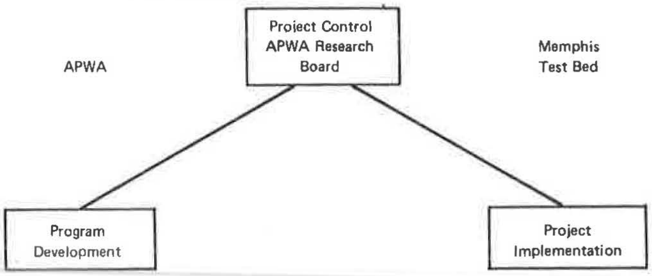
Figure 5. CAMRAS organization.



1. APWA Staff – Documentation
   - – Reports
   - – Evaluation
   - – Testing
   - – Training
2. Program Manager
3. Program Advisory Committee
4. Program Steering Committee
5. Technical Advisory Committee
6. User Requirements Committee
7. Supplier Liaison Committee

Staff Role – "Here's How To Do It"

1. Project Manager
2. User Requirements
3. Operational Group
4. Technical Group
5. Management Advisory Grp.

Line Role – "Do It"

Note: APWA, Chicago.

utilities and public-works agencies in their participation in one-number-to-call utility-location systems, to procurement guidelines for future users, and to guidelines for the establishment of a joint-user system.

Therefore, to the advantages of computerized mapping, we now add the benefits of standardization. With standardization, we add the capability for computer-to-computer exchange of data, which implies compatibility with private records systems. Vendor performance is clarified because the entire procurement process is simplified. Procurement documents that have clear performance standards will focus vendors' developmental activities, and a better evaluation can be used to justify vendor selection. Perhaps in summary of all of the above: For all future users, the experimental risk is reduced.

Governments at all levels profit from the existence of widely accepted standards. One small example is that the fine-grain, ground-control networks of local municipalities can be more readily referenced to a national network through computer-controlled conversion systems. Those who are interested in land records, including surveyors, particularly benefit by standards for reference and recording. Conveyors, agents, and legal representatives are more assured by standard descriptive systems. Insurors are more certain of the permanent existence of parcel descriptions and parcel-adjacency references. Therefore, the courts benefit because there is a reference method in the computerized standard-recording procedure that can be compared to the methods of the case in hand. Buyers and sellers of land are more readily assured of the conveyance records. Permit agencies and recorders of rights-of-way, contractors, and designers and engineers are more assured that their records are mutually compatible with those of others whom they may affect (and who may affect them). Finally, utilities are more assured that the locations of their systems are reliably referenced. However, with the daily installation of new systems, the ability of those already involved to adjust to a reference standard is constantly being reduced. With each new system that is installed, it becomes more difficult to promulgate a generally accepted benchmark standard. AWPA is unique in that the needs for and benefits from these standards cross the full spectrum of its membership.

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Eliminating Vehicle Rollovers on Turned-Down Guardrail Terminals

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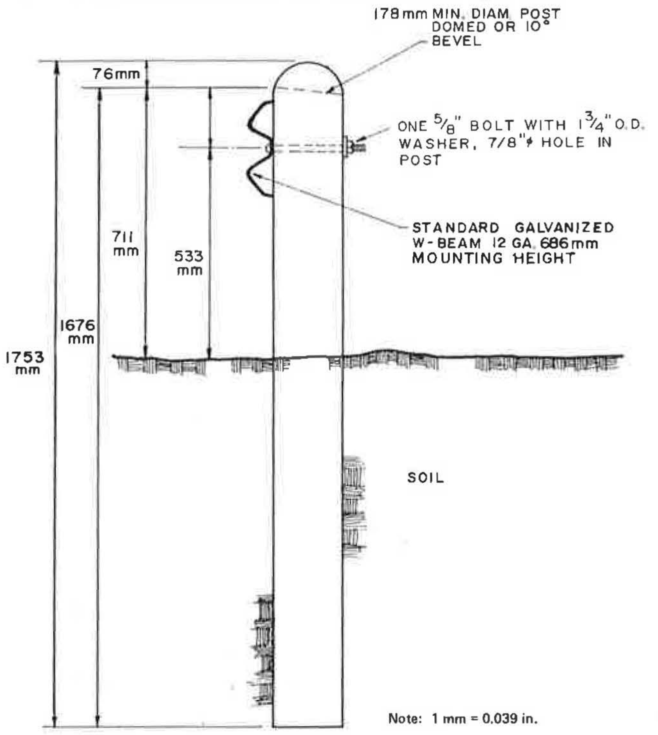
A relatively simple method has been found to modify the turned-down ends of highway guradrails to eliminate or minimize the probability that a vehicle impacting them will ramp and roll over. To modify the standard guardrail, the $\frac{5}{8}$-in diameter bolts are removed from the first five posts. With these bolts removed, the rail will drop to the ground if the turned-down terminal section is struck by a vehicle, which eliminates ramping of the vehicle. To hold the rail at its proper height [69 cm (27 in) in Texas] before and during a vehicle impact along the length of need, backup plates are bolted to the first five posts. The action of this modified guardrail terminal is simple. When a vehicle tire or bumper pushes down on the turned-down terminal, the rail drops from the first five posts, which allows the vehicle to pass over the rail. If the vehicle bumper impacts the rail on the length of need and pushes it laterally against the backup plates on the posts, the rail is held at its proper height and the vehicle is redirected. The test program included the four crash tests for longitudinal barrier terminals. All of the tests were successful, and no vehicles rolled over.

The steel flex-beam W-beam guardrail is used extensively on highways. In the late 1950s and early 1960s, the dangers of guardrail ends became apparent after

Figure 1. Standard bolted guardrail-to-post connection.



Note: 1 mm = 0.039 in.

spectacular accidents in which guardrail ends pierced and ran through vehicles. The remedy for this has been to turn down and bury the ends of the guardrail. This simple treatment eliminates the vehicle-piercing and impalement accident and, at the same time, anchors the guardrail so that it has the tensile strength necessary for effective vehicle redirection.

However, in the late 1960s, the California Division of Highways and the Southwest Research Institute conducted several crash tests (1, 2) on turned-down guardrail terminals and found that these ends can launch an impacting vehicle and cause it to roll over. Because of these crash tests, safer end treatments have been sought, and several alternatives have been developed (3), but even these have had certain deficiencies.

Because Texas has thousands of turned-down guardrail terminals, engineers at the Texas Transportation Institute and in the Texas State Department of Highway and Public Transportation have been seeking a relatively simple method to modify these terminals to eliminate or minimize the probability that a vehicle impacting on them will ramp and roll over. A relatively simple solution has been found.

MODIFIED TURNED-DOWN TERMINAL

The standard guardrail in Texas is made of 10 or 12-gauge steel flex beam and mounted 69 cm (27 in) high. It is fastened with $^{5}/_{8}$-in diameter steel bolts to either wood or steel posts, and blockouts for the rail are optional. In some of the older installations, there is an intermediate post at the midspan of the 7.6-m (25-ft) turned-down section and, in many installations, two 3.8-m (12.5-ft) post spacings are used at the beginning of the length of need.

The design chosen for modification and evaluation was a non-blocked-out guardrail mounted on 18-cm (7-in) diameter wood posts. This design, which is the most commonly used in existing installations, offers the greatest potential for cost-effective improvements. The standard bolted connection used in this design is shown in Figure 1.

The modifications of this design were designed to prevent the launching and rolling over of a vehicle that can result from its impact with the turned-down section. A number of modifications were proposed and analyzed. The design chosen for full-scale testing and evaluation is essentially that shown in Figure 2. The guardrail-to-post connection for the first five posts was modified as shown in Figure 3. A standard W-section backup plate 0.3 m (1 ft) long is fastened to the post with a standard $^{5}/_{8}$-in dimaeter bolt, but the continuous rail element is not connected by this bolt. The rail element nests in the backup plate and is lightly held in place by a clip made of 0.32 by 1.9-cm ($^{1}/_{8}$ by $^{3}/_{4}$-in), mild-steel strap 20 cm (8 in) long. This weak connection allows the rail to be depressed downward under a small vertical load.

With this construction, the rail will drop to the ground if the turned-down terminal is struck by a vehicle. This action eliminates the undesirable situation of the vehicle ramping and rolling over. The backup plates hold the rail at the proper height [69 cm (27 in) in Texas] before and during vehicle impacts along the length of need. These plates are 30 cm (12 in) long for posts 1 through 4 and 15 cm (6 in) long at post 5 where the first standard lap splice occurs. At post 1, the standard lap splice is modified by reversing the splice bolts and placing the nuts on the outside of the rail.

The action of this modified guardrail terminal is excitingly simple. When a vehicle tire or bumper pushes down on the turned-down terminal, the rail quickly drops from the first 5 posts, which allows the vehicle to pass over it without the violent ramping effect of a rigidly turned-down end. If the vehicle bumper impacts the rail at the length of need (or any other high point) and pushes it laterally against the backup plates on the posts, the rail is held at the proper height and the vehicle is redirected. The backup plate resists the downward force component of the turned-down terminal.

CRASH TEST RESULTS

Five full-scale, vehicle crash tests of the modified turned-down guardrail terminals were made between July 30 and August 24, 1976. The test conditions are summarized below (1 kg = 2.2 lb).

Test	Vehicle Mass (kg)	Impact Point
1	1024	Midpoint of turned-down terminal section
2	2068	Beginning of turned-down terminal section
3	2068	On length of need
4	1021	End of turned-down terminal section
5	2068	End of turned-down terminal section

The data taken from high-speed film are given in Table 1, and selected frames from the film are shown in Figures 4 through 11. The data taken from accelerometer measurements made with a 100-Hz, low-pass, maximum flat filter and the vehicle-damage classifications are given in Table 2.

Test 1

The guardrail installation evaluated in this test was a variation of the final design described above. In this installation, posts 2 and 4 (Figure 2) were omitted, and 15-cm (6-in) long backup plates were used on posts 1, 3, 5, 6, and 7. The remainder of the rail was installed as shown in Figure 1. This installation is shown in Figure 12.

Figure 2. Modified standard guardrail with turned-down terminal: bolts removed from posts 1 through 5.

