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16. Abstract

Current specifications by the American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges set forth certain structural design requirements for bridge railings and the corresponding bridge decks. Observations of deck failure patterns in recent crash tests and observed deck failures at vehicle collision sites have raised questions concerning current specifications. The Texas Transportation Institute, in conjunction with the Texas State Department of Highways and Public Transportation, has been studying the problem on three types of bridge rails used in Texas. Full-scale deck sections with a post, a parapet, or an 8 ft section of concrete safety shaped railing were built and tested. The three types tested were the Texas T101, T202, and T5 bridge railings. The findings of this testing are reported herein.

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BRIDGE DECK DESIGNS FOR RAILING IMPACTS

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Research Report No. 295-1F on
Research Study 2-5-81-295
Bridge Deck Designs for Railing Impacts

Sponsored by
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The Texas A&M University System
College Station, Texas 77843

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The contents of this report reflect the views of the authors, who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas State Department of Highways and Public Transportation. This report does not constitute a standard, specification, regulation, or policy.

KEY WORDS

Bridge Rails, Bridge Decks, Traffic Barriers, Safety

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IMPLEMENTATION STATEMENT

As of the writing of this report none of the findings or conclusions presented have been implemented.

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BRIDGE DECK DESIGNS FOR RAILING IMPACTS

INTRODUCTION

Current specifications by the American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges (1) set forth certain structural design requirements for bridge railings and the corresponding bridge decks. The AASHTO Specifications call for bridge railings to meet specific geometric criteria and to resist specific static lateral and longitudinal loads without exceeding the allowable stresses in their elements. AASHTO also specifies the manner in which these static forces are to be transferred to the concrete deck. However, these bridge deck specifications are questioned on the basis of observed deck failure patterns in recent crash tests (2,3) and observed deck failures at actual vehicle collision sites.

It has been observed that when vehicles collide with a metal or concrete traffic railing the traffic railing usually contains them but extensive damage may occur to the concrete bridge deck. Repair of a bridge deck is costly, time consuming, and dangerous. To repair a bridge deck, portions of the highway must be blocked off from traffic for several days while the damaged deck is removed, damaged steel is replaced, forms are built, and concrete is placed and allowed to cure. During this time traffic becomes congested because of reduced lanes, and the construction work is hazardous to traffic as well as to workers.

The Texas Transportation Institute (TTI), in conjunction with the Texas State Department of Highways and Public Transportation (TSDHPT) have been studying the problem on three types of bridge railing used in Texas. Full-scale sections of deck with a post, a parapet, or an 8-ft section of railing were built and tested. Twenty-six tests, twenty-four static and two dynamic tests were conducted on three Texas standard bridge railings and on design variations of these railings. The three types of railings studied were the Texas T101, T202, and T5 bridge railings. Appendix A contains summary results for each test.

TESTS PERFORMED ON THE TEXAS TYPE T101 BRIDGE RAILING, POST, AND CONCRETE DECK

The T101 bridge railing is a W-beam rail element mounted on strong posts anchored to a 7 1/2 in. deck by means of four 3/4 in. diameter A325 bolts. One inch formed holes in the slab allow the post to be bolted through the slab to a bottom 8 in. x 1/4 in. x 9 in. plate with 7/8 in. diameter bolt holes. The galvanized T101 post is constructed of a 26 1/8 in. length W6 x 20 (A36) wide flange welded to a 10 in. x 9 in. x 7/8 in. base plate with 1 in. x 1 1/2 in. slotted bolt holes. An anchor plate cast inside the concrete deck made of 1 1/2 in. x 39 in. x 1/4 in. A36 steel plates distributes the load from the bolts to the concrete. Figure 1 is a drawing of the standard bridge deck with the T101 post. Figure 2 is a composite drawing showing the different variations of this design. Figure 3 shows the three types of bolt anchor plates used. Photographs of typical crack patterns are shown in Figure 4. Table 1 is a summary of the tests performed on the T101 post and concrete bridge deck.

TESTS PERFORMED ON THE TEXAS TYPE T101 STEEL POST ON A RIGID SUPPORT

Two static tests (T101-1P0 and 2P0) were performed on the T101 steel post connected to a rigid foundation to determine the strength of the post. The bolts, nuts, and washers on the first test were of sufficient strength to force the failure to occur in the post. The peak load was

42.7 kips at 3.6 in. deflection. The compression flange buckled and there was yielding in the tension flange and web.

In the second test, standard A325 bolts, 3/4 in. diameter nuts and washers were used to determine the strength of the system. The main failure mode was in the washers, which pulled through the 1 in. x 1 1/2 in. slotted holes in the post base plate. There was also some buckling in the compression flange and some yielding in the tension flange and web of the post. The peak load was 23.7 kips at 0.8 in. deflection. From these tests it is shown that the bolts and washers are weaker than the W6 x 20 steel posts.

TESTS PERFORMED ON THE STANDARD TEXAS TYPE T101 POST WITH CONCRETE DECK

Two static tests (T101-1S and 2S) were performed on the standard T101 post with a 7 1/2 in. deck to determine the strength of the existing systems. The peak loads were 18.6 kips and 19.0 kips occurring at 1.6 in. deformation. The general crack patterns depicted the post punching through the deck with major cracks through the bolt holes. The bolt anchor plate was broken and a #5 top bar that was located under the post between the anchor bolts broke 6 in. from its end. These loads are not enough to develop the anchor bolts as evident by the failure mode in test T101-2PO.

Two dynamic tests (T101-1D and 2D) were performed on the standard T101 post with a 7 1/2 in. concrete deck to determine the dynamic strength and the energy absorbing capabilities. The peak loads were 57.9 kips and 36.2 kips at 1.8 in. deflection. The difference in these two values can be attributed to the different types of pendulum noses used in each test. The energy absorbed was 17,475 and 28,608 kip-ft. Cracking patterns were identical with the static tests.

These tests indicated that methods of strengthening the slab needed to be investigated.

TESTS ON THE VARIATIONS OF THE TEXAS TYPE T101 POST AND CONCRETE DECK

It was hypothesized that the punching effect of the post through the slab was due to high stress concentrations under the post base plate. To spread out these forces in the slab it was suggested that more tension and longitudinal steel be used in the top of the slab. To do this, a 48 in. x 18 in. welded wire fabric mat made of D20 bars was placed on top of the existing steel. The existing top and bottom steel was extended to within 1 in. of the edge of the deck. The longitudinal steel was increased to include two #4 bars on top and two #5 bars on bottom between the outside bolts and the edge of the deck. This steel configuration was statically tested in a 7 1/2 in. deck (T101-3S) and a 10 in. deck (T101-4S). An immediate increase in the deck strength was observed. The 7 in. deck reached a peak load of 24.0 kips at 2.0 in. deflection, and the 10 in. deck reached a peak load of 27.0 kips at 3.3 in. deflection. The bolts used in this test were 7/8 in. diameter to develop the strength of the slab before developing that of the bolts to determine the net increase in slab strength. Crack patterns in the deck were similar to the previous test; however, no broken steel was found.

Since it was determined that the slab strength could be increased above the strength of the bolts, more economical designs were sought. The anchor plate was enlarged (modification #1) to replace the welded wire fabric. The longitudinal top steel was reduced to one bar between the outside bolt and the deck edge. All other steel modifications remained the same as in the previous two tests. The deck depths tested were 8 in. (T101-5S) and 10 in. (T101-6S). The standard 3/4 in. A325 bolts, nuts, and washers were used. For the 8 in. deck the peak load was 21.4 kips at 2.0 in. deflection and for the 10 in. deck the peak load was 21.2 at 4.7 in. deflection. The toughness of the slabs was increased as seen in the load deflection curves. THe load on the 8 in. deck did not drop off until the bolt broke at 20.5 kips and 7 in. deflection. The load on the 10 in. deck was steadily increasing until the bolt broke. In both tests the base plate was bent and some yielding of the post was evident. Cracking of the concrete in the 8 in. deck was similar to that in previous tests. In the 10 in. deck, major cracks occurred only through the bolt holes on the field side of the bridge rail.

Post edge distance was considered a problem. The last two tests in this series were performed on an 8 in. deck (T101-7S) and a 10 in. deck (T101-8S) with the post edge distance increased from 1 3/4 in. to 3 1/2 in. The modified anchor plate was reduced (modification #2) and the top longitudinal steel was increased to a peak load of 22.0 kips at 2.3 in. deflection, at which time an anchor bolt broke. The 10 in. deck reached a peak load of 25.4 kips at 2.1 in. deflection. At a load of 21.0 kips and 6 in. deflection one bolt and washer had pulled through the base plate hole and the test was terminated. Cracking of concrete occurred only through the field side bolt holes and in the edge of the deck in both tests.

CONCLUSIONS

The static strength of the W6 x 20 post was 42.7 kips; however, the strength of the post with standard bolts and washers was only 23.7 kips. In order for easy repair, the deck must be able to withstand this load with minimal cracking. The standard Texas bridge deck was unable to withstand these loads. However, all modifications to the Texas T101 post and concrete decks tested were capable of developing the full strength of the bolts before severe damage occurred to the deck. These modifications were: (1) extend the reinforcing steel in the deck to within 1 in. of the anchor bolts and the deck edge, (2) increase the number of longitudinal bars between the anchor bolts and the deck edge, (3) addition of welded wire fabric under the posts, (4) enlarge the bolt anchor plate as shown, (5) increase the post edge distance, and (6) increase the depth of the bridge deck to about 10 in.

RECOMMENDATIONS

The ideal failure mode for the W6 x 20 steel post and the concrete slab would be bolt failure before severe damage occurs to the slab. Using standard 3/4 in. diameter A325 bolts to the limiting load value ranges from 21 to 25 kips.

The bolt failure mode varies in these tests by: (1) bolt and washers pull through large holes in base plate, (2) traffic side bolts fail in tension, and (3) concrete deforms in compression to the extent that all four bolts go into tension before any bolt failure occurs, thus increasing the load. Two recommendations to alleviate these problems and to force a tension failure in the bolts are: (1) stronger washers are needed, and (2) a larger base plate is necessary to prevent crushing failure of the concrete under the compression flange.

TESTS PERFORMED ON THE TEXAS T202 CONCRETE BRIDGE RAIL AND DECK

The T202 bridge rail is a parapet type concrete rail with 5 ft 0 in. posts and 5 ft 0 in. spacing which supports a continuous concrete beam.

The "posts" are 7 in. deep with thirteen #4 tension bars in the traffic side that bend to join the bottom steel in the deck and five #4 straight compression bars in the field side. The post sits on the deck 1 1/2 in. from the edge. The post reinforcing was all grade 60 steel, whereas the standard deck reinforcing was grade 40 steel. Figure 5 details the standard T202 concrete bridge rail and deck. Figure 6 is a composite drawing of the modifications tested. Figure 7 details the welded wire fabric and Figure 8 details the #4 stirrups noted in the modifications. Photographs of typical crack patterns are shown in Figure 9. Table 2 is a summary of the tests performed on the T202 concrete bridge rail and deck.

TESTS PERFORMED ON THE STANDARD TEXAS TYPE T202 CONCRETE BRIDGE RAILING AND DECK

One static (T202-1S) and one dynamic test (T202-1D) were performed on the standard T202 concrete bridge rail. The peak load on the static test was 26.3 kips at 0.3 in. deflection. For the dynamic test the peak load was 109 kips at 1.6 in. deflection. The energy absorbed was 79,677 kip-ft. Concrete along the deck edge was spalled off and cracks appeared in the deck at each end of the 5 ft 0 in. concrete post. No cracks appeared in the post.

TESTS ON THE VARIATIONS OF THE TEXAS TYPE T202 POST AND CONCRETE DECK

It was decided that the deck needed strengthening to force a failure in the post. To do this, 48 in. x 18 in. welded wire fabric was added to the top steel in the deck, and the top and bottom steel was lengthened to within 1 in. of the edge of the deck. The peak load in this test (T202-2S) was 25.1 kips at 0.5 in. deflection. There is no appreciable difference in the shape of this load deflection curve and the test on the standard design. Concrete spalling occurred and the cracking mode was similar to the previous tests.

The design for test T202-3S was the same as T202-2S except the tension and compression steel in the post had an 8 in. lap splice beginning on top of the deck. The compression steel from the post to the deck was bent to join the bottom steel similar to the tension steel configuration. The peak load was 21.4 kips at 0.4 in. deflection. Severe cracking occurred in the deck at each end of the post, but the concrete did not spall off the edge of the deck.

This design was modified to contain an 85 in. x 24 in. welded wire fabric mat for test T202-4S. The peak load was 21.7 kips at 0.9 in. deflection. The crack pattern was the same as test T202-3S with no spalling of concrete.

It was determined that the welded wire fabric gave no advantage to the system and was eliminated.

The next step was to drastically modify the steel in the deck. The #5 bars at 5 1/4 in. centers in the top of the deck were bent up to form the tension steel in the post with a 12 in. lap splice. The compression steel in the post was continuous and straight. On either side of this compression steel a longitudinal #4 bar was placed in the top of the deck and a longitudinal #5 bar in the bottom of the deck. A #4 bar stirrup (see Figure 8) was placed at 45 degrees in the deck connecting the top and bottom steel to strengthen this joint. In an 8 in. deck (T202-5S) the peak load was 24.9 kips at 0.8 in. deflection. In a 10 in. deck (T202-6S) the peak load was 31.0 kips at 0.7 in. deflection. Severe spalling and cracking of the concrete occurred in the 8 in. deck and in the post. However, in the 10 in. deck, severe cracks appeared in the wall along the 12 in. lap splice before cracking appeared in the deck. Even after the load fell to 12 kips at 1.5 in. deflection the cracks in the deck were repairable.

To improve on this design the lap splice in the tension steel was increased to 17 in. in tests T202-7S and 8S. The post edge spacing was increased from 1.5 in. to 3.5 in. to try to curtail the spalling of concrete. Two top longitudinal #4 bars in the deck were placed between the post compression steel and the edge of the deck. In this 8 in. deck (T202-7S) the peak load was 23.4 kips at 1.1 in. deflection with no spalling of concrete. The post had cracks along the 17 in. lap splice and the deck had cracks at each end of the post. The 10 in. deck (T202-8S) had a peak load of 29.2 kips at 0.9 in. deflection. The crack pattern was similar to the 8 in. deck test.

The last pair tested was on a simplified design. The top and bottom reinforcing steel in the deck was straight and continued to within 1 in. of the edge of the deck. The compression steel in the post was five #4 bars that were straight and continued into the deck to the bottom steel. The thirteen #4 tension bars were continuous from the post to bend into the bottom reinforcing steel of the deck with an 8 in. splice in the deck. The post edge distance was 3 1/2 in. and there were two longitudinal #4 bars continuous in the top steel of the post and two #5 bars bottom steel. For the 8 in. deck (T202-9S) the peak load was 35 kips and 0.9 in. deflection. For the 10 in. deck (T202-10S) the peak load was 40 kips at 0.9 in. deflection. In both of these tests the concrete was cracked along the edge of the deck but did not spall off. The cracking may be due to the lack of stirrups, however the increased edge distance and additional longitudinal steel keep the concrete from spalling off.

CONCLUSIONS

Four of the modifications to the T202 railing and deck gave it added strength. These modifications are: (1) extending the slab reinforcing steel to within 1 in. of the deck edge, (2) increasing the edge distance from 1.5 in. to 3.5 in., (3) increasing the slab thickness, and (4) additional longitudinal reinforcing bars in the slab. The modifications that did not increase the strength were the addition of welded wire fabric and the addition of the #4 bar stirrup. However, the #4 bar stirrup appeared to reduce cracking in the deck.

RECOMMENDATIONS

The best design is the design used in test T202-9S. It has an 8 in. deck thickness with a 3 1/2 in. post set back. It contains four longitudinal reinforcing bars (two #4 bars-top and two #5 bars-bottom). Thirteen #4 bars from the post bend to form an 8 in. lap splice with the bottom steel of the deck. No special made stirrups or welded wire fabric was used. The peak load of this design was 35 kips and 0.9 in. deflection. Only hairline cracks appeared at this loading. At 8 in. deflection large cracks had appeared but no spalling of concrete had occurred. Increased load capacity can be achieved with this design using an increased deck thickness. Where the situation demands it, the 10 in. deck can be used to obtain a peakload of 40 kips at 0.9 in. deflection.

TESTS PERFORMED ON THE STANDARD TEXAS TYPE T5 CONCRETE BRIDGE RAIL AND DECK

The T5 bridge railing is a continuous concrete parapet type railing. The standard design is shown in Figure 10. The railing contains seven #4 bars continuous along the length and #5 bar stirrups at 8 in. centers that are formed in the shape of the rail with a 1 1/4 in. clearance. The concrete rail element is connected to the deck by a #5 "hair pin" bar at 8 in. on center. The "hair pin" bar contains two legs that connect the rail to the deck. The tension leg is 8 3/4 in. from the edge. One static test was performed on the standard design and three static tests were performed on modified designs. Figure 11 is a composite drawing of the modifications made on the rail. Photographs of typical crack patterns are shown in Figure 12. Table 3 is a summary of the tests performed on the T5 railing.

TEST ON THE STANDARD TEXAS TYPE T5 CONCRETE BRIDGE RAIL AND DECK

One test (T5-1S) was performed on the standard T5 bridge rail with an 8 in. deck. It revealed the peak load to be 45 kips at 1.2 in. deflection. The rail sustained no cracking, while the deck sustained severe cracking along the tension side of the "hair pin" plates. Prying action of the rail on the deck was considered the major problem.

TESTS ON MODIFICATIONS OF THE TEXAS TYPE T5 CONCRETE BRIDGE RAIL AND DECK

For the first modification (T5-2S) the top and bottom steel of the deck was extended to within 1 in. of the edge of the deck. The "hair pin" bar was modified so that it had only one leg connecting the rail to the deck at 10 3/4 in. from the edge of the deck. The backside of the rail was chamfered 2 in. to help reduce the prying action. The chamfer effectively increases the edge distance from 1 1/2 in. to 3 1/2 in. without moving the rail or increasing the width of the bridge slab. The peak load was 36.2 kips at 0.4 in. deflection. The crack pattern was similar to the crack pattern of the standard design.

To reduce the cracking in the slab a #4 bar stirrup was placed in the deck of the previous designs. For an 8 in. (TS-35) deck the peak load was 42.2 kips at 0.6 in. deflection.

This modified design without a bar stirrup was performed on a 10 in. deck (TS-4S). The peak load was 49.1 kips at 0.5 in. deflection.

Major cracks occurred in the deck along the tension leg of the "hair pin" bar except in the design with the #4 bar stirrup. In this test the related crack formed at the traffic edge of the parapet and angled 45 degrees into the deck. The 10 in. deck also had a hairline crack where the deck thickness was reduced to join the 8 in. standard deck thickness.

CONCLUSIONS

Four modifications were made on the standard design. They were: (1) change the #4 "hair pin" bar from two legs with the tension member at 8 3/4 in. to a modified "hair pin" bar with one leg (tension member) at 10 3/4 in., (2) increase the edge distance by adding a 2 in. chamfer at the back of the rail, (3) add a #4 bar stirrup, and (4) increase the deck thickness. Of these, only the increased deck thickness gave added strength to the deck/rail design.

RECOMMENDATIONS

From examining the four tests performed, the standard design (T5-1S) appears to be the most economical. It has a peak load of 45 kips at 1.2 in. deflection and the load does not drop off quickly. An increased load of 49.1 kips at 0.5 in. deflection was achieved using an increased deck thickness, a modified "hair pin" bar, and a 3 in. post set back. However, this may not be the most efficient design since this was the only test with the 10 in. deck thickness.

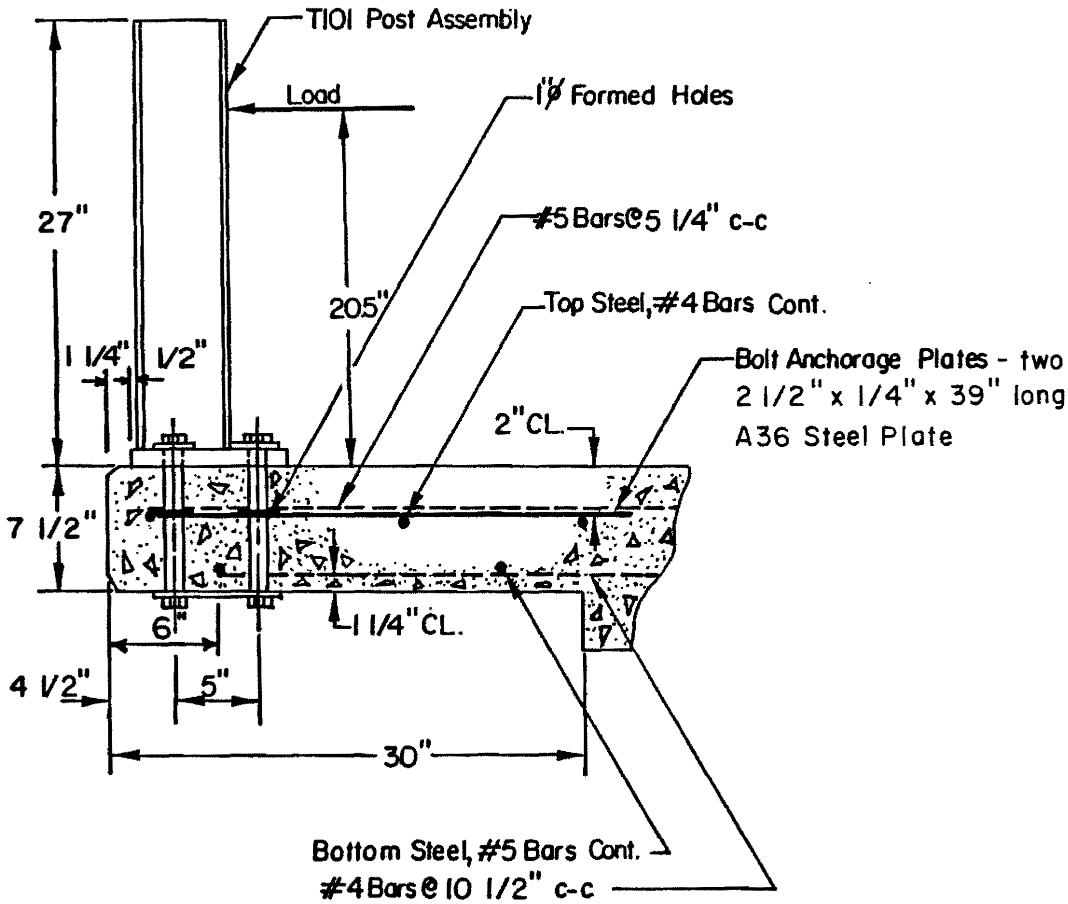


Figure 1. Standard Bridge Deck with Texas Type T101 Post.

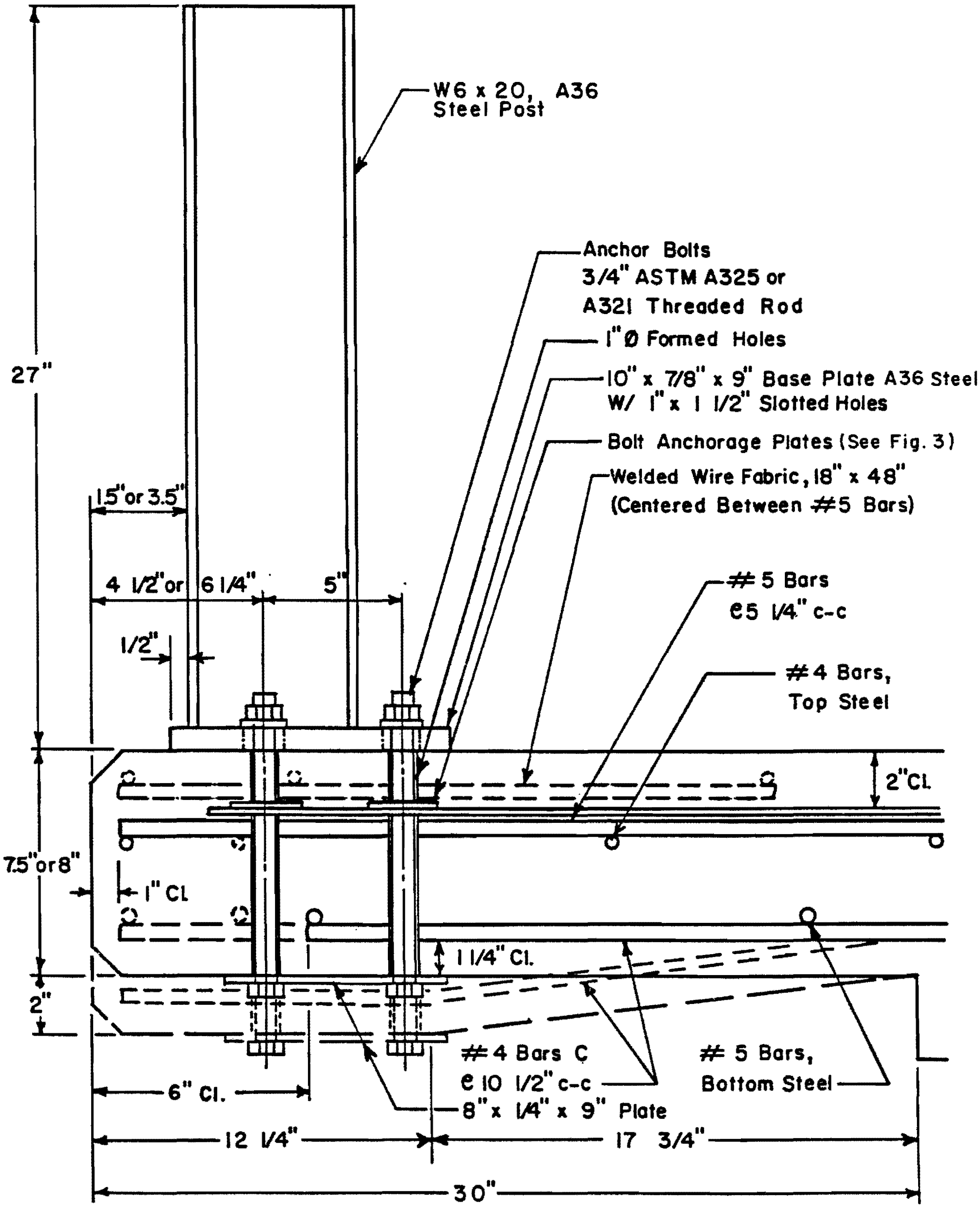


Figure 2. Composite Drawing of Modifications to the Texas Type T101 Post and Concrete Bridge Deck.

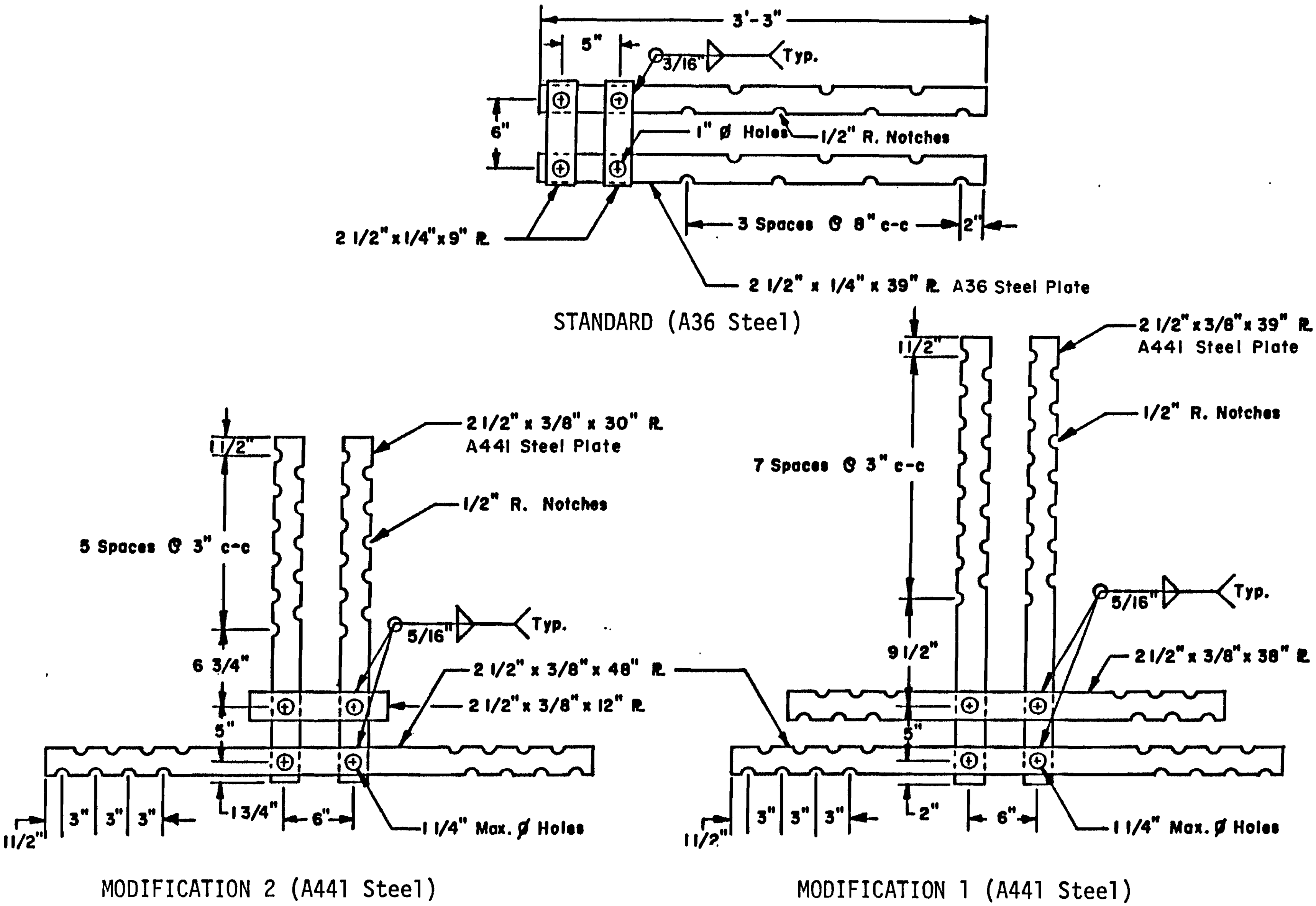


Figure 3. Types of Anchor Plates Used in the Texas Type T101 Bridge Deck.

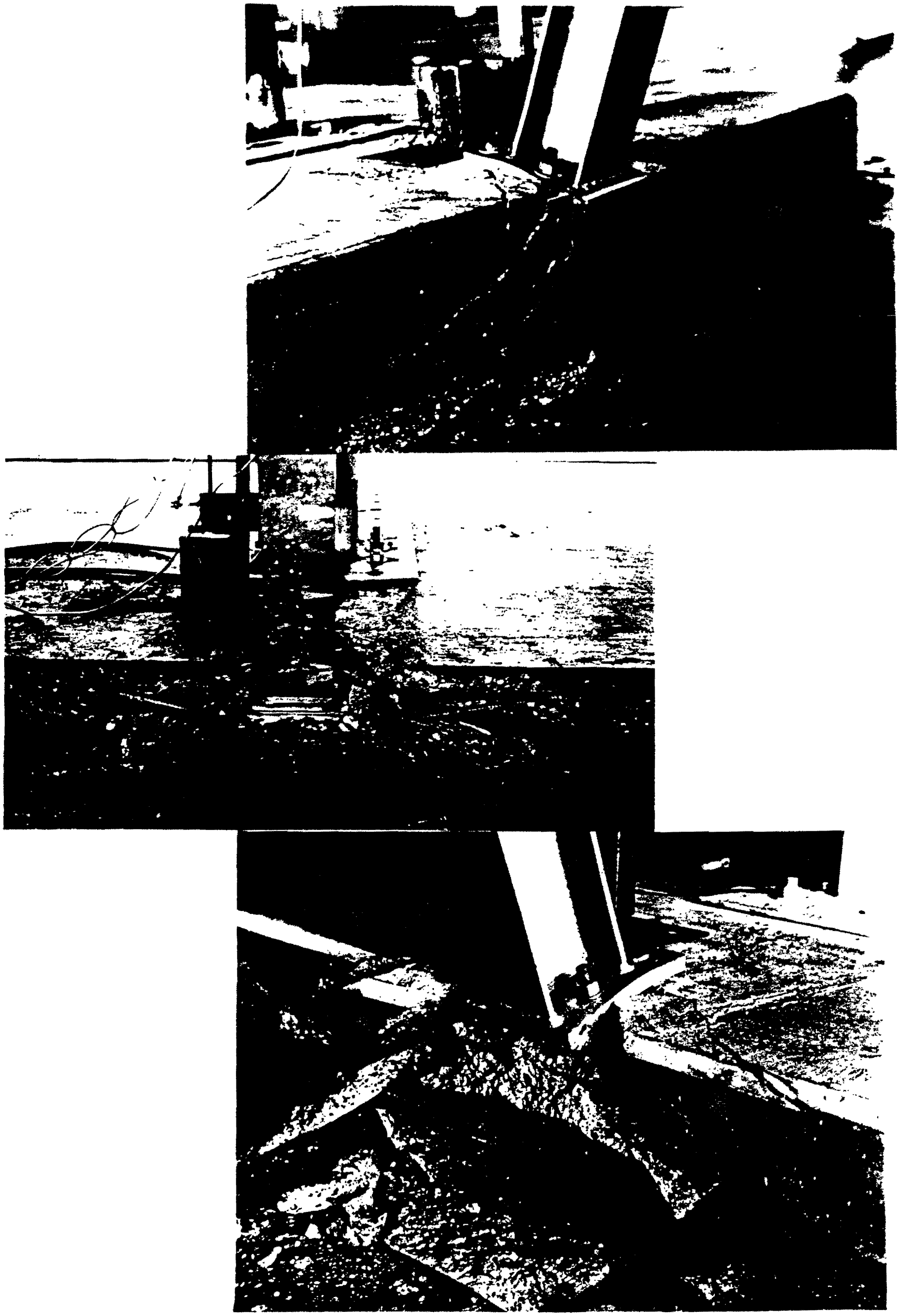


Figure 4. Typical Crack Patterns for Texas T101 Post with Concrete Bridge Deck.

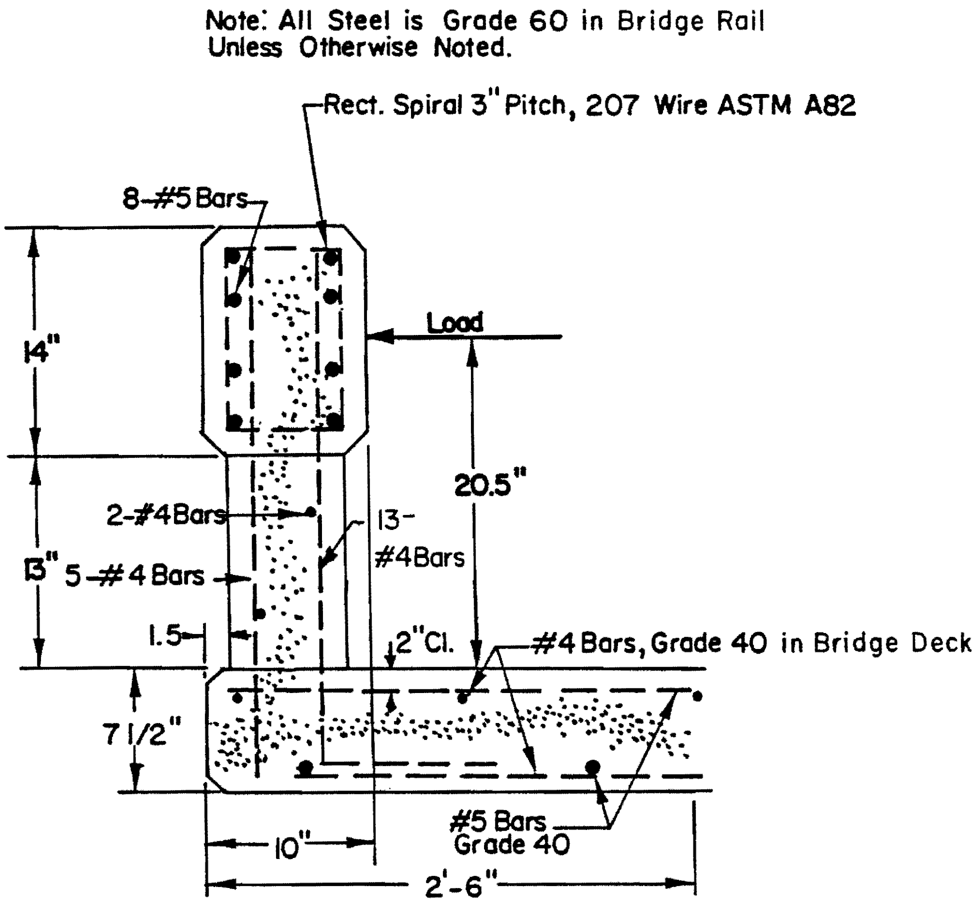


Figure 5. Standard Texas Type T202 Concrete Bridge Rail and Deck.

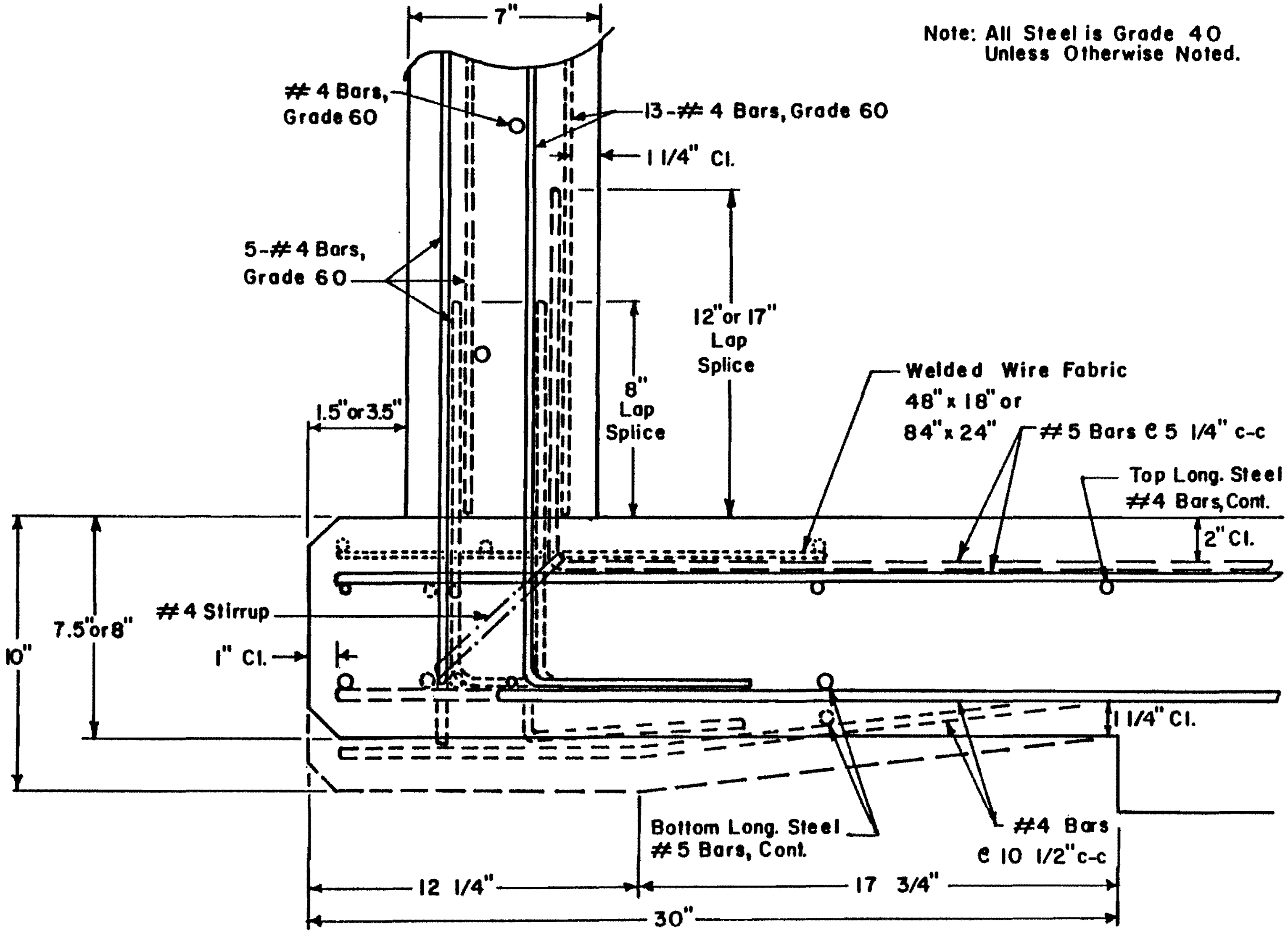
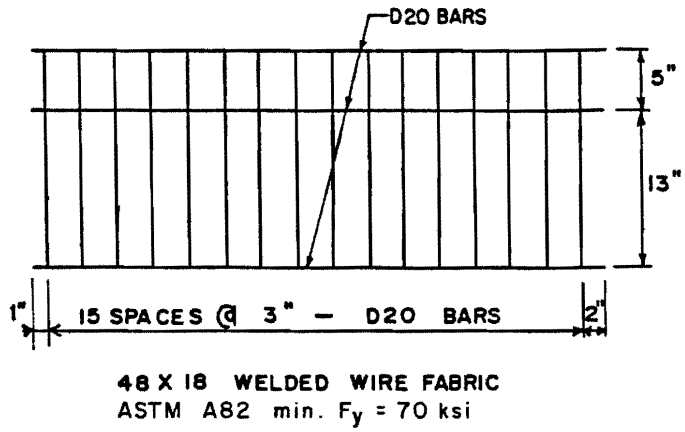


Figure 6. Composite Drawing of the Modifications to the Texas Type T202 Concrete Bridge Rail and Deck.



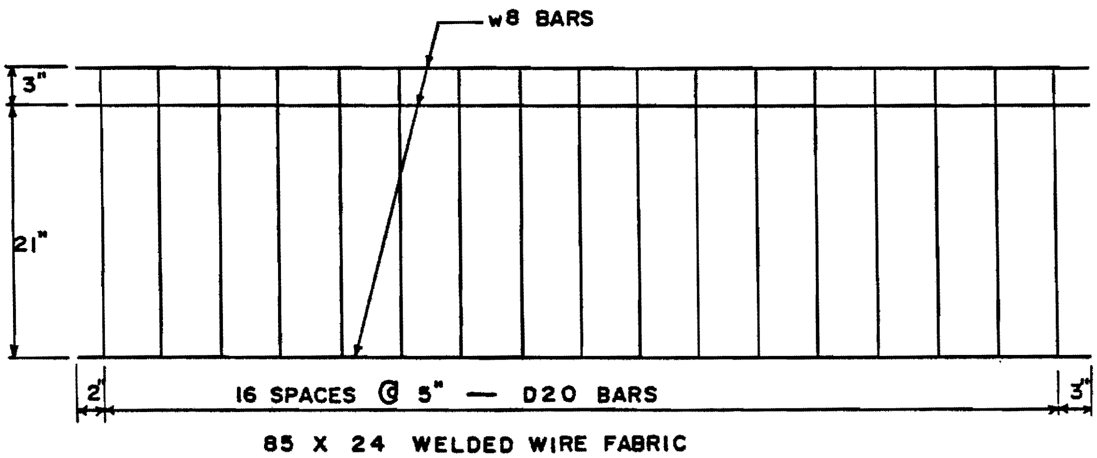


Figure 7. Welded Wire Fabric Used in the Modified Texas Type T202 and T5 Concrete Bridge Decks.

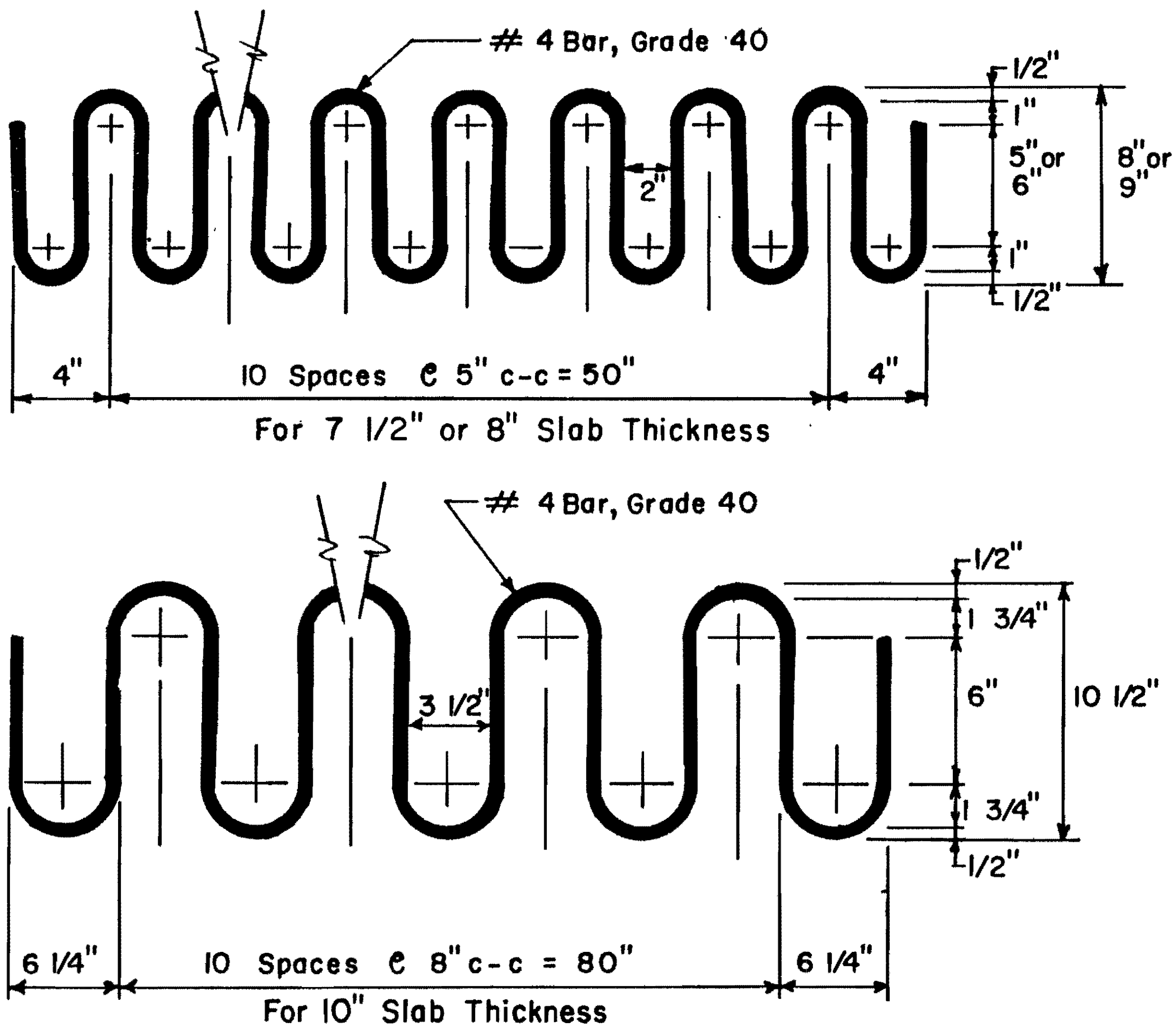


Figure 8. Configurations of the #4 Stirrups Used in the Modified T202 and T5 Bridge Railings.

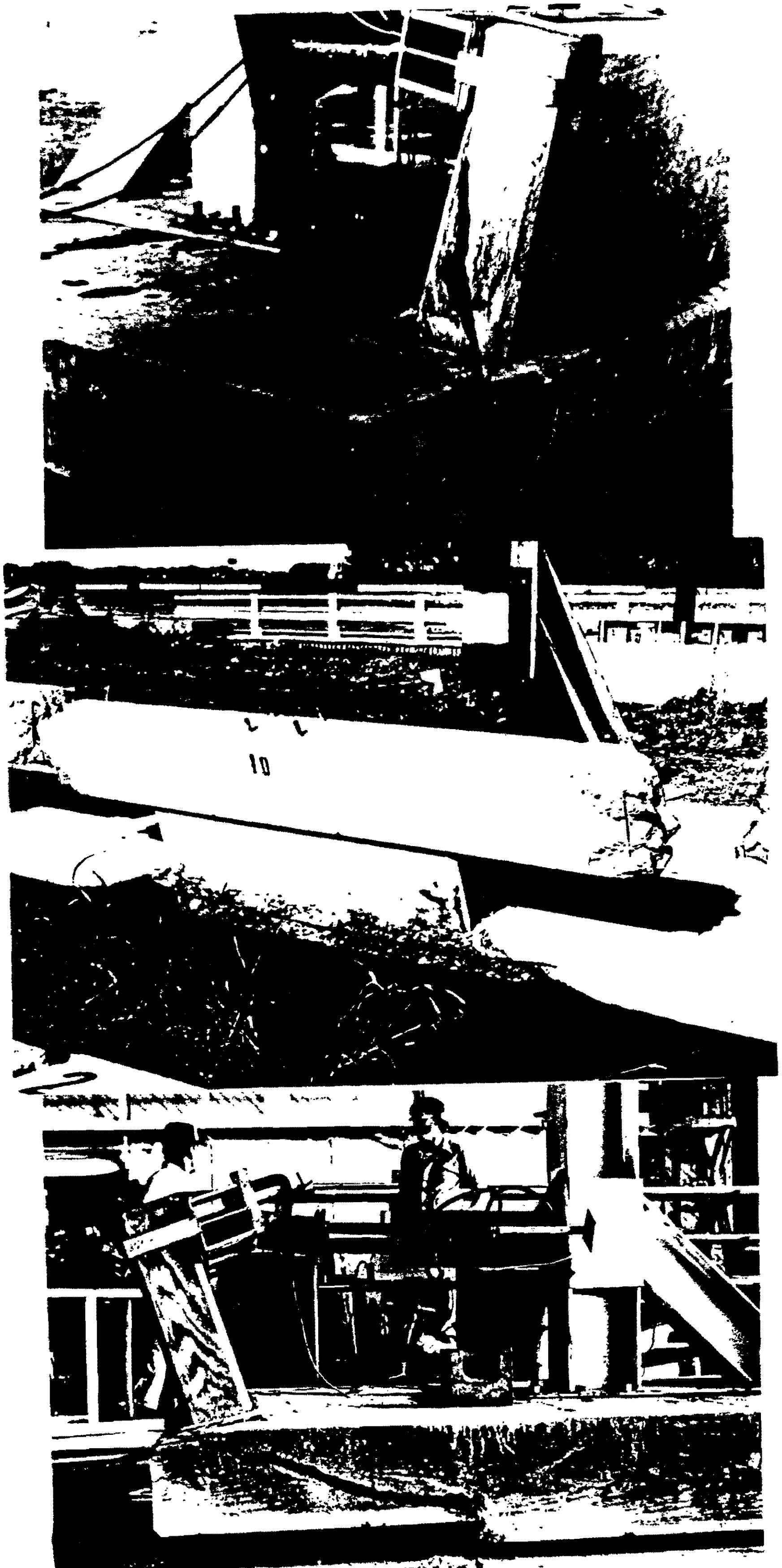


Figure 9 . Typical Crack Patterns for Texas T202 Concrete Post and Bridge Deck.

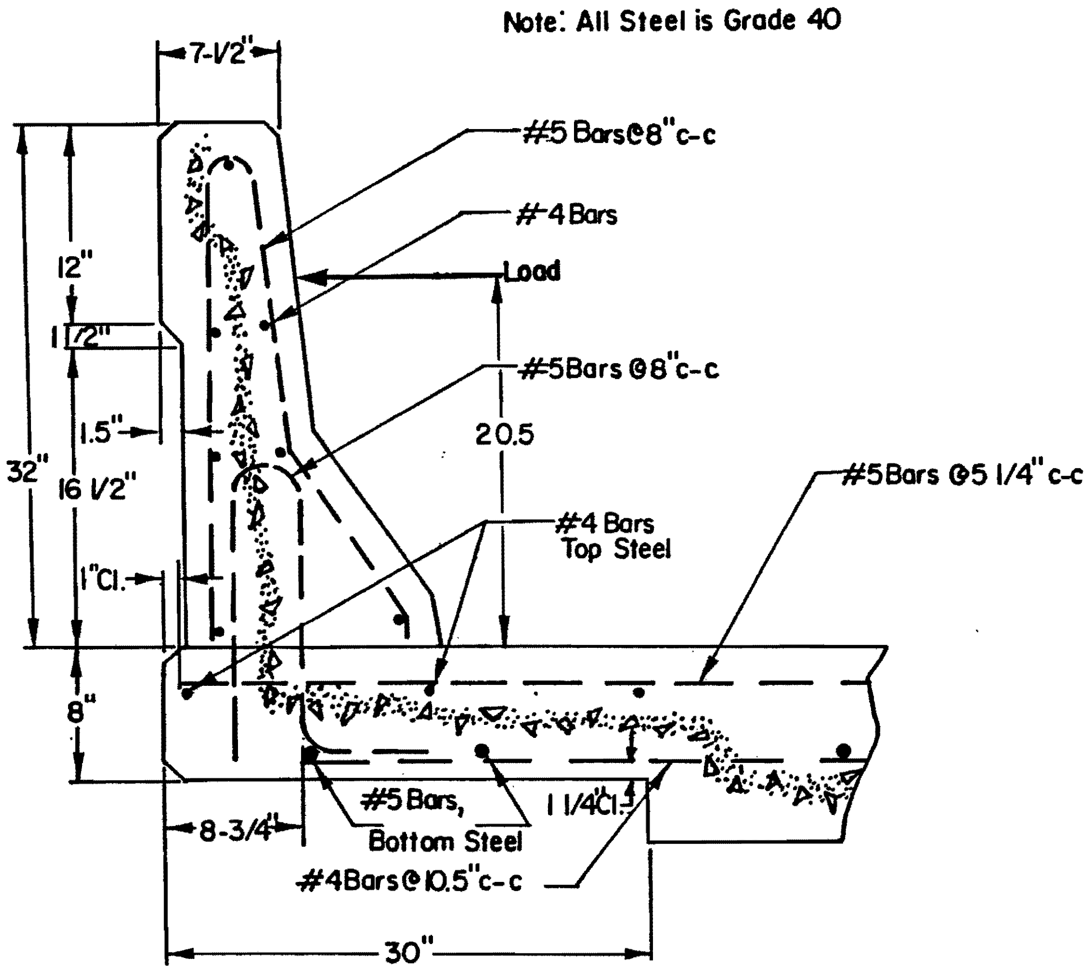


Figure 10. Standard Texas Type T5 Concrete Bridge Rail and Deck.

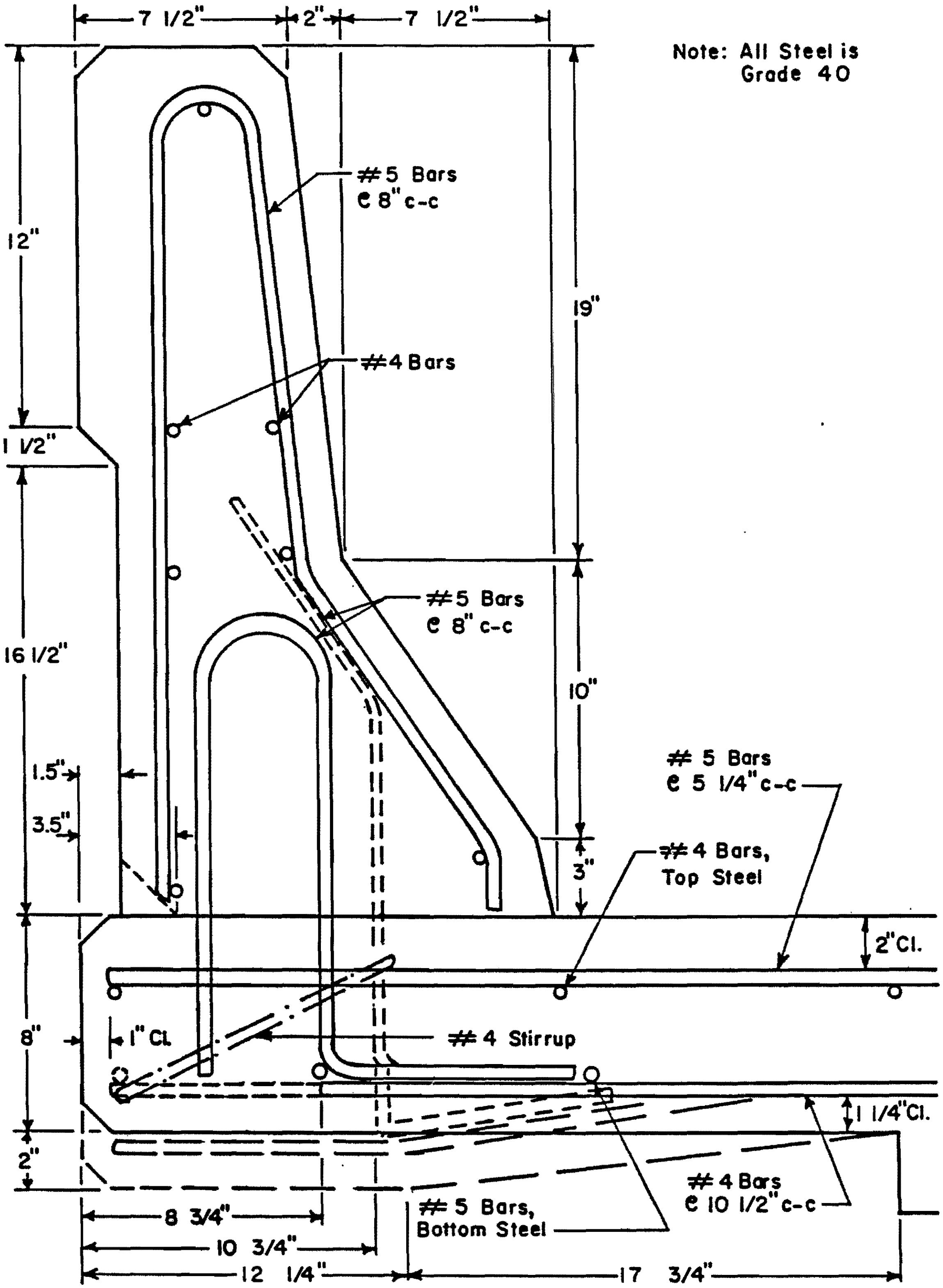


Figure 11. Composite Drawing of Modifications to the Texas Type T5 Concrete Bridge Rail and Deck.

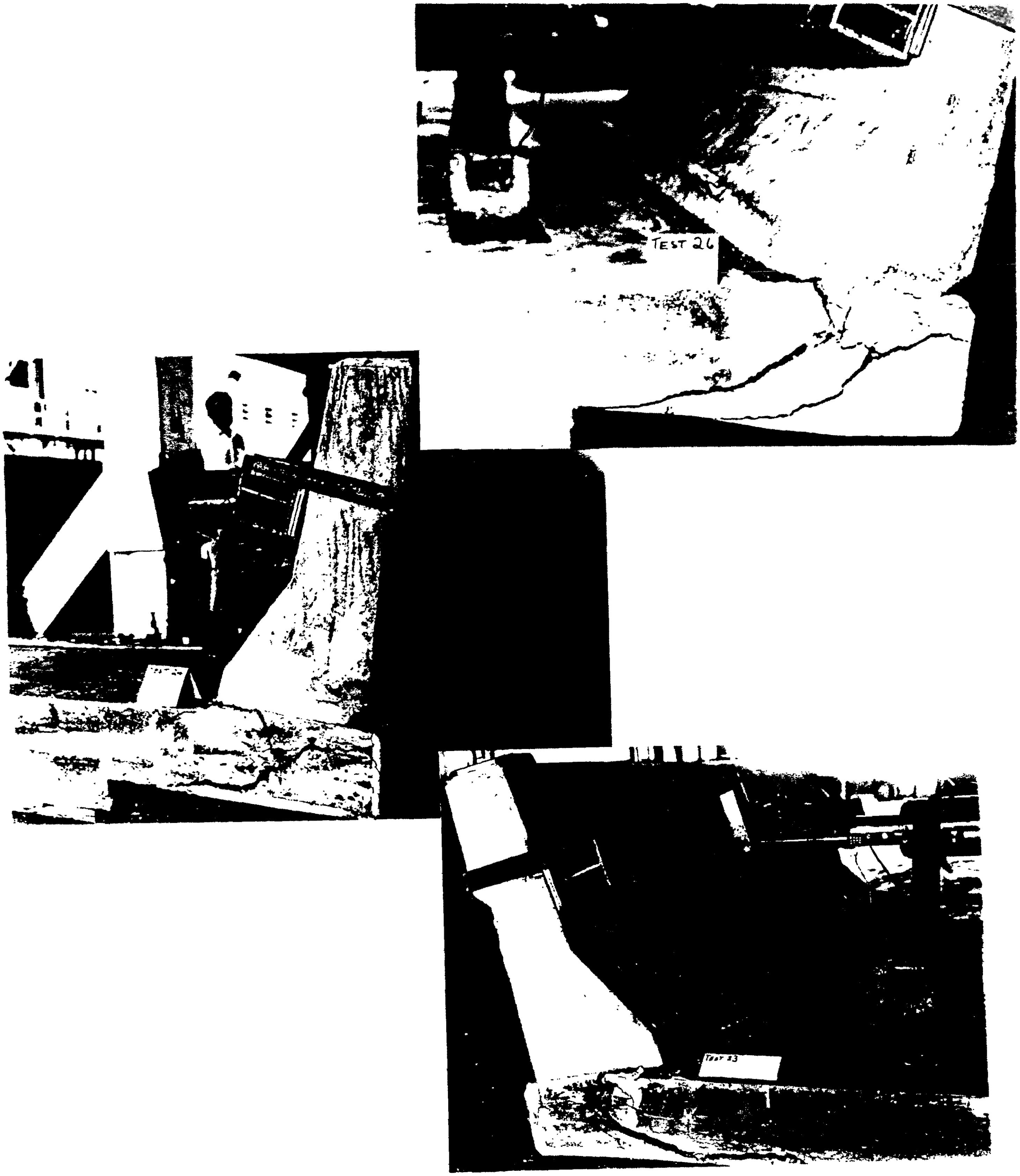


Figure 12. Typical Crack Patterns for Texas T5 Concrete Post and Bridge Deck.

TABLE 1. SUMMARY OF TEST RESULTS ON BRIDGE DECK CONNECTION TO TEXAS TYPE T101 STEEL POST *

TEST NO. AND TYPE	SLAB DEPTH (in.)	EDGE DIST. (in.)	TDR	BDR	B (in.)	BOLT AP	SPECIAL REINF.	PEAK LOAD (Kips)	DISPL (in.)	REMARKS
T101-1D	7.5	1.75	1-#4	1-#5	6	Std.	-	57.9	1.8	2115 lb pendulum at 20 mph, plywood nose. Severe slab cracking and spalling. 2 K load at 16"
T101-2D	7.5	1.75	1-#4	1-#5	6	Std.	-	36.2	1.8	2293 lb pendulum at 20 mph. rubber nose. Severe slab cracking and spalling.
T101-1S	7.5	1.75	1-#4	1-#5	6	Std.	-	18.6	1.6	Severe slab cracking and spalling of concrete. Load falls off to 9.5K at 7.2" displacement.
T101-2S	7.5	1.75	1-#4	1-#5	6	Std.	-	19.0	1.6	Severe slab cracking and spalling of concrete. Load falls off to 3.0 K at 11" displ. Zero load @ 8.8"
T101-3S	7.5	1.75	2-#4	2-#5	1	Std.	Welded Wire Fab.	24.0	2.0	7/8" bolts used. Severe slab cracking but taut. Final load 25K at 9.6"
T101-4S	10	1.75	2-#4	2-#5	1	Std.	Welded Wire Fab.	27.0	3.3	7/8 in. bolts used. Severe slab cracking but taut. Final load 23.5K at 9.4"
T101-5S	8	1.75	1-#4	2-#5	1	Mod. 1	-	21.4	2.0	Anchor bolts broke at 20.5 K and 7" displ. Severe cracking.
T101-6S	10	1.75	1-#4	2-#5	1	Mod. 1	-	21.2	4.7	Anchor bolts broke at 21.2 K and 4.9" displ. Moderate cracking.
T101-7S	8	3.5	2-#4	2-#5	1	Mod. 2	-	22.0	2.3	Anchor bolts broke at 21.7 K and 2.3 in. displ. Moderate cracking.
T101-8S	10	3.5	2-#4	2-#5	1	Mod. 2	-	25.4	2.1	Test terminated at 21.0 K and 6" displ. Moderate cracking.
T101-1PO	- - - Oversize bolts and washers used. - - -							4 .7	3.6	Post failure; flange buckled
T101-2PO	- - Std. 3/4 in. A325 anchor bolts used. - -							23.7	0.8	Nut and washer pulled through hole in base plate at 2.8 in.

*See Key To Abbreviations - Tables 1, 2, & 3.

TABLE 2. SUMMARY OF TEST RESULTS ON BRIDGE DECK CONNECTION TO TEXAS TYPE T202 CONCRETE WALL 5 FT LONG*

TEST NO. AND TYPE	SLAB DEPTH (in.)	EDGE DIST. (in.)	REINF. PATTERN	TDR	BDR	B (in.)	SPECIAL REINF.	PEAK LOAD (Kips)	DISPL (in.)	REMARKS
T202-1D	7.5	1.5	Std.	1-#4	1-#5	6	-	109	1.6	Severe cracking of concrete slab Load falls to 9 K at 10"
T202-1S	7.5	1.5	Std.	1-#4	1-#5	6	-	26.3	0.3	Severe cracking & spalling of concrete slab. Load falls to 4 K at 10"
T202-2S	7.5	1.5	Std.	1-#4	1-#5	1	Welded Wire Fab. 48"x18"	25.1	0.5	Severe cracking of concrete slab. Load falls to 7.5 K at 7.5 K at 9"
T202-3S	7.5	1.5	Std.	1-#4	1-#5	1	Welded Wire Fab. 48"x18"	21.4	0.4	Severe cracking of concrete slab. Load falls to 7 K at 8"
T202-4S	7.5	1.5	Std. w/ Wall Lap spl.	1-#4	1-#5	1	Welded Wire Fab. 85"x24"	21.7	0.9	Severe cracking of concrete slab. Load falls to 9 K at 8"
T202-5S	8	1.5	Mod. 1	2-#4	2-#5	1	Stir. #4 @ 2 5/8"	24.9	0.8	Severe cracking of concrete slab. Load falls to 9 K at 10"
T202-6S	10	1.5	Mod. 1	2-#4	2-#5	1	Stir. #4 @ 2 5/8"	31	0.7	Minor slab cracking. Wall cracks at end 12 in. lap spl. Load falls to 7.5 K at 4"
T202-7S	8	3.5	Mod. 2	2-#4	2-#5	1	Stir. #4 @ 2 5/8"	23.4	1.1	Minor slab cracking. Wall cracks at end 17 in. lap spl. Load falls to 3.5 K at 3"
T202-8S	10	3.5	Mod. 2	2-#4	2-#5	1	Stir. #4 @ 2 5/8"	29.2	0.9	Minor slab cracking. Wall cracks at end 17 in. lap spl. Load falls to 8 K at 5"
T202-9S	8	3.5	Std.	2-#4	2-#5	1	-	35	0.9	Slab cracking. Load falls 6 K at 8"
T202-10S	10	3.5	Std.	2-#4	2-#5	1	-	40	0.9	Slab cracking.Load falls to 8K at 9"

*See Key To Abbreviations - Tables 1, 2, & 3.

TABLE 3. SUMMARY OF TEST RESULTS ON BRIDGE DECK CONNECTION TO TEXAS TYPE T5 SAFETY SHAPE CONCRETE BARRIER*

TEST NO. AND TYPE	SLAB DEPTH (in.)	EDGE DIST. (in.)	REINF. PATTERN	TDR	BDR	B (in.)	SPECIAL REINF.	PEAK LOAD Kips	DISPL (in.)	REMARKS
T5-1S	8	1.5	Std.	1-#4	1-#5	6	-	45	1.2	Moderate slab cracking. Load falls to 15 kips at 5 in.
T5-2S	8	3.5	Mod. 1	1-#4	1-#5	1	-	36.2	0.4	Moderate slab cracking. Load falls to 10 kips at 3 in.
T5-3S	8	3.5	Mod. 1	1-#4	1-#5	1	Stir. #4 @ 2 5/8"	42.2	0.6	Moderate slab cracking. Load falls to 18 kips at 3.5 in.
T5-4S	10	3.5	Mod. 1	1-#4	1-#5	1	Stir. #4 @ 2 5/8"	49.1	0.5	Moderate slab cracking. Load falls to 10 kips at 5 in.

*See Key To Abbreviations - Tables 1, 2, & 3.

KEY TO ABBREVIATIONS - TABLES 1, 2, & 3

TEST NO. AND TYPE - The test number is given. The type of loading is indicated by the last letters: D - dynamic loading, and S - static loading.

SLAB DEPTH - Depth of the slab at the edge.

EDGE DIST. - Distance between the edge of the deck and the field side of the post.

REINF. PATTERN - four types of reinforcing patterns were used:

Std. - The standard reinforcing pattern currently used.

Std. w/Wall Lap Spl. - Standard with an 8" wall lap splice.

Mod. 1 - In the first modification the top steel bends into the traffic side with a 12-in. lap splice in the post.

Mod. 2 - In the second modification the top steel bends into the traffic side with a 17-in. lap splice in the post.

TDR - Top deck reinforcing located at the edge of the deck

BDR - Bottom deck reinforcing located at the edge of the deck

B - Bottom transverse reinforcing steel clearance.

SPECIAL REINF. - Two sizes of welded wire fabric and the #4 bar stirrups were used as special reinforcing.

PEAK LOAD Kips - The ultimate (failure) load in kips the system withstood.

DISPL in. - The lateral displacement of the post at the loading height at the peak load.

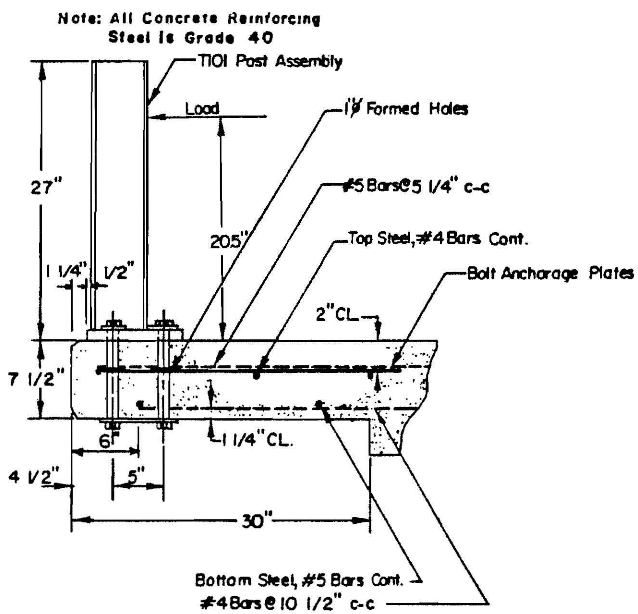
REFERENCES

1. American Association of State Highways and Transportation Officials, _Standard Specifications for Highway Bridges_, Twelfth Edition, 444 North Capitol Street, N.W., Suite 225, General Offices, Washington, D.C., 1977.

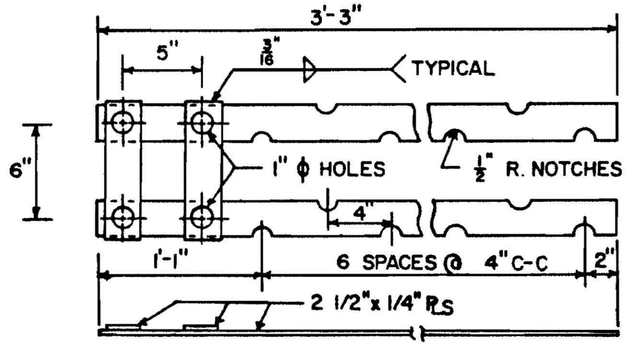
2. Hirsch, T. J., "Analytical Evaluation of Texas Bridge Rails to Contain Buses and Trucks," Research Report 230-2, Texas Transportation Institute, Texas A&M University, College Station, Tx, 1978.

3. Buth, C. E., Noel, J. S., Arnold, A., Hirsch, T. J., "Safer Bridge Railings," Final Report on Contract DOT-FH-11-9181, Texas Transportation Institute, College Station, Tx, May 1983.

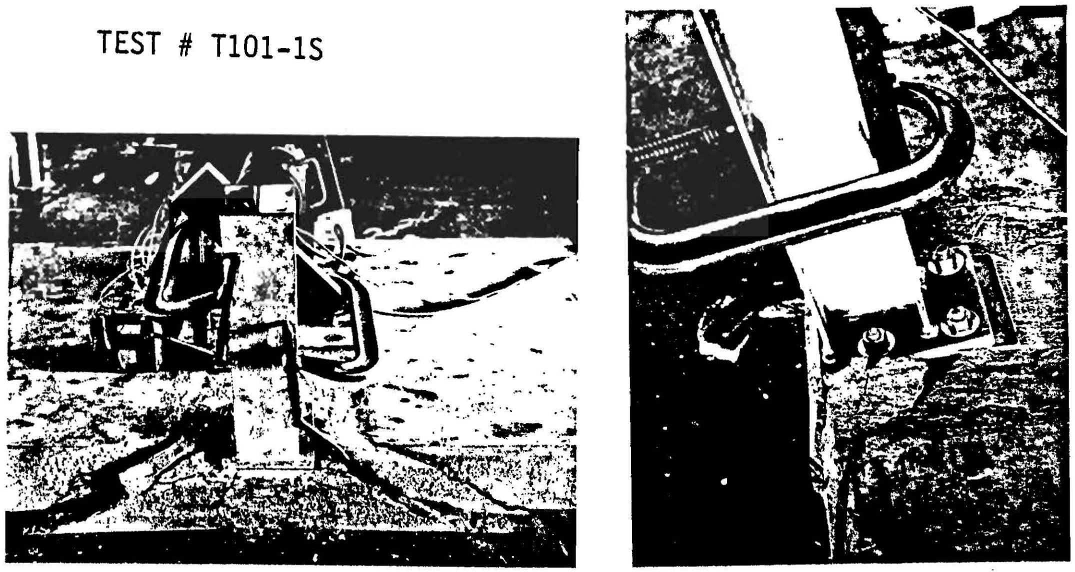
APPENDIX A. SUMMARY OF RESULTS FOR EACH TEST



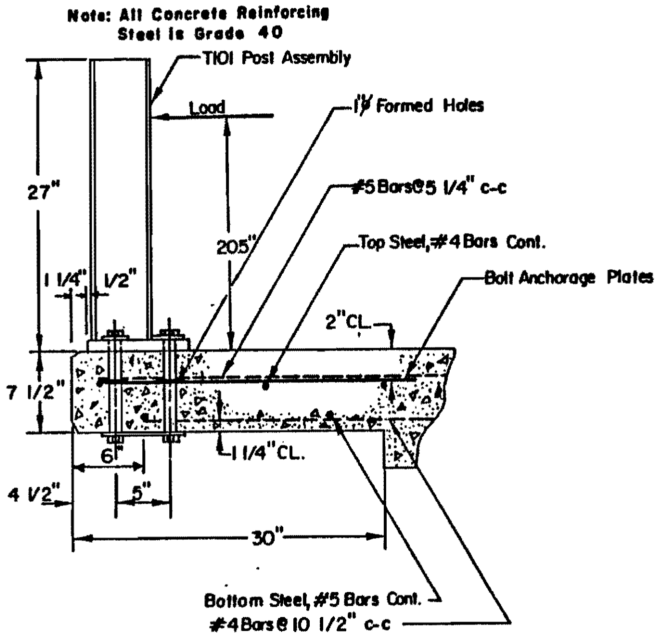
TEST # T101-1S

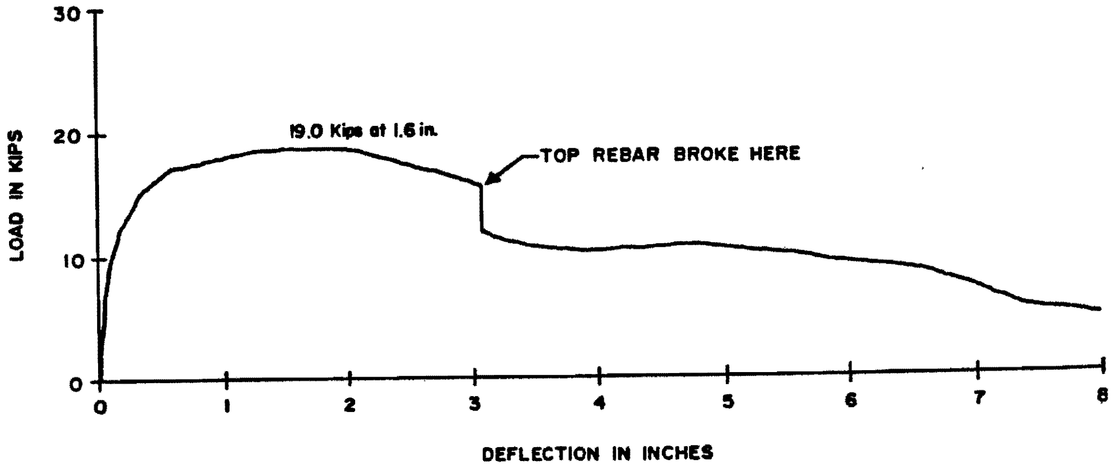


Bolt Anchor Plates

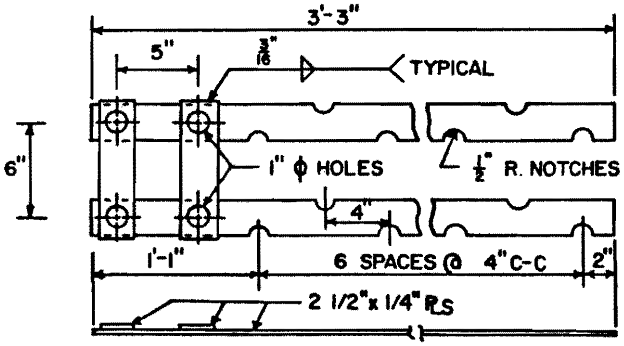


Crack Pattern In Deck After Test





TEST # T101-2S



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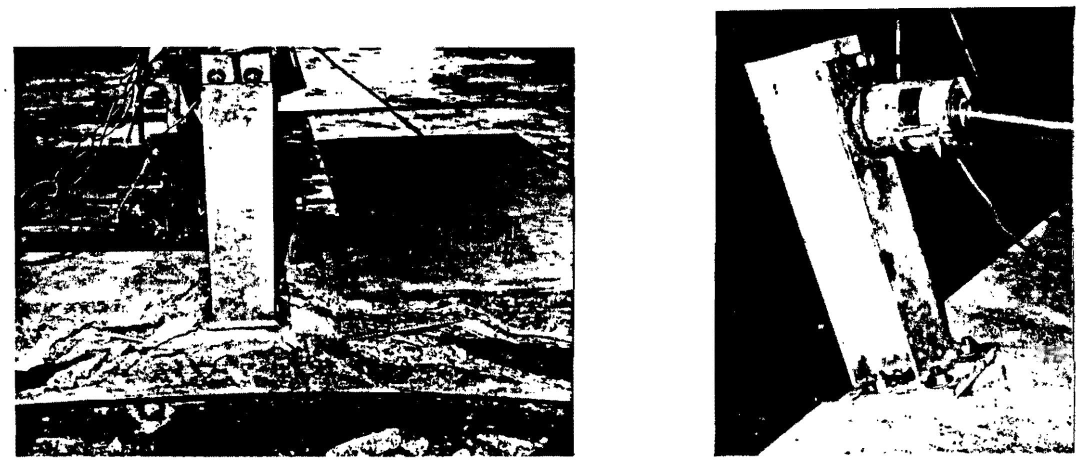
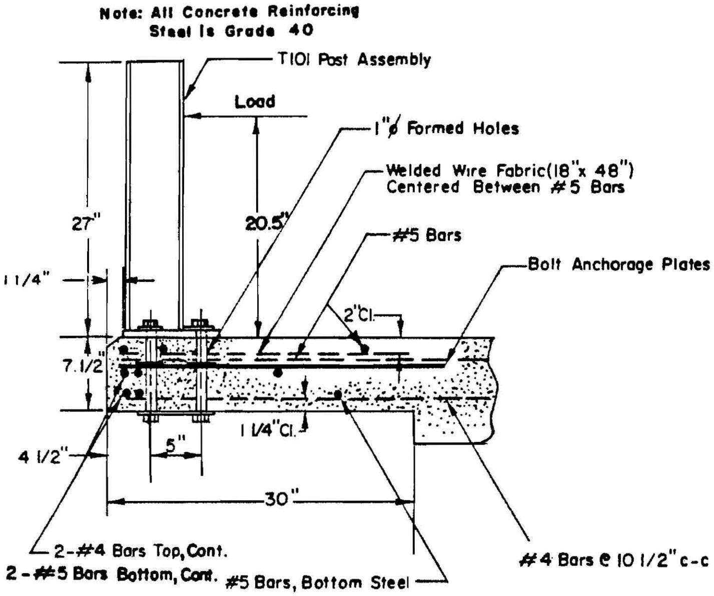
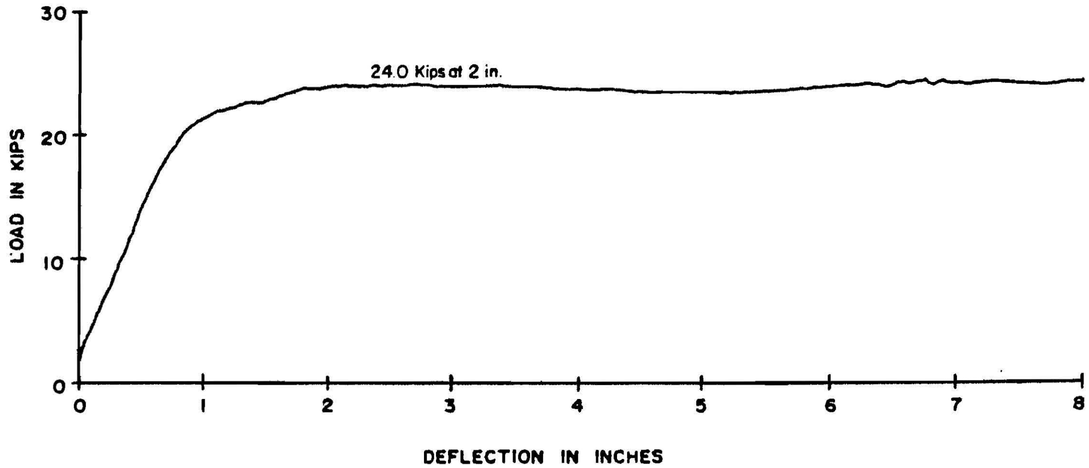
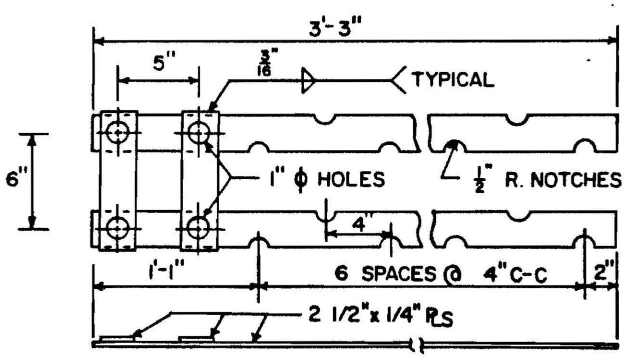


Crack Pattern in Deck After Test

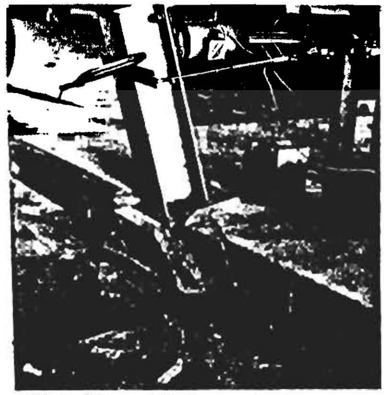






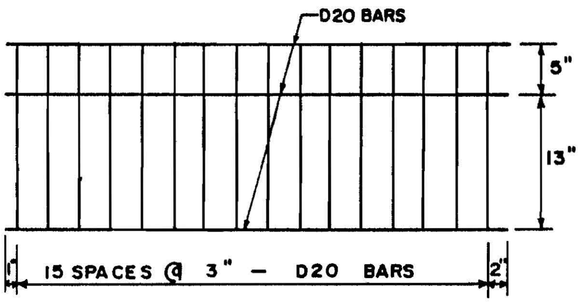
Bolt Anchor Plates

TEST #
T101-3S



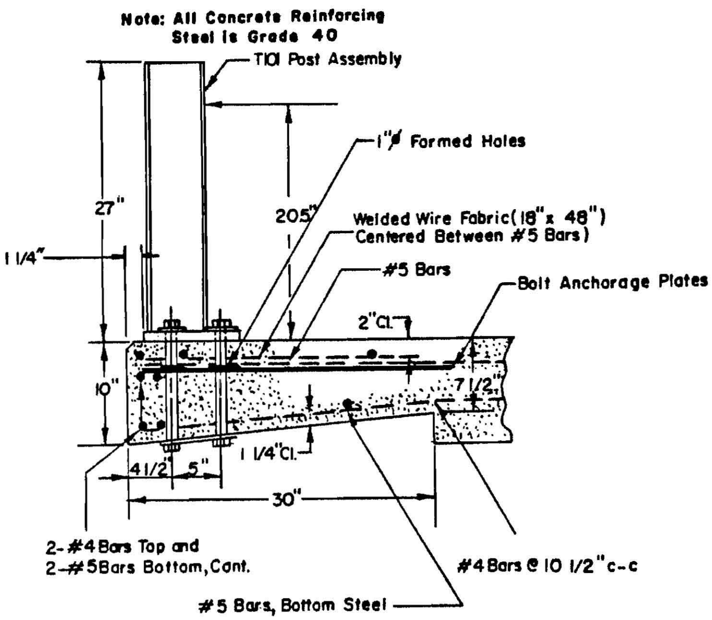
Slab After 10" Post Displacement

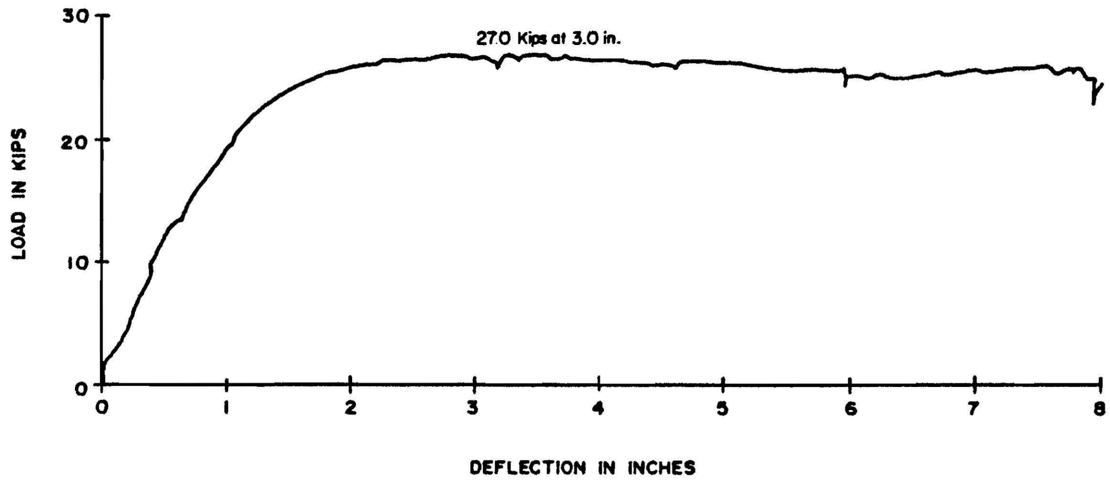
Slab After 2" Post Displacement

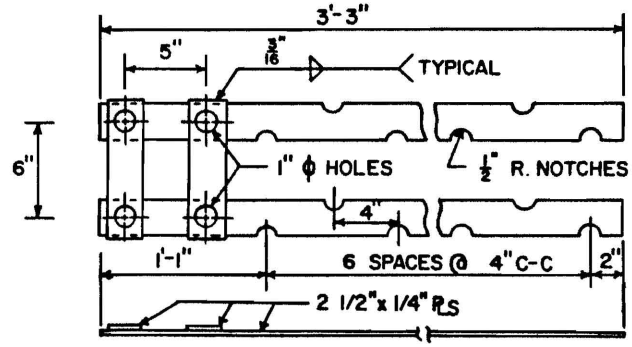


48 X 18 WELDED WIRE FABRIC

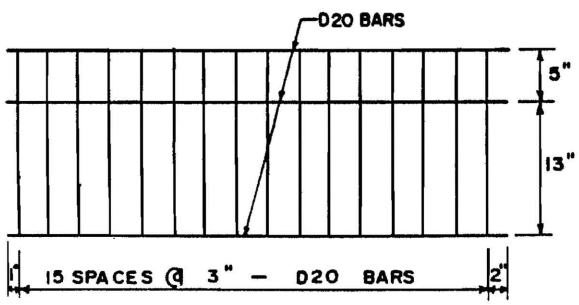
Concrete Removed to Expose Steel



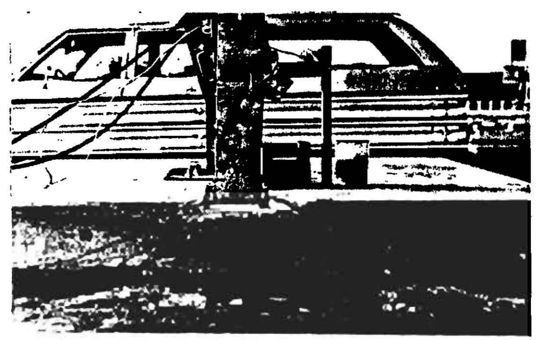




Bolt Anchor Plate



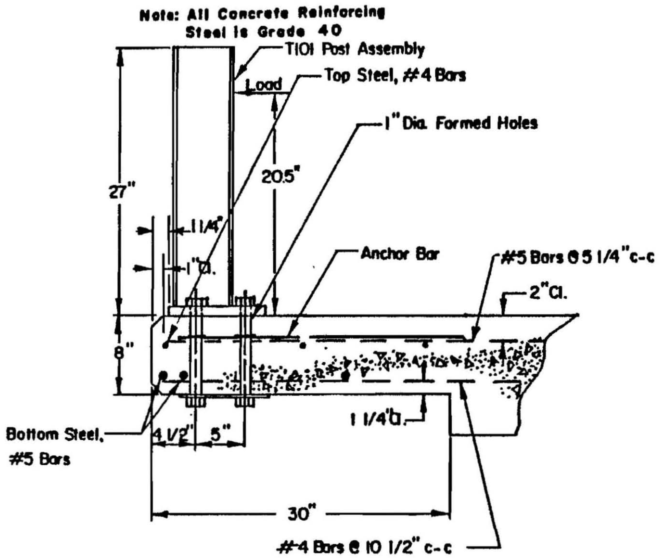
TEST # T101-4S

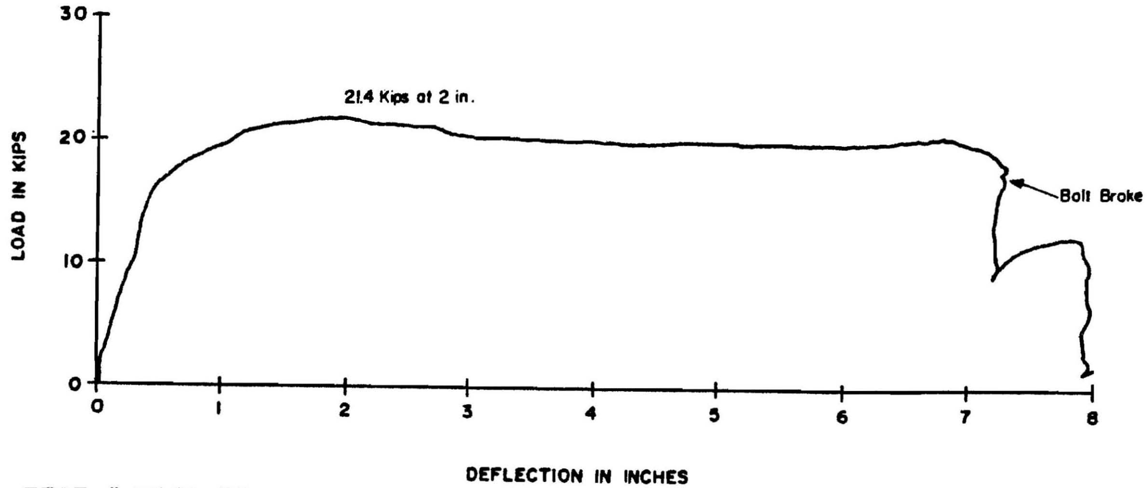


Slab After 10" Post Displacement

Post Base Plate

Concrete Removed to Expose Steel

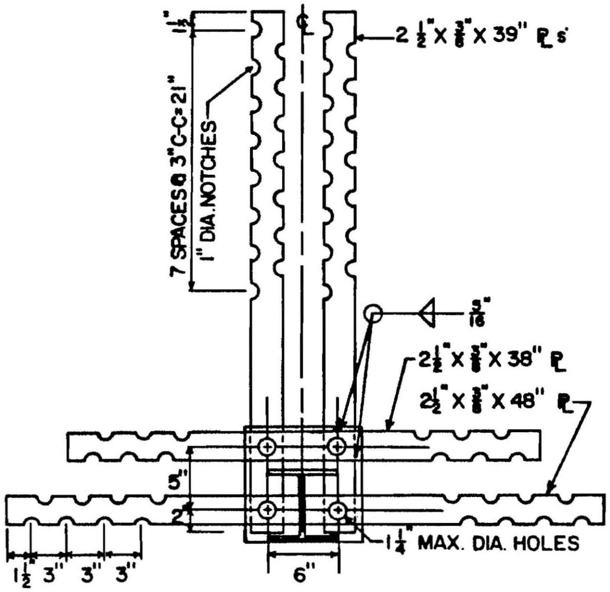




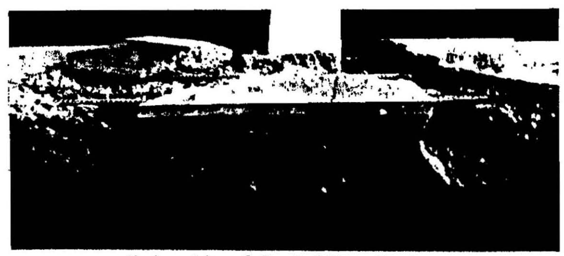
TEST # T101-5S

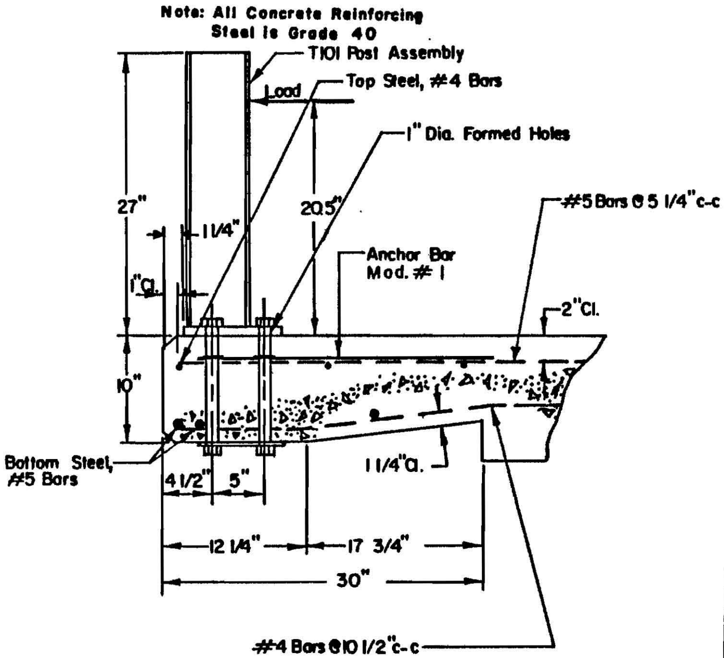

Cracked Deck and Bent Base Plate After Test

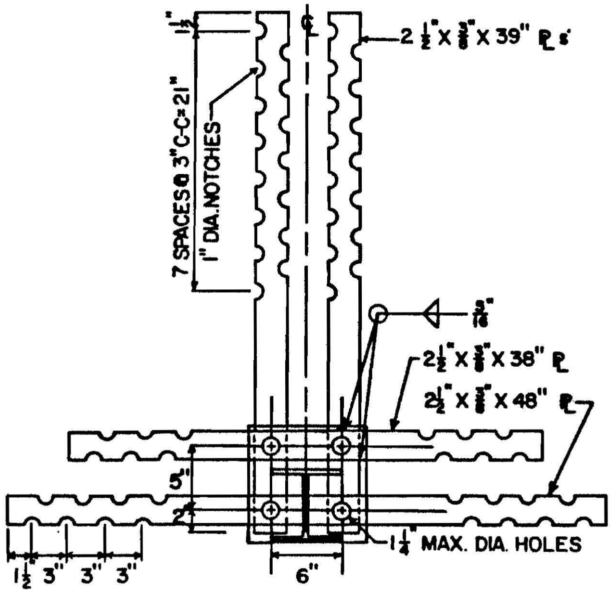

Deck After Test Shown With Anchor Bar



Bolt Anchor Plate


Underside of Deck After Test





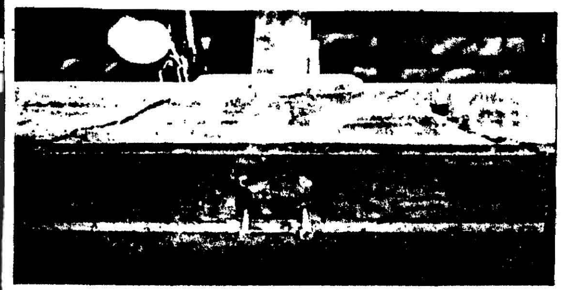
Bolt Anchor Plate

TEST # T101-6S

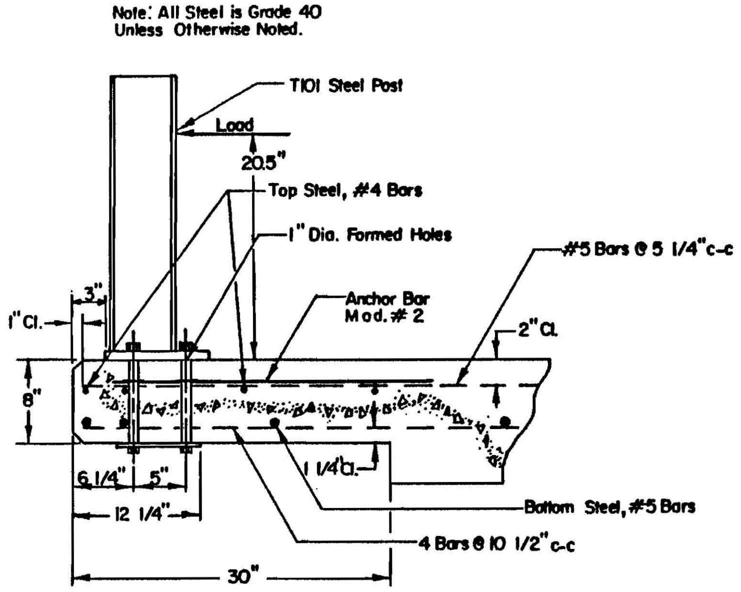

14 Kip Load - 1/2" Deflection

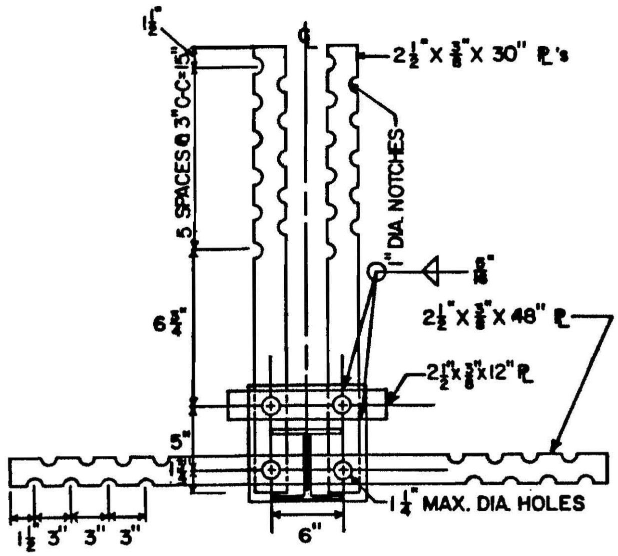

22 Kip Load - 5" Deflection


Concrete Removed to Expose Steel

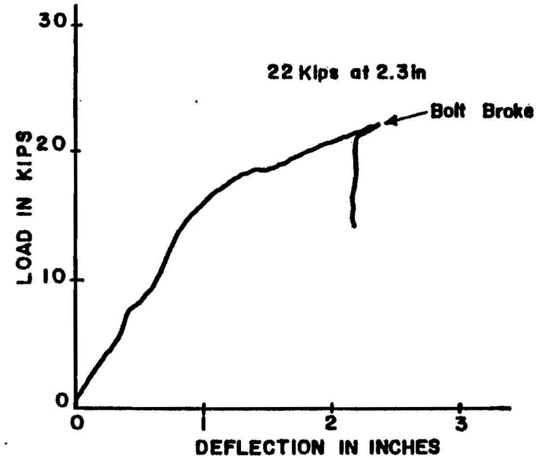

Underside of Deck After Test

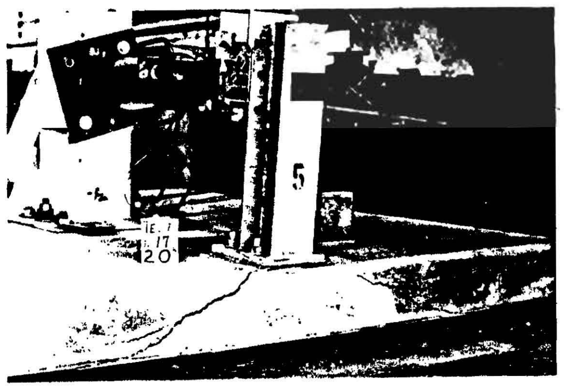
TEST # T101-7S



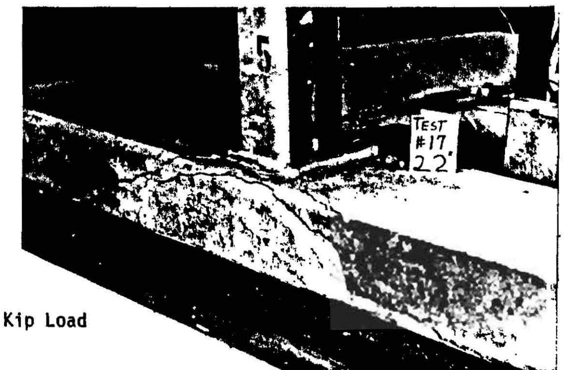


Bolt Anchor Plate



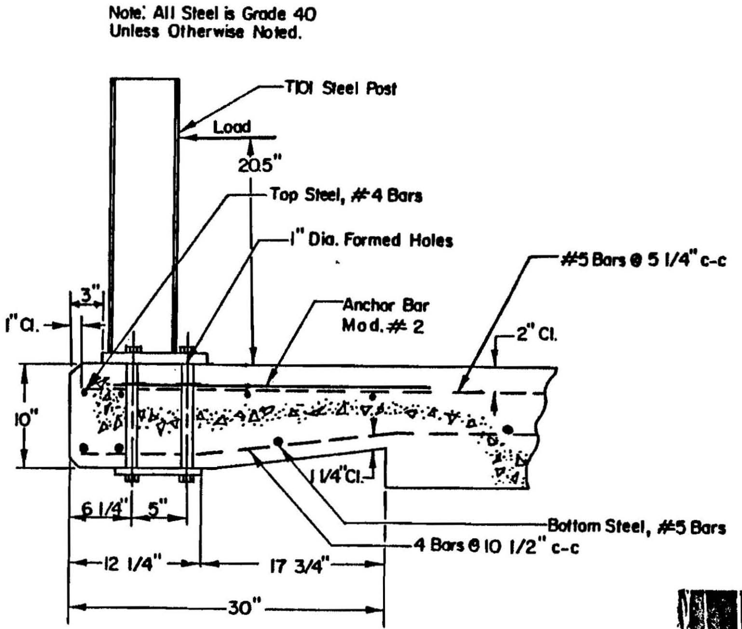


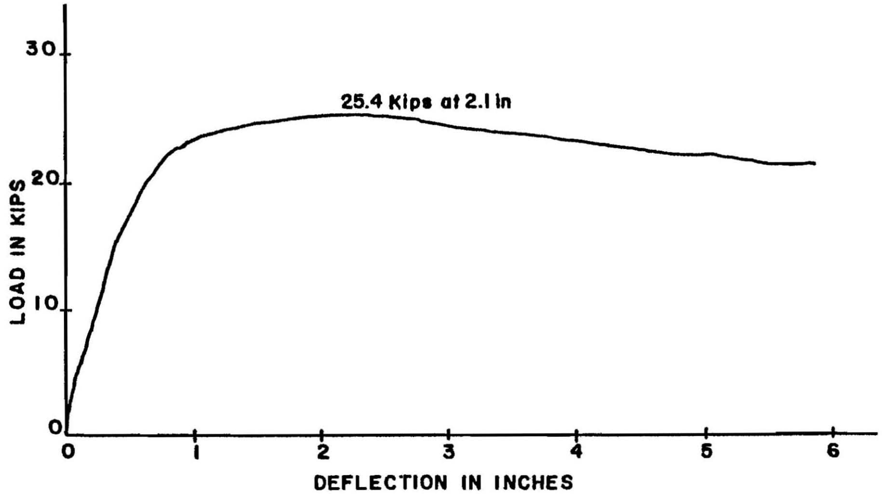
20 Kip Load



22 Kip Load

Bolt Broke

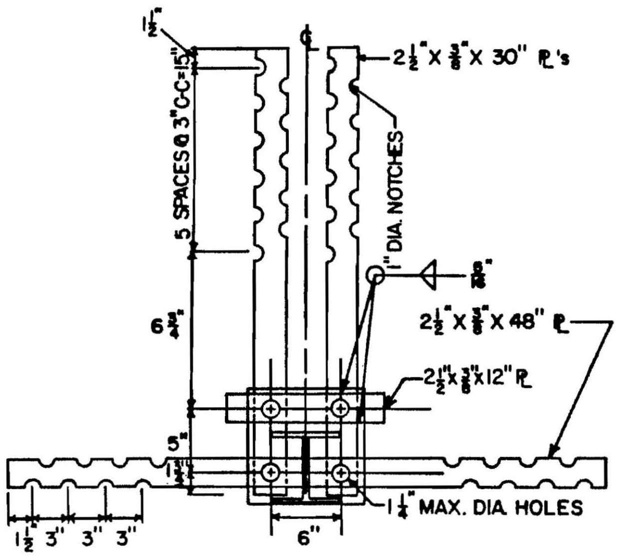




TEST # T101-8S

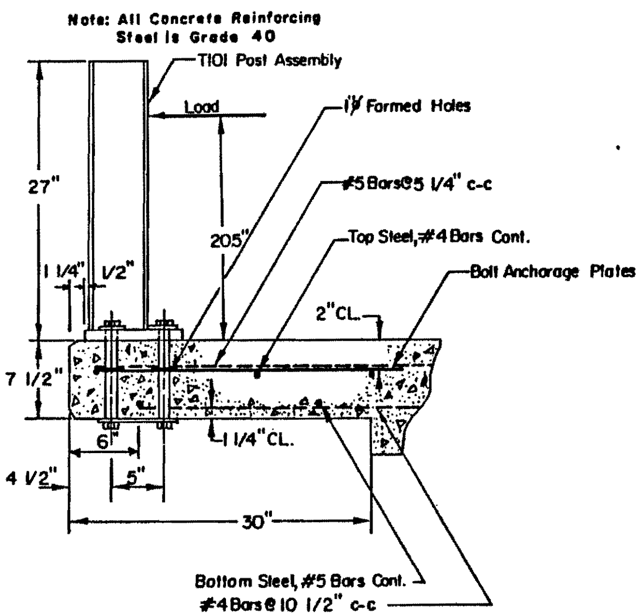
20 Kip Load - 6.0" Post Displacement

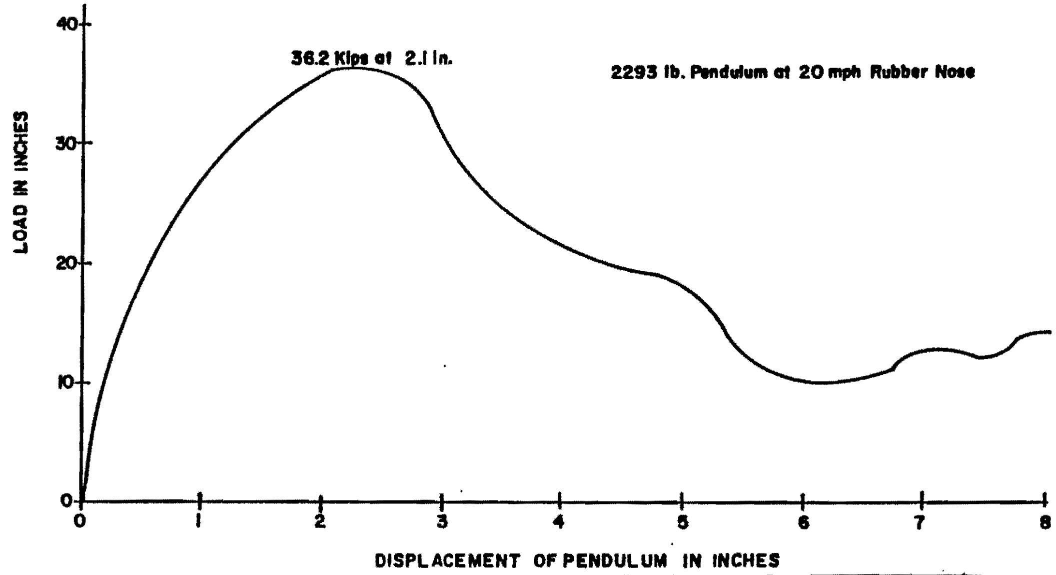
20 Kip Load - 0.8" Post Displacement

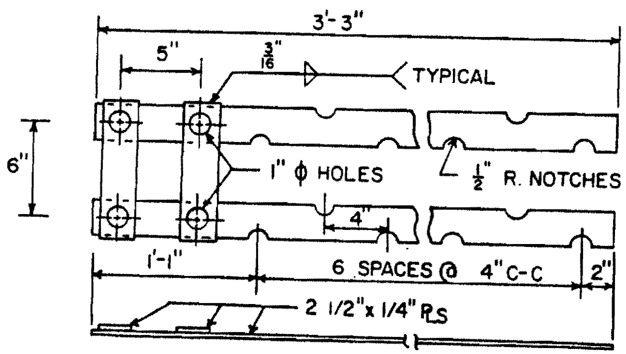


Bolt Anchor Plate

24 Kip Load - 1.3" Post Displacement

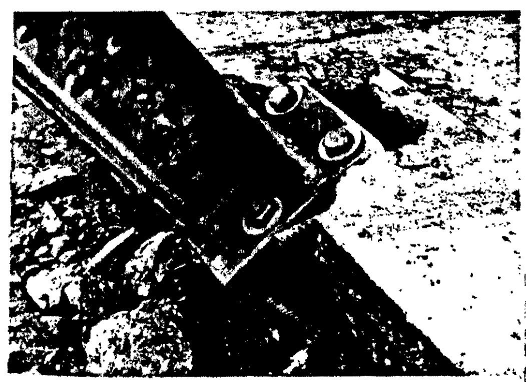




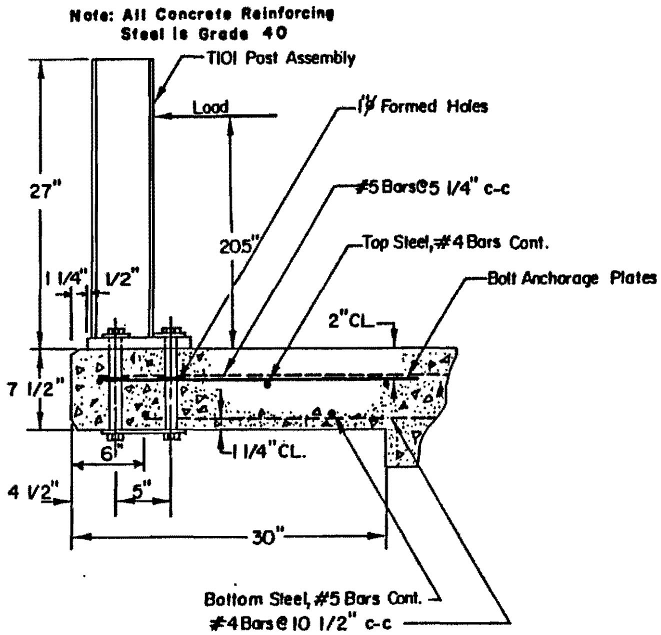


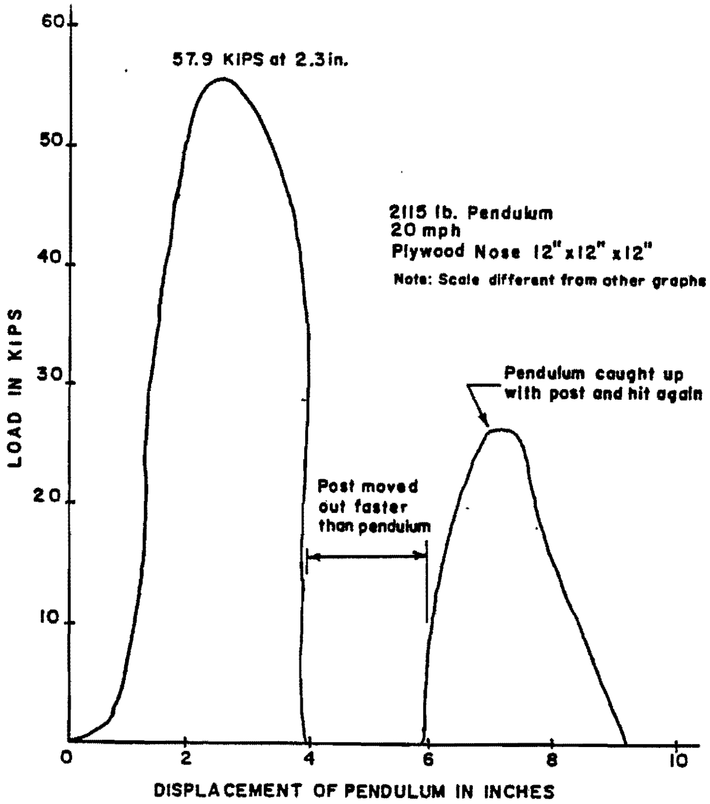
Bolt Anchor Plates

TEST # T101-1D

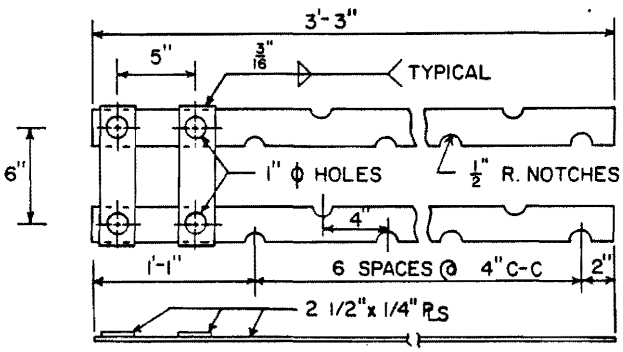


Deck Cracking in T101 Deck After Dynamic Test

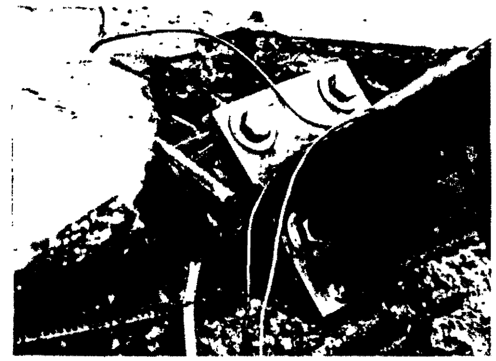


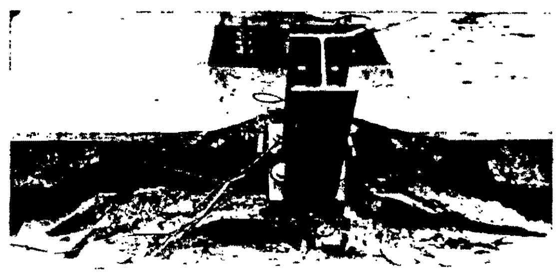


TEST # T101-2D

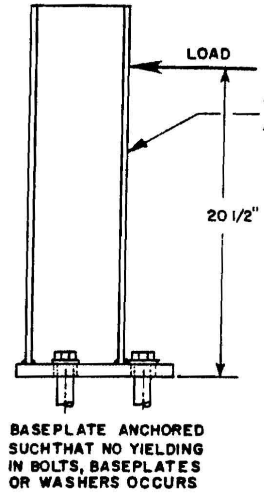


Bolt Anchor Plates

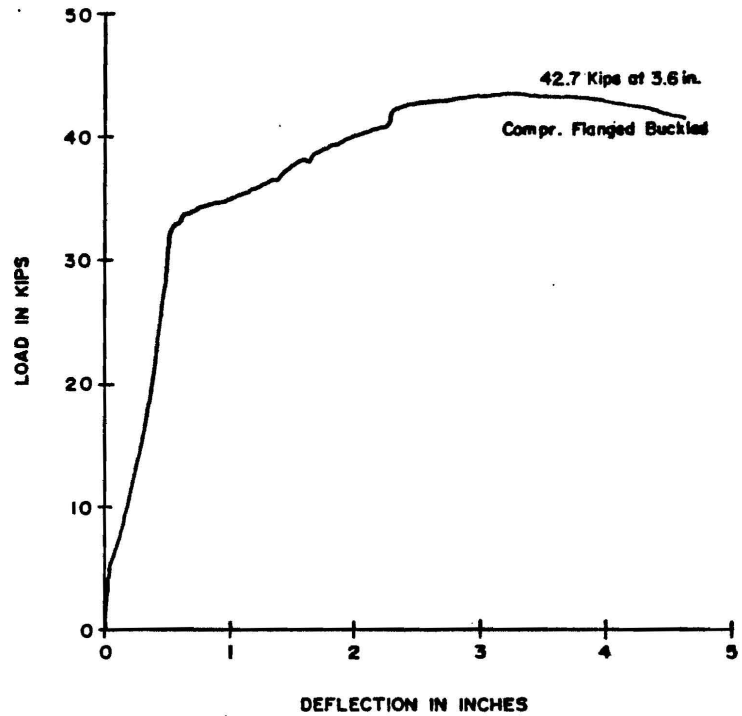




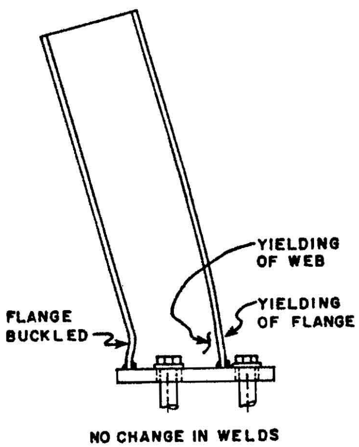
Deck Cracking in T101 Deck after Dynamic Test



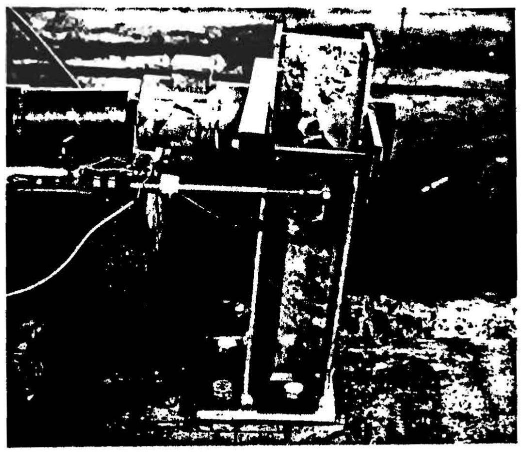
BEFORE TEST



TEST # T101-1PO

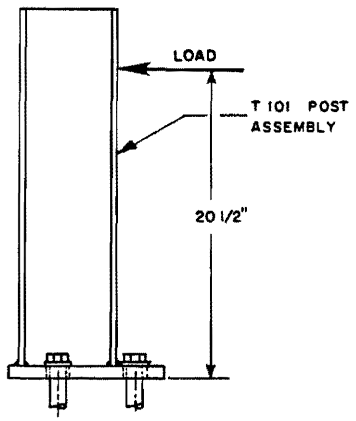


AFTER TEST



Post Deflection of 2 Inches

Post Deflection of 4 1/2 Inches



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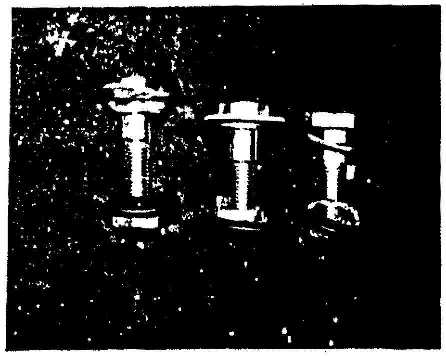
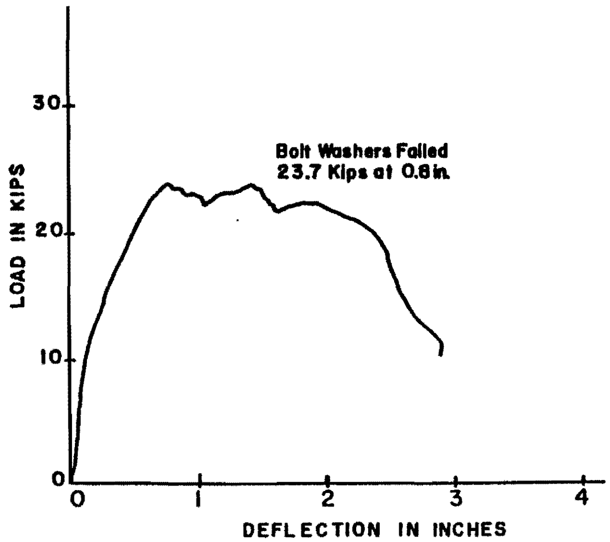
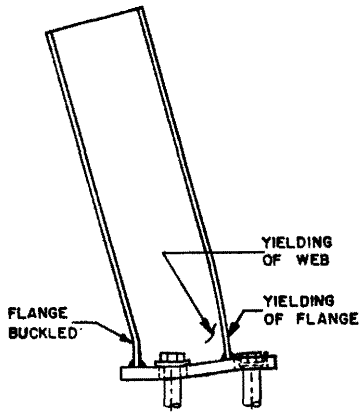


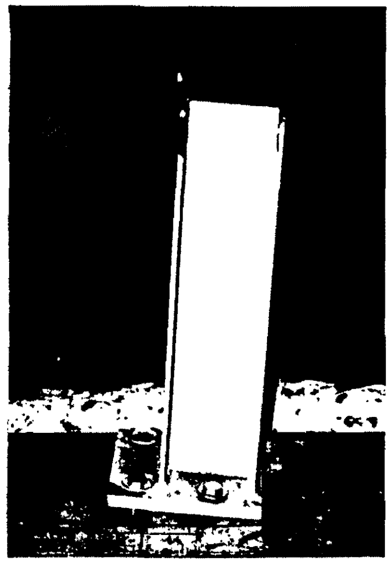
Bolts With Washer After Test

TEST # T101-2PO

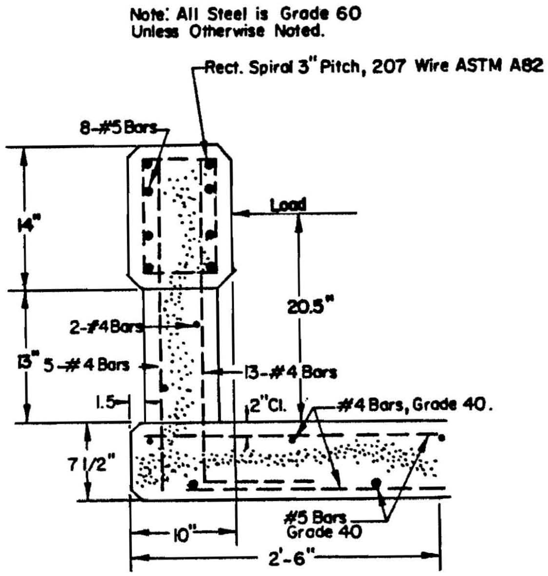


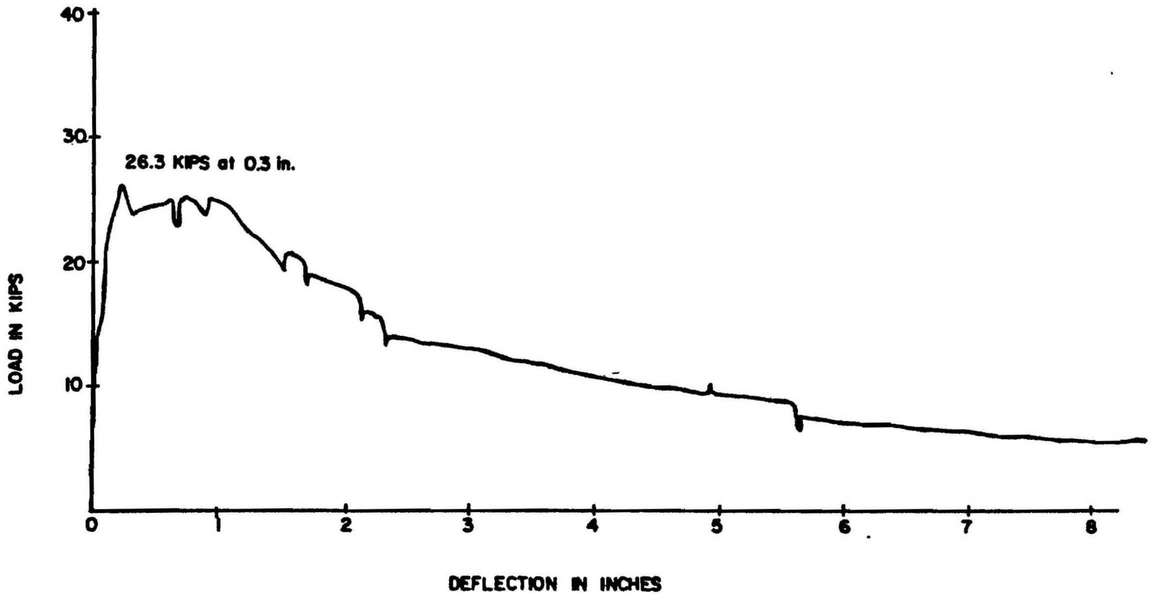


AFTER TEST

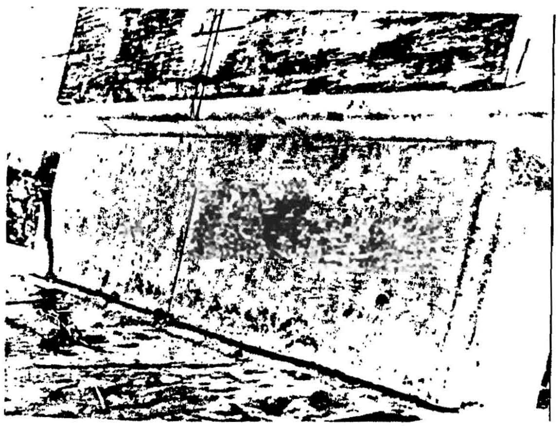


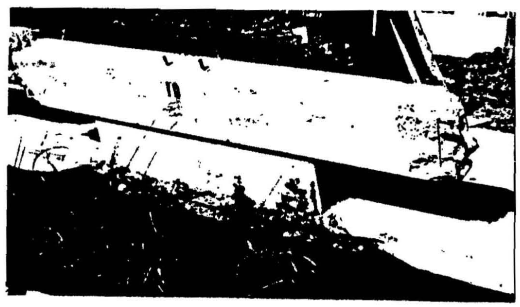
Posts After Test



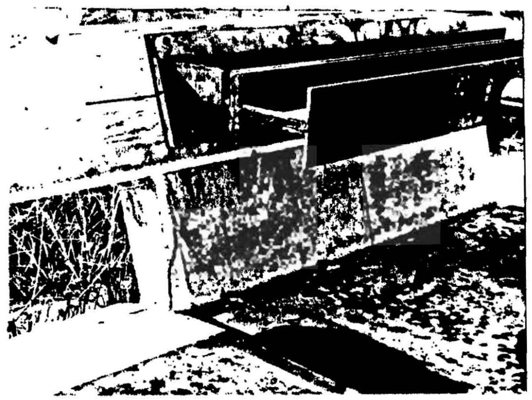


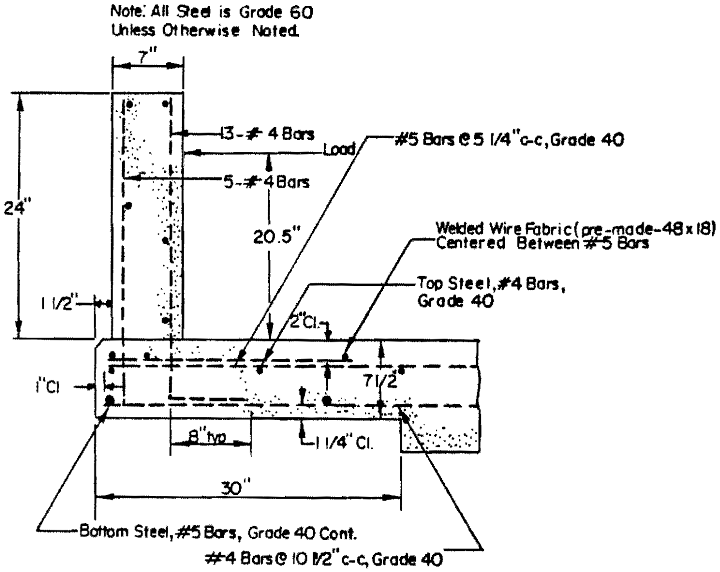
TEST # T202-1S

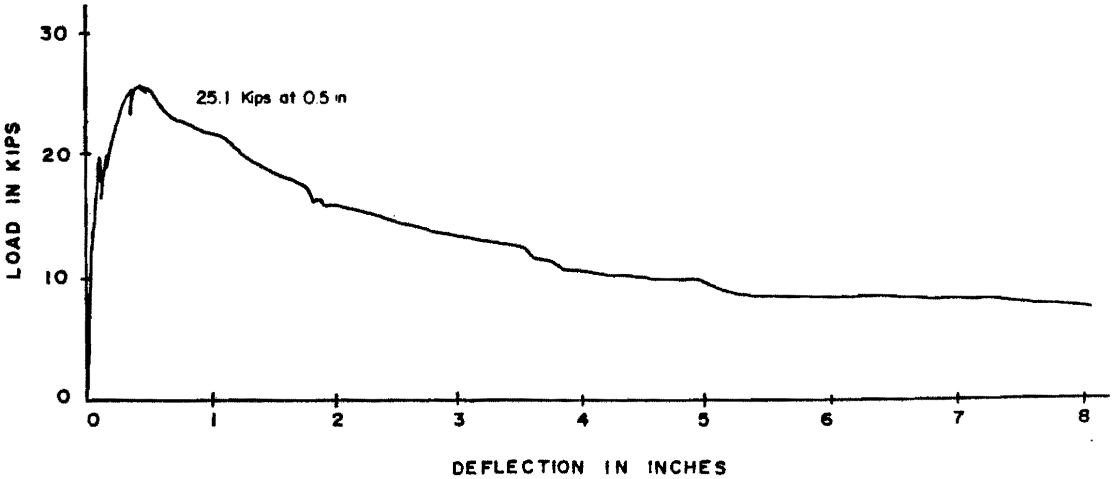




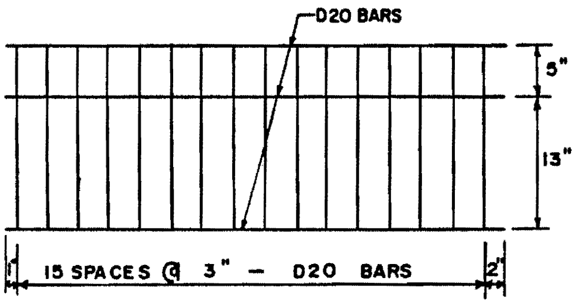
Cracking in Modified T202 Post and Slab After Test





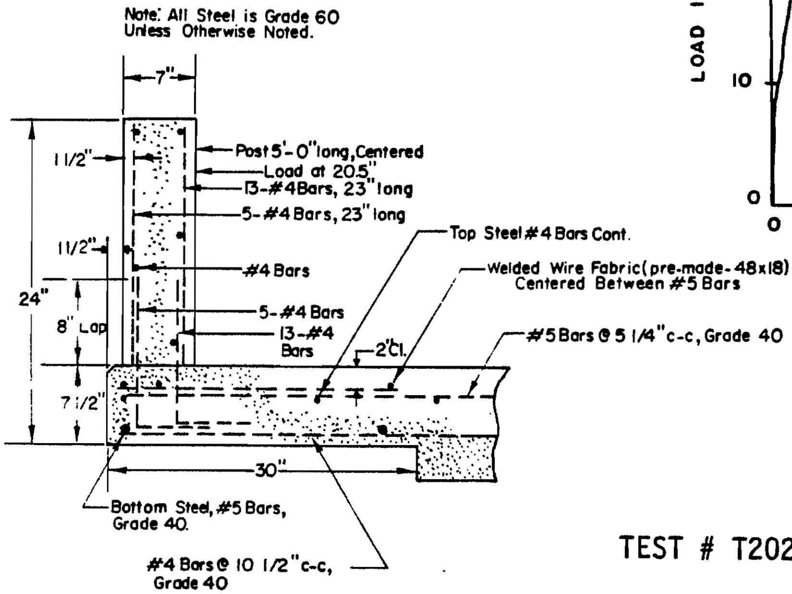


TEST # T202-2S

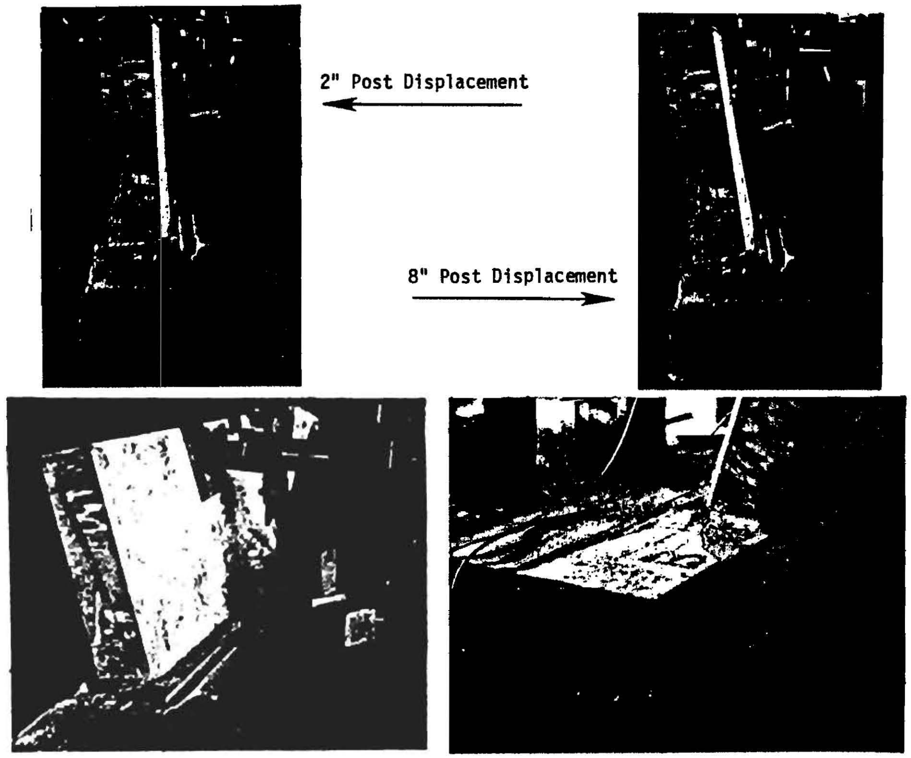


48 X 18 WELDED WIRE FABRIC

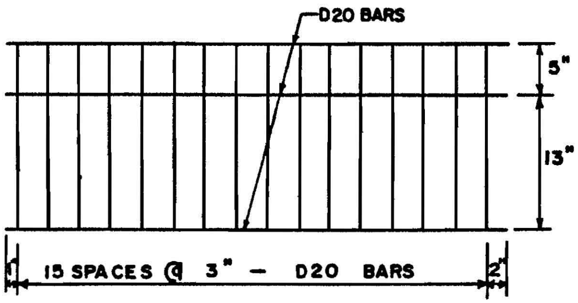
Modified T202 Post With 7 1/2" Deck and Welded Wire Fabric After Test



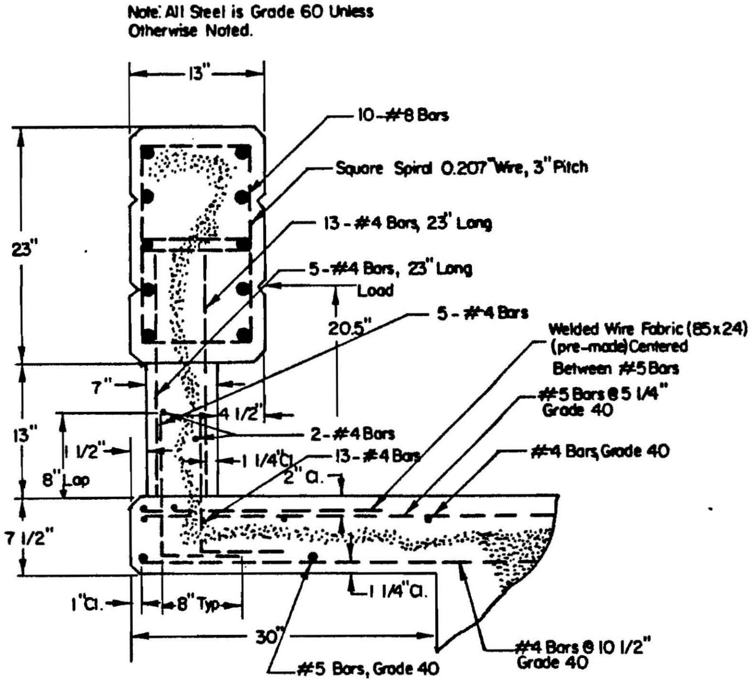
TEST # T202-3S



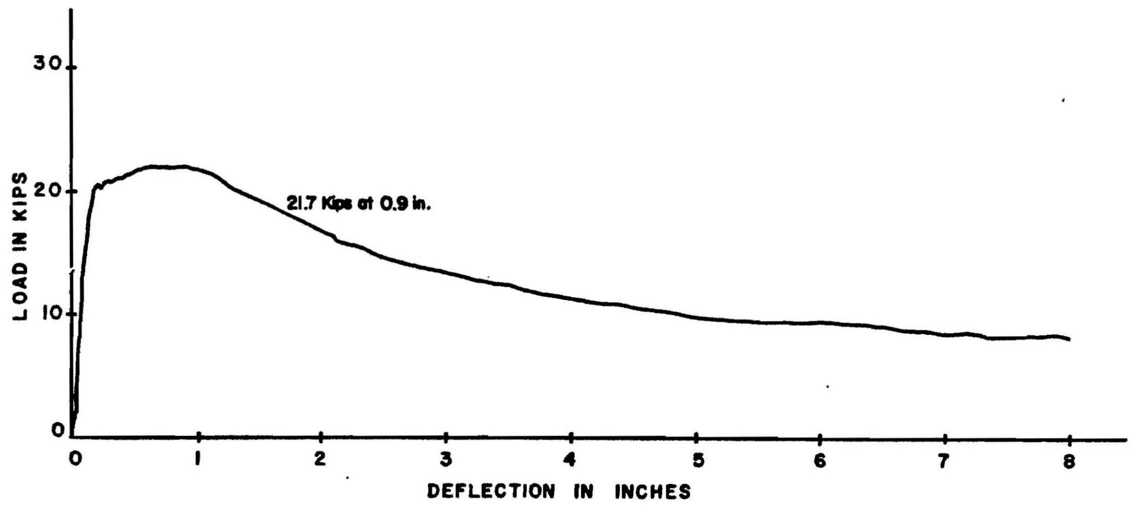
Modified T202 Post With 7 1/2" Deck and Welded Wire Fabric After Test

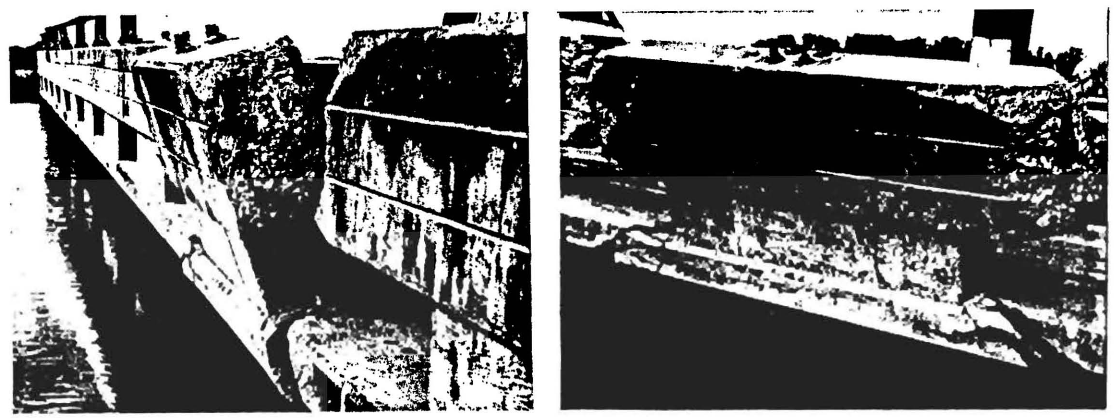


48 X 18 WELDED WIRE FABRIC

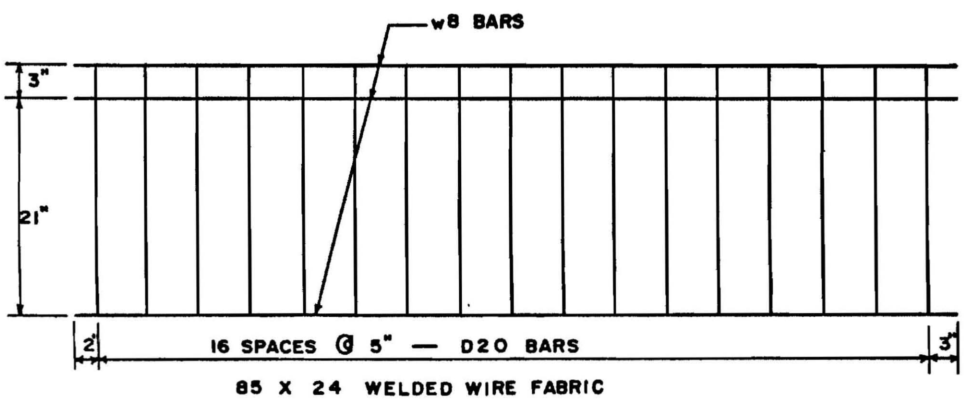


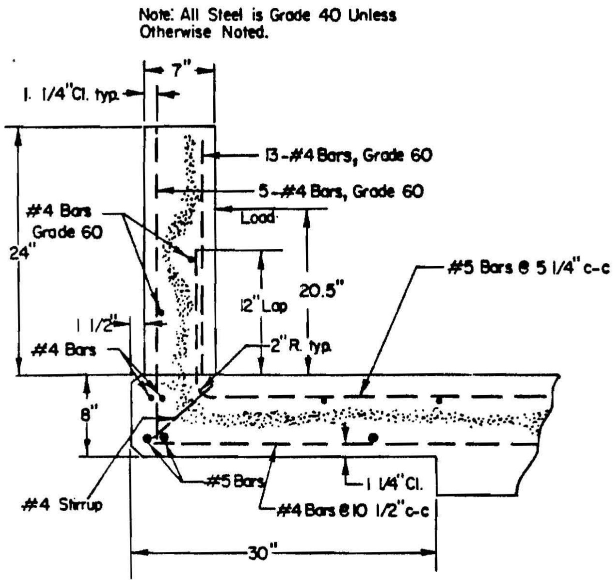
TEST # T202-4S

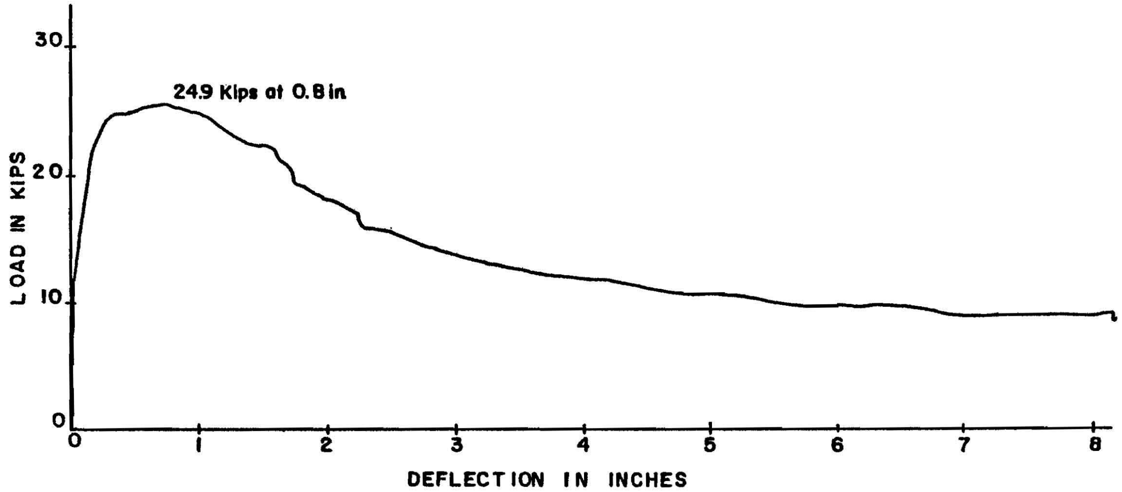


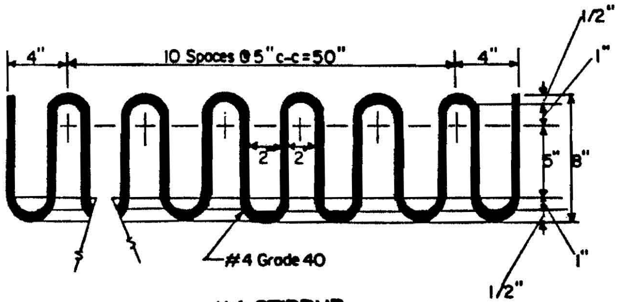


Modified T202 Post With 7 1/2" Deck After Test





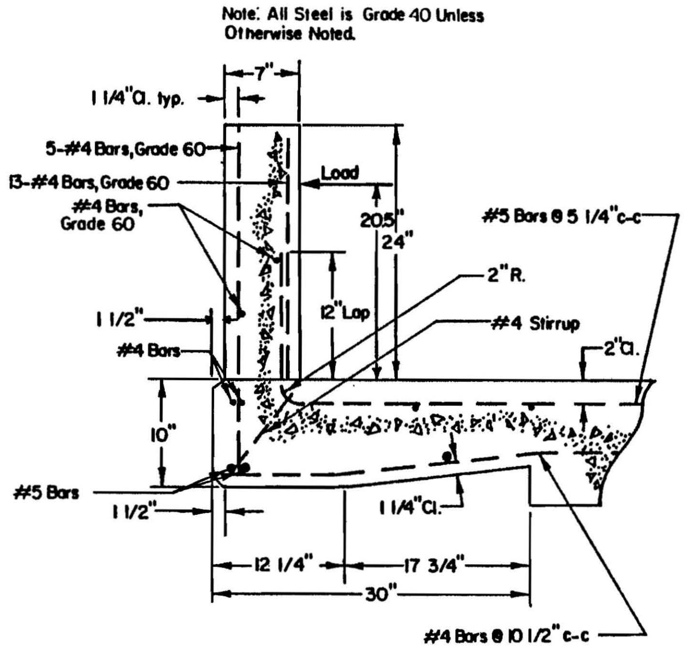


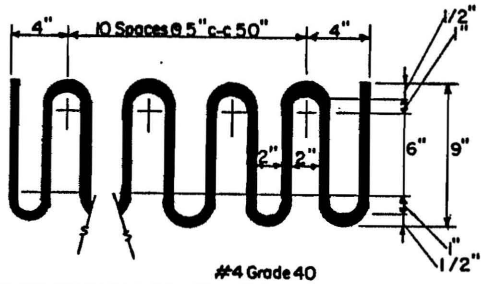


#4 STIRRUP

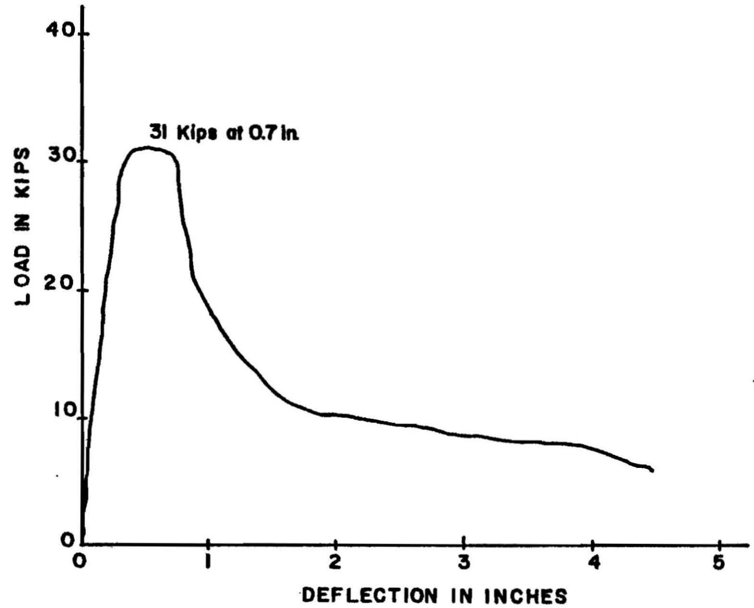
TEST # T202-5S

Cracking in Modified T202 Post and Deck After Test.

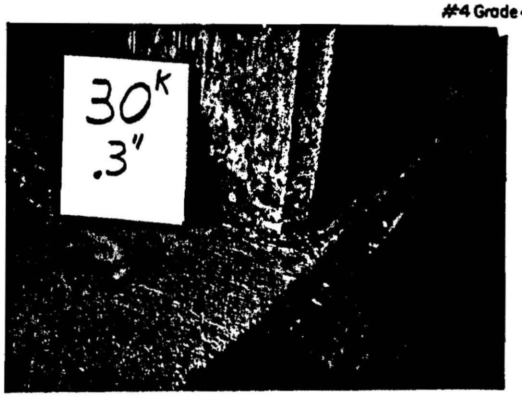




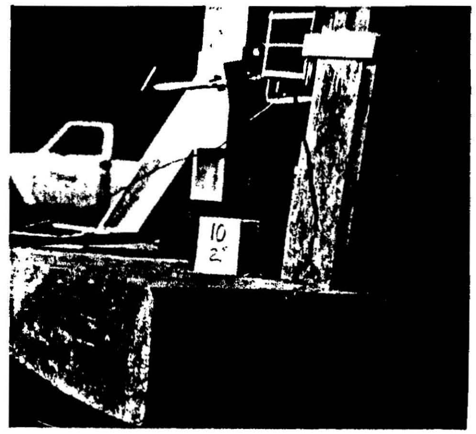
#4 STIRRUP



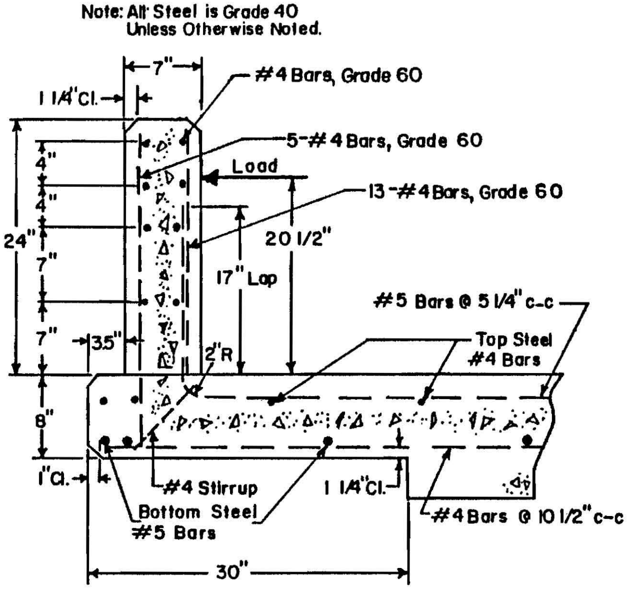
TEST # T202-6S

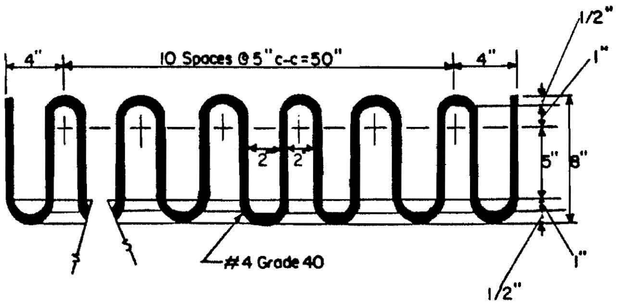


30 Kip Load -
0.3" Post Deflection

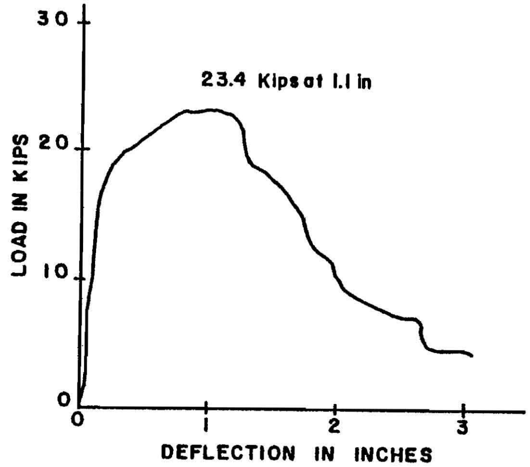


10 Kip Load - 2" Post Deflection

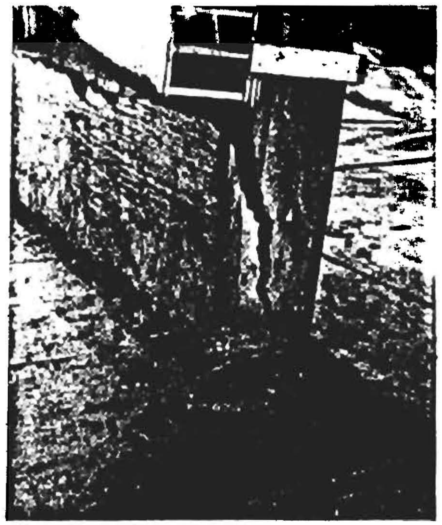


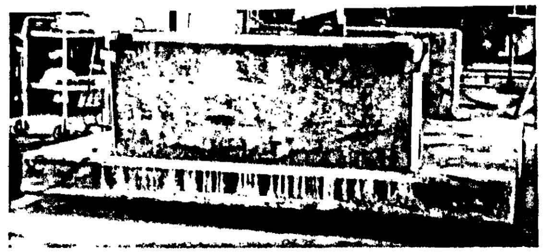


#4 STIRRUP

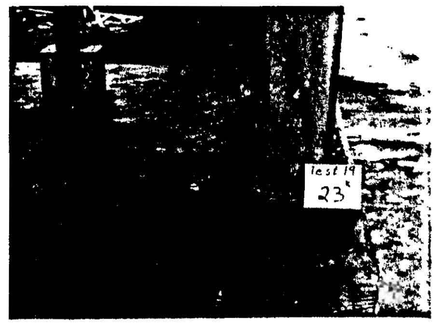


TEST # T202-7S

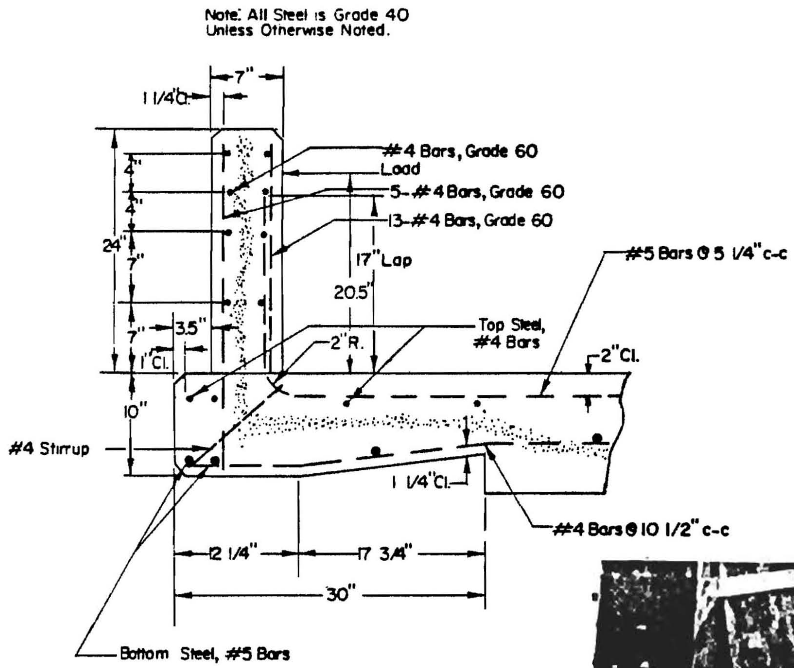


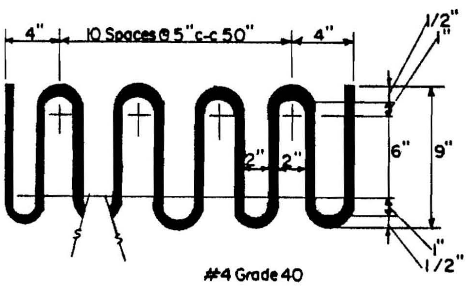


Modified T202 Post With 8" Deck After Test

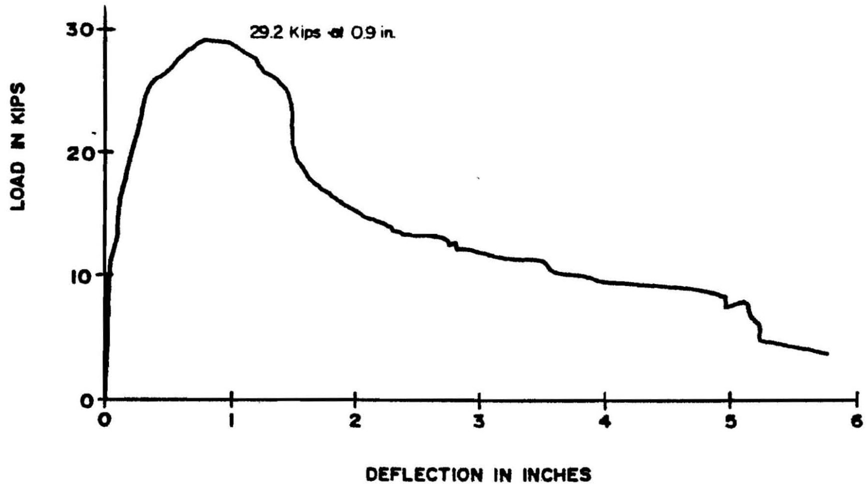


23 Kip Load - 1.0" Post Deflection



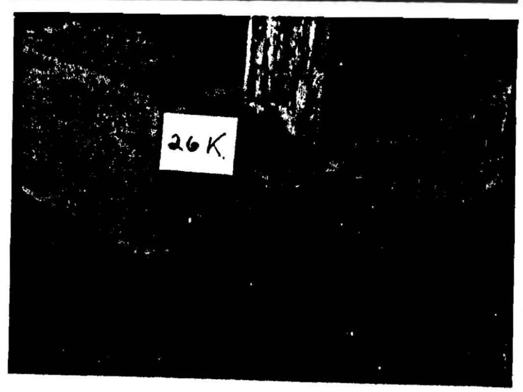


#4 STIRRUP

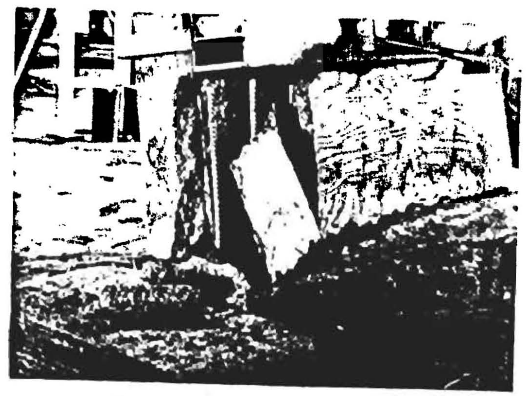


TEST # T202-8S

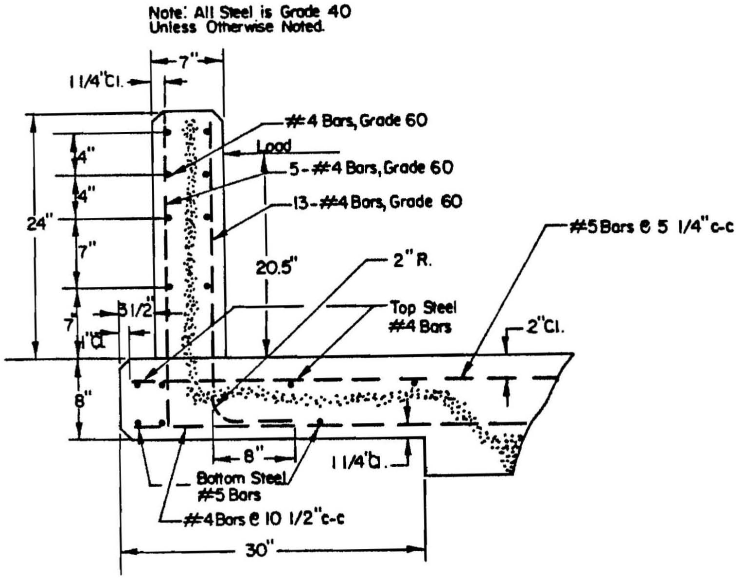
← 26 Kip Load - 0.3" Post Deflectior

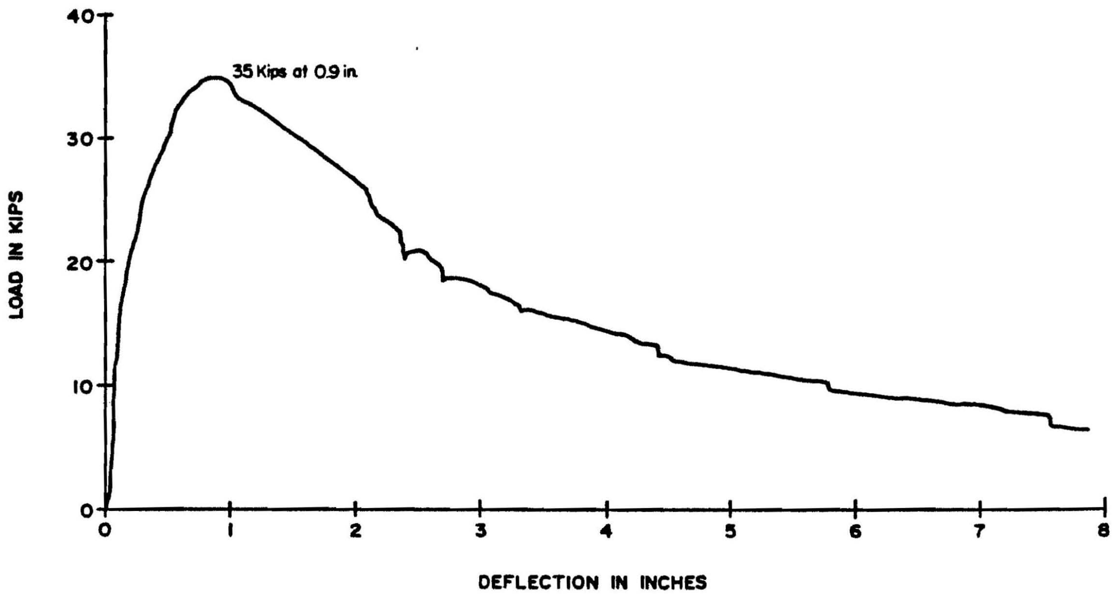


← 29 Kip Load - 1.0" Post Deflection

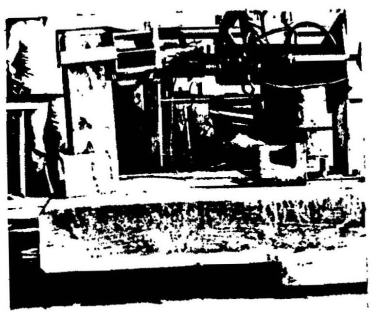


5 Kip Load - 5.0" Post Deflection

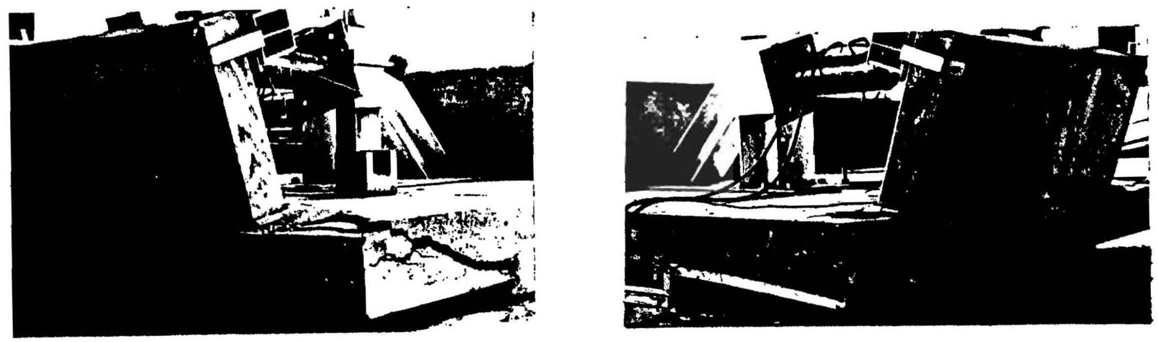




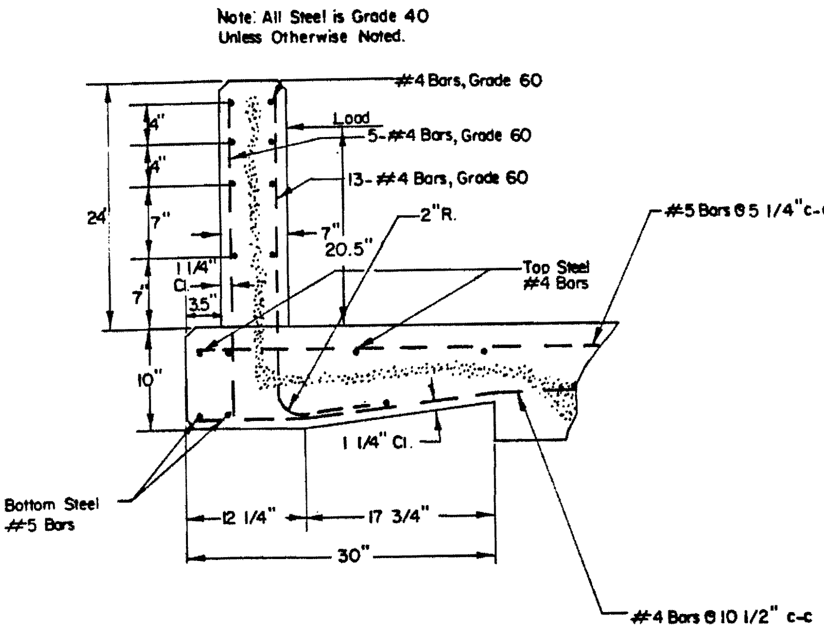
TEST # T202-9S

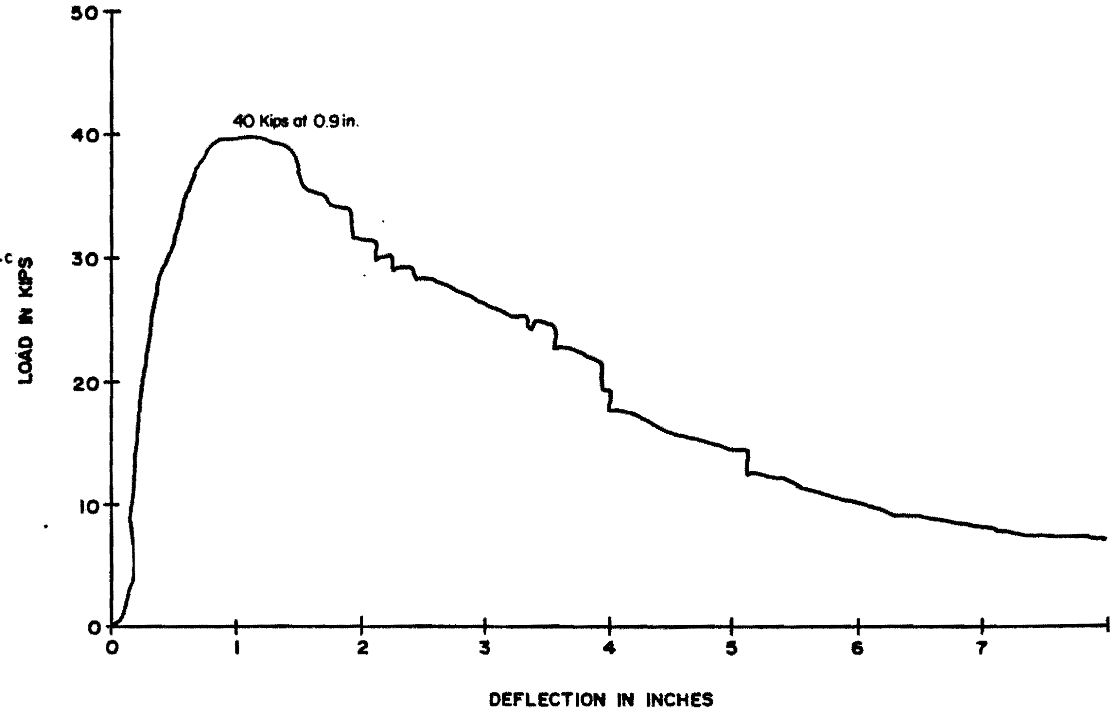


35 Kip Load - 0.85" Post Deflection



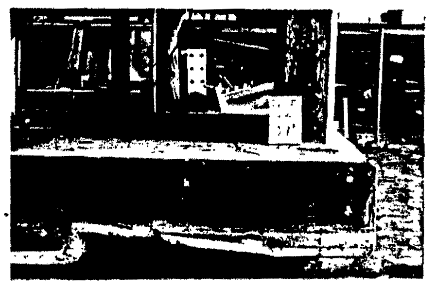
Modified T202 Post With 8" Deck After Test





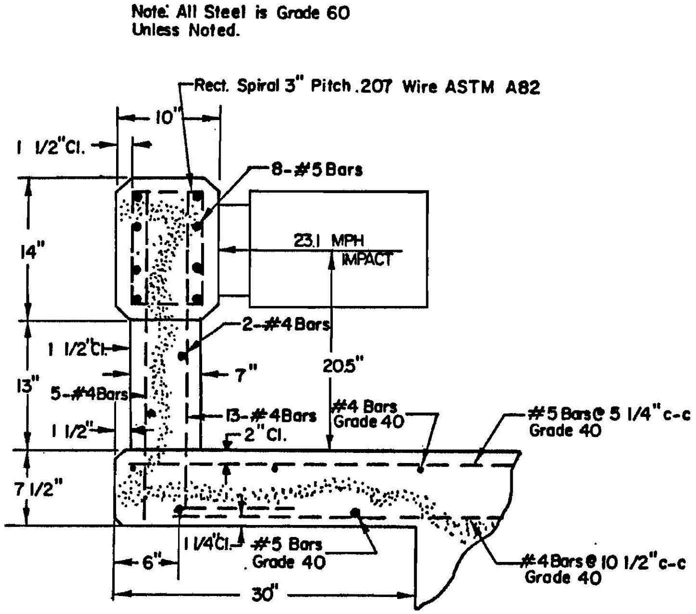
TEST # T202-10S

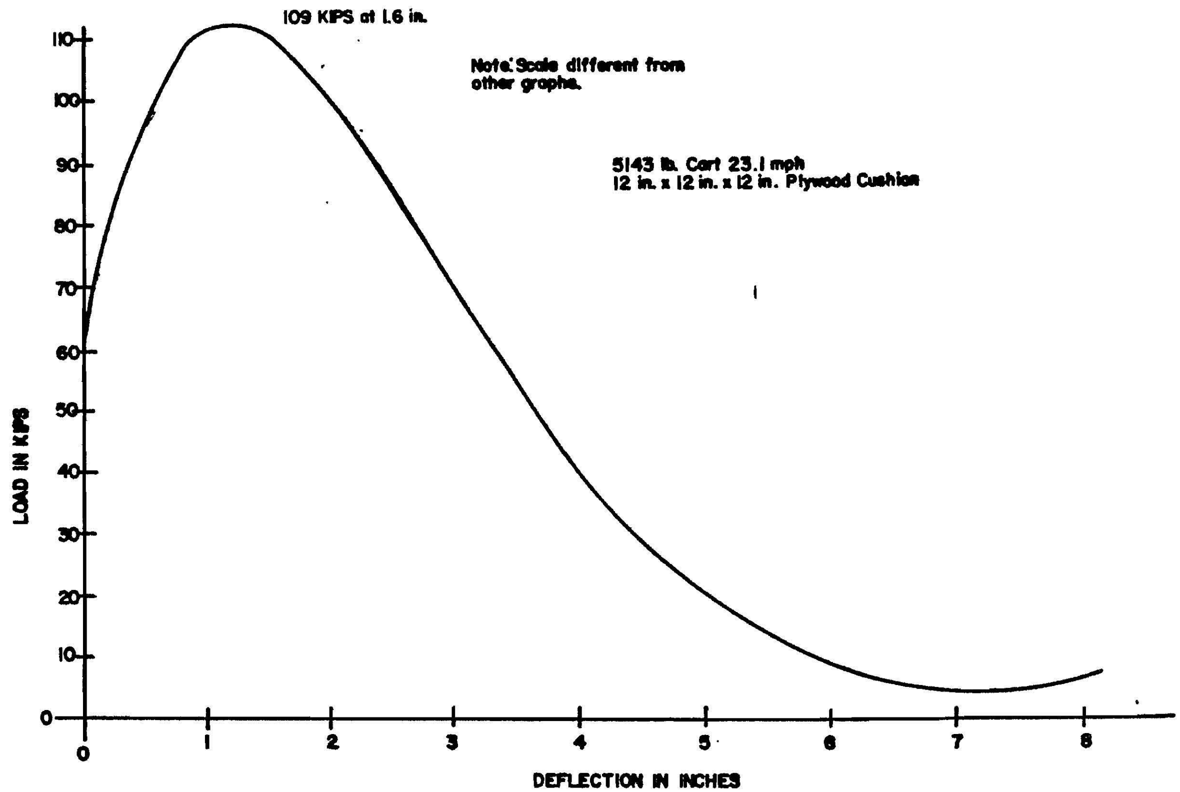
20 Kip Load - 0.2" Post Deflection



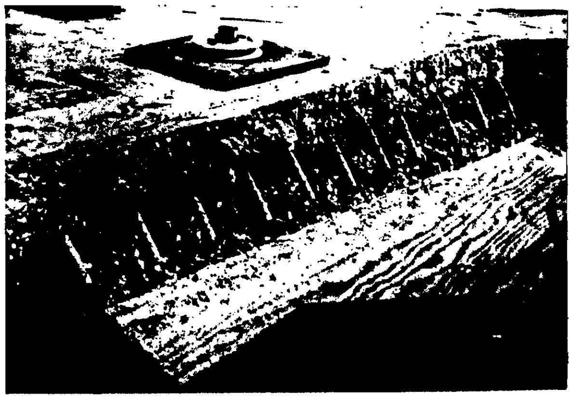
39 Kip Load - 1.0" Post Deflection

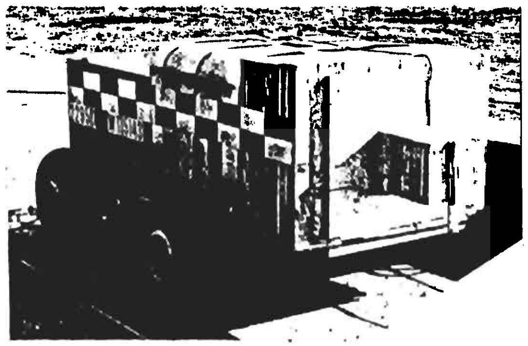
8 Kip Load - 9.0" Post Deflection



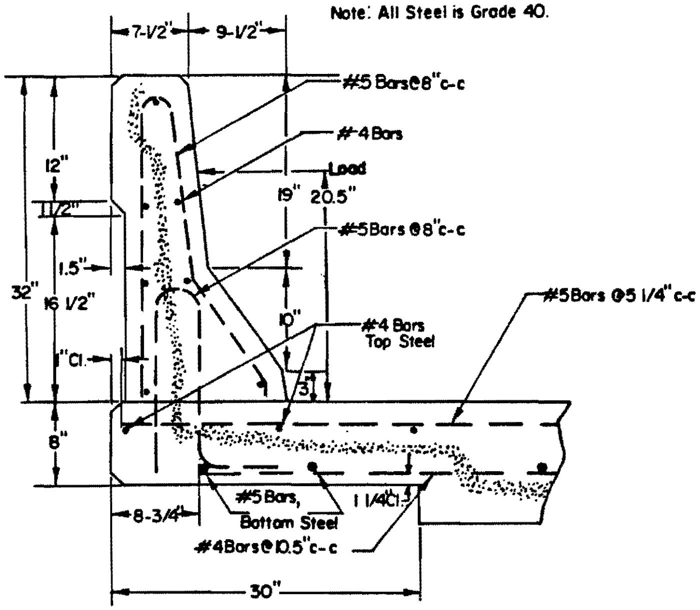


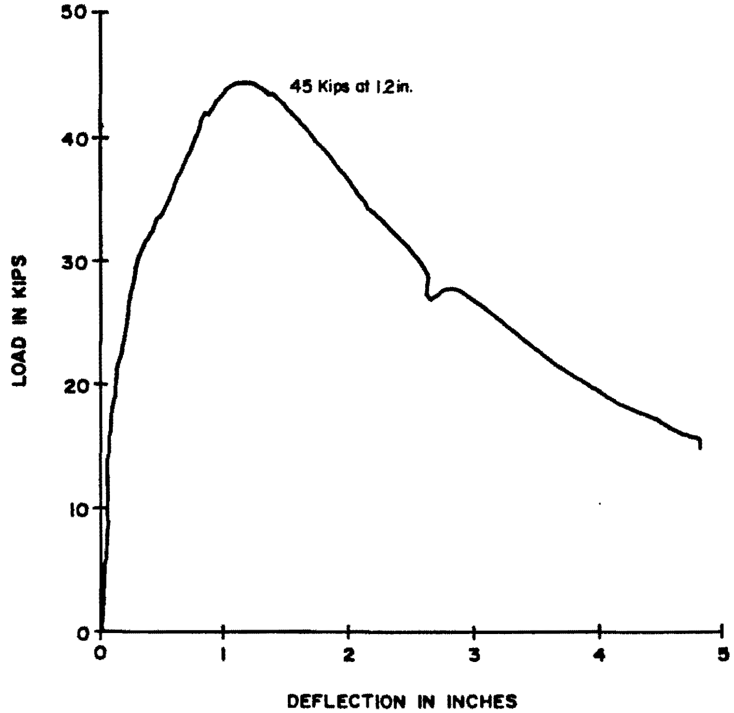
TEST # T202-1D



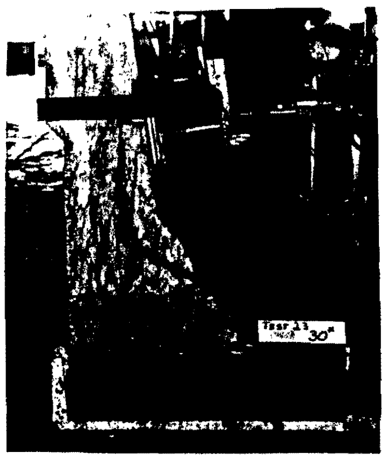


Cart and Modified T202 Post and Slab after Dynamic Test





TEST # T5-1S

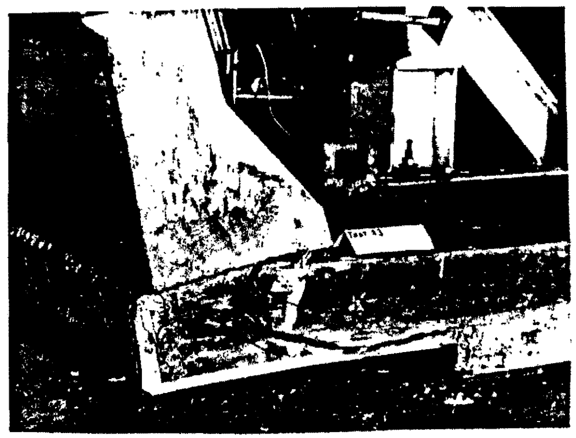


30 Kip Load -

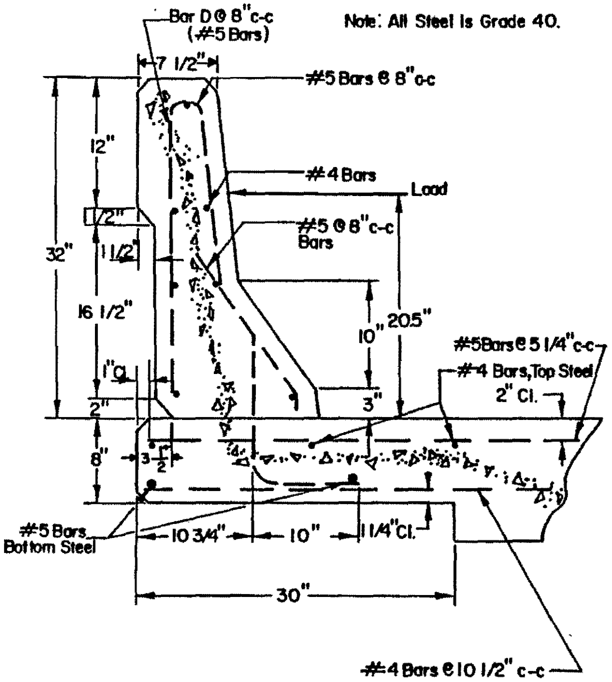
0.3" Post Displacement

45 Kip Load -

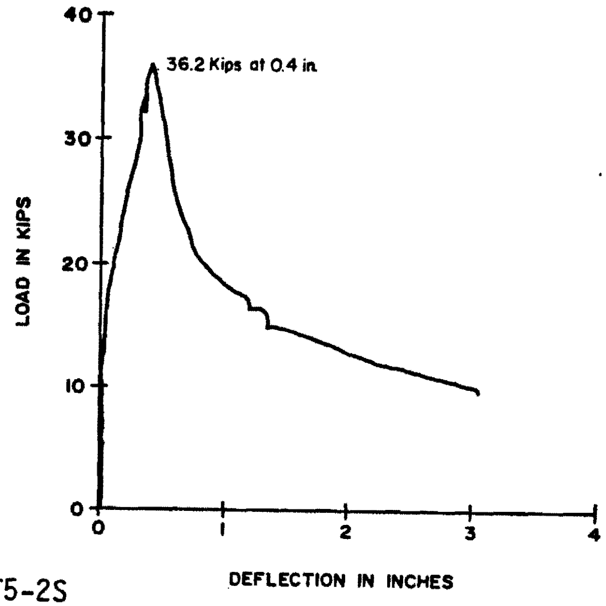
1.18" Post Displacement



Modified T5 Traffic Rail With 8" Deck After Test



TEST # T5-2S



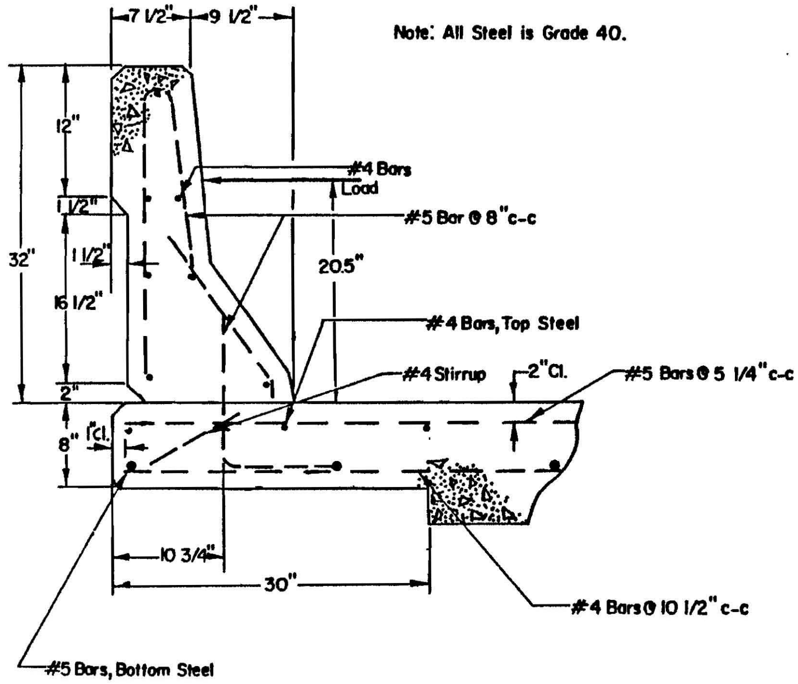
30 Kip Load -

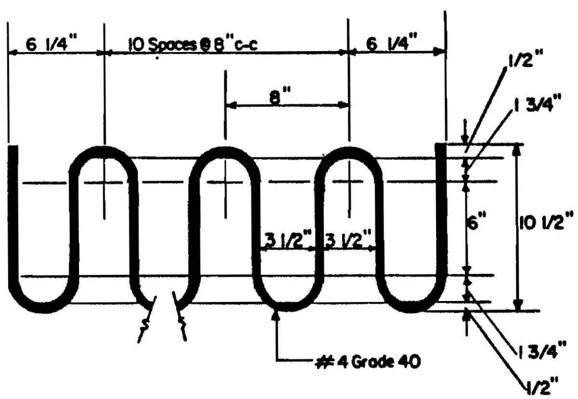
0.25" Post Displacement

Modified T5 Traffic Rail With 8" Deck After Test

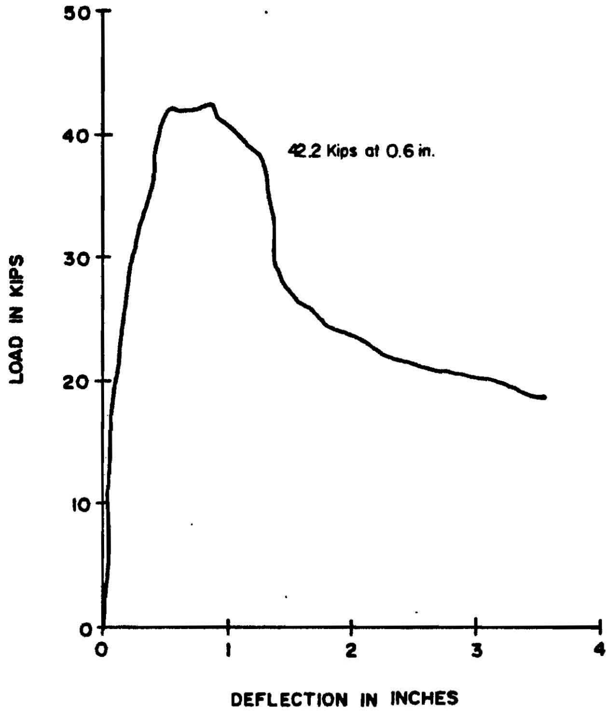
35 Kip Load -

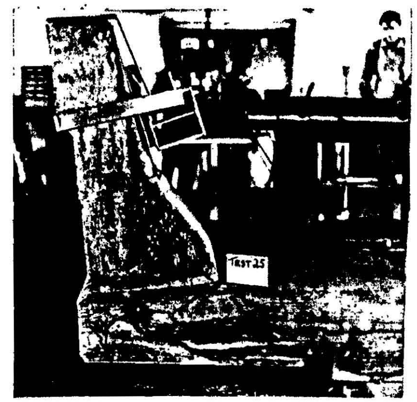
0.35" Post Displacement





#4 STIRRUP

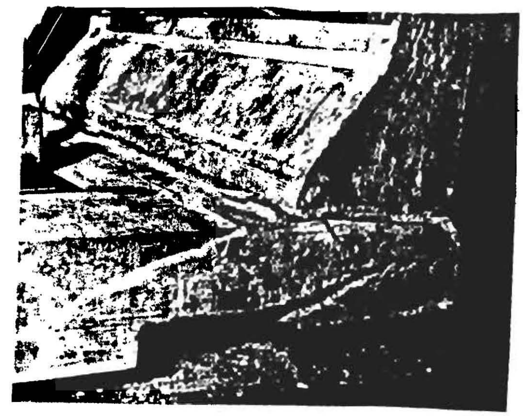




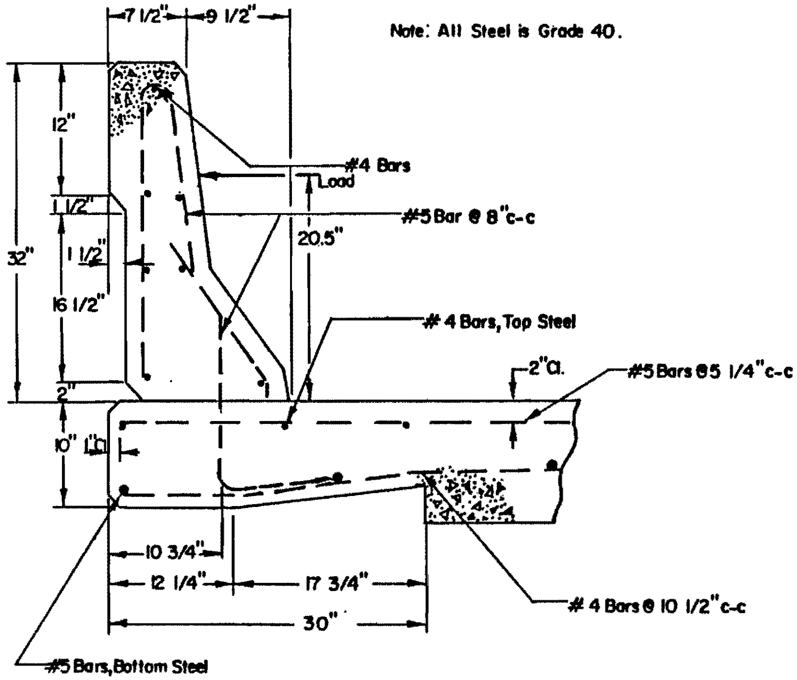
TEST # T5-3S

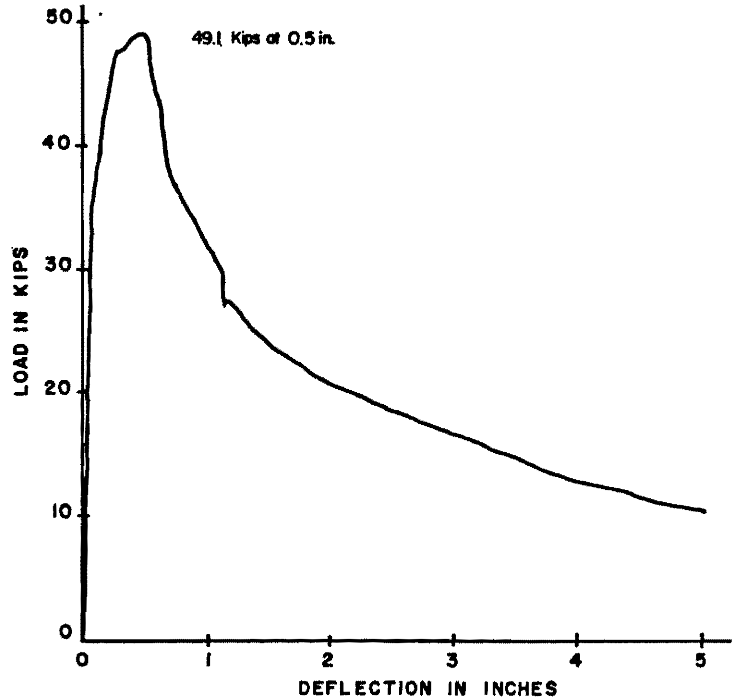
42 Kip Load -

0.57" Post Displacement

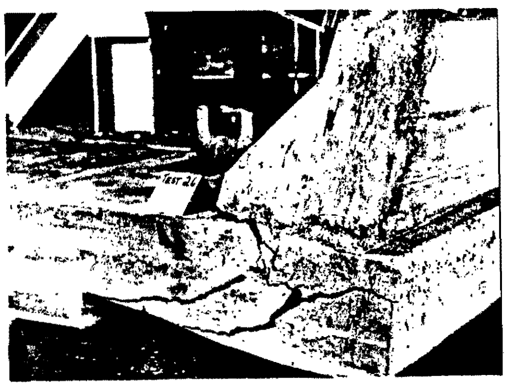


T5 Traffic Rail With 8" Deck After Test

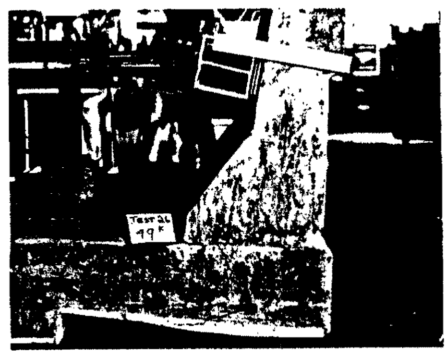




TEST # T5-4S



Modified T5 Traffic Rail With 10" Deck After Test



49 Kip Load - 0.5" Post Deflection