Crash Test Evaluation of the Vehicle-Attenuating Terminal (V-A-T)

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An energy-absorbing guardrail terminal (end treatment) was designed and partially developed in a Federal Highway Administration contract at Southwest Research Institute (SwRI). The development of this device was completed by Syro Steel Company under contract to SwRI. The vehicle-attenuating terminal (V-A-T) described in this paper is a unique energy-absorbing design to attenuate vehicle energy in end-on impacts. The basic principle of this design uses the tearing of metal between slots specially punched in W-beam sections to absorb the energy. The design also provides essential anchorage for guardrail impacts downstream of the terminal. This paper reports the results of a crash test series conducted according to the terminal test requirements of NCHRP Report 230 with 1,800-lb (820-kg) and 4,500-lb (2040-kg) test vehicles. Results of the crash test series indicate compliance with Report 230, and recommendations for V-A-T use are given.

An energy-absorbing guardrail terminal was conceived and partially developed in an FHWA contract *(1)* at Southwest Research Institute (SwRI). Because the development was not completed in the FHWA contract, Syro Steel Company approached FHWA and SwRI about the possibility of completing the development under a Syro contract to SwRI. An agreement was reached and this report describes the completion of the development of the new guardrail terminal.

Before work on this project began, a meeting among Syro, FHWA, and SwRI personnel was held to finalize the design with a goal of cost reduction and simplicity. As a result of this meeting, several significant changes were made in the design details from the previously mentioned FHWA contract effort.

The purpose of this project was to demonstrate the performance of the vehicle-attenuating-terminal (V-A-T) system in a series of crash tests. NCHRP Report 230 *(2)*, the currently recognized recommendated procedures for highway safety appurtenances, requires four tests to qualify a barrier terminal. This test program was conducted by using the procedures of Report 230, and the results are compared with the criteria recommended in this report.

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FINDINGS

The V-A-T system (Figures 1 and 2) is designed to provide adequate anchorage for W-beam guardrail systems and to be a crashworthy energy-absorbing system when struck end-on by errant vehicles. The V-A-T is a three-stage system utilizing energy-absorbing beam elements, breakway timber posts, and a cable anchorage system.

The first stage uses flat beam elements to facilitate cable anchorage hardware, and the second and third stages use standard W-beam elements with slots installed along the splice bolt lines in the corrugations. Sequential energy absorption for end-on impacts is achieved as follows.

Stage 1: The vehicle readily collapses the leading nose element and fractures Post 1, releasing the anchor cable. The flat plate elements (Span 1) continue to collapse.

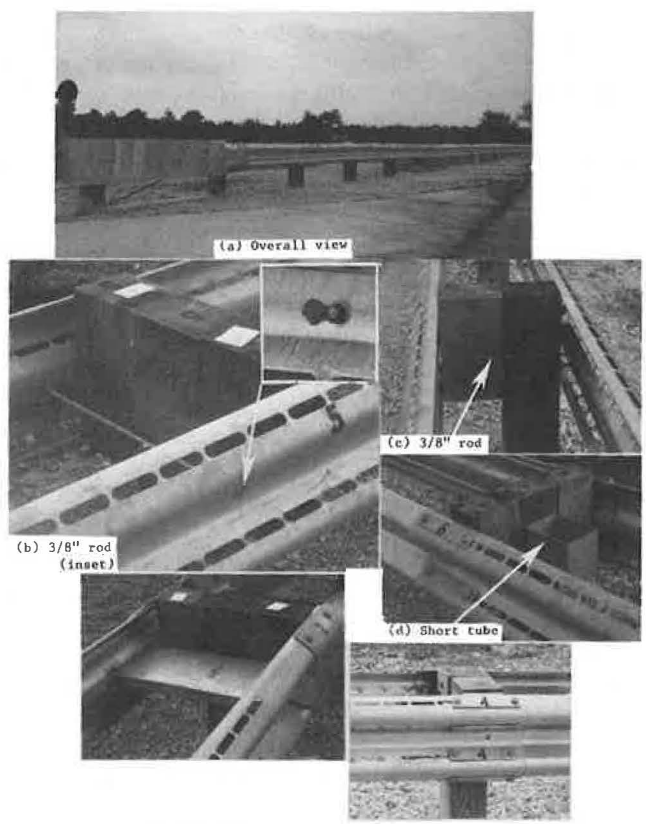

FIGURE 1 V-A-T before test.

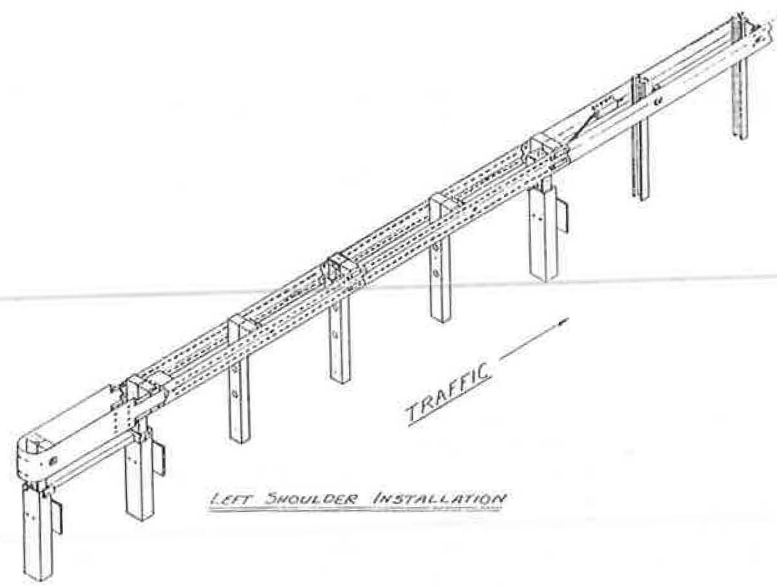

FIGURE 2 Design drawing, V-A-T system.

Stage 2: After the first span beams have collapsed, strips between the second beam (12-gauge W beam) slots are forced through the splice bolts at a predetermined force level; Post 2 is fractured shortly after this stripping begins and later Post 3 fractures before all the 12-gauge strips separate.

Stage 3: After all the strips in the 12-gauge beams (Spans 2 and 3) are stripped, stripping of the 10-gauge beam (Spans 4 and 5) begins, and Posts 4 and 5 fracture as the vehicle continues into the system.

Staging of the system is such that the 1,800-lb (820-kg) car at 60 mph (95 km/hr) is only involved in the first three spans; more severe impacts, including the 4,500-lb (2040-kg) car at 60 mph, require that the third stage be activated. The three stages are sequentially activated, so damage is related to the severity of the impact. A functional description of all V-A-T components is given in Table 1.

CRASH TEST FINDINGS

Six crash tests were conducted in this project. One of the four terminal tests was repeated twice before satisfactory results were obtained. The crash test series as summarized in Table 2 is briefly described in this paper; detailed test reports including the data may be found in the final report of this project *(3)*.

Test Syro-1

Test Syro-1 evaluated the V-A-T for the 60-mph end-on condition with the 4,500-lb car centered on the nose of the terminal. As shown in Figure 3, the vehicle struck the nose and was brought to rest in contact with the barrier after 27 ft (8.3 m) of travel. All values measured during the test were in conformance with the recommended requirements of NCHRP Report 230 with the exception of the 16-*g* ridedown acceleration; however, this value is below the 20-*g* threshold value. Photographs taken after the test are shown in Figure 4.

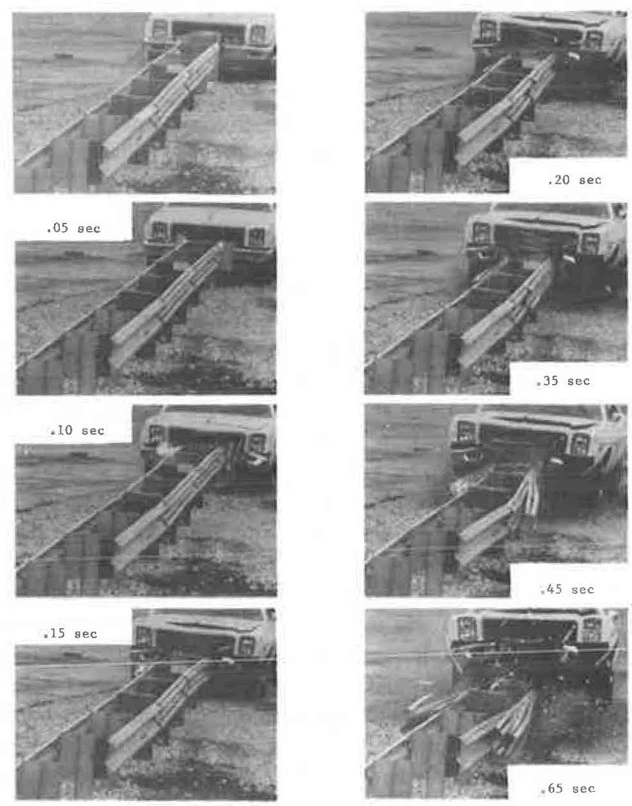

FIGURE 3 Test Syro-1 sequential photographs.