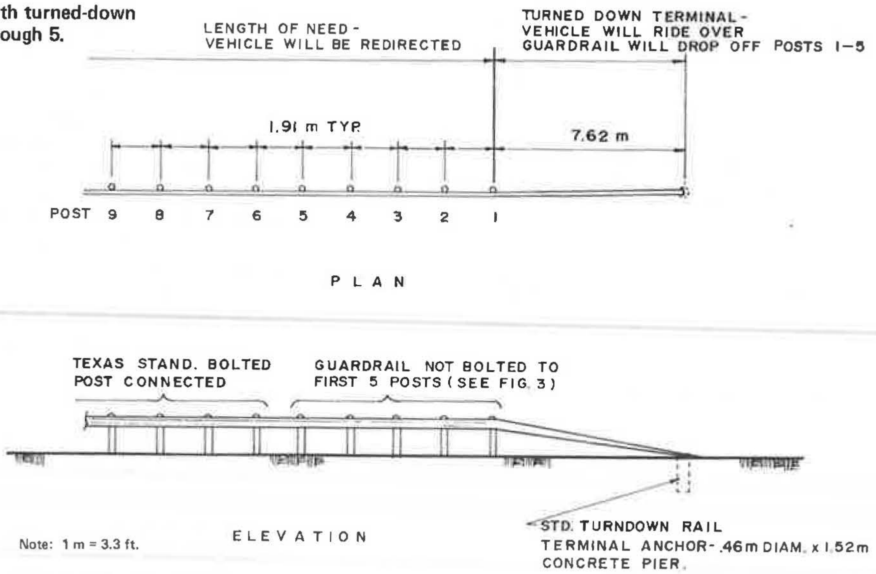
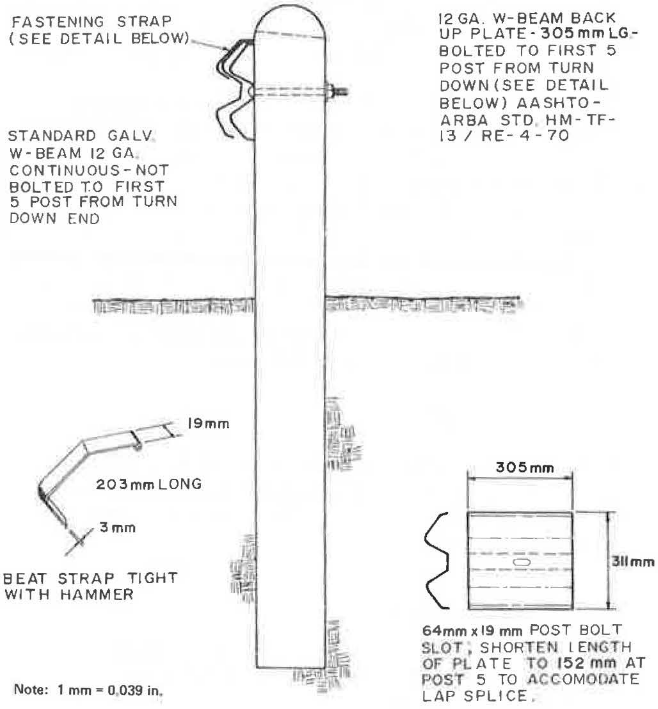


Figure 3. Modified guardrail-to-post connection.



In this test, a 1034-kg (2280-lb) 1971-model automobile impacted the turned-down terminal section of the guardrail at an angle of 17.5° and a speed of 101.7 km/h (63.2 mph). The point of impact was midway between the end anchor and the beginning of the length of need. On impact, the right front wheel of the test vehicle mounted the turned-down section. As the vehicle continued forward, the W-section disengaged from the backup plates and was pushed down. The vehicle rode over the rail, impacted the first post (breaking it near ground level), and continued upright on its path for about 100 m (330 ft) behind the guardrail. After crossing the guardrail, the vehicle was airborne for a short distance and then exhibited oscillatory roll motion to a maximum displacement of about 29°. The vehicle did not roll over, and the performances of the turned-down terminal section and the vehicle were considered good. The critical roll angle of such an automobile is about 53.4°. The damage to the vehicle and the guardrail is shown in Figures 13 and 14 respectively. One post and two 7.6-m (25-ft) pieces of W-section of the guardrail had to be replaced.

Test 2

The guardrail installation evaluated in this test was identical to that used in test 1, except that 0.32 by 1.9-cm ($^1/_8$ by $^3/_4$-in), mild-steel straps 20 cm (8 in) long were added at the guardrail-to-post connections having backup plates. This installation is shown in Figure 15.

In this test, a 2068-kg (4560-lb) 1970-model automobile impacted the guardrail at an angle of 27.5° and a speed of 88.8 km/h (55.2 mph) at a point 30 cm (1 ft) upstream of the beginning of the length of need. The behavior of the guardrail was similar to that in test 1 in that the rail was depressed and the vehicle rode over it. There was some partial redirection (yaw displacement) of the vehicle during its interaction with the rail. The vehicle was partially airborne after leaving the rail and exhibited oscillatory roll motion to a maximum displacement of approximately 45°. The critical roll angle for such a heavy automobile is about 60°. The vehicle did not roll over, and the performance of the turned-down terminal section was considered acceptable because the actual point of impact was 30 cm (1 ft) upstream of the beginning of the length of need. At this location of the impact point, redirection is not a necessary requirement. The damage to the vehicle and guardrail is shown in Figures 16 and 17 respectively. The first post of the guardrail was displaced laterally, and the second post was displaced and fractured. It was necessary to replace both posts and two pieces of W-section.

