Mr. Gerrit A. Dyke, P.E.
Barrier Systems, Inc.
3333 Vaca Valley Parkway, Suite 800
Vacaville, CA 95688

Dear Mr. Dyke:

This letter is in response to your request for the Federal Highway Administration (FHWA) acceptance of a roadside safety system for use on the National Highway System (NHS).

Name of system: X-TENuator (X-TEN); and,
  X-TENuator (X-TEN) with Slider Panel Modification
Type of system: Redirective Non-Gating Crash Cushion
Test Level: TL-3
Testing conducted by: Safe Technologies Inc.
Task Force 13 Designator: SCI23
Date of request: February 25, 2010
Request Initially acknowledged: March 16, 2010
Date of Modification received: July 28, 2010 (letter dated July 23, 2010)
Date of completed Modification received: October 5, 2010

You requested that we find this system acceptable 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.”

Requirements
Roadside safety devices should meet the guidelines contained in the NCHRP Report 350 or the American Association of State Highway and Transportation Officials’ Manual for Assessing Safety Hardware (MASH). The FHWA Memorandum “Identifying Acceptable Highway Safety Features” of July 25, 1997 provides further guidance on crash testing requirements of longitudinal barriers.

Description
The X-TEN system is a redirective, non-gating crash cushion. The system is designed to safely decelerate an errant vehicle to a safe stop or redirect an errant vehicle away from roadside or median hazards. Enclosure 1 shows assembly of the X-TEN system. Enclosures 2 through 18 illustrate the details of each element used in the system. The system is comprised of an energy
absorbing nose cover, an energy absorbing nose cartridge, dual impact heads and cables, front cable anchors, W-Beam side panels, specially designed posts (Enclosure 8), and an independent backstop. Standard W-Beam block-out spacers (Enclosure 15) attach the side panels to the posts. The block-out spacers are tethered to the posts by wire ropes.

The system is designed to absorb the kinetic energy of the impacting vehicle. When a vehicle hits the system head-on, first energy is absorbed by the nose cover and the nose cartridge (Enclosure 13 and Enclosure 14). As the impact head is pushed back two cables (Enclosure 2) pull through a brake mechanism, dissipating energy. The depth of penetration of a vehicle into the system is dependent upon both the original impact speed and the mass of the impacting vehicle. When hit at an angle along the side beyond the first post, the system is restrained laterally by the W-Beam panels (Enclosure 6 and Enclosure 7) and cables that run the length of the system inside the panels. The front ends of the cables are attached to plates (Enclosure 12 and Enclosure 17) that are bolted to the foundation and the rear ends of the cables terminate in the backstop (Enclosure 4 and Enclosure 5) assembly.

The effective length of X-TEN system is 7.5 m (24 ft. 9 in.) and the effective overall height is 0.792 m (31.19 in.). The width of the system is 0.926 m (36.44 in.).

In addition, the following modifications and subsequent testing as submitted July 23, 2010 are as follows:

a. **Anchor Indicator Notches**: This modification consists of small triangular notches added on the front cable anchors and backstops to indicate which holes to use when anchoring to a concrete foundation. All holes are used when anchoring onto an asphalt foundation.

b. **Cable Retainers**: This modification consists of two small holes added to the front cable anchors to permit a plastic tie to be inserted. This plastic tie ‘tacks’ the cable in place in a slot during installation process.

c. **Plastic Nose Cartridge**: This modification consists of changing the existing energy absorbing nose piece cartridge to a thin-wall polyethylene canister consisting of steel mesh reinforced cardboard tube. This canister is filled with the same substance as the existing cartridge (i.e., polyurethane foam).

d. **Plastic Nose Cover**: This modification consists of changing existing nose cover design from a riveted multiple piece section to a single piece polyethylene shell section.

e. **Cable Length**: This modification consisted of changing the length of the existing cables slightly to allow a better fit and improve the release function.

f. **Bolted Slider Panel**: This modification consists of changing existing slider plate design from a welded section to a bolted section for ease of assembly purposes. The slider panels consist of the front W-Beam side panels that attach to the impact heads in the front of the system and wrap around the rear panels at the mid-point of the system. The original slider panel utilized a formed plate that was welded directly to the W-Beam panel and wrapped around the rear panel that is nested inside at the lapped joint. The welded connection was modified to incorporate a bolted connection. The bolt connection allows the rear panel to be nested inside the slider panel and then bolted in place during system assembly. Prior assembly required feeding the entire rear panel through the slider panel. The bolted connection was designed to be equal to or stronger than the welded connection to ensure equivalent function as was tested. The attached
computational analysis demonstrates that structural capacity of the proposed bolted joint is greater than that of the existing welded connection.

