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BRIDGE BARRIER RAIL-TO-GUARDRAIL ANCHORING SYSTEM

MICHIGAN DEPARTMENT OF TRANSPORTATION

MATERIALS and TECHNOLOGY DIVISION

BRIDGE BARRIER RAIL-TO-GUARDRAIL ANCHORING SYSTEM

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At their June 12, 1985 meeting, the Barrier Advisory Committee requested that an expansion system be developed to accomodate the movement between bridge barrier rail and guardrail.

The Department now constructs many bridges that have the expansion joints located at the abutments. This creates a problem in accommodating the combined movements of both the bridge barrier railing and the guardrail caused by thermal expansion and contraction. At present, the Department's solution is to cast a barrier extension which is fixed to the independent backwall. Another section of bridge barrier railing is then cast atop this extension, and the guardrail is attached to this section of barrier. This process eliminated the need to compensate, at a single location, for the combined effect of the expansion/contraction of both the guardrail and the superstructure. The slots in the existing end shoe were not long enough to accommodate the total movement. Each block is cast at a cost of approximately $12,000 per quadrant. In an effort to reduce these costs, an investigation was undertaken to develop a guardrail expansion system that could accommodate greater motion, be attached to the barrier atop the superstructure and utilize existing guardrail hardware.

Present Methods

The current anchorage hardware consists of the special end shoe shown in Standard Plan III-67B (Fig. 1). This has 29/32 by 3-in. slots for splicing to the guardrail element. The splice bolts are 5/8 by 1-1/4 ± 1/8 in. with an oval, 7/32-in. deep shoulder.

Current practice is to bolt a special end shoe to the concrete block cast adjacent to the bridge rail and splice the guardrail element to the shoe using the splice bolts described above. This method provides for about 2 in. of travel within the splice slot, which accommodates the thermal expansion of the guardrail section. When the anchor shoe is installed behind the guardrail element, a nominal 5/8-in. washer is used between the nut and shoe. The rounded bolt head is always placed towards traffic.

Materials Used

All materials used were standard W-beam elements and shoes. No Thrie beam components were used.

In an effort to keep testing costs down, test Nos. 1 through 6 were conducted using materials that had been salvaged after use on the highway. The anchor shoes and guardrail elements were picked from a scrap stockpile at the Grand Ledge Maintenance Garage. Some of the guardrail beams had been reformed. The reforming of the guardrail beam changed the **W** shape just enough to hinder nesting the anchor shoe to the guardrail. This caused additional pressure between the shoe and guardrail after tightening and increased the loads required for movement of the assembly.

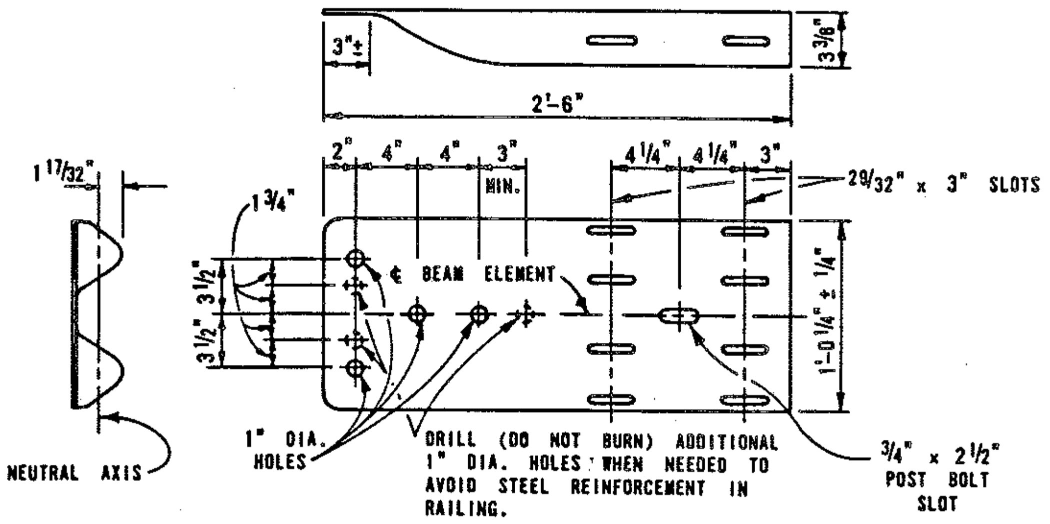


Figure 1. Standard anchorage shoe.

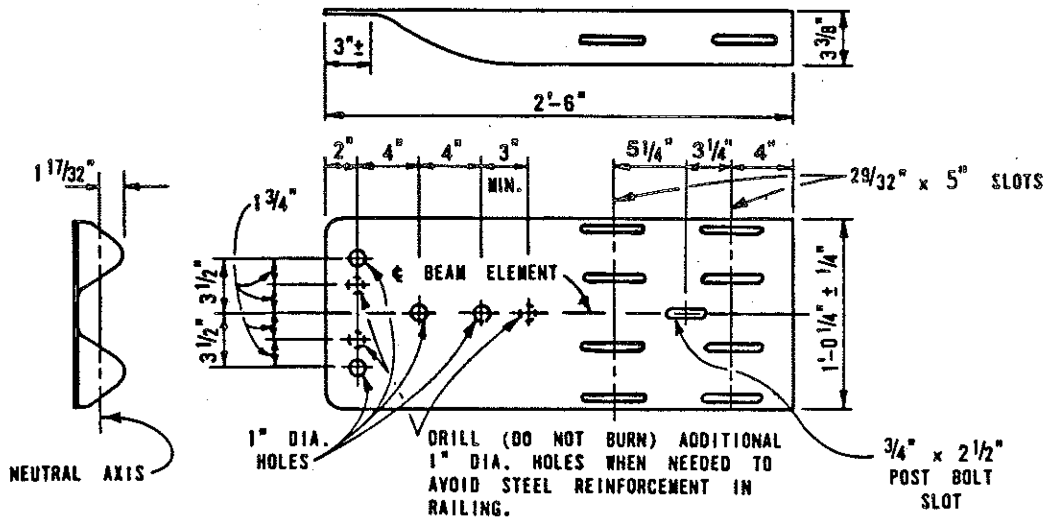


Figure 2. Anchorage shoe as modified. Note that the slots were extended toward the 1-in. diameter holes. This was done to retain the end clearance on the right-hand slot.

Test Nos. 7 to 10 and T1 to T6 were performed using new materials obtained from the central warehouse. Even with new materials there was a problem nesting the shoe to the guardrail. The shoe is formed to fit over the guardrail, but when placed behind the guardrail the shape is too wide and must be forced into position. The anchor shoe is formed from 10-gage material and the guardrail elements are from 12-gage. Bolts, nuts and washers were stock items from the warehouse. The slots in the special end shoes were elongated by the Materials and Technology machine shop to a length of 5 in. as shown in Figure 2. The 5-in. length was chosen because it should accommodate the expected thermal movement of the system. Current design criteria for bridge expansion joints requires 1/8 in. of expansion capability for every 10 ft of structure expansion length.

Test Procedure

Test Nos. 1 through 10 were done using the load fixture shown in Figure 3. The fixture was mounted over a 100,000-lb capacity ram with a 6-in. stroke length. This allowed a 4-in. cycling range with sufficient stroke left to test the specimen to failure. Because several samples required

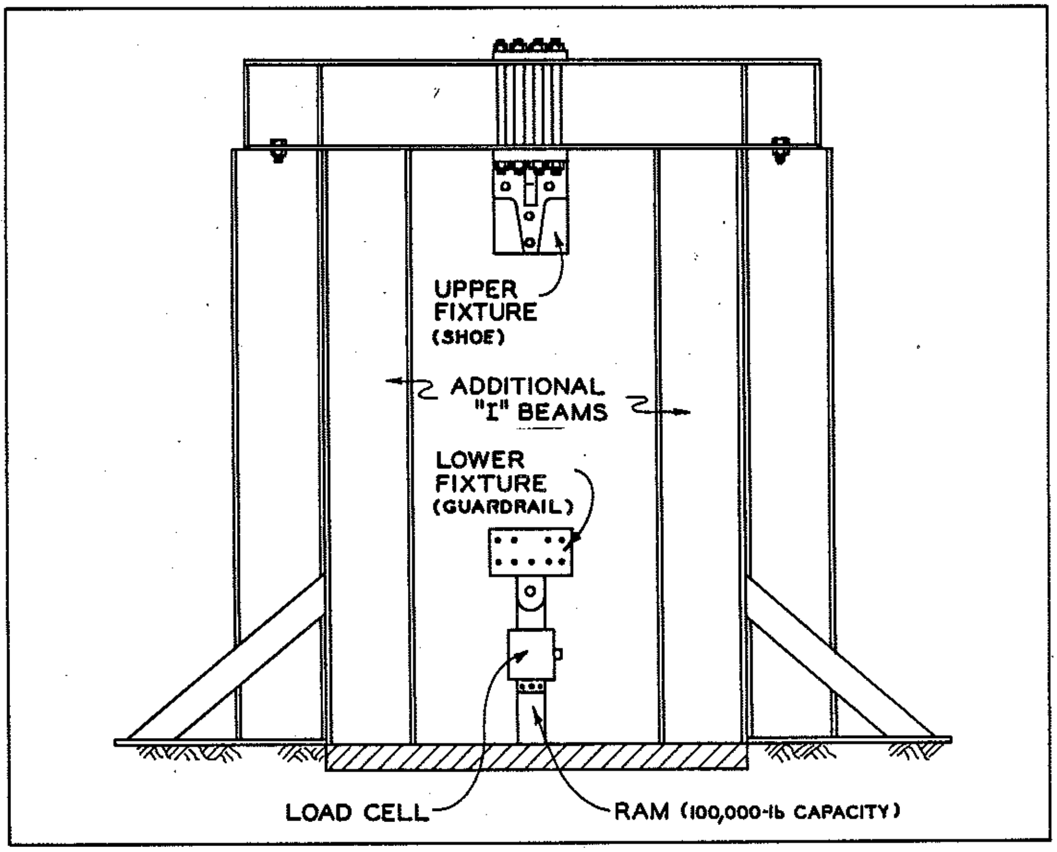


Figure 3. Load frame used for test Nos. 1 through 10. Some deformation of the upper crossbeam was noted. This was due to the high loads required to fail the specimens.

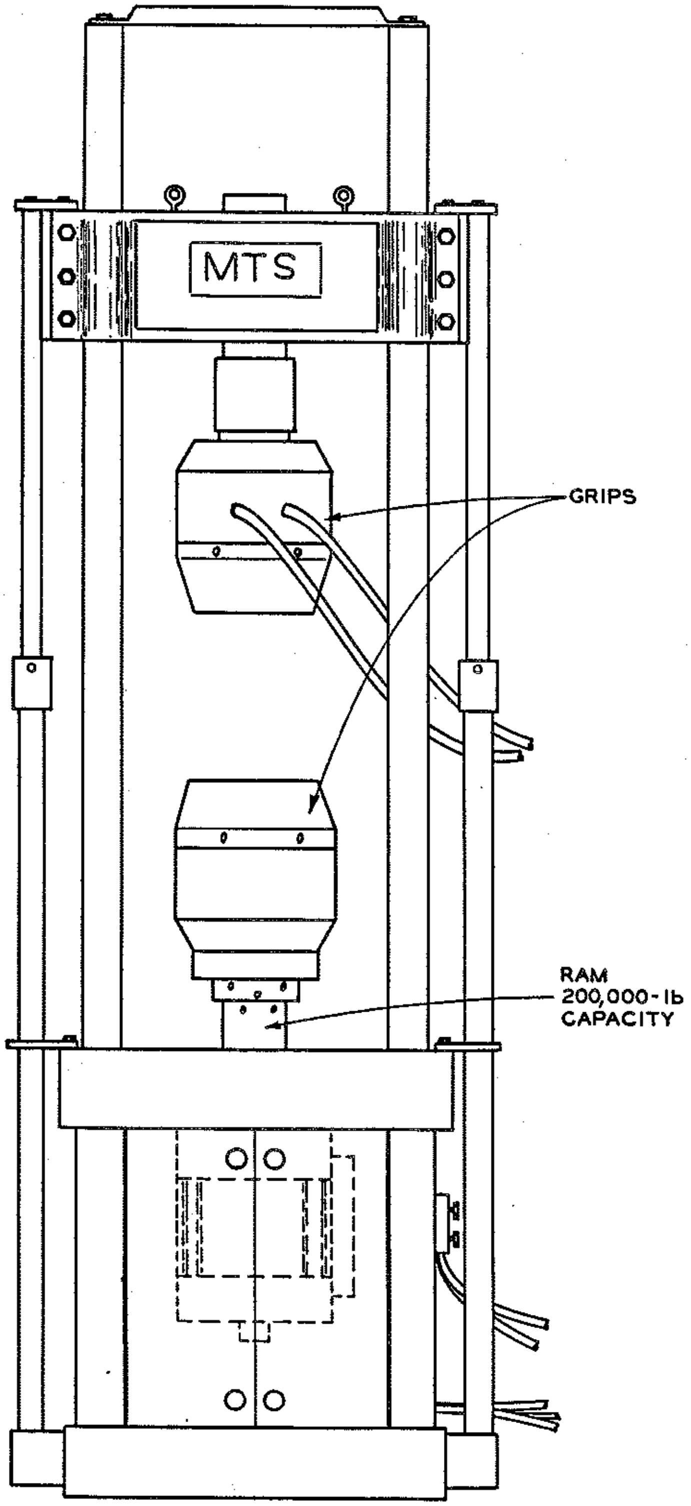


Figure 4. Ram with 200,000-lb capacity, used for test Nos. T1 through T6. The fixtures were mounted in the grip. The crosshead allowed adjustments for height differences to be made more easily than the load frame used for the previous 10 tests.

greater failure loads than 100,000 lb, test Nos. T1 to T6 were conducted using a 200,000-lb capacity MTS load frame as shown in Figure 4. The MTS load frame facilitated greater loading, but only allowed a 2-in. stroke for cycling.

The specimens were mounted with the anchor shoe bolted to the upper portion of the fixture and the guardrail element bolted to the bottom portion. After the splice bolts were inserted and before they were tightened, the ram was positioned so that the splice bolts were centered within the slots. At this point the splice bolts were tightened, with the amount of nut engagement dependent upon the test run. Test Nos. 1 to 6 were tightened with a wrench similar to guardrail splice connections. Test Nos. 7 to 9 were tightened 1/4 turn with a wrench after finger-tightening. Test Nos. 10 and T1 to T6 were finger-tightened, with a minimum of one thread beyond the end of the nut. After the specimen had been cycled, it was tested to failure. AASHTO M180 specifications for the shoe and beam elements were used to determine if the assembly had met the required strengths. The time required for one full cycle was 16 minutes 36 seconds. In test Nos. T1 to T6, tensile samples were then removed from the shoes and guardrail elements used, and tested to check for compliance with AASHTO M180 specifications (Table 1). This was done because some of the anchorage shoes were tearing at the bridge end. It was determined after tensile testing that this tearing was due to the fixture separating.

The Standard Plan III-67B has the only note referencing tightness of the splice bolts used for the shoe to guardrail splice. It reads as follows:

> "Standard splice bolts shall be used when splicing Thrie beam terminal connector to Thrie beam expansion section. The nut shall be installed finger-tight, followed by upsetting of the first thread on the outside of the splice bolt nut with a center punch or cold chisel so it will not loosen. The same applies when connecting special end shoe to transition section."

The impression given in this note, is that only splices where Thrie beam guardrail is used have the splice bolts finger-tight. There are no stated requirements for any other guardrail-to-anchor shoe connections. Also, the question arose, what constitutes "finger-tight?" When splicing the guardrail element to the anchor shoe, the pieces did not always fit together well. When the nuts are installed finger-tight, the bolt could be four to five threads below the back surface of the nut (not protruding through) or the nut could be fully engaged. At least one bolt diameter nut engagement is required to develop the tensile strength of the bolt plus, for this application, an additional thread is required for upsetting. The note should be changed to reflect the need for at least one full thread exposed beyond the nut. Also it should cover other guardrail-to-anchorage shoe splices, unless they are covered on a separate standard.

When the splice connection is placed in tension, as can happen during a collision, the splice bolts will rotate as the guardrail and shoe material

TABLE 1
TENSILE SPECIMENS

(Averages for tensile specimens removed from the anchor shoes and guardrail beams used in tests T1 through T6. The "S" denotes the shoe for the specific test)

	Specimen	Yield, psi	Ultimate, psi	Reduction of Area, percent	Elongation, percent
Guardrail Specimens	1	67,900	76,100	42	21
	2	67,400	75,000	47	20
	3	67,200	75,600	41	21
	4	65,100	73,300	49	22
	5	68,600	76,200	53	19
	6	66,400	74,100	46	19
	Average for Rail	67,100	75,100	46	20
	AASHTO M180 Required	50,000	70,000		
Anchor Shoe Specimens	1S	50,300	64,800	51	20
	2S	52,000	67,300	54	18
	3S	42,200	49,100	59	23
	4S	51,500	67,600	53	
	5S	41,000	52,100	55	20
	6S	50,900	66,700	51	17
	Average for Shoe	48,000	61,300	54	20
	AASHTO M180 Required	33,000	45,000		

yield. The strength requirements for the splice bolts change from a shear load to a tensile load, thus the need for one full bolt diameter engagement to develop the strength of the bolt.

It was felt that the worst connection would occur when the anchorage shoe was placed behind the guardrail beam. This is due to the elongation of the slot in the anchor shoe, which could allow the nut to pull through at a lower loading. Therefore, this method was used for most of the tests.

Testing

Test Nos. 1, 2, 3, T4, T5, and T6 were conducted using the standard 3-in. slots. This was done to provide baseline data for comparison.

Test No. 1 information is given in Table 2, but the data were not considered due to the failure of the guardrail at the lower fixture. The guardrail did not have sufficient material beyond the holes used for attachment to the fixture. This problem was solved by notching the guardrail to fit lower on the fixture. It should be noted that even though the guardrail beam failed at the fixture due to insufficient material, it still met the AASHTO tensile requirements.

Test No. 2 was run for 328 cycles to determine if any change would occur due to the great number of cycles. The load values required to cycle the assembly continued to drop until about cycle 88 at which time they stabilized and further significant reduction was not noted. Allowing for two full cycles per year (winter to summer and summer to winter), this test represented 164 years of movement.

TABLE 2
COMPARISON OF BEGINNING AND ENDING
CYCLE LOAD VALUES, lb

Test No.	Start Load	End Load	Load at 10 Cycles	Ultimate Load	Total Cycles
1	16,000	12,000	12,000	71,000	17
2	30,500	9,500	20,000	100,000	328
3	21,500	11,000	15,500	100,000	67
4	14,000	6,000	6,000	100,000	
5	27,000	17,000	21,000	86,000	28
6	17,500	9,500	9,500	100,000	10
7	8,000	4,000	5,000	100,000	19
8	1,400	1,400		96,000	7
9	6,400	5,000	5,000	74,000	10
10	1,400	2,700		82,000	9
T1	300	600		95,000	8
T2	1,400	2,500	2,500	97,000	11
T3	2,800	2,800		82,000	8
T4	2,300	1,700	2,900	96,000	65
T5	2,000	2,000	2,000	82,000	19
T6	600	850		98,000	8
Avg Nos. 2-10	14,200	7,300		93,100	
Avg Nos. T1-T6	1,600	1,700		91,700	

The values which are shown in the column after 10 cycles are not noted where there were less than 10 cycles.

Test No. 1 data are not included in average.

Test No. 3 was performed using a standard shoe without the flat washers installed. This was done to determine if the nut would gouge the rail or slide freely, and also to determine if the washer contributed to the ultimate load capabilities. The lack of washers had no adverse affect on the loads during cycling. The load values were less than those experienced in test Nos. 2 and 5. Further, the lack of washers did not significantly change the ultimate load capabilities of the assembly. However, we do not recommend that the assemblies be bolted without flat washers.

Test No. 4, splice slots were extended to 5 in. Test was conducted for 22 cycles with a 4-in. stroke. No failure was noted at 100,000 lb, the ultimate loading capacity of this system.

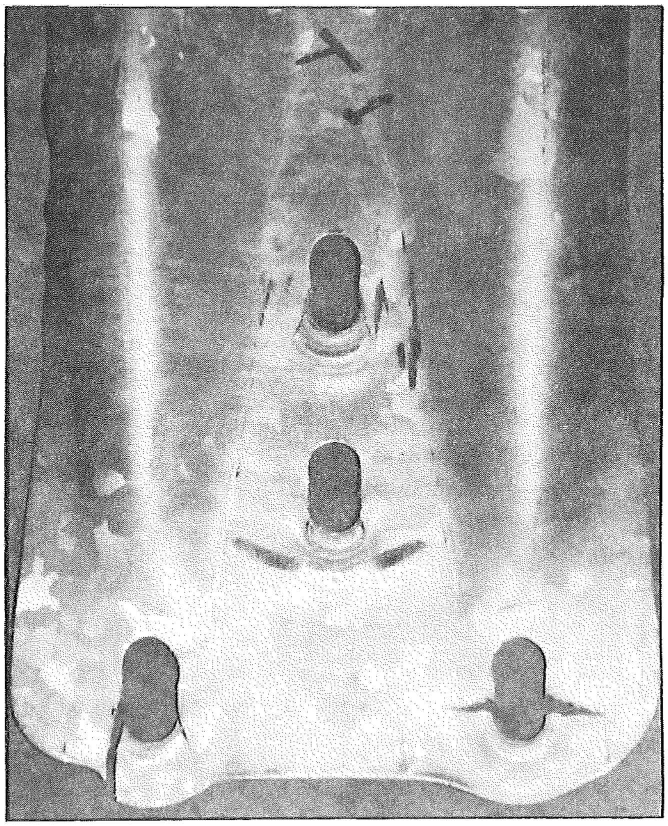
Test No. 5, 5-in. slots in shoe; 4-in. stroke for 28 cycles with the shoe nested behind the beam element.

Test No. 6, 5-in. slots in shoe. Splice bolts had 5/16-in. instead of the standard 7/32-in. shoulder and were snugged with a wrench. Ten cycles were run with a 4-in. stroke. Test Nos. 6 and 7 were performed using splice bolts with a heavier shoulder to determine if this would affect the load values. No difference was noted in either test.

Test No. 7, 5-in. slots in shoe. Splice bolts had 5/16-in. shoulder. The bolts were snugged with a wrench. The test was run for six cycles then a spray-on lubricant (Dri-Slide, a liquid graphite lubricant used to reduce friction) was applied to the surface between the shoe and guardrail. The test was continued for 13 more cycles. No change in cycle load was noticed after applying the lubricant.

Test No. 8. In this test the splice bolts were given 1/4 turn with a wrench after they had been finger-tightened. Orientation of the splice bolts in the slots has a pronounced effect upon the loads experienced. The shoulders on the splice bolts contacted the ends of the slot, thus producing a higher load near the ends of each cycle. Due to the high load required for the samples to fail, the upper fixture deformed slightly when this test was conducted. This deformation prevented the fixture from making full contact with the shoe at the bridge end; thus, the material sheared at the bridge end of the shoe (Fig. 5). Although, the anchor shoe failed at the bridge end, the sample sustained an ultimate load of 96,000 lb.

Test No. 9. A thin teflon sheet was sandwiched between the shoe and the guardrail. The bolts were tightened 1/4 turn with a wrench after finger-tightening. The teflon did not reduce the loads, it seemed to have increased the loads compared with test No. 8. Here again, the shoe sheared through the bolt holes at the bridge end. Both in test Nos. 8 and 9 the crosshead height had to be increased after the tensile cycle was started. This was due to elongation of the specimen which exceeded the stroke of the ram.



Test T1

Figure 5. Typical damage sustained to the anchorage shoe where it would attach to the bridge railing. This was due to the upper fixture deforming and not gripping the specimen properly. Test Nos. 8, 9, T1 and T3.

Test Nos. 10 and T1 through T6 were done with the splice bolts finger-tight. Finger-tight means nuts were tightened by hand with at least one full thread showing beyond the nut. As can be seen in Tables 2 and 3, the cycle loads were significantly reduced compared to the previous nine tests. Figure 6 shows typical failure modes for tests. Figures 7 and 8 are comparisons of the beginning and ending cycle load values of the tests.

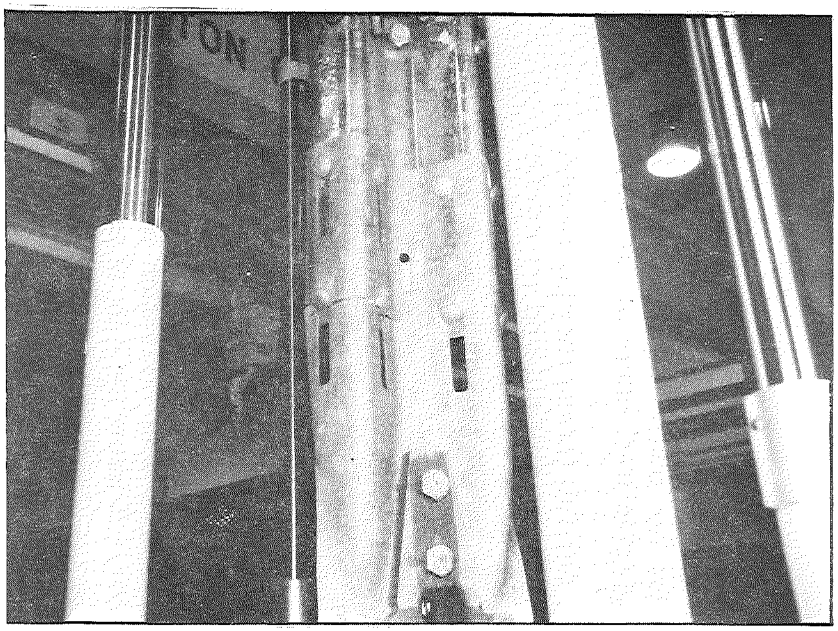
The method of finger-tight with at least one full thread showing beyond the end of the nut provided adequate strength, yet still allowed the cyclic loads to remain low.

Conclusions

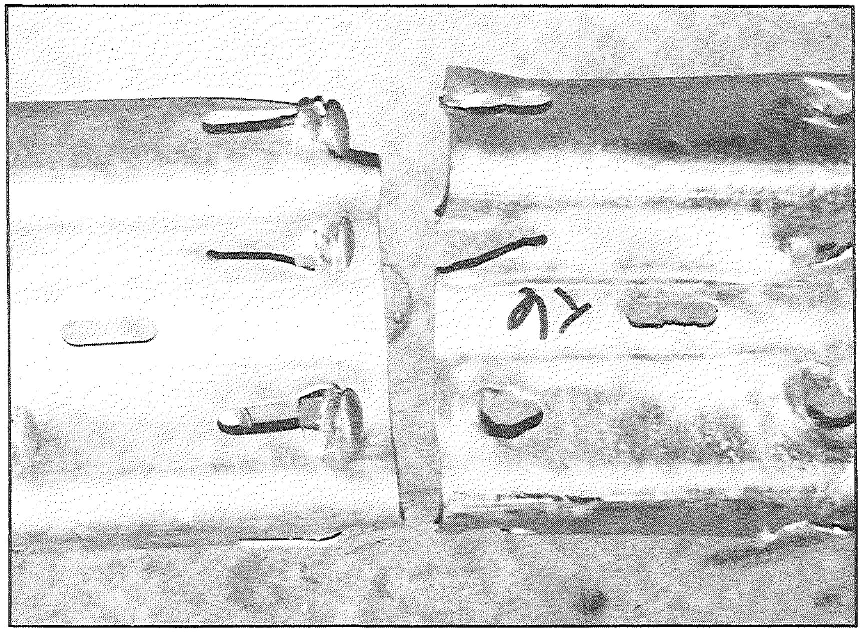
1) Splice bolts should be only finger-tight, with a minimum of one full thread beyond the nut. Obtaining one full thread beyond the nut may, in some instances, require the use of a wrench.

2) The placement of the anchorage shoe (in front of or behind the guardrail) does not affect the load values.

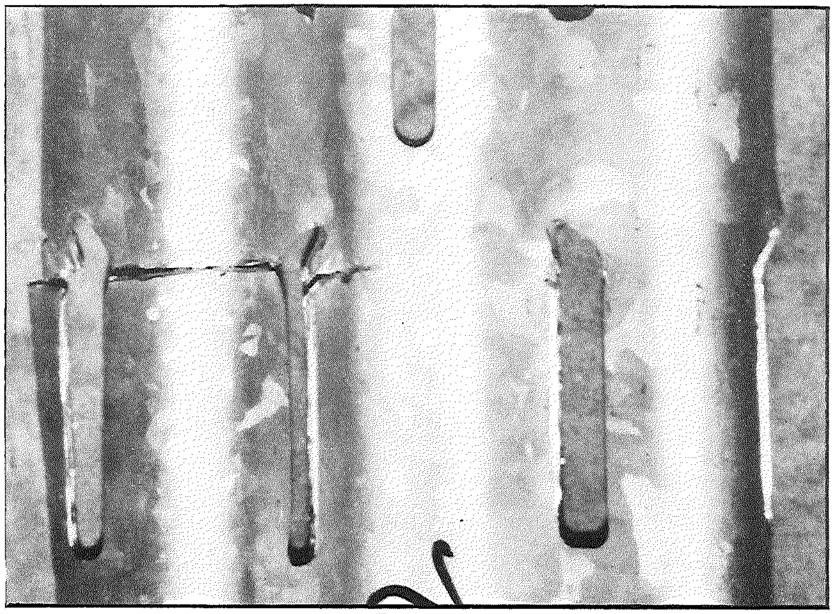
3) Use of existing guardrail hardware with a 2-in. extension of the existing 3-in. slot in the anchorage shoe will allow for 4 in. of travel.



Test T2



Test T6



Test T2

Figure 6. Typical test results showing comparison between a standard 3-in. slot length in test T6 and the 5-in. slot length in test T2. Test T2 failed at 97,000 lb and test T6 failed at 98,000 lb.

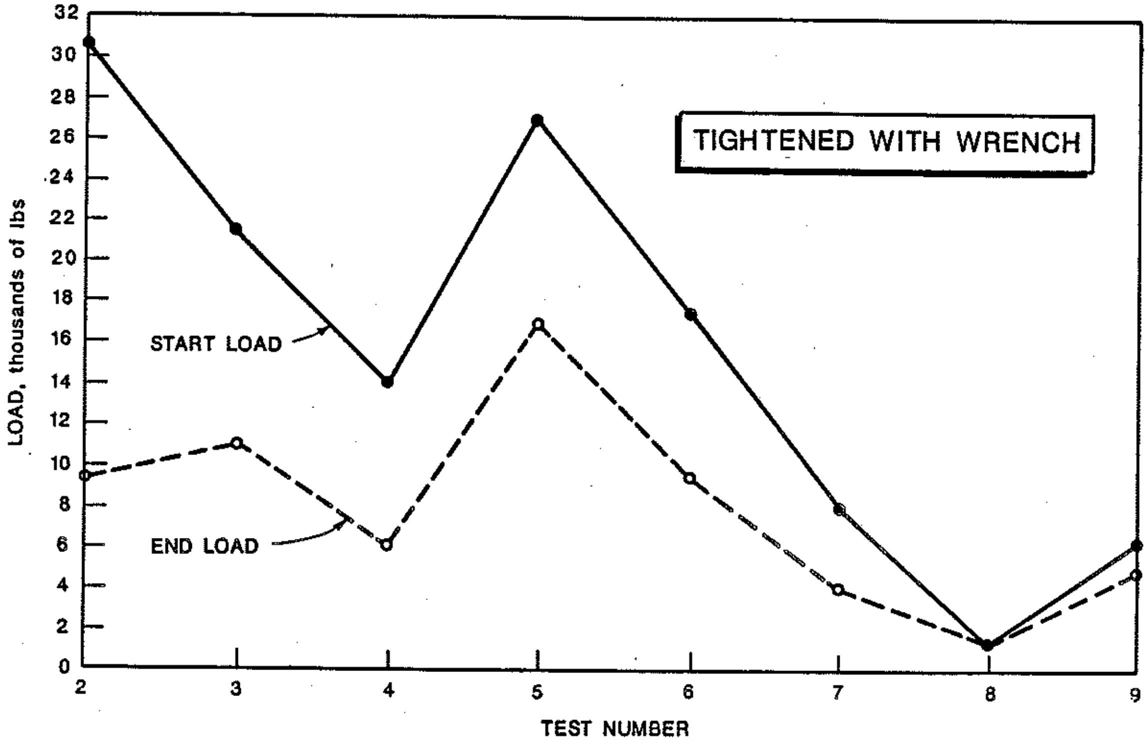


Figure 7. Comparison of starting cycle loads and ending cycle loads of test Nos. 2 through 9. Test Nos. 2 through 6 were conducted using previously installed guardrail beams and anchorage shoes. Test Nos. 8 and 9 used new materials.

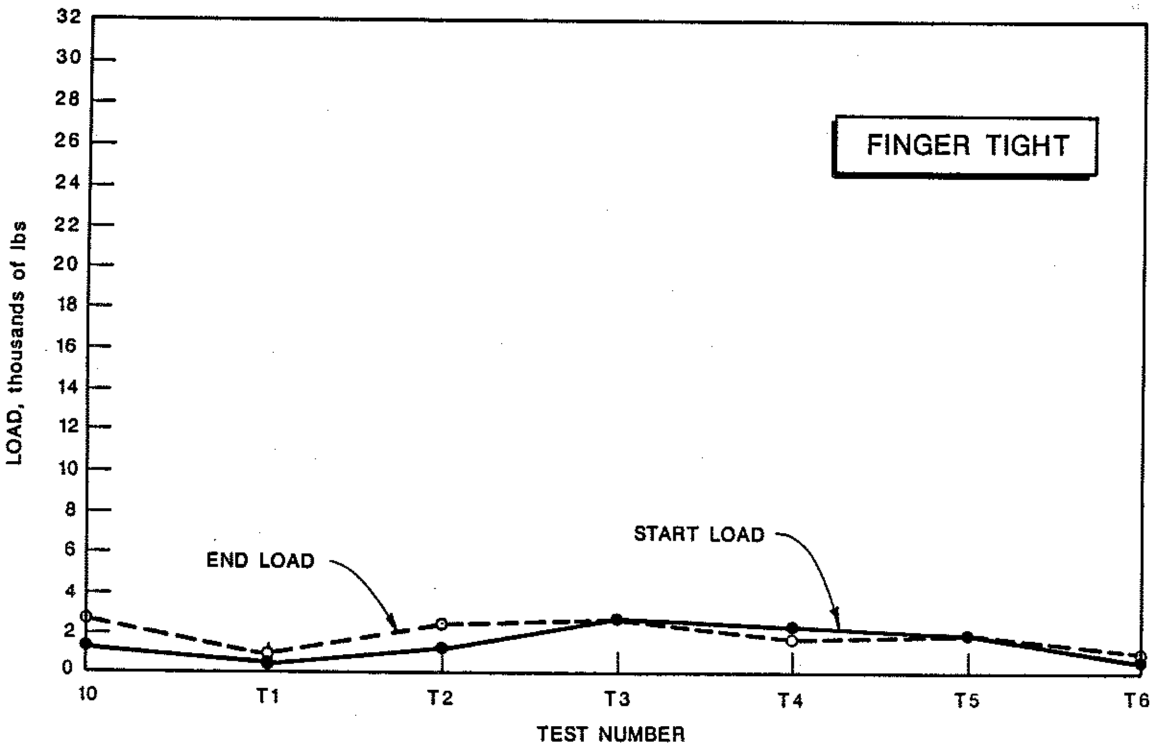


Figure 8. Comparison of starting cycle loads and ending cycle loads of test Nos. 10 and T1 through T6. New materials were used in all tests.

TABLE 3
SUMMARY OF TEST DATA

Test No.	Slot Length, in.	Stroke Length, in.	Bolt Shoulder Thickness	Shoe Location		Bolts Tightened		No. of Cycles	Ultimate Load, lb	Failure Mode
				Front	Back	Wrench	Finger-Tight			
1	3	2	7/32			X		17	71,000	Failed at bottom fixture due to insufficient material at bolts. Splice held.
2	3	2	7/32		X	X		328	100,000	No failure noted.
3	3	2	7/32		X	X		67	100,000	No failure noted.
4	5	4	7/32	X		X		22	100,000	No failure noted.
5	5	4	7/32		X	X		28	86,000	
6	5	4	5/16		X	X		10	100,000	Splice holes slightly elongated.
7	5	4	5/16		X	X		19	100,000	Splice holes slightly elongated.
8	5	4	7/32		X	X		7	96,000	Splice holes slightly elongated and dimpled. Shoe failed at bridge end.
9	5	4	7/32		X	X		10	74,000	Shoe failed at bridge end. Splice holes in rail dimpled.
10	5	4	7/32		X		X	9	82,000	Shoe holes dimpled. Load was at end of stroke. Rail holes elongated and dimpled.
T1	5	3	7/32		X		X	8	82,000	Shoe failed at bridge rail end.
T2	5	3	7/32	X			X	11	97,000	Fractured across splice slots in shoe.
T3	5	3	7/32	X			X	8	82,000	Shoe failed at bridge rail end.
T4	3	2	7/32	X			X	65	96,000	Splice bolts pulled through shoe.
T5	3	1-1/2	7/32	X			X	19	82,000	Fractured across splice slot in shoe.
T6	3	1-1/2	7/32		X		X	8	98,000	Splice bolts pulled through GR element.

4) The anchorage shoe will develop adequate strength even with the slot elongated to 5 in.

5) The shoulders on the splice bolts occasionally make contact with the ends of the slots and produce higher load values.

Recommendations

1) It is recommended that a new standard be developed, allowing use of the special end shoe with 5-in. splice slots for use where required on special bridges. Slots should be lengthened toward the anchor end rather than toward the guardrail end of the shoe.

2) The Design Division modify the note concerning the tightness of splice bolts to include the statement that at least one full thread must be exposed beyond the nut, and that the thread be upset in at least two places. Also the note should reference other guardrail-to-anchorage shoe connections.

3) A chart of where to set the rail in comparison to the slots for the temperature at the time of installation, needs to be developed.