U.S. Department
of Transportation
Federal Highway
Administration

1200 New Jersey Ave., S.E.
Washington, DC 20590

January 24, 2008

In Reply Refer To:
HSSD/WZ-266

Mr. Andrew Markunas, P.E.
Manager, Work Zone Traffic Control Section
Bureau of Highway Safety and Traffic Engineering
Pennsylvania Department of Transportation
400 North Street
Harrisburg, PA 17120

Dear Mr. Markunas:

In your letters of December 1 and December 20, 2007, you requested the Federal Highway Administration's (FHWA) acceptance of the Pennsylvania Department of Transportation's (PennDOT) H-base and X-base portable sign stands as a crashworthy traffic control device for use in work zones on the National Highway System (NHS). Accompanying your letter was the FHWA Office of Safety Design form that included a drawing and a detailed description of the sign stands, test report, and videos of the crash tests and LS-DYNA crash simulations. The drawings and detailed descriptions are enclosed with the acceptance form for the H-base and X-base portable sign stands. You requested that we find these sign stands acceptable for use on the NHS under the provisions of National Cooperative Highway Research Program (NCHRP) Report 350 "Recommended Procedures for the Safety Performance Evaluation of Highway Features".

This letter is the acknowledgement of the FHWA's acceptance of your requests. The original completed forms have been modified by the addition of the FHWA acceptance letter number, the date of our review, and minor editorial changes. The form will be posted on our website in the near future.

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

- This acceptance is limited to the crashworthiness characteristics of the devices and does not cover their structural features, nor conformity with the Manual on Uniform Traffic Control Devices.
- Any changes that may adversely influence the crashworthiness of the device will require a new acceptance letter.

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Mr. Andrew Markunas, P.E.
Manager, Work Zone Traffic Control Section
Bureau of Highway Safety and Traffic Engineering
Pennsylvania Department of Transportation
400 North Street
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This letter is the acknowledgement of the FHWA's acceptance of your requests. The original completed forms have been modified by the addition of the FHWA acceptance letter number, the date of our review, and minor editorial changes. The form will be posted on our website in the near future.

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

- This acceptance is limited to the crashworthiness characteristics of the devices and does not cover their structural features, nor conformity with the Manual on Uniform Traffic Control 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 WZ-266, 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.
- If proprietary devices are specified by a highway agency for use on Federal-aid projects, except exempt, non-NHS projects, they: (a) must be supplied through competitive bidding with equally suitable unpatented items; (b) the highway agency must certify that they are essential for synchronization with the existing highway facilities or that no equally suitable alternative exists; or (c) they 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.
- 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,

David A. Nicol

David A. Nicol
Director, Office of Safety Design
Office of Safety

Enclosures

PENNSTATE

TEL: (814) 863-7925
FAX: (814) 865-3039
E-Mail: zrado@psu.edu

The Pennsylvania Transportation Institute
Vehicle Systems & Safety Program

The Pennsylvania State University
201 Research Office Building
University Park, PA 16802-4710

Federal Highway Administration
Office of Safety Design

Category 2 Work Zone Device Acceptance Letter

Letter Number: WZ-266
Date: 1/3/2008

CONTACT INFORMATION:	**Petioner / Developer Name:**	**Andrew Markunas, PE**
	Title:	**Manager, Work Zone Traffic Control Section**
	Company:	**Pennsylvania Department of Transportation Bureau of Highway Safety & Traffic Engineering Work Zone Traffic Control Section**
	Street:	**400 North Street, 6th Floor**
	City, State, and Zipcode:	**Harrisburg, PA 17120**
	I herby certify that the device(s) covered by this Acceptance Letter meet(s) the crash – worthiness test and evaluation requirements of the FHWA and NCHRP Report 350.	
	Signature:	
	Telephone Number:	**(717) 783-6080**
	E-mail Address:	**amarkunas@state.pa.us**
	Engineer Name:	**Dr. Zoltan Rado**
	Laboratory Name:	**The Pennsylvania Transportation Institute**
	Street:	**201 Transportation Research Bldg.**
	City, State, and Zipcode:	**University Park, PA, 16802**
	Check One:	
	☑	I hereby certify that the testing that supports this Acceptance Letter was conducted in accordance with NCHRP Report 350 guidelines, that the device(s) tested is/are accurately described on this form, and that the test results indicate that the device meets all applicable NCHRP Report 350 evaluation criteria.
		I have evaluated the requested modifications to these devices previously found acceptable by the FHWA in Acceptance Letter WZ-____, and hereby certify that, in my opinion, the modifications do not adversely affect the crash performance of the devices. I also certify that these devices are accurately described on this form.
	Signature:	
	Telephone Number:	**(814)-863-7925**
	E-mail Address:	**zxr100@psu.edu**

KEYWORDS	**Please select from the following Keywords for "Type of Device":** Longitudinal Channelizing Barricade Curb (Curb channelizer system with or without road tubes or other channelizers) Drum H-Footprint Sign Stand X-Footprint Sign Stand Trailer Mounted Signs (Does not include arrow boards or variable message signs or other Category 4 trailer mounted devices.) Automated Flagger Device (not trailer mounted) Tripod Sign Stand Type I Barricade Type II Barricade Type III Barricade Vertical Panel Intrusion Detector Ballast (Action relates to ballast on one or more devices) Channelizer (Individual units unlike cones, road tubes, or drums) Other (Please describe on form)	**Type of Device:** **H-Footprint Sign Stand**
	Please Select from the following Keywords for Composition of Sign or Rail Substrate: Roll-up / Fabric (with fiberglass spreaders – aluminum or steel spreaders are not allowed.) Plywood Aluminum – Solid Aluminum – Laminate Corrugated Plastic Extruded Plastic Waffleboard Plastic Wood / Lumber	**Compositon of Sign or Rail Substrate:** **Aluminum - Solid**

Thickness of substrate (inches):

Indicate the height of sign from the ground (inches), if applicable:

Low	12 to 18 inches above the pavement
Mid-A	20 to 24 inches above the pavement
Mid-B	25 to 36 inches above the pavement
Mid-C	37 to 59 inches above the pavement
[✓ Tall]	60 to 71 inches above the pavement
Oversized	72 inches and taller

Height of Sign: 60"

Flags and or lights present during test? Indicate number of each:

# of flags: 0	# of lights: 1	Weight of lights: ea. 2lbs

DEVICE NAME: Provide Detailed Description of Device, Materials, sizes, Fasteners, Substrates, Foundation, Aux. Features Ballast, etc. (May be attached on separate page(s))

Description:

The sign's horizontal support legs consist of ASTM A500 Grade B steel tubes that are 44.5mm (1.75in) × 44.5mm (1.75in) × 2.78mm (0.11in) thick. The cross member used for the H-shaped base is 610mm (24in) in length. The two side members of the H-shaped base are both 914mm (36in) in legth. The aluminum sign panel fastened onto the vertical support beam is 914mm (36in) × 914mm (36in) square × 5.54mm (0.22in) thick. The sign panel is rigidly bolted to the vertical post made of ASTM A500 Grade B steel tubing. The vertical post is 50.8mm (2in) × 50.8mm (2in) square × 2.78mm (0.11in) thick and 2438mm (96in) in height. The sandbags used for temporary stabilization of portable sign structure are placed on the end of each of the four horizontal legs. Each sandbag is 406mm (16in) wide × 203 (8in) mm in height × 101mm (4in) in length. The safety light has a radius of 187.3mm (7.4in) and is positioned on top of the sign. Bolts that attached the sign panel to the vertical post are made of nylon 6/6 material and are fully threaded. The diameter of each head and thread is 12mm (0.47in), and 7mm (0.28in).

Material list:

Part	Description	Dimensions	Material	Qty
1	Veritcal steel tubular stub	1.75" sq. x 0.109" wall x 16" long	ASTM A500 Grade B steel tubing	1
2	Legs cross member	1.75" sq. x 0.109" wall x 24" long	ASTM A500 Grade B steel tubing	1
3	Legs	1.75" sq. x 0.109" wall x 36" long	ASTM A500 Grade B steel tubing	2
4	Vertical upright mast	2.0" sq. x 0.109" wall x 96" long	ASTM A500 Grade B steel tubing	1

Mast slides outside vertical stub fastened with 5/16" (0.3125") diameter 2 1/4" (2.25") long stainless steel or grade 5 zinc plated bolts and nylon insert lock nuts. Use 3/8" steel and nylon washers under both the bolt and nut.

The sign panel is placed on the vertical sign post with top edge aligned with post top end and fastened with 5/16" (0.3125") diameter 2 1/4" (2.25") long nylon 6/6 fully threaded hex headed bolts and nylon insert lock nuts. Use 3/8" steel and nylon washers under both the bolt and nut.

Drawings:

The engineering drawings are attached separately.

MANDATORY ATTACHMENTS:	**Please include those pages as separate electronic files as they will be posted on the FHWA website in lieu of the entire final report.**	
	Attachment #1: Test data summary page(s)	
	Attach. #1a	Test #: PennDOT 02
	Attach. #1b	Test #-
	Attach. #1c	Test #-
	Attach. #1d	Test #-
	Alternative	
	Attachment #1: Description and discussion of modification(s) to crash tested and/or accepted device.	
	Date:	
	Attachment # 2: PDF drawing(s) of device(s) - **Mandatory Attachments: Please include those pages as separate electronic files as they will be posted on the FHWA website in lieu of the entire final report.**	
	Attach. #2a	Drawing Title: H-Stand
		Drawing #: S-H-001
	Attach. #2b	Drawing Title:-
		Drawing #:-
	Attach. #2c	Drawing Title:-
		Drawing #:-
	Attach. #2d	Drawing Title:-
		Drawing #:-
	Attach. #2e	Drawing Title:-
		Drawing #:-
	Attach. #2f	Drawing Title:-
		Drawing #:-
	Attach. #2g	Drawing Title:-

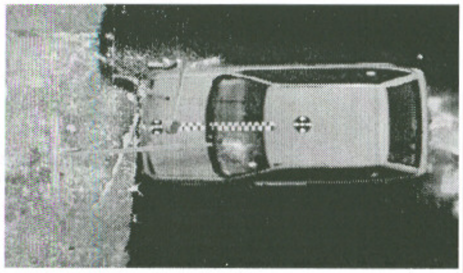
Attachment #1a: (a) Test summary sheet 0 degree Sign Post


0.03s


0.06s


0.08s


0.13s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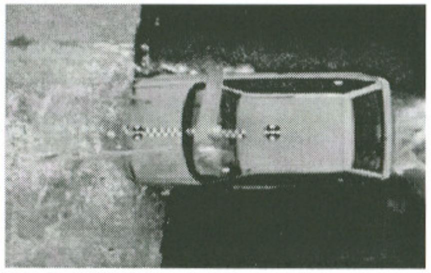
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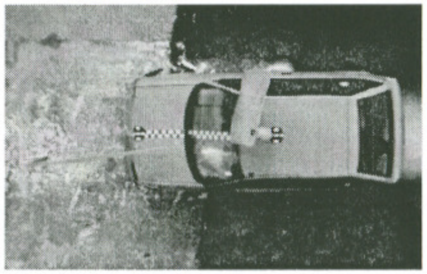
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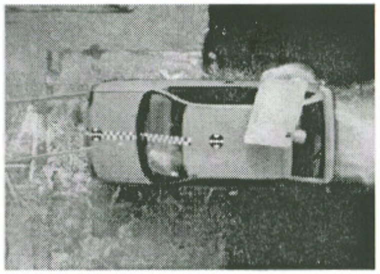
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General Information

Test Agency .... Pennsylvania Transportation Institute
Test No. .... PennDOT 02
Date .... 28 September 2007

Test Article

Type .... PennDOT – H Portable Sign Post
....