The original objective of this test had been to impact the guardrail along the length of need and obtain a redirection of the vehicle. The vehicle, however, pushed down the rail and rode over it without rolling over. There are two apparent reasons for this: (a) The right front bumper of the vehicle actually impacted the rail 30 cm (1 ft) upstream of post 1 on the terminal section and not on the length of need and (b) the rail was only 61 cm (24 in) high at post 1 because of the repairs after test 1 (Figure 14) and, consequently, the bumper of the

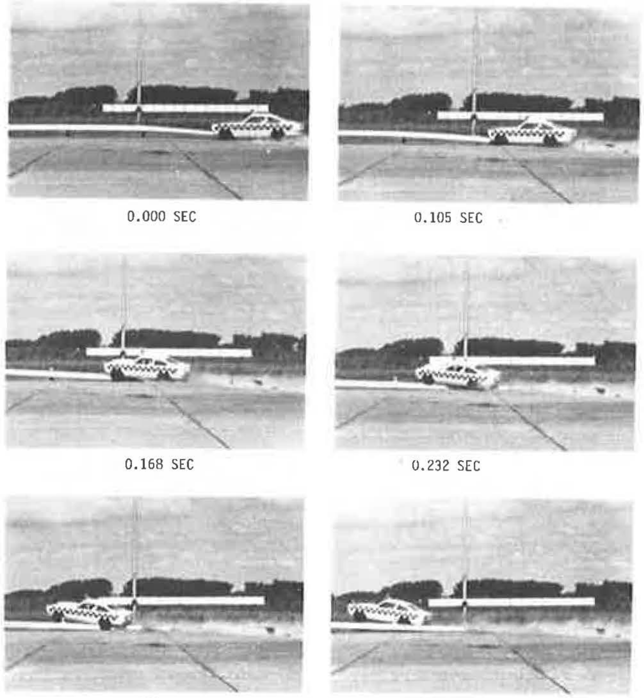
Table 1. Results of film data of crash tests.

	Speed (km/h)			Angle From Rail Line (°)		Time (s)		Barrier Displacement (m)			Distance to Parallel (m)		Avg Deceleration, Displacement (*g*)		
Test	Initial	Parallel	Final (departure)	Impact	Departure	To Parallel	Of Contact	Dynamic	Residual	Stopping Distance	Longitudinal	Lateral	Longitudinal	Lateral	Total
1	101.7	–	–	17.5	–	–	0.383	KGD[a]	–	–	–	–	–	–	–
2	88.8	–	–	27.5	–	–	0.447	KGD[a]	–	–	–	–	–	–	–
3	94.4	59.0	58.1	25	17.5	0.298	0.685	0.76	0.70	–	6.46	1.86	2.3	2.4	4.1
4	47.9	–	–	3.5	–	–	0.893	KGD[a]	–	–	–	–	–	–	–
5	89.0	–	–	5.5	–	–	4.450	KGD[a]	–	57.3	–	–	0.54	–	–

Note: 1 km/h = 0.6 mph; 1 m = 3.3 ft.

[a] KGD = knocked guardrail down.

Figure 4. Sequential photographs of test 1 (side view).

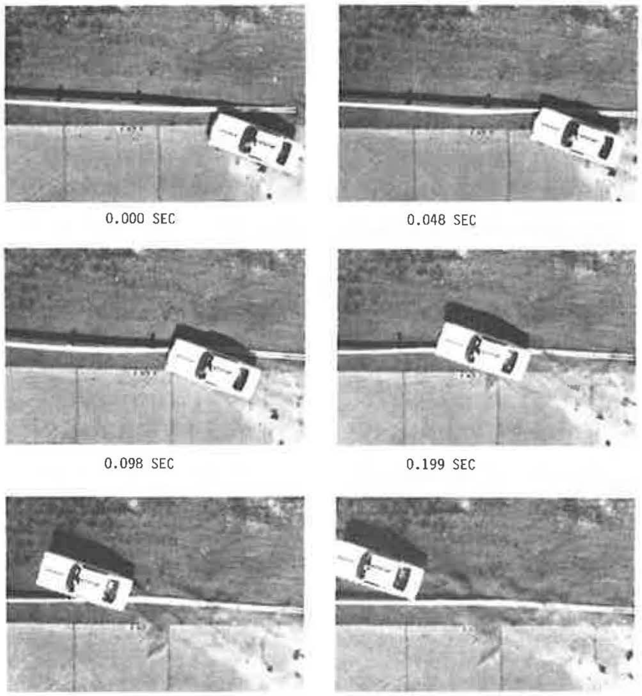


0.000 SEC 0.105 SEC

0.168 SEC 0.232 SEC

0.309 SEC 0.373 SEC

Figure 5. Sequential photographs of test 1 (overhead view).



0.000 SEC 0.048 SEC

0.098 SEC 0.199 SEC

0.324 SEC 0.400 SEC

automobile was above the terminal and pushed it down. Several modifications were made in the installation and in the conduct of test 3 to eliminate these problems. Test 2 was still considered a success in that the vehicle struck the terminal section, pushed it down, and rode over it without rolling over.

