Dynamic Tests of Short Sections of Corrugated Metal Beam Guardrail

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The results of six full-scale vehicle impact tests into anchored short sections (less than 100 ft) of 27-in. high blocked-out corrugated metal beam guardrail are reported. Tests were performed on three free-standing sections using two different end anchorage systems. Tests were also performed on three simulated bridge approach guardrail flares using a cable anchor assembly on the upstream or approach end and a rigid attachment to the concrete bridge rail end post at the other end. The tests were conducted at speeds ranging from 56 to 63 mph and approach angles varying from 24 to 33 deg, using 1964 to 1966 sedans weighing approximately 4500 lb.

The results of two tests on short guardrail sections with sloping beam anchorage ("Texas twist") indicate that this system is structurally adequate when struck in the center, but performance is questionable with regard to impacts into the ramped ends. As a result of four tests, an effective cable-type end anchorage system for short free-standing sections of guardrail was developed. In addition, an efficient bridge approach guardrail flare design was developed that provides a relatively smooth transition from the semiflexible blocked-out beam guardrail (8 by 8-in. posts 6-ft 3-in. O.C.) through a semirigid system (10 by 10-in. posts 3-ft 1½-in. O.C.) to a rigid reinforced concrete bridge rail.

•UNTIL recently, short sections of free-standing unanchored metal beam guardrail (less than 100 ft) have been installed rather indiscriminately as protection from striking almost every conceivable highway appurtenance. However, operational experience, confirmed by recent full-scale testing (1), has shown that these short sections can be completely ineffective in preventing penetration when subjected to a severe impact by an errant vehicle.

It was the purpose of this research effort to test and/or develop corrugated metal beam guardrail end anchorage systems that would be effective both in preventing penetration and in redirecting a 4500-lb vehicle impacting the metal beam guardrail at a speed of 60 mph and an approach angle of 25 deg.

PROCEDURE

Test Parameters

The test vehicles used in this study were 1964-66 sedans weighing approximately 4500 lb with dummy and instrumentation. Under their own power, they were guided into the guardrail test installation by radio remote control. Impact speeds ranged from 56 to 63 mph at approach angles of 24 to 33 deg. The procedures followed to prepare, remotely control, and target the test vehicles were generally similar to those used in past test series and are detailed in previous reports (2, 3).

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Figure 1.

All tests generally followed the criteria outlined by the HRB Committee on Guardrails and Guideposts in 1962 for full-scale testing of guardrails (4).

Instrumentation

Photographic and mechanical instrumentation procedures and equipment employed in this test series were generally similar to those used in past test series and are detailed in previous reports (2, 3).

Design and Performance

Common to each of the six test installations was the basic guardrail design. The current California standard metal beam guardrail consists of a 12-gage (0.105-in.) corrugated steel beam mounted 27 in. high overall, blocked-out with 8 by 8-in. by 1-ft 2-in. treated Douglas fir blocks on 8 by 8-in. by 5-ft 4-in. treated Douglas fir posts spaced 6 ft 3 in. on centers.

The guardrail test installations varied in length and/or end anchorage system. Specific installation details and the results of each dynamic test follow.

Test 133—The first guardrail end anchorage design tested was developed by the Texas Highway Department and is referred to as the "Texas twist". The installation for Test 133 consisted of a 62.5-ft section of corrugated metal guardrail beam. The 25-ft long center portion of California standard guardrail was anchored at each end with 18 ft 9 in. of the beam section twisted 90 deg axially, bent down and bolted to fabricated steel posts cast in 18-in. diameter by 5-ft deep concrete cylindrical footings. The sloped end anchorage beam had no intermediate supports (Fig. 1).

The test vehicle impacted near the center of the barrier at 56 mph and 30 deg and remained in contact for about 35 ft before being effectively redirected at an exit angle of 7 deg (see Plate A, Appendix). Vehicle dynamics through impact were considered good, with the vehicle sustaining moderate front end damage (Fig. 2). The permanent deflection of the guardrail beam was 2.8 ft horizontally (back) and 6 in. vertically (up).

All beam sections were damaged. A $^{3}/_{8}$-in. wide crack was opened in the downstream concrete footing and the upstream footing was displaced approximately $2^{1}/_{2}$ in. toward impact (Fig. 3).

Figure 2.

Figure 3.

Figure 4.

Figure 5.