Test Vehicle

Type 820C
Designation ....
Model .... Geo Metro
Mass (Kg)
Test Inertial .... 1945 lbs (882 kg)
Gross Static .... 1780 lbs (807 kg)

Impact Conditions

Speed (km/h) .... 100.4 km/h (62.4 mi/h)
Angle (deg) .... 0 degrees

Test Article Deflections (m)

Dynamic .... See Evaluation and Assessment of Test Results
Permanent .... See Evaluation and Assessment of Test Results

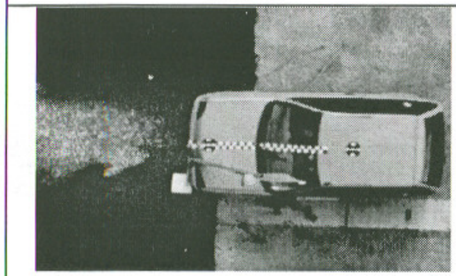
Attachment #1a: (b) Test summary sheet 90 degree Sign Post


0.03s


0.06s


0.08s


0.13s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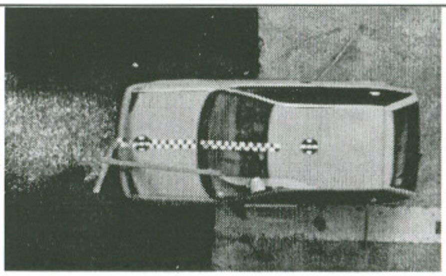
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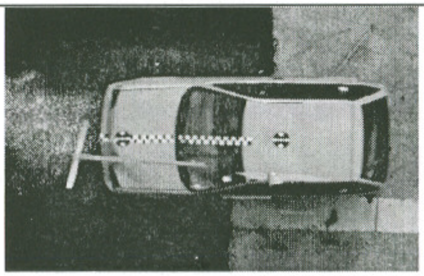
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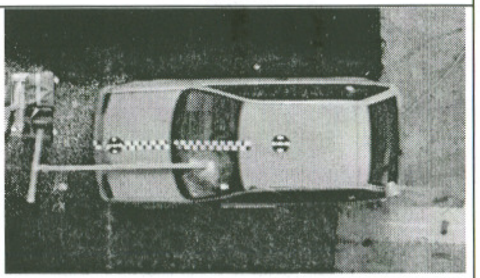

0.13s

General Information	
Test Agency	Pennsylvania Transportation Institute
Test No.	PennDOT 02
Date	28 September 2007
Test Article	
Type	PennDOT – H Portable Sign Post
Test Vehicle	
Type	820C
Designation	
Model	Geo Metro
Mass (Kg)	
Test Inertial	1945 lbs (882 kg)
Gross Static	1780 lbs (807 kg)

Impact Conditions	
Speed (km/h)	100.4 km/h (62.4 mi/h)
Angle (deg)	90 degrees
Test Article Deflections (m)	
Dynamic	See Evaluation and Assessment of Test Results
Permanent	See Evaluation and Assessment of Test Results

Attachment #1a: (c) Evaluation and Assessment of Test Results

Test Article Damage and Vehicle Damage

Sign and vehicle crash performance was visually addressed through crash and post-crash images. In addition, crash performance from LS-DYNA simulations and full-scale crash testing were compared and assessed following evaluation criteria from NHCRP 350.
Post-crash performance photographs are shown in Figure 1. The pictures in Figure 1show that both the 0 and 90 degree H-base structures were severely deformed approximately 43 cm (17in) in height above the ground, which was approximately equal to the front bumper height. It can be seen that horizontal legs were also severely deformed at their connection joint. The deformations of the two signs were very similar. Both sign posts buckled at the point where the bumper of the crash vehicle came into contact with the vertical poles. One of the signs bent to almost 90 degrees while the other suffered a similar but somewhat smaller deformation. Both of the signs show that the base structure which carried all of the weights from the stabilizing sand bags became fractured and separated from the sign posts. Figure 2shows that the 820C vehicle was damaged mildly according to expectations. The front bumper on both sides near the quarter points suffered small dents and also the hood of the vehicle was dented by the buckling sign posts to a small degree.

Figure 1. Crash performances for H-base sign structures.

Figure 2. Post-test photographs of test vehicle.

Windshield Deformation and Damage Assessment

Windshield Damage Data Measured according to E-TECH Technique:

Location #	Vertical Ref. Dim.	Horizontal Ref. Dim.	Crash Vehicle Meas.	Ref. Vehicle Meas.	Deformation
1	14”	15 ¼”	5 ¾”	4 1/16”	1 2/16”

Windshield Damage Index according to WDI procedure:

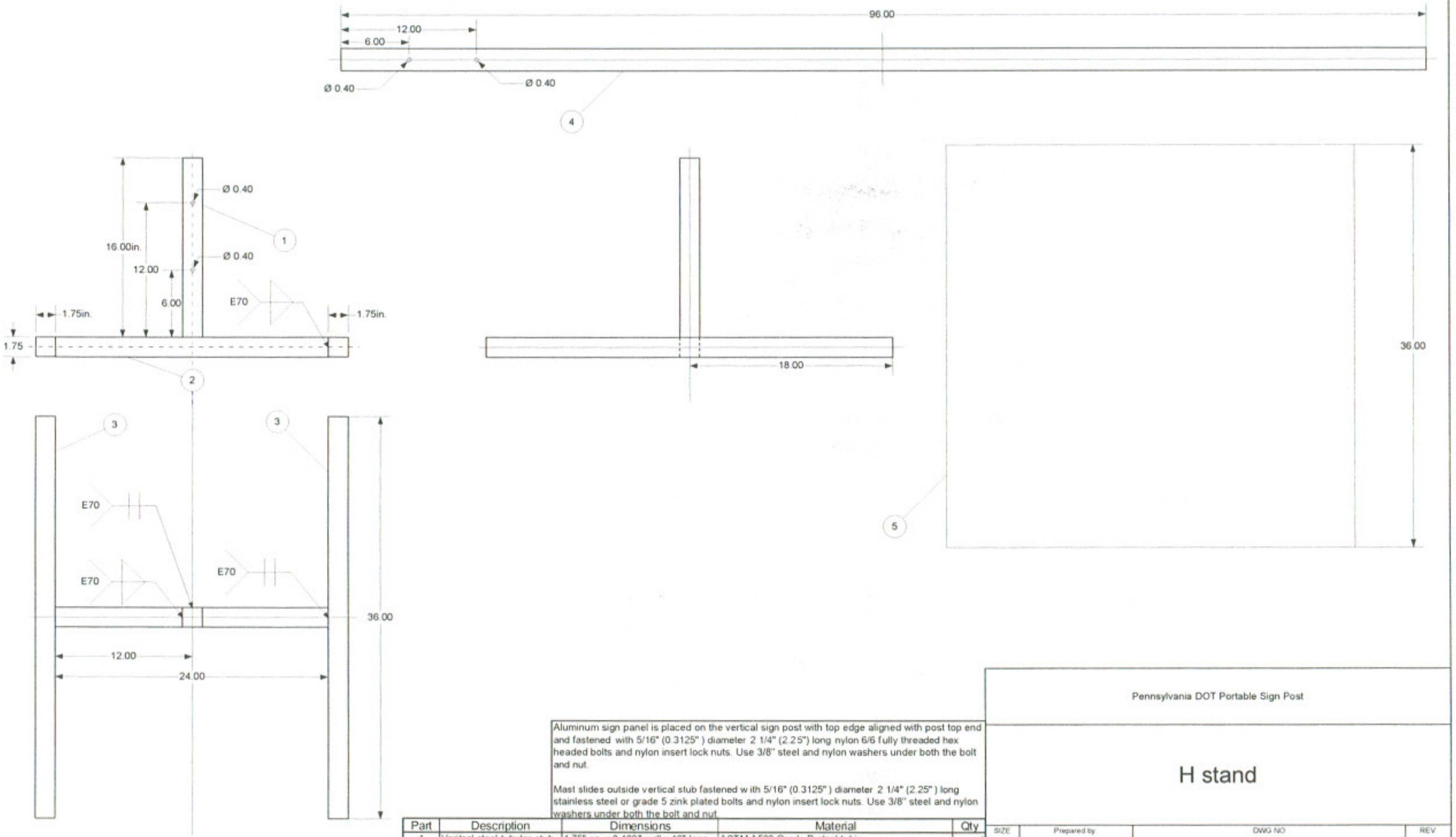
Zone: **1** (Left 1/3 quadrant), Vertical Position: **C** (center horizontal slice),
Horizontal Position: **R** (Right side of slice), Shape: **E** (Elliptical)
Depth of Indentation: **3** (1<DI<1 ½”), Extent of Indentation: **3** (20<EI<50 in^2)