Test 3

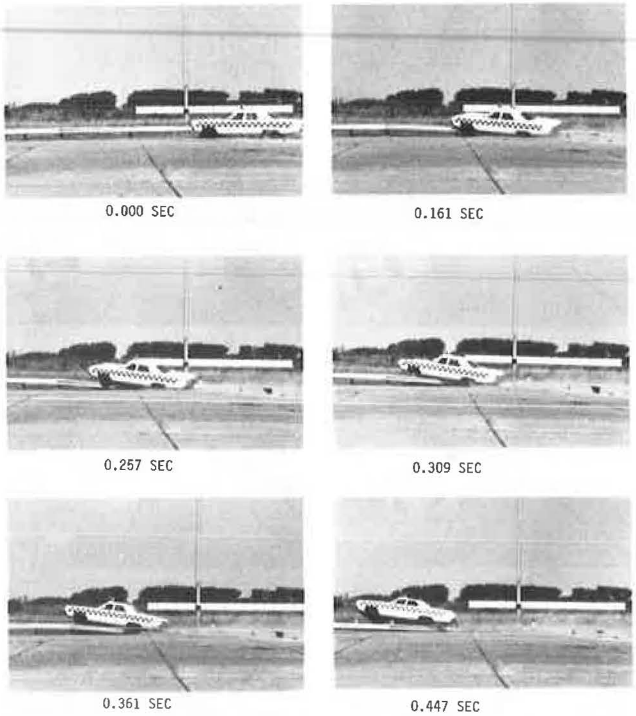
As a result of the behavior of the guardrail and the vehicle in test 2, several changes were made in the guardrail design and in the test procedure.

1. The point of impact of the vehicle was moved 30 cm (1 ft) downstream from post 1 into the length of need.
2. In the repair of the guardrail and terminal section, care was taken to ensure that the rail was 69 cm (27 in) high at post 1. During installation, the end piece of rail was bolted to post 1 and pretwisted through an angle of slightly more than 180° to put a permanent 90° twist in it. This gave a neater fit and closer dimensional tolerance after the bolt was removed from post 1 and the backup plates were installed. The installation at post 1 is shown in Figure 18.
3. The length of the backup plates was increased from 15 cm (6 in) to 30 cm (12 in) and posts 2 and 4 were added to make the guardrail post spacing uniformly 1.9 m (6.25 ft). This strengthened and stabilized the guardrail and increased vehicle redirection when the rail was impacted on the length of need.

These slight modifications should not affect the results of test 1 in which the vehicle engaged the terminal section and pushed it down and the guardrail rotated away from the posts and backup plates.

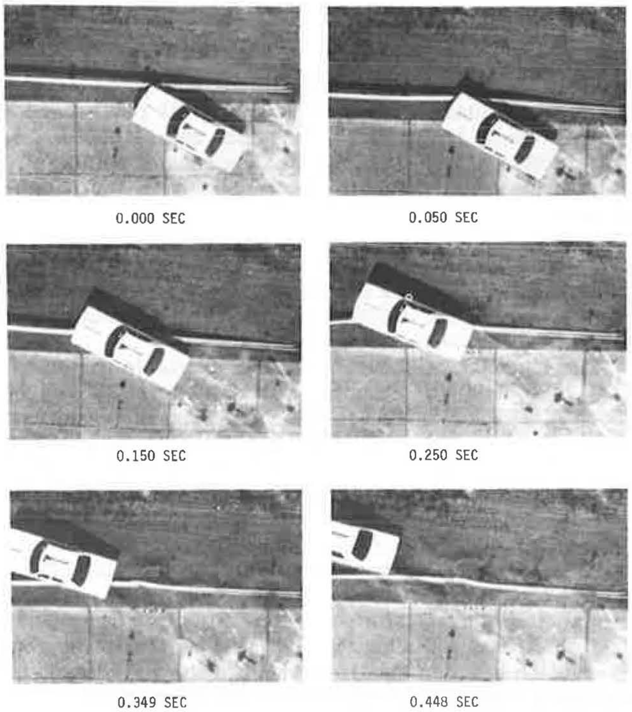
The installation shown in Figure 19 was impacted by a 2037-kg (4490-lb) automobile at an angle of 25° and a speed of 94.4 km/h (58.7 mph). The point of impact was 30 cm (1 ft) downstream of the beginning of the length of need. The guardrail contained and redirected the vehicle without adverse pocketing and snagging, and therefore its performance was good. The vehicle left the rail at an angle of 17.5° and a speed of 58.1 km/h (36 mph). Damage to the front wheel caused the vehicle to follow a curved path and return to the guardrail with another impact at a point approximately 61 m (200 ft) downstream. During the redirection, there was some interaction between the front wheel of the vehicle and the guardrail posts, but there was no snagging effect. The damage to the vehicle and guardrail is shown in Figures 20 and 21 respectively. The rail remained nested in the backup plates and at the intended height. Post 3 was broken off at ground level and post 2 and 4 were bent back. The repairs to the guardrail consisted of replacing one post and one 7.6-m (25-ft) section of flex beam. This test was considered very successful.

Figure 6. Sequential photographs of test 2 (side view).



0.000 SEC
0.161 SEC
0.257 SEC
0.309 SEC
0.361 SEC
0.447 SEC

Figure 7. Sequential photographs of test 2 (overhead view).



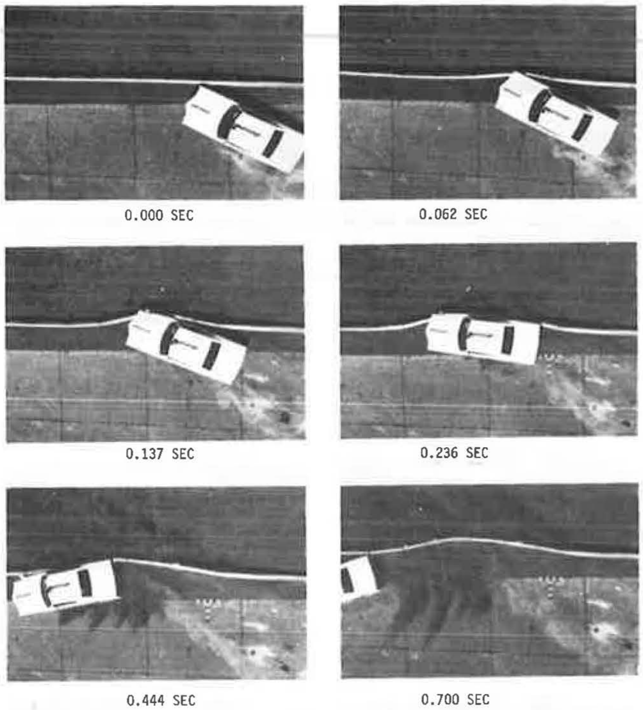
0.000 SEC
0.050 SEC
0.150 SEC
0.250 SEC
0.349 SEC
0.448 SEC

Test 4

The guardrail installation for this test was identical to that used in test 3.

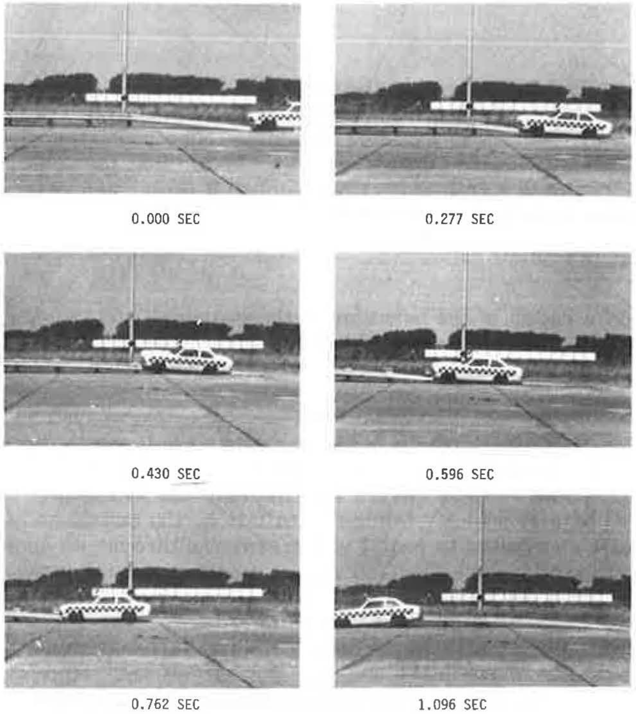
Test 4 was essentially a head-on test of the terminal section and a small vehicle. The 1021-kg (2250-lb) 1971-model automobile impacted the terminal section at a negative angle of 3.5° and a speed of 47.5 km/h (29.5

Figure 8. Sequential photographs of test 3 (overhead view).



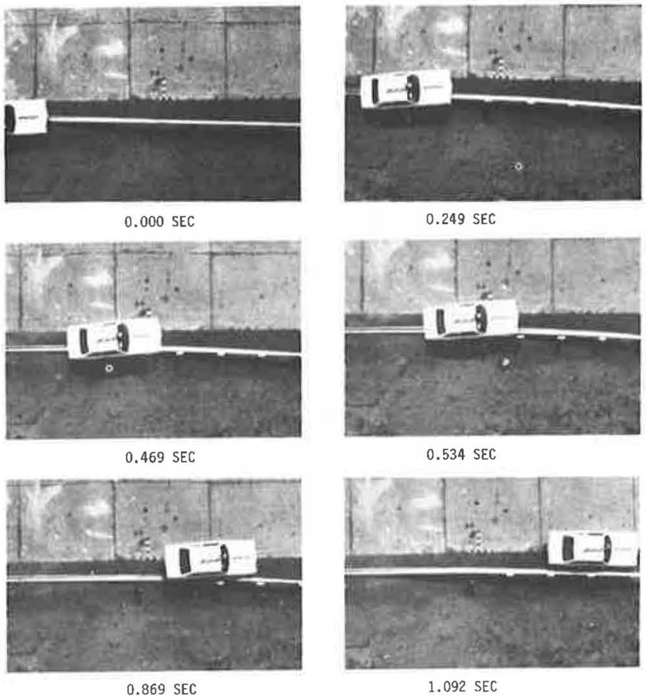
0.000 SEC
0.062 SEC
0.137 SEC
0.236 SEC
0.444 SEC
0.700 SEC

Figure 9. Sequential photographs of test 4 (side view).



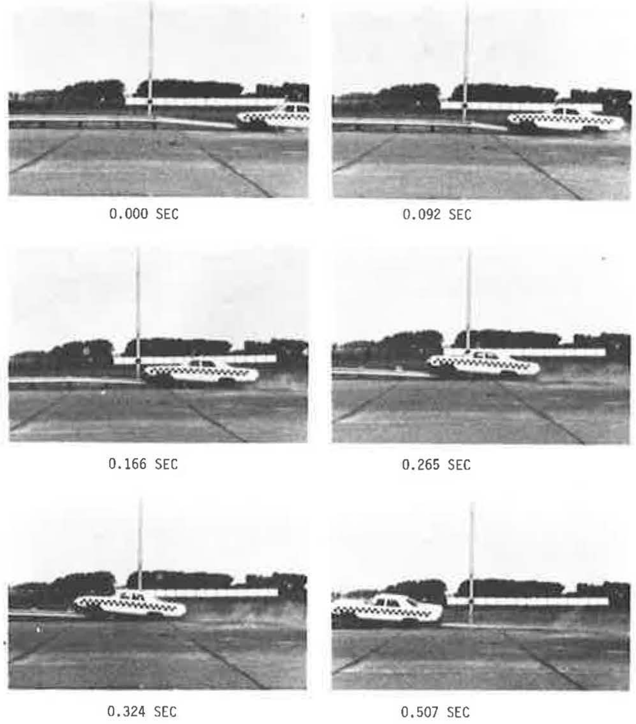
0.000 SEC
0.277 SEC
0.430 SEC
0.596 SEC
0.762 SEC
1.096 SEC

Figure 10. Sequential photographs of test 4 (overhead view).



0.000 SEC
0.249 SEC
0.469 SEC
0.534 SEC
0.869 SEC
1.092 SEC

Figure 11. Sequential photographs of test 5 (side view).



0.000 SEC
0.092 SEC
0.166 SEC
0.265 SEC
0.324 SEC
0.507 SEC

Table 2. Results of accelerometer data and vehicle-damage classifications of crash tests.

	Max Avg 0.050-s Deceleration (*g*)		Avg Deceleration Over Contact Time (*g*)		Peak Deceleration (*g*)		Vehicle-Damage Classification		
Test	Longitudinal	Lateral	Longitudinal	Lateral	Longitudinal	Lateral	TAD[a]	SAE[b]	Remarks
1	2.1	1.8	0.75	0.65	10.0	11.0	FC-2	12FECW1	Rode over terminal section; no rollover
2	2.1	1.5	0.65	0.55	5.7	6.9	FR-1	01RYMS1	Rode over terminal section and rail; no rollover
3	5.1	7.9	1.2	2.2	14.1	21.1	FRQ-5	01RDEE2	Smooth redirection
4	1.8	1.0	0.2	0.2	4.5	4.4	RF-1	01FFEE1	Rode over terminal section; no rollover
5	3.0	1.2	0.57	nil	5.3	5.5	FC-3	12FCEN8	Straddled rail for 57 m (188 ft) before stopping

[a] TAD = traffic-accident data project.

[b] SAE = Society of Automotive Engineers.

Figure 12. Terminal before test 1.

Figure 13. Vehicle after test 1.

mph). On contact with the turned-down terminal section, the vehicle began to ride up. The rail disengaged from the backup plates and was depressed. The right front corner of the bumper of the vehicle impacted the first post and split it vertically. The vehicle continued forward, rode over the rail, returned to the roadway side of the guardrail, and finally came to rest against the rail. The position of the vehicle and the damage to the guardrail are shown in Figure 22.

The performance of the rail in this test was very good. The maximum average 0.050-s longitudinal deceleration was less than 1.8 *g* and all peak values were less than 4.5 *g*. The damage to the vehicle is shown by Figure 23. The repairs to the rail consisted of replacing one post and one backup plate. (Before this test, it had been anticipated that the vehicle would remain astraddle of the rail and knock down several posts, but this did not happen.)

Figure 14. Guardrail and terminal after test 1.

Figure 15. Guardrail and terminal before test 2.

Figure 16. Vehicle after test 2.

Figure 17. Guardrail and terminal after test 2.

Figure 18. Post 1 with backup plate and metal clips before test 3.

Figure 19. Guardrail and terminal before test 3.

Figure 20. Vehicle after test 3.

Figure 21. Guardrail after test 3.

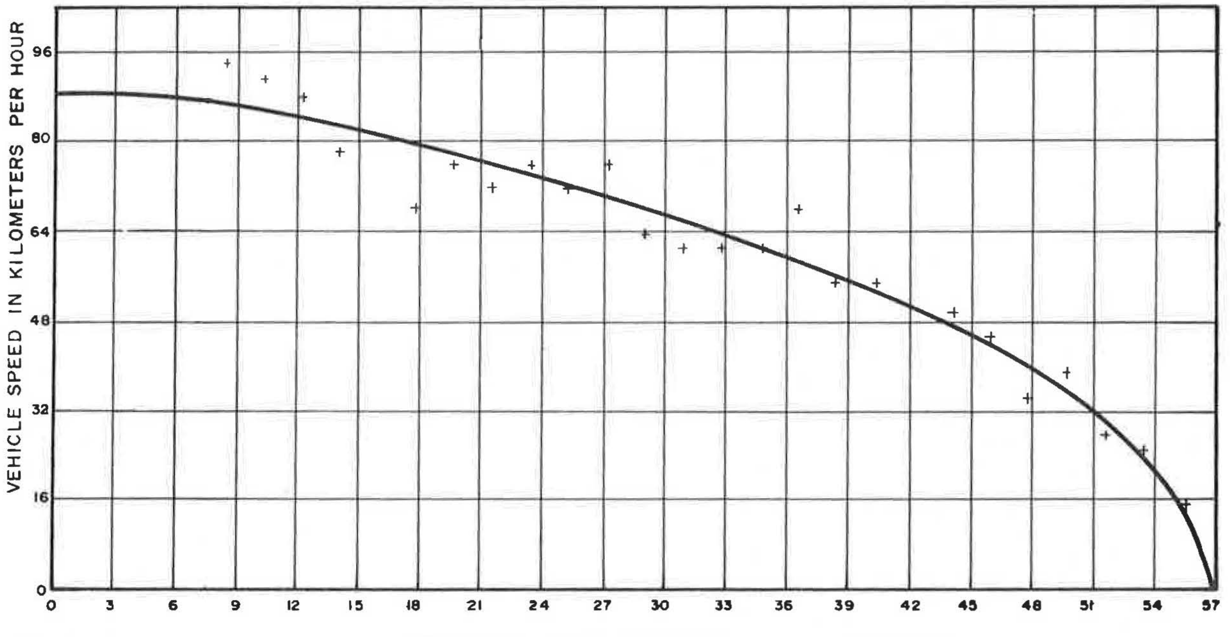
Figure 22. Position of vehicle and damage to guardrail after test 4.

Figure 23. Vehicle after test 4.

Figure 24. Position of vehicle and damage to guardrail and terminal after test 5.

Figure 25. Vehicle after test 5.

Figure 26. Vehicle speed versus distance from beginning of guardrail (test 2189-4).



Note: 1 m = 3.3 ft; 1 km/h = 0.62 mph.

Test 5

The guardrail installation for this test was identical to that used for tests 3 and 4.

In this (essentially head-on) test, a 2068-kg (4560-lb) 1970-model automobile impacted the turned-down terminal section at an angle of 5.5° and a speed of 89.0 km/h (55.3 mph). On impact, the vehicle depressed the rail in a manner similar to that of the vehicle in test 4. It then continued astraddle of the rail, exhibiting a low-amplitude, oscillatory pitching and rolling motion, and eventually stopped on the top of the rail approximately 57 m (188 ft) from the end anchor. The position of the vehicle and the damage to the guardrail are shown in Figure 24. Twenty-six posts were split, broken, or bent over. The maximum average 0.050-s longitudinal deceleration was approximately 3 g, and the peak values were all below 5.5 g. The extensive damage to the undercarriage of the vehicle is shown in Figure 25. The repairs to the guardrail consisted of replacing 26 posts and eight 7.6-m (25-ft) sections of rail.

In some installations, e.g., bridge abutments and other fixed obstacles, the approach length of guardrail may be less than the 57 m (188 ft) traveled by this test vehicle. If a vehicle became captive at the end of the rail, it could impact the obstacle from which it was being protected. To obtain some indication of the potential severity of such impacts, a curve of velocity versus distance traveled by the test vehicle was developed from the documentary movie film and is given in Figure 26. To avoid the possibility of such head-on impacts, guardrail terminals should be flared away from the roadway.

CONCLUSIONS

A relatively simple method of modifying the turned-down ends of guardrail terminals has been developed. This method should eliminate or greatly minimize the probability that a vehicle impacting them will ramp and roll over. The hardware used in the design are either standard guardrail components or items that are readily available commercially.

Successful crash tests were conducted as described in the NCHRP Recommended Procedures (4). In three of the tests, the vehicle impacted the modified terminal section, depressed the rail, and rode over it without rolling over.

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Design of Barrel Trailer for Maximum Collision Protection

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This report describes a Texas type, steel-barrel trailer developed by the Highway Wayside-Equipment Research Office and the Equipment Office of the Ontario Ministry of Transportation and Communications. When attached to a sign truck, the trailer provides maximum crash protection for occupants of impacting automobiles in rear collisions at impact speeds of up to 100 km/h (60 mph). This means that restrained occupants will survive such collisions without serious injuries. (Crash protection is expected to be somewhat less for angular impacts.) The trailer can be towed at traveling speed and backed up at slow speed on a closed traffic lane. For full protection of a working crew, the trailer should be attached to the kind of heavy sign truck that is presently used in maintenance operations. Although the trailer is an extra piece of equipment and requires special driver skill in backing, it is recommended for use on high-speed highways with high traffic volumes, expressways, or freeways. The trailer reduces impact severity considerably and is more effective than nontrailer attachments at impact speeds of 80 km/h (50 mph) or less. The first prototype tried on the road has been involved in two collisions. In both instances, the impact attenuation and redirectional capabilities of the steel barrels were sufficient to prevent injuries. The connections between the barrel modules, which were originally welded, now consist of bolts and hard rubber spacers and are still being developed.

In September 1974, a car traveling at an estimated speed of 130 km/h (80 mph) struck the rear of a sign truck that was protecting a night crew who were making illumination measurements. The driver of the car was killed instantly, and the truck was severely damaged (Figure 1).

Although there were warning systems in operation and the driver was exceeding the legal speed limit, the case nevertheless dramatically illustrates the need for greater protection from such collisions for the driving public. The solid backs and rigid bumpers of the trucks now in use are road hazards of the greatest severity. Moreover, in the following year, from December 1974 to November 1975, there were 34 collisions with Ministry of Transportation and Communications sign trucks in