Test 134—Although Test 133 demonstrated that the "Texas twist" anchorage system was structurally adequate, it was felt that the geometric characteristic of the sloping beam end anchorages presented a potentially hazardous condition. The sloping beam could form a ramp upon which an impacting vehicle might climb and vault the barrier. Therefore, in Test 134 (installation identical to Test 133), the point of impact was shifted upstream, with the vehicle impacting the barrier within the sloping beam portion, 4.9 ft from the concrete end anchor, at 63 mph and 24 deg. The beam at this point was too low to effectively resist the vertical downward force of the impacting left front wheel, which deflected the beam down, permitting the front wheel to ride up and over the beam. This reaction of the beam imparted a rolling moment to the vehicle, which completely overturned as it vaulted the barrier. The vehicle came to rest 180 ft beyond impact in a regained upright position (Plate B). The end section of beam was flattened and one post and block-out block was shattered (Fig. 4). The vehicle sustained major front, side, and top damage and was considered a total loss (Fig. 5). These test results were later substantiated by a test on a sloped-end anchorage design by the Ontario Highway Department (5) in which similar vehicle reaction was observed.

Test 135—In an attempt to provide adequate and efficient end anchorage, a cable end anchor system was developed which has subsequently been adopted as a California standard (see Exhibit 1, Appendix). Test 135 was the first test using this system of anchorage. The test installation consisted of a 50-ft length of corrugated metal beam guardrail constructed as a parabolic flare In order to reduce the lever arm effect of the axial force acting about the posts, block-out blocks were not installed on the end posts and 4-in. thick blocks were used on the posts next to the end. Each end of the beam was secured with a $\frac{3}{4}$-in. steel cable (breaking strength 21.4 tons) attached to the beam with a special fitting between the first and second posts (Fig. 6 and Exhibit 1). The other end of each cable was clamped to a $1\frac{1}{4}$-in. eyebolt cast in an 18-in. diameter by 5-ft deep cylindrical concrete footing (Figs. 7 and 8).

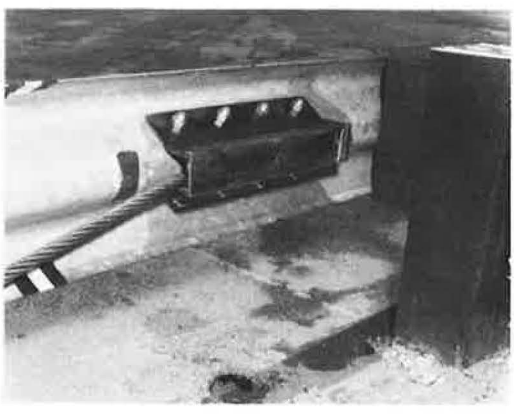

Figure 6.

The vehicle in Test 135 impacted the barrier between posts 2 and 3 at 59 mph and 28 deg. The vehicle remained in contact with the barrier for approxi-

Figure 7.

Figure 8.

mately 22 ft before being effectively redirected at an exit angle of 24 deg (Plate C). All beam sections were damaged and both anchors were displaced approximately $^5/_8$ in. toward impact (Fig. 9). The test vehicle sustained moderate front-end damage (Fig. 10).

Although vehicle dynamics and barrier reaction were considered satisfactory through impact, deceleration forces were fairly severe, as there was a tendency for the vehicles to pocket the beam. Analysis of high-speed film revealed that this pocketing was due, at least partially, to the parabolic configuration of the barrier, since the curved beam had to deform through a straight line before the restraining force of the anchor was effectively developed. As a result, it has been recommended that all short sections of guardrail be flared and placed on a straight line between anchor points, even though there is a possibility of increasing the collision impact angle by doing so.

Test 136—Since the cable anchor was effective in adding beaming strength to a short section of free-standing guardrail, it was felt it would also be satisfactory for anchoring the upstream end of a bridge approach guardrail flare.

The installation for Test 136 consisted of a 53-ft section of California standard guardrail with enough curvature in the first 12 ft from the bridge rail end so the remainder of the barrier could be placed on a straight line with a 4-ft end offset from a projection of the bridge rail line (Fig. 11). The downstream end of the guardrail beam

Figure 9.

Figure 10.

Figure 11.

Figure 12.

was secured to a nonreinforced concrete simulated bridge rail with two 1-in. diameter high-strength bolts through $1\frac{1}{8}$-in. diameter holes bored through the concrete. An 8 by 12 by 18-in. wood block was placed between the beam and the concrete (Fig. 12).

The test vehicle impacted the guardrail at 60 mph and 33 deg 18 ft upstream of the end of the simulated bridge rail, pocketing the beam severly (Fig. 13 and Plate D). As the vehicle was being redirected, the nonreinforced concrete bridge rail failed through the connection holes, allowing the beam to pull free and permitting the vehicle to penetrate the barrier. As the vehicle progressed through impact, the right front wheel struck the end of the concrete rail, throwing the vehicle into a violent roll-over. The vehicle came to rest 45 ft beyond initial impact in an upright position. Two sections of beam were damaged, three timber posts broken off, and four block-out blocks shattered. The vehicle sustained major front, side and top damage and was considered a total loss (Fig. 14).

Analysis of the data film indicated that even if the concrete bridge rail connection had not failed, beam deflection and pocketing had already occurred to such an extent

Figure 13.

Figure 14.

Figure 15.

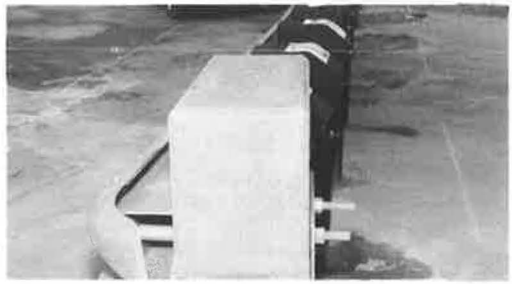

Figure 16.

that the vehicle would not have been redirected sufficiently to avoid an end-on collision into the concrete rail.

Test 137—To correct the deficiencies noted in Test 136, several modifications were made for the Test 137 installation. To depict a typical installation more accurately, a simulated California standard Type 1 bridge rail end post was constructed of reinforced concrete in accordance with design details typical of current operational installations. A 50-ft section of metal beam guardrail was constructed on a straight line so that the upstream end was offset 4 ft from the projected bridge rail line (Fig. 15).

The block between the guardrail beam and the concrete end post was constructed of $\frac{1}{4}$-in. steel plate rather than wood (Fig. 16 and Exhibit 2) to add rigidity to the system and prevent the crushing of the block that occurred in the previous test.

To minimize the pocketing noted in Test 136 and to provide a smooth transition from the semiflexible guardrail to the rigid bridge rail, the guardrail post spacing near the bridge rail was decreased from 6 ft 3 in. to 3 ft $1\frac{1}{2}$ in. and the size of the three wood posts immediately adjacent to the bridge rail was increased from 8 by 8 in. to 10 by 10 in. The upstream end of the guardrail was anchored with the same cable anchorage installation used in Test 136 (Exhibits 1 and 2).

The vehicle impacted near the center of the guardrail section at 61 mph and 27 deg and remained in contact with the barrier for approximately 22 ft before being effectively redirected at an exit angle of 16 deg (Plate E).

The guardrail beam sustained a permanent deflection of 2.1 ft (Fig. 17). Although vehicle dynamics in this high-speed oblique angle collision were considered good through impact, the left front wheel was torn off and the vehicle sustained major front-end and undercarriage damage. The vehicle was considered a total loss (Fig. 18).

Test 138—Although operational experience in California indicates the chances for a head-on collision involving "beam spearing" into the end of a flared guardrail section

Figure 17.

Figure 18.

Figure 19.

Figure 20.

are not great, the upstream cable anchorage system does present a potential hazard. In Test 138 (installation identical to Test 137) the vehicle impacted the guardrail at 61 mph and 25 deg into the end terminal section, upstream of the cable-to-beam connection. The beam bent, the left front wheel rode up and over the cable anchor eye-bolt, and the vehicle, straddling the cable, impacted post No. 1. The cable failed in tension as the vehicle, pushing the beam ahead of it, penetrated the barrier (Plate F and Fig. 19).

The vehicle sustained major front-end damage, with both front wheels smashed back under the engine compartment, and was considered a total loss (Fig. 20). It is significant to note that, although the cable parted and the vehicle penetrated the barrier, there was no roll-over action and deceleration forces were no more severe than those recorded in the oblique angle impact of Test 137. However, the primary decelerating force was in the longitudinal direction (the more critical) rather than in the lateral direction as experienced in most oblique-angle barrier impacts.

CONCLUSIONS

The following conclusions relative to corrugated metal beam guardrail are based on analysis of the results of the full-scale tests conducted during this series as well as two pertinent previous tests and operational experience:

1. The results of Tests 131 and 132 reported in an earlier publication (1) indicate that an unanchored corrugated metal beam guardrail section up to 62.5 ft in length is ineffective under severe impact loading. These tests further indicate that any unanchored guardrail section, regardless of length, is vulnerable to penetration when struck within 30 ft of either end.
2. Although Test 133 demonstrated the structural adequacy of the "Texas twist" design in providing effective anchorage for short sections of guardrail, Test 134 showed that a hazardous condition exists when vehicle impact occurs at the upstream sloping beam end anchorage.
3. Tests 135 and 137 illustrated the effectiveness of the cable-type end anchorage in preventing penetration of vehicles impacting short sections of guardrail.
4. Test 135 indicated that a parabolic layout line for an anchored guardrail section will increase the likelihood of pocketing over that of a straight section between the same two end anchor points under similar conditions of impact.
5. Test 138 indicated that the effect of a high-speed oblique angle impact into the upstream end of a cable-anchored guardrail, although severe, is less hazardous than a similar impact into sloping beam guardrail end anchorage systems. This would be particularly true for sections of guardrail that are flared away from the traveled way, thereby minimizing the chances of head-on end impact.

