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SIMPLIFIED BRIDGE LOAD RATING METHODOLOGY USING THE NATIONAL BRIDGE INVENTORY FILE

Final Report

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16. ABSTRACT

The purpose of this research was to develop a computerized system to determine the adequacy of a bridge or group of bridges to carry specified overload vehicles. The system utilizes two levels of analysis. The Level 1 analysis is the basic rating system for the Arizona Department of Transportation. This analysis computes the overload capacity with a limited amount of data. A Level 2 evaluation, which conducts a more detailed evaluation, uses an enhanced NBIF database, Standard Plans, or a more detailed analysis similar to Brass. A Special Level 2 analysis was also developed to analyze continuous slab bridges by utilizing data from standard slab plans.

Detailed case studies were conducted on twenty-five typical Arizona bridges to verify the methodology used in the Level 1 procedure and to correlate the bridge plans with data in the NBIF. The Level 1 procedure gives ratings which are within 10% of the Level 2 procedure for bridges which satisfy the level one assumptions. Similarly, the Special Level 2 analysis for reinforced concrete continuous bridges gives ratings within 10% of the Level 2 analysis. The NBIF compared well with general bridge plans and is applicable to Level 1 analysis for "typical bridges".

The research results are reported in three documents:
1. Final Report
2. Volume I: Users Manual
3. Volume II: Program Listing

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1.0 INTRODUCTION

1.1 Background

The bridge engineer responsible for operating and maintaining a network of bridges on a modern roadway system is continually faced with the task of evaluating the load-carrying capacity of existing bridges. With the current trend in the trucking industry of increasing gross vehicle weights to reduce energy costs, the maintenance engineer is often subjected to political pressures to increase the legal load limits on our roadway systems. In addition, vehicle load configurations are changing as new vehicles are designed to accommodate transported goods at the maximum possible payload. Faced with these problems, it is important that the maintenance engineer has at his disposal the information needed to make critical decisions on a day-to-day basis.

1.2 Objectives

The primary objectives of the research were to evaluate the bridge rating and overload permit procedures of the Arizona Department of Transportation and to develop a computerized system to improve procedures used to determine the adequacy of a bridge or group of bridges to carry certain overload vehicles. Computer input for the overload rating system was to be simple, consisting essentially of the given truck load configuration and desired routes. The output was to be simple and easily interpreted so the user could readily select an adequate route for a given overload vehicle.

1.3 Level 1 and Special Level 2 Procedure

Considering both the required response time and the number of bridges on the Arizona State Highway System, a Level 1 evaluation will be the basic rating system. The advantage of the Level 1 evaluation is that it computes the overload rating capacity rapidly with a limited amount of data. The Level 1 procedure does not represent a detailed vehicle/structure load analysis for individual bridges. Rather, it is based on a simplified rating technique with associated assumptions. A Level 2 evaluation, which conducts a more detailed evaluation, would use an enhanced NBIF database, standard plans, or a more detailed frame analysis similar to BRASS. In addition to the Level 1 procedure a Special Level 2 analysis for continuous slab bridges was developed by utilizing data from standard slab plans.

The Level 1 procedure transforms the given load capacity ratings for the specified vehicles as contained in the NBIF at the operating level into the overload load ratings. This procedure is expressed mathematically as:

$$OVLDRR = T^{*}RF_{op}$$

where

OVLDRR = Overload rating ratio calculates the bridge capacity as a decimal fraction of the overload vehicle. A value of 1.0 indicates that the bridge has the capacity to support the overload vehicle. Values between 0.7 and 1.0 indicate potential under capacity, but are inconclusive for a given bridge unless a more detailed Level 2 evaluation is considered. Values under 0.70 indicate an inadequate capacity to support overload vehicles.

T = Function transforming the AASHTO load rating factor, RF_{op}, to the OVLDRR.

RF_{op} = Rating factor contained in NBIF at the operating level that indicates the capacity of the bridge as a decimal fraction of the rating vehicle.

The transformation function T, which takes into account the difference in the load effects of the overload and the rating vehicles is expressed mathematically as:

$$T = f\left(R_L, C, R_T, R_I\right) = \frac{1}{R_L\, C\, R_T\, R_I}$$

where

R_L = Ratio of the controlling simple span longitudinal response of the overload vehicle to that of the rating vehicle.

C = Correction factor applied to continuous bridges.

R_T = Ratio of the transverse load distribution factor of the overload vehicle to the AASHTO design vehicle.

R_I = Ratio of the impact effects of the overload vehicle to the AASHTO design formula.

The Special Level 2 procedure uses standard reinforced concrete slab plans to calculate the overload rating capacity for this bridge type only. Other types use the Level 1 procedure mentioned above. The motivation for using this procedure is explained in detail in Chapter 2. This procedure is expressed mathematically as:

$$OVLDRR = \frac{M_{CAPACITY} - M_{DL}}{M_{(LL+I)}\, R_T\, R_I}$$

where

OVLDRR = Overload rating ratio that is calculated directly. The values of OVLDRR limits are similar to those of the Level 1 procedure.

$M_{CAPACITY}$ = Working stress moment capacity calculated from standard plans for a unit foot width.

M_{DL} = Dead load moment calculated from standard plans for a unit foot width.

$M_{(LL+I)}$ = AASHTO live load plus impact moment using a three-span influence line for a unit foot width.

R_T = Ratio of the transverse load distribution factor of the overload vehicle to the AASHTO design vehicle.

R_I = Ratio of the impact effects of the overload vehicle to the AASHTO design formula.

1.3.1 NBIF Data Utilized

The National Bridge Inspection Standards (NBIS) were developed by the US Department of Transportation, in consultation with state highway departments and other interested parties. The NBIS requires states to inventory all bridges located on all public roads. Inventory data collected by the various states are submitted to and compiled in the National Bridge Inventory File (NBIF). Ninety data items contain information about the physical characteristics of all public highway bridges (13).

The data from the NBIF that is used directly in the Level 1 procedure is:

- Structure type main (Continuity included) (Item 43)
- No. of spans in main unit (Item 45)
- No. of approach spans (Item 46)
- Length of maximum span (Item 48)
- Structure length (Item 49)
- Operating rating (Item 64)

The Level 1 procedure depends strongly on the accuracy of this data. These items should be checked for accuracy before conclusions are reached for the overload capacity rating.

1.3.2 Statistical Data from Arizona NBIF

The statistics for primary, secondary, and interstate routes from the NBIF for various bridge types is shown in Table 1-1. The majority of bridges shown are reinforced concrete slab, steel stringer, P/S concrete stringer, reinforced concrete T-Beam, P/S concrete Box-M, P/S concrete Box-S, timber stringer, and reinforced concrete Box-S. These bridge types comprise ninety percent of the bridges in the NBIF. The frequency of the number of bridges versus the number of spans is shown in Figure 1-1 to Figure 1-10. The plots indicate that a three-span configuration occurs most frequently for reinforced concrete slab, steel stringer, reinforced concrete T-beam and reinforced concrete Box-S bridges while a simple span occurs most frequently for P/S concrete stringer, P/S concrete Box-M, P/S concrete Box-S, and timber stringer bridges. The frequency of the number of bridges versus the maximum span length range is shown in Figure 1-11 to Figure 1-20. The plots indicate that the maximum span length range varies based on bridge type.

1.4 Assumptions

The following assumptions were made relative to the Level 1 evaluation and Special Level 2 analysis and the data stored in the NBIF:

1. Level 1 is applicable to those types of bridges designed or constructed as "slab," "stringer/multi-beam or girder," "girder and floorbeam system," "T-beam," "box beam or girders-multiple," "box beam or girders-single," and "culverts." Also Level 1 is applicable to those types of bridges designed with materials as "concrete," "steel," "prestress concrete," and "timber." Bridges not applicable to those bridge types are screened for a Level 2 analysis which requires a more detailed evaluation (i.e. BRASS). The overload rating in Level 1 is applicable to primary members in the bridge, while secondary members are ignored.

2. Special Level 2 analysis is applicable to reinforced concrete continuous slab bridges that have three or more spans and that were designed using Arizona standard plans. The controlling rating is assumed not to be effected by hinges in the bridge.

3. AASHTO impact and load distribution formulae are used in the NBIF. For girder type bridges the girder spacing is assumed constant from span to span.

4. The operating rating in the NBIF is coded correctly and that it is based only on the flexure mode using AASHTO working stress method of design for both positive and negative moment. The operating rating for bridges that have been administratively rated (i.e., $RF_{IN} = RF_{op} = 236$) and that are coded with structural conditions of 7 and greater will be increased by a factor of 1.36 (i.e., 0.75/0.55). Also, other data compiled in the NBIF is correct and that the condition of the bridge has not changed significantly since the last reported maintenance inspection.

5. The longitudinal moment ratio, R_L , is based on the simple beam moment for the maximum span length. The positive moment is computed at the 0.4 and 0.5 point in the maximum span.

6. The longitudinal moment continuity correction factor, C, is computed for a two-span and three-span continuous bridge. For two-span bridges both spans are assumed equal to the maximum span. The positive moment is computed at the 0.4 point and the negative moment is computed at the middle support. For bridges having three or more spans, the "three-span" influence line configuration is used. The interior spans are assumed equal to the maximum span length and the exterior spans are calculated as the remainder based on the overall length and maximum span length of the bridge. The positive moment is computed at the 0.4 point of Span 1 or the exterior span and at the 0.5 point of Span 2 or the

interior span. The negative moment is computed at the support. All supports are assumed to be on rollers and the cross section of the bridge is uniform.

The longitudinal moment ratio and continuity factor are computed by "marching" the AASHTO and overload trucks over the computed influence lines for a one-span, two-span, or three-span configuration, as shown in Figures 1-21, 1-22, and 1-23, respectively. Each axle is placed at the lead position and marched at each 10th point on the spans to determine the maximum moment. For influence lines that are nonsymmetrical, the truck is marched forward and backward. For H20 and HS20 type vehicles the lane loading is also considered in the evaluation.

7. Moment envelopes produced by the overload vehicles were approximately the same shape as those produced by the rating vehicles used in the NBIF.

1.5 Limitations

The following limitations are applicable for the Level 1 evaluation and Special Level 2 analysis:

1. Only the State of Arizona has been considered for evaluation. Bridges that fall outside this state may use different rating procedures, but the procedure could be easily extended to include other states.

2. Secondary members are ignored for rating which may lead to errors for "stringer/multi-beam or girder" type designs or other similar bridge types.

3. The shear mode for rating has been ignored.

4. The end span calculation for continuous spans may be in error in the Level 1 evaluation if the maximum span length and overall length are coded incorrectly in the NBIF or the bridge has an unusual span configuration.

5. Monolithic columns are ignored in the Level 1 procedure and may introduce conservative results for the overload rating capacity.

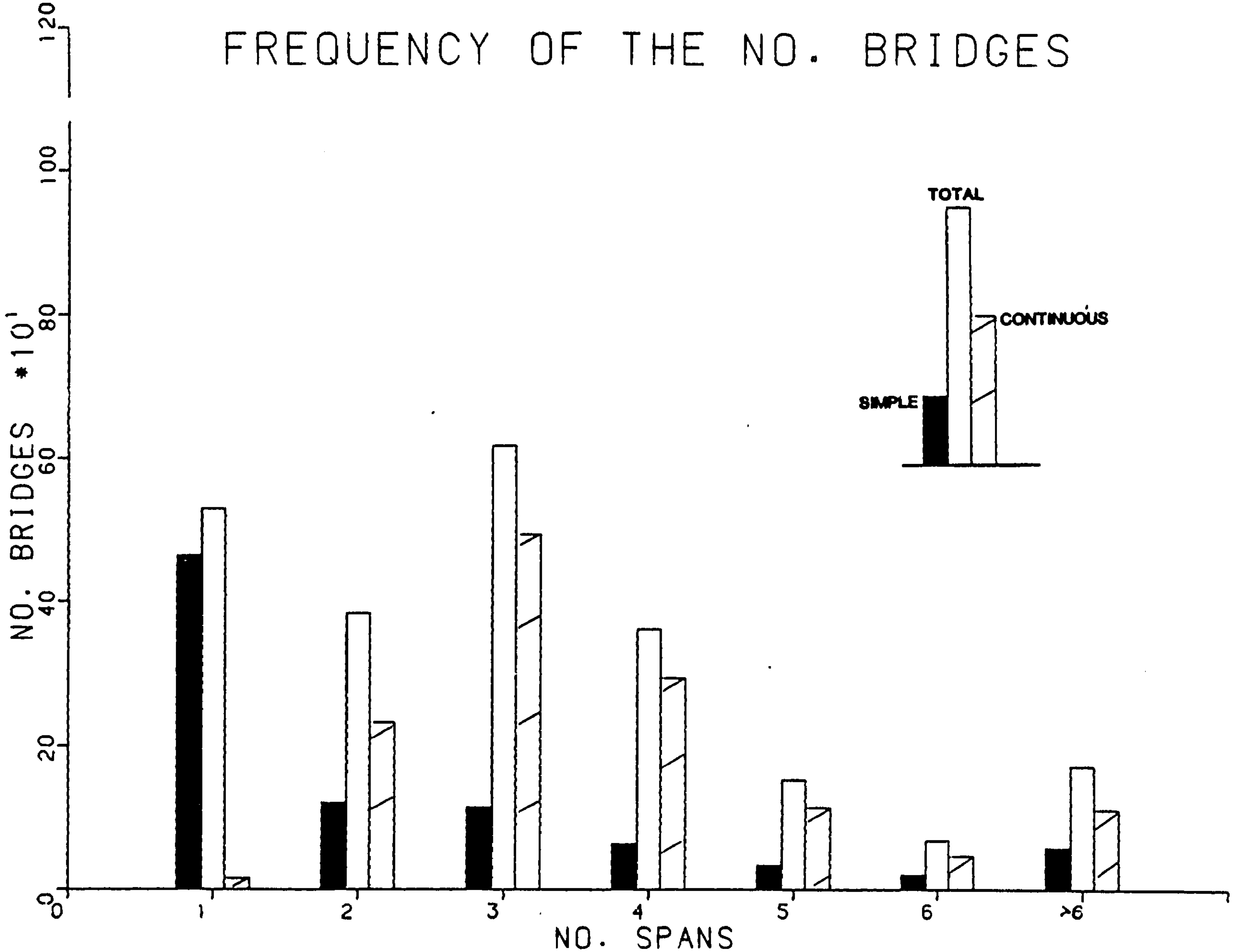

FIGURE 1-1. NUMBER OF SPANS - BRIDGES

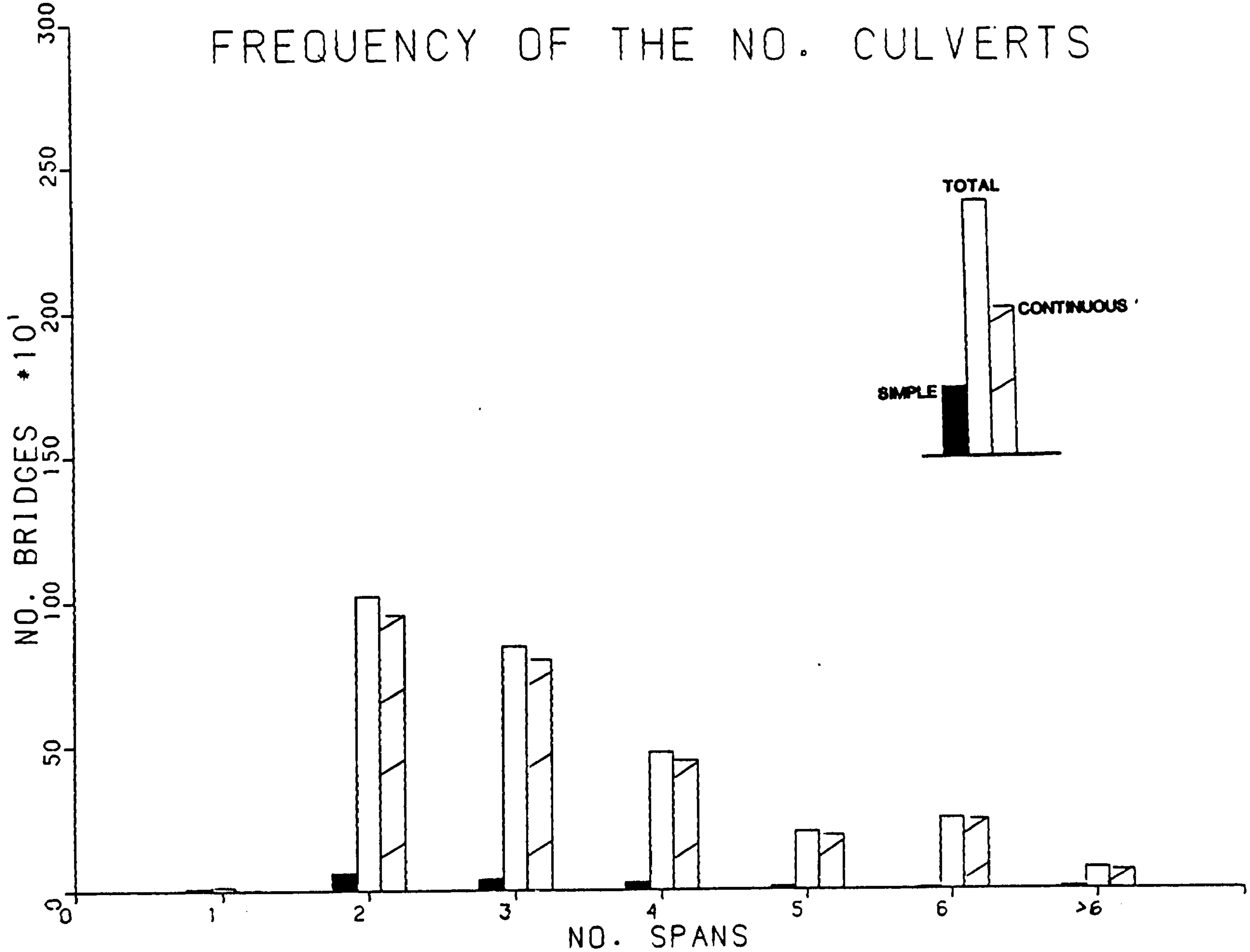

FIGURE 1-2. NUMBER OF SPANS - CULVERTS

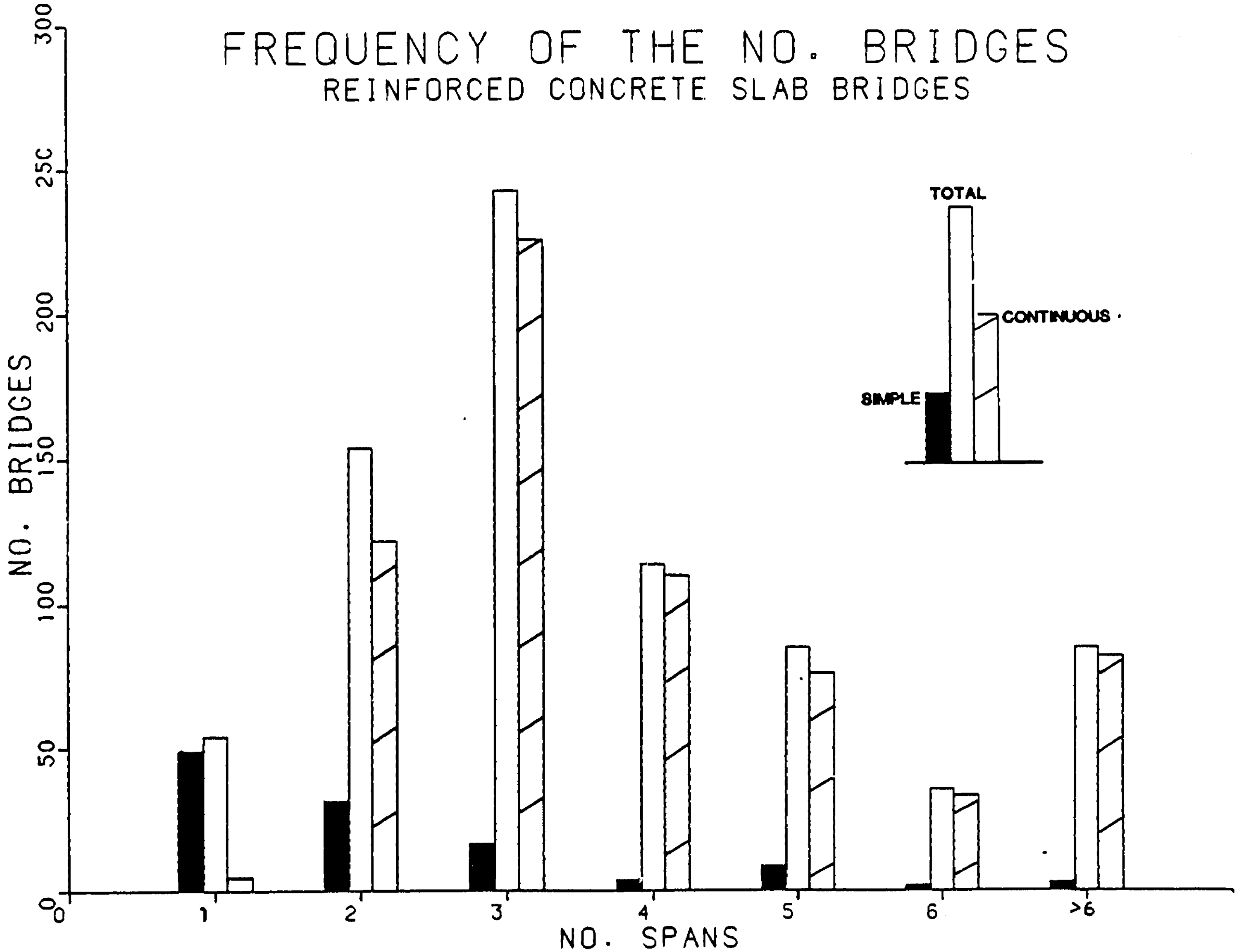

FIGURE 1-3. NUMBER OF SPANS - REINFORCED CONCRETE SLAB

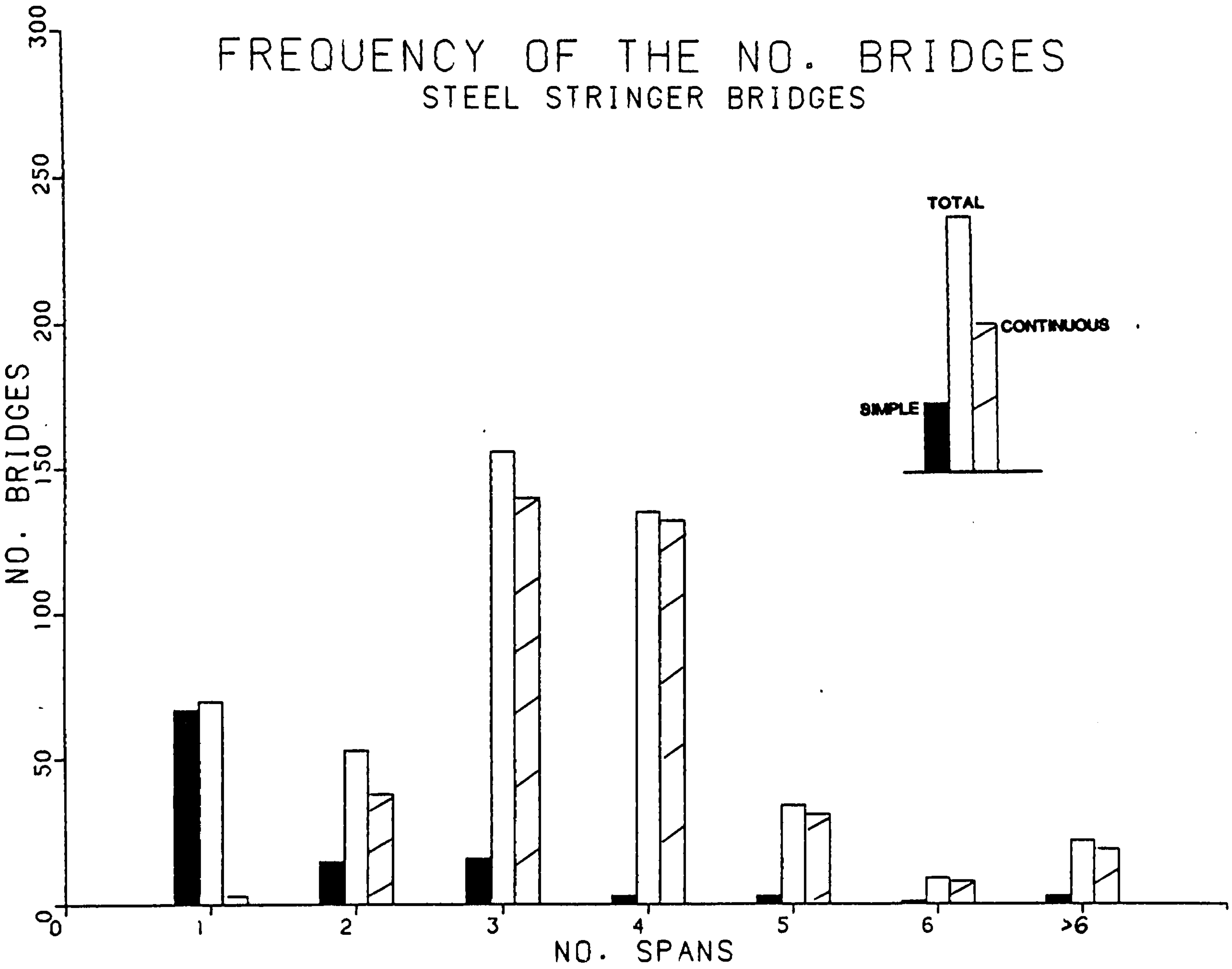

FIGURE 1-4. NUMBER OF SPANS - STEEL STRINGER

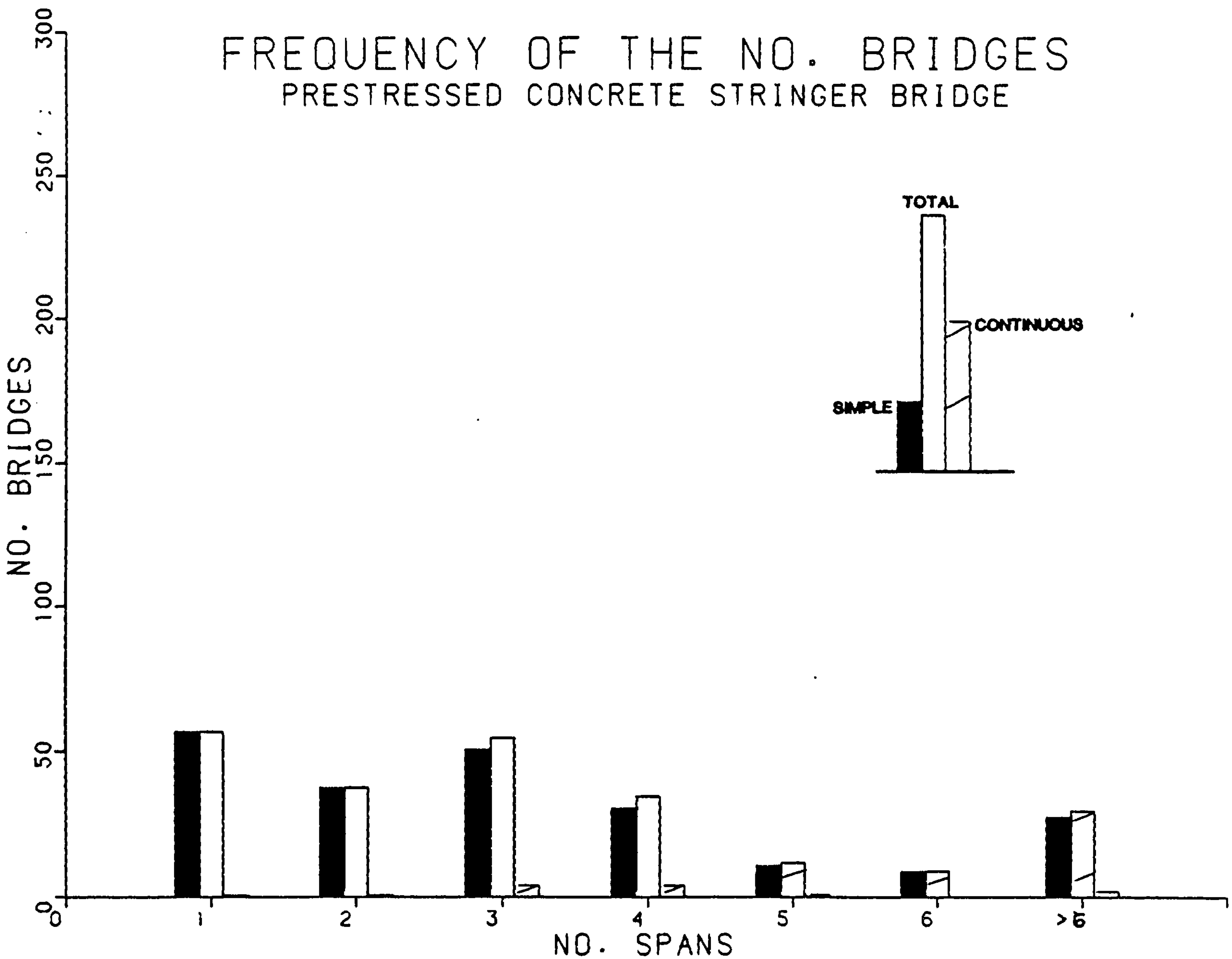

FIGURE 1-5. NUMBER OF SPANS - P/S CONCRETE STRINGER

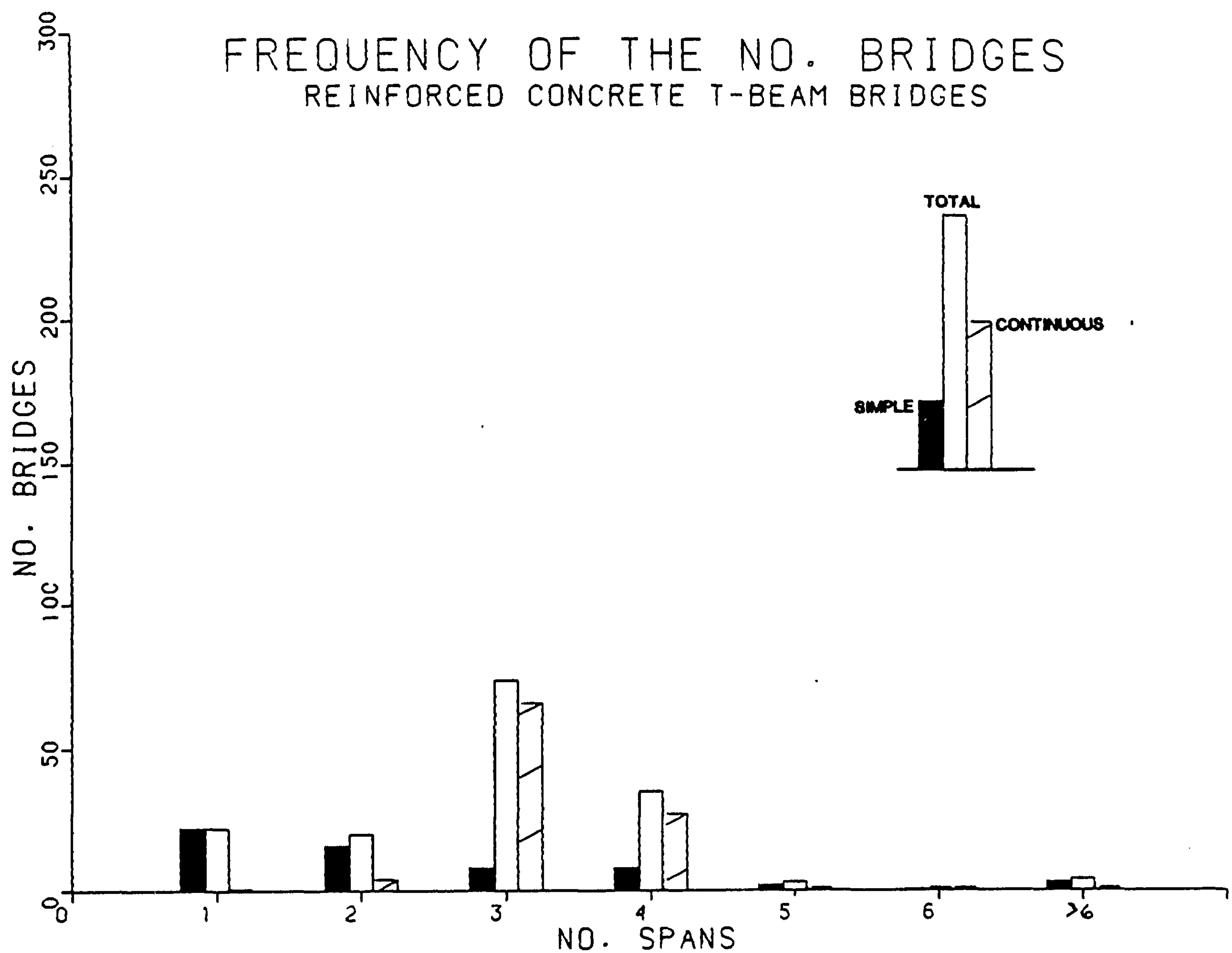

FIGURE 1-6. NUMBER OF SPANS - REINFORCED CONCRETE T-BEAM

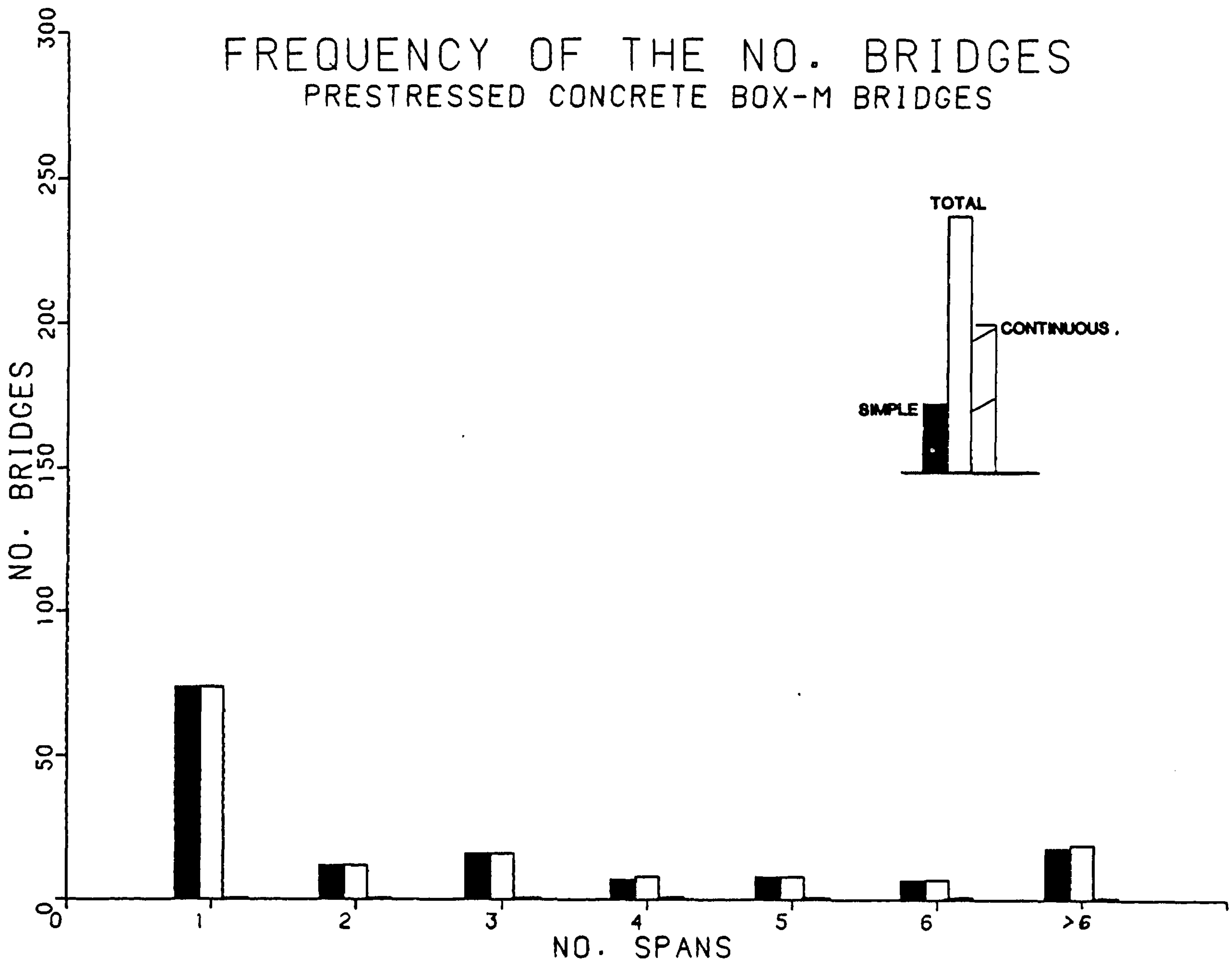

FIGURE 1-7. NUMBER OF SPANS - P/S CONCRETE BOX-M

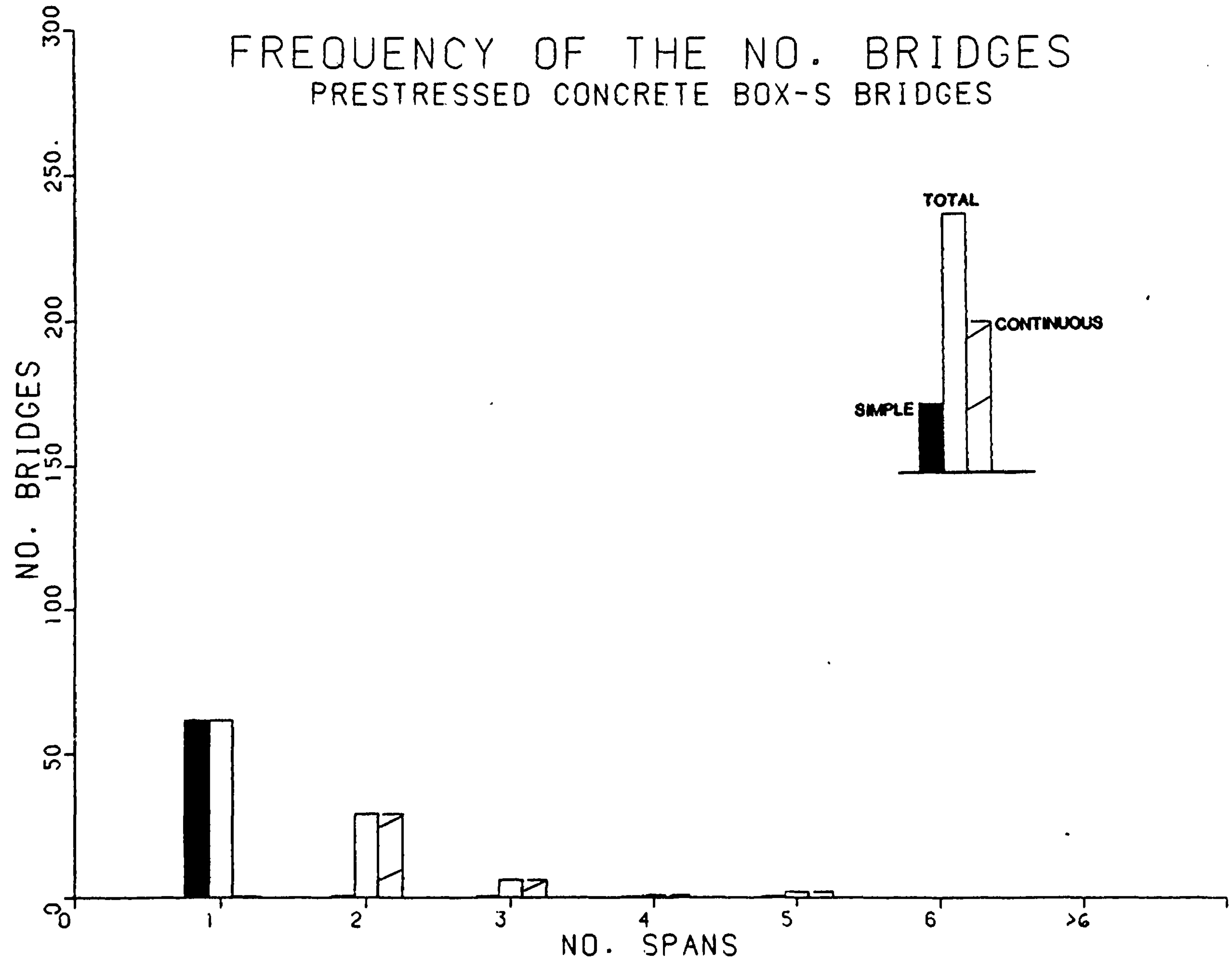

FIGURE 1-8. NUMBER OF SPANS - P/S CONCRETE BOX-S

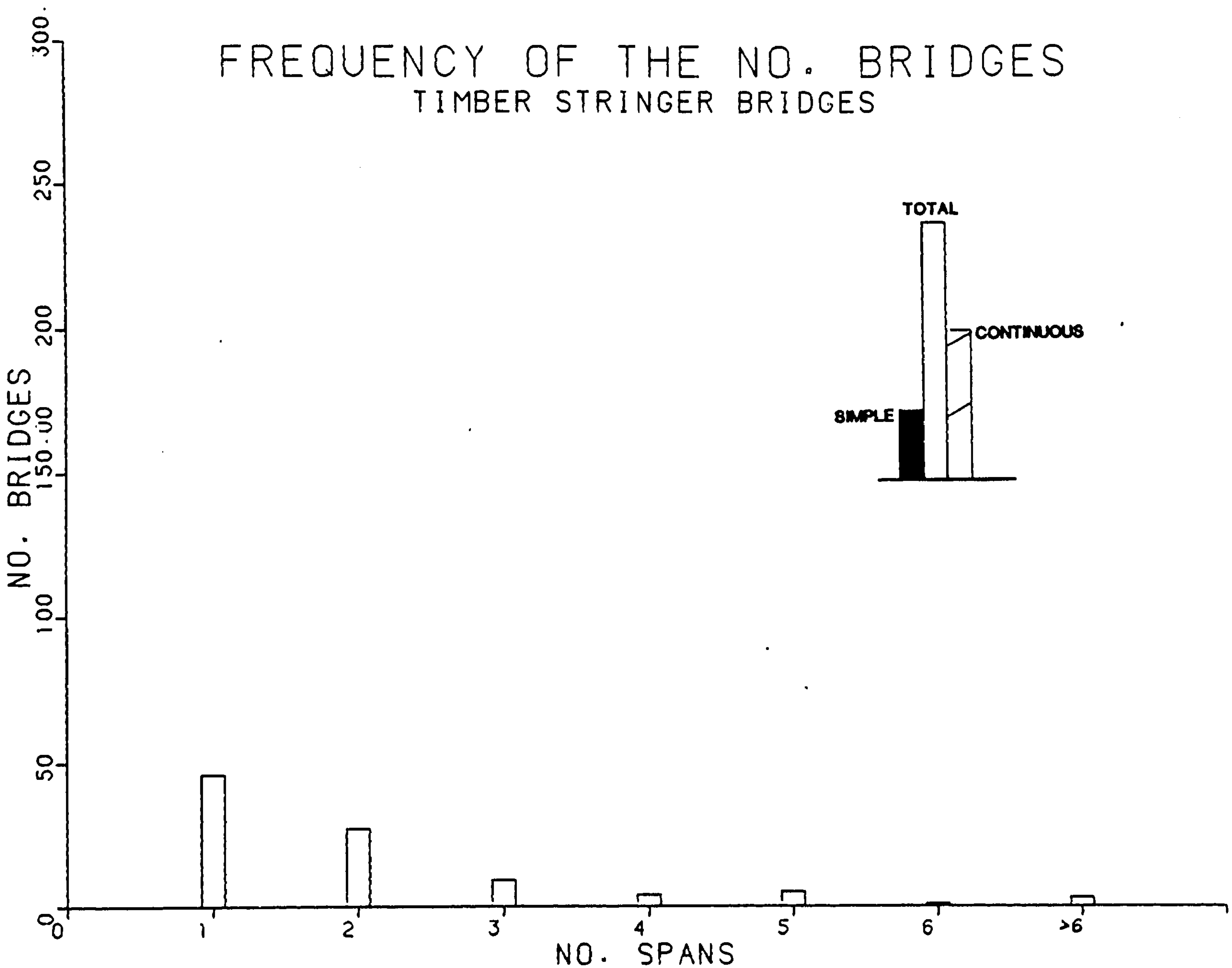

FIGURE 1-9. NUMBER OF SPANS - TIMBER STRINGER

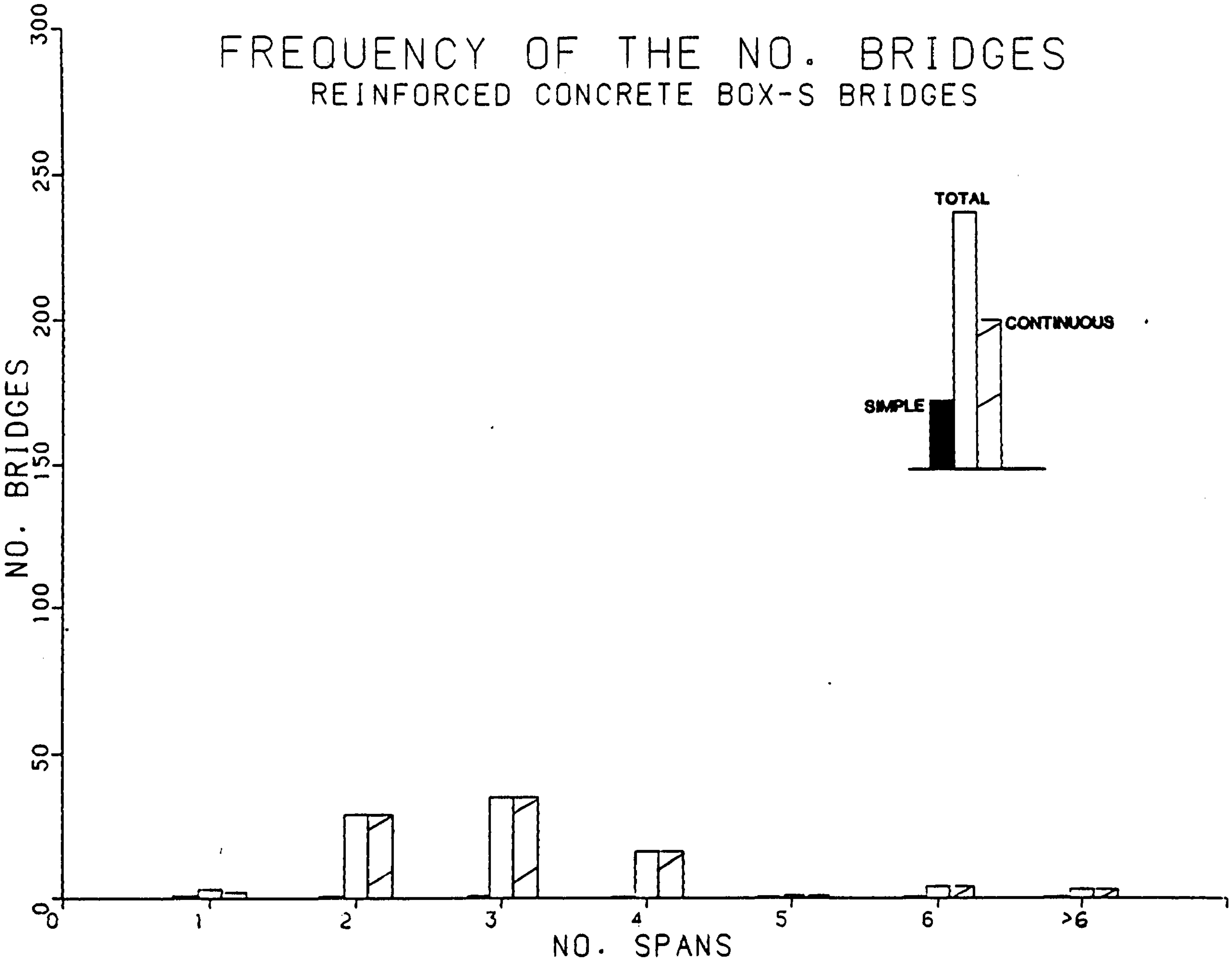

FIGURE 1-10. NUMBER OF SPANS - REINFORCED CONCRETE BOX-S

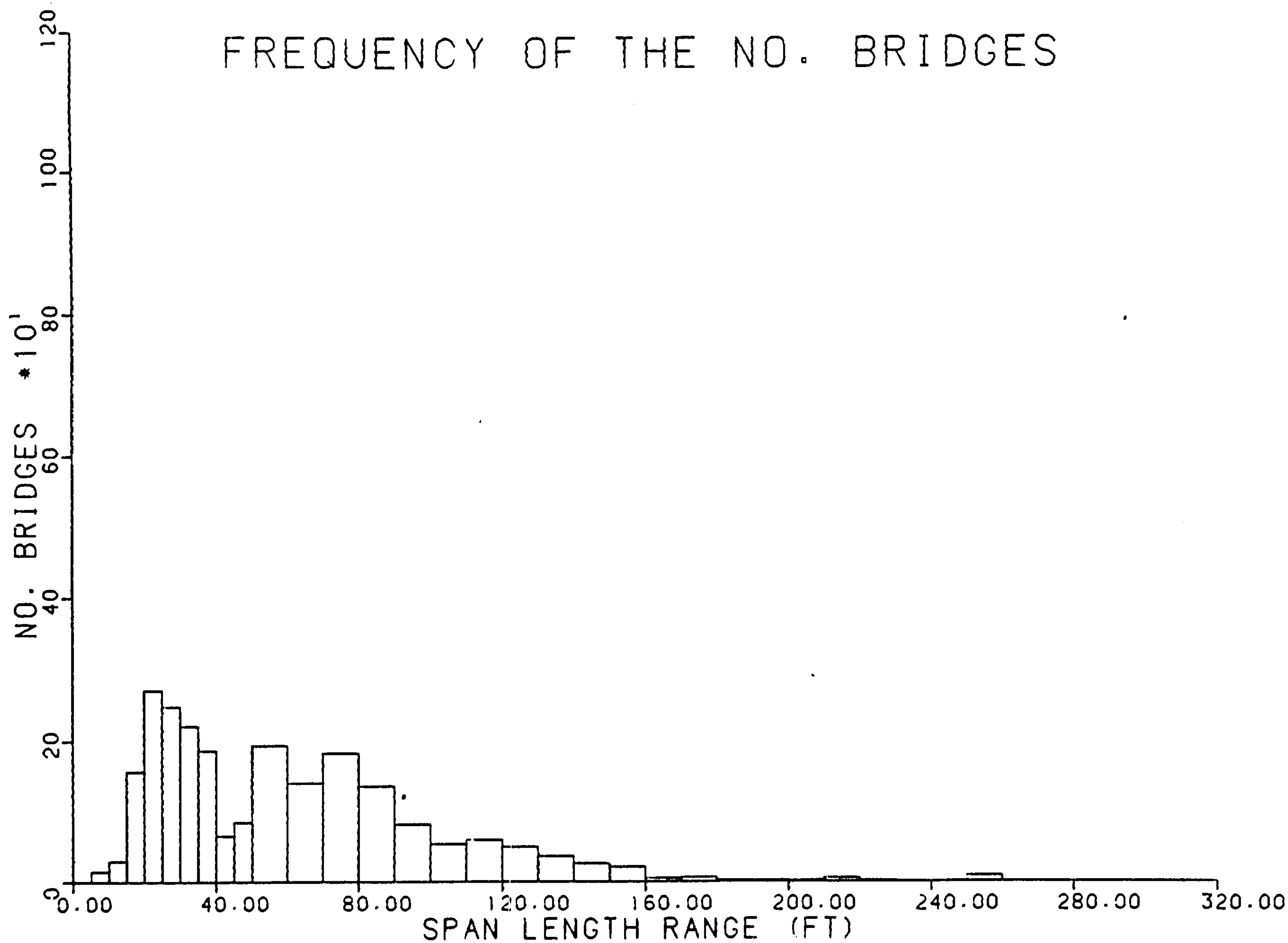

FIGURE 1-11. SPAN LENGTH RANGE - BRIDGES

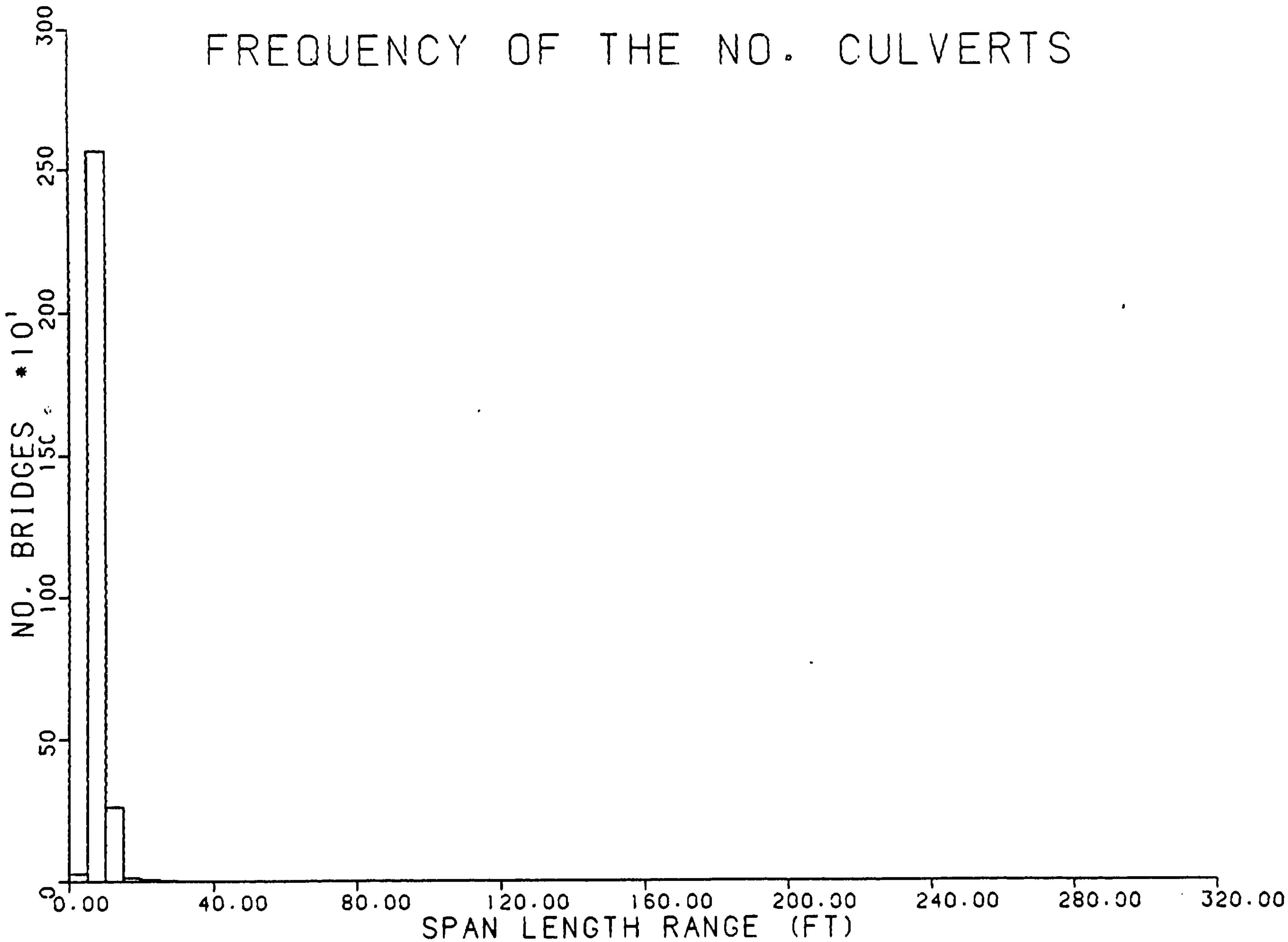

FIGURE 1-12. SPAN LENGTH RANGE - CULVERTS

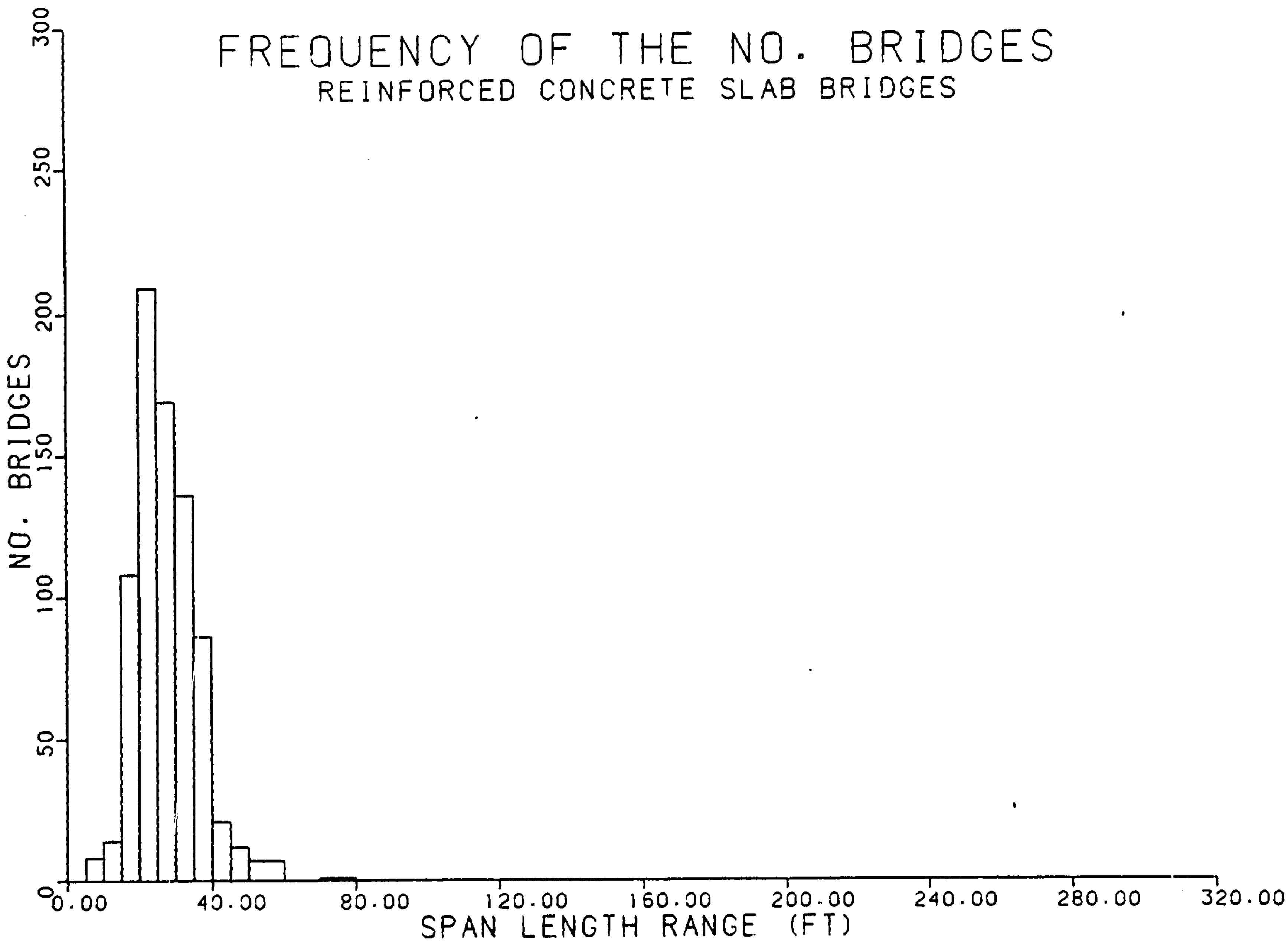

FIGURE 1-13. SPAN LENGTH RANGE - REINFORCED CONCRETE SLAB

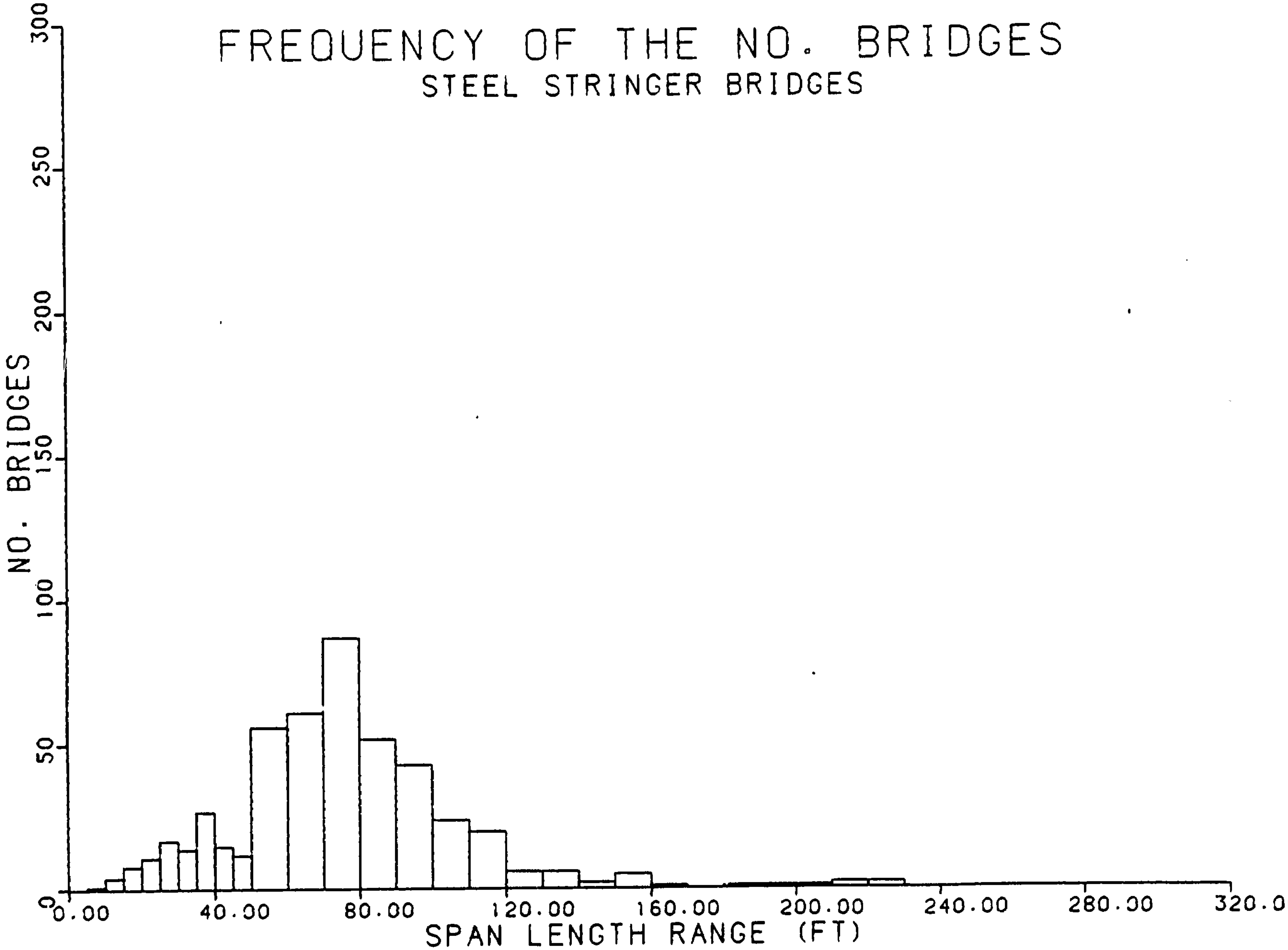

FIGURE 1-14. SPAN LENGTH RANGE - STEEL STRINGER

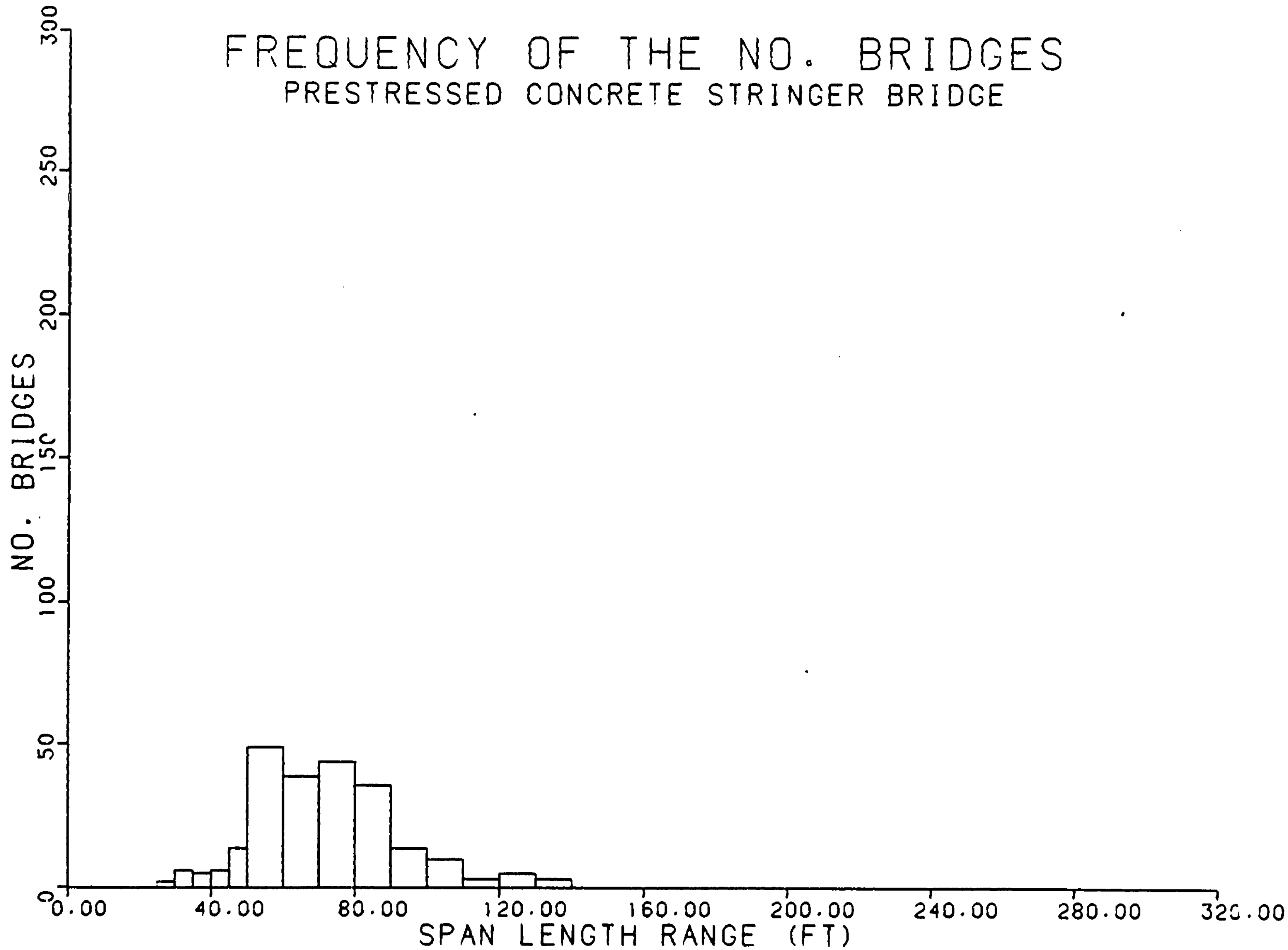

FIGURE 1-15. SPAN LENGTH RANGE - P/S CONCRETE STRINGER

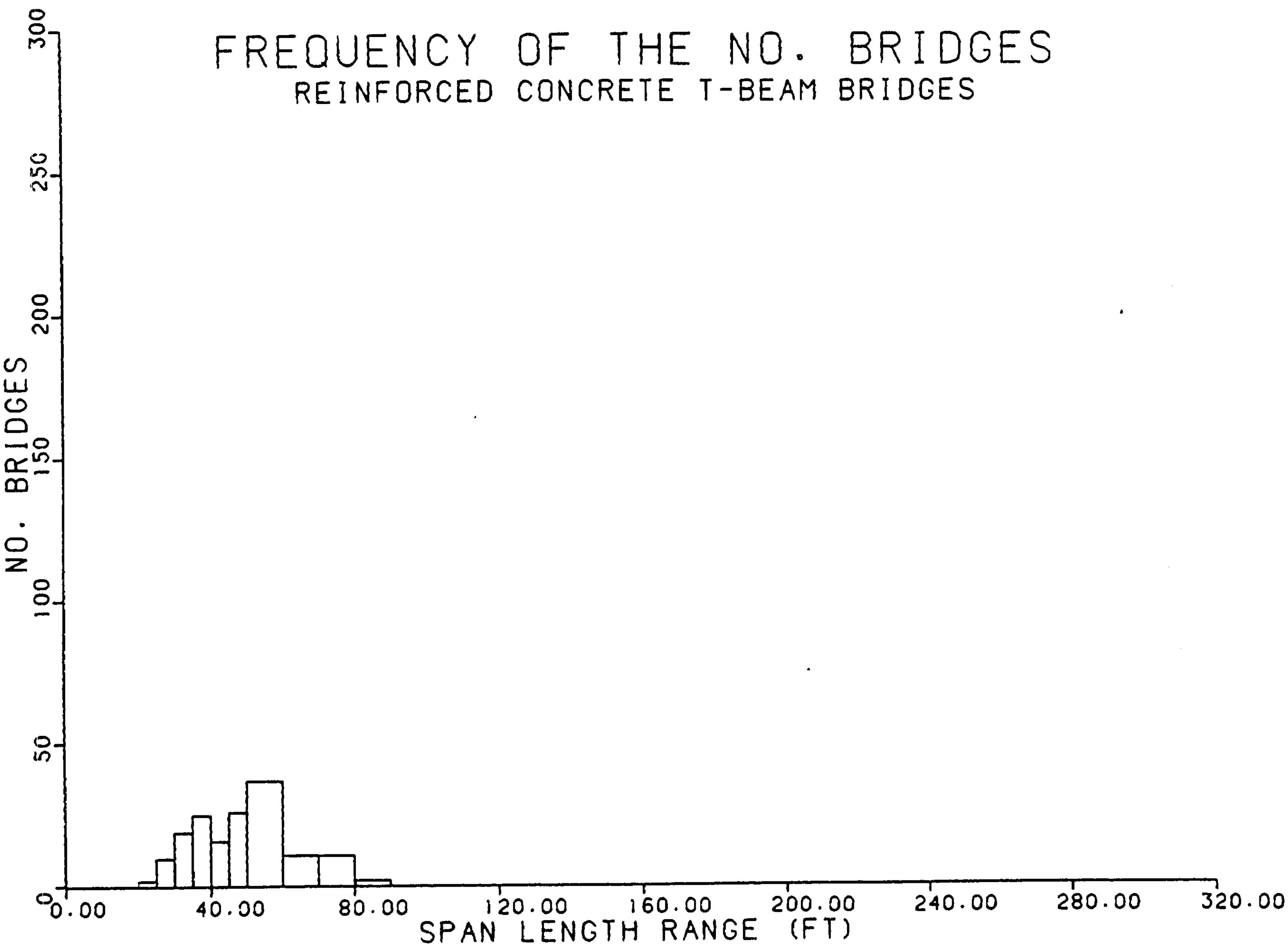

FIGURE 1-16. SPAN LENGTH RANGE - REINFORCED CONCRETE T-BEAM

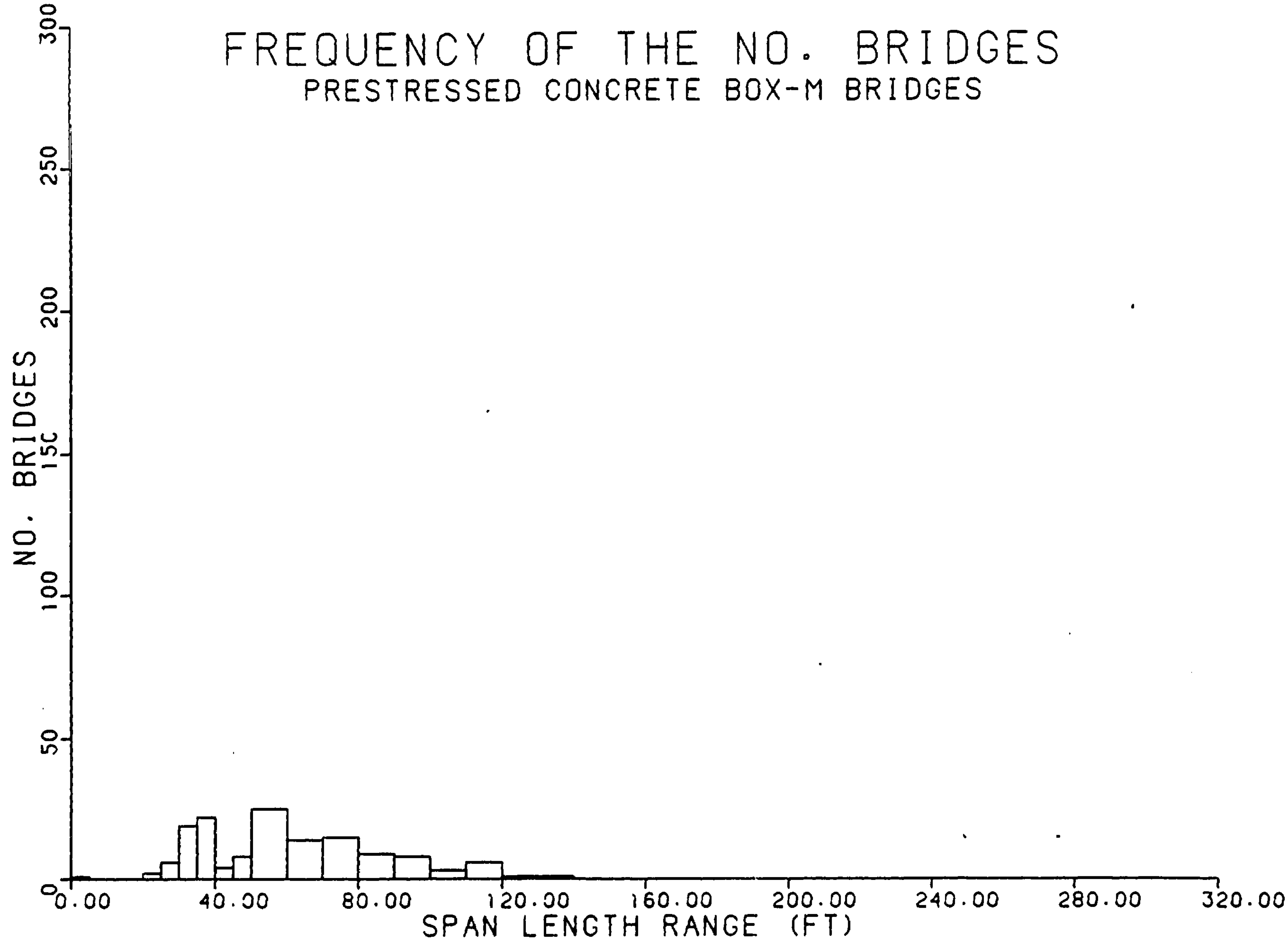

FIGURE 1-17. SPAN LENGTH RANGE - P/S CONCRETE BOX-M

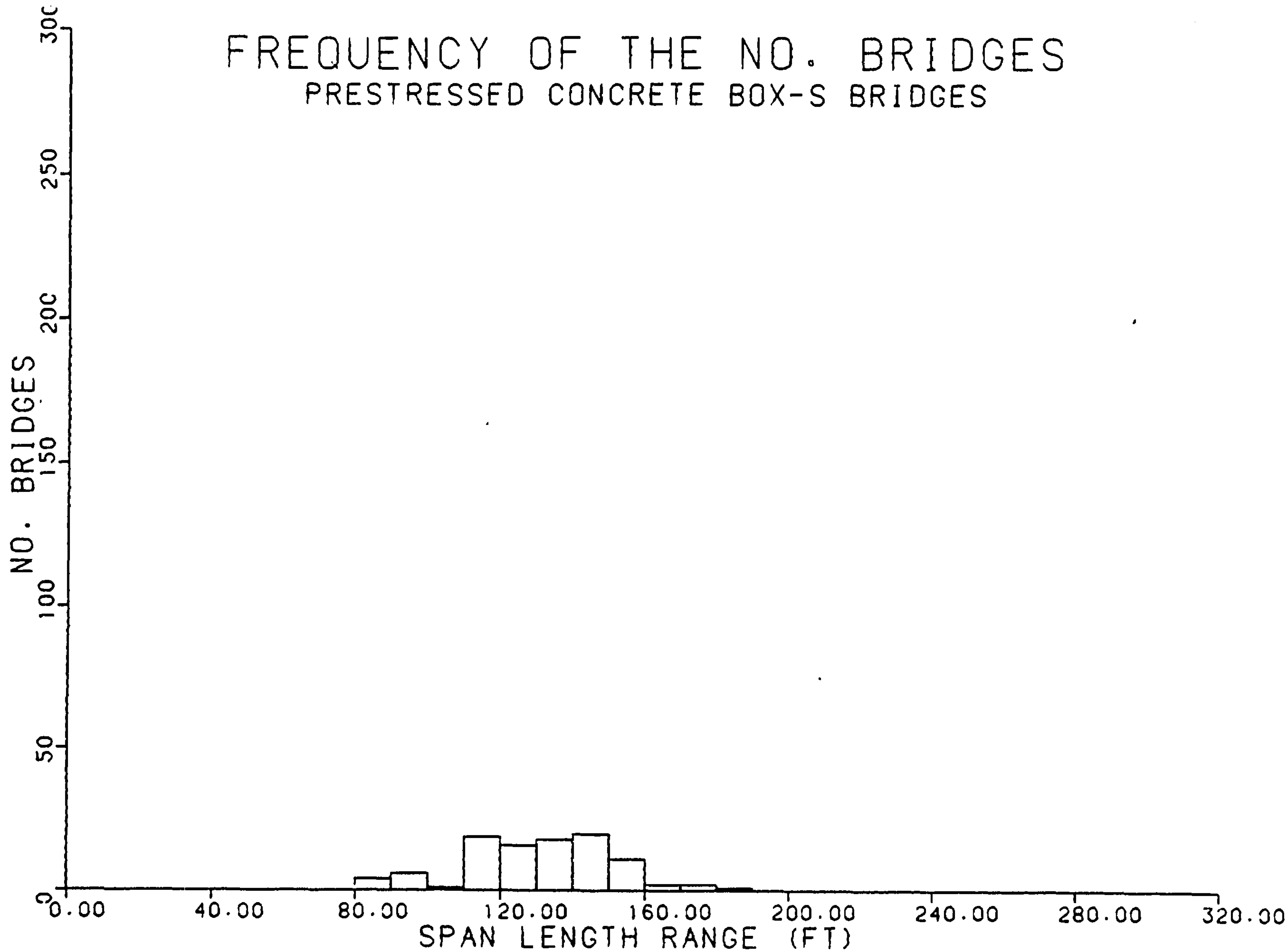

FIGURE 1-18. SPAN LENGTH RANGE - P/S CONCRETE BOX-S

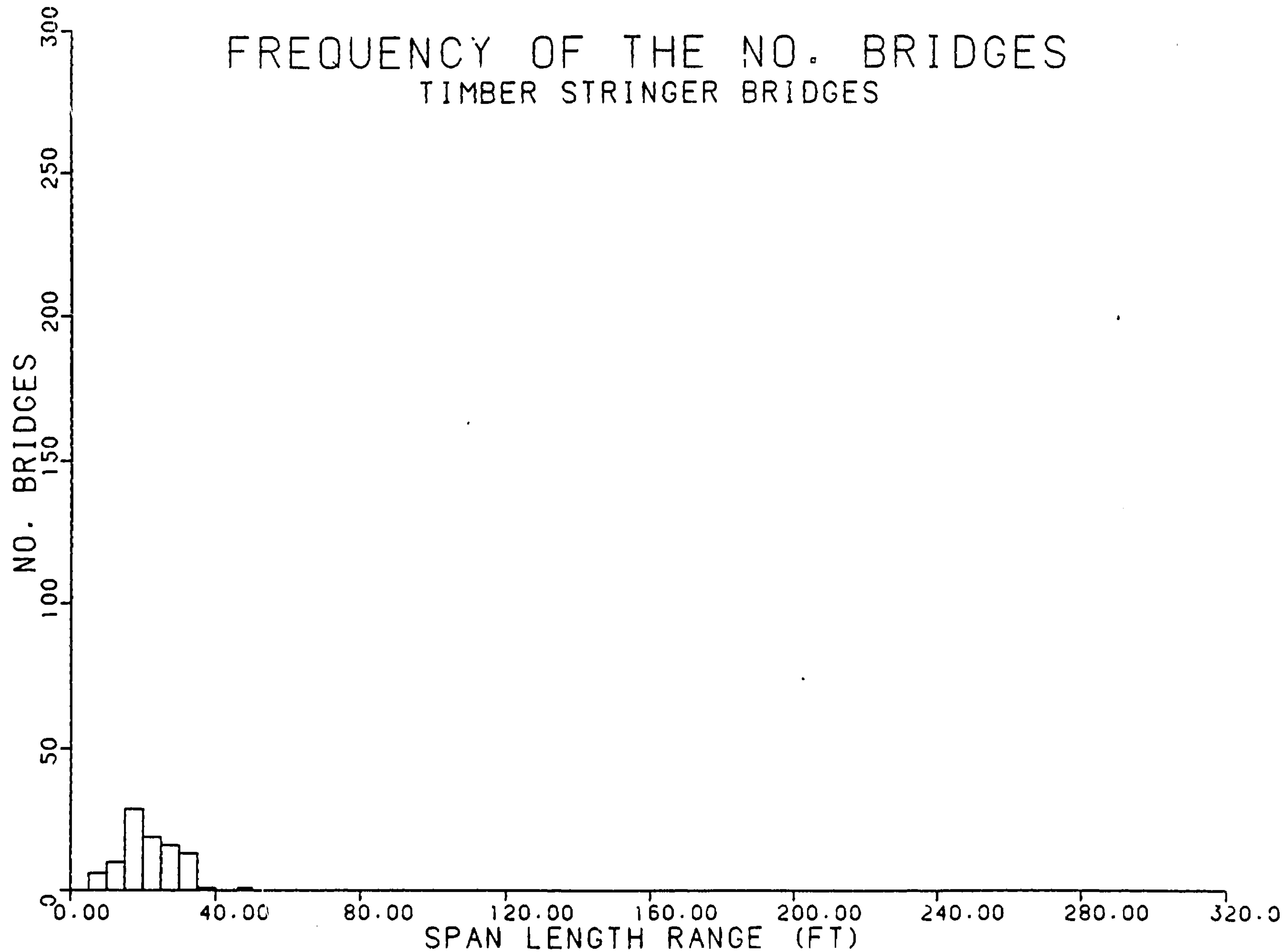

FIGURE 1-19. SPAN LENGTH RANGE - TIMBER STRINGER

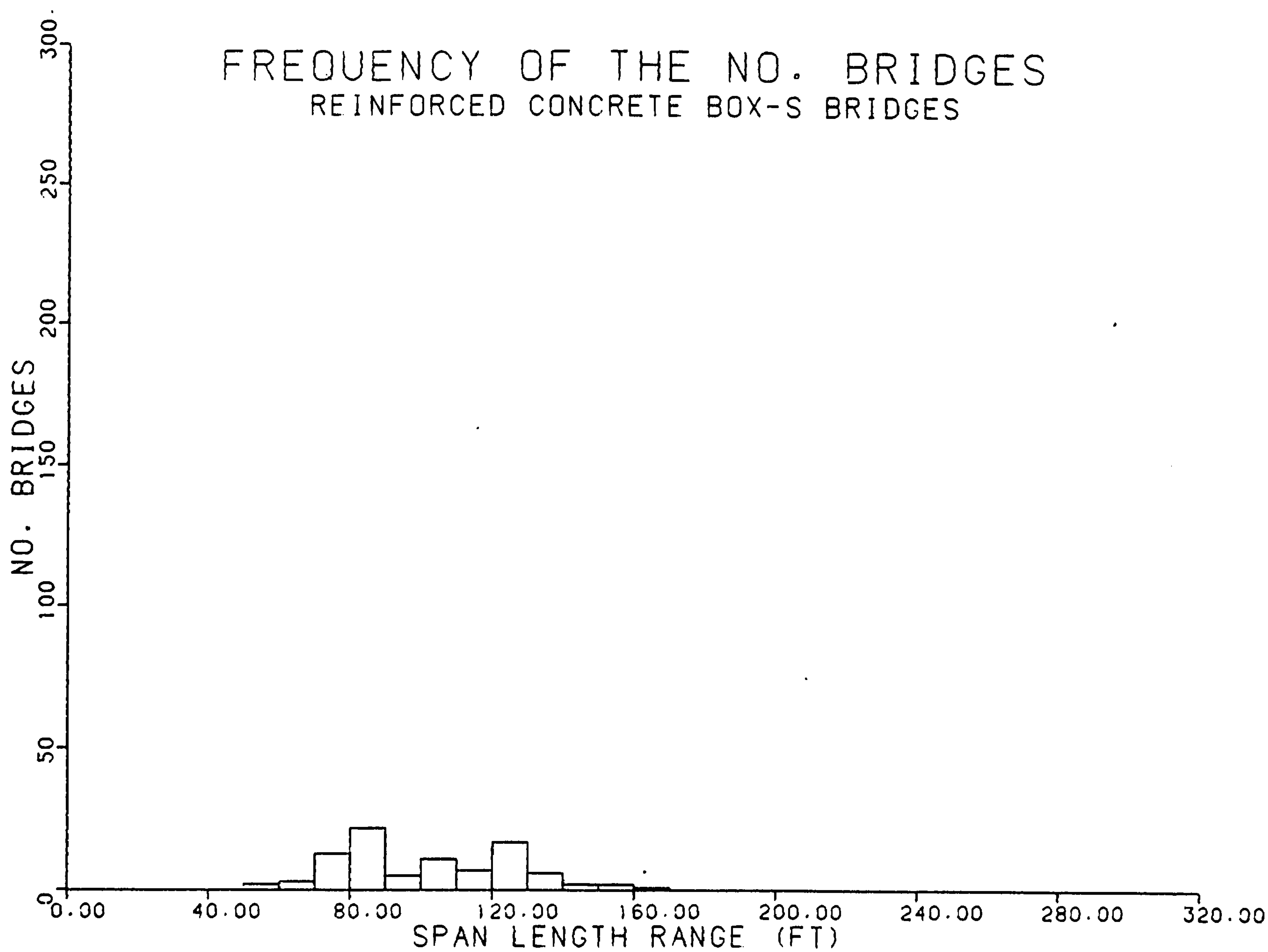

FIGURE 1-20. SPAN LENGTH RANGE - REINFORCED CONCRETE BOX-S

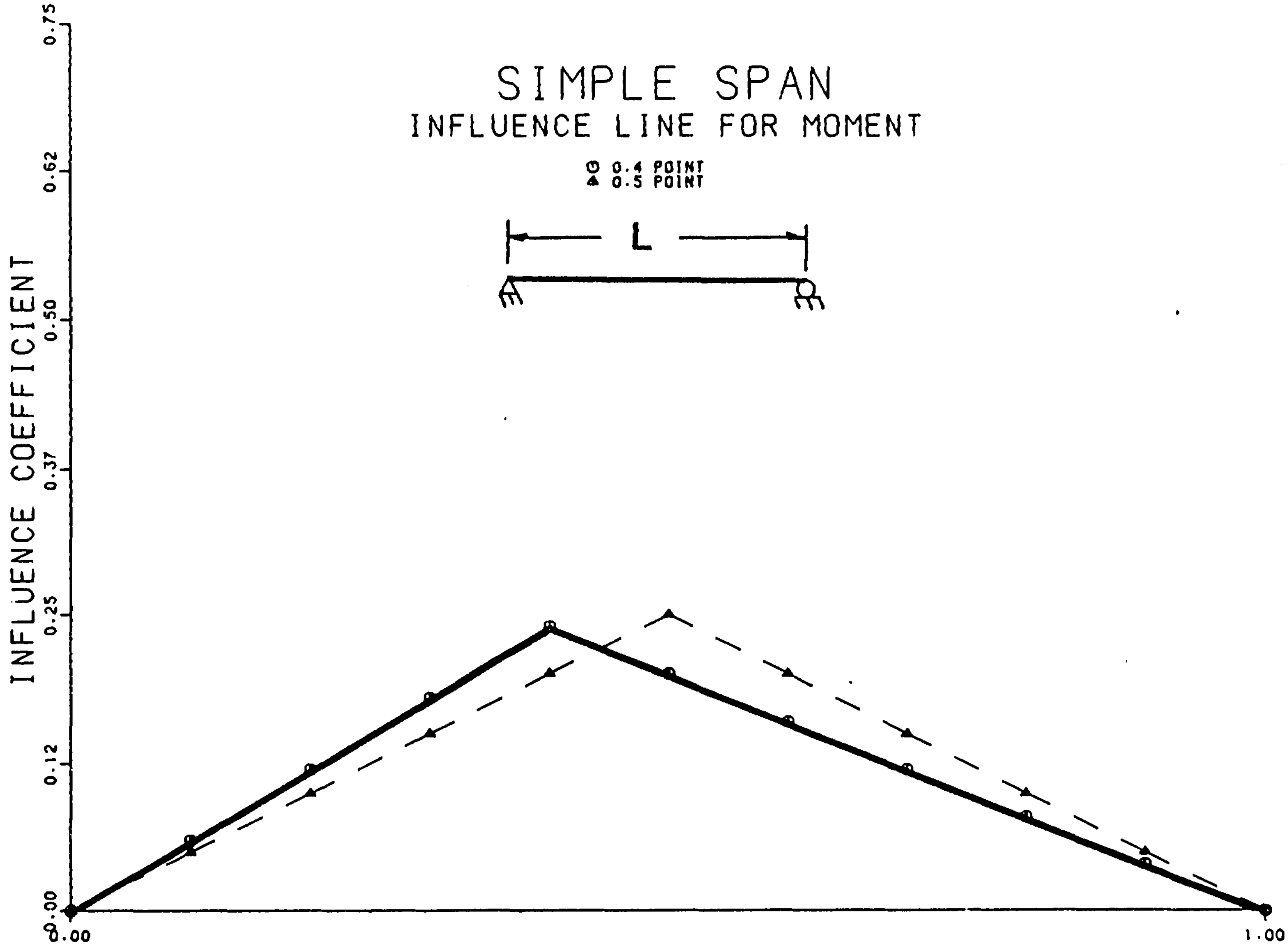

FIGURE 1-21. INFLUENCE LINE FOR A ONE-SPAN BRIDGE

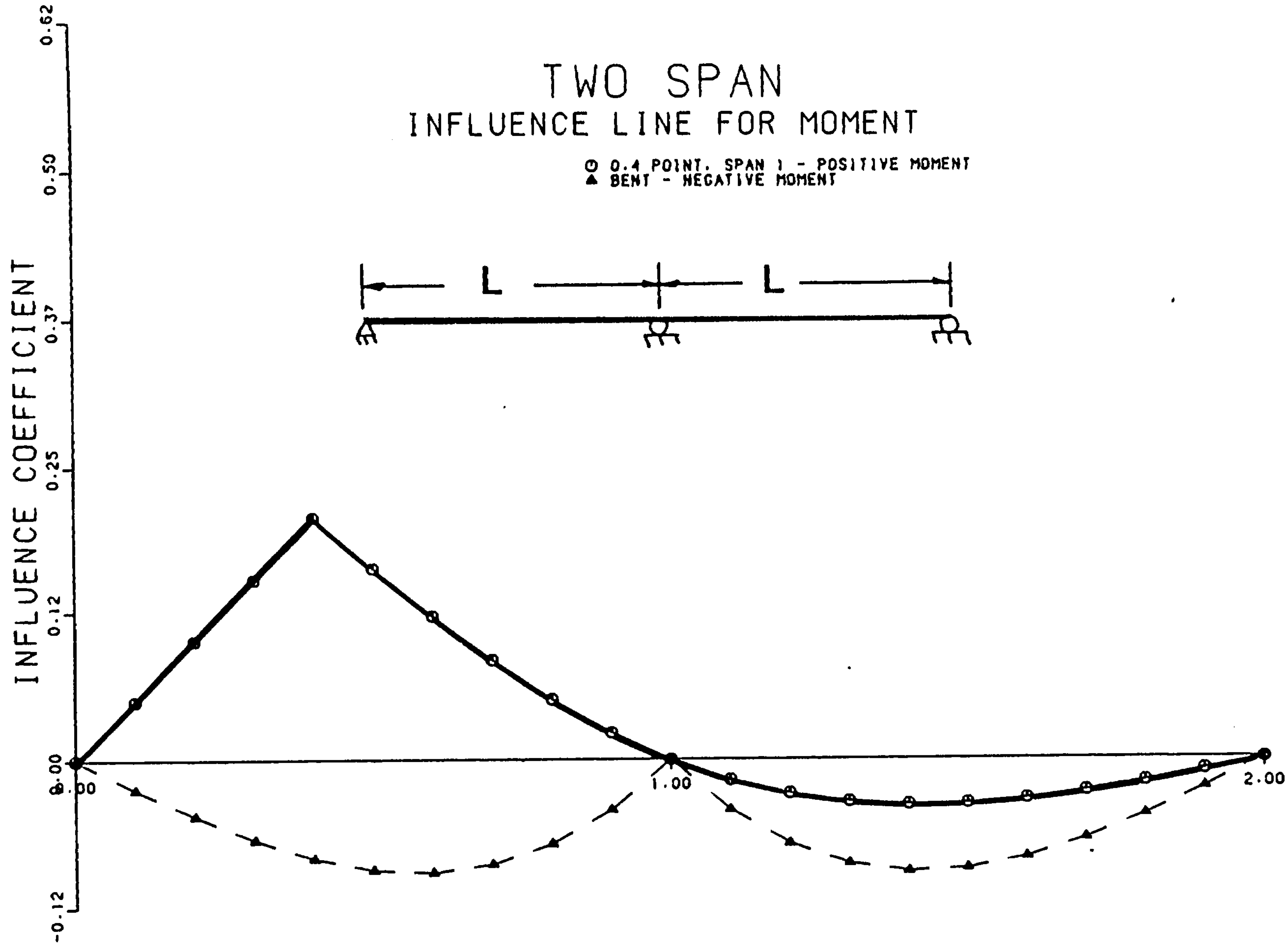

FIGURE 1-22. INFLUENCE LINE FOR A TWO-SPAN BRIDGE

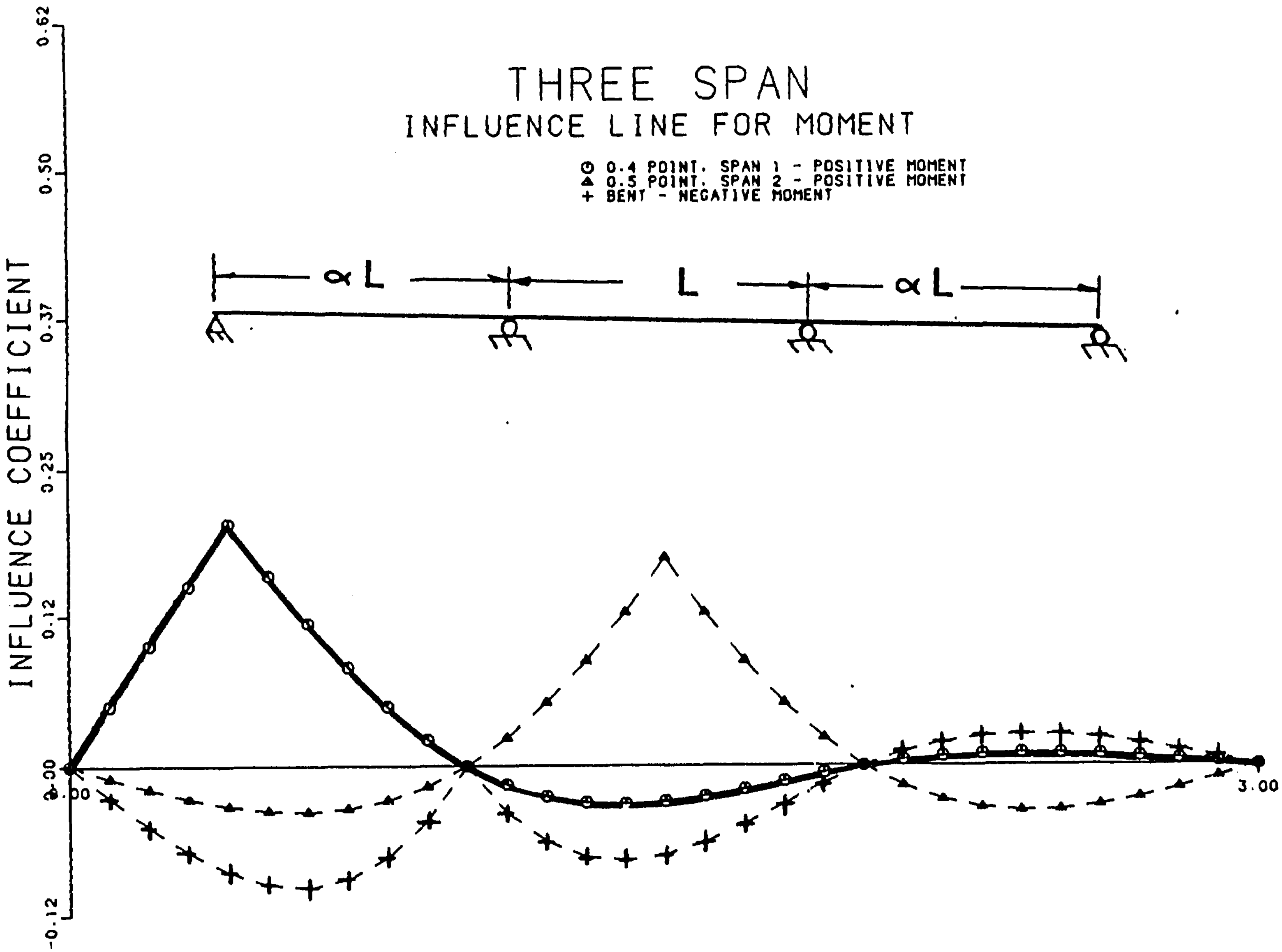

FIGURE 1-23. INFLUENCE LINE FOR A THREE-SPAN BRIDGE

TABLE 1-1. STATISTICS FROM THE NATIONAL BRIDGE INVENTORY FILE

	Total	Percent of Bridges
Bridges and Culverts	5177	---
Bridges Only	2292	---
Culverts Only	2885	---
Reinforced Concrete Slab Bridges	771	34
Steel Stringer Bridges	479	21
Prestressed Concrete Stringer Bridges	236	10
Reinforced Concrete T-Beam Bridges	159	7
Prestressed Concrete Box-M Bridges	144	6
Prestressed Concrete Box-S Bridges	100	4
Timber Stringer Bridges	95	4
Reinforced Concrete Box-S Bridges	91	4
	TOTAL	90

2.0 CASE STUDIES

2.1 Objective

Detailed case studies were conducted on twenty-five Arizona bridges that were selected as typical of those evaluated by the Level 1 procedure. The case studies were conducted to:

- Verify the methodology used in the Level 1 procedure
- Correlate the bridge plans with the data in the NBIF

2.2 Selection and Description of Candidate Bridges

Thirty bridges were selected from the State of Arizona for possible evaluation. Of those thirty bridges twenty-five were actually evaluated for the comparison of Level 1 and Level 2. Those evaluations included these bridge types:

- 6 Reinforced concrete slab bridges
- 7 Steel stringer bridges
- 3 Prestressed concrete I-girder bridges
- 3 Reinforced concrete T-beam bridges
- 2 Prestressed concrete box girder bridges
- 2 Reinforced concrete box girder bridges
- 2 Timber stringer bridges

These selections were based on the statistical data obtained from the NBIF as shown in Table 1-1. Table 2-1 to Table 2-7 for Case Study 1 to Case Study 7, respectively, show data for the structure number, year built, maximum span length, overall length, number of spans, girder spacing, bridge width and end span length. Comparisons between the actual plans and the NBIF gave these results:

1. The maximum span length compared within 3%.

2. The overall length was within 7%, except for Case Study 1-E, reinforced concrete slab, which included the approach span length in the NBIF, Case Study 4-B, a reinforced concrete T-beam, and Case Study 5-E, a voided slab.

3. The number of spans gave excellent comparison except bridge 1-E, a reinforced concrete slab, which included approach spans in the NBIF.

4. The bridge width (curb-to-curb) gave the most variation, but this data item is not currently used in the Level 1 evaluation.

5. The end span length was within 7% except bridge 1-E, which included approach spans; bridge 2-A, a steel girder, which had nonuniform span lengths; bridge 4-A and 4-B, both reinforced concrete T-beams; and 5-E, a voided slab.

6. The continuity condition of the bridges, Item 43 in the NBIF, compared well, except Case Studies 3-B and 3-C, prestressed concrete I-girder, which was continuous for live load although the NBIF coded the span as simple.

These results indicate that the NBIF compares well with the general bridge plans and that it will be applicable to the Level 1 procedure for "typical" bridges. Bridges that have approach spans, hinges, varying girder spacings from span-to-span, monolithic columns, or simple spans where live load is continuous may give erroneous overload capacity ratings for the Level 1 procedure.

2.3 Rating Procedures of Arizona

There are 5,177 bridges in the State of Arizona that have been inventoried for the NBIF. Most of the bridges in Arizona have been load rated at both inventory and operating levels using the AASHTO working stress method except prestressed bridges where ultimate strength is used. The method of rating is accomplished according to procedures described in the American Association of State Highway and Transportation Officials (AASHTO) Manual for Maintenance and Inspection of Bridges (1).

2.4 Results Comparing Level 1 to Level 2

Six representative trucks that are "typical" Arizona overload vehicles were used in the evaluation comparison as shown in Figure 2-1. Trucks designated as B, G, and K were rated on all the bridge types. The additional trucks designated as E, L, and M were used for the evaluation of reinforced concrete slab bridges.

Level 1 analysis used the OVERLOAD program to evaluate the overload capacity ratings. A one-span, two-span, and three-span influence configuration was used in the analysis so that comparisons could be made for continuity. For reinforced concrete bridges the Special Level 2 procedure was used.. Typical standard slab plan curves which were incorporated into the OVERLOAD program are shown in Figure 2-2.

Level 2 analysis used the BDS program (14) to evaluate the bridges. Briefly, BDS uses a plane frame model to analyze or design reinforced and prestressed concrete bridges for dead loads and live load configurations. The Hardy-Cross method of moment distribution is used to solve the simultaneous equations. The working stress method of design was used to calculate the moment capacities.

2.4.1 Inventory and Operating Ratings

Plots of Level 2 versus the NBIF rating factor are shown in Figures 2-3 and 2-4 for inventory and operating rating, respectively. The solid diagonal line is the hypothetical correlation line between Level 1 and Level 2. The inventory rating gives excellent correlation except for administratively-rated bridges, while the operating rating is less reliable. Because the operating rating in the NBIF is more likely to deviate from the true value, the OVERLOAD program allows the user to overwrite the NBIF operating rating. These plots indicate that the bridge engineer should check the accuracy of the operating rating as coded in the NBIF when making conclusions with regards to the overload capacity rating.

2.4.2 Overload Ratings

This section will present the results for a one-span or simple span, two-span, and three-span influence line or continuity comparison. All the bridges in each case study with the corresponding truck loading will be plotted on one figure.

The overload rating capacity for the Level 1 procedure used the Level 2 operating rating for the rating vehicle. Figure 2-5 to Figure 2-11 show the comparison between Level 1 and Level 2 for Case Study 1 to Case Study 7, respectively, for a one-span continuity configuration. The solid diagonal line is the hypothetical correlation line between Level 1 and Level 2. The results of the correlation coefficient, percent maximum, percent minimum, and percent average are shown in Table 2-8. The correlation coefficient indicates the degree of linear relationship between two variables which are in this case Level 1 and Level 2 overload rating capacities. A value equal to +1 implies a perfect linear relationship with a positive slope, while a value equal to -1 results from a perfect linear relationship with a negative slope. This implies that sample estimates close to unity imply a good correlation or linear association between two variables while a value near zero indicate little or no correlation. The dashed diagonal line on the plots is the least square fit estimate for the sample points. Dashed lines situated above the solid line would indicate Level 1 is conservative, while dashed lines below would indicate unconservative results for Level 1. From Table 2-8 the results indicate that there is excellent linear relationships for Case Studies 1, 5, 6 and 7. The percent maximum indicates the upper bound or unconservativeness of the Level 1 procedure, while the percent minimum indicates a lower bound or conservativeness of the Level 1 procedure. The percent average indicates how the sample points behave on an average or mean range. The results from Table 2-8 indicate the percent maximum, percent minimum, and percent average for Case Studies 5, 6, and 7 are within 10%. For Case Studies 2 to 4 plotted in Figure 2-6 to Figure 2-8, respectively, the dashed line indicates unconservative results for Level 1.

Figure 2-12 to Figure 2-17 show the comparison between Level 1 and Level 2 for Case Study 1 to Case Study 6, respectively, for a two-span continuity configuration. Case Study 7, timber stringer bridges, does not apply for this situation because the spans were simple. The results from the plot are tabulated in Table 2-9. The correlation coefficient indicates excellent comparison for Case Studies 1, 2, 3, 5 and 6. Case Study 4 contained a three-span reinforced concrete T-beam with monolithic columns. Unfortunately, Level 1 cannot capture this effect, but the results are conservative. The percent average indicates excellent correlation for Case Studies 2, 3, 5 and 6. Case Study 1, reinforced concrete slab bridges, did not improve because Level 1 is predicting that negative moment controls while Level 2 gives positive moment controlling. Unfortunately, Level 1 assumes the cross section to be uniform across the span, but continuous slab bridges are haunched at the bents to provide greater moment and shear capacity.

Figure 2-18 to Figure 2-22 show the comparison between Level 1 and Level 2 for Case Study 1 to Case Study 4, respectively, for a three-span continuity configuration. The other case studies did not contain a three or greater span configuration. The results from the plot are tabulated in Table 2-10. The results indicate excellent comparison for all the cases except Case Study 1 for a Level 1 procedure. The Special Level 2 procedure for reinforced concrete slabs show that the results are within 7%.

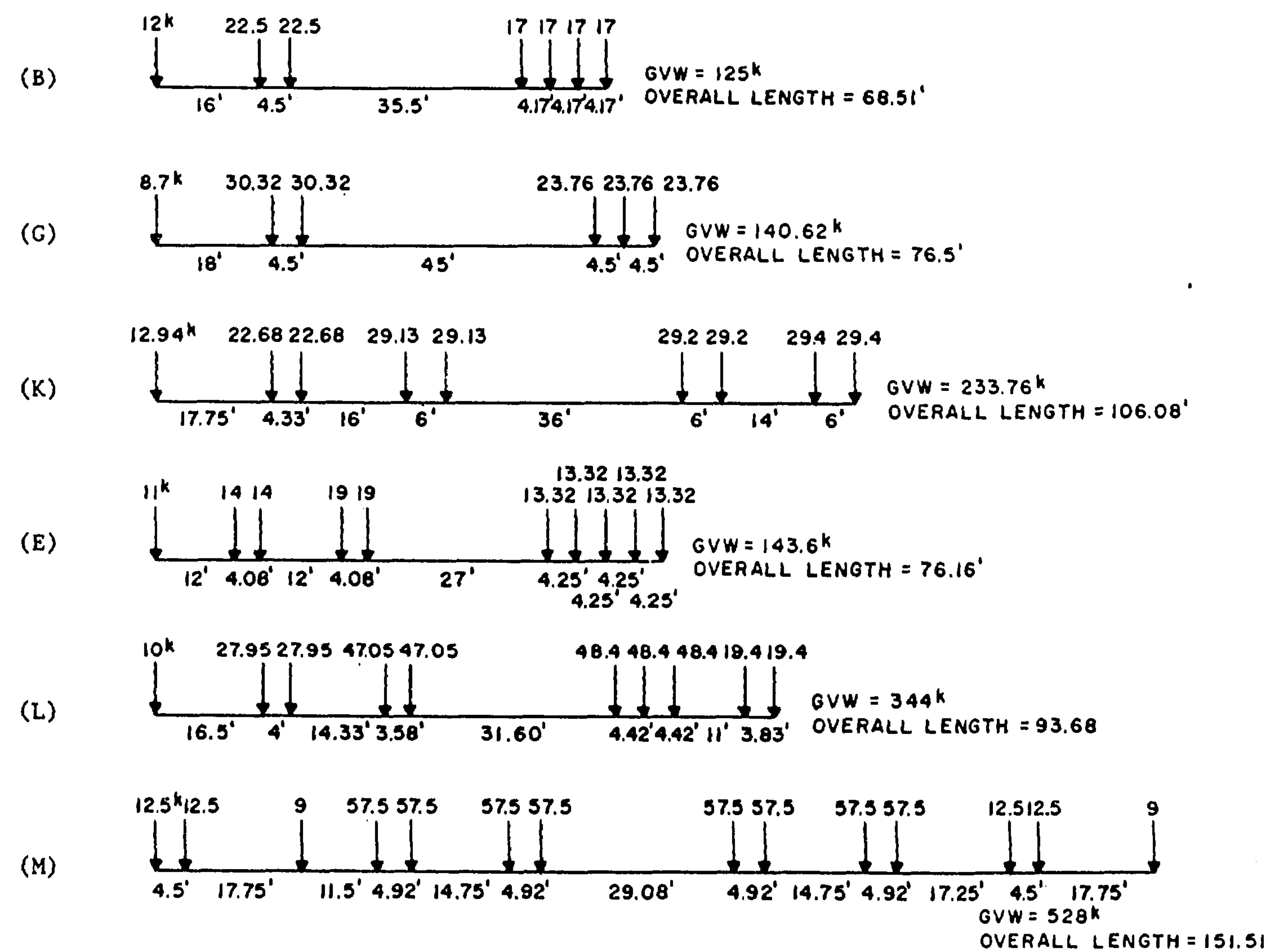

FIGURE 2-1. TRUCK CONFIGURATIONS USED IN THE CASE STUDIES

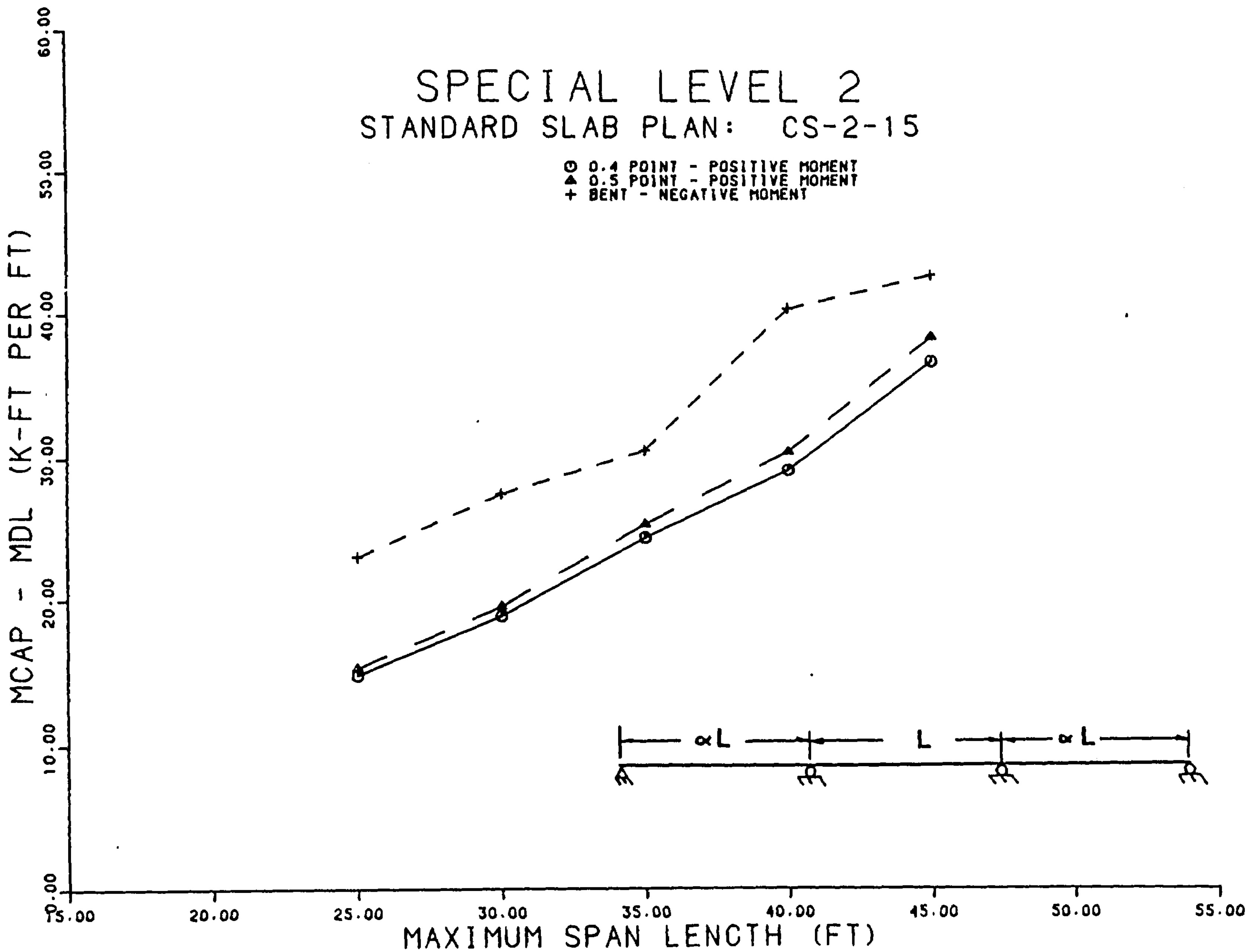

FIGURE 2-2. TYPICAL STANDARD SLAB PLAN CURVE USED IN SPECIAL LEVEL 2 PROCEDURE

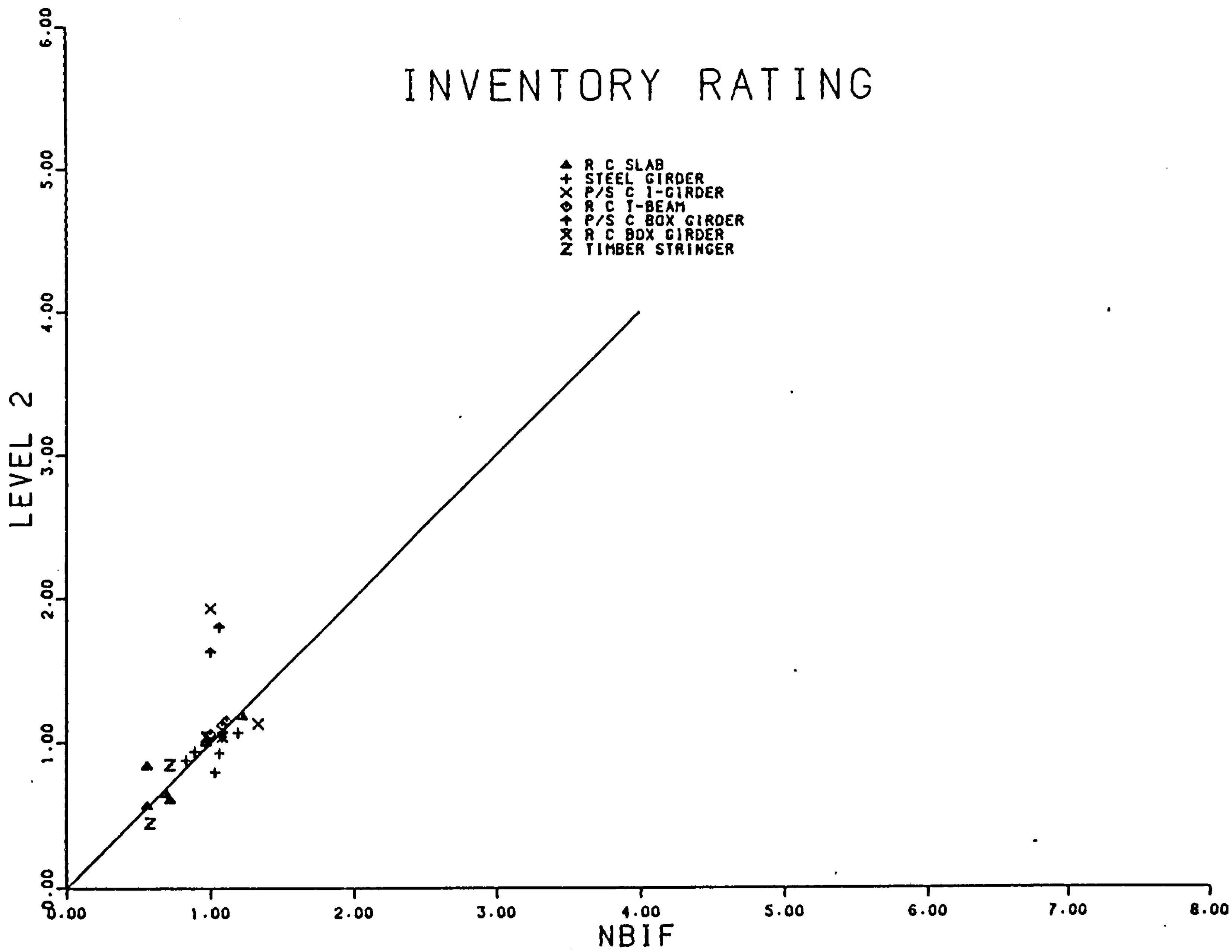

FIGURE 2-3. LEVEL 2 VERSUS NBIF - INVENTORY RATING

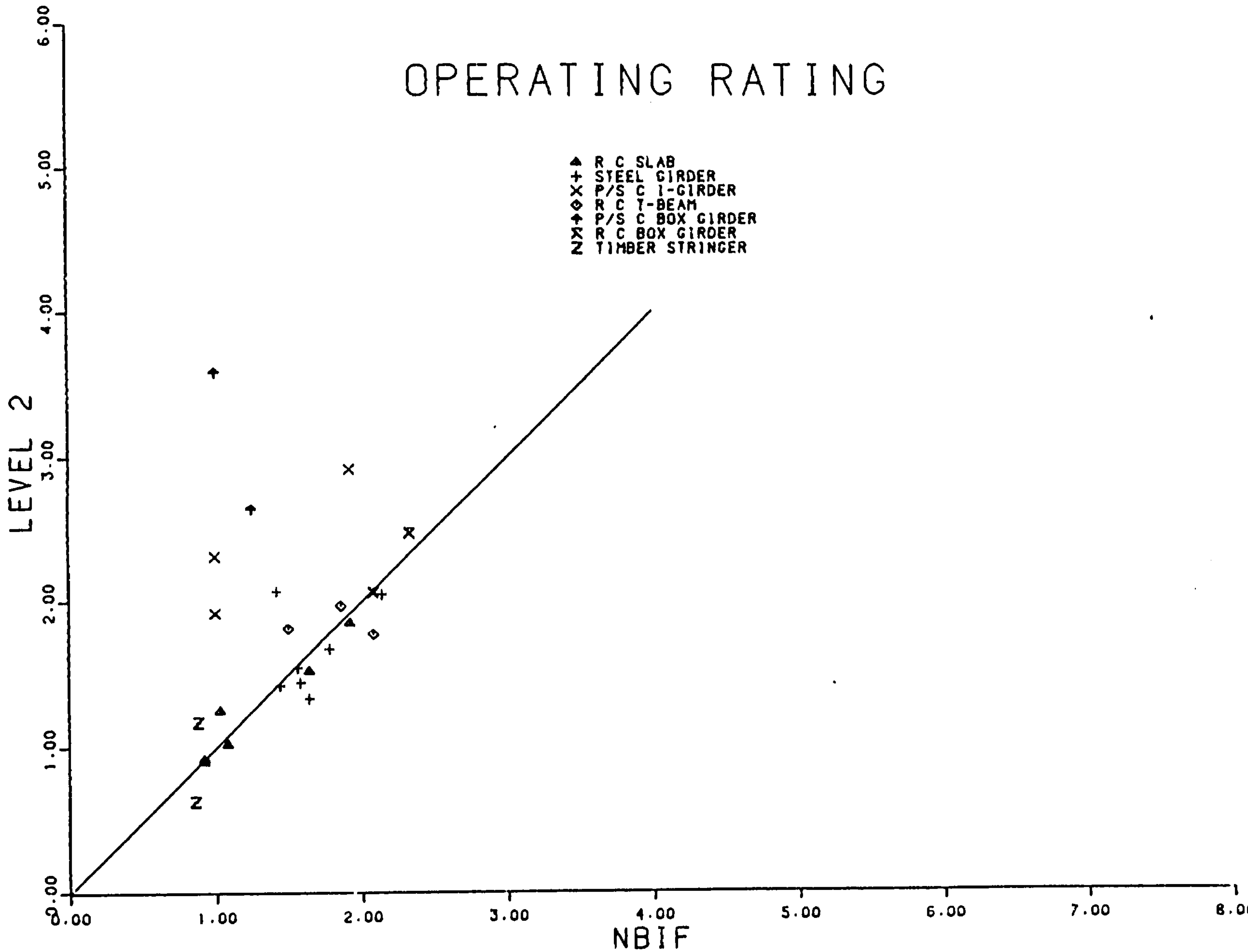

FIGURE 2-4. LEVEL 2 VERSUS NBIF - OPERATING RATING

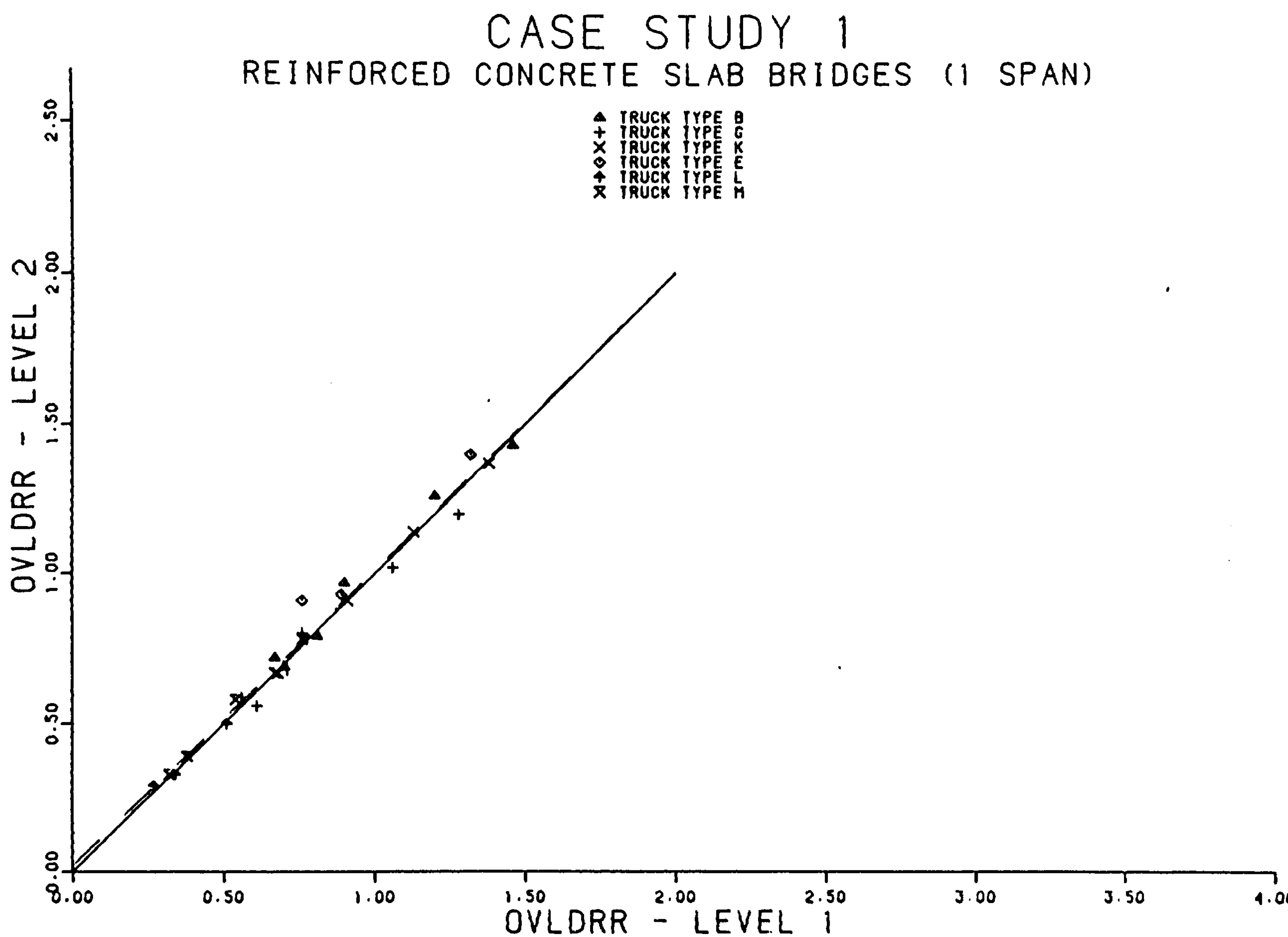

FIGURE 2-5. CASE STUDY 1 (1 SPAN)

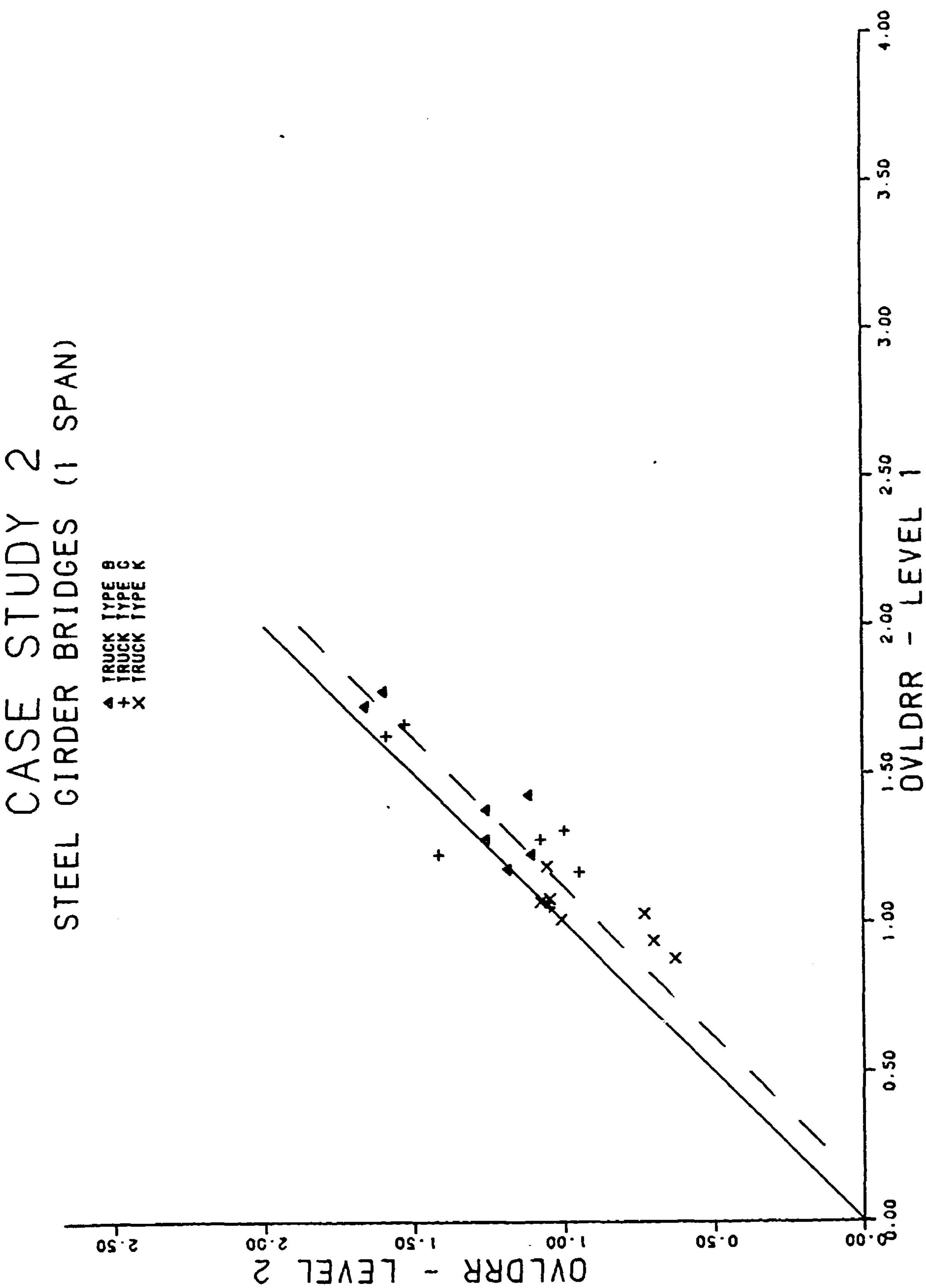

FIGURE 2-6. CASE STUDY 2 (1 SPAN)

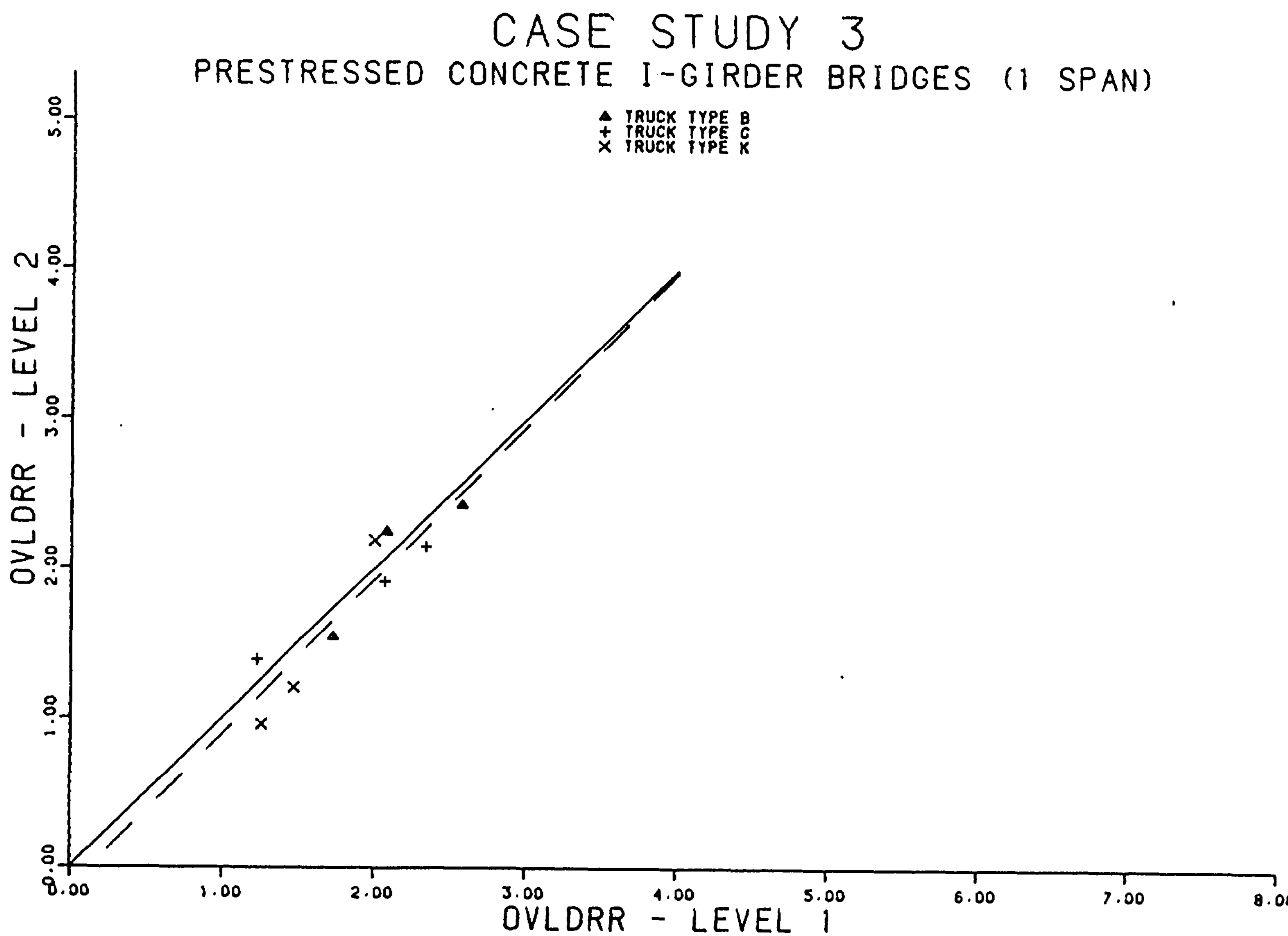

FIGURE 2-7. CASE STUDY 3 (1 SPAN)

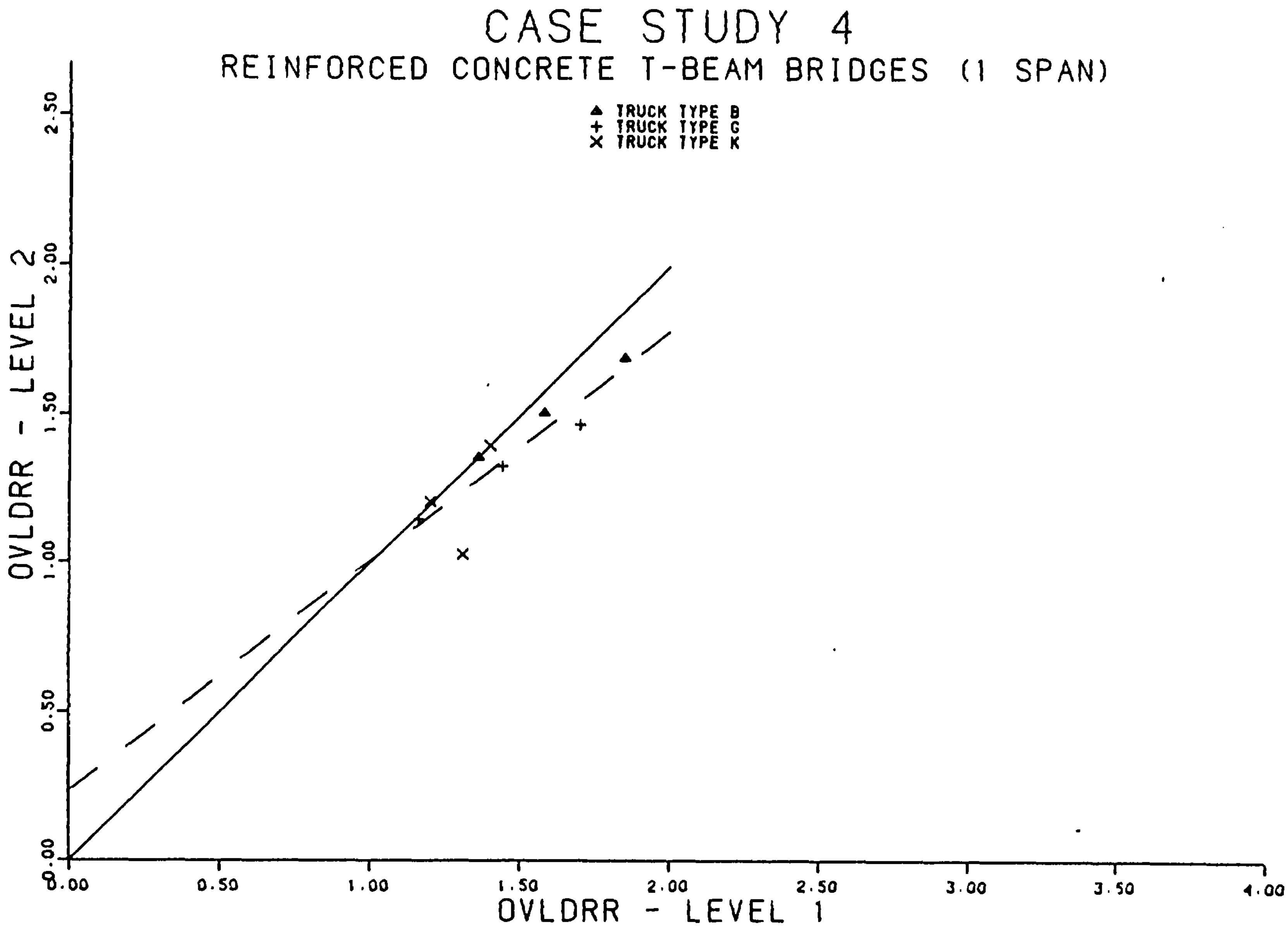

FIGURE 2-8. CASE STUDY 4 (1 SPAN)

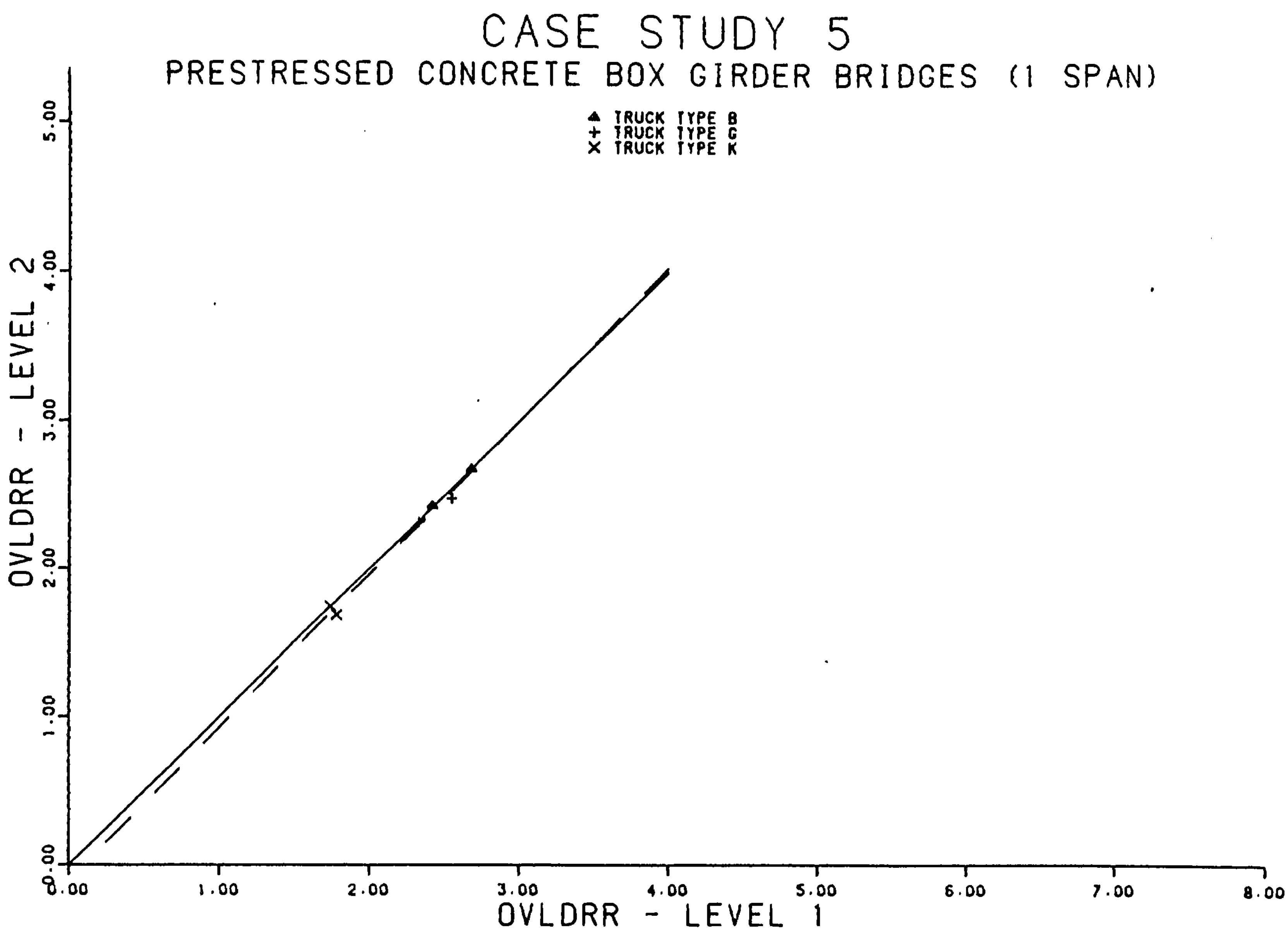

FIGURE 2-9. CASE STUDY 5 (1 SPAN)

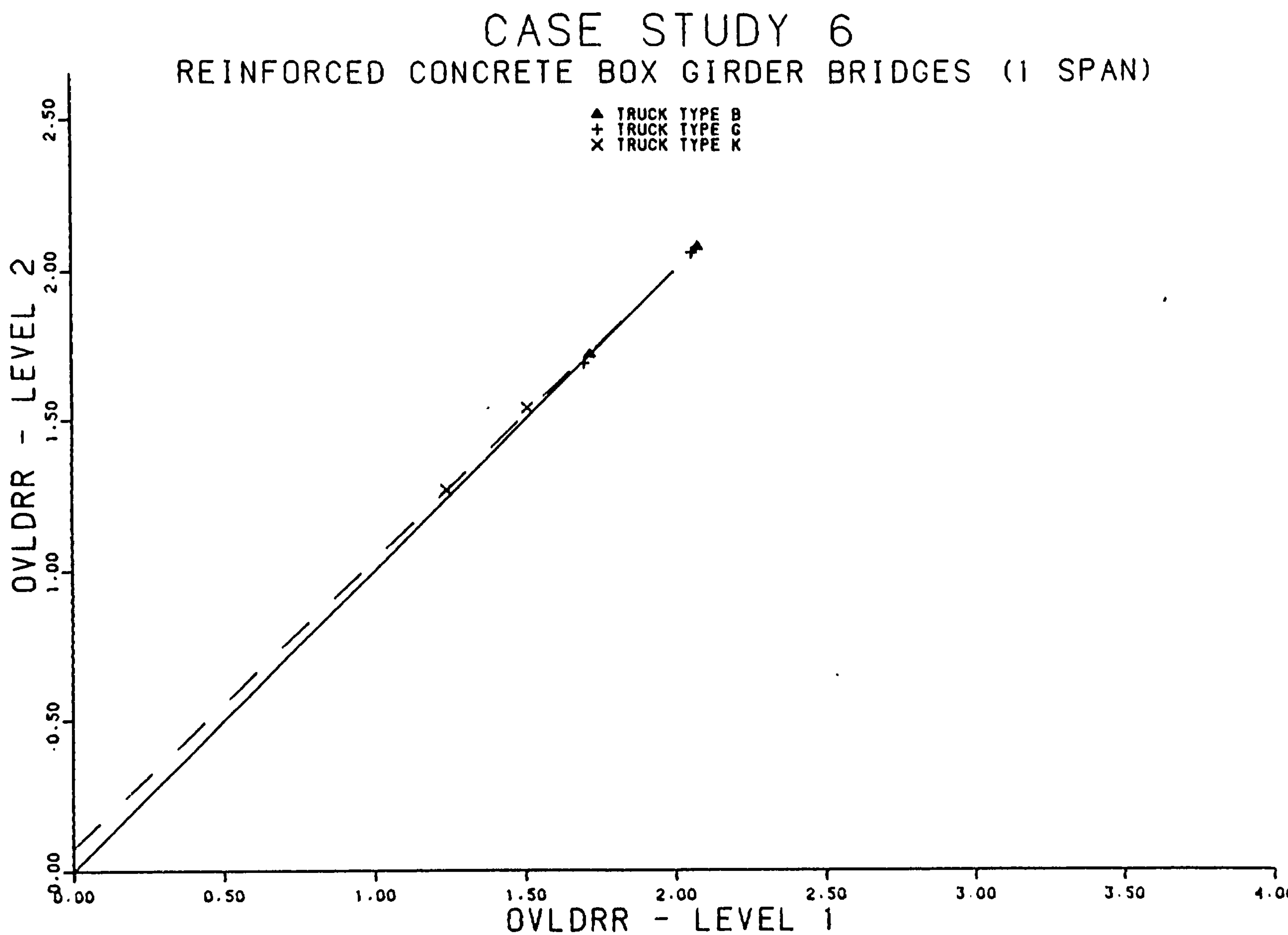

FIGURE 2-10. CASE STUDY 6 (1 SPAN)

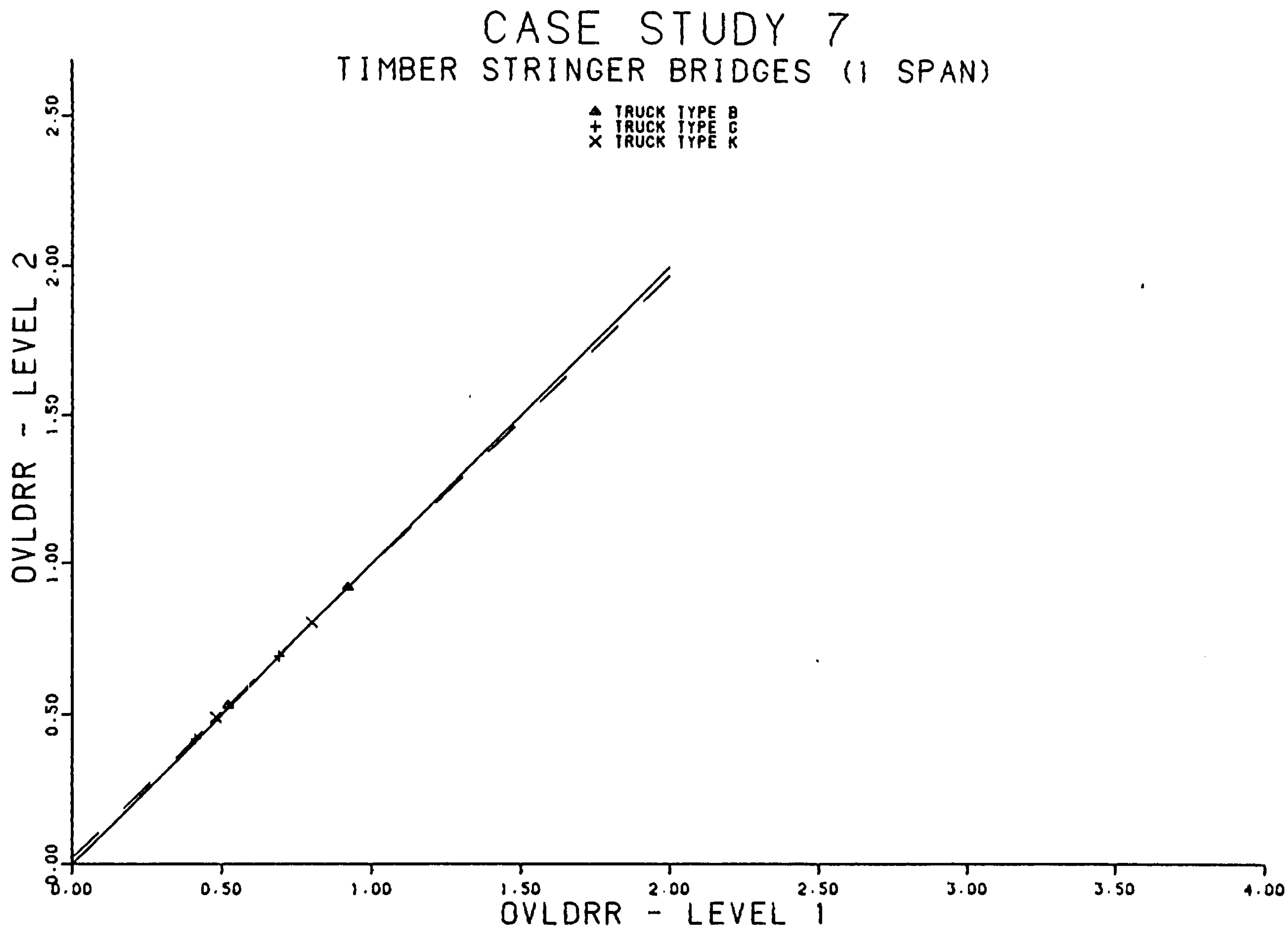

FIGURE 2-11. CASE STUDY 7 (1 SPAN)

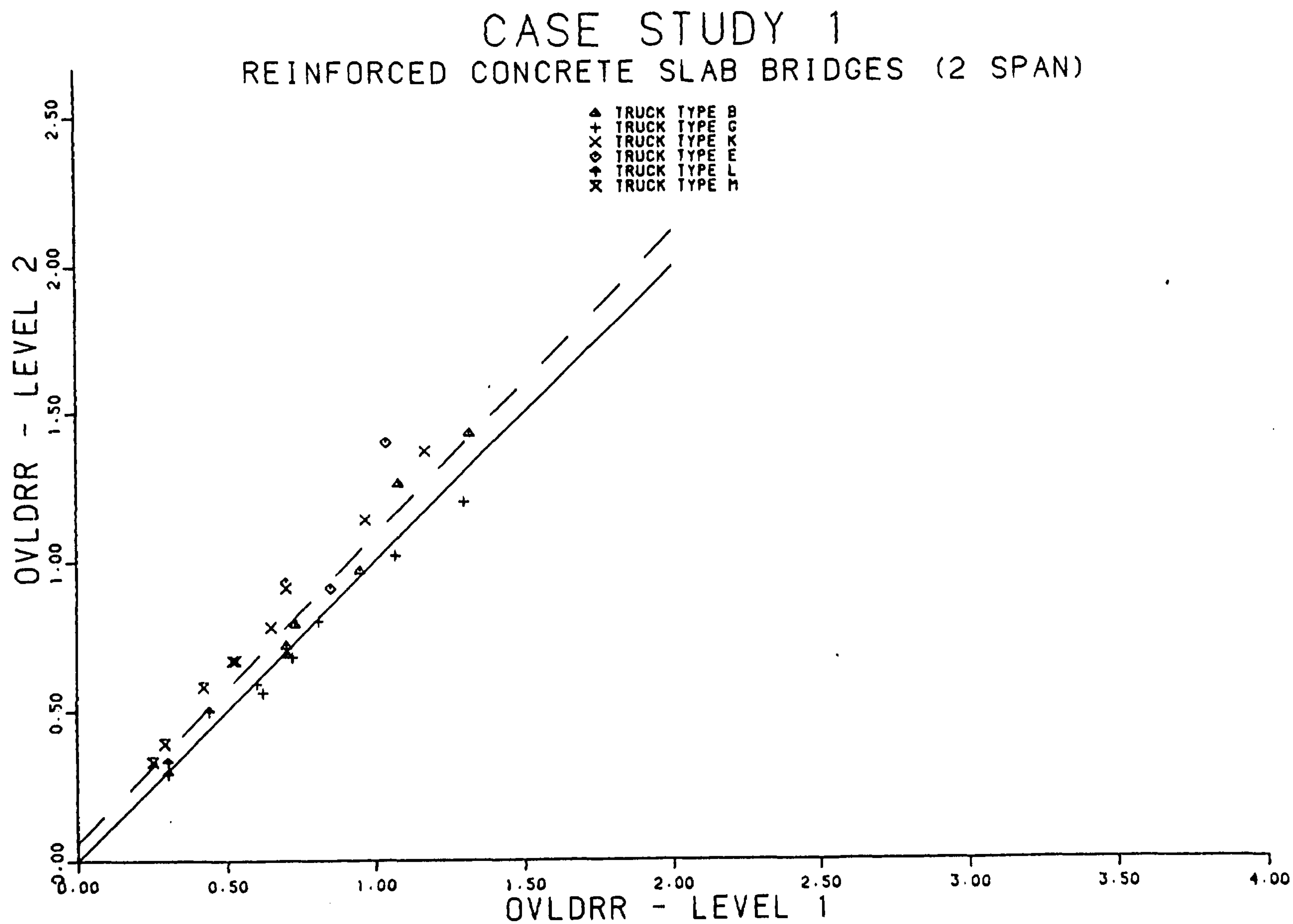

FIGURE 2-12. CASE STUDY 1 (2 SPAN)

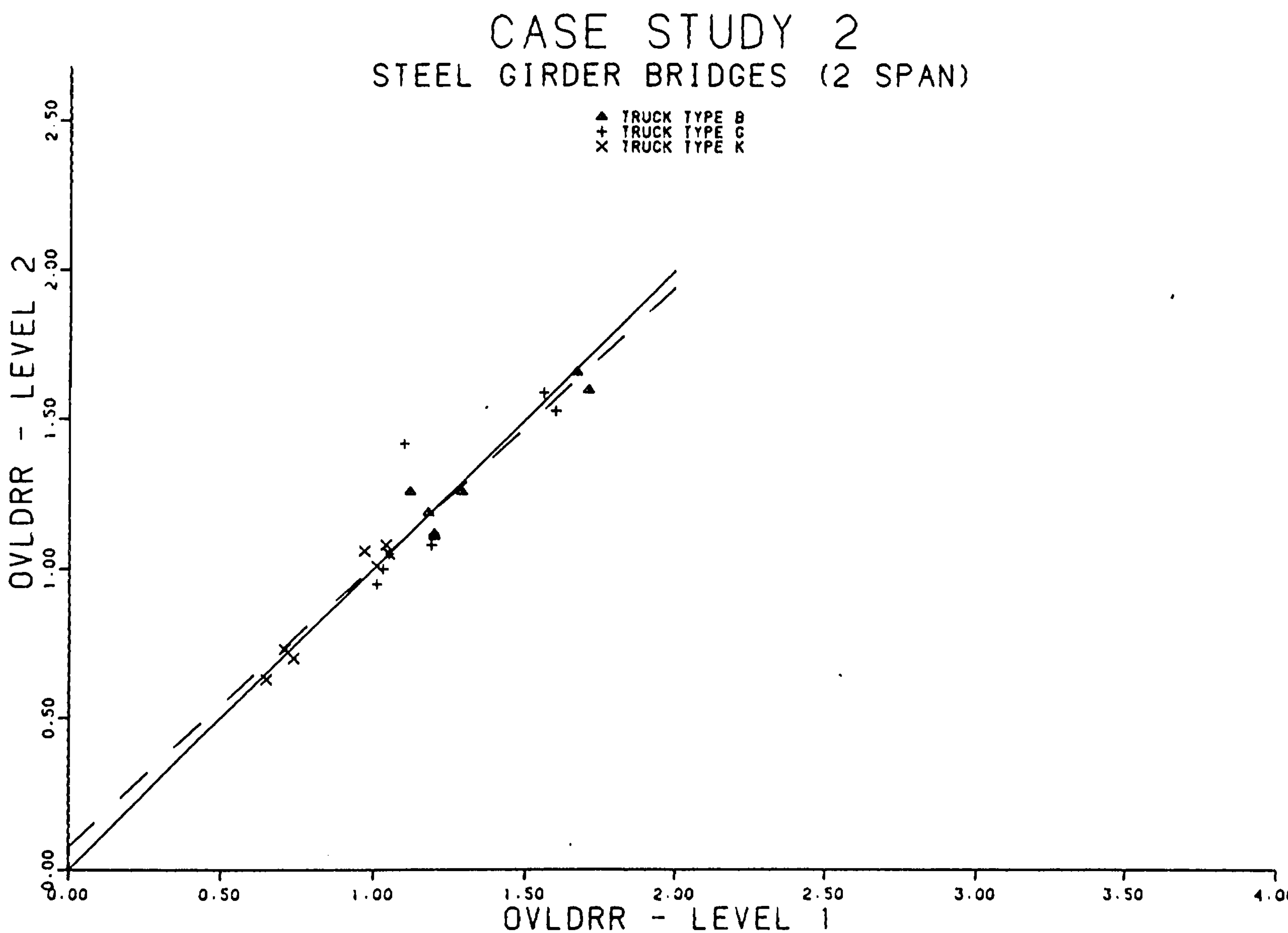

FIGURE 2-13. CASE STUDY 2 (2 SPAN)

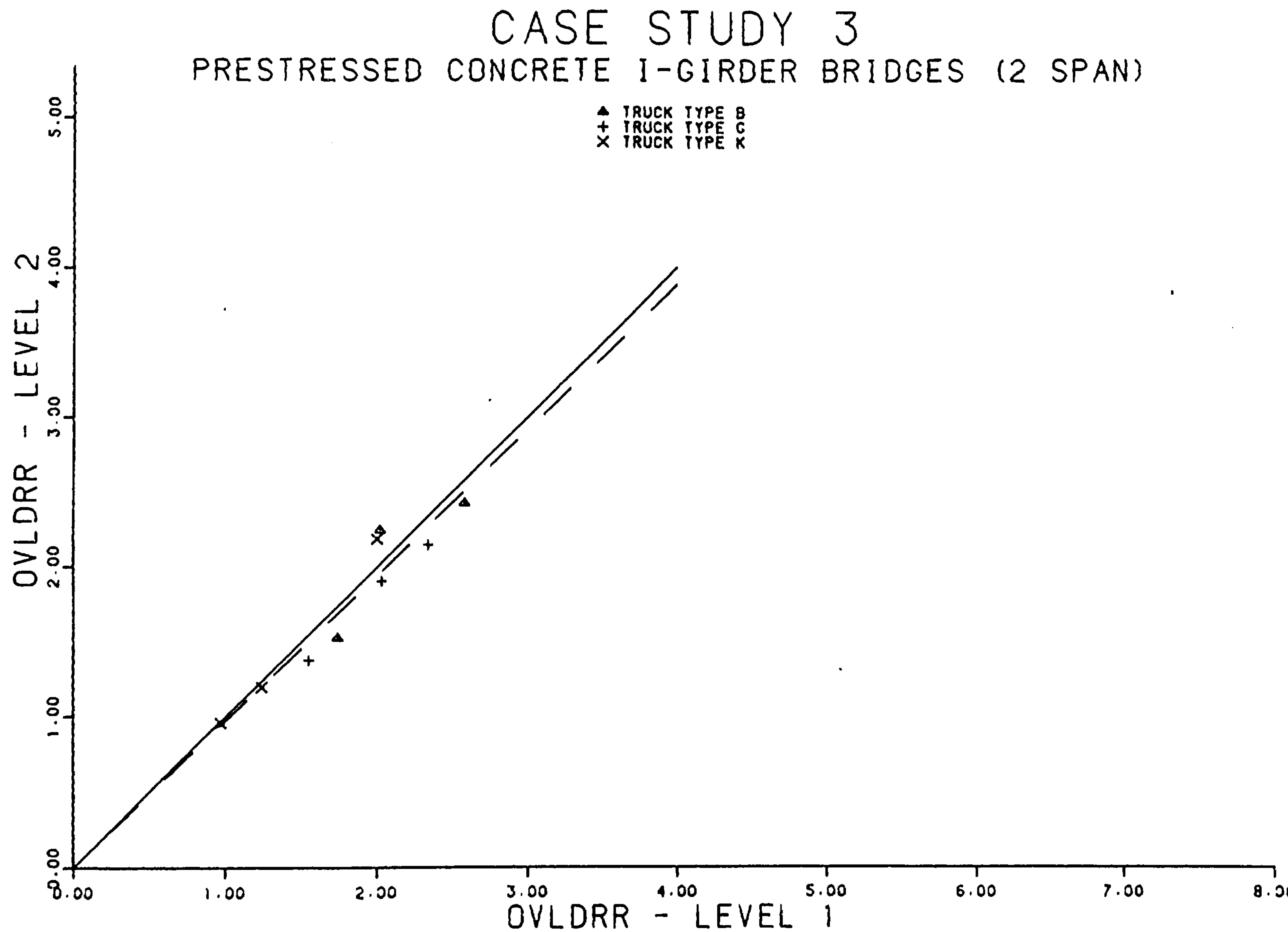

FIGURE 2-14. CASE STUDY 3 (2 SPAN)

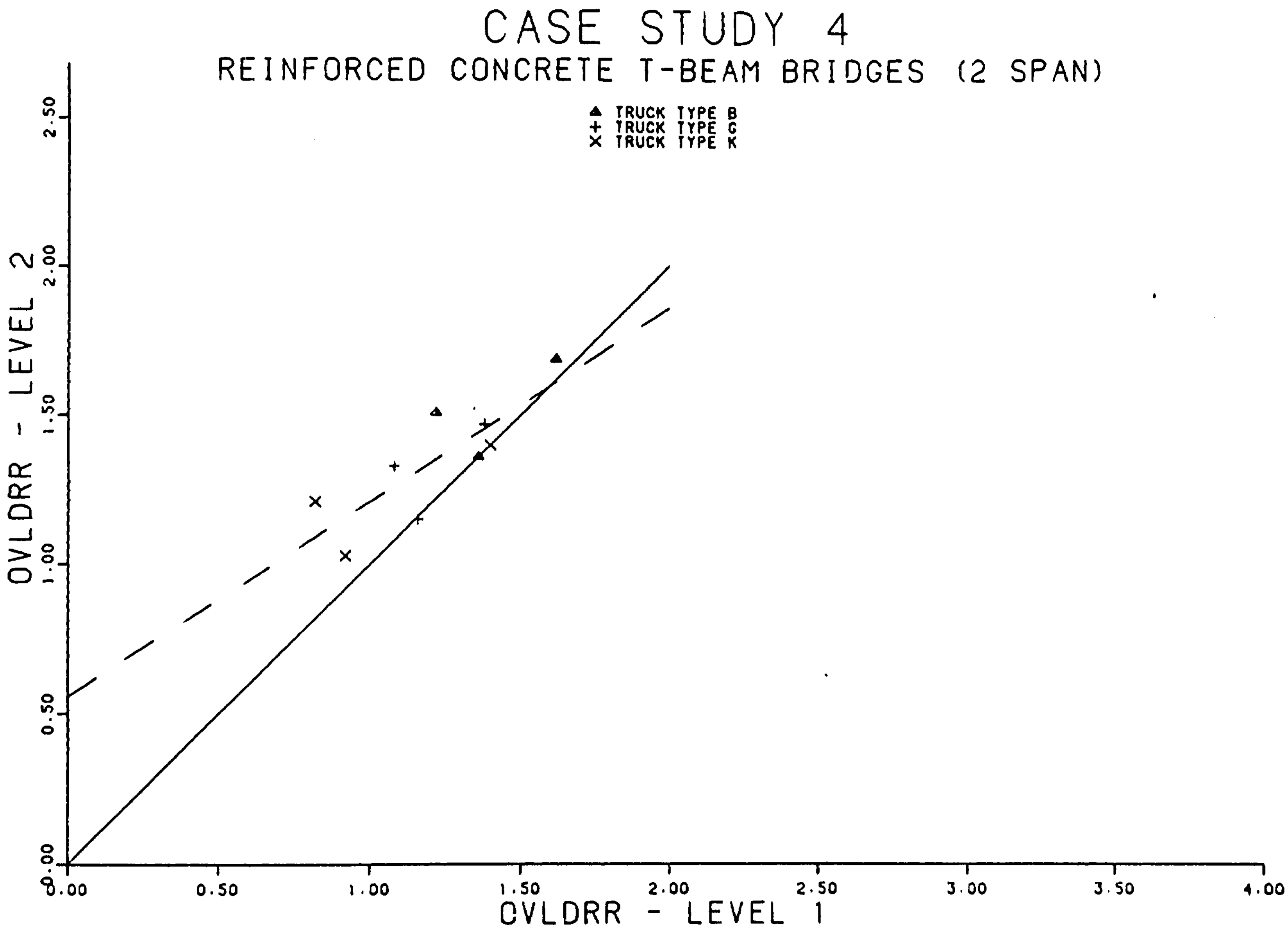

FIGURE 2-15. CASE STUDY 4 (2 SPAN)

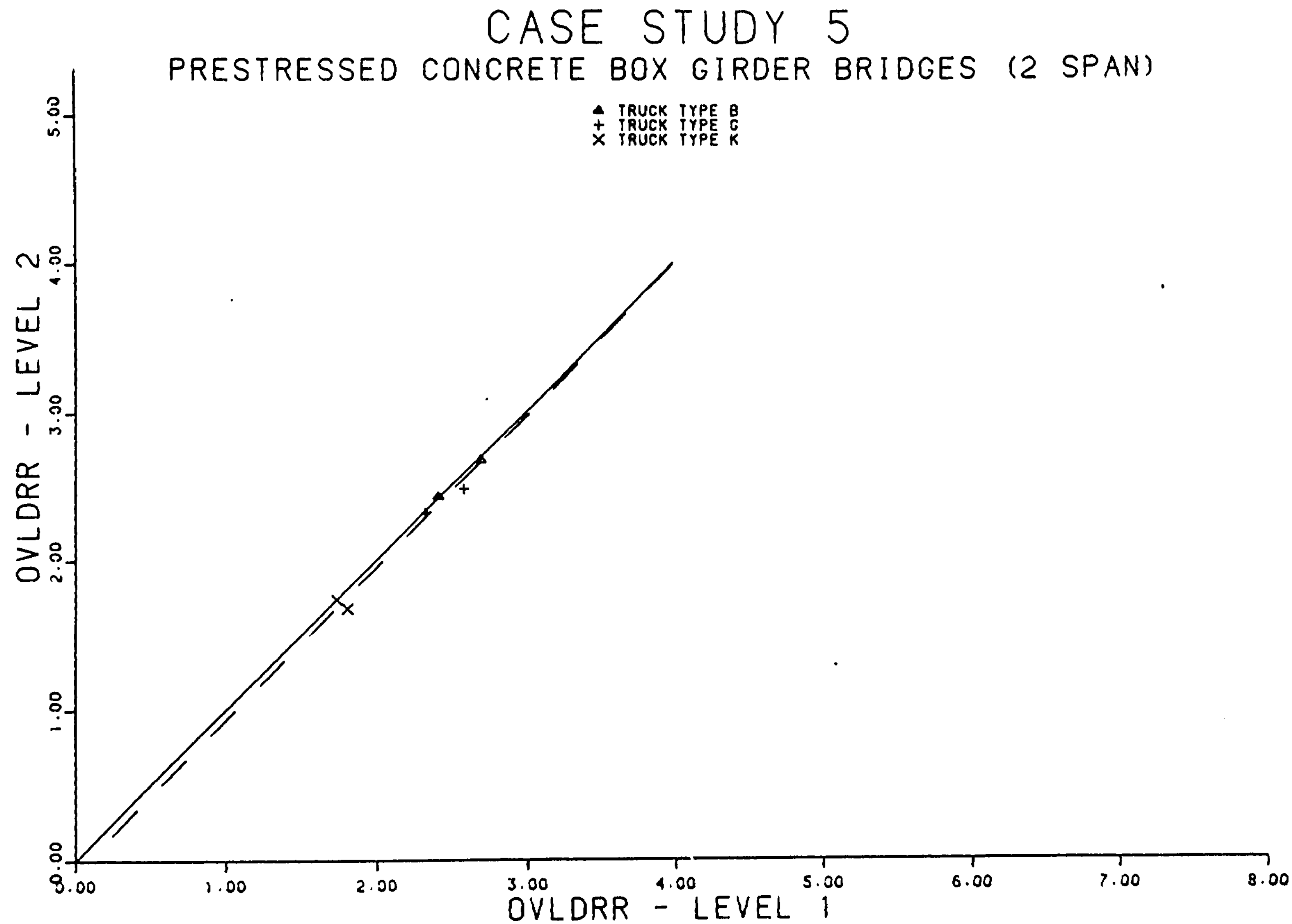

FIGURE 2-16. CASE STUDY 5 (2 SPAN)

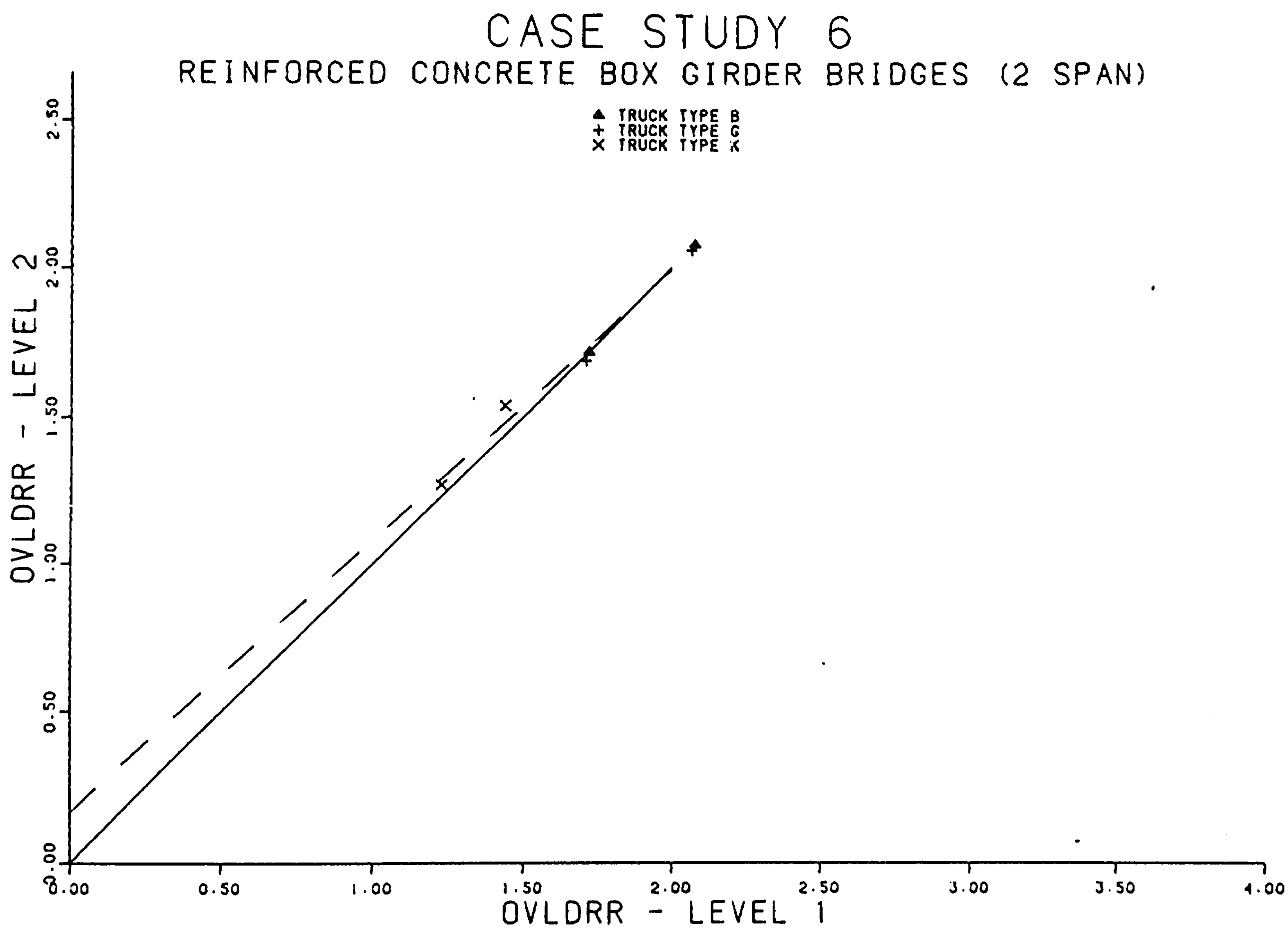

FIGURE 2-17. CASE STUDY 6 (2 SPAN)

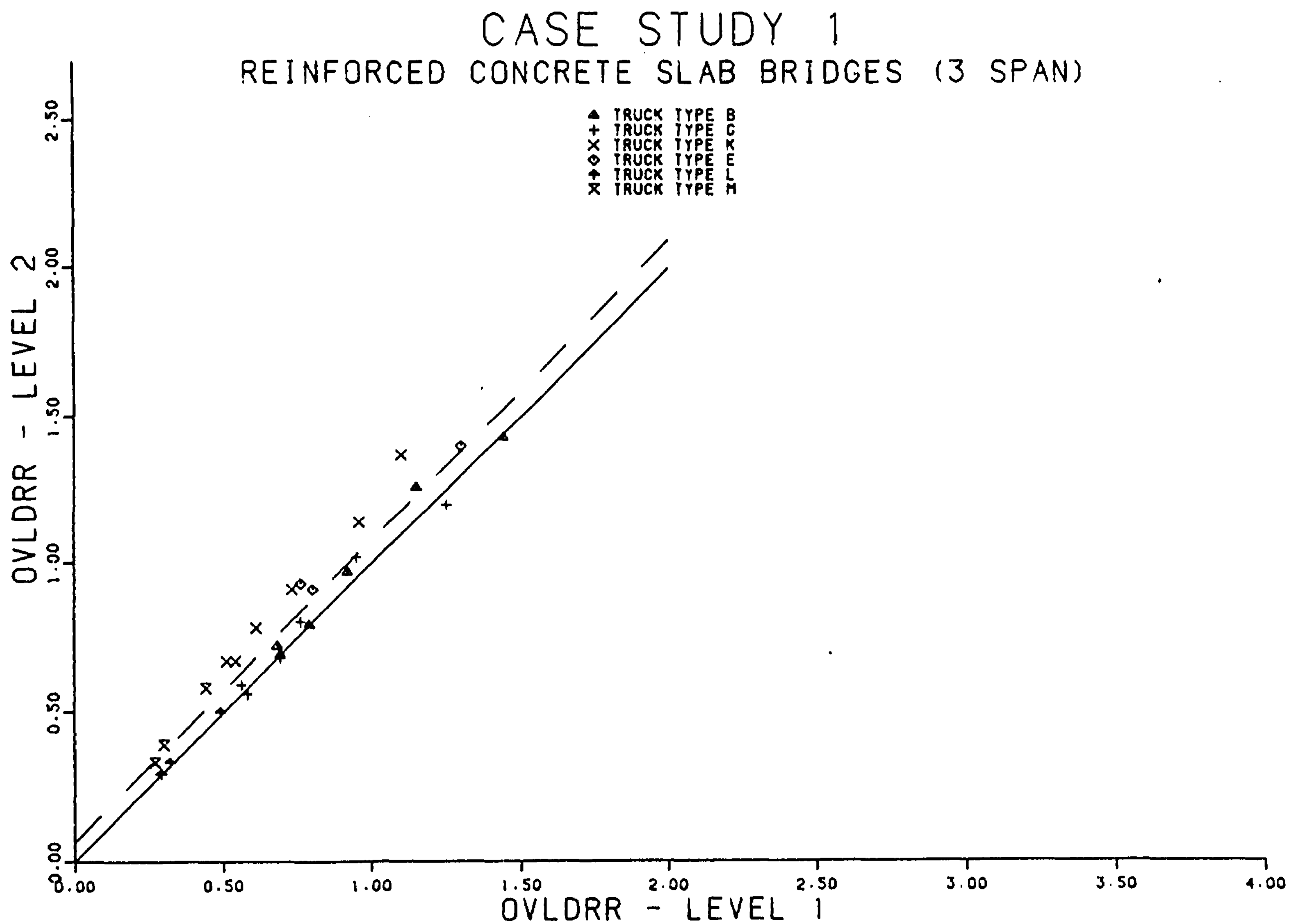

FIGURE 2-18. CASE STUDY 1 (3 SPAN)

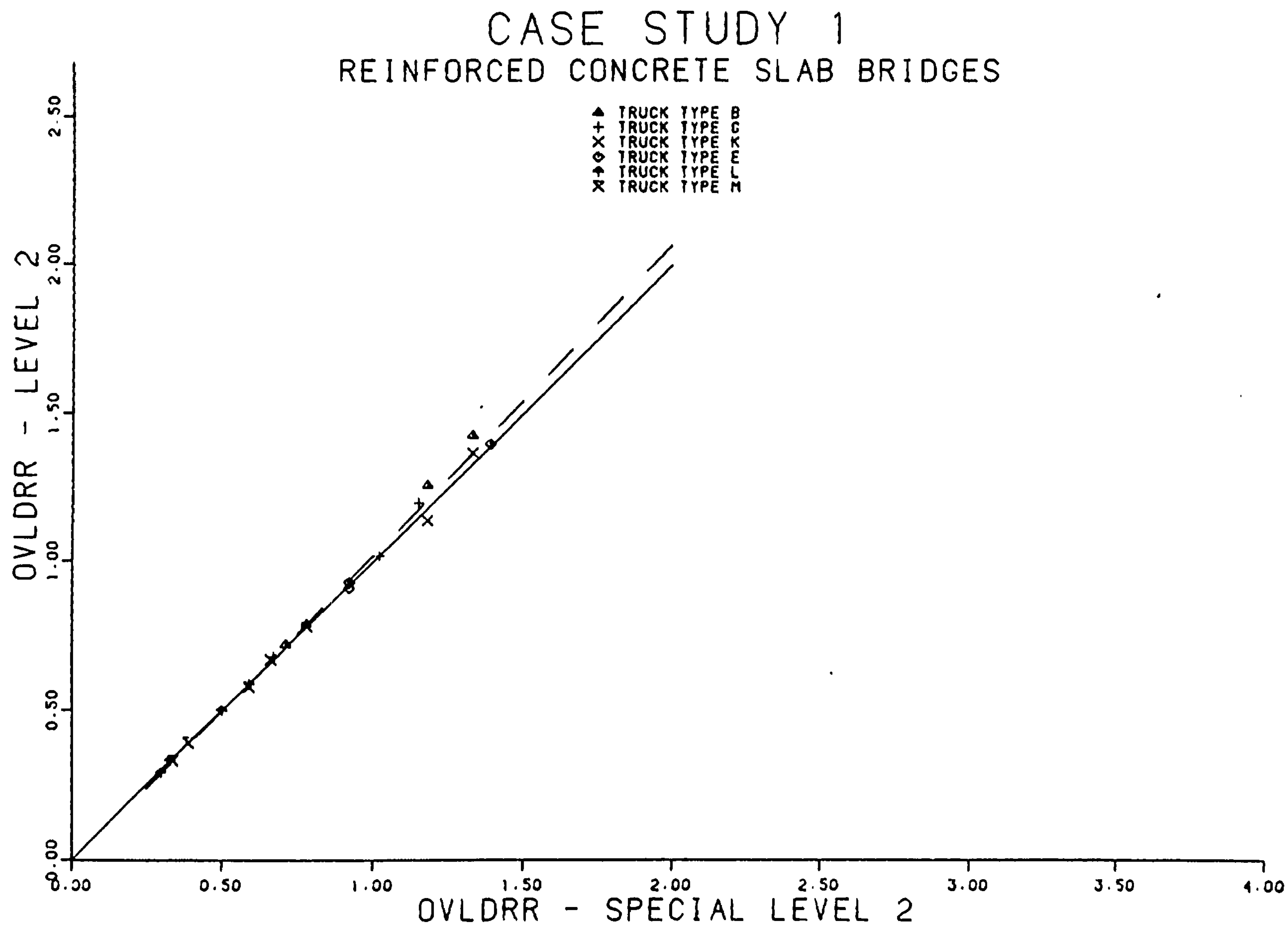

FIGURE 2-19. CASE STUDY 1 (3 SPAN) - SPECIAL LEVEL 2

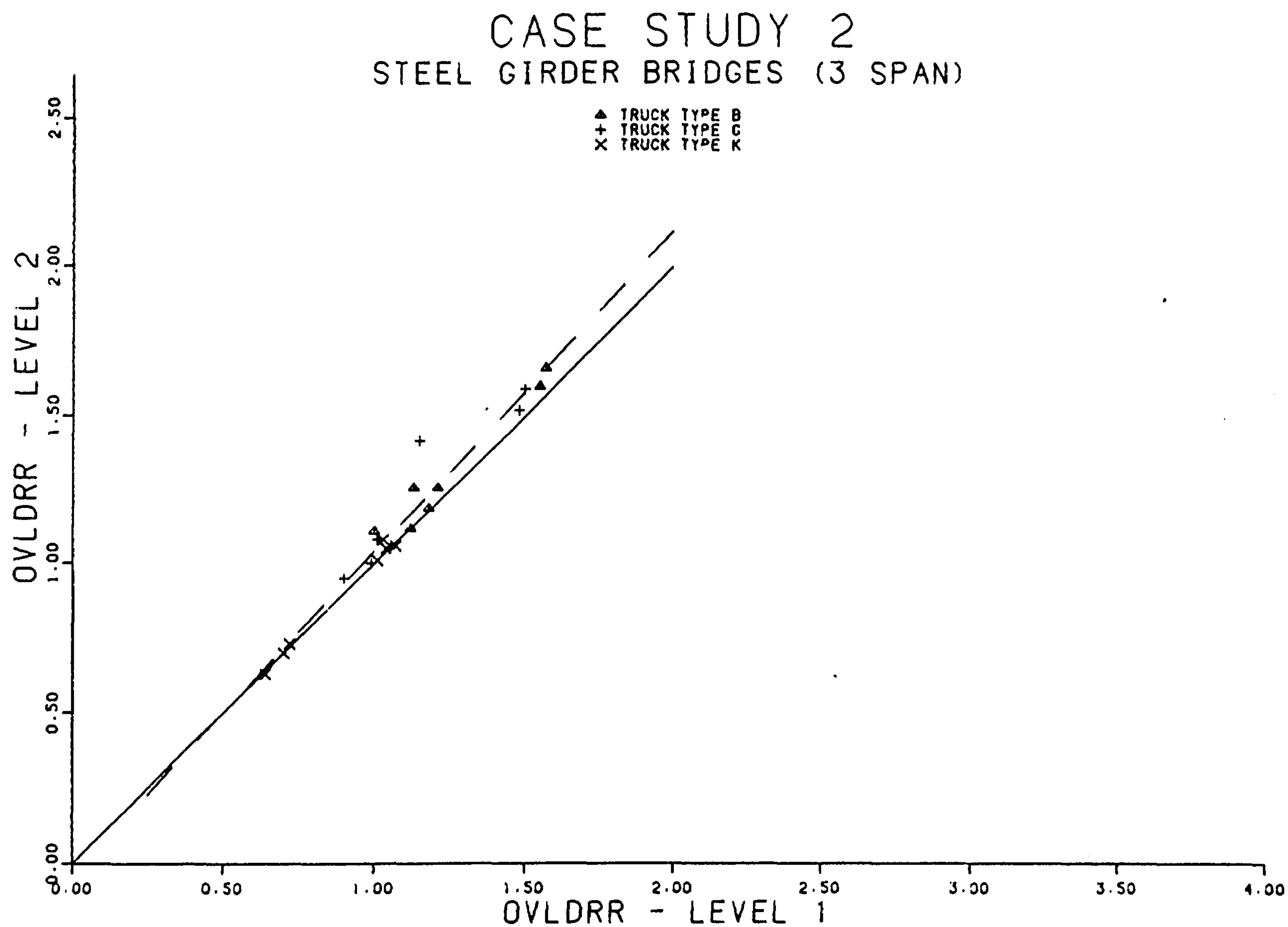

FIGURE 2-20. CASE STUDY 2 (3 SPAN)

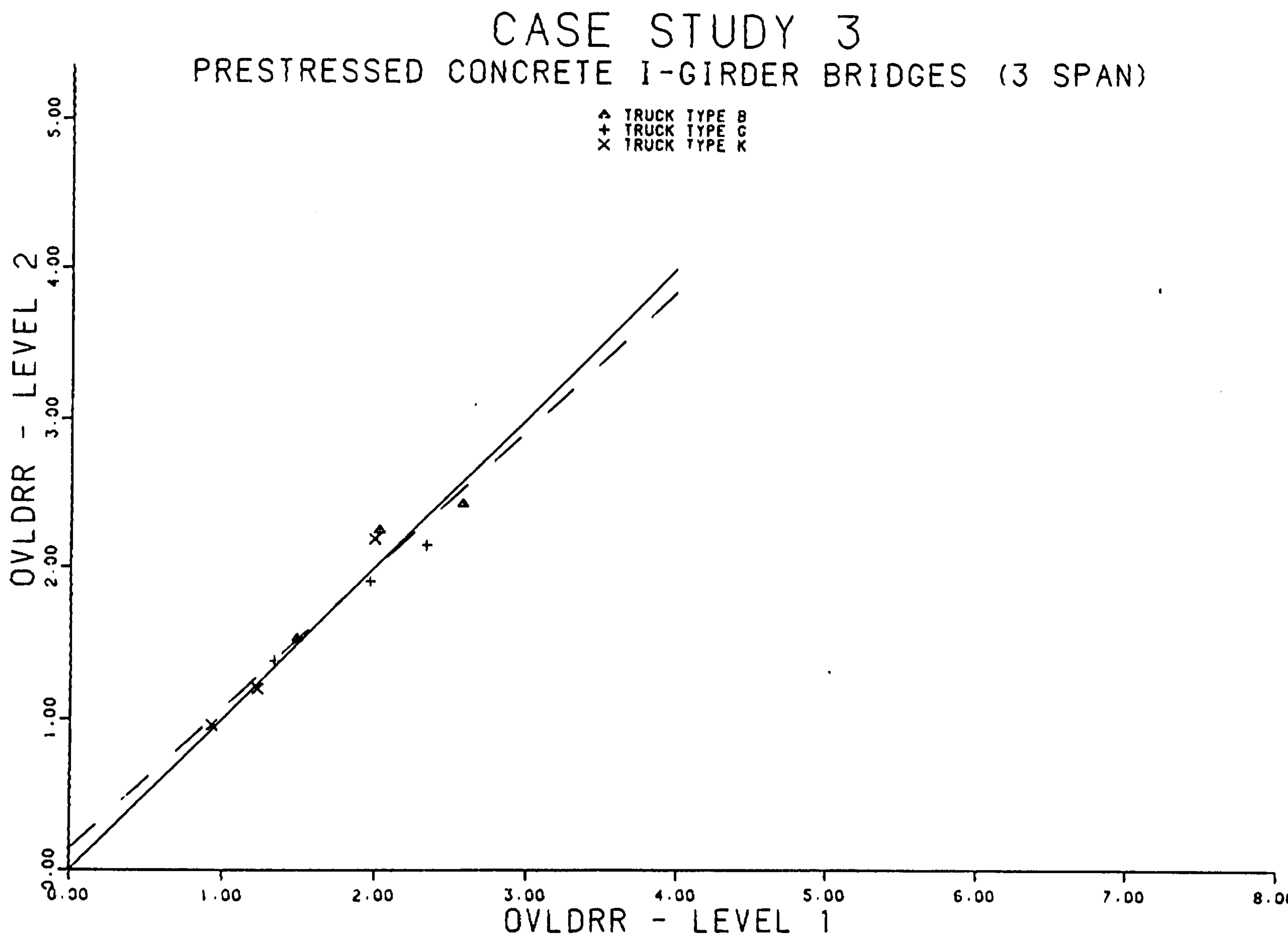

FIGURE 2-21. CASE STUDY 3 (3 SPAN)

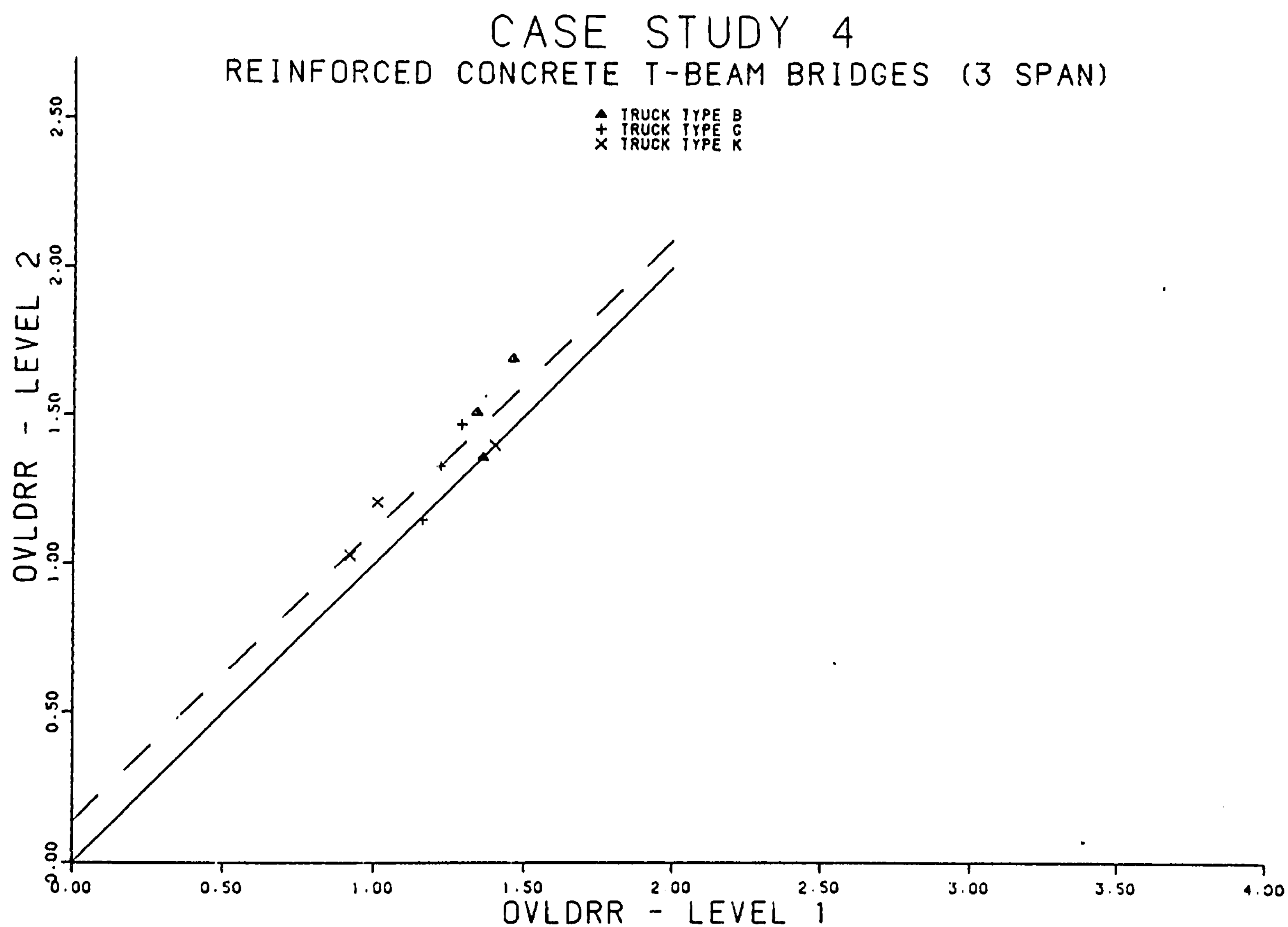

FIGURE 2-22. CASE STUDY 4 (3 SPAN)

TABLE 2-1. CASE STUDY 1: REINFORCED CONCRETE SLAB BRIDGES

Case Study	Struct. No.	Year Built	Maximum Span Length (ft)		Overall Length (ft)		Number of Spans		Girder Spacing	Bridge Width c-to-c (ft)		End Span (ft)		End Span Max. Span Length	
			As-Built	NBIF	As-Built	NBIF	As-Built	NBIF	As-Built	As-Built	NBIF	As-Built	Calc.	As-Built	Calc.
1-A	364	1952	25	OK	118.5	119	5	OK	0.	30.0	30.0	20.5	22.0	0.820	0.880
1-B	790	1963	35	OK	268.8	269	8	OK	0.	30.0	42.0	28.5	29.5	0.814	0.843
1-C	9050	1957	35	OK	94.5	95	3	OK	0.	26.0	26.3	28.5	30.0	0.814	0.857
1-D	463	1956	25	OK	93.5	94	4	OK	0.	36.0	35.9	20.5	22.0	0.820	0.880
1-E	1274	1969	35	OK	373.7	748	11	22	0.	40.0	40.0	28.5	24.0	0.814	0.686
1-F	390	1953	32	OK	342.5	343	11	OK	0.	35.7	42.0	26.0	27.5	0.813	0.859

TABLE 2-2. CASE STUDY 2: STEEL GIRDER BRIDGES

Case Study	Struct. No.	Year Built	Maximum Span Length (ft)		Overall Length (ft)		Number of Spans		Girder Spacing	Bridge Width c-to-c (ft)		End Span (ft)		End Span Max. Span Length	
			As-Built	NBIF	As-Built	NBIF	As-Built	NBIF	As-Built	As-Built	NBIF	As-Built	Calc.	As-Built	Calc.
2-A	505	1961	86	OK	524.96	525	7*	OK	9.00		30.0	67	47.5	0.779	0.552
2-B	617	1958	67	OK	178.5	178	3	OK	9.50	30.00	30.0	53	55.5	0.791	0.828
2-C	827	1959	79	OK	254.0	254	4	OK	8.83	30.00	30.0	46	48.0	0.582	0.608
2-D	116	1934	41	OK	41.0	44	1	OK	7.00	22.00	22.0	NA	NA	NA	NA
2-E	190	1937	40	OK	100.0	104	3	OK	7.50	32.00	40.0	30	32.0	0.750	0.800
2-F	1618	1973	212.5	212	495.8	496	3	OK	17.50	30.75	29.8	141	142.0	0.664	0.670
2-G	1236	1967	196	OK	495.96	496	3	OK	18.50	28.00	28.0	147	150.0	0.750	0.765

* Spans not uniform in length.

TABLE 2-3. CASE STUDY 3: PRESTRESSED CONCRETE I-GIRDER BRIDGES

Case Study	Struct. No.	Year Built	Maximum Span Length (ft)		Overall Length (ft)		Number of Spans		Girder Spacing	Bridge Width c-to-c (ft)		End Span (ft)		End Span Max. Span Length	
			As-Built	NBIF	As-Built	NBIF	As-Built	NBIF	As-Built	As-Built	NBIF	As-Built	Calc.	As-Built	Calc.
3-A	881	1964	50.8	52	157.48	160	4	OK	8.00	52	52	29.0	28.0	0.571	0.538
3-B	1827	1970	83.0	84	432	432	6	6	6.83	40	40	45.0	48.0	0.542	0.571
3-C	2006*	1983	91.0	OK	455	OK	5	5	8.00	95	92	89.7	91.0	0.986	1.000
3-D	1596	1972	77.0	OK	1004	1004	13	13	7.00	38	38	76.3	78.5	0.991	1.019
3-E	1085	1964	78.5	79	1337	1337	17	OK	5.58	30	30	77.6	76.0	0.989	0.962

* Structure not in NBIF.

TABLE 2-4. CASE STUDY 4: REINFORCED CONCRETE T-BEAM BRIDGES

Case Study	Struct. No.	Year Built	Maximum Span Length (ft)		Overall Length (ft)		Number of Spans		Girder Spacing	Bridge Width c-to-c (ft)		End Span (ft)		End Span Max. Span Length	
			As-Built	NBIF	As-Built	NBIF	As-Built	NBIF	As-Built	As-Built	NBIF	As-Built	Calc.	As-Built	Calc.
4-A	1615	1973	71	71	822	822	12*	OK	8.00	29.8	29.8	67.0	56	0.944	0.789
4-B	1382	1967	55	55	129	199	3	3	7.00	38.0	38.0	37.5	32	0.682	0.582
4-C	8066	1929	28	28	32	OK	1	OK	5.67	28	28	NA	NA	NA	NA

* Includes approach spans.

TABLE 2-5. CASE STUDY 5: PRESTRESSED CONCRETE BOX GIRDER BRIDGES

Case Study	Struct. No.	Year Built	Maximum Span Length (ft)		Overall Length (ft)		Number of Spans		Girder Spacing	Bridge Width c-to-c (ft)		End Span (ft)		End Span Max. Span Length	
			As-Built	NBIF	As-Built	NBIF	As-Built	NBIF	As-Built	As-Built	NBIF	As-Built	Calc.	As-Built	Calc.
5-A	1562	1972	81	OK	245.8	245	3	OK	4.00	42.0	42.0	80.6	82	0.995	1.012
5-B	1725	1976	140	OK	271	274	2	OK	8.00	26.0	26.0	131.0	134	0.936	0.957
5-C	1881	1983	126	OK	126	129	1	OK	8.67	118.0	118.0	NA	NA	NA	NA
5-D	1723	1978	160	OK	160	163	1	OK	9.00	42.3	42.3	NA	NA	NA	NA
5-E	541*	1959	32	33	416	482	15	OK		30.0	30.0	31.5	33	0.984	0.803

* Voided slab bridge.

TABLE 2-6. CASE STUDY 6: REINFORCED CONCRETE BOX GIRDER BRIDGES

Case Study	Struct. No.	Year Built	Maximum Span Length (ft)		Overall Length (ft)		Number of Spans		Girder Spacing	Bridge Width c-to-c (ft)		End Span (ft)		End Span Max. Span Length	
			As-Built	NBIF	As-Built	NBIF	As-Built	NBIF	As-Built	As-Built	NBIF	As-Built	Calc.	As-Built	Calc.
6-A	1378	1969	100	OK	200	205	2	OK	9	40	40	100	105	1.000	1.050
6-B	1323	1967	104	102	204	204	2	2	7	38	47	97	102	0.951	1.000

TABLE 2-7. CASE STUDY 7: TIMBER BRIDGES

Case Study	Struct. No.	Year Built	Maximum Span Length (ft)		Overall Length (ft)		Number of Spans		Girder Spacing	Bridge Width c-to-c (ft)		End Span (ft)		End Span Max. Span Length	
			As-Built	NBIF	As-Built	NBIF	As-Built	NBIF	As-Built	As-Built	NBIF	As-Built	Calc.	As-Built	Calc.
7-A	8436		14	OK		32	2	OK	1.75	OK	21.0	14	18	1.000	1.286
7-B	8144	1935	19	OK	38	39	2	OK		OK	19.1	19	20	1.000	1.053

TABLE 2-8. ONE-SPAN INFLUENCE LINE

Case Study	Correlation Coefficient	Percent Maximum (+)	Percent Minimum (-)	Percent Average
1	0.99	+9	-16	-2
2	0.89	+41	-14	+11
3	0.93	+31	-11	+7
4	0.88	+28	-1	+7
5	0.99	+6	0	+2
6	1.00	0	-2	-1
7	1.00	0	-1	-1

Plus (+) indicates Level 1 unconservative.
Negative (-) indicates Level 1 conservative.

TABLE 2-9. TWO-SPAN INFLUENCE LINE

Case Study	Correlation Coefficient	Percent Maximum (+)	Percent Minimum (-)	Percent Average
1	0.95	+11	-27	-10
2	0.94	+10	-22	+1
3	0.94	+13	-10	+5
4	0.91	-4	-32	-15
5	1.00	+8	+1	+4
6	0.99	+1	-6	-1

Plus (+) indicates Level 1 unconservative.
Negative (-) indicates Level 1 conservative.

TABLE 2-10. THREE-SPAN INFLUENCE LINE

Case Study	Correlation Coefficient	Percent Maximum (+)	Percent Minimum (-)	Percent Average
1	0.97	+4	-24	-10
1-Special Level 2	1.00	+4	-7	-1
2	0.98	+1	-19	-4
3	0.98	+3	-10	-2
4	0.98	-8	-16	-12

Plus (+) indicates Level 1 unconservative.
Negative (-) indicates Level 1 conservative.

3.0 CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusions

1. Level 1 computes the overload capacity ratings rapidly with a limited amount of data. The Level 1 procedure gives ratings which are on a percent average basis within 10% of a Level 2 procedure for bridges which satisfy the Level 1 assumptions. The percent maximum or upper bound limit for Level 1 gave results which were +8% of a Level 2 procedure and the percent minimum or lower bound limit for Level 1 gave results which were -19%.

2. The Special Level 2 analysis for reinforced concrete continuous bridges gives ratings on a percent average basis within 10% of a Level 2 procedure. The upper bound limit for Level 2 gave results +4% of Level 2 and the lower bound limit -7%.

3. The NBIF compares well with general bridge plans and that it is applicable to the Level 1 procedure for "typical bridges." Bridges that have approach spans, hinges, varying girder spacings from span-to-span, monolithic columns, or simple spans where live load is continuous may give erroneous overload capacity ratings.

4. The rating factor at operating level as coded in the NBIF should be checked for accuracy.

3.2 Recommendations

1. Addition of different continuity configurations for hinges and monolithic columns may be desirable.

2. Addition of physical bridge characteristics to a database such as span lengths and girder spacing would enhance the Level 1 procedure.

3. Calculation of the transverse distribution ratio should be incorporated into the program.

4. Addition of a routing system may be desirable.

4.0 REFERENCES

1. "Manual for Maintenance Inspection of Bridges," AASHTO, 1978.

2. "Load Capacity Evaluations of Highway Bridges and Culverts Carrying HML Vehicles," Earth Technology Corporation, Long Beach, California, Report E-TR-87, Vol. A, 1985.

3. "Development of Improvements to the Level 1 HML Bridge Rating Methodology," Engineering Computer Corporation, Sacramento, California, June 30, 1986.

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