WDI: 441CRE33

Figure 3. Windshield Damage

Figure 4. Case 5: Significant local damage

Attachment #2a



Aluminum sign panel is placed on the vertical sign post with top edge aligned with post top end and fastened with 5/16" (0.3125") diameter 2 1/4" (2.25") long nylon 6/6 fully threaded hex headed bolts and nylon insert lock nuts. Use 3/8" steel and nylon washers under both the bolt and nut.

Mast slides outside vertical stub fastened w ith 5/16" (0.3125") diameter 2 1/4" (2.25") long stainless steel or grade 5 zink plated bolts and nylon insert lock nuts. Use 3/8" steel and nylon washers under both the bolt and nut.

Part	Description	Dimensions	Material	Qty
1	Veritcal steel tubular stub	1.75" sq. x 0.109" wall x 16" long	ASTM A500 Grade B steel tubing	1
2	Legs cross member	1.75" sq. x 0.109" wall x 24" long	ASTM A500 Grade B steel tubing	1
3	Legs	1.75" sq. x 0.109" wall x 36" long	ASTM A500 Grade B steel tubing	2
4	Vertical upright mast	2.0" sq. x 0.109" wall x 96" long	ASTM A500 Grade B steel tubing	1
5	Aluminum sign panel	36" x 36" x 0.22" thick	ASTM B221 Multipurpose Aluminum (Alloy 6061)	1

Pennsylvania DOT Portable Sign Post

H stand

SIZE	Prepared by	DWG NO	REV
11x17	Pennsylvania Transportation Inst.	S-H-001	1.2

SCALE 1/8 : 1
SHEET 1 OF 1

Federal Highway Administration
Office of Safety Design

Category 2 Work Zone Device Acceptance Letter

Letter Number: WZ-266
Date: 1/3/2008

CONTACT INFORMATION:	**Petioner / Developer Name:**	**Andrew Markunas, PE**
	Title:	**Manager, Work Zone Traffic Control Section**
	Company:	**Pennsylvania Department of Transportation** **Bureau of Highway Safety & Traffic Engineering** **Work Zone Traffic Control Section**
	Street:	**400 North Street, 6th Floor**
	City, State, and Zipcode:	**Harrisburg, PA 17120**
	I herby certify that the device(s) covered by this Acceptance Letter meet(s) the crash – worthiness test and evaluation requirements of the FHWA and NCHRP Report 350.	
	Signature:	
	Telephone Number:	**(717) 783-6080**
	E-mail Address:	**amarkunas@state.pa.us**
	Engineer Name:	**Dr. Zoltan Rado**
	Laboratory Name:	**The Pennsylvania Transportation Institute**
	Street:	**201 Transportation Research Bldg.**
	City, State, and Zipcode:	**University Park, PA, 16802**
	Check One:	
		I hereby certify that the testing that supports this Acceptance Letter was conducted in accordance with NCHRP Report 350 guidelines, that the device(s) tested is/are accurately described on this form, and that the test results indicate that the device meets all applicable NCHRP Report 350 evaluation criteria.
	☑	I have evaluated the requested modifications to these devices previously found acceptable by the FHWA in Acceptance Letter WZ-____, and hereby certify that, in my opinion, the modifications do not adversely affect the crash performance of the devices. I also certify that these devices are accurately described on this form.
	Signature:	
	Telephone Number:	**(814)-863-7925**
	E-mail Address:	**zxr100@psu.edu**

KEYWORDS	**Please select from the following Keywords for "Type of Device":** Longitudinal Channelizing Barricade Curb (Curb channelizer system with or without road tubes or other channelizers) Drum H-Footprint Sign Stand X-Footprint Sign Stand Trailer Mounted Signs (Does not include arrow boards or variable message signs or other Category 4 trailer mounted devices.) Automated Flagger Device (not trailer mounted) Tripod Sign Stand Type I Barricade Type II Barricade Type III Barricade Vertical Panel Intrusion Detector Ballast (Action relates to ballast on one or more devices) Channelizer (Individual units unlike cones, road tubes, or drums) Other (Please describe on form)	**Type of Device:** **X-Footprint Sign Stand**
	Please Select from the following Keywords for Composition of Sign or Rail Substrate: Roll-up / Fabric (with fiberglass spreaders – aluminum or steel spreaders are not allowed.) Plywood Aluminum – Solid Aluminum – Laminate Corrugated Plastic Extruded Plastic Waffleboard Plastic Wood / Lumber	**Compositon of Sign or Rail Substrate:** **Aluminum - Solid**