6. Test 136 pointed out the need for more rigidity in the bridge approach guardrail near the concrete bridge rail end post to provide a smooth transition from the semiflexible corrugated beam guardrail to the rigid bridge rail. Results of this test also indicated the need for a structurally adequate and properly blocked-out connection of the guardrail beam to the bridge rail end post.

7. Test 137 proved that an effective bridge approach corrugated metal beam guardrail can be achieved by halving the guardrail post spacing, increasing the post size adjacent to the bridge rail, and by using a structurally adequate blocked-out connection to the bridge rail end post.

ACKNOWLEDGMENTS

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Appendix

Plate A. Test 133
Plate B. Test 134
Plate C. Test 135
Plate D. Test 136
Plate E. Test 137
Plate F. Test 138
Exhibit 1. Cable end anchor details.
Exhibit 2. Guardrail connection details at concrete bridge rail.

PLATE A TEST 133

Impact

I + 0.10 Sec

I + 0.25 Sec

I + 0.65 Sec

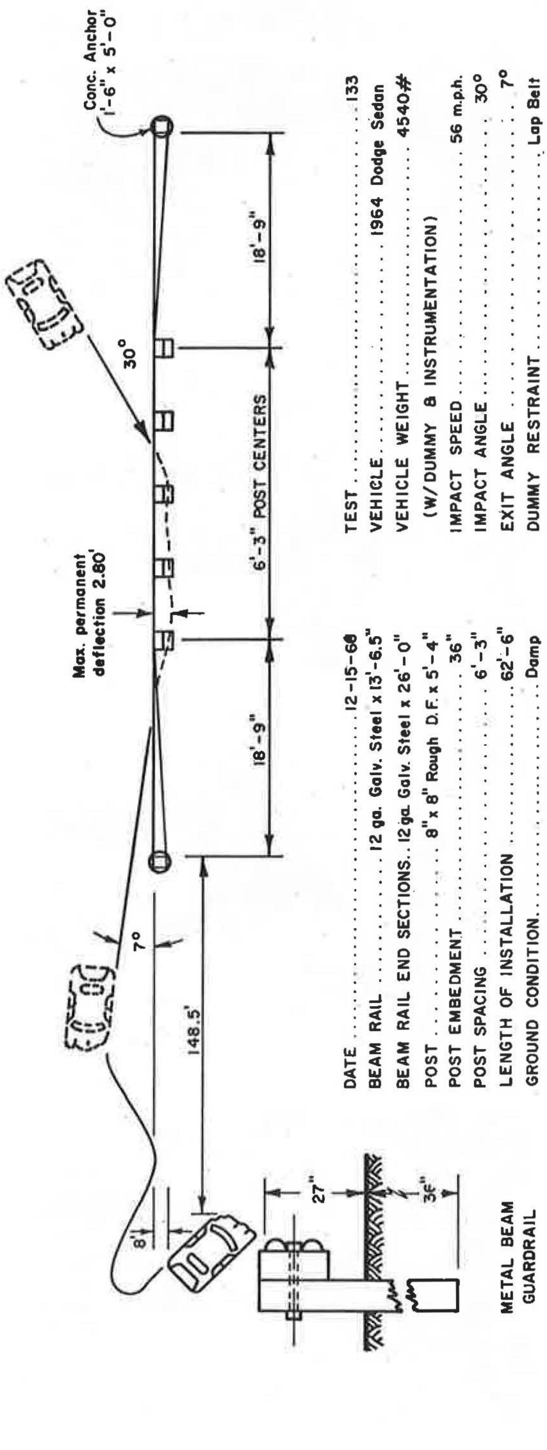
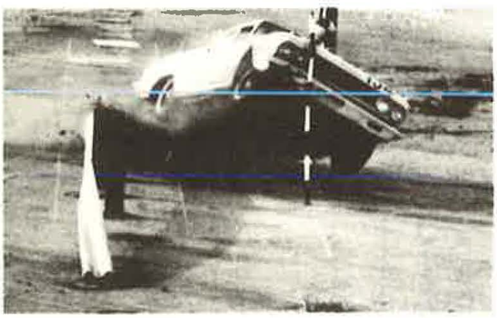


