National Cooperative Highway Research Program

RESEARCH RESULTS DIGEST

DIGEST 84 - MARCH 1976

Breakaway Cable Terminals for Guardrails and Median Barriers

An NCHRP staff digest of the essential findings from the final report on Phase II of 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

Approach ends of traffic barriers have been shown to be unduly hazardous to errant traffic. The W-beam in upright terminals has penetrated the passenger compartment in numerous end-on impacts, and ramped terminals have caused impacting vehicles to be launched, rolled, and tumbled. Although accident statistics are unavailable to pinpoint the number of these fatal collisions, it has been readily apparent to the highway community that safety improvement of barrier terminals is needed. One solution to this problem would be to utilize a crash cushion device; however, these devices are expensive ($3,500 to $15,000) and have been used primarily in high accident-rate locations (such as gores). There is a need to develop and evaluate low-cost traffic barrier terminals that perform satisfactorily when impacted by a range of vehicles. By reducing the cost in comparison to crash cushions, more of these devices can be used. Although the performance of these terminals may not be comparable to the better crash cushion devices, the trade-off is attractive considering the particularly large number of potential applications.

Southwest Research Institute conducted NCHRP Project 22-2 with the objective of developing improved terminals for longitudinal traffic barriers. Findings from research on the breakaway cable terminal (BCT) have been reported in *NCHRP Report 129* and *Research Results Digests 43* and *53*. The BCT has been the subject of two Federal Highway Administration Notices (HNG-32, December 11, 1972, and HHO-31, May 24, 1973) encouraging its installation as part of National Experimental and Evaluation Program (NEEP) Project 17. More than a dozen states have already installed BCTs.

Following these earlier publications, additional development of BCTs for both guardrails and median barriers was carried out in a second phase of NCHRP Project 22-2.

Component testing, analytical simulation, and full-scale crash testing were used in Phase II to obtain additional insight on terminal performance. Several modifications to the earlier BCT designs are recommended in the agency's final report.

The purpose of this digest is to call attention to this information for early application. Loan copies of Southwest Research Institute's final report can be obtained upon request to the NCHRP Program Director.

A separate task that was completed earlier as part of Phase II resulted in publication of *NCHRP Report 153*, "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances." Crash tests were conducted on terminals concurrently with the development of these recommended procedures, which were utilized to the maximum extent possible in this program.

FINDINGS

The breakaway cable terminal (BCT) was developed for both guardrail and median barriers in previous programs[1,2,3,4] and was recommended for trial in-service use. The guardrail BCT utilized two 8x8-in. timber posts set in concrete footings, and its performance was considered satisfactory except for low-speed, end-on impacts with subcompact vehicles. The median barrier BCT was developed using either steel or timber terminal posts. The steel-post BCT employed a breakaway base with a fillet weld as the fracture mechanism. Comments from in-service users have indicated concern for the repeatability and control of a "weld failure mechanism," particularly for the end post, because it anchors the system.

The objectives of this second phase of Project 22-2 were: (1) to improve the performance in the guardrail BCT for head-on impacts with small cars; (2) to develop a guardrail BCT using steel posts; (3) to further refine BCT designs for improved economy relative to first cost, maintenance, and repair.

In order to achieve these objectives, an evaluation of breakaway posts was first performed in the SwRI pendulum facility, and BCT assemblies were later appraised by vehicle crash tests. In addition, input from barrier manufacturers was used to provide cost ideas and to project costs of proposed BCT modifications. Due to unforeseen results from one crash test (No. 160), the program work plan was modified to add a task whereby the vehicle-terminal impact behavior would be mathematically simulated using the computer program BARRIER VII.[10] Program funds for this effort were diverted from other tasks and were therefore limited. Unfortunately, the simulation study results were disappointing and did not contribute to BCT design improvements.

The crash-test programs for the guardrail and median barrier BCTs are outlined in Tables 1 and 2, respectively. Seven full-scale crash tests were carried out on BCT designs in Phase II, in addition to the 29 previously reported on in Phase I. Based on the results of these tests, modifications have been made to the BCT designs shown in *NCHRP Research Results Digests 43* and *53*. The recommended modifications are reflected in the drawings and photographs in Figures 1 through 6.

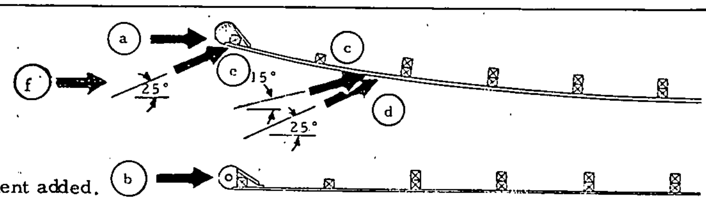
Table 1

SUMMARY OF GUARDRAIL BCT TESTS

Test No.	Project No.	Barrier System*	Vehicle Weight (lbs)	Vehicle Speed (mph)	Impact Angle (deg)	Maximum Average Decelerations Long. (g)	Lat. (g)	Remarks
130	15-1(2)	A, C, E	4138	61	0	10.8**	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**	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**	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**	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.
159	22-2/1	B, C, K, L	2402	38.0	0	7.4	3.3	Vehicle directed behind rail.
160	22-2/1	B, C, K, L	4000	58	25.5	7.0	4.7	Vehicle pocketed, spin out occurred.
162	22-2/1	B, C, K, M	4202	58	24	8.2	5.6	Vehicle redirected, significant wheel/post involvement. Maximum roll of 11 deg away from barrier.
164	22-2/1	B, C, K, M	4423	62	0	9.0	2.4	Vehicle directed behind installation without passenger compartment intrusion.
165	22-2/1	B, C, K, M	2130	31.5	0	7.1	3.5	Vehicle decelerated in contact with barrier, 90 deg yaw.

*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. dia and mesh reinforcement added.
- K - Nose not stiffened.
- L - Slip base terminal posts (two)
- M - Slip base terminal posts (two), Spans 3, 4 and 5 - 4'-2" with 25-ft W-beam section at end.

**Highest 50 msec average.



a. Tests 130, 133, 134, 135, 138, 140, 142, 159
b. Test 132
c. Test 131
d. Tests 137, 139, 141, 162, 160
e. Test 136
f. Test 164, 165

Table 2

SUMMARY OF MEDIAN BARRIER BCT CRASH TESTS

Program 22-2 References 2 and 14

Test	Barrier System	Terminal Length (ft-in.)	Terminal* Post	Terminal Beam Elements	Terminal Rail Height (in.)	Vehicle Weight (lbs)	Vehicle Speed (mph)	Impact Angle (deg)	Max Average Deceleration + Long. (g)	Max Average Deceleration + Lat (g)	Remarks
150	D, E, F	25-0	W6x8.5 steel	3/16 x 30 in. (two)	42	3800	63.0	.5	7.2	1.2	Vehicle smoothly decelerated in contact with barrier (30 ft stopping distance).
151	D, E, F	25-0	W6x8.5 steel	3/16 x 30 in. (two)	42	2200	41.5	.4	5.7	2.4	Vehicle smoothly decelerated in contact with barrier (13 ft stopping distance).
152	D, E, F	25-0	W6x8.5 steel	3/16 x 30 in. (two)	42	3900	57.0	27	6.2	2.5	Vehicle impacted rail just upstream of second post; no redirection was evident as vehicle penetrated the system. Local anchorage failure occurred.
153	D, F, G	25-0	TS6x6x0.1875	3/16 x 30 in. (two)	42	4000	54.5	26.7	7.0	3.3	Vehicle impacted rail 2 ft upstream of second post; little redirection occurred as vehicle penetrated system. Local anchorage failure occurred.
154	D, F, G	25-0	TS6x6x0.1875	3/16 x 30 in. (two)	42	4000	61.1	26	7.1	7.6	Vehicle impacted at third post and was smoothly redirected.
155	D, F, G.	25-0	TS6x6x0.1875	3/16 x 30 in. (two).	42	2400	62.4	1.5	13.3	2.7	Vehicle came to rest in contact with barrier with little change in direction (16 ft stopping distance).
156	F, G, H	25-0	TS6x6x0.1875	3/16 x 30 in. (two)	42	3800	60	25	-	-	Vehicle was redirected although unanchored box beam spans disengaged from posts.
157	F, G, H	25-0	TS6x6x0.1875	3/16 x 30 in. (two)	42	3900	58	25	8.5	6.4	Vehicle was redirected, noticeable roll away from barrier was evident in redirection. Vehicle impacted rail upstream of third post.
158	A, C, F	25-0	6x8 timber posts with hole through neutral axis	3/16 x 30 in. (two)	42	3900	64.8	1.2	11.6	5.0	Vehicle decelerated in contact with barrier; stopping distance 22 ft.

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166	D, I	31-3	TS6x6x 0.1875	3/16 x 30 in. (two)	42	4500	59.7	1.7	9.7	3.0	Vehicle smoothly decelerated until snagging of base by barrier elements occurred. Vehicle ramped, but remained in contact with barr.
167	D, J	31-3	TS6x6x 0.1875	3/16 x 30 in. (two)	42	4500	62	26	6.0	6.5	Vehicle ramped over W-beam due to excessive deflection of terminal beams.

*All terminal posts set in 24" dia reinforced concrete footing x 41" deep.

Barrier System Code:
- A - Timber post "W" beam median barrier MB4W
- B - Rub rail terminated at second post
- C - Rub rail terminated at sixth post
- D - Steel post "W" beam median barrier MB4S, no rub rail
- E - W6x8.5 terminal posts welded to base plate at grade
- F - 55-gallon drum added to end, interior terminal beams 12 in. wide and placed at top of outside rail elevation
- G - TS6x6x0.1875 steel posts welded to base plate at grade
- H - MB3 steel box beam median barrier

+Maximum deceleration averaged over 50 millisecond duration obtained from high-speed cine. Parenthesis indicates deceleration based on stopping distance.

I: Slip base terminal post design, base projects 4 in. above grade.
J: Slip base terminal post design, base flush with grade.

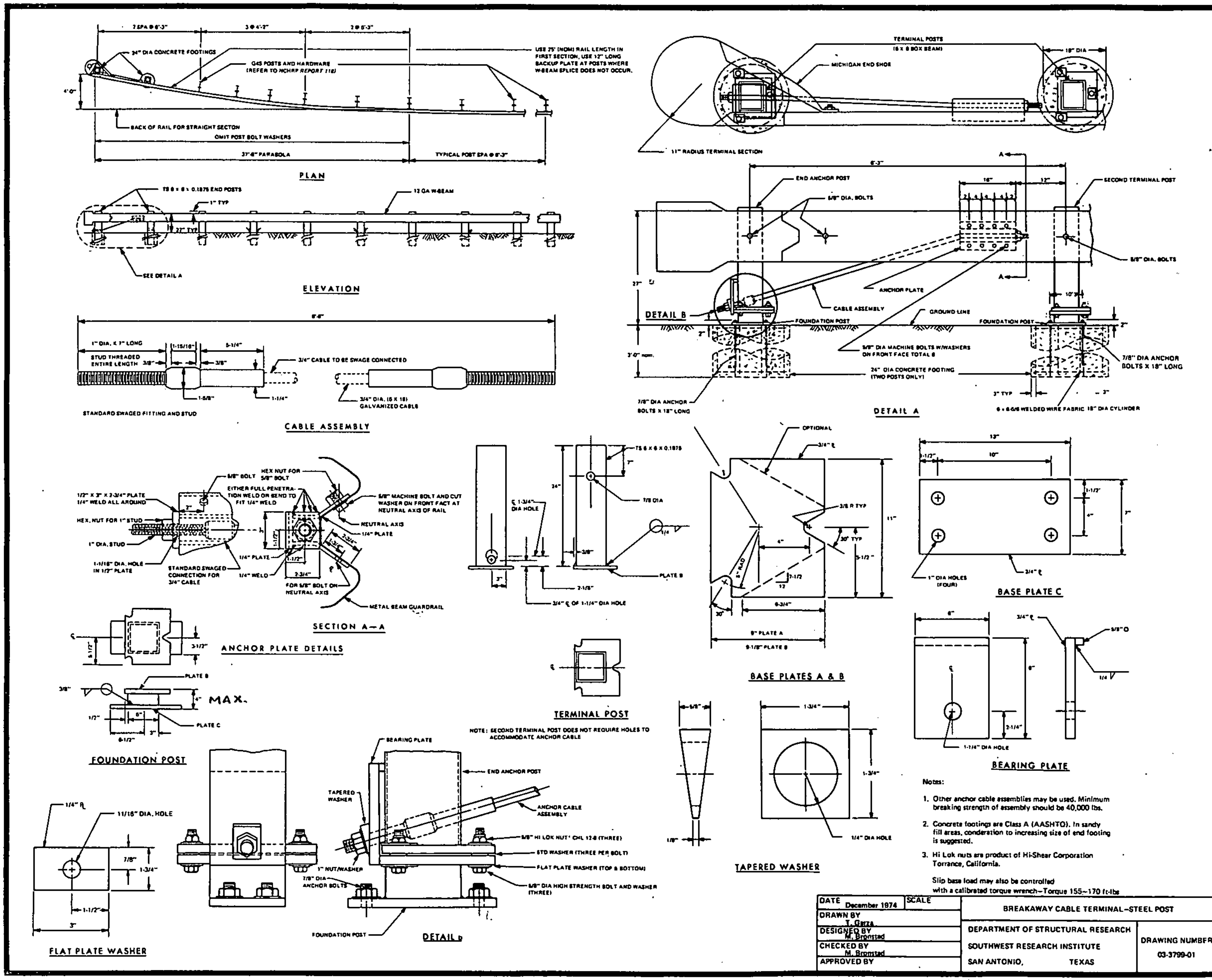


Figure 1 - Guardrail BCT Installation Drawing

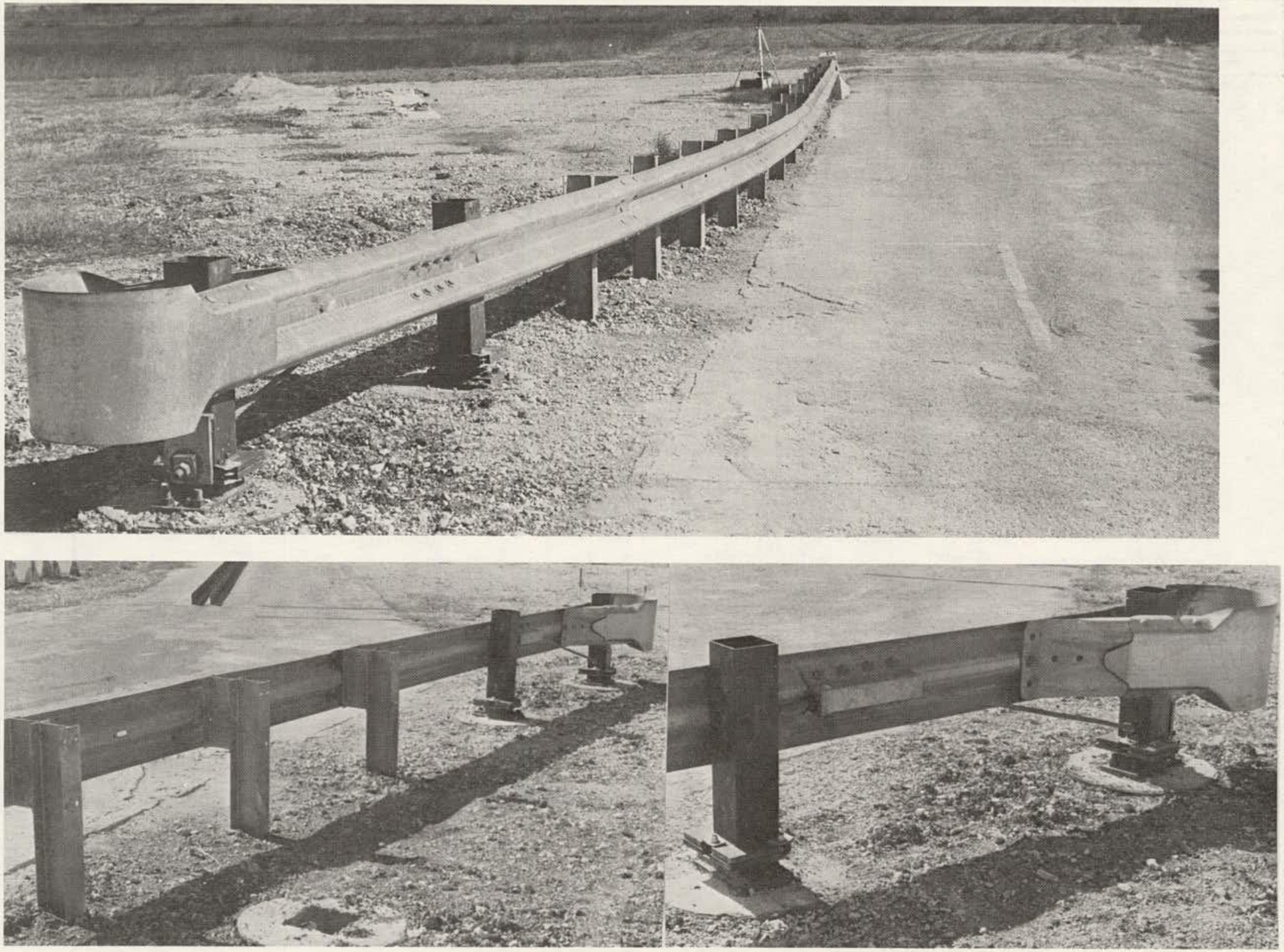


Figure 2 - Guardrail BCT With Steel Slip Base Terminal Posts

Guardrail Terminal. The significant modifications to the guardrail BCT are:

- Slip-base steel posts were used in the terminal for the G4S guardrail system.

- The cross-sectional dimensions of the timber posts in the BCT for the G4W system were changed from 8x8 inches to 6x8 inches.

- Post spacing in the third, fourth, and fifth spans from the end was reduced from 6' - 3" to 4' - 2".

- A 25-ft (nominal) W-beam element was substituted for the two 12.5-ft elements in the first four spans.

- One-piece anchor replaced the more costly device previously used to secure the cable to the rail element.

- Diaphragms were eliminated from the nose element.

Terminal posts with slip bases were tested in the pendulum facility. A three-bolt pattern utilizing ASTM A325 bolts with Hi-Lok nuts was developed and validated through full-scale crash tests. The BCT that was evaluated in Tests 162, 164, and 165 included the previously mentioned modifications and is shown in Figure 1. These slip-base terminal posts reduced the severity of the head-on impact of the small car and performed satisfactorily in all other crash tests; therefore, they are recommended for use in the BCT. On the basis of pendulum test results, 6x8-in. timber posts are recommended for use in the BCT to provide improved performance for small cars.

In addition to providing breakaway performance for end-on impacts, the end post in the BCT concept must provide the necessary anchor strength for downstream impacts. A design concept utilizing a bearing plate to beam the anchor loads from the cable directly to the rigid foundation was conceived and developed for slip-base and timber posts, as shown in Figure 6. The length of the bearing plate determines the portion of the load that is resisted directly by the foundation post and the portion that must be resisted by the friction force at the slip base or by shear in the net timber-post section. The capacity of this design to develop the minimum breaking strength of the anchor cable (42 kips) was demonstrated by pendulum testing.

The results of Test 160 demonstrate that the BCT horizontal flare when used with steel (G4S) posts results in marginal performance. Because pocketing and spin-out occurred in Test 160, it was deemed desirable to stiffen the flared barrier segment by means of reduced post spacing to minimize vehicle penetration. In addition, the use of a single 25-ft (nominal) W-beam section was proposed as a means of reducing the longitudinal resistance for end-on impacts. The W-beam splice detail stiffens the section locally, and inasmuch as early buckling of the W-beam is desired for end-on impacts, use of a one-piece section should provide less resistance. The local post spacing reduction resulted in vehicle redirection in Test 162; however, the advantages over the previous standard post spacing do not appear to be conclusive.

The agency final report recommends that washers be omitted in the flared section between the mounting bolt head and beam to promote separation of the beam from posts for end-on impacts.

Use of a BCT nose assembly without diaphragm plates was demonstrated in three crash tests; its performance was considered satisfactory.

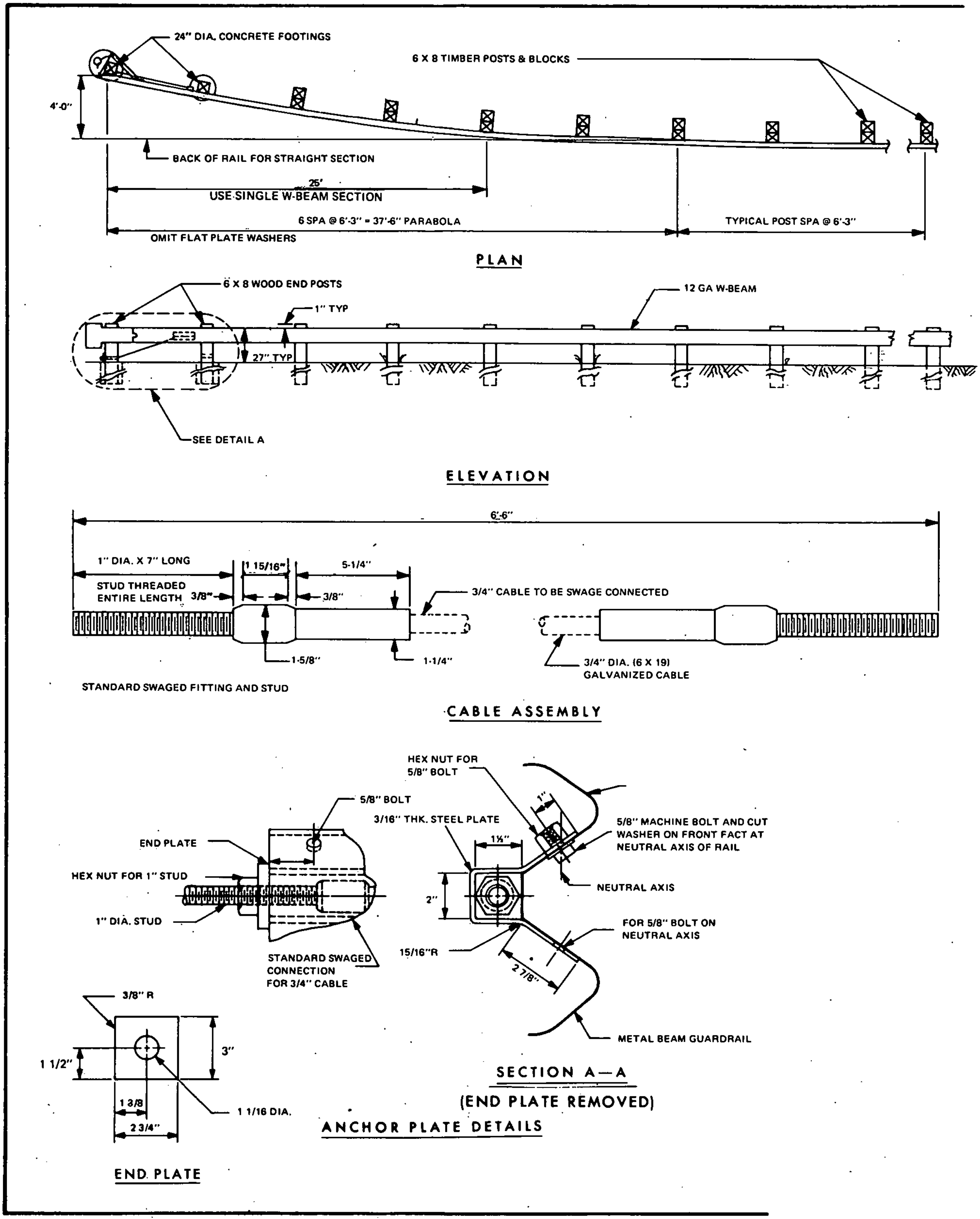
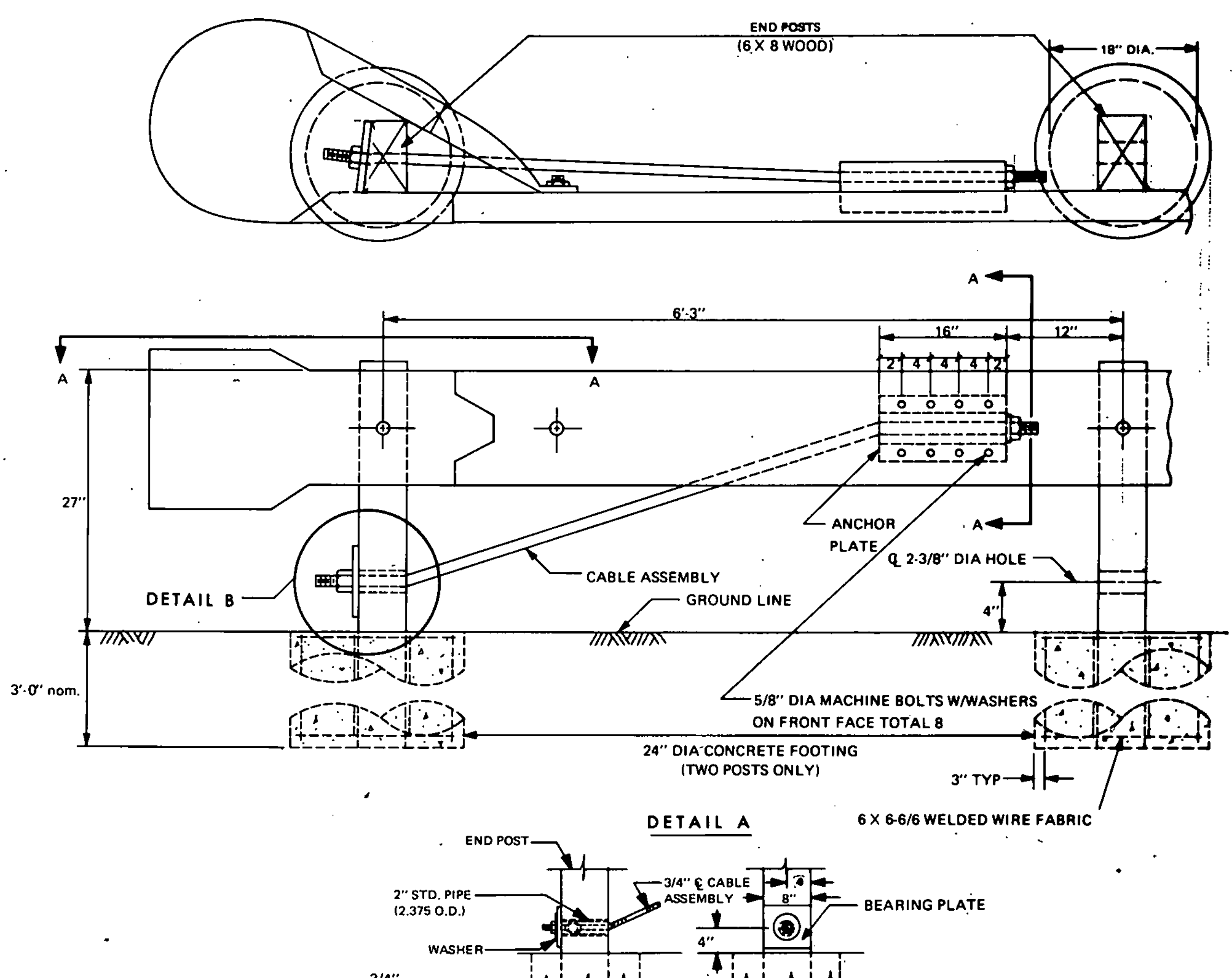
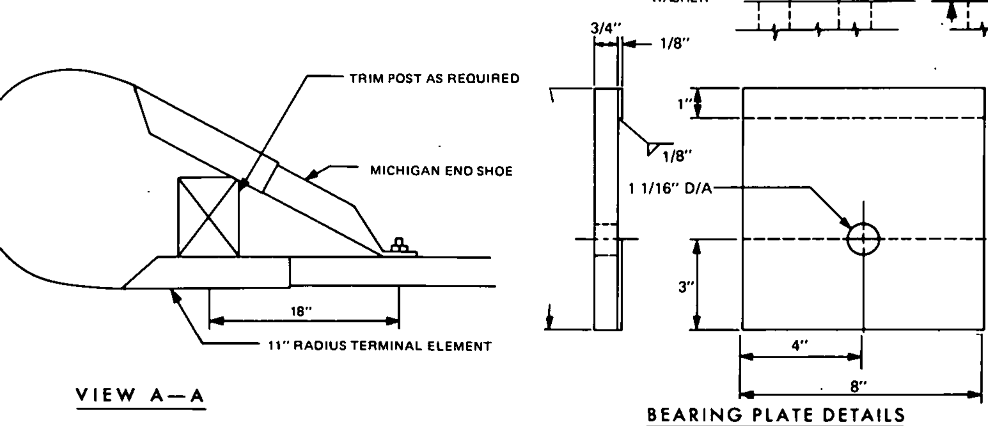


Figure 3 - Recommended Timber Post BCT Improvement

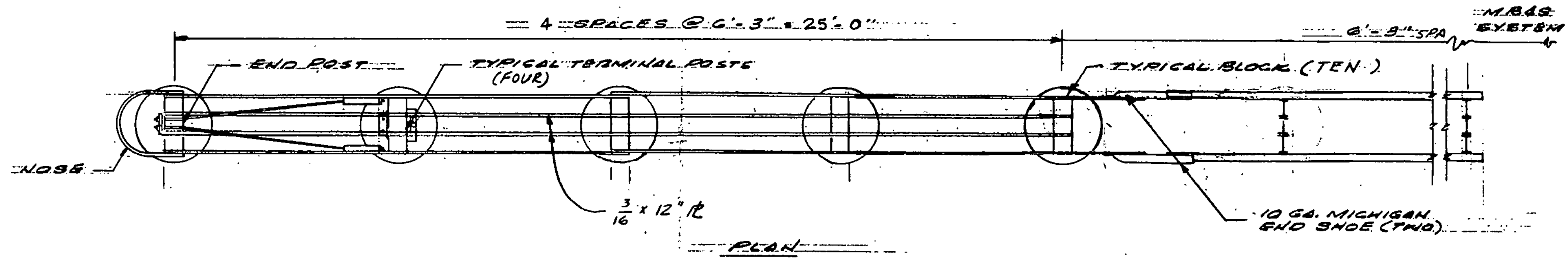


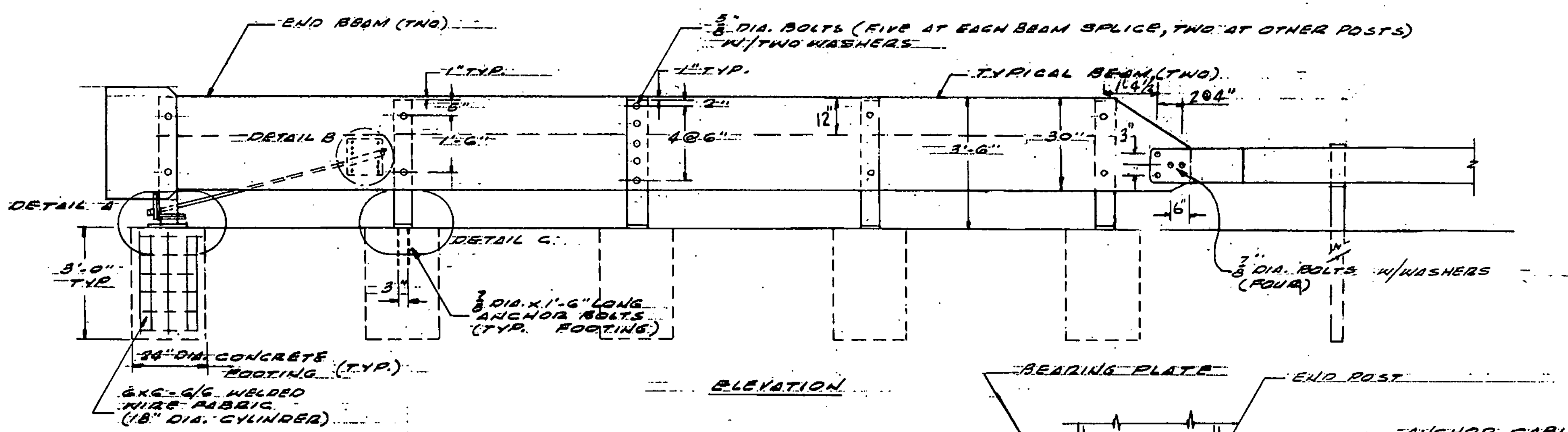


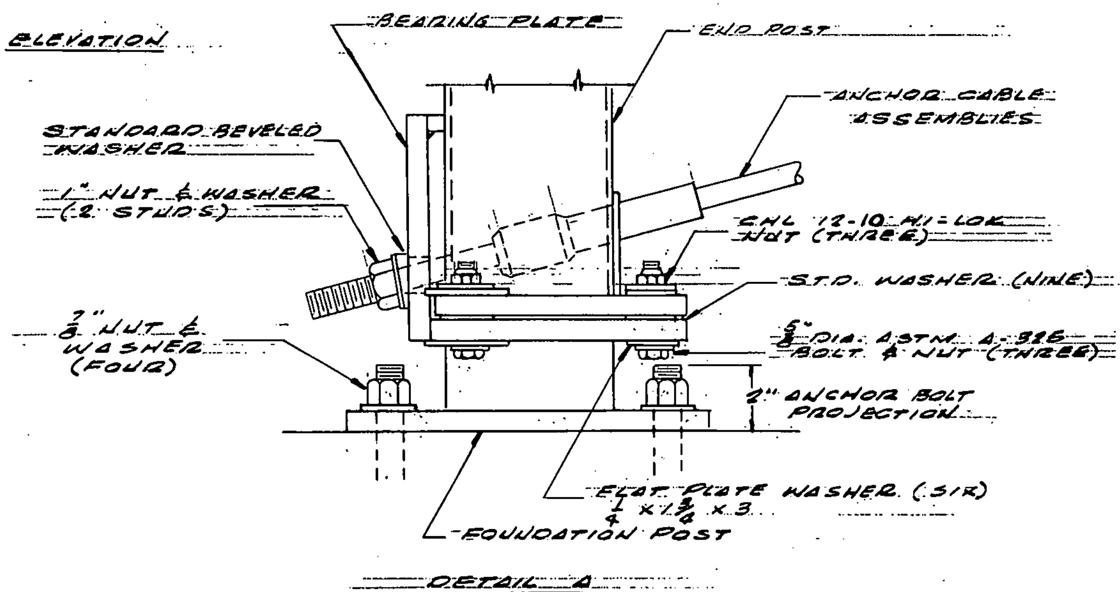
Notes:

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 and with 6 X 8 timber posts, replacing 8 X 8 timber posts in Report 118.
4. A double wrap of composition paper around end posts before concrete placement will facilitate replacement of damaged posts.

DATE June 1975	SCALE	BREAKAWAY CABLE TERMINAL – 6 X 8 TIMBER POSTS
DRAWN BY T. Garza		
DESIGNED BY M. Bronstad		DEPARTMENT OF STRUCTURAL RESEARCH / DRAWING NUMBER
CHECKED BY M. Bronstad		SOUTHWEST RESEARCH INSTITUTE / 03-3799-01
APPROVED BY		SAN ANTONIO, TEXAS







Notes:

1. The following specifications are applicable:

Box beam posts	-	ASTM A500 or ASTM A501
Sheet steel	-	ASTM 283, Grade D
Steel plate	-	ASTM A-36
Terminal bolts	-	Slip base ASTM A325; other, ASTM A307
Concrete	-	AASHTO Type A
Welded wire fabric	-	ASTM A-185

2. Torque on slip base bolts may be controlled by use of Hi-Lok CHL 12-10 nuts (product of Hi-Shear Corp., Torrance, Calif.) or bolt torque of 155-170 ft lbs.

3. The typical terminal post utilizes a breakaway weld at the base plate. The fillet weld should be 5/16" max., 1/4" minimum.

Figure 4 - Median Barrier BCT Terminal

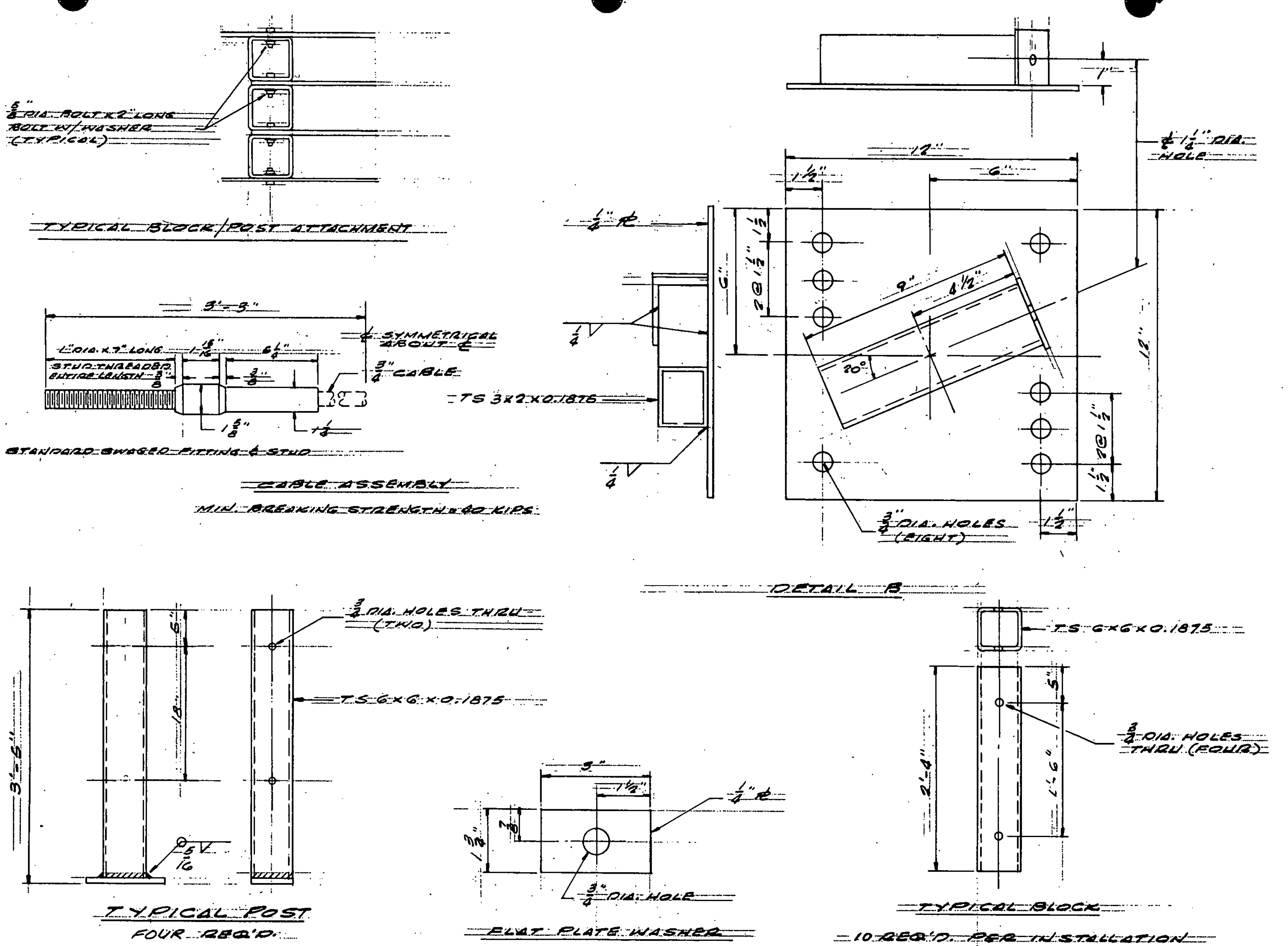


Figure 4 (continued)

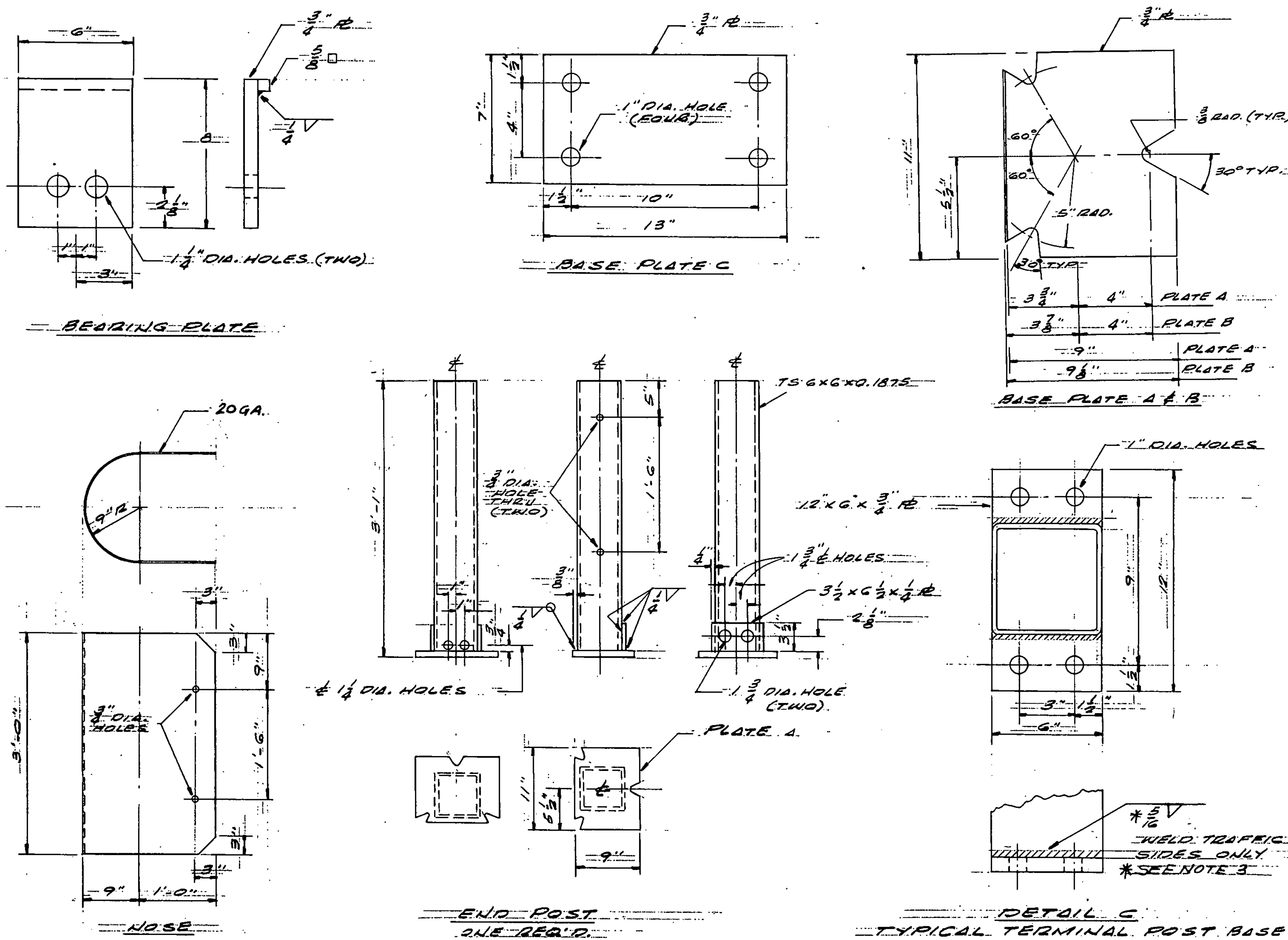
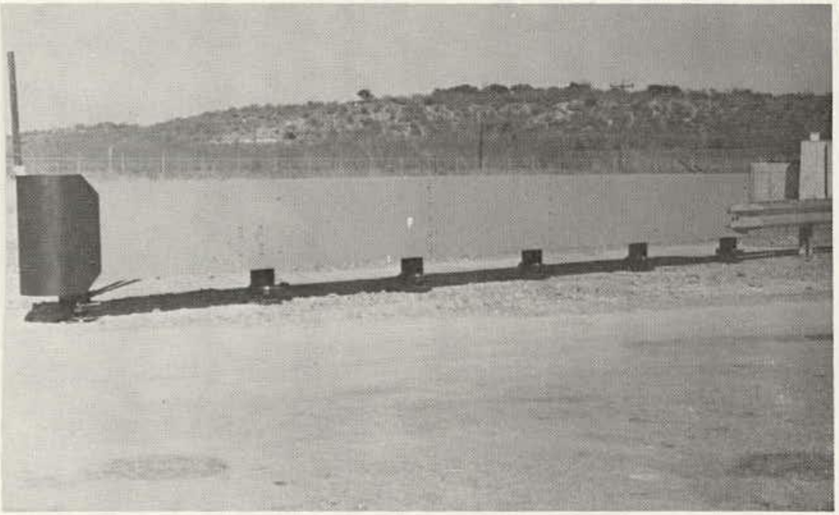
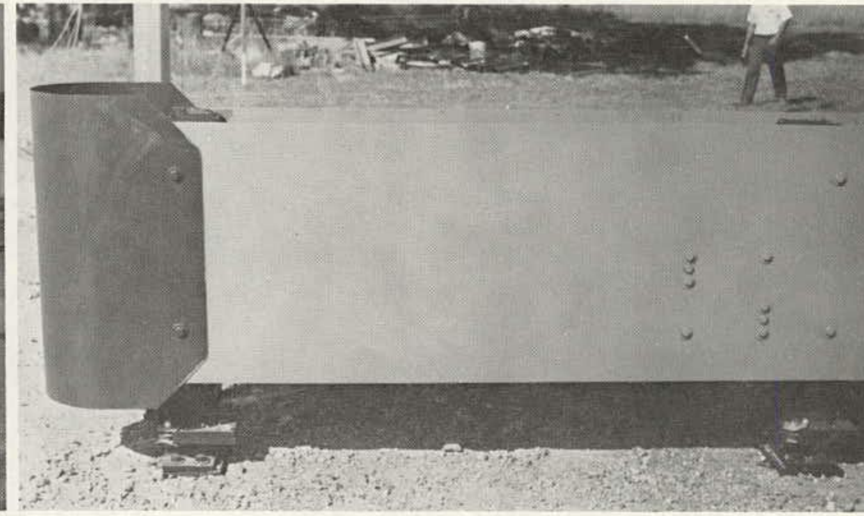


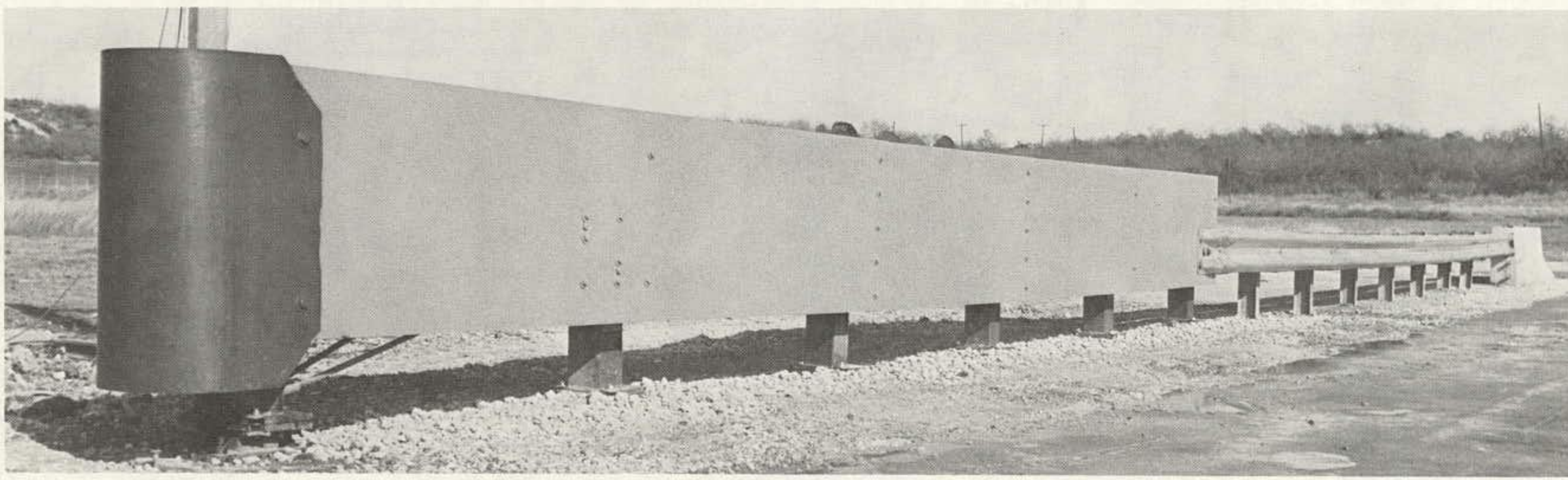
Figure 4 (continued)



Test 166



Test 166



Test 167

Figure 5 - Median Barrier BCT Photographs

Note: Typical terminal posts are same without anchor cable, bearing plate, etc.