Crash Testing
The X-TEN crash cushion system was successfully crash tested as per NCHRP Report 350 test designations 3-31 through 3-33 and 3-36 through 3-39 by Safe Technologies Inc. In tests 3-31, 3-37, 3-38, and 3-39, the X-TEN system was attached to an Asphalt Concrete (AC) pad set over dense graded aggregate with forty two (42) 20 mm (3/4 inch) all thread studs embedded 400 mm (16 in.) and epoxied in place (Enclosure 19). In test 3-32, test 3-33, and test 3-36, the X-TEN system was attached to a Portland Cement Concrete (PCC) pad with twenty-six (26) 20 mm (3/4 in.) all thread studs embedded 150 mm (6 inch) and epoxied in place (Enclosure 20). Enclosures 21 through 23 summarize the results of test 3-31 through 3-33 respectively and Enclosures 24 through 27 summarize the results of test 3-36 through 3-39.

In addition, the X-TEN with slider panel modification crash cushion submission dated July 23, 2010 proposed the following:
1. One crash test as per NCHRP Report 350 Test 3-31 was conducted.
2. Request for equivalence to original crash testing for following crash tests:
   • During frontal impacts, the slider panel moves rearward, around the rear panel, and knocks the blockouts and panel connections free. When the end of the slider panel reaches the backstop, it interacts with a ramp on the backstop, forcing the nested panels outward and disengaging the cable from the backstop. Test 3-31 was performed on the system to demonstrate acceptable (and equivalent) function of the modified slider (and other system modifications) in the most severe loading of the effected connection. Other frontal impact tests including tests 3-30, 3-32, and 3-33, are not affected as critically by the slider modification as the system is not stroked far enough to engage many of functions of the component.
   • During side impacts, the slider panel provides lateral support to the re-direction of the impacting vehicle and transmits the tension to the rear panel. The slider panel also provides the fit to keep the panels nested properly during reverse side impacts. The original slider panel connection was proven adequate for transmitting longitudinal tension in tests 3-36, 3-37, 3-38, and 3-39. The bolted joint is capable of resisting a higher load, therefore, the modification was determined to not affect the performance of the system in these tests. The dimensional characteristics of the slider panel were maintained to ensure consistent gaps and clearances for proper nesting and resistance to snagging in reverse impacts.
   • For tests 3-36, 3-37, and 3-38, the slider panel connection is not loaded to failure or cause tension loading in excess of the front panel/rear panel joint capacity. While local deformation of the components is evident, research personnel indicate the excess strength of the bolted version of the slider panel does not affect the performance of the system or the occupant risk factors. Additional information can be reviewed in the research crash test report No. STI X-TEN-02.
   • In test 3-39, the front panel/rear panel joint is loaded beyond capacity. When excessive longitudinal forces are transmitted across the joint, the “slider bracket” yields and pulls through the slider panel, allowing the panels to separate. The slider bracket consists of a section of angle iron attached to the rearward panel. The welded
slider panel was not damaged. Therefore, the excess strength of the bolted version of the slider does not affect the performance of the system or the occupant risk factors.

Findings
As stated in your letter dated February 25, 2010, in accordance with NCHRP 350 tests 3-30 through 3-33 and tests 3-36 through 3-39 are to be conducted for test level 3 non-gating crash cushions approval. The system was crash tested under all of these required tests, except for test 3-30. The system described above and shown in Enclosure 1 passed all tests that were conducted. Occupant Impact Velocities (OIV) associated with all tests are below the “preferred” limit and Occupant Ridedown Acceleration (ORA) for all tests except test 3-31 are below the “preferred” limit. The ORA for test 3-31 was calculated 20 G which is the maximum allowable limit according to NCHRP 350.

