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DOT-TSC-1051

PILOT STUDY FOR THE CHARACTERIZATION AND REDUCTION OF WHEEL/RAIL LOADS

FIELD MEASUREMENT AND DATA REDUCTION PLAN

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June, 1976

TEST PLAN

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Prepared For

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Rail Safety Research
Washington, D. C. 20590

Revised Version
July, 1976

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16. Abstract

This report was prepared as part of the Improved Track Structures Research Program sponsored by the Office of Rail Safety Research of the Federal Railroad Administration. A survey of available wheel/rail load data was conducted (see the Interim Report, DOT-TSC-1051, April, 1976) and noticeable gaps in the existing data and formats of presentation were reported. In this report a test plan for gathering a comprehensive set of wheel/rail load data from both trackside and vehicle-borne transducer measurements is outlined. Primary uses of the resulting data will include the characterization of wheel/rail loads under revenue traffic at a representative track site, the characterization of wheel/rail loads from a representative vehicle (a 100-ton freight car) over varied track conditions, and validation of load-predictive models by comparison of computed and measured response.

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Wheel/rail loads, load measurement instrumentation, track dynamic response, vehicle dynamic response, data reduction

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UNITED STATES GOVERNMENT

Memorandum

DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER
KENDALL SQUARE
CAMBRIDGE, MA 02142

DATE: Sept. 20, 1976

In reply refer to: 612

SUBJECT: SPD-40 Locomotive Test Proposal

FROM: Herbert Weinstock, TSC

TO: John Harding, RRD-11, FRA

I am attaching some notes that I had Len Kurzweil prepare which you may find helpful in the development of a test plan for the proposed Locomotive Instrumented Wheel Set effort. I am also enclosing draft copies of report material which may be relevant. This material was prepared by Battelle-Columbus Laboratories and IIT Research Institute.

Herbert Weinstock

Attachments

TSC F 1325.4 (4/73)

UNITED STATES GOVERNMENT

Memorandum

DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER
KENDALL SQUARE
CAMBRIDGE, MA 02142

DATE: September 17, 1976

In reply refer to: 612

SUBJECT: Development of an Experimental Design for a Locomotive Evaluation Program

FROM: Leonard Kurzweil

TO: Herbert Weinstock, 612

Attached is a summary of the major considerations in the development of a field measurement program for the evaluation of a locomotive. It does not constitute the actual experimental design. The material included here were derived largely from in-house experience gained in part through the monitoring of Contract No. DOT-TSC-1051: Pilot Study for the Characterization of Wheel/Rail (W/R) Loads. Battelle also contributed to this material in the form of a letter report which I integrated into the present memo.

Leonard Kurzweil
Leonard Kurzweil

Attachment

Development of an Experimental Design for a Locomotive Evaluation Program

OUTLINE

I. Definition of Objectives

II. Selection of Performance Criteria and Evaluation Parameters (dependent variables)

III. Identification of Parameters Influencing Performance (independent variables)

IV. Design of Test Strategy (Site selection, train operations, statistical considerations)

V. Instrumentation Requirements and Selection

VI. Calibration Procedures

VII. Data Recording, Reduction, and Presentation (Documentation)

DISCUSSION

I. Definition of Objectives

It is important to clearly define a set of objectives or questions which the test program is intended to answer. This greatly aids in the design of the test strategy.

Possible overall objectives can include:

1. To determine the acceptability of a locomotive for operation in U.S. railroad service.

2. To characterize the dynamic performance of a locomotive under a variety of operating conditions.

In particular, the following questions might be addressed:

1. What combination of train speed, train handling, and track geometry (or class) result in the "worst" (i.e., most critical from a safety, comfort, and/or track and vehicle degradation point of view) dynamic performance of the locomotive in each train consist of interest?

2. Can the particular cause of any unsatisfactory behavior be determined?

II. Selection of Performance Criteria and Evaluation Parameters (dependent variables)

Performance criteria are required to assess the acceptability or comparative merit of a given locomotive design. Performance criteria can be related to safety, operator comfort, track maintenance, and vehicle maintenance. Current criteria suffer from lack of knowledge of quantitative limits for safety, comfort, and maintenance. Thus, it may be necessary to judge performance on the basis of a comparative evaluation with other locomotives.

Possible evaluation parameters for various performance criteria are suggested below:

[excerpted from Battelle letter report]

A. Safety

1. Wheel climb (L/V individual wheels--angle of attack and load duration are also important)
2. Rail rollover (L/V forces all wheels each side of truck)
3. Track lateral shift (L/V axle forces)
4. Vehicle overturning ($\frac{\Delta V}{V}$ individual wheels)

B. Operator Comfort

1. Cab acceleration and jerk (3 axis)

C. Track Maintenance

1. Rail wear (vertical and lateral W/R loads at curves, rail joints, switches)
2. Track surface deterioration (vertical wheel loads)
3. Track alignment deterioration (lateral, L/V wheel loads)
4. Gage deterioration

D. Vehicle Maintenance

1. Axle accelerations (3 axes)

III. Identification of Parameters Influencing Performance (independent variables)

What parameters (in addition to the evaluation parameters) must be selected, controlled, or (at least) monitored in order to evaluate the locomotive performance data and determine "worst cases" as well as possible causes? A partial list of such parameters includes:

1. Operating speeds
2. Train handling (accel. or braking)
3. Train consist (very important for freight service, but not for passenger service).
4. Track geometry
5. Track impedance (vertical and lateral)
6. Environmental conditions (temperature, rain, etc.).
7. Wheel profile and gage
8. Rail profile (in problem areas)

IV. Design of Testing Strategy

The measurement program must be designed to accomplish the objectives and to provide statistically significant data. This requires that the following issues be addressed:

1. How many locomotives should be instrumented? Assuming the answer is 1 (or an insignificant number from a statistical point of view) how can one demonstrate the "typicalness" of the selected locomotive (i.e., in comparison to other locomotives of the same nominal design)? One way would be to instrument one or more sections of track (perhaps at "critical" locations) and monitor the W/R loads resulting from each locomotive of the selected type. This would provide a distribution of W/R loads due to this type of locomotive under known operating conditions. Comparison of the W/R loads, measured on the instrumented locomotive while passing over the instrumented track section, with the wayside measured distribution would indicate the "typicalness" of the instrumented locomotive.

2. Is train consist going to be a variable in the measurement program? If so, what train make-ups are to be considered? How many locomotives are to be used in the train? Which locomotive (1st, 2nd, 3rd, ...) will be instrumented?

3. For the selected locomotive, which wheels, axles, or trucks will be instrumented?

4. Having selected the locomotive and consist, what strategy should be used to identify "critical" or "worst" cases? Should the locomotive travel over the "whole universe" under normal operating conditions; over selected track sections many times at various speeds; over a particular track anomaly for a variety of train handling situations? [This item is essentially concerned with selection of test sites and operating conditions].

5. How many miles of track and how many locomotives are required to define a statistically useful sample? (See, for example, Reference [12], pp. 159-164, 180).

Suggestions addressing some of the above questions are given below: [excerpted from Battelle letter report]

1. Test Site Selection

A. Cover spectrum of operating speeds typical for bolted and CWR track to select specific track sections for more detailed evaluation and repeated runs.

   1. Maximum speeds (unbalance) on tight curves (curving forces)
   2. Rough track (cover operating speed range to identify resonant conditions)
   3. High-speed tangent track (hunting evaluation)

B. Evaluate sensitivity of vehicle operation to regional differences in track geometry (NEC runs tighter gage - problem with uni-point wheels)

C. Evaluate vehicle under severe track geometry conditions based on known dynamic response characteristics for vehicle and one or more specific track anomalies representing track class limits. Combinations of maximum allowable deviations in cross-level and alignment together with specified phasing and wavelength characteristics are not adequately covered by track geometry standards, and represent critical excitations for locomotives.

(General Comment: Difficult to satisfy all interested parties that a complete evaluation has been accomplished.)

2. Train Operations

   A. Cover entire operating speed range plus overspeed to insure adequate margin for engineer error.

   B. Cover power, drift and braking.

      1. Dynamic and independent air braking retard only locomotive and cause compressive draw bar forces.

      2. Train air braking causes tensile draw bar forces.

   C. Train handling on curves and grades is critical problem for freight operations - secondary importance for passenger operations.

   D. Repeated runs needed to check repeatability of load measurements for selected worst case conditions.

3. Track Instrumentation

   A. Selected locations identified from runs on revenue track

   B. Artificial track geometry irregularities

   C. Track instrumentation used to verify accuracy of vehicle instrumentation and to record data for other locomotives as base for comparative evaluation

   D. Track instrumentation can also supplement vehicle instrumentation where only 1 axle or 1 truck is instrumented.

V. Instrumentation Requirements and Selection

Instrumentation requirements must address themselves to, at least, the following:

1. Frequency response
2. Anticipated amplitude range
3. Temperature range (thermal sensitivity of transducers as well as operating range)
4. Reliability (need for extended field use)
5. Operational constraints (size, electrical shielding, etc.).

Discussion of some of the above requirements and a review of both vehicle - and track-borne instrumentation for the measurement of wheel/rail loads is described in Ref. [12] (pp. 35-42, 53-92, 132-153, 164-175) and Ref. [13] (pp. 13-24, 28-39).

Some suggestions for vehicle instrumentation are included below: [excerpted from Battelle letter report].

A. Instrumented Wheels (V, L and ΔV)

1. All wheels on one truck needed for safety criteria
2. Instrumentation of both trucks is a second priority choice
3. Continuous versus sampled V & L force measurements
4. Frequency response compatible with safety criteria

B. Coupler Forces and Angle

1. Needed for evaluating train handling with freight locomotives
2. Low priority for passenger trains

C. Cab Accelerations (Operator comfort and model validation)

1. Indicates operating margins relative to stress (suspension stops, axle clearances)
2. Used for diagnosis of unacceptable operating conditions.

E. Complete Track Geometry Package

1. Chordal system attenuates long wavelength geometry irregularities ($>$100 ft.) that are suspected critical for locomotive response.

VI. Calibration Procedures

Dynamic calibration should be considered if the required frequency range for W/R load data extends above about 5 Hz. A comparison of vehicleborne and trackside W/R load data would provide a useful cross-check of both systems. (See discussion in Ref. [13], pp. 44, 45, 48-53).

VII. Data Recording, Reduction, and Presentation (Documentation)

The test planning should, where possible, be brought to the point of indicating how the data will be recorded, reduced, and presented. This should help in determining whether the planned measurements are likely to provide answers to the original objectives. It will also be useful in avoiding an accumulation of unnecessary data. Various formats for presenting W/R load data are described in Ref. [12], (pp. 56-101, 154-159) and Ref. [13] (Table 2-1, p. 4). Specific suggestions for data recording and reduction are presented below: [excerpted from Battelle letter report]

1. Data Recording

A. On-board read-out of critical L/V's for wheels and trucks as related to performance criteria (time histories)

B. On-board read-out of track geometry parameters (time histories)

C. All data recorded on magnetic tape for later analysis/reproduction

D. Cab acceleration read-out directly or from ride quality package giving ride index.

E. Real time level monitoring of critical W/R load signals and track geometry signals to insure specific locations of abnormal conditions do not go undetected during test.

2. Data Reduction and Analysis

A. Data reduction formats selected for direct comparison with acceptability criteria (L/V vs. time duration vs. number of occurrences)

B. Data formats selected for comparison with any available analytical models (PSD, average curving forces etc.)

Related Bibliography

[References 1 thru 11 excerpted from Battelle letter report]

1. Amtrak data from previous SDP40F evaluations conducted in Illinois during spring of 1976.

2. EMD data on many different locomotives (proprietary?)

3. Dolecki, E. A. and Hartzell, C. E., "Optimization and Ride Quality - 3 Axle Floating Bolster Truck" GE Report No. DF74LC2690 (Proprietary Class 3), February 8, 1974. (Tests of E60CP truck with U30C locomotive)

4. Amtrak/Ensco test reports on NEC E60 tests.

5. Data from current Amtrak evaluation of ASEA locomotive.

6. EMD published reports on locomotive curving forces.

7. Konishi, S., "Measurement of Loads on Wheel Set", Japanese Railway Engineering, Vol. 8, No. 3, September, 1967, pp 26-30.

   A method for measuring the loads and stresses on a wheel set is outlined. The Japanese National Railway operation schedules are determined based on yearly field tests of running safety by measurements of the derailment quotient (side thrust/vertical load). Field measurements of the loads on a wheel set include the lateral force, the vertical force, and the tangential force in the longitudinal direction acting between the wheels and rails. The paper describes measurement techniques using wire strain gauge bridges on either a spoked or disc wheel. The bridge signals are transmitted to an amplifier in the vehicle using a silver-copper-cadmium slip ring attached to the axle box.

8. Anon., Question B10, Constructional Arrangements for Improving the Riding Stability and the Guiding Quality of Electric and Diesel Locomotives and Vehicles, Interim Report No. 11: A comparison of the methods of measuring on the track and on wheels the lateral forces (Y) and vertical loads (Q) caused by rolling stock traveling round a curve at Vallorbe, 1962, ORE, UIC, Utrecht, October, 1964, B10/RT11/E.

9. Olson, P. E., and Johnson, S., "Lateral Forces Between Wheels and Rails - An Experimental Investigation", ASME Paper No. 60-RR-6, April, 1960, Available in Anthology of Rail Vehicle Dynamics: Vol. III - Axles Wheels and Rail-Wheel Interaction, edited by S. G. Guins and C. E. Tack, ASME, 1973, pp 253-261.

10. Koci, L. F., and Marta, H. A., "Lateral Loading Between Locomotive Truck Wheels and Rails due to Curve Negotiation", ASME Paper No. 65-WA/RR-4, November, 1965, Available in Anthology of Rail Vehicle Dynamics: Vol. III - Axles, Wheels and Rail-Wheel Interaction, edited by S. G. Guins and C. E. Tack, ASME, 1973, pp 119-129.

Curve-negotiation mechanics and forces resulting when locomotive trucks negotiate curves are well recognized. Recent theoretical analysis has made possible analytic explanation of such curving phenomena. However, meaningful and reasonable prediction of forces resulting in service conditions has been limited owing to the lack of experimental data pertaining to the friction-creep relation between railway wheel and rail. An instrumented wheel-axle assembly was developed and used on 2,3, and 4-axle trucks to study the effect of creep and the transverse load reactions resulting between wheel and rail. Instrumentation was used to measure these forces and the reactions between axles and truck frame under operating conditions. Test results confirm predicted phenomena and indicate the effect of creep on resulting loads. This paper includes a brief and general review of curve-negotiation mechanics and presents the test results and their relation to the theoretical analysis.

11. Peterson, L. A., Freeman, W. H., and Wandrisco, J. M., "Measurement and Analysis of Wheel-Rail Forces", ASME Paper No. 71-WA/RT-4, December, 1971.

This paper describes a method used to continuously measure, record, and analyze the lateral and vertical forces between wheels and rails of several types of railroad freight cars under a variety of car and track conditions. The method, using analog-to-digital conversion and computerized data handling, has produced results relating to a multitude of car and track behavior subject areas. Especially important is the definition, development, and verification of performance "signatures" which are generated in a unique and characteristic manner by each car in negotiating a given curve. The finding of such "signatures" to be completely reproducible and yet sensitive enough to change with relatively minor track or car component variations, i.e., modifications, supports the belief that these techniques can be applied beyond pure experimental scopes into routine (a) trackside inspection of cars in passing trains; (b) mechanized track inspection; and (c) truck design evaluation.

12. Ahlbeck, D. R. et al, "Evaluation of Analytical and Experimental Methodologies for the Characterization of Wheel/Rail Loads", Rept. No. FRA-OR&D-76-276, Aug. 1976 [to be published].

13. Ahlbeck, D. R. et al, "Pilot Study for the Characterization and Reduction of Wheel/Rail Loads - Field Measurement and Data Reduction Plan", Planning Report (unpublished), June 1976.

PREFACE

This report was prepared by Battelle's Columbus Laboratories (BCL) and the IIT Research Institute (IITRI) under Contract No. DOT-TSC-1051 as part of the Improved Track Structures Research Program managed by the Transportation Systems Center (TSC). This program was sponsroed by the Office of Rail Safety Research, Improved Track Structures Research Division, of the Federal Railroad Administration, Washington, D.C.

The overall objective of this contract is to apply existing data, analyses and instrumentation to develop a characterization of wheel/rail loads for U.S. railroads and to evaluate strategies for the reduction of these loads. In this report the field measurement and data reduction plan for obtaining needed wheel/rail load and track response information is outlined.

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PILOT STUDY FOR THE CHARACTERIZATION AND REDUCTION OF WHEEL/RAIL LOADS
CONTRACT NO. DOT-TSC-1051

FIELD MEASUREMENT AND DATA REDUCTION PLAN

1.0 OBJECTIVES

The field measurement and data reduction phase of the overall wheel/rail load characterization program will fulfill two basic objectives:

- To provide a comprehensive description of the wheel/rail loads to which the specific track sites and test vehicle are subjected, and
- To provide sufficient data to validate a prediction methodology capable of extrapolating wheel/rail load data to alternate track, vehicle, and operating conditions.

Because the loads measured from the track and from the vehicle are fundamentally different in character, the specific objectives of measurements from the two points of view are somewhat different. The primary objectives of the trackside measurements in this pilot study are:

- To define the statistical characteristics of wheel/rail loads and track dynamic response under revenue traffic,
- To provide wheel/rail load and track dynamic response time-histories for validating wheel/rail load prediction models,
- To determine typical track vertical and lateral deflection characteristics under static and dynamic wheel/rail loads,
- To demonstrate and evaluate the performance of track and vehicle-borne wheel/rail load measurement systems by comparison of simultaneous track and vehicle-borne measurements.

The primary objectives of the vehicle-borne measurements are:

- To provide sufficient data in time-history, power spectral density, and amplitude statistical formats for validation of the load prediction methodology,
- To define the statistical characteristics of the wheel/rail loads of the test vehicle over a range of track conditions,
- To characterize the test vehicle parameters for the load predictive vehicle/track models,
- To demonstrate and evaluate the performance of the vehicle-borne measurement system.

As the end-product of the field measurement and data reduction phase of this program, a complete set of data will be generated describing the wheel/rail load environment from both the vehicle and trackside locations, presented in time-domain, frequency-domain, and amplitude statistical formats required for both load characterization and load predictive model validation.

2.0 BACKGROUND

A characterization of the rail loading environment is a key factor for all aspects of improved track performance. The quantitative description of rail loads will be used as inputs to other concurrent programs on cross-tie track improvement, rail stress analysis, and rail failure prediction, as well as for other research and testing of rail and track structural components. A preliminary characterization of the wheel/rail load environment was included in the Interim Report [1] using published results of a number of load measurement programs. However, these results often lack sufficient detail on the measurement conditions, or the formats in which results are presented cannot be used directly to validate a load-predictive model or to analyze track strength or fatigue life. The field measurement and data reduction phase of this program is intended to fill in some of the noticeable gaps in the present W/R load characterization to provide a more comprehensive description of the load environment and to provide data that can be used for model validation.

The measurement of wheel/rail loads from either trackside for a vehicle presents one dimension in what is basically a two-dimensional matrix. Wheel/rail loads at each track site consist of a series of pulses for each passing vehicle, and these loads encompass a full range of rail vehicle types and condition. Wheel/rail loads on a specific vehicle are continuous, fluctuating forces covering a broad spectrum of track conditions. Data from a number of combinations of track sites and vehicles would be needed to completely fill the matrix using measured data. However, available analytical procedures provide a more efficient method for characterizing a wide range of conditions once the analytical procedures have been validated by measurements.

Data formats recommended for the presentation of wheel/rail loads and associated response measurements (tie plate loads, deflections, accelerations, etc.) are summarized in Table 2-1 under the three generic data categories: the time-domain (time history), frequency-domain (power spectral density or amplitude spectra), and amplitude statistical descriptions. Some of the specific uses of data in these formats are also listed in the table.

A characterization of the amplitude statistics of wheel/rail loads and track response measurements will combine the statistical variations due to several distinct causes:

- The vehicle population (statistical characteristics of the train consists, which may vary by the day of the week or seasonally)
- Variations in vehicle parameters within one class of vehicle (manufacturing tolerances, maintenance level)
- Variations in operating techniques (train speed, train handling)
- Variations in ambient conditions (wet rail vs. dry rail, for example).

Spatial variations can also influence the measurements, resulting in some uncertainty in the statistical characterization of results from a single location. These include:

- Constructional variations within an otherwise uniform section of track
- Track dynamic impedance variations from one location to another or from one season to another (ambient changes)
- Track geometry deterministic or random variations.

TABLE 2-1. FORMATS FOR PRESENTATION OF WHEEL/RAIL LOAD CHARACTERIZATION DATA

Category	Data Format	Uses of Data in Format
Time Domain Description	Load Time History (Vehicle-Borne Measurements)	Validation of vehicle model in response to track geometry and operating conditions Prediction of W/R load variations along track in response to track geometry Evaluation of dynamic transient response to track geometry anomalies
	Load Time History (Wayside Measurements)	Validation of track model in response to vehicle passage Prediction of track component loads, stresses and deflections due to vehicle passage Evaluation of track dynamic response to track or wheel geometry anomalies
Frequency Domain Description	Power Spectral Density vs. Frequency (speed/wavelength)	Validation of vehicle-track model by comparison with vehicle-borne measurements Evaluation of important vehicle/track resonances and system response to track geometry
	Load Spectral Peak vs. Wavelength and Speed	Prediction of discrete differential settlement in response to random or periodic excitation for specific vehicle and speed (operating condition)
	Static plus One-Sigma (or 3-Sigma) Load vs. Speed	Validation of W/R load-predictive model by comparison with vehicle-borne measurements Description of fatigue-related W/R load environment for predicting track degradation and failure
Amplitude Statistics	Load Probability Density and Cumulative Distribution	Statistical description of W/R load experienced by vehicle over range of track conditions Statistical description of W/R loads experienced by track under range of vehicles and operating conditions Description of W/R loads for cumulative damage calculations and laboratory fatigue tests
	Load Mean and Variance	Statistical indices for description of W/R load environment Description of loads for cumulative damage calculations and laboratory fatigue tests Estimates of track degradation and failure for track, vehicle, and operating parameters
	Load Joint Probability Density	Statistical description of joint occurrence of loads (L/V vs. V, Transverse moment vs. V, etc.) Definition of biaxial load environment for track component and design laboratory test

The choice of the number of measurement locations for achieving a desired statistical confidence level with regard to spatial variations can be influenced by several of these factors. The dynamic loading of uniform tangent track can be assumed to be randomly distributed along the track, with equal probability of peak loads occurring at any given point. Therefore, the effect of spatial variations from track geometry or construction on wheel/rail loads is minimal. If a significant track geometry disturbance is present in the immediate vicinity, however, the spatial location of the peak loads is then deterministic rather than random, and the location then depends on the vehicle/track response to the geometry error. In this case, measurements made at a single point in the track are not sufficient to characterize spatial variations in the load environment, and several measurement points must be chosen based on vehicle/track response wavelengths and desired spatial resolution.

Wheel/rail load measurements from vehicle-borne transducers provide a means for monitoring load variations caused by track geometry and dynamic stiffness variations. The measured loads, however, are quite specific to the particular test vehicle. While the load environment for a variety of random or deterministic track conditions may be characterized from the vehicle, the resulting characterization is unique to the geometry, masses and suspension parameters of this vehicle. For this reason, wheel/rail loads from the vehicle will be used primarily to validate the load-predictive models, and to establish the variance in loads due to spatial variations in track geometry and stiffness. Wheel/rail loads from track measurements will be used primarily to characterize the load environment due to variations in vehicle population and train handling, and to provide a common point of reference between track and vehicle-borne load measurements. The choice of a 100-ton open-top hopper car as the test vehicle provides wheel/rail load data from a vehicle representative of a substantial population of cars in current service.

3.0 TEST SITE CRITERIA AND TEST FACILITIES

3.1 Wayside Measurement Test Sites

Based on the discussion in Section 2 of the Interim Report [1], three wayside measurement test sites are recommended for this pilot study, two on high-speed tangent track, the third on curved track. Wayside measurements of wheel/rail forces generated in the vicinity of a discrete geometry error (specifically a low rail joint) have a low priority for track instrumentation and are not included in this plan. However, measurements of wheel/rail loads from low joints and other discrete track anomalies will be made using the vehicle-borne measurement system.

3.1.1 Tangent Track Site

A high-speed tangent track of good geometry (Class 5 or 6 as defined by the Track Safety Standards) is recommended for one wayside site. This site is intended to have minimal spatial variation effects on wheel/rail loads. The track should be of uniform tie and ballast conditions with CWR or 78-ft bolted rail with high-quality joints, with no culverts, grade crossings, turnouts or other track anomalies within 500 ft of the primary measurement location. This length will provide at least four damped oscillations[*] at the highest expected train speed and lowest rigid-body frequency prior to the measurement point. General freight traffic of at least 20-30 MGT/yr density on a single track, with a speed limit of 65-70 mph is recommended.

3.1.2 Secondary Tangent Track Site

A second high-speed tangent track site with somewhat rougher, but still random track geometry (as defined by the analysis of track geometry measurements) is recommended for additional tangent track measurements. This will provide a direct comparison of the effect of track geometry on wheel/rail loads, with other parameters as similar as possible. Site criteria noted in Section 3.1.1 are the same, and the track construction should be as similar as possible to provide a comparable track dynamic impedance at the two sites.

(*) Assume $f_n = 0.8$ Hz, $V = 70$ mph on tangent, $V = 40$ mph on curve.

3.1.3 Curved Track Site

A curved track of good geometry (Class 5 or 6 as defined by the Track Safety Standards) with 3° to 6° curves of long duration (400 ft or longer in the body of the curve) is recommended for the second wayside site. This track should also be of uniform tie and ballast conditions with CWR or 78-ft bolted rail with high-quality joints, with no culverts, grade crossings, turnouts, or other track anomalies within 300 ft* of the primary measurement location. The curve should be on a continuous grade of 1 percent or greater to determine the effects of both traction and braking-induced forces on lateral wheel/rail forces in the curve. General freight traffic of 20-30 MGT/yr density on a single track is recommended.

3rd

3.1.3 Site Logistics

Both tangent and curved track sites must be accessible by road, with a maintenance lane or road near the track and sufficient level parking space off the lane for an instrumentation van. The instrumentation van will be parked from 25 to 250 ft from the track centerline. Test sites should be within 50 miles of supply facilities (motel, stores, gas station, etc.)

3.2 Vehicle-Borne Measurement Test Sites

The length of a vehicle-borne test or "run" under a particular set of conditions (speed, etc.) is dependent on several conflicting requirements. These include, for example, finding a length of track with reasonably uniform characteristics of geometry, modulus and construction over its entire length. This "test track" must be of sufficient length to provide for averaging a statistically significant number of cycles of the lowest frequency of interest for developing power spectral density curves with good resolution. On the other hand, the test section length must also address the logistics of testing in terms of the number of runs at different speeds that can be made within a normal crew shift, without disrupting revenue traffic.

(*) Assume $f_n = 0.8$ Hz, V = 70 mph on tangent, V = 40 mph on curve.

Since integration time is inversely proportional to frequency bandwidth and the low-frequency range is of particular interest in the validation of the analytical model, integration time up to 5 minutes may be required. For this reason, test track lengths of 3 to 5 miles (or longer) will be needed. It is recommended that four sections of track be chosen as "test sections", 3 to 5 miles in length, with relatively uniform characteristics within each section. The test vehicle will then be run several times over each test section at constant speed, in 5 or 10 mph speed increments. Data will also be recorded on other portions of track, to and from the test sections, to sample a varity of track features. The wayside measurement site should be included in the appropriate test section.

3.2.1 Tangent Track Sections

A section of high-speed tangent track, 3 to 5 miles in length, with reasonably uniform characteristics and good track geometry (Class 5 or 6) is recommended for one test section. Track should be CWR or 78-ft bolted joint rail and grades should not exceed about 0.5 percent within this 3 to 5 mile section.

A second high-speed tangent track site of rougher track geometry (see Section 3.1.2), but still Class 5 or 6 track, is recommended to compare the effects of track geometry alone on the wheel/rail load characterization. A limited number of test runs can be made on this second section.

3.2.2 Curved Track Section

A section of track with a series of curves, preferably in the 3° to 6° range, and from 3 to 5 miles in length for the complete section, is recommended for a second test section. Grades over the complete test section are not important to test vehicle measurements, since the test vehicle brakes must be disconnected for strain gage thermal stability. Operation of the test vehicle in both directions should be considered. Track should be CWR or 78-ft bolted joint rail.

3.2.3 Branch-line Track Section

For a third test section, a branch-line track, secondary main or long siding with rougher track geometry (Class 3 or 4) is recommended, with 39-ft bolted joint rail or shorter cropped rail lengths. This section may include both tangent and curved track, and should be between 10 and 30 miles in length.

3.2.4 Test Section Accessibility

Test sections will be located within a reasonable distance from terminal (engine and crew) facilities, based on railroad operating requirements. Track accessibility (track time) will depend on local traffic patterns, and consideration will be given to the location of sidings convenient to the test sections to clear the main line for revenue traffic. The need to run the test train in both directions (at least for the curved track section) makes it necessary to "wye" the train at some convenient location.

3.3 Test Facilities

3.3.1 Instrumented Freight Car Truck

The vehicle-borne load measurement system is designed to measure wheel/rail loads in two frequency ranges, designated the low- and high-frequency ranges. The low-frequency measurement system will record vertical loads on the right and left pairs of wheels and lateral loads on the lead and trailing wheelsets over a frequency range of 0 to 10 Hz. Transducers for these measurements will consist of strain gages on the truck side frames and axles. For measurement of higher-frequency forces over a range of 0 to about 100 Hz, an extensive array of strain gages will be applied to one wheel of the instrumented truck.

The load measurement system will be applied to a 100-ton capacity freight car truck with 6-1/2 x 12-in. journals and 36-in. diameter wheels with new or slightly worn profiles. Because of the demonstrated importance of wheel profile in freight car dynamic response (particularly in the hunting modes), the wheel profiles will be carefully documented prior to the tests. Instrumented wheelsets will be shipped to the car maintenance facility nearest to the test sites for assembly with other truck components. Strain gages will be applied to the side frames at this time. Because thermal strains will interfere with the wheel/rail load measurements, the tread brakes on the instrumented truck will have to be disabled during the test runs.

3.3.2 Instrumentation Car

During the test runs the instrumentation and data recording system will be transported in an instrumentation car coupled adjacent to the instrumented freight car truck. Space requirements for housing the equipment are as follows: the electronic modules are mounted in standard low rack cabinets (maximum 42 inches high), and the tape recorders and oscillograph are laboratory type and will mount on a bench. Approximately 45 square feet (18 ft x 2-1/2 ft) of bench space will be required with at least 42 in. of head space above bench level. Alternate floor mounted racks for the electronic equipment can be used, provided that adequate tie down points are available. The minimum power required is 5 kw at 120 v ± 10%, 50 to 62 Hz.

3.3.3 Test Vehicle

A 100-ton capacity open-top hopper car will be required as the test vehicle. This should be a car with 3300 to 3900 cu ft capacity with a truck center spacing of 37 to 41 ft. Crushed stone or ballast is suggested as a load, although other materials may be acceptable. The second truck on this car should have wheelsets with wheel profiles that are similar to the instrumented wheelsets.

3.3.4 Wayside Instrumentation Facility

An instrumentation van will be used to house the wayside instrumentation and data recording system. This equipment will provide self-contained power of roughly 6 kw for the system, as well as instrumentation crew facilities for 24-hr operation of the site. Air conditioning will maintain temperatures of 85° F or less to assure reliable operation of equipment and crew.

3.4 Railroad Support

The host railroad will provide support in terms of both equipment and personnel from both operating and engineering (maintenance of way) departments. Prior to the formulation of the Railroad Subcontract and a formal Test Procedures document, assistance will be required from test engineering and research and development personnel to coordinate site selection and to review the Test Plan.

3.4.1 Test Train Operation

The railroad will provide a test train consisting of a locomotive, test vehicle (100-ton freight car), instrumentation car, crew car (caboose), and whatever additional cars are required to compensate for the loss in braking capacity of the test car. In addition to an operating crew, a road foreman of engines and whatever additional supervisory personnel necessary will be needed to coordinate operations. It is estimated that the test train will be needed for 1 or 2 days at each test track section (4 total), plus an additional 1 day of runs with the test vehicle empty.

3.4.2 Wayside Test Site

The assistance of a track foreman and 1 or 2 additional men will be required at installation and tear-down of each wayside site (3 total). This will involve installation of instrumented tie plates in place of the standard 1:40, 14-inch plates, plus assistance in installation of the displacement measurement fixture. A track jack and other standard track tools will be required. A watchman will be needed during the preparation and installation of rail web strain gages. Since 24-hr operation of the site is anticipated, no watchman will be required for site security (assuming a high-vandalism area is not chosen).

3.4.3 Communications

Radio communications between the instrumentation car and the locomotive, and between the test train and the wayside site will be required. If possible, a telephone patch from the wayside site to the dispatcher's office will be provided to aid in identification of revenue traffic due at the test site, as well as coordination of the tests with the operating department. A system for advanced warning of trains is highly desirable. Recent Track Train Dynamics Program tests on the Union Pacific Railroad in Idaho used an annunciator and colored lights, patched into the CTC signal system with relays, to provide about 5 to 10 miles of warning (plus direction) of approaching trains.

In addition to standard communications, it is highly desirable that the wayside test site be provided copies of train consists for all revenue trains through the site during each 24-hr period of load measurements. This will aid in the identification of particular types of equipment passing the site for later statistical analyses of wheel/rail loads.

3.4.4. Test Vehicle Modifications

Assistance and facilities will be required to assemble the instrumented wheelsets and side frames with other components into a complete truck, and to place the truck under the test vehicle. Assistance will also be needed in loading and unloading the test vehicle, as well as in some phases of calibration and checkout of the vehicle-borne system (see Section 5.2).

4.0 TEST MEASUREMENTS

4.1 Wayside Measurements

Dynamic measurements recorded from wayside transducers have been selected to define the wheel/rail load environment at specific points in the track and to define the track dynamic characteristics under load. The recommended wayside measurements, discussed in Section 5 of the Interim Report [1], are summarized in Table 4-1, along with the desired recording bandwidth, maximum number of recorded channels, and a data priority level.

4.1.1 Vertical and Lateral Wheel/Rail Loads

Transducers for measurement of wheel/rail loads will consist of strain gage patterns applied to the rail web to measure vertical or lateral strain. Gage patterns for measuring lateral wheel/rail force are illustrated in Figure 4-1. For this application a weldable strain gage (attached to the web by a number of tiny spot welds along the gage case flange) will be used. The Ailtech SG129 Type 65 gage (with a temperature range of 0° to 180° F) is approximately one inch in length.

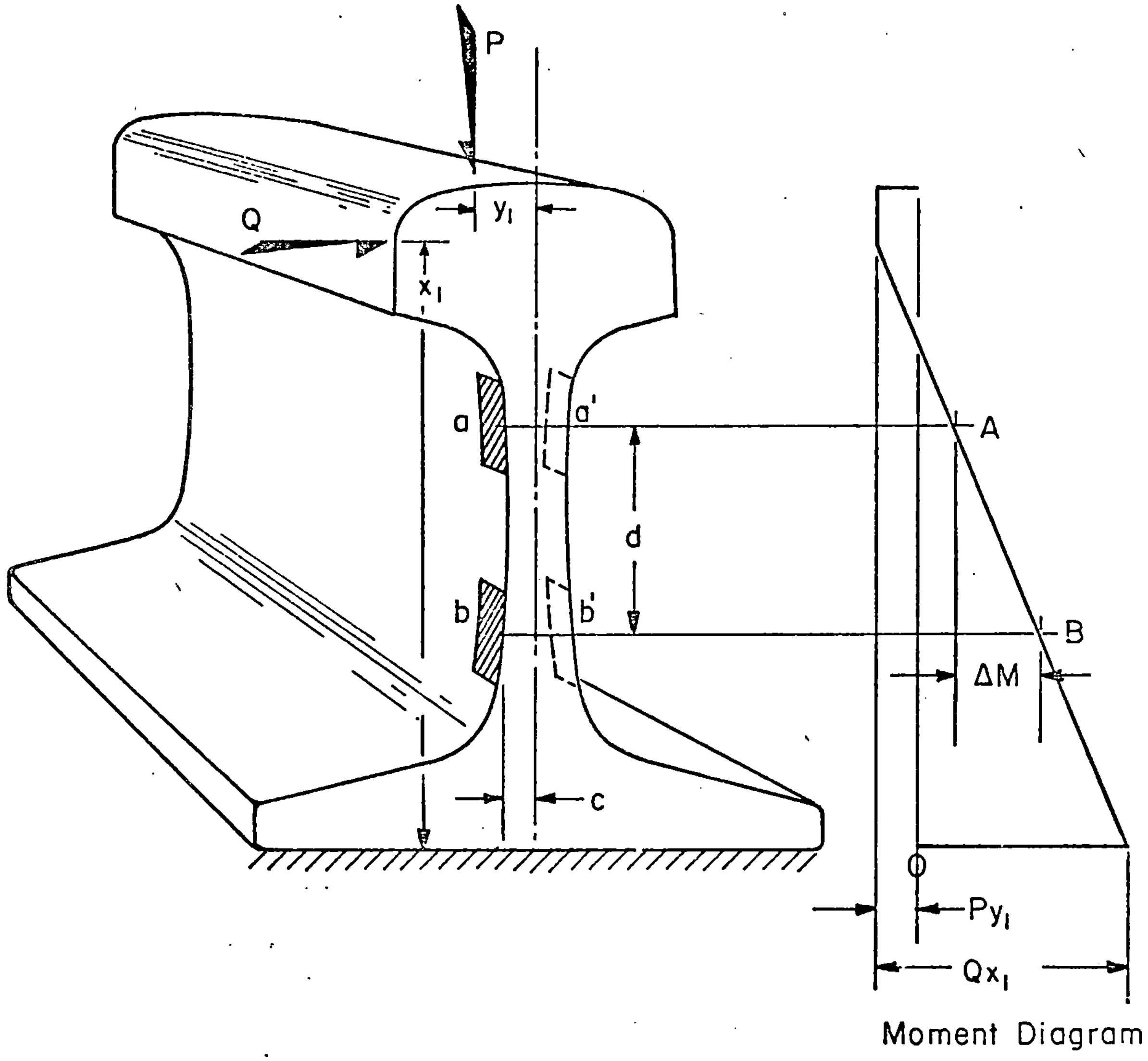
Measurement of vertical wheel/rail loads will use the strain gage patterns shown in Figure 4-2. Gages are placed in the chevron pattern about the neutral axis of the rail section as shown in the figure. Oriented at 45° to the neutral axis, the gages measure the principal normal strains due to rail shear force from the vertical wheel/rail load and act to cancel bending effects. A pair of gage patterns as shown, placed between two ties, will measure the vertical load (P) directly, while a pair bracketing a tie will measure the load minus the tie reaction (P-R). The "influence zone" for these gage circuits is limited to the zone between two gage patterns. This measurement "window" can be expanded by summing combinations of gage patterns and adding the tie plate load (R) when the wheel is over the tie. This concept is illustrated in Figure 4-3. A standard FET analog switch would be triggered by the load pulse (P-R) to add the tie plate signal at the proper time.

TABLE 4-1. RECOMMENDED WAYSIDE MEASUREMENTS FOR CHARACTERIZATION OF W/R LOADS AND TRACK DYNAMIC PROPERTIES

Measurement	Transducer*	Recommended Bandwidth	Anticipated Max. Range	Recorded Channels	Priority
Vertical W/R Load (sample)	RV_1 -- RV_{12}	DC-2000 Hz	+100K lb -0	9	I
Vertical Tie Plate Load	TP_1 -- TP_6	DC-100 Hz	+40K lb -0	6	I
Lateral W/R Load (sample)	RL_1 -- RL_6	DC-100 Hz	+50K lb -10K	6	I
Vertical W/R Load (continuous)	RV_3 -- RV_8 RP_2 -- TP_4	DC-2000 Hz	+100K lb -0	1**	I
Transverse Tie Plate Moment	TP_1 -- TP_6	DC-100 Hz	+100K lb-in -40K	6	III
Rail Vertical Abs. Deflection	ΔV_1	DC-100 Hz	+0.2 in (up) -0.8	1	II
Rail/Tie Vertical Deflection	ΔV_2	DC-100 Hz	±0.2 in	1	III
Rail Head/Tie Lat. Deflection	ΔL_3	DC-100 Hz	+0.5 in	1	II
Tie Lateral Abs. Deflection	ΔL_1	DC-100 Hz	±0.2 in	1	II
Rail Rotation	$\Delta L_3 - \Delta L_2$	DC-100 Hz	+0.1 rad -0.02	1**	III
Dynamic Gage	$\Delta L_3 - \Delta L_4$	DC-100 Hz	+0.5 in -0.2	1**	III
Rail Vertical Acceleration	AV_1	DC-2000 Hz	±500 g	1	II
Tie Vertical Acceleration	AV_2	DC-500 Hz	±50 g	1	II

* Refer to Figures 4-4,4-5.

** Overlaps with other measurement channels.



$Q \propto V$ (shear force)

$V = \frac{\partial M}{\partial X}$ (independent of P, x_1, y_1)

$$V = \frac{M_B - M_A}{d}$$

$$M_A = \left(\frac{EI}{cd}\right)\epsilon_A$$

$$V = \frac{EI}{cd}\left(\epsilon_B - \epsilon_A\right)$$

$$Q \propto (\epsilon_B - \epsilon_A) \text{ where } \begin{cases} \epsilon_A = \epsilon_a - \epsilon_{a'} \\ \epsilon_B = \epsilon_b - \epsilon_{b'} \end{cases}$$

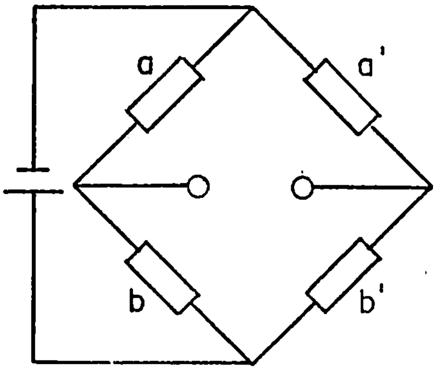
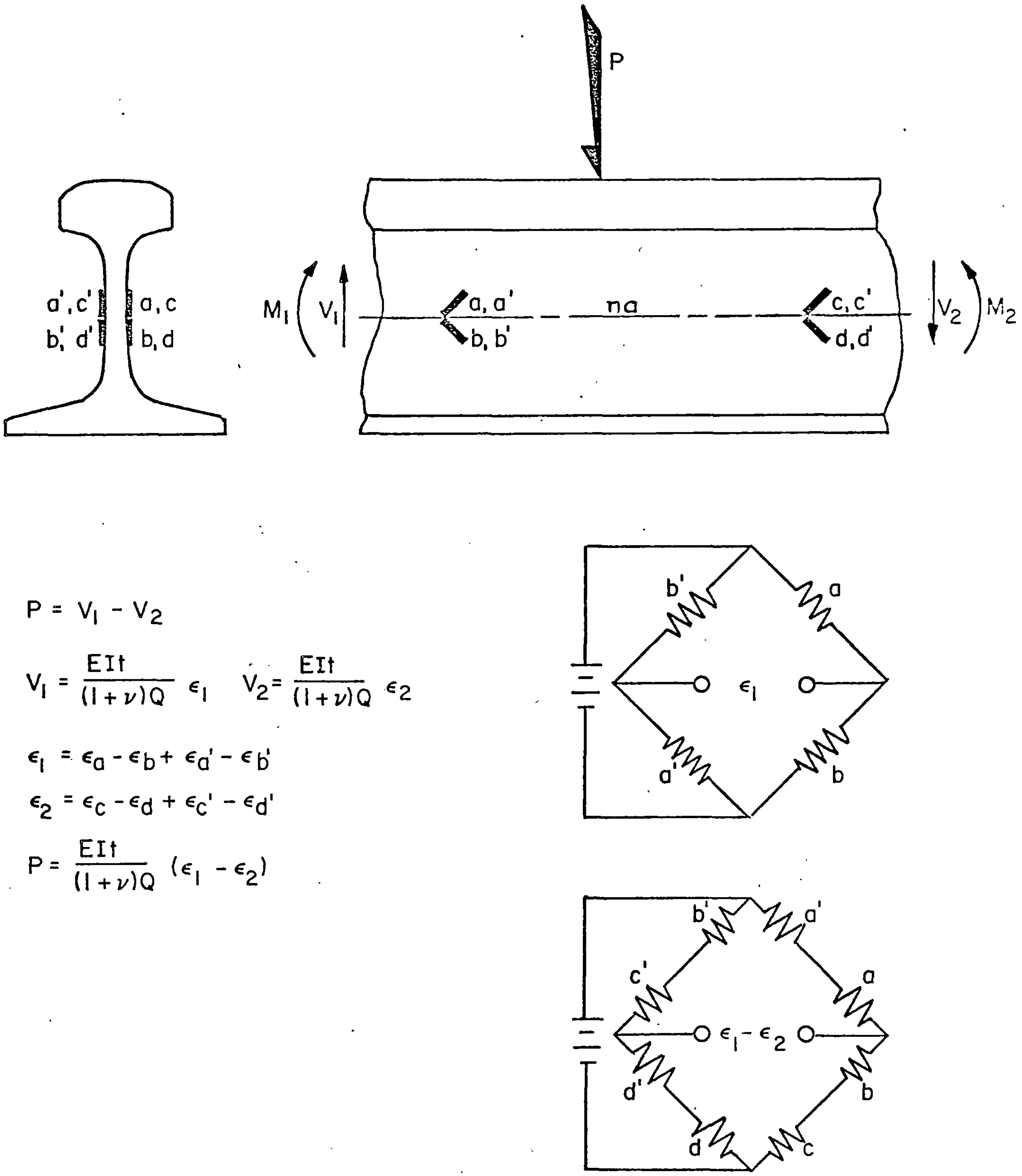


FIGURE 4-1. STRAIN GAGE CIRCUITS FOR MEASURING LATERAL WHEEL/RAIL LOAD



$$P = V_1 - V_2$$

$$V_1 = \frac{EIt}{(1+\nu)Q}\,\epsilon_1 \qquad V_2 = \frac{EIt}{(1+\nu)Q}\,\epsilon_2$$

$$\epsilon_1 = \epsilon_a - \epsilon_b + \epsilon_{a'} - \epsilon_{b'}$$

$$\epsilon_2 = \epsilon_c - \epsilon_d + \epsilon_{c'} - \epsilon_{d'}$$

$$P = \frac{EIt}{(1+\nu)Q}\,(\epsilon_1 - \epsilon_2)$$

FIGURE 4-2. STRAIN GAGE CIRCUITS FOR MEASURING VERTICAL WHEEL/RAIL LOADS

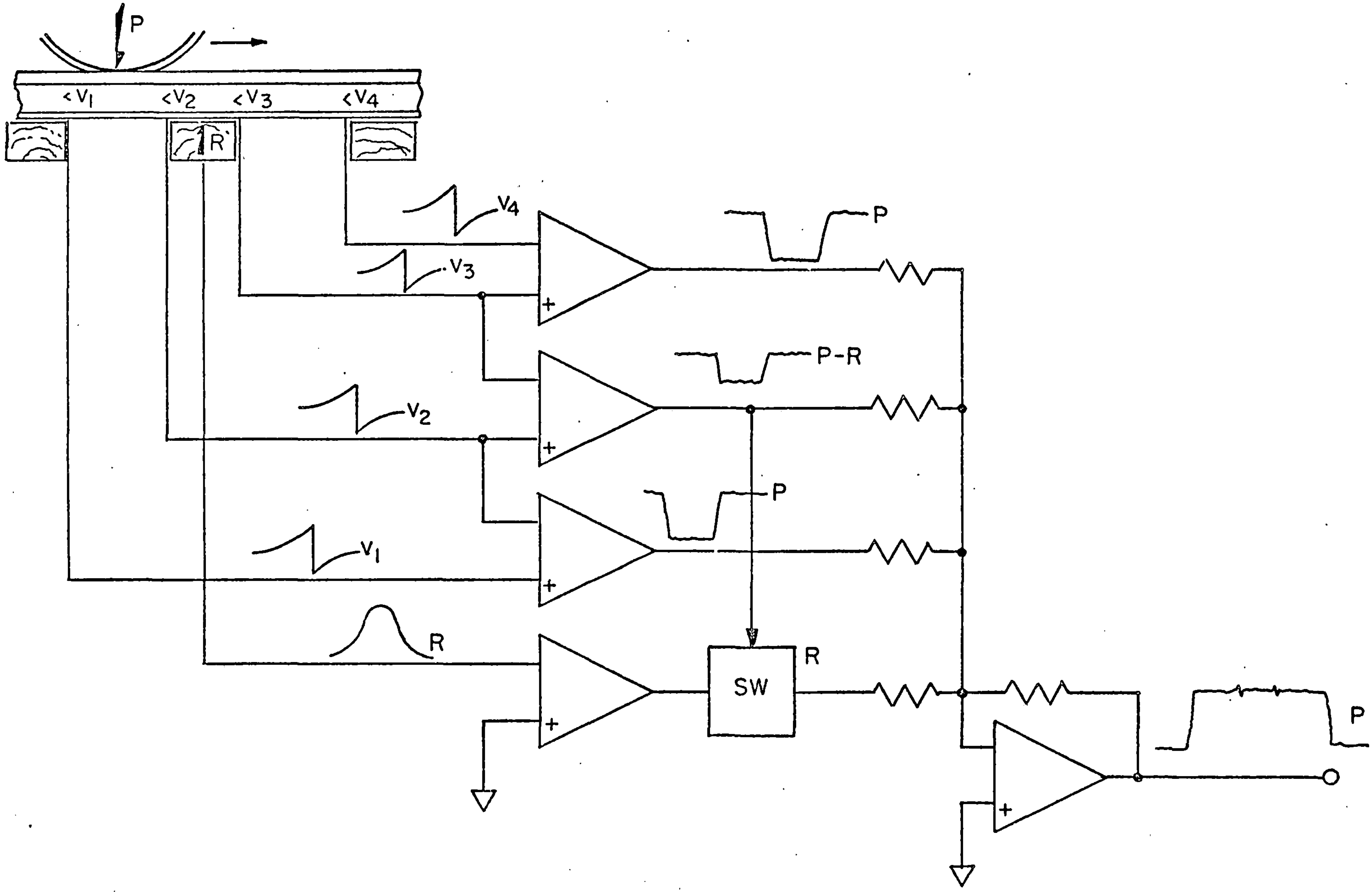


FIGURE 4-3. SWITCHING CIRCUIT FOR GENERATING CONTINUOUS VERTICAL WHEEL/RAIL LOAD SIGNAL OVER MEASUREMENT ZONE

4.1.2 Tie Plate Load and Moment

Vertical tie plate load and transverse moment between the rail base and the tie plate will be measured using instrumented tie plates of the type used in recent AAR-sponsored Track Train Dynamics Program studies. The tie plate consists of strain-gaged load cells supporting the rail base on a special plate machined to a standard 1:40 cant and fitting into the space envelope for a standard 14-inch tie plate. Vertical tie plate load is measured by summing the load cell signals, while transverse moment is measured by the difference of outer and inner cell signals. Vertical tie plate load will be used in conjunction with the vertical W/R load strain gage patterns to provide the extended load "window". In addition, the vertical tie plate loads will provide information on the distribution of load from the rail to the ties, as well as some statistical data on the tie load environment. Transverse moments will provide additional information on the nature of the wheel/rail loading (in conjunction with vertical and lateral whee/rail loads) in the transverse plans.

4.1.3 Rail and Tie Deflections

Several relative and absolute rail and tie displacements will be measured at the test sites. These measurements are needed to describe fully the upper track structural characteristics for validation of the track model and to determine track dynamic response to load. In order of decreasing priority, these deflection measurements are:

(1) Rail vertical absolute deflection -- used to define the track modulus and dynamic load/deflection characteristics.

(2) Rail head/tie lateral deflection -- used to measure track lateral stiffness characteristics under both lateral and vertical loading. Joint probability densities of lateral deflection, lateral load and vertical load can be developed using this measurement in conjunction with the simultaneous load measurements.

(3) Tie/ground lateral deflection -- data under revenue traffic to document the infrequent occurrence of lateral shift of the tie in the ballast.

(4) Rail rotation (difference of rail head and base lateral deflections) -- used to document the mode of track deflection for more detailed, future track model.

(5) Dynamic gage (difference of left and right rail head displacements) -- used to document track dynamic lateral response and to provide a reference to previous track response studies.

(6) Rail/tie vertical deflection -- used to define the relative stiffness or "slack" between the rail and tie.

These deflection measurements are shown in Figure 4-4, and a sketch of the installation used on the Track Train Dynamics Program is shown in Figure 4-5. A modified version of this fixture incorporating improved features will be used for these field measurements. Direct-current differential transformers (DCDT) will be used for the displacement transducers, mounted as shown in Figure 4-5 to a reference base attached to the tie. The DCDT cores will be attached to the rail through non-magnetic stainless steel ready rod, which is in turn screwed into phenolic blocks cemented to the rail. This arrangement provides both electrical and mechanical isolation from the rails.

4.1.4 Rail and Tie Accelerations

Representative measurements of vertical accelerations of the rail head and the tie near the rail seat will be made to allow an assessment of the frequency content and vibration amplitudes at these points in the track structure. A capacitance-type accelerometer will be used for this application (such as the Setra Model 114) to provide full frequency range of response -- DC to 2000 Hz for the rail, DC to 500 Hz for the tie --, as well as ease of calibration, mechanical overload protection, and electronics compatible with the rest of the measurement system.

4.1.5 Wayside Transducer Locations

The layout of track instrumentation recommended for this program is shown in Figure 4-6. The main instrument array consists of 5 consecutive ties

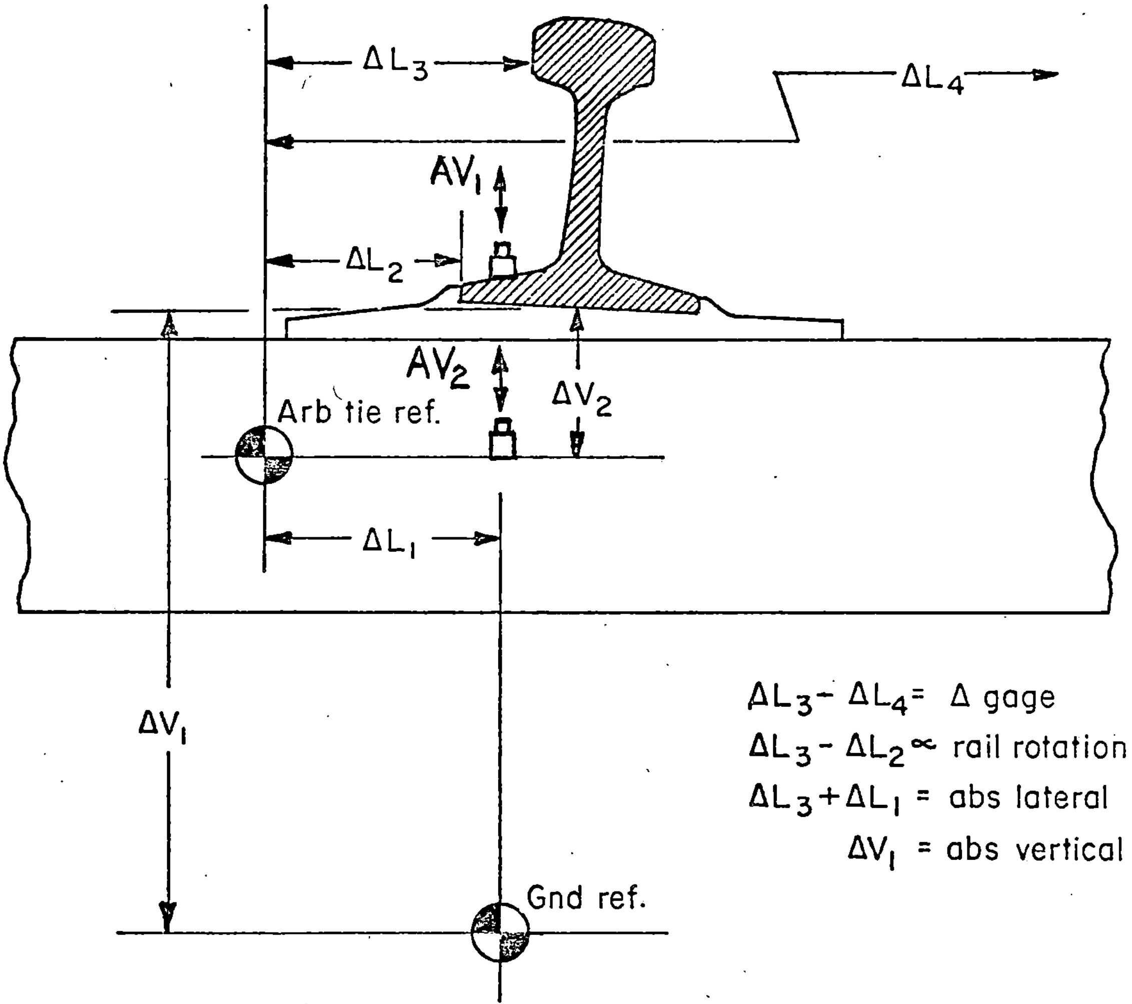


FIGURE 4-4. MEASUREMENTS OF RELATIVE AND ABSOLUTE DISPLACEMENTS NEEDED TO DEFINE UPPER TRACK STRUCTURE DYNAMIC RESPONSE TO W/R LOADS

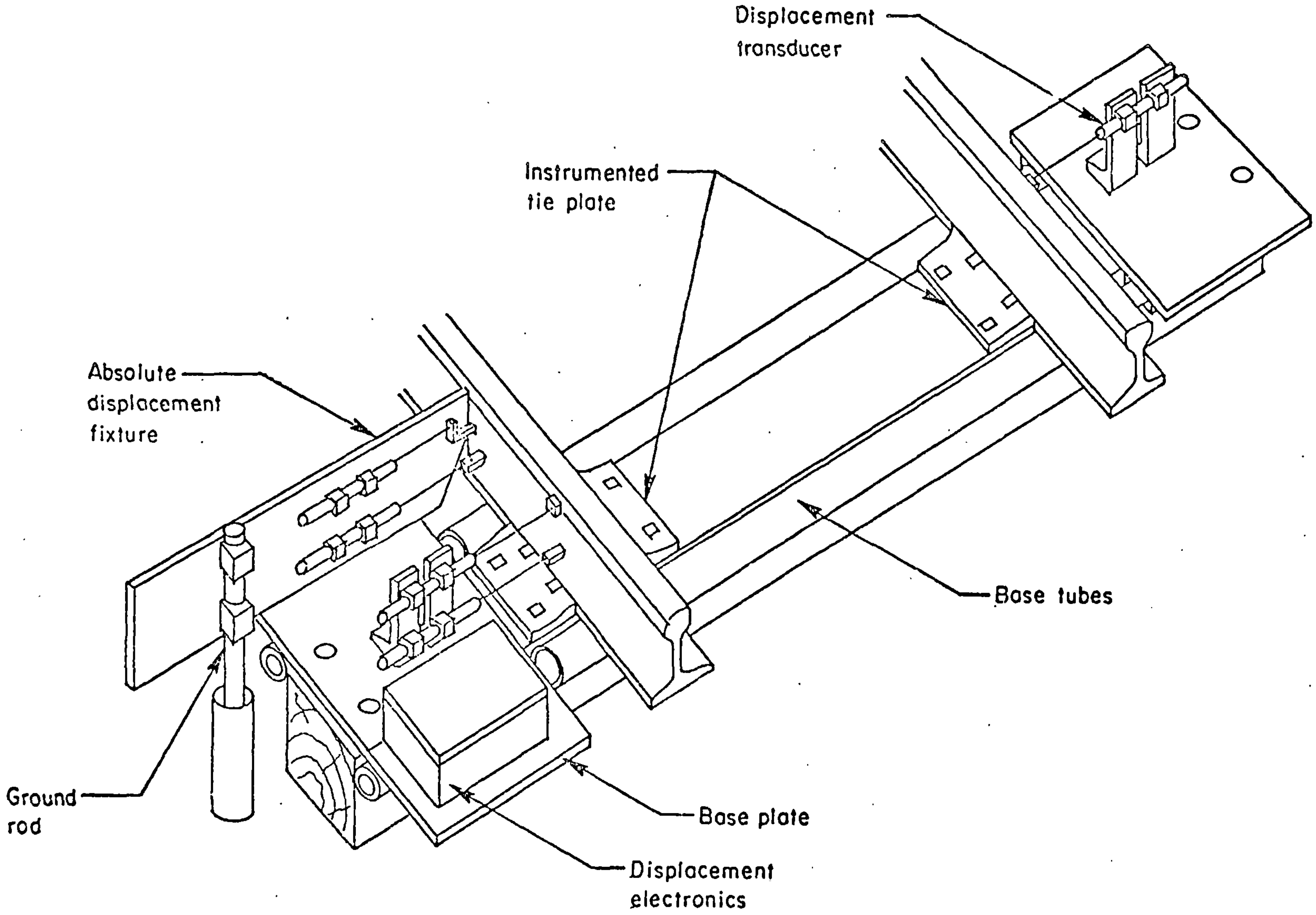
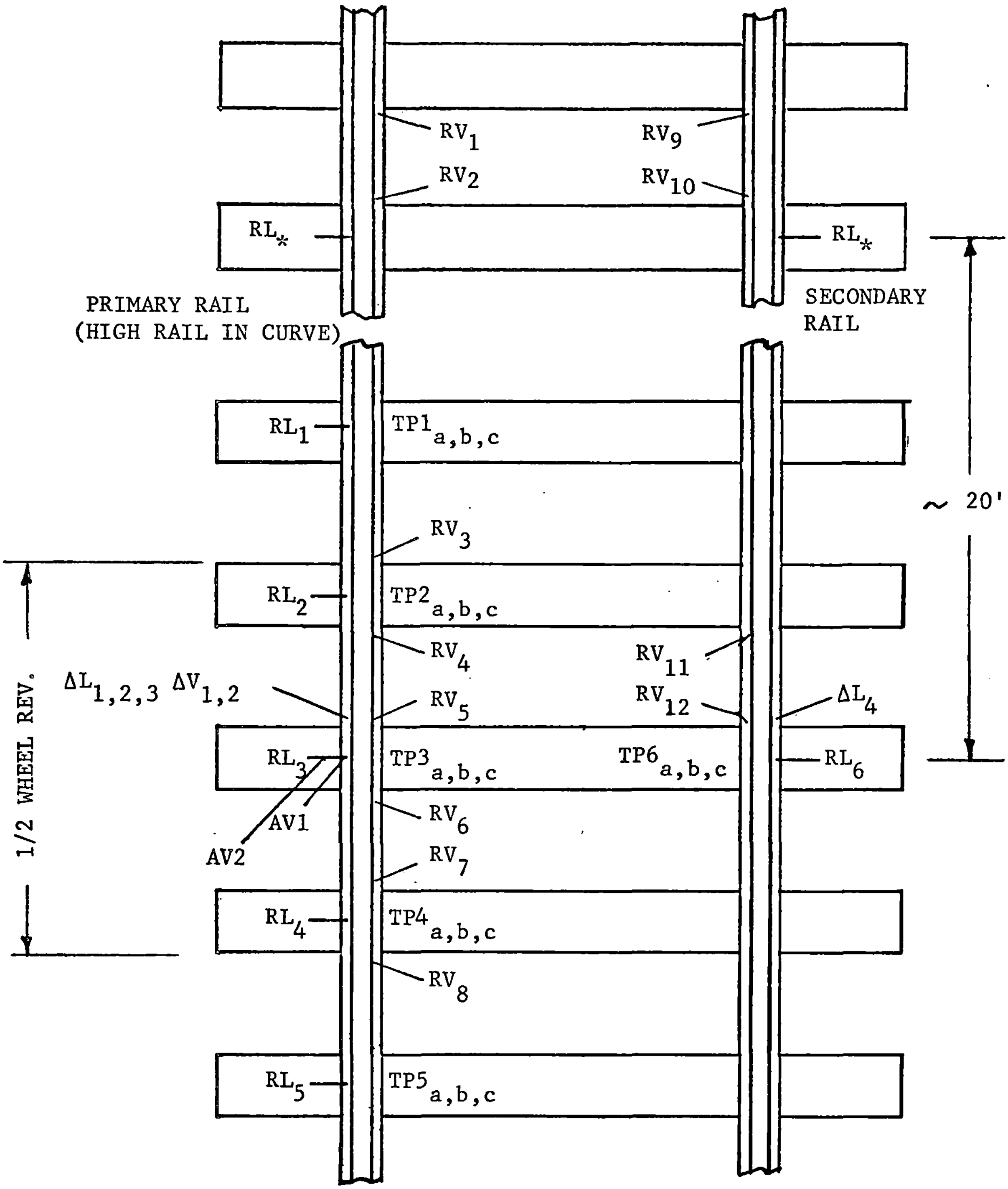


FIGURE 4-5. ARRANGEMENT OF TRANSDUCERS FOR TRACK DYNAMIC RESPONSE MEASUREMENTS IN WIDE GAGE STUDY

having instrumented tie plates and sets of vertical and lateral strain gage circuits distributed along the primary rail. The center tie in this array also has an instrumented tie plate and wheel/rail load circuits on the secondary rail. This tie will be used for deflection and acceleration measurements.

Selection of five ties for the main array is based on several considerations. First, the installation of five consecutive instrumented tie plates will remove any dimensional bias possibly introduced in rail support by substitution of the instrumented for standard tie plates. This will account for constructional variations within the five-tie zone, and will provide amplitude statistics for peak tie plate loads within an acceptable tolerance band for the desired confidence level. In addition, the five ties are estimated to support more than 90 percent of the wheel load when over the center tie. The deflected length of track (as a beam on an elastic foundation) is typically 8 to 7 feet for track moduli of 3000 to 5000 lb/in/in. Therefore load distribution and deflection in the vertical direction can be adequately defined by measurements over this 5-tie zone.

A continuous measurement of vertical wheel/rail load over one complete wheel revolution (113 inches for the test vehicle) is possible by combining gage patterns RV_1 to RV_{10} and tie plates TP_1 to TP_5, as originally shown in Figure 5-10 of the Interim Report [1]. Since the adjacent wheel (70-72 inches away) will simultaneously occupy the measurement zone part of the time, a more sophisticated switching arrangement would be required to separate the loads of each wheel. The recommended alternative shown in Figure 4-6 is to limit the measurement zone to one-half a wheel revolution (RV_3 to RV_8 plus TP_2 to TP_4, 50-60 inches in length), and use gage patterns RV_1, RV_2, RV_9 and RV_{10} for vertical load sample measurements on the right and left rails at a point some distance from the primary measurement site. It is recommended that this secondary measurement point be placed 15 to 20 feet away, approximately one-quarter wavelength of the important rigid-body oscillations (between 1 to 2 Hz) in the higher speed range. Lateral loads on the primary rail are sampled in sequence by transducers RL_1 through RL_5 in Figure 4-6 with time resolution from 20 to 100 milliseconds, depending on train speed. Peak loads at RL_1 and RL_4, or RL_2 and RL_5 will provide almost simultaneous total-truck lateral forces on the



RL = RAIL LATERAL LOAD GAGE CIRCUIT
RV = RAIL VERTICAL LOAD GAGE CIRCUIT
TP = INSTRUMENTED TIE PLATE
ΔL = LATERAL DISPLACEMENT (SEE FIG. 4-4)
ΔV = VERTICAL DISPLACEMENT " " "
AV = VERTICAL ACCELERATION " " "
* OPTIONAL LOCATION

FIGURE 4-6. LOCATION OF WAYSIDE TRANSDUCERS rail from a freight car. Peak loads at RL_3 and RL_6 will provide a sample of total wheelset lateral force. It is recommended that two additional lateral strain gage patterns be added to the rails at the secondary measurement site (15 to 20 feet away), and some data be recorded at this point.

4.1.6 Auxiliary Data

In addition to the dynamic measurements, certain auxiliary measurements will be required at the test site. Train speed can be calculated accurately from the oscillographic traces based on the distance/time relationship from the leading edges of vertical load pulses at two locations under the lead axle of the train. For long trains, speed will be calculated also under the trailing axle of the caboose. Time and date will be recorded on the magnetic tape from a time code generator, and logged manually onto a run description sheet for run location on the tape at a later time. Other data to be logged will include rail temperature (using a standard rail thermometer), the ambient temperature, rail surface condition (dry, wet, sanded, contaminated), and commentary on operating or test conditions.

4.1.7 Length of Test

Amplitude statistics, including mean value, standard deviation, probability density and cumulative distributaion functions, have been recommended for presenting the wheel/rail load environment. The number of data samples required from wayside measurements of revenue traffic is governed by the statistical requirements of the probability density function [2]. Statistical data from wayside measurements will consist of one peak value for each axle pass, so that the number of data samples is identically the number of axles. To generate a peak amplitude probability histogram, the load range must be established and divided into a minimum number of intervals (or "bins") compatible with the desired resolution for the statistical description. The number of data points in each interval divided by the total number of points would be calculated to give the probability histogram. The total range must be adequate to cover the desired low-probability events.

Different criteria may be used to establish the necessary number of intervals and data points. One criterion [3] recommends that each interval have at least 5 data points (although 2 may be acceptable in the last interval). The number of data points required for at least 5 values in the last interval within a specified number of standard deviations from the mean value (assuming a normal distribution) is shown in Figure 4-7. For example, data from about 1100 axles are needed using 12 intervals, and about 3000 axles using 24 windows, to define the $\pm 3\sigma$ load range. The data requirements would be reduced substantially by requiring only 2 data entries in the last interval, or by reducing the number of standard deviations.

A recommended number of intervals (K) required for N data points may also be based on applying a Chi-Square goodness-of-fit equivalence test between a hypothetical and measured probability density function [3]. If a 5 percent level of significance is assumed, the approximate relationship is:

$$K = 1.87\ N^{0.4}\ \text{intervals}$$

For the same number of data points, this relationship will recommend a greater number of load intervals for an hypothesis test; or conversely, for a given number of intervals, fewer data points are needed.

The length of the test then depends on traffic density (number of axles per day), the number of data categories (which may include speed intervals, vehicle categories, train handling conditions, track conditions), as well as the measurement range and desired resolution (number of intervals, K). Two basic track experiments are recommended: tangent and curved track. Other categories may be based on prior experience from the Track Train Dynamics Program experiments in Idaho and Southern California. These are:

(1) Vehicles -- Locomotives will be considered separately as a vehicle population with a high mean value and relatively small variance in vertical load. Freight cars may be divided into four categories of interest: long or short cars (50 ft truck center distance as the dividing line), heavy or light cars (50 gross tons as the dividing point).

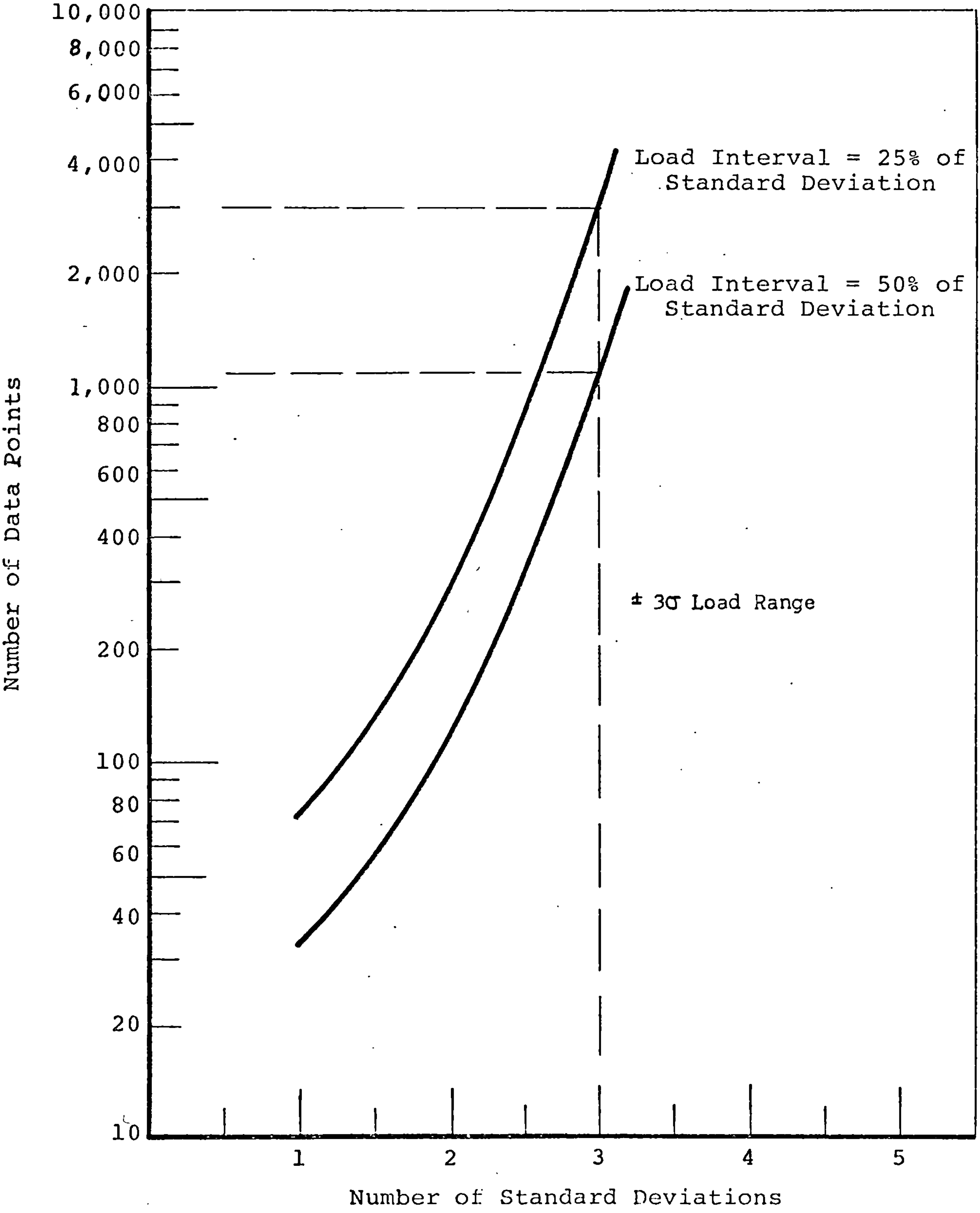


FIGURE 4-7. NUMBER OF DATA POINTS REQUIRED TO HAVE A MINIMUM OF 5 SAMPLES AT A SPECIFIED STANDARD DEVIATION

(2) Train handling -- On tangent track, train handling characteristics are assumed to have statistically little effect on wheel/rail loads. On curved track, however, lateral components of tractive and braking loads will be substantial, and must be considered in the statistical analysis.

The following data category matrix is recommended for the two wayside measurement sites:

Data Categories	Number -- Tangent	Number -- Curved	Remarks
Speed Bands	5	4	10 mph speed bands
Vehicles	5	5	Locomotives, Car <50 GT, <50' truck centers Car >50 GT, <50' truck centers Car <50 GT, >50' truck centers Car >50 GT, >50' truck centers
Train Handling	--	4	Powered Drifting Dynamic braking Train air braking

Estimates of vehicle populations from the Noble, Illinois concrete tie experiments [4] and the Idaho TTD experiments [5] indicate that for a 20 million gross ton traffic density, about 3700 axles per day will pass the measurement site. For the five given vehicle categories, the following percentages are typical:

Vehicle	Percent of Axles
Locomotives	7
Car, <50 GT, <50 ft t.c.	32
Car, >50 GT, <50 ft t.c.	19
Car, <50 GT, >50 ft t.c.	26
Car, >50 GT, >50 ft t.c.	16

Because of local traffic patterns and operating conditions, some speed bands or train handling categories may have substantially more or less data points than the average, unless some control can be maintained over the revenue operations. (Little can be done if heavy tonnage is predominantly in one direction, upgrade for example). However, assuming reasonable uniformity in the speed and handling categories (if applicable) for 5 subcategories per vehicle on tangent track, 16 per vehicle on curved track, a trade-off between resolution and test length may be established. This is shown (based on the above percentage "mix" of vehicles, and the Chi-Square test) in Figure 4-8. From this figure it can be seen that good resolution will be achieved (except, perhaps, for the locomotives) with 4 to 5 days of revenue data from the tangent track site; but a similar level of resolution on curved track will require a substantially longer test period. Therefore a test length of 6 to 8 days is recommended on curved track, with some reduction in resolution (number of intervals).

4.2 Vehicle-Borne Measurements

Dynamic measurements recorded from vehicle-borne transducers are intended to define the wheel/rail load environment at the test vehicle in response to a variety of track conditions and to provide data for validation of the vehicle/track load predictive model. The transducers to be used on the vehicle-borne load instrumentation system are listed in Table 4-2. The locations of strain gages on the test truck are shown in Figure 4-9.

The vehicle-borne load measurement system is similar to one which was used in November 1975 to determine wheel plate strains and temperatures associated with long drag brake applications. The system performed in a highly reliable manner and provided a wealth of data which are still being analyzed. Based on these results, a satisfactory performance is expected of the system described in this report.

4.2.1 Side Frame Vertical Load Gages
(Gage Channels 1 and 2)

Experience has shown that the use of instrumented side frames is a reliable method for measuring the low-frequency vertical load at the side frame/bearing adapter. Four strain gages will be used on each side frame, one on each of the two tension members and one on each of the two compression members, as illustrated in Figure 4-10. These gages will be wired into a four active arm bridge. The output of these bridges as a function of load will be determined by calibration loads applied to the truck. Each bridge will measure the

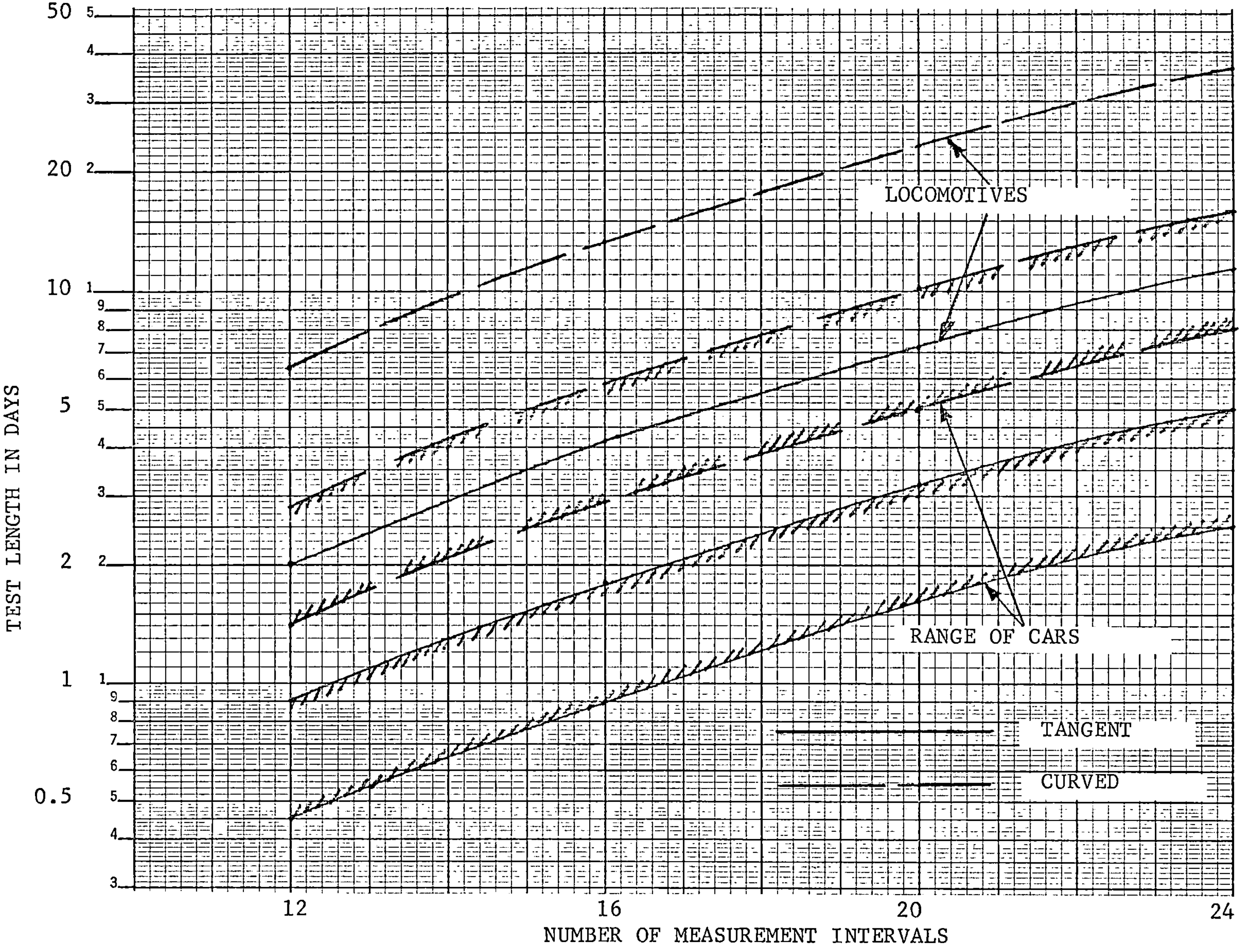


FIGURE 4-8. LENGTH OF WAYSIDE MEASUREMENT TEST VERSUS NUMBER OF MEASUREMENT INTERVALS IN PROBABILITY DENSITY HISTOGRAM -- TYPICAL MIX OF TRAFFIC, 3700 AXLES PER DAY

TABLE 4-2. INSTRUMENTATION DATA CHANNELS

Gage Channel	Type of Transducer	Measured Parameter	Location
1 2	Strain Gage Bridge (four active arms)	Vertical Load	Left Side Frame Right Side Frame
3 4 5	Strain Gage Bridge (two active arms)	Axle Bending Moment	First Axle 0° Left Side 60° 120°
6 7 8	Strain Gage Bridge (two active arms)	Axle Bending Moment	First Axle 0° Right Side 60° 120°
9	Switch	Wheel Rotational Position	First Axle
10 11 12	Strain Gage Bridge (two active arms)	Axle Bending Moment	Second Axle 0° Left Side 60° 120°
13 14 15	Strain Gage Bridge (two active arms)	Axle Bending Moment	Second Axle 0° Left Side 60° 120°
16	Switch	Wheel Rotational Position	First Axle
17 thru 26	Wheel Plate Strain Gage Bridge (two active arms)	Radial Strain	First Axle, Left Side. Bridges at 18° Spacing
27 28	Accelerometer	Vertical Acceleration	Center Sill near B End Center Sill near A End
29 30	Accelerometer	Vertical Acceleration - 2 gage outputs combined one gage each side at B end body bolster	Gage Outputs Summed, each side Gage outputs difference each side
31	Event Marker	Passage of Fixed Site, etc.	-
32	Time Code	-	-

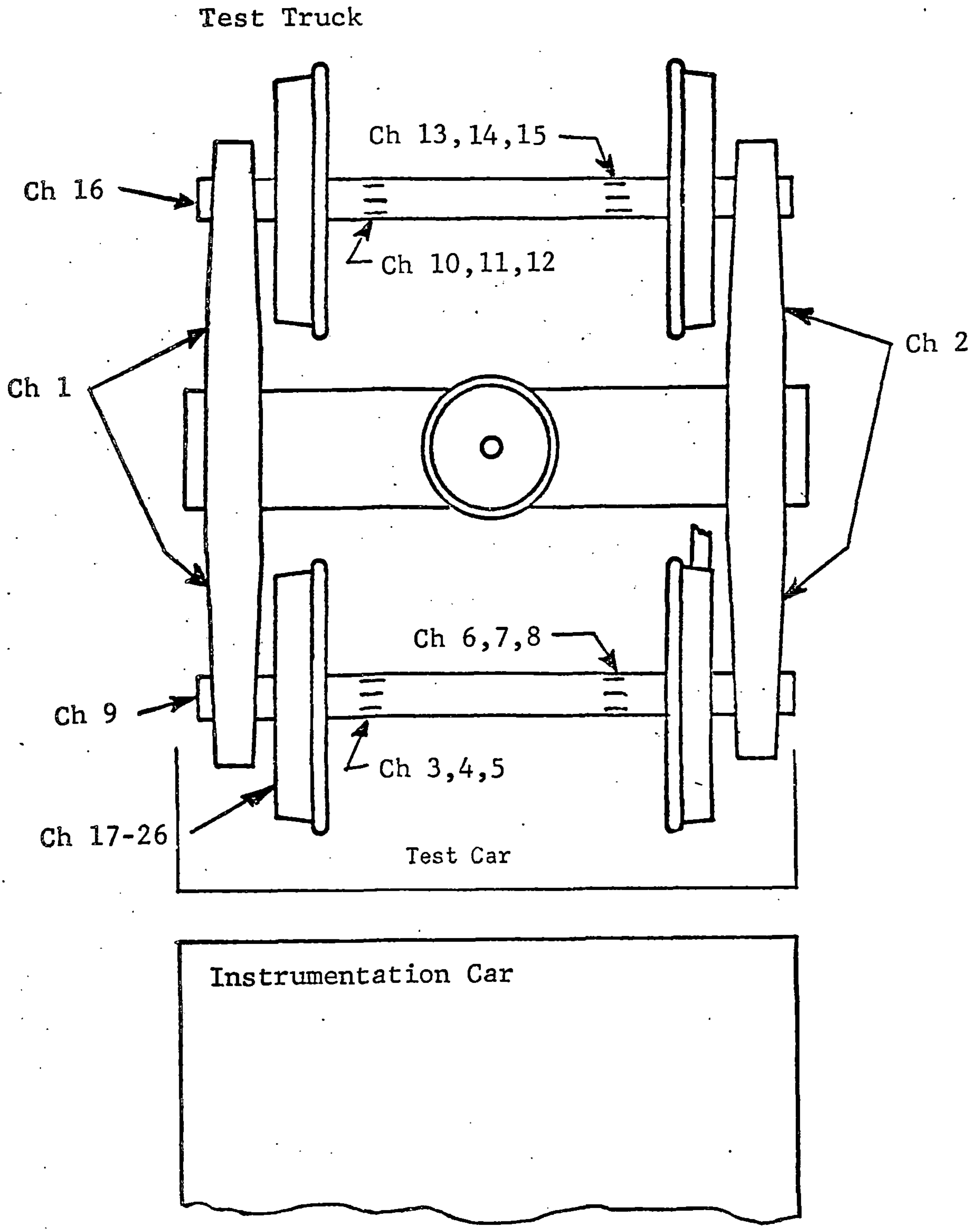


FIGURE 4-9. TRANSDUCER PLACEMENT ON TEST TRUCK

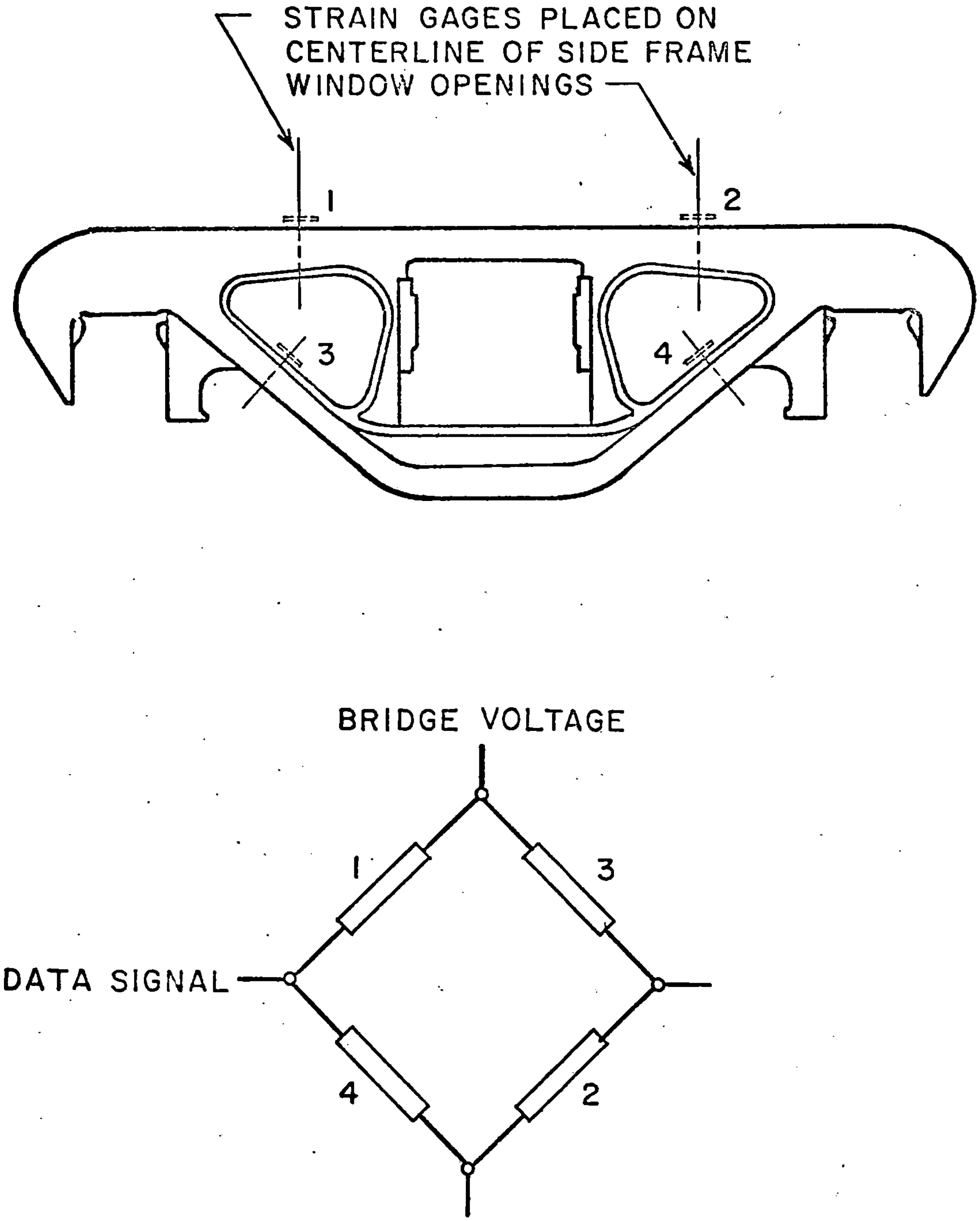


FIGURE 4-10. TRUCK SIDE FRAMES STRAIN GAGED FOR VERTICAL LOAD MEASUREMENT

sum of front and rear bearing adapter loads, and when divided by two will give the average low-frequency load.

4.2.2 Axle Bending Moment Gages (Gage Channels 3-8 and 10-15)

Measurement of bending moment in the axle is required for the determination of wheel lateral loads. The positions of these bending moment bridges is shown in Figure 4-11.

The bending moments in the axle at locations M_L and M_R will be determined by strain gage measurements at these locations. A strain gage bridge sensitive to the bending moment will consist of two active gages mounted at diametrically opposite positions on the axle and two dummy gages to complete the bridge. Since one is interested in the bending moment acting in the vertical plane, each pair of active gages will provide a measurement of the bending moment twice per revolution when the plane of the gages is oriented in the vertical direction. At other orientations of the axle the output of the strain gage bridge resulting from a bending moment in the vertical plane will be reduced by a factor equal to the cosine of the angle of rotation. Since the loss of sensitivity of the bridges becomes substantial as it rotates to a near horizontal orientation, two additional bridges will be installed on the axle at each measurement position. These bridges will be oriented at 60 deg intervals around the axle.

During the analysis of the data the output from each bridge will be sampled as it rotates within ±30 deg of the vertical plane. The output of the bridge must be adjusted to take into consideration the decrease in sensitivity with increasing angular displacement from the vertical within this angular range.

The equilibrium equations yield the following results for the loads acting at the wheel/rail interface from the measured vertical bearing adapter load and axle bending moment data:

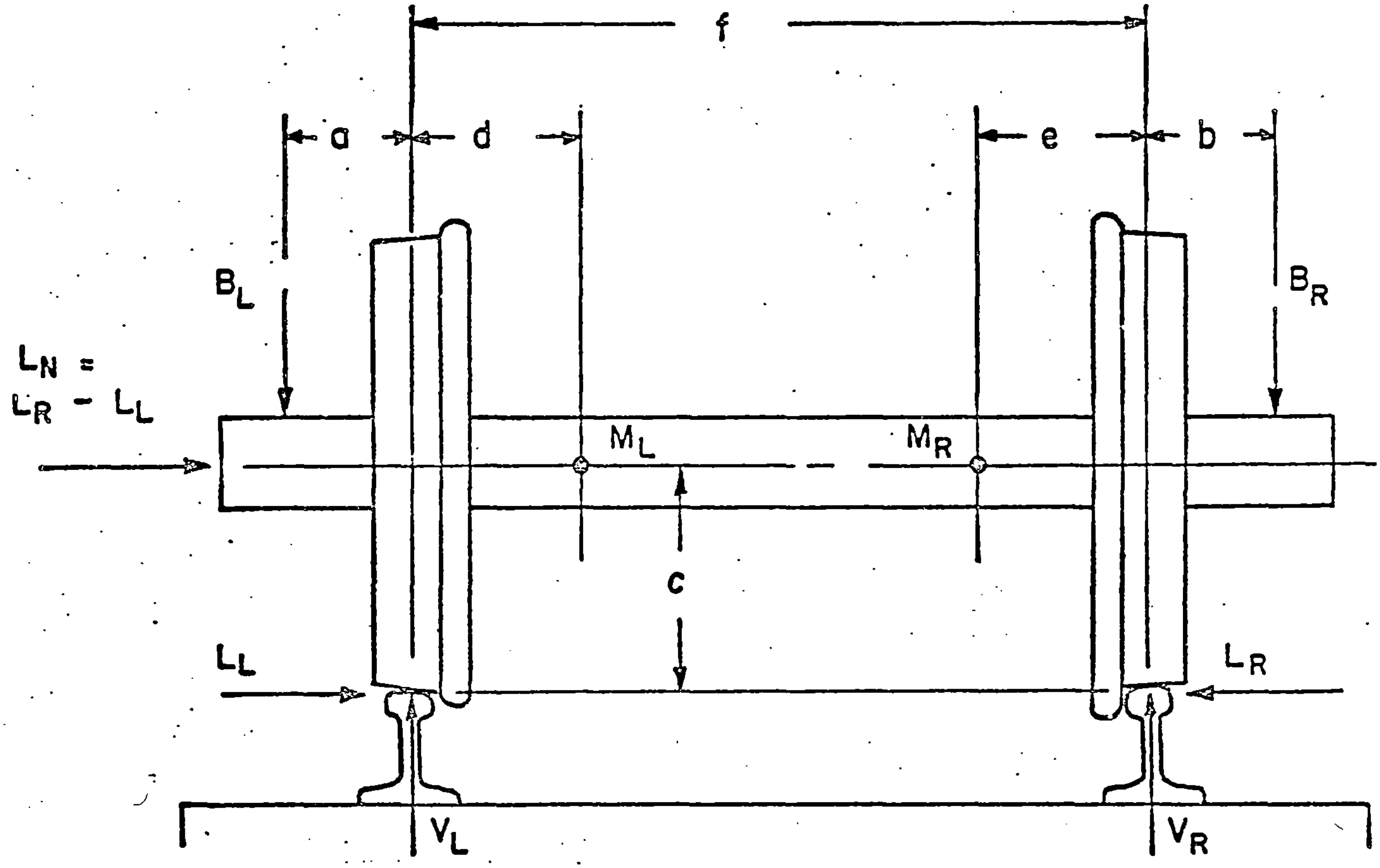


FIGURE 4-11. FREE BODY DIAGRAM OF AXLE

$$V_L = B_L + \frac{(M_R - M_L)}{(f-e-d)}$$

$$V_R = B_R + \frac{(M_L - M_R)}{(f-e-d)}$$

$$L_L = \frac{1}{c}\left[\frac{M_R d - M_L(f-e)}{(f-e-d)} - B_L a\right]$$

$$L_R = \frac{1}{c}\left[\frac{M_L e - M_R(f-d)}{(f-e-d)} - B_R b\right]$$

Substituting the following values:

$a = b = 10.25$ in.

$c = 18$ in.

$d = e = 12$ in.

$f = 58.5$ in.

The expressions for the loads become:

$$V_L = B_L + (.029)(M_R - M_L)$$

$$V_R = B_R + (.029)(M_L - M_R)$$

$$L_L = (.019)M_R - (.075)M_L - .57(B_L)$$

$$L_R = (.019)M_L - (.075)M_R - .57(B_R)$$

4.2.3 Wheel Plate Strain Gage Bridges
(Gage Channel Nos. 17 thru 26)

To determine the vertical and lateral loads from wheel mounted gages a series of equally spaced, radially oriented, strain gages will be mounted to the wheel on a circular reference line. The radius of the reference line and its location on either the front face or back face of the wheel is selected to give maximum strain output to the desired load being sensed (vertical or lateral). Strains from loads in the opposite direction should be a minimum at this location.

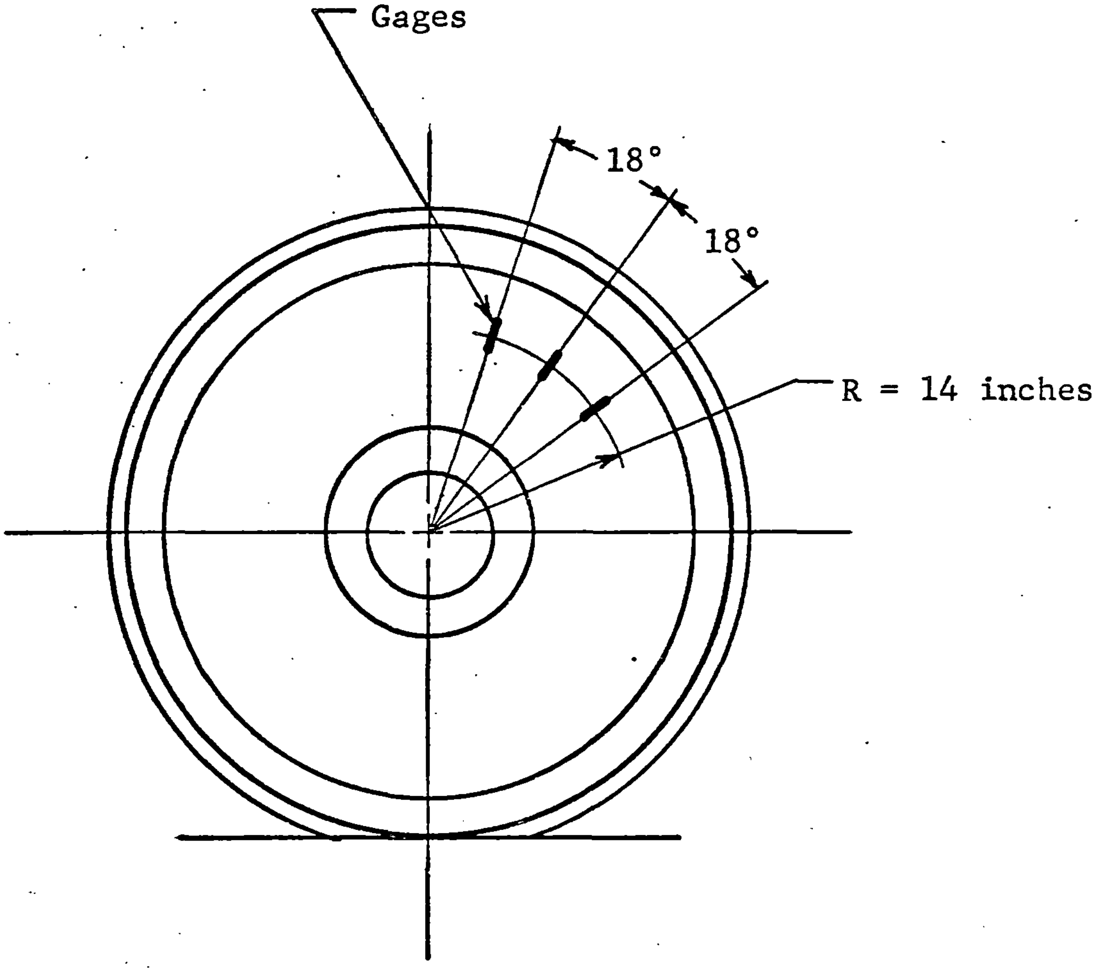


FIGURE 4-12. PLACEMENT OF GAGES ON WHEEL FOR HIGH FREQUENCY LOAD MEASUREMENT SYSTEM

The output signal of the wheel mounted gages will be utilized only as it passes through the zone of maximum strain. This is done in the analysis of the data by referring to the output of the wheel position sensor. The gage output will be utilized only as it passes through an angle equal to ± 1/2 of the spacing angle between gages, with reference to the vertical orientation. In addition, within this zone, the gage output is modified by a weighting function to account for the fact that there is a dropoff in sensitivity with increasing angle from the vertical.

A detailed analysis has been conducted of the 36 in. diameter, H36, wheels which are available for the tests to be performed under this project. The surface strains on the wheel which are developed from vertical and lateral loading have been predicted. Calculations indicate that gage placement at a 14.1 in. radial distance is optimum. The results from this analysis also indicate that the use of 20 radially oriented strain gages spaced at 18 deg is an acceptable gage array for sensing vertical loads. The change in sensitivity of the signal is not large as a gage passes through its "window" and the change that does occur can be compensated for when processing the signal. The resulting array of gages is shown in Figure 4-12. The output of the gages is negligible when they are in the top position of the wheel, 180 deg away from the wheel-rail contact. Therefore, it is feasible to incorporate two of these gages, located at diametrically opposite positions, into a single bridge.

4.2.4 Wheel Position Indicators
(Gage Channels 9 and 16)

A wheel position signal will be obtained for each axle from a reed switch mounted on the side frame adjacent to the axle bearing plate. Small bar magnets will be cemented to the bearing plate and will actuate the switch and generate a 1 volt pulse positional reference signal. The angular positions of switch closure will be aligned with selected reference lines.

The wheel position signal can also be used to establish the velocity of test car by noting the time required for one wheel revolution. This data will be used when processing the recorded data. During the tests the velocity will be monitored by speedometers located in the instrumentation car.

4.2.5 Accelerometers (Gage Channels 27-30)

Several accelerometers will be mounted on the test car to define the acceleration response of the car body during test runs. These signals will be used to validate the load-predictive vehicle/track model. Of primary interest are the car rigid-body motions, including bounce, pitch, roll, lateral and yaw oscillations, which occur in the 0.5 to 10 Hz range.

A maximum of four data channels will be available for accelerometers. Accelerometer mounts will be attached to the test vehicle at several points to allow placement of the strain gage accelerometers in different orientations. Mounts for vertical and lateral orientation will be attached to the center sill just ahead of the center plate at either end; and two mounts for vertical orientation will be attached to each end of the body bolster above the test truck. For some runs the two accelerometers on the center sill will be mounted vertically, and for others laterally. Each accelerometer will be recorded on a separate channel, and combined later as a sum or difference to define the appropriate rigid-body acceleration. Isolation pads will be used where necessary to protect the accelerometers from high-frequency shock and vibration, and the acceleration signals will be filtered at 20 Hz prior to analysis.

4.26 Event Marker (Gage Channel No. 31)

One channel will be reserved for recording specific events, such as passing milepost markers, bridges or turnouts, that can be used to pinpoint train location. This channel will also provide a precise correlation between wayside and on-board data channels. Precise location of the vehicle on the wayside data is no problem because each wheel is clearly defined (within a few inches) by the vertical load circuits. On-board data must be correlated by use of a location detector. Several methods of generating an event pulse will be considered, including magnetostrictive transducers, optical detectors, and a simple frangible switch, and the most reliable method will be chosen for the test series.

4.27 Time Code (Gage Channel No. 32)

A precise time reference will be established by recording a time code generator signal on each data tape. If possible, the on-board and wayside time code generators will be synchronized prior to each test series to provide an alternate means for correlating wayside and on-board data.

4.3 Test Site Description

4.3.1 Track Geometry

A detailed description of track geometry will be required for each test section (see Section 3.2) over which the test vehicle will be run at different speeds. This is needed to provide an input (or forcing function) for the vehicle/track load predictive model, and is an important step in the model validation. Track geometry in the form of power spectral density curves on log-log plots (in^2/cy/ft vs. cy/ft or equivalent) of track surface (average of left and right rail surface profiles), track alignment (average of right and left rail alignments), and cross level (difference of left and right rail surface profiles) over a range of wave lengths from 3 to 150 ft are of particular importance. Gage, curvature and warp are of secondary importance, as are the cross spectra (surface-cross level, etc.), but may prove valuable for other purposes in defining the wheel/rail load environment. Track geometry data may be generated by the DOT/FRA track geometry car or the host railroad's track geometry equipment, if the PSD description can be generated from the available recorded data. Scheduling the track geometry measurements constitutes the longest "lead time" item in the field test program, so this task must be addressed as soon as the site selection and test dates are confirmed.

Track geometry measurements that can be translated into an approximate space curve will be taken in the immediate vicinity (± 300 ft) of the wayside measurement site. Manual measurements of the unloaded track will include gage, cross level, surface (both rails), alignment (one rail), curvature, and superelevation. Surface and alignment will consist of midchord offset measurements every 15.5 ft on a 31-ft chord, with additional measurements taken at rail joints.

4.3.2 Track Description

Copies of track charts for the test sections and wayside sites will be needed to describe rail size, type of ballast, and pertinent features within the test sections. Tie spacing, type of subgrade and other pertinent information will be determined at the wayside sites. Rail head profiles will be plotted at several points in the test section to determine parameters relative to effective wheel/rail conicity and other hunting-related factors.

For determining track vertical modulus, rail loads and deflections will be monitored during a slow roll-by with the test train. A pair of longitudinal strain gages will be attached to the top-edge of the rail base to measure rail bending during this test, and will be used as a cross-check on the load/deflection measurements.

While direct measurement of track impedance at the test site would provide valuable information in terms of track dynamic stiffness, damping and effective mass versus frequency and preload, these measurements are not practical within the scope of this field measurement program. Data will therefore be derived indirectly through measurements under the test train and revenue traffic.

4.4 Vehicle Description

The static and dynamic characteristics of the test vehicle (100-ton freight car and trucks) will be determined for use in the vehicle/track load predictive model. The following parameters will be determined:

(1) Weights -- vehicle tare weight, plus weights of major components such as wheelsets, side frames, bolsters, centersill, side sheets, etc. Gross weight after loading will also be determined. Component weights will be determined from manufacturer's data, shipping weights, calculation, or direct measurement.

(2) Weight distribution -- the weight distribution or weight geometry of major components will be determined so that the mass

moments of inertia of the major components can be calculated. Shop drawings of car body and truck components will be used for these calculations.

(3) Geometry -- locations of mass centers of the major components and locations of spring groups and snubbers, relative to the rail running surface (vertical) and the kingpin centerline (lateral and longitudinal) will be determined. Other dimensions of interest are truck wheelbase, truck center distance, effective gage, centerplate diameter and height from rail, side bearing location and clearance, and car body overall dimensions. Some of these dimensions will be taken from the shop drawings, others will be determined by direct measurement.

(4) Suspension parameters -- vertical and lateral stiffness for the spring groups and the vertical and lateral components of snubbing force (constant or variable with load) will be determined from manufacturer's data, calculation, or available laboratory test data.

(5) Natural frequencies -- the important car body natural frequencies and damping ratios will be determined to aid in validation of the computer model. These may be determined during the checkout and calibration of the vehicle-borne load measurement system (see Section 5.2).

5.0 TEST PREPARATION

5.1 Wayside Measurements

5.1.1 Instrumentation and Recording Equipment

A block diagram of the wayside measurement and recording system is given in Figure 5-1, showing the specific instrumentation and recording equipment recommended for this program. All of the equipment, with the exception of the transducers, is available for the field measurement program. Transducers will be acquired under Task 8 of this contract.

The recording system shown in Figure 5-1 consists of two 14-channel Frequency Division Multiplexors (FDM) and a 14-channel FM tape recorder (Wide Band Group I). The 28 data channels from the multiplexors will be recorded on two tape channels; and an additional 10 data channels will be recorded directly on FM tape. The remaining two channels will be used for the time code signal and tape synchronization.

Data will be monitored during recording at the site by use of the demodulator and an oscillograph. Some channels will be combined at this stage (individual tie plate load cell signals, for example, to give vertical load), and signals will be filtered as appropriate for oscillograph time-history recordings. A real-time analyzer will be used to provide a preliminary analysis of the frequency spectra in the field. In addition to the equipment shown in Figure 5-1, standard electronic diagnostic gear will include a portable oscilloscope and a digital voltmeter.

A reference base and DCDT mounting fixtures will be fabricated (see Figure 4-5), along with a protective, hermetically-sealed box for the DCDT electronics. Instrumentation cables and connectors will also be prepared prior to moving the equipment to the measurement site.

5.1.2 Installation of Transducers

The rail will be prepared for strain gage application by grinding smooth patches on both sides of the rail web at each gage pattern location,

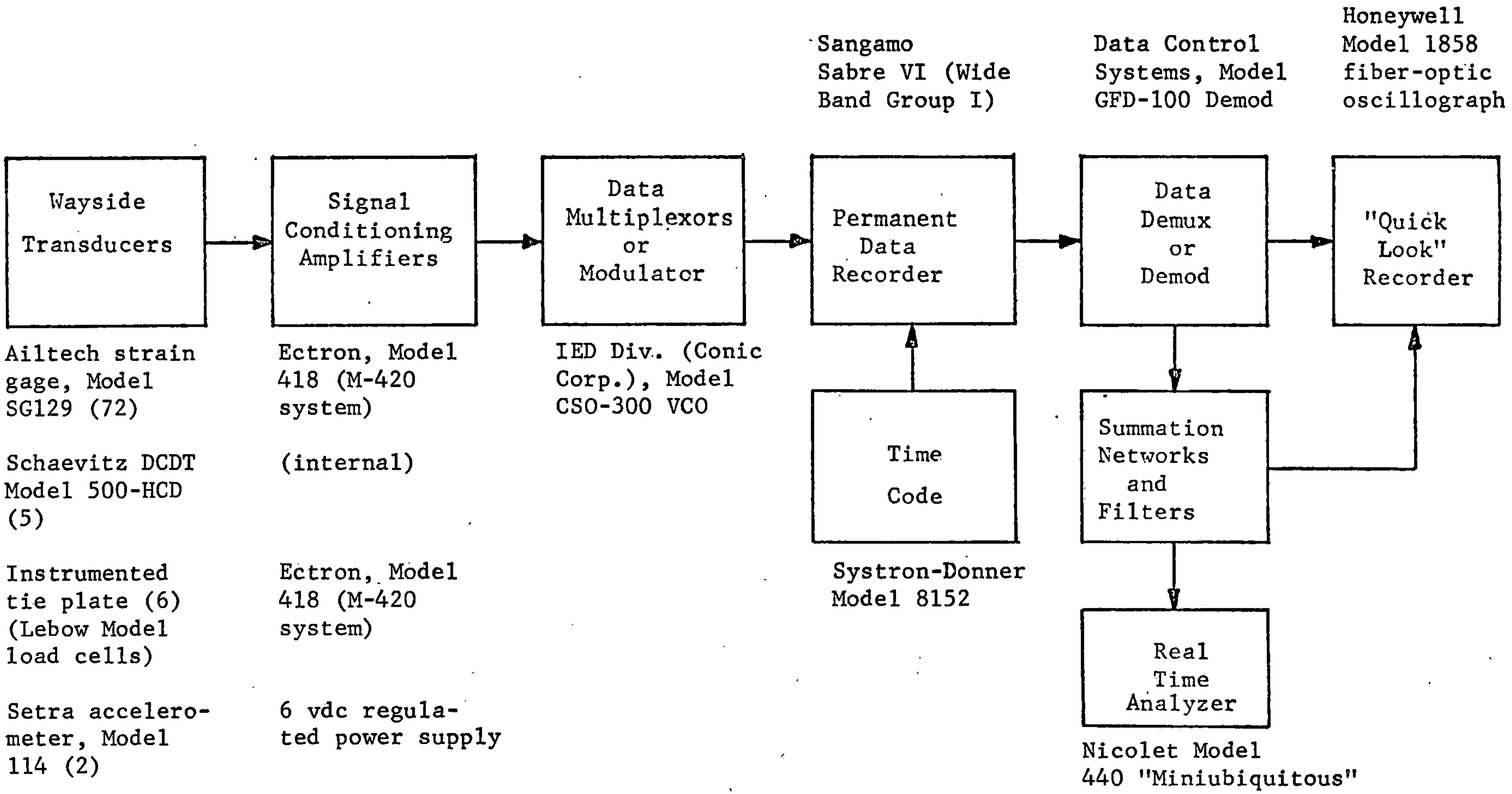


FIGURE 5-1. BASIC MEASUREMENT SYSTEM COMPONENTS

about 4 inches in width, removing all rust and mill scale. A scribing fixture will be used to mark the gage locations simultaneously on both sides. Weldable strain gages (Ailtech SG129) will then be applied using a special electric-discharge spot welder designed for this purpose. Integral leads from the gages will be routed to terminal boards and protected from dragging equipment, etc.

About 3 inches of ballast will be removed from the crib on either side of the center tie of the 5-tie array for installation of the displacement transducer reference base. Care will be taken not to disturb the seating of this tie. The reference base will then be assembled and attached to the tie at either end with lag screws. Small clean patches (about 1 inch square) will be ground on the field side of the rail head and on the rail base, and the phenolic blocks for the DCDT core rods will be cemented with epoxy to the rail. (All elements of the displacement measurement systems are below the running surface of the rail, outside the field side of the rail, with protective dragging-equipment shields).

Installation of the instrumented tie plates will involve use of a track jack to lift the rail just enough to relieve the load on the tie plate. The standard plate will be removed, and the instrumented plate slipped into place and spiked.

5.1.3 System Calibration and Checkout

An end-to-end calibration (transducer to recorder output) will be established for each transducer in the measurement system. The instrumented tie plates will be calibrated in the laboratory for the individual load cells and for the complete tie plate, using the same cable lengths assigned in the field. Shunt resistor calibration factors will be established at this time, and shunt calibration will then be used during the tests. A post-test calibration will be run on the tie plates after completion of the field measurements.

Other transducers will be calibrated in the field. Physical calibration of the lateral strain gage circuits will be done with a lateral load applied between the rail heads with a laboratory-calibrated hydraulic jack. Recent field experiments have shown that if the rail base is reasonably well-supported by the tie, there is negligible difference in circuit sensitivity with or without vertical wheel load: therefore a vertically-unloaded calibration in load increments up to 6000-7000 lb will be adequate. For reference, one vertically-loaded calibration will also be run. In conjunction with this exercise, lateral load/deflection curves will be established at the displacement fixture location for three conditions: vertically-unloaded, under light axle load, and under heavy axle load. A sprayed coating of molybdenum disulphide powder will be used at the wheel/rail interface to limit the lateral frictional force component. (It has been noted that due to wheelset lateral stiffness, about 10% of the lateral load is shunted through this parallel load path, which must be considered in the calibration.)

Pairs of vertical strain gage patterns between ties will be calibrated under known vertical wheel loads. For all of the strain gage circuits, a shunt calibration will be run after each test run to provide a functional check of the transducer and to establish correct end-to-end gain. Physical calibration of the DCDT displacement transducers will be done by moving the DCDT body a measured distance relative to the core (which is fixed to the rail). A voltage-insertion calibration (from a stable oscillator voltage source) will be used to establish system gains after each test run. Calibration of the accelerometers will be done by turning the transducer upside down to establish a 2 G reference signal.

A complete checkout of the measurement system will be provided by several days of revenue traffic recordings prior to runs with the test vehicle.

5.2 Vehicle-Borne Measurements

5.2.1 Strain Gages

Strain measurements will be taken using conventional compensated foil strain gages since temperatures will be at or near ambient.

5.2.2 Installation of Transducers

The strain gages which are to be applied to the wheels and axles will be installed at IITRI prior to the shipment of this equipment to the test site. All of the remaining transducers will be installed at the yard which will serve as the base of operations for the tests.

5.2.3 Slip Rings

Slip rings will be used to transmit the data signals from the rotating parts. The wheel sets which are available have two 20-circuit slip ring assemblies on each axle. The axles of the wheel sets contain central axial holes and radial ports both inside and outside of each wheel so that power and signal leads can be routed from the sensors to the slip rings. The slip rings are fitted with an electrical connector so that they can be disconnected for shipping and maintenance.

5.2.4 Strain Gage Circuits

Rotating strain gage circuits will be arranged in groups with a common reference half bridge for 6 or 12 measurements. Each group of strain gages will share a common bridge voltage supply furnished through a separate pair of slip rings. Where single strain gages are used, precision resistors will be mounted on the rotating parts to form half bridges. The strain and reference signal circuits will be brought out individually through the slip rings. A typical arrangement is shown in the schematic diagram of Figure 5-2.

Circuit wiring on the rotating parts will be protected from accidental damage and the environment. Sensors will be provided with strain loops and gages will be armored if required. All sensors and cables will be sealed with a protective coating and further protected with a tough outer coating such as RTV.

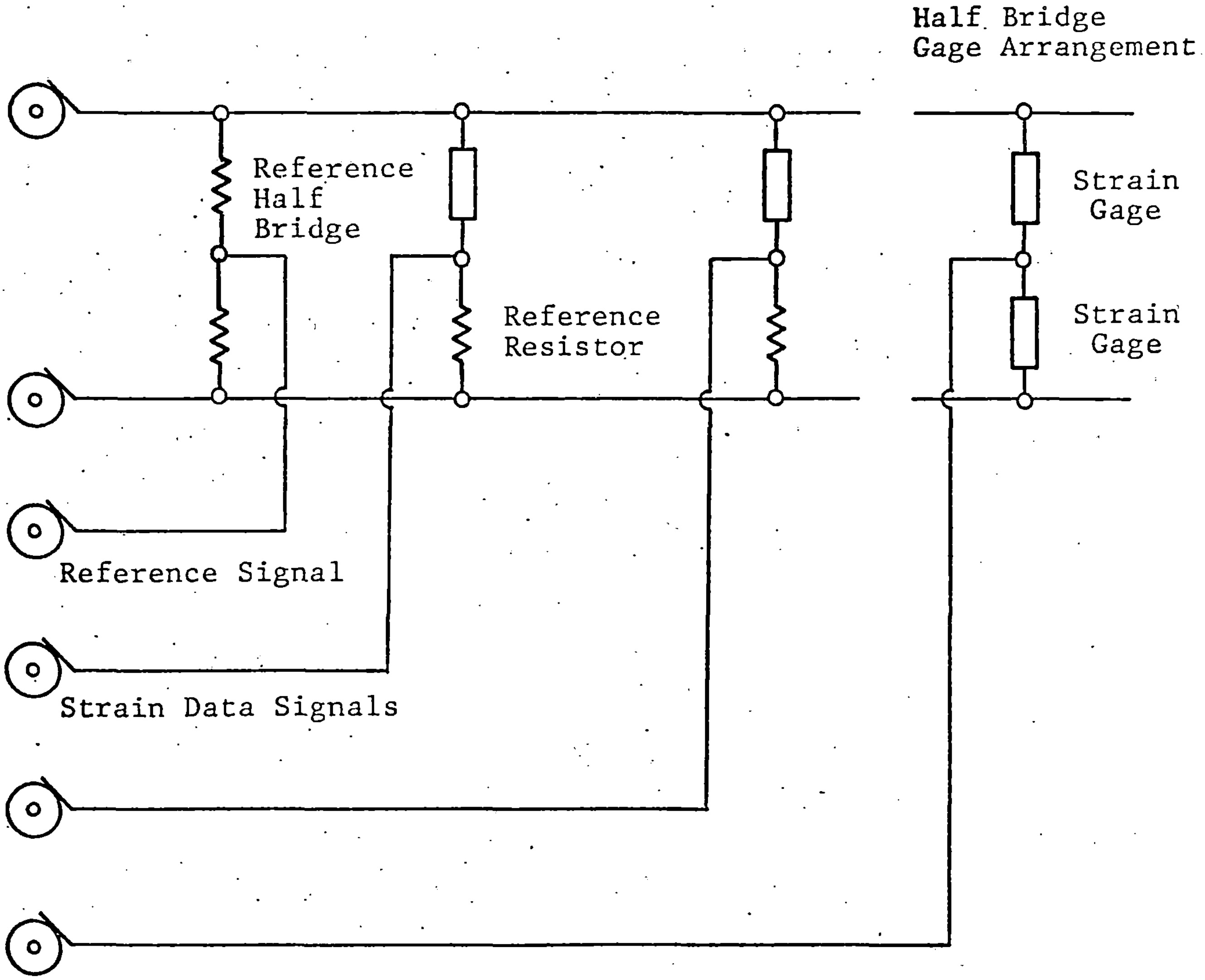


FIGURE 5-2. TYPICAL STRAIN GAGE CIRCUITS USING SLIP RINGS TO TRANSMIT DATA SIGNALS FROM THE ROTATING WHEEL-AXLE

5.2.5 Signal Conditioning Equipment

Signal conditioning equipment and amplifiers will be furnished for strain and other data channels to provide suitable signal levels for tape recording. Shunt strain gage calibration circuits will be used to record calibration reference signals on the tape, as required, before and during the tests.

5.2.6 Recording

Frequency modulated (FM) analog recording will be used since it has the advantage of permitting a greater number of alternatives when processing the data. Three magnetic tape recorders will be used in the FM mode. Two recorders will use the IRIG intermediate band FM system with a tape speed of 1-7/8 ips and a bandwidth of 625 Hz. These recorders will be used to record the low frequency system data. Each recorder will take the data channels from one axle along with vertical load and miscellaneous reference signals. The other recorder will be operated at a 7-1/2 ips tape speed and a bandwidth of 2500 Hz for the high-frequency wheel load data. Each recorder will have one track dedicated to an IRIG B time code as a precise reference for data processing. Voice commentary will be recorded on an edge track. The assignment of the gage channels to the three recorders is indicated in Table 5-1.

A direct-write oscillograph will be included to monitor selected data channels during the conduct of the test. Playback signals will be obtained directly from the reproduce amplifiers of the tape recorder while data is being recorded. All channels will be observed periodically during the tests to insure the data is being properly recorded on the tape.

5.2.7 Calibration

Pretest calibration will be performed to relate the response of the vehicle-borne transducers to lateral and vertical load.

TABLE 5-1. RECORDER GAGE CHANNEL ASSIGNMENTS

Recorder Channel	Gage Channel Numbers		
	First Recorder	Second Recorder	Third Recorder
1	1	1	1
2	2	2	2
3	3	10	9
4	4	11	17
5	5	12	18
6	6	13	19
7	7	14	20
8	8	15	21
9	9	16	22
10	27	29	23
11	28	30	24
12	31	31	25
13	32	32	26
14	-	-	32

4

DOT-TSC-1051

PILOT STUDY FOR THE CHARACTERIZATION AND REDUCTION OF WHEEL/RAIL LOADS

FIELD MEASUREMENT AND DATA REDUCTION PLAN

Donald R. Ahlbeck
Milton R. Johnson
Harold D. Harrison
Robert H. Prause

June, 1976

TEST PLAN

DOCUMENT IS AVAILABLE TO THE PUBLIC
THROUGH THE NATIONAL TECHNICAL
INFORMATION SERVICE, SPRINGFIELD,
VIRGINIA 22151

Prepared For

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Rail Safety Research
Washington, D. C. 20590

Revised Version
July, 1976

The contents of this report reflect the views of Battelle-Columbus Laboratories, and the IIT Research Institute, which are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Department of Transportation. This report does not constitute a standard, specification, or regulation.

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15. Supplementary Notes

* Under contract to: U.S. Department of Transportation
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Kendall Square
Cambridge, Massachusetts 02142

** IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616
(Subcontractor)

16. Abstract

This report was prepared as part of the Improved Track Structures Research Program sponsored by the Office of Rail Safety Research of the Federal Railroad Administration. A survey of available wheel/rail load data was conducted (see the Interim Report, DOT-TSC-1051, April, 1976) and noticeable gaps in the existing data and formats of presentation were reported. In this report a test plan for gathering a comprehensive set of wheel/rail load data from both trackside and vehicle-borne transducer measurements is outlined. Primary uses of the resulting data will include the characterization of wheel/rail loads under revenue traffic at a representative track site, the characterization of wheel/rail loads from a representative vehicle (a 100-ton freight car) over varied track conditions, and validation of load-predictive models by comparison of computed and measured response.

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UNITED STATES GOVERNMENT

Memorandum

DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER
KENDALL SQUARE
CAMBRIDGE, MA 02142

DATE: Sept. 20, 1976

In reply refer to: 612

SUBJECT: SPD-40 Locomotive Test Proposal

FROM: Herbert Weinstock, TSC

TO: John Harding, RRD-11, FRA

I am attaching some notes that I had Len Kurzweil prepare which you may find helpful in the development of a test plan for the proposed Locomotive Instrumented Wheel Set effort. I am also enclosing draft copies of report material which may be relevant. This material was prepared by Battelle-Columbus Laboratories and IIT Research Institute.

Herb Weinstock

Herbert Weinstock

Attachments

UNITED STATES GOVERNMENT

Memorandum

DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER
KENDALL SQUARE
CAMBRIDGE, MA 02142

DATE: September 17, 1976

In reply refer to: 612

SUBJECT: Development of an Experimental Design for a Locomotive Evaluation Program

FROM: Leonard Kurzweil

TO: Herbert Weinstock, 612

Attached is a summary of the major considerations in the development of a field measurement program for the evaluation of a locomotive. It does <u>not</u> constitute the actual experimental design. The material included here were derived largely from in-house experience gained in part through the monitoring of Contract No. DOT-TSC-1051: Pilot Study for the Characterization of Wheel/Rail (W/R) Loads. Battelle also contributed to this material in the form of a letter report which I integrated into the present memo.

Leonard Kurzweil

Leonard Kurzweil

Attachment

Development of an Experimental Design for a Locomotive Evaluation Program

OUTLINE

I. Definition of Objectives

II. Selection of Performance Criteria and Evaluation Parameters (dependent variables)

III. Identification of Parameters Influencing Performance (independent variables)

IV. Design of Test Strategy (Site selection, train operations, statistical considerations)

V. Instrumentation Requirements and Selection

VI. Calibration Procedures

VII. Data Recording, Reduction, and Presentation (Documentation)

DISCUSSION

I. Definition of Objectives

It is important to clearly define a set of objectives or questions which the test program is intended to answer. This greatly aids in the design of the test strategy.

