National Cooperative Highway Research Program

RESEARCH RESULTS DIGEST

DIGEST 43 - OCTOBER 1972

Evaluation of Breakaway Cable Terminals for Guardrails

An NCHRP staff digest of the essential findings from progress reports on NCHRP Project 22-2, "Traffic Barrier Performance and Design," by M. E. Bronstad and J. D. Michie, Southwest Research Institute, San Antonio, Texas

THE PROBLEM AND ITS SOLUTION

Traffic barrier systems are presently being widely applied by highway and bridge engineers. All of these existing systems have some deficiences that make their performance somewhat less than ideal. New concepts are therefore needed for economical, standardized longitudinal traffic barrier systems that can provide a consistent degree of protection when installed as highway shoulder guardrails, median barriers, and bridge rails.

As outlined in *NCHRP Report 54* and *NCHRP Report 118*, properly designed guardrails and median barriers make highways safer by:

1. Preventing errant vehicle penetration.
2. Redirecting errant vehicles to a direction parallel to traffic flow.
3. Minimizing hazard to vehicle occupants during impact.

These objectives are appropriate for the center section or "length-of-need," but only the third one is considered appropriate for a guardrail terminal.

Approach terminals of guardrails and median barriers have been recognized as some of the more formidable roadside obstacles with which traffic must contend. Full-scale crash tests have further demonstrated that many current end treatments or terminals do not perform in a manner consistent with the general safety performance of the guardrail systems. Ramped terminals, which prevent spearing of the car by the guardrail beam element, have launched vehicles impacting within the terminal length. Approach terminals are subject to end-on as well as oblique impacts.

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A degree of protection consistent with that of the length-of-need section would be furnished by the approach terminal if impacting vehicles are either redirected or permitted to penetrate the end with resulting decelerations within the limit experienced by vehicles that impact along the length-of-need. Penetration of the terminal is permissible if a proper procedure is utilized for geometric layout.

Service requirements developed for guardrail terminals are listed in the following. The order of emphasis is first on safety, second on economics, and third on aesthetics. A guardrail terminal should:

1. Develop tensile and/or flexural strength necessary to ensure desirable redirection performance of the length-of-need section.

2. Either by redirection, containment, or controlled penetration, minimize vehicle/occupant decelerations for terminal section impacts. This implies that the impacting vehicle is not launched, rolled, or pocketed. (In some cases end-on impacts can be eliminated; e.g., extending the rail end into the back slope.)

3. Minimize the possibility of penetration of the vehicle passenger compartment by a system component.

4. Be economical in construction, damage repair, and maintenance.

5. Minimize vehicle damage.

6. Have a pleasing and functional appearance.

Although vehicle/barrier interactions during impacts have been characterized analytically, full-scale crash tests are needed to evaluate the general performance of guardrail/median barrier installations. Because the guardrail end is at least as difficult to evaluate analytically, full-scale crash tests are used for evaluation of terminal effectiveness.

This Digest is intended to make available, for early implementation, the details of a terminal concept that has met these service requirements in crash tests conducted in NCHRP Projects 15-1(2) and 22-2.

The Southwest Research Institute (SwRI) has conducted research on barrier systems under NCHRP Project 15-1(2) and the current Project 22-2. *NCHRP Reports 54, 115, 118* and *129* have emanated from Project 15-1(2). *Report 129* presented the results of three full-scale guardrail terminal crash tests and pointed out that the need for improved end designs for longitudinal traffic barriers is still critical. NCHRP Project 22-2 has extended the SwRI research to provide for an additional series of 25 full-scale crash tests to evaluate additional prototype end designs. The initial tests in NCHRP Project 22-2 were intended to further develop the breakaway cable terminal (BCT) concept presented in *NCHRP Report 129*. Table 1 contains results of the three terminal tests in Project 15-1(2) and the ten tests conducted in the current study. A novel feature of the current program is the inclusion of crash tests using sub-compact cars (tests 133 and 138, Table 1). The lower impact speed of 40 mph is expected to result in more severe conditions for lighter vehicles. High rates of deceleration were measured in tests 133 and 138. These results seem to indicate that the BCT neither eliminates nor increases the danger in small-car end-terminal collisions. The BCT has been tested with both timber- and steel-post W-beam guardrail systems (G4W and G4S, respectively). Modifications to the concept as it was presented in *NCHRP Report 129* were developed and tested and are included in this Digest. Based on these tests (summarized in Table 1) the breakaway cable terminal, as modified herein, is recommended for immediate field use on a trial basis.