PLATE B TEST 134

Impact

I + 0.25 Sec



I + 0.40 Sec

I + 0.50 Sec

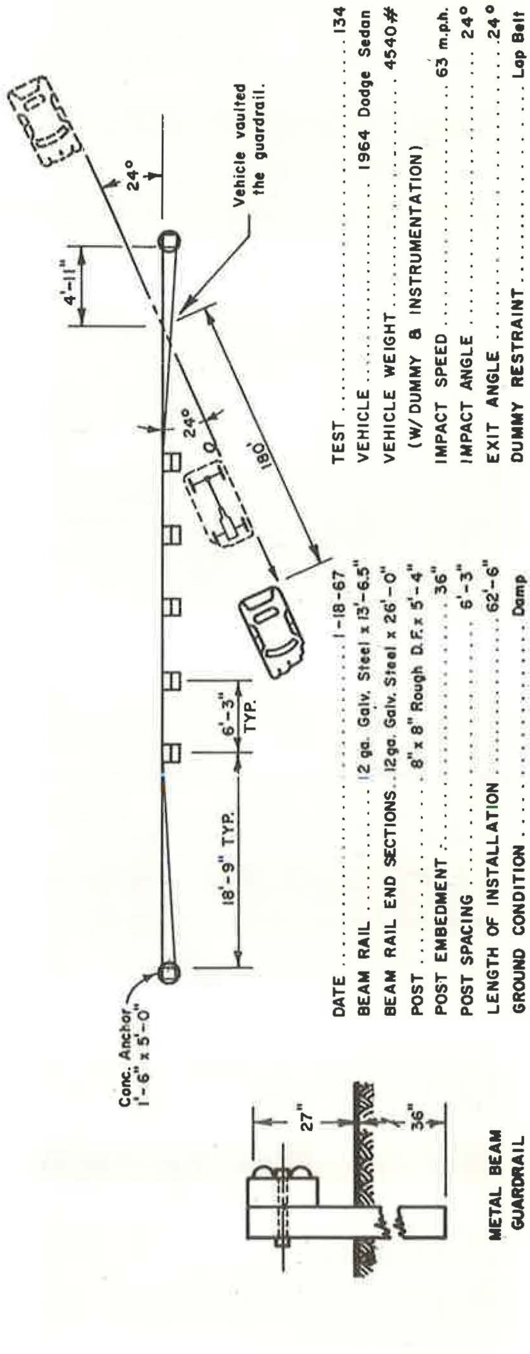


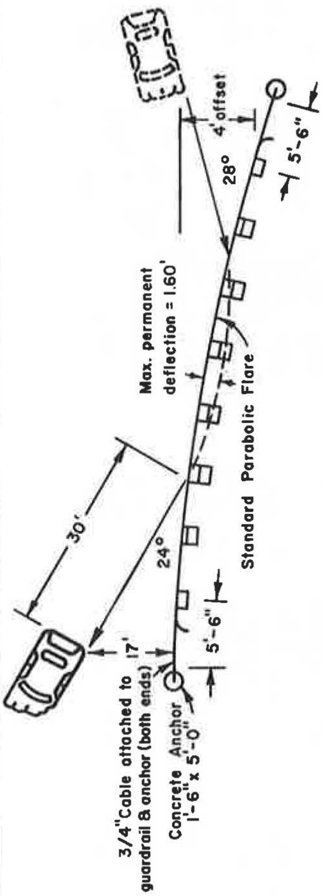
PLATE C TEST 135

Impact

I + 0.25 Sec

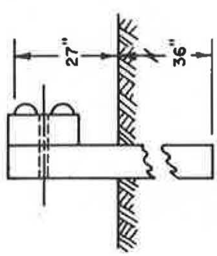
I + 0.40 Sec

I + 0.80 Sec



TEST NO.	135
VEHICLE	1964 Dodge Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4540 #
IMPACT SPEED	59 m.p.h.
IMPACT ANGLE	28°
EXIT ANGLE	24°
DUMMY RESTRAINT	Lap Belt

DATE	8-10-67
BEAM RAIL	12 ga. Galv. Steel x 13'-6.5"
POST	8" x 8" Rough D.F. x 5'-4"
POST EMBEDMENT	36"
POST SPACING	6'-3"
LENGTH OF INSTALLATION	50'
GROUND CONDITION	Dry



METAL BEAM GUARDRAIL

PLATE D TEST 136

IMPACT

I + 0.10 Sec

I + 0.40 Sec

I + 0.55 Sec

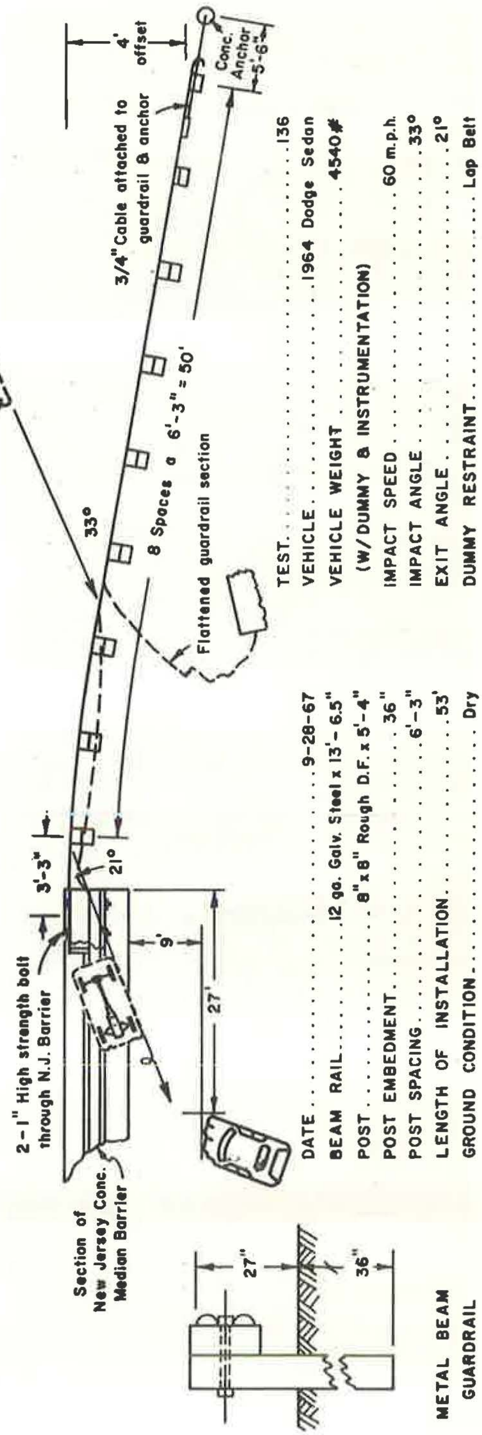


PLATE E TEST 137

Impact

I + 0.15 Sec

I + 0.25 Sec

I + 0.50 Sec

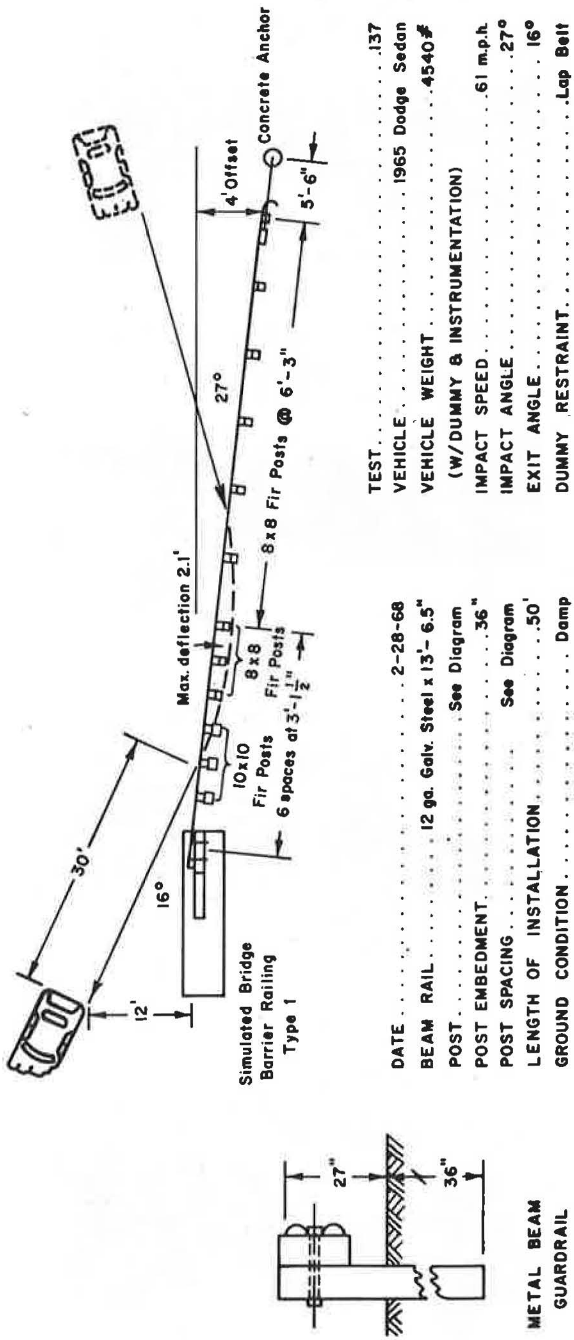
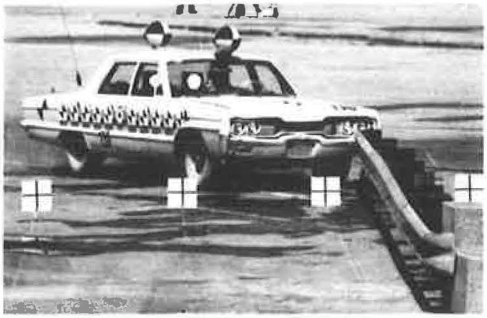
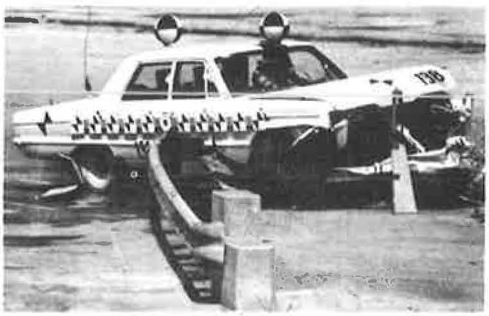


PLATE F TEST 138



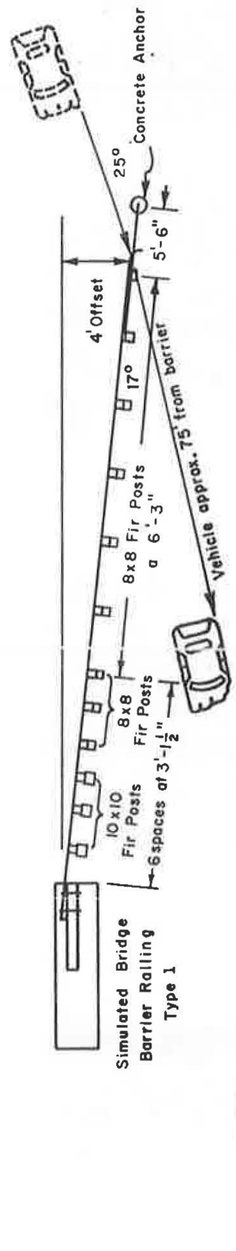
Impact

I + 0.10 Sec



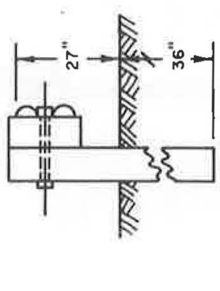
I + 0.50 Sec

I + 0.70 Sec



TEST NO.	138
VEHICLE	1966 Dodge Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4670#
IMPACT SPEED	61 m.p.h.
IMPACT ANGLE	25°
EXIT ANGLE	17°
DUMMY RESTRAINT	Lap Belt

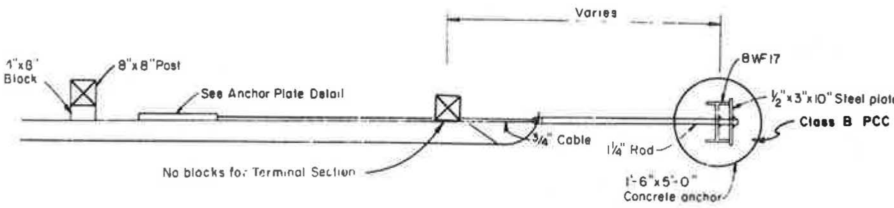
DATE	5-2-68
BEAM RAIL	12 ga. Galv. Steel x 13'-6.5"
POST	See Diagram
POST EMBEDMENT	36"
POST SPACING	See Diagram
LENGTH OF INSTALLATION	50'
GROUND CONDITION	Dry



