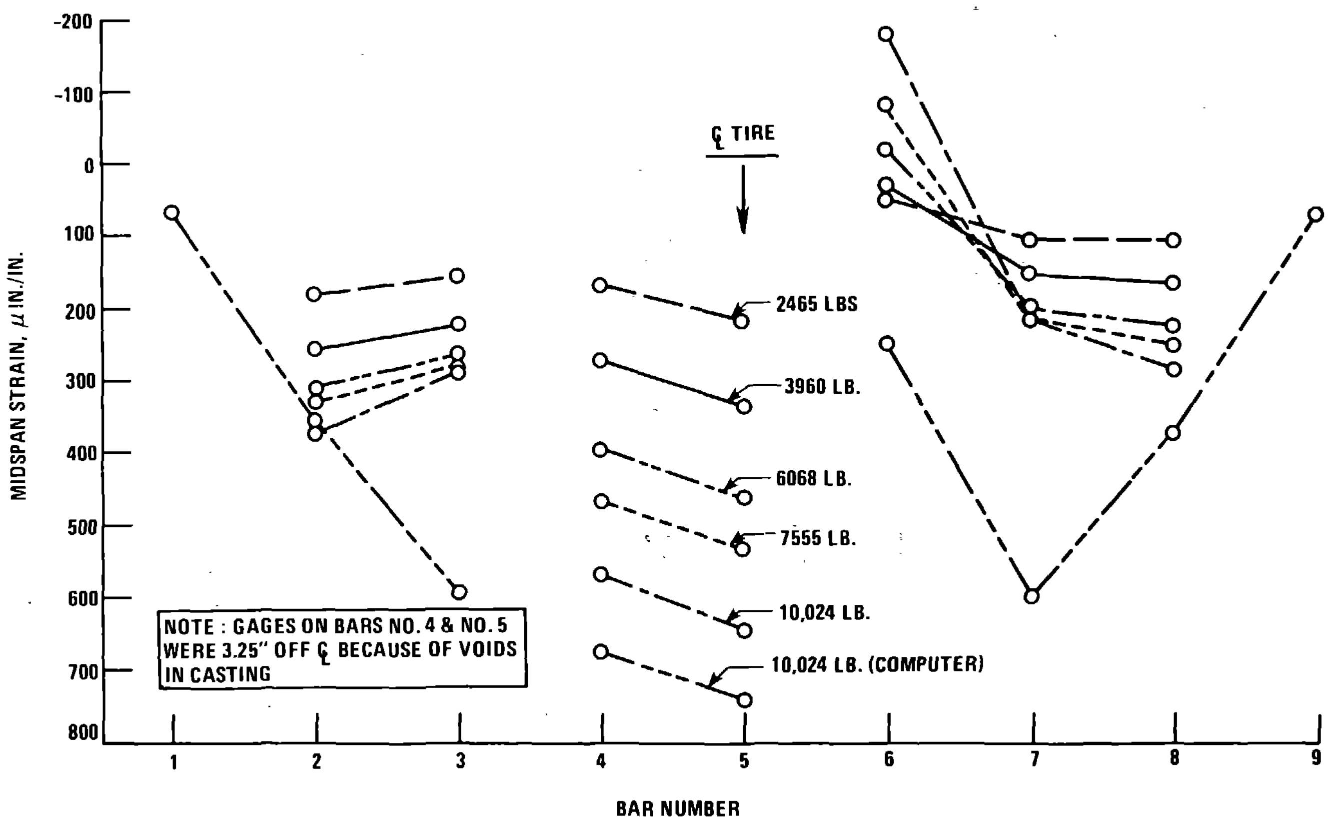

Figure 46. Grate E - Static Wheel Load Strains on Transverse Centerline (Longitudinal)

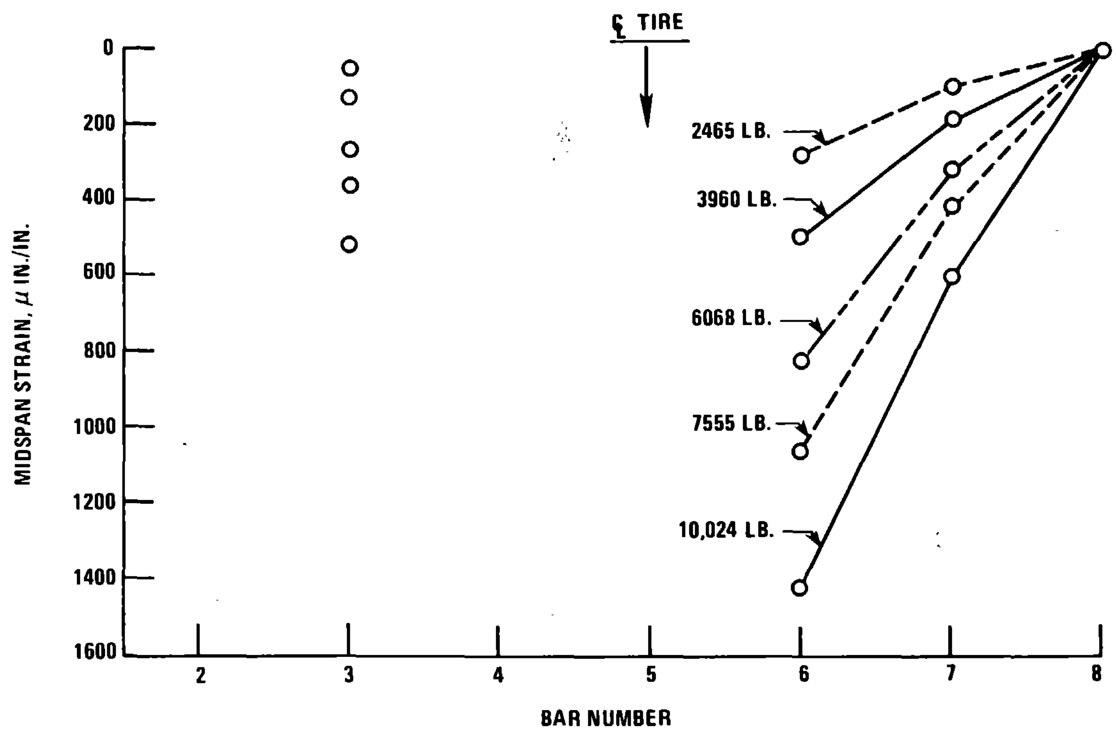

Figure 47. Grate E - Static Wheel Load Strains on Transverse Centerline (Transverse)

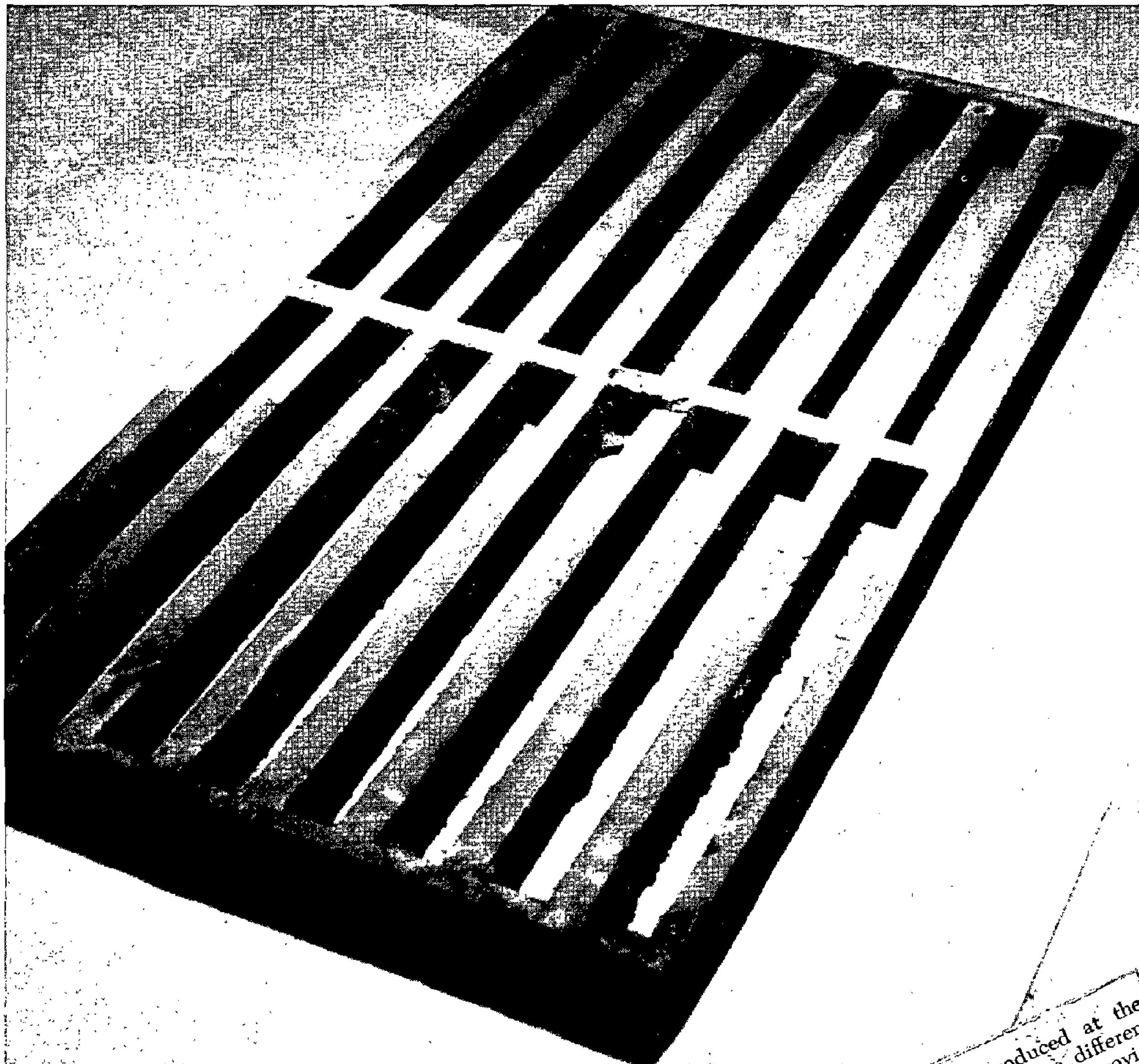

Figure 48. Voids in Grate "E" Casting

In order to make a computer analysis of this grate, it was necessary to measure the voids in the casting, and to attempt to model their effect on the structural behavior of this grate. Because of the variability in the properties of cast iron, it was also necessary to remove a section of the grate (after the plate load test) for fabrication and testing of a reduced section tensile specimen. The stress-strain curve from this test is shown on Figure 49. This material had a modulus of elasticity of 12,970,000 psi. and an ultimate strength of 27,930 psi. The results of the computer analysis for longitudinal bending are shown on Figure 46. Although the computed strains are greater than those measured during the static tests they are reasonably close, expecially considering the problems caused by the voids in the casting.

The results of the field rolling load dynamic tests are shown on Figures 50 and 51, for longitudinal and transverse bending strains, respectively; with the 6000-lb. static tire test data for comparison. Considering only maximum values, this data indicates rolling load dynamic factors of 1.20 (longitudinal) and 0.82 (transverse).

The results of the field dynamic impact load tests are shown on Figures 52 and 53, for longitudinal and transverse bending strains, respectively; with the 6000-lb. static tire test data for comparison. Considering only maximum values, this data indicates dynamic impact factors of 2.11 (longitudinal) and 1.39 (transverse).

Results of the static plate load tests are shown on Figures 54 to 56. Figures 54 and 55 show comparisons between the plate load and static tire load test data, for longitudinal and transverse bending strains, respectively. It may be seen that the results of these tests are very close. Figure 56 shows a plot of deflection versus load, up to 12,700 lb. Although this load was not the ultimate load capacity of this grate, the transverse midspan structural member fractures at this load, and the test was terminated. This result was not unexpected, considering the higher strains measured in this member over those of the longitudinal members. It should be noted that the load-deflection line was perfectly linear up to failure, which is typical of cast iron. This grate did not meet the requirements of the Federal Specification.

5.7. Data and Analysis for Grate "F".

This grate was subjected to four increments of static load (2500 lb., 5900 lb., 7500 lb., and 10,000 lb.) in the following two tire positions.

(1) Midspan loading symmetrical about the centerline of the grate.

(2) Midspan loading symmetrical about the midline between grate bars No. 7 and 8.

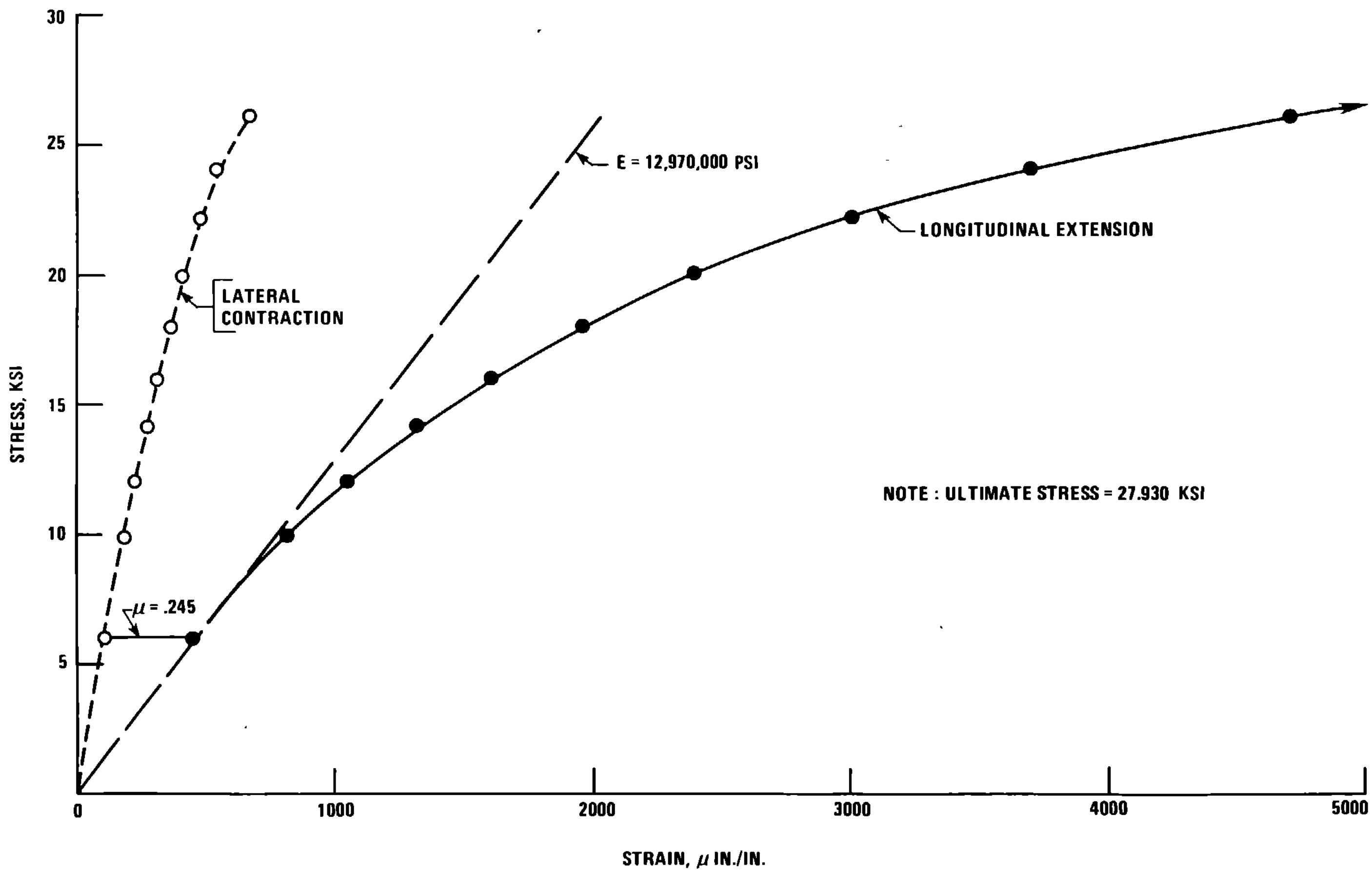

Figure 49. Grate E - Tensile Test of Reduced Section Specimen

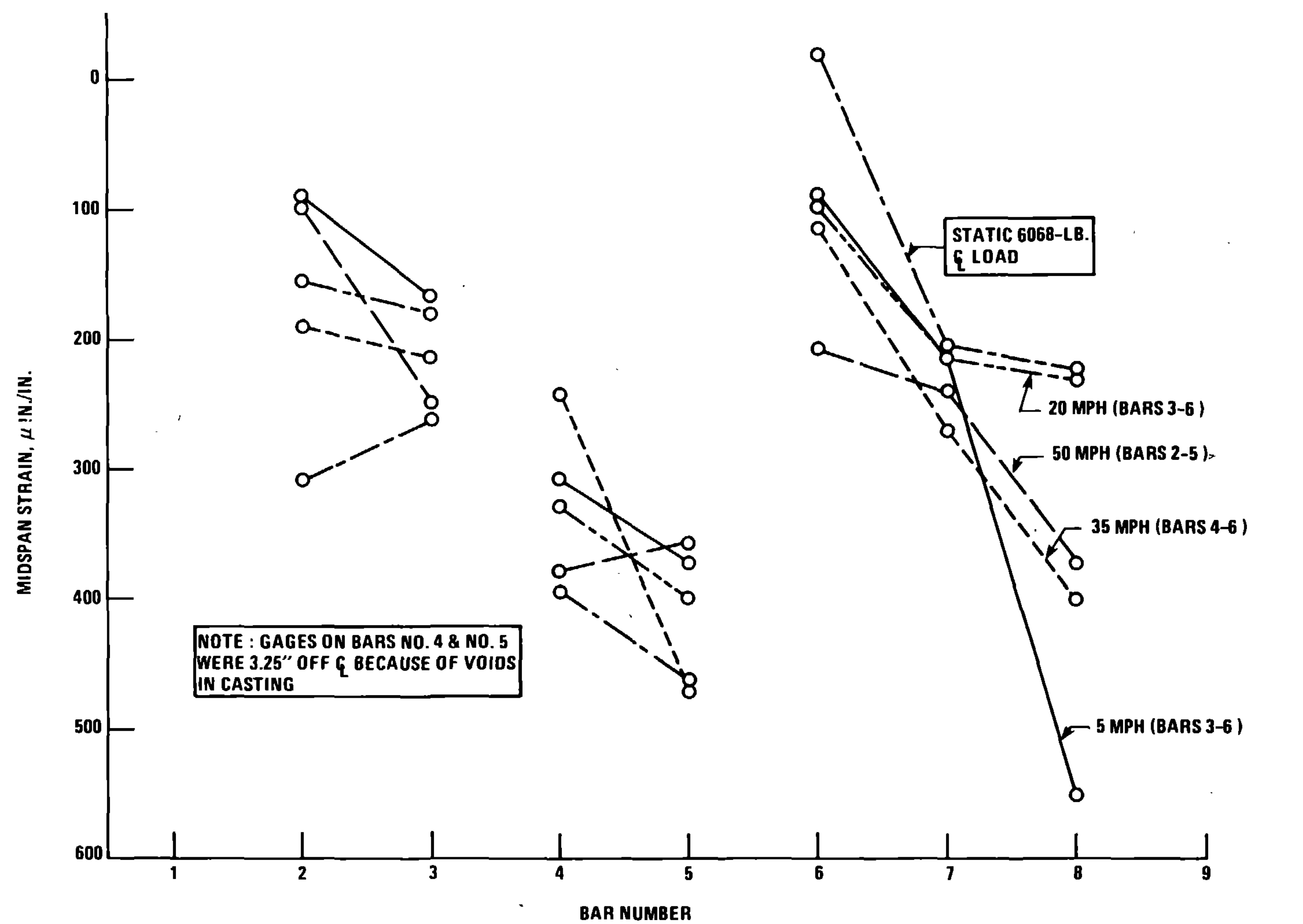

Figure 50. Grate E - Rolling Load Strains on Transverse Centerline (Longitudinal)

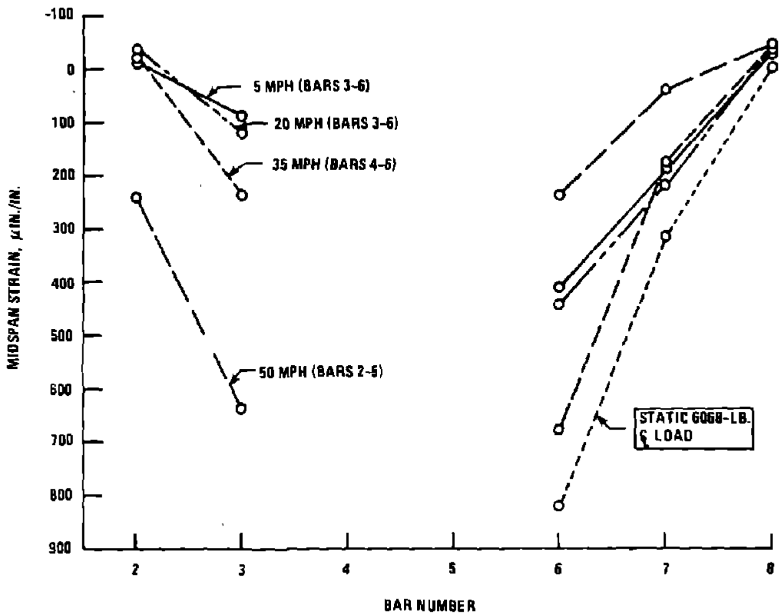

Figure 51. Grate E - Rolling Load Strains on Transverse Centerline (Transverse)

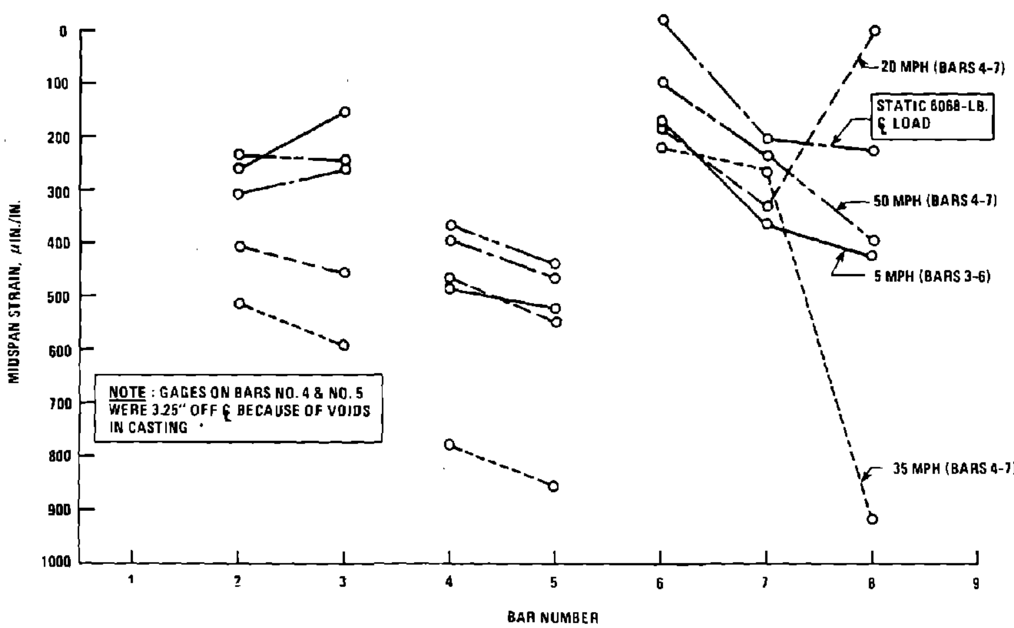

Figure 52. Grate E - Impact Load Strains on Transverse Centerline (Longitudinal)