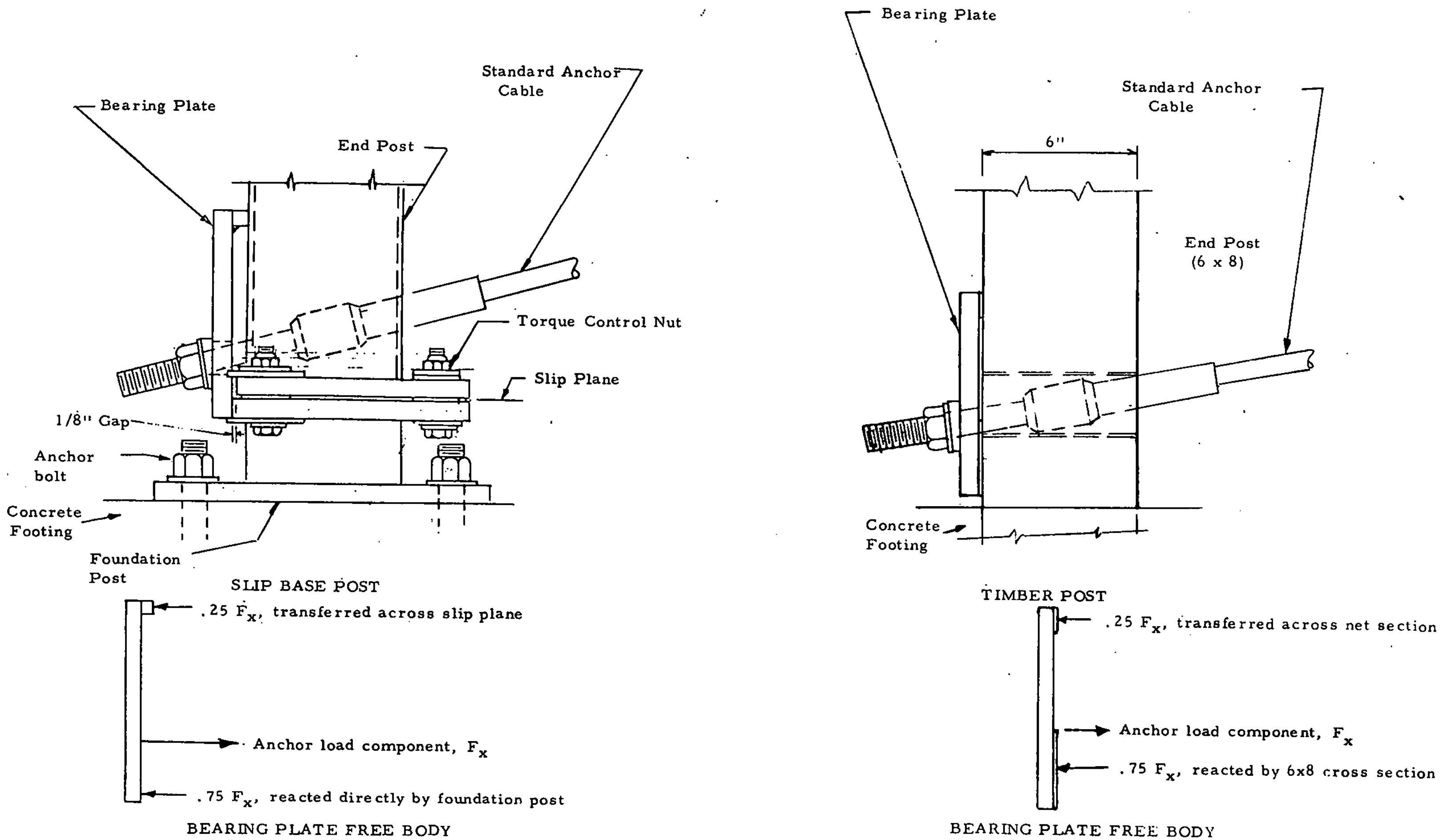


Figure 6 - Breakaway Terminal Posts

Median Barrier Terminal. The BCT recommended for use with median barriers was modified as follows:

- A three-bolt slip base provides the breakaway mechanism for the end post.
- A nose formed of 20-ga steel plate replaces the 55-gal. drum.

Table 2 contains information on the two full-scale crash tests conducted in Phase II to evaluate the median barrier BCT for end-on and angular impacts by a 4,500-lb vehicle at 60 mph. The system tested included the previously mentioned modifications except that the three-bolt slip base was used for all six posts of the 5-span terminal, and the 12-in.-wide interior plates were eliminated.

In Test 166, the end-on impact, the vehicle was decelerated in a very stable attitude; however, the foundation posts, which projected 4 in. above grade, became involved with posts that had previously broken away. This involvement is thought to have caused the unacceptable ramping of the vehicle.

As a result of the snagging associated with foundation post projection in Test 166, the foundation posts were lowered to grade for Test 167. The test vehicle impacted the terminal at the third post at 63 mph and an angle of 26 degrees. The vehicle penetrated more than 5 ft into the barrier and was launched as it climbed the W-beam, remaining airborne for 50 ft before contacting the downstream concrete anchor block (see Fig. 5). Although the end-post footing moved more than 4 in. downstream, the anchor cable/end post was intact. Pocketing in the system is attributed to the lack of sufficient lateral restraint provided by the breakaway post/flat plate combination. Except for the end post, all terminal posts slipped from their supports.

The three-bolt slip-base post is considered a significant improvement when considering anchor strength and breakaway performance requirements of the end post. The slip-base post was shown to develop the essential anchor strength in pendulum tests and Test 167. Thus, the recommended design shown in Figure 4 incorporates the superior end post developed in Phase II with the terminal posts validated in the first phase.[2]

It should be emphasized that no tests have been conducted on the system shown in Figure 4 as of this writing. However, the results of Tests 154, 156, and 157, reported in Reference[4], demonstrated the satisfactory redirectional capacity of the welded-post concept in side impacts. The slip-base end post provided essential anchorage for a severe angular impact in Test 167; however, downstream translation of the concrete end footing indicates that the footing size is marginal for some soil conditions.

The slip-base concept worked well for end-on impact in Test 166 until post involvement with the projecting foundation posts occurred. The one-piece nose appeared to perform on a par with the 55-gal. drum used previously; this results in cost savings and provides a more attractive, less conspicuous end. However, in the absence of a test on the recommended system, concern exists that substitution of the nose piece for the drum could cause vehicle ramping in end-on impacts. The Federal Highway Administration plans to investigate this possibility by full-scale impact testing in late Spring 1976.

APPLICATIONS

Over-all, the BCTs for guardrail and median barriers are judged to meet service requirements and will perform satisfactorily for most vehicle impact

conditions. Although results from several of the more demanding vehicle crash tests may be considered less than ideal, the BCT offers significant improvement over other existing designs.

The guardrail BCT designs as detailed in Figures 1 and 3 are recommended for trial use. This relatively low-cost system (about $300) provides the designer with a terminal that has been evaluated over a wide range of impact conditions, using both timber and steel posts. A slip-base breakaway steel post was developed and demonstrated to improve the dynamic performance. In addition, cost-saving concepts are presented for future implementation.

The two median barrier crash tests performed in this program failed to demonstrate conclusively the improved performance of the median barrier BCT with slip-base terminal posts. Nevertheless, the system detailed in Figure 4 is suggested for in-service trial use. Pending results of additional impact testing to validate the one-piece nose, the drum nose shown in Figure 1 of Reference(4) may be used as a successfully tested alternative.

Based on available data, cost of the median barrier BCT should be in the $2,000 to $2,500 range. This is considerably lower than other currently used crash cushions that have redirection capability for angular impacts. Use of median barrier BCTs for fixed-object envelopes in medians is considered to be a promising application for this concept.

The findings of the two phases of Project 22-2 demonstrate acceptable performance of BCT terminal designs applied to the following traffic barrier systems shown in *NCHRP Report 118*:

System	Description	Tests
G4S	Blocked-out W-beam guardrail, steel post	141, 142, 159, 164, 165
G4W	Blocked-out W-beam guardrail, timber post	135, 136, 137
MB3	Steel box beam median barrier	150, 151, 155, 157
MB4S	Blocked-out W-beam median barrier, steel post	150. 151, 155, 154
MB4W	Blocked-out W-beam median barrier, timber post	158

Although not documented by crash tests, it is conjectured that these BCT designs could also be applied to these other systems in *NCHRP Report 118:*

System	Description
G2	W-beam on weak steel post guardrail
MB2	W-beam on weak steel post median barrier
MB5	Concrete median barrier
MB6	Concrete median barrier

Users of the BCT should pay careful attention to details of the designs that may significantly influence performance of the terminal. The researchers warn that:

> Significant modification or deviation from proven details is discouraged, unless verified by full-scale testing. Retention of proven breakaway resistance values, anchorage capacity, W-beam and plate stiffness, etc., is essential to assure effective terminal performance and integrity.
>
> Breakaway terminal tests were performed on a relatively level surface; careful attention is suggested to assure this same condition for field applications in order to maintain proper terminal height relative to the vehicle's center of gravity. Accordingly, use of the terminals on raised islands or behind curbs is not recommended because of the potentially adverse effects of these elements on the terminal performance.

Those considering application of these terminals may wish to request loan copies of the agency's uncorrected draft final report from the NCHRP Program Director. Specific questions may also be directed to the Southwest Research Institute researchers through NCHRP.

The NCHRP Projects Engineer responsible for Project 22-2 is Dr. Robert J. Reilly, who can be reached at (202) 389-6741.

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