Test Syro-2

Test Syro-2 evaluated the anchorage strength of the terminal with a 4,500-lb car at 60 mph in a 25-degree angle impact. This length-of-need for the V-A-T begins at Post 4, which is the initial impact point for this test. As shown in Figure 5, the vehicle's impact was at Post 4 and it was smoothly redirected

TABLE 1 FUNCTIONAL DESCRIPTION OF V-A-T COMPONENTS

Component	Description	Function
Nose	10-ga flat beam w/curved end	Provide collapsible connection for anchor cable.
Cable anchorage 1	3/4-in. cable assembly w/hardware	Anchors traffic side beam for downstream impacts.
Cable anchorage 2	3/4-in. cable assembly w/hardware	Anchors opposite traffic side beam for third stage reaction; not needed for median barrier V-A-T.
Posts 1 and 2	6x8 breakaway wood post/ steel tube	Provide cable anchorage and beam support. Steel tubes increase soil resistance.
Strut	Steel channel w/tabs	Couples steel tube foundations at Posts 1 and 2 to react cable anchorage forces.
Posts 3 and 5	6x8 breakaway wood posts (2 holes)	Provides lateral beam support; not connected to beams. As tested, used full length posts w/2 breakaway holes.
Spreader channel	Sheet metal weldment	Couples the slotted W-beams behind Post 2 to promote uniform beam translation for off-center end-on impacts.
Post 4	6x8 breakaway wood posts	Provides beam support; upstream end of span 4 beam is attached to this member.
Beam-Spans 2 and 3	12-ga slotted W-beam	Absorbs energy of vehicles impacting end-on by tearing of strips between slots - second stage.
Beam-Spans 4 and 5	10-ga slotted W-beam	Absorbs energy of vehicles impacting end-on; a higher force level than the 12-ga beam of stage 2.
5/8 dia splice bolts	Hex head bolt w/ unthreaded shank	This bolt transfers tension for downstream impacts and causes tearing of strip for end-on impacts. Unthreaded shank prevents excessive clamping of splice joints, thus facilitating telescoping action
Plate washer	Rectangular washer used at splice bolts	Holds splice together as stripping action occurs.
3/8-in. dia rods	Threaded rod or bolt w/ threads at both ends	Holds beam sections together downstream of Posts 3 and 5.
Short steel tube	6x8 box beam	Placed upstream at Posts 4 and 6 to separate 3/8-in. dia rods from assembly after required translation has occurred.
Post plate	1/2-in. thick steel plates	Placed at upper part of Post 4 to prevent splitting when end-on impacts occur. This is the only post that is connected to a beam between Posts 2 and 7.

TABLE 2 SUMMARY OF V-A-T CRASH TESTS

Test No.	Syro-1	Syro-2	Syro-4	Syro-6
Report 230 Test No.	41	40	44	45
Barrier	V-A-T	V-A-T	V-A-T	V-A-T
Test Vehicle	1978 Dodge	1978 Dodge	1980 Honda	1980 Honda
Gross Vehicle Weight, lb	4400	4340	1804	1840
Impact Speed (film), mph	59.3	60.0	60.6	60.6
Impact Angle, deg	0.5	24.4	16.0	0.9
Impact Duration, sec	0.68	0.71	0.26	0.42
Maximum Deflection				
Dynamic	27 ft	3.2 ft	0.5 ft	17.4
Permanent	25 ft	2.1 ft	0.1 ft	16.0
Exit Angle, deg				
Film	did not exit	-17.2	-3.6	29.3
Yaw Rate Transducer	did not exit	not avail	-2.7	28.6
Exit Speed, mph				
Film	did not exit	34.9	50.7	-1.4
Accelerometer	did not exit	not avail	51.8	-2.3
Maximum 50 msec Avg Accel (film/accelerometer)				
Longitudinal	-4.9/-8.8	-3.6/-5.6	-2.9/-3.1	-8.0/-9.8
Lateral	0.2/-1.8	-3.9/-5.7	-5.6/-8.0	-4.0/2.6
Occupant Risk, NCHRP Report 230+ (film/accelerometer)				
ΔV long., fps (30)	24.5/22.6	n/a	12.9/7.9	30.4/27.6
ΔV lat, fps (20)	++	n/a	18.8/21.6*	-7.5/-5.6
Ridedown Acceleration, g's (accelerometer)				
Longitudinal (15)	-16.3*	n/a	++	-16.9*
Lateral (15)	5.4	n/a	-6.6	5.7
NCHRP Report 230 Evaluation (Table 6)				
Structural Adequacy	passed (C,D)	passed (C,D)	passed (C,D)	passed (C,D)
Occupant Risk	passed (E,F*)	passed (E)	passed (E,F*)	passed (E,F)
Vehicle Trajectory	passed (H)	passed (H,I)	passed (H)	passed (H,I**)

+ Numbers in parentheses are recommended values for NCHRP Report 230.
++Occupant did not travel the flail distance.
* Higher than recommended (Report 230, Table 8) but lower than threshold values (Report 230, Table 6)
**See Conclusions in text.
n/a - not applicable.

as desired. This test met the criteria of NCHRP Report 230. Photographs after the test are shown in Figure 4.

Test Syro-3

Test Syro-3 evaluated the V-A-T for the 1,800-lb car end-on test at 60 mph with a 15-in. (38-cm) offset (centerline of car to centerline of barrier). The actual offset at impact was 17.5 in. (44.5 cm) and resulting performance of the system was not as desired because only one side of the span two-slotted beams was actuated in the strip-tearing mode. The vehicle spun away from the barrier after only 4 ft (1.2 m) of beam had "stripped." Analysis of the data was suspended pending a decision on retest in light of the extreme offset dimension.

Test Syro-4

Test Syro-4 evaluated the terminal for the NCHRP Report 230 test specifying impact of an 1,800-lb car midway between the terminal end and the length-of-need at 60 mph and a 15-degree angle. As shown in Figure 6, the vehicle's impact was midway between Posts 2 and 3, and it was smoothly redirected. Test values measured were in conformance with NCHRP Report 230, as described in Table 2; photographs after the test are shown in Figure 4.

Test Syro-5

A decision to repeat the planned test conditions of Syro-3 was made. A similar result occurred in this test and a design

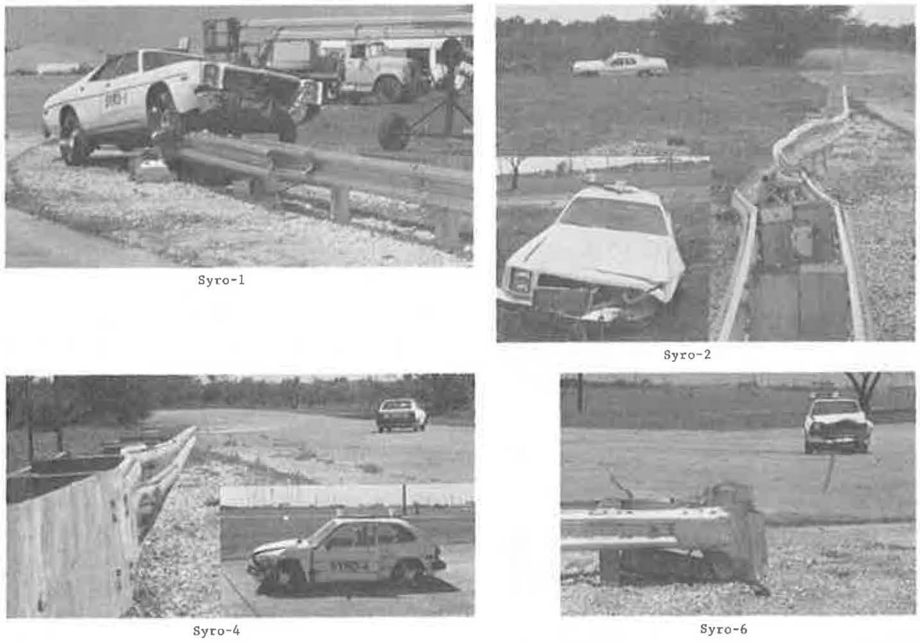

FIGURE 4 After-test photographs, Tests Syro-1, Syro-2, Syro-4, Syro-6.

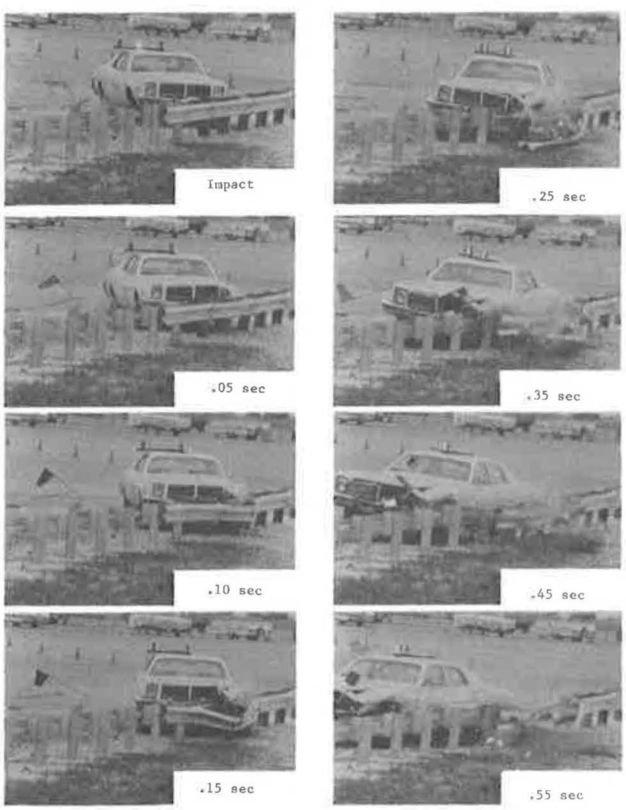

FIGURE 5 Test Syro-2 sequential photographs.

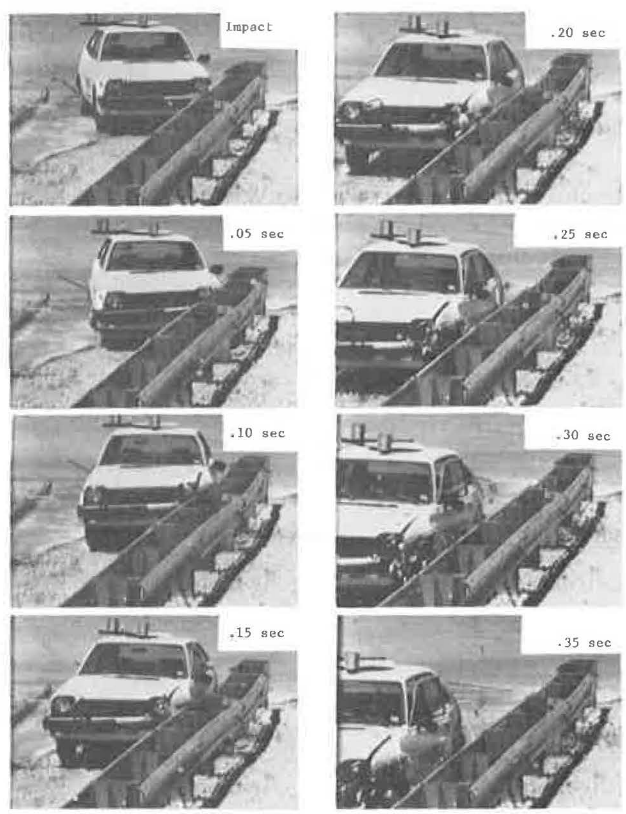

FIGURE 6 Test Syro-4 sequential photographs.

modification was indicated. Specifically it was noted that the off-center impact was causing a differential translation of the Span-2 beams because of the lack of vehicle contact with the far-side beam. A spreader channel as shown in Figure 1 and described in Table 1 was designed to couple the beams and promote uniform translation in cases where only one beam was essentially in contact with the vehicle.

Test Syro-6

The spreader channel was installed before this test; all other details were identical to those used in previous tests. The 1,800-lb vehicle struck the nose of the terminal at 60.6 mph (97.6 km/hr) and 15 in. (38 cm) offset (from centerline of nose toward the traffic side). As shown in Figure 7, the test vehicle struck the nose and began yawing as the first two stages were

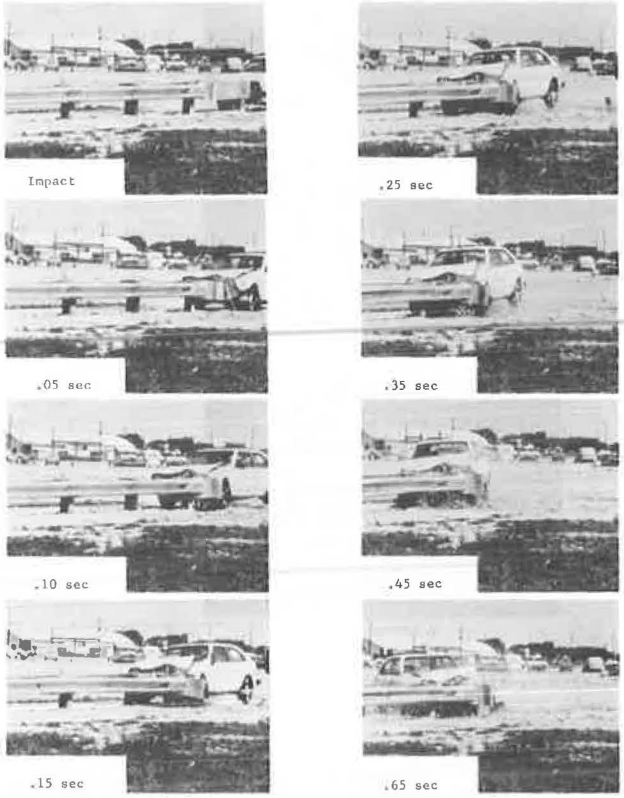

FIGURE 7 Test Syro-6 sequential photographs.

essentially consumed. The vehicle was brought to a stop in contact with the barrier; elastic spring in the system pushed the car away from the barrier when the yaw angle was 29.3 degrees. The occupant risk criteria for longitudinal and lateral ΔV-values were in compliance with NCHRP Report 230. The maximum ridedown acceleration of 16 *g* was greater than the 15-*g* recommended value but below the 20-*g* threshold value. Vehicle trajectory values did not conform with NCHRP Report 230 guidelines; this is discussed in a following section. Photographs after the test are shown in Figure 4.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

On the basis of the findings of this project, the following conclusions are drawn.

1. The V-A-T system as evaluated in this project essentially passed the criteria of NCHRP Report 230. Unlike other terminals that redirect vehicles with uncertain and often unstable postimpact trajectories, the V-A-T captures vehicles striking end-on and absorbs the energy of the vehicle in a controlled manner.

2. Trajectory values as given in NCHRP Report 230 guidelines (*2*, Table 6) have proved difficult to meet, particularly in off-center impacts with the 1,800-lb car. An energy-absorbing terminal or crash cushion with a reasonable force level (in order to minimize length) will cause the rear wheels of the minicar to lose traction, and when this is coupled with the off-center impulse, severe yawing of the vehicle often results. This makes it difficult to meet Table 6 trajectory requirements H and I when the offset is to the traffic side. The performance of Test Syro-6 is considered to be as good as can be expected without lowering the energy-absorbing force to a level that would require an unreasonably long terminal or crash cushion.

3. The placement of the spreader channel for Test Syro-6 was considered an essential modification with desired performance demonstrated. The addition of this member is not considered important to the results of previous tests, and thus retesting is not considered necessary. Regarding this matter, the following observations are made:

a. The spreader channel was not in the impact zone for Tests Syro-2 and Syro-4; no potential effect on either of these tests is considered to exist.

b. The function of the spreader channel is to promote the uniform translation of two beams when only is loaded. Because the beams moved uniformly in Syro-1, no significant change in the barrier performance is envisioned with the addition of the spreader.

Recommendations

On the basis of the findings of this test series, the V-A-T system as described in Figures 1 and 2 is recommended for immediate application as an experimental device.

Use of steel foundation tubes at all posts in the V-A-T length could be specified at sites where frequent impacts and damage repair are expected. Post removal and replacement are facilitated by the use of these steel tubes.

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3. M. E. Bronstad and J. B. Mayer, Jr. *Crash Test Evaluation of the Vehicle Attenuating Terminal (V-A-T)*. Final Report, Southwest Research Institute Project 06-1004. Southwest Research Institute, San Antonio, Tex., May 1986.