	Thickness of substrate (inches):		
	Indicate the height of sign from the ground (inches), if applicable:	Low	12 to 18 inches above the pavement
		Mid-A	20 to 24 inches above the pavement
		Mid-B	25 to 36 inches above the pavement
		Mid-C	37 to 59 inches above the pavement
		[✓ Tall]	60 to 71 inches above the pavement
		Oversized	72 inches and taller
		Height of Sign: 60"	
	Flags and or lights present during test? Indicate number of each:		
	# of flags: 0	# of lights: 1	Weight of lights: ea. 2lbs

DEVICE NAME: Provide Detailed Description of Device, Materials, sizes, Fasteners, Substrates, Foundation, Aux. Features Ballast, etc. (May be attached on separate page(s))

Description:

The sign's horizontal support legs consist of ASTM A500 Grade B steel tubes that are 44.5mm (1.75in) × 44.5mm (1.75in) × 2.78mm (0.11in) thick. The four cross members of the X-shaped base are both 914mm (36in) in length. The aluminum sign panel fastened onto the vertical support beam is 914mm (36in) × 914mm (36in) square × 5.54mm (0.22in) thick. The sign panel is rigidly bolted to the vertical post made of ASTM A500 Grade B steel tubing. The vertical post is 50.8mm (2in) × 50.8mm (2in) square × 2.78mm (0.11in) thick and 2438mm (96in) in height. The sandbags used for temporary stabilization of portable sign structure are placed on the end of each of the four horizontal legs. Each sandbag is 406mm (16in) wide × 203 (8in) mm in height × 101mm (4in) in length. The safety light has a radius of 187.3mm (7.4in) and is positioned on top of the sign. Bolts that attached the sign panel to the vertical post are made of nylon 6/6 material and are fully threaded. The diameter of each head and thread is 12mm (0.47in), and 7mm (0.28in).

Material list:

Part	Description	Dimensions	Material	Qty
1	Veritcal steel tubular stub	1.75" sq. x 0.109" wall x 17.75" lon	ASTM A500 Grade B steel tubing	1
2	Legs	1.75" sq. x 0.109" wall x 21" long	ASTM A500 Grade B steel tubing	4
3	Vertical upright mast	2.0" sq. x 0.109" wall x 96" long	ASTM A500 Grade B steel tubing	1
4	Aluminum sign panel	36" x 36" x 0.22" thick	ASTM B221 Multipurpose Aluminum (Alloy 6061)	1

Mast slides outside vertical stub fastened with 5/16" (0.3125") diameter 2 1/4" (2.25") long stainless steel or grade 5 zinc plated bolts and nylon insert lock nuts. Use 3/8" steel and nylon washers under both the bolt and nut.

The sign panel is placed on the vertical sign post with top edge aligned with post top end and fastened with 5/16" (0.3125") diameter 2 1/4" (2.25") long nylon 6/6 fully threaded hex headed bolts and nylon insert lock nuts. Use 3/8" steel and nylon washers under both the bolt and nut.

Drawings:

The engineering drawings are attached in Attachment 2a.

MANDATORY ATTACHMENTS:	**Please include those pages as separate electronic files as they will be posted on the FHWA website in lieu of the entire final report.**	
	Attachment #1: Test data summary page(s)	
	Attach. #1a	Test #: FEA Analysis of PennDOT Sign Structure
	Attach. #1b	Test #-
	Attach. #1c	Test #-
	Attach. #1d	Test #-
	Alternative	
	Attachment #1: Description and discussion of modification(s) to crash tested and/or accepted device.	
	Date:	
	Attachment # 2: PDF drawing(s) of device(s) - **Mandatory Attachments: Please include those pages as separate electronic files as they will be posted on the FHWA website in lieu of the entire final report.**	
	Attach. #2a	Drawing Title: X-Stand
		Drawing #: S-X-001
	Attach. #2b	Drawing Title:-
		Drawing #:-
	Attach. #2c	Drawing Title:-
		Drawing #:-
	Attach. #2d	Drawing Title:-
		Drawing #:-
	Attach. #2e	Drawing Title:-
		Drawing #:-
	Attach. #2f	Drawing Title:-
		Drawing #:-
	Attach. #2g	Drawing Title:-

Attachment #1a:

FEA Analysis of PennDOT Sign Structure

Background

To evaluate the performance of the "X" based portable sign post a three tiered modeling and analysis approach was taken first a complete FEA analysis of the "H" based structure was undertaken where all the characteristics of a full scale NCHRP 350 crash test were computed. Te second phase was to conduct the actual full scale crash test of the physical "H" based structure built to the exact specifications used in the LS-DYNA modeling. Using the results of the full scale crash test the parameters predicted by the FEA analysis were verified. The validated model of the sign structure then was modified to the "X" shaped base and tested in the FEA analysis software.

This approach guarantees the high fidelity of the evaluation of the modified sign post structure and delivers very high confidence in the simulation results.

Numerical crash-testing was performed using LS-DYNA for each of the two PennDOT structures the "H" footed and the "X" footed structures. Each sign structure was subjected to virtual crash tests identical to those performed in NCHRP 350 Level 3-71 crash tests, using a Geo Metro vehicle (a standard 820C vehicle according to NCHRP 350 designation) with the sign oriented facing the vehicle and at 90° with respect to the vehicle. These tests were run with the top of the sign placed at 96"(2438mm) from the ground.

Model Construction

Sign Structure Construction

The horizontal legs and vertical stands having 0.109'' (2.77mm) thickness were modeled using shell elements provided by LS-DYNA. The aluminum sign panels consisting of a 36'' (914.4mm)x36'' (914.4mm) square plate with a 0.1'' (2.54mm) thickness were also created using shell elements. The steel H-support, vertical mast and sleeve with 0.109'' (2.77mm) thicknesses were modeled using shell elements. The steel stands were modeled using nominal A36 steel properties available in LS-DYNA and standard aluminum properties (i.e., 6061-T6) were used for representing the aluminum panels. All sign structures were constructed according to the design plans. All sign panels were modeled separately from their support structures and placed onto them using constrained rivets provided by LS-DYNA, which couple the models together. The safety light placed on top of the sign was modeled matching published dimensions and weights to represent a worst case scenario with respect to low speed crash tests. It was modeled using a hard plastic material and affixed to the top of the sign using the constrained rivets.

