



U.S. Department
of Transportation
Federal Highway
Administration

April 9, 2007

400 Seventh St., S.W.
Washington, DC 20590

In Reply Refer To: HSSD/CC-98

Mr. Dallas James
Managing Director
Armorflex Ltd.
P.O. Box 303 177
North Harbor, Auckland, 1330, New Zealand

Dear Mr. James:

Thank you for your letter requesting the Federal Highway Administration's (FHWA) acceptance of your company's Armorwire Terminal End (ATE) for Wire Rope Barrier Systems for use on the National Highway System (NHS). Accompanying your letter were reports of crash testing conducted by the University of Canterbury and video of the tests. You requested that we find this device acceptable as a Test Level 3 (TL-3) and TL-4 device for use on the NHS under the provisions of the National Cooperative Highway Research Program (NCHRP) Report 350 "Recommended Procedures for the Safety Performance Evaluation of Highway Features."

Introduction

The FHWA guidance on crash testing of roadside safety hardware is contained in a memorandum dated July 25, 1997, titled "INFORMATION: Identifying Acceptable Highway Safety Features."

A description of the ATE follows:

Trigger Release Head and Post

The trigger release head is fabricated from hot rolled steel galvanized after fabrication in accordance with AS/NZS 4680. The hot rolled steel complies with the following specifications; ASM A36, AS 3678-250, JISG3101 – SS400, and BS4360 – 43A. The trigger release head is attached to the top of the first post (same section as Steel Line Post) by a weld around the back side of the post only. This head effectively joins the two cables that are attached to the ground strut to the three cables forming the barrier.

Steel Line Posts

These posts are fabricated from 42 x 97 x 3 mm flat sided oval "Yard rail." Standard grade for this section is: Ptd/NOPC:AS 1163. Three notches are cut into the sides of the posts to hold and retain the three cables. The posts are 1220 mm long and Hot Dip Galvanized after cutting in accordance with AS/NZS 4680. The cable heights are 530, 640 and 750 mm above ground level.

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Plastic socket

The sockets are molded from high density polyethylene (HDPE) and form a 350 mm deep socket in the concrete foundation that is 5 mm larger than the post outside dimensions.

Plastic post cap and cable retaining strips

The cap and retaining strips are molded from PVC with UV stabilizers. The cap is fitted into the top of the posts with two 350 mm long strips of plastic protruding down the inside of the post to help retain the cables.

Barrier Cables

The three cables are constructed using 19 mm 3 x 7 strand galvanized cable, pre-stretched by 35 percent. The cable specification is DSR Galvanized 320, lay – RHRL. The cables are tensioned to a nominal 25 kN at an ambient temperature of 21 degrees Celsius. The cable heights are 530, 640 and 750 mm above ground level. The cable breaking strain has an ultimate tensile capacity of 110 kN.

Cable Fittings

All cable terminations are achieved with self-swaging fittings. These fittings consist of three tapered "jaws" that fit inside a tapered casing and a tail piece that is screwed into the rear of the casing. These fittings have been failure tested to 240 kN.

Cable Adjustment

The cable tension is adjusted using turnbuckles fabricated from 10 x 20 mm low tensile steel side arms, and welded to 30 mm thick end "washers."

Terminal End Anchor Foundation

The anchor point foundation consists of three 300 x 1000 mm deep holes at 1000 mm centers filled with 25 MPa concrete. The rebar cages are constructed from D12 rebar, complete with M24 studs, and are inserted into the concrete so that the ground strut can be bolted to the protruding studs. The ground strut connects all three foundations together to form one unit.

Ground Strut

The ground strut is fabricated from RHS and Angle sections of mild steel made to match the dimensions of the anchor foundations. The mild steel conforms to the following specifications ASTM A36, AS 3678-300, JISG3101 – SS400, BS4360 - 43A.

Terminal Cables

The terminal cables are two 2000 x 19 mm wire rope assemblies complete with M24 x 345 mm HDG swage fittings. The wire rope is 19 mm 6x9/9/1 IWRC Galvanized.

Line Post Foundation

The line post foundations consist of 300 x 750 mm deep holes at various centers filled with 25 MPa concrete (see figure 2.1.1). One D10 x 175 diameter rebar ring is placed in each foundation 100 mm down from the top. One plastic socket is pushed into the concrete so that the top lip of the socket sits flush with the top of the concrete.

Fasteners

The ATE is assembled with standard galvanized fasteners. The bolts and studs are galvanized Grade 4.6 with matching nuts and heavy washers.

The key element of the ATE terminal end is the trigger post assembly. This assembly connects the terminal cables and the barrier cables by placing the adjustment nuts on the rope fittings into slots located in the trigger release head. When a vehicle impacts on the end of the barrier, the two terminal cables projecting from the ground strut are forced downward out of their slot in the terminal head. This allows the trigger post to bend backward under the tension of the barrier cables, thereby releasing the tension from the barrier. The trigger release head is welded to the back of the trigger post allowing the head to detach on impact and ensuring the barrier cables are fully released when a vehicle impacts at the end of the terminal.

Testing

Three different test article installations were used for the Armorflex ATE test program.

The installation details are as follows:

Test 057053302 (Test 3-30) and Test 057053351 (Test 3-35)

The test article installation for these two tests consisted of 68 meters of barrier installed in prepared and existing soils at the high speed vehicle test facility, running parallel to the main test track. The first 38 meters of the barrier was installed standard soil conforming to the NCHRP 350 specifications. The last 30 meters of the installation was located in the in situ soil. All of the impacts occurred on posts installed in the prepared ground. The upstream end of the installation was fitted with the ATE, and the downstream end fitted with a plain ground anchor that did not form part of the product test.

Test 057053321 (Test 3-32)

The test article installation for this test consisted of 35.5 meters of barrier installed in prepared and existing soils at the high speed vehicle test facility, and laid out at an angle of 15 degrees to the main test track. The first 25.5 meters of the barrier was installed in the prepared ground. The last 7 meters of the installation was located in the in situ soil. All posts were installed with 2 metre post spaces. The distance between posts 2 and 3 (not counting the trigger post) was 2.96 meters and the gap between posts 4 and 5 was 3.9 meters. All of the impacts occurred on posts installed in the prepared ground. The upstream end of the installation was fitted with the ATE, and the downstream end fitted with a plain ground anchor that did not form part of the product test.

Test 057053392 (Test 3-39)

The test article installation for this test consisted of 15.8 meters of barrier installed in prepared soils at the high speed vehicle test facility, and laid out at an angle of 20 degrees to the main test track, with the terminal end located at the downstream end. The entire length of barrier was installed in standard soil conforming to the NCHRP 350 specifications. All posts were installed with approximately 2 metre post spaces. The three cables at the upstream end of the installation were attached to a section of concrete median barrier, acting as an anchor. The concrete anchor was remote from the point of impact on the terminal end and barrier.

Design Changes During Test Program

There were several design changes made to the Armorflex ATE during the testing program. The NCHRP 350 allows changes to be made to a test article during the testing program provided good engineering judgment indicates that the design change would not adversely affect the outcome of a test that has already been passed. Under these circumstances it is considered reasonable not to repeat that test.

The chronological order of testing was as follows - Test 057053392, Test 057053321, Test 057053351, Test 057053302. All of the design changes were made after Test 057053321 and before Test 057053351. The design changes were as follows:

Trigger Post - To prevent the vertical strain plates (Part 1 of figure 2.1.2) of the trigger post spreading during impact, the top of the trigger post was notched and a M8 x 75 mm grade 4.6 bolt was fitted. The anchor cable connection to the trigger post was modified by slotting the top plate to allow the common washer for the two front cables to sit higher relative to the ground strut cable plates (Part 4 of figure 2.1.2). This increases the bearing area for the washer and allowed a retainer pin to be fitted to prevent the cables dropping when the terminal end is assembled.

This modification was implemented as it was felt that the vertical strainer plates may bend under high impact loads on the wire rope barrier. No damage was observed to the vertical strainer plates of the trigger head in the test completed prior to the modification.

Ground Strut - The ground strut was changed from a 75 x 50 x 5mm RHS with the cables placed on top to a strut manufactured from 50 x 100 x 5mm RHS and angle with the cables located inside of the RHS. The angles at which the cables come up from the strut to the trigger post were not altered. This design change was made to reduce the height of the strut and simplify its construction.

Post 1 'J' Bolts - Line post was modified from a notched post to a plain post with M8, 4.6 grade, J bolts fitted to capture the barrier cables. The expectation was that the modification would prevent the released cable fittings from being carried along with the impacting vehicle in end-on impacts. This modification did not prevent the release of the cable fittings, as evidenced by Test 057053302. All production barriers will use standard line post for post 1.

Cable Retaining Strips – The retaining strips are used as part of the top cap fitted to the top of the line posts. The strips 340 mm long and are made from white, 1 mm thick PVC plastic. The strips act to both cover the notches in the posts, and to help prevent the cables from "unzipping" in side impacts.

The design changes would have no adverse effect on the tests completed before the changes were made and no tests were repeated following the design changes.

The Test Data Summary Pages are attached to this letter for reference.

Findings

The Armorflex ATE was judged to have satisfied the NCHRP 350 evaluation criteria for Test Level 3 when installed on Armorflex Armorwire wire rope barrier embedded in a standard soil foundation. Test 057053302 (3-30) allowed controlled penetration of the vehicle and brought it to rest, while incurring localized damage near the occupant compartment. The ATE gated cleanly for tests 057053321(3-32) and 057053392 (3-39). For Test 057053392 (3-39) the vehicle impact point was closer to the end of the terminal than is generally recommended, however developmental testing showed a design flaw that the reverse-direction test is supposed to expose. We concur that the impact point of the successful 3-39 test was appropriate. For Test 057053351 (3-35), the ATE successfully redirected the vehicle from the length of need.

You also requested that the Armorflex ATE be an acceptable terminal for other cable/wire rope systems where the number of cables, the cable heights and tension are the same as Armorwire. We concur in this request.

Although the barrier performed well under ideal test impact conditions the likelihood of passenger car underrides of any cable system may increase as the post spacing increases, particularly when the barrier is installed on non-level or slightly irregular terrain and the cables are not restrained from lifting at each post. Consequently, some transportation agencies have limited post spacing to approximately 6 m for cable barriers. The dynamic deflection of the barrier is likely to increase when it is installed along the convex sides of horizontal curves, and when distances between anchorages exceed the normal 100 m test length.

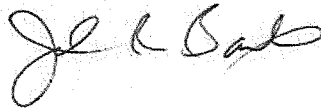
The results of the testing met the FHWA requirements and, therefore, the devices described in the various requests above and detailed in the enclosed drawings are acceptable for use on the NHS under the range of conditions tested, when proposed by a highway agency.

Please note the following standard provisions that apply to the FHWA letters of acceptance:

- Our acceptance is limited to the crashworthiness characteristics of the devices.
- Any changes that may adversely influence the crashworthiness of the device will require a new acceptance letter.
- Should the FHWA discover that the qualification testing was flawed, that in-service performance reveals unacceptable safety problems, or that the device being marketed is significantly different from the version that was crash tested, it reserves the right to modify or revoke its acceptance.
- You will be expected to supply potential users with sufficient information on design and installation requirements to ensure proper performance.
- You will be expected to certify to potential users that the hardware furnished has essentially the same chemistry, mechanical properties, and geometry as that submitted for acceptance, and that they will meet the crashworthiness requirements of the FHWA and the NCHRP Report 350.
- To prevent misunderstanding by others, this letter of acceptance, designated as number CC-98, shall not be reproduced except in full. This letter, and the test documentation upon which this letter is based, is public information. All such letters and documentation may be reviewed at our office upon request.

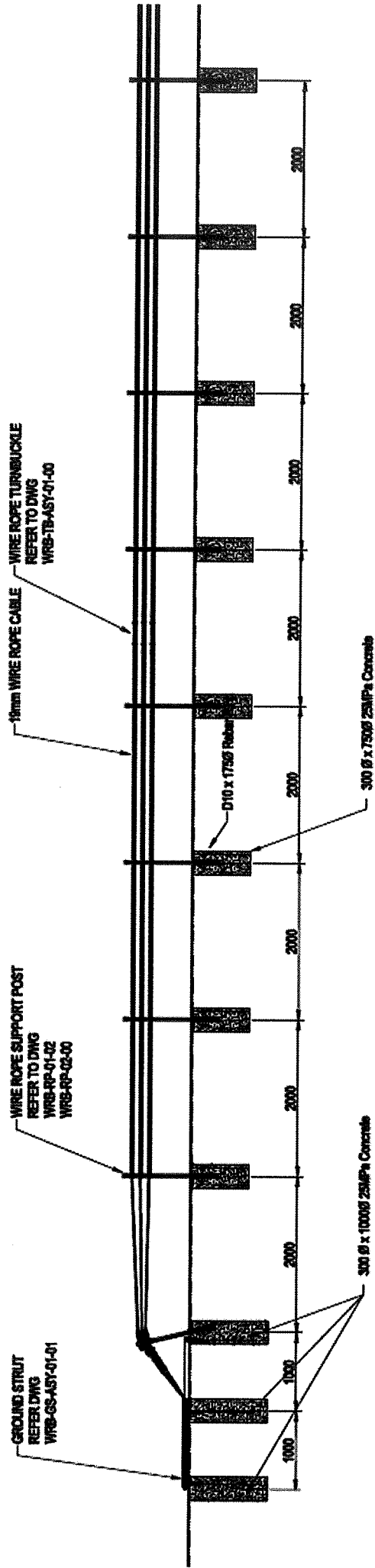
- The Armorwire ATE is a patented device and is considered "proprietary." The use of proprietary devices *specified by a highway agency* for use on Federal-aid projects must meet one of the following criteria: (a) it must be supplied through competitive bidding with equally suitable unpatented items; (b) the highway agency must certify that it is essential for synchronization with existing highway facilities or that no equally suitable alternative exists; or (c) it must be used for research or for a distinctive type of construction on relatively short sections of road for experimental purposes. Our regulations concerning proprietary products are contained in Title 23, Code of Federal Regulations, Section 635.411, a copy of which is enclosed.
- This acceptance letter shall not be construed as authorization or consent by the FHWA to use, manufacture, or sell any patented device for which the applicant is not the patent holder. The acceptance letter is limited to the crashworthiness characteristics of the candidate device, and the FHWA is neither prepared nor required to become involved in issues concerning patent law. Patent issues, if any, are to be resolved by the applicant.

Sincerely yours,

A handwritten signature in black ink, appearing to read "John R. Baxter". The signature is fluid and cursive, with the first letters of the first and last names being capitalized and prominent.

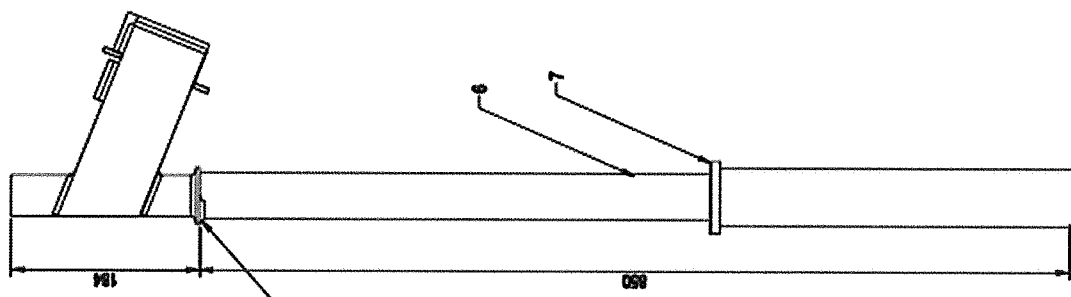
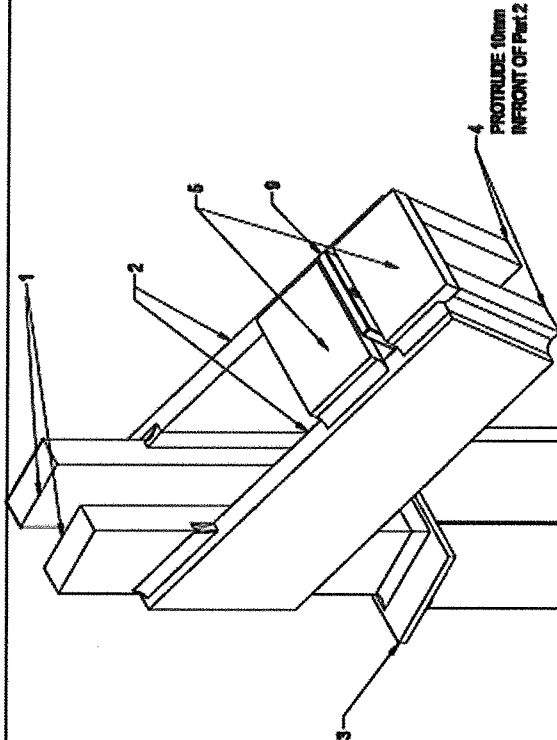
John R. Baxter, P.E.
Director, Office of Safety Design
Office of Safety

2 Enclosures



2		WRB-ASY-01-00	
WIRE ROPE BARRIER		DATE: 31/08/2005	
DESIGNED BY: [Blank]		DRAWN BY: [Blank]	
CHECKED BY: [Blank]		DATE: [Blank]	
APPROVED BY: [Blank]		DATE: [Blank]	
DESCRIPTION OF WORK		DATE	
3	ERECT FOUNDATIONS	NO	DU
2	INSTALL REBAR	NO	DU
1	CONCRETE POUR	NO	DU
0	COMPLETION	NO	DU





Trigger Post Assembly

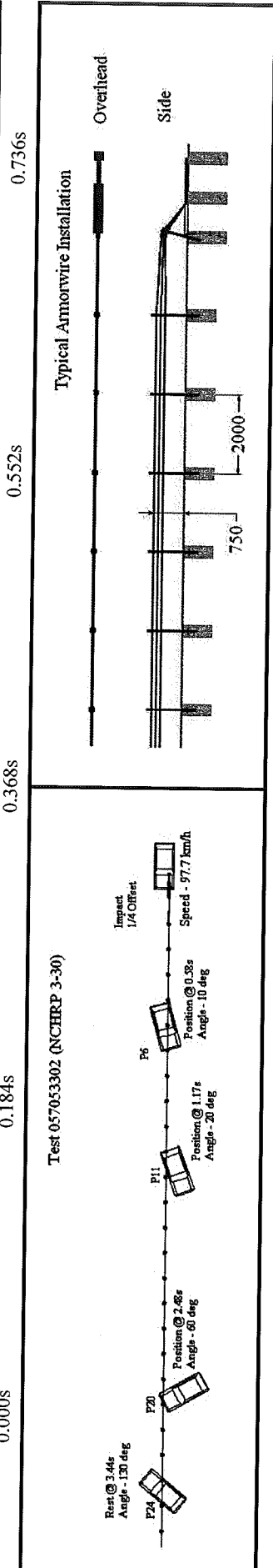
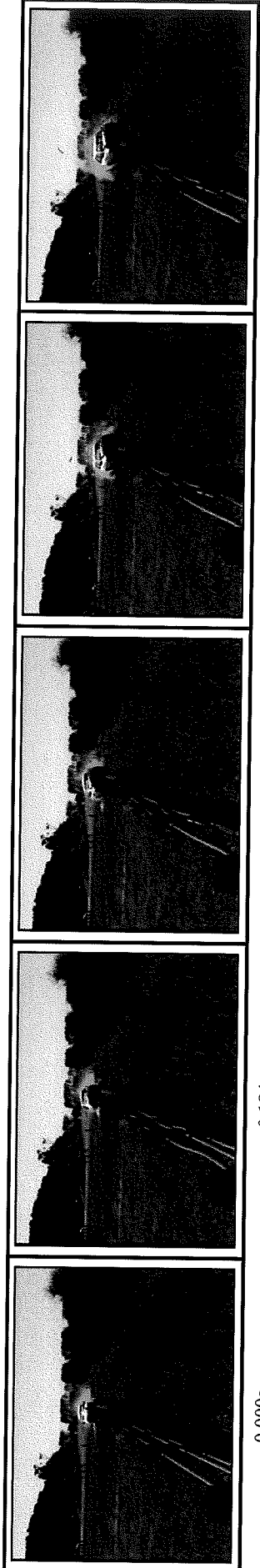
ITEM	PARTN	REV	MATERIAL	Quantity	DESCRIPTION	FINISH
1	WRB-TP-01	01	40 x 16 Flat Bar	2	VERTICAL STRAIN PLATE	
2	WRB-TP-02	01	75 x 10 ms Flat Bar	2	SIDE PLATE	
3	WRB-TP-03	01	105mm x 55mm x 4 ms Flat Bar	1	POST TRANSITION PLATE	
4	WRB-TP-04	01	40mm x 75mm x 16mm Flat Bar	2	GROUND STRUT CABLE PLATES	
5	WRB-TP-05	01	60mm x 40mm x 10mm Flat Bar	2	TOP PLATE	
7	WRB-RP-04	01	97 x 46 x 3 ms	1	POST	
8	WRB-RP-03	01		1	SOCKET	
9	WRB-CF-04	01	110 x 60 x 5mm Plinth	1		HOT DIPPED GALVANISED

WIRE ROPE BARRIER

TRIGGER POST ASSEMBLY

WRB-TP-ASY-01-01

REVISION	DATE	BY	CHK
2	20/01/2005	RE	DU
1		RE	DU
01		RE	DU



General Information

Test Agency..... Holmes Solutions Limited, NZ
 Test Designation..... NCHRP 350 Test 3-30
 Test No..... 057053302
 Date..... 15 March 2006

Test Article

Type..... Gaing wire rope barrier terminal end
 Name or Manufacturer..... Armorflex Ltd
 Installation Length..... 38 m
 Material or Key Elements..... Armorflex Armourwire Terminal End fitted to Armorflex Armourwire rope barrier.
 AASHTO 'standard' soil M147-64 (1990)

Soil Type and Condition

Test Vehicle Type..... Production Model
 Designation..... 820C
 Model..... 1992 Toyota Starlet -Solitel
 Mass (kg)..... 747
 Curb..... 823.5
 Test Inertial..... 76.5
 Dummy..... 900
 Gross Static.....

Impact Conditions

Speed (km/h)..... 97.7
 Angle (deg)..... 0

Exit Conditions

Speed (km/h)..... N/A
 Angle (deg)..... N/A

Occupant Risk Values

Impact Velocity (m/s)
 x-direction..... 3.4
 y-direction..... 1.0
 THIV (km/h)..... 12.1
 Ridedown Accelerations (g's)
 x-direction..... -7.0
 y-direction..... -6.3
 PHD (g's)..... 7.5
 ASI..... 0.36
 Max. 0.050-s Average (g's)
 x-direction..... -3.6
 y-direction..... 3.2
 z-direction..... 2.9

Test Article Deflections (m)

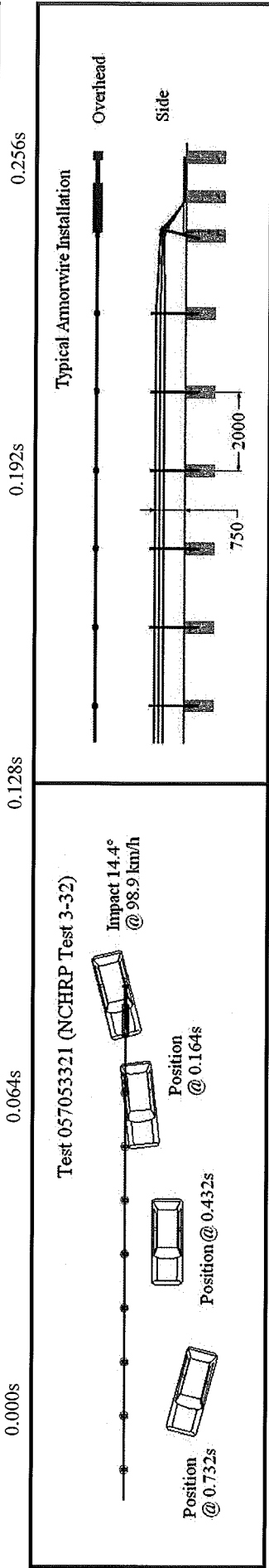
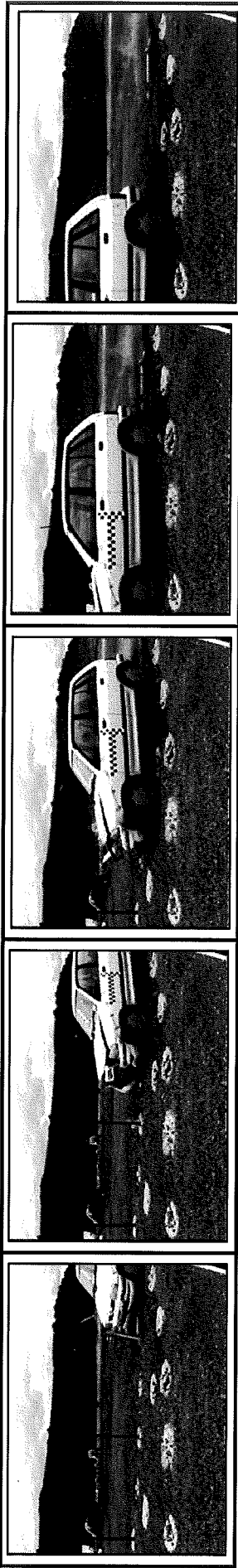
Dynamic..... N/A
 Permanent..... N/A

Vehicle Damage

Exterior..... 12-FD-5
 VDS..... 12FDEW2
 CDC.....
 Maximum Exterior Vehicle Crush (mm)..... 450mm
 Interior..... LFF0101000
 Max. Occ. Comptmt. Deformation (mm)..... 50

Post-Impact Behaviour

Max. Yaw Angle (deg)..... 135.8
 Max. Pitch Angle (deg)..... 11.3
 Max Roll Angle (deg)..... -14.2



Test 057053321 (NCHRP Test 3-32)

Impact 14.4°
@ 98.9 km/h

Position @ 0.164s

Position @ 0.432s

Position @ 0.732s

General Information

Test Agency Holmes Solutions Limited, NZ
 Test Designation NCHRP 350 Test 3-32
 Test No. 057053321
 Date 28 October 2005

Test Article

Type Gating wire rope barrier terminal end
 Name or Manufacturer Armorflex Ltd
 Installation Length 32.5 m
 Material or Key Elements Armorflex Armorwire Terminal End fitted to
 Armorflex Armorwire wire rope barrier.
 AASHTO 'standard' soil M147-64 (1990)

Soil Type and Condition

Test Vehicle

Type Production Model
 Designation 820C
 Model 1992 Ford Festiva
 Mass (kg) 820
 Curb 830.5
 Test Inertial 75
 Dummy 905.5
 Gross Static

Impact Conditions

Speed (km/h) 98.9
 Angle (deg) 14.4

Exit Conditions

Speed (km/h) 92.5
 Angle (deg) N/A

Occupant Risk Values

Impact Velocity (m/s)

x-direction 2.6
 y-direction -0.3
 THIV (km/h) 9.8
 Ridedown Accelerations (g's)

x-direction -2.5
 y-direction 2.5
 PHD (g's) 2.8
 ASI 0.27
 Max. 0.050-s Average (g's)

x-direction -2.2
 y-direction 1.4
 z-direction 1.9

Test Article Deflections (m)

Dynamic N/A
 Permanent N/A

Vehicle Damage

Exterior 12-FC-3
 VDS 12FCENI
 Interior 150mm
 Maximum Exterior AS0000000
 Vehicle Crush (mm) 0
 OCCI 160.4
 Max. Occ. Comptmnt. -13.5
 Deformation (mm) 14.2
Post-Impact Behaviour



0.000s

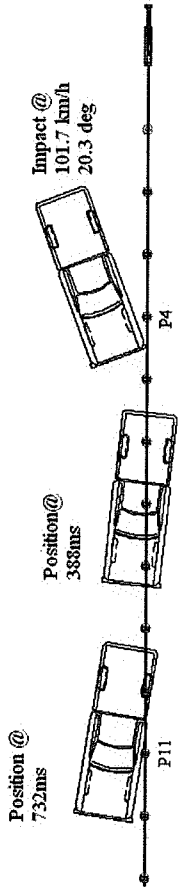
0.256s

0.512s

0.768s

1.024s

Test 057053351 (NCHRP Test 3-35)



General Information

Test Agency Holmes Solutions Limited, NZ
 Test Designation NCHRP 350 Test 3-35
 Test No. 057053351
 Date 17 February 2006

Test Article

Type Gating wire rope barrier terminal end
 Name or Manufacturer Armorflex Ltd
 Installation Length 68.8 m
 Material or Key Elements Armorflex Armorwire Terminal End fitted to
 Armorflex Armorwire wire rope barrier.
 AASHTO 'standard' soil M147-64 (1990)

Soil Type and Condition

Test Vehicle

Type Production Model
 Designation 2000P
 Model 1998 Chevrolet Cheyenne

Mass (kg) 2143
 Curb 2035
 Test Inertial N/A
 Dummy 2035
 Gross Static 2035

: Summary of results for test 057053351 (NCHRP 350 Test 3-35).

Impact Conditions

Speed (km/h) 101.7
 Angle (deg) 20.3

Exit Conditions

Speed (km/h) 73
 Angle (deg) 10

Occupant Risk Values

Impact Velocity (m/s)
 x-direction 3.3
 y-direction -4.2
 THIV (km/h) 17.2
 Ridedown Accelerations (g's)
 x-direction -4.6
 y-direction -6.6
 PHD (g's) 8.1
 ASI 0.54
 Max. 0.050-s Average (g's)
 x-direction -2.9
 y-direction 4.6
 z-direction 2.9

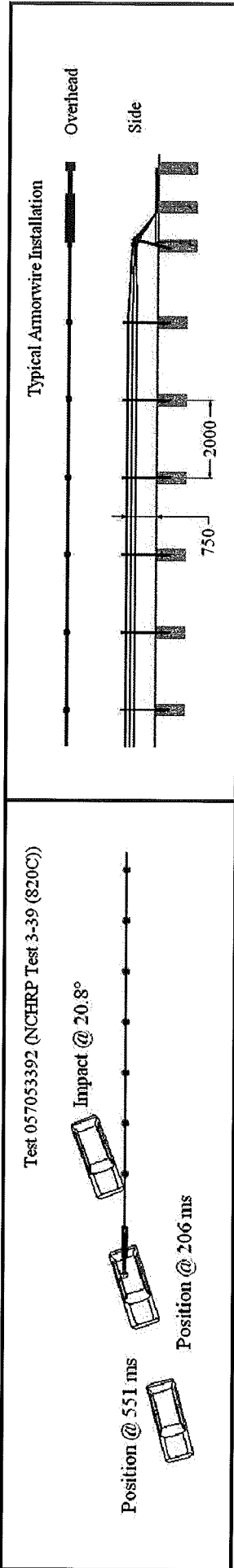
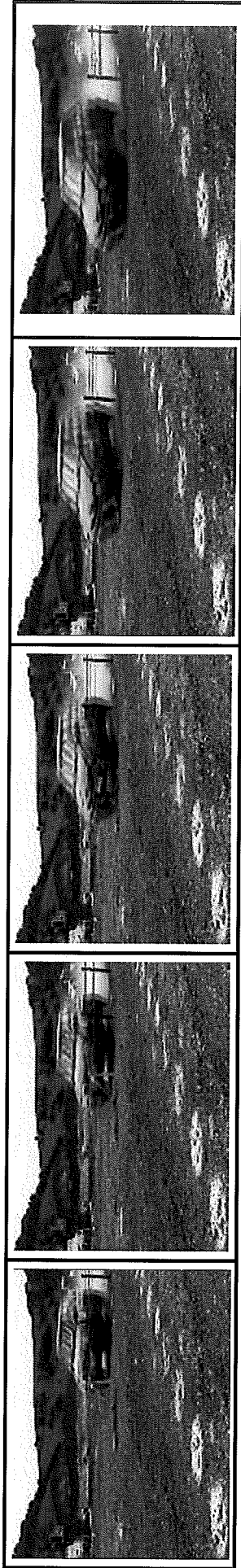
Test Article Deflections (m)

Dynamic 1.2
 Permanent ≈ 0

Vehicle Damage

Exterior VDS
 CDC 11-FL-3
 11FLEC2
 09LBKLW1

Maximum Exterior 250 mm
 Vehicle Crush (mm)
 Interior AS0000000
 OCCI
 Max. Occ. Compmtnt. 0
 Deformation (mm)
Post-Impact Behaviour
 Max. Yaw Angle (deg) 42.3
 Max. Pitch Angle (deg) -3.2
 Max Roll Angle (deg) -7.1



General Information					
Test Agency.....	Holmes Solutions Limited, NZ				
Test Designation.....	NCHRP 350 Test 3-39 (820C)				
Test No.	057053392				
Date.....	27 October 2005				
Test Article					
Type.....	Gating wire rope barrier terminal end				
Name or Manufacturer.....	Armorflex Ltd				
Installation Length.....	18.2 m				
Material or Key Elements.....	Armorflex Armourwire Terminal End fitted to Armorflex Armourwire rope barrier. AASHTO 'standard' soil M147-64 (1990)				
Soil Type and Condition.....					
Test Vehicle					
Type.....	Production Model				
Designation.....	820C				
Model.....	1991 Ford Festiva				
Mass (kg)	783				
Curb	804				
Test Inertial.....	75				
Dummy	879				
Gross Static.....					
: Summary of results for test 057053392 (Test 3-39)					

Impact Conditions					
Speed (km/h).....	101.5				
Angle (deg).....	20.8				
Exit Conditions					
Speed (km/h).....	90				
Angle (deg).....	-22				
Occupant Risk Values					
Impact Velocity (m/s)					
x-direction.....	7.2				
y-direction.....	-1.0				
THIV (km/h).....	26.5				
Ridedown Accelerations (g's)					
x-direction.....	-1.1				
y-direction.....	-1.6				
PHD (g's).....	1.6				
ASL.....	1.06				
Max. 0.050-s Average (g's)					
x-direction.....	-12.6				
y-direction.....	3.0				
z-direction.....	-1.6				
Test Article Deflections (m)					
Dynamic.....	N/A				
Permanent.....	N/A				
Vehicle Damage					
Exterior.....	VDS.....				11LQ-2
Interior.....	CDC.....				11FLENI
Maximum Exterior Vehicle Crush (mm).....	200 mm				
OCDI.....	AS0000000				
Max. Occ. Compart. Deformation (mm).....	0				
Post-Impact Behaviour					
Max. Yaw Angle (deg).....	11.3				
Max. Pitch Angle (deg).....	-4.4				
Max. Roll Angle (deg).....	4.0				