In addition, you have requested test 3-30 be waived. Your request is accepted on the grounds that test 3-32 is historically more critical than test 3-30. In your letter, you have also requested FHWA acceptance of the following for the X-TEN system:

• The X-TEN system secured to Asphalt Concrete (AC) roadways,
• The X-TEN system secured to Portland Cement Concrete (PCC) foundations,
• The X-TEN system has redirective capacity beginning at the impact head behind the nose cover,
• The X-TEN system can be attached to other roadside barriers by using standard transitions that have been accepted for attaching “W” profile guardrails to rigid barrier systems.

The above additional requests are also accepted. Based on the provided videos of the crash tests conducted on the X-TEN attached to AC roadways or PCC foundations, none of the bolts were pulled out. In these tests either posts collapsed or the bolts sheared. Consequently, we concur that the X-TEN system can be attached to both AC roadways and PCC foundations.

In the crash test videos associated with tests 3-31, 3-32, and 3-33 (in which the test vehicle hits the test article head-on) the test articles confirm that the vehicle is captured when impacting the first post (does not gate through) and confirms the redirective capacity beginning at the impact head behind the nose cover.

Your last request in regards to attaching to other roadside barriers is also accepted on the grounds that attaching the X-TEN system using an appropriate standard connection will not likely degrade the performance of the system.

As requested in your letter dated July 23, 2010, referencing the X-TEN with modified slider plate crash cushion, we concur that modifications (a.) through (e.) inclusive will not adversely degrade the successful crash test performance of the system and are acceptable for use on the NHS system.

In addition and in reference to modification (f.), we concur with your request for equivalence in that a bolted slider plate (vs. original welded detail) does not adversely affect the successful crash test performance of the system and is acceptable for use on the NHS system.
Also, the results of the NCHRP Report 350 Test 3-31 as conducted on the X-TEN with slider panel modification crash cushion was found to successfully meet all Test 3-31 testing criteria. A summary of the crash test is attached. Therefore, the system described in the requests above and detailed in the enclosed drawings is acceptable for use on the NHS under the range of conditions tested, when such use is acceptable to a highway agency.

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

- This acceptance is limited to the crashworthiness characteristics of the systems 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 system 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 system being marketed is significantly different from the version that was crash tested, we reserve the right to modify or revoke our 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 it will meet the crashworthiness requirements of the FHWA and the NCHRP Report 350.
- To prevent misunderstanding by others, this letter of acceptance is designated as number CC-109 and shall not be reproduced except in full. This letter and the test documentation upon which it is based are public information. All such letters and documentation may be reviewed at our office upon request.
- The X-TEN system is a patented product and considered proprietary. If proprietary systems are specified by a highway agency for use on Federal-aid projects, except exempt, non-NHS projects, (a) they 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 system for which the applicant is not the patent holder. The acceptance letter is limited to the crashworthiness characteristics of the candidate system, 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,

Michael S. Griffith
Director, Office of Safety Technologies
Office of Safety

29 Enclosures
NOTES UNLESS OTHERWISE SPECIFIED
1. MATERIAL: ASTM A36
2. FINISH: GALVANIZED PER ASTM A123
NOTES UNLESS OTHERWISE SPECIFIED
1. MATERIAL: ASTM A36
2. FINISH: GALVANIZED PER ASTM A123
NOTES UNLESS OTHERWISE SPECIFIED:
1. MATERIAL: ASTM A36
2. FINISH: GALVANIZED PER ASTM A123
1. MATERIAL  ASTM A36 & A606
2. FINISH  GALVANIZED PER ASTM A123

ENCLOSURE 6

BACK PANEL WELDMENT, X-TEMUATOR

BARRIER SYSTEMS

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REV.  CHANGES  DATE  BY  REVD  NEXT ASSY.  ITEM

1 OF 1  B100263-US  0
NOTES UNLESS OTHERWISE SPECIFIED:
1. MATERIAL: ASTM A36 & A606
2. FINISH: GALVANIZED PER ASTM A123
1. MATERIAL: ASTM A36
2. FINISH: GALVANIZED PER ASTM A123
NOTES UNLESS OTHERWISE SPECIFIED
1. MATERIAL: ASTM A36
2. FINISH: GALVANIZED PER ASTM A123
NOTES UