U.S. Department of Transportation
Federal Highway Administration

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

April 9, 2007

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.

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,

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

2 Enclosures

FHWA:HSSD:NArtimovich:tb:x61331:3/14/07
REVISED: 3/28/07
File: s://directory folder/nartimovich/CC98-ArmorwireATE-FIN.doc
cc: HSSD (Reader, HSA; Chron File, HSSD; N.Artimovich, HSSD; MMcDonough, HSSD)

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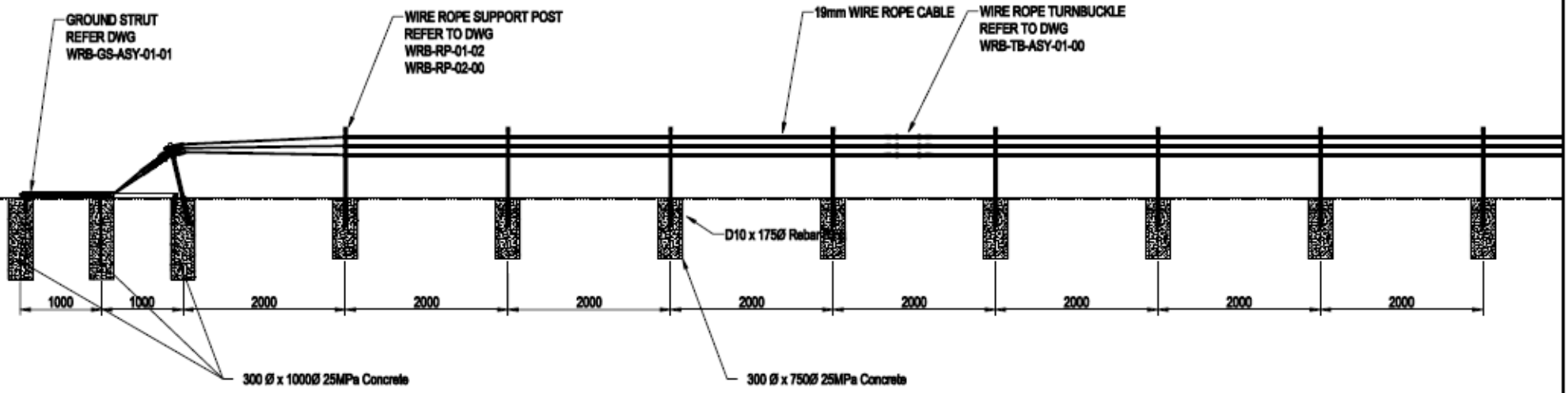
Sincerely yours,

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

2 Enclosures



REV	DESCRIPTION OF REVISION	BY	CHK	DATE
2	REVISED FOUNDATIONS	ND	DJ	20/01/2006
1	INITIAL RELEASE	ND	DJ	

ARMORFLEX New Zealand

WIRE ROPE BARRIER

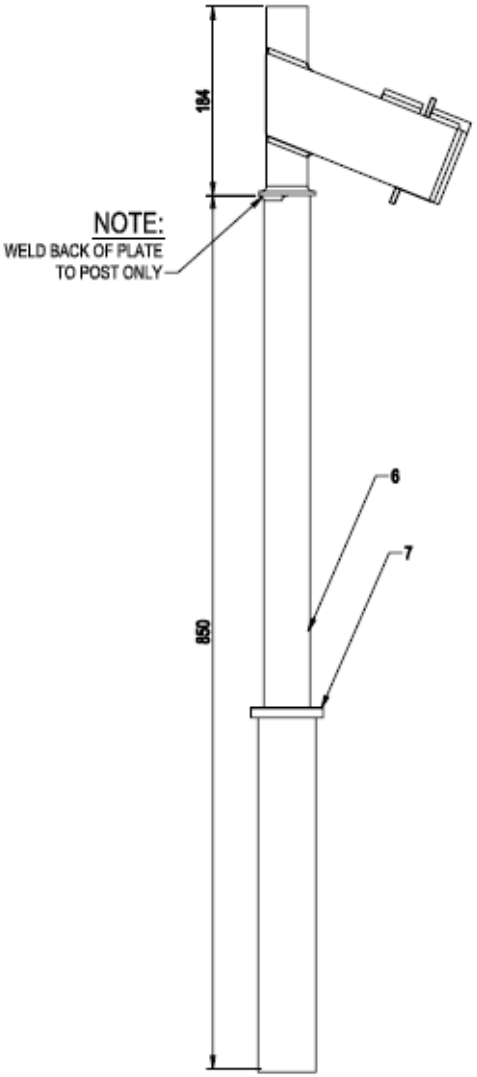
Designed: D. JAMES
Drawn: N.DUKE
Checked: D. JAMES
Approved:
Date: 31/08/2005

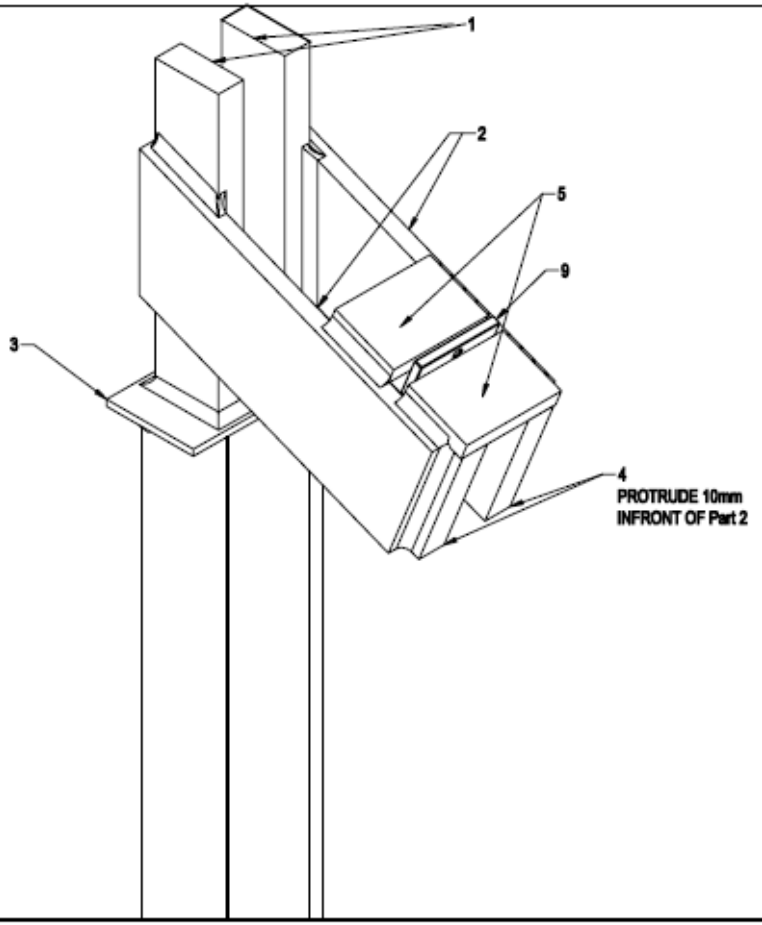
WIRE ROPE BARRIER

DGN REFERENCE:
SCALE: NTS
DRAWING CONTINUES ON SHEET:
CAD FILE NAME:

DRAWING NUMBER: WRB-ASY-01-00

REVISION: 2





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 x16mm Flat Bar	2	GROUND STRUT CABLE PLATES	
5	WRB-TP-05	01	60mm x 40mm x10mm 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 50 x 5mm **Plate**	**1**		**HOT DIPPED GALVANISED**

REV	DESCRIPTION OF REVISION	BY	CHK	DATE
2	REVISED ASSEMBLY	ND	DJ	20/01/2006
1	INITIAL RELEASE	ND	DJ	

ARMORFLEX New Zealand

WIRE ROPE BARRIER

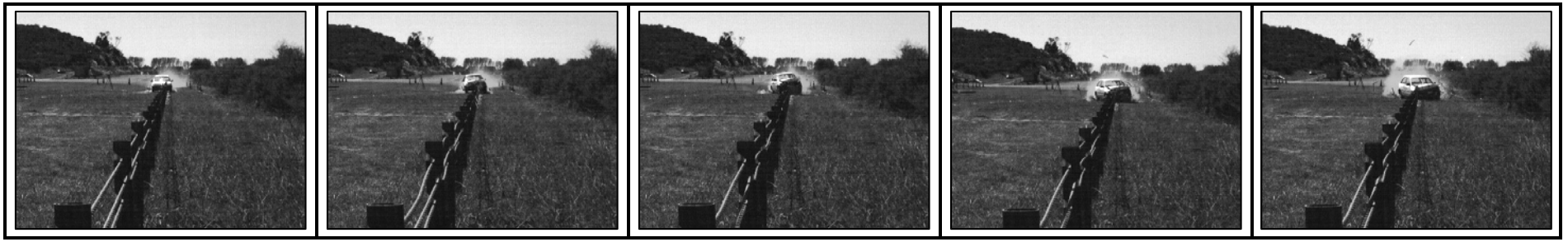
Designed: D. JAMES
Drawn: N.DUKE
Checked: D. JAMES
Approved:
Date: 31/08/2005

TRIGGER POST ASSEMBLY

REFERENCE
SCALE: NTS
DRAWING CONTINUED ON SHEET:
DXF FILE NAME: WRB-TP-ASY-01-00

DRAWING NUMBER: WRB-TP-ASY-01-01

REVISION: 2



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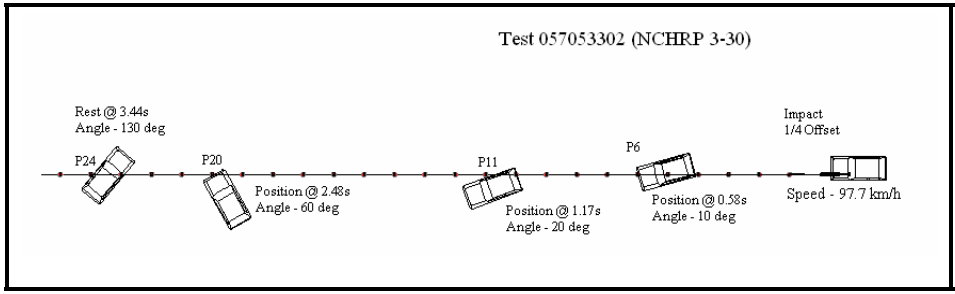

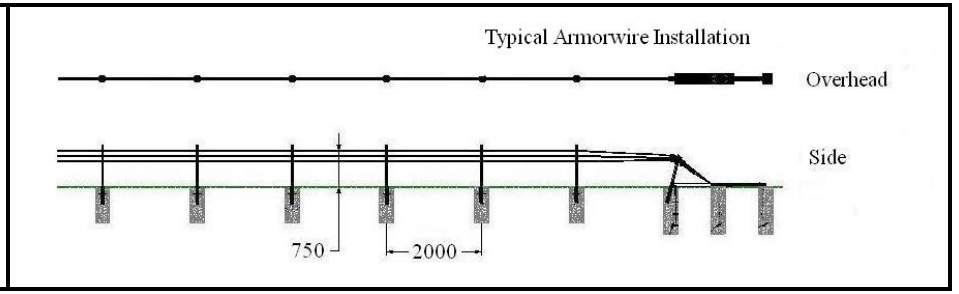

General Information

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

Test Article

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

Test Vehicle

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

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	
VDS	12-FD-5
CDC	12FDEW2
Maximum Exterior Vehicle Crush (mm)	450mm
Interior	
OCDI	LF0101000
Max. Occ. Comptmnt. Deformation (mm)	50

Post-Impact Behaviour

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

Summary of results for test 057053302 (NCHRP 350 Test 3-30).

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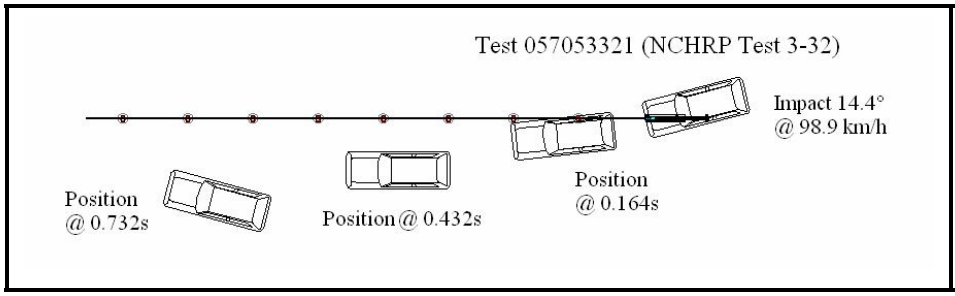
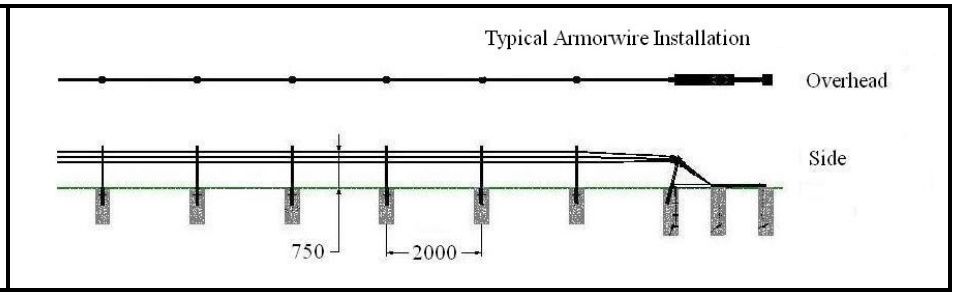




General Information

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.
Soil Type and Condition	AASHTO 'standard' soil M147-64 (1990)

Test Vehicle

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

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

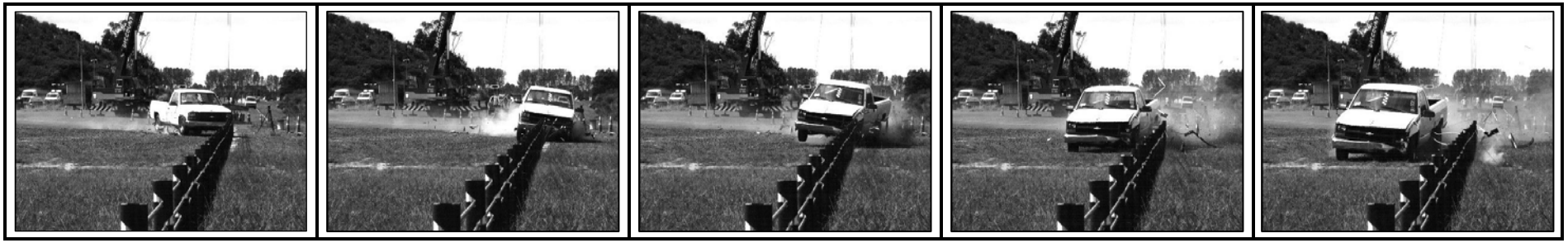
Vehicle Damage

Exterior	
VDS	12-FC-3
CDC	12FCEN1
Maximum Exterior	
Vehicle Crush (mm)	150mm
Interior	
OCDI	AS0000000
Max. Occ. Comptmnt.	
Deformation (mm)	0

Post-Impact Behaviour

Max. Yaw Angle (deg)	160.4
Max. Pitch Angle (deg)	-13.5
Max Roll Angle (deg)	14.2

Summary of results for test 057053321 (NCHRP 350 Test 3-32).



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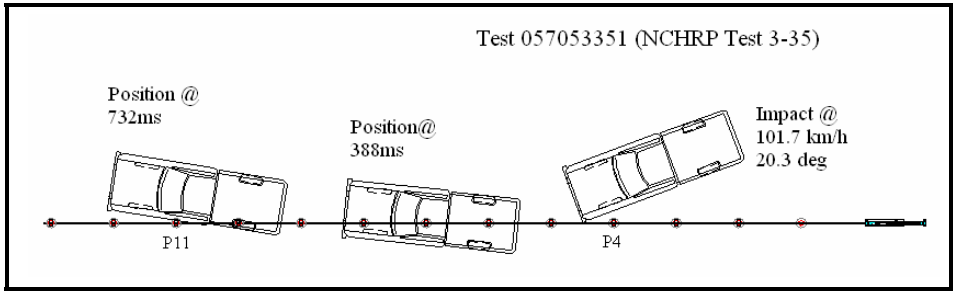

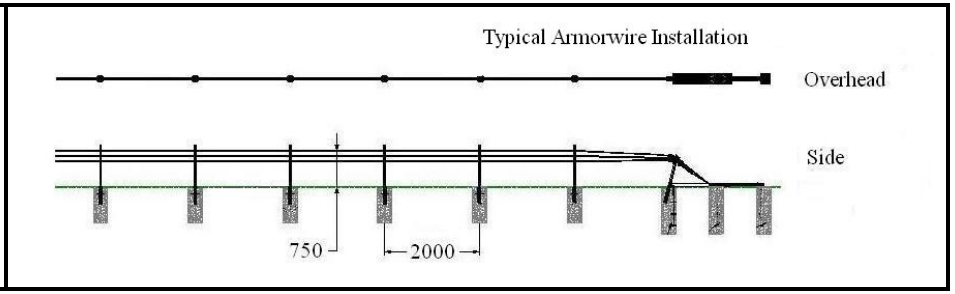

General Information

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.
Soil Type and Condition	AASHTO 'standard' soil M147-64 (1990)

Test Vehicle

Type	Production Model
Designation	2000P
Model	1998 Chevrolet Cheyenne
Mass (kg)	
Curb	2143
Test Inertial	2035
Dummy	N/A
Gross Static	2035

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	11-FL-3
CDC	11FLEC2
	09LBKLW1
Maximum Exterior	
Vehicle Crush (mm)	250 mm
Interior	
OCDI	AS0000000
Max. Occ. Comptmnt.	
Deformation (mm)	0

Post-Impact Behaviour

Max. Yaw Angle (deg)	42.3
Max. Pitch Angle (deg)	-3.2
Max Roll Angle (deg)	-7.1

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

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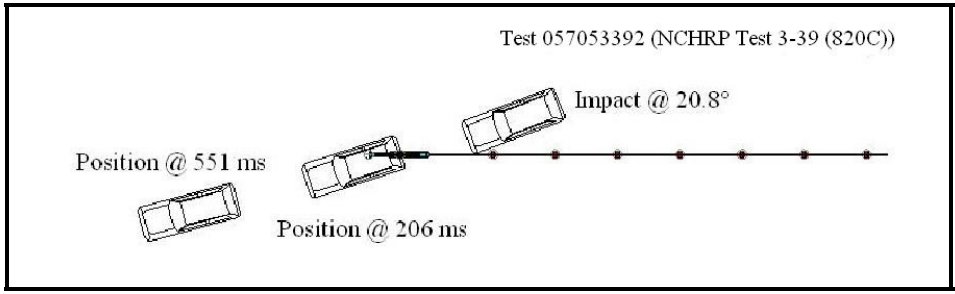

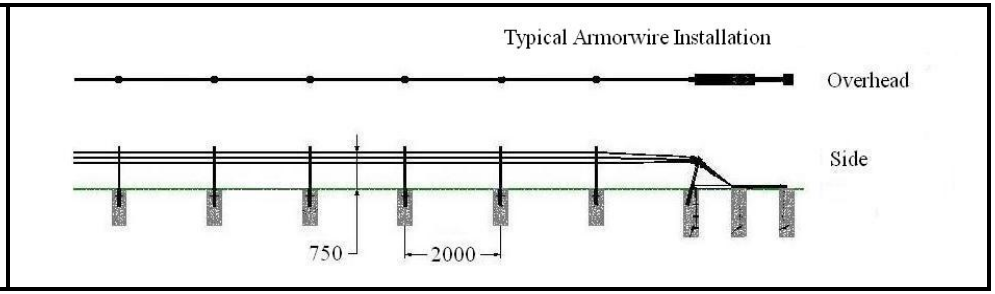

General Information

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 Armorwire Terminal End fitted to Armorflex Armorwire wire rope barrier.
Soil Type and Condition	AASHTO 'standard' soil M147-64 (1990)

Test Vehicle

Type	Production Model
Designation	820C
Model	1991 Ford Festiva
Mass (kg)	
Curb	783
Test Inertial	804
Dummy	75
Gross Static	879

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
ASI	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	11LFQ-2
CDC	11FLEN1
Maximum Exterior	
Vehicle Crush (mm)	200 mm
Interior	
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

: Summary of results for test 057053392 (Test 3-39)