Comments are called for concerning the results of test 139 and 141. Both of these tests were carried out on the G4S system anchored by the BCT under duplicate impact conditions (approximately a 4,000-lb vehicle, at 60 mph, and a 25° angle of impact at the third post). In test 139 the BCT appeared to properly perform its anchoring function, but the vehicle penetrated the system, tearing the rail near the fourth post. This outcome was surprising although other researchers have reported rail penetrations under similar test conditions. Although test 139 might be considered to be a success insofar as the terminal is concerned, the same conditions were rerun as test 141. This system was modified for test 141 to include back-up plates at the posts where the rail is not spliced. The back-up plate is simply a 12-in. length of W-beam connected between the steel post and the rail. This modification has been used by others and is expected to distribute the post forces over a longer rail length and to discourage sharp-radius bends in the rail near the posts. The vehicle did not penetrate the rail in test 141 and the entire system behaved satisfactorily. However, the tests reported herein are insufficient to justify general conclusions regarding the necessity for back-up plates with the G4S system. The tests were intended to evaluate the BCT and the possibly unnecessary use of back-up plates was justified in order to preclude premature failure of the rail which would interfere with that evaluation. Detailed test results will be published following the conclusion of NCHRP Project 22-2. Until then, additional information is available upon request to the NCHRP Program Director.

FINDINGS

The BCT as described in *NCHRP Report 129* had performed sucessfully in the three crash tests (Nos. 130, 131, 132) conducted as part of NCHRP Project 15-1(2). The modifications in the terminal as described herein were for the most part inspired by the results of test 134 of NCHRP Project 22-2 (Fig. 1). In this test the vehicle rolled over. The first post, which was mounted in concrete and weakened by a drilled hole, broke away cleanly on impact as expected. However, the second post did not break but leaned when hit, causing one side of the vehicle to ramp and the resulting turnover. The researchers concluded that rain-softened soil caused the yielding behavior of the second post. The system was modified to include a concrete footing and drilled hole at the second post. This modified terminal performed satisfactorily in test 135 (Fig. 2), which was conducted for the same impact conditions as test 134.

The unacceptable vehicle damage experienced in test 140 was attributed to the failure of the second post to break away as intended. In this test the concrete footing failed by splitting along a vertical plane, the post leaned, and the right side of the vehicle suffered massive damage resulting from its contact with the rigid post and rail debris. Modifications have been made to the footings to prevent such behavior. The footing diameter was increased from 18" to 24" and spiral reinforcement was introduced. The impact conditions of test 140 were rerun in test 142 to evaluate these modifications. The results of test 142 were satisfactory, and the modifications have been incorporated into the recommended terminal.

The BCT is shown in Figure 3 and described in detail in Figure 4. The terminal utilizes components from the California design shown on Sheet 2 of *NCHRP Report 118* and is similar to a design concept of the Idaho Highway Department.

Principal features of the BCT are the end post and the beam end design. As shown in Figure 3, the anchor cable is attached to the end post, which is set in concrete. The 2 3/8-in.-diameter hole in the end post weakens the member in flexure and shear for forces applied above the hole; however, the post exhibits adequate strength for forces introduced via the anchor cable. When impacted end-on, the anchor post breaks at the hole, preventing the cable from developing "beam-spearing" forces. Accordingly, the end post is weak for direct or near direct hits, but is sufficiently strong to develop the cable load for barrier hits beyond the first 6.25-ft panel. The beam end or nose, a special 11-in.-radius bend, is stiffened with lightweight concrete or steel diaphragms to prevent collapse and possible beam-spearing during direct-on hits. The principle of the BCT and the functions of its various components are summarized in Table 2.

The flared system was stated in *NCHRP Report 129* to be superior for end-on impacts and is recommended for use with the BCT until methods for reducing the spearing tendency of straight systems may be developed.

Additional development and full-scale crash test evaluation of the breakaway cable terminal will be carried out during the remaining months of the program. Emphasis will be placed on median barrier systems. The researchers will also investigate ways of reducing the longitudinal resistance of the rail in the terminal length for end-on impacts.

APPLICATION

The flared breakaway cable terminal with the nose stiffened by either steel diaphragms or vermiculite concrete is recommended for immediate trial implementation for anchoring the G4W and G4S guardrail systems shown in *NCHRP Report 118*.

Additional details on this system may be found in *NCHRP Reports 118* and *129*.

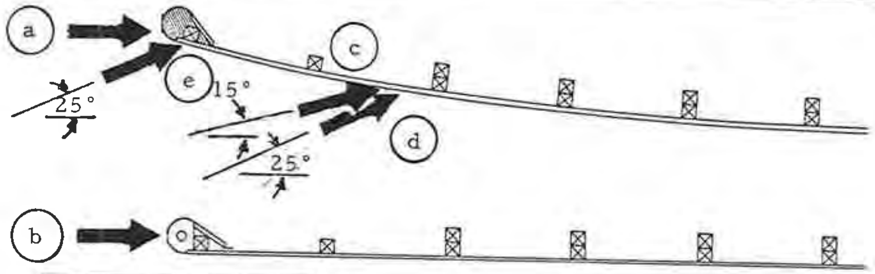
TABLE
SUMMARY OF GUARDRAIL TERMINAL TESTS

Test No.	Project No.	Barrier System*	Vehicle Weight (lbs)	Vehicle Speed (mph)	Impact Angle (deg)	Maximum Average Decelerations		Remarks
						Long. (g)	Lat. (g)	
130	15-1(2)	A, C, E	4138	61	0	10.8** 2.5***	1.7**	Vehicle was redirected behind rail. Vehicle stability was good.
131	15-1(2)	A, C, E,	4000	59.4	15	4.6**	4.6**	This was a successful test of the anchorage for a downstream impact. Vehicle redirected at a large angle.
132	15-1(2)	A, D, E	4100	58.5	0	8.6** 3.4***	1.2**	Vehicle redirected behind rail, considerable upward pitch of vehicle noted. Rail did not penetrate passenger compartment.
133	22-2	A, C, F	2400	42.5	0	13.7** 8.8***	3.1**	Vehicle stopping distance was 6.8 ft.
134	22-2	A, C, F	4200	62.8	0	-	-	Second post leaned, auto ramped and rolled over.
135	22-2	A, C, F, G	3800	60.7	0	9.2**	1.5**	Result similar to Test 130.
136	22-2	A, C, F, G	3800	59.7	27	7.5**	5.2**	Vehicle impacted end post at 27 deg angle (measured from straight rail line); vehicle stability was good throughout.
137	22-2	A, C, F, G	3900	62	27	7.2**	3.4**	This was a successful test of the anchorage for a downstream impact (i.e., within the second span).
138	22-2	B, C, F, G	1900	41.3	0	22.5** 11.6***	3.2**	Vehicle stopping distance was 4.5 ft.
139	22-2	B, C, F, G	3900	59.0	25	-	-	Rail was penetrated due to beam failure at fourth post. BCT was undamaged.
140	22-2	B, C, F, G	4000	60.0	0	7.8**	3.7**	Passenger compartment of vehicle was deformed but not penetrated on right side.
141	22-2	B, C, F, G, H	3900	62.0	27.4	5.4**	3.7**	Vehicle redirected. BCT developed anchorage strength without damage.
142	22-2	B, C, F, G, J	3850	52.5	0	7.6**	2.3**	Vehicle was redirected behind rail. No evidence of passenger compartment damage.

*Barrier system code:
- A - Timber-post W-beam guardrail G4W.
- B - Steel-post W-beam guardrail G4S.
- C - Flared end treatment.
- D - Straight end treatment.
- E - Nose stiffened by vermiculite concrete.
- F - Nose stiffened by steel diaphragms.
- G - Hole drilled in second post and post embedded in concrete.
- H - Back-up plates at posts without rail splices.
- J - Concrete footings increased from 18-in. to 24-in. diameter and spiral reinforcement added.

**Highest 50 msec average.

***Based on stopping distance.



a. Tests 130, 133, 134, 135, 138, 140, 142
b. Test 132
c. Test 131
d. Tests 137, 139, 141
e. Test 136

TABLE 2

BREAKAWAY CABLE TERMINAL CONCEPT PERFORMANCE PRINCIPLES

COMPONENT OR FEATURE	DESIGN FUNCTION	
	END-ON IMPACTS	DOWNSTREAM IMPACTS
1. End post	Post breaks away at bored hole, releasing cable, thus minimizing spearing forces.	Post is designed to transfer breaking strength of cable to the concrete footing.
(a) Pipe insert	No function	Distributes forces due to vertical component of cable to the post. Size was determined from bearing strength of southern pine.
(b) Bearing plate	No function	Distributes horizontal forces from cable to post. Size was determined from bearing strength of southern pine.
2. End nose	Large nose is stiffened by vermiculite concrete or steel diaphragms to distribute loads over a large area, thus reducing chances of rail penetration into passenger compartment.	No function
3. Anchor cable	The cable does not perform for end-on impacts, but it is essential that it does not develop spearing forces in the W-beam.	Cable transfers tensile forces from beam to end post. Proper anchorage is essential for angle impacts downstream from the end.
4. Concrete footing	Reduces tendency for post to rotate in soil.	Distributes loads from post to soil.
5. End flare	For end-on impacts, the curvature of the flared terminal causes the vehicle forces to be introduced into the rail eccentrically, thereby reducing the column strength of the rail and reducing the tendency for spearing.	No function
6. Second post	Post breaks away at bored hole, eliminating tendency to act as a ramp.	No function

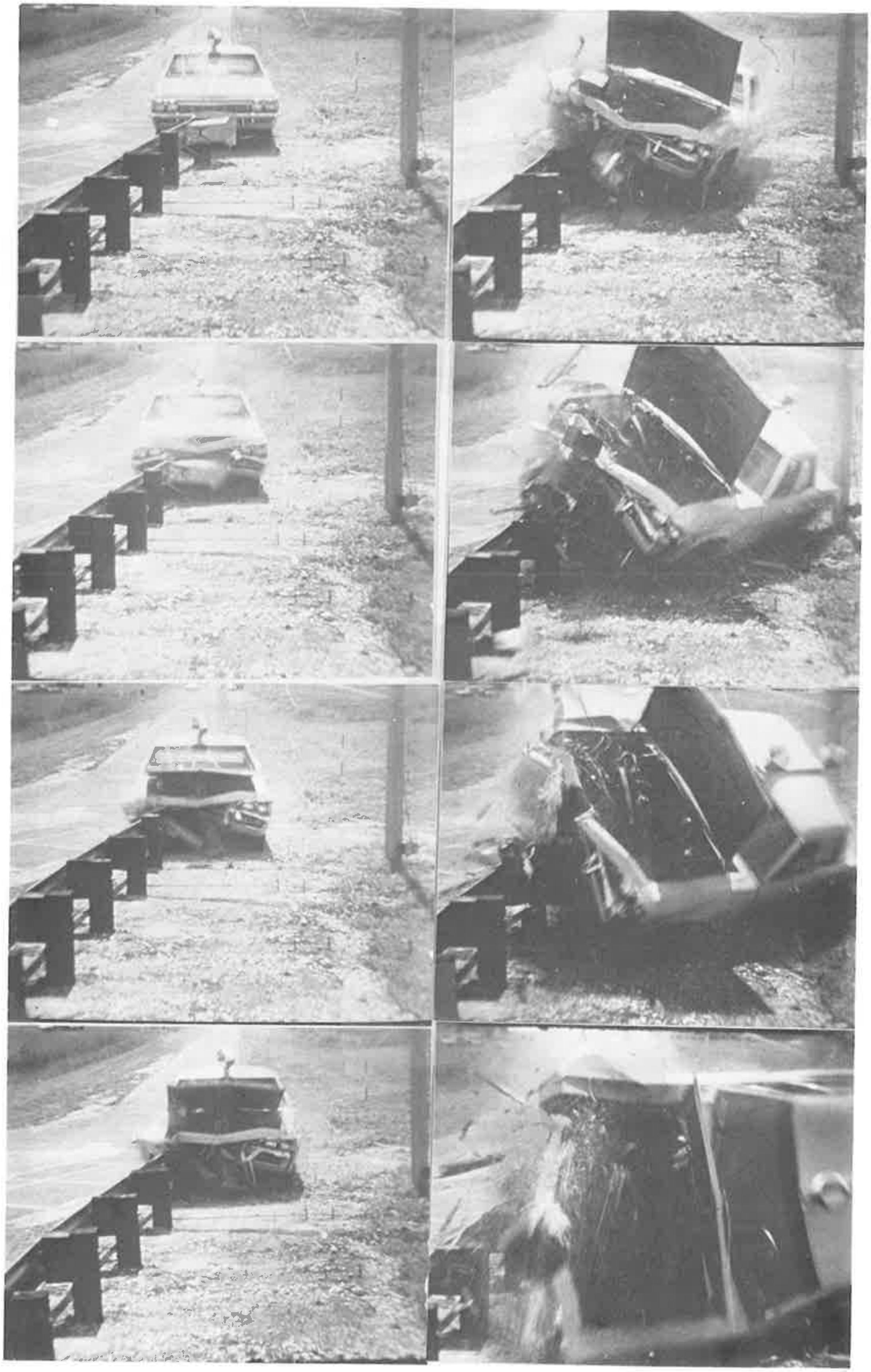


Figure 1. Sequence of events, test 134.

