Box-Beam Guardrail Terminal Section

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North Dakota and several other states use the type G3 box-beam roadside barrier with modifications. The box beam has been chosen because of its narrow profile and low resistance to wind forces and the low probability of causing snow and sand drifts. There is no acceptable narrow profile end treatment and the North Dakota State Highway Department was seeking a simple and inexpensive treatment that would eliminate or reduce the probability of a vehicle ramping or rolling, or the rail end from penetrating the vehicle. Full-scale crash testing by the Texas Transportation Institute (TTI) for the North Dakota State Highway Department indicates that an acceptable solution has been developed. A 7 in. x 60 ft long American Standard Channel was used in the design of the end treatment. A 25 ft-6 in. (7.8 m) portion of a channel was twisted with a permanent 90-degree twist so that the web would be vertical at the first post and horizontal at the foundation with the flanges pointing down. This section was pushed to the ground, offset away from the traffic, and attached to a concrete footing centered 24 ft (7.3 m) from the first post. The remaining 34 ft-6 in. (10.5 m) of channel extended downstream to a splice with the standard box beam. The post at the beginning of the length of need was a brittle 6 in. x 6 in. (140- x 140-mm) wood post. All other posts were S3 x 5.7 steel. Beveled blocks were attached to each post holding up the channel. A wire clip was used to hold the rail laterally to the wood post.

Some states have used the box-beam roadside barrier for many years (1). Many of these states are in the northern portion of the United States in hilly and mountainous areas where limited barrier deflections under impact are considered advantageous and where the problem of snow drifts caused by an obstacle in the path of the wind exists. Taking these factors into consideration the North Dakota State Highway Department (NDSHD) therefore elected to develop, with the assistance of the Texas Transportation Institute (TTI), a guardrail terminal for a box beam.

The first attempt was simply to slope down and flare a section of box beam. This method was not successful. NDSHD then selected from several options a terminal whose primary member was a standard rolled steel channel C7 x 9.8. This section is 1 in. (25 mm) deeper than the box beam and easily fits over the box beam. A terminal that is constructed of this rail will meet federal requirements contained in Transportation Research Circular 191 (2).

BOX-BEAM GUARDRAIL TERMINAL SECTION

A North Dakota box-beam terminal section with flared, turned-down end treatment was to be tested. This design varied slightly from the standard in that the three posts originally proposed between the anchor and first full-height post at 24 ft (7.32 m) were removed and the rail was attached to the next seven posts with two 3/8-in. bolts. The rail was installed on S3 x 5.7 posts.

These modifications were made to preclude launching and rollover of the vehicle as a result of longitudinal impacts with the turned-down section. The modifications were partly suggested by tests of rail terminal treatment conducted in 1977 and 1978 (3,4). When this treatment failed to work, it was decided to use a different type of rail for the terminal section instead of the original box beam. Important factors in selecting the rail section for end treatment were the smoothness and depth of the rail, both of which are important factors in reducing the buildup of drifting snow. The final design selected for full-scale testing is shown in Figure 1. Because the W-section had been crash tested successfully, a smooth shallow section with similar structural characteristics was selected for the end treatment, a C7 x 9.8. This channel is slightly weaker in bending about both axes than the W-beam, though more stable. It has more cross-sectional area, which makes it stronger in tension and about 12 times stronger in torsion. The C7 x 9.8 was used to replace the first 58.5 ft (17.8 m) of box beam. From a review of previous testing programs (3,4), the researchers determined that the first post needed to be brittle, and a 6 x 6 in. (140 x 140 mm) treated wood post was chosen. Next it was decided that the second post should be at least 12 ft (3.66 m) from the first post to prevent the second post from tripping an impacting vehicle, as in test 1. The remaining posts were the standard S3 x 5.7. A tapered wood block covered with sheet metal was added to each post supporting the channel rail. The channel was attached only to the first post by a clip, as shown in Figure 1. The connection between the channel and box beam was made to function like a vertical hinge without sacrificing longitudinal strength. The first 18 ft (5.5 m) of box beam also was hinged in its vertical direction to allow the rail to be depressed downward with a small vertical load. The connection to the posts in this first section of box beam was with a 3/16-in. bolt. With these bolts removed the rail will drop down when the turned-down segment is struck by a vehicle and allow the vehicle to pass over the rail for a controlled penetration.

The action of this modified rail terminal is simple. When a vehicle tire or bumper pushes down on the turned-down terminal, the rail will quickly drop from the first eight posts. This allows the vehicle to pass over the rail without the violent ramping effect produced by a rigid turned-down terminal. If the vehicle bumper engages the rail at the length-of-need and pushes it laterally against the backup blocks on the posts, the rail is held at the proper height and the vehicle is redirected. The backup block resists the downward tension force component of the turned-down terminal. The sheet metal covering on the backup blocks is important in that it allows the channel to slip off the block.

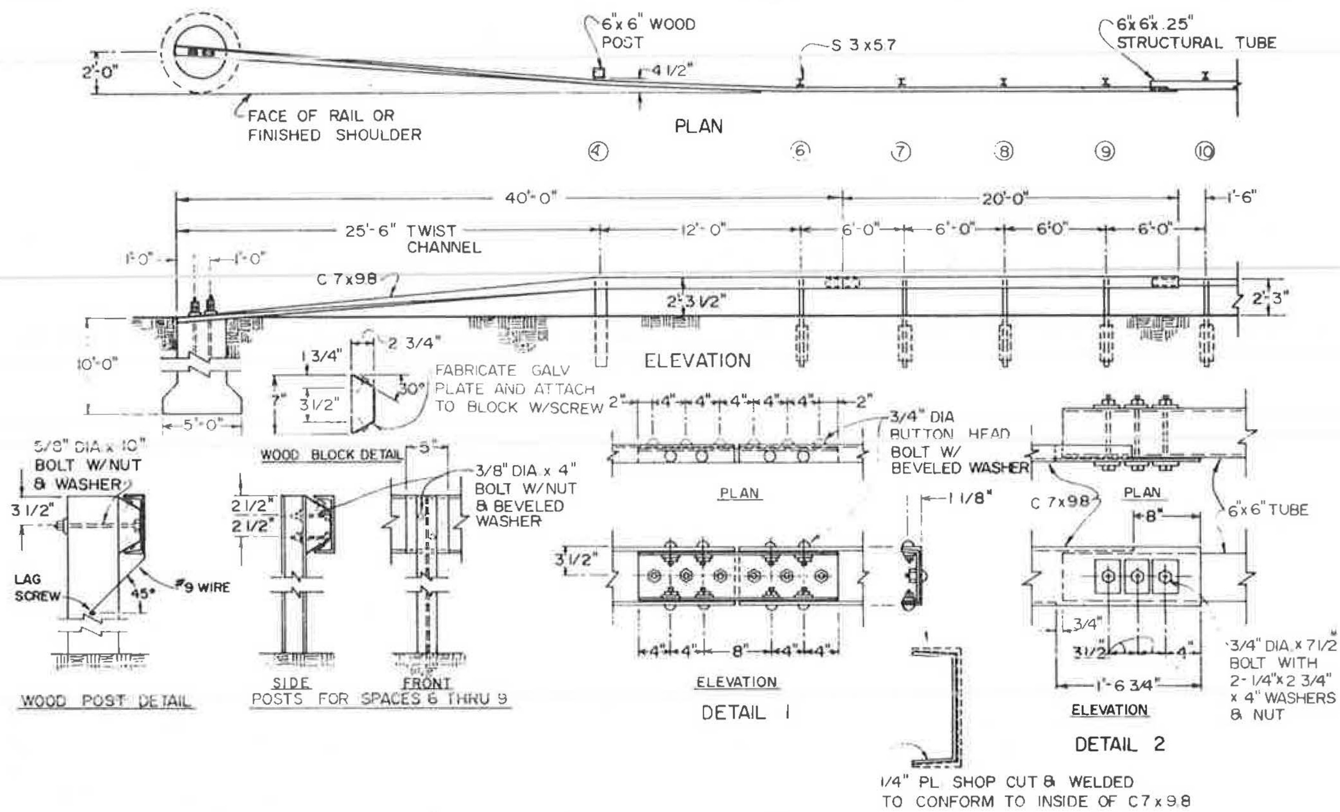
CRASH TESTS

Six full-scale crash tests were conducted from July 1979 to June 1980 on modified designs of a box-beam guardrail. The test conditions and results are given in Table 1 and are discussed in detail in the following pages.

A 250-ft (76.2-m) section of standard North Dakota box-beam guardrail was constructed at the TTI Research Center. The site was prepared according to specifications in Transportation Research Circular 191 (2) by digging out the space for the posts and replacing the soil with crushed stone that meets the requirements of Circular 191 for the soil foundation for longitudinal barrier posts. The basic rail was similar to the AASTHO G-3 rail except that the wall thickness was 0.250 in. (6.35 mm) rather than the usual 0.180 in. (4.57 mm).

Test 1 was conducted by using a box-beam drop-down as an extension of a North Dakota standard box-beam guardrail. This test was unsuccessful in that the vehicle was partly redirected, vaulted, and rolled. A detailed review of test 1 led to the final recommended design shown in Figure 1. The principal changes involved changing the first 56 ft

Figure 1. Modified turned down end using standard C-section.



(17.1 m) of rail started at the upstream anchor from box beam to C7 x 9.8 and changing the first post from an S3 x 5.7 steel to a 6 x 6 wood. Crash tests 2, 3, 4, 5, and 6 were conducted on the final recommendation except that tests 2 and 3 were conducted using a welded splice between channel sections and tests 4, 5, and 6 were conducted using the recommended bolted splice. Tests 2, 4, 5, and 6 were successful and verified that the recommended design of Figure 1 will meet the safety evaluation guidelines of Circular 191 (2).

Test 1 was unsuccessful in that the vehicle was redirected, ramped, and rolled over several times, violating the traffic lane. Test 3 was unsuccessful in that the weld at the splice parted, which allowed an unwanted penetration of the guardrail. No data were collected for test 3.

Test 1

The flared and turned-down end was installed at the beginning of the length of need according to North Dakota standards. The two standard 3/8-in. bolts that hold the rail clip to the posts were replaced with one 3/16-in. bolt in each of the first nine posts, and at the same time posts in the turned-down section were removed.

The vehicle used in the test was a 1974 Vega weighing 2,340 lb (1061 kg). The impact velocity was 64.2 mph (103.4 km/h). The impact angle was 16 degrees. The impact point was 12 ft from the end anchor. The impact data are given in Table 1. The 50-msec average for accelerations is within the limits suggested by Circular 191 (2). Subsequent vehicle behavior was not within the limits of criteria.

The vehicle behavior during the test was reviewed by studying the high-speed photography of the test. Within 10 msec after impact, the 3/16-in. bolts that attached the rail to the post had sheared and the rail had started to fall as designed. The front fender in contact with the rail collapsed, the tire compressed, and at approximately 34 msec the vehicle began to redirect. Penetration was not achieved. The bumper, which was higher than the box beam at impact, appeared to be in contact with the rail. As time progressed the rail was falling but also the rail was launching the vehicle. At 239 msec three wheels were off the ground. At 300 msec all four wheels were off the ground. The rail fell to the ground at approximately 0.5 sec. After the vehicle became airborne no additional time displacement data were developed. However, the vehicle rolled, hit on its roof, then cartwheeled to a stop 190 ft (58 m) from the impact point and 20 ft (6.1 m) on the traffic side of the rail. The test was not successful. Pictures of the rail and vehicle after the test are shown in Figures 2 and 3.

Test 2

Before test 2 several changes were made to the guardrail and terminal as a result of the lessons learned in test 1 and testing previously accomplished (3,4) (see Figure 1). Approximately 56 ft (17.1 m) of the box beam from the terminal end to midway between post positions 9 and 10 were replaced with a like length of steel channel C7 x 9.8. The 24 ft (7.32 m) between the terminal end and post position 4 were twisted 90 degrees in the shop before installation. Two sections of the channel were butt welded between posts 6 and 7. The S3 x 5.7 post at position 4 [24 ft (7.32 m) from the terminal] was replaced with a 6- x 6-in. (140- x 140-mm) wood post, and the post at position 5 was removed

Table 1. Summary of crash tests on North Dakota box-beam guardrail terminal section.

Item	Test 1	Test 2	Test 4	Test 5	Test 6
Significant terminal features	Box beam turned in 24 ft, end flared 2 ft, all steel posts, first post 24 ft from terminal	C7 x 9.8 used in lieu of box beam beginning at terminal and extending for 57 ft, vertical hinge installed between channel and box beam and at end of first box beam, first post 24 ft from terminal was 6 x 6 wood, second post 12 ft from wood post was steel I-beam (S3 x 5.7), all remaining posts were S3 x 5.7 at 6 ft, channel was attached to wood post with wire clip			
Impact point	Mid-length of terminal, 15-degree angle	Mid-length of terminal, 15-degree angle	Guardrail length of need, 25-degree angle	End of terminal, head-on	End of terminal, head-on
Vehicle type	Vega	Vega	Plymouth	Vega	Plymouth
Vehicle mass (lb)	2,340	2,360	4,500	2,350	4,500
Film data					
Initial speed (mph)	64.24	56.25	56.05	29.85	61.13
Parallel speed (mph)	61.38	NA, car jumped rail	42.11	NA	NA
Final speed (mph)		44.97	NA	Vehicle stopped on rail	NA
Impact angle (degrees)[a]	16	15.5	28.0	0	0
Departure angle (degrees)[a]		-13.0	Vehicle does not exit	Vehicle does not exit	NA
Vehicle roll angle (max degrees)[a]	720	46.5	7.0	6.5	38.25
Time to parallel (sec)	0.185	NA	0.363	NA	NA
Time to loss of contact (sec)	0.390	0.422	1.237	Vehicle stopped on rail	NA
Dynamic barrier displacement (ft)	6.611	0.491	9.1	NA	NA
Residual barrier displacement (ft)	0.597	-0.256	6.5	NA	NA
Longitudinal distance to parallel (ft)	16.253	NA	30.75	NA	NA
Lateral distance to parallel	3.567	NA	11.28	NA	NA
Accelerometer data (100 Hz 10-pass max flat filter)					
Max avg 0.050-sec deceleration					
Longitudinal (g)	-2.5	-2.4	-2.7	-1.6	-2.35
Lateral (g)	-6.5	-2.7	-4.0	1.39	-2.11
Vertical (g)	2.1	3.6	-1.8	-1.43	2.53
Resultant (g)	6.5	4.2	4.6	2.36	2.97
Deceleration over contact time					
Longitudinal (g)	-0.636	-0.45	-1.47[b]	-0.52[c]	
Lateral (g)	-3.44	-0.30	-2.15[b]	0.19	Not available[d]
Peak deceleration					
Longitudinal (g)	-12.1	-16.1	-17.9	-9.60	-17.49
Lateral (g)	-26.9	22.1	-12.4	-13.25	-10.54
Vertical (g)	11.9	22.5	11.2	13.92	-19.71
Resultant (g)	25.3	26.4	18.7	30.00	21.83
Vehicle damage classification					
Traffic Accident Data Project	2-R&T-4.6	1FR2	11LFQ3	NA	12FD1
Society of Automotive Engineers	2-FDAQ-2	01FREE9	11LDWE3	12UDLW9	12UDLW2
Remarks	Vehicle redirected; rolled over two revolutions	Vehicle rode over terminal; max roll angle, 46.5 degrees	Vehicle redirected smoothly	Vehicle pushed terminal down, bent over 8 posts; stopping safely (left field of view); stopped on rail between post 11 and 13	Vehicle pushed terminal down, bent over 8 posts; traveled 168 ft; jumped off rail, was stopped remotely before impacting downstream barrier
	Test unsuccessful, terminal modified	Test successful	Test successful	Test successful	Test successful

[a]Degrees from rail line. [b]Over 1st 600 ms of contact. [c]Over 1st 0.723 sec of contact. [d]Dust obscured view of vehicle leaving barrier.

Figure 2. Rail after test 1.

Figure 3. Vehicle after test 1.

completely. Details for post 4 and posts 6 through 9 are shown in Figure 1. The box beam was attached to posts 10, 11, and 12 with a 3/16-in. bolt.

The test conditions were similar to those of test 1. A 1974 Vega weighing 2,360 lb (1071 kg) impacted the rail at 56.3 mph (90.6 km/h). The impact was midway between the anchor and the length of need and at an angle of 15.5 degrees with respect to the straight portion of the rail. The vehicle pushed the rail down approximately 0.035 sec after impact, was redirected slightly, and struck and broke the wood post at 0.121 sec. The vehicle then continued across the rail in a straight path without varying until the brakes were applied. The maximum average longitudinal acceleration over 0.050 sec was 2.4 _g_ and the maximum average transverse acceleration was 2.7 _g_. The performance of this test was considered excellent.

The results of this test are summarized in Table 1. To repair the rail the wood post had to be replaced; all other posts and the rail elements were reusable.

Test 3

The installation for this test was identical to that of test 2. The configuration is shown in Figure 1.

The test consisted of a 1974 Plymouth impacting the rail at the wood post (beginning at the length of need). The vehicle weighed 4,500 lb (2043 kg) and was traveling at 60 mph (96.5 km/h). The impact angle was 25 degrees. The weld splice failed and the vehicle went through the rail. The test was not successful and no data were produced.

Test 4

The installation for test 4 was the same as for tests 2 and 3 except that the welded splice was replaced with a bolted splice.

The test conditions were similar to those in test 3. A 1974 Plymouth weighing 4,500 lb (96.5 kg) impacted the rail at 56.1 mph (90.2 km/h). The point of impact was at the wood post or at the beginning of the length of need. The impact angle was 28 degrees. The rail deflected laterally 9.1 ft (2.77 m) and began to redirect the vehicle as it reached the first metal post at 0.179 sec after impact. The maximum 0.050-sec average longitudinal and transverse accelerations began about this time; they were 2.7 and 4.0 _g_, respectively. The right rear side of the vehicle came in contact with the rail at 0.350 sec and was parallel at 0.426 sec. The exit angle was approximately 7 degrees and the exit velocity was 42.1 mph (67.8 km/h). Damage to the left front tire and the application of brakes caused the vehicle to yaw to the left and come to a stop 210 ft (64 m) downstream from the point of impact and 15 ft (4.6 m) from the traffic face of the rail. The rail height was maintained throughout the collision and the reduction performance of the rail was considered good.

The results of this test are presented in Table 1. Rail damage is shown in Figure 4.

Test 5

The installation evaluated in test 5 was identical to that of test 4.

The test consisted of a 1974 Vega impacting the terminal head-on with respect to the straight portion of the rail. The vehicle weighed 2,350 lb (1066 kg) and was traveling at a speed of 29.9 mph (48.0 km/h) when impact occurred. The point of impact was the anchor with the vehicle straddling the rail. The vehicle raised slightly just before impacting the wood post, but the wheels did not leave the ground at this point. The rail disengaged from the wood post and then from posts 6 through 13 in

Figure 4. Rail damage after test 4.

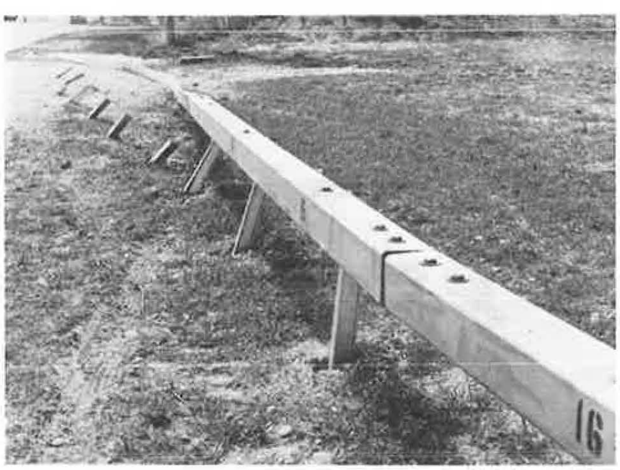


Figure 5. Vehicle and rail after test 5.

Figure 6. Rail after test 6.

Figure 7. Vehicle after test 6.

sequence. The wood post fractured at the ground line and was deflected behind the rail. Posts 5 through 12 were bent out of line. The vehicle came to rest just past post 12 while straddling the rail and resting primarily on the back side of the rail. The maximum vehicle roll angle was 6.5 degrees. Figure 5 shows the vehicle and the rail after the test. The rail was rebuilt by replacing the eight posts and straightening the kink at the splice between the channel and the box beam.

Test 6

The installation evaluated in test 6 was identical to that of tests 4 and 5. The rail from the turned-down anchor to the far terminal was reused. The posts damaged by impact in test 5 and their hardware were replaced in preparation for this test.

The test consisted of a 4,500-lb (2043-kg) Plymouth traveling 61.1 mph (93.4 km/h) impacting the terminal head-on. The point of impact was the anchor with the vehicle straddling the rail. The vehicle rode the rail 168 ft (51 m) before jumping off the rail on the traffic side near post 28.

The vehicle was stable, and the maximum roll angle reached 38.3 degrees. A roll angle of 55 degrees or more is required before this vehicle will roll over. The vehicle did not stop of its own accord or slow down sufficiently, and remote-controlled brakes were applied after the vehicle left the rail and before it was involved in a secondary impact with another test facility +300 ft (90 m) from the point of impact. Had this been a real-life accident then in all probability the engine compression would have acted as a braking force and slowed the vehicle to a reasonable speed before it reached the end of the rail installation. The maximum 50-msec deceleration was 2.97 *g*. Figure 6 shows the rail after the test. Figure 7 shows the vehicle after remote-controlled brakes were applied after the test.