Possible overall objectives can include:

1. To determine the acceptability of a locomotive for operation in U.S. railroad service.
2. To characterize the dynamic performance of a locomotive under a variety of operating conditions.

In particular, the following questions might be addressed:

1. What combination of train speed, train handling, and track geometry (or class) result in the "worst" (i.e., most critical from a safety, comfort, and/or track and vehicle degradation point of view) dynamic performance of the locomotive in each train consist of interest?
2. Can the particular cause of any unsatisfactory behavior be determined?

II. Selection of Performance Criteria and Evaluation Parameters (dependent variables)

Performance criteria are required to a~~cc~~ssess the acceptability or comparative merit of a given locomotive design. Performance criteria can be related to safety, operator comfort, track maintenance, and vehicle maintenance. Current criteria suffer from lack of knowledge of quantitative limits for safety, comfort, and maintenance. Thus, it may be necessary to judge performance on the basis of a comparative evaluation with other locomotives.

Possible evaluation parameters for various performance criteria are suggested below:

[excerpted from Battelle letter report]

A. Safety

1. Wheel climb (L/V individual wheels--angle of attack and load duration are also important)
2. Rail rollover (L/V forces all wheels each side of truck)
3. Track lateral shift (L/V axle forces)
4. Vehicle overturning ($\frac{\Delta V}{V}$ individual wheels)

B. Operator Comfort

   1. Cab acceleration and jerk (3 axis)

C. Track Maintenance

   1. Rail wear (vertical and lateral W/R loads at curves, rail joints, switches)
   2. Track surface deterioration (vertical wheel loads)
   3. Track alignment deterioration (lateral, L/V wheel loads)
   4. Gage deterioration

D. Vehicle Maintenance

   1. Axle accelerations (3 axes)

III. Identification of Parameters Influencing Performance (independent variables)

What parameters (in addition to the evaluation parameters) must be selected, controlled, or (at least) monitored in order to evaluate the locomotive performance data and determine "worst cases" as well as possible causes? A partial list of such parameters includes:

1. Operating speeds
2. Train handling (accel. or braking)
3. Train consist (very important for freight service, but not for passenger service).
4. Track geometry
5. Track impedance (vertical and lateral)
6. Environmental conditions (temperature, rain, etc.).
7. Wheel profile and gage
8. Rail profile (in problem areas)

IV. Design of Testing Strategy

The measurement program must be designed to accomplish the objectives and to provide statistically significant data. This requires that the following issues be addressed:

1. How many locomotives should be instrumented? Assuming the answer is 1 (or an insignificant number from a statistical point of view) how can one demonstrate the "typicalness" of the selected locomotive (i.e., in comparison to other locomotives of the same nominal design)? One way would be to instrument one or more sections of track (perhaps at "critical" locations) and monitor the W/R loads resulting from each locomotive of the selected type. This would provide a distribution of W/R loads due to this type of locomotive under known operating conditions. Comparison of the W/R loads, measured on the instrumented locomotive while passing over the instrumented track section, with the wayside measured distribution would indicate the "typicalness" of the instrumented locomotive.

2. Is train consist going to be a variable in the measurement program? If so, what train make-ups are to be considered? How many locomotives are to be used in the train? Which locomotive (1st, 2nd, 3rd, ...) will be instrumented?

3. For the selected locomotive, which wheels, axles, or trucks will be instrumented?

4. Having selected the locomotive and consist, what strategy should be used to identify "critical" or "worst" cases? Should the locomotive travel over the "whole universe" under normal operating conditions; over selected track sections many times at various speeds; over a particular track anomaly for a variety of train handling situations? [This item is essentially concerned with selection of test sites and operating conditions].

5. How many miles of track and how many locomotives are required to define a statistically useful sample? (See, for example, Reference [12], pp. 159-164, 180).

Suggestions addressing some of the above questions are given below: [excerpted from Battelle letter report]

1. Test Site Selection

A. Cover spectrum of operating speeds typical for bolted and CWR track to select specific track sections for more detailed evaluation and repeated runs.

   1. Maximum speeds (unbalance) on tight curves (curving forces)
   2. Rough track (cover operating speed range to identify resonant conditions)
   3. High-speed tangent track (hunting evaluation)

B. Evaluate sensitivity of vehicle operation to regional differences in track geometry (NEC runs tighter gage - problem with uni-point wheels)

C. Evaluate vehicle under severe track geometry conditions based on known dynamic response characteristics for vehicle and one or more specific track anomalies representing track class limits. Combinations of maximum allowable deviations in cross-level and alignment together with specified phasing and wavelength characteristics are not adequately covered by track geometry standards, and represent critical excitations for locomotives.

(General Comment: Difficult to satisfy all interested parties that a complete evaluation has been accomplished.)

2. Train Operations

    A. Cover entire operating speed range plus overspeed to insure adequate margin for engineer error.

    B. Cover power, drift and braking.

        1. Dynamic and independent air braking retard only locomotive and cause compressive draw bar forces.

        2. Train air braking causes tensile draw bar forces.

    C. Train handling on curves and grades is critical problem for freight operations - secondary importance for passenger operations.

    D. Repeated runs needed to check repeatability of load measurements for selected worst case conditions.

3. Track Instrumentation

    A. Selected locations identified from runs on revenue track

    B. Artificial track geometry irregularities

    C. Track instrumentation used to verify accuracy of vehicle instrumentation and to record data for other locomotives as base for comparative evaluation

    D. Track instrumentation can also supplement vehicle instrumentation where only 1 axle or 1 truck is instrumented.

V. Instrumentation Requirements and Selection

Instrumentation requirements must address themselves to, at least, the following:

1. Frequency response
2. Anticipated amplitude range
3. Temperature range (thermal sensitivity of transducers as well as operating range)
4. Reliability (need for extended field use)
5. Operational constraints (size, electrical shielding, etc.).

Discussion of some of the above requirements and a review of both vehicle - and track-borne instrumentation for the measurement of wheel/rail loads is described in Ref. [12] (pp. 35-42, 53-92, 132-153, 164-175) and Ref. [13] (pp. 13-24, 28-39).

Some suggestions for vehicle instrumentation are included below: [excerpted from Battelle letter report].

A. Instrumented Wheels (V, L and ΔV)

  1. All wheels on one truck needed for safety criteria
  2. Instrumentation of both trucks is a second priority choice
  3. Continuous versus sampled V & L force measurements
  4. Frequency response compatible with safety criteria

B. Coupler Forces and Angle

  1. Needed for evaluating train handling with freight locomotives
  2. Low priority for passenger trains

C. Cab Accelerations (Operator comfort and model validation)

  1. Indicates operating margins relative to stress (suspension stops, axle clearances)
  2. Used for diagnosis of unacceptable operating conditions.

E. Complete Track Geometry Package

  1. Chordal system attenuates long wavelength geometry irregularities (>100 ft.) that are suspected critical for locomotive response.

VI. Calibration Procedures

Dynamic calibration should be considered if the required frequency range for W/R load data extends above about 5 Hz. A comparison of vehicleborne and trackside W/R load data would provide a useful cross-check of both systems. (See discussion in Ref. [13], pp. 44, 45, 48-53).

VII. Data Recording, Reduction, and Presentation (Documentation)

The test planning should, where possible, be brought to the point of indicating how the data will be recorded, reduced, and presented. This should help in determining whether the planned measurements are likely to provide answers to the original objectives. It will also be useful in avoiding an accumulation of unnecessary data. Various formats for presenting W/R load data are described in Ref. [12], (pp. 56-101, 154-159) and Ref. [13] (Table 2-1, p. 4). Specific suggestions for data recording and reduction are presented below: [excerpted from Battelle letter report]

1. Data Recording

  A. On-board read-out of critical L/V's for wheels and trucks as related to performance criteria (time histories)

  B. On-board read-out of track geometry parameters (time histories)

C. All data recorded on magnetic tape for later analysis/ reproduction

D. Cab acceleration read-out directly or from ride quality package giving ride index.

E. Real time level monitoring of critical W/R load signals and track geometry signals to insure specific locations of abnormal conditions do not go undetected during test.

2. Data Reduction and Analysis

A. Data reduction formats selected for direct comparison with acceptability criteria (L/V vs. time duration vs. number of occurrences)

B. Data formats selected for comparison with any available analytical models (PSD, average curving forces etc.)

Related Bibliography

[References 1 thru 11 excerpted from Battelle letter report]

1. Amtrak data from previous SDP40F evaluations conducted in Illinois during spring of 1976.

2. EMD data on many different locomotives (proprietary?)

3. Dolecki, E. A. and Hartzell, C. E., "Optimization and Ride Quality - 3 Axle Floating Bolster Truck" GE Report No. DF74LC2690 (Proprietary Class 3), February 8, 1974. (Tests of E60CP truck with U30C locomotive)

4. Amtrak/Ensco test reports on NEC E60 tests.

5. Data from current Amtrak evaluation of ASEA locomotive.

6. EMD published reports on locomotive curving forces.

7. Konishi, S., "Measurement of Loads on Wheel Set", Japanese Railway Engineering, Vol. 8, No. 3, September, 1967, pp 26-30.

   A method for measuring the loads and stresses on a wheel set is outlined. The Japanese National Railway operation schedules are determined based on yearly field tests of running safety by measurements of the derailment quotient (side thrust/vertical load). Field measurements of the loads on a wheel set include the lateral force, the vertical force, and the tangential force in the longitudinal direction acting between the wheels and rails. The paper describes measurement techniques using wire strain gauge bridges on either a spoked or disc wheel. The bridge signals are transmitted to an amplifier in the vehicle using a silver-copper-cadmium slip ring attached to the axle box.

8. Anon., Question B10, Constructional Arrangements for Improving the Riding Stability and the Guiding Quality of Electric and Diesel Locomotives and Vehicles, Interim Report No. 11: A comparison of the methods of measuring on the track and on wheels the lateral forces (Y) and vertical loads (Q) caused by rolling stock traveling round a curve at Vallorbe, 1962, ORE, UIC, Utrecht, October, 1964, B10/RT11/E.

9. Olson, P. E., and Johnson, S., "Lateral Forces Between Wheels and Rails - An Experimental Investigation", ASME Paper No. 60-RR-6, April, 1960, Available in Anthology of Rail Vehicle Dynamics: Vol. III - Axles Wheels and Rail-Wheel Interaction, edited by S. G. Guins and C. E. Tack, ASME, 1973, pp 253-261.

10. Koci, L. F., and Marta, H. A., "Lateral Loading Between Locomotive Truck Wheels and Rails due to Curve Negotiation", ASME Paper No. 65-WA/RR-4, November, 1965, Available in Anthology of Rail Vehicle Dynamics: Vol. III - Axles, Wheels and Rail-Wheel Interaction, edited by S. G. Guins and C. E. Tack, ASME, 1973, pp 119-129.

Curve-negotiation mechanics and forces resulting when locomotive trucks negotiate curves are well recognized. Recent theoretical analysis has made possible analytic explanation of such curving phenomena. However, meaningful and reasonable prediction of forces resulting in service conditions has been limited owing to the lack of experimental data pertaining to the friction-creep relation between railway wheel and rail. An instrumented wheel-axle assembly was developed and used on 2,3, and 4-axle trucks to study the effect of creep and the transverse load reactions resulting between wheel and rail. Instrumentation was used to measure these forces and the reactions between axles and truck frame under operating conditions. Test results confirm predicted phenomena and indicate the effect of creep on resulting loads. This paper includes a brief and general review of curve-negotiation mechanics and presents the test results and their relation to the theoretical analysis.

11. Peterson, L. A., Freeman, W. H., and Wandrisco, J. M., "Measurement and Analysis of Wheel-Rail Forces", ASME Paper No. 71-WA/RT-4, December, 1971.

This paper describes a method used to continuously measure, record, and analyze the lateral and vertical forces between wheels and rails of several types of railroad freight cars under a variety of car and track conditions. The method, using analog-to-digital conversion and computerized data handling, has produced results relating to a multitude of car and track behavior subject areas. Especially important is the definition, development, and verification of performance "signatures" which are generated in a unique and characteristic manner by each car in negotiating a given curve. The finding of such "signatures" to be completely reproducible and yet sensitive enough to change with relatively minor track or car component variations, i.e., modifications, supports the belief that these techniques can be applied beyond pure experimental scopes into routine (a) trackside inspection of cars in passing trains; (b) mechanized track inspection; and (c) truck design evaluation.

12. Ahlbeck, D. R. et al, "Evaluation of Analytical and Experimental Methodologies for the Characterization of Wheel/Rail Loads", Rept. No. FRA-OR&D-76-276, Aug. 1976 [to be published].

13. Ahlbeck, D. R. et al, "Pilot Study for the Characterization and Reduction of Wheel/Rail Loads - Field Measurement and Data Reduction Plan", Planning Report (unpublished), June 1976.

PREFACE

This report was prepared by Battelle's Columbus Laboratories (BCL) and the IIT Research Institute (IITRI) under Contract No. DOT-TSC-1051 as part of the Improved Track Structures Research Program managed by the Transportation Systems Center (TSC). This program was sponsroed by the Office of Rail Safety Research, Improved Track Structures Research Division, of the Federal Railroad Administration, Washington, D.C.

The overall objective of this contract is to apply existing data, analyses and instrumentation to develop a characterization of wheel/rail loads for U.S. railroads and to evaluate strategies for the reduction of these loads. In this report the field measurement and data reduction plan for obtaining needed wheel/rail load and track response information is outlined.

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PILOT STUDY FOR THE CHARACTERIZATION AND REDUCTION OF WHEEL/RAIL LOADS
CONTRACT NO. DOT-TSC-1051

FIELD MEASUREMENT AND DATA REDUCTION PLAN

1.0 OBJECTIVES

The field measurement and data reduction phase of the overall wheel/rail load characterization program will fulfill two basic objectives:

- To provide a comprehensive description of the wheel/rail loads to which the specific track sites and test vehicle are subjected, and
- To provide sufficient data to validate a prediction methodology capable of extrapolating wheel/rail load data to alternate track, vehicle, and operating conditions.

Because the loads measured from the track and from the vehicle are fundamentally different in character, the specific objectives of measurements from the two points of view are somewhat different. The primary objectives of the trackside measurements in this pilot study are:

- To define the statistical characteristics of wheel/rail loads and track dynamic response under revenue traffic,
- To provide wheel/rail load and track dynamic response time-histories for validating wheel/rail load prediction models,
- To determine typical track vertical and lateral deflection characteristics under static and dynamic wheel/rail loads,
- To demonstrate and evaluate the performance of track and vehicle-borne wheel/rail load measurement systems by comparison of simultaneous track and vehicle-borne measurements.

The primary objectives of the vehicle-borne measurements are:

- To provide sufficient data in time-history, power spectral density, and amplitude statistical formats for validation of the load prediction methodology,
- To define the statistical characteristics of the wheel/rail loads of the test vehicle over a range of track conditions,
- To characterize the test vehicle parameters for the load predictive vehicle/track models,
- To demonstrate and evaluate the performance of the vehicle-borne measurement system.

As the end-product of the field measurement and data reduction phase of this program, a complete set of data will be generated describing the wheel/rail load environment from both the vehicle and trackside locations, presented in time-domain, frequency-domain, and amplitude statistical formats required for both load characterization and load predictive model validation.

2.0 BACKGROUND

A characterization of the rail loading environment is a key factor for all aspects of improved track performance. The quantitative description of rail loads will be used as inputs to other concurrent programs on cross-tie track improvement, rail stress analysis, and rail failure prediction, as well as for other research and testing of rail and track structural components. A preliminary characterization of the wheel/rail load environment was included in the Interim Report [1] using published results of a number of load measurement programs. However, these results often lack sufficient detail on the measurement conditions, or the formats in which results are presented cannot be used directly to validate a load-predictive model or to analyze track strength or fatigue life. The field measurement and data reduction phase of this program is intended to fill in some of the noticeable gaps in the present W/R load characterization to provide a more comprehensive description of the load environment and to provide data that can be used for model validation.

The measurement of wheel/rail loads from either trackside for a vehicle presents one dimension in what is basically a two-dimensional matrix. Wheel/rail

Vertical Load

The vertical load calibration of the wheel-plate strain gages (the high frequency system) will be performed in a special test fixture at IITRI before the wheel sets are moved to the test site. The purpose of this test is to relate vertical strain gage bridge output to load, and to determine weighting factors which can be applied to the bridge outputs of the high frequency system when these gages are not positioned in a vertical plane. The experimental factors will be compared with the theoretical values. A vertical load will be applied using a hydraulic cylinder acting through a load cell. The load will be applied at each of the 20 gage positions to check out the calibration for the individual gages and at selected positions between the gage lines to experimentally verify the weighting factor between gage reference lines. At this time, tests will also be conducted to determine the effects of movement, in a transverse direction on the wheel tread, of the line-of-action of the wheel/rail contact load.

The vertical load calibration of the side frames (the low-frequency system) is tentatively planned to be conducted in the field at the time the tests are run. First, the test car equipped with the instrumented truck will be weighed empty to establish a reference signal level. (This will depend on locating an accurate car scale at a terminal near the test site.) The car will be moved slowly for at least one revolution of the wheels while data are recorded on both the vertical high-frequency and low-frequency systems. Next, the car will be partially loaded to establish a load approximately 25 percent under the maximum allowable rail load and the above steps will be repeated. Next, the car will be overloaded to approximately 125 percent of the maximum rail load and the above steps repeated. Finally, the overload will be removed to bring the car to its normal allowable maximum weight on rail (e.g., 263,000 lb) and again the above steps repeated.

An alternative to this field calibration of the vertical load measurement systems is to load the assembled truck in a static test machine. The Association of American Railroads (AAR) Research Center in Chicago has facilities for performing this full-scale test, if it should prove necessary.

Lateral Load

The lateral load calibrations will be performed on the individual wheel/axle sets before they are assembled in the test truck. Lateral loads will be applied between the wheel rims utilizing a fixture like that illustrated in Figure 5-3. The tests will be used to calibrate both the axle bending moment gages and the wheel plate strain gages. The axle bending moment gages will be calibrated using at least two load levels at 30° positions around the rim. The wheelset will be placed on low-friction supports as shown in the figure. Data will be recorded on Gage Channels 3-8 on the first axle and Gage Channels 10-15 on the second axle. The calibration data will be used to determine the output of the axle bending moment bridges as a function of lateral load and an experimental weighting factor for loads applied between the planes of the axle bending moment gages.

The wheel plate strain gages will be calibrated by applying the lateral load at a minimum of 20 positions around the rim (at an 18° spacing on the radial line of each strain gage). These data will be used to verify the output of the wheel plate gages sensitive to lateral load.

Combined Loads

The effects of lateral loads on vertical gage outputs, and vice versa, need to be examined so that the independence of these measurements can be verified. The test fixtures which will be utilized for the previously described wheel vertical and lateral load calibrations will also be capable of applying lateral and vertical wheel loads simultaneously. This will permit an experimental determination of the cross-talk between the high-frequency system, wheel plate gages, sensitive to vertical and lateral load respectively. It will also permit experimental determination of the interaction of vertical journal loads and lateral wheel loads on the axle bending moment gages used on the low-frequency system.