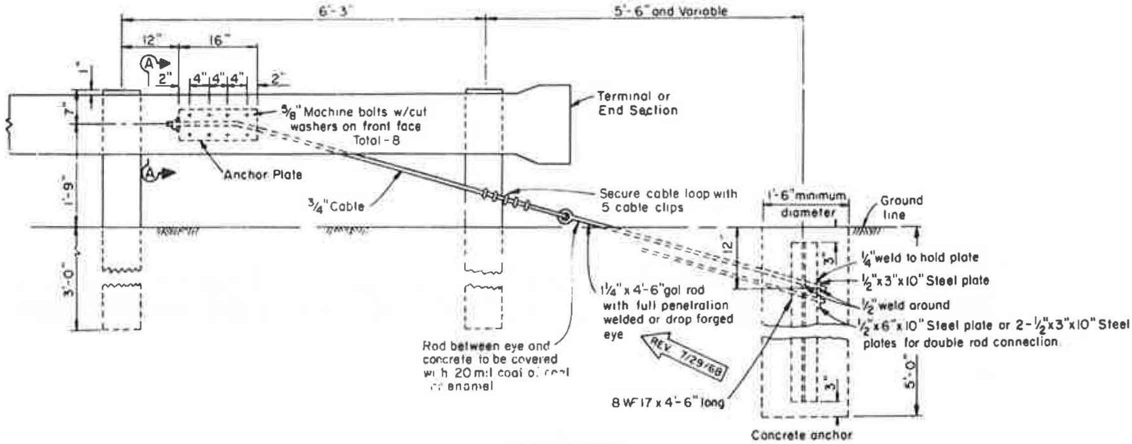
METAL BEAM
GUARDRAIL

EXHIBIT 1

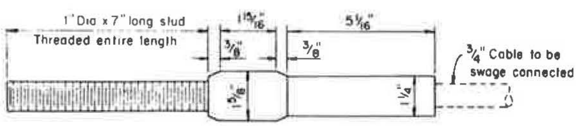
Note
Cable to be parallel to guard rail for straight runs of rail Cable may have angle point at anchor plate if guard rail is curved



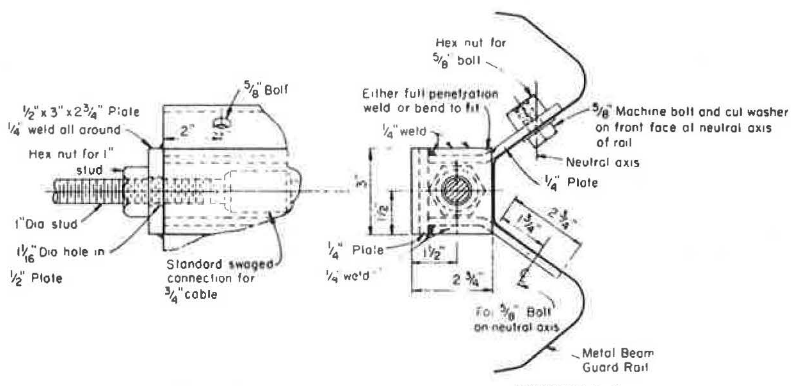
PLAN VIEW



ELEVATION



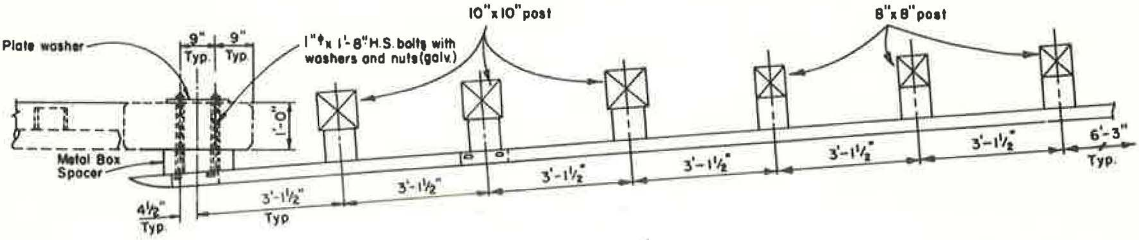
SWAGED FITTING AND STUD



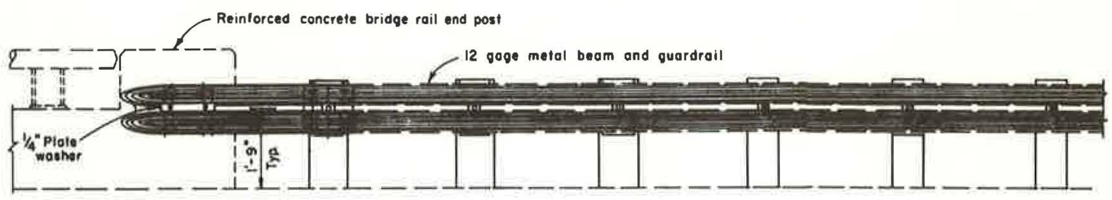
ANCHOR PLATE DETAILS

CABLE END ANCHOR DETAILS

EXHIBIT 2



PLAN VIEW



ELEVATION

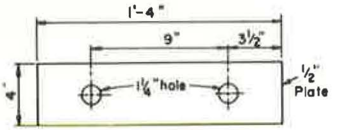


PLATE WASHER
FOR BACKSIDE OF PARAPET

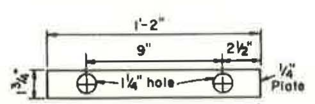
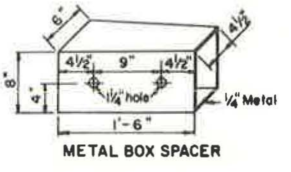


PLATE WASHER
FOR GUARD RAIL



METAL BOX SPACER

When metal box spacer is installed, place 1¼"x5" and 1¼"x4" pipe spacers on 1" bolts passing through interior of box.

GUARDRAIL CONNECTION DETAILS AT CONCRETE BRIDGE RAIL