Vehicle Model Construction

A standard NCHRP approved vehicle model developed by the FHWA/NHTSA National Crash Analysis Center (NCAC) was used for the numerical crash tests. Model information is as follows:

1.	Number of Parts	230
2.	Number of Nodes	100348
3.	Number of Solids	1209
4.	Number of Springs	8
5.	Number of mass elements	76
6.	Number of Elements	16000

The vehicle model can be observed in Figure 1.

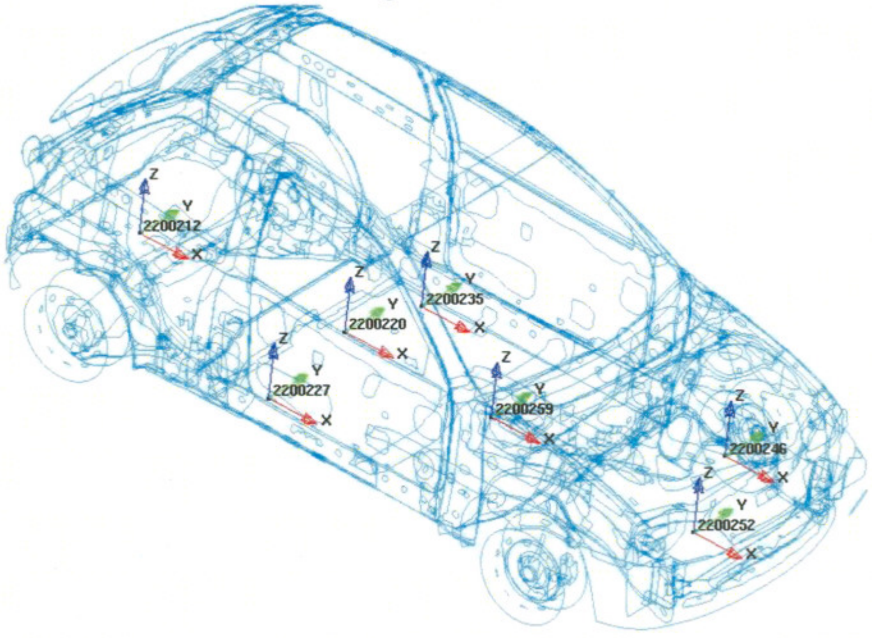


Figure 1. Detailed vehicle model (http://www.ncac.gwu.edu/vml/models.html)

Crash Scenario Modeling

The crash scenarios were selected using the NCHRP 350[1] Section 3.2.3, "Support Structures, Work Zone Traffic Control Devices, and Breakaway Utility Poles". Using a test matrix from the guide it was decided to employ Level 3 test requirements of the "support Structures" category with test level 3-71.

These tests include a high speed crash scenario as described below:

Test Level 3-70. The test comprised two separate full crash scenarios at 100 km/h (62 mph) with the 820C vehicle (Geo Metro) using sign impact angles of 0 and 90 degrees as described above. Each portable sign structure crash scenario was analyzed twice. The first analysis was performed with the sign structure facing the approaching vehicle and impacting its front either at the vehicle's geometric middle or at one of the quarter points with respect to its longitudinal centerline. The second analysis had the sign structure rotated 90 degrees from its initial position and placed at the middle or at the other quarter point of the approaching vehicle.

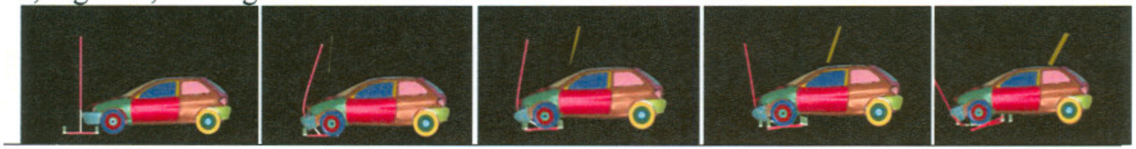
The virtual crash scenarios were developed following these conditions. The model was created so that each support structure was placed at the geometric longitudinal middle of the approaching vehicle to represent the critical scenario for each individual crash test. The structures were placed a short distance from the original location of the vehicle to ensure that the vehicle was in a dynamically stable condition with a constant direction and speed free from dynamic effects before impact. The structure was placed on an infinitely rigid smooth surface representing the ground and was given a nominal coefficient of friction of 0.3 at contact locations with the ground. The portion of the structure in contact was then loaded with a model representing four sand bags on the end of each support leg. The incorporation of the sand bags represented real life conditions. Prior to the numerical crash test the vehicle was initialized to the following conditions:

- Initial speed of all components was set to the desired nominal test speed.
- Rotational speed of the tires was set to matching angular velocities to avoid differential frictional and inertial effects from the moving vehicle.
- The vehicle, at its defined initial speed and tires angular velocities, was placed on a perfectly smooth and level infinitely rigid surface with a friction coefficient of 0.3.

Results

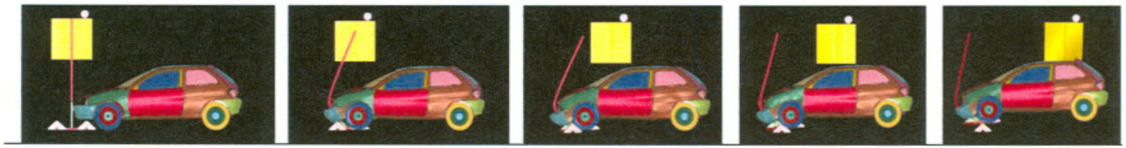
Since the actual dimensions, materials and construction of the signposts were kept identical to the original structures the inertial and kinetic properties of the crash with regard to vehicle deceleration, vehicle trajectory and occupant aggregate risk factors caused by vehicle dynamics remained statistically the same.

