Research and Test Department

Freight Car Fatigue - Coal Car Simuloader Demonstration Test

Report No. R-747

V. Sharma

Chicago Technical Center

ASSOCIATION OF AMERICAN RAILROADS

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Association of American Railroads
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December, 1990

AAR Technical Center
Chicago, Illinois

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13. ABSTRACT

A full scale fatigue test of a 100-ton coal gondola car on the Transportation Test Center's (TTC) Simuloader facility was successfully completed recently. With a short test encompassing 270 hours of Simuloader testing, the freight car was subjected to fatigue damage equivalent to 600,000 miles of revenue service. The test car developed fatigue cracks at locations where similar cracks had been experienced earlier in revenue service.

An over-the-road test was run to collect data required to "drive" the Simuloader and to characterize the structural and dynamic response of the coal car in revenue service.

The road test route information was then "condensed" by selecting, from the 120 hours time history, events which were fatigue significant, that is, when the freight car experienced high loads and stresses at critical locations. The uneventful miles were edited out. The 2,200 miles road test route of 120 hours travel time was condensed to the simuloader test load cycle of only one hour. So, during the simuloader test the car was subjected only to the high loads which may cause fatigue damage to the car structure.

We observed during our simuloader tests that the car body dynamic response at critical strain gage locations was quite similar to what was observed in our road test. It was also established that, for accurate simulation of coupler loads, it is important to remove as much slack as possible from the draft gear pocket. Also, the gains of the Simuloader actuators can be increased as needed to further accelerate the fatigue test.

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ACKNOWLEDGMENTS

The author wishes to thank the Portland General Electric Company for the loan of the test car and the technical assistance provided by Messrs. Larry Quinn and Philip Groelz. Mr. Gus Holabeck, consultant, provided help in test planning and Mr. G. J. Moyar, consultant, provided help in test planning, data analysis, Simuloader testing and report preparation.

A dedicated locomotive was provided by Burlington Northern and the over-the-road tests were conducted on the Burlington Northern, Montana Rail Link and the Union Pacific. The test car was refurbished at the National Steel Car Company and the transportation to and from was provided by the Canadian Pacific.

Mark Dembosky and Mark Reedy helped in the pre-test instrumentation check, and data aquisition software. Road test crew consisted of John Dincher, Dave Johns, Steve Luna and Gene Woy. Ms. Vivian Brown and Ms. Susan Whetzel helped in post test data reduction. The Simuloader operations were conducted by Messrs. Dan Inskeep, Dennis Kido and Marvin Starkweather. Mr. F. Irani provided help during test planning, the data reduction for simuloader operations and during all other phases of this project.

Many thanks are also due to Mr. S. K. Punwani and Mr. A. J. Peters for their continued guidance and support during the entire project.

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EXECUTIVE SUMMARY

A full scale fatigue test of a 100-ton coal gondola car on the Transportation Test Center's Simuloader facility was successfully completed. With a short test encompassing 270 hours of Simuloader testing, the freight car was subjected to fatigue damage equivalent to 600,000 miles of revenue service.

The Simuloader built originally by Union Tank Car in Conroe, Texas, was installed at the Transportation Test Center, Pueblo in 1984. The test car body, without the trucks, is placed on simulated truck bolsters of the Simuloader. Typical truck bolster inputs based on road test data are generated for the Simuloader operation. A longitudinal actuator applies coupler loads to the car. This loads the car in buff (compression) or draft (tension).

The Simuloader when first installed at TTC, Pueblo was not capable of applying coupler longitudinal loads greater than 200,000 lbs. in buff or draft mode. This was because of foundation and installation differences as compared with the original installation. Modifications were subsequently made to strengthen the support system so that higher coupler loads could be applied.

An over-the-road test was run to collect data required to "drive" the Simuloader and to characterize the structural and dynamic response of the coal car in revenue service. These data were then analyzed and reduced for use on the Simuloader.

The road test data were obtained for loaded as well as empty unit coal train operations. This unit train operated between coal mines at Gillette, Wyoming and a power plant in Boardman, Oregon. Continuous time history data were obtained for 32 channels. There were fifteen transducers at various locations to measure accelerations and displacements of the test car. Total center plate load and coupler loads were also measured. Fourteen strain gages at critical locations measured the freight car stress response during the test.

The road test route information was then 'condensed' by selecting, from the 120 hours time history, events which were fatigue significant; that is, when the freight car experienced high loads and stresses at critical locations. The uneventful miles of information were edited out. The 2,200 mile road test route of 120 hours travel time was condensed to the Simuloader test load cycle of only one hour. So, during the Simuloader test the car was subjected only to the heavy loads which may cause fatigue damage to the car structure.

We observed during our Simuloader tests that the car body dynamic response at critical strain gage locations was quite similar to what was observed in our road test. It was also established that, for accurate reproduction of coupler loads on the Simuloader, it is important to remove as much slack as possible from the draft gear pocket. Also, it was established that the gains of the actuators can be increased as needed to further accelerate the fatigue test.

Fatigue cracks were observed at the following locations, during Simuloader tests.

1. On the side sill near tub end sheet connection.
2. Stub sill to shear plate connection.
3. Center plate connection to body bolster.

These cracks were observed at locations similar to the fatigue cracks observed in these types of cars operating in the same unit train service. However, the propensity of cracks induced in our Simuloader testing was much less than observed during early 1980's in the same unit train service. In fact very little evidence of damage was found in the car body on the A end that had been restored to original structural conditon prior to our tests.

A review of operational history revealed that the original practice was to use head end power only on the unit coal trains. In the most mountainous regions these 110 car trains were broken into two sections and again pulled with head end power. Coupler loads in excess of 700,000 lbs. were measured in 1982. Current practice, followed in our road test, involved distributed locomotive power at head, center and rear of the train. This apparently resulted in significantly less severe and fewer instances of slack run-in and run-out during the loaded car moves. Coupler loads measured during our road test of 1988, were no more than 300,000 lbs. Since this stub sill car structure is particularly sensitive to coupler loading it follows that some of the car body strains, such as those at the side sill juncture location and in the stub sill, were much larger in the original service. Hence, the observed lack of cracking in the Simuloader test relative to the original service.

1.0 INTRODUCTION

1.1 Need for a Simuloader Facility

Historically freight carbodies and components have been overdesigned to minimize in-service fatigue failures. Safety being of utmost importance in railroad operations, any in-service fatigue failures of major components or carbodies can be catastrophic. Higher safety margins in design of freight cars are introduced to keep stress/strain in freight cars to minimal levels. This practice produces inconsistent results and uncertainties in fatigue performance of freight cars in-service.

The design of smaller components such as brake beams, truck bolsters etc. can be done very efficiently because laboratory facilities are available to test a component before placing it in service. So, any deficiencies of a design prototype will be revealed in laboratory and the component design improved accordingly to withstand the fatigue load environment to be imposed in freight service. However, a laboratory facility for fatigue testing of a prototype freight carbody, as a whole, has not been available to the railroad industry so far. One of the reasons being that the freight carbodies were overdesigned, and weight of the carbody in relation to its lading capacity was not of major concern, because fuel costs were very low and also cost of steel was comparatively low. The arriving of energy crises in the 1970's and fierce competition by road haulers has changed the scenario substantially.

What is now needed is that the light weight of a freight car be as small as possible in comparison to its total fully loaded weight. Needless, to say, such freight carbodies with optimum design become a necessity, and a facility where a carbody can be tested in a laboratory controlled environment was needed. A laboratory facility capable of testing full scale cars (called Simuloader) could test a 'prototype' in an accelerated test and reveal weak points or parts of a car in a matter of a few weeks.

1.2 The Simuloader Facility

The Union Tank Car Company was the first in U. S. Railroad Industry to own and install a Simuloader. It was then called "UTLX Simuloader - The Rail Car Load Simulator," and was installed at their Conroe, Texas facility. It was available as a contract service to the entire railcar industry in the late 1970's. The following excerpt on how the Simuloader works is reproduced from earlier literature[1].

1.3 How The Simuloader Works

The total Simuloader research system involves several stages of testing.

First, static tests are conducted on railcars to determine areas of significant stress, thus narrowing the scope of tests to follow.

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1 "UTLX SIMULOADER" brochure by Union Tank Car Company

These initial tests also provide for the accurate placement of more sophisticated measuring instruments, a vital key in the overall program results.

A typical road test route is selected, prior to simulation, which best portrays the use and abuse a railcar must withstand. These routes may be selected from previous shipping experience or they may be determined by computer.

Data are gathered and stored by computer while the car actually travels a predetermined route under normal operating conditions. Once gathered, the trip information is condensed by "editing" out uneventful miles and leaving only those which represent some type of force being applied against the car. So, in simulation, the car will experience only the heavy loads of travel.

Then through a unique combination of computer and hydraulic technology, pressures are applied against 13 individual loading points to help re-create virtually every conceivable aspect of wear and tear. Movement is governed by computers which both imitate "real life" stress and record its effect on the car. The length of the test simulation is totally variable. If desired, the average life of a railcar, about 30 years, can be simulated in three months.

Once the simulation is complete, information about stress and fatigue is subjected to both computer and personal analysis. It then becomes a source of design information about the car, provides valuable data related to safety and allows judgments to be made as to the cost/benefit ratios of design modification.

This facility was donated to the Federal Railroad Administration in 1983 and was later installed at the Transportation Test Center, Pueblo. This test center is now operated by the Association of American Railroads.

1.4 The Proposed Work

The Association of American Railroads proposed to conduct tests including over-the-road and Simuloader tests, to demonstrate the capabilities of the Simuloader device. The funding to support this Simuloader demonstration was provided by the Federal Railroad Administration under Subtask 3 of Task Order No. 3 titled "Freight Car fatigue Test Demonstration" of Contract DTFR53-86-C-00011).

1.4.1 Technical Objectives

The principal objectives of this work were:

1. To develop a means for realistic estimation of fatigue life of freight car components through a full-scale test of a whole car.
2. Demonstrate Simuloader capabilities by simulating failure of a freight car specimen of a type known to have experienced fatigue failures.
3. Verify the capabilities of the Simuloader test device by comparative analysis.

1.4.2 The Methodology and Test Program

The methodology called for establishing a test program and analysis procedure to demonstrate the applicability of the use of the Simuloader test device for determination of safety criteria for freight car fatigue characteristics and behavior. The test program was to include comparison of results of over-the-road tests and Simuloader laboratory tests of a specimen railcar preferably of a type known to have experienced component fatigue failures, as well as data and test results from other appropriate sources. The principal elements of the test program are described in items 1 through 12 below:

1. Select and arrange for use in testing a railcar such as a coal gondola car. Preferably, the car will be one which is known to have experienced component failure resulting from fatigue. Select candidate components of the railcar for fatigue failure monitoring during testing. This selection will be based on a review of in-service failures and available stress/fatigue analysis of the car. Additional stress/fatigue analysis is also contemplated.
2. Retrofit the selected car, if necessary, at a contract shop in preparation for the testing.
3. Move the selected car from the owner to the contract shop, and from the contract shop to the Transportation Test Center, Pueblo.

4. Design and install instrumentation for the over-the-road and laboratory data collection. This instrumentation will include:

   a. Measurements (loads and accelerations) required for the purposes of "driving" the Simuloader during the laboratory data collection phase of the tests.

   b. Measurements necessary to evaluate the car structural/fatigue response both during the over-the-road tests and during the laboratory Simuloader tests.

5. Measure and collect over-the-road carbody strain, acceleration, and coupler force data from the specimen railcar associated with a track route representative of the track route conditions which contributed to the original failure. These data are to be used as inputs to the Simuloader for the comparison of the responses of the car structure in over-the-road tests, Simuloader tests, and other laboratory tests. Up to 32 channels of data are to be collected with a portable data acquisition system.

   The selected test car shall be run in a unit train consist. The data acquisition system shall be installed in a locomotive unit which shall be coupled to the test car during the runs. Reduce the over-the-road data to select "active" road mileage load environment to drive the Simuloader.

6. Return the car to TTC. Inspect the car and prepare it for the Simuloader tests as necessary.

7. Prepare Simuloader for test. This includes but is not limited to laboratory instrumentation and data acquisition system.

8. Develop laboratory fatigue test methodology and prepare detailed test plan. This test plan will specify the method for identifying fatigue failure(s), and will provide for the evaluation of the Simuloader use in the determination of fatigue life safety criteria. The test plan will be divided into two parts:

   a. Initial runs to determine the range of responses of various transducer channels and system calibration.

   b. Actual fatigue testing of the test car.

9. Conduct a full-scale, sustained fatigue test of the specimen railcar intending to cause failure of one or more candidate components, utilizing the Simuloader test device.

10. Reduce the Simuloader test data. Compare the car responses in the over-the-road test data and the Simuloader test data.

11. Analyze the results of the test program. A principal focus will be to understand the principal safety issues and to evaluate the Simuloader facility's use for full-scale fatigue tests.

12. Prepare (as a minimum) a report describing the test results, including safety-related aspects, and recommending procedures for use of the Simuloader test device for car structural fatigue testing.

1.5 Organization and Intent of This Report

The intent of this report is:

1. To demonstrate the capabilities of the Simuloader device,
2. To show by comparison of road test data and Simuloader data, the fatigue behavior of a freight carbody in the two environments and the similarities and dissimilarities of the two environments.
3. To show how the Simuloader can be effectively used to address safety issues such as fatigue failures of freight cars.

The report is organized in the same general order as test program items 1 through 12 as detailed in Section 1.3B, followed by Conclusions from this work and Recommendations for future works of this nature.

2.0 RAIL CAR SELECTION

One of the main criteria for the rail car selection was that the car would be one which had experienced component failure resulting from fatigue. Also, it was desirable that the car be part of a large fleet or one of many of the same kind (and therefore, be not one of a only a few). Accordingly, after a survey of freight car types satisfying the desired criteria, we picked a bathtub type coal gondola car originally known as the 'Teoli' car. These types of cars were first built in 1969 in Canada and by 1981 approximately 2400 cars were built by various car builders in Canada. In the U.S. these types of cars were first built in 1976 and by 1981 approximately 3700 had been built.

The car selected was from a fleet of cars (230 in all) owned by Portland General Electric. The car number was PGEX250 and was built in 1978. This car is referred to as the 'test car' and Exhibit 2.1 shows a photograph of this test car.

2.1 Test Car Fatigue Concerns

In 1980-81, the PGE fleet of cars was experiencing the following fatigue related problems.

2.1.1 Major Concerns

1. Cracking of the weld joining draft sill web to the bolster web was the major cause for the cars being rejected.
2. Most welds in the body bolster were cracking.

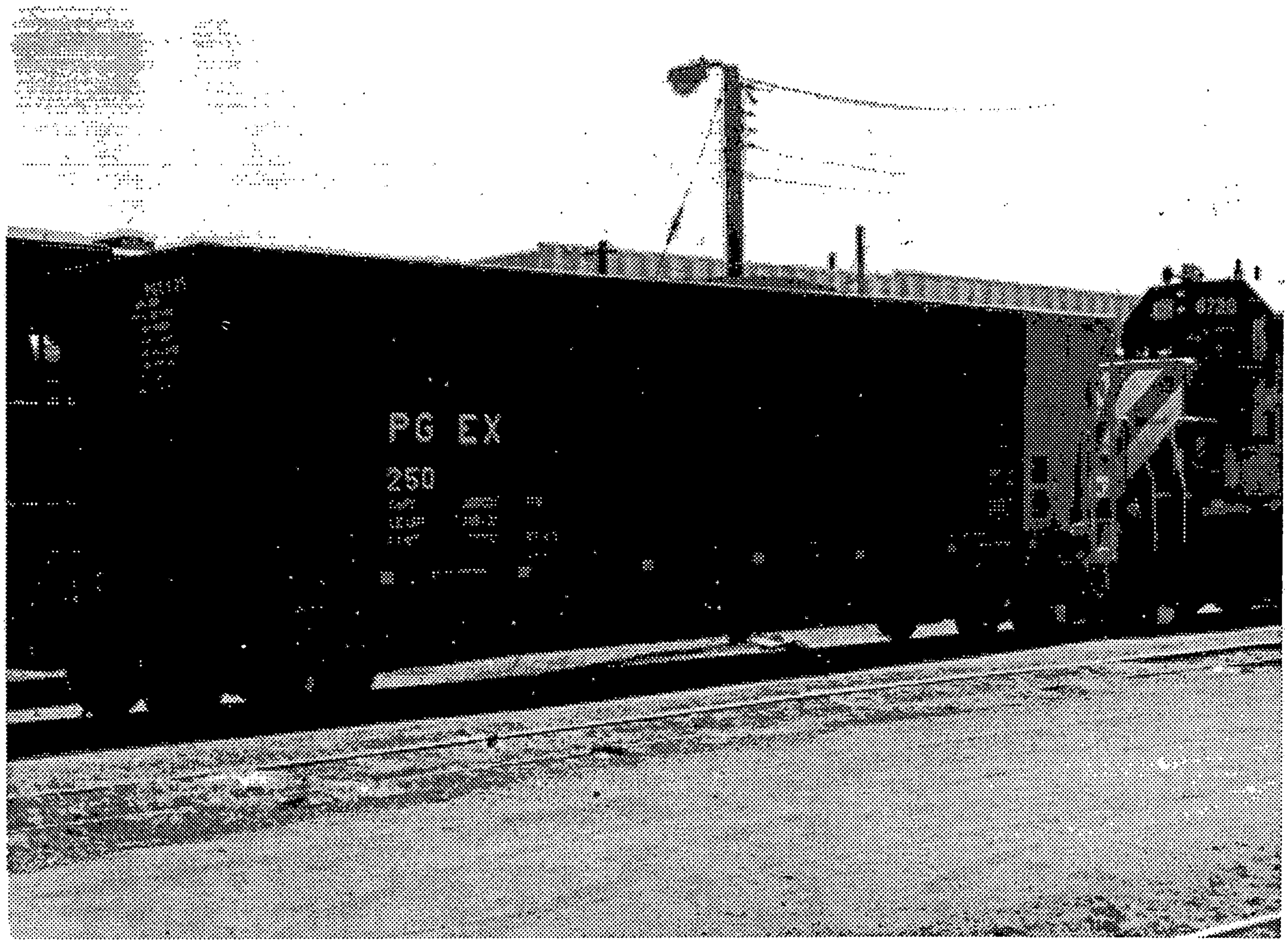


Exhibit 2.1 Photograph Of The Test Car.

Many cracks lead into the base metal. Included were welds attaching C-PEP (Center Plate Extension Pads).

3. Ends of slot welds joining striker casting to draft sill webs had cracks on a few cars.
4. Belly tub sheet to side sills, including cove piece (tub end to bottom closure plate) cracked.
5. Slot welds attaching the bolster bottom cover plate to the sole plate were cracking. The sole plate is the tie plate carrying flange loads across the bottom of the draft sill.
6. Internal stiffening webs of the center plate had been breaking.

2.1.2 Less Severe Problems

1. Top corners had cracks on several cars behind the webs of the diagonal "V" braces where they were welded to end chords.
2. Bottom corner of the weld joining the end sheet to side plate had cracked on several cars.
3. The angle-cock shear plate cut-out support brace had cracked on many cars.

2.1.3 Other Problems

1. Center plate bolts were breaking.
2. Draft sill webs in area of draft gear were bulging outward. Two cracks had been observed in the bulges.

3. Some C-PEP wear plates were breaking and others were wearing out.
4. Truck wear was considered excessive by operations department.
5. Knuckles and coupler pins were failing.
6. The coupler-follower blocks were showing excessive wear, but this problem had been observed on cars of other manufacturers as well. This, as well as the problem with the knuckles and coupler pins, may be generic to unit train operations and require an industry-wide solution.
7. Air reservoir attachment bolts were breaking. The reservoir may be acting as a tie back between diagonal "V" braces.

2.1.4 Problems with Other Cars of This Design

1. Welds joining the "V" brace web to the shear plate had cracked.
2. End sheets had been cracking about 2 feet below the top chord.
3. Constant Contact Side Bearing elastomer blocks shift and extrude through the open end of the side bearing cages. The constant contact side bearing supplier had modified the design and has apparently solved the problem.
4. Cars which did not have internal bracing had experienced bowing of the tops of the car sides.

5. Welds joining the Dresser low profile center filler and center plate to the underframe structure cracked, and the crack then passed into the center filler and underframe members.

2.2 Test Car Modification

The bathtub gondola cars owned by the Portland General Electric company had many fatigue related problems, as described earlier. These cars are used to haul coal from the Powder River Basin to the utility company's power plants in Oregon. The PGE had (1980-1981) undertaken some road tests, stress analyses (including finite elements stress analyses) to gain more understanding of the fatigue problems on these cars. As a result of these studies, (some results of these studies will be presented later in this report) the PGE's fleet of cars was repaired to strengthen the stub sills and body bolsters. This repair was also done by Union Pacific on some of their own cars. The repair consisted mainly of stiffener plates on all four quadrants of the stub sill and body bolster interSection. This repair was generally referred to as 'The UPFIX'.

The test car (PGEX 250), when received by the AAR for use in this program, had this 'UPFIX' already in place, and the car had already logged approximately 200,000 miles.

Since one of the objectives of our test program was to demonstrate the Simuloader's capability to duplicate the fatigue environment of revenue service, we decided that we would get the car refurbished to its original new condition at one end of the car. This would give us a car with one end in 'virgin' condition. Accordingly, the A-end of this car was completely removed from the tub back to the coupler, including stub sills, body bolster and shear plate. A new A-end was then installed in its place. The new A-end was of the same design and material as the car had when it was new.

2.3 Test Car Description

The bathtub car consists of seven main components which are: two underframe Sections with stub sills, shear plates and bolsters; two side girders; two ends with diagonal stiffeners; and the curved belly sheet with end closures.

These freight cars had a lightweight of 53,000 lbs. and a payload of 210,000 lbs or 105-tons, which was about four tons more than any other steel car in service at that time. The lightweight was achieved by using a weldable "stelcoloy 70." This steel had a minimum yield strength of 70,000 psi and minimum Charpy V-notch test of 20 ft. lbs. at -25°F. Other significant features of the original car design included the following:

1. A volume of 5000 cu. ft. based on a density of coal of 42 to 45 lbs/cu. ft. and an allowance of six inches of free space above the load to reduce wind loss in transit.
2. A curved bottom floor sheet which dropped to within 12" from top of rail, thus eliminating much hardware such as crossbearers, crossties,

stringers, and center sill, and also, when loaded, reducing the center of gravity far below the AAR maximum.

3. The Diagonal end stiffeners which transfer the end loads directly into the bolster or center plate area.
4. 45-foot truck centers which reduce the propensity to rock and roll.
5. A two-phase springing arrangement on the trucks which permits the light car to ride on inner coils supported by cups which in turn are supported by the main coils. This reduces or eliminates excessive vibrations which give the light car a hard ride and tend to damage it.

The car design was altered slightly for U.S. service conditions because of higher density coal (50 lbs/cu. ft); the required volume was 4200 cubic feet and the dumpers in U.S. at that time would accept cars of 53'1" over couplers without uncoupling cars in the train.

In addition, the test car did not have center plate extension pads nor constant contact side bearings. Instead it was equipped with standard roller side bearings.

The physical dimensions of the test car are as follows:

<u>DIMENSIONS</u>:

Capacity (level full).	4200 Cu.Ft.
Weight at rail (maximum)	263,000#
Light weight of car (Est.)	52,300#
Load limit	210,700#

Length between pulling faces of couplers . . .	53'-"
Length over end sills	48'-4-1/4"
Length over strikers	50'-5-1/2"
Length between truck centers	40'-6"
Length of truck wheel base	5'-10"
Length inside end sheets (at top).	46'-10"
Width inside side sheets (at top).	9'-9-5/8"
Width center to center of side bearings. . . .	4'-2"
Height from rail to top of top chord	12'-4-3/16"
Height from rail to bottom of side sills . . .	3'-6-3/4"
Height from rail to bottom of shear plate. . .	3'-6-7/17"
Height from rail to center plate bearing surface.	2'-1-1/16"
Height from rail to underside of bottom sheet.	1'-1-1/8"
Height inside (Maximum).	11'-4"

3.0 THE SIMULOADER

The Simuloader was installed at the Transportation Test Center, Pueblo in 1984. Exhibit 3.1 shows a photograph of the Simuloader and Exhibit 3.2 shows a schematic of the Simuloader system. The capacities of various actuators of the original system are listed below:

3.1 Simuloader Actuators

Actuators

- One coupler Actuator:-

  Force: 500,000 lb force draft

  750,000 lb force buff

  Stroke: 12 in.

  Servovalve: 400 gpm

- Four Yaw Actuators:-

  Force: ± 22,000 lb force

  Stroke: 6 in.

  Servovalve: 180 gpm

- Four Vertical Actuators:-

  Force: ± 110,000 lb. force

  Stroke: 6 in.

  Servovalve: 180 gpm

- Two Lateral Actuators:-

  Force: ± 77,000 lb. force

  Stroke: 5 in.

  Servovalve: 180 gpm

- Two Tandem Vector Actuators:-

  (Lateral Coupler Force)

Force:	A-end	B-end
127,000 lb. force	left	right
169,000 lb. force	right	left

  Stroke: 10 in.

  Servovalve: 15 gpm

The two tandem vector actuators for applying lateral coupler forces at A and B end were not operational and are not a part of the present Simuloader system.

3.2 <u>Simuloader Modifications</u>

The Simuloader when first installed at TTC, Pueblo was not permitted to apply coupler longitudinal loads of more than 200,000 lbs in buff or draft mode. This was because of insufficient strength of the West-end support connection to the building floor. The following modifications were made to strengthen the support system so higher coupler loads could be applied.

- Redesign and stiffening of the West-end support. The West-end support now can transfer higher coupler loads of up to 500,000 lbs force to the floor system.
- The connection of the West-end support to the floor system was redesigned to transfer loads more effectively to the floor without cracking the concrete floor.

- Two longitudinal I-beams were installed (one on each side) to help transfer the longitudinal loads. These beams act like a conventional squeeze frame. These beams are supported at three different locations to minimize any buckling.

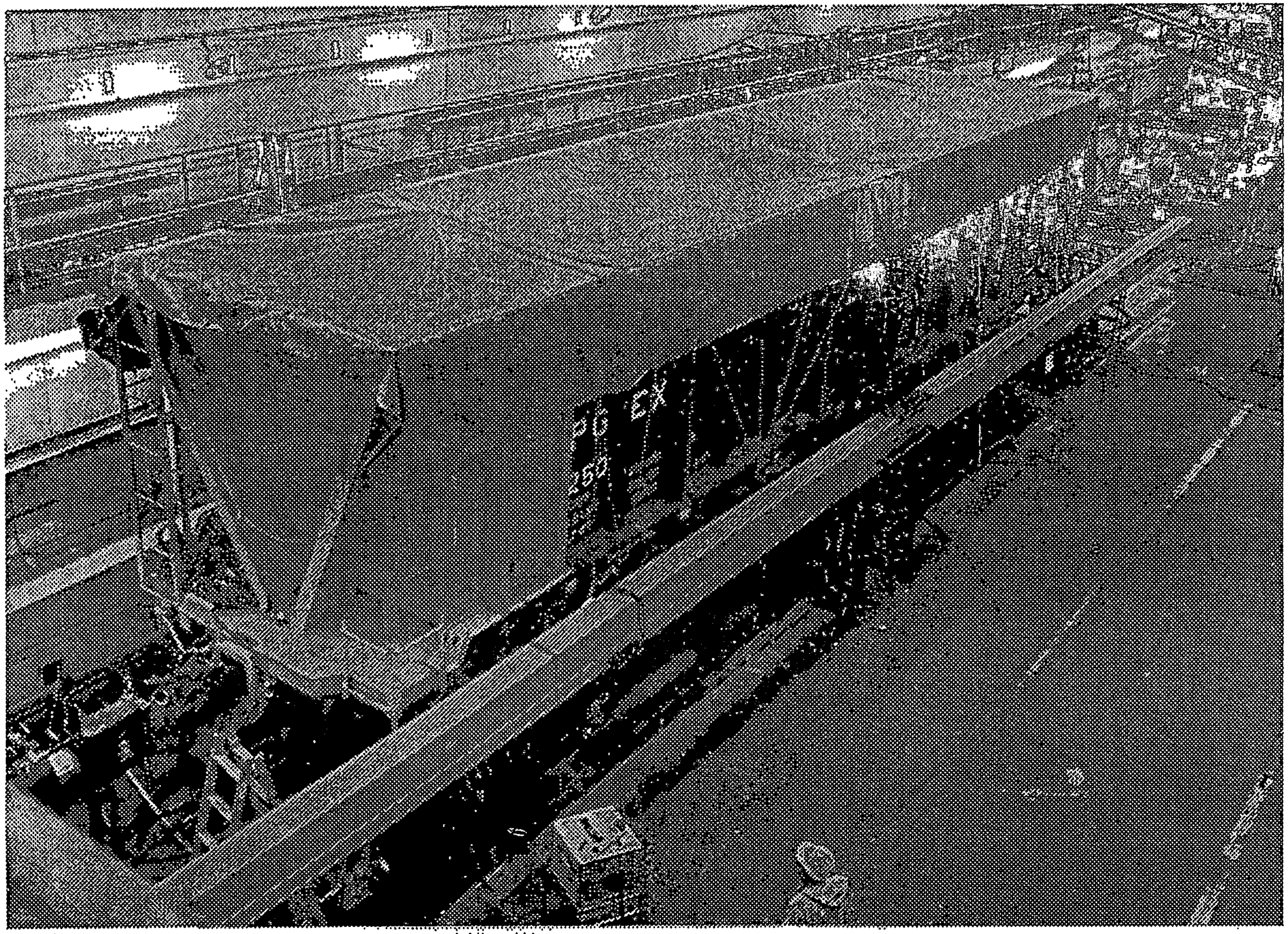


Exhibit 3.1 Photograph Of The Simuloader Facility.

SCHEMATIC OF SIMULOADER AND ACTUATOR CAPACITIES

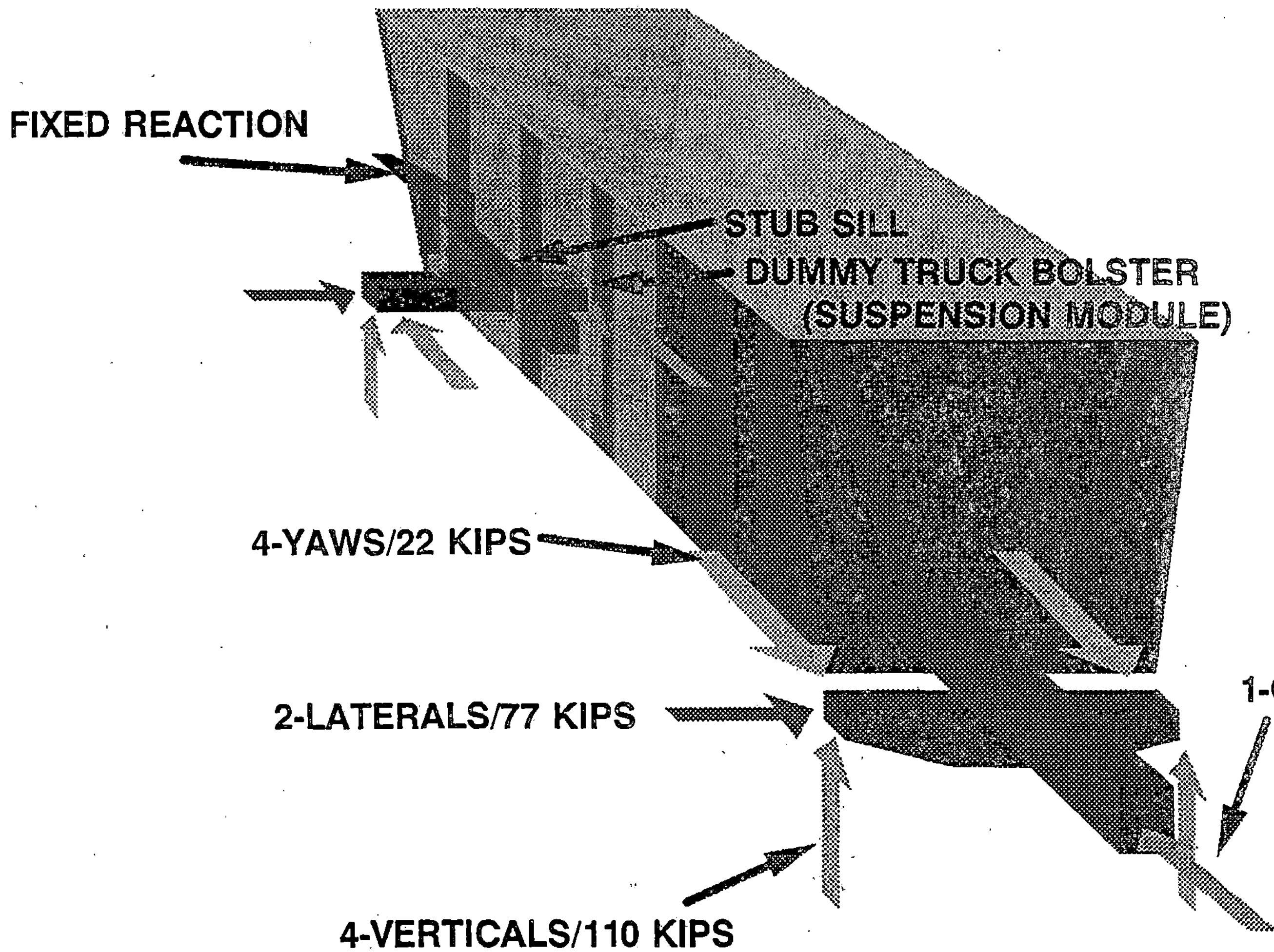


Exhibit 3.2 Schematic of Simuloader System.

4.0 INSTRUMENTATION

The measured test car responses and instrument locations are described in the paragraphs below.

4.1 Car Responses Measured

The test car was instrumented to measure:

1. The vertical and lateral motions of the car caused by track irregularities. These track induced motions were measured by a set of three accelerometers installed at ends of each truck bolster. One set of three accelerometers at A-end truck bolster measured vertical accelerations at the left and right sides and also lateral accelerations of the truck bolster. A set of three accelerometers on the B-end truck bolster measured vertical accelerations at the left and right sides and lateral accelerations of the B-end truck bolster.
2. The car body vertical and lateral accelerations were measured at the A-end right side and B-end left side.
3. The longitudinal load environment was obtained by measuring coupler loads (using instrumented couplers) at the A and B-ends of the test car. In addition, the accelerations and displacements of the two couplers were also measured.

4. The total vertical load on the A-end truck bolster was measured by strain gages located on the bottom flange of the bolster. The total load on the truck bolster is a measure of the vertical dynamic loads induced into the freight car body.

5. The test car stress-strain response was measured by a total of fourteen strain gages strategically located near the A-end of the car. Initially, thirty-two strain gages were installed on the A-end of the car and trial tests in bounce and Rock-and-roll regimes were conducted at the TTC. Also, the trial tests included squeezing and pulling apart (Buff and draft loads) in static condition. The objective of preliminary testing at TTC was to select strain gages most sensitive to various types of load environments such as bounce, rock-and-roll and longitudinal loads. The thirty-two strain gages were placed in most sensitive locations based on the history (cracks in service) of the car. From these thirty-two gages we selected fourteen most sensitive ones for measuring car response during field testing.

6. The speed of the car was also measured.

4.2 Instrument Locations

Exhibit 4.1 shows a schematic of the test car and the locations of strain gages and other transducers. Exhibit 4.2 gives a more detailed description along with the assigned channel/numbers to various transducers. Exhibit 4.3 shows the data stream flow chart from the transducers to disc storage. Sampling rate was 128 per second and 30 Hz filtering was employed. Analog as well as digital recording was done to provide back-up data in case of malfunction of either recorder type. The recorders and signal conditioning and necessary drives and computer and printer were mounted inside the cab of a locomotive on a specially designed shock proof rack. This locomotive was placed adjacent to the test car during the road test and all the power requirements of the instrumentation were met by the locomotive generators.

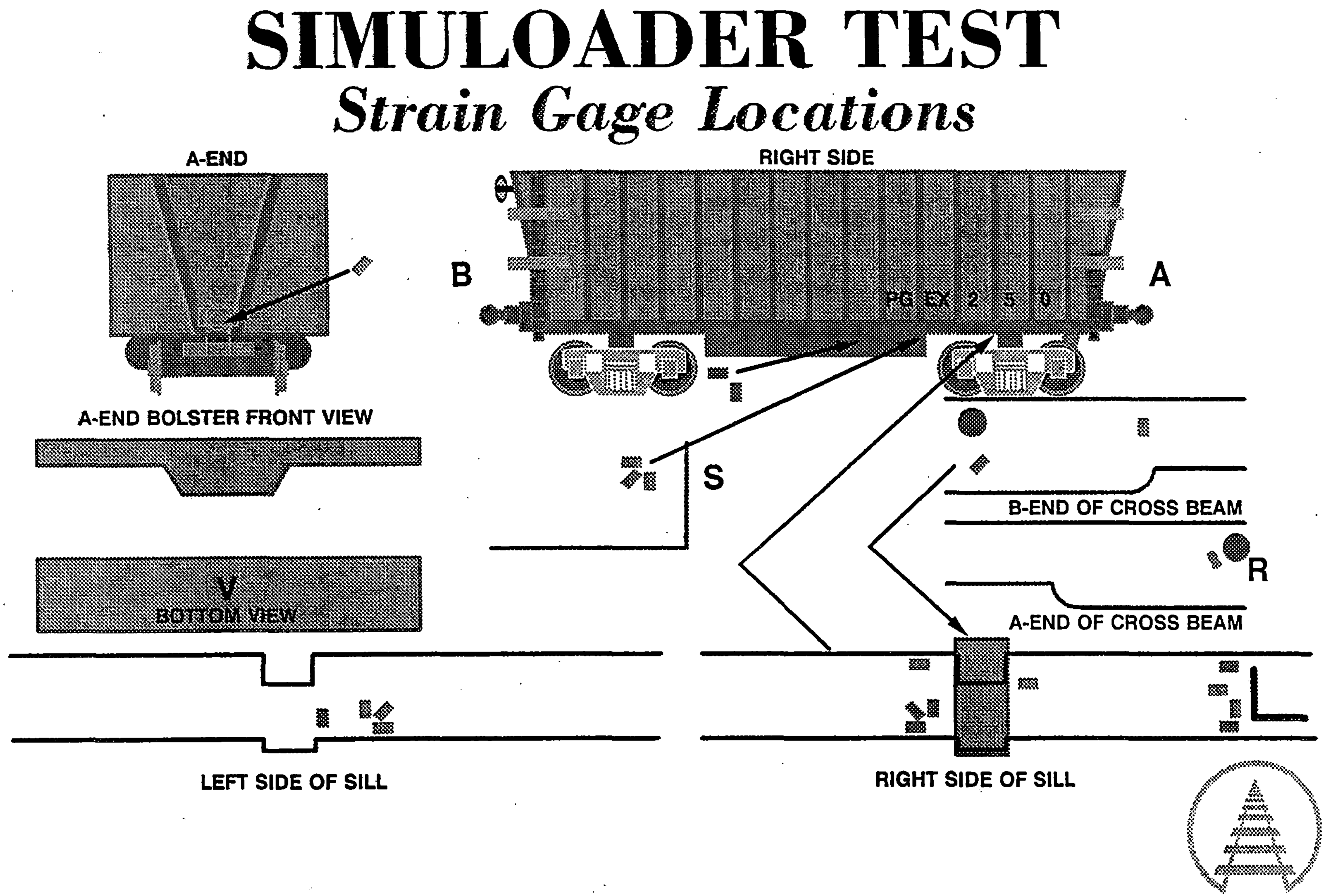


Exhibit 4.1 Schematic of The Test Car Showing Location of Transducers For Road Test.

Exhibit 4.2 Instrumentation Channels for Road Tests.

Channels.	Transducer Description
1	Speed
2	Truck Bolster Strain (A-end)
3	Accelerometer - A-end Coupler
4	Displacement - A-end Coupler
5	Accelerometer - B-end Coupler
6	Displacement - B-end Coupler
7	A-end right Vertical Acceleration
8	A-end left Vertical Acceleration
9	A -end right Lateral Acceleration
10	A-end right Car Body Vertical Acceleration
11	A-end right Car Body Lateral Acceleration
12	B-end right Vertical Acceleration
13	B-end left Vertical Acceleration
14	B-end left Lateral Acceleration
15	B-end left Car Body Vertical Acceleration
16	B-end left Car Body Lateral Acceleration
17	A-end Coupler Longitudinal Load
18	B-end Coupler Longitudinal Load
19 - 32	Strain Gages (14 strain gages)

DATA STREAM FLOW CHART

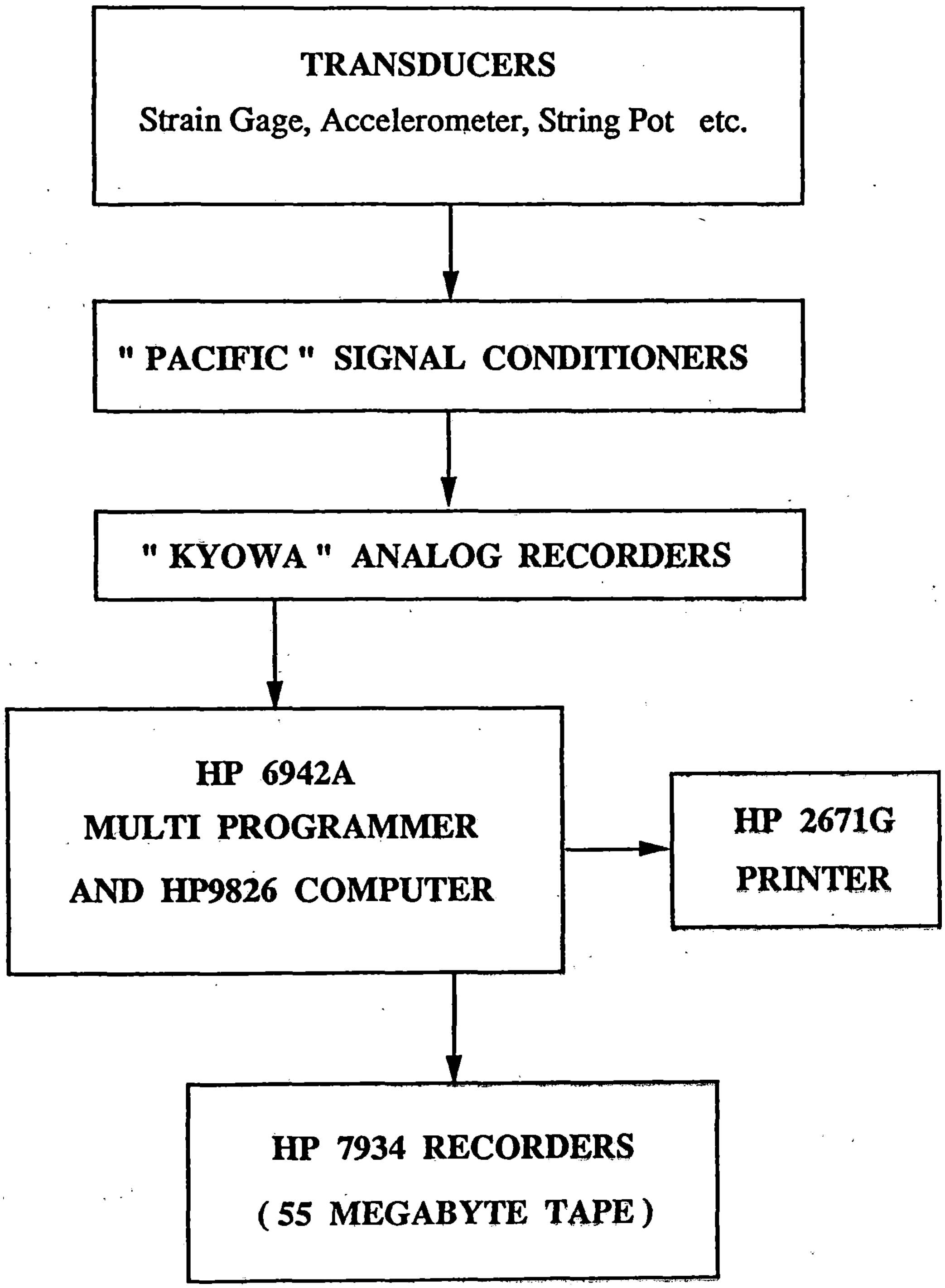


Exhibit 4.3 Data Acquisition System Flow Chart.

5.0 ROAD TEST ROUTE

The test car was the lead car of a coal unit train. The road test data were obtained for loaded as well as empty unit train operations. This unit train operated between coal mines at Gillette, Wyoming and a power plant in Boardman, Oregon. Exhibit 5.1 shows the test route map. Route distance was 1150 miles each way. Continuous time history data for the thirty-two channels of instrumentation were recorded for the loaded as well as the empty train operations.

5.1 Road Test Logistics

The test car was transported from TTC Pueblo to BN yard in Denver, Colorado. The instrumentation racks and data acquisition system were mounted in a locomotive cab and all the transducer cables from the test car were connected to this dedicated locomotive. This locomotive supplied all the power needs of the instrumentation and the cab provided working space for two test engineers to tend to the instrumentation needs and maintain a test log.

The data acquisition for the road test began when the test car was attached to the unit train at the head of the mine before loading coal in the cars. The data acquisition was continuous except for periods when the train was stopped for crew changes or other operation reasons.

Our first crew of two men with this test car was relieved by the second crew of two men at Livingston, Montana. This second crew was with the test car from

Livingston to Spokane, Washington, a time period of about 28 hours. The first crew, in the meantime had arrived at Spokane by air and rested and was ready to undertake responsibilities from Spokane to the power plant where the train was unloaded. The empty unit-train testing began at the power plant and the first crew stayed with the test car on its return journey to Spokane. The second crew had in the meantime rested in Spokane and was ready to relieve the first crew. Crew swap was done again at Livingston and the empty unit-train test was finished at Gillette, Wyoming.

The test car along with its dedicated locomotive was returned to Denver for removing all the instrumentation. However, before returning, it was loaded with coal again because the loaded test car was needed for testing on the Simuloader. The loaded test car was then sent to TTC, Pueblo for Simuloader tests.

SIMULOADER DEMONSTRATION
Road Test Route

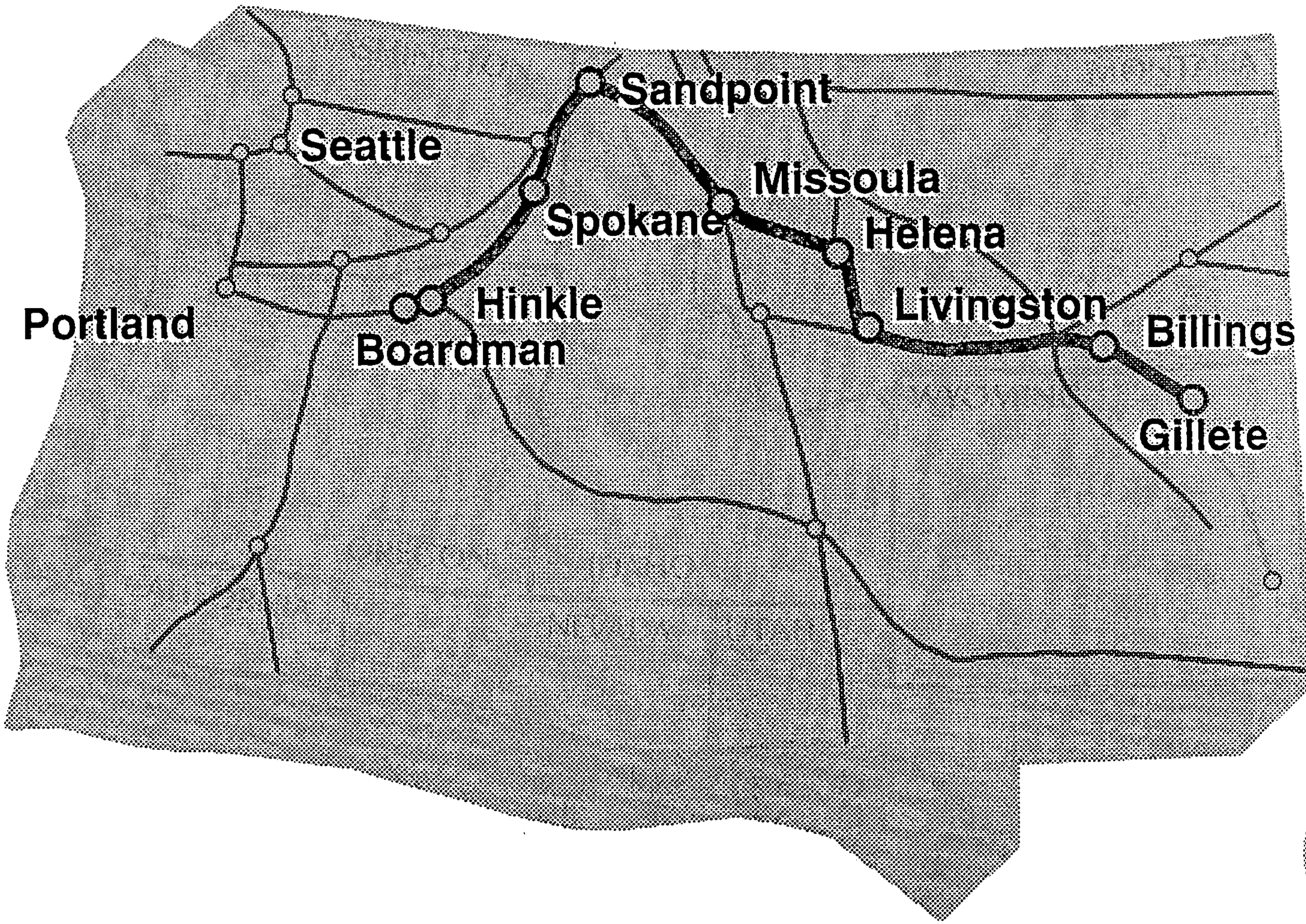


Exhibit 5.1 The Road Test Route.

6.0 ILLUSTRATIONS OF ROAD TEST DATA

The vertical loads and the longitudinal loads transferred into a freight car body are the two most important causes of freight car fatigue. These dynamic loads are caused by:

1. Pitch and bounce of the car body
2. Rock and roll of the car body
3. High in-train coupler longitudinal loads including run-ins and run-outs.

The truck bolster strain at the A-end of the car was measured during the road test and was a good indicator of the vertical dynamic motion (pitch and/or bounce) of the freight car. This strain gage is labelled 'V' in Exhibit 6.0. The car body bolster web had strain gages and one of these strain gages labelled 'R' in Exhibit 6.0 was sensitive to rocking and rolling motion of the car body. This strain gage 'R' was near the hole of the body bolster web.

The longitudinal load environment was measured by the A and B-end coupler longitudinal loads. Also, a strain gage labelled 'S' near the shear plate to side sill connection was found to be a good indicator of longitudinal loads transferred through the car body.

Some typical examples of road test data demonstrating the relationship between car dynamic and strain gage responses are now presented here.

ROAD TEST
Strain Gage Locations

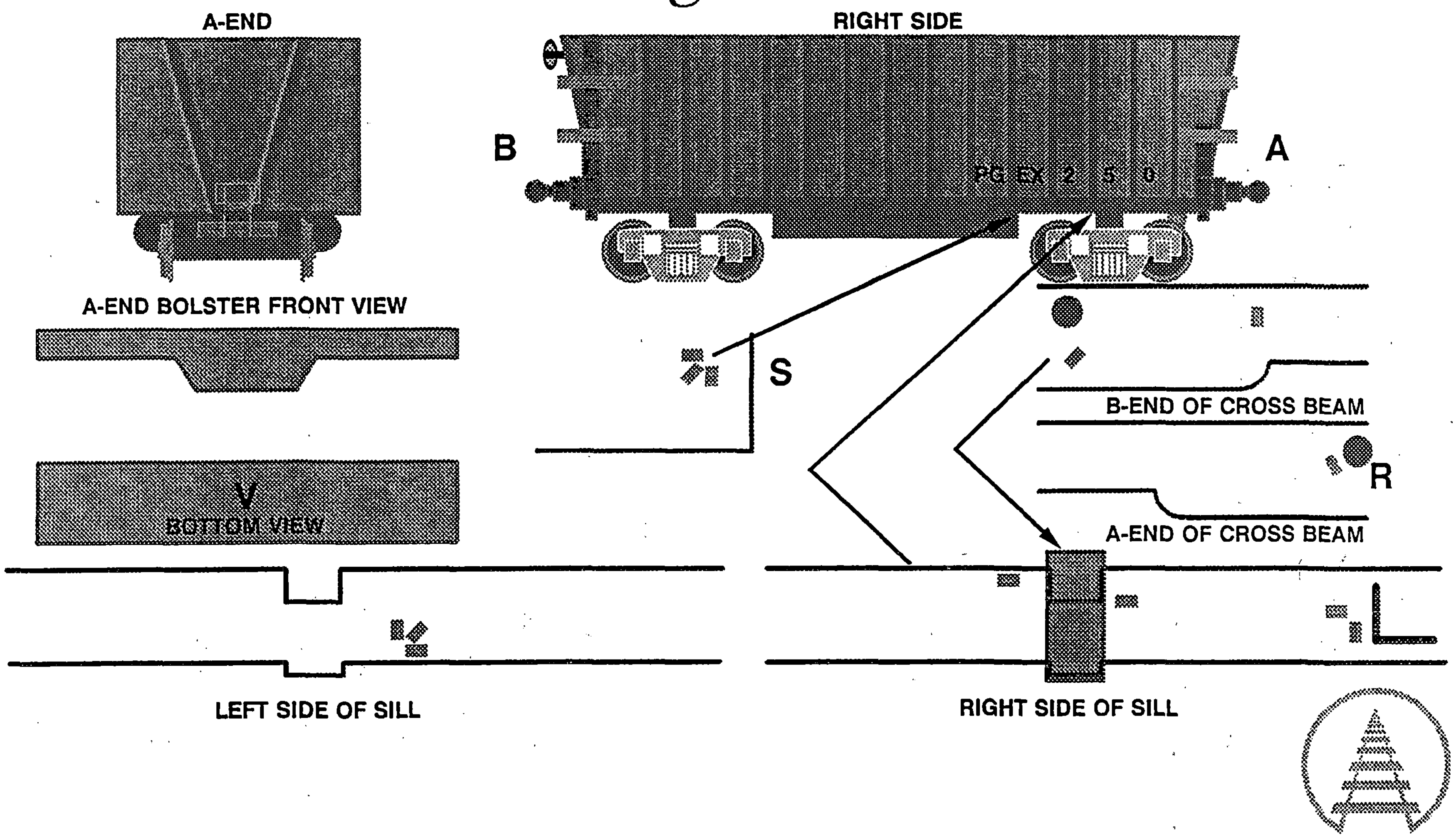


Exhibit 6.0 Schematic-Strain Gage Locations for Road test.

6.1 Pitch and Bounce

Exhibit 6.1A shows the plot of train speed, truck bolster dynamic strains ('V') and the strains at gage 'R'. The y-axis scales for the three plots are:

1. Speed in mph
2. Truck Bolster Strain, (microstrain). Zero strain implies no dynamic activity, (static load only), and a strain range of 160 microstrains is equivalent to 1g dynamic load; which is equivalent to 2g total load (static load plus 1g dynamic load).
3. Strain at gage 'R' in microinches. A zero reading implies static load only, with no dynamic activity. Strain range at the gage is a measure of dynamic roll activity.

Exhibit 6.1A shows that the train speed was about 15 mph during the four second time period 582 to 586 seconds. The truck bolster strain ('V') shows dynamic range of 200 microinches which is equivalent to 200/160 = 1.25g dynamic load. This corresponds to a total load factor of 2.25. The body bolster gage 'R' does not show much dynamic activity, but the behavior of that gage is cyclic. There are approximately five cycles in three seconds i.e. 1.6 cycles per second.

Exhibit 6.1B shows A and B-end coupler loads and the strain response of gage 'S'.

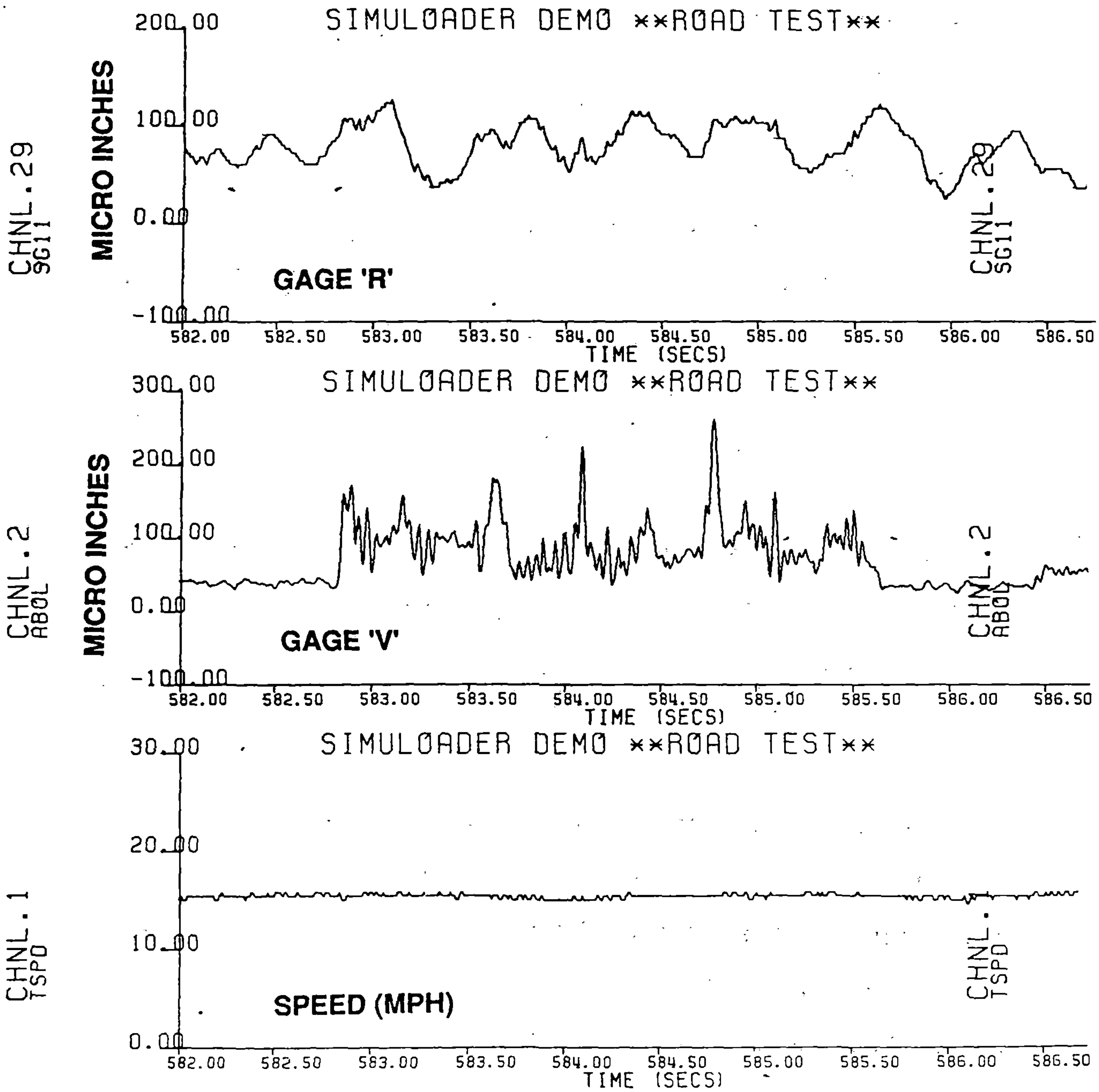


Exhibit 6.1A Road Test Data - Time Histories for Pitch & Bounce Case.

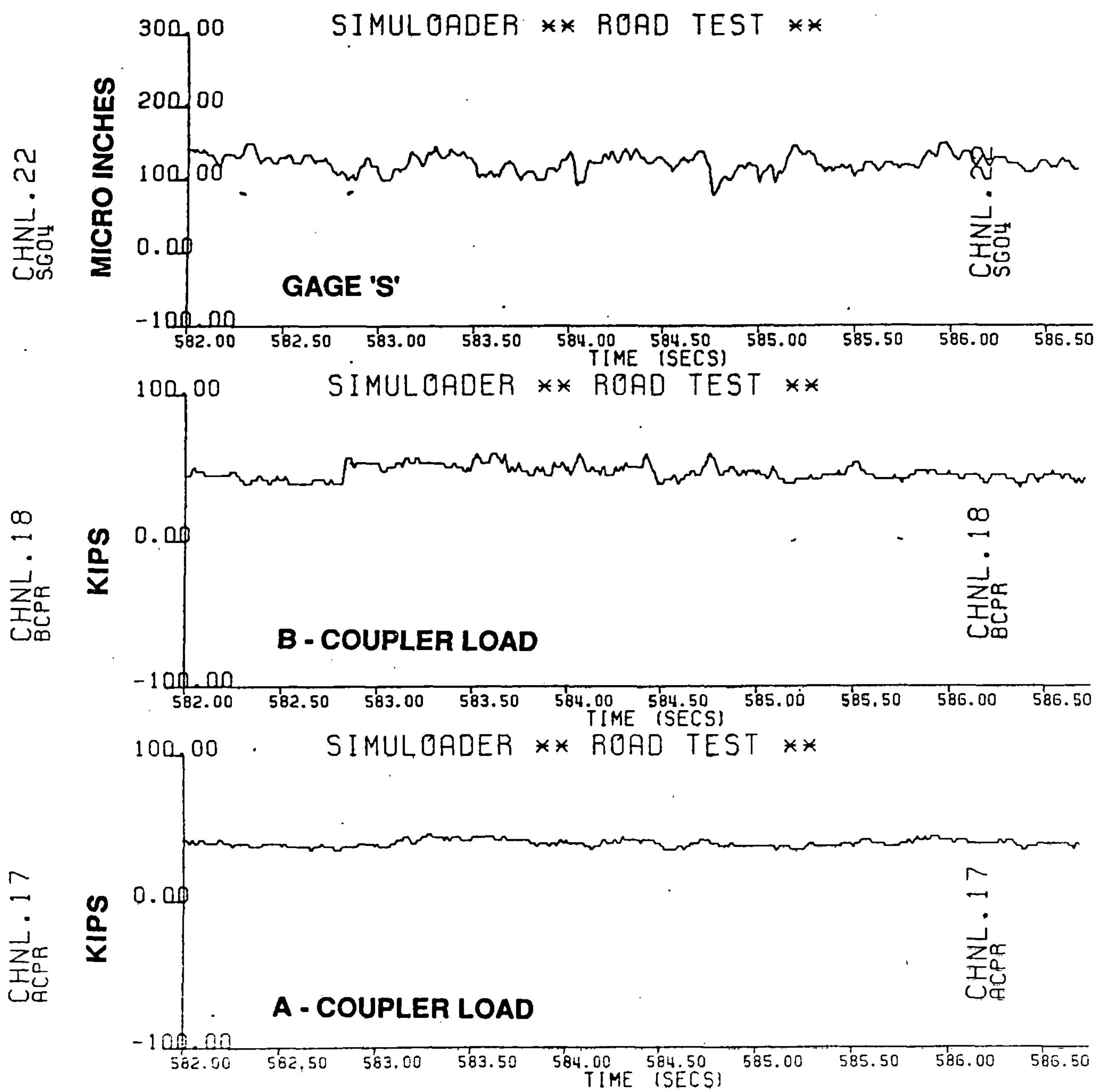


Exhibit 6.1B Road Test Data - Time Histories for Pitch & Bounce Case (Continued).

The two coupler loads are in the 45 to 50,000 lbs. range and the side sill gage also shows little activity. This leads us to believe that this incident of high vertical bolster loads was due to bounce and some accompanied pitching.

6.2 Coupler Run-In With Accompanied Bounce

Exhibit 6.2.A shows plots of coupler loads at A and B-ends. The B-end coupler receives a run-in buff load of approximately 150,000 lbs. This buff load gets attenuated by the freight car body and coal lading; the run-in load at A-end coupler is approximately 50,000 lbs. Exhibit 6.2B shows the bounce load on the truck bolster causing a strain ('V') range of approximately 160 microinches which is equivalent to a 1g dynamic load. The body bolster dynamic strain ('R') range during this episode is just under 100 microinches while the side sill dynamic strain range is barely 25 microinches.

6.3 Sustained Run-In With Sustained Bounce

Exhibits 6.3A and 6.3B show the A and B-end coupler loads and truck bolster strains ('V') and strains at gages S and R. The run-in is observed at the B coupler at approximately 99.25 seconds and the A coupler experiences the run-in at 99.4 seconds. At about the same time the strain gage 'S' shows a strain plot very similar to the A-end coupler load plot. The speed plot shows a speed increase beginning at 99.25 seconds. Truck bolster strains ('V') indicate a slight unloading at 99.5 seconds followed

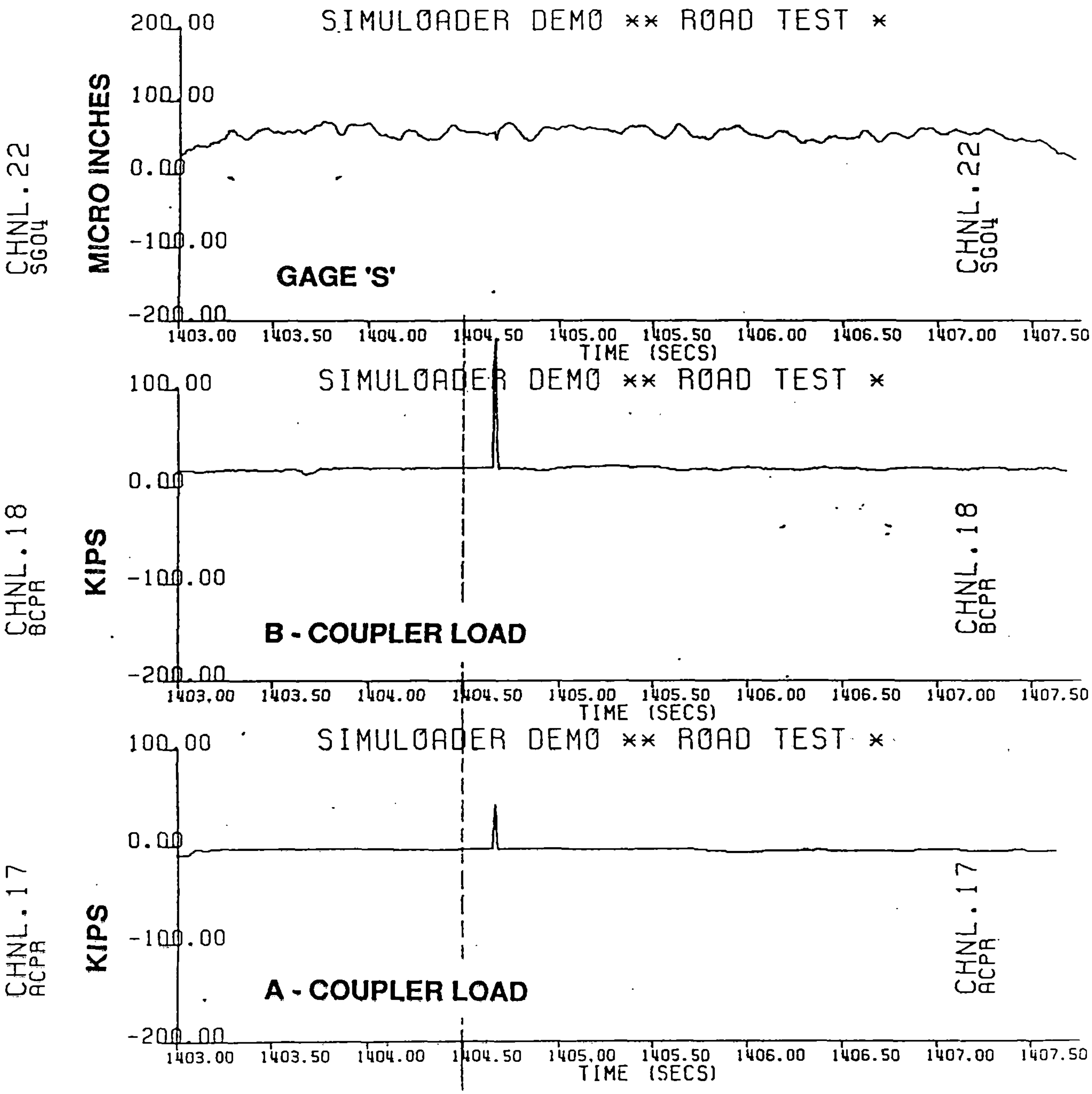


Exhibit 6.2A Road Test Data - Time Histories For Coupler Run-In Accompanied Bounce Case.

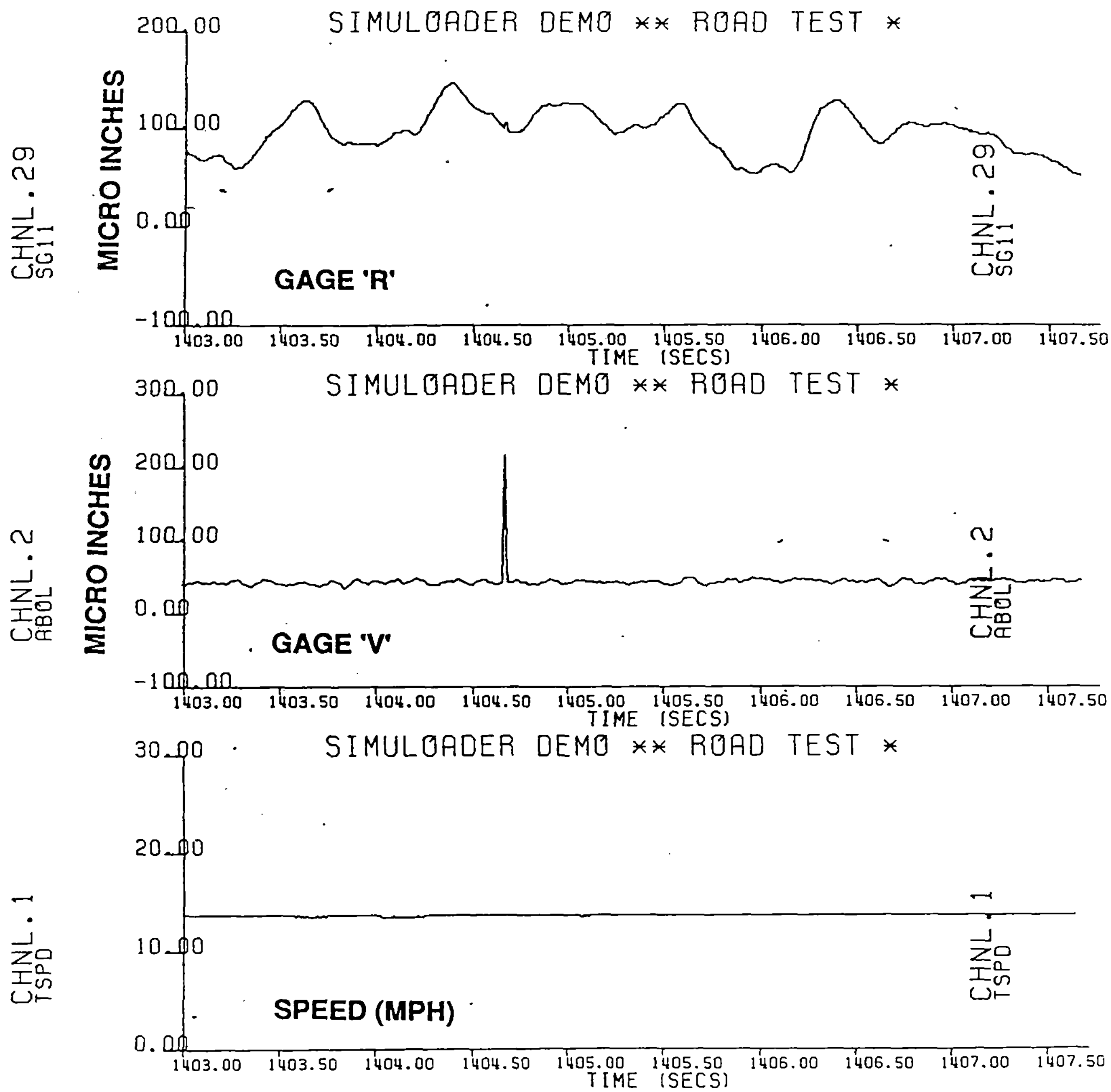


Exhibit 6.2B Road Test Data - Time Histories For Coupler Run-In With Accompanied Bounce Case(Continued).

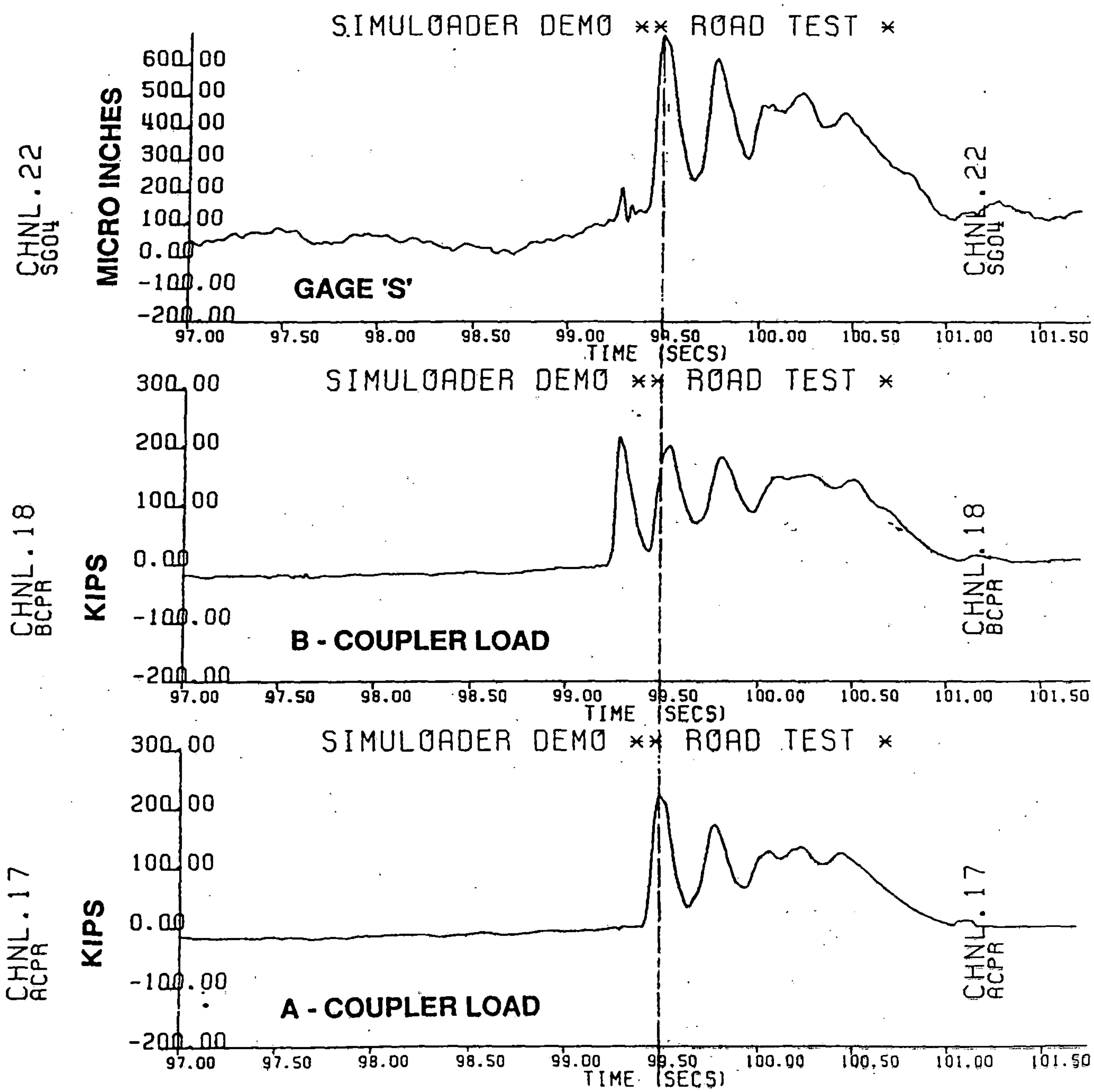


Exhibit 6.3A Road Test Data - Time Histories For Sustained Run-In With Sustained Bounce Case.

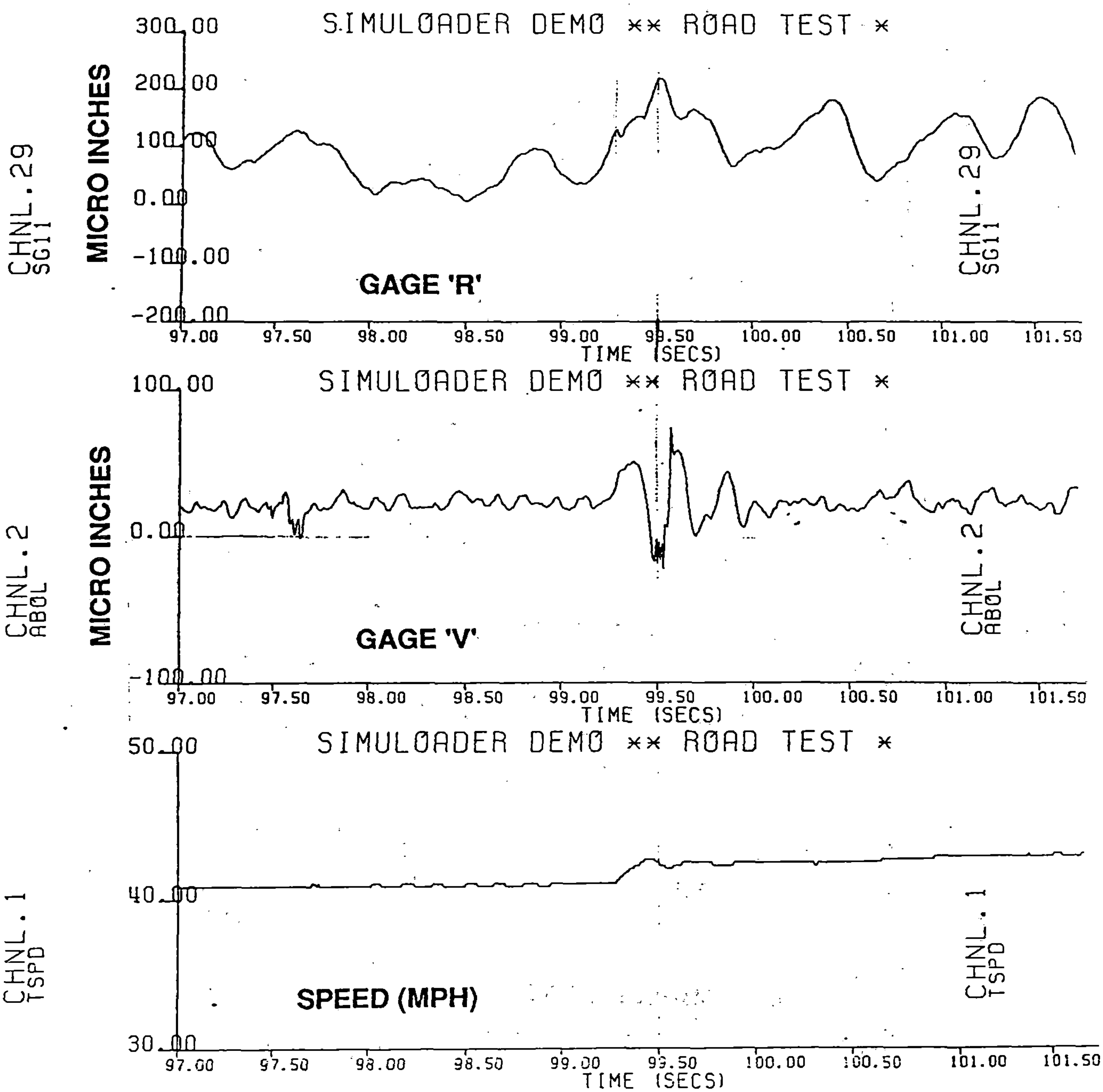


Exhibit 6.3B. Road Test Data - Time Histories For Sustained Run-In With Sustained Bounce Case (Continued).

by a bounce of approximately 0.7g dynamic load. Strain gage R' responses slightly to this bounce event. Cyclic behavior of gage 'R' before and after this event indicates slight rocking motion, also seen by the truck bolster gage before and after the event.

6.4 Rock and Roll Response

Exhibits 6.4A and 6.4B show the car body bolster strain gage "R" response to what apparently is rock and roll motion of the car body as also seen in the cyclic response of the truck bolster vertical gage "V" at a speed of 30 MPH. This action takes place during moderate sustained draft load of 100 KPS as shown in Exhibit 6.4B. There is some modest response of side sill gage "S" to this motion.

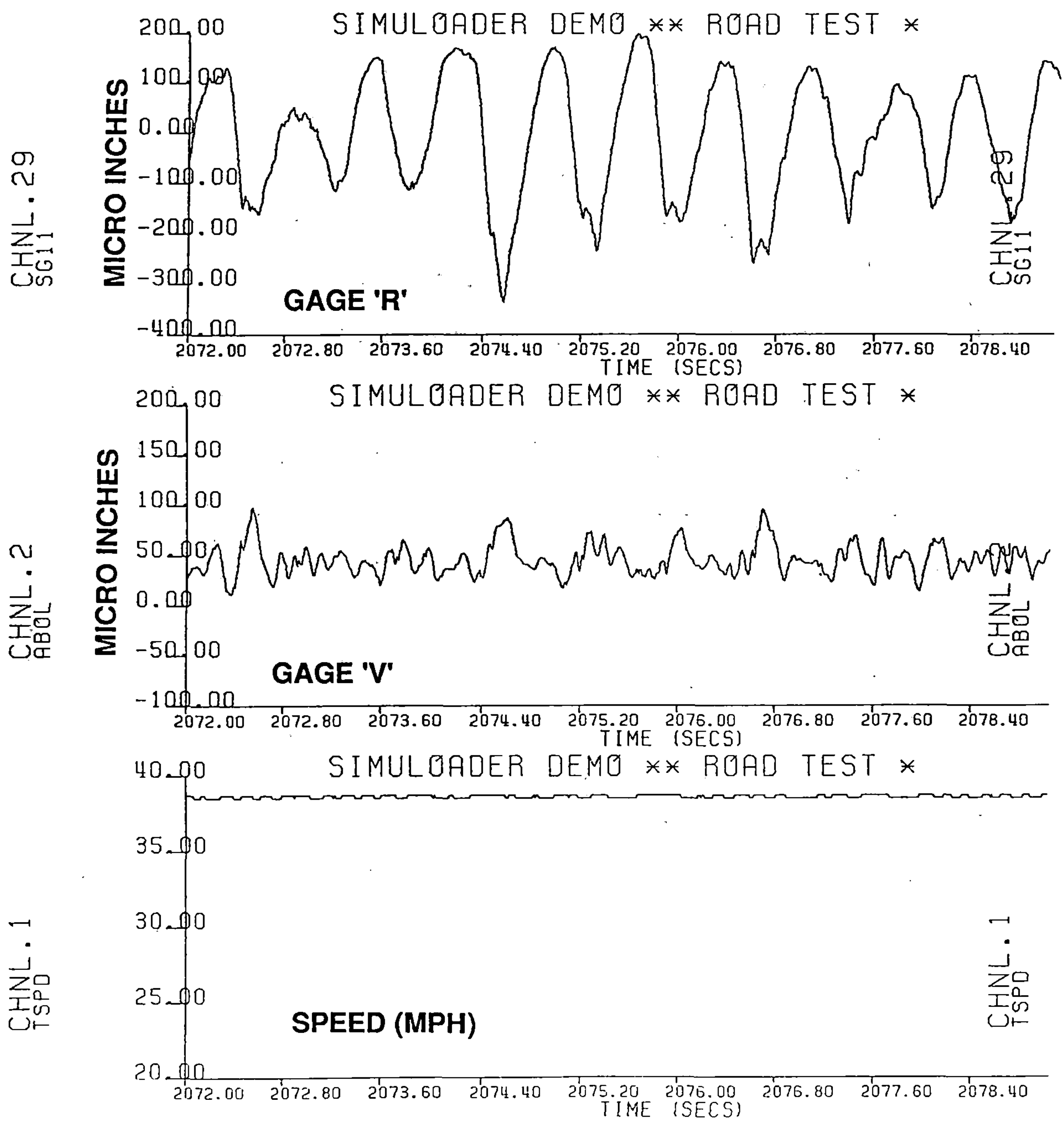


Exhibit 6.4A Road Test Data - Time Histories for Rock and Roll Case.

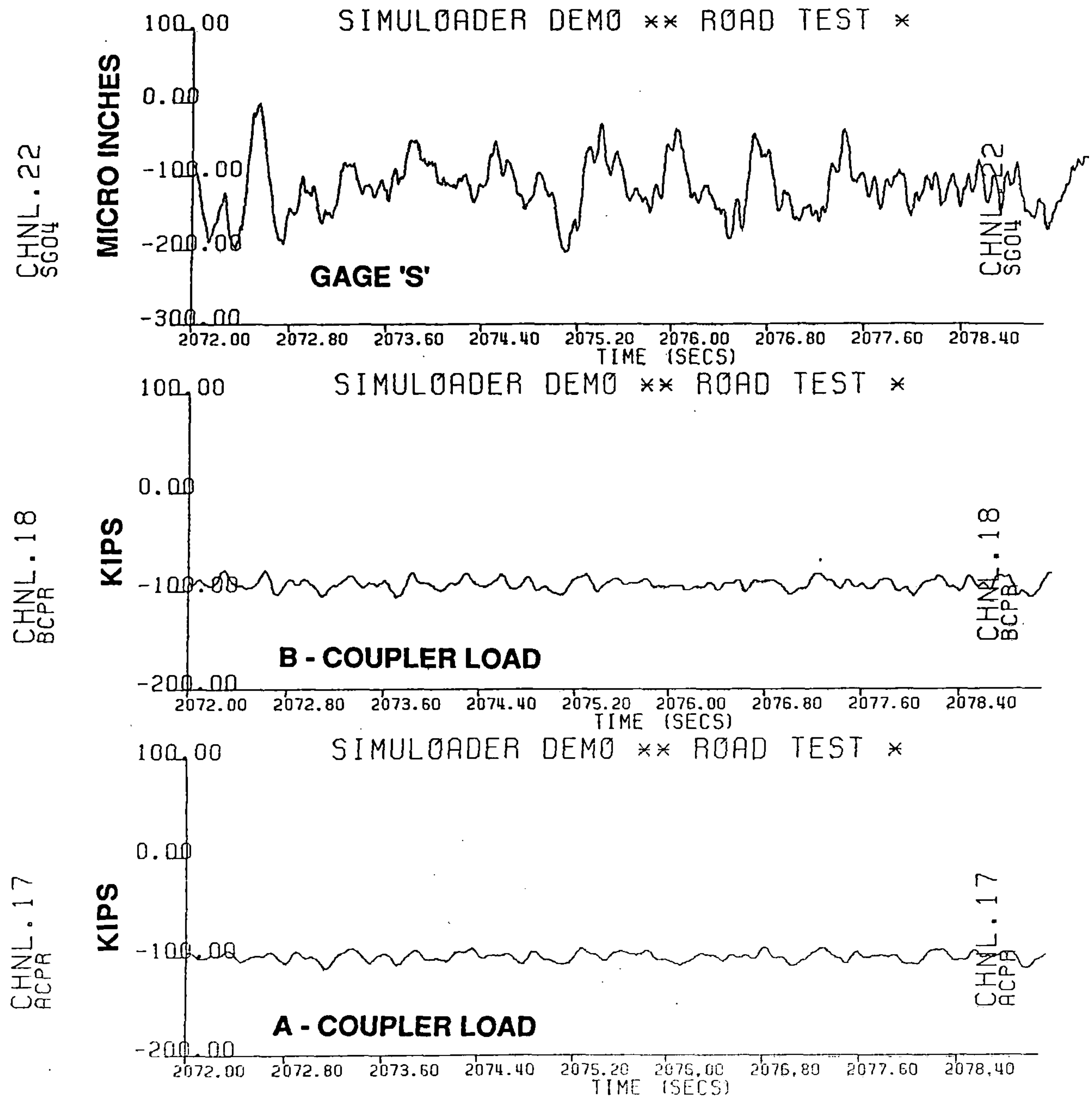


Exhibit 6.4B Road Test Data - Time Histories For Rock and Roll Case (Continued).

7.0 STRUCTURAL LOAD FLOW PATHS & SENSITIVE GAGES

The "bathtub" coal car selected for test on the Simuloader has several unique structural features that determine the load flow paths through the structure in response to both vertical truck bolster and coupler longitudinal loading. A brief discussion of these features may be appropriate then in order to better understand the rationale for strain gage placement and selection and to interpret their response.

7.1 Bounce & Rock And Roll Response

The vertical load path departs from convention in that most of the center plate load (around 80 percent) flows to the car sides up through the relatively stiff end "V" braces or beams rather than to the sides through the car body bolster. The resulting concentration of loading in the stub sill at the body bolster interSection causes relatively high stresses in the center sill web where some cracking was observed.

The car body bolster web stresses on the other hand are not as strongly influenced by vertical centerplate loads but would be expected to be more sensitive to rock and roll car motions causing side bearing strikes. In fact diagonal cracks have been reported emanating from the brake pipe access hole in the body bolster web. The sensitivity of a body bolster gage in this region, designated "R", to such motion is illustrated in Exhibit 6.4A where a strain range of about 500 microinches may be seen. This response may be contrasted to the same gage's response to vertical bounce loading in Exhibit 6.1A where the maximum strain range is only about 100 microinches.

Therefore gage "R" was selected as the most sensitive indicator of structural response to car body rock and roll while the truck bolster strain gage, designated "V" was taken as the most direct and sensitive indicator of car vertical center plate load or "bounce." As previously stated in Section 6.0 above, a strain range of 100 microstrains in gage "V" corresponds to a dynamic load factor of 1.6g and was taken as one of the threshold levels for condensation of road test data. The threshold level selected for gage 'R' indication of significant rock and roll events was 500 microinches. This corresponds to a nominal stress level of about 15,000 psi.

7.2 Coupler Load Response

The lack of a continuous through sill means that a buff or draft coupler force is an eccentric force that causes a reaction moment at the front of the V-brace/shear plate/stub sill interSection leading to high stresses at the side sills and at the draft sill end tub connection. So not only must the shear plate structure transfer longitudinal loading into the side sills, but vertical reactions are created in the stub sill/shear plate structure by the eccentric coupler forces.

Several of the vertically oriented gages deployed on the draft sill web in-board and out-board of the body bolster were expected to sense such a moment reaction to the eccentric coupler loads. However, as stated in Section 6.0, the most sensitive car body structural response to coupler loading appears to be the vertically oriented leg of the strain gage rosette, designated 'S'. Indeed cracking has been observed here in service and in test. It is a region of structural discontinuity subjected to both shear transfer of the car end coupler longitudinal loading as well as the vertical shear plate reaction loads to the eccentrically loaded stub sill coupler carrier.

Such a significant reaction strain of over 500 microstrains at 'S' is seen in Exhibit 6.3A in direct response to an A-end coupler buff load of about 200 kips. Again, a threshold level of 500 microstrains was selected for purposes of road test data condensation to be discussed below in Section 8.0.

7.3 Other Structural Considerations

In the original car configuration center plate extension pads (C-PEP) were provided on the body bolster but were subsequently removed or not installed in follow-on cars. It was noted that since the webs of the body bolster were not reinforced at the C-PEP supports, a "clean" flow of vertical reaction load up the webs was not realized.

Finally, it should be noted that the car was fabricated with thinner Section thicknesses than conventional in an attempt to reduce empty weight through use of higher yield strength (70 ksi) steel.

8.0 CONDENSATION OF ACTIVE ROAD DATA

It is not economical and indeed not practical or required to attempt to reproduce in the laboratory the entire dynamic response of the car structure over the full 1100 mile road test route in order to satisfactorily simulate the fatigue significant events. As already indicated in Sections 6.0 and 7.0 above threshold levels of response were selected for several sensitive transducers to serve as indicators for those periods of time wherein car structural response was judged to be potentially significant from a fatigue standpoint.

8.1 Condensation Goals

The challenge was to except or "slice" out and reassemble such time periods of significant dynamic behavior so that a condensed test cycle could be defined, enforced on the Simuloader and repeated sufficiently to simulate a half million miles of service operation (quarter million loaded) within the budgeted or allocated 300 hours of lab test time. In view of the service and maintenance/repair history of this car type, it was believed that a one-half million mile simulation should be sufficient to produce cracks and other structural distress or wear representative of that seen in actual service. In other words, the goal or target was to condense the 1100 mile road test cycle into approximately one hour of Simuloader testing time.

8.2 Time Slice Approach

With this goal in mind the significant time slices from the road test data were identified and condensed into a Simuloader time "history" as illustrated schematically in Exhibit 8.1. Only two transducer responses are represented in this schematic, having noncoincident significant event. Of course, it often happened that threshold levels were exceeded essentially simultaneously in several transducers.

From an examination of the actual transducer or structural response time in the period around a "significant" dynamic event on the road, such as those shown in Exhibits 6.1 through 6.4, it was decided that a time "slice" of 10 second duration containing the "event" would be adequate to stimulate this peak response on the Simuloader without introducing spurious accelerations or structural responses.

The theoretical discontinuity in response at the juncture of time slices presented no practical problem with enforcement during test, as it turned out, so that it was unnecessary to build in a "buffer" or transition period between time slices. Actually the greatest changes or load rates or required displacement rates occurred during the significant event within the time slices.

The Simuloader test cycle or "synthetic time history" assembled from such significant 10 second time slices lasted 2600 seconds (about 43 minutes). The Simuloader actuator program of loading was then derived from the LTHD road history recordings for this condensed history.

The success of such a condensation scheme depends both on its remaining within test constraints as well as producing adequate simulation of structural fatigue damage. Such an evaluation, involving so-called rain flow cycle counting and comparison of preliminary or theoretical fatigue damage predictions for the Simuloader and full road test cycles, is discussed in Section 11.0.

COAL CAR SIMULOADER TEST
Condensation Scheme

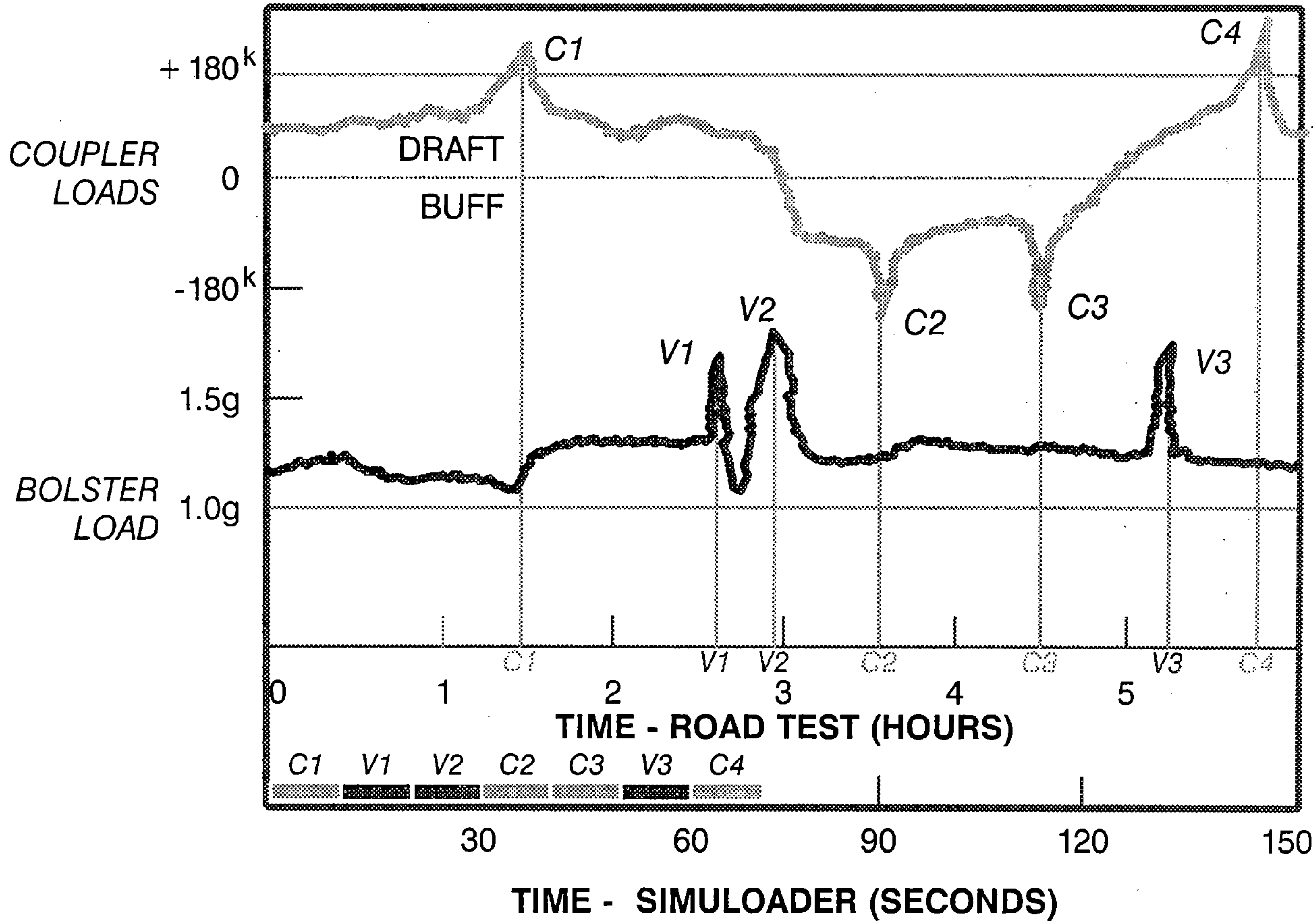


Exhibit 8.1 Methodology for Condensation - The Time Slice Approach.

8.3 Long Duration Coupler Load Cycles

However, even before such detailed evaluations, it became apparent that the simple assemblage of short time slices containing only "peak" or transient dynamic events would not include some longer duration longitudinal coupler force behavior that could be expected to cause significant structural strain ranges and fatigue. This became apparent when periods of sustained coupler force (buff or draft) occurred whose sign or sense was thereafter reversed because of changes in train operation such as occur in mountainous terrain. Such a "long" duration coupler load change over a 3 minute period is illustrated for example in Exhibit 8.2.

In order to account for such long duration coupler load cycles a supplemented coupler load period was created and appended to the 10 second time slice assemblage. The criterion for this selection or inclusion in this appended coupler loading period was the occurrence of a coupler load range of at least 180 kips that was not already included by virtue of one of the original threshold or dynamic exceedance criterion. Such a selection scheme is illustrated in Exhibit 8.3. From the total of 167,360 coupler load cycles determined from a rain flow counting of the full road history, only 81 were selected as meeting the significant range of 180 kips. A resulting artificial assemblage of this supplemental coupler load history was then itself cycle-counted for comparison to the significant cycles seen in the full road history. The resulting count of 82 was considered satisfactory.

LONG DURATION COUPLER LOAD CYCLES
Road Test Run 24

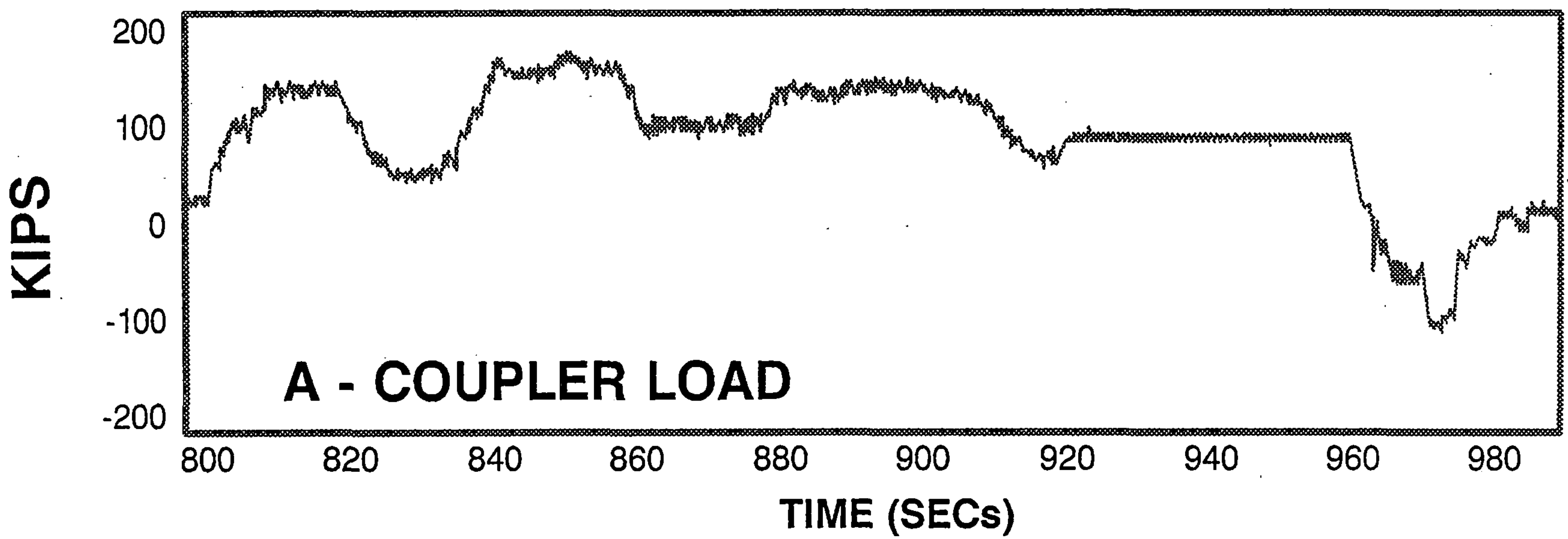


Exhibit 8.2 Illustration of Long Duration Coupler Load Cycles.

LONGER DURATION COUPLER LOAD CYCLES

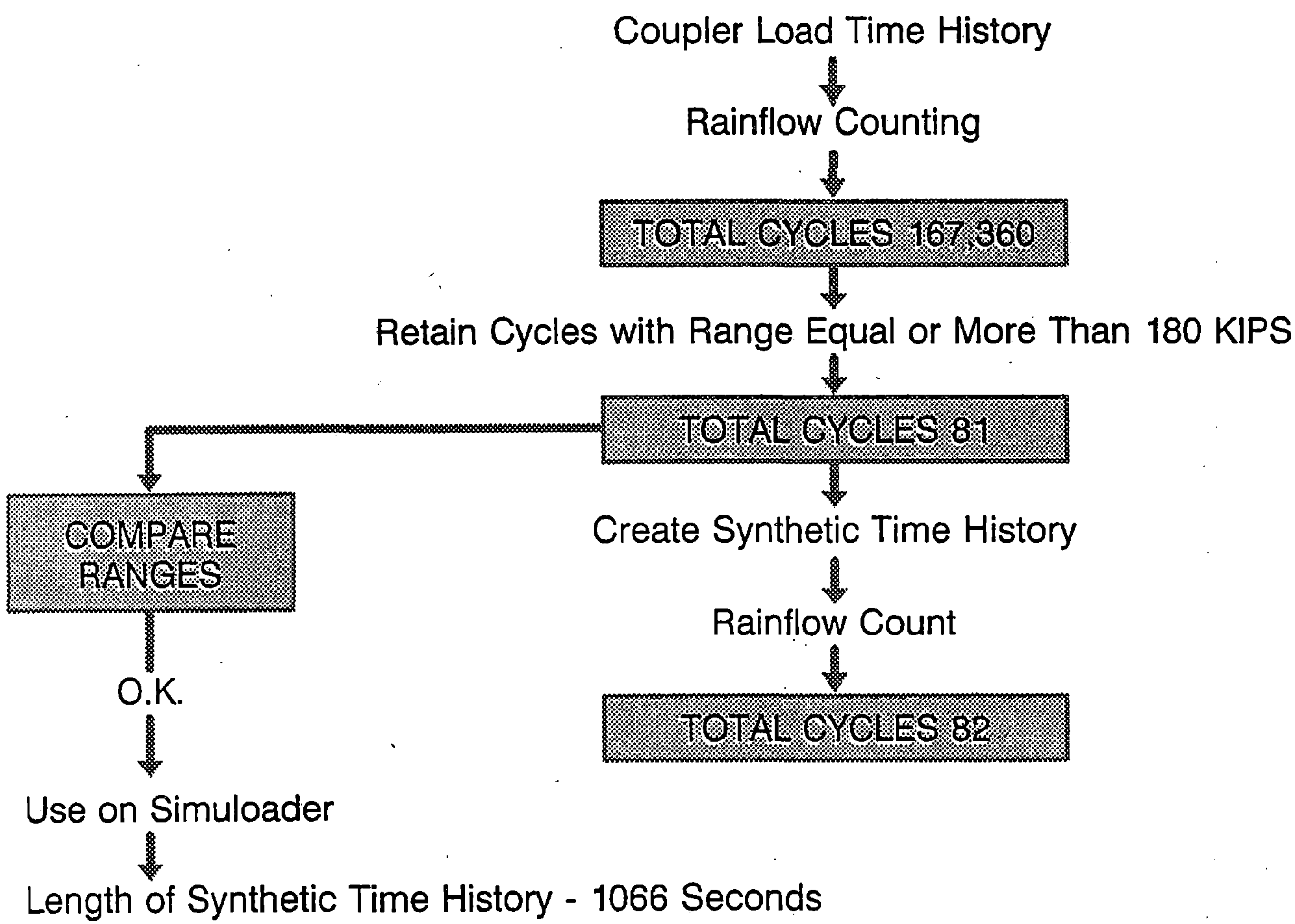


Exhibit 8.3 Selection Scheme for Long Duration Coupler Load Cycles.

A coupler load "ramp rate" was selected within the capabilities of the Simuloader that resulted in a synthetic appended time history of 1066 seconds. When this period was added the total test cycle duration became about 3666 seconds (61 minutes), close to the initial target of one hour. The vertical car body excitation during this appended coupler loading period was simply a selected segment of history representative of typical road test vertical input.

9.0 SIMULOADER TEST PROGRAM

Given the condensed road time history selected above, it remained to implement or enforce these vertical lateral and longitudinal motions and forces in the test car in the Simuloader. Brief comments on the methods of implementation, some limitations and history of obstacles overcome are given below for the several test modes. A tabulation of Simuloader operation history is provided in Exhibit 9.1 and is explained in the following paragraphs.

9.1 Vertical Load Cycle Implementation

The truck bolster vertical dynamic input was represented on the Simuloader by vertical displacement histories derived from the selected LTHD data recordings.

9.1.1 Vertical Actuator Program

The two vertical actuators on each end of the car were driven by displacement command programs created by a double integration of the selected LTHD acceleration condensed history.

9.1.2 Vertical Actuator Limitations

Throughout most of the test (261 of the 270 test hours) the range of vertical motion was restricted to $\pm$ 2 inches. In fact this restriction prevented the full simulation of some of the peak vertical dynamic motions, so during the final 9 hours of testing this limit was changed to $\pm$ 3 inches, or the ultimate system limit.

SIMULOADER OPERATIONS

RUN	*SIMULOADER HOURS*	*ACTUATOR GAINS*			*YAW*	*COUPLER SLACK*
		VERTICAL	*LATERAL*	*LONGITUDINAL*		
1-24	1-240	1.0	1.0	1.0	YES	YES
25-26	240-261	1.0	1.0	1.0	NO	NO
27		1.5	1.0	1.3	NO	NO
28		1.75	1.0	1.3	NO	NO
29		1.75	1.0	1.0	NO	NO
30		1.75	1.0	1.3	NO	NO
31-39	262-270	1.75	1.0	1.3	NO	Enhanced Inputs

Exhibit 9.1 The Simuloader Operations Summary.

In order to cause car body strains as high as occurred on the road and to attempt some "acceleration" of fatigue damage input in the remaining test time available, the "gain" of vertical motion driver program was also increased up to a level of 1.75 in the final hours as shown in Exhibit 9.1.

9.2 Lateral Load Cycle Implementation

The lateral dynamics implementation method was the same as that employed with the vertical actuators, however no restriction difficulties or gain increases were involved in this case.

9.3 Coupler Load Cycle Implementation

In order to enforce the condensed coupler load history on the Simuloader, the longitudinal hydraulic actuator program was created to drive the A-end (restored end) of the test car. However, because of the amount of coupler and draft gear slack, as well as inherent hydraulic capacity limitations, it was not possible, especially during the first 240 hours of testing to, faithfully reproduce all the target time history. Steel shims were subsequently more thoroughly used to remove as much slack as possible from the draft gear assembly.

It should be further noted that only one instrumented coupler was used on the test car in the Simuloader and it was placed on the B-end of the car against the Simuloader reaction structure. Therefore there was some inertial attenuation of the most severe A-end impacts through the loaded car body before the coupler force was sensed at the instrumented coupler on the B-end.

This effect may be seen in Exhibit 6.2A from the road test. The sharp "spike" in B-end coupler load is apparently "filtered" out in transmission through the loaded car. However, for a more moderate yet still severe run-in coupler history such as Exhibit 6.3A, there is relatively non diminished force transmission. Since all plots of coupler force and fatigue analyses in this report are based on the reaction B-end coupler force, this fact should be borne in mind.

9.4 Yaw Actuator Interference

There was another obstacle to complete simulation of coupler force history that was discovered and removed after 240 hours of testing. This was the interference of the yaw actuators to full transmission of the coupler load from A-end to B-end of the car. Since there was no enforcement of yaw action intended in this test, and the yaw restraint was not needed for safety purposes, they were disconnected for the remainder of the test. It should be noted that this interference did not reduce the coupler force experienced by the A-end restored structure, but did reduce the magnitude of the B-end coupler reaction of about 70 kips.

Finally, after about 261 hours of testing, the coupler loading inputs were "enhanced" through use of a gain of 30 percent. The net effect of this enhanced loading and removal of yaw interference is illustrated in Exhibits 9.2A and 9.2B. Both the restoration of certain peak loads and general enforcement or increase in level relative to the road data are evident in Exhibit 9.2B.

9.5 Added Strain Gages

Following the road test experience and prior to the Simuloader test, 14 strain gages were added to the existing car instrumentation. These new gage positions are highlighted on the car body drawings given in Exhibit 9.3. These gages were added in an attempt to provide a more complete picture of car body structural response in the Simuloader. They were positioned based on road test experience as well as a review of earlier tests and structural analyses made available to AAR.

10.0 SELECTED TEST RESULTS

A selection or summary of results both in terms of car body dynamic response and loss of structural integrity (cracks, wear etc) observed during the course of Simuloader testing is provided in this Section.

10.1 Dynamic Results

As discussed in the foregoing Sections, the dynamic results of the Simuloader test may be adequately illustrated by an appropriate selection and data reduction of time periods containing structurally fatigue significant events recorded on only four of the more than 40 transducers employed on the car. These transducers, or data channels are, in summary:

- 'R' Car body bolster diagonal strain gage
- 'S' Car side sill vertical strain gage near tub end junction
- 'C' Coupler load cell (on B-end in Simuloader)
- 'V' Truck bolster strain gage calibrated for vertical load.

Even with this forcing or restriction of attention to only four channels it is still necessary to employ a meaningful scheme to reduce and display selected periods of the Simuloader test cycles and, most significantly, compare them to the corresponding road test which we are "simulating." With this objective in mind the following data reduction "scheme" or method was adopted.

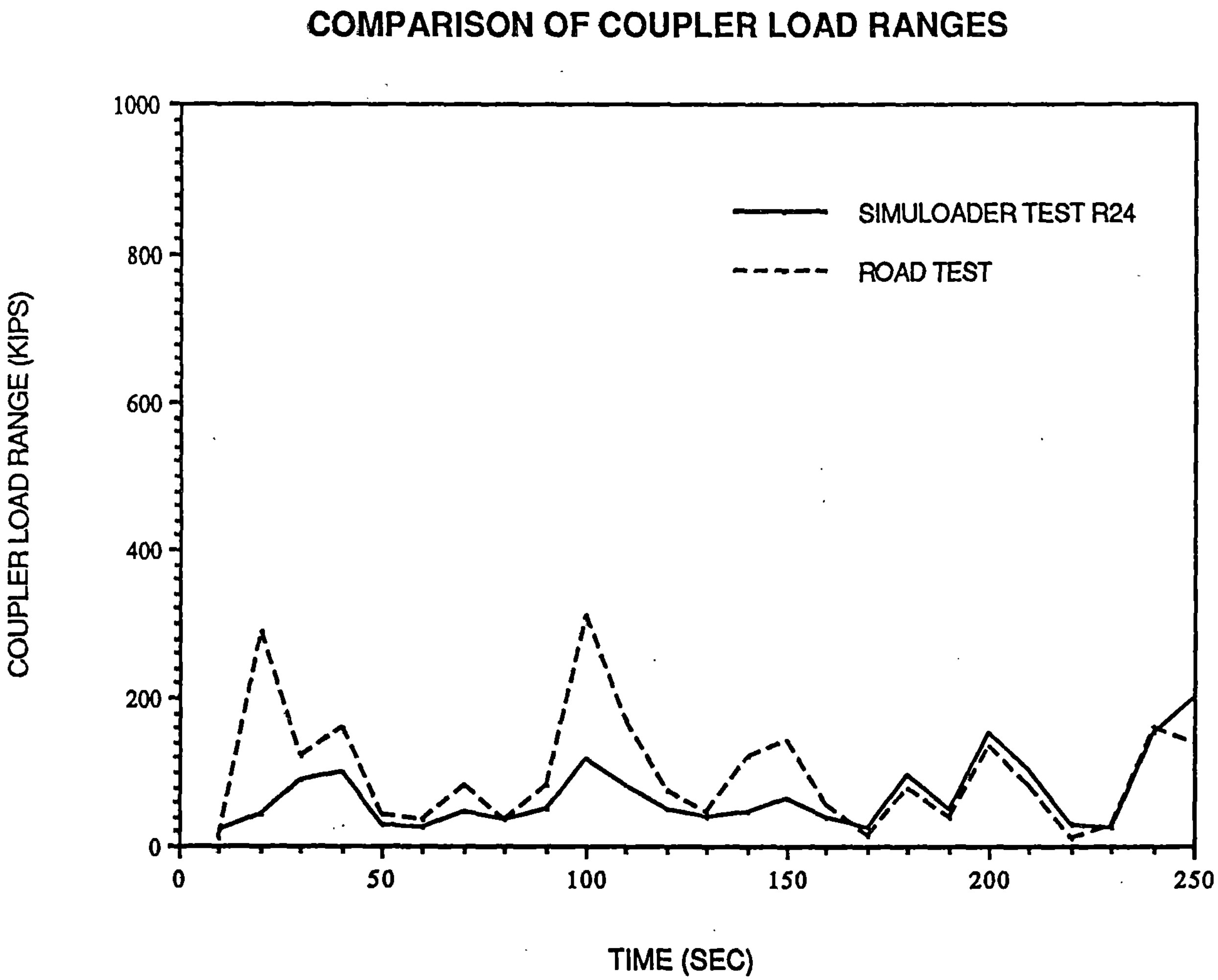


Exhibit 9.2A Comparison of Coupler Loads - Road Test vs. Simuloader Test Before Input Enhancement.

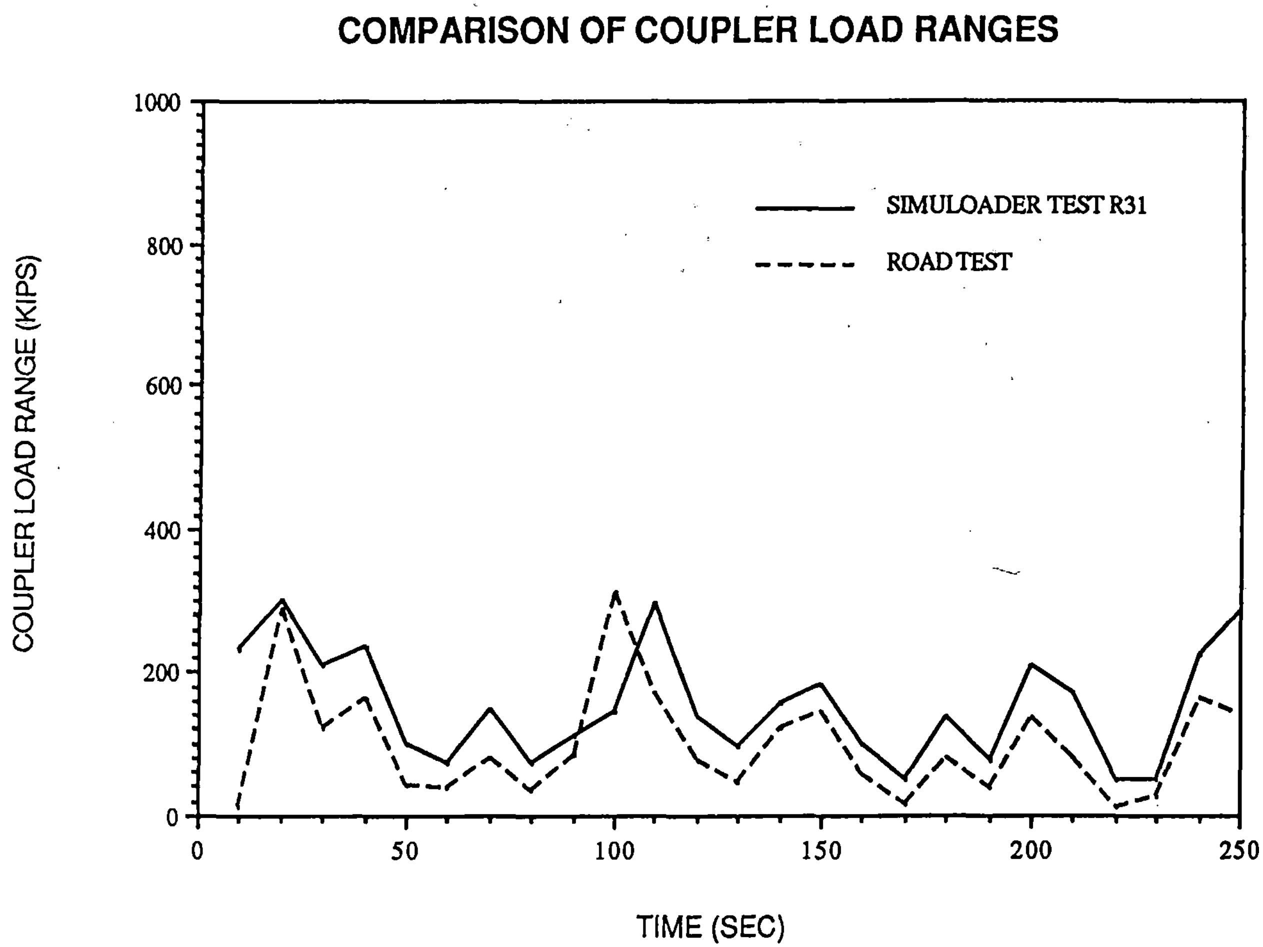


Exhibit 9.2B Comparison of Coupler Loads - Road Test vs. Simuloader Test After Input Enhancement.

10.2 Data Reduction/Display Scheme

Load or strain range is the most significant measure of a dynamic history from a fatigue standpoint. Therefore, the transducer ranges over a given time interval (10 seconds was selected as discussed in Section 8) were obtained for these four channels over the course of the road test and those intervals with ranges meeting an established threshold criterion were selected for the composite test cycle. This scheme is illustrated in Exhibit 10.1a, b and c for three of the four channels, R, S and C. The upper diagrams display an assemblage of 10 second time "slices" of actual transducer responses or assembled real time histories from a 50 second period from test cycle or run #31 (an "enhanced" or amplified loading cycle which followed the initial 261 hours of test). The lower diagrams in Exhibit 10.1a, b and c show the corresponding ranges of strain or load that were reduced from the data above. For example, the maximum range during the first 10 seconds in the upper diagram is plotted at 10 seconds in the lower diagram.

10.3 Selected Dynamic Responses

It should be remembered that the drivers for the Simuloader cycle were based on the actual coupler force and bolster displacement (acceleration based) histories during these selected time "slices." The structural responses or "results" of such excitation are principally the strain gage signals during the Simuloader tests. These responses are displayed in terms of the reduced load or strain range

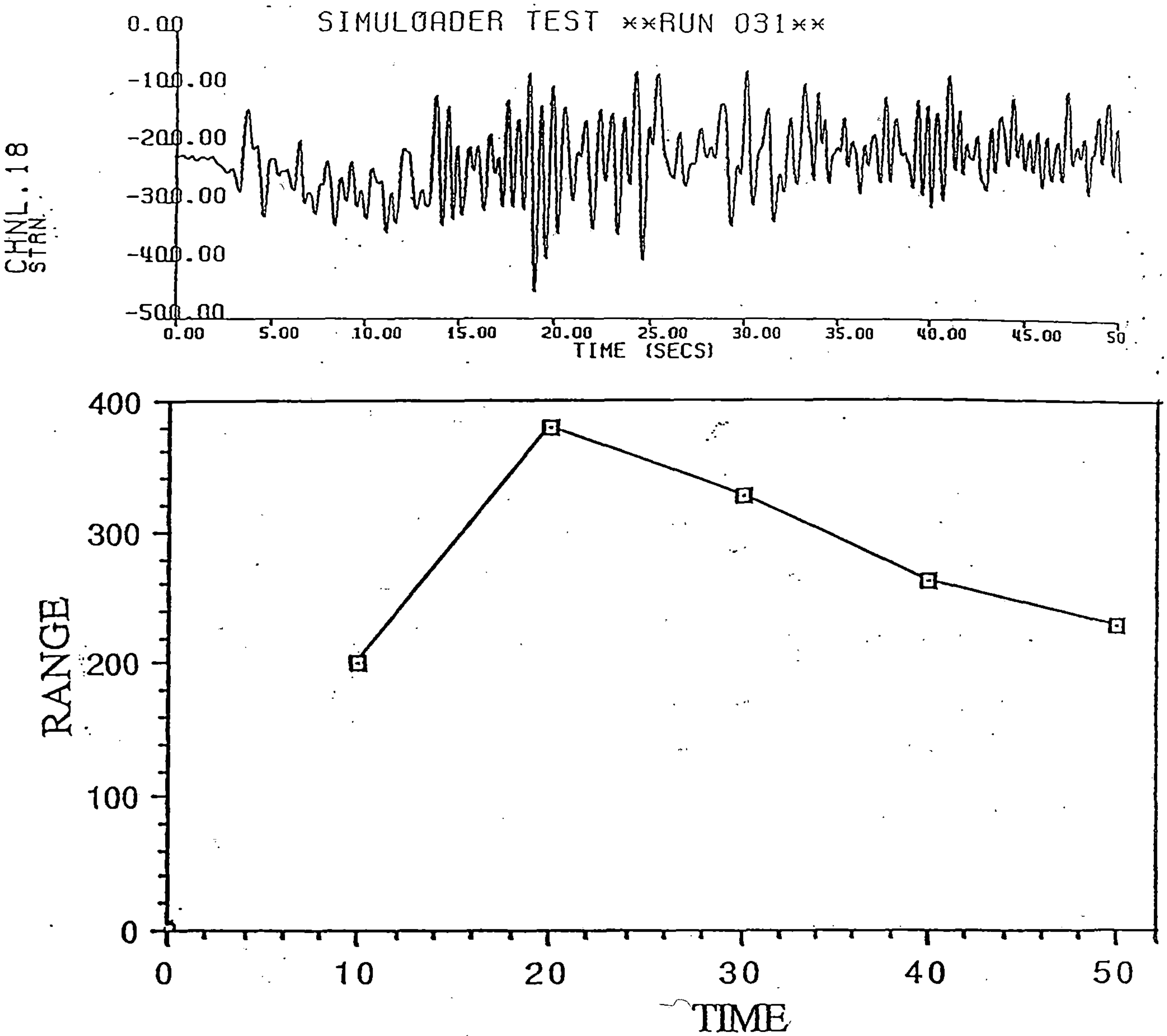


Exhibit 10.1A Example of Data Display Scheme - For Gage 'R'.

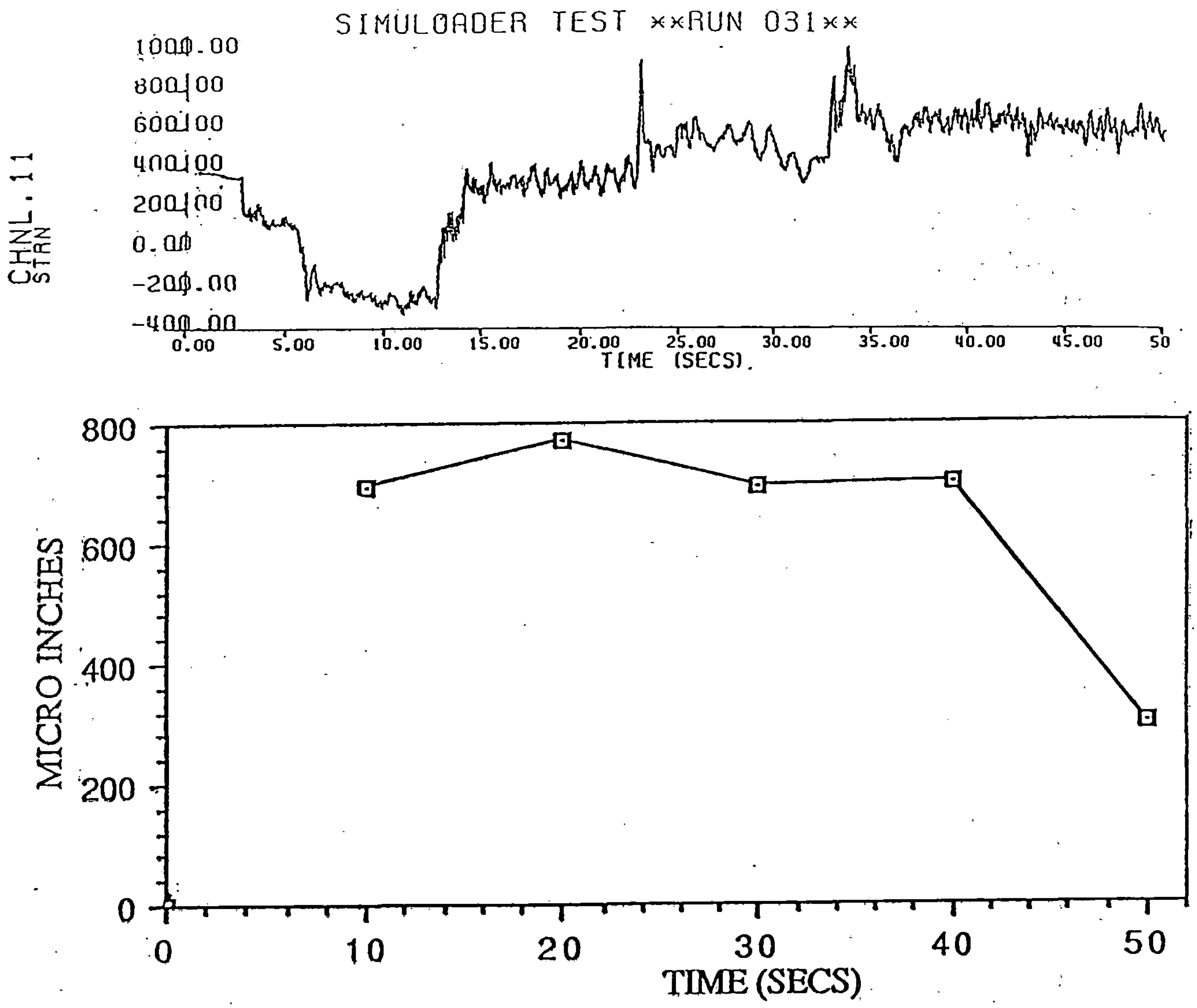
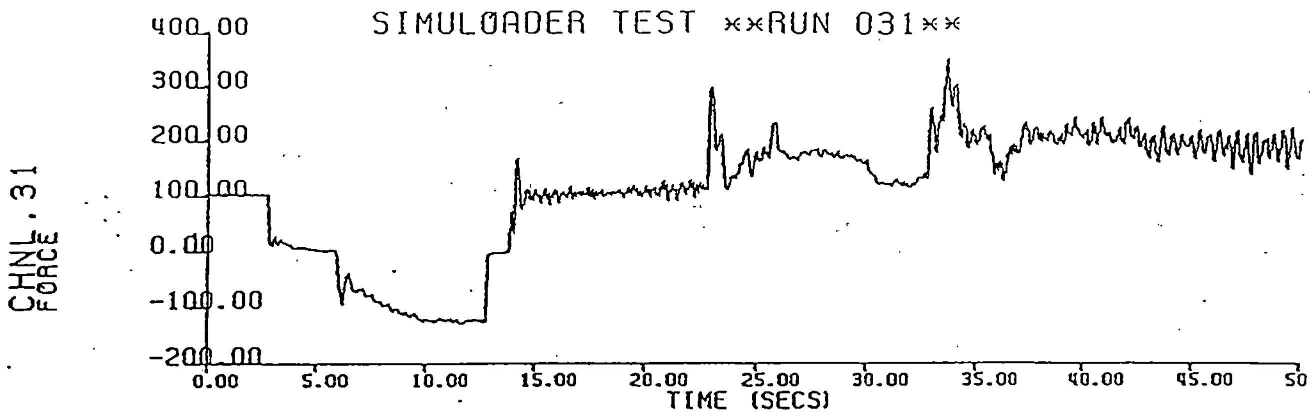


Exhibit 10.1B Example of Data Display Scheme - For Gage 'S'.



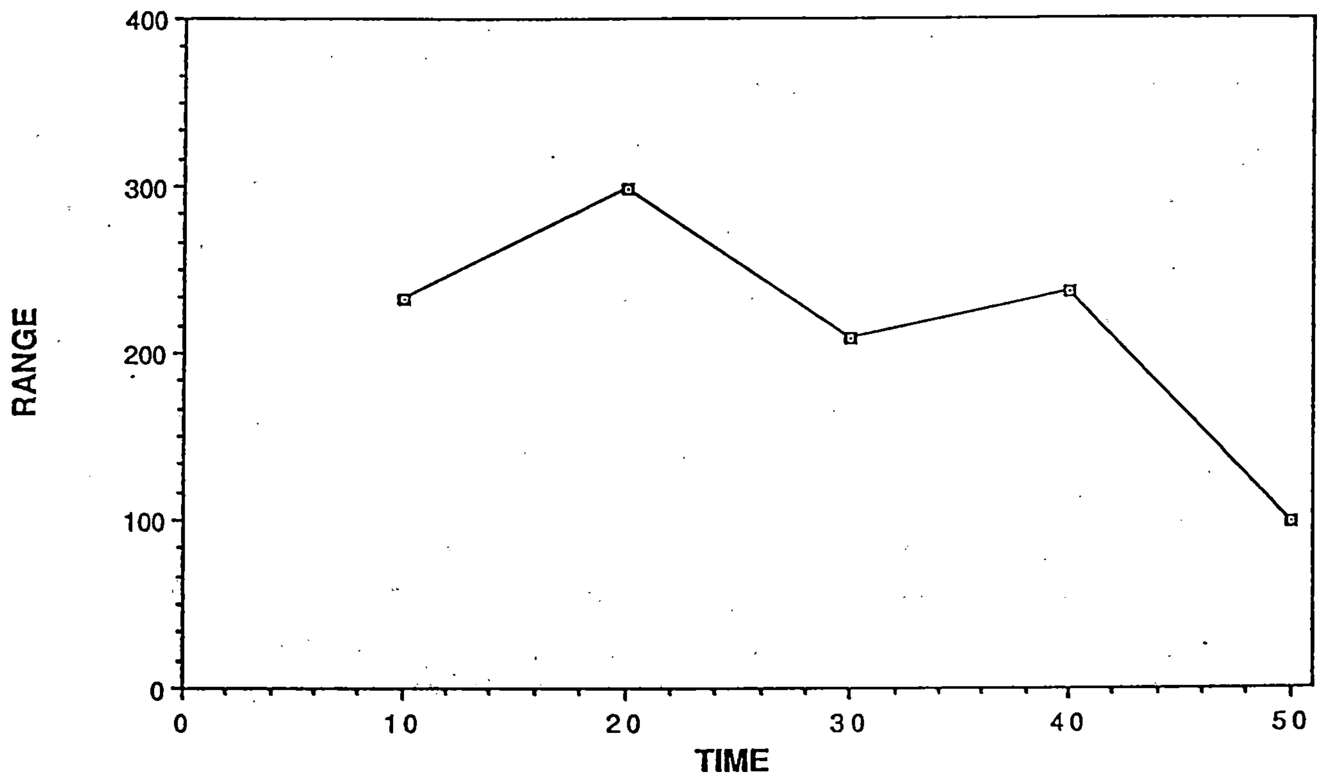


Exhibit 10.1C Example of Data Display Scheme - For Coupler Loads.

histories in many of the exhibits that follow in this report.

As an example of the use of this type of response presentation, Exhibit 10.2, parts a, b and c, provide a comparison of the side sill strain response, S, from the road test data (dotted line) versus the corresponding response during the Simuloader cycle for a selected 4 minute period. It can be seen from Exhibit 10.2a that the Simuloader generally follows the road response but on occasion falls below the peak road ranges. This was one of the reasons that the Simuloader loading cycle was "enhanced" or amplified during the final hours of testing. Exhibit 10.2b shows the gage response during the first cycle after test enhancement and Exhibit 10.2c shows the response on the last cycle of testing, indicating that the cycle is repeatable and does appear to produce strain range response peaks that are at least as large as the road test. In this case the coupler load enhancement was most responsible for this increase in side sill gage "S" response.

10.4 Cracks and Other Observations

Another anticipated result of the testing, of course, was the appearance of cracks and other signs of wear that would have been representative of that originally reported from early service operation. Although some cracking was observed, during the course of testing as described below, it was not nearly as prevalent as expected.

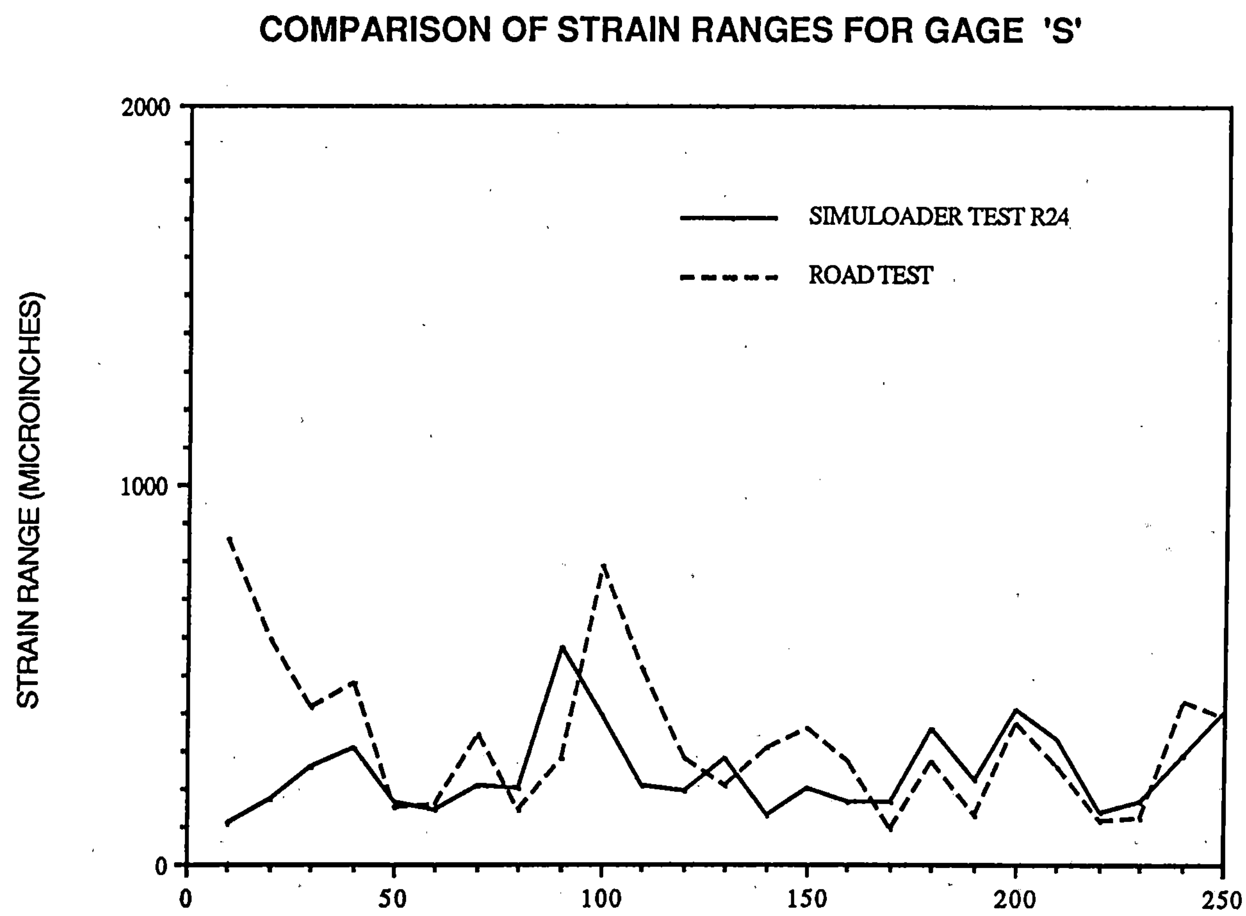


Exhibit 10.2A Comparison of Strain Ranges at Gage 'S' - Road Test vs. Simuloader Test Run 24.

[redacted]

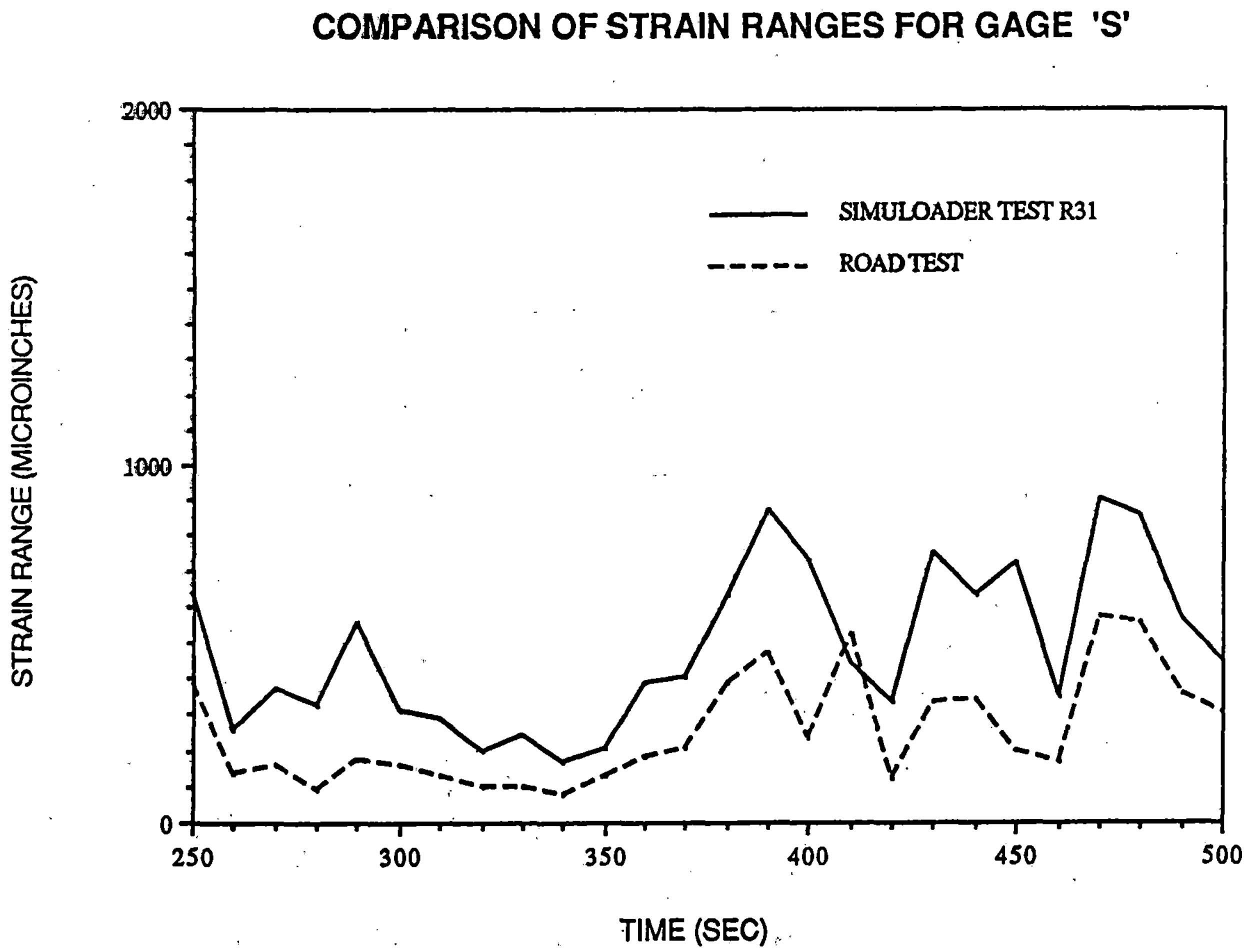


Exhibit 10.2B Comparison of Strain Ranges at Gage 'S' -
Road Test vs. Simuloader Test Run 31.

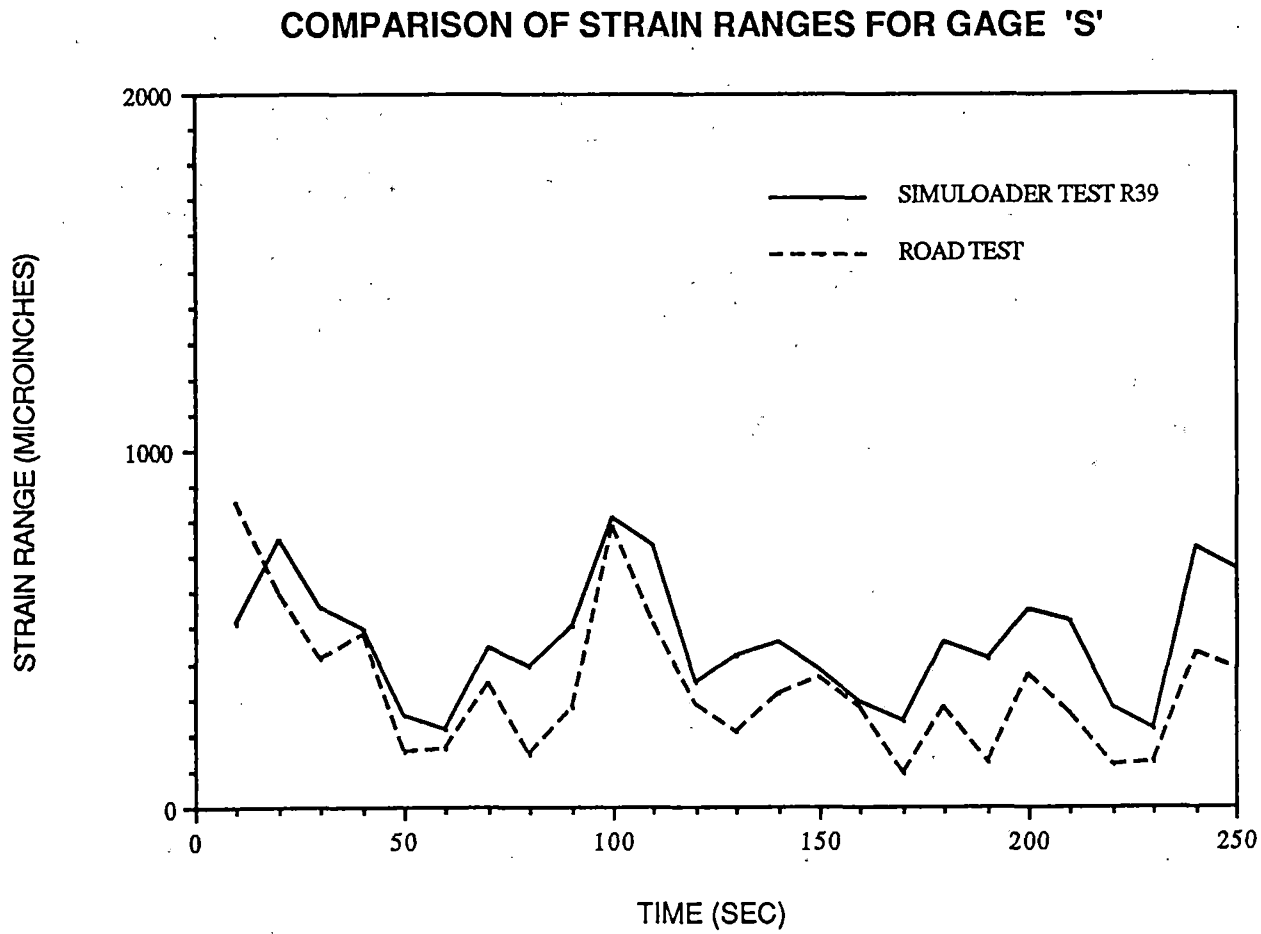


Exhibit 10.2C Comparison of Strain Ranges at Gage 'S' - Road Test vs. Simuloader Test Run 39.

Reasons for this, related to both the adequacy of simulation of the so-called "Road Test" as well as how representative the 1988 road test was of the 1982 service, are discussed later in Section 12.0. For the time being, however, we will summarize the results of careful car visual inspections before and after road test as well as during the Simuloader testing.

10.4.1 Side Sill Crack

After about 100 hours of Simuloader testing a 1/2 inch long crack was observed at the side sill to shear plate extension tab weld on the left B-end of the car. The location is shown schematically in Exhibit 10.3. The crack was a couple of inches inboard of the strain gage "S" location. By the end of testing the crack had grown to a length of 1 1/2 inches. A photograph of this crack is shown in Exhibit 10.4.

10.4.2 Stub Sill to Shear Plate Crack

Also in the left B-end of the car an inch long crack was observed in the horizontal weld between the inboard end of the stub sill and the shear plate near the tub end enclosure. See Exhibit 10.3 again for location. This crack, which was first observed after about 200 hours of testing, grew to 3 inches at 260 hours. See Exhibit 10.5 for a photograph of this crack.

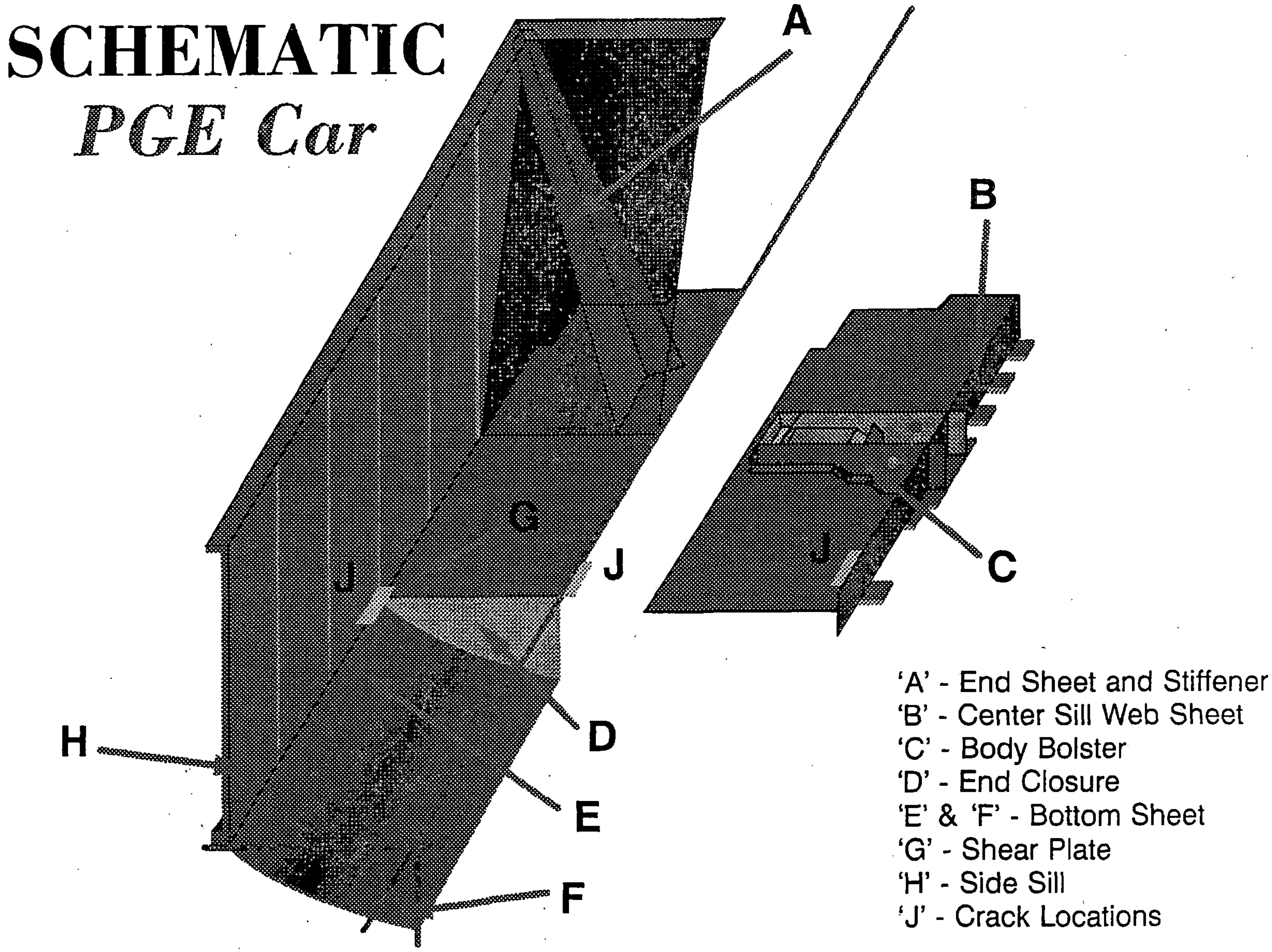


Exhibit 10.3 Schematic of Location of Side Sill Crack.

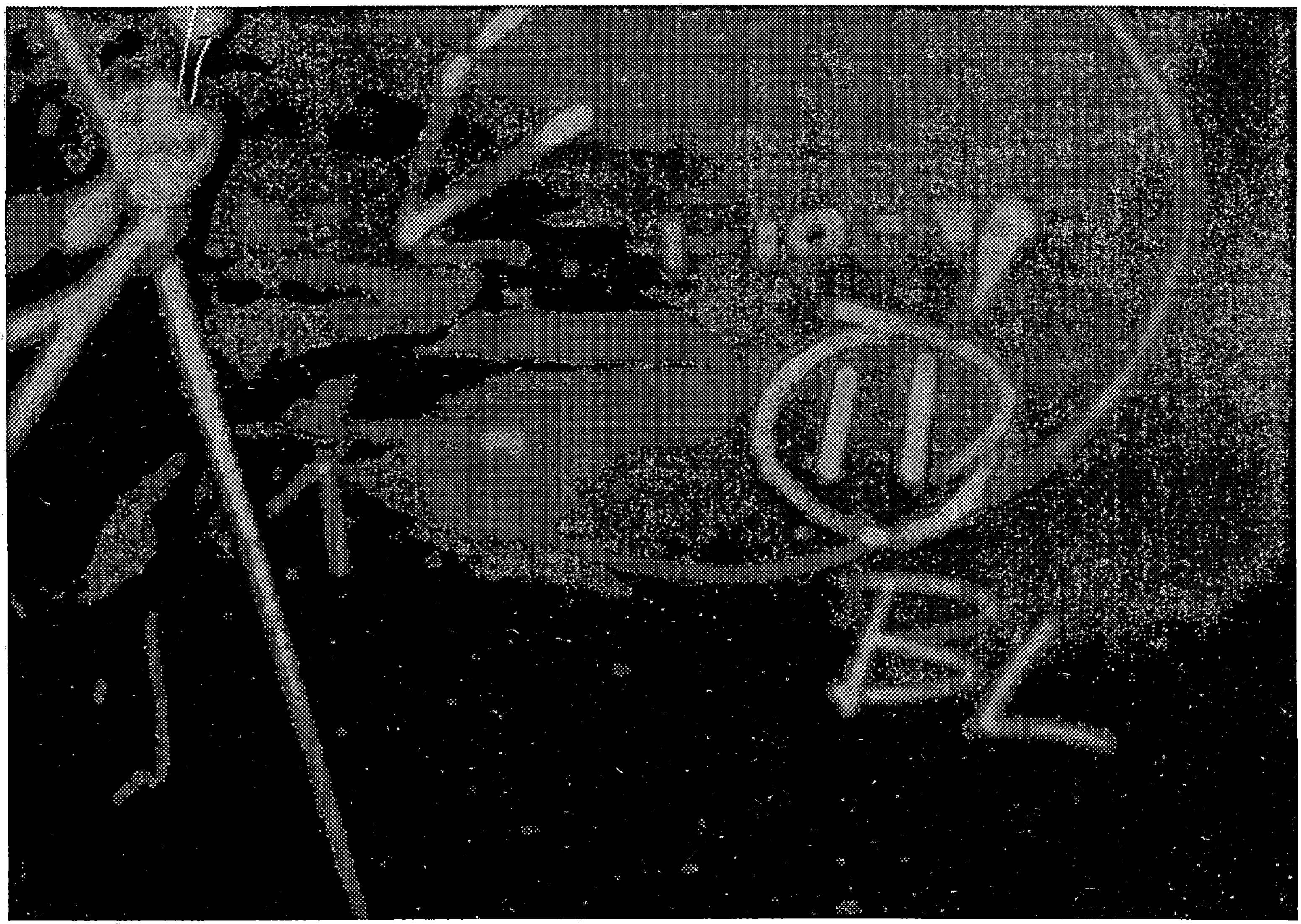


Exhibit 10.4 Photograph of Side Sill Crack on 'B' End Left Side of Test Car.

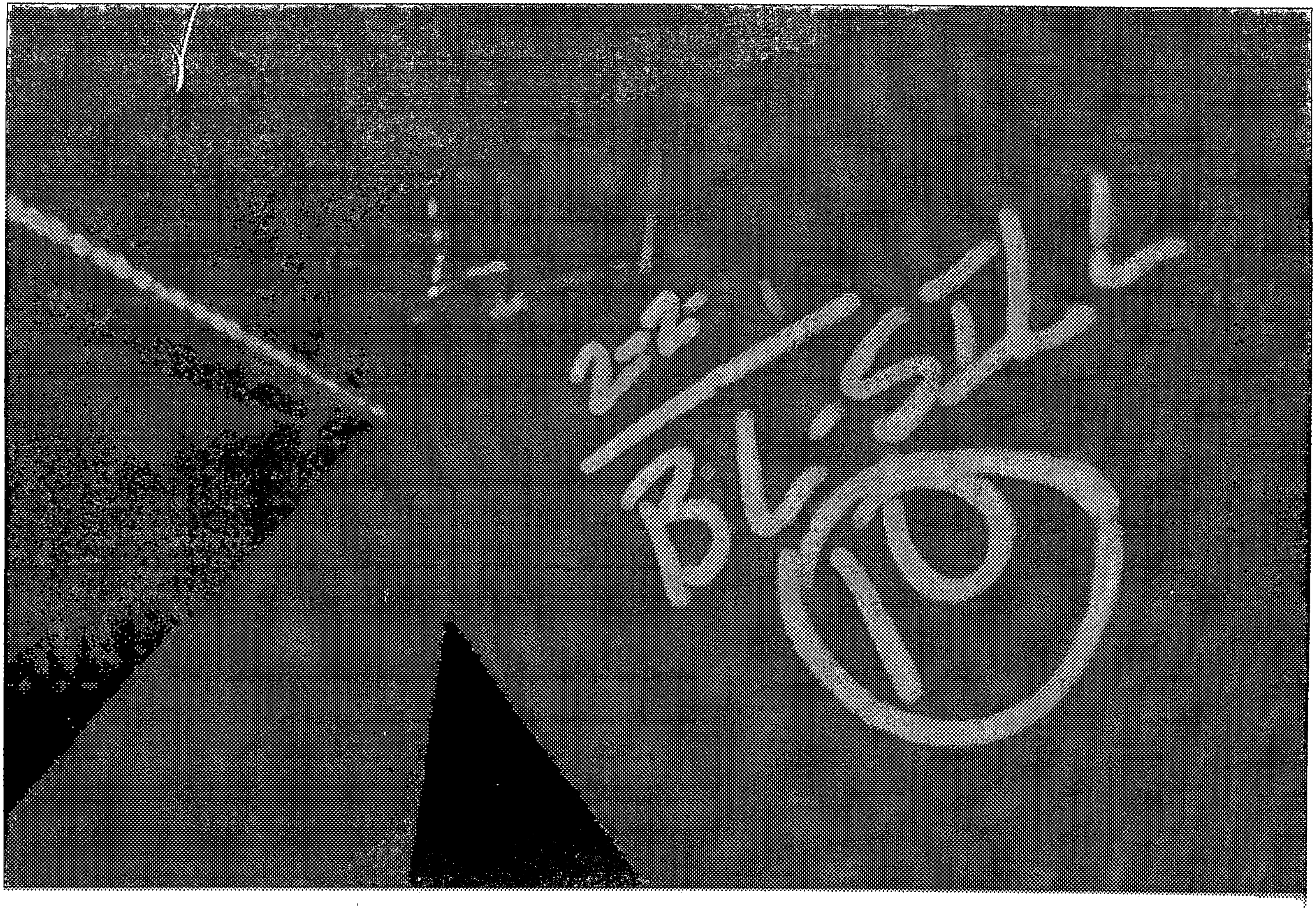


Exhibit 10.5 Photograph of Stub Sill Crack.

10.4.3 Center Plate Cracks

At the conclusion of testing, when the car bodywas removed from the Simuloader, cracking along the welds joining the integral car body center plate to the body bolster was observed at both ends of the car. Exhibit 10.6 shows a photograph of one such crack which extends practically the full length of center plate side.

10.4.4 Other Deformation & Wear

In addition to coupler wear and pin breakage a crack in a coupler knuckle (see Exhibit 10.7) was observed.

Finally, some small deformation or buckling of the shear plate was seen on the A-end of the car near the coupler carrier. This is shown in the photograph of Exhibit 10.8.

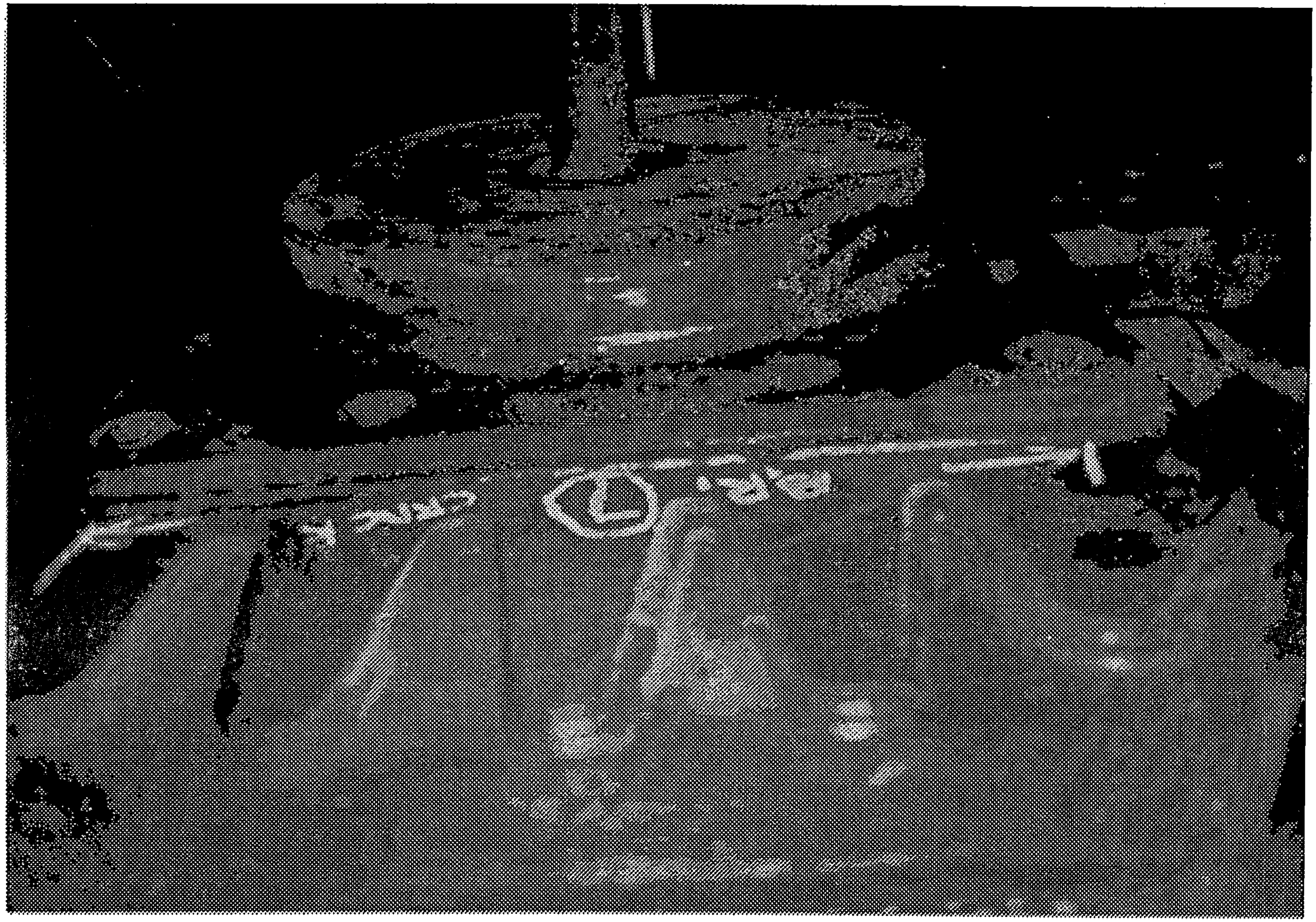


Exhibit 10.6 Photograph of Crack on A-End - Center Plate to Body Bolster Connection.

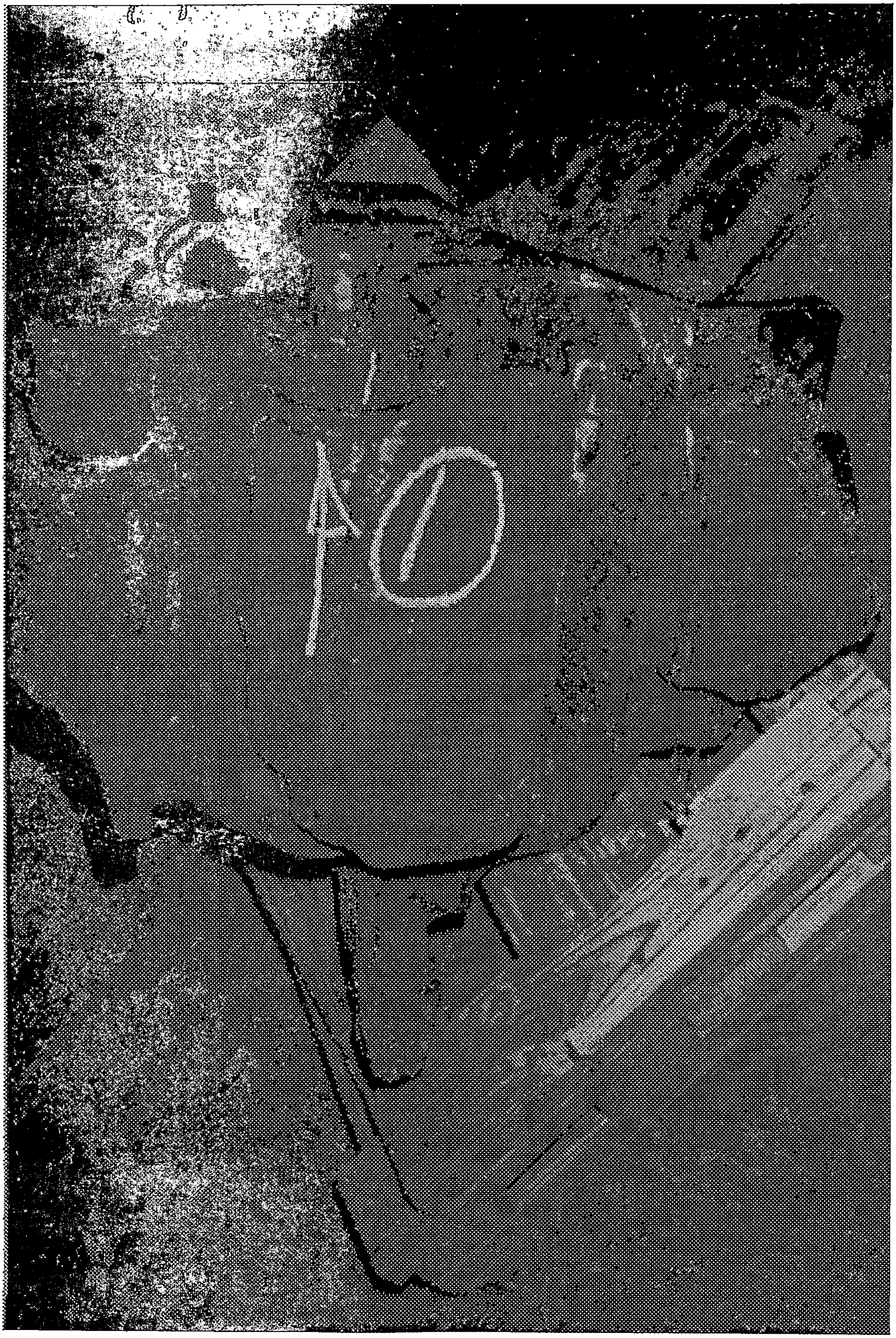


Exhibit 10.7 Photograph of Crack in Coupler Knuckle at A-End of the Test Car.

Exhibit 10.8 Photograph of Shear Plate Deformation Near A-End Coupler Carrier.

11.0 COMPARISONS

Our purpose in this Section is to provide a number of comparisons of the Simuloader responses, and measure of damage, to those observed, recorded or reported in the following:

- AAR road test
- Prior (1982) road tests

Where appropriate, these comparisons will be discussed and illustrated under each of the response made subSections that follow.

11.1 Strains

The reduced data or condensed strain range response for the first 500 seconds of the Simuloader test cycle are plotted in Exhibits 11.1a and b for the side sill gage "S" and Exhibits 11.2a and b for body bolster gage "R". The data plots from the entire test cycle for these gages are provided in Appendices B and C. On each plot both a road test strain range and the corresponding Simuloader response for a test run taken from the first 240 hour test period are superimposed. As discussed in Section 9.0, steps were taken to "enhance" the Simuloader loading after the first 261 hours of testing to more closely simulate the higher strain range peaks observed in road testing. These "enhanced" strain responses are shown in Exhibits 11.1c and d for the side sill gage "S" and Exhibits 11.2c and d for the body bolster gage "R". The entire enhanced test cycles for these gages are also provided in Appendices R and S.

COMPARISON OF STRAIN RANGES FOR GAGE 'S'

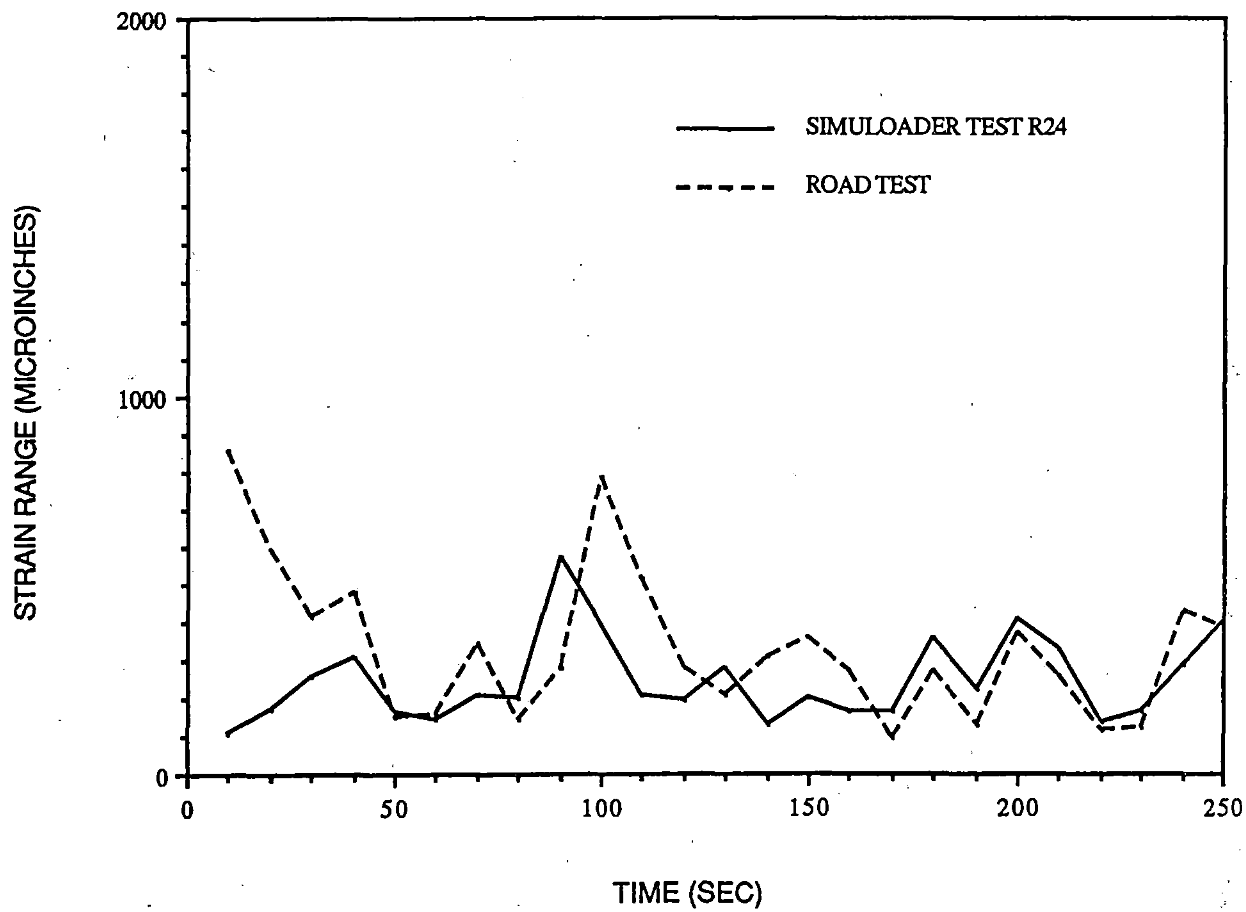


Exhibit 11.1A Comparison of Road Test Data vs. Simuloader Test for Gage 'S'; t = 0 to 250 Sec.

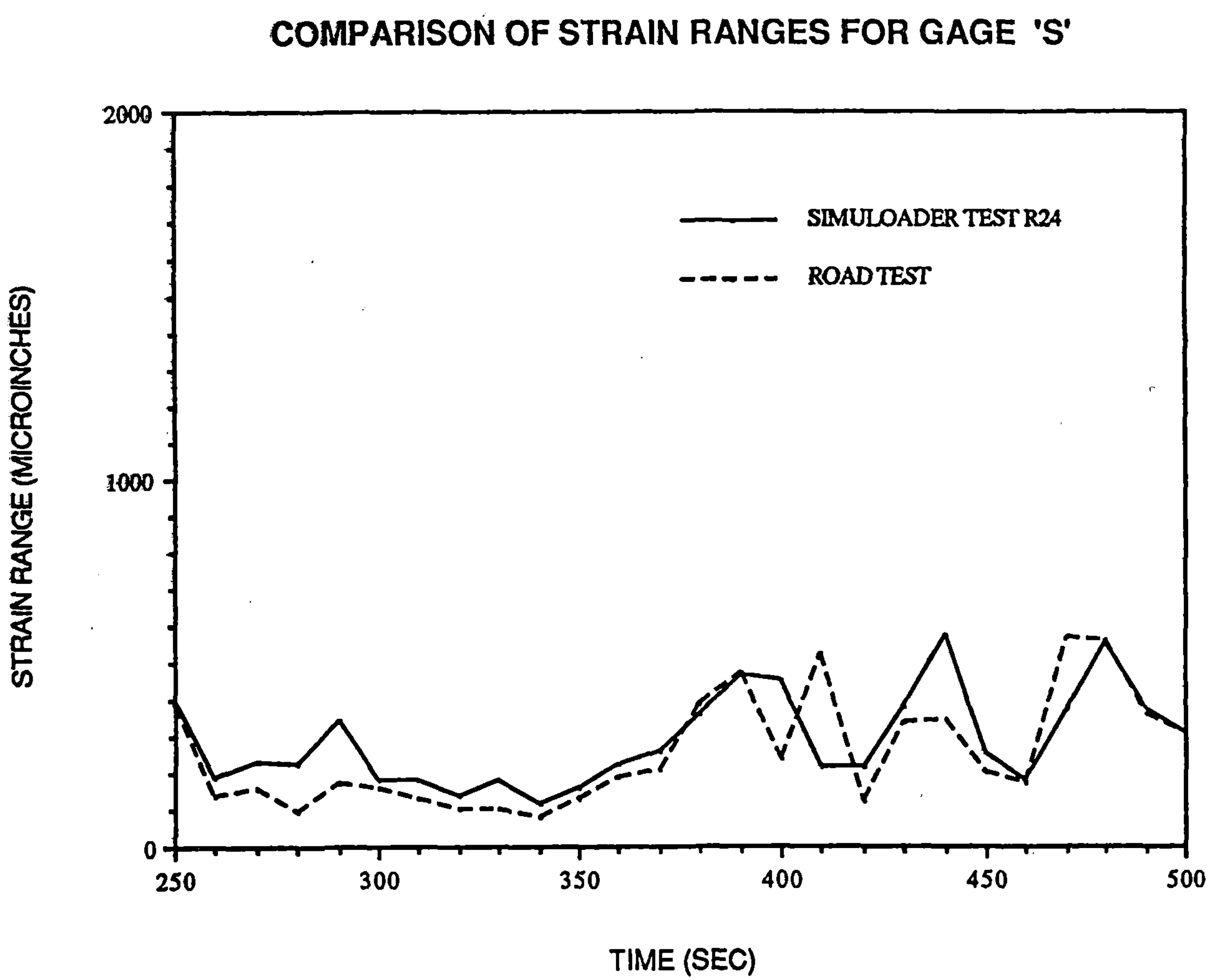


Exhibit 11.1B Comparison of Road Test Data vs. Simuloader Test for Gage 'S'; t = 250 to 500 Sec.

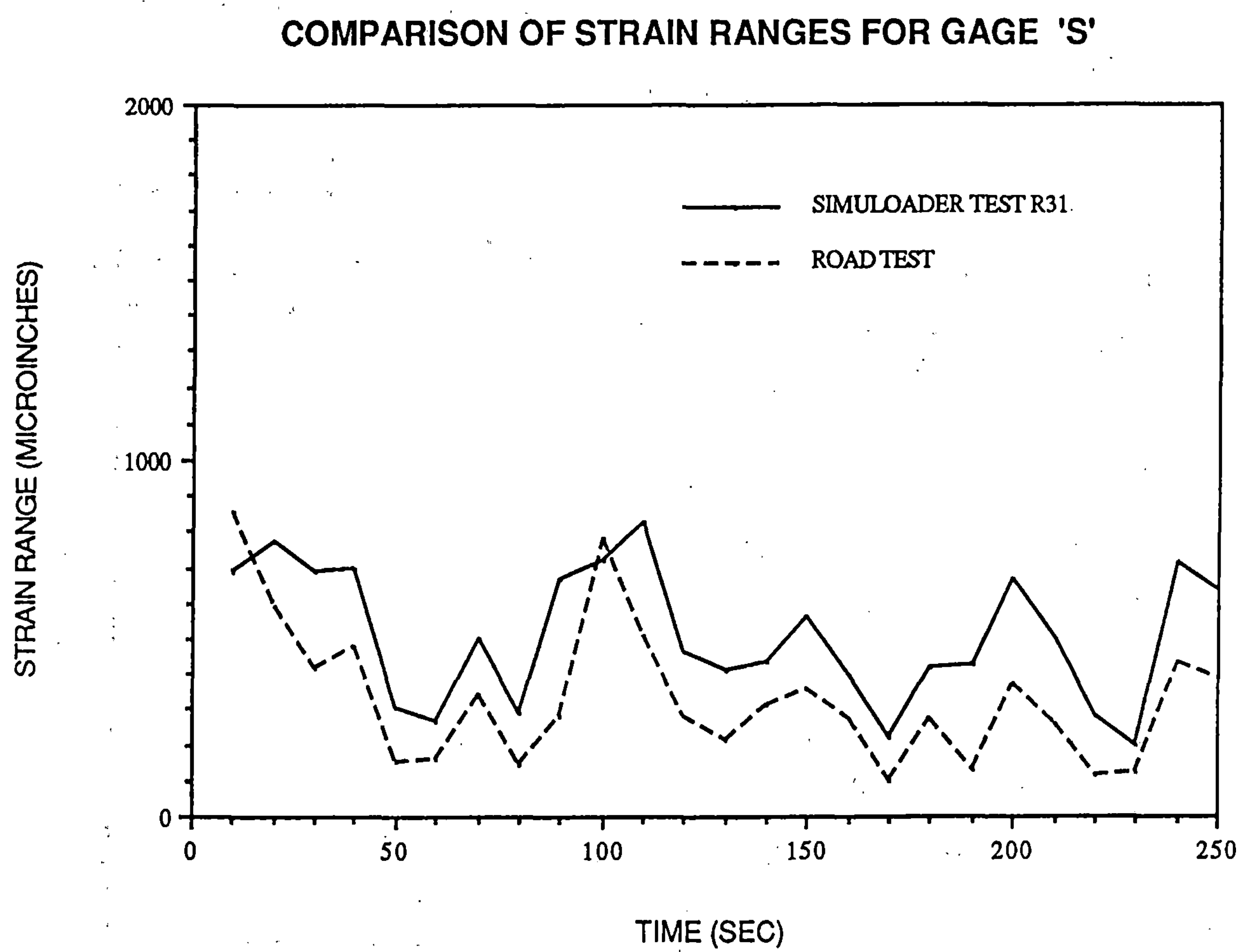


Exhibit 11.1C Comparison of Road Test Data vs. Enhanced Simuloader Test for Gage 'S'; t = 0 to 250 Sec.

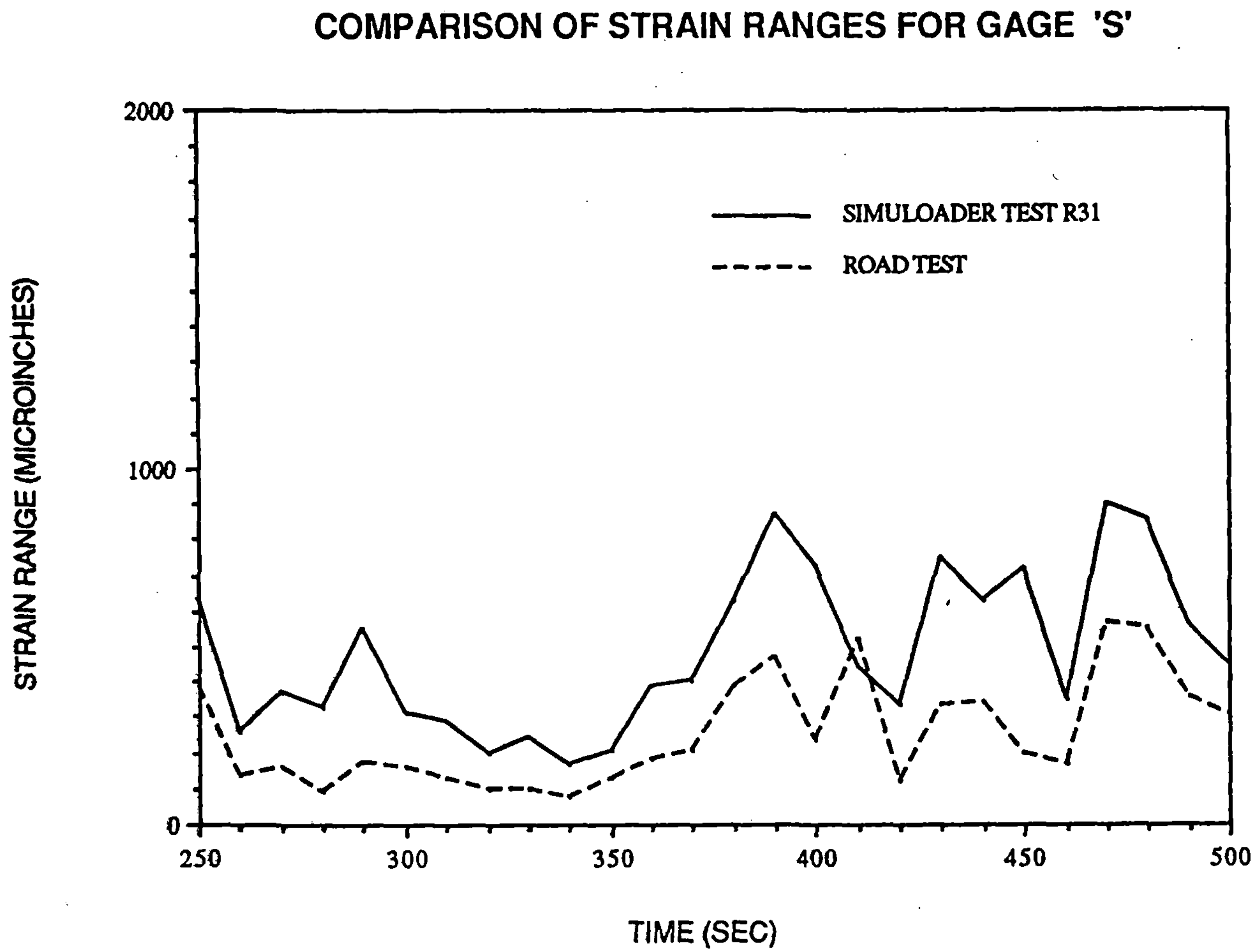


Exhibit 11.1D Comparison of Road Test Data vs. Enhanced Simuloader Test for Gage 'S'; t = 250 to 500 Sec.

COMPARISON OF STRAIN RANGES FOR GAGE 'R'

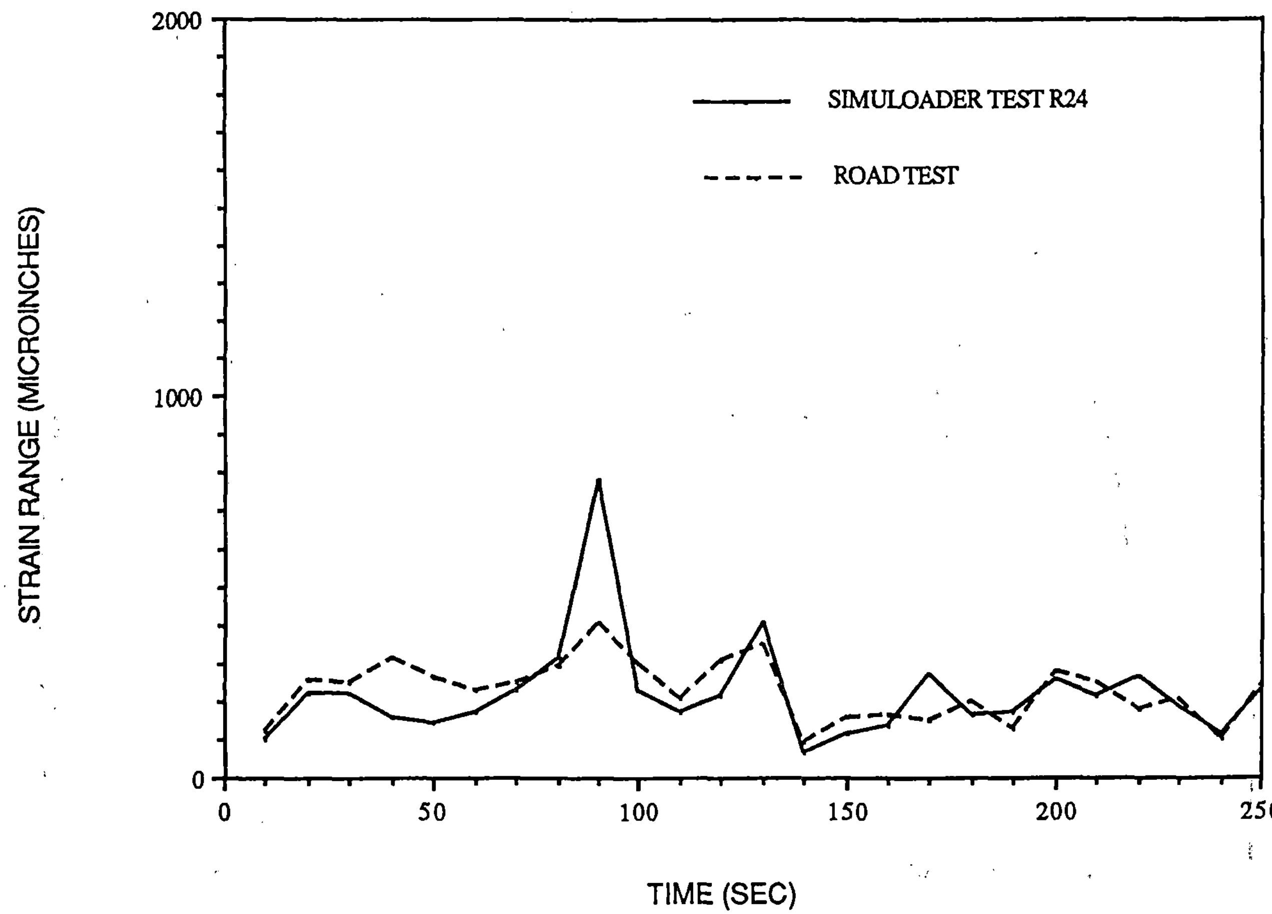


Exhibit 11.2A Comparison of Road Test Data vs. Simuloader Test for Gage 'R'; t = 0 to 250 Sec.

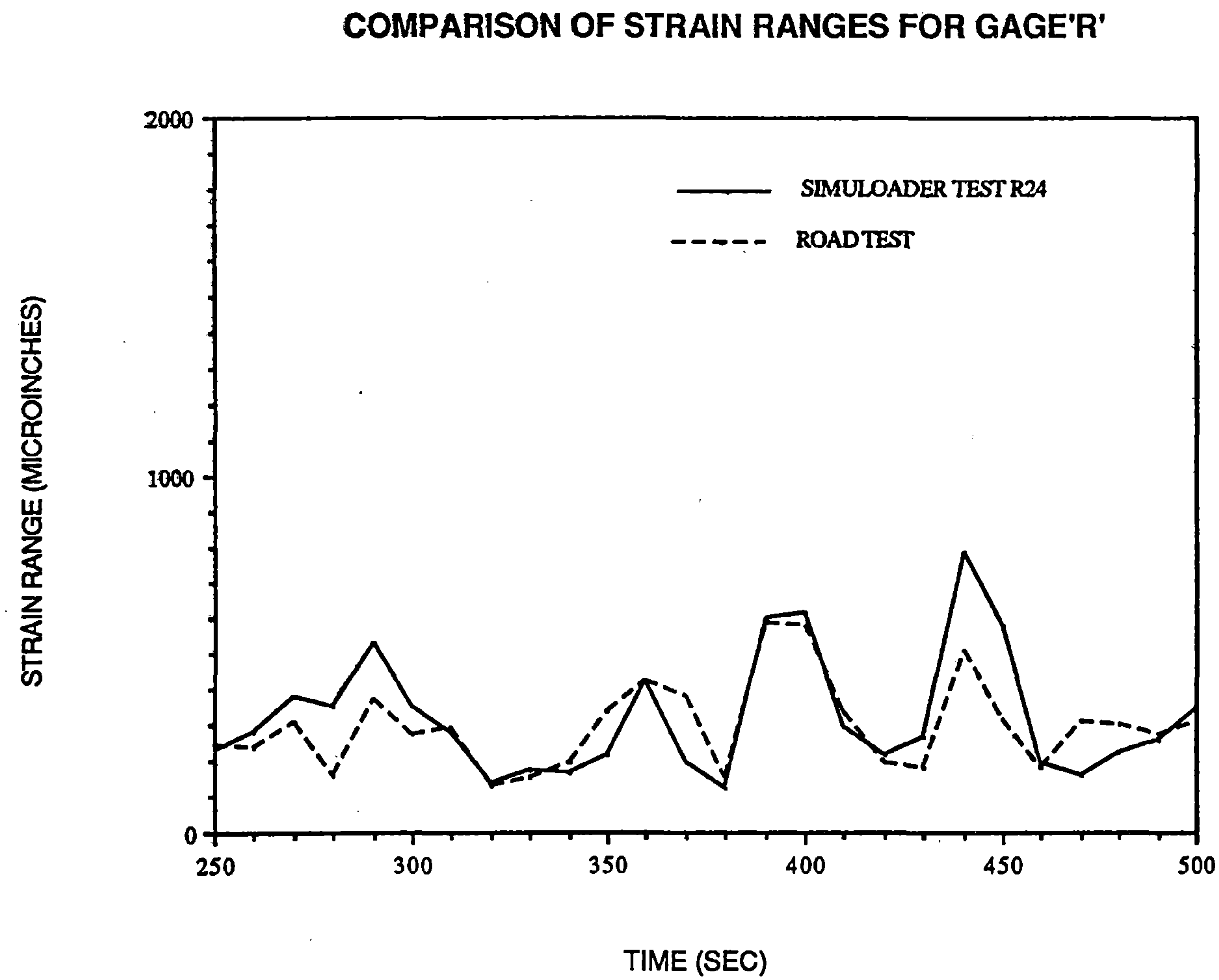


Exhibit 11.2B Comparison of Road Test Data vs. Simuloader Test for Gage 'R'; t = 250 to 500 Sec.

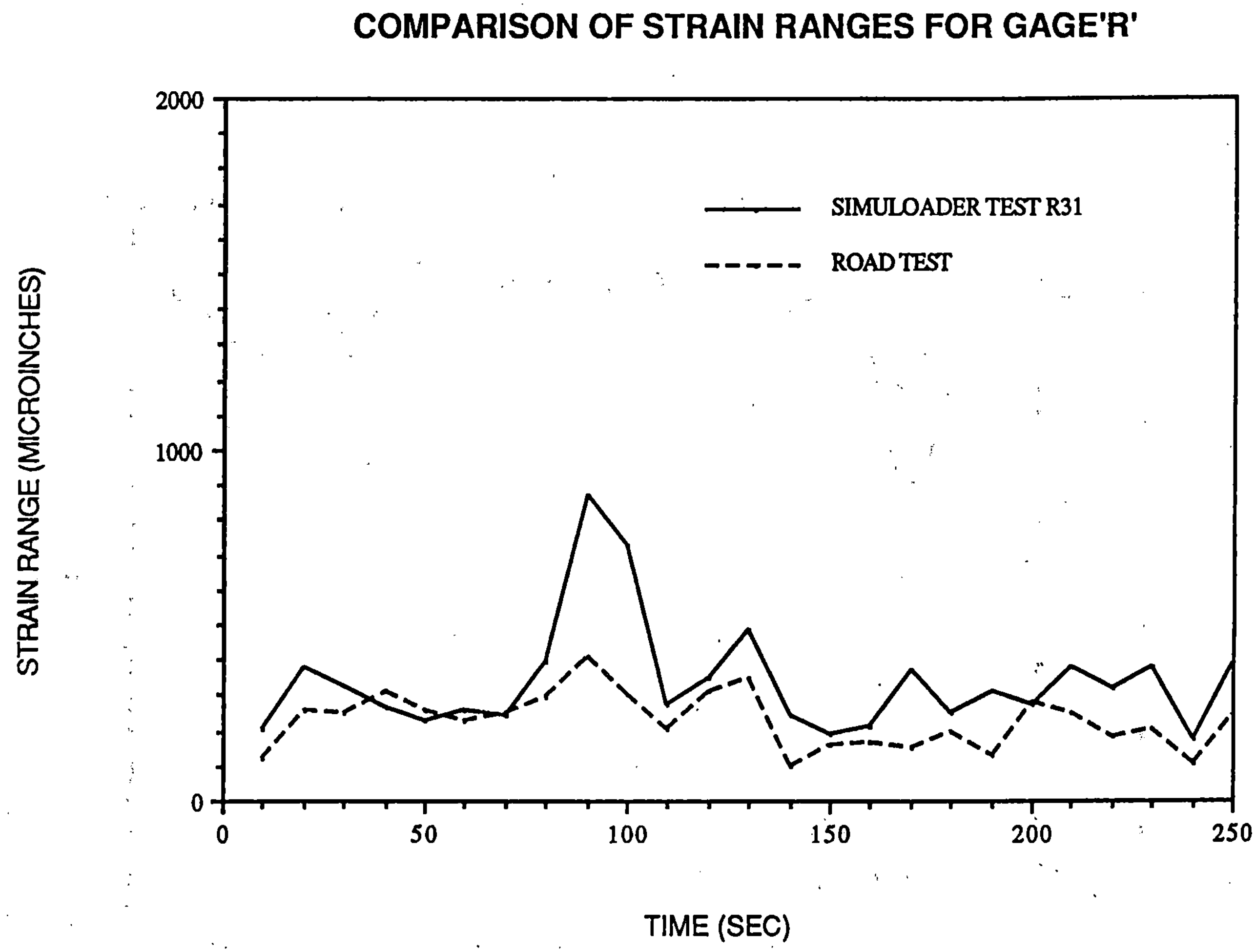


Exhibit 11.2C Comparison of Road Test Data vs. Enhanced Simuloader Test for Gage 'R'; t = 0 to 250 Sec.

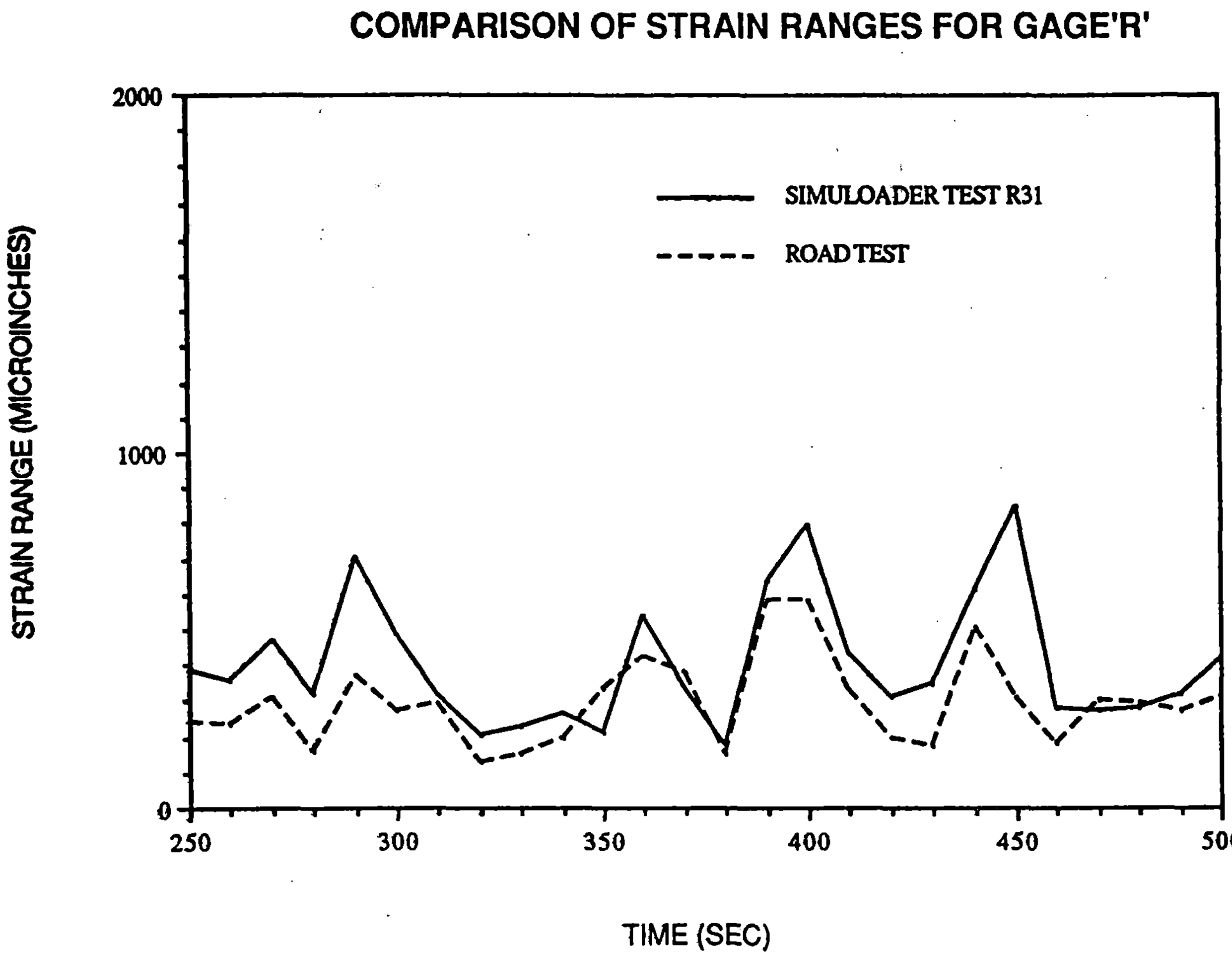


Exhibit 11.2D Comparison of Road Test Data vs. Enhanced Simuloader Test for Gage 'R'; t = 250 to 500 Sec.

A direct comparison of these strain ranges to those reported from the 1982 service tests is not possible since the strain gage locations are not identical. Nevertheless, some appreciation of the relative severity of the structural strain response from the original road tests and our subsequent tests, may be gained by reference to strain range histograms selected from a portion of the original service route. Accordingly two histograms selected from this early study are represented in Exhibit 11.3 for a gage ("H") similar to our gage "S" and Exhibit 11.4 for a gage similar to our gage "R". It is evident that strains (of magnitude 2400 microinches) were much higher in the early study of 1982.

11.2 <u>Coupler Loads</u>

In a manner similar to the strain transducer presentation in the last subSection, the coupler load range history for the first 500 seconds of the test cycle is shown in Exhibit 11.5a and b. The comparable data after load enhancement are shown in Exhibits 11.5c and d. Again, a comparison of the coupler load range data from the road test and that enforced on the Simuloader is provided on each plot. The entire coupler load history for the test cycle is provided in Appendix C. Exhibit 11.6 shows coupler load histograms for 1982 road tests (done by others) and our road test of 1988.

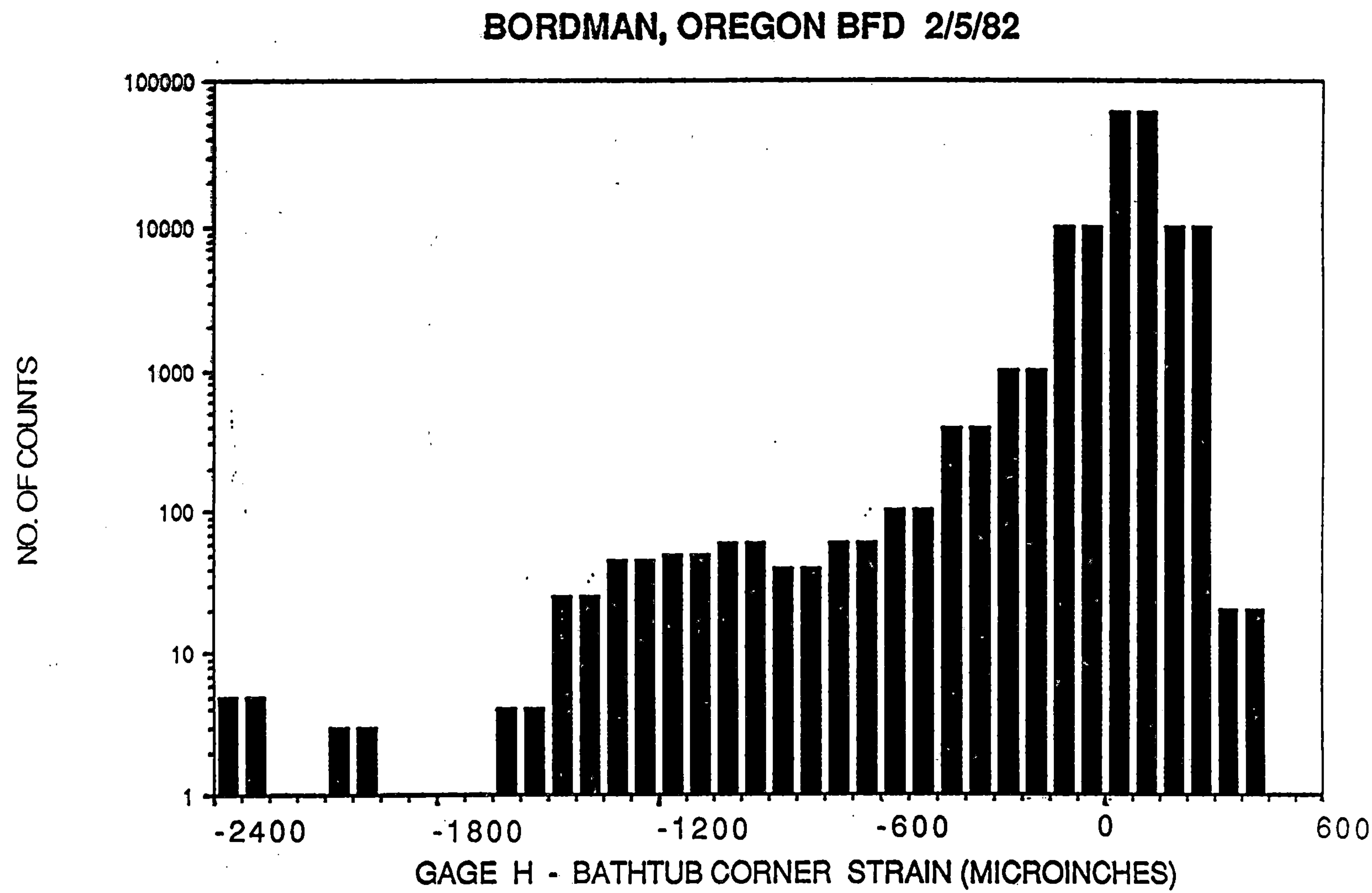


Exhibit 11.3 Histogram of Strains at Gage Similar to 'S' from 1982 Road Test.

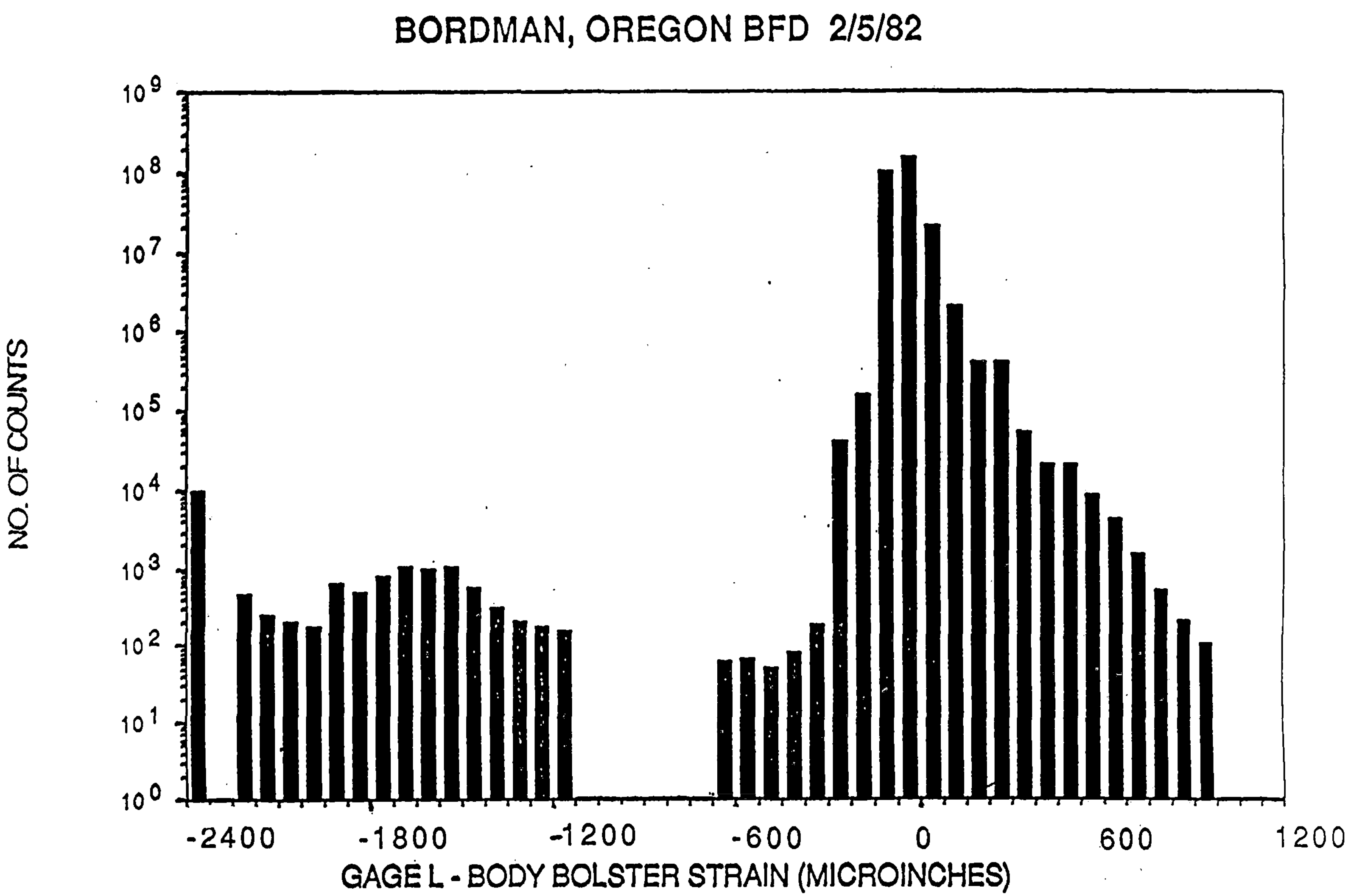


Exhibit 11.4 Histogram of Strains at Gage Similar to 'R' from 1982 Road Test.

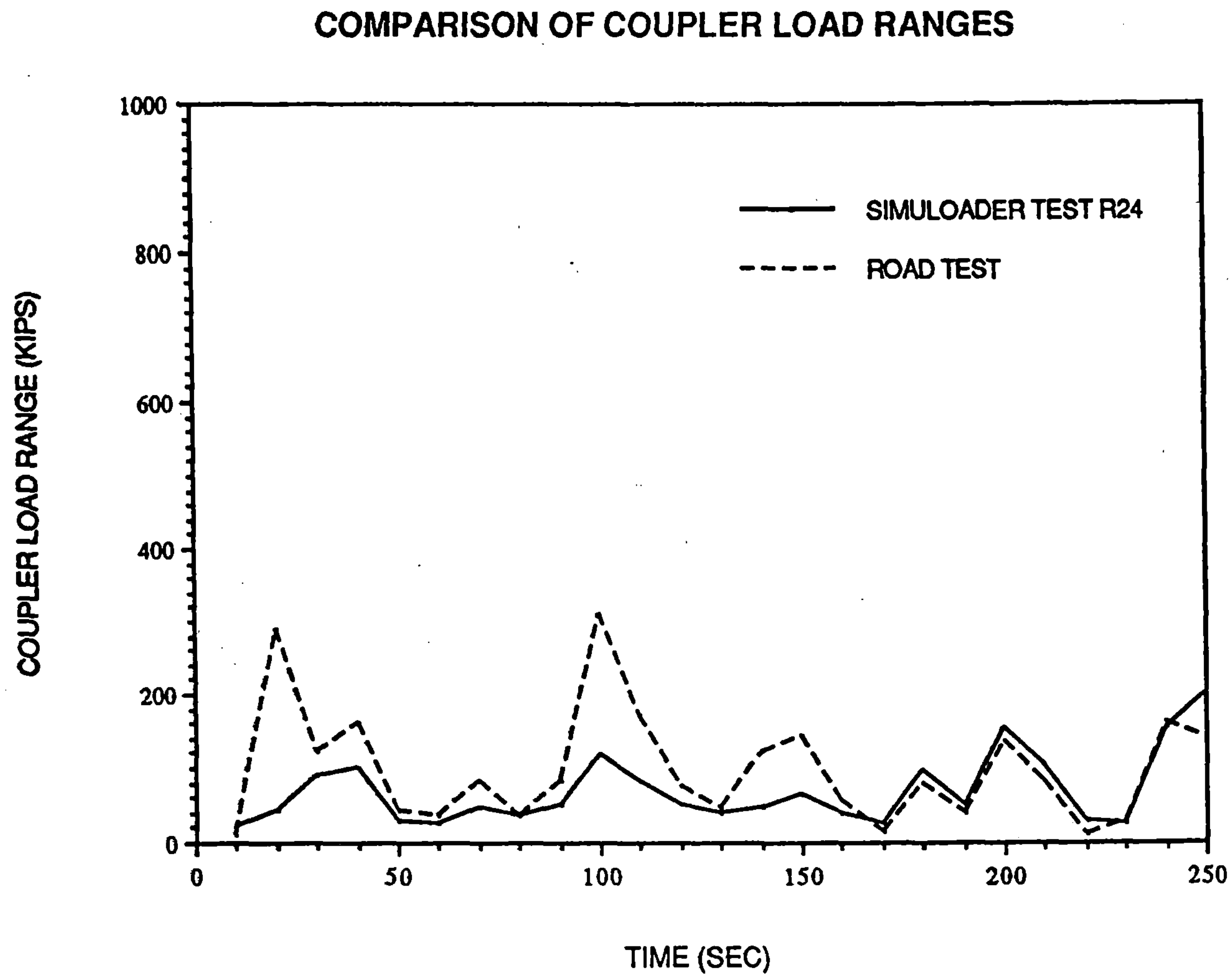


Exhibit 11.5A Comparison of Coupler Loads - Road Test Data vs. Simuloader Test; t = 0 to 250 Sec.

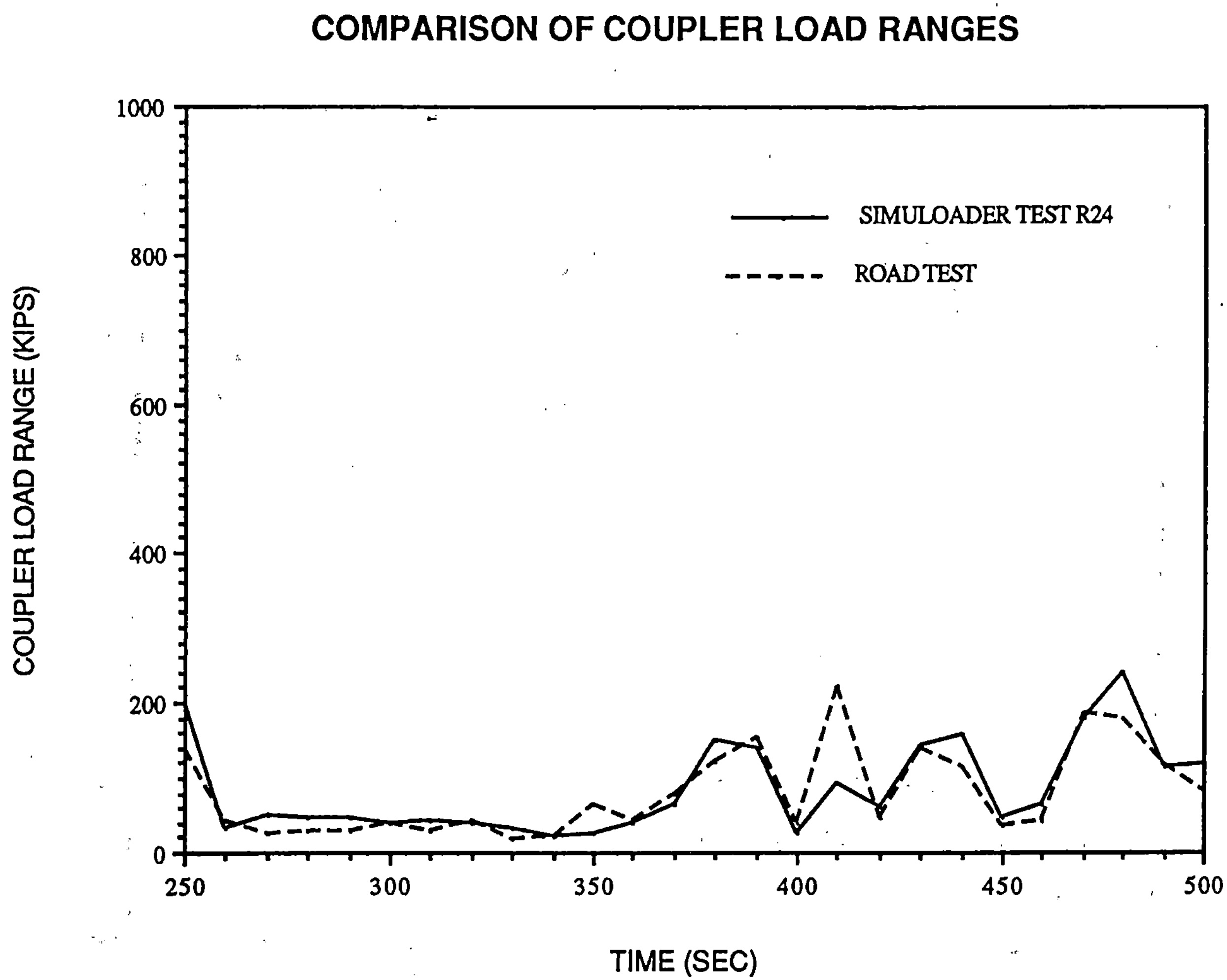


Exhibit 11.5B Comparison of Coupler Loads - Road Test Data vs. Simuloader Test; t = 250 to 500 Sec.

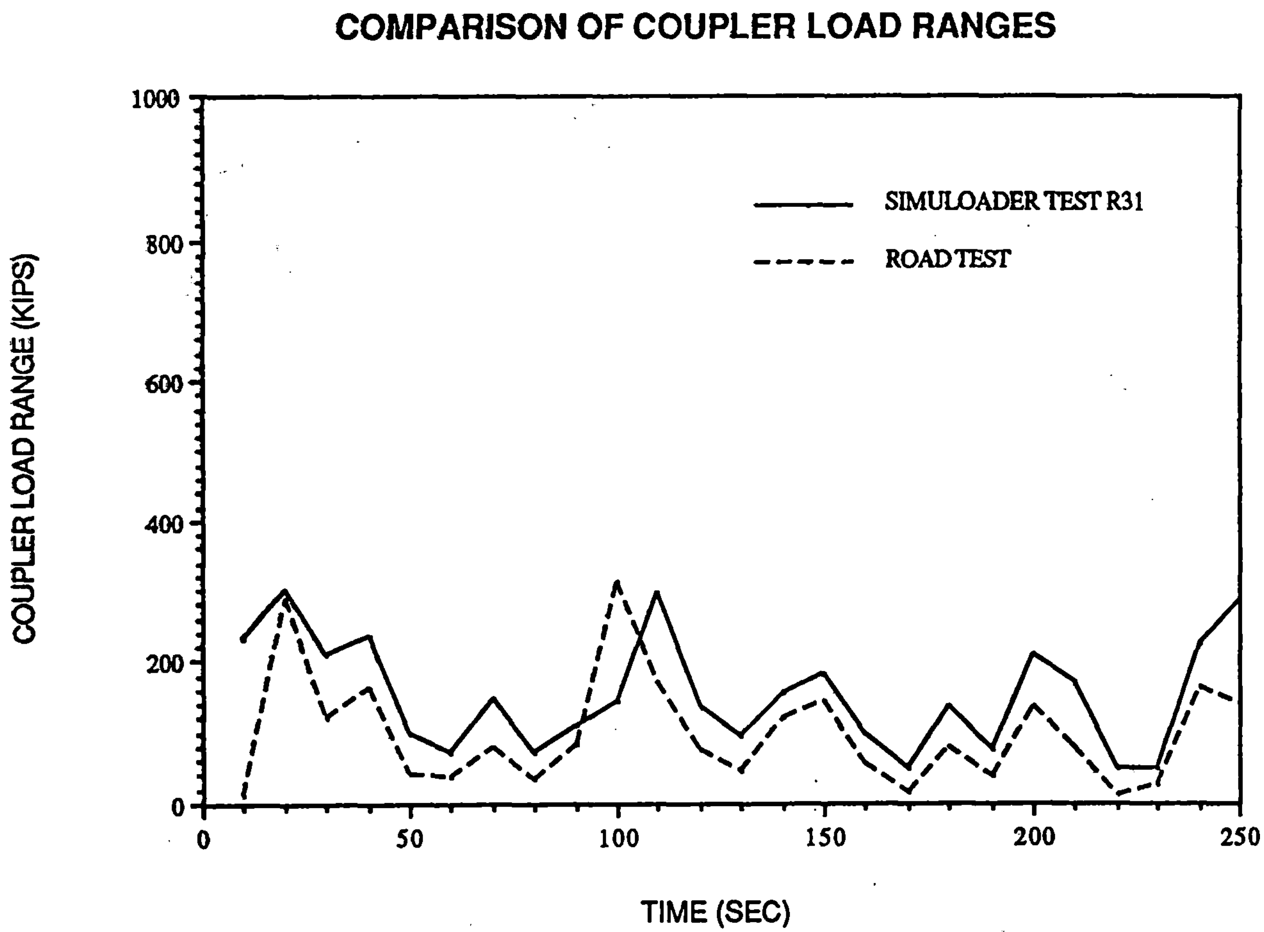


Exhibit 11.5C Comparison of Coupler Loads - Road Test Data vs. Enhanced Simuloader Test; t = 0 to 250 Sec.

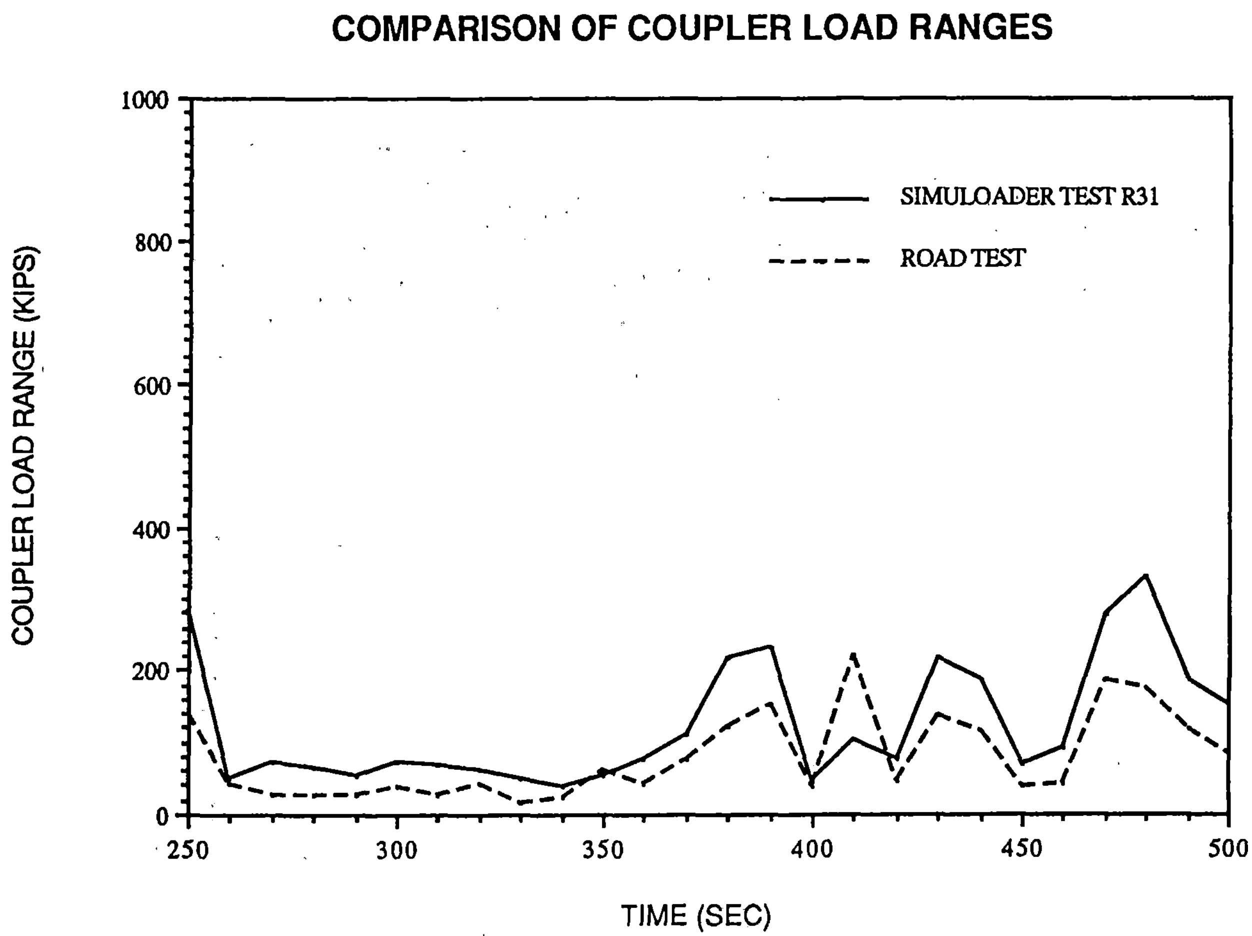
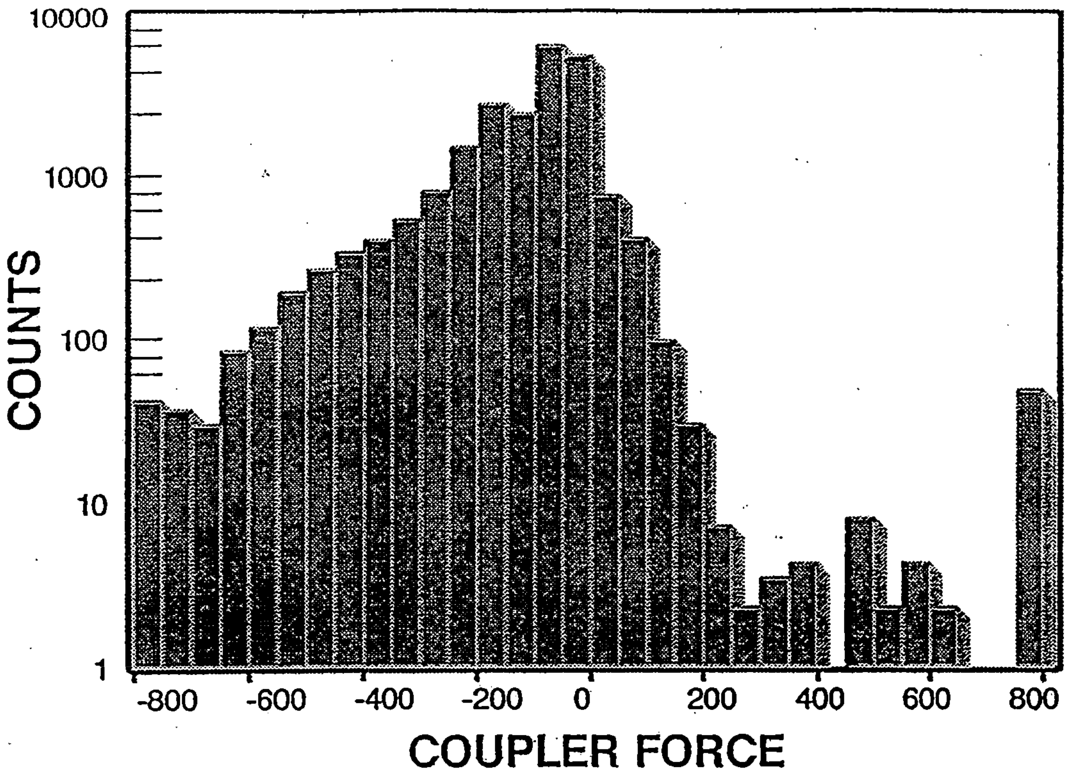


Exhibit 11.5D Comparison of Coupler Loads - Road Test Data vs. Enhanced Simuloader Test; t = 250 to 500 Sec.

[redacted]

COUPLER LOAD ENVIRONMENT

1982



1988

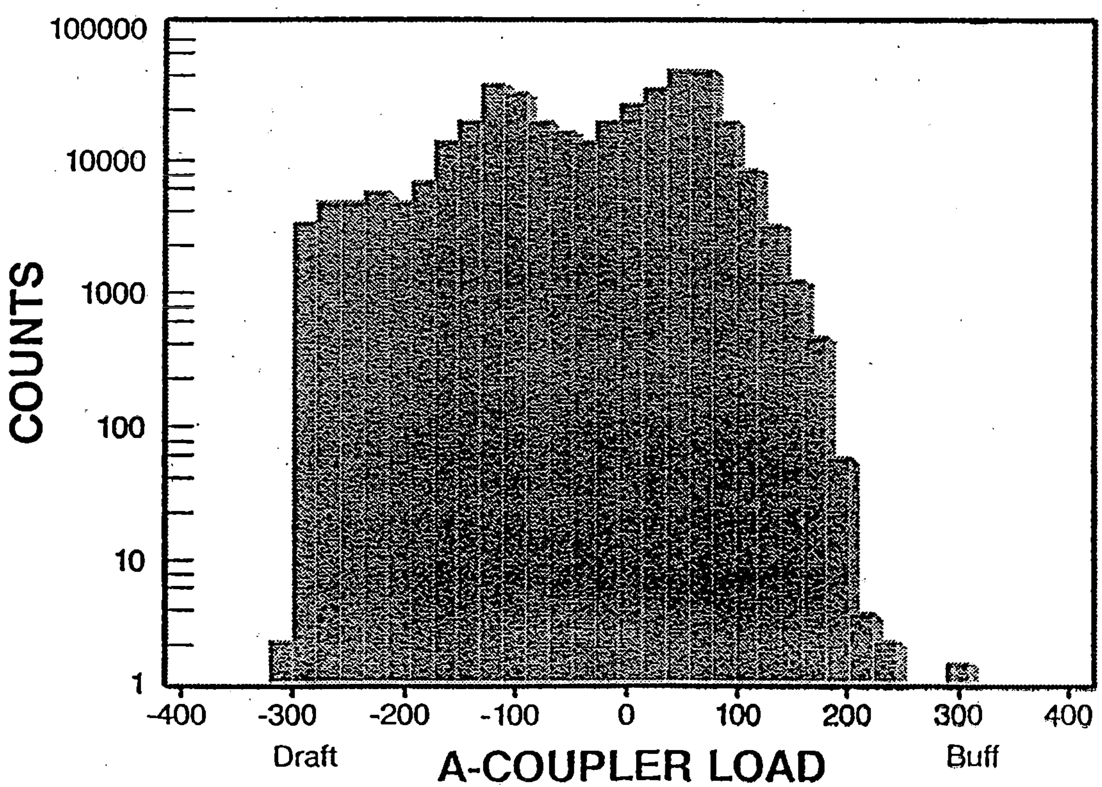


Exhibit 11.6 Coupler Load Range Histograms for 1982 and 1988 Road Tests.

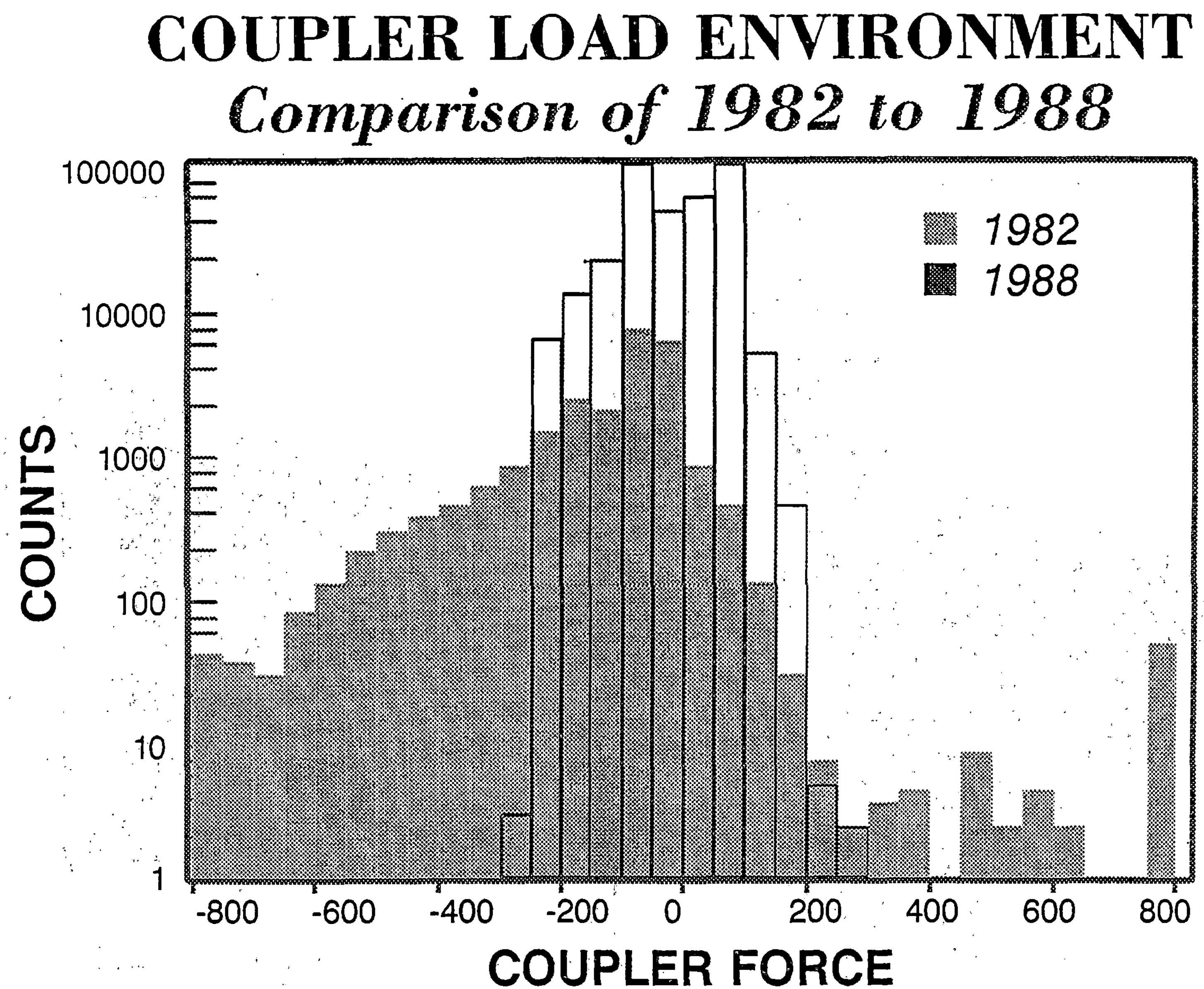


Exhibit 11.7 Comparison of Coupler Loads - 1982 Road Test vs. 1988 Road Test.

A comparison of coupler load counts during our road tests of 1988 to the early (1982) road tests is made possible by the superposition of selected load histograms in Exhibit 11.7. Note that the old coupler load histogram contains many more high loads than our road test.

11.3 Differences in Train Operations

As noted in the above subSections the strain ranges and coupler loads appear to be more severe for the original 1982 service road tests than for our subsequent road test of 1988 and Simuloader tests. The principal difference appears to be due to the more severe longitudinal train action experienced in original service.

A review of operational history revealed that the original practice was to use head end power only on the car coal trains. In the most mountainous regions these 110 car trains were broken into two Sections and again pulled with head end power. Current practice, followed in our road test, involved distributed locomotive power of head, center and rear of the train. This apparently resulted in significantly less severe and fewer instances of slack run-in and run-out during the loaded car moves. Since this stub sill car structure is particularly sensitive to coupler loading it follows that some of the car body strains, such as those at the side sill juncture location "S", are much larger in the original service. Hence one would expect the lack of cracking in the Simuloader test relative to original service.

11.4 Fatigue Damage Assessment

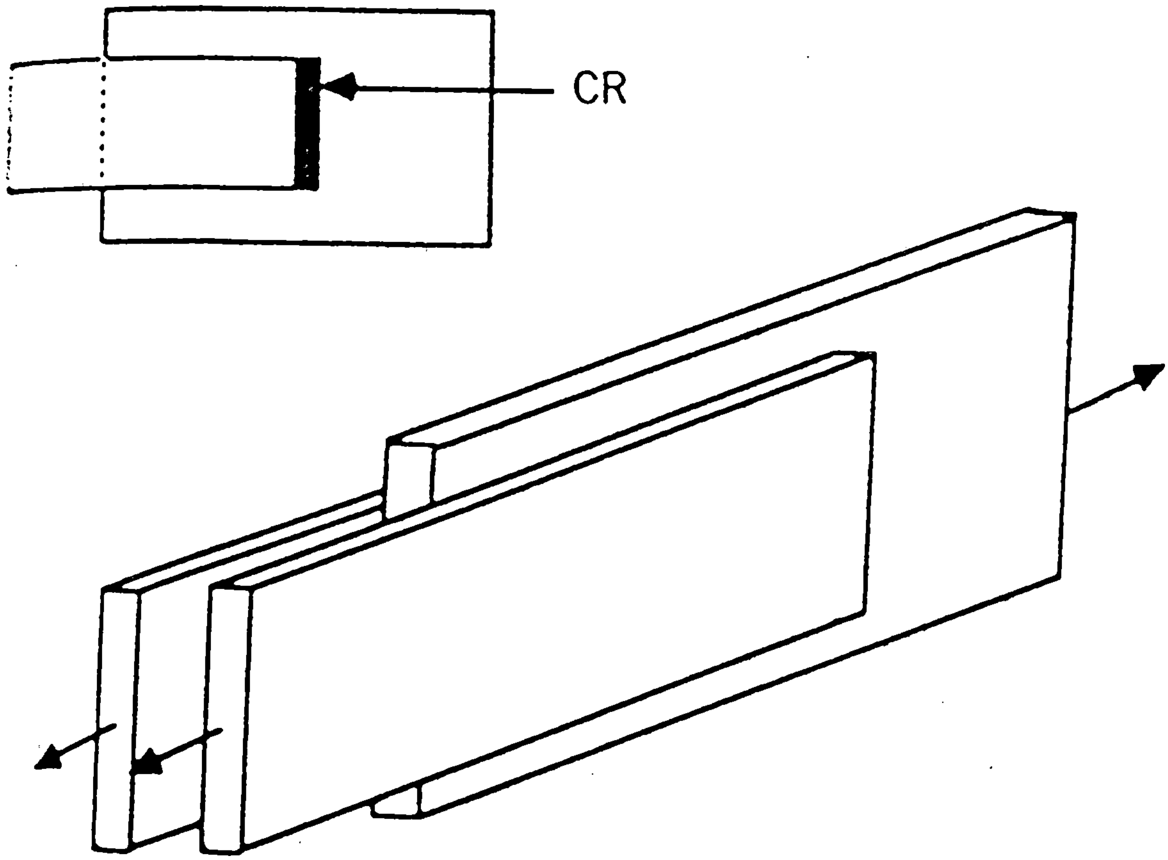
The expectation of cracking must be based, of course, on a fatigue damage assessment or life prediction and not simply on peak strain or load range observed. In order to compare the relative fatigue damage environment in the original 1982 road test to the 1988 Simuloader or road test an analysis method such as that described in Chapter VII, "Fatigue Design of New Freight Cars" document M-1001 will be employed for a particular car structure location. Since the difference in coupler load history is likely to be the reason for little cracking observed in the Simuloader test and side sill gage "S" is the most sensitive to coupler load, we will illustrate the fatigue damage assessment for that area of the car structure.

For such a fatigue assessment we need: (1) a REPOS or histogram of coupler load ranges; (2) a relation between coupler load and nominal stress in the regime of interest and (3) a modified Goodman Diagram (MGD) for a similar structural detail.

The coupler load range histograms for the 1982 and 1988 road tests are shown in Exhibit 11.6. A listing of these histogram ranges is also provided in Exhibit 11.7.

The relation between coupler load and nominal stress can be estimated based on the experimental ratio of gage "S" strain to coupler load obtained from transducer histories such as those presented in Exhibits 6.1 through 6.4. From this the ratio would be 1.0 microinches or in terms of nominal stress about 3.0 KSI per 100 KIPS of coupler load.

Now the appropriate level of stress to use also depends on the load structural detail. Let us assume a detail such as that shown schematically in Exhibit 11.8.



4.2.2 - LAP WELDED JOINT - WITH TRANSVERSE WELD ONLY (AXIAL LOAD)

Exhibit 11.8 Schematic of the Connection Detail - Lap Joint with Transverse Weld.

The strain gage was on the side sill oriented in the vertical direction, perpendicular to the crack direction along the weld to the tub sheet. The nominal stress in the tub sheet may have been a factor of 1.5 higher than the vertical stress in one wall of the side sill. Therefore, for purposes of a parametric study we will assume a stress to coupler load ratio maximum of 6.0 KSI/100 KIPS.

The MGD detail that may be most appropriate is the lap joint with transverse weld shown in Exhibit 11.8. The associated fatigue properties are then taken from the detail 4.2.2 of the AAR Fatigue Design Manual as

b = 11 KSI at 2 million cycles

k = 0.18

Note that these values are assumed to be the same for 50 and 100 KSI yield steels.

A tabulation of the fatigue crack initiation lives based on these assumptions is presented in Exhibit 11.9.

It is apparent from this table that much shorter fatigue lives are predicted for the 1982 road tests than the 1988 road test or 1988 condensed Simuloader test. We further note with satisfaction that comparable lives are predicted for the 1988 road environment and the Simuloader condensed environment. Finally, we can understand why more cracking wasn't observed in our Simuloader tests.

Fatigue Life Estimates

Load environment	Fatigue Life (miles)
1982, Coupler Loads	218,000
1988, Coupler Loads	Infinite
Simuloader Run #24	36 Million
Simuloader Run #31	7.6 Million
Simuloader Run #39	7.2 Milion

Exhibit 11.9 Estimates of Fatigue Crack Initiation Lives.

12.0 CONCLUSIONS AND RECOMMENDATIONS

As a preface to our overall conclusions and recommendations, it may be appropriate to recall our principal test objective. That objective was to reinforce and demonstrate the utility of the Simuloader for full scale freight car fatigue testing in order to provide a capable and efficient facility for verification of operational safety and structural integrity of various car designs. As a result of our testing and analysis described in this report the following conclusions and recommendations relative to this objective are made:

12.1 Conclusions

1. The modified and reinforced Simuloader facility is now capable of full scale freight car fatigue testing based on this demonstration test of the "bathtub" coal car.
2. A methodology for recording and representing in a condensed time test cycle, a specific route vertical and longitudinal load history was developed and demonstrated.
3. The Simuloader has been demonstrated to be capable of "enhancing" or increasing these road environment load levels in order to accelerate structural fatigue processes.
4. A comparative analysis of road and Simuloader tests is possible and was made in terms of reduced strain and load range histories as well as fatigue

damage accumulation predictions.

5. Some fatigue cracking was induced during the Simuloader testing. Although the extent and severity of this cracking and its appearance on the restored A-end of the test car was not as great as expected based on original service reports, an explanation of this, in terms of the greater severity of coupler loading in original train operation was advanced.

6. It should be recognized that a successful Simuloader test cycle must be developed on the basis of both route and train operation specific information.

12.2 Recommendations

In recognition of some of the limitations of the Simuloader and future uses of this facility and methodology, the following recommendations are made.

1. Center plate load is an important mode of loading input to a car body, therefore some provision for measuring center plate loads should be added to the Simuloader system.

2. A direct means of measuring coupler load at both ends of the car on the Simuloader is desirable.

3. There are limitations in the treatment of abrupt discontinuities in vertical loading on the Simuloader. This is due to the current method of accelerations data reduction of the LTHD recording

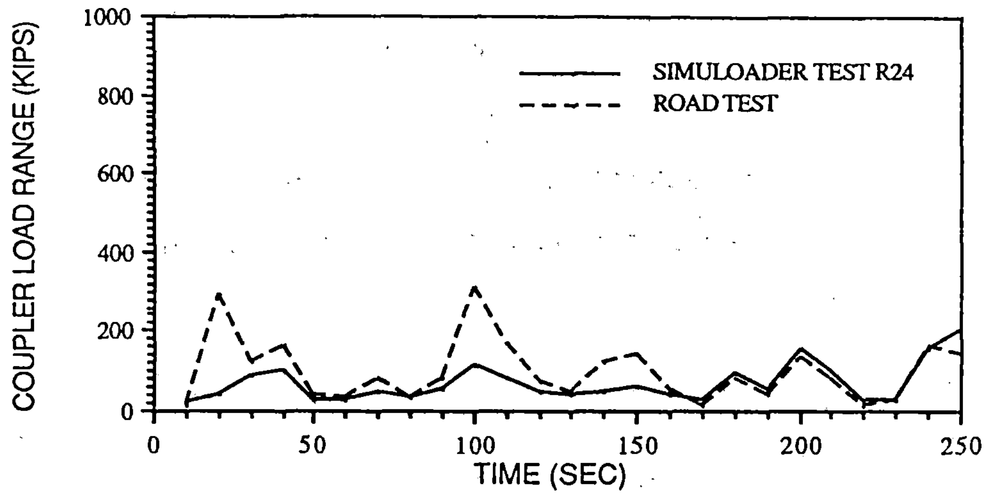
devices on the truck bolster. Alternate methods of LTHD data reduction should be explored.

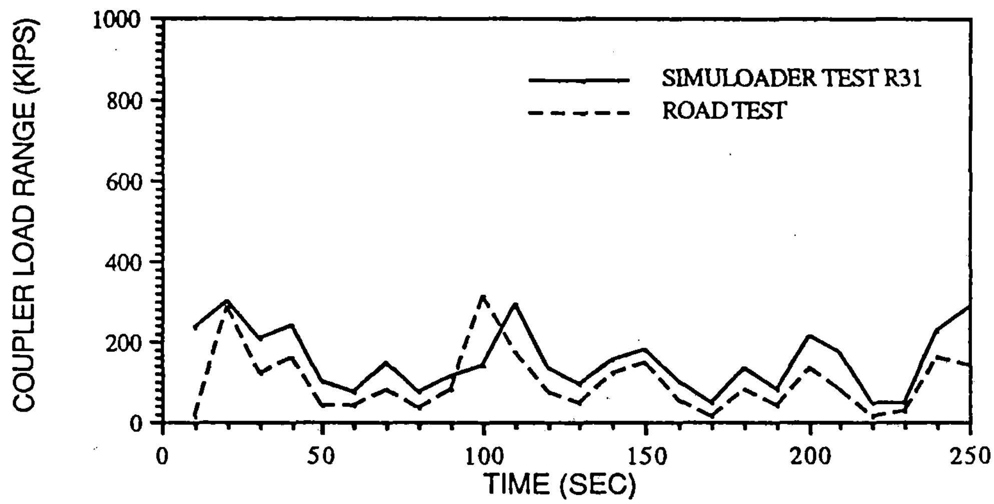
4. The existence of coupler slack in the Simuloader test interferes with the full simulation of high peak coupler loads. Therefore, an improved means of eliminating as much slack as possible in the Simuloader test car is needed.

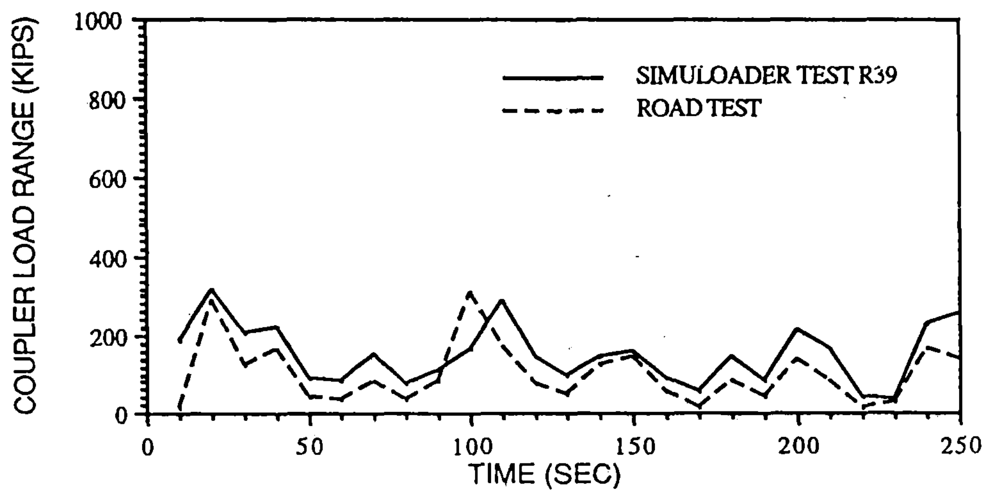
APPENDIX A

COMPARISON OF COUPLER LOAD RANGE HISTORY FROM SIMULOADER AND ROAD TESTS

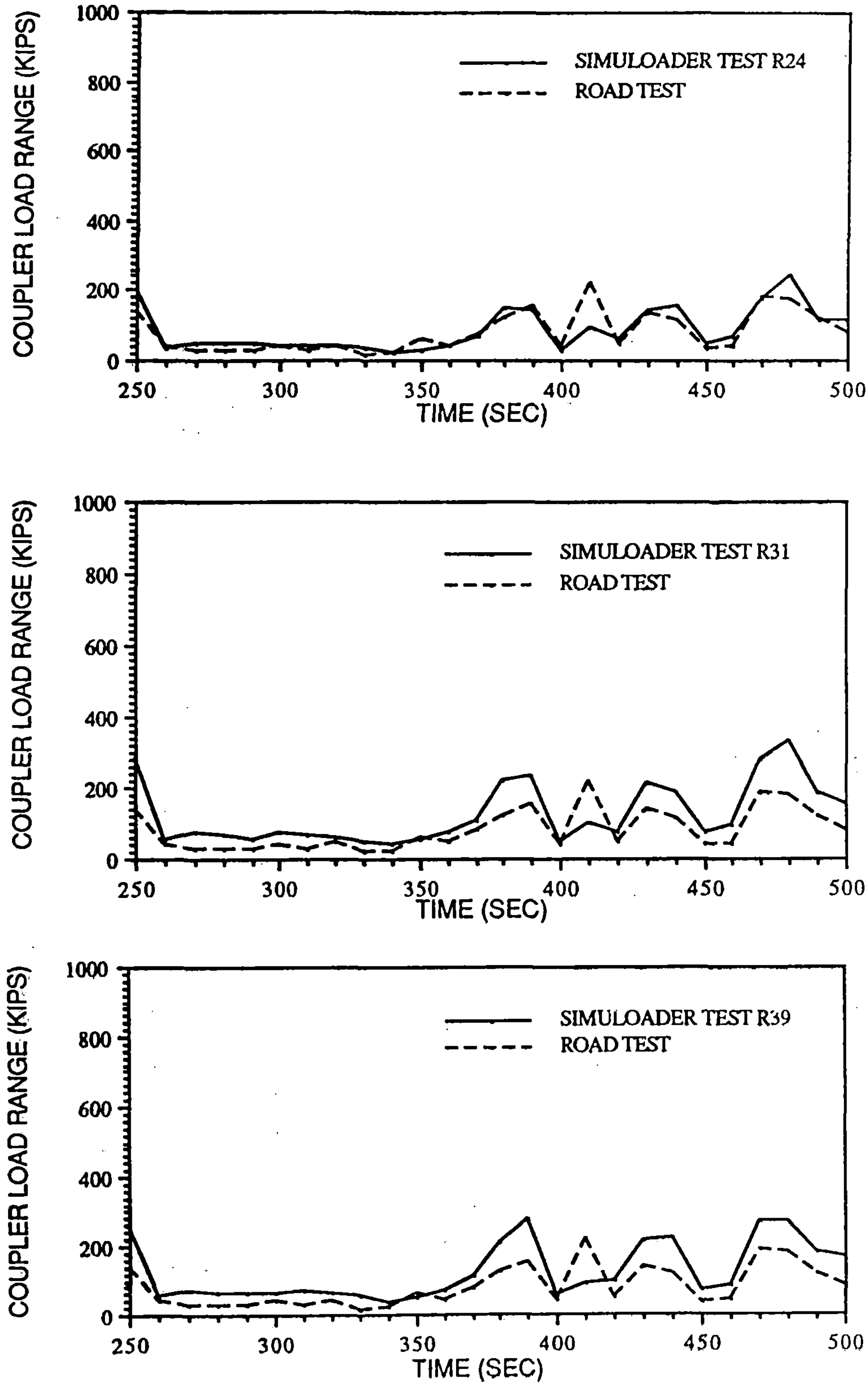
COMPARISON OF COUPLER LOAD RANGES



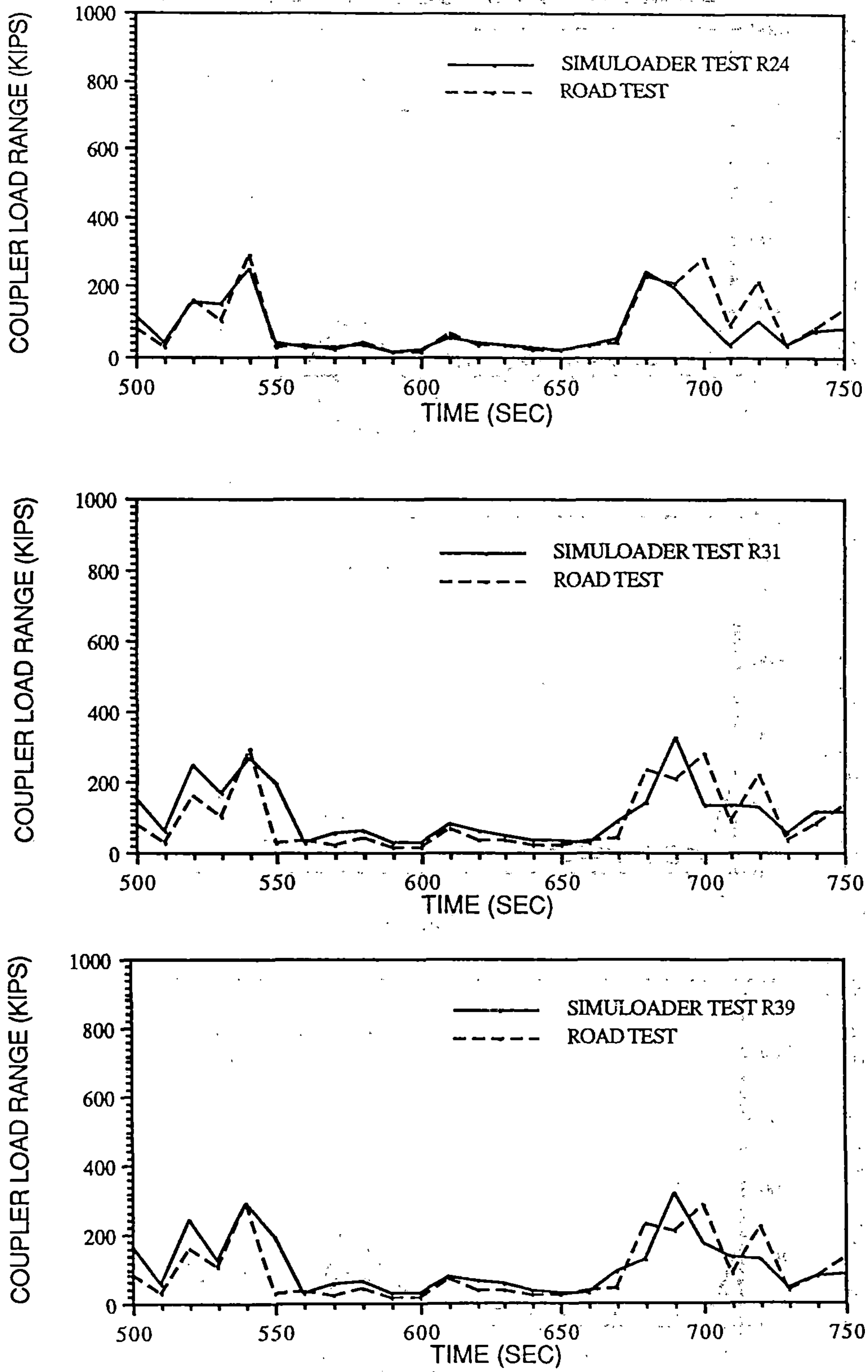




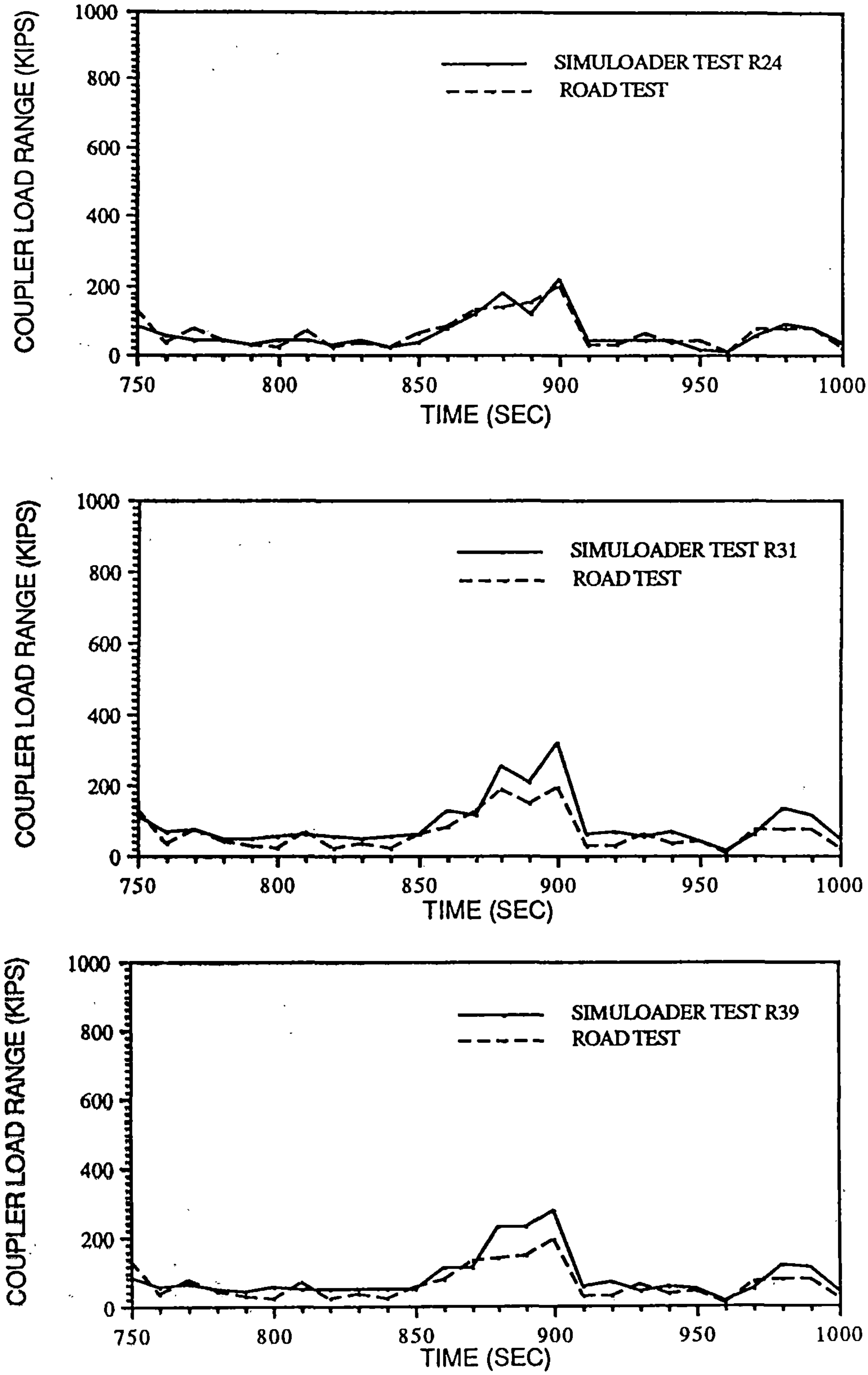
COMPARISON OF COUPLER LOAD RANGES



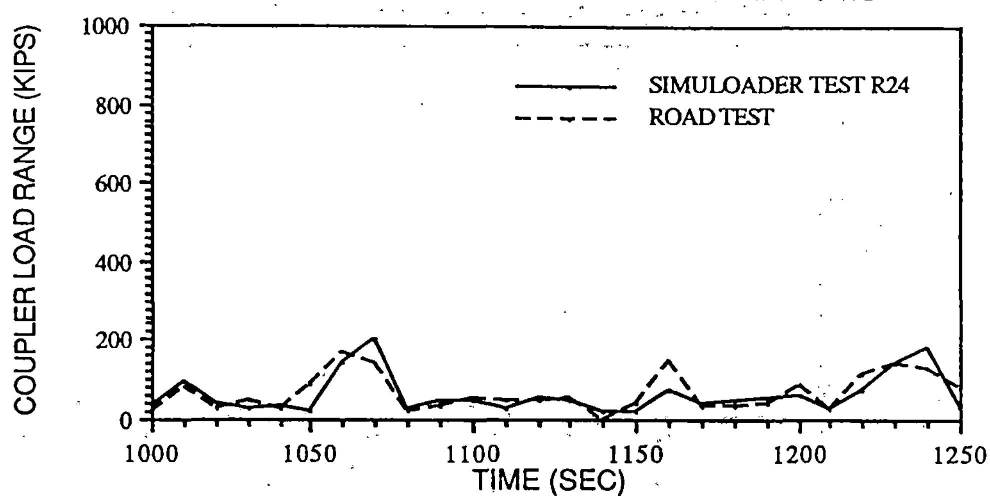
COMPARISON OF COUPLER LOAD RANGES

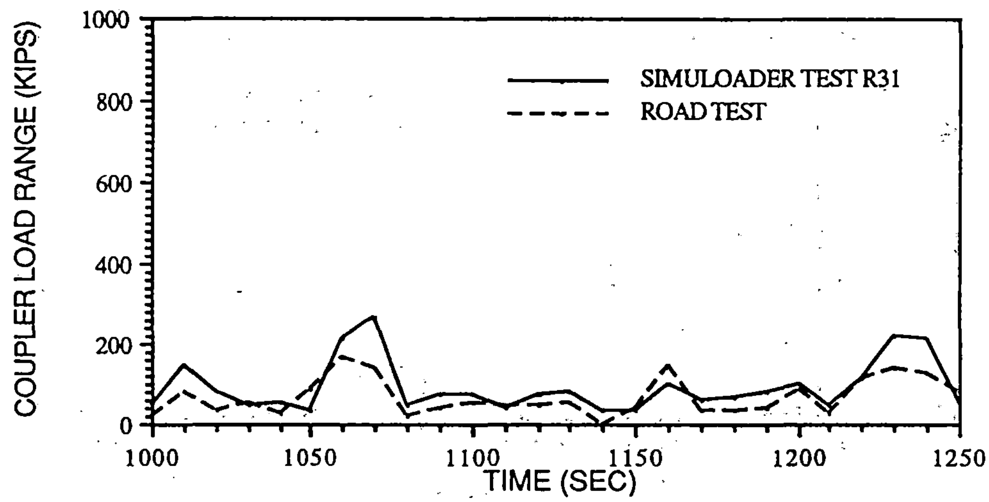


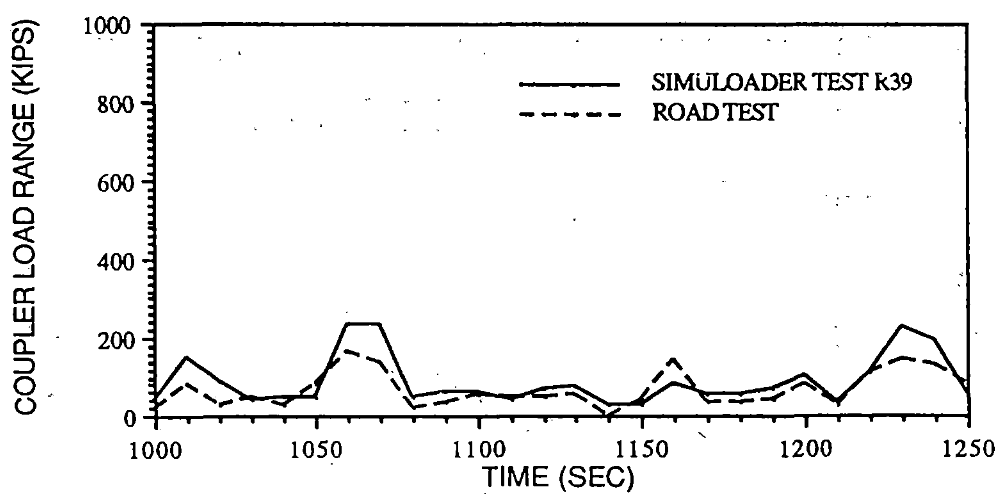
COMPARISON OF COUPLER LOAD RANGES



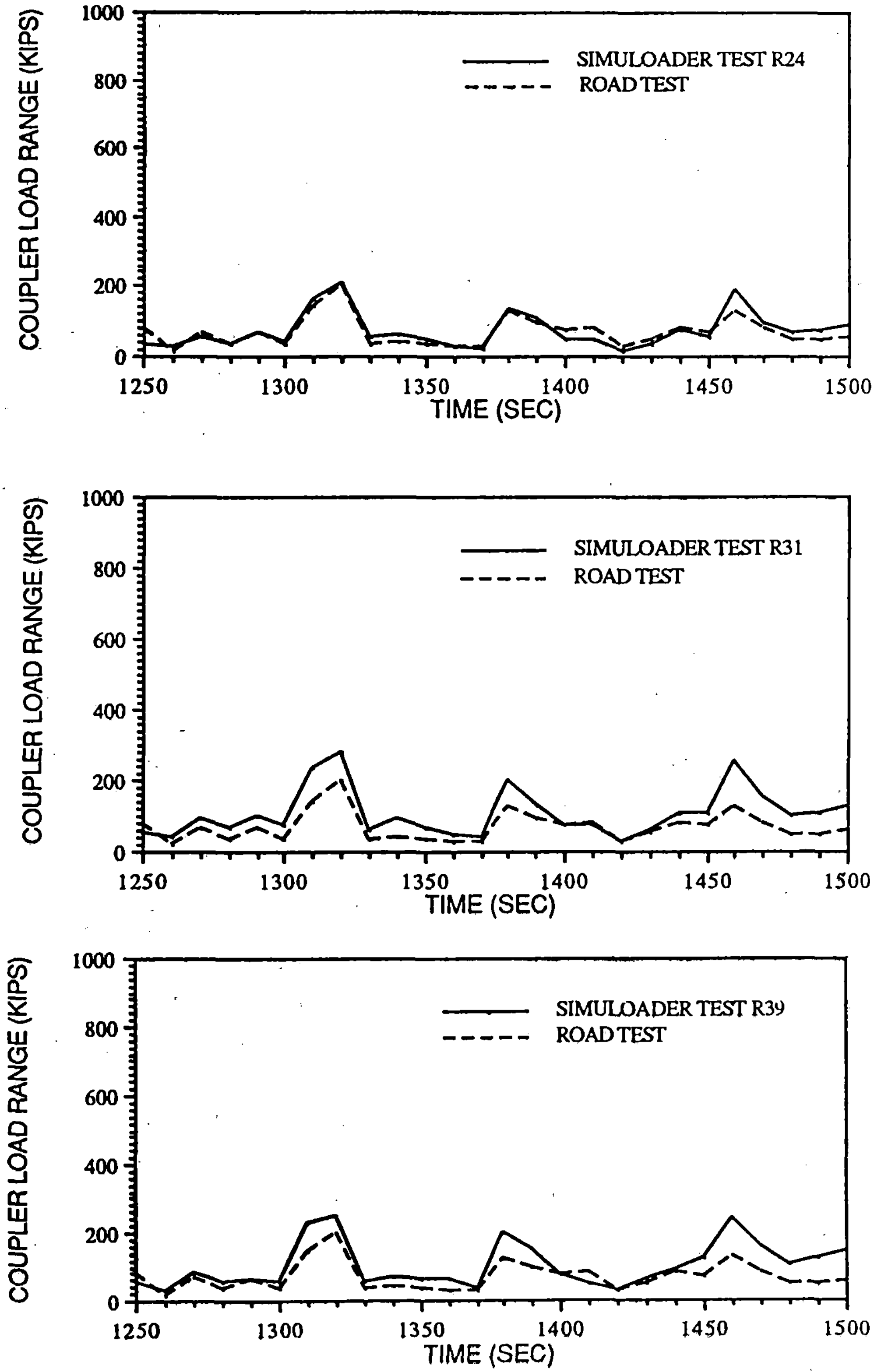
COMPARISON OF COUPLER LOAD RANGES







COMPARISON OF COUPLER LOAD RANGES



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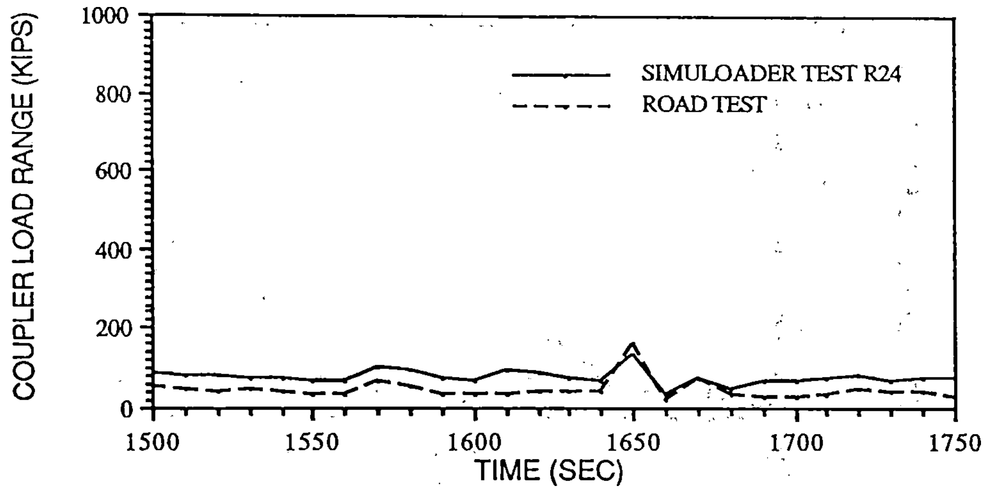

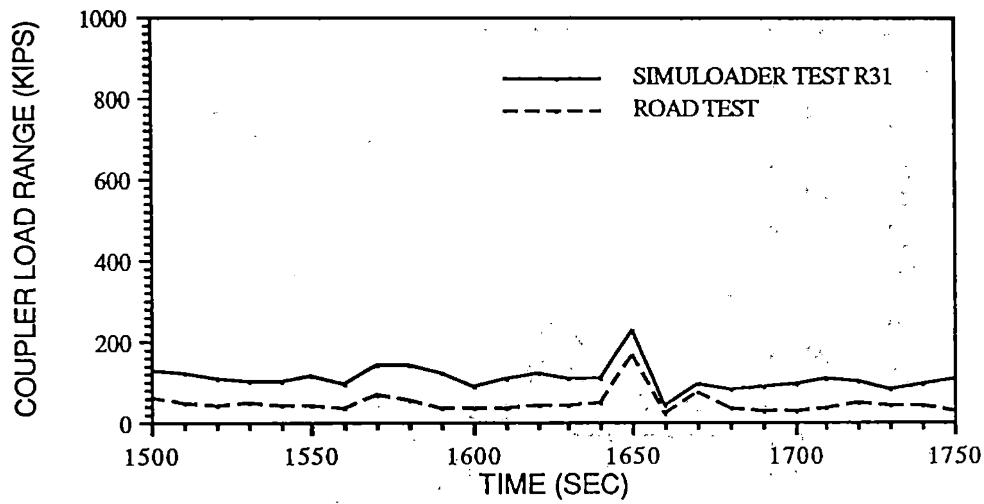

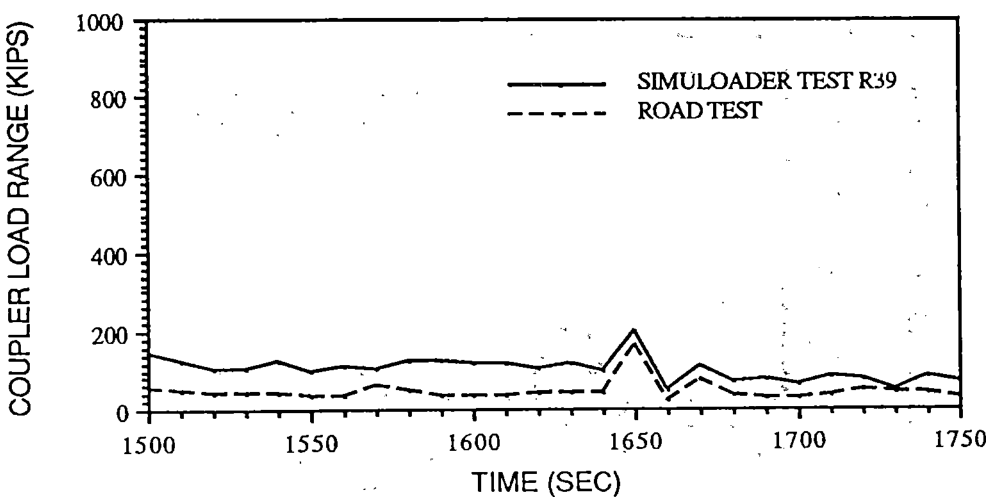

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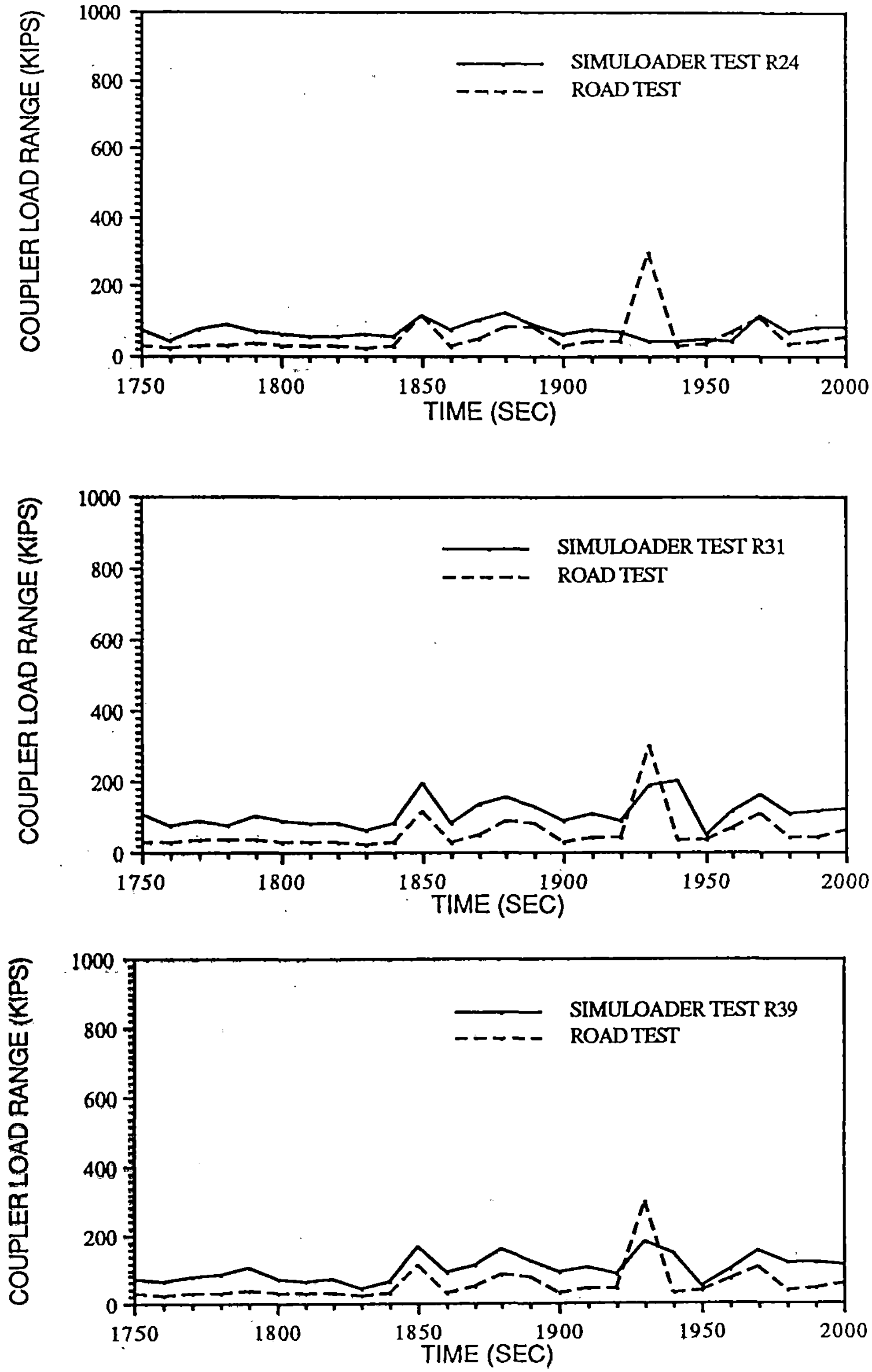

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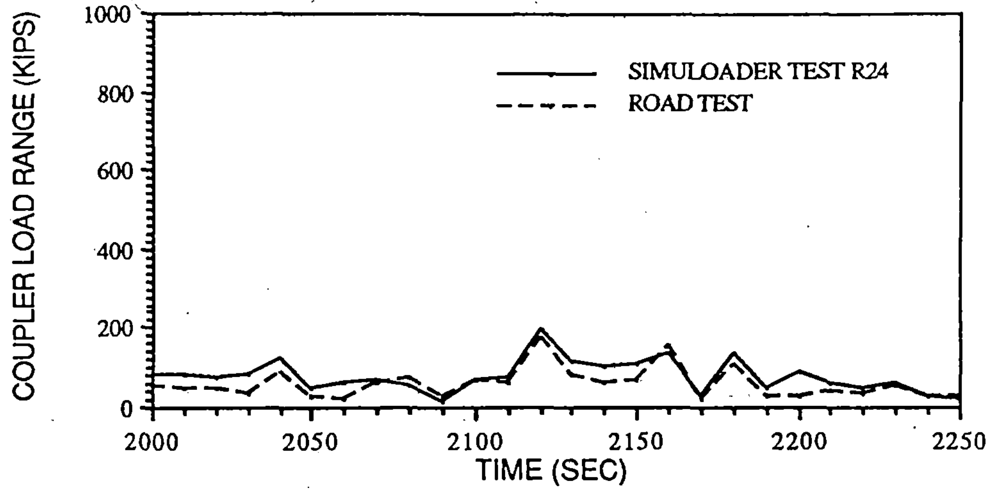

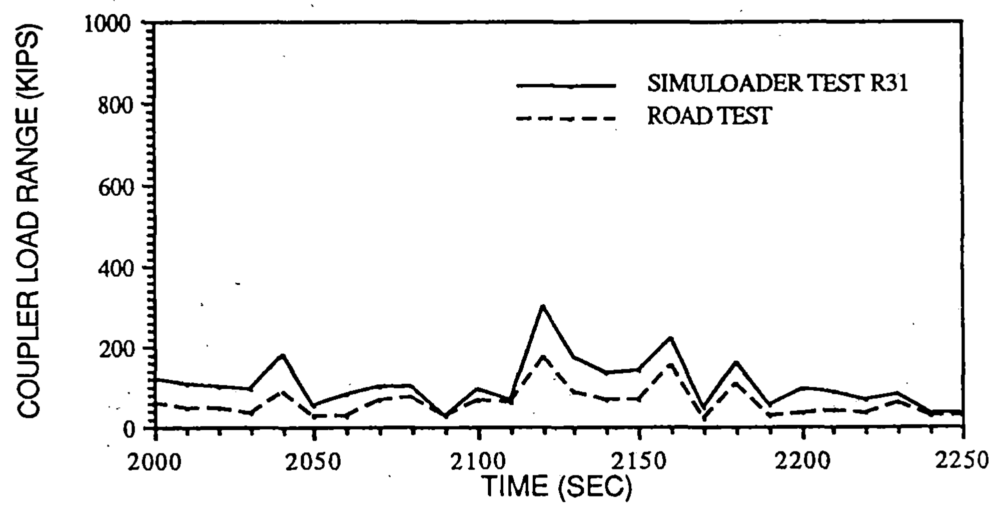

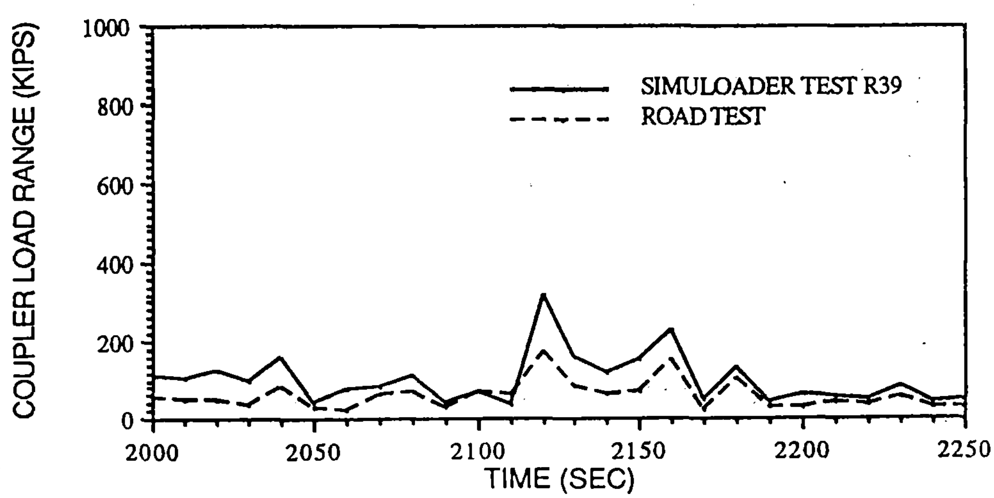

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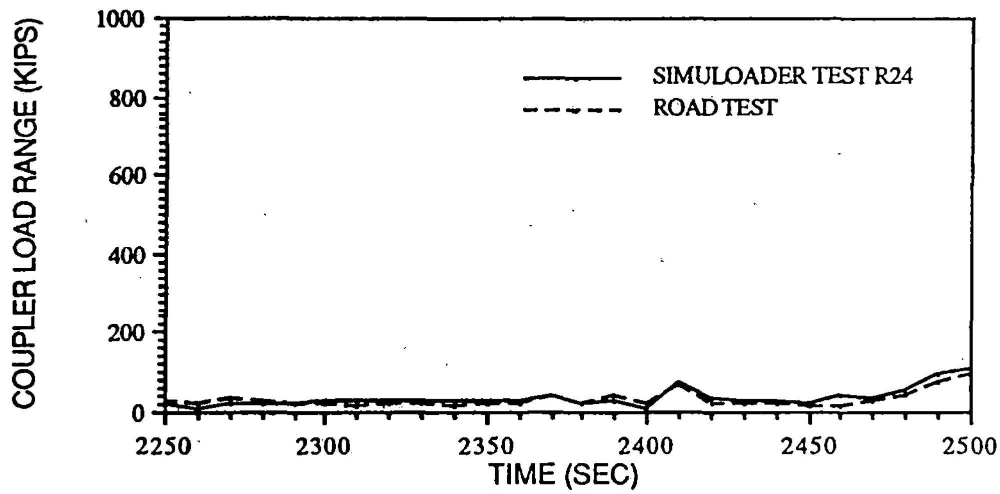
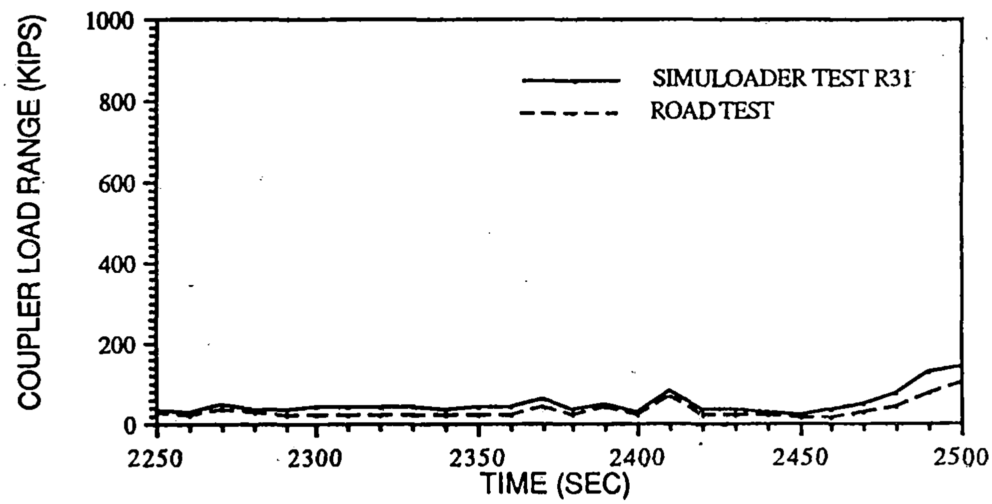
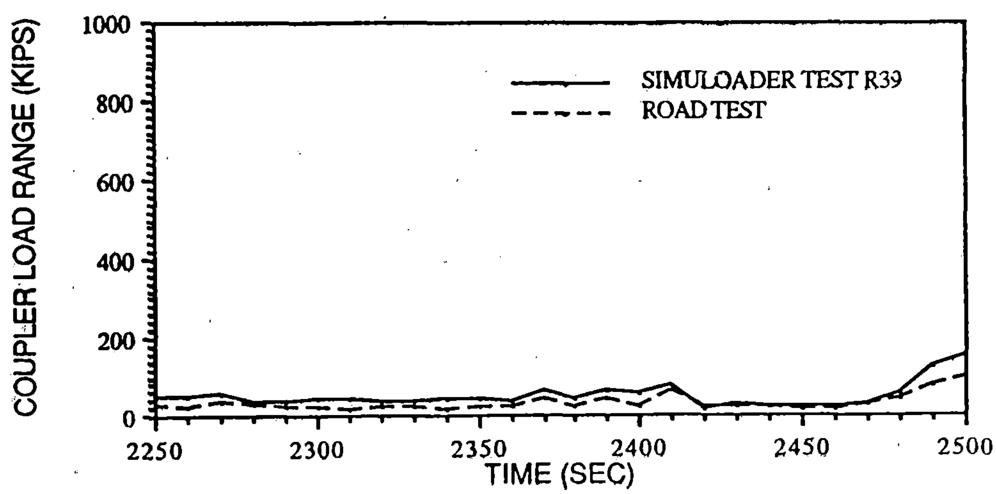


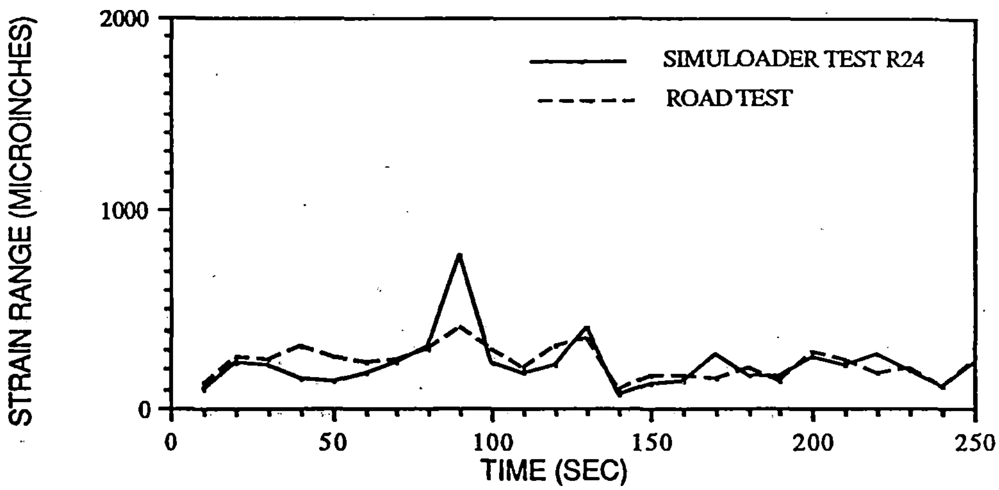


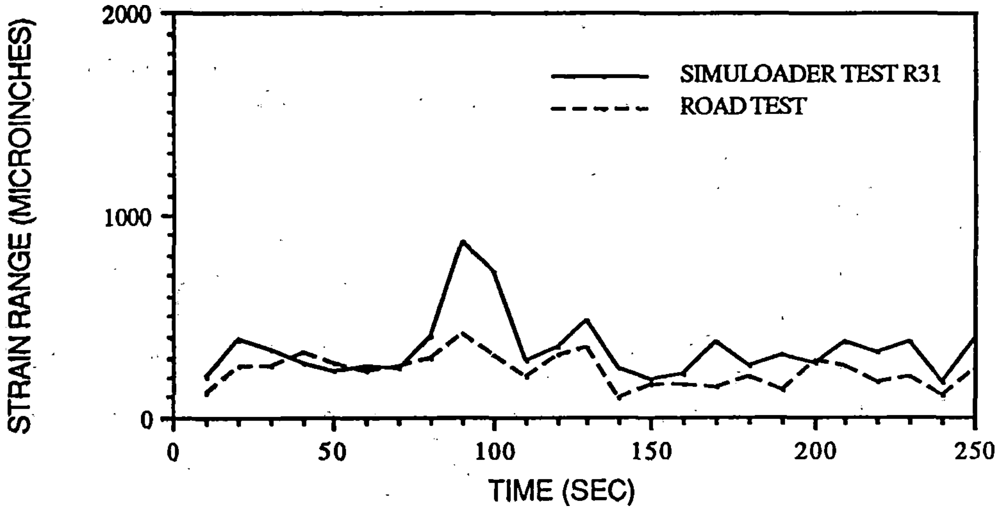


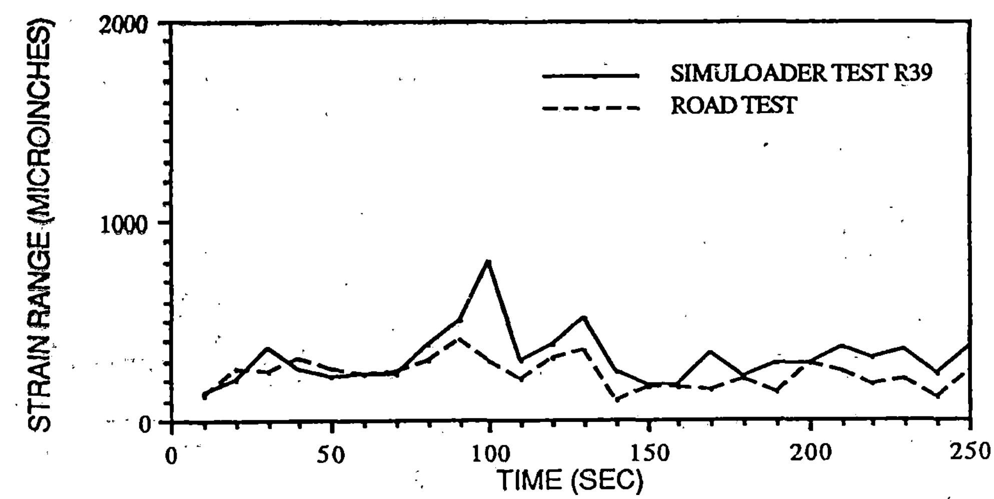
APPENDIX B

COMPARISON OF BODY BOLSTER GAGE "R" STRAIN RANGE HISTORY FROM SIMULOADER AND ROAD TESTS

COMPARISON OF STRAIN RANGES FOR GAGE 'R'







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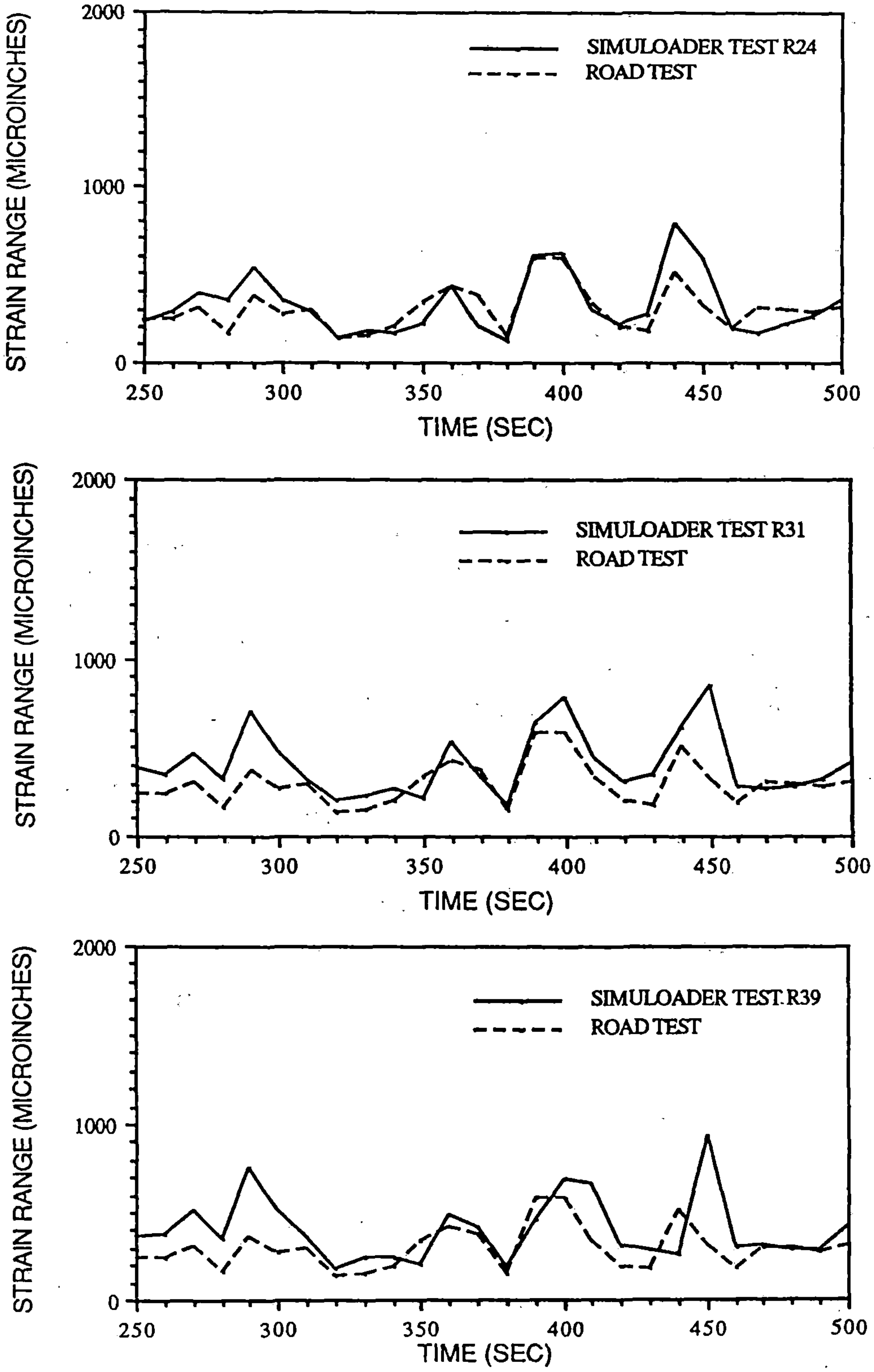

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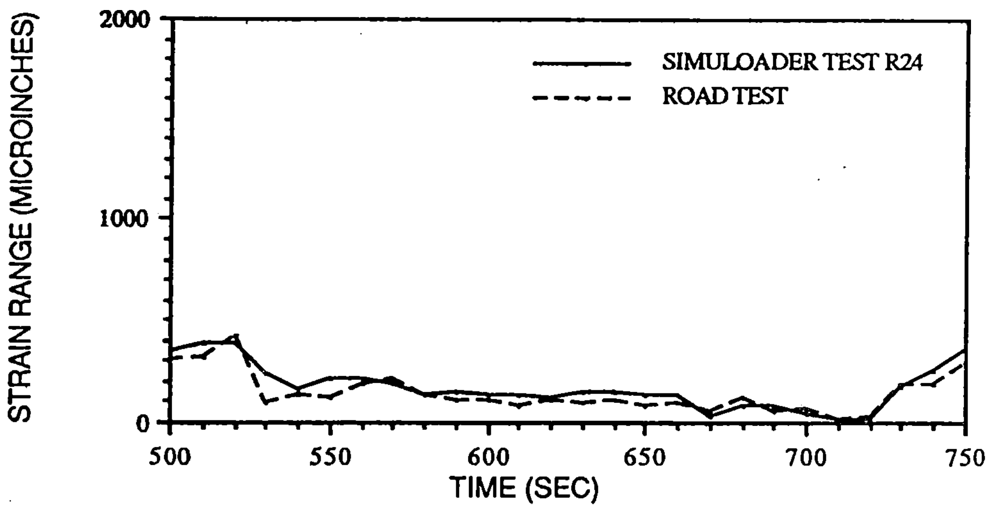
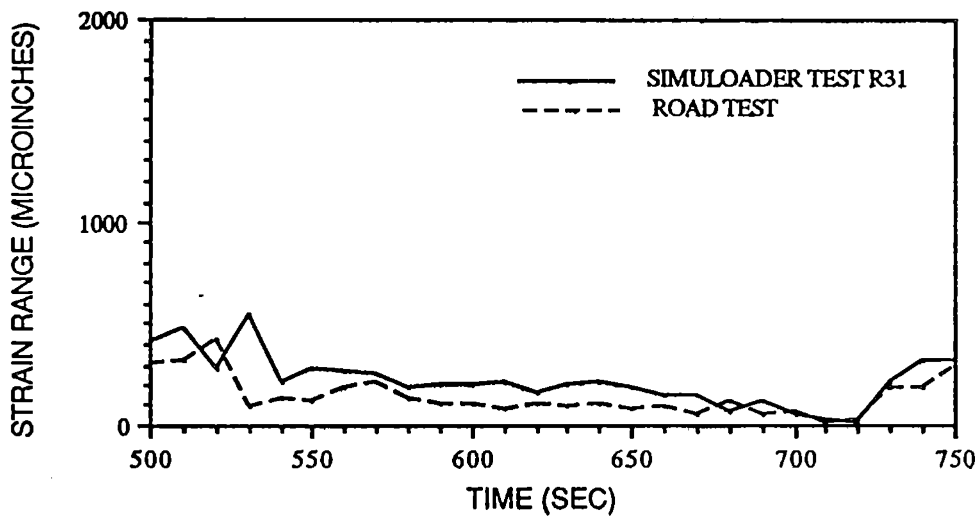
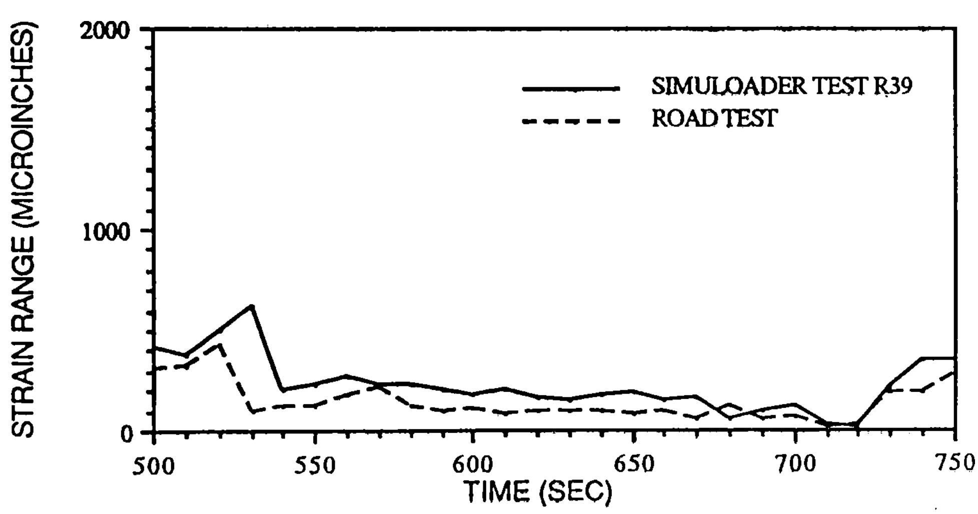
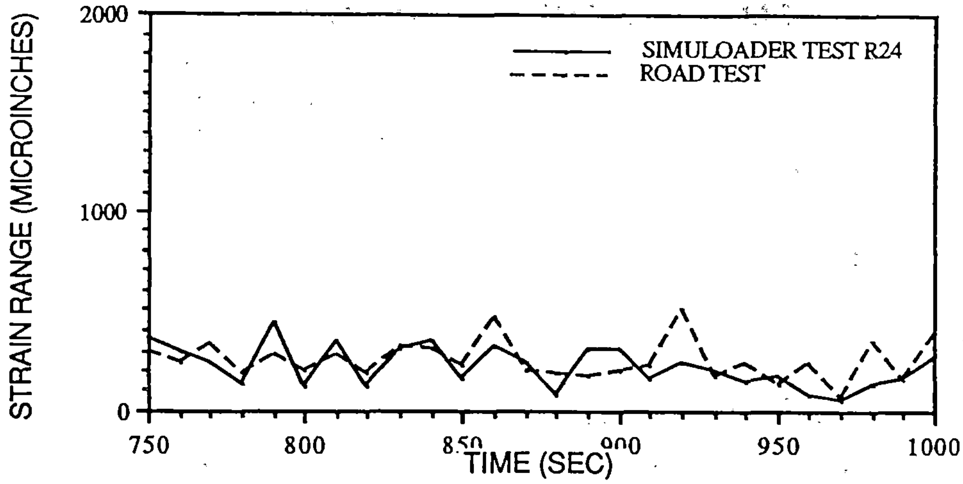
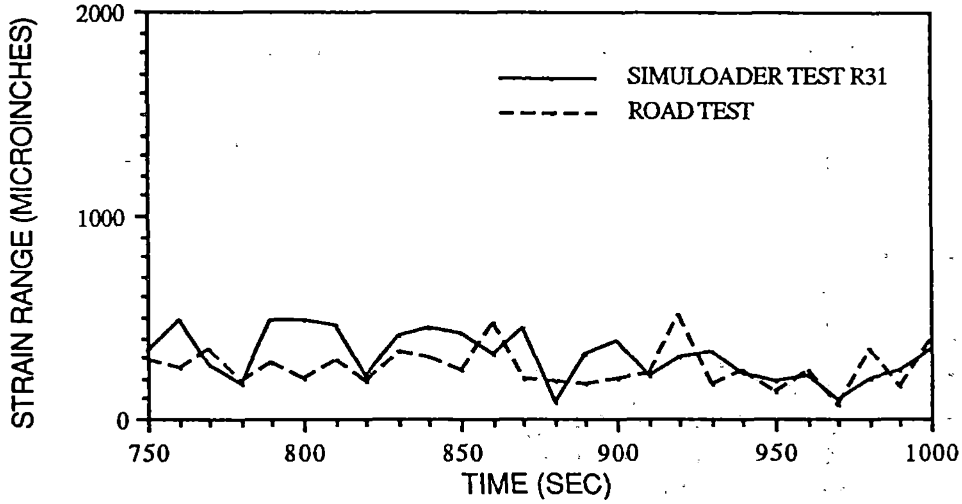


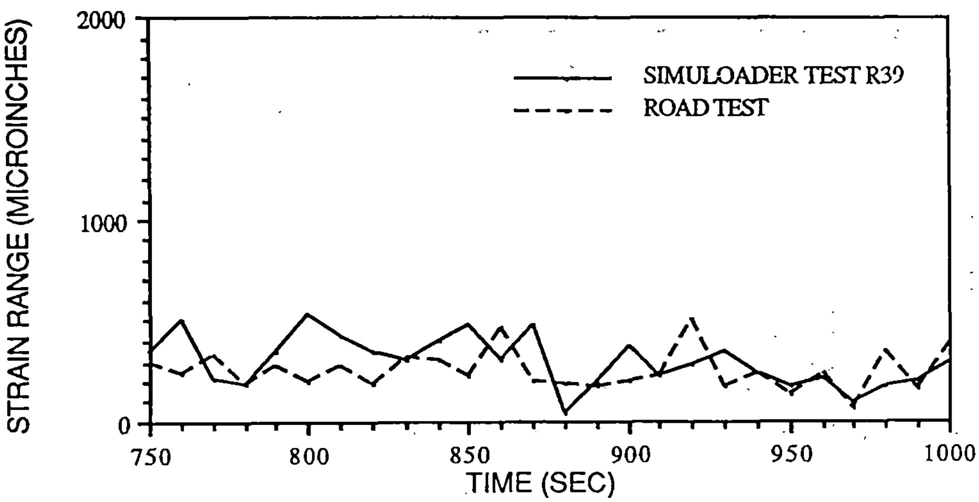




COMPARISON OF STRAIN RANGES FOR GAGE 'R'







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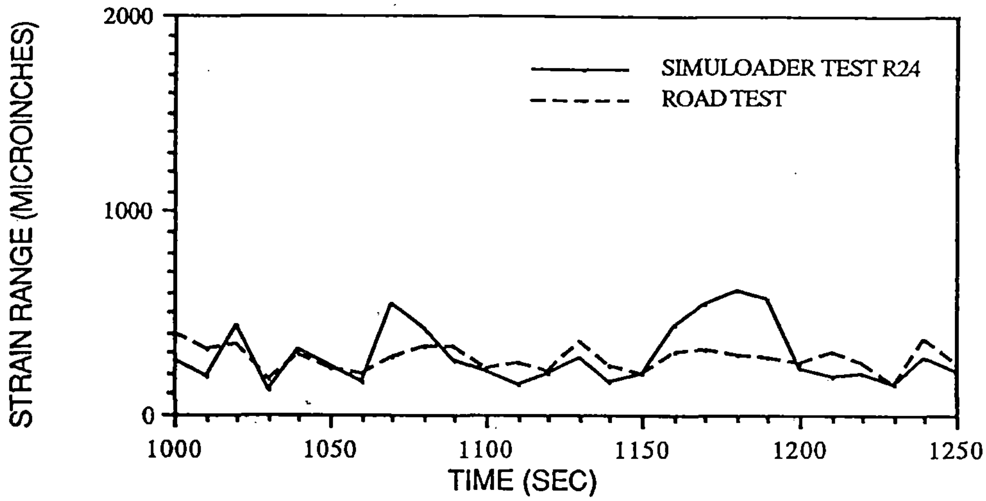

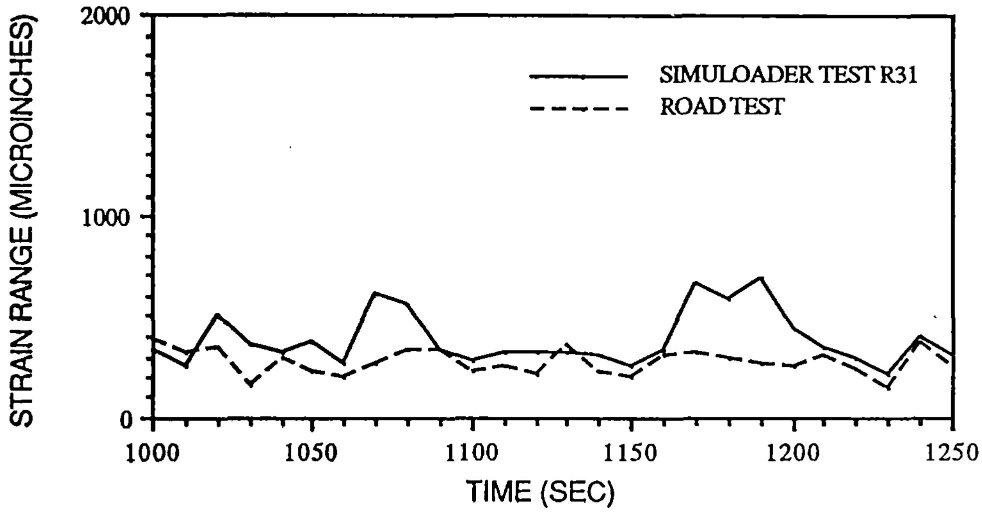

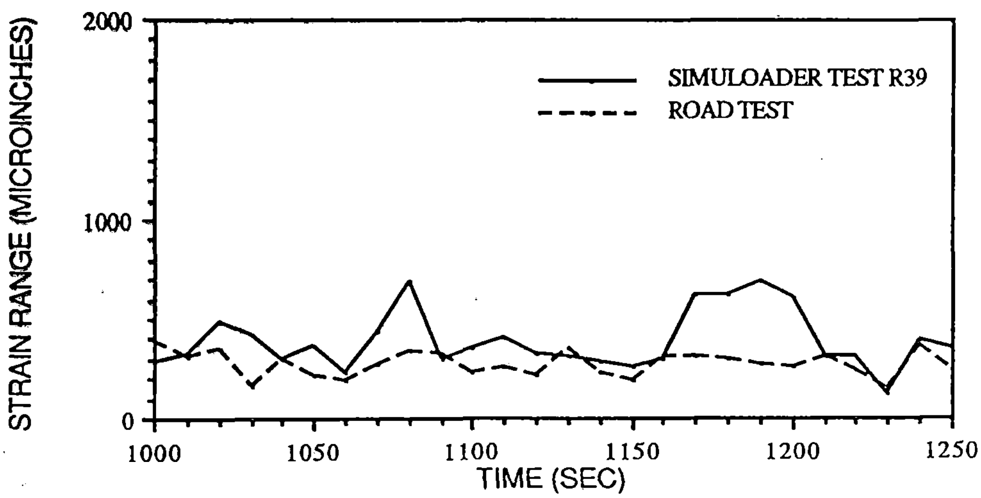

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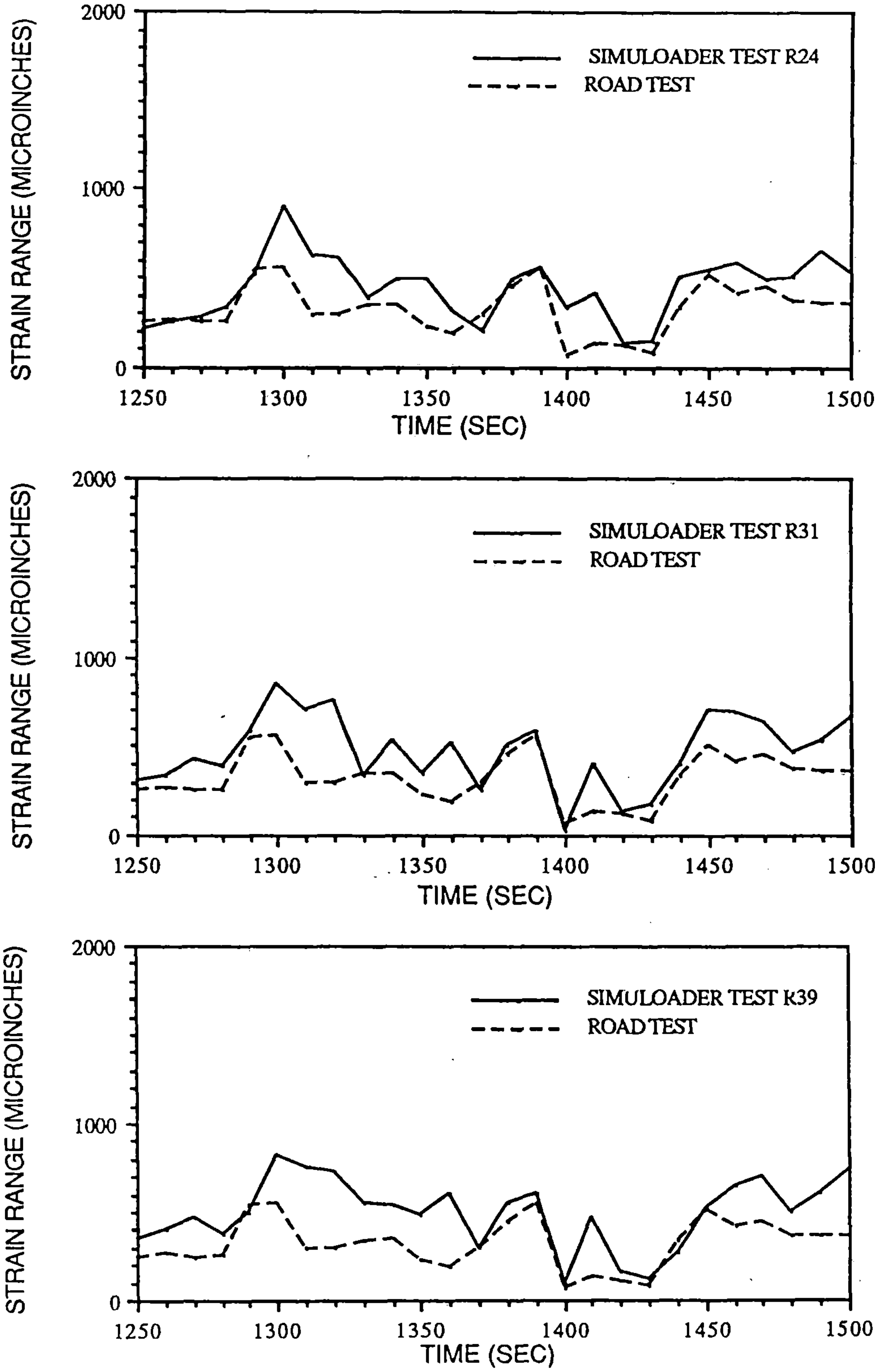

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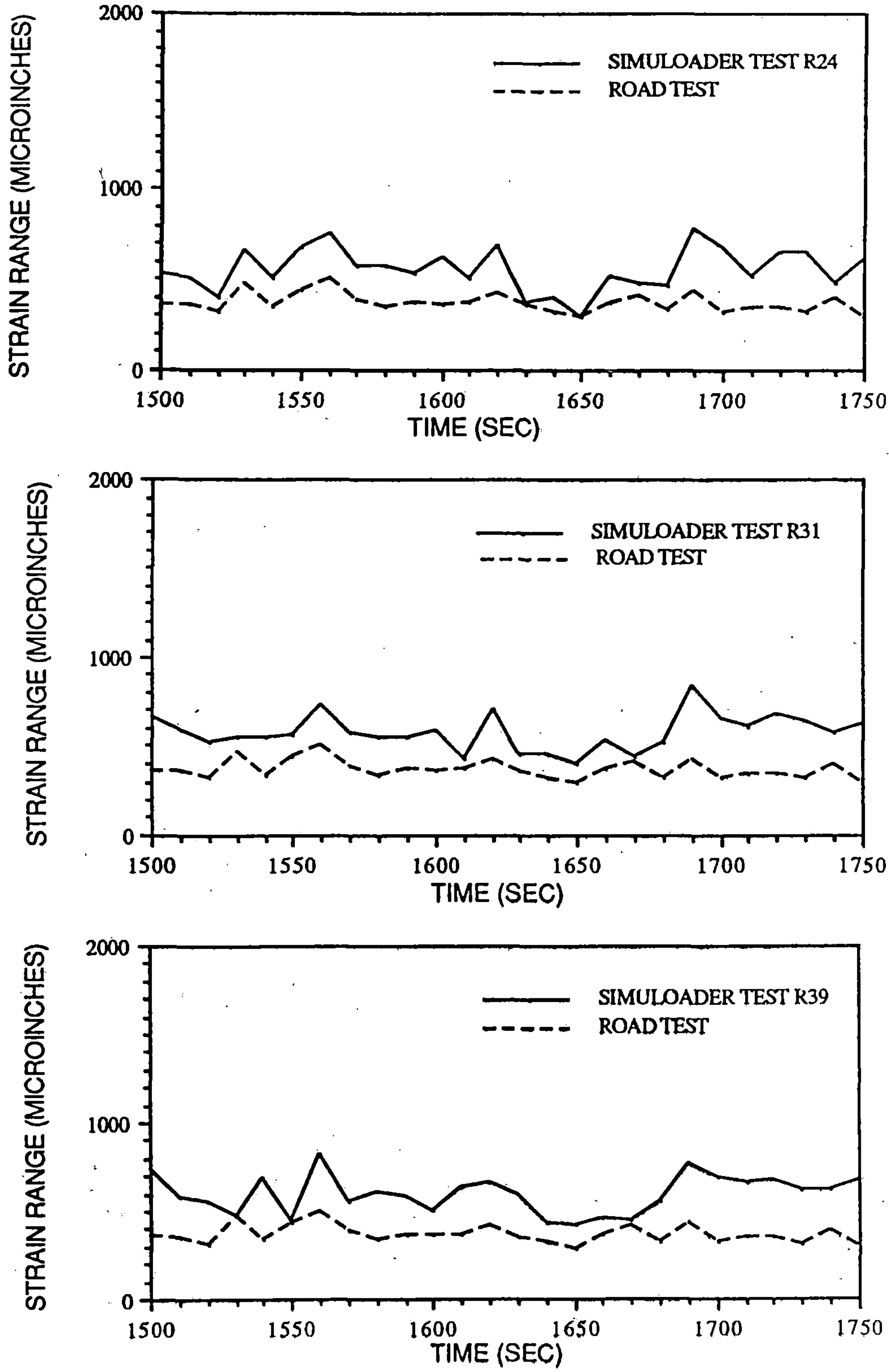

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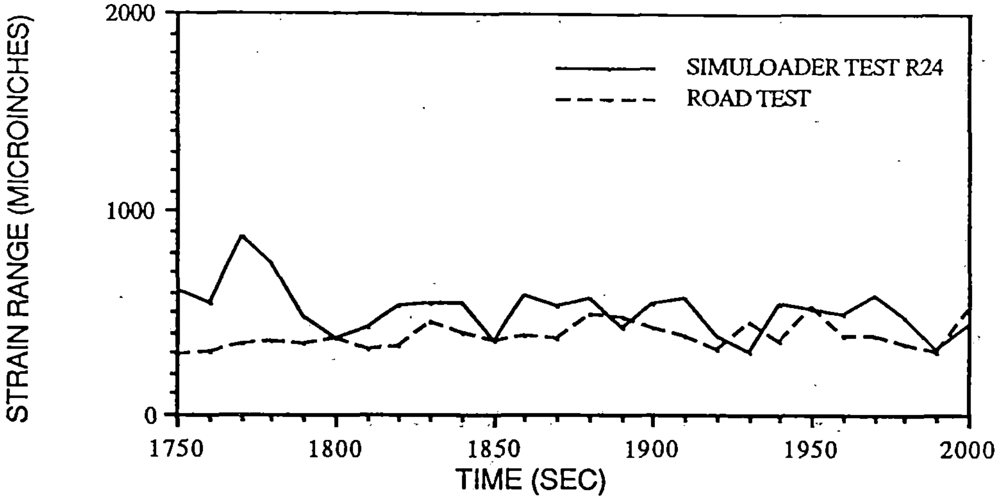

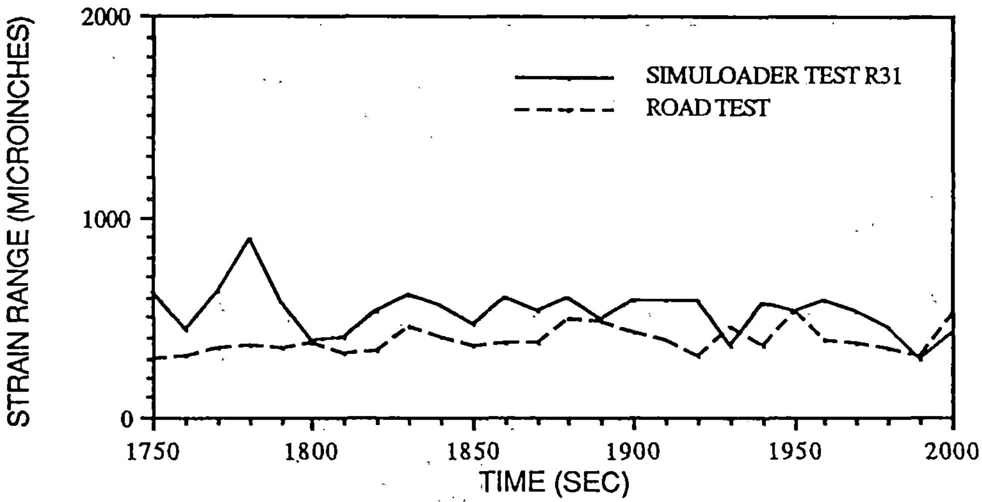

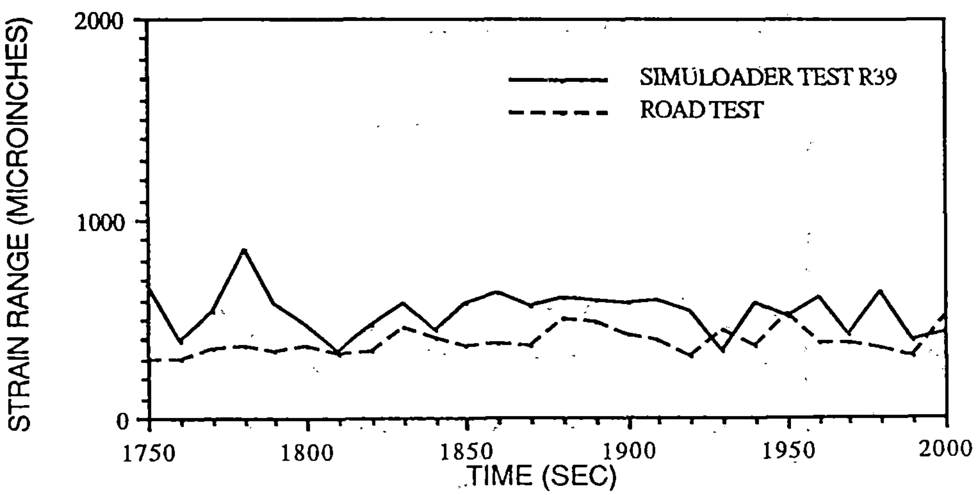

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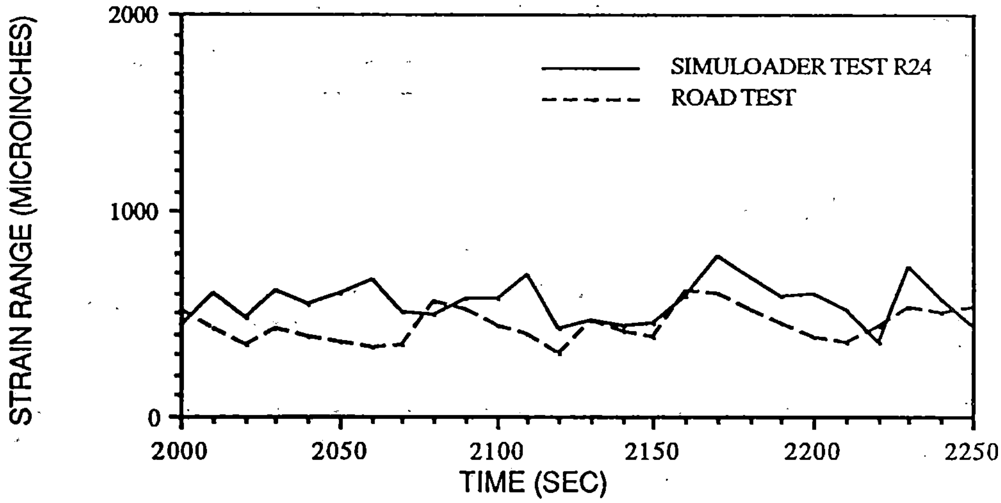

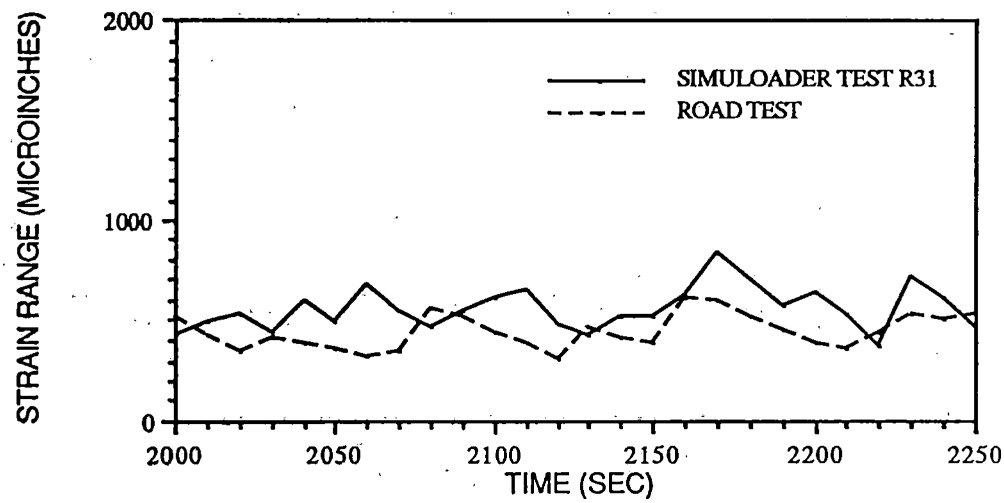

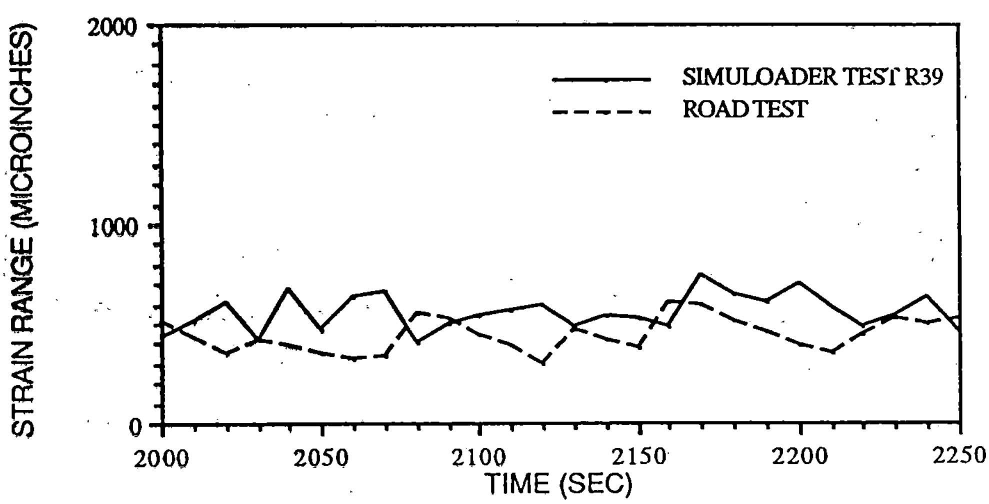

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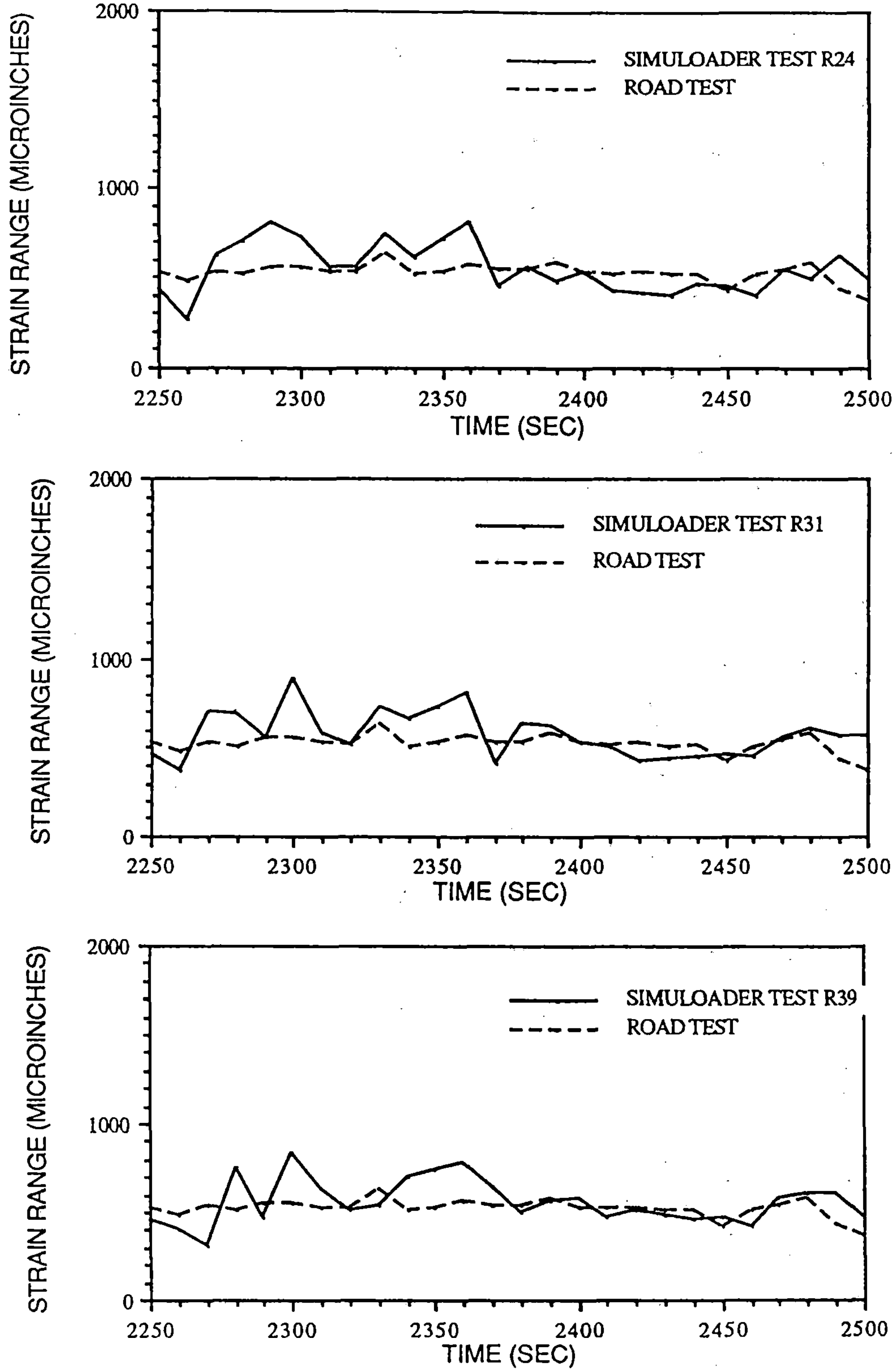
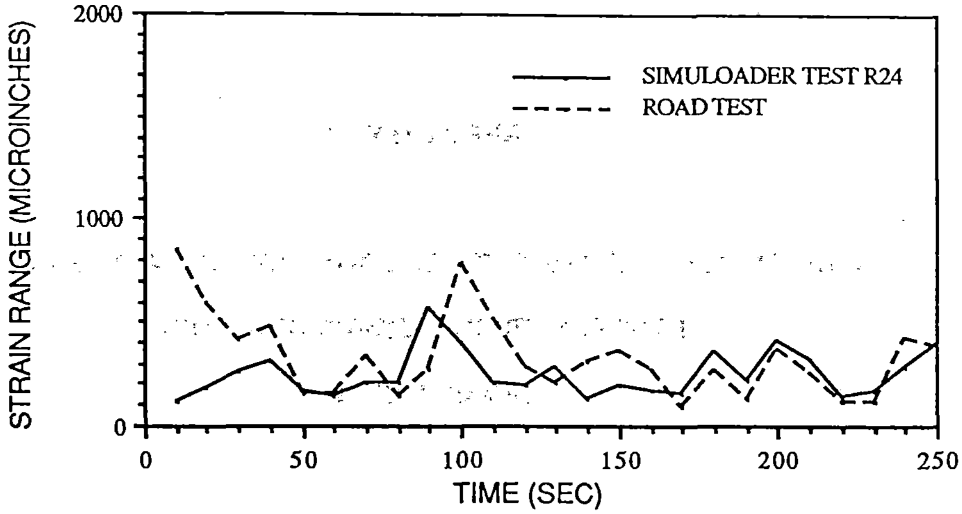
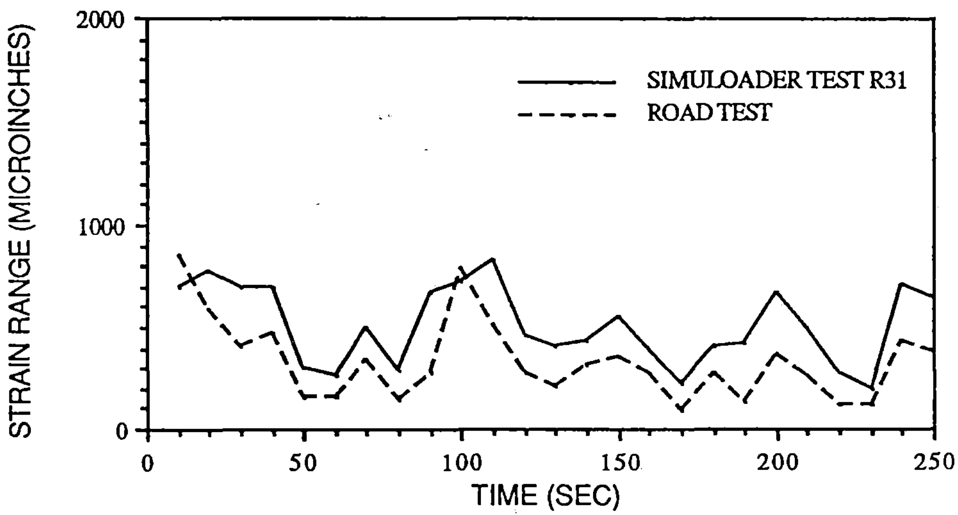


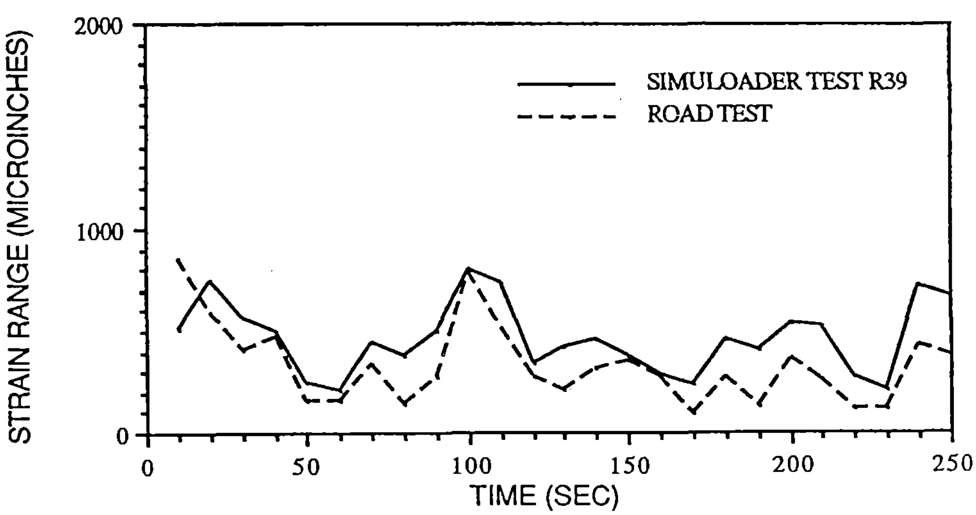
APPENDIX C

COMPARISON OF SIDE SILL GAGE "S" STRAIN RANGE HISTORY FROM SIMULOADER AND ROAD TESTS

COMPARISON OF STRAIN RANGES FOR GAGE 'S'







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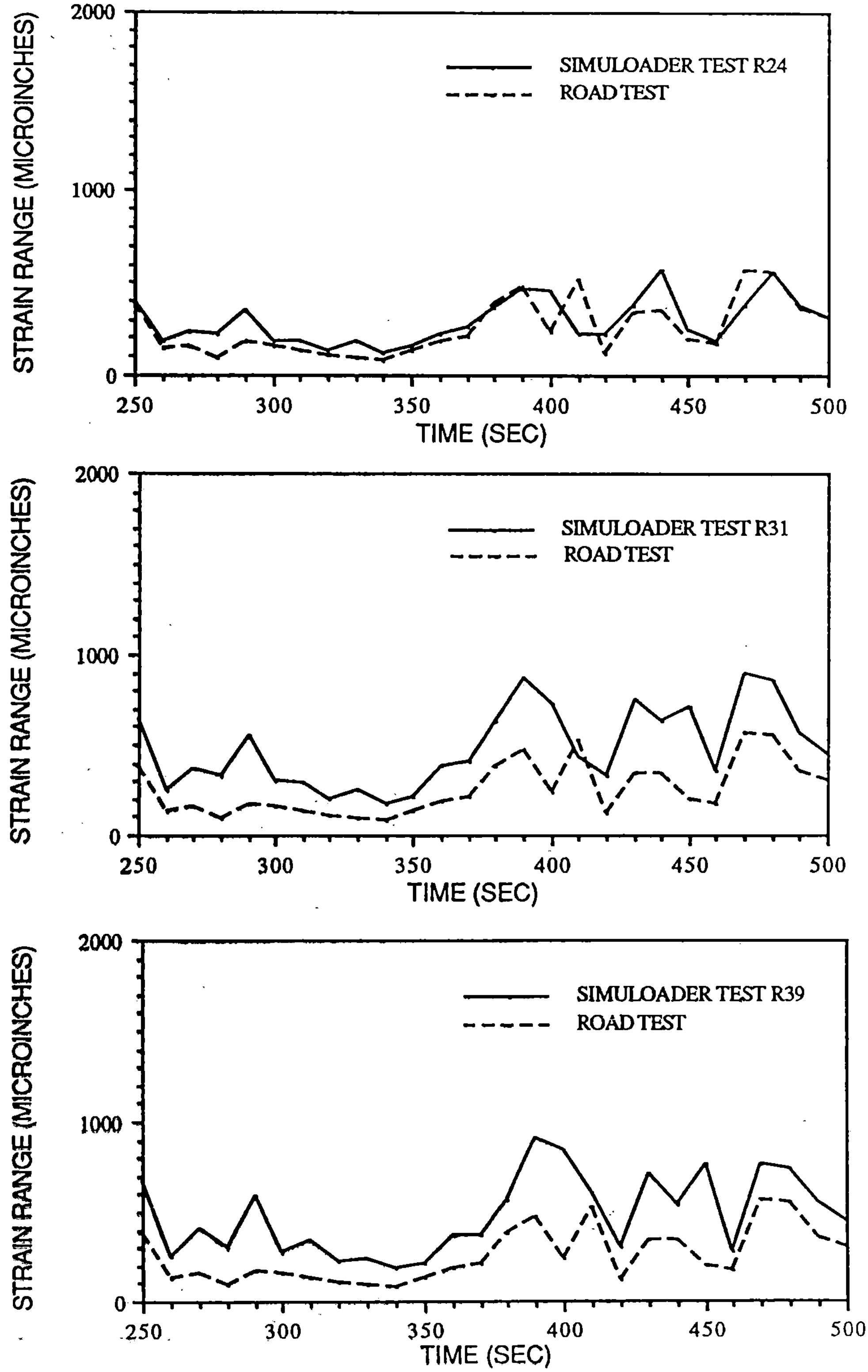

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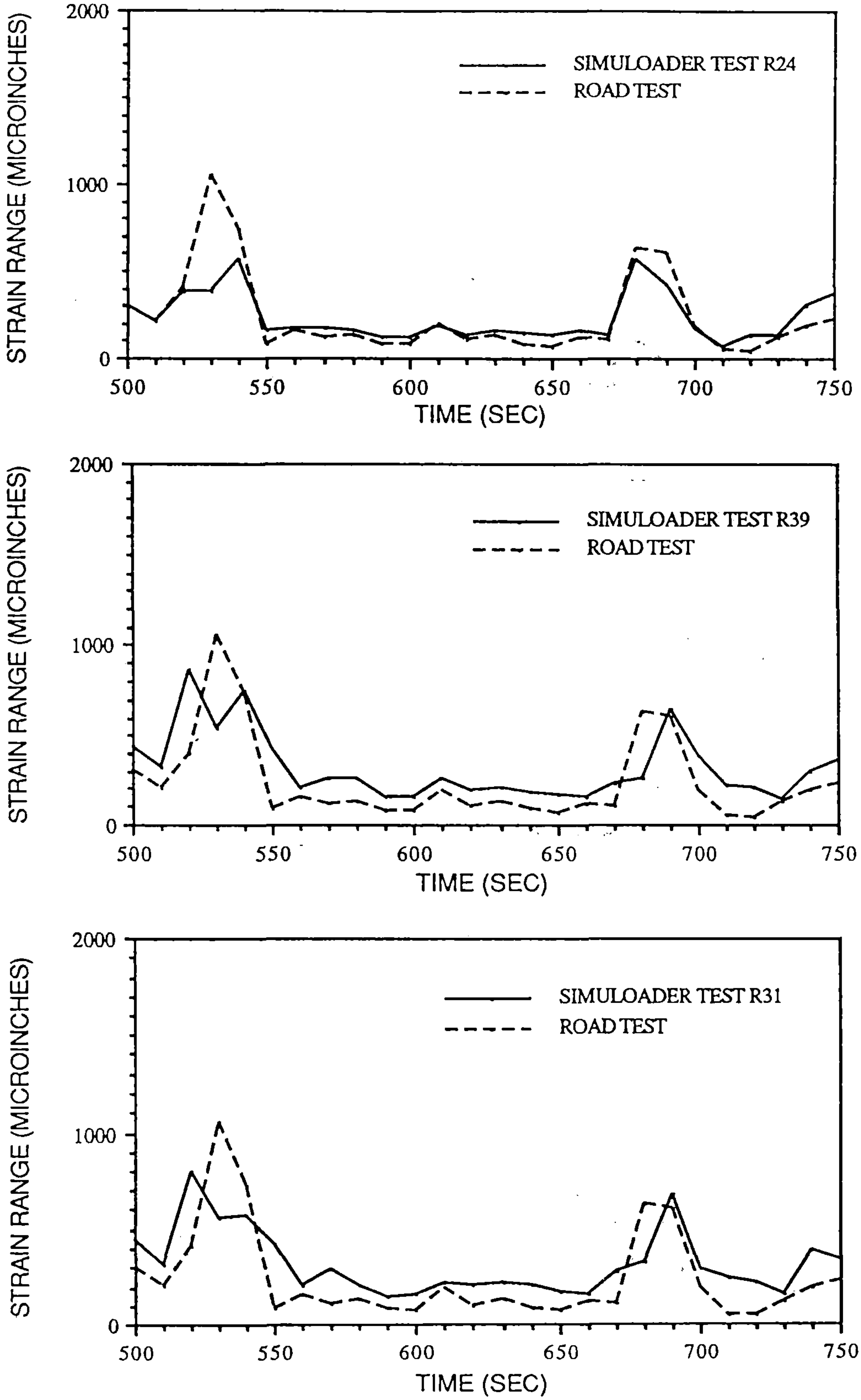

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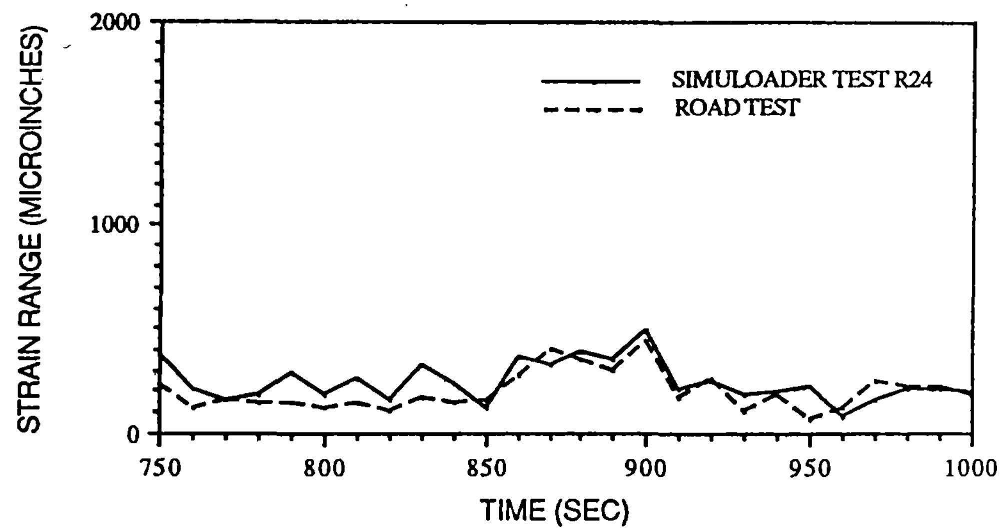

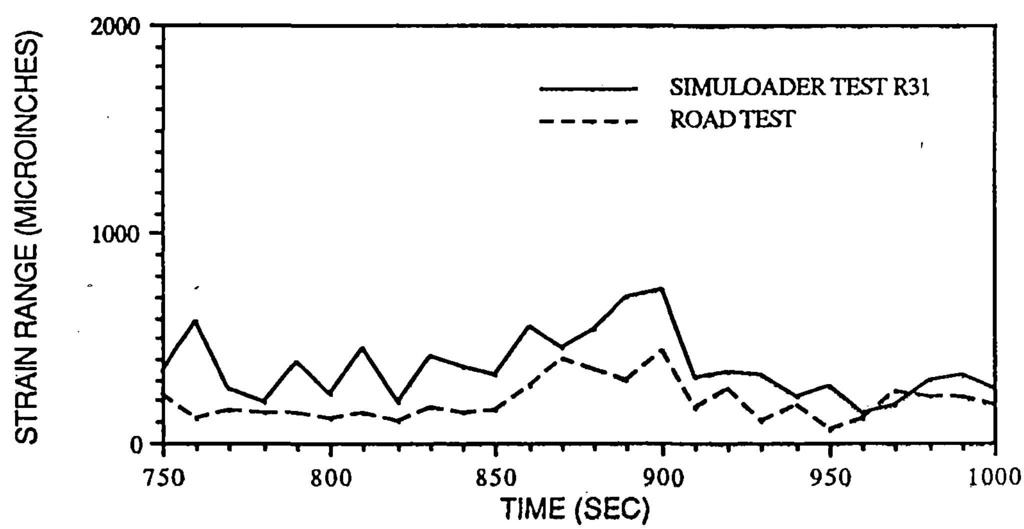

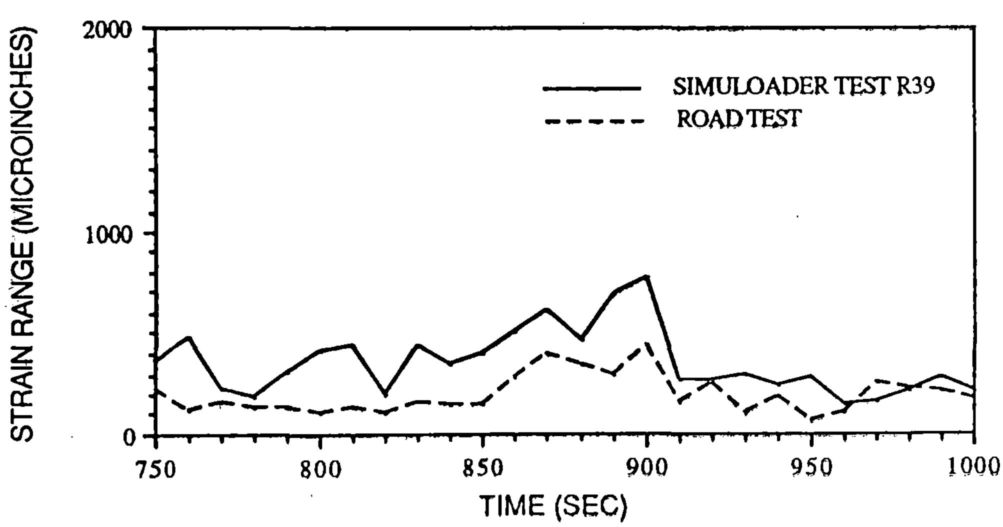

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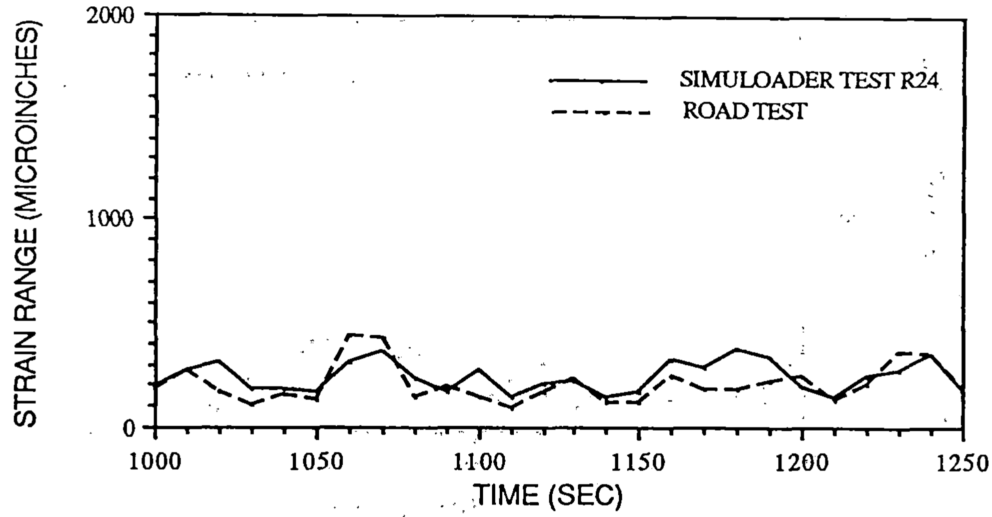

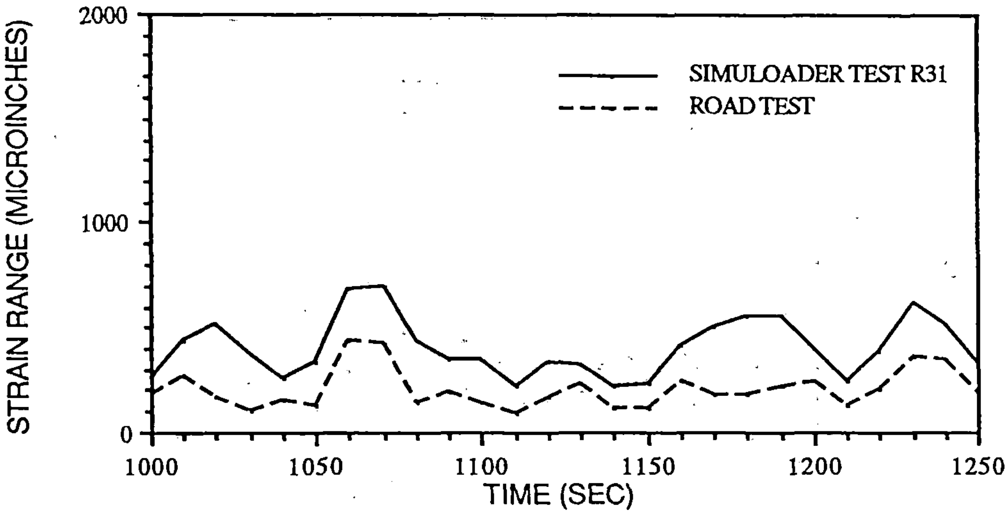

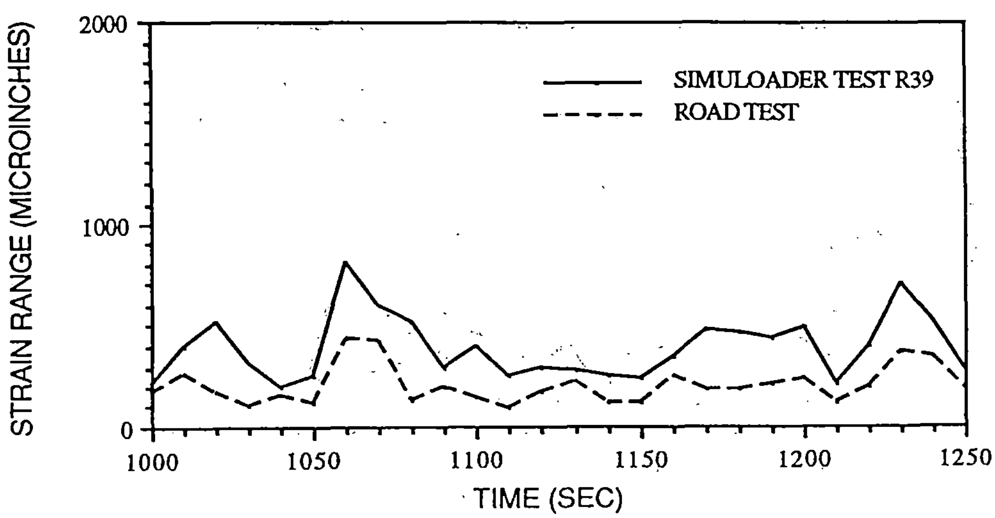

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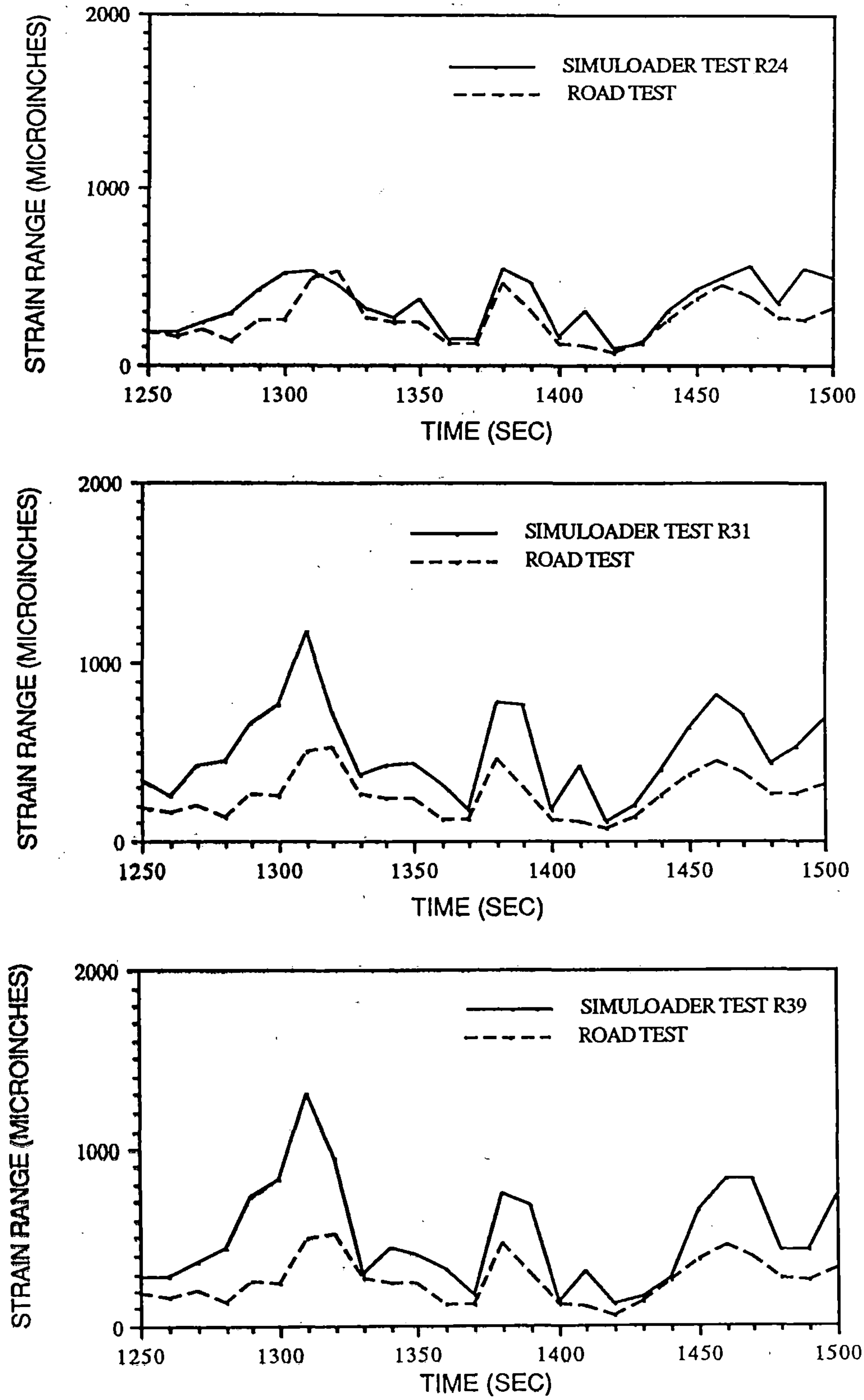

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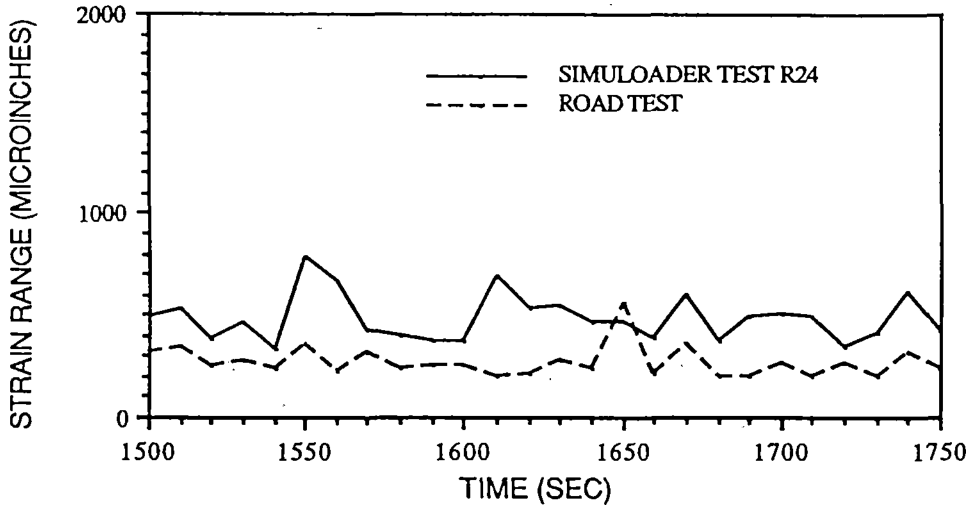

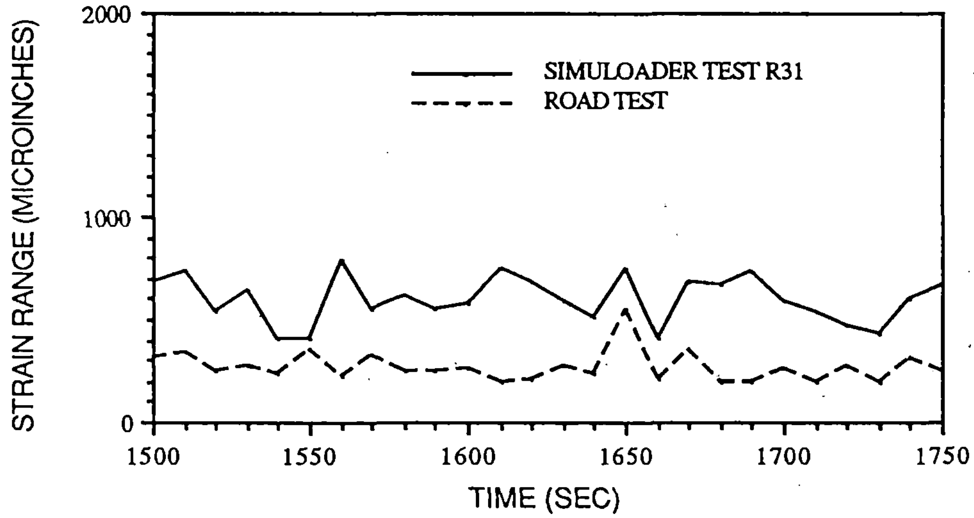

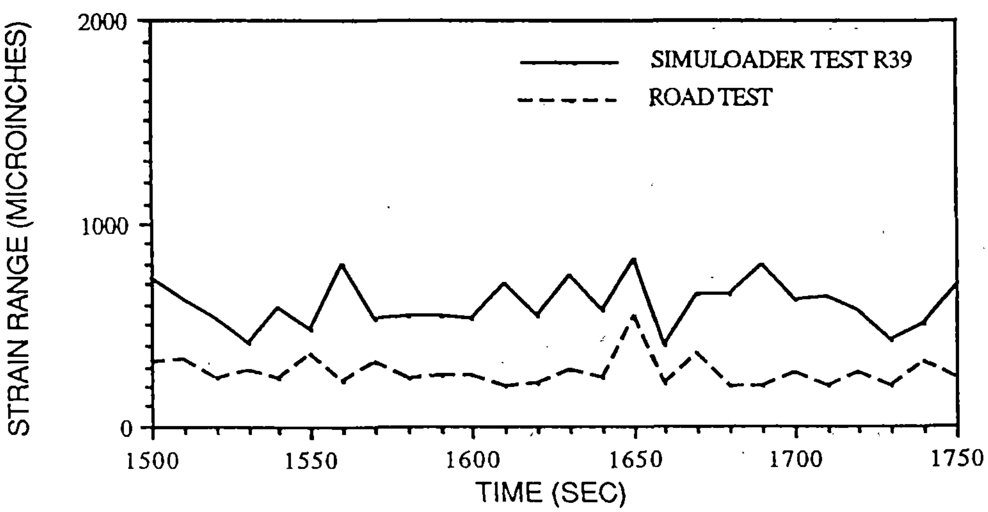

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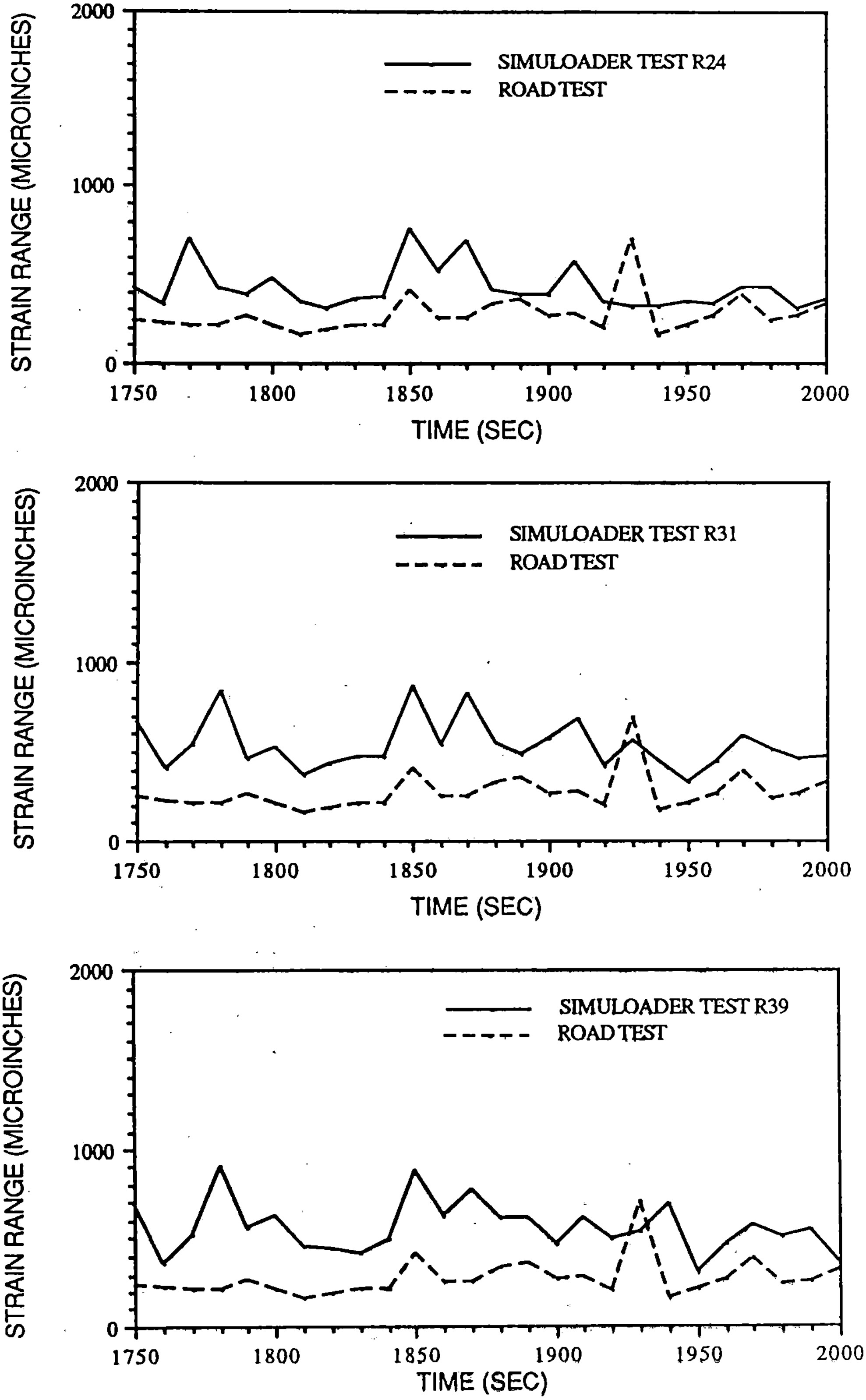

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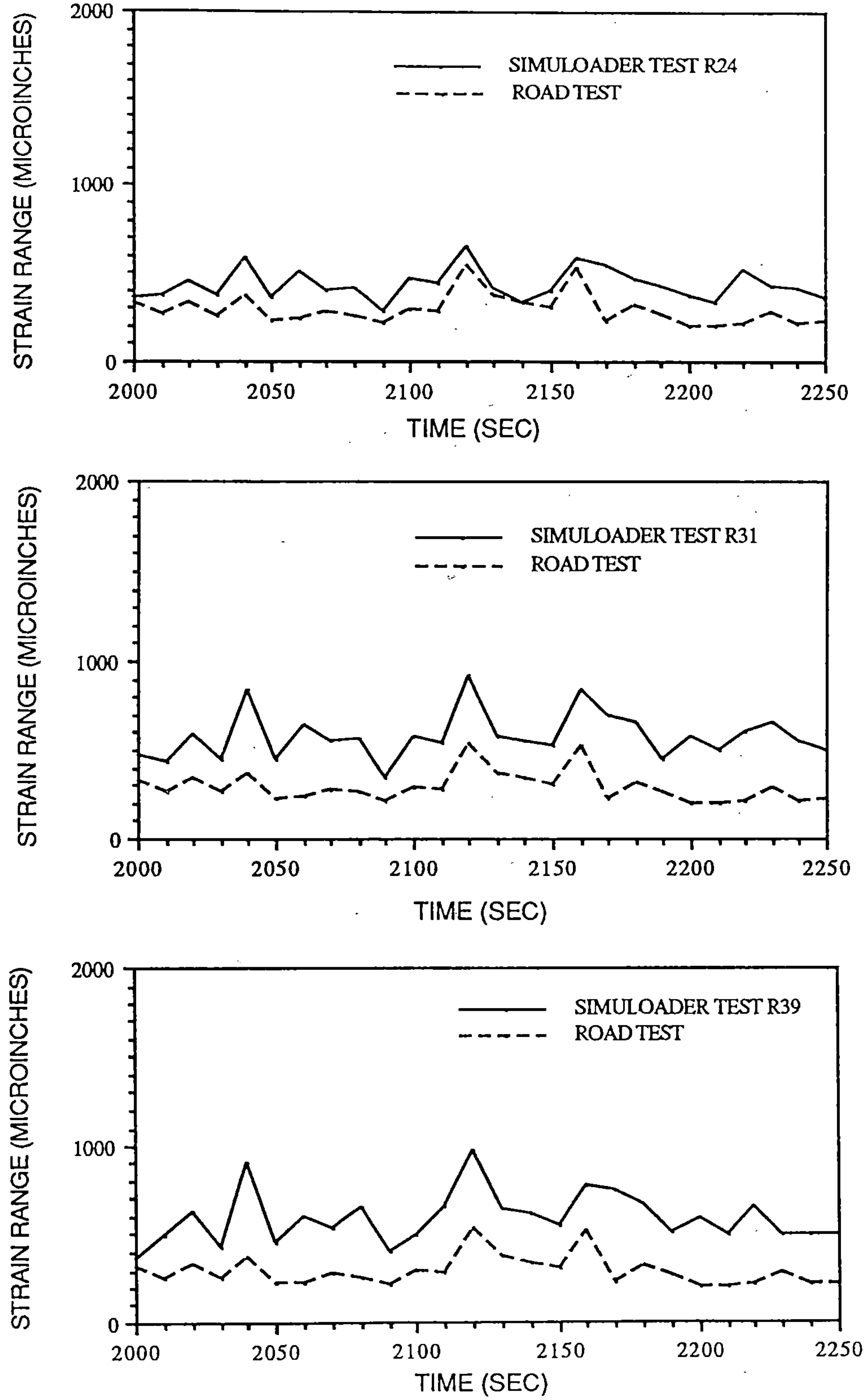

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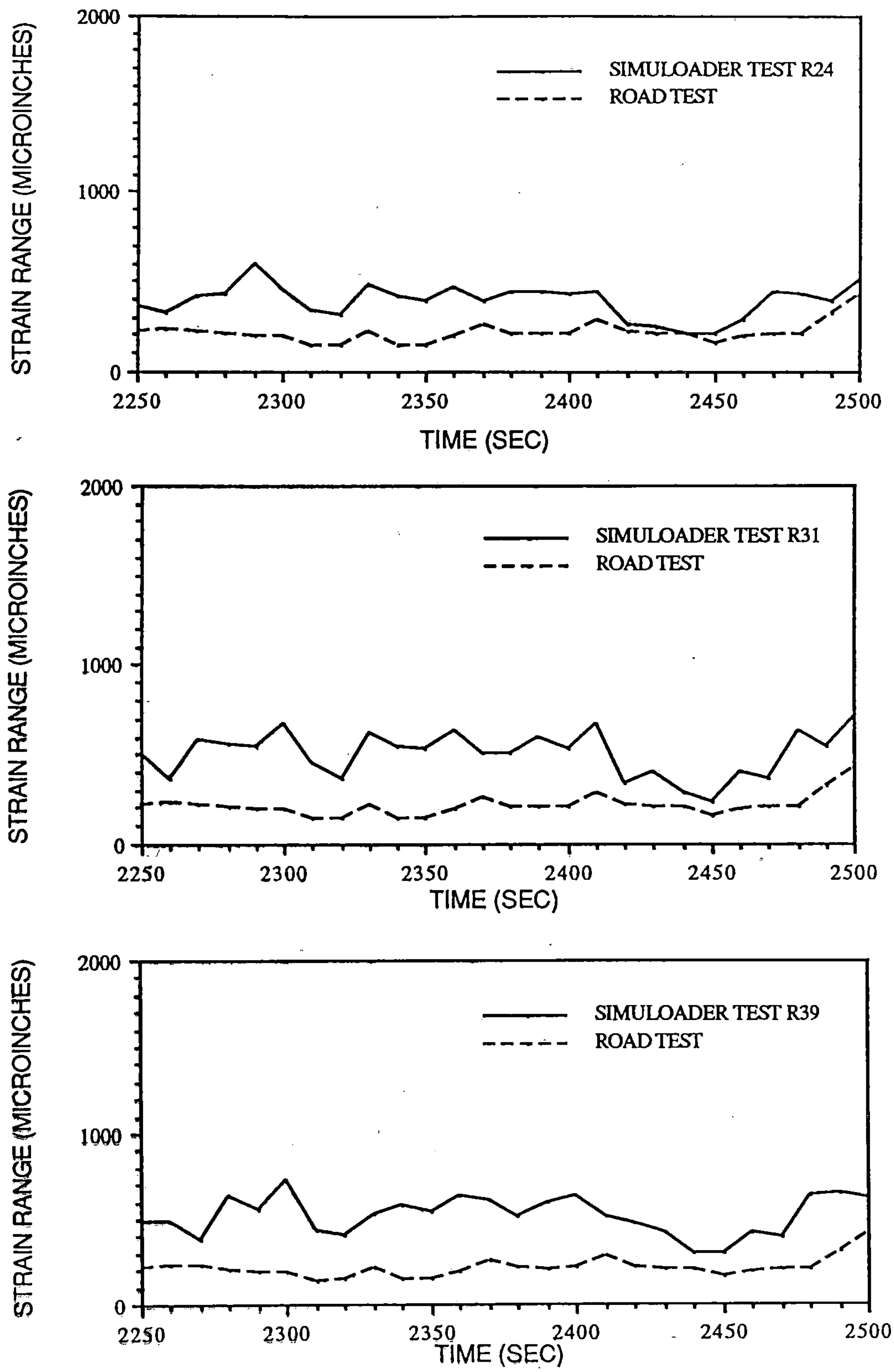

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