SUMMARY AND CONCLUSIONS

North Dakota has unique problems with snow drifting against and dynamic deflection of roadside barriers. The W-section barriers G-2 and G-4 (1) both cause snow drifts across travelways that are hazardous to the traveling public. Also, a large portion of the roadside barrier installations are in locations that would make large lateral deflection of the G-1 cable barrier (1) inappropriate. Therefore, NDSHD elected to use a modified G-3 box-beam barrier (1). The North Dakota standard varies from the G-3 in that the box-beam tube thickness is 0.250 in. (6.35 mm) in lieu of the standard 0.180 in. (4.57 mm) and the support angles are attached to the posts by two 3/8-in. bolts. Testing by North Dakota has shown that the snow drifting characteristics exhibited by the box beam are reasonable and satisfactory, particularly when compared with those exhibited by the deeper W-beam rail systems. Also, the state can design within the expected dynamic deflection characteristics of the box beam whereas the deflection of the cable system would be excessive. There are no existing standard designs for end treatment or rail termination that will meet the requirements as established by the state. NDSHD embarked on a design-test program to develop a suitable end treatment.

The final design uses a 6- x 6-in. (140- x 140-mm) wood post 24 ft (7.3 m) from the anchor. The next post is spaced at 12 ft (3.66 m), and all remaining posts are spaced at 6 ft (1.83 m). The end treatment and next 30 ft (9.14 m), for a total of 54 ft (16.46 m), of rail were replaced by a C7 x 9.8 rolled section of A36 steel. The channel is held to the wood post by a no. 9 wire clip. There is no positive attachment of the channel to the steel posts. The box beam is attached to the first three posts by 3/16-in. bolts and thereafter by two 3/8-in. bolts. The length of need begins at the wood post.

Successful crash tests as recommended by Transportation Research Circular 191 (2) have been conducted to verify the satisfactory behavior of the modified rail. The vehicle impacted the midpoint of the modified terminal, depressed the rail, and rode over the rail without vehicle roll over. When the guardrail and terminal were impacted at 1 ft (0.3 m) downstream of the length of need, the 4,500-lb (2040-kg) vehicle was redirected smoothly as required.

In the head-on test at 61.13 mph (98.38 km/h) the vehicle remained astraddle the rail for 168 ft (51 m) before it jumped off and in front of the rail. Highway engineers should keep this in mind when using this installation with rails tied to bridge piers or other rigid objects.

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Development of Safer Utility Poles

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This paper is based on a FHWA-sponsored research program to develop a breakaway retrofit concept for roadside timber utility poles. Southwest Research Institute's efforts to achieve this goal are described. The research included analytical (simulations) as well as experimental efforts. The experimental efforts involved static bending tests, pendulum tests, and full-scale tests of poles with subcompact automobiles. A slip-base concept, called Slipbase, is recommended for implementation along roadsides. Slipbase is capable of reducing significantly the inherent roadside hazards associated with in situ timber utility poles while maintaining a high level of wind-ice resistant bending strength. The slipbase concept cannot be applied universally at this time because no tests have been conducted on poles that carry multicircuit electric lines or on poles that carry joint electric and telephone lines.

Timber poles are not designed to be breakaway structures. Figures 1 and 2 illustrate the result of subcompact cars colliding at 49 km/h (30 mph) and 97 km/h (60 mph) with such poles. In both cases the vehicles sustained substantial damage, but damage to the pole was not appreciable. Accident statistics reveal the frequency and severity of this type of collision. According to the National Highway Traffic Safety Administration (1)

1. More than 4,400 fatal accidents involving utility poles occurred between 1975 and 1977 and
2. More than 8,300 people died in these accidents.

Further, Texas accident files show an injury-to-fatality ratio of 45 to 1 involving this type of accident. If this ratio represents a nationwide average, then an estimated 373,500 injuries involving utility poles occurred between 1975 and 1977 (125,000 injuries per year).

Southwest Research Institute (SwRI) has been investigating the problem of vehicle collisions with utility poles for several years. In an earlier study (2) SwRI investigated the feasibility of developing retrofit designs for in situ timber poles. The objective of the study was to develop an inexpensive retrofit concept that would enable currently nonfrangible poles to break away. The retrofit design was to satisfy the following criteria:

1. Breakaway of pole and acceptable momentum change of vehicle on impact,
2. Sufficient structural integrity of pole to withstand ice- and wind-induced loads,

Figure 1. Unmodified pole crash test at 49 km/h.