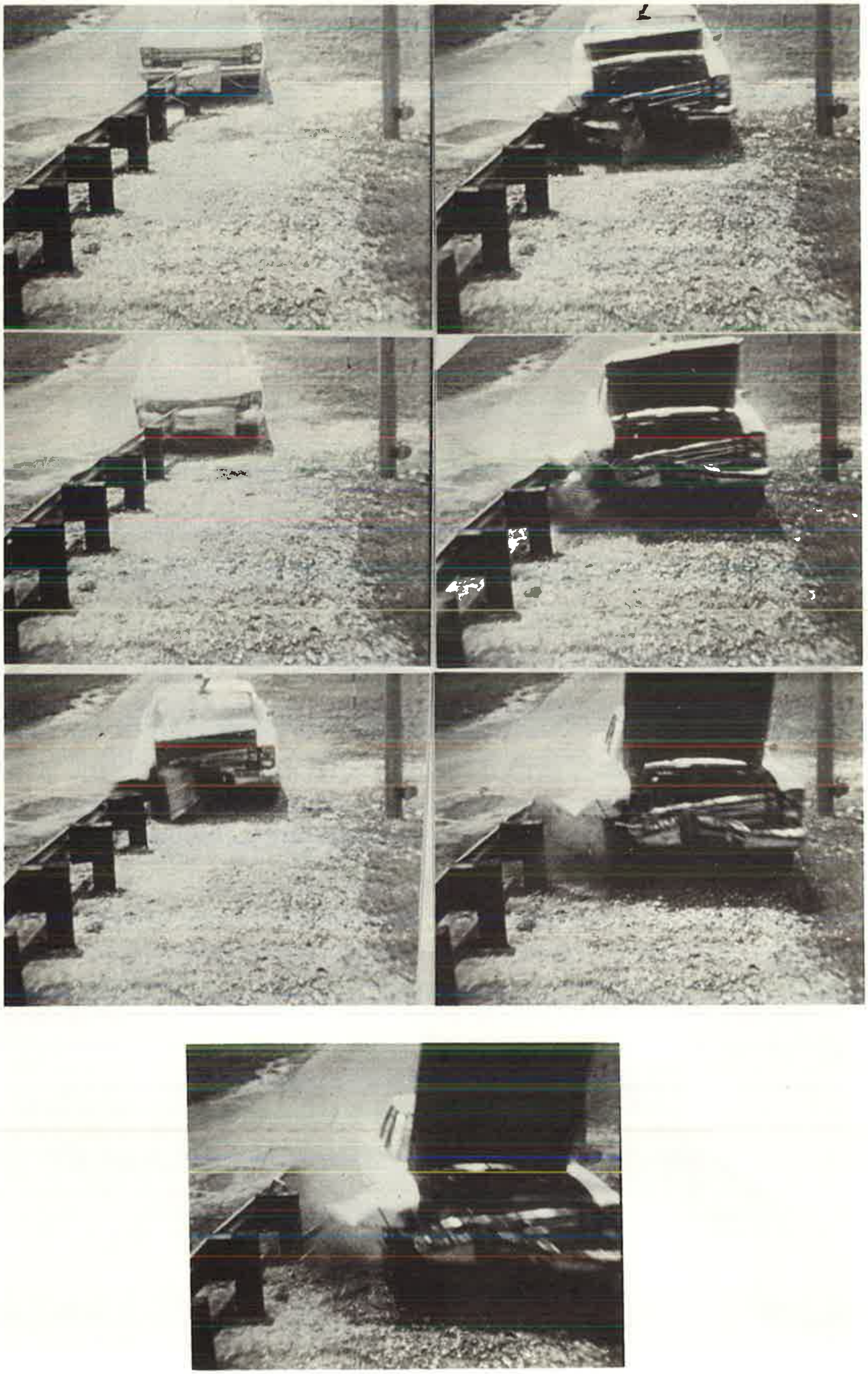
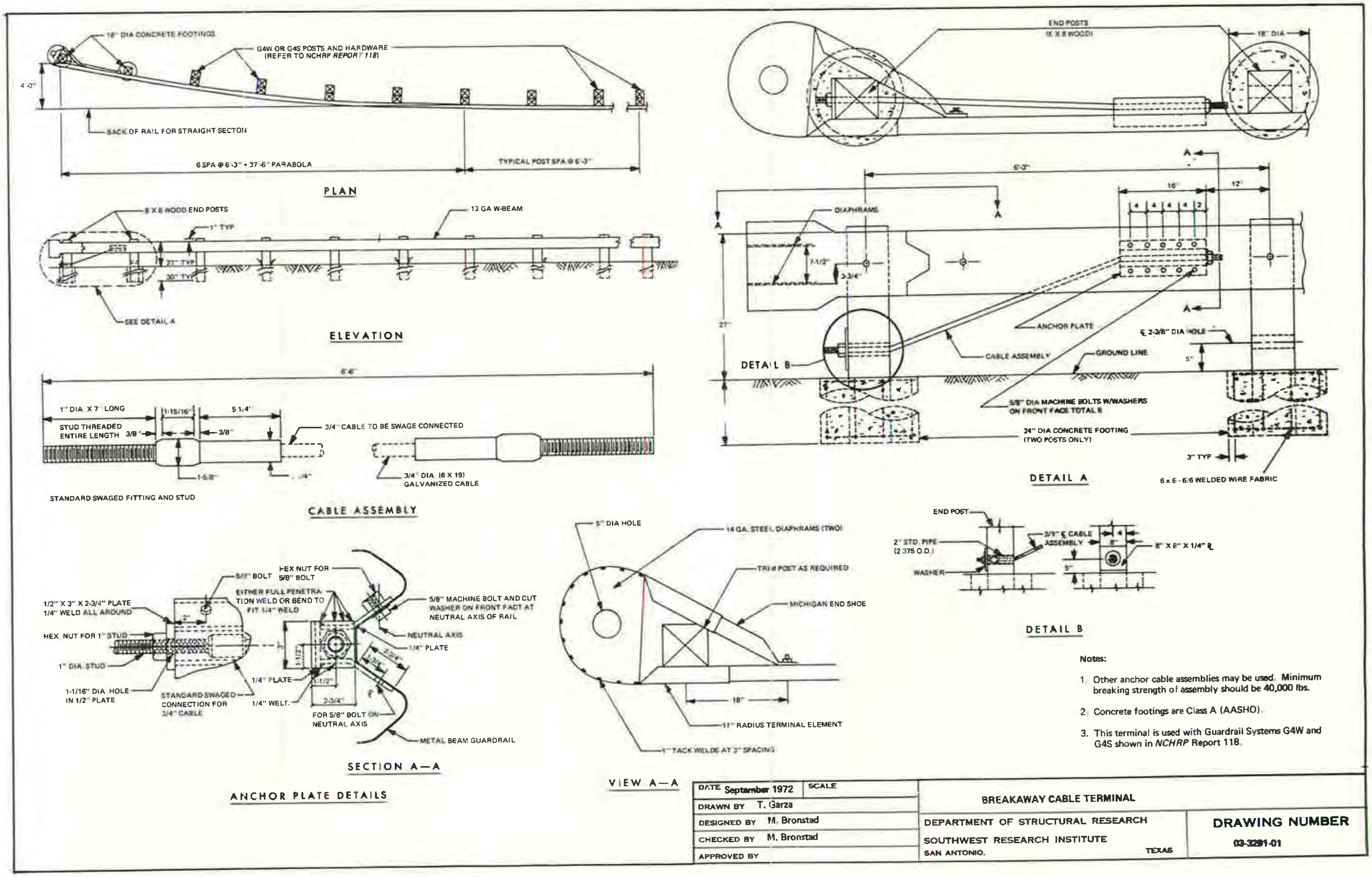


Figure 2. Sequence of events, test 135.

Figure 3. Details of breakaway cable terminal.



Notes:

1. Other anchor cable assemblies may be used. Minimum breaking strength of assembly should be 40,000 lbs.
2. Concrete footings are Class A (AASHO).
3. This terminal is used with Guardrail Systems G4W and G4S shown in *NCHRP* Report 118.

DATE September 1972	SCALE
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BREAKAWAY CABLE TERMINAL

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DRAWING NUMBER
03-3291-01

Figure 4. Installation drawing of breakaway cable terminal.