1977

Use of bartonsville bridge to weigh trucks in motion, April 1977

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to Weigh Trucks in Motion

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Fritz Engineering Laboratory Report No. 415.1

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-PA-RD-75-17-1		

4. Title and Subtitle USE OF BARTONSVILLE BRIDGE TO WEIGH TRUCKS IN MOTION	5. Report Date April 77 6. Performing Organization Code
7. Author(s) J. Hartley Daniels	8. Performing Organization Report No. Fritz Engineering Laboratory Report No. 415.1
9. Performing Organization Name and Address Fritz Engineering Laboratory, Building #13 Lehigh University Bethlehem, PA 18015	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Research Project 75-17
12. Sponsoring Agency Name and Address Pennsylvania Department of Transportation P. O. Box 2926 Harrisburg, PA 17120	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U. S. Department of Transportation, Federal Highway Administration

16. Abstract

Results of a mission oriented pilot study are presented. The study has three main objectives; 1) design two instrumentation systems (main and back-up) incorporating a span of the Bartonsville Bridge on I-80 near TR-33 to weigh mainly 5-axle trucks in motion and without driver awareness, 2) field test the systems to determine their feasibility, and, 3) if feasible, collect sufficient data to evaluate the possible extent of overloaded 5-acle trucks on I-80.

The main system employs strain gages on all girders at two cross-sections. The back-up system employs deflection gages on all girders at the same cross-sections. A single output from each system was recorded using the oscillograph trace recorders on board the FHWA instruments trailer. Calibration was by means of two trucks of known weight and axle spacing travelling periodically over the span. Results are presented in the form of frequency histograms showing the frequency distributions for tractor weight (steering plus drive axles), trailer weight (trailer axles), individual drive and trailer axle weight and gross vehicle weight as determined from each instrumentation system. The main system appeared to give more realistic results.

The study concluded that of the total 5-axle truck traffic recorded during the sample period, about 20% exceeded the Pennsylvania legal gross vehicle weight for 5-axle trucks.

17. Key Words	18. Distribution Statement
Highways; highway bridges; highway traffic; interstate highway system; live loads; structural design; transportation; trucks; vehicles; weight measurement	No restrictions. This document is available to the public through the National Technical Information Services, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	86	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

COMMONWEALTH OF PENNSYLVANIA

Department of Transportation

Bureau of Materials, Testing and Research

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Project 75-17: Use of Bartonsville Bridge to Weigh Truck in Motion

USE OF BARTONSVILLE BRIDGE TO WEIGH TRUCKS IN MOTION

by

J. Hartley Daniels

This work was sponsored by the Pennsylvania Department of Transportation and the U. S. Department of Transportation, Federal Highway Administration. The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Pennsylvania Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

LEHIGH UNIVERSITY

Office of Research

Bethlehem, Pennsylvania

April 1977

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USE OF BARTONSVILLE BRIDGE TO WEIGH TRUCKS IN MOTION

1. INTRODUCTION

1.1 Background

A major question has arisen regarding the possible extent of overload truck traffic on Interstate I-80 in Pennsylvania. Visible distress in the concrete pavement indicates that many trucks, particularly 5-axle trucks, may be loaded beyond permissible weights. Pavement distress is noticeable especially in the eastbound lanes of I-80 between White Haven and Stroudsburg.

Existing truck weighing efforts apparently are unable to capture the real spectrum of axle or gross vehicle weight (GVW) of trucks traversing the major traffic routes in Pennsylvania, such as I-80. Many legal or overloaded trucks do not wish to encounter a weighing station in operation because of loss of travel time or fear of penalty. Regardless of driver inconvenience or penalties, it is important to monitor truck weights and essential to know the extent of overload truck traffic since the safety of bridges and the integrity of pavements depends on a knowledge of the expected loads.

Alternate methods of weighing trucks are required which will overcome the shortcomings mentioned above. The methods should be capable of weighing trucks in motion without requiring a change in normal truck highway speeds or interference with other vehicular traffic, and preferably without driver awareness.

A nationwide concern with this problem led to a United States Department of Transportation (USDOT), Federal Highway Administration (FHWA) sponsored study to determine the feasibility of utilizing highway bridges to weigh vehicles in motion[1,2,3]. The study consisted of three parts. One part was primarily concerned with the potential use of exotic forms of sensors, ie: military and law enforcement intrusion detectors, pressure-sensitive elastomers, and thin-film plastics. A second part was concerned with the potential use of strain gages at bridge bearings. A third part involved the potential use of strain gages on the main longitudinal girders of the bridge. Specifically, this part dealt with the feasibility of using steel girder-concrete slab highway bridges for weighing trucks in motion, obtaining dynamic loads, and evaluating truck traffic conditions.

At this writing little has been done to implement the findings of the FHWA feasibility study.

1.2 Objectives

The pilot study reported herein is of small scope, with limited objectives and is mission oriented. Although the techniques used are similar to those discussed in the third part of the FHWA study, they are based on principles, discussed herein in Chapter 2, which were not suggested in that study.

The primary objectives of this pilot investigation are as follows:

1. Design and a back-up main instrumentation systems, incorporating the recording equipment on board the FHWA instruments trailer, for use with an existing bridge span on I-80 between White Haven and Stroudsburg, which are suitable primarily for obtaining the approximate static gross weights of 5-axle trucks and their

individual axles as they cross the bridge span at highway speeds.

2. Conduct a field test of the systems to determine their feasibility.

3. If the systems appear feasible, collect a sufficient quantity of data to estimate the actual load spectrum of mostly 5-axle trucks crossing the bridge for the purpose of estimating the extent of overloaded 5-axle trucks travelling eastbound on I-80. If possible this is to be carried out without driver awareness.

1.3 Scope

The instrumentation systems use one span of the Bartonsville Bridge on I-80 near TR-33. The main system employs electrical resistance strain gages top and bottom of all girders along two right cross-sections symmetrically located in the span. A single output was recorded by one of the four 16 channel ultraviolet oscillograph trace recorders located in the FHWA instruments trailer which was situated under the bridge span. The system was calibrated using two test trucks of known weights and axle configurations. No attempt was made to stop and weigh truck traffic by traditional means since it was desired to weigh trucks without driver awareness.

Since the study is mission oriented a possible failure of the instrumentation system and/or recording system required that a back-up instrumentation system and alternative recording systems be provided.

The back-up system employs electrical deflection gages mounted on the bottom of all girders along the same two right cross-sections discussed above. A single output was recorded by another of the ultraviolet oscillograph trace recorders in the FHWA trailer. The back-up system was also calibrated using two test trucks. This system was operated along with the main system during the entire data collection stage. Although the deflection gages are more easily attached to the bridge span, this system is not expected to provide as reliable data as the main strain gage system for reasons discussed in the report.

Several alternate recording systems were available. In addition to the two remaining oscillograph units in the FHWA trailer, a smaller 12 channel ultraviolet oscillograph trace recorder from Fritz Engineering Laboratory was on standby. None of these extra units was required, however.

The FHWA trailer is also equipped with an analog-digital converter unit. This unit was also available in case of complete breakdown of other recording systems.

The field study was conducted in November 1975 during which a total of 2,120 trucks were weighed. The weighing operation was on a continuous 24 hr/day basis for a total of 86 hours. The report conclusions are based on a 1,227 truck sample.

The design of the two instrumentation systems and the results obtained are reported herein in Chapters 2 through 6.

2. TRUCK WEIGHING SYSTEMS

2.1 Basic Principle of Main System

The design of the main strain gage system for weighing 5-axle trucks is based on the following basic principle:

> Given a simple, right (non-skew), multiple girder bridge span, if, for a particular longitudinal position of a single wheel load in the span, the sum of the statical bending moments in all the girders along one right cross-section is constant, regardless of the lateral (lane) position of the wheel load, then, the sum of the influence coefficients for statical bending moment in all the girders along two right cross-sections located symmetrically in the span is constant for all lateral and longitudinal positions of the wheel load provided it is located entirely in the region between the two cross-sections.

The above principle is easily extended to include more than one wheel load where all loads are located entirely in the region between the two cross-sections. In this case the sum of the influence coefficients for statical bending moment in all the girders along the two right cross-sections is constant for all lateral and longitudinal positions of all the wheel loads in the region.

Figure 1 shows a schematic of a simple, right, multiple girder bridge span of length L. Cross-sections 1 and 2 are symmetrically located distance b from each support. Wheel loads P_1, P_2, --- P_i, --- P_n are located in the region between the two cross-sections. Figure 1 also shows the influence lines for bending moment at the two cross-sections and their sum.

For load P_i, distance χ_i from a support, where $b \leq \chi_i \leq (L-b)$, the sum of the bending moments at the two cross-sections shown in Fig. 1 is $P_i b$. For all the wheel loads, the sum is $\Sigma P_i b$ where i = 1, 2, --- n.

The usefullness of the basic principle for weighing trucks is evident. A single output, proportional to the sum of the bending moments in all the girders at the two cross-sections can be recorded by an ultraviolet oscillograph trace recorder. If one or more axles are travelling in any lane between the two cross-sections while all other axles are off the bridge span, then, neglecting all other influences, the oscillograph trace will exhibit a level plateau. The plateau height above datum is proportional to the magnitude of axle load(s), ΣP_i, and the distance b (Fig. 1). The plateau length is proportional to either the distance the axle(s) travel in the region between the two cross-sections without leaving the region or the distance they travel before another axle enters the bridge span.

The expected form of the oscillograph recorder trace can easily be computed as shown in Fig. 2 using the principle discussed above. The example shown in the figure is based on an assumed 5-axle truck travelling from left to right over a bridge span of 68.5 ft. The bridge span and the locations of the two cross-sections 16.0 ft. from each end have been taken from the Bartonsville Bridge span which was selected for the field study and discussed in Chapter 3 of this report.

In the figure, S denotes the steering axle. Similarly D1, D2 and T1, T2 denote the two drive and two trailer axles, respectively. The total trace length is proportional to the bridge span length of 68.5 ft. plus the truck length of 46 ft. from axle S to axle T2. The trace is computed as proportional to the sum of the statical bending moments at cross-sections 1 and 2 as the five axles completely cross the span. In the figure the vertical axles are scaled to the known axle weights corresponding to the two plateaus.

The height of the first plateau, S + D1 + D2, is proportional to the weight of the 3 tractor axles. The plateau length is proportional to the distance the 3 axles travel after D2 crosses section 1 and before T1 enters the span.

The height of the second plateau T1 + T2 is proportional to the weight of the 2 trailer axles. The plateau length is proportional to the distance the 2 axles travel after D2 leaves the bridge span and before T1 crosses section 2.

It is evident that a third plateau which would relate to the total truck weight cannot be obtained in the example shown in Fig. 2. To achieve that plateau, which would occur approximately mid-length of the trace, the distance between cross-sections would have to exceed the total truck length of 46 ft.

2.2 Required Span Length and Cross-Section Locations

From the discussion in Art. 2.1, the required bridge span length and cross-section locations are functions of the truck axle spacings and the number of axles to be weighed simultaneously. For example, different results will be obtained depending on whether each axle is to be weighed individually or the complete truck is to be weighed. The bridge span and location of cross-sections will also influence the plateau height above datum and the plateau length. The relative accuracy is increased with increasing plateau height. The plateau length should be such that it can be readily identified on the oscillograph trace.

As part of a recent stress history study of the Lehigh Canal Bridge on PA 22 near Allentown which was conducted by Fritz Engineering Laboratory, the Bureau of Planning and Statistics of the Pennsylvania Department of Transportation (PennDOT) stopped, weighed and determined the axle spacings of over 250 trucks, mostly 5-axle. Although axle spacings varied considerably the predominant spacings for 5-axle trucks were similar to those shown in Fig. 2 for the example truck. (The axle loads shown are not necessarily typical, however.) Based on the axle notation and spacings shown in Fig. 2 the required bridge span lengths and cross-section locations can be determined for five different assumptions on the axle or axle groups to be weighed as follows: (1) weigh each axle (S, D1, D2, T1, T2), (2) weigh steering (S), drive (D1 + D2) and trailer (T1 + T2) axles separately, (3) weigh tractor (S + D1 + D2) and trailer (T1 + T2) separately, (4) weigh tractor (S + D1 + D2), trailer (T1 + T2) and truck (S + D1 + D2 + T1 + T2) separately, and (5) weigh only the entire truck (S + D1 + D2 + T1 + T2).

Referring to the basic principle discussed in Art. 2.1, the above five assumptions and maintaining the condition that only the axle(s) to be weighed can occupy the region between the two cross-sections while all other axles must be off the bridge span, the inequality conditions governing the required span length L and distance b from the supports to the two cross-sections (Fig. 1) are as follows:

(1) S, D1, D2, T1, T2

$$b \leq 4 \text{ ft.} \tag{1}$$

$$(L - b) \leq 4 \text{ ft.} \tag{2}$$

The development of the several inequality conditions for this case are illustrated in Fig. 3.

For the maximum span length of 8 ft. the two cross-sections coincide at midspan and the resulting oscillograph trace plateau length is zero. A detectable plateau might be observed if L = 7 ft., b = 3 ft. and a high trace speed is used. However, obvious difficulties arise in finding such a span length and with the accuracy of recording the expected relatively weak signal due to the small bending moments involved.

(2) S and (D1 + D2) and (T1 and T2)

$$b \leq 12 \text{ ft.} \tag{3}$$

$$\text{and } L \leq 42 \text{ ft.} \tag{4}$$

In this case, with the maximum span of 42 ft. and b = 12 ft. a plateau would occur only for the trailer axles. The other two plateaus would probably be of sufficient length if the span were maintained at 42 ft. and b reduced to 10 ft.

(3) <u>(S + D1 + D2) and (T1 + T2)</u>

$b \leq 26$ ft. (5)

and $L \geq 16 + 2b$ ft. (6)

(4) <u>(S + D1 + D2) and (T1 + T2) and (S + D1 + D2 + T1 + T2)</u>

$b \leq 26$ ft. (7)

and $L \geq 46 + 2b$ ft. (8)

(5) <u>(S + D1 + D2 + T1 + T2)</u>

$b \geq o$ ft. (9)

and $L \geq 46 + 2b$ ft. (10)

It is interesting to note here that with b = o, Eq. 10 gives the span length condition for the double ended approach concept discussed in Ref. 2.

2.3 Implementation Decisions

Although the system design principle, as described in Art. 2.1, is relatively straight forward in concept, some difficulties are expected when it is implemented in a real truck weighing situation. The moving truck is an oscillating system having many frequencies, not necessarily in phase, travelling over a bridge superstructure which itself is an elastic system with its own natural frequencies. The superstructure responds dynamically to the moving truck in an oscillating manner which depends mainly on (1) truck weight, speed and axle configuration, (2) superstructure mass, material and configuration, (3) truck and superstructure natural frequencies and, (4) truck lane position. In addition the superstructure response is dependent on the roughness of the deck surface and the presence of other vehicles in the same and other lanes. Experience indicates that the dynamic response is influenced mainly by truck weight and speed, lane position and type and condition of superstructure for a single truck traversing the bridge[2].

A thorough investigation of the use of the system design principle described herein requires that each of the above variables be examined and accounted for in the weighing system. Such an investigation is not possible within the scope of this pilot study. Implementation of the weighing system is therefore based on the following decisions.

(1) The determination of dynamic wheel or axle loads is not within the project scope. Therefore dynamic effects resulting from oscillations of the bridge and truck will be eliminated as much as possible by suitable filtering of the signal at the oscillograph trace recorder.

(2) Static axle and truck weights are to be determined without driver awareness. Therefore truck traffic will not be stopped and weighed by conventional means. The study will rely on the use of travelling test trucks to calibrate the oscillograph trace.

(3) Several bridges on I-80 within the interest area have previously been studied by Fritz Engineering Laboratory in connection with other investigations. If possible, within the limitations discussed in Art. 2.2, the span selected for implementation of this pilot study should have lateral load distribution characteristics known to conform closely to the requirement implicit in the basic principle stated in Art. 2.1. Lateral (lane) truck position can

therefore be assumed to have little static or dynamic effect on the results of the field study.

(4) Additional considerations in the selection of the bridge span selected for implementation of this pilot study are to include; (a) a simple, right (non-skew) span to eliminate the effects of other spans, (b) a span with relatively high damping characteristics to help reduce dynamic effects, (c) a span which allows one of the weighing conditions outlined in Art. 2.2 to be implemented, (d) a span with a relatively smooth deck to reduce impact, (e) a span with relatively straight, long and level approach conditions so that isolated trucks can be easily identified and weighed under both day and night field conditions, and (f) a span relatively close to a power source suitable for operation of electrical instrumentation systems.

2.4 Back-Up System

As applied to the design of the back-up deflection gage system, the basic principle discussed in Art. 2.1 requires that, 1) the sum of girder deflections along a cross-section of the span is constant with variable lateral (lane) position of the wheel load, and, 2) the influence lines have straight line segments. Although the former condition may be closely approximated, the latter condition is not. Influence lines for girder deflection consist of curved rather than straight line segments.

However, an analysis indicated that identifiable curved plateaus could be expected to occur on an oscillograph trace if the deflection gage system is designed operate in exactly the same way as the main system. In addition, any error involved should be reduced since the actual traces produced by the sample traffic will be calibrated from traces produced by travelling test trucks.

On this basis, both the main and back-up systems were designed to operate in an identical manner. If the main system should fail, the back-up system should provide useful data. If both systems operate satisfactorily useful comparative results are available.

3. BARTONSVILLE BRIDGE INSTRUMENTATION AND RECORDING SYSTEM

3.1 Bridge Selection

A visual inspection was made in July 1975 of many of the bridges in the east and west bound lanes of Interstate I-80 between White Haven and Stroudsburg, Pennsylvania. One of the simple spans in the eastbound lanes of the Bartonsville Bridge, shown in Fig. 4, was selected for this study since it more closely satisfies the several conditions discussed in Chapter 2 and is within that portion of I-80 of interest (Chapter 1).

A view of the span is shown in Fig. 5. A typical cross-section is shown in Fig. 6. The span consists of a reinforced concrete slab on 5 parallel AASHO-PCI Type III (nearest PennDOT equivalent: Type 24/25) prestressed I-girders with a 68'-6" span center-to-center of bearings.

Besides being a simple, right (non-skew) span, the primary reasons for the selection of the particular span shown in Fig. 5 are as follows:

1. The same span was extensively studied by Fritz Engineering Laboratory in connection with PennDOT Project 67-12: "Lateral Distribution of Load for Bridges Constructed with Prestressed Concrete I-Beams".[4,5] One of the principle objectives of that study was to evaluate the lateral distribution of live load. It was concluded that the sum of the girder distribution coefficients for bending moment and deflection for this span was close to 100 percent, thus essentially satisfying the hypothesis of the basic principle stated in Art. 2.1.

2. Referring to Art. 2.2, although the 68'-6" span will not allow weighing individual axles or the steering axle separate from the tractor

drive axles, the tractor and trailer can be weighed separately. It is also possible to weigh the entire 5-axle truck with the span length available. However, to ensure sufficient plateau length, the distance b, defined in Art. 2.1, would necessarily be somewhat less than the maximum 11'-3" (Eq. 8) and probably closer to 5 to 8 ft. It is preferable to select b as large as possible to increase the relative accuracy of measuring the sum of the bending moments at the two cross-sections, which increase in proportion to b. In this case, however, b was selected as 16 ft., as shown in Fig. 5, primarily to instrument nearly the same cross-section as in the study reported in Ref's. 4 and 5 (test section Q, Fig. 3, Ref. 4 for example). Thus the capability of weighing the entire 5-axle truck was eliminated in this study, although the gross vehicle weight is determined by the sum of the tractor and trailer axle weights.

3. Field test experience shows that dynamic effects (amplitude and frequency of oscillations) associated with concrete girder superstructures are less than for steel girder bridges, thereby reducing problems with signal filtering.

4. The span is located in a bridge with a long, straight, level approach with an ideal location above the west bridge abutment for truck spotting and identifying.

5. A new asphalt surface layer was applied to the eastbound bridge lanes just prior to the field data collection part of this study, thereby providing a fairly smooth deck surface.

6. The span is easily accessible from below for instrumentation, as shown in Fig. 4.

3.2 Instrumentation of Girders

The two cross-sections in the span which were selected for instrumentation are each 16 ft. from the center of the girder bearings as shown in Fig. 5. The two cross-sections therefore define ten girder locations for instrumentation.

The basic principle stated in Art. 2.1 as applied to the main system requires the summation of the influence coefficients for statical bending moments in the slab-girder structure along both cross-sections. This is accomplished herein, in an equivalent manner, by summing the differences in the strains, top and bottom of each girder, at each of the ten instrumented locations. Assuming simple bending (no torsion) and complete interaction between the slab and the girders, the difference in strain top and bottom of a girder is directly proportional to the bending moment in the effective slab-girder Tee beam through the moment-curvature relation for linear elastic structures.

Four, 5 in. long Type SR4-A9-3, 120 ohm, electrical resistance strain gages were mounted on each girder at the ten locations as shown in Fig. 7, between Oct. 29 and Nov. 6, 1975. The gages were oriented parallel to the girder and wired as a full bridge as shown in the figure. The output (signal) therefore provides the average difference in strain between the two top (B and D) and two bottom (A and C) gages.

The photo in Fig. 7 shows gages A (left) and C (right) which are framed by the black tape used to protect the gages and to secure the small wires leading to the gages. The clamp shown attached across the bottom of the girder is used to secure the heavy electrical cables (at the right in the photo) leading to the FHWA instruments trailer. The clamp is also used to mount the deflection gage (below center of the girder in the photo) used in the back-up system.

The photo in Fig. 5 shows the top gage (gage D, Fig. 7) on the outside of the north girder at both cross-section locations. The clamps and the electrical cables leading to the FHWA trailer are also shown in the figure.

The back-up system employs electrical deflection gages mounted on the bottom of all the girders at the same cross-sections used for the main strain gage system and shown in Fig. 5. The gages are wired as a full bridge circuit.

The photo in Fig. 7 shows a typical deflection gage mounted on the clamp attached to the bottom of a girder. The deflection gage consists of a triangular metal plate having strain gages mounted on both faces. The base of the plate is bolted to the arm of the clamp. The tip of the plate is attached to a concrete block resting on the ground directly under the gage by a small steel wire under initial tension. The plate behaves as a cantilever beam which bends as the girder deflects. As the girder deflects downwards the tip of the plate moves upward with respect to the base thus relieving the initial bending moment in the plate. The strain gages measure the resulting change in the surface strains, which for small deflections are proportional to girder deflection.

3.3 Recording System

A schematic of the recording system for the main strain gage system is shown in Fig. 8. The recording system for the deflection gage system is similar. The signal from each of the ten full bridge circuits on the girders is brought to the instrumentation trailer by shielded cable (Fig. 5). For clarity only one girder is shown in the figure. The trailer was placed under the adjacent span west of the instrumented span and can be seen to the right of the photo in Fig. 4. Each signal first passes through a strain gage conditioner then to a high gain amplifier. The ten amplified signals are then brought to a summing amplifier (gain of one) where all ten signals are summed. After passing through a low pass filter set at 4 Hz the signal is recorded by one of the ultraviolet oscillograph trace recorders in the instruments trailer. The summing amplifier can also be bypassed as shown in the figure so that each of the ten signals can be recorded separately.

Electrical power for all systems was brought from existing power-lines near the west end of the bridge.

4. TRUCK WEIGHT DATA RECORD

4.1 Record Period and Sample Description

Instrumentation of the bridge span and a check of all recording systems was completed by late afternoon Nov. 6, 1975. The collection of truck weight data began at 6:45 p.m. Nov. 6 and proceeded on a continuous 24 hr. per day basis until 8:45 a.m. Nov. 10, 1975. During the 86 hour recording period data was obtained for a total of 2,120 trucks travelling eastbound on I-80 across the span.

As stated in Chapter 1, one of the primary objectives is to estimate the load spectrum of mostly 5-axle trucks crossing the span. Referring to the FHWA truck classification shown in Fig. 9, approximately 75% of the 2,120 truck sample are of the 5-axle, 3S-2, type. The remaining 25% consist mostly of types 3, 2S-1, 4, and 2S-2. A few cars, buses and 2-axle trucks are also included. In addition one 5-axle truck sampled is a 2S-3 (a variation not shown in Fig. 9, but having one steering, one drive and 3 trailer axles).

The primary factors influencing the choice of a particular sample truck from the total vehicular traffic are as follows:

1. Select a sample truck every 2 to 3 minutes on the average. The actual rate is about one truck every 2.5 minutes.

2. Select an isolated sample truck crossing the span alone. Often, the presence of cars crossing with the truck is unavoidable. However, it was determined that one or two cars on the span has a negligible effect on the trace produced by the truck.

3. Select any 5-axle truck which appears to be heavily loaded so that extreme values are included in the truck weight spectrum. Often the truck loads are visible. If not, an experienced spotter can usually tell from the truck and tire noise if the truck is heavily loaded.

4. Even though the system is designed to weigh 5-axle trucks of the general dimensions shown in Fig. 2 it can obviously weigh other trucks particularly 3 and 4 axle trucks less than about 36 ft. in length. A selection from most of the vehicles crossing the span is therefore included in the sample. Although much of this data had to be discarded in the subsequent analysis it did prove useful in the field for defining the limits of capability of the weighing system and in distinguishing between good and bad traces.

5. Include in the sample trucks travelling at low and high speeds for comparative analysis. It was noticed in the field for example that the heavier faster trucks produced the best traces.

The sample rate (ratio of number of trucks sampled to total vehicular traffic, excluding cars and other light vehicles) was estimated at intervals during the record period. For example over a 6 hour period during the day on Nov. 8 the sample rate was observed to be 45%. On Nov. 9 the sample rate at night was under 40%. For purposes of this study an average sample rate of 40% is used.

4.2 Field Operations

The field operation requires a minimum of one man at each of three stations, (1) the truck spotter on a ledge or in the median at the west bridge approach, (2) the button box operator about 100 ft. directly south of the truck weighing span (Fig. 4), and, (3) the data recorder at the oscillograph trace recorder in the FHWA instruments trailer. It is desirable to rotate the three men between the three positions or to add standby personnel about every one to two hours to prevent boredom. Thus about 6 men are required each 8 hour shift. The personnel requirements are therefore about 18 men for each 24 hours of operation. Personnel were recruited from the project team as well as from the Fritz Laboratory technician group and undergraduate civil engineering student help. In all, about 30 different individuals worked full or part shifts during the 86 hour field operation.

The sequence of daylight field operations from the selection of a potential truck for weighing through to the acquisition of the oscillograph trace of the truck is as follows (night time operations are similar):

1. During daylight hours the truck spotter is positioned on a ledge above the west approach to the bridge as shown in Fig. 10. During night time hours, the spotter takes up the same position of the photographer that took the view shown in Fig. 10 so that the axle configurations are more easily visible. From the ledge, the spotter can select a potential truck for weighing as it approaches from up to a mile from the bridge as shown in Fig. 11. When the truck is about in the position shown in Fig. 11 and the spotter has determined that the truck will probably cross the weighing span alone (or with no more than one or two cars) he radios to the button box operator to "standby", the signal to be on the alert for the next truck to weigh.

2. The view to the east from the spotter's position on the ledge is shown in Fig. 12. When the truck enters the bridge, approximately at the start of the asphalt surface layer shown in Fig. 12, the truck is in view of the button box operator. The spotter then radios "mark" which is the signal to the button box operator that this truck is to be weighed.

3. Figure 13 shows the position of the button box operator in the tent directly south of the weighing span and his view of the west end of the bridge. The spotter is just behind the right side of the signboard shown in Fig. 13.

4. The button box operator follows the progress of the truck across the bridge. When the truck is crossing the span immediately to the west of the weighing span, as shown in Fig. 14, he starts the oscillograph trace recorder shown in Fig. 15.

5. When the truck has crossed over the truck weighing span the button box operator stops the oscillograph trace recorder.

6. The spotter, after observing the truck to have crossed to the east end of the bridge radios to the data recorder in the trailer telling him the truck classification (Fig. 9), a description of the truck ("flatbed", "closed box", etc.), the lane position ("right lane" for travelling lane or "left lane" for passing lane), his estimate of relative loading ("light", "medium", or "heavy"), and truck speed (fast, moderate or slow).

7. The data recorder writes the above information beside the traces and in addition notes the date and time every fifth trace. Traces produced by both the main and back-up systems were output parallel to each other on the recording paper (see Figs. 18 to 33 for example).

4.3 Calibration Trucks

Two trucks of known weights and axle spacings were used to calibrate the oscillograph trace records. The calibration truck provided by PennDOT is shown in Fig. 16, together with the axle weights and spacing. The PennDOT calibration truck can also be seen in the travelling lane of Fig. 11.

The calibration truck provided by FHWA is shown in Fig. 17 together with the axle weights and spacing.

Together the PennDOT and FHWA trucks made 174 passes over the weighing span (100 for FHWA and 74 for PennDOT). Both trucks travelled a closed circuit during daylight hours on Nov. 7 and 8, 1975 which took them across the bridge about every 15 or 20 minutes. The FHWA truck also operated during the day on Nov. 9 and for an hour on Nov. 10, 1975.

Each truck paced itself while approaching the bridge from the west to ensure that it crossed the weigh span alone (except for one or two cars). The truck spotter maintained radio communication with the truck drivers so that speed and lane position over the weighing span could be controlled and noted on the oscillograph trace.

4.4 Typical Oscillograph Trace Records

Oscillograph trace records typical of most of the satisfactory traces produced by the sample truck traffic and the two calibration trucks travelling over the weighing span are shown in Figs. 18 through 33. In each figure the truck is travelling from left to right. The upper trace is produced by the main strain gage system. The lower trace is produced by the back-up system which employs electrical deflection gages on the girders.

In the following, reference is made primarily to the upper trace in Figs. 18 to 33, although the lower trace is usually quite similar.

Figures 18 and 19 compare two traces produced by the PennDOT calibration truck travelling at 60 miles per hour in the right and left lanes respectively. The corresponding average plateau heights at A and B in the figures are very similar, indicating that the traces are essentially independent of the lane position of the truck. Except for the pronounced wave patterns in the vicinity of the plateaus, the traces are also similar in shape to the predicted trace shown in Fig. 2.

The wave patterns are thought to be produced by dynamic increments which are not completely eliminated by the low pass filter. This is discussed further in Chapter 5.

Figure 20 can be compared with Figs. 18 and 19 to show the effect of a change in truck speed from 30 to 60 miles per hour. The trace is distinctly more irregular at the slower speed.

The effect of truck speed is shown even more clearly in Figs. 21 and 22 by comparing the traces produced by the FHWA calibration truck travelling at 60 and 20 miles per hour. The trace in Fig. 21 is similar to the expected trace shown in Fig. 2. The trace in Fig. 22 is much more irregular and does not resemble the expected trace.

Irregular traces were observed to occur for any relatively slow moving truck as well as for trucks that obviously were, or suspected to be, relatively lightly loaded. The more predictable traces are nearly always associated with fast moving (50 to 60 miles per hour) heavier (exc-eding 30 to 40 kips gross vehicle weight) trucks of the 3S-2 type. Example traces taken from the total truck sample are shown in Figs. 23 to 29. In each case the truck is moving quickly and fairly heavy. In the figures, "box" refers to the familiar tractor-semi trailer truck with completely enclosed trailer. "Flat bed" refers to tractor-semi trailer trucks with open or partially open trailers. "Dump" refers to open topped semi trailers used to carry bulk materials. From the ledge above the west approach to the bridge it is easy for the truck spotter to observe the relative loading in the case of flat bed and dump trucks.

Figure 30 is included to indicate the shape of trace produced by a loaded 2-axle truck, in this case a 2D (see Fig. 9). The axle spacing of this truck was observed to be short enough to produce plateaus for each axle separately as well as a plateau for the gross vehicle weight. Although the trace is irregular the tendency towards three plateaus is evident. Similar traces were observed for shorter loaded trucks of types 3 and 4.

Figure 31 is included to illustrate the very irregular trace produced by a type 3 dump truck which was observed to be empty.

Figures 32 and 33 are included to show a comparison of the filtered and unfiltered traces. Examination of Figs. 18 through 31 indicate that for a particular truck the two traces produced by the strain gage system and the back-up electrical deflection gage system are nearly identical. Thus the effects of filtering to 4 Hz are evident by comparing the two traces in Fig. 32 and the two traces in Fig. 33.

5. TRUCK WEIGHT DATA ANALYSIS

5.1 Comparison of Actual and Predicted Traces for the Main System

The upper traces in Figs. 18, 19 and 21 show a comparison of the actual traces recorded by the strain gage system with the predicted traces computed for the PennDOT and FHWA calibration vehicles. Prediction traces for the deflection gage system were not prepared.

The predicted traces for the main system were computed as discussed in Art. 2.1 and are based on the actual axle weights and spacings shown in Figs. 16 and 17. The trace length was determined from the known truck speed (from speedometer in truck) and the known speed of the recording paper ejecting from the oscillograph recorder. The paper speed was held constant at 4 inches per second duirng the field operation. This speed is converted to an equivalent one second interval shown on Figs. 18, 19 and 21. The height of the prediction traces is arbitrary since the amplitude of the actual traces could be varied arbitrarily within the boundaries of the record paper. The amplitude adjustment was held constant however during the duration of the field operation. To allow comparison of the actual and predicted traces in the figures, one of the two plateau levels of each prediction trace is set to coincide with the average height of the corresponding plateau of the actual trace.

Figures 18, 19 and 21 indicate that reasonable agreement exists between the actual and predicted traces for the main system for each of the two calibration vehicles. The actual traces however exhibit pronounced wave patterns. These patterns occurred to a greater or lesser extent on most of the traces produced by the calibration vehicles and traffic sample. The wave patterns are believed to result from low frequency oscillations of the span which are not completely eliminated by the low pass filter as was mentioned in Art. 4.4.

5.2 Calculation of Calibration Factors

The plateau heights for all actual traces produced by the calibration vehicles and truck sample were established as the average trace height at the plateau locations. Figures 18, 19 and 21 for example show the plateau heights corresponding to the tractor axle weights and trailer axle weights for selected actual traces produced by the PennDOT and FHWA calibration vehicles. Similarly Figs. 23 to 29 show the plateau heights established for selected traces from the truck sample.

Many traces appear to exhibit more than two plateaus because of the wave patterns discussed above. For example, the trace in Fig. 23 appears to have three plateaus. In all such cases, however, the two plateaus of interest were quite easily identified by computing their approximate spacing on the trace from the known paper speed, an approximate truck speed (Art. 4.2) and an average axle spacing (Fig. 2).

The calculation of truck and axle weights for the 1,227 vehicles in the truck sample first required the calculation of average or mean calibration factor for both the main and back-up systems from the traces produced by the 174 passes of the PennDOT and FHWA calibration vehicles. Individual calibration factors were computed for each plateau of each trace produced by a calibration vehicle by dividing the known sum of axle weights corresponding to a particular plateau by the height of the plateau in tenths of an inch.

The resulting histogram for the strain gage system is shown in Fig. 34. The computed mean and mode values are 3.63 and 3.38 respectively with a standard deviation of 0.67. In the figure n refers to the number of values used to plot the histogram.

Figure 35 shows the histogram obtained for the deflection gage system. The computed mean and mode values are both 2.38 with a standard deviation of 0.38.

5.3 Truck and Axle Weight Distribution

Figures 36 to 39 show the calculated weight distributions based on the mean calibration factor of 3.63 computed for the strain gage system (Fig. 34). In the figures n refers to the total number of values used to determine the histograms.

Figure 36 shows the distribution of steering plus drive axle weights (S + D1 + D2) for the 1,227 truck sample. The minimum and maximum values obtained are 15 and 90 kips respectively. The legal load level of 58.4 kips on the three axles (computed for a 5 axle truck) is shown in the figure.

Figure 37 shows the distribution of trailer axle weights (T1 + T2) for the 1,227 truck sample. The minimum and maximum values obtained are 5 and 70 kips respectively. The legal load level of 36 kips on the two axles is shown in the figure.

Figure 38 shows the distribution of individual drive and trailer axle weights for the 1,227 truck sample. Individual drive axle weights were obtained by assuming a constant value of 8 kips for the steering axle and distributing the remaining weight equally to the drive axles. Similarly the total weight of the trailer axles was distributed equally to the trailer axles. For example, for a type 3S-2 truck, S=8 kips, D1 = D2 and T1 = T2. In the figure n = 4,857 refers to the total number of drive and trailer axles used to compute the histogram. The distribution of truck types in the 1,227 truck sample are as follows: 1176 type 3S-2; 49 type 2S-2; 1 type 2S-1; and 1 type 2S-3. The minimum and maximum values obtained are 5 and 45 kips respectively. The legal load of 18 kips for one axle is shown in the figure.

Figure 39 shows the distribution of gross vehicle weights for the 1,227 truck sample. The minimum and maximum values obtained are 20 and 125 kips respectively. The legal load level of 73.28 kips (for a 5 axle truck) is shown in the figure.

Similarly Figs. 40 to 43 show the calculated weight distributions based on the mean and mode calibration factor of 2.38 computed for the deflection gage system (Fig. 35).

5.4 Overload Distribution

Figures 44 to 47 shows the overload distribution based on the mean calibration factor of 3.63 computed for the strain gage system (Fig. 34). These figures show the distribution of vehicle weights in excess of the legal load levels shown in Figs. 36 to 39.

Similar Figs. 48 to 51 show the overload distribution based on the mean (and mode) calibration factor of 2.38 computed for the deflection gage system (Fig. 35).

5.5 Summary of Results

One of the objectives of this study as stated in Art. 1.2 is to estimate the extent of overloaded 5-axle trucks travelling eastbound on I-80.

TABLE 1 - Percent of Overloaded Trucks in Sample

	Main Strain Gage System		Back-up Deflection Gage System
Calibration Factor	3.38	3.63	2.38
Steering Plus Drive Axles	1.6	2.9	19.4
Trailer Axles	6.0	9.5	28.3
Individual Axles	25.2	33.5	55.9
Gross Vehicle Weight	20.8	35.2	57.7

Table 1 shows the percent of overloaded (mostly) 5-axle trucks (individual axles, axle combinations or gross vehicle weight) computed from the distributions shown in Figs. 36 to 47 for the 1,227 trucks in the analysis sample. Percentages are shown corresponding to the mode and mean calibration factors for both the main and back-up systems.

Overload is defined in relation to the legal load limits for 5-axle trucks shown in Figs. 36 to 47. The overload percentages shown for individual axles in the table include only the drive and trailer axles. The steering axle of each truck was assumed to weigh 8 kips.

The results shown in Table 1 can be correlated with the overload distributions shown in Figs. 44 to 51 as follows: The percentages of the total sample used to construct the distributions shown in Figs. 44, 45, 46 and 47 are 2.9%, 9.5%, 33.5% and 35.2% respectively. Similarly the percentages of the total sample used to construct the distributions shown in Figs. 48, 49, 50 and 51 are 19.4%, 28.3%, 55.9% and 57.7% respectively.

It should be noted that because of a certain bias present in the results of this study, the percent of overload axles and trucks shown in Table 1 are slightly inflated. When determining the 2,120 truck record at the bridge site a concious effort was made to exclude some of the obvious or suspected light 5-axle trucks in order to reduce the volume of data being recorded. In addition, when selecting the final 1,227 truck sample for analysis, the poorer traces usually were associated with some of the lighter 5-axle trucks and these also were excluded. The weight distributions shown in Figs. 36 to 39 based on the mean calibration factor for the main system are therefore biased towards the heavier vehicles. That is, the frequency of heavier loads should be a little less and that of the lighter loads a little greater. The percentages listed in Column 2 of Table 1 are therefore conservative. A more realistic assessment of overload, based on the total 86 hour

5-axle truck traffic is somewhat less and perhaps closer to the values shown in Column 1 which are based on the mode value of calibration factor. The values shown in Column 3 of Table 1 appear to be unrealistically high based on actual field observations. The error involved is probably due to the fact that the deflection gage system does not meet the assumptions of the basic principle stated in Art. 2.1 as was discussed in Art. 2.4.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Because existing truck weighing efforts apparently are unable to capture the real spectrum of vehicle loads on major traffic routes in Pennsylvania, such as on I-80, an alternate method of weighing trucks is required. The method is to be capable of weighing trucks in motion without requiring a change in truck speed and preferably without driver awareness.

The results of a small scope, limited objective, mission oriented, pilot study is reported herein. The objectives of the study were threefold; 1) design a main and a back-up instrumentation system, incorporating a bridge span on I-80 as the weighing platform to weigh mostly 5-axle trucks in motion, 2) conduct a field test of both systems to determine their feasibility, and, 3) if feasible, collect a sufficient quantity of data to estimate the load spectrum of the 5-axle trucks and to estimate the extent of overloaded trucks travelling eastbound on I-80.

The main system uses electrical resistance strain gages on the bridge girders. The back-up system uses electrical deflection gages also mounted on the bridge girders. Both systems were mounted on one span of the eastbound lanes of the Bartonsville Bridge on I-80 near TR-33. The field study was conducted in November 1975 during which a total of 2,120 trucks were weighed. Of this number, data from 1,227 trucks was found suitable for the detailed analysis.

The results obtained from the main instrumentation system appear more realistic. Analysis indicates that of the total number of 5-axle trucks travelling eastbound on I-80 during the sample period, about 20 percent exceed the 73.28 kip gross vehicle weight limitation in Pennsylvania. In addition, about 25 percent of the individual drive and trailer axle weights exceed the 18.0 kip permissible load.

The truck weight spectra presented herein are not precise and have a relative accuracy consistent with the dispersions evident in Figs. 34 and 35 as characterized by the values of the standard deviations shown in the figures.

6.2 Recommendations

The second objective of this pilot study (Art. 1.2) was to determine the feasibility of the two instrumentation systems developed for the study. It can be reasonably concluded that, insofar as the limited objectives of this pilot study are concerned, the study was a success, and both systems, but particularly the main strain gage system, produced useful (if not precise) truck weight information. In addition, both systems show considerable potential for continuing development.

In the following, specific recommendations are made with respect to immediate implementation of the two systems as designed, with minor modifications, and for further research and development of one or both systems for future implementation.

6.2.1 Immediate Implementation

At the present stage of development neither system is suitable for determining reliable and precise truck weight information. At best, the results can be used, as was done herein, to obtain the approximate spectra of truck and axle weights for a large sample of loaded 5-axle trucks traversing the bridge span at about the legal speed limit.

If this pilot study were repeated in the near future, without the benefit of further research and development, the following modifications would be considered:

(1) The Bartonsville Bridge span was too short to develop the third plateau near the middle of the trace which is required to obtain the gross weight of long 4- and 5-axle trucks. If this plateau were available, two values of the gross weight of a single truck would be available, thereby providing a comparative check on the results. The span length required can be determined from inequality condition (5), Art. 2.2. For example, for a 46 ft. truck length, plus 14 ft. to produce an identifiable plateau, and instrumentation at the two fifth points of the span so that significant strains or deflections are measured, the required span length is 100 ft.

(2) In addition to the use of one or two calibration trucks, a few trucks from the truck sample should be stopped and weighed. A direct estimate of the accuracy of the weighing systems is then available. (This was not done in the pilot study because an attempt was made to weigh trucks without driver awareness).

(3) The filtering system used in the pilot study was capable of filtering the analog signal to eliminate frequencies exceeding about 4 Hz. Since a precise cut-off at 4 Hz is apparently not possible, oscillations at 5 to 6 Hz, near the natural frequency of the span, occurred, which made it impossible to

obtain level plateaus. An attempt should be made to filter frequencies down to 2 to 3 Hz to improve the trace characteristics.

(4) An attempt should be made to measure truck speed across the span and to determine when the truck enters the span so that a precise determination of plateau length and position can be made.

Assuming that the relative degree of accuracy obtained in this pilot study is acceptable, and assuming one or both systems are used on a 5-girder span with the above modifications, optimistic estimates of time, manpower and equipment requirements can be determined from the following:

(1) <u>Installation</u>:

<u>Strain Gage System</u>:

(a) 3 to 5 days to install depending on weather and temperature conditions (strain gage application is difficult in cold or humid weather)

(b) 1 skilled technician required to install gages on girders

(c) 1 unskilled technician required to assist

(d) 1 engineering supervisor

(e) 1 platform truck plus operator

(f) strain gages, power source, miscellaneous tools and equipment.

Deflection Gage System:

(a) 1 day or less to install girder clamps to girders and mount pre-gaged deflection plates

(b) 2 unskilled technicians required to install gage system

(c) 1 engineering supervisor

(d) platform truck plus operator

(e) girder clamps, deflection plates, wire, weights and miscellaneous tools and equipment

(2) Hookup and Systems Check (Applicable to Both Systems)

(a) normally 1 or 2 days or less providing installation has been properly done

(b) oscillograph recorder and related filters and equipment plus operator (operator will be skilled technician or engineer)

(c) 1 skilled technician to make installation adjustments if necessary

(d) 2 unskilled technicians to assist in hookup of gage system(s) to oscillograph recorder

(e) platform truck plus operator

(f) 1 or 2 calibration trucks plus operators to produce sample oscillograph traces (calibration trucks are previously loaded and weighed)

(g) power source

(h) oscillograph traces for a few vehicles from the traffic stream are produced and examined and adjustments made if necessary.

(3) Truck Weighing Operation

The following is based on a one-day 24 hour continuous sampling and weighing period, having three 8-hour shifts and a sampling rate of 2 to 3 trucks per minute. It is also assumed that during the 24 hour period trucks are stopped and weighed to provide data correlation.

(a) 3 engineering supervisors (1 per shift)

(b) 6 skilled technician recorders (2 per shift, alternating every 2 hours)

(c) 6 unskilled technician button-box operators (2 per shift alternating every 2 hours)

(d) 6 skilled technician spotters (2 per shift, alternating every 2 hours)

(e) 3 unskilled technician assistants (1 per shift to assist with all other duties such as photography, total traffic counts, arranging for meals and beverages to avoid interruptions, etc.)

(f) up to 6 additional unskilled technicians to assist with the actual stopping and weighing of trucks using portable scales.

6.2.2 Research and Development

The mission oriented aspects of this pilot study required the development of main and back-up systems plus testing and implementation of the systems in an actual truck weighing operation within a very short period of time. At best only a conceptually simple main system could be tried which would interface with the FHWA oscillograph recording equipment that fortunately became available in time for the testing and weighing stages. Because the influence lines produced by the main system are linear, the plateaus on the oscillograph traces are theoretically linear, level and independent of the number and spacing of axles on the tractor and trailer units. This also simplified the selection of suitable calibration trucks. However, tedious and time consuming manual data reduction was required. Even though the principle of the main system is simple, considerable scatter in the data was observed and the traces could have been improved. There was no time, however, to make the necessary improvements.

The back-up system does not produce linear influence lines. As a result, truck weights cannot be predicted based on the principles discussed herein. However, because the back-up system is very easy to install it was selected partly to provide some information in the event of a main system failure and partly to explore the characteristics of the traces produced by this system. Again, no time was available to research the system characteristics to any depth. Consequently, the relative accuracy of the back-up system results is unknown.

Looking beyond the truck weight spectrum results of this pilot study to the systems themselves and their characteristics, this study strongly suggests that both the strain gage and deflection gage systems should be investigated more thoroughly in a larger scope research and development project. The following points should be considered when defining the scope of the proposed investigation:

(1) There are essentially two aspects to the overall objective of weighing trucks in motion. The first consists of obtaining nearly instantaneous, accurate, on-site weights of individual trucks as they cross the span, presumably to initiate legal action against overloaded trucks. The second consists of sampling and collecting truck weight data on a continuing basis throughout Pennsylvania. The resulting knowledge of the real load spectrum and its change with time for the major traffic routes would be extremely valuable in highway and bridge design and research. The former requires the development of a sophisticated, self-contained, automated, portable, electronic data collection and processing system which can be coupled to a bridge instrumentation system which itself must be developed further. The latter requires the development of a relatively simple, automated, electronic data collection system which will receive data from the bridge instrumentation system which also requires further development. Data processing can be done in the laboratory using existing hardware and new software. The state-of-the-art strongly suggests development of this capability first before developing full on-site capability.

(2) With an automated data collecting system, bridge instrumentation systems based on linear or non-linear influence lines can be equally viable. Thus both strain gage and deflection gage systems should receive further development. The advantage of the deflection gage system lies in its ease of installation and removal. In addition, variaions and alternates to these systems should be investigated.

(3) Filtering of the analog signal from the bridge instrumentation system requires further study and improvement. Since truck weight data (static) is desired, and not wheel-pavement interface forces (dynamic) the emphasis should be on complete filtering of all dynamic oscillations from the analog signal.

(4) The pilot study considered instrumentation on simple spans only. Consideration could be given to the development of a system suitable for multiple span bridges.

(5) The instrumentation system should be capable of use with steel and concrete bridge spans.

(6) Additional data collection capability should be built into the system, some of which may be necessary input to the data processing stage. This could include truck speed, type and axle configurations.

(7) The system should be capable of weighing most of the truck types shown in Fig. 9 and be sensitive to heavy as well as lightly loaded trucks.

7. ACKNOWLEDGMENTS

This study was conducted in the Department of Civil Engineering and Fritz Engineering Laboratory, under the auspices of the Lehigh University Office of Research, as a part of a research investigation sponsored by the Pennsylvania Department of Transportation and the Federal Highway Administration. Dr. D. A. VanHorn is chairman of the Department of Civil Engineering and Dr. L. S. Beedle is Director of Fritz Engineering Laboratory, Lehigh University.

The field test equipment was made available through Mr. C. F. Scheffey, Director, Office of Research, Federal Highway Administration, U. S. Department of Transportation. The operation of the test equipment was supervised by Mr. H. Laatz from the Federal Highway Administration, and Mr. H. Sutherland of Lehigh University. Instrumentation of the bridge span was supervised by Mr. Russell Longenbach, of Lehigh University.

The basic research planning and administrative coordination of this study were executed in cooperation with Messrs. Leo D. Sandvig, Director; Wade L. Gramling, Research Engineer; and Kenneth L. Heilman, Research Engineer; all from the Bureau of Materials, Testing and Research, Pennsylvania Department of Transportation.

The following members of the faculty and staff of Lehigh University made major contributions in the conduct of the study and in the reduction and processing of the test data: Dr. D. A. VanHorn, Dr. R. G. Slutter, Kenneth R. Harpel, Hugh Sutherland, Donald P. Erb and Robert P. Batcheler.

The manuscript was typed by Ms. Antoinette Larkin, and the figures were prepared under the direction of John M. Gera.

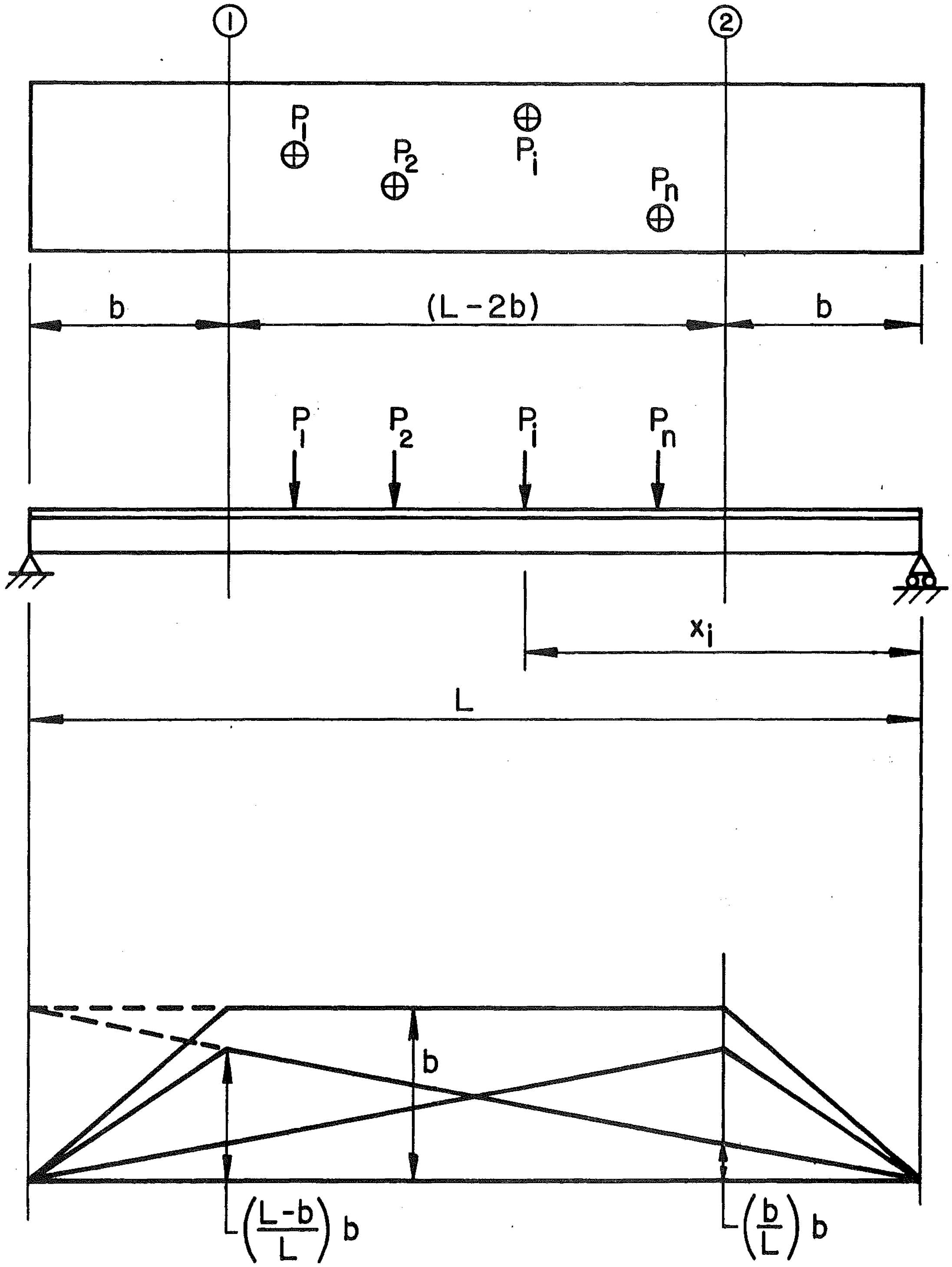


Fig. 1 Schematic of a Simple, Right (Non-Skew), Multiple Girder Bridge Span and Influence Lines for Bending Moment at Cross-Sections 1 and 2.

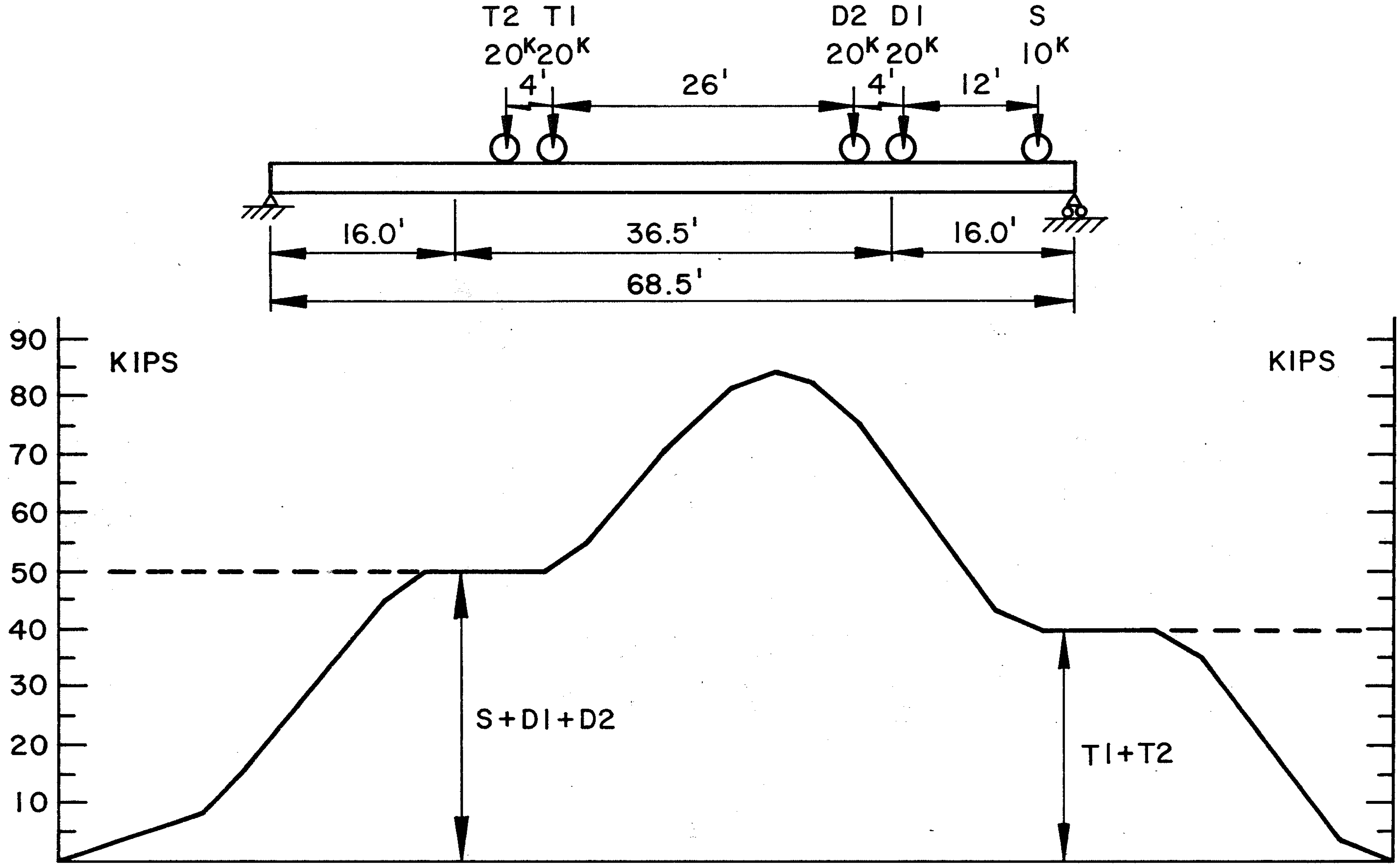


Fig. 2 Example Trace for 5-Axle Truck

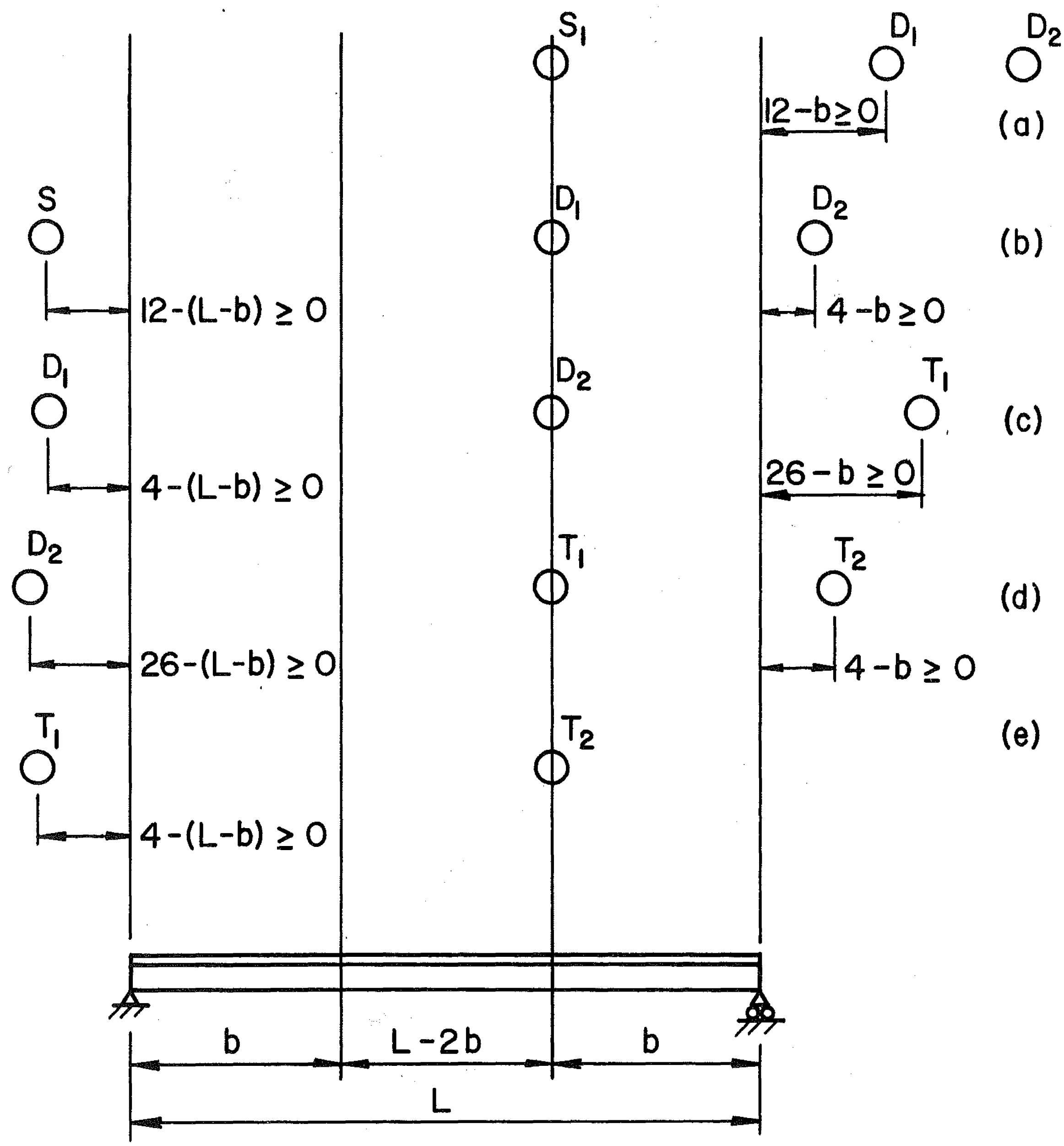


Fig. 3 Illustration of Computation of Inequalities Governing Magnitudes of L and b for Condition of Weighing All Axles Separately

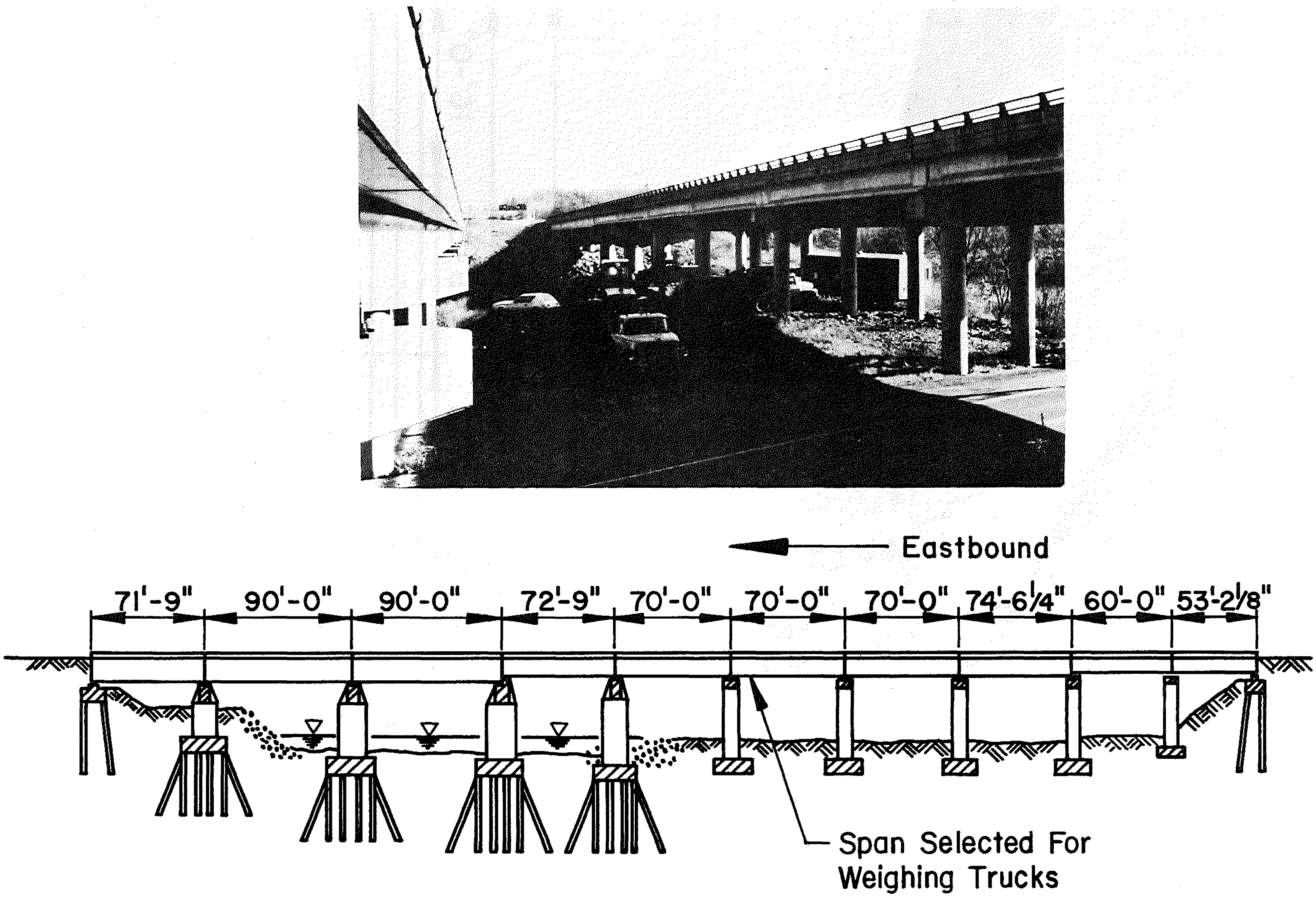
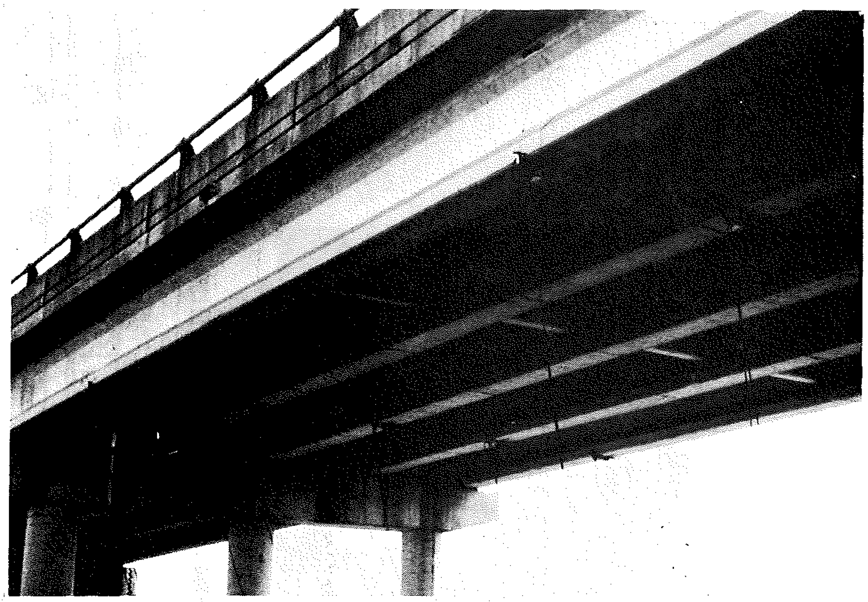


Fig. 4 Eastbound Half of Bartonsville Bridge on I-80



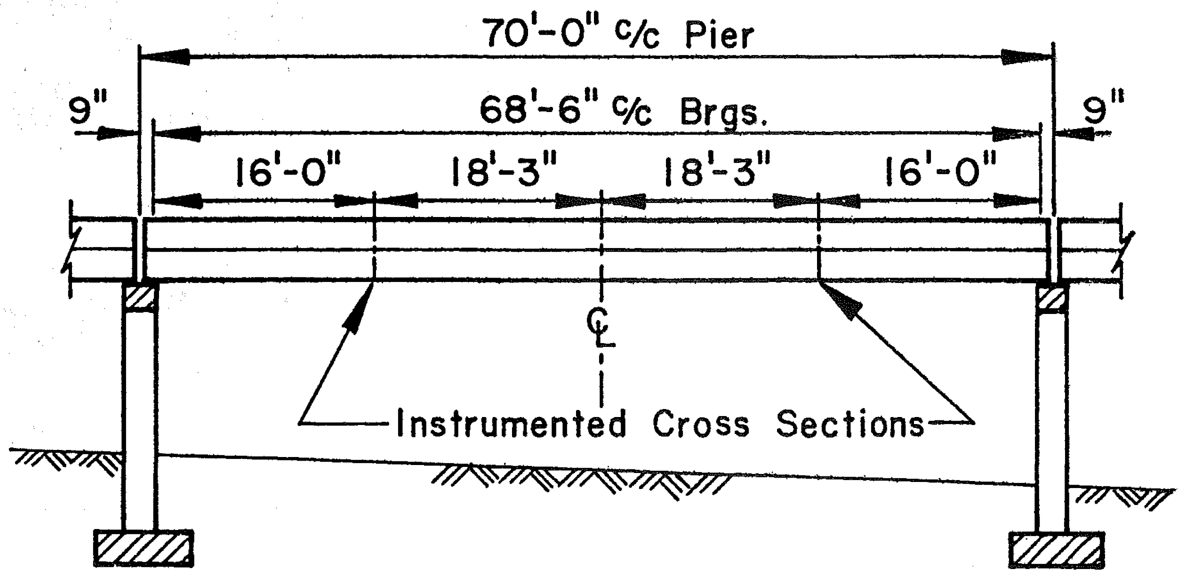
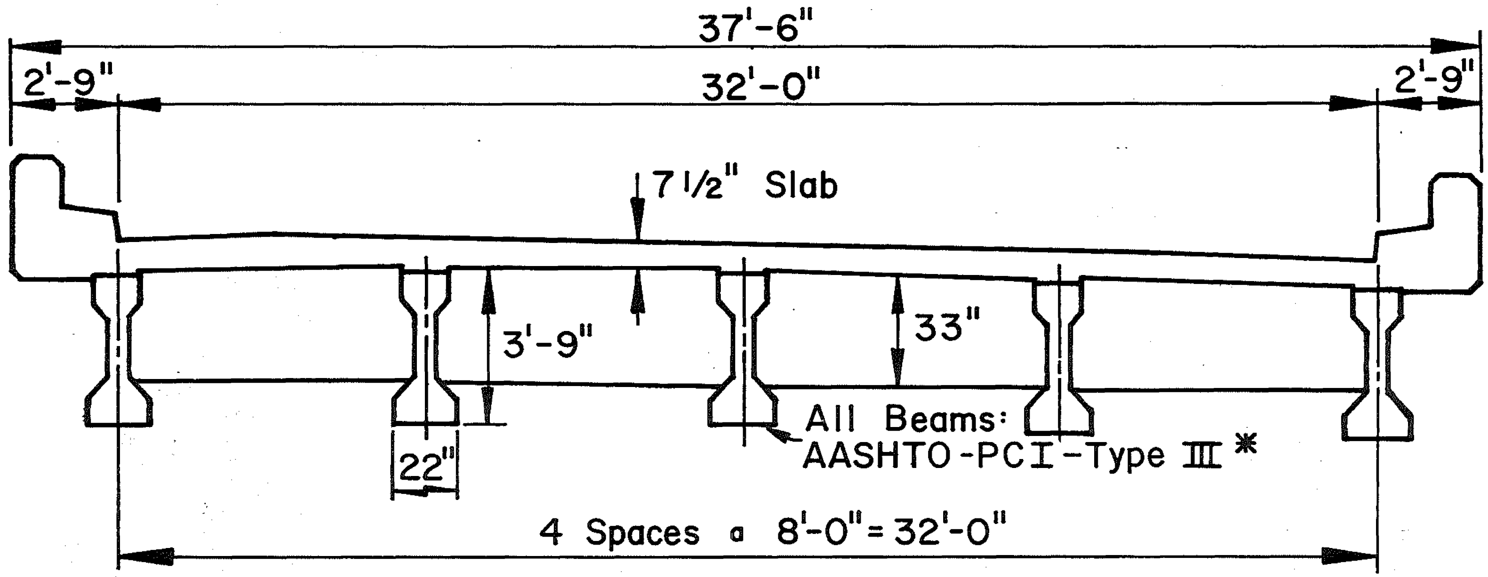
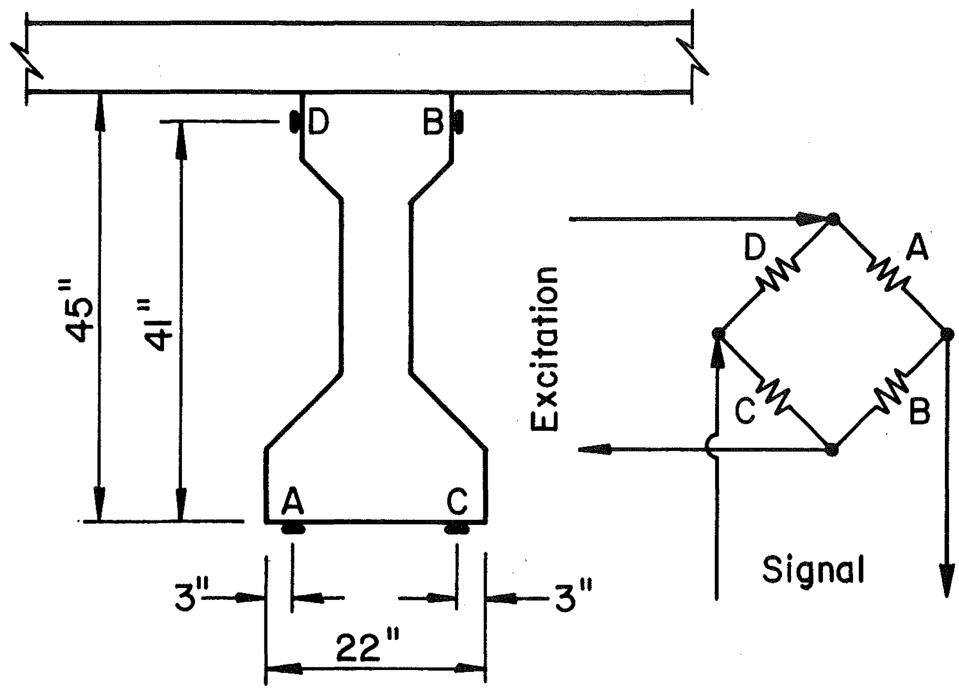


Fig. 5 Elevation of Span Used to Weigh 5-Axle Trucks Using I-80



* Nearest PennDOT Equivalent - Type 24/45

Fig. 6 Typical Cross-Section of Truck Weighing Span



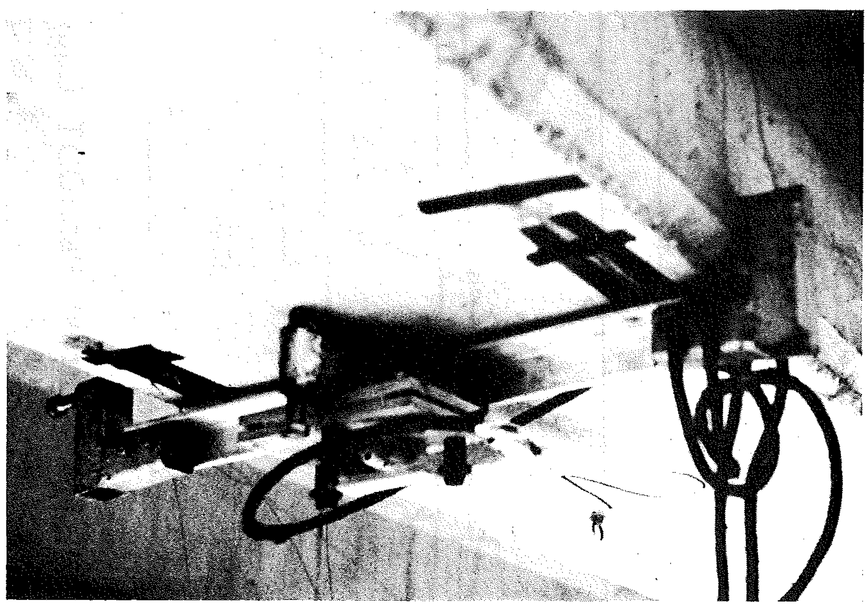


Fig. 7 Typical Strain Gage Locations and Full Bridge Hookup

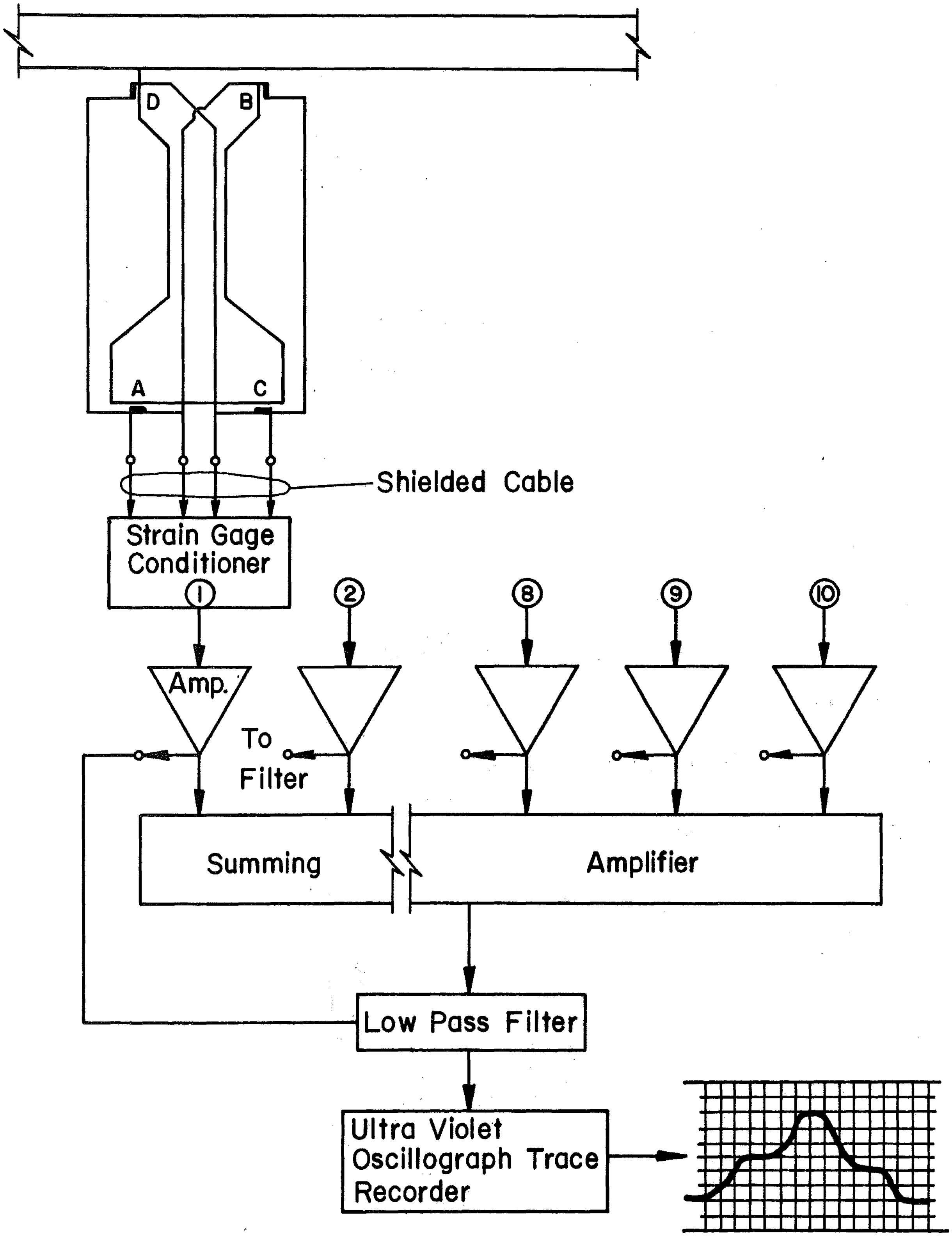


Fig. 8 Schematic of Recording System

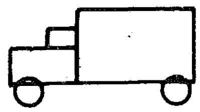
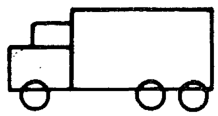
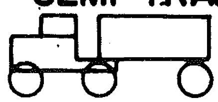
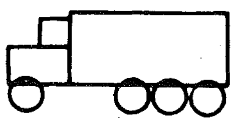
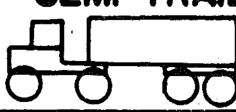
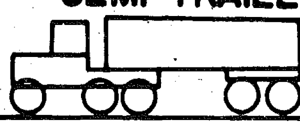
TYPE	CODE
BUS	B
2-AXLE TRUCK 	2D
3-AXLE TRUCK 	3
3-AXLE TRACTOR SEMI-TRAILER 	2S-1
4-AXLE TRUCK 	4
4-AXLE TRACTOR SEMI-TRAILER 	2S-2
5-AXLE TRACTOR SEMI-TRAILER 	3S-2

Fig. 9 FHWA Truck Classifications

Fig. 10 Spotter in Position 1 on Ledge Above West Approach to Bridge

Fig. 11 View from Spotter's Ledge to the West

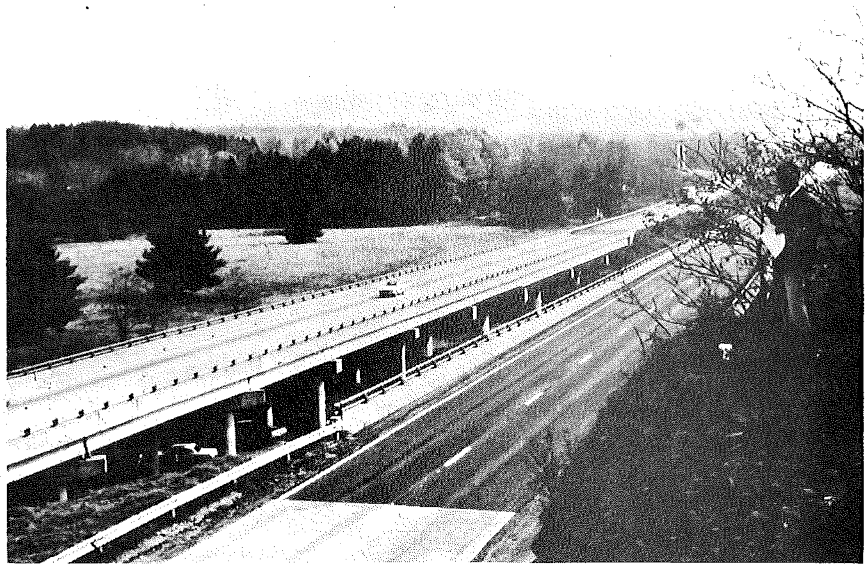


Fig. 12 View from Spotter's Ledge to the East

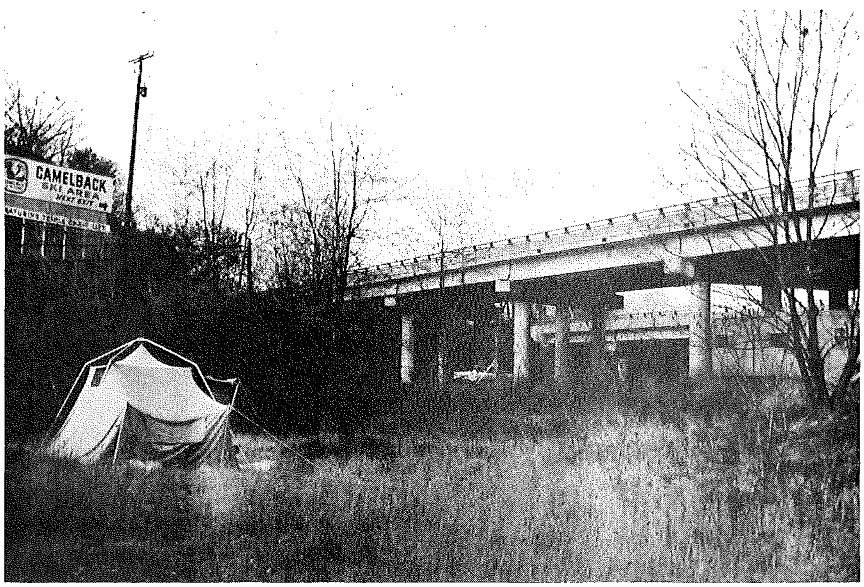


Fig. 13 View from Button Box Operator's
Tent to West End of Bridge

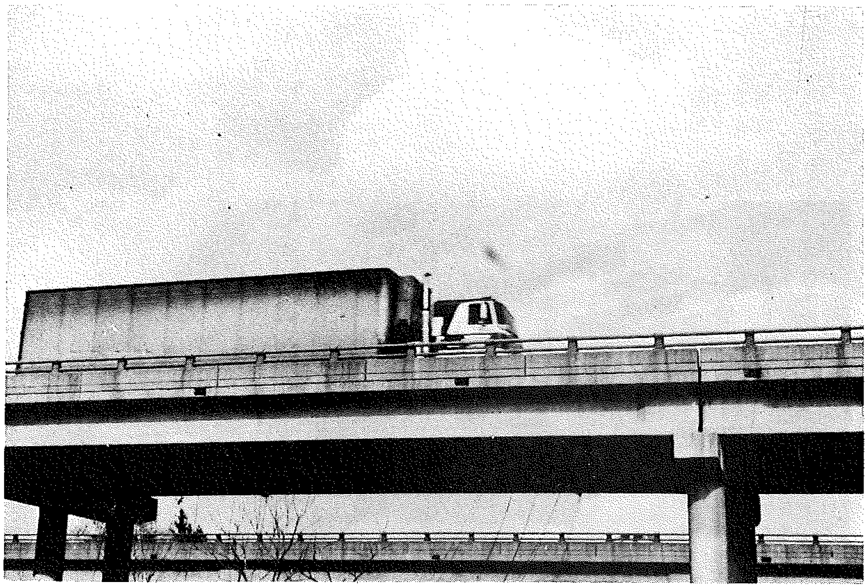


Fig. 14 Truck Crossing Immediately West of Truck Weighing Span

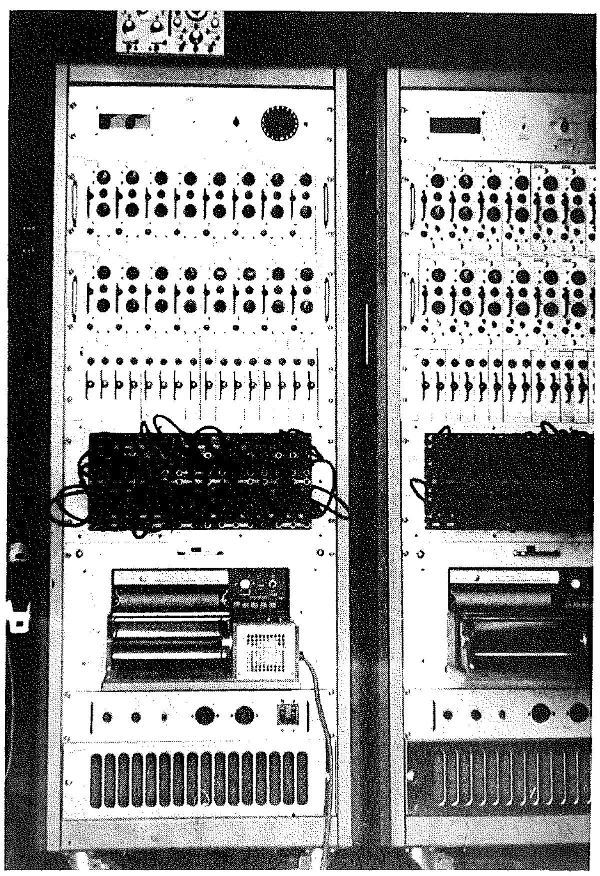


Fig. 15 Ultraviolet Oscillograph Trace Recorder in FHWA Instruments Trailer

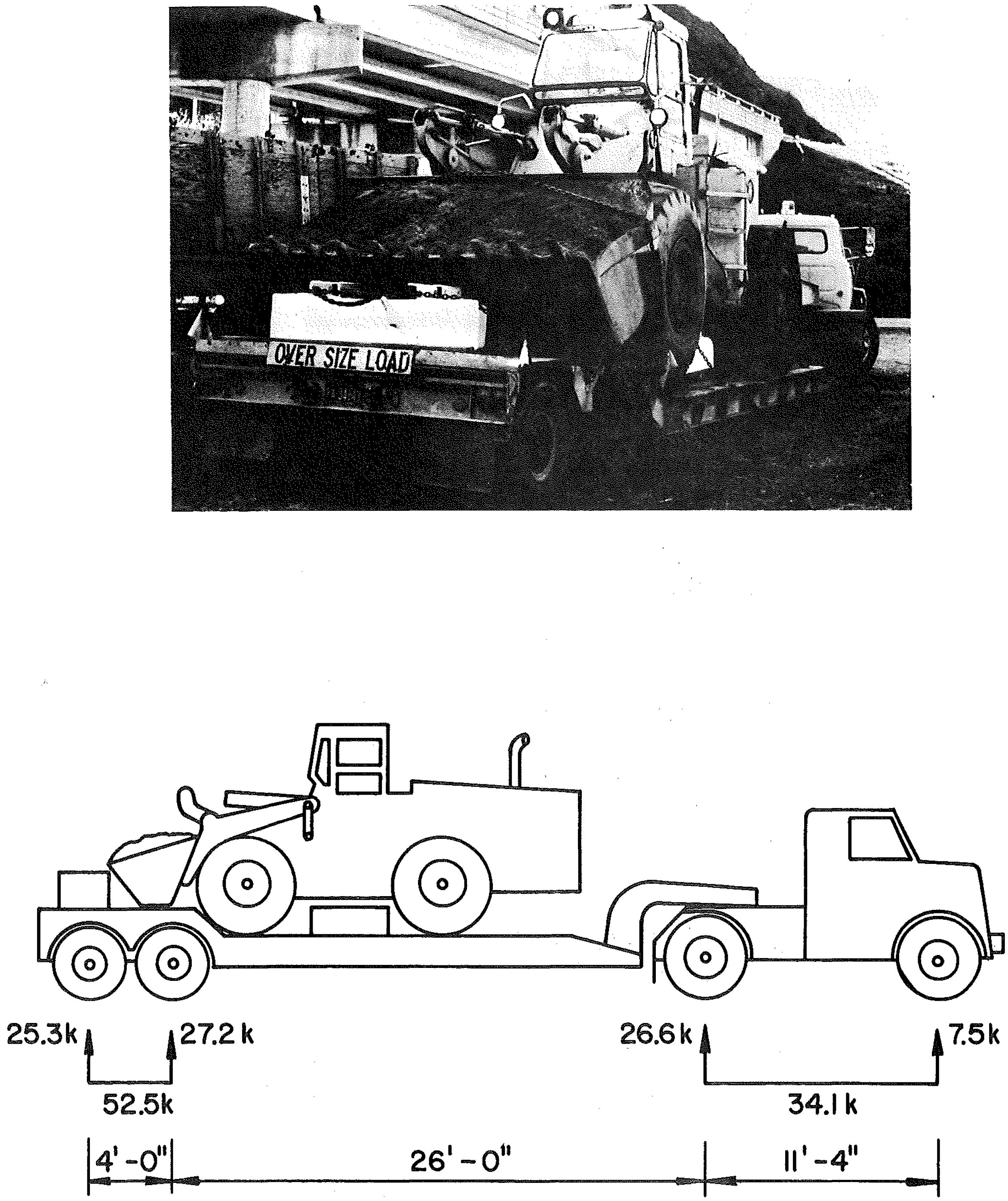


Fig. 16 PennDOT Calibration Truck

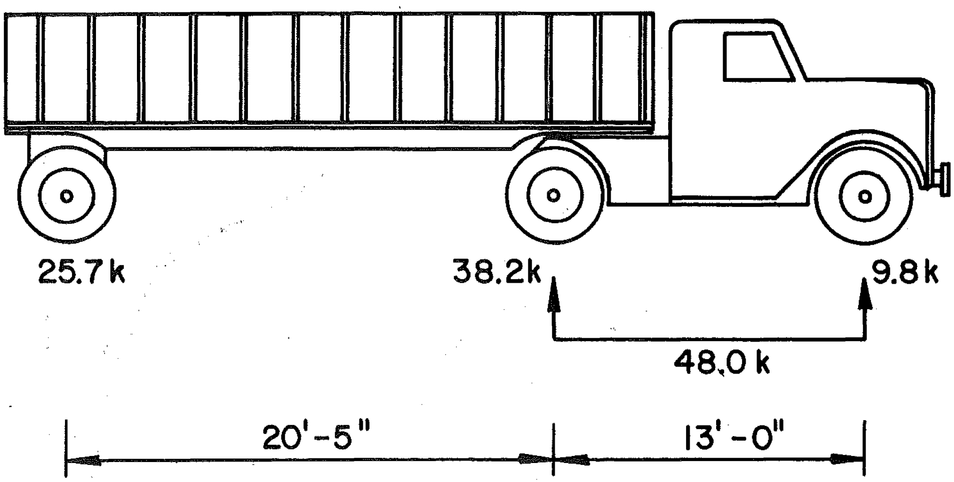


Fig. 17 FHWA Calibration Truck

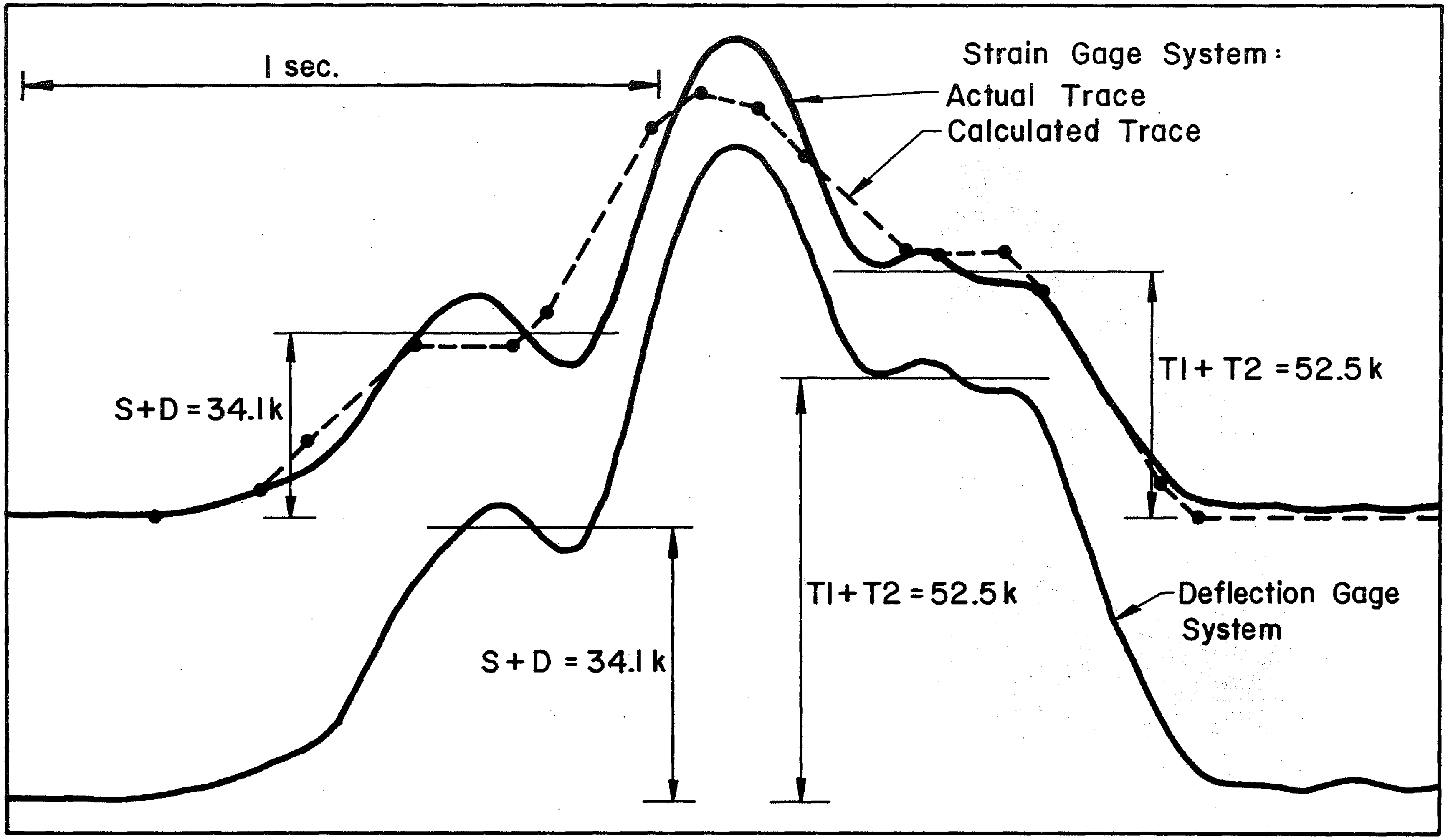


Fig. 18 PennDOT Truck - 60 mph - Right Lane

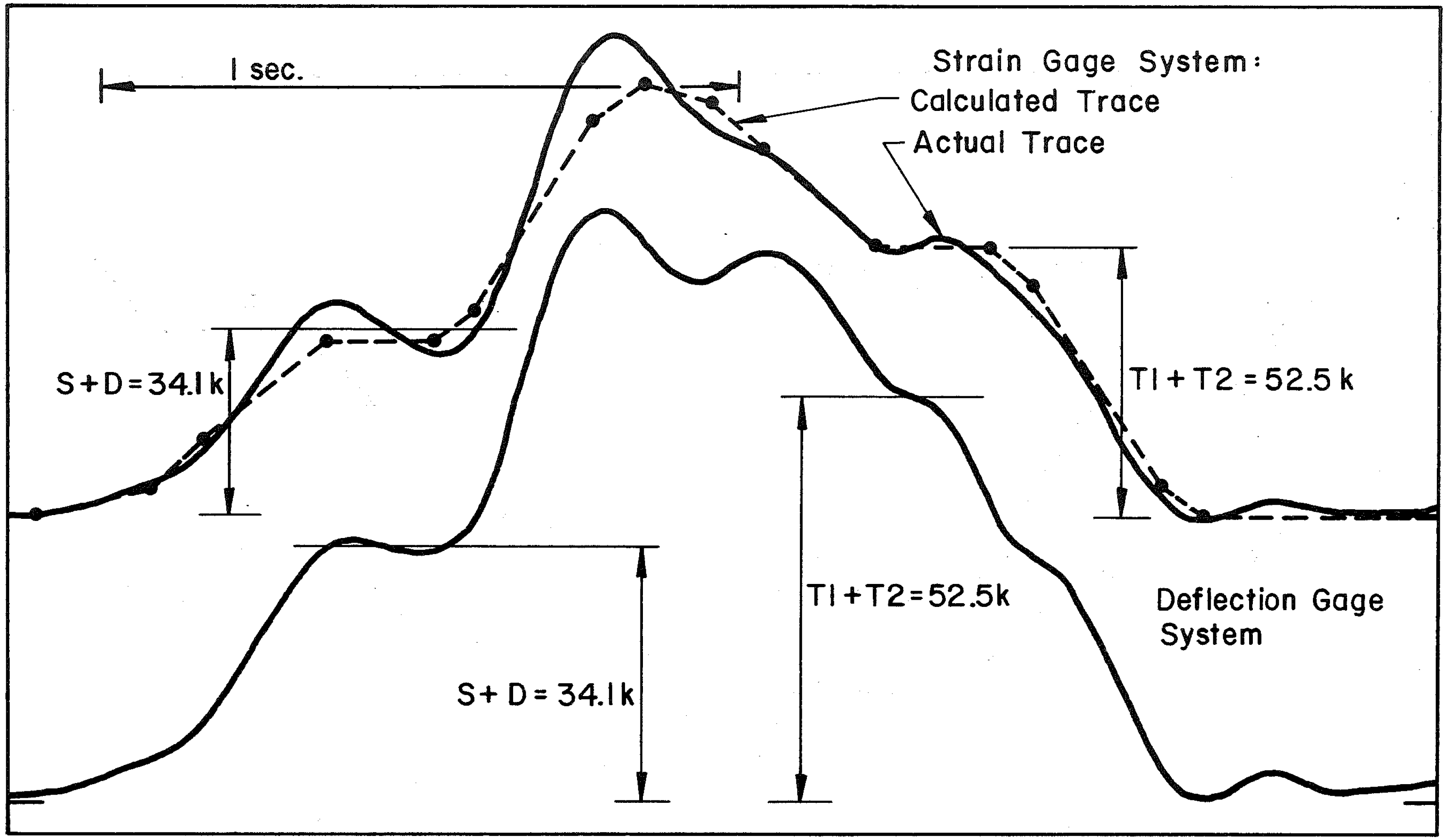


Fig. 19 PennDOT Truck - 60 mph - Left Lane

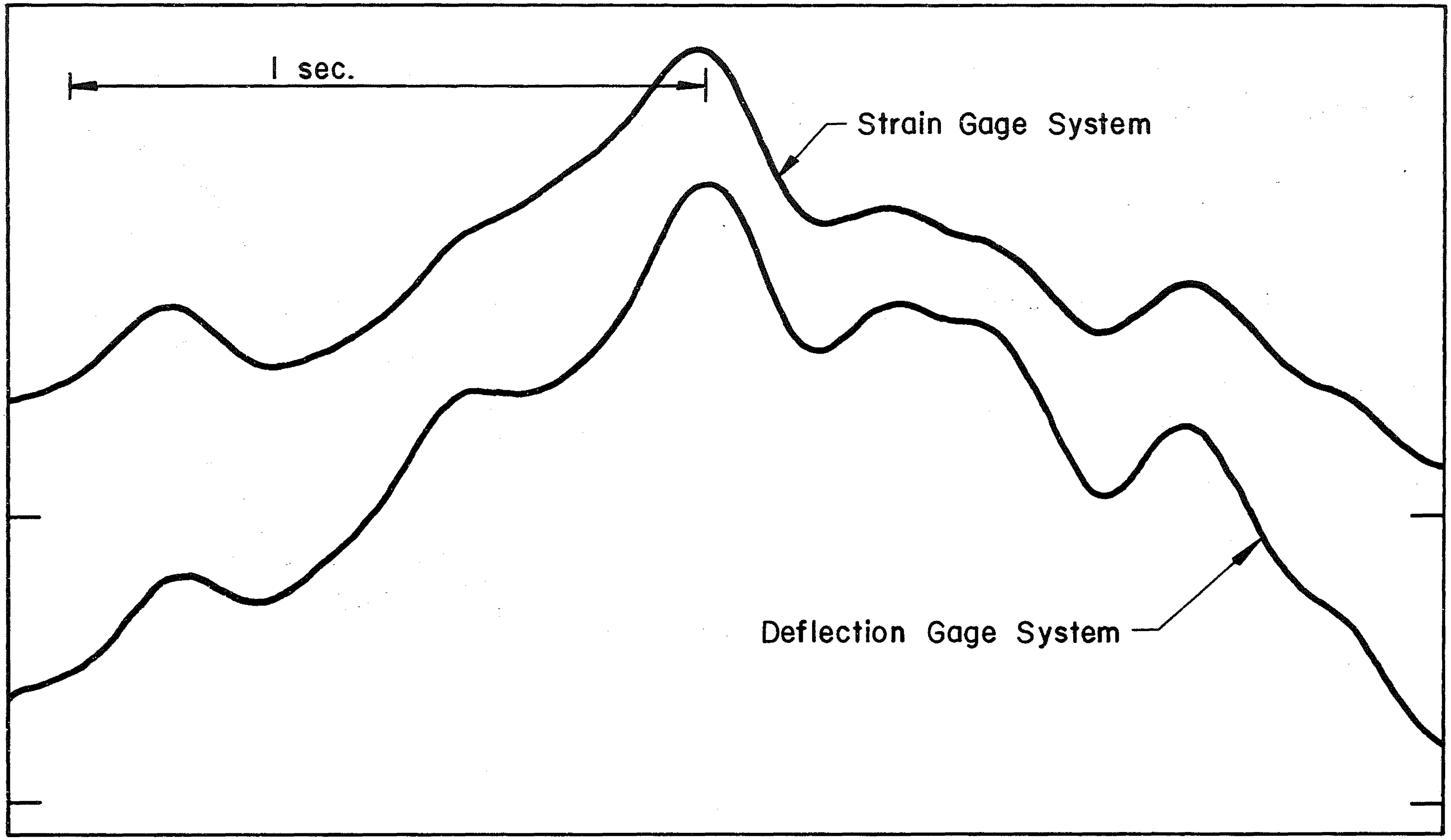


Fig. 20 PennDOT Truck - 30 mph - Right Lane

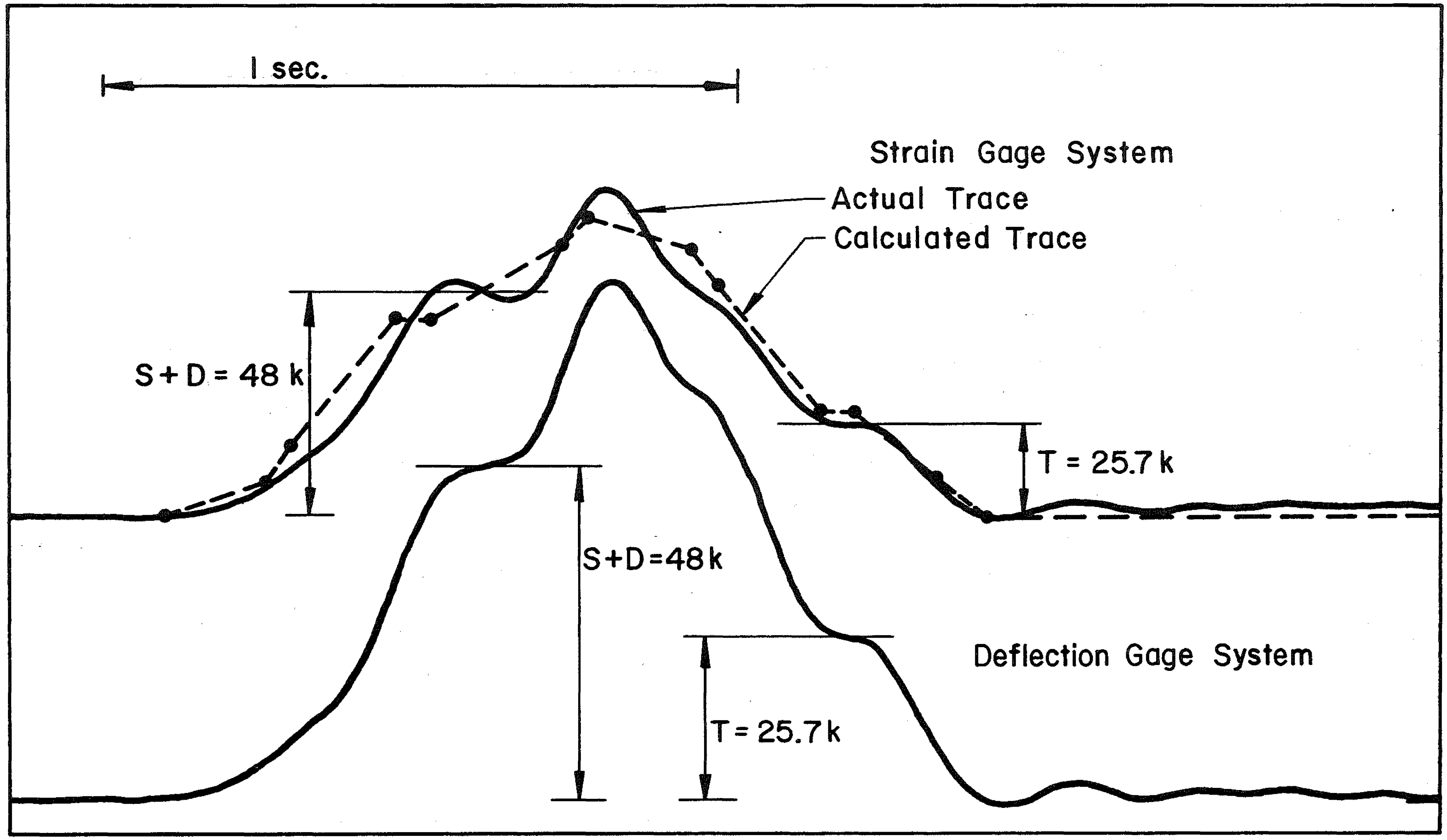


Fig. 21 FHWA Truck - 60 mph - Right Lane

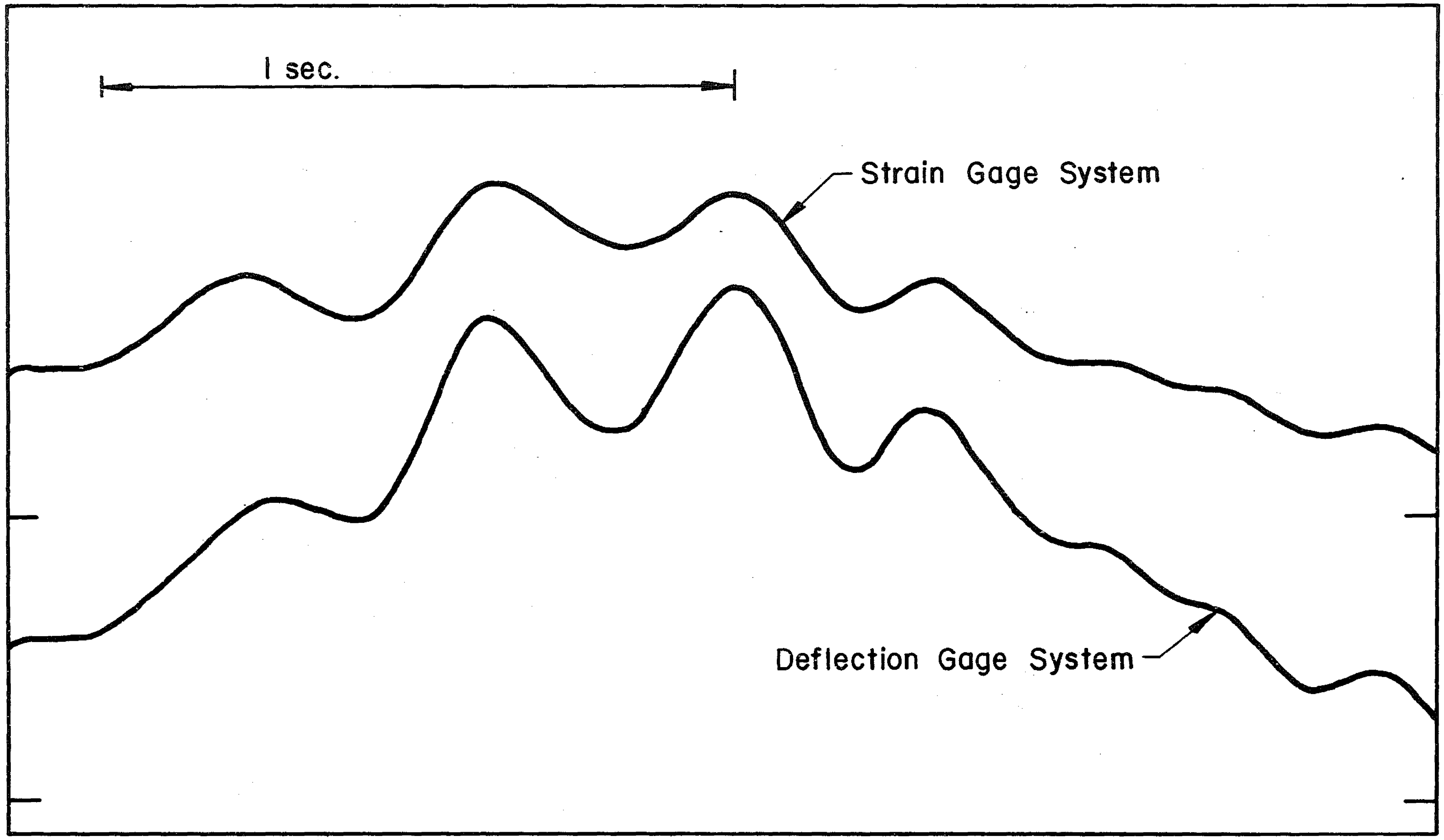


Fig. 22 FHWA Truck - 20 mph - Right Lane

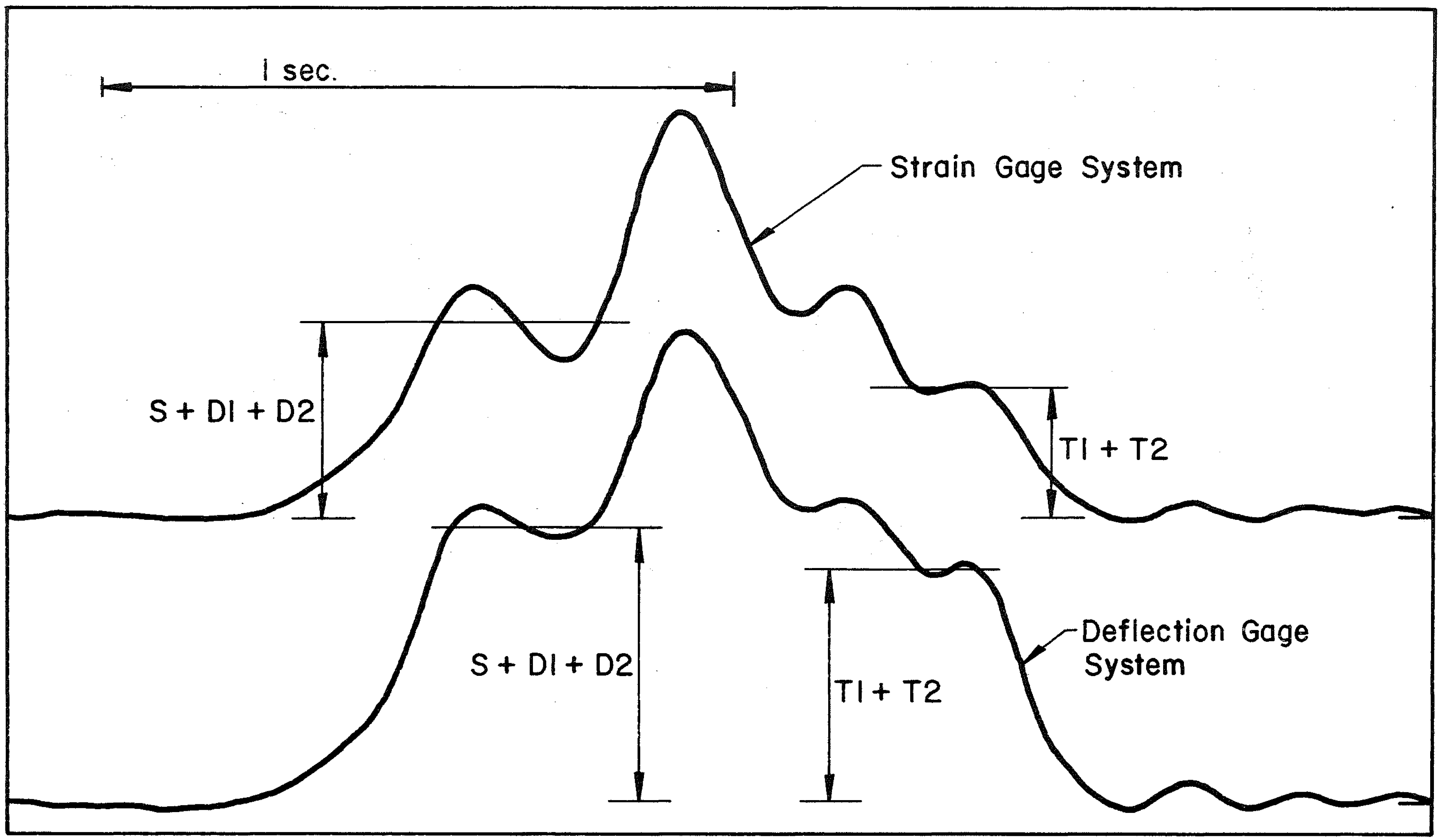


Fig. 23 3S-2 - "Box" - Right Lane

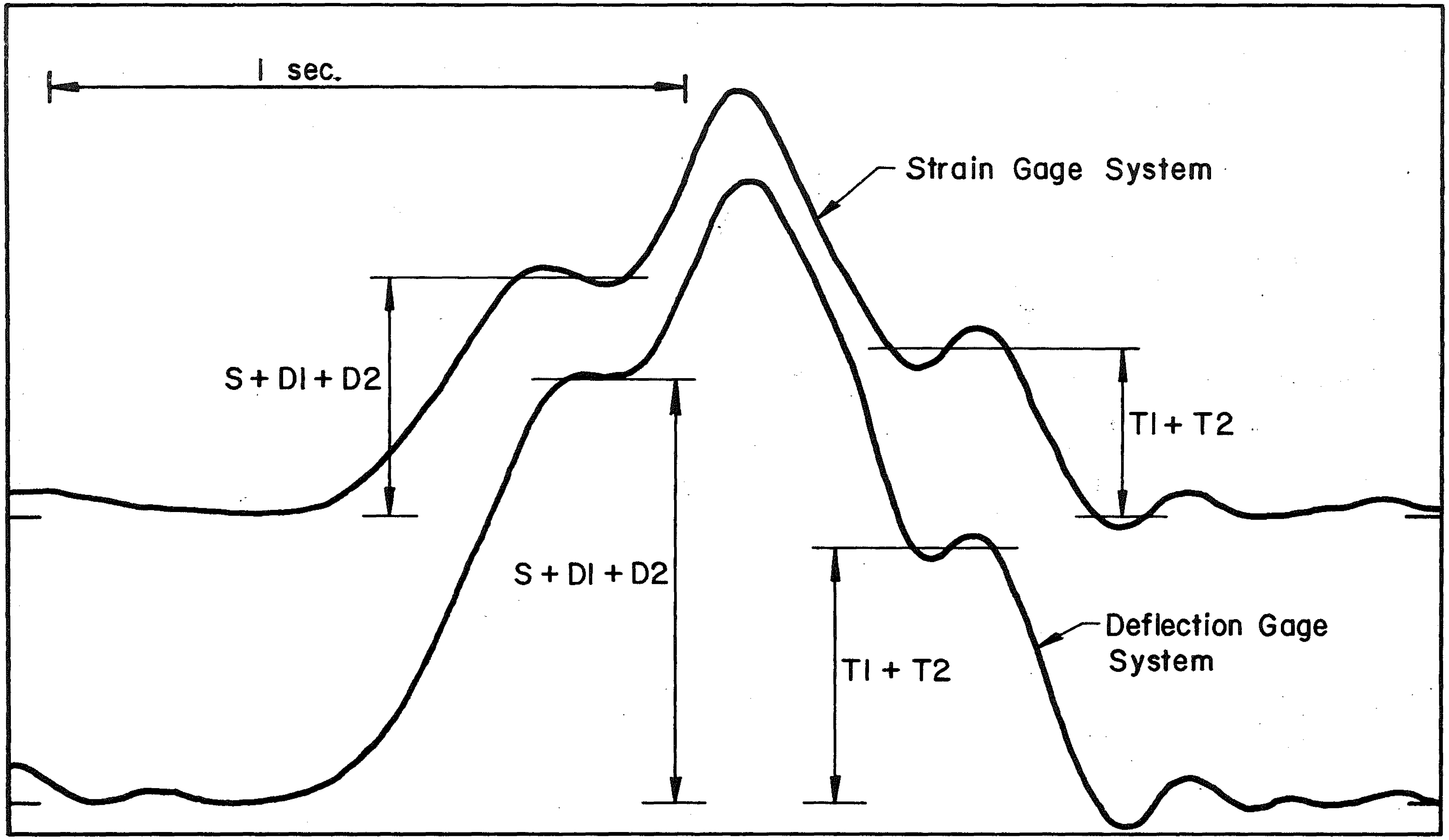


Fig. 24 3S-2 - "Flat Bed" - Loaded - Left Lane

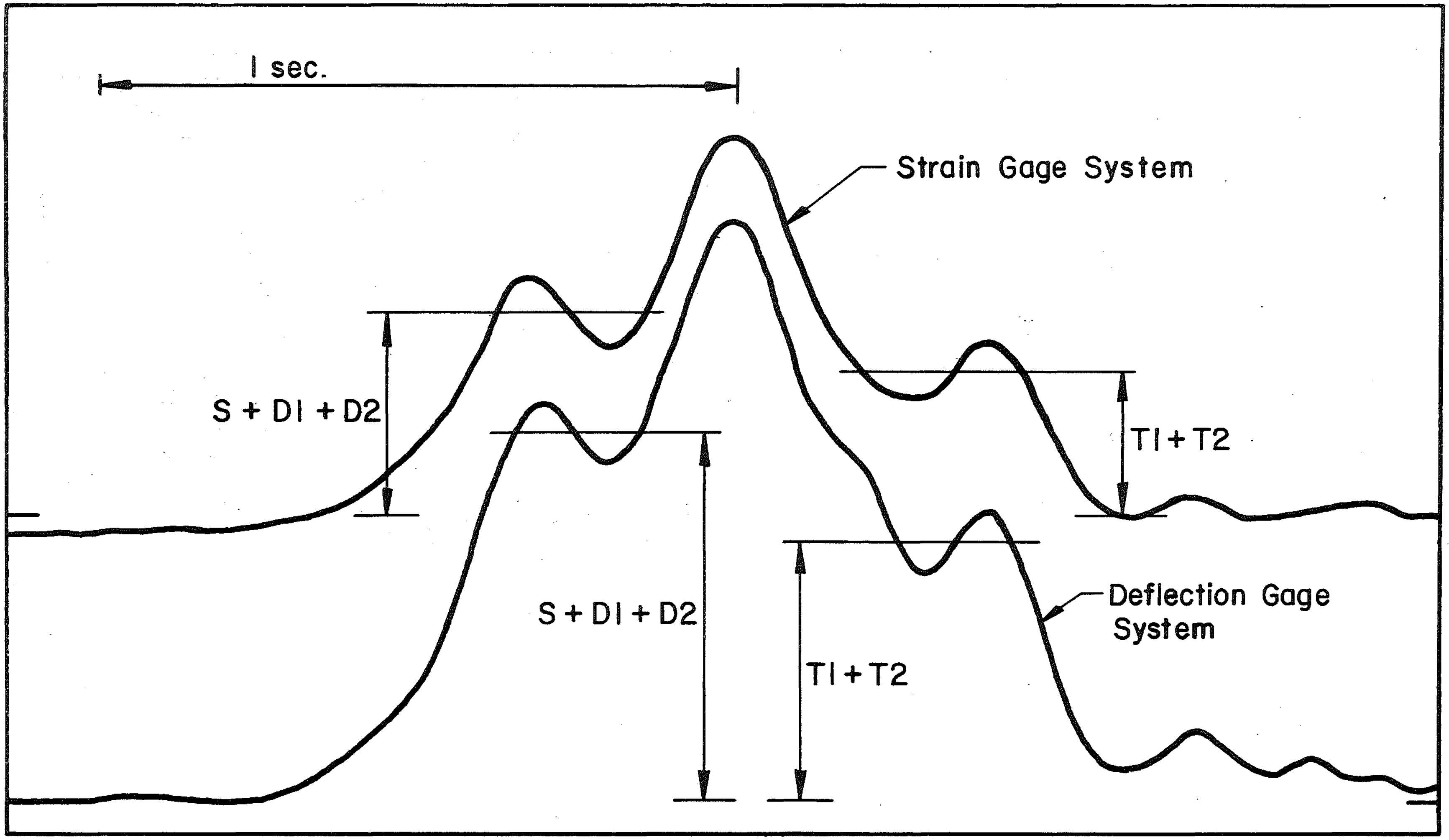


Fig. 25 3S-2 - "Box" - Left Lane

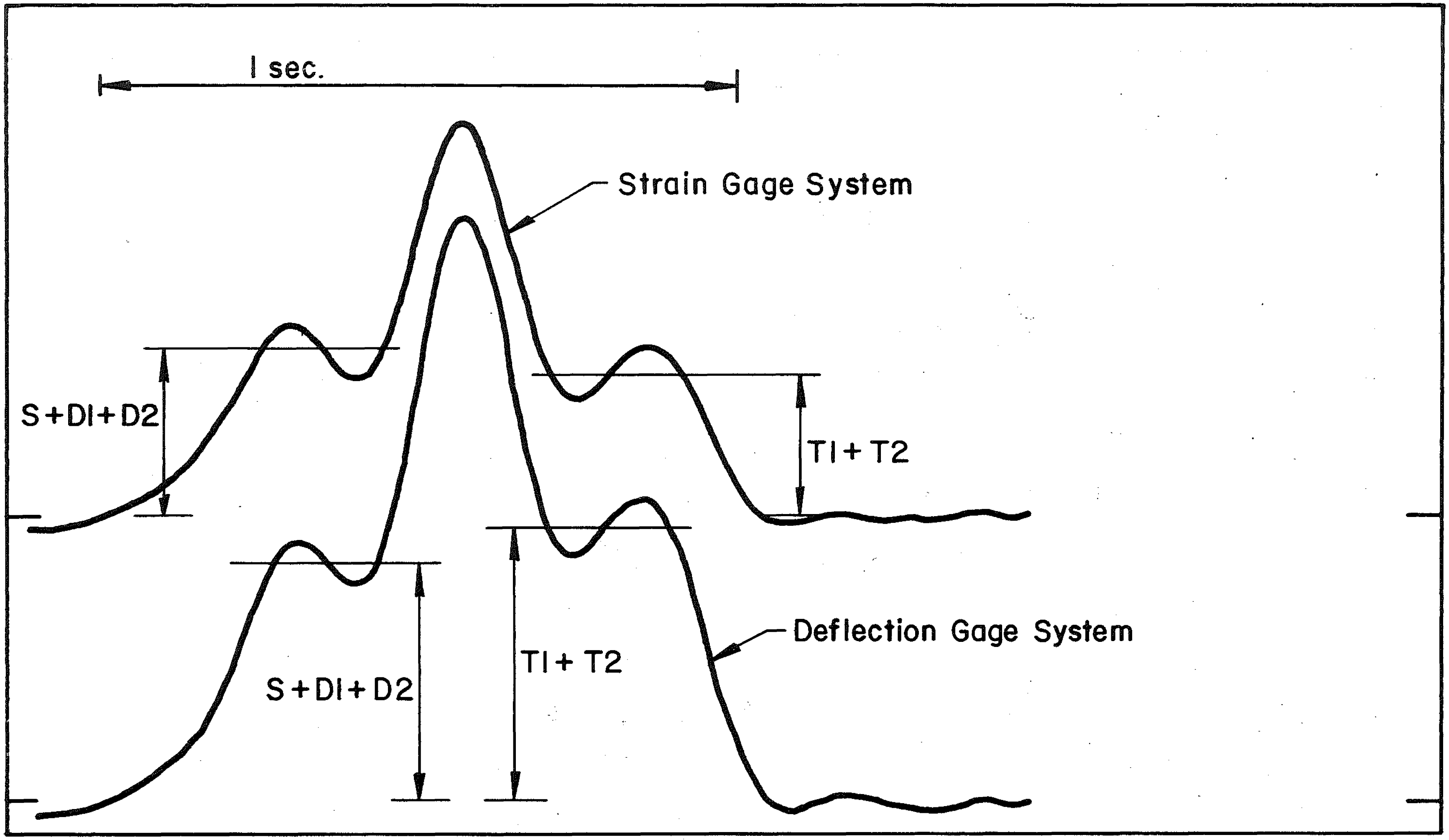


Fig. 26 3S-2 - "Box" - Right Lane

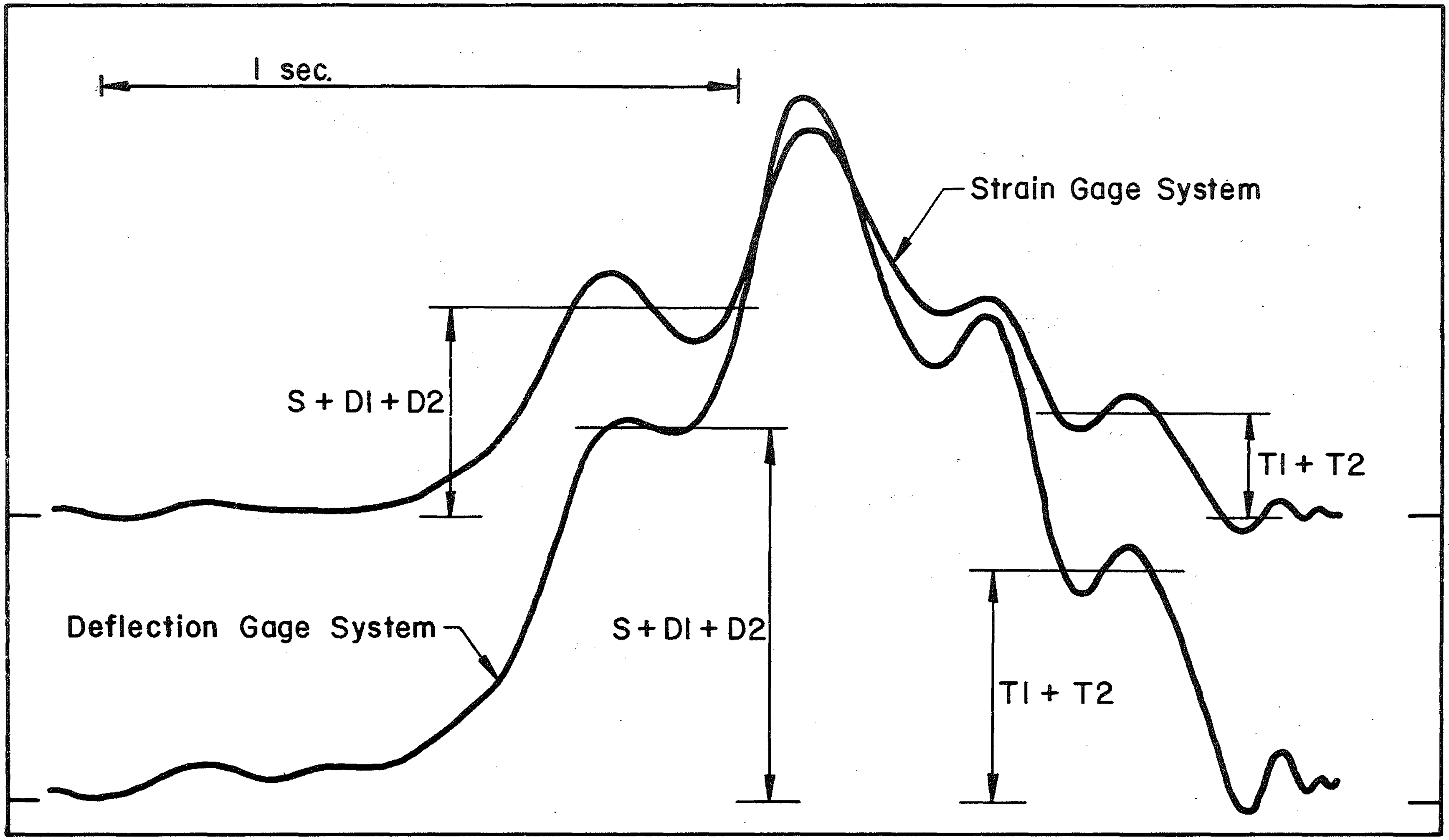


Fig. 27 3S-2 - "Dump" - Right Lane

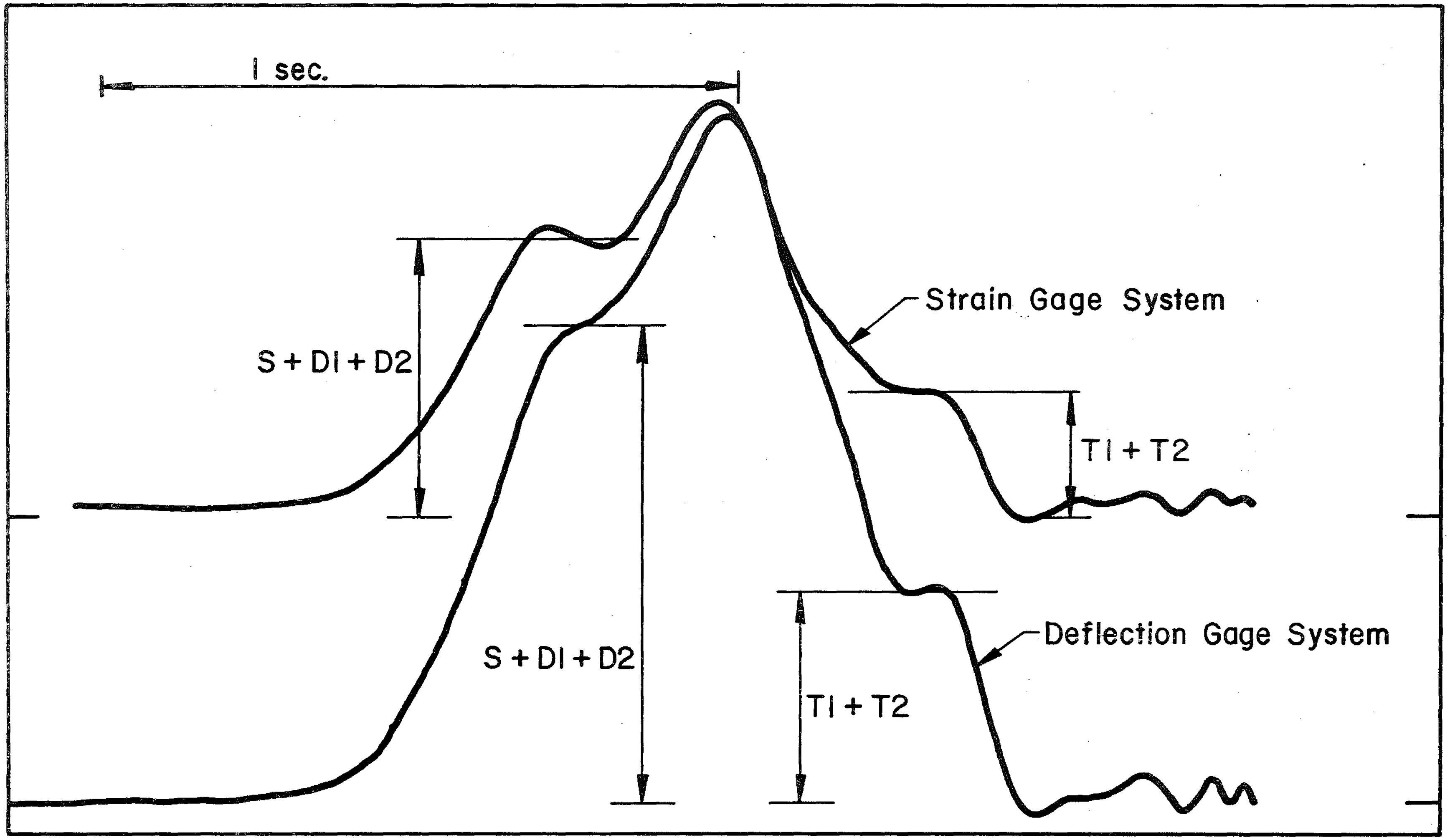


Fig. 28 3S-2 - "Stake Bed" - Right Lane

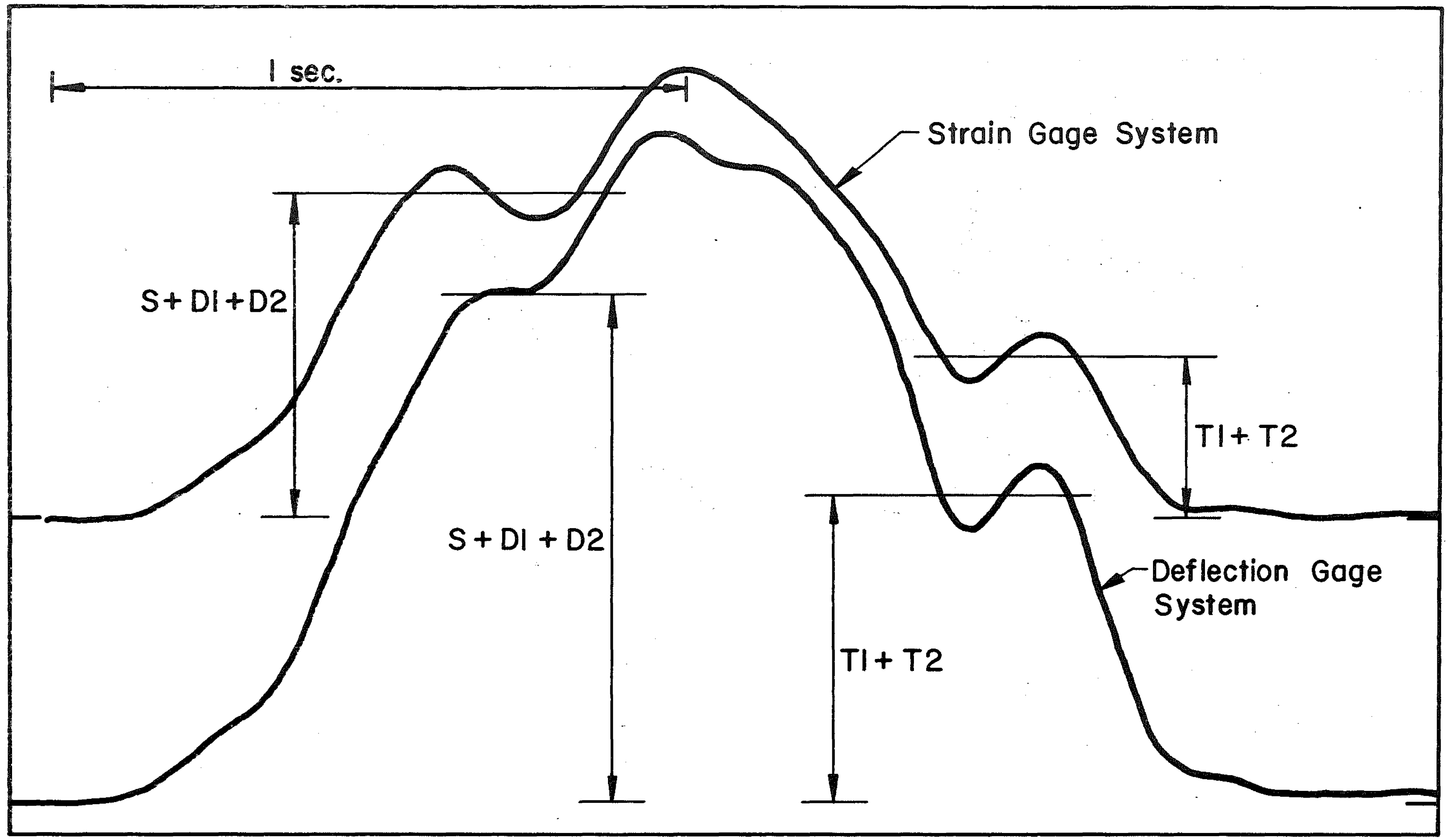


Fig. 29 3S-2 - "Flat Bed" - Loaded - Right Lane

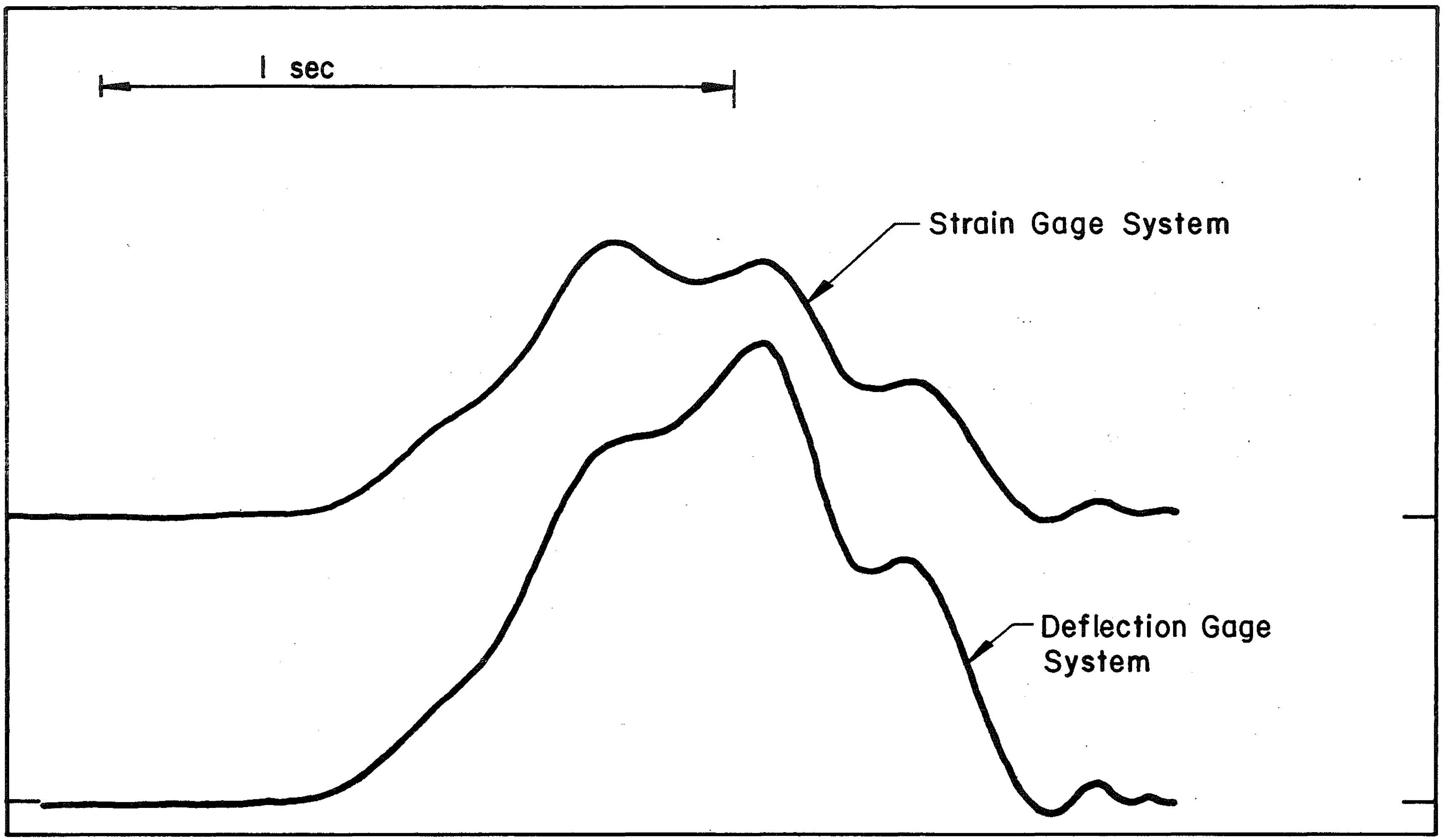


Fig. 30 2D - Right Lane - Loaded

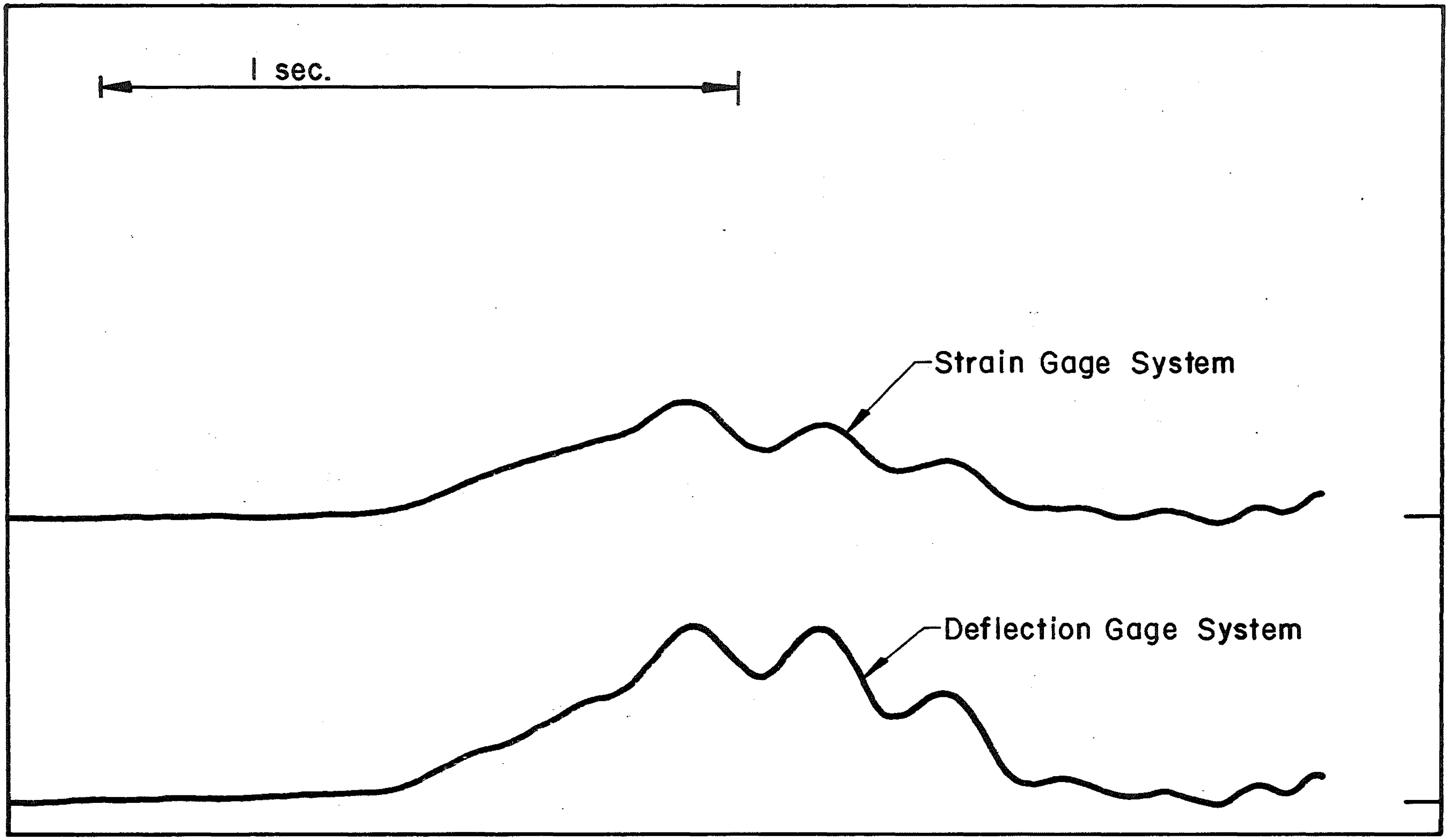


Fig. 31 3 - "Dump" - Unloaded - Left Lane

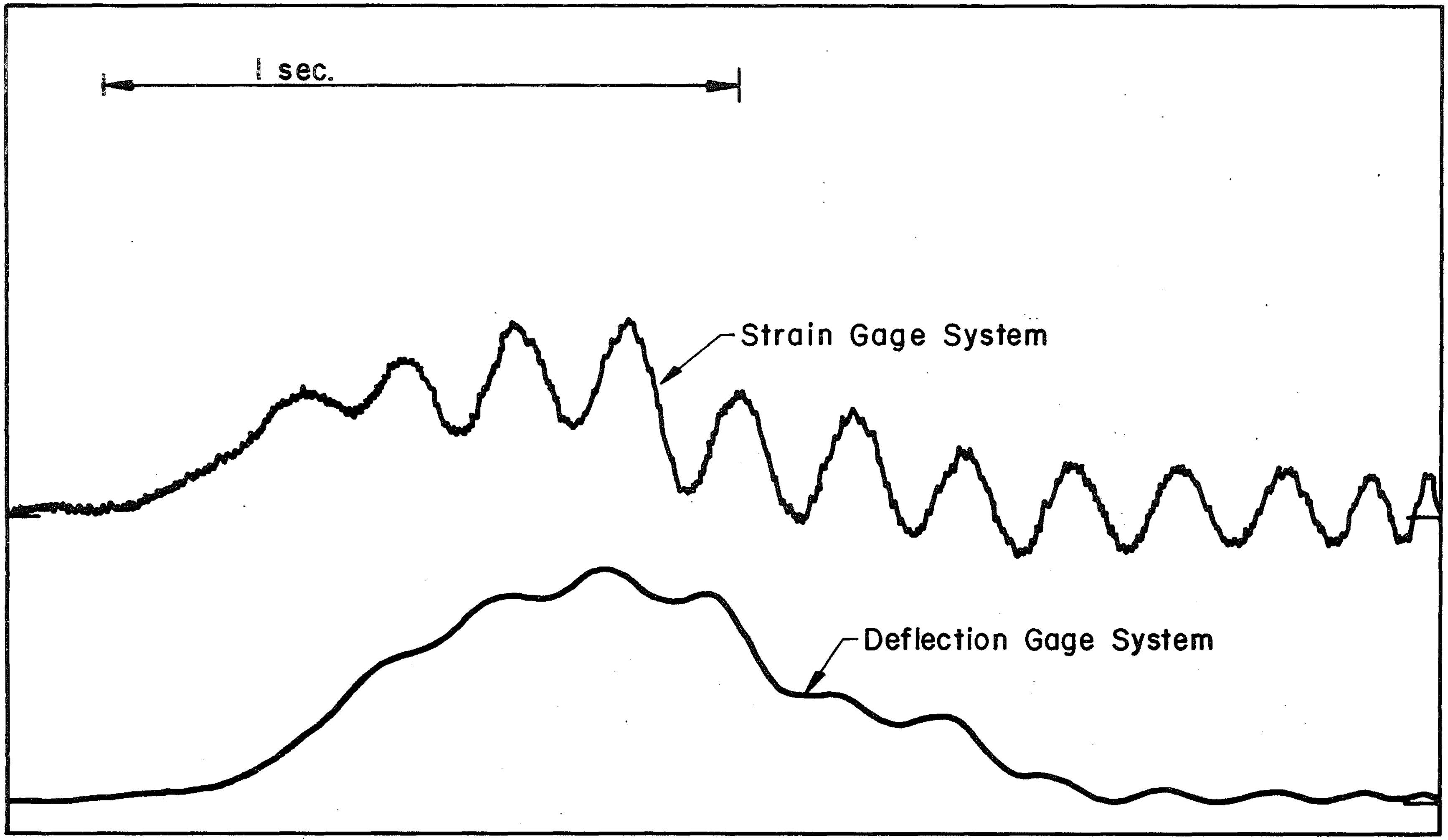


Fig. 32 3S-2 - Box - Right Lane - Strain Gage Signal Unfiltered

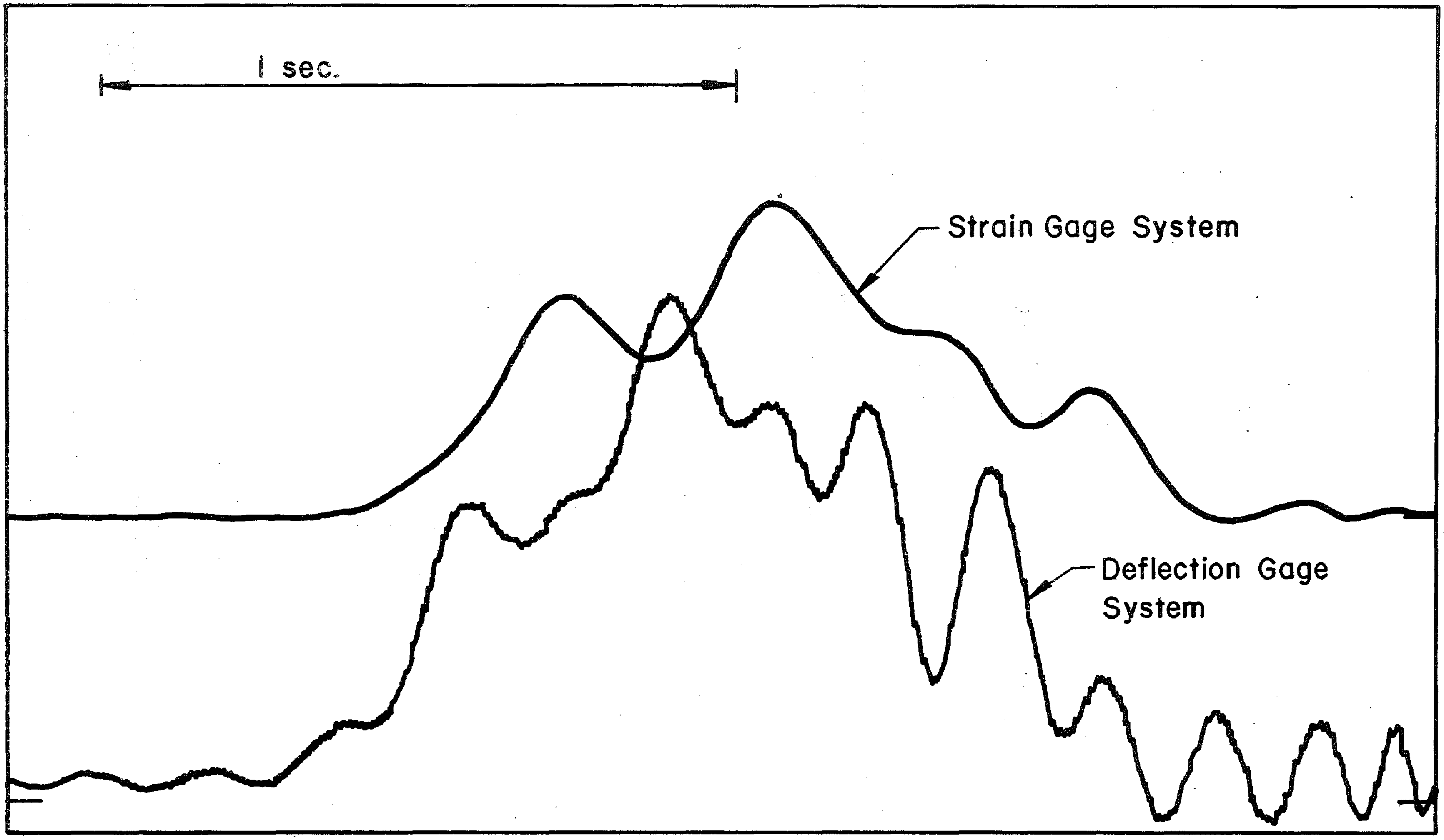


Fig. 33 3S-2 - "Box" - Right Lane - Deflection Gage Signal Unfiltered

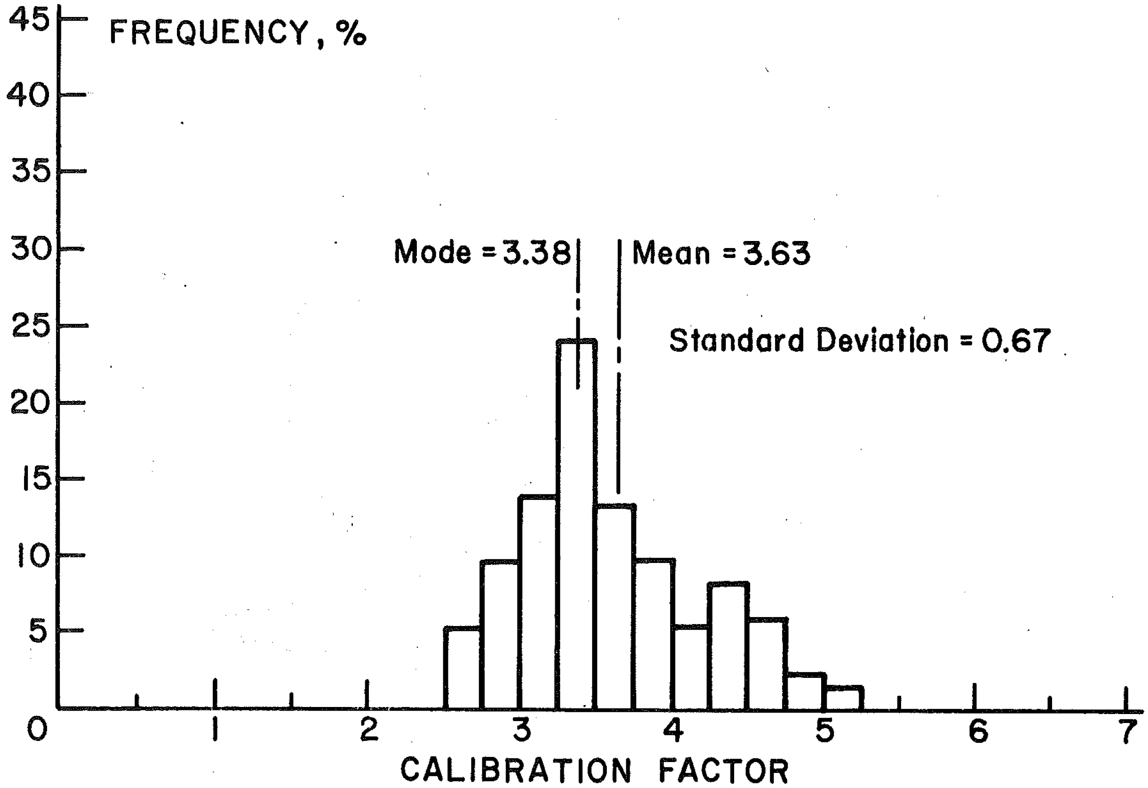


Fig. 34 Strain Gage System Calibration Factor - PennDOT plus FHWA Calibration Vehicles (n = 348)

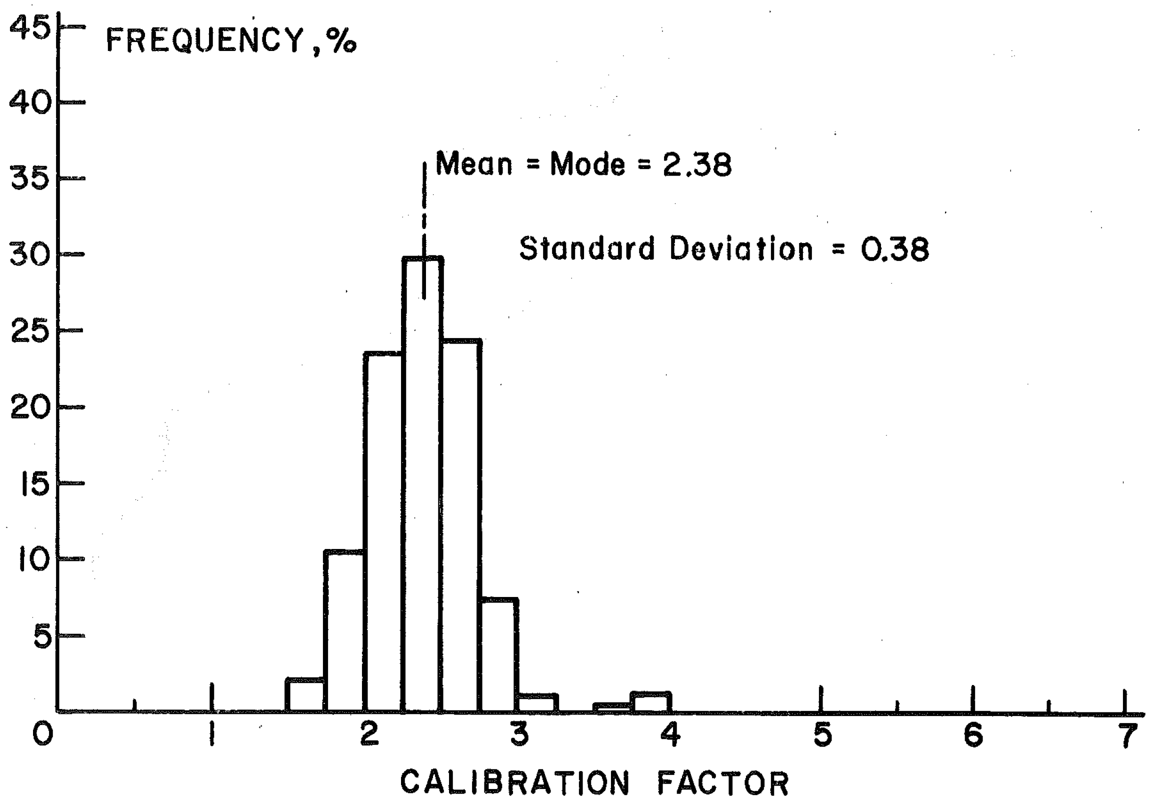


Fig. 35 Deflection Gage System Calibration Factor - PennDOT plus FHWA Calibration Vehicles (n = 348)

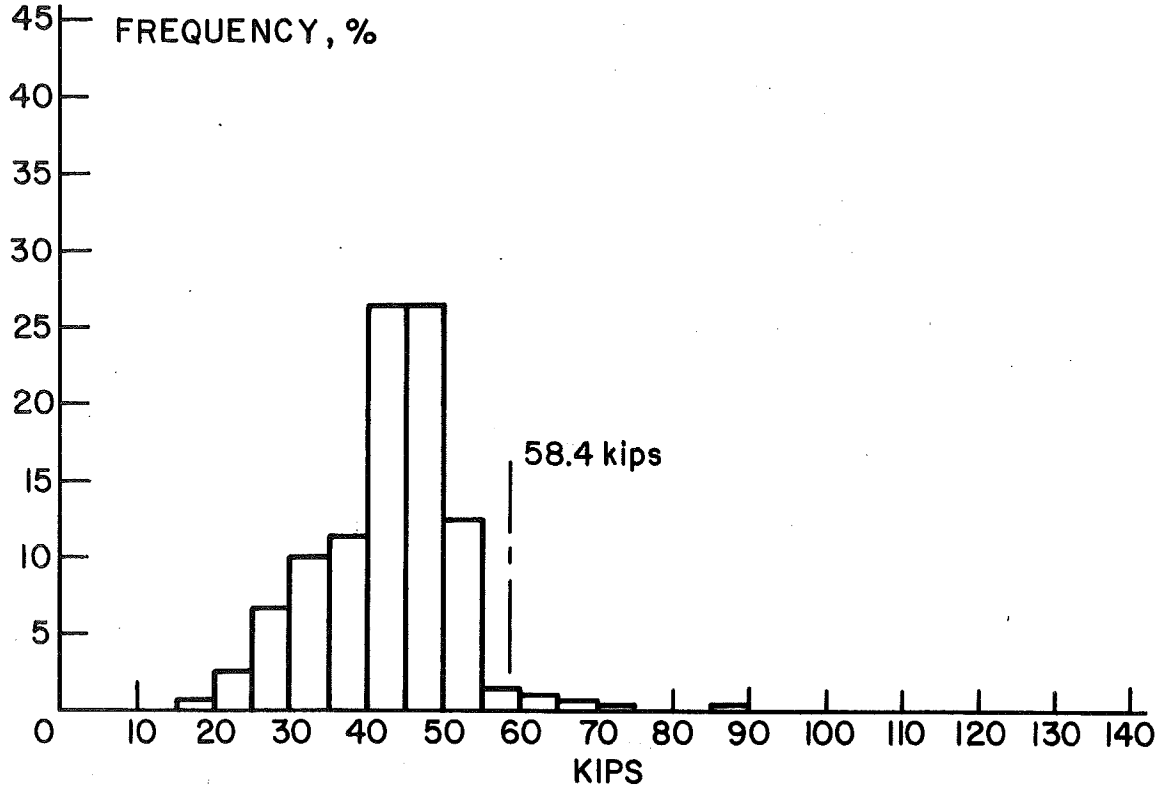


Fig. 36 Steering plus Drive Axle Weights -
Strain Gage System (n = 1227)

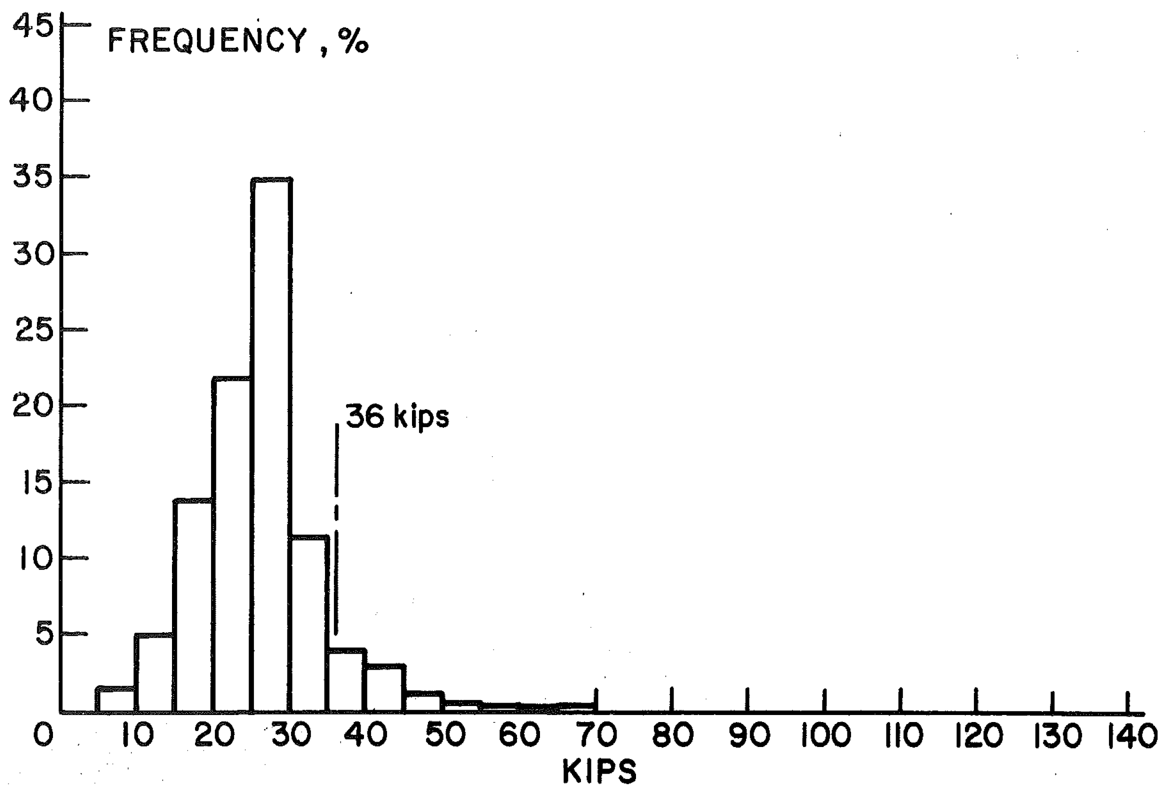


Fig. 37 Trailer Axle Weights -
Strain Gage System (n = 1227)

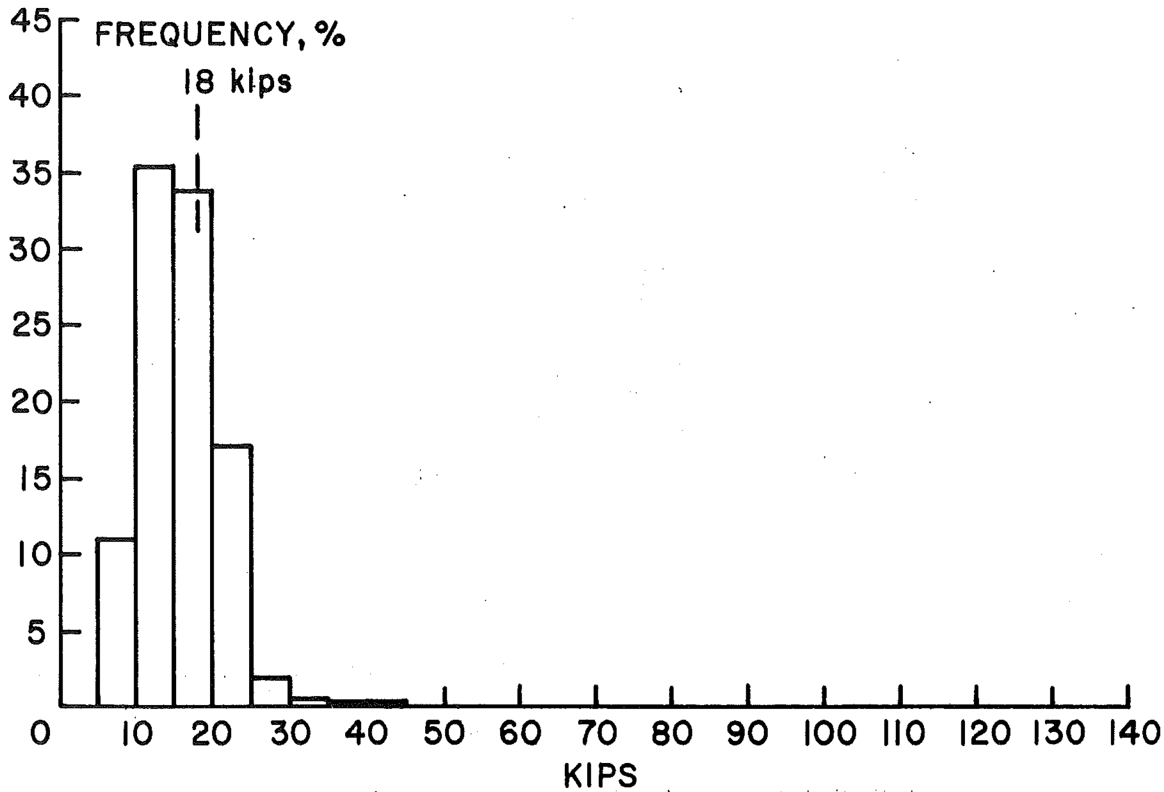


Fig. 38 Individual Axle Weights - Strain Gage System (n = 4857)

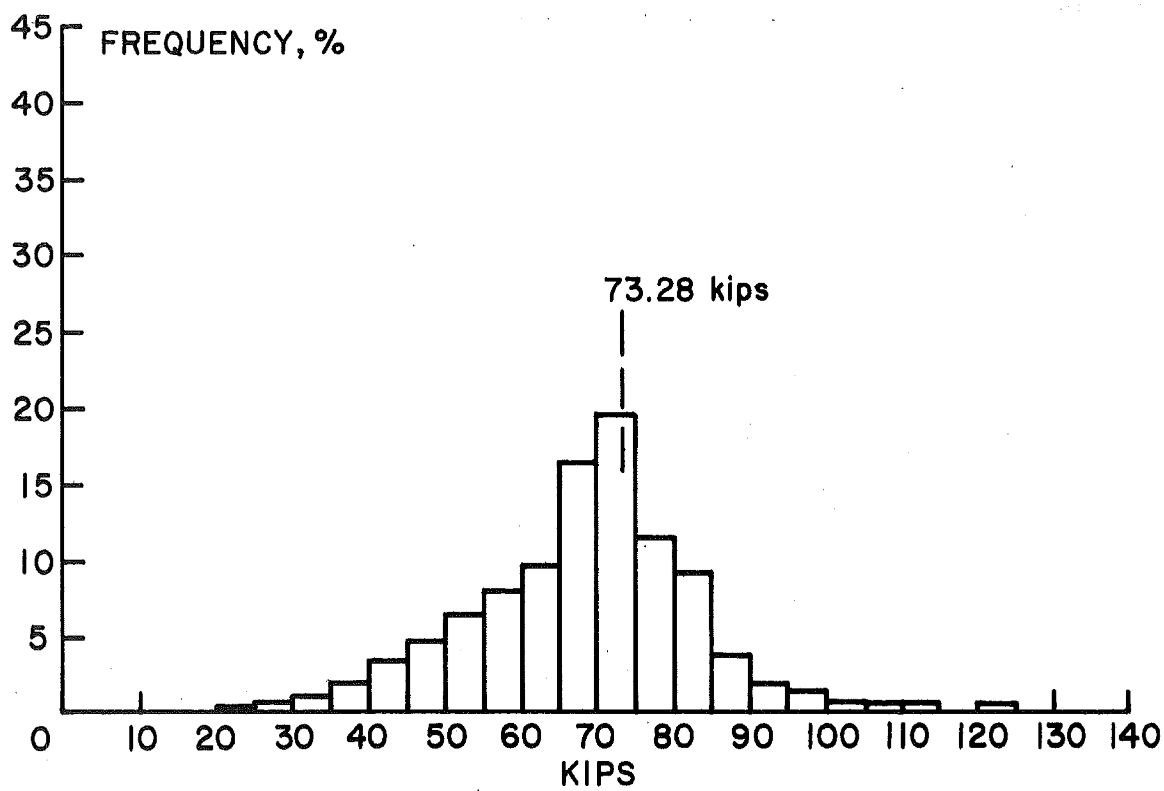


Fig. 39 Gross Vehicle Weight - Strain Gage System (n = 1227)

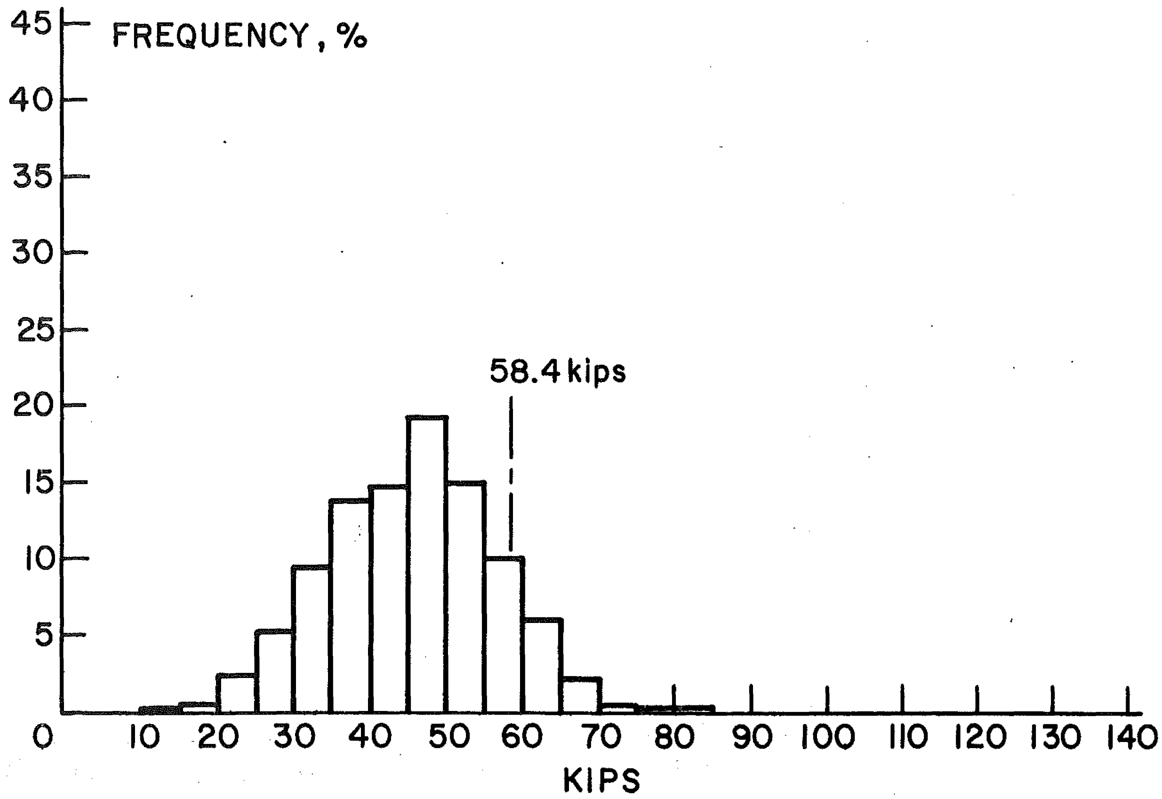


Fig. 40 Steering plus Drive Axle Weights - Deflection Gage System (n = 1227)

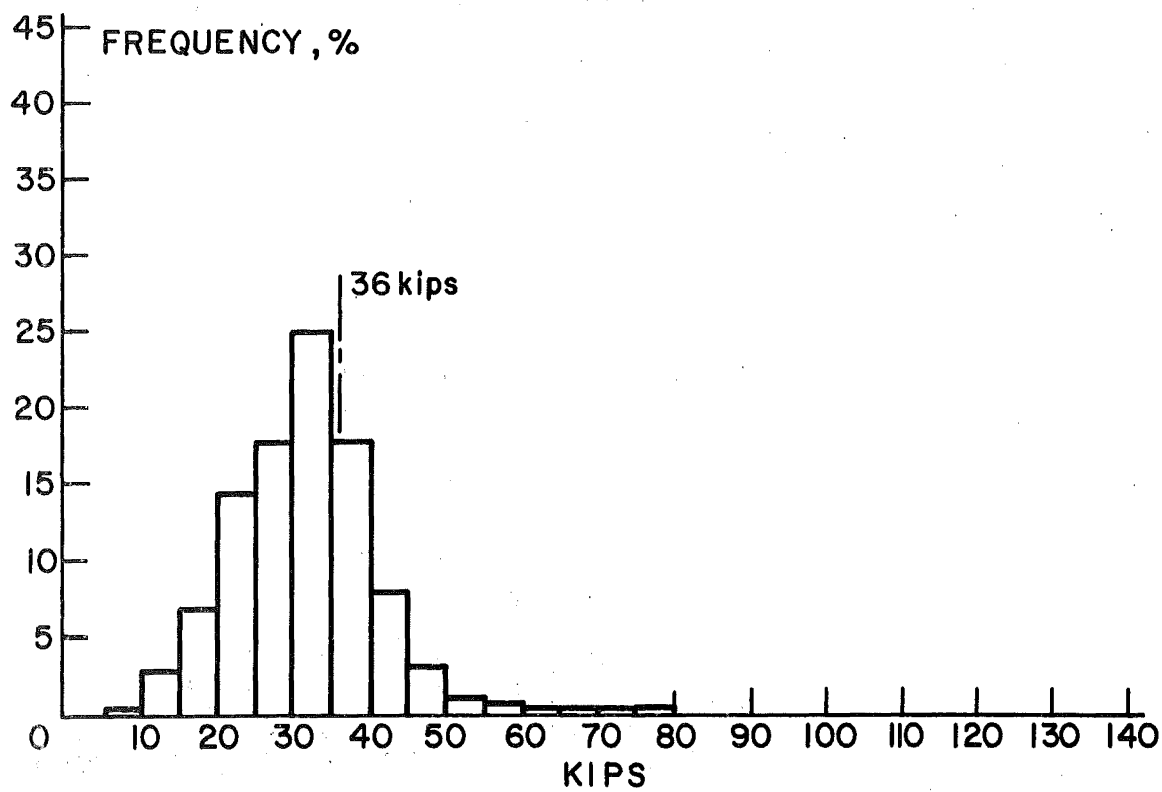


Fig. 41 Trailer Axle Weights - Deflection Gage System (n = 1227)

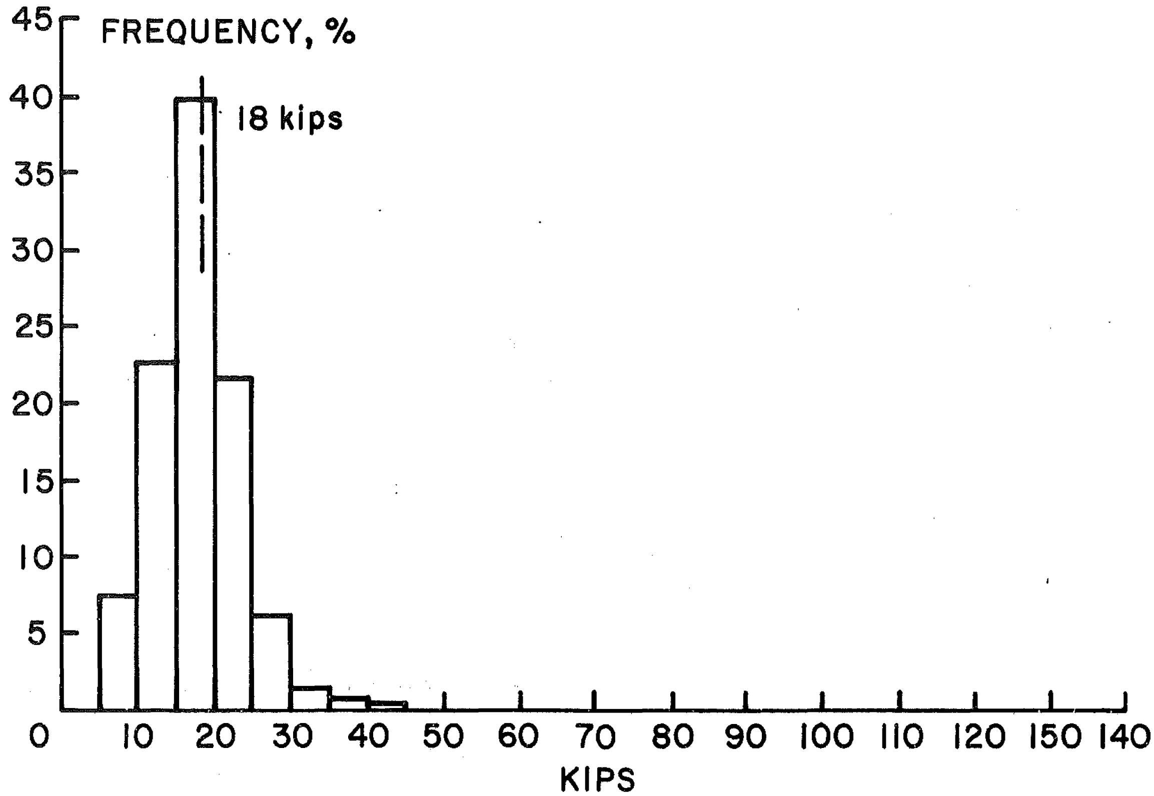


Fig. 42 Individual Axle Weights -
Deflection Gage System (n = 4857)

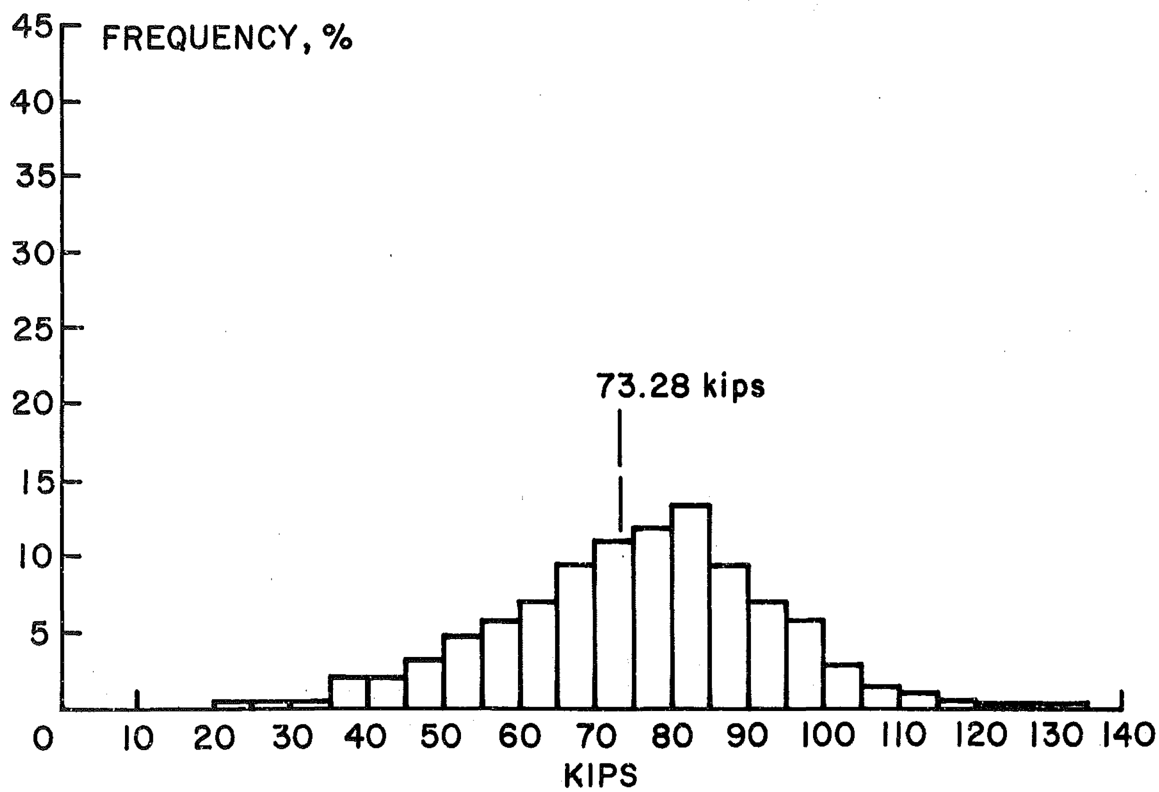


Fig. 43 Gross Vehicle Weights -
Deflection Gage System (n = 1227)

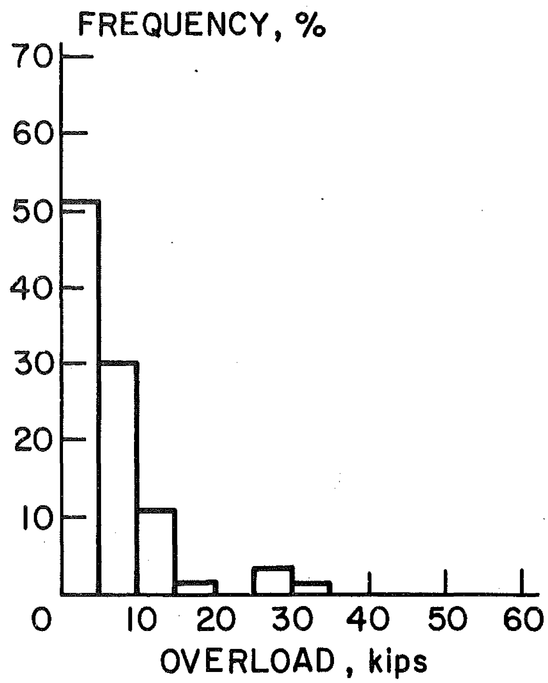


Fig. 44 Steering plus Drive Axles - Strain Calibration

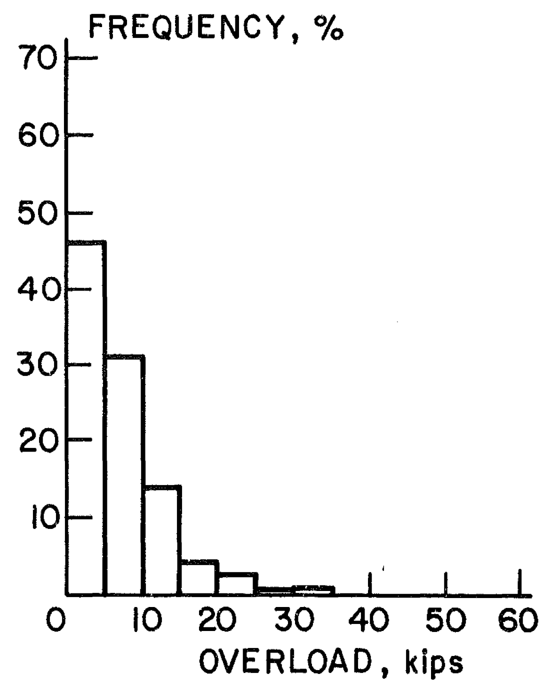


Fig. 45 Trailer Axles - Strain Calibration

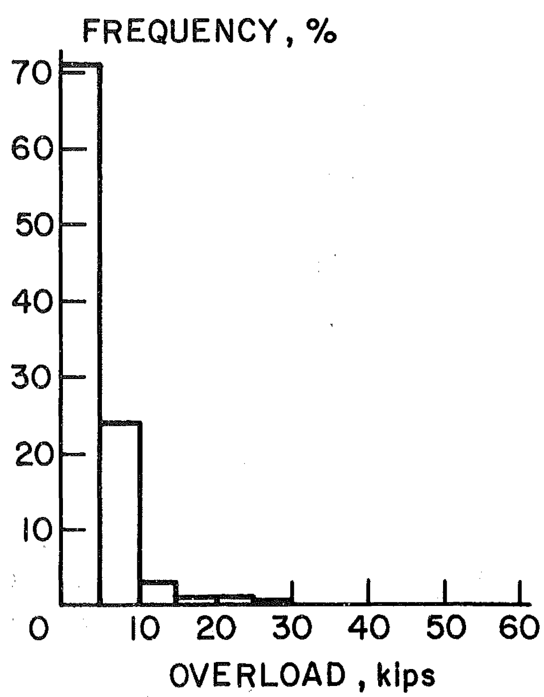


Fig. 46 Individual Axles - Strain Calibration

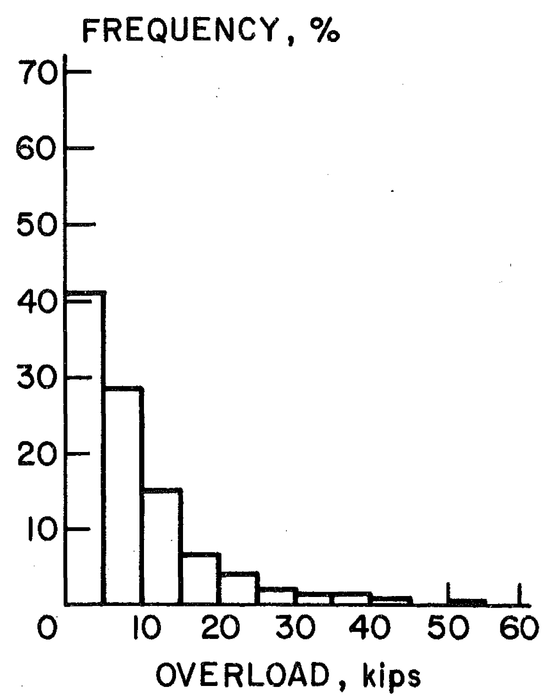


Fig. 47 Gross Vehicle Weight - Strain Calibration

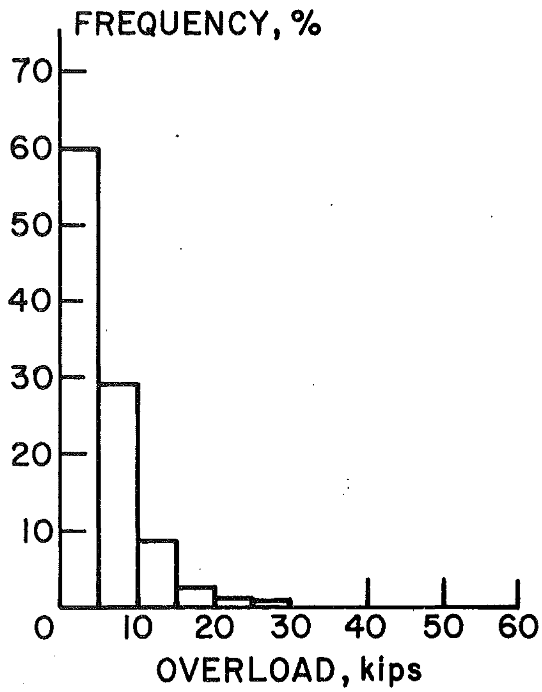


Fig. 48 Steering plus Drive Axles - Deflection Calibration

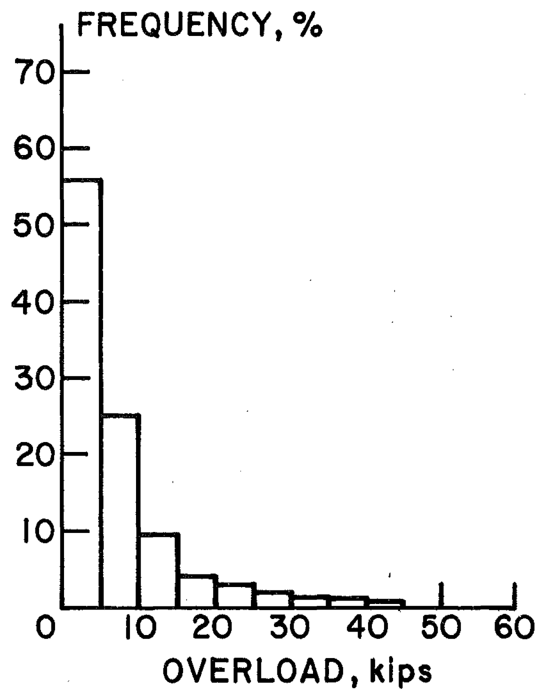


Fig. 49 Trailer Axles - Deflection Calibration

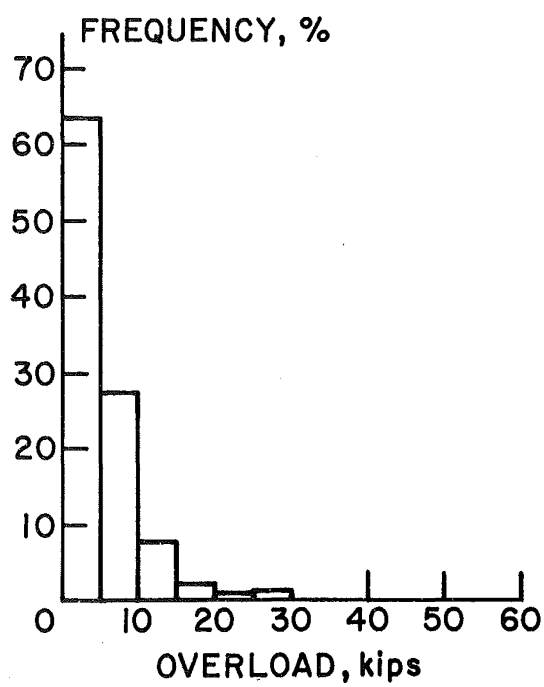


Fig. 50 Individual Axles - Deflection Calibration

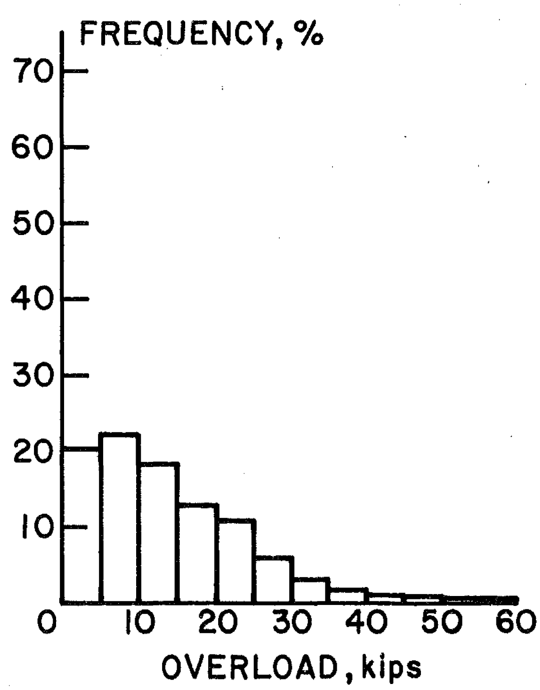


Fig. 51 Gross Vehicle Weight - Deflection Calibration

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