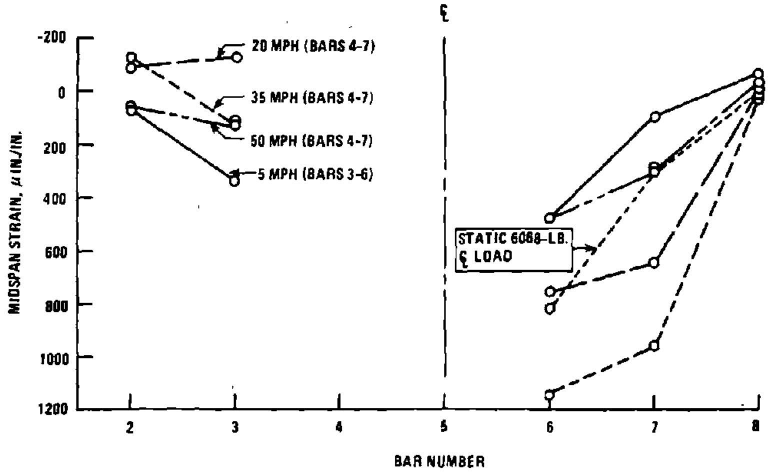

Figure 53. Grate E - Impact Load Strains on Transverse Centerline (Transverse)

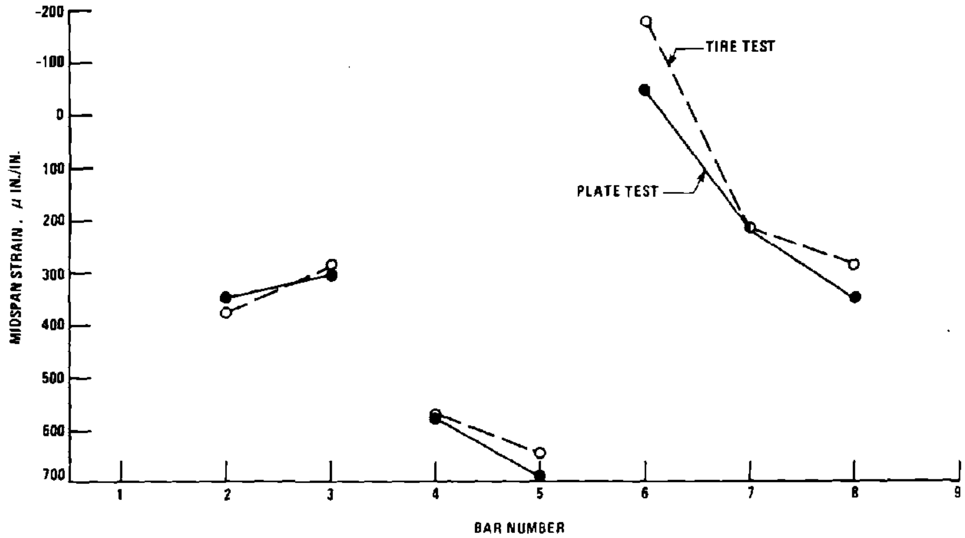

Figure 54. Grate E - Comparison of Static Tire and Plate Load Test Results (Longitudinal Strains at Transverse Centerline for 10,000-lb. Load)

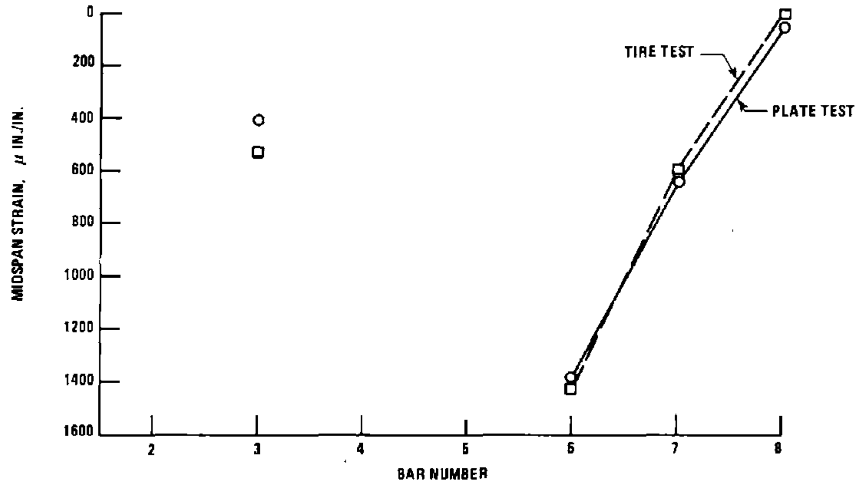

Figure 55. Grate E - Comparison of Static Tire and Plate Load Test Results (Transverse Strains at Transverse Centerline for 10,000-lb. Load)

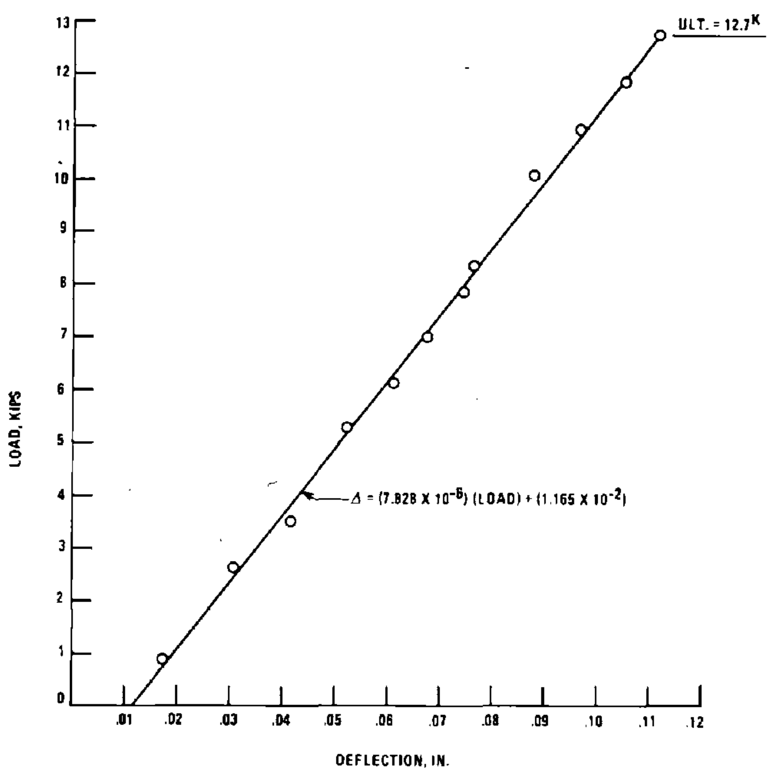

Figure 56. Grate E - Centerpoint Deflection Under Plate Load Test

The data from these tests are shown on Figures 57 and 58, as strain profiles. As shown on Figure 8, this is a heavy cast iron grate with bowed, deep section, longitudinal members inclosed in a substantial box-shaped rim. The strength of the longitudinal members can be surmised from the very low strains which were measured during these tests.

In order to make a computer analysis of this grate it was necessary to model the effect of the bowed longitudinal members, and to test a reduced section tensile specimen to obtain materials properties. The stress-strain curve from the tensile test is shown on Figure 59. This material had a modulus of elasticity of 16,250,000 psi. and an ultimate strength of 30,408 psi. The results of one computer analysis is shown on Figure 57. Considering the problems in modeling the geometry of the subject grate, the agreement between the test and computer results is considered acceptable.

The results of the field rolling load dynamic tests are shown on Figure 60, as strain profiles, with the 5900-lb. static tire test curve for comparison. Considering only maximum values, this data indicates a maximum rolling load dynamic factor of 1.06.

The results of the field dynamic impact load tests are shown on Figure 61, with the 5900-lb. static tire test curve for reference. It may be noted that the measured strains for all impact runs except the 20 mph. run are less than those measured during the static tire test. Considering only the maximum value for the 20 mph. impact test and the static data, this data indicates a maximum impact factor of 1.20.

The results of the static plate load test are shown on Figures 62 and 63. Figure 62 shows a comparison of the plate load and static tire test results, at the 10,000-lb. load level. Considering the problems in modeling the geometry of this grate the agreement between these test results is quite good. Figure 63 shows a plot of deflection versus load, up to the ultimate load of 90,100 lbs. It should be noted that this is a linear relationship to the ultimate load. Therefore, this grate greatly exceeds the requirements of the Federal Specification.

5.8. Data and Analysis for Grate "G".

As described in Section 4.7., this is a four I-beam median grate. Because of the spacing of the beams, and the modest end connections, it was assumed that the beams would act independently (essentially as simply supported beams) under wheel loads. Therefore, this grate was not subjected to various levels of static tire loads in the laboratory. However, during the field tests the test vehicle was parked at the midspan of beams number 1, 2, and 3. The data from these tests, using the 6000-lb. wheel load, are shown on Figure 64. It may be seen that the beams do essentially act independently, with little transfer of strain into the adjacent beams.

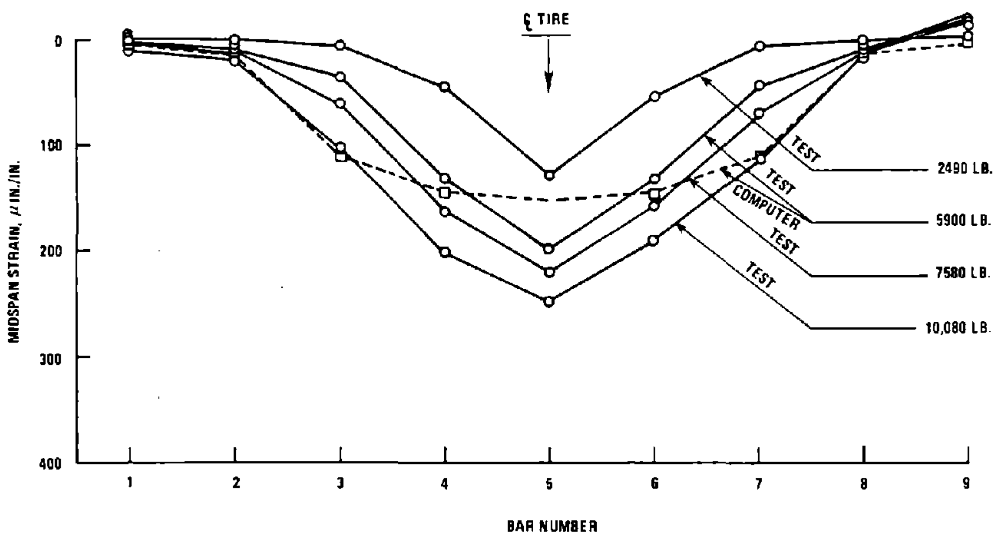

Figure 57. Grate F - Static Wheel Load Strains on Transverse Centerline

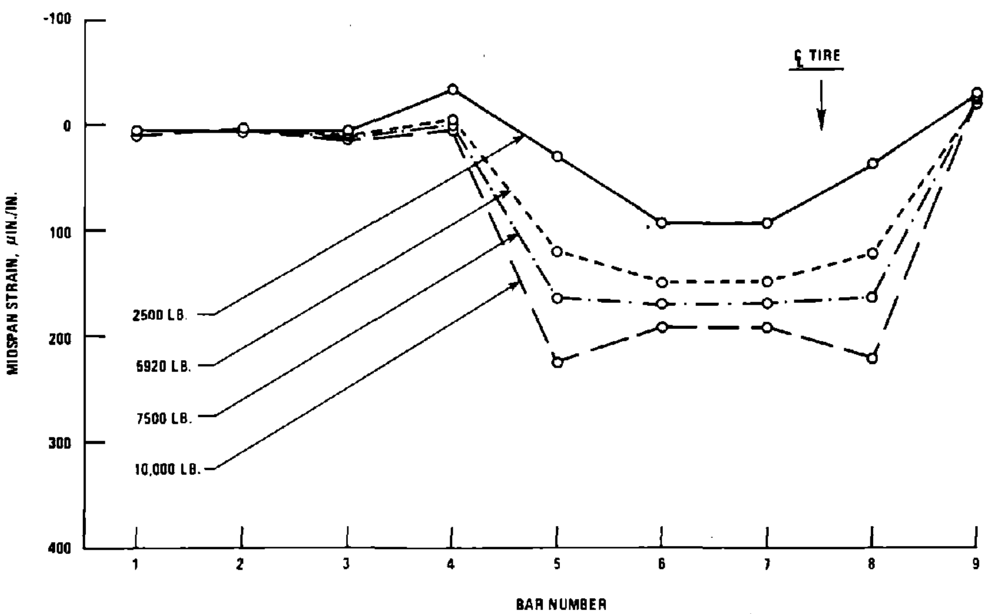

Figure 58. Grate F - Offcenter Static Wheel Load Strains on Transverse Centerline

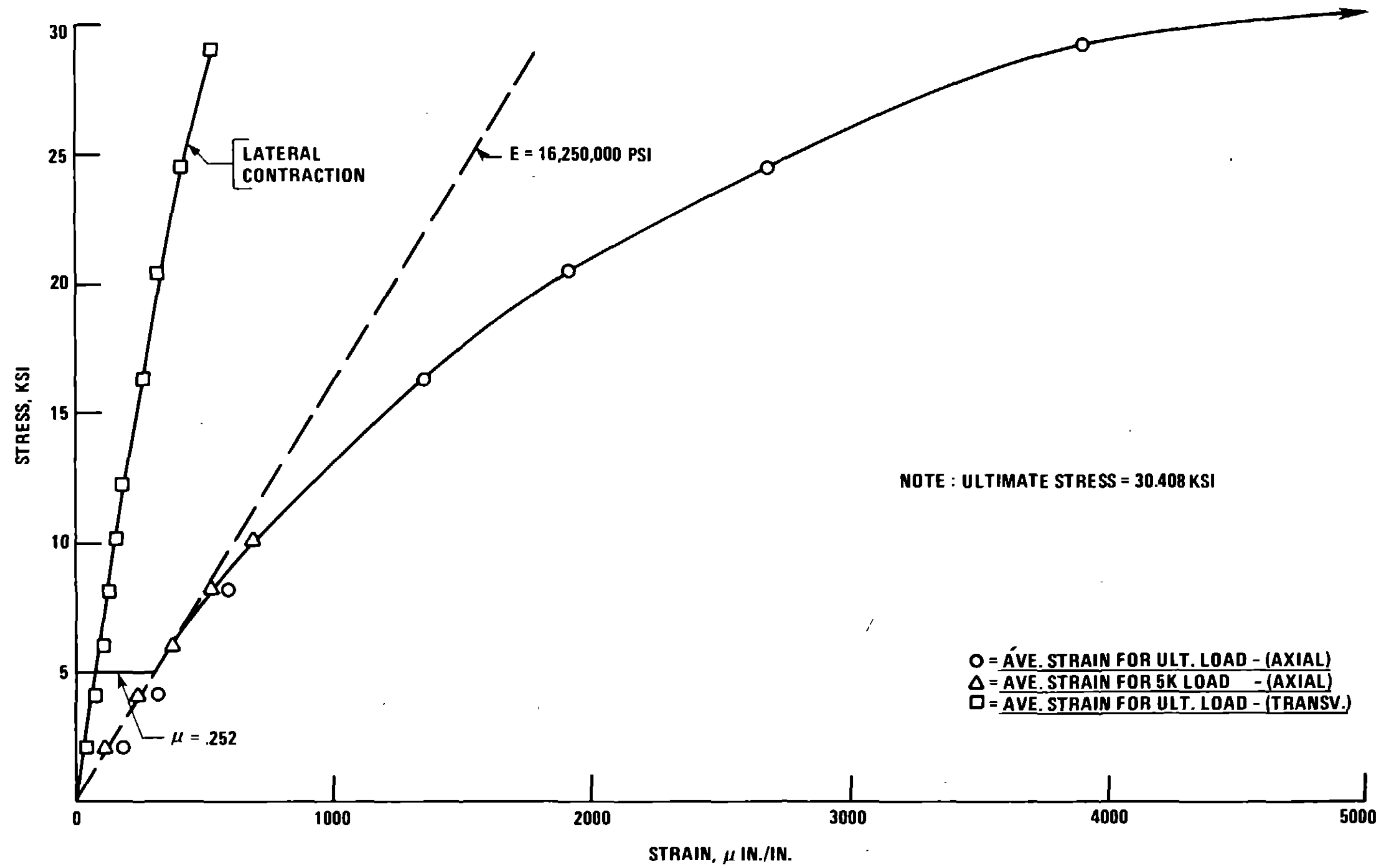

Figure 59. Grate F - Tensile Test of Reduced Section Specimen

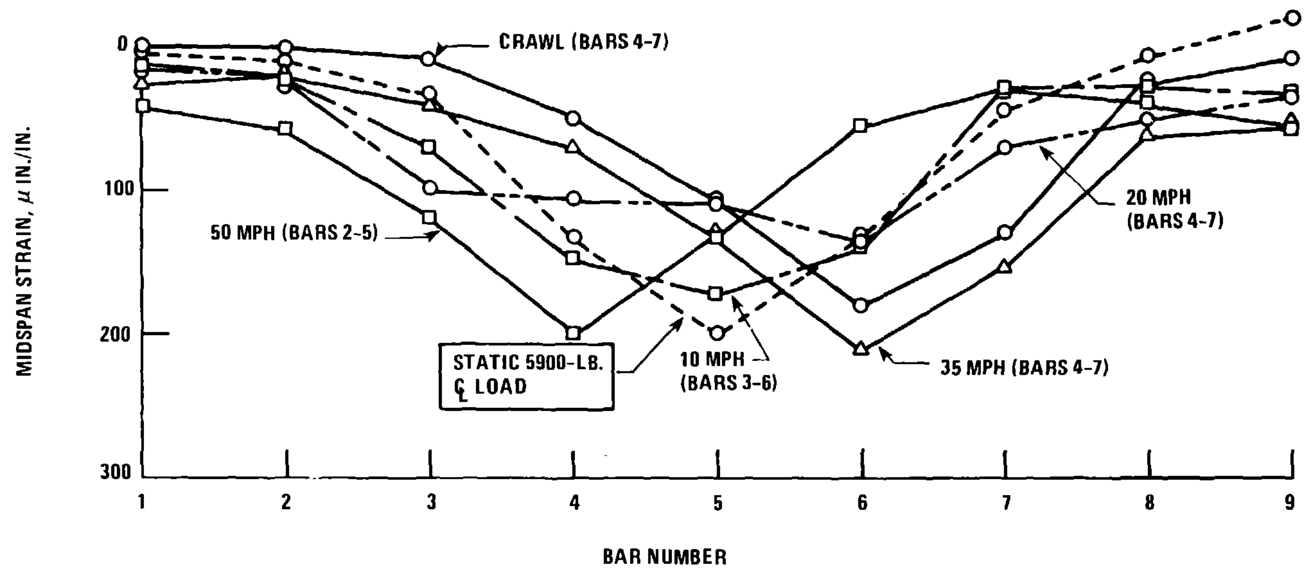

Figure 60. Grate F - Rolling Load Strains on Transverse Centerline

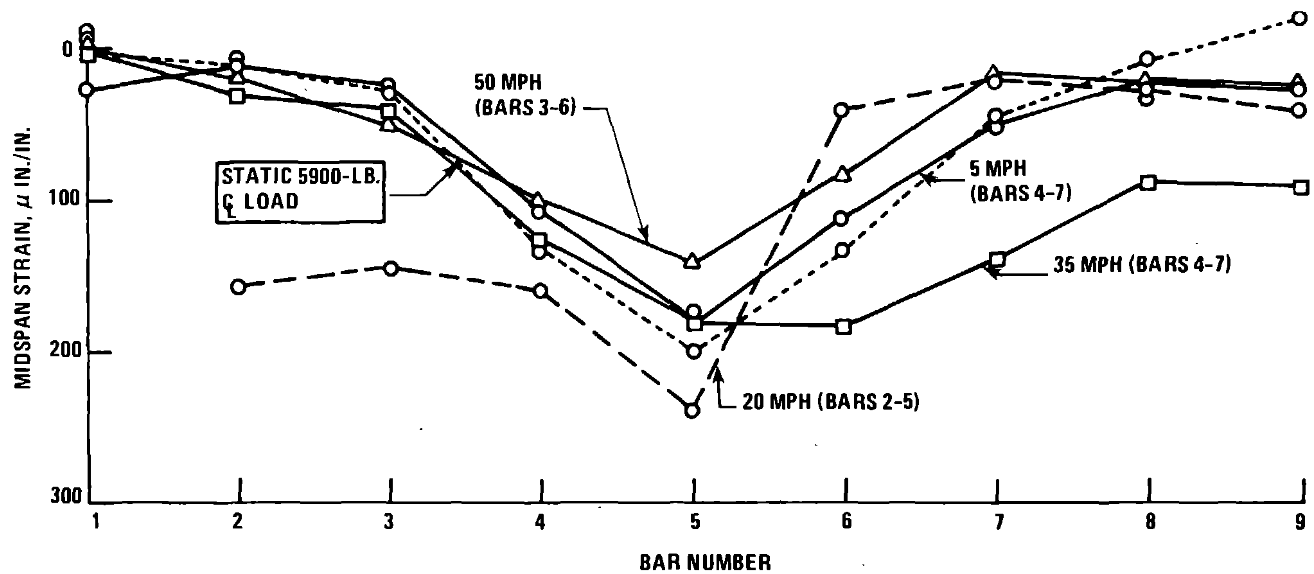

Figure 61. Grate F - Impact Load Strains on Transverse Centerline

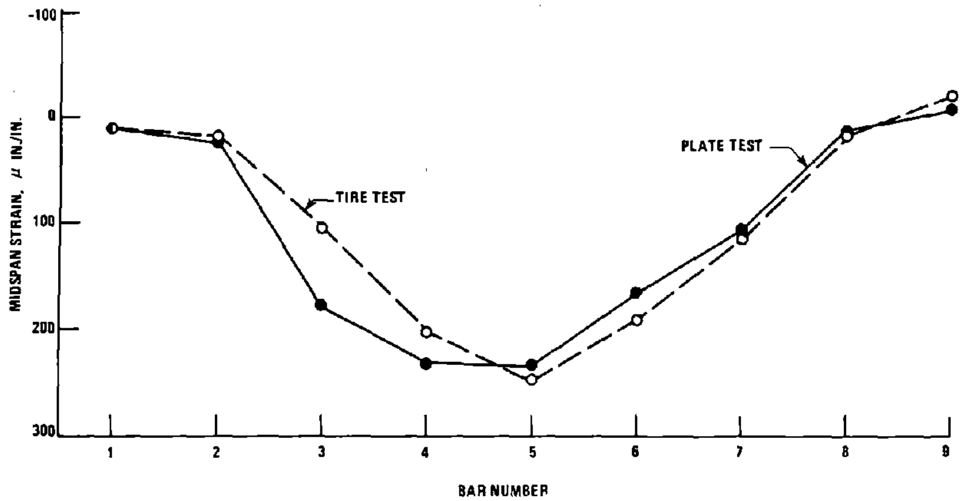

Figure 62. Grate F - Comparison of Static Tire and Plate Load Test Results (Strains at Transverse Centerline for 10,000-lb. Load)

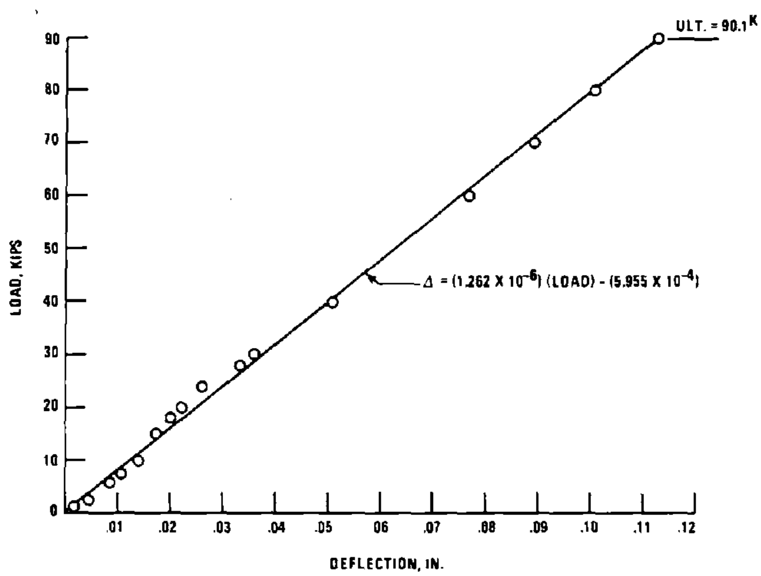

Figure 63. Grate F - Centerpoint Deflection under Plate Load Test

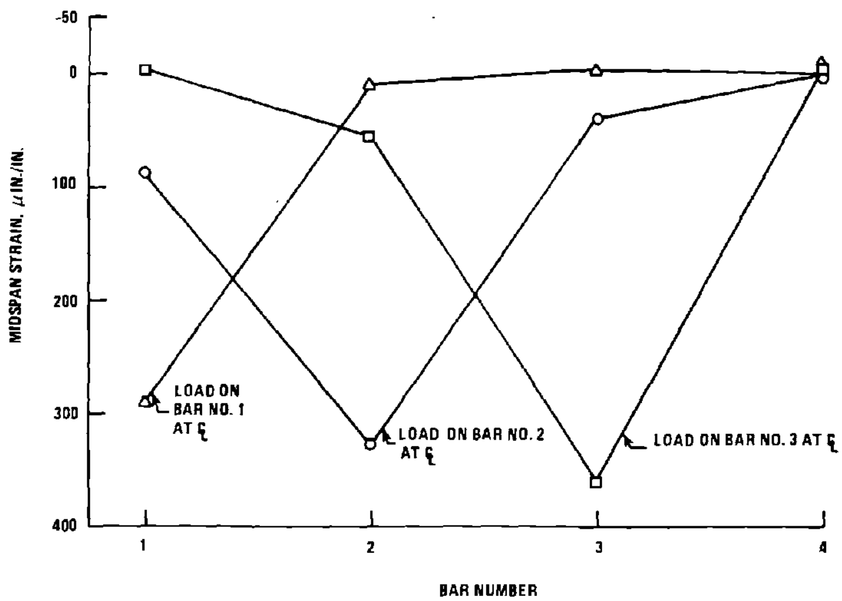

Figure 64. Grate G - Static Wheel Load Strains on Transverse Centerline (Wheel Load = 6,000 lb.)

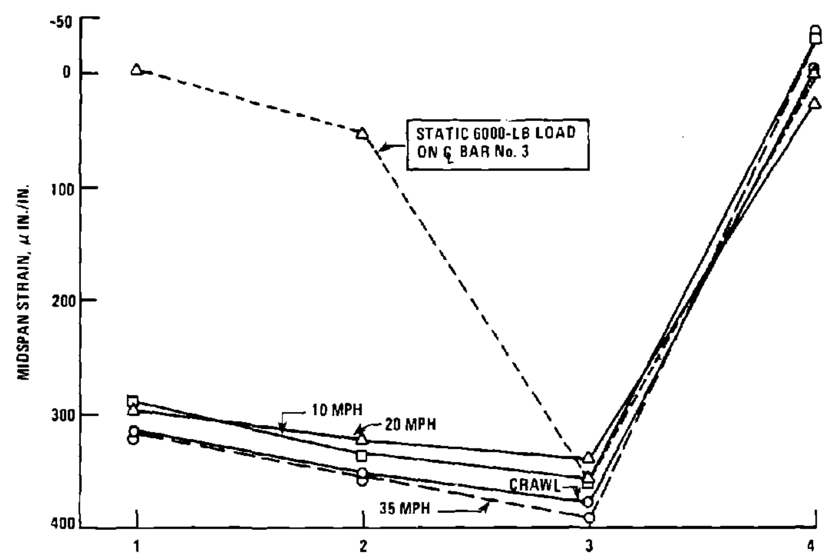

Figure 65. Grate G - Rolling Load Strains on Transverse Centerline

The results of the field rolling load dynamic tests are shown on Figure 65, with the results of the static test for comparison. The main difference between the curves is due to loading two beams in the rolling loan tests. Although it may not be appropriate, this data would indicate a rolling load dynamic factor of 1.08.

The results of the field dynamic impact load tests are shown on Figure 66, with the results of the static loading of beam No. 3 for comparison. However (again) under the static test only one beam was loaded, whereas two beams were loaded during the impact tests. Considering these data, a dynamic impact factor of 1.58 is indicated, but it might be higher if the impact loads were applied to only one beam.

The results of the static plate load test are shown on Figure 67. Since the plate load was applied to two beams it is difficult to compare these results with those from the static tire loading of one beam. This figure shows strain profiles for plate loads of 5920 lbs. and 10,000 lbs., and the 6000-lb. static tire test. Figure 68 shows a plot of deflection versus load, up to 60,000 lbs. The initial concave (upwards) portion of the line is probably due to rocking of the grate in the frame, and initial bending as uniform bearing was achieved. This grate had an ultimate load capacity of 68,300 lbs. Failure was by yielding of the two loaded beams, with rotational yield of the beam flanges under the loading plate. There was some torsional yielding of the end connecting plates. From this curve it is estimated that yield (permanent deflection) of this grate occured at about 50,000 lbs., which satisfies the minimum requirements of the Federal Specification. A picture of this grate after the plate load test is shown on Figure 69.

5.9. Data and Analysis for Grate "H".

Grate "H" is a median grate, comprised of seven double-extra strong steel pipes, connected at the ends with angles (Figure 10). Because of the spacing of the pipes, and the light end connections, it was assumed that the pipes would act as simply supported beams under midspan loading. Therefore, this grate was not subjected to a range of static tire loads in the laboratory. However, during the field tests the test vehicle was parked at several locations across the grate midspan, thereby applying a 6000-lb. static wheel load. The results of these tests are shown on Figure 70. It may be seen that there is some transfer of strain into adjacent "unloaded" grate members.

The results of the field rolling load dynamic tests are shown on Figure 71, with the results of two static wheel load tests for comparison. Considering only maximum values, this data indicates a rolling load dynamic factor of 1.10.

The results of the static plate load test are shown on Figures 73 and 74. Figure 73 shows a comparison of the static plate and tire

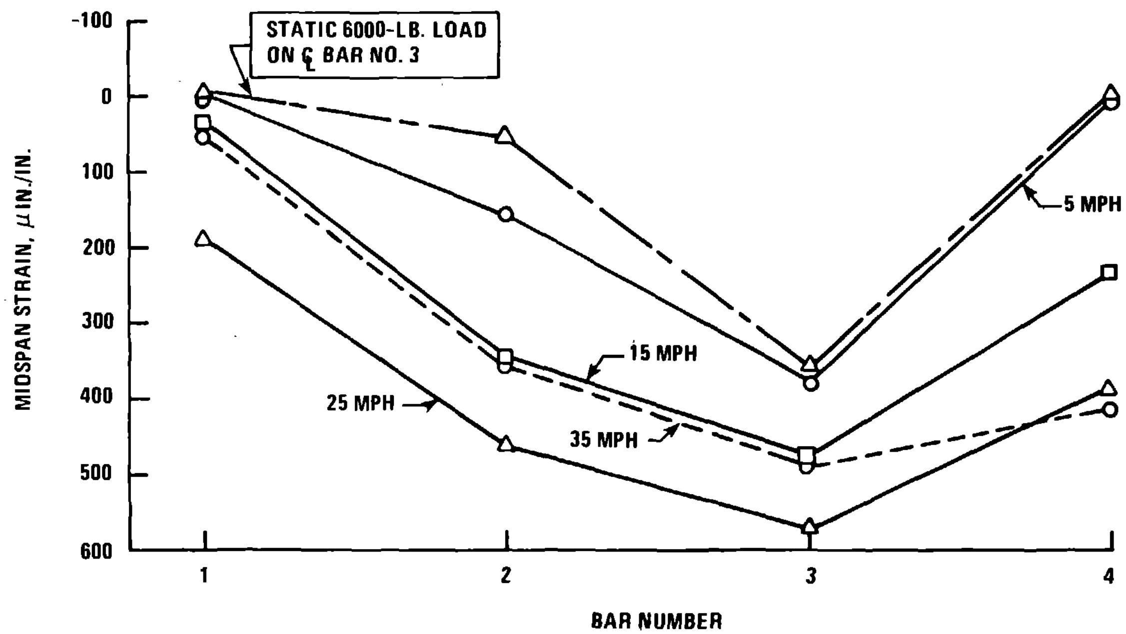

Figure 66. Grate G - Impact Load Strains on Transverse Centerline

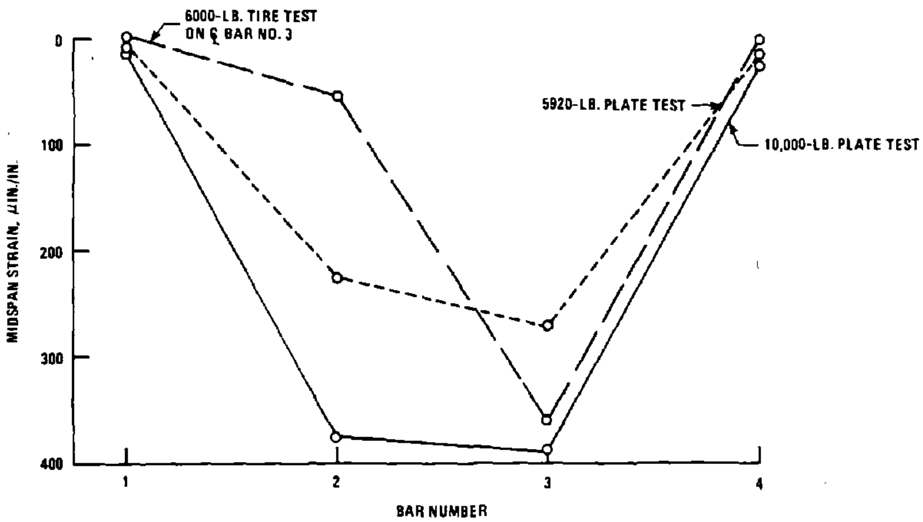

Figure 67. Grate. G - Comparison of Static Tire and Plate Load Test Results (Strains on Transverse Centerline)

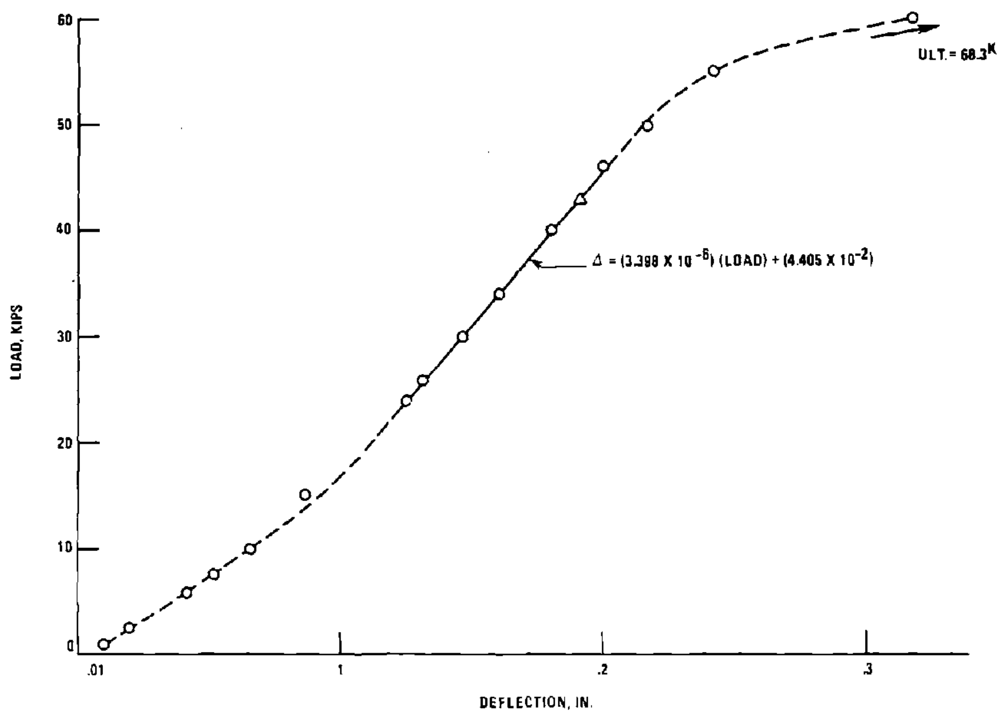

Figure 68. Grate G. - Centerpoint Deflection under Plate Load Test

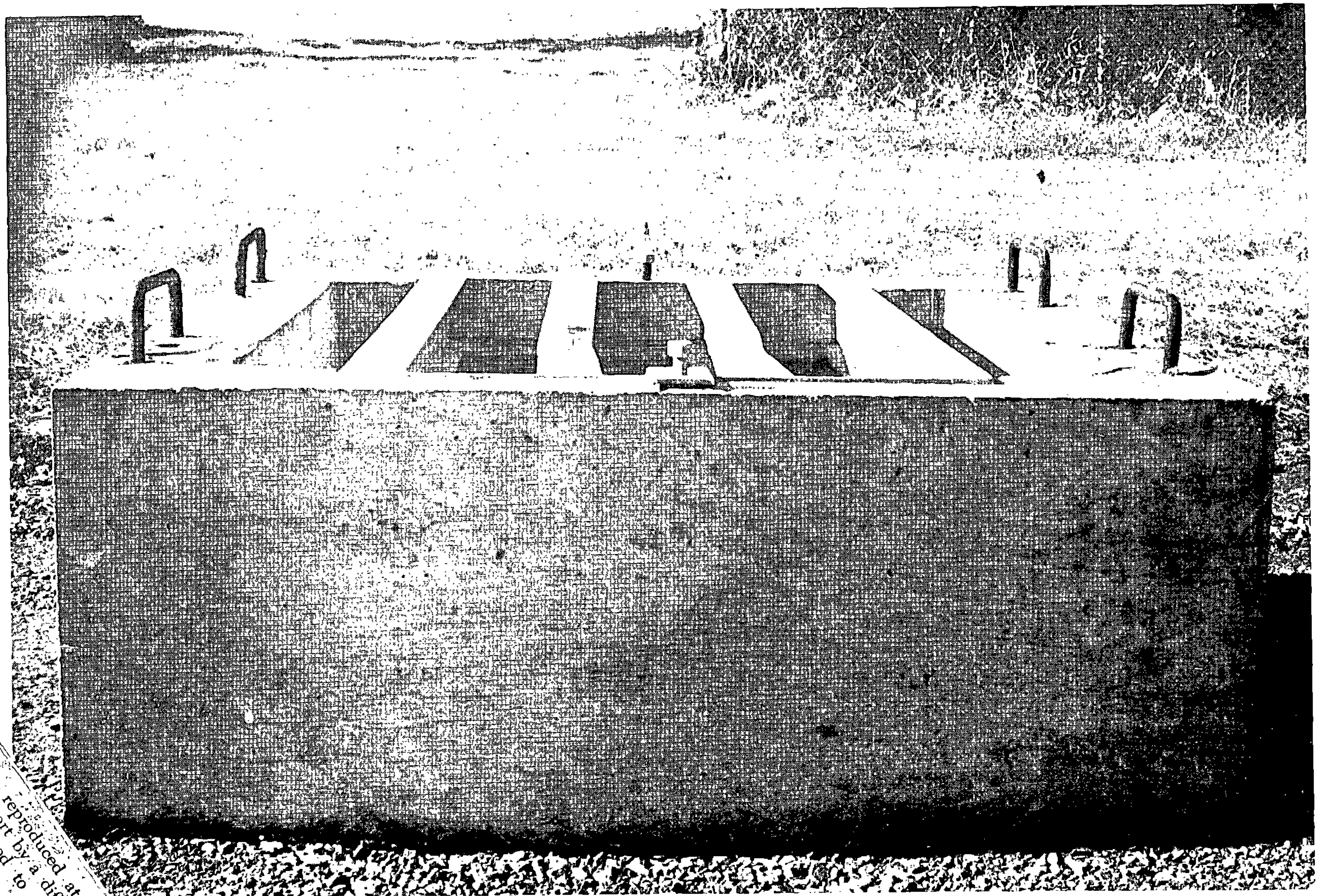

Figure 69. Grate G - After Plate Load Test to Failure

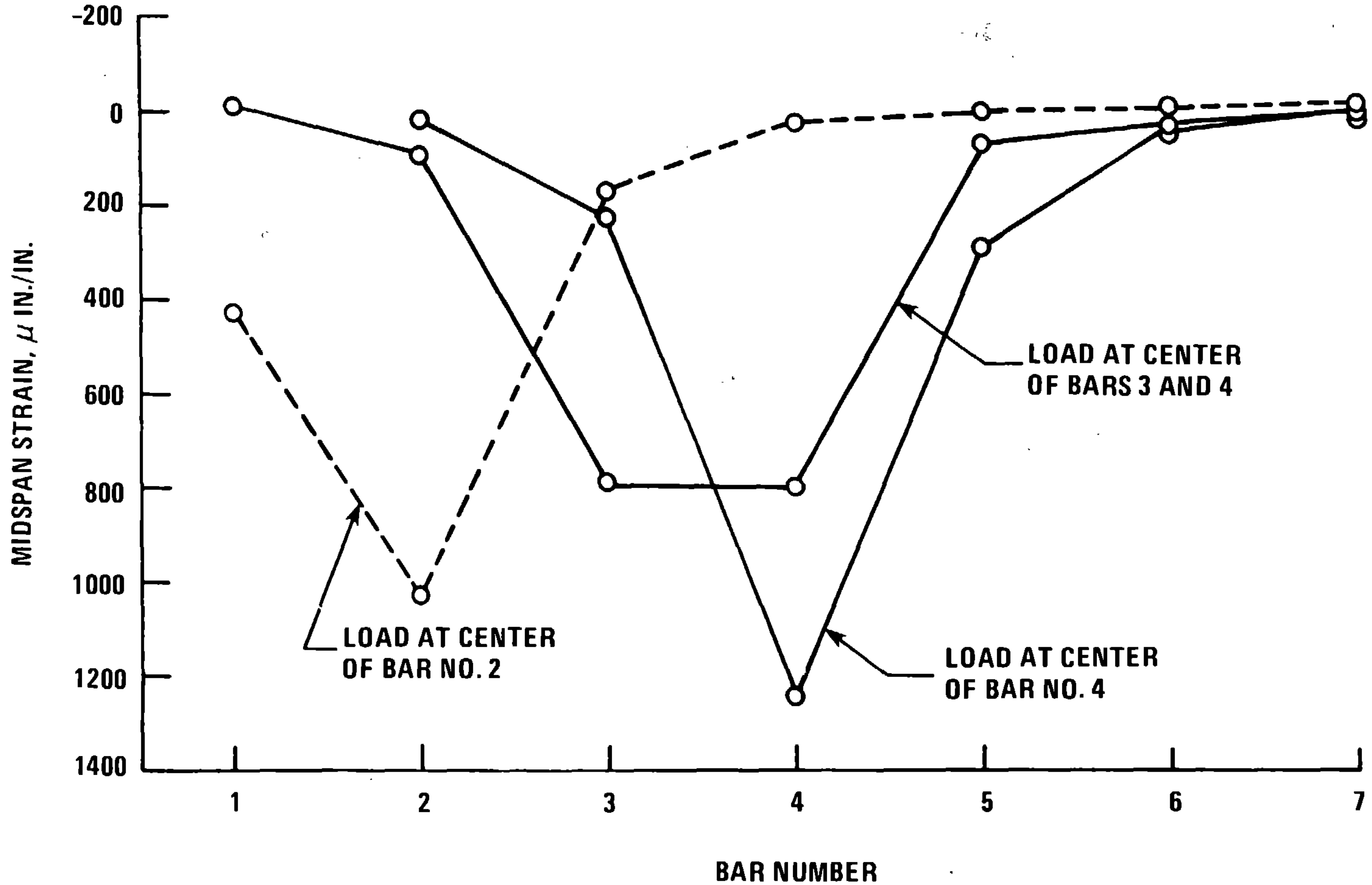

Figure 70. Grate H - Static Wheel Load Strains on Transverse Centerline (Wheel Load = 6,000 lb.)

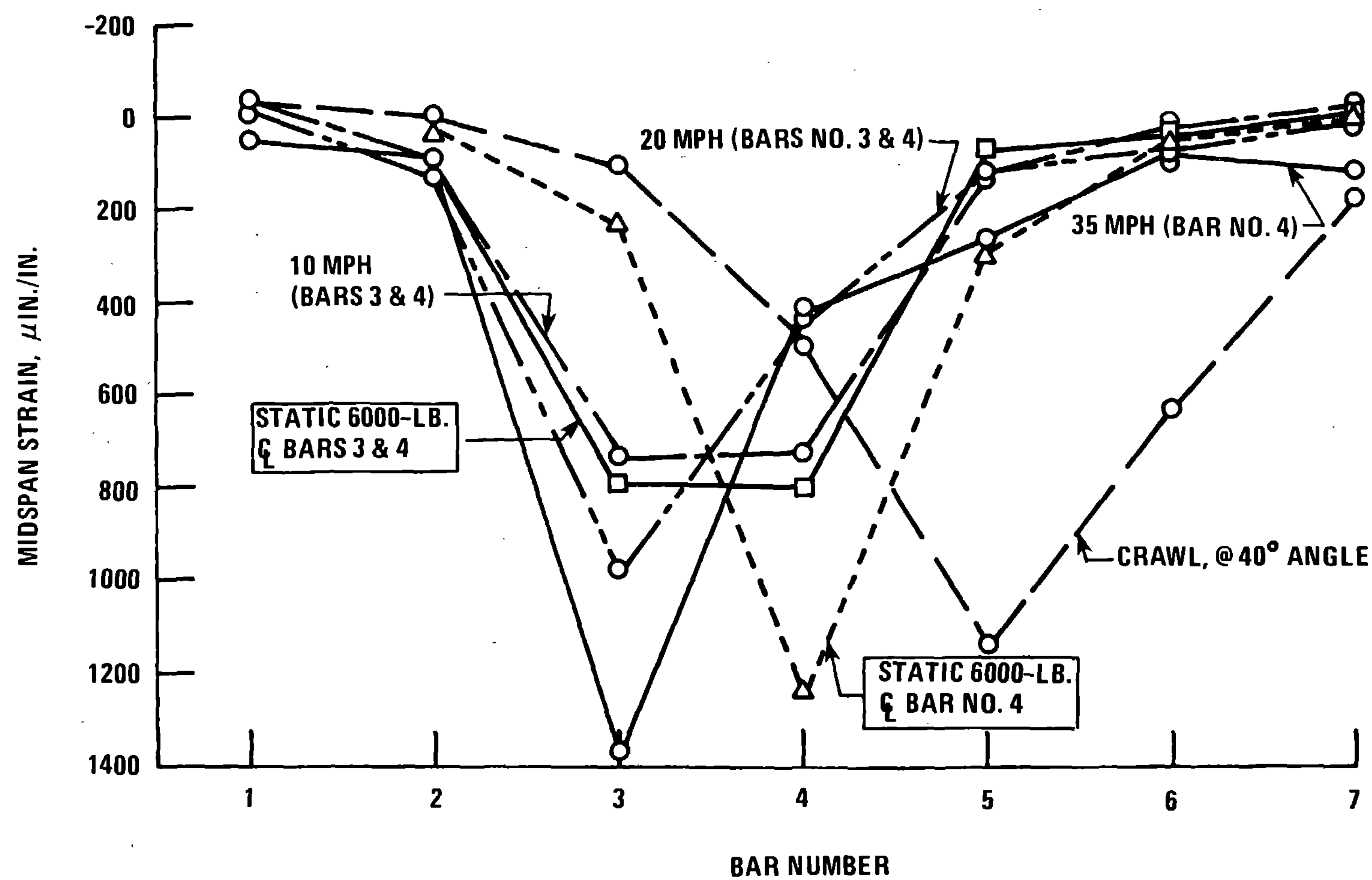

Figure 71. Grate H - Rolling Load Strains on Transverse Centerline

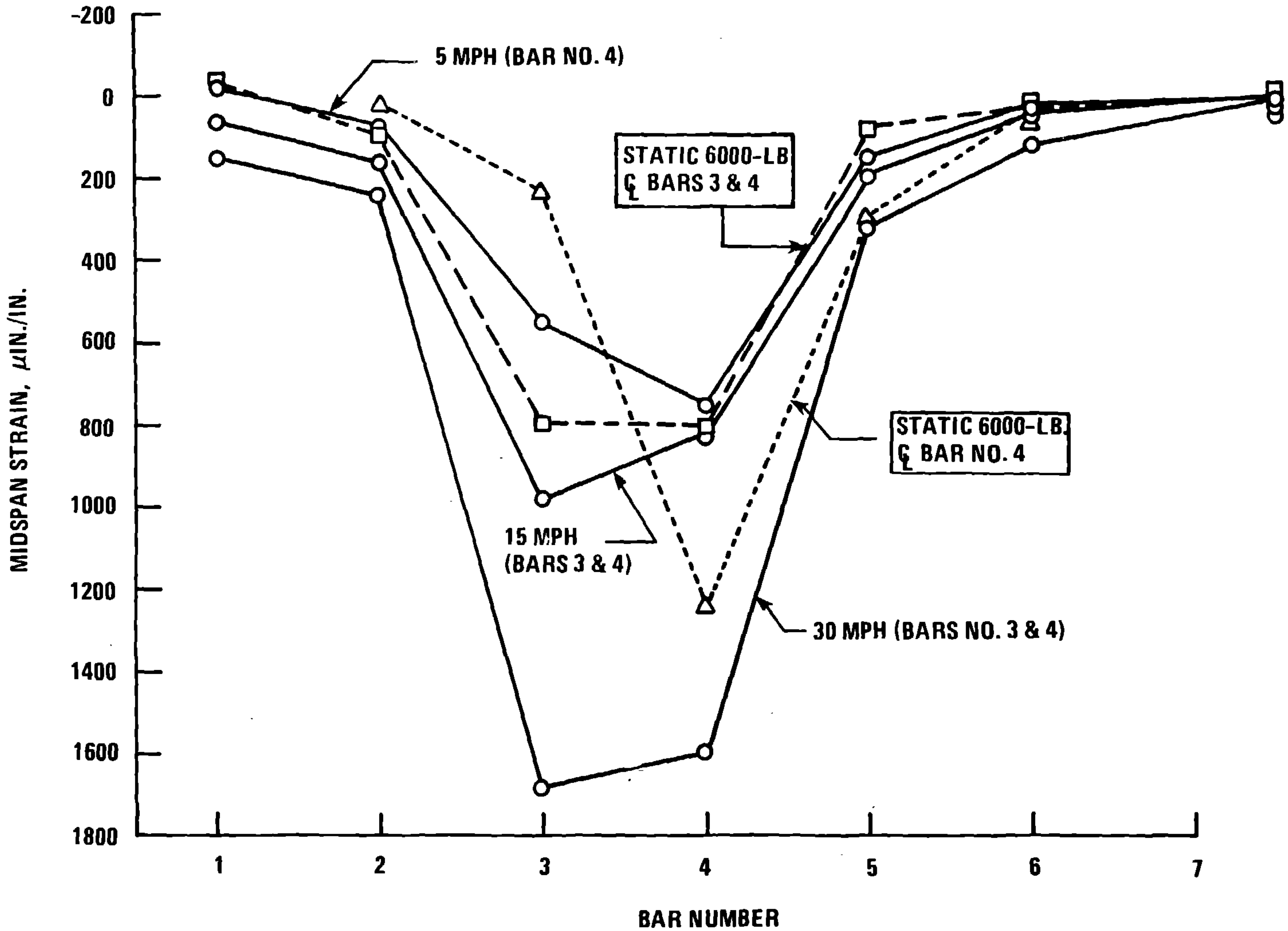

Figure 72. Grate H - Impact Load Strains on Transverse Centerline

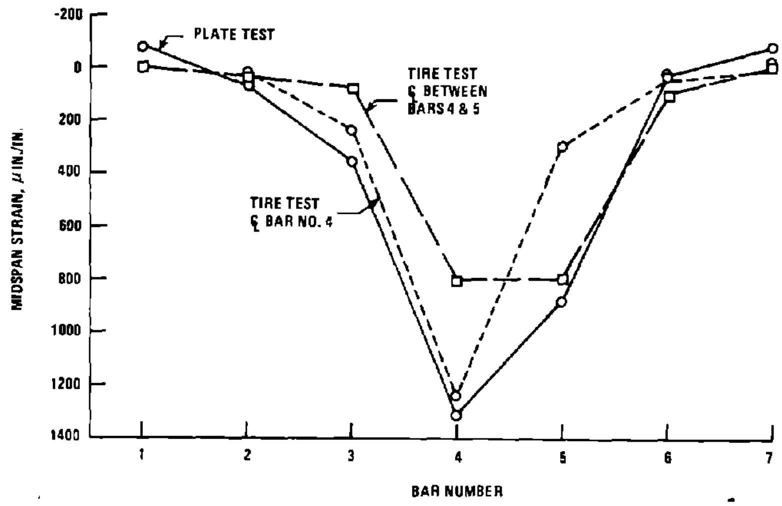

Figure 73. Grate H - Comparison of Static Tire and Plate Load Test Results (Strains at Transverse Centerline for 5,920-lb. Load)

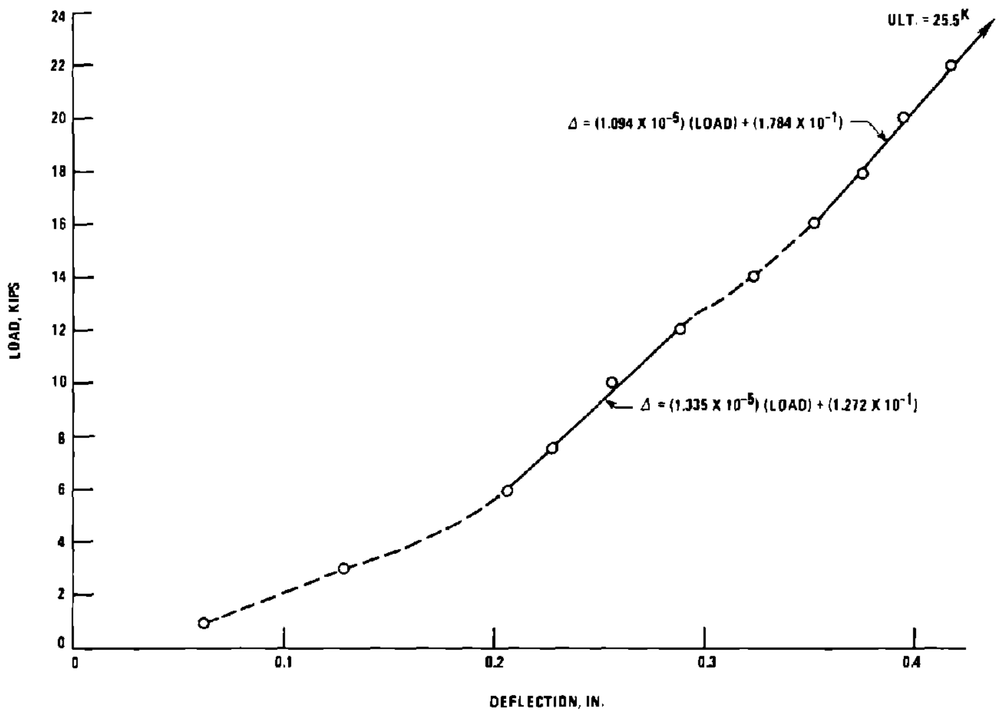

Figure 74. Grate H - Centerpoint Deflection under Plate Load Test

tests results. It should be noted that the 9-in. square loading plate "just" contacted grate member No. 3 and 5. During the loading the plate slipped off of member No. 3, thereby creating an eccentric loading on grate members No. 4 and 5. The shifting of the load was "permitted" by the rubber pad between the grate and the steel loading plate. The agreement between the static tire and plate load test results is only fair. Figure 74 shows a plot of grate midpoint deflection versus load. It is difficult to determine yield (permanent deflection) of the grate from this curve. The grate had an ultimate load capacity of 25,500 lbs., which is less than that required by the Federal Specification. A picture of this grate after the plate load test is shown on Figure 75.

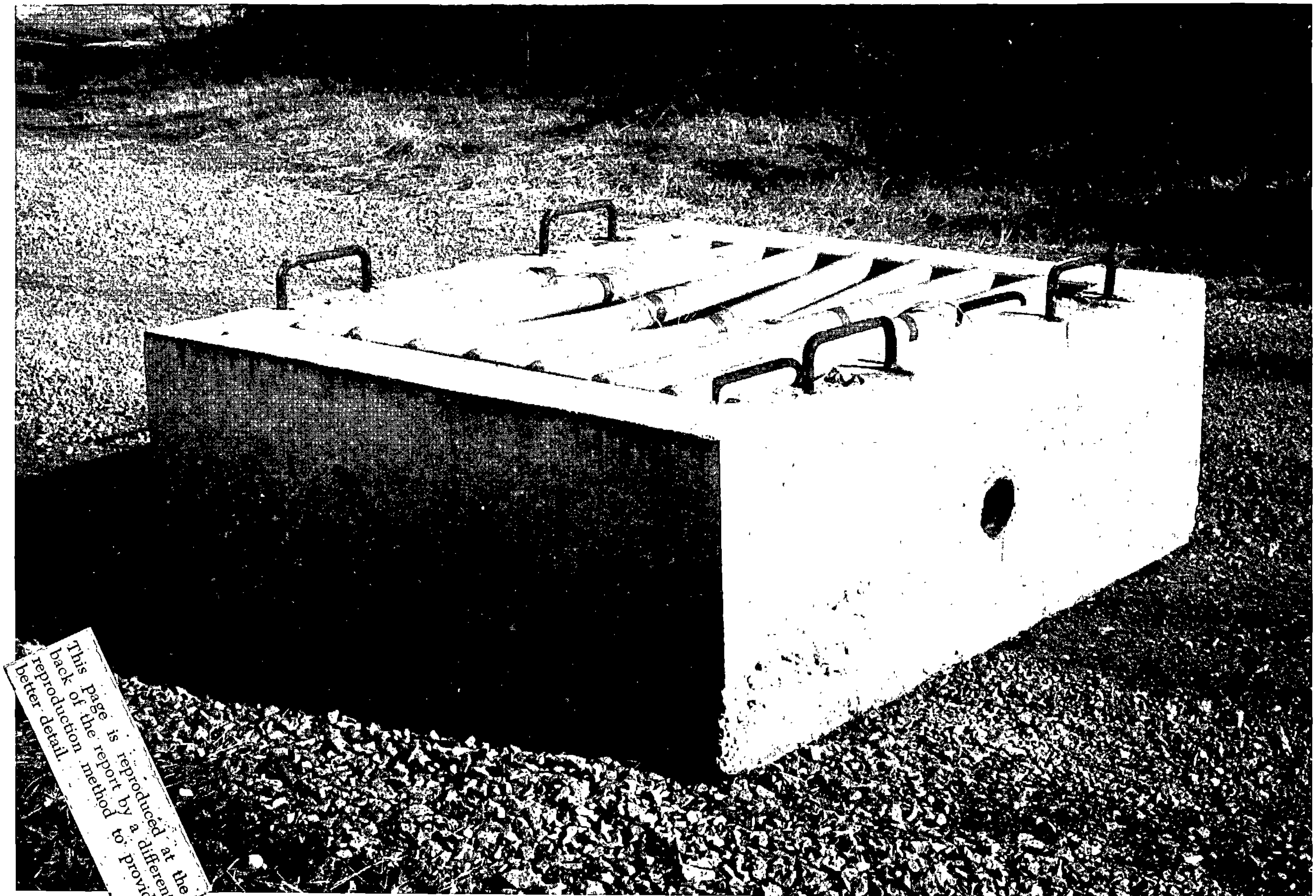

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Figure 75. Grate H - After Plate Load Test to Failure

6. SUMMARY AND CONCLUSIONS

This study involved the testing and structural analysis of eight types of inlet grates. Six were roadway grates and two were median grates. Other structural variables were: steel or cast-iron, section and span of grate members, and flat or sloped installed surface position. The objectives of the study were: (1) to determine the structural behavior of the selected grates under static and dynamic loading conditions, (2) to develop criteria for designing inlet grates on the basis of structural strength and behavior, and (3) to make recommendations for possible revision of Federal Specification RR-F-621b, which may be used for acceptance of inlet grates. A list of specific conclusions drawn from this study are given below, followed by a summary of test results.

1. Correlations between the computer analyses and the experimental data indicate that the behavior of highway inlet grates subjected to static wheel (or plate) loads can be predicted analytically within an acceptable degree of accuracy. However, it is necessary to give due consideration to the effect on the analytical model of welds, end connections, and special geometrical shapes and to tire loading factors such as variation in unit tire pressure across the tire and the length and number of grate bars contacted by the tire.

2. It was found that there is close agreement between the results of the plate load and static wheel tests, up to 10,000 lbs. Therefore, it appears that the plate load test method may be used to evaluate the behavior of inlet grates under service load conditions, as well as in the post-elastic load range.

3. The results of the plate load tests indicate that all of the inlet grates tested are stronger than necessary to meet the requirements of current vehicle traffic, which emphasizes the need for grates to be <u>designed</u> to make efficient use of structural materials. Three of the eight inlet grates tested in this study apparently failed to meet the requirements of Federal Specification RR-F-621b. However, there is a strong probability that these "rejected" grates are more than adequate for carrying current highway vehicle loadings.

4. It was found that under load the roadway grates acted as a grid system (in plate bending), with the wheel loads being distributed to grate bars not under the wheel. However, the bars of the median grates acted (essentially) independently, with little transfer of stresses into adjacent bars.

5. The results of the dynamic wheel loading tests indicate that the design wheel load for inlet grates should be increased by a

"dynamic amplification factor." For flat roadway grates the following factors seem reasonable: rolling loads - 1.20, impact loads - 1.40. Because a short transition ramp was required between the flat approach roadway and the surface of the sloped surface grates, it is difficult to evaluate the dynamic factors which were calculated from tests on those grates. A dynamic factor as high as 2.10 may be required for median grates. However, it is recognized that the 2-1/4 in. high ramp used for the impact tests probably caused more severe impact than the most extreme service conditions.

6. It is apparent that there are two possible drawbacks for using cast iron for inlet grates. (1) Poor design or casting practices may cause voids in the casting at critical locations, which will affect the load carrying capacity of the grate. (2) Cast iron has a low modulus of elasticity and little (if any) ductility.

SUMMARY OF TEST DATA

Grate	Type	Weight 1/	Ultimate Plate Load	Yield Load 2/	Maximum ℄ Bending Stress, 6000 lb. Wheel Load 3/	Dynamic Factors 4/	
						Rolling	Impact
		lbs.	lbs.	lbs.	psi.		
A	Roadway	191	76,000	40,000	12,060	1.11	1.37
B 5/	Roadway	109	40,000	18,000	19,050	1.04	1.09
C	Roadway	168	98,500	42,500	8,280	1.13	1.49
D	Roadway	144	109,300	> 30,000	10,680	1.65	2.10
E 5/	Roadway	165	12,700	12,700 6/	10,506 7/	1.20	2.11
F	Roadway	224	90,125	90,125	3,220	1.06	1.20
G	Median	131	68,325	50,000	10,800	1.08	> 1.58
H 5/	Median	272	25,500	< 25,500	37,200	1.10	2.10

1. The weight shown does not include the weight of the grate frame.
2. Yield is herein defined as deviation from linearity of the load-deflection curve from the static plate load test.
3. Static load stresses computed from maximum bending strain in longitudinal grate members.
4. Ratios of maximum field dynamic to laboratory static strains.
5. The subject grate does not meet the requirements of Federal Specification RR-F-621b.
6. At this load the transverse midspan structural member fractures; the loading was not increased to determine the ultimate load capacity of the grate.
7. Maximum stress in transverse member at location of one longitudinal member away from the centerline of the grate. A strain gage was not applied at the centerline because of voids in the casting.

7. RECOMMENDATIONS

1. Design Criteria

A. Vehicle safety should be a major consideration in the design of inlet grates. In addition to providing adequate load capacity, the transverse spacing of the grate bars should not permit the wheels of narrow tired cars, motorcycles, or bicycles to fall between the bars. If wide spacing of the longitudinal bars is necessary, then numerous cross bars should be provided for vehicle safety. These requirements are in addition to providing adequate hydraulic capacity and protection against vandalism.

B. Inlet grates should be structurally designed, in accordance with provisions of the American Association of State Highway Officials (AASHO) Standard Specification for Highway Bridges, especially regarding allowable stresses and fatigue resistance.

C. Inlet grate design values for shear, moment, and deflection may be calculated by using most modern computer programs for the structural analysis of grid systems. The analytical model must reflect the effect of end plates, welds, and connection details upon the torsional and bending stiffness of the inlet grate.

D. The influence of AASHO HS-15 and 20-44 vehicle wheel loads on inlet grates may be evaluated by either of the following two methods. (1) Estimating the actual wheel load distribution across the grate, effect of tire sidewall stiffness, and the number and length of grate bars contacted by the tire. (2) Assume that the wheel load is applied on a 9-in. square steel plate. The loading for each grate bar may be represented by two equivalent loads located at 2-1/4 in. on each side of the transverse centerline of the plate. A design based on the latter method will be conservative, but usually more practical to calculate.

E. Design computations for dual wheels may consider two single wheels side-by-side. However, the outside edges of dual wheels which are centered on certain grates may be beyond the edge (and frame) of the grate, which would affect the wheel load distribution on the grate bars. The designer may wish to consider the possibility of one tire being either under-inflated or removed.

F. The following dynamic amplification factors for wheel loads should be considered in the design.

Flat roadway grates: Rolling - 1.20, Impact - 1.40

Flat median grates: Rolling - 1.20, Impact - 2.10

G. If the design computations consider impact and fatigue, then the the following factors should also be considered. Average daily truck traffic (ADTT), wheel loads, location of trucks in the roadway lane (do all truck wheel paths cross the grate, as opposed to cars which tend to avoid grates), and location of the grate. A statistical treatment of these factors may influence the design of inlet grates.

H. The individual State Highway Departments might benefit from surveys to ascertain the frequency of damage and failure of the various types of inlet grates used on their highways, to better assess the need for revising their present grate designs.

I. In lieu of structurally designing inlet grates it appears feasible that an inlet grate "design" might be fabricated and then subjected to a plate load test to evaluate the structural behavior.

2. Federal Specification RR-F-621b, "Frames, Covers, Gratings, Steps, Sump and Catch Basin, Manhole"

A. The acceptance criteria based on a 25,000-lb. proof load seems to be unduly conservative. Consideration should be given to reducing this load to perhaps 12,000 or 15,000 lbs. to reflect more reasonable service loadings with a reasonable factor of safety. It is recognized that this may not be feasible, since this specification applied to many items. If that is the case, efforts should be initiated to establish a separate Federal Specification which applied only to highway inlet grates.

B. The Federal Specification, or a commentary on it, should recognize the value of the cited plate load test method for evaluating the behavior of inlet grates subjected to single wheel loads in the service load range, and for evaluating the behavior of inlet grates in the post elastic load range.

8. REFERENCES

1. U. S. Government, "Federal Specification RR-F-621b - Frames, Covers, Gratings, Steps, Sump and Catch Basin, Manhole," September, 1967. (Available from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. or the Business Service Centers at Government Services Administration (GSA) regional offices.

2. Doherty, W. P. and Wilson, E. L., "Analysis of Two-Dimensional Grid Structures," (Computer Program), University of California, Berkeley, California, September, 1967.

3. A.A.S.H.O., "Standard Specifications for Highway Bridges," American Association of State Highway Officials, eleventh edition, 1973.

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