The results from the FEA analysis for the four scenarios are depicted in Figure 2, Figure 3, Figure 4, and Figure 5:



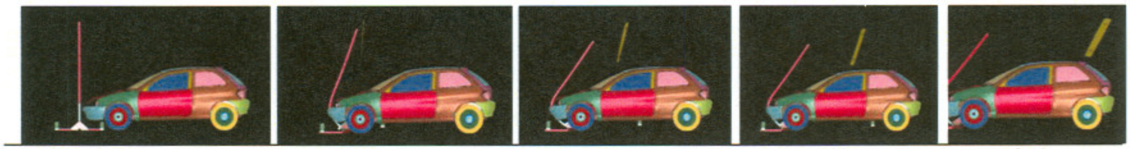
t=0.00s t=0.03s t=0.06s t=0.08s t=0.13s

Figure 2. Crash Behavior of "H" footed sign at 0 degree



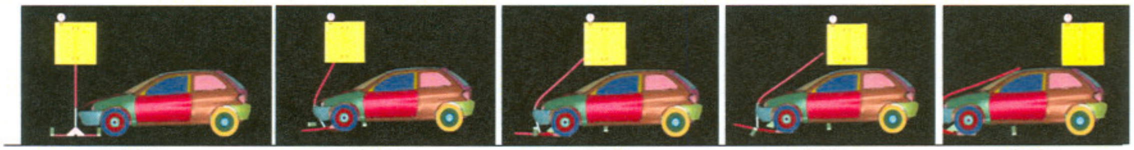
t=0.00s t=0.03s t=0.06s t=0.08s t=0.13s

Figure 3. Crash Behavior of "H" footed sign at 90 degree



t=0.00s t=0.03s t=0.06s t=0.08s t=0.13s

Figure 4. Crash Behavior of "X" footed sign at 0 degree



t=0.00s t=0.03s t=0.06s t=0.08s t=0.13s

Figure 5. Crash Behavior of "X" footed sign at 90 degree

In all four virtual crash scenarios for both structures (the "H" shaped foot and the "X" shaped foot structures) the virtual crash simulation indicated the expected crash behavior of the structure. In all four cases the aluminum sign panels have separated from the vertical sign post upon impact. The fastening bolts from the nylon material have failed as expected.

In the zero degree crash setup where the sign posts are facing the approaching crash vehicle the tensional forces created by the impact acceleration and inertial forces of the solid aluminum sign panel exceeded the tensile strength of the new bolt material and the screw on both the upper and lower fastening points of the sign panel broke. The sign panel become separated from the rest of the sign structure and in its free fall to the ground has cleared the vehicle moving underneath. The vertical sign post free from the relatively high inertial forces that would have been caused by a non-separated sign panel are showing buckling but with a much slower rate and the damage to the front bumper and hood of the vehicle also reduced substantially.

In the 90 degree crash setup where the sign posts are turned parallel to the approaching crash vehicle the shear forces created by the impact acceleration and inertial forces of the solid aluminum sign panel exceeded the shear strength of the new bolt material and the screw on both the upper and lower fastening points of the sign panel broke. The sign panel become separated from the rest of the sign structure and in its free fall to the ground has cleared the vehicle moving underneath. The vertical sign post free from the relatively high inertial forces that would have been caused by a non-separated sign panel are showing buckling but with a much slower rate and the damage to the front bumper and hood of the vehicle also reduced substantially.

Figure 6 shows the comparison of the FEA analysis predicted behavior of the "H" based sign structure in relation to the actual behavior captured throughout the actual crash test executed after the FEA analysis was completed.

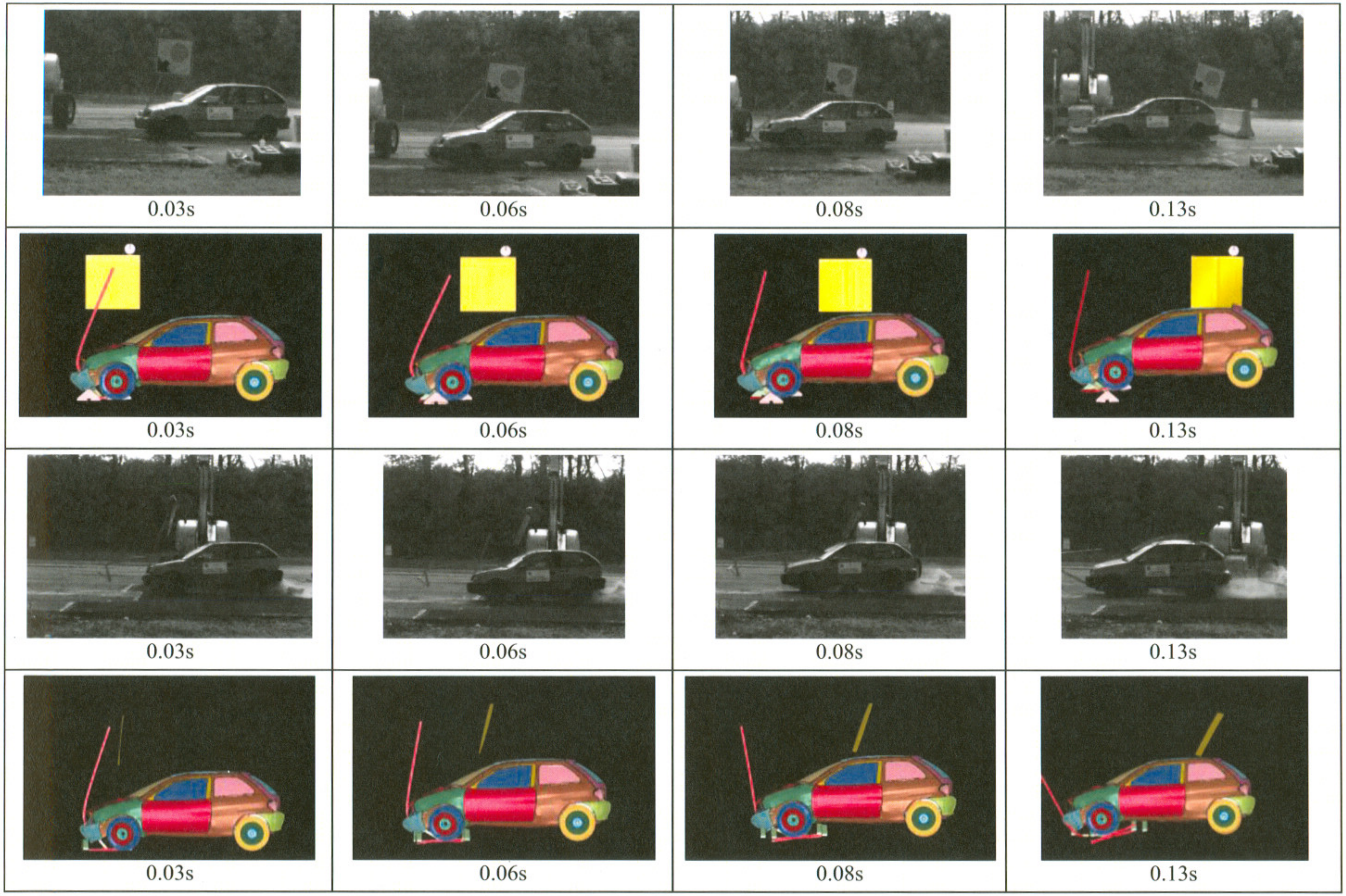


Figure 6. **Simulation summary of the "H" based Sign Post.**

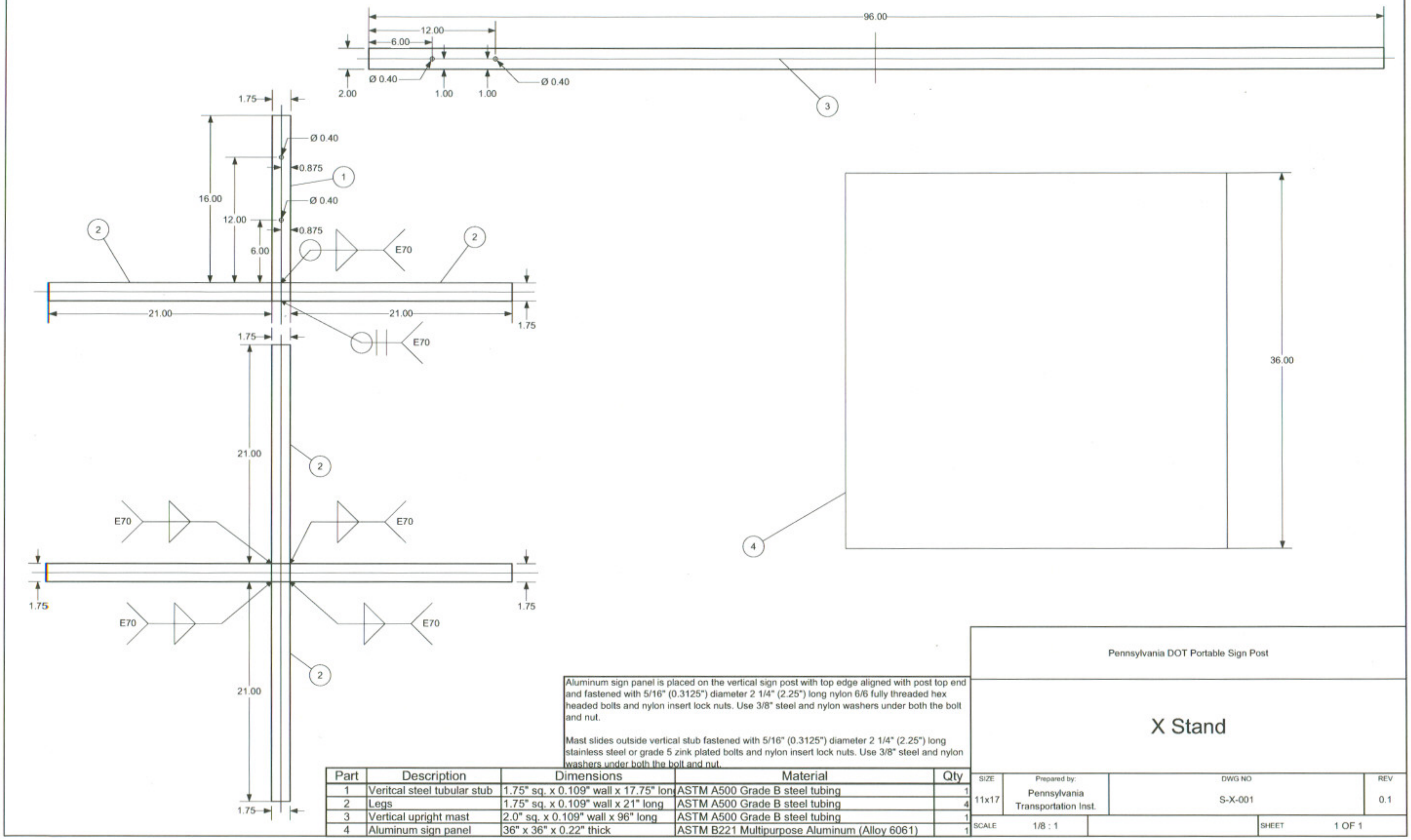
As it can easily be observed from the time sequences of the LS-DYNA produced results and the actual crash test in Figure 6 the simulation predicted behavior of the sign structure matches the actual observed real crash behavior to a very large degree.

Conclusion

Based upon the conducted analysis, full scale crash test, and analysis validation using both the "H" and "X" shaped sign structures it can be concluded that both of the structures have proven to exhibit the same crash performance subjected to the NCHRP 350 crash test. The evaluation of the modification to the PennDOT "H" based portable sign structure replacing the base to an "X" shaped base do not adversely affect the crash performance of the device.

It can be concluded based upon the engineering analysis and the executed crash test that both structures pass the necessary criteria set forth by the NCHRP 350 guide.

Attachment #2a



Aluminum sign panel is placed on the vertical sign post with top edge aligned with post top end and fastened with 5/16" (0.3125") diameter 2 1/4" (2.25") long nylon 6/6 fully threaded hex headed bolts and nylon insert lock nuts. Use 3/8" steel and nylon washers under both the bolt and nut.

Mast slides outside vertical stub fastened with 5/16" (0.3125") diameter 2 1/4" (2.25") long stainless steel or grade 5 zink plated bolts and nylon insert lock nuts. Use 3/8" steel and nylon washers under both the bolt and nut.

Part	Description	Dimensions	Material	Qty
1	Veritcal steel tubular stub	1.75" sq. x 0.109" wall x 17.75" lon	ASTM A500 Grade B steel tubing	1
2	Legs	1.75" sq. x 0.109" wall x 21" long	ASTM A500 Grade B steel tubing	4
3	Vertical upright mast	2.0" sq. x 0.109" wall x 96" long	ASTM A500 Grade B steel tubing	1
4	Aluminum sign panel	36" x 36" x 0.22" thick	ASTM B221 Multipurpose Aluminum (Alloy 6061)	1

Pennsylvania DOT Portable Sign Post

X Stand

SIZE	Prepared by:	DWG NO	REV
11x17	Pennsylvania Transportation Inst.	S-X-001	0.1

SCALE 1/8 : 1

SHEET 1 OF 1