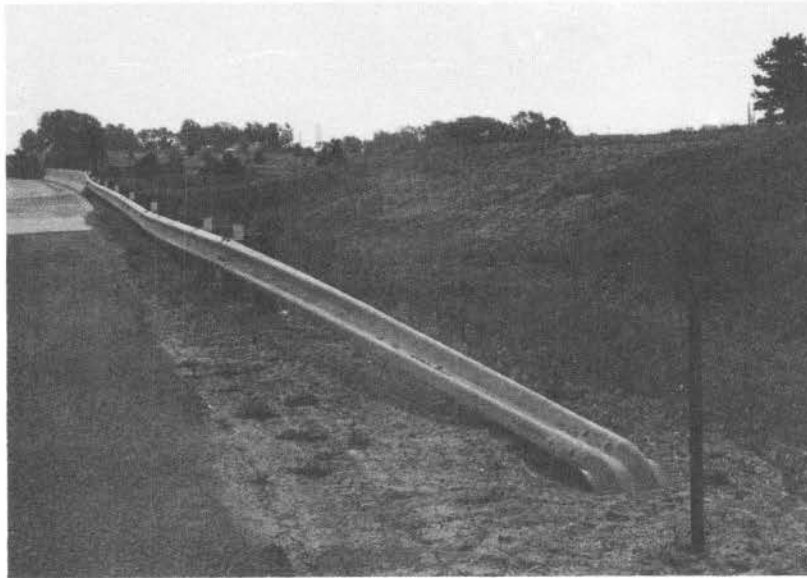


Jim L.

# STATIC TESTS ON COLLAPSING GUARDRAIL DESIGNS



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## **ABSTRACT**

A modified turned-down guardrail terminal which uses retrofit clips to hold up the guardrail has been in use on Nebraska Highways for several years. During this time, the Nebraska Department of Roads has become aware of a problem with this design. After being exposed to temperature fluctuations and vibrations from passing traffic the retrofit clips expand and the guardrail drops to the ground.

Twelve different designs were tested on an actual guardrail field installation and a design consisting of strategically placed shear bolts was recommended.

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## A. INTRODUCTION

### A.1. Problem Statement

Recently, much work has been done on modifying the ends of turned-down guardrail terminals to eliminate or minimize the probability of errant vehicles impacting them, ramping, and rolling over (1 and 2). One of the more recent designs which is being used on state highways today consists of retrofit clips which hold the guardrail in place at a specified height. This design is shown in Figures 1A and 1B. When the barrier is subjected to a transverse impact, the backup plates hold the guardrail in place and the vehicle is redirected. However, when a vehicle begins to ride up the turned-down section, it produces a downward vertical force which causes the clips on the first five posts to release and the guardrail drops to the ground. This prevents any vehicle ramping motion. As the vehicle travels along the top of the collapsed guardrail, it breaks off or knocks over the posts which had been supporting it and eventually comes to rest.

This modified turned down terminal was tested at the Texas Transportation Institute. A detailed report of these tests can be found in the Transportation Research Record 631 (1).

A problem has become apparent with this design since its implementation on Nebraska highways. The vibration from passing traffic and fluctuations in temperature cause the retrofit clips to expand, causing the guardrail to drop to the ground without being impacted.



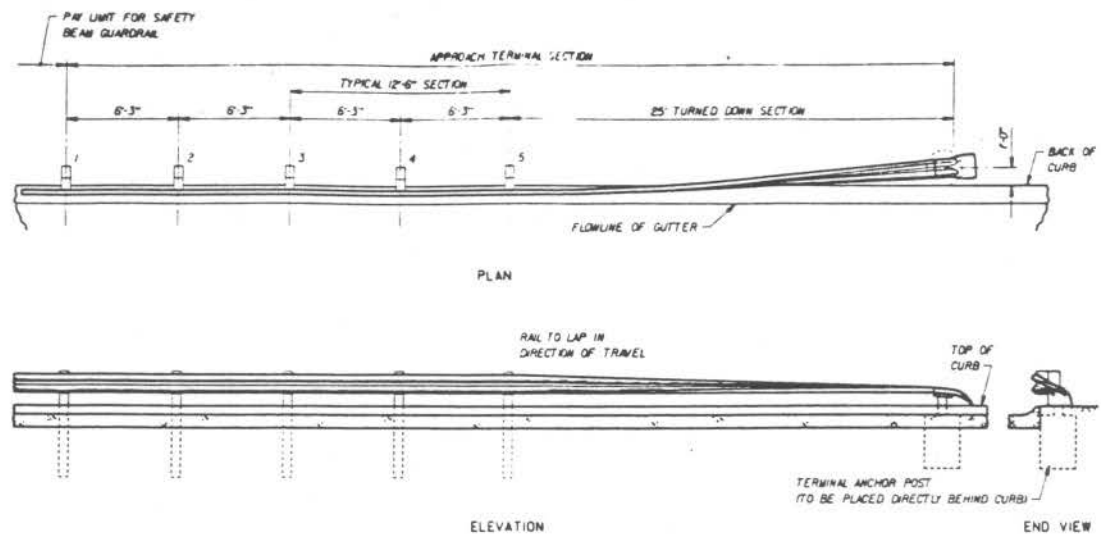
## A.2. Objectives

The objective of this study was to find an alternate design for the retrofit clip which is currently in use on many guardrail terminals. The new design must be able to withstand vibrations from traffic and fluctuations in temperature.

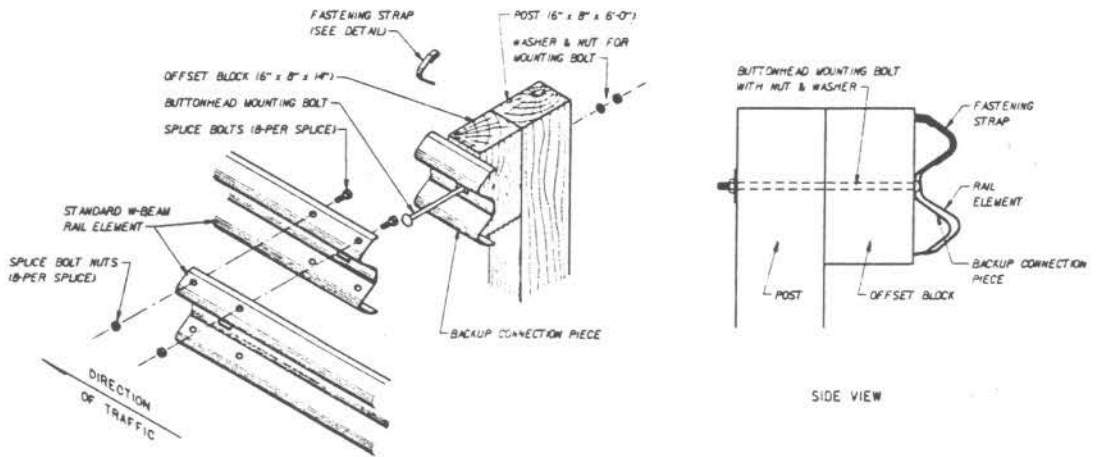
The proposed design consists of a shear bolt being added to the design at the top crest of the W-beam as shown in Figure 2. This shear bolt should support the weight of the beam before impact and shear off when a downward vertical force approximately equal to the weight of a minicompact sedan is applied to the guardrail. Static tests were run on an actual guardrail field installation to determine the vertical force required to drop the guardrail to the ground.

## A.3. Goals

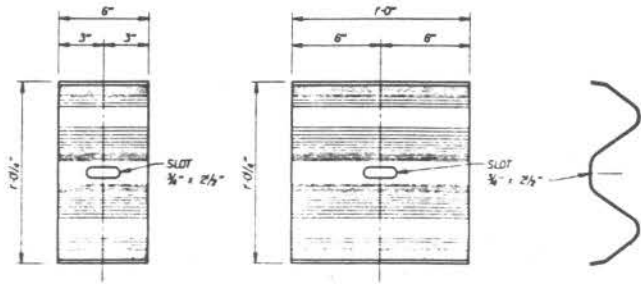
The goals of this test are (1) to determine the most advantageous position(s) for the shear bolt(s), (2) to determine the optimum shear bolt size, and (3) to determine the downward vertical force required to drop the guardrail to the ground in each case.



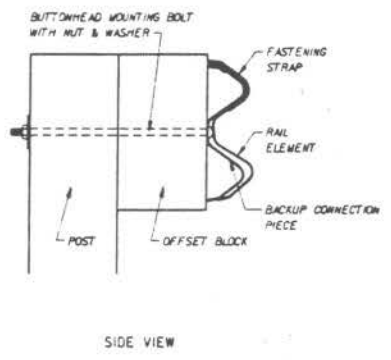
INSTALLATION AT CURBED LOCATIONS



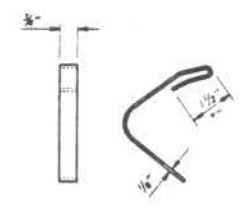
ASSEMBLY DETAIL



DETAILS OF BACKUP CONNECTION PIECE



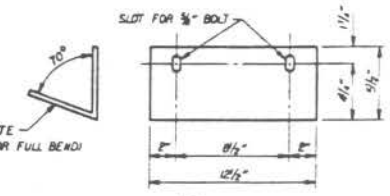
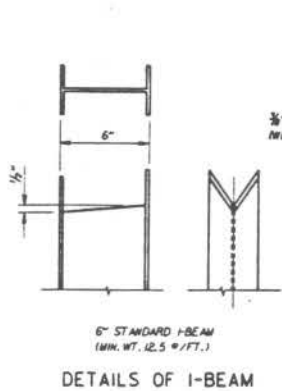
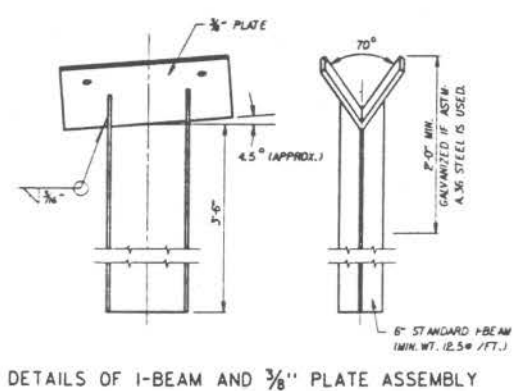
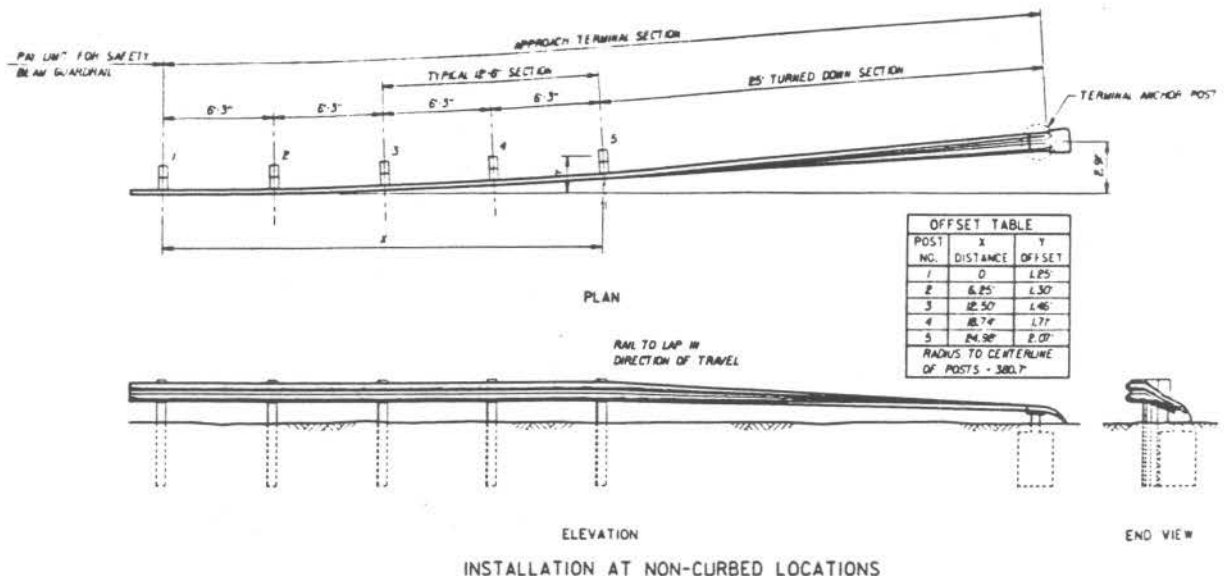
SIDE VIEW



1/4" x 3/8" x 9" A36 (MILD) STEEL PLATE  
FIELD SHAPED WITH HAMMER FOR TIGHT  
FIT. HOOK FITS OVER BACKUP CONNECTION  
PIECE AND RAIL ELEMENT TO FORM A WEAR  
CONNECTION.

DETAILS OF FASTENING STRAP

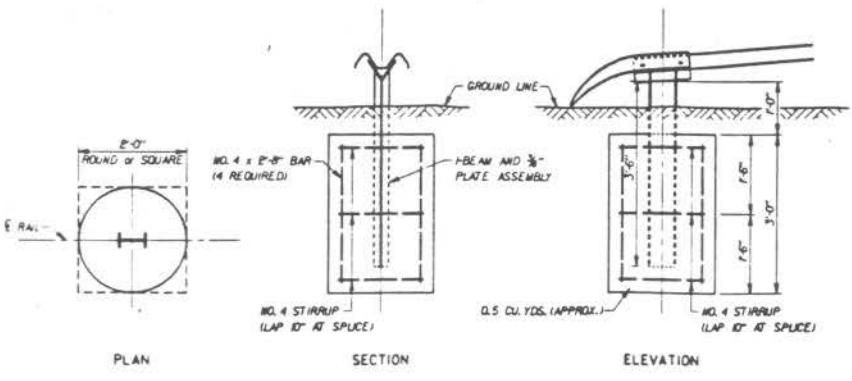
Figure 1A. Diagram of original guardrail terminal design.



DETAILS OF 3/8" PLATE

NOTES

- BACKUP CONNECTION PIECES SHALL BE 12-GAUGE GALVANIZED STEEL W-BEAM.
- FOR POST NO. 1 THE BACKUP CONNECTION PIECE SHALL BE 6' LONG & FOR POSTS NO. 2 THRU 5 THE ELEMENT SHALL BE 12' LONG.
- THE RAIL ELEMENT SHALL NOT BE CONNECTED TO POSTS NO. 1 THRU 5. RAIL ELEMENT SHALL BE FASTENED TO BACKUP CONNECTION PIECES USING STEEL FASTENING STRAPS.
- SPLICE BOLTS SHALL BE CUT IF REQUIRED; SO THAT THEY EXTEND THRU THE FULL THICKNESS OF THE NUT & NO MORE THAN 3/8" BEYOND IT.
- THE SPLICE BOLTS AT POSTS NO. 3 & 5 SHALL HAVE HEX NUTS MOUNTED ON THE FRONT (TRAFFIC) SIDE OF THE RAIL. FOR THE SPLICE AT POST NO. 1 THE HEX NUTS SHALL BE MOUNTED ON THE REAR SIDE OF THE RAIL ELEMENTS.
- THE 25' TURNED DOWN SECTION SHALL BE EITHER SHOP OR FIELD BENT SO THAT A PERMANENT 90° DEFLECTION IS ACCOMPLISHED PRIOR TO INSTALLATION. THIS WILL NECESSITATE A ROTATION THROUGH 220°.



DETAILS OF TERMINAL ANCHOR POST

APPROACH TERMINAL SECTION  
SPECIAL PLAN C

Figure 1B. Diagram of original guardrail terminal design.

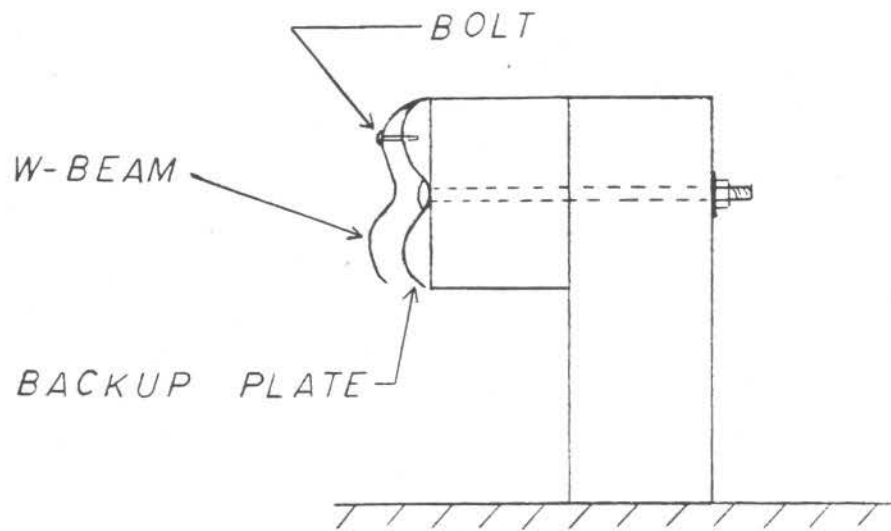


FIGURE NO. 2: PROPOSED BREAK-AWAY DESIGN

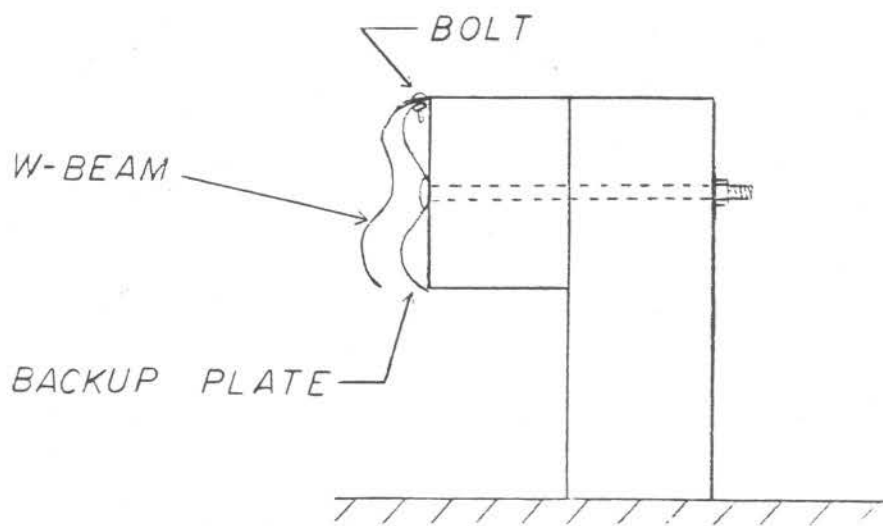


FIGURE NO. 3: MODIFIED BREAK-AWAY DESIGN

## **B. TEST CONDITIONS**

### **B.1. Test site**

The site for this test was a newly installed guardrail terminal on the east bound lane of Interstate 80, one mile east of the NW 48th Street interchange exit near Lincoln, Nebraska.

### **B.3. Test Article**

A detailed diagram of the guardrail which was tested is shown in Figure 1. Photographs of the test article can be seen in Figure 4. The test article was a W-beam section connected to a concrete bridge rail on the downstream end and turned-down with a 90 degree twist on the upstream end. The W-beam was connected to the first five posts by a retrofit clip which allows the barrier to drop when a large, downward, vertical load is applied. The guardrail transition was installed in 1988, so it was the newest guardrail of its type in the area.

### **B.3. Testing Apparatus**

The testing apparatus used in testing the guardrail terminal consisted of four major components. A ratchet puller to apply the load, a dynamometer to measure the load, a 1/4 in. steel cable to transfer the load, and a pulley system to direct the applied load. A diagram of this testing apparatus can be seen in Figure 5 and photographs can be seen in Figure 6. The 1/4 in. cable was wrapped around the W-beam 6 inches upstream of post No. 5. The cable was strung straight down and through a chute with two 3 in. pulleys which redirected the load. This chute was attached to post No. 5 by four 1/2" X

24" bolts and a 3/8 in. steel clamping plate. The cable was then hooked to a dynamometer so that its tension could be measured. The dynamometer rested on two boards with rollers between them to minimize any error due to friction. A ratchet puller was attached to the other end of the dynamometer and to post No. 3 for an anchor. As a load was applied by the ratchet puller, the W-beam was subjected to a downward force. This force simulated the downward vertical force applied by an errant vehicle riding up the guardrail and was measured by the dynamometer.

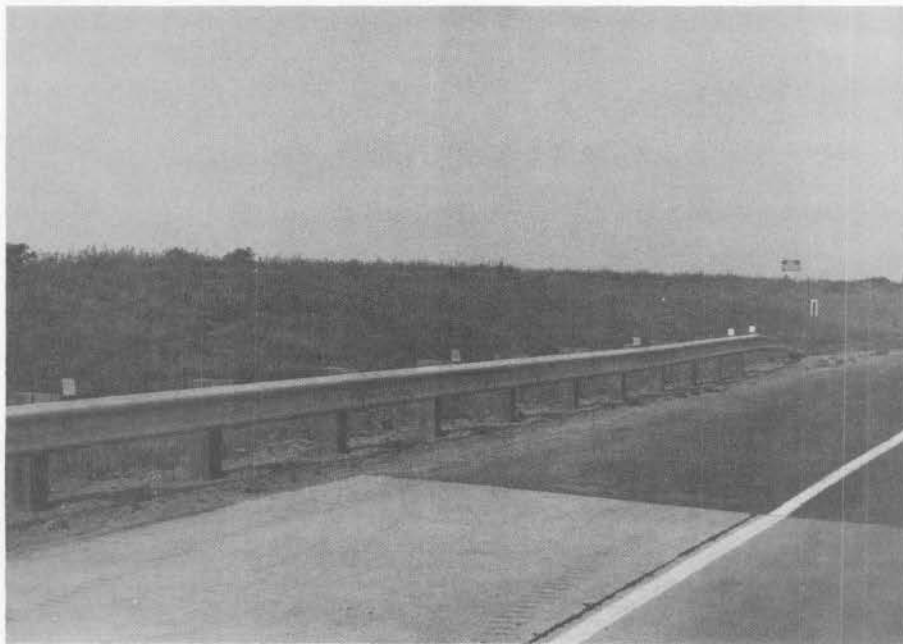
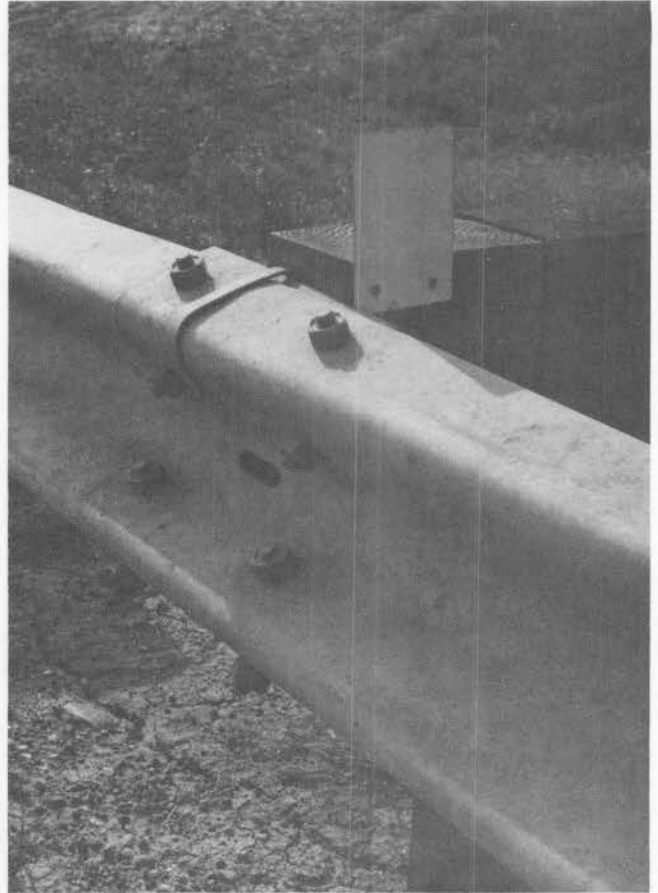


Figure 4. Photographs of test article.

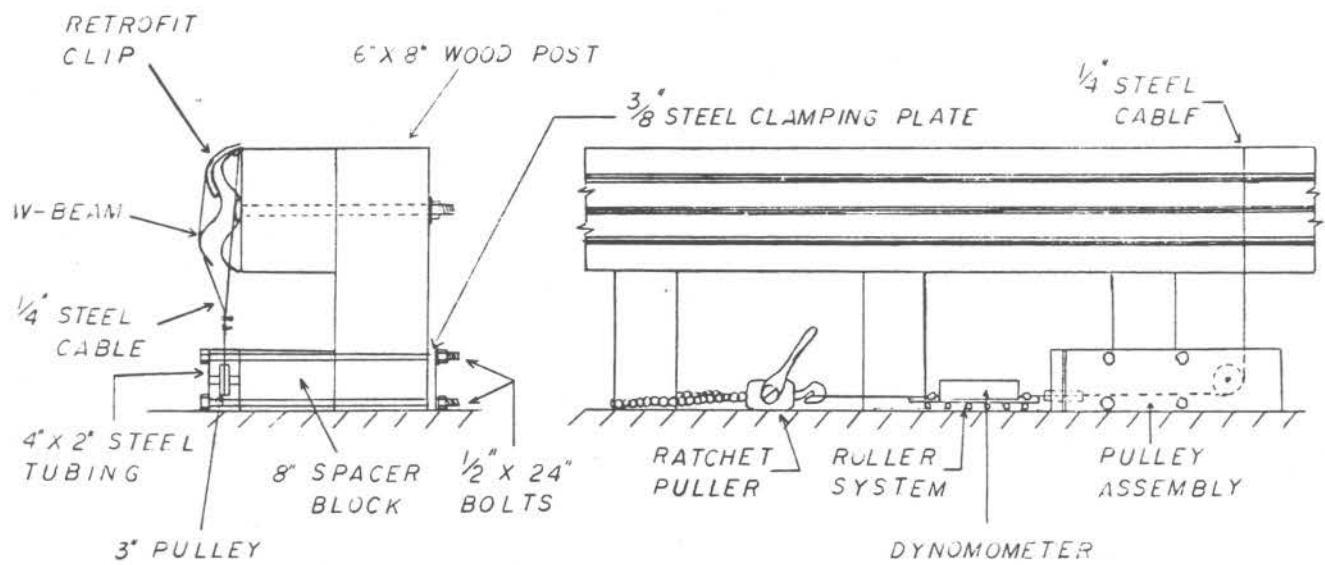


Figure 5. Diagram of testing apparatus.



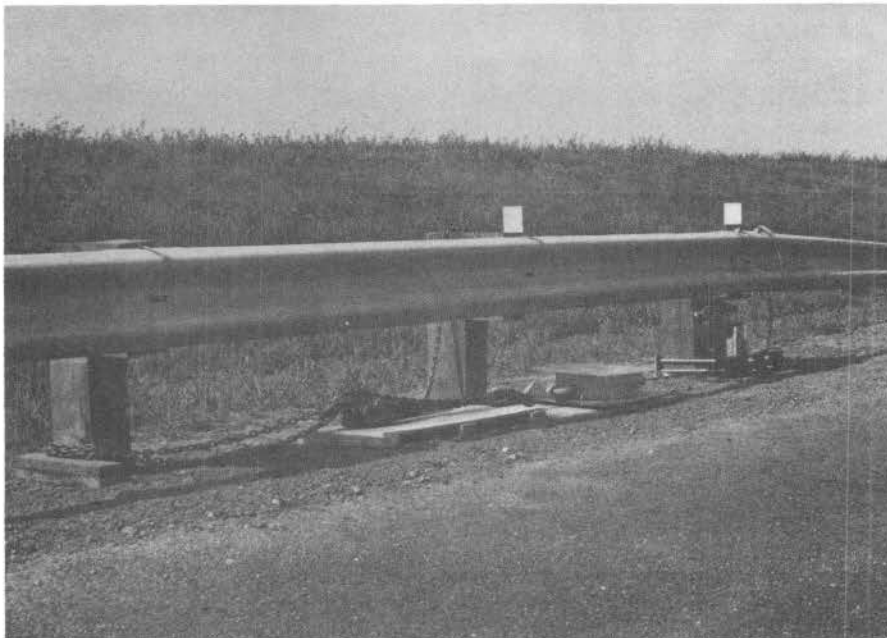
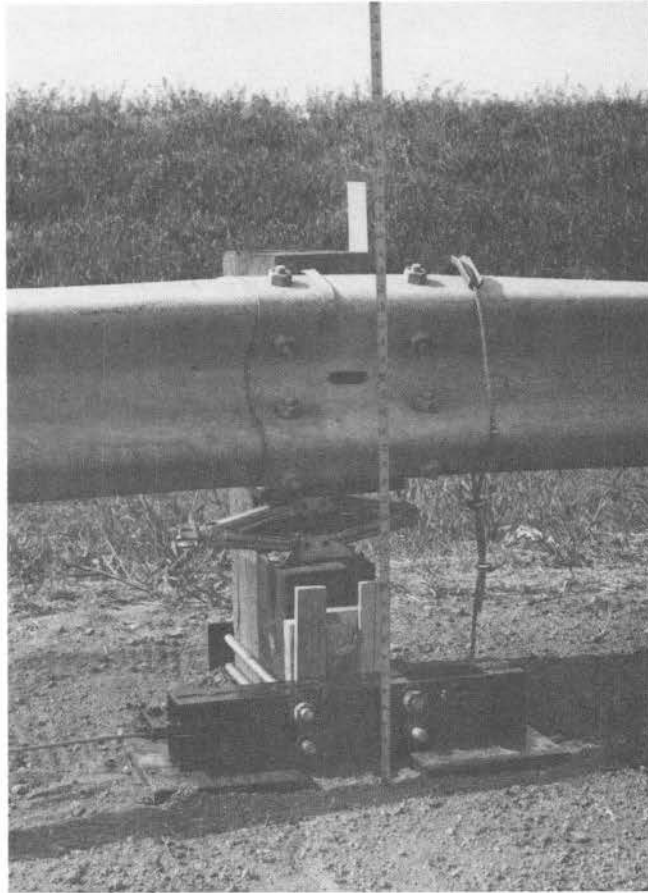


Figure 6. Photographs of testing apparatus.

### **C. TECHNICAL DISCUSSION**

Twelve tests were conducted in the process of determining the optimum shear bolt size and location. Each test used a different combination of retrofit clip location, bolt size, and bolt location.

Two bolt positions were used. The first was positioned on the top crest of the W-beam as shown in Figure 2. The second position was 1.5 in. down from the top edge of the W-beam as shown in Figure 3. This difference in position is not clearly evident in photographs so none are included.

Photographs of the collapsed rail are shown in Figure 7 and a summary of these tests can be found in the Test Matrix shown in Table 1.

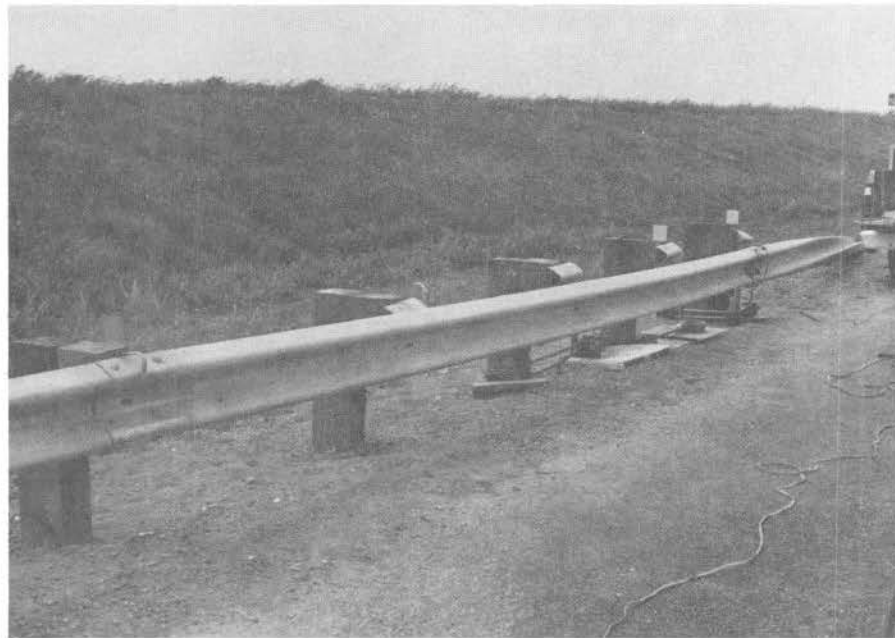
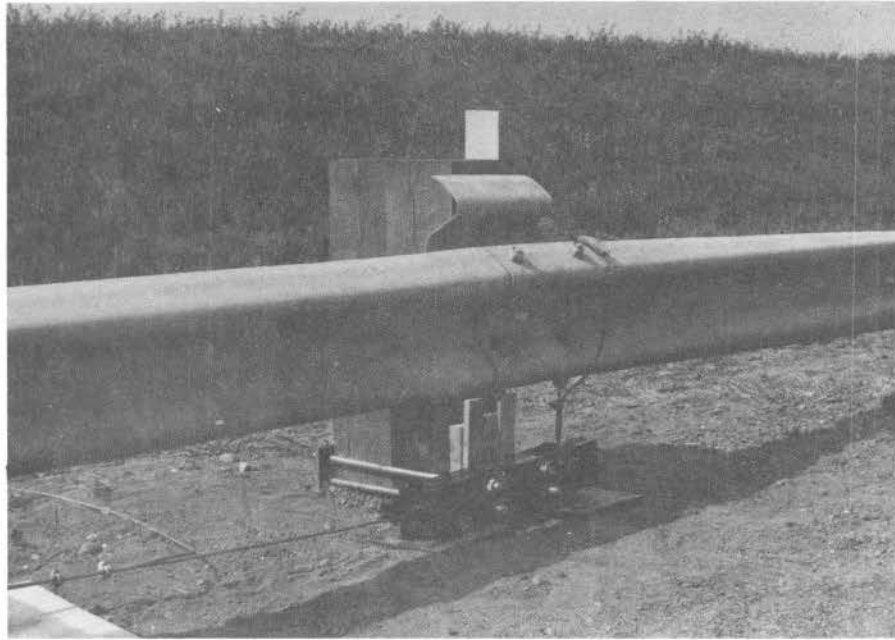


Figure 7. Photographs of collapsed guardrail terminal.

Table 1. TEST MATRIX

Test Matrix: Collapsible Guardrails

Test No.	Washer on bolt supporting backup plate	Bolt Size	Bolt Location (Post No.)	Bolt Position (Fig. No)	Clip Location (Post No.)	Number of tests conducted	Average failure load (lbs)
1					1,2,3,4,5	2	1,740
2		#8	5	2	1,2,3,4	3	1,890
3		#8	3,5	2		2	2,000
4		#8	3,5	2	1,2,4	2	2,000
5		#8	5	3	1,2,3,4	4	1,200
6		#8	3,5	3	1,2,4	2	1,460
7		#8	3,5	3		2	N.A.
8	x	#10	5	3	1,2,3,4	3	1,490
9	x	#10	5	3	1,2,3,4,5	2	1,590
10	x	#8	5	3	1,2,3,4,5	2	1,510
11	x	#10	3,5	3		2	1,240
12	x	#8	3,5	3		2	1,170

## **D. TEST RESULTS**

### D.1. Test No. 1

The first test conducted was on the existing guardrail design with retrofit clips on each of the first five posts. As in all of the tests, a downward vertical load was applied 6 inches upstream of Post No. 5. Two tests were performed on this installation. In Test (1a) the guardrail collapsed at 1900 lbs., and in Test (1b) it failed at 1580 lbs. The average of the two tests was 1740 lbs.

When comparing this number to the other tests, one should consider the fact that this field installation guardrail was less than a year old and the retrofit clips were stronger than those on older guardrail installations. This is true because they haven't been subjected to true field conditions as long as older systems.

### D.2. Test No. 2

This test was conducted with a No. 8 bolt on the top crest of the W-beam on post No. 5 as pictured in Figure 2. Post Nos. 1, 2, 3, and 4 were fastened to the W-beam using the retrofit clip.

At this point we found it necessary to place a 1/2" X 20" bolt between the W-beam and the 1/4" cable to distribute the load and therefore minimize the damage to the W-beam.

Four tests were performed with this arrangement. In Test (2a) a 2000 lb. capacity dynamometer was used to measure the load. The force was increased to 1960 lbs. with no reaction from the guardrail so the load was released and a dynamometer with a 5000 lb. capacity was used on all the remaining tests.

Tests (2b), (2c), and (2d) were conducted using a 5000 lb. dynamometer. In Test

(2b) the retrofit clip on post No. 4 released at 2000 lbs. and the bolt on post No. 5 failed at 2125 lbs. On test (2c) the retrofit clip on post No. 4 and the bolt on post No. 5 both failed at 1775 lbs. Test (2c) had similar results with the clip on post No. 4 releasing at 1500 lbs. and the bolt on post No. 5 failing at 1750 lbs. The average force required for failure with this design was approximately 1890 lbs.

It should be noted that the No. 8 bolts did not actually fail but the nuts were pulled off of the bolts with a stripping action. This contradicted the shearing which was expected to take place.

In the remaining tests a 5000 lb. capacity dynamometer was used to alleviate the problem encountered in this test.

#### D.3. Test No. 3

This test was conducted with No. 8 bolts in the top crest of post Nos. 3 and 5 as shown in Figure 2. No clips were used to hold the W-beam up on the other posts. Two tests were run with this design.

On Test (3a) the bolt in post No. 5 failed at 1950 lbs. and the bolt in post No. 3 did not fail. Similar results were obtained from Test (3b) in that the bolt on post No. 5 failed at 2050 lbs. and the bolt in post No. 3 did not fail.

The average downward vertical force required to drop this barrier design to the ground is 2000 lbs.

As in Test No. 2, the bolts did not fail but the nuts were stripped from them.

#### D.4. Test No. 4

In this test, No. 8 bolts were placed in the top crest of the W-beam as shown in Figure 2 in post Nos. 3 and 5, and retrofit clips were placed on post Nos. 1, 2, and 4.

Two tests were run with this design, both with similar results.

In Test (4a) the bolt in post No. 5 failed at 2100 lbs. and the clip on post No. 4 released at the same time. The bolt on post No. 3 did not fail. Test (4b) had very similar results with the bolt in post No. 5 failing at 1900 lbs. and the retrofit clip on post No. 4 failing at the same time. Again, the bolt on post No. 3 did not fail. The average force required to drop this design to the ground was 2000 lbs.

Again it should be noted that the bolt did not fail in shear; rather, the nut was stripped from the bolt, causing failure.

#### D.5. Test No. 5

At this point the position of the No. 8 bolt was moved to the top of the W-beam as shown in Figure 3. Four tests were conducted with a bolt supporting the W-beam at post No. 5 and retrofit clips on posts Nos. 1, 2, 3, and 4.

In Test (5a) the bolt failed and the clips released at 1700 lbs. In this test, as well as all of the following tests with the bolt in this position, the bolt failed in shear instead of the nut being stripped from it.

In Test (5b) the retrofit clip on post No. 4 released at 375 lbs., the clip on post No. 3 released at 1000 lbs., and the No. 8 bolt in post No. 5 failed at 1050 lbs.

At this point the backup plate was beginning to become bent out of shape so it was replaced for Test (5c). In Test (5c) the bolt on post No. 5 failed and the clips on post Nos. 2, 3, and 4 released at 800 lbs. Similar results were obtained from Test (5d) where the bolt on post No. 5 failed, and the clips on post Nos. 2, 3, and 4 released at 1250 lbs.

The average downward force required to drop this barrier design to the ground was 1200 lbs.

#### D.6. Test No. 6

Two tests were conducted with No. 8 bolts attaching the W- beam to the backup plate on post Nos. 3 and 5. These bolts were positioned at the top of the W-beam as shown in Figure 3. Retrofit clips were placed on post Nos. 1, 2, and 4.

In Test (6a) the retrofit clip on post No. 4 released at 1190 lbs. and the bolt on post No. 5 failed at 1380 lbs. The bolt on post No. 3 did not fail, and the clips on posts Nos. 1 and 2 did not release.

A similar result was obtained in Test (6b) where the clip on post No. 4 released at 1000 lbs. and the bolt on post No. 5 failed at 1540 lbs. Again, the bolt on post No. 3 did not fail and the clips on posts Nos. 1 and 2 did not release.

The average downward vertical force required to collapse this guardrail design was 1460 lbs.

#### D.7. Test No. 7

Two tests were conducted with No. 8 bolts connecting the W- beam to the backup plates on post Nos. 3 and 5. These bolts were positioned at the top of the W-beam as shown in Figure 3. Nothing was used to connect the W-beam to post Nos. 1, 2, and 4.

In Test (7a) a load of 1050 lbs. was applied and the backup plate on post No. 5 was pulled completely from the post. It was suspected that this occurred as a result of the backup plate being used for several of the previous tests so a new backup plate was installed and a second test was conducted.

In Test (7b) a 1250 lb. load was applied and the backup plate on post No. 5 buckled over. This indicated that this particular design was too strong and would not collapse as designed.



In each of the following tests a washer was used between the head of the buttonhead mounting bolt and the backup plate to prevent the plate from being pulled from the bolt. This washer also served as a stiffener for the backup plate and the release system worked much more smoothly with it in place. The backup plate was also replaced after each of the following tests to insure more uniform results.

#### D.8. Test No. 8

Three tests were conducted with a No. 10 bolt connecting the W-beam to the backup plate on post No. 5. This bolt was positioned on the top of the W-beam as indicated in Figure 3. Retrofit clips were placed on post Nos. 1, 2, 3, and 4.

In Test (8a) the retrofit clip on post No. 4 released at 1375 lbs. The bolt failed and clips on post Nos. 2 and 3 released at 1450 lbs.

Test (8b) had similar results with the bolt on post No. 5 failing and the clips on post Nos. 2, 3, and 4 releasing at 1560 lbs.

In Test (8c) the clips on post Nos. 2, 3, and 4 released, and the bolt on post No. 5 failed at 1470 lbs.

The average downward vertical force required to collapse this barrier design was 1490 lbs.

#### D.9. Test No. 9

Two tests were performed with a No. 10 bolt connecting the W-beam to the backup plate on post No. 5. The bolt was located at the top of the W-beam as shown in Figure 3. Retrofit clips were also installed on post Nos. 1, 2, 3, 4, and 5.

In Test (9a) the clip on post No. 5 released at 800 lbs. so it had no effect on the outcome of the test. At 1675 lbs. the bolt on post No. 5 failed and the retrofit clips on

post Nos. 2, 3, and 4 were released.

The results of Test (9b) were very similar to those of Test (9a). The retrofit clip on post No. 5 released at 750 lbs. and the bolt on post No. 5 failed at 1500 lbs. The clips on post Nos. 2, 3, and 4 were also released at 1500 lbs.

The average force required to drop this barrier design to the ground was 1590 lbs.

#### D.10. Test No. 10

Two tests were conducted with a No. 8 bolt supporting the guardrail at post No. 5 as shown in Figure 3. Retrofit clips were also used to support the guardrail at post Nos. 1, 2, 3, 4, and 5.

In Test (10a) the clip on post No. 5 released at 750 lbs. and the bolt supporting the W-beam at post No. 5 failed at 1520 lbs. The clips on post Nos. 2, 3, and 4 were also released at 1520 lbs.

Test (10b) had similar results with the clip on post No. 5 releasing at 1050 lbs. The bolt on post No. 5 failed, and the retrofit clips on post Nos. 2, 3, and 4 released at 1500 lbs.

The average force required to collapse this guardrail design was 1510 lbs.

#### D.11. Test No. 11

Two tests were conducted with No. 10 bolts in post Nos. 3 and 5 supporting the W-beam. The bolts were positioned as shown in Figure 3. No clips were used to support the guardrail.

In Test (11a) the bolt at post No. 5 failed at 1375 lbs. and in Test (11b) it failed at 1100 lbs. In both tests the bolt in post No. 3 did not fail.

The average load required to collapse this design was 1240 lbs.

#### D.12. Test No. 12

Two tests were performed on a guardrail with No. 8 bolts supporting the W-beam at post Nos. 3 and 5 as shown in Figure 3.

In Test (12a) the bolt at the No. 5 post failed at 1200 lbs., and the bolt at the No. 3 post did not fail.

Test (12b) was very similar as the bolt in post No. 5 failed at 1130 lbs., and the bolt in post No. 3 remained intact.

The average force required to collapse this barrier design was 1170 lbs.

## **E. CONCLUSIONS AND RECOMMENDATIONS**

The results of these tests on collapsing guardrails are summarized in Table 1. Almost all of the guardrail designs released under an allowable load, so the problem became that of determining which design would hold up best under actual field conditions.

The design recommended for use on public highways is that described in Test No. 11. This design consisted of a No. 10 bolt located in post Nos. 3 and 5, positioned at the top of the W-beam as shown in Figure 3. The No. 10 bolt was chosen over the No. 8 bolt because it provides more stability without much increase in the vertical force required to drop the terminal. The retrofit clips are not recommended because of their poor performance in actual field conditions.

A washer is recommended between the backup plate and the head of the bolt supporting it. This washer stiffens the backup plate and greatly improves the shearing action of the bolt.

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