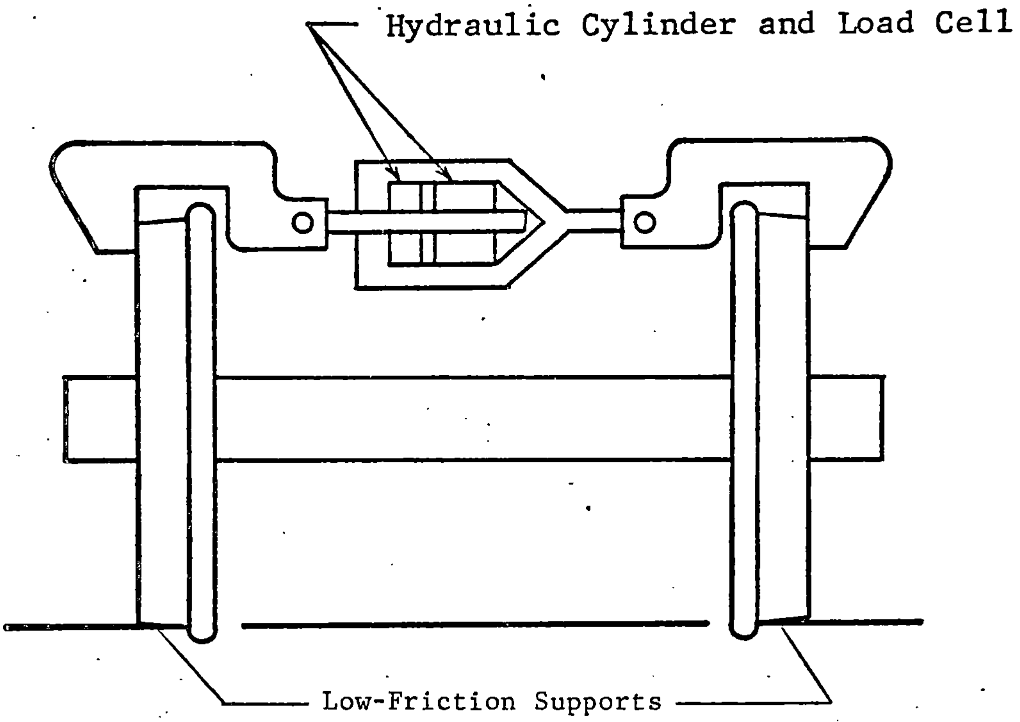

FIGURE 5-3. LATERAL LOAD CALIBRATION FIXTURE

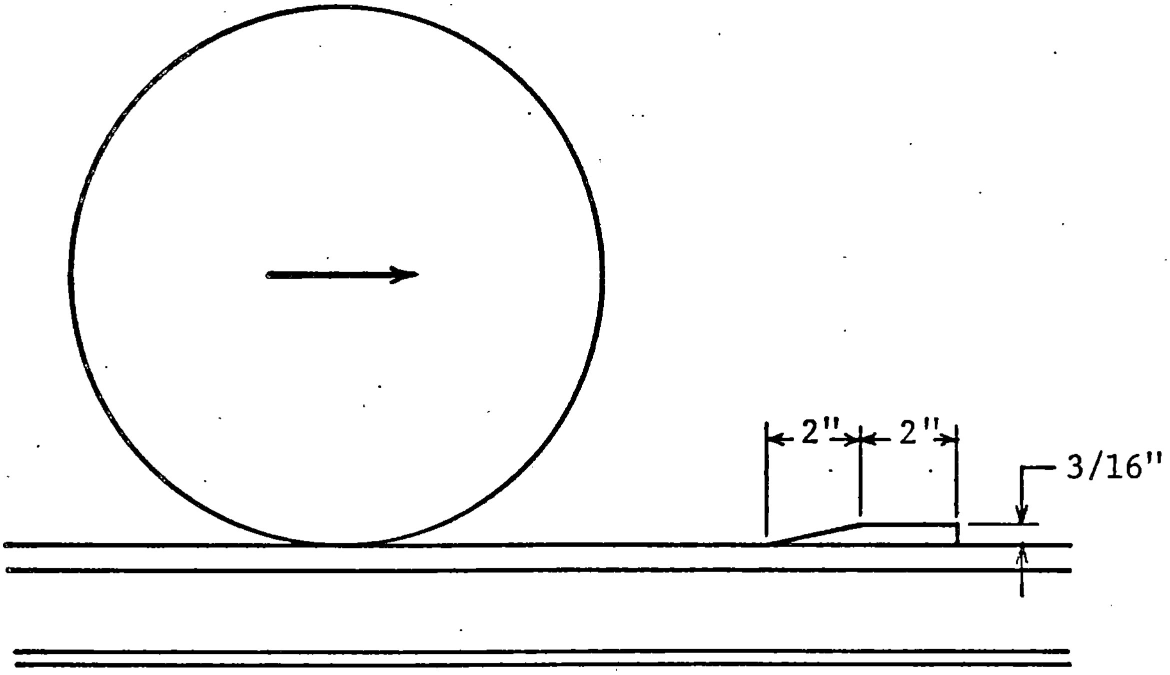

FIGURE 5-4. SHIM USED FOR DYNAMIC LOAD CALIBRATION

Dynamic Calibration

A dynamic calibration of both low and high frequency systems is required to determine the effective transfer function between the wheel/rail load and the point of actual load measurement. The most promising procedure for calibration is to generate an impulsive vertical force directly over one of the rail strain gage circuits, and generate the transient response spectra for the wheel load, the rail load, and the difference (wheel minus rail). (The bandwidth of the rail load instrumentation is estimated to be substantially wider than the wheel load response.) A suggested method for generating the impulsive force is to center the high frequency wheel over the rail strain gage circuit, partially relieve the static wheel load with a quick-release jack, and record both the wheel load (from the gage directly over the contact patch) and the rail load simultaneously. These two signals will then be analyzed with the wayside site real-time analyzer.

To provide a dynamic calibration of the low frequency system, a different procedure is suggested. A set of inclined shims clamped to the rail head just ahead of the rail strain gage circuit position will be used to generate a load impulse, clamped either to opposite rails, or clamped on one rail at the axle spacing, to excite either the bounce or roll motions. Wheel and rail loads would be recorded on separate systems as the car was rolled at low speed (5 to 10 mph) over the shims. In addition, the car body accelerations would be recorded to verify the natural frequencies of oscillation and the effective damping through calculation of the log decrement of these oscillations. Accelerations will be singly or doubly-integrated to provide a better resolution of these low-frequency oscillations, as well as analyzed on the real-time analyzer. The shims are illustrated in Figure 5-4.

6.0 TEST PROCEDURES

The preparation of test procedures must logically follow the confirmation of a host railroad and a final choice of test sites and track sections. Test procedures, particularly in operation of the test vehicle, will depend on the particular railroad -- location of terminal facilities, sidings, traffic patterns, operating procedures, etc. -- and precise details cannot be planned a priori. Test procedures will, however, generally follow the outline presented below.

6.1 Wayside Measurements

Wayside measurements will include both revenue traffic and test train runs. If normal traffic patterns are encountered, the test train runs will be made during daylight hours, and most revenue traffic will pass the site during the night. Therefore the test site will be manned on a 24-hour basis. Crew shifts will be set according to available manpower and site needs, but a minimum of two people will be at the site at all times for safety reasons.

The measurement system will be operated continuously in the "ready" state; and functional checks will be made shortly before a train passes. After recording the train, shunt and voltage insertion calibrations will be made on FM tape and oscillograph recordings. Run number, time and date, train identification, and other information will be recorded on the tape edge track (voice) and on the log sheet. A sample of the log sheet is shown in Figure 6-1. On the curved-track site, additional information will be needed from the engine crew, including throttle position and amperes, brake pipe pressure, or dynamic brake amperes. All unusual conditions will be logged under "comments".

6.2 Vehicle-Borne Measurements

The test procedure for making the vehicle-borne measurements will involve the use of a work train for a total of 3 to 5 days. The test consist (see Section 3.4) will be run over each selected track section and the instrumented wayside site at constant train speeds (± 2 mph). On tangent track 10 mph speed increments from 20 mph to the maximum track speed will be required in one direction, with one or two check runs in the opposite direction. On curved track, 5 or 10 mph speed increments from 15 mph to the maximum track speed in both directions (depending on local conditions, track time allotted, etc.) will be required. A delay of several days will be needed between tangent and curved track runs to relocate the wayside instrumentation. In addition to the 1 to 2 days of tests at each instrumented site, one day will be allotted for measurement with the test consist over branchline track with bolted-joint track and rougher track geometry. A few runs may be needed with the empty test car for reference load measurements.

A typical log sheet for use with the vehicle-borne measurement system is shown in Figure 6-2.

PROJECT NO. ____________________ PAGE _____

DATE ______________ TEST SITE ____________________________

RUN NO.	TIME*	TAPE NO.	TRAIN I.D., DIRECTION	SPEED, MPH		LOCO'S		TEMP., °F		COMMENTS
				IN	OUT	NO.	NO. AXLES	AMB.	RAIL	

TAPE SPEED _______ IPS

* FROM BEGINNING TIME CODE

FIGURE 6-1. EXAMPLE OF WAYSIDE TEST LOG

Date: ____________________

Recorded by: ______________ Special conditions: ____________________

Time	Mile-Post	Speed (mph)	Test Ref*	First Recorder			Second Recorder			Third Recorder			Remarks
				On/Off	Counter	Tape No.	On/Off	Counter	Tape No.	On/Off	Counter	Tape No.	

FIGURE 6-2. EXAMPLE OF VEHICLE-BORNE MEASUREMENT DATA LOG

7.0 DATA REDUCTION AND ANALYSIS

7.1 Wayside Measurements

The objective of the data reduction and analysis plan is to make maximum use of the recorded data to meet the program requirments for validation of the predictive models and characterization of the W/R load environment within reasonable time and cost constraints. Detailed statistical analyses will be made for key data channels, with other channels providing supportive data for more limited analyses. All data will be preserved on FM magnetic tape so that it will be available for additional data reduction and analysis, as required.

Wayside measurement data reduction and analysis requirements are summarized in Table 7-1 for all priority levels of the measurement parameters in Table 4-1. The key data channels will be processed after completion of the field test program to generate peak amplitude probability distribution and density curves (PAPD). All data from these channels will be monitored in the field on the oscillograph to verify the data quality. Since the oscillograph can record "comfortably" 10 to 14 maximum channels at a time, other channels of data will be recorded on a second and third "pass" through the tape. A switching manifold will be fabricated to facilitate this task. Time histories of test train runs and a few samples of revenue traffic will be run for these additional channels; otherwise just short samples plus calibrations will be recorded on the oscillograph to check measurement system operation.

A spectrum analysis of certain data channels will be performed in the field using a real time analyzer to establish important frequencies of oscillation and relative signal strengths. This will be the primary tool for analyzing the rail and tie acceleration signals. Spectrum analysis will also be used to define the frequency content of the continuous vertical W/R load, tie plate vertical load, and the rail absolute and relative displacement measurements.

Data time histories will be used for several purposes: to check the quality of recorded data, to establish load and deflection characteristics through the test site, and to provide preliminary estimates of vertical and

TABLE 7-1. SUMMARY OF WAYSIDE MEASUREMENT DATA REDUCTION AND ANALYSIS REQUIREMENTS

MEASUREMENT	TRANSDUCERS*	ANALYSIS FORMAT
Vertical Wheel/Rail Load	$RV_1 + RV_2$ **	PAPD
Vertical W/R Load	$RV_4 + RV_5$	PAPD
Vertical W/R Load	$RV_9 + RV_{10}$**	PAPD
Vertical W/R Load	$RV_{11} + RV_{12}$	PAPD
Vertical Continuous W/R Load	RV_3 -- RV_8 TP_2 -- TP_4	PAPD, TH, SA
Lateral W/R Load	RL_1	TH
Lateral W/R Load	RL_2	TH
Lateral W/R Load	RL_3	PAPD, TH
Lateral W/R Load	RL_4	TH
Lateral W/R Load	RL_5	TH
Lateral W/R Load	RL_6	PAPD, TH
Tie Plate Vertical Load	TP_1	TH, ST, PAPD #
Tie Plate Vertical Load	TP_2	TH, ST, PAPD #
Tie Plate Vertical Load	TP_3	PAPD, TH, ST, SA
Tie Plate Vertical Load	TP_4	TH, ST, PAPD #
Tie Plate Vertical Load	TP_5	TH, ST, PAPD #
Tie Plate Vertical Load	TP_6	TH, ST, PAPD #
Tie Plate Moment	TP_1	TH
Tie Plate Moment	TP_2	TH
Tie Plate Moment	TP_3	PAPD, TH
Tie Plate Moment	TP_4	TH
Tie Plate Moment	TP_5	TH
Tie Plate Moment	TP_6	TH
Rail Vertical Abs. Deflection	ΔV_1	TH, SA
Rail Head/Tie Lat. Deflection	ΔL_3	TH, SA
Tie Lateral Abs. Deflection	ΔL_1	TH
Rail Rotation	$\Delta L_3 - \Delta L_2$	TH, SA
Dynamic Gage	$\Delta L_3 - \Delta L_4$	PAPD, TH, SA

TABLE 7-1. (Continued)

MEASUREMENT	TRANSDUCERS	ANALYSIS FORMAT
Rail Vertical Acceleration	AV_1	SA
Tie Vertical Acceleration	AV_2	SA
L/V Ratio	$RL_3/(RV_5-RV_6+TP_3)$	PAPD
L/V Ratio vs. V	(see above)	JAPD
Rail Vertical Force/Deflection	$(RV_5-RV_6+TP_3)$ vs. $(\Delta V_1+\Delta V_2)$	JAPD
Rail Lateral Force/Deflection	RL_3 vs. $(\Delta L_1+\Delta L_3)$	JAPD

* See Figure 4-4, 4-6.

** Vertical force transducers at recommended location, 15-20 ft from primary site.

Optional statistical data pertinent to cross tie study.

TH = Time history (representative)

SA = Spectral analysis (amplitude or power spectral density)

ST = Statistical mean and variance under limited vehicle population (limited number of axles)

PAPD= Peak amplitude probability distribution and density (including mean and variance)

JAPD= Joint amplitude probability distribution lateral loads under both the test vehicle and the revenue traffic. An abbreviated statistical analysis (ST) under a limited number of axles -- probably locomotive axles -- will be made to determine mean and variance (or standard deviation) values for tie plate vertical loads, and vertical (pulse sample) and lateral W/R loads.

A detailed statistical analysis of the key data channels will be performed after completion of the field test program. In this analysis, the first step will involve an analog/digital conversion of data, calculation of peak values within the data "window" for each axle, and storage of these data points on a digital tape. This step will utilize a Honeywell DDP-516 minicomputer. This digital tape of "raw" data, digitized voltages blocked as sequential axles of a train, will then be further processed by converting voltages to physical units (pounds, inches, etc.) and adding an identifying number for test category, vehicle type, average speed, and measured variable. Five vehicle categories are recommended: (1) locomotives, (2) freight car under 50 gross tons (GT) and truck centers less than 50 ft, (3) freight car over 50 GT, truck centers <50 ft, (4) freight car under 50 GT, truck centers >50 ft, and (5) freight car over 50 GT, truck centers >50 ft. These categories provide a breakdown of major interest to the railroad community. An additional category of unclassified equipment (cabooses, business cars, maintenance equipment) may be desired, otherwise these axles can be "throwaways". The four classes of freight car will be sorted by the computer by establishing average car weight from vertical W/R load (using RV_4+RV_5 and $RV_{11}+RV_{12}$) and truck center distance from the time base between the first and third axles and the average speed. (Six-axle cars must therefore be provided a separate category or eliminated).

The third step of data processing will involve the sorting of data and storage according to identification number on a disk file. The final step, then, will be the actual statistical evaluation of the data, including the calculation of mean value and standard deviation. The overall range of each measurement will be divided into the required number of intervals, and the number of peaks falling in each interval or amplitude "bin" for a given subcategory of test, vehicle, speed band and measurement will be counted. These categories will then be stored on disk according to the subcategory identification number. Subcategories and certain combinations of categories can then be called by identification number from the CDC Cyber 70 computer, and the statistical probability density and cumulative distribution plots may be generated on a Tektronix 4012 remote graphical display console. Hard copy of these plots will be generated at this remote terminal.

7.2 Vehicle-Borne Measurements

The principal parameters which will be derived from the vehicle-borne test data are:

(a) lateral and vertical wheel/rail load components on each wheel of the truck (low frequency)

(b) vertical wheel/rail load on left wheel of first axle (high frequency)

(c) rigid body (low-frequency) accelerations of the test car.

It will be possible to review time-history data from selected data channels during the course of the test through the use of oscillograph playback. This will permit quick-look estimates of transient load levels. However, most of the data reduction and analysis will require processing the data on a computer where the information from several channels is combined (e.g., the computation of lateral load).

Data processing will be performed at IIT Research Institute in Chicago following the test runs. The data processing system is built around the use of a NOVA 1220 computer (32 K memory, floating point hardware). Analog data would first be filtered and sampled at frequencies consistent with the phenomena being measured. For example, the low frequency system data could be filtered at 20 Hz and sampled at 50 to 100 samples per second. Much higher sampling rates would be required for high frequency data.

The digitized data will be combined to give running load parameters. The assignment of gage channels to the three recorders was made to minimize the need to correlate data on the different tapes, although this can be accomplished with reference to the time code generator. All low frequency load data from the first axle are on the first recorder, all low frequency data from the second axle are on the second recorder, and all high frequency data are on the third recorder.

A flow chart illustrating the steps in processing the data is shown in Figure 7-1. This chart refers, in general, to both low and high frequency measurement systems, although there would be some difference in the details of the calculations. The first step in the process is the establishment of the proper scale factors by referencing the signal levels to the values of the calibration input. Next, adjustments are made in parametric values which depend on the angular position of the wheel/axle sets. This step is necessary for data from the axle bending moment gages and the wheel plate gages for the high frequency load measurement system. Values of the output parameters are then calculated. As indicated in the figure, the data can be presented in any one of three ways. First, a simple plot of the parameter time-history can be displayed. Second, the data may be further processed to develop a load statistic such as percentage exceedance of a specified load level, which can then be plotted or tabulated. Third, a frequency analysis of the data can be performed to develop and plot the power spectral density of the parameter.

Data formats will be utilized in the following manner:

- Time-history plots: this type of data display will be used to present load data in the vicinity of the wayside measurement system. It will also be used to determine the character of the highest loads measured during the course of a test run.
- Load summaries: load summaries will be developed for individual test runs. These will include percentage load exceeding given values, load spectra, lateral to vertical load ratio summaries, etc.
- Power-spectral density: frequency analyses will be performed on selected load signals for individual test rungs. These data will primarily be used to verify model predictions of load phenomena

Data from the accelerometer attached to the car body will be processed as required to define vehicle response accelerations. These data will primarily be used to verify analytic predictive models of vehicle response.

Specific data formats for particular track test sections, vehicle speeds, etc. will be selected in the detailed Test Procedures document.

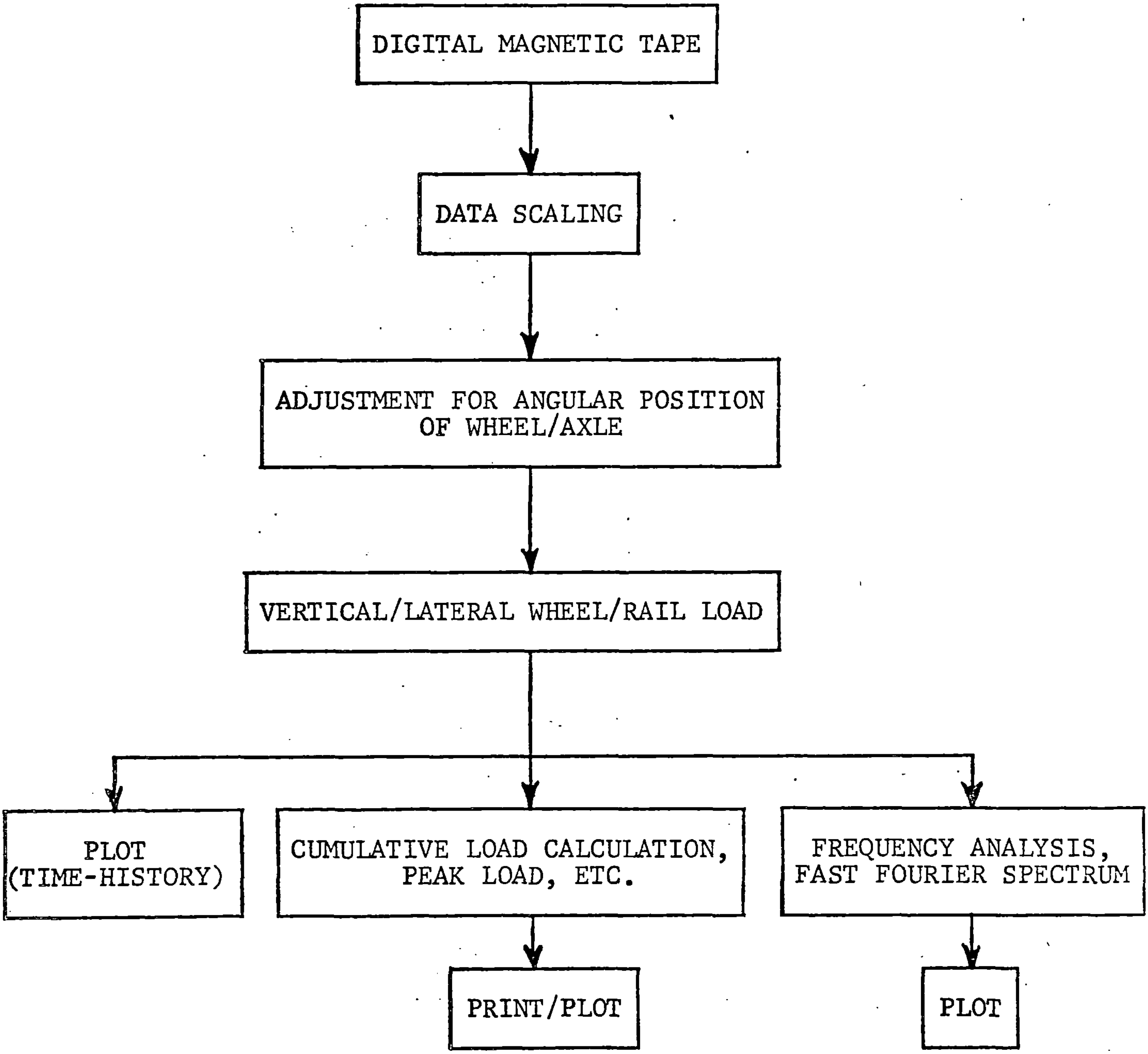

FIGURE 7-1. FLOW CHART FOR PROCESSING LATERAL AND VERTICAL WHEEL/RAIL LOAD DATA

8.0 SCHEDULE

A firm schedule of test events must (like the detailed Test Procedures) wait until a specific host railroad and test sites have been chosen. Certain guidelines on scheduling should be observed, however, depending on geographical location of the test sites. If an area in the Southwest is chosen, tests should be scheduled for late September and October 1976, when daytime temperatures are more moderate. If an area in the Northwest is chosen (Wyoming or Idaho, for example), tests should be scheduled for August and early September 1976, to avoid delays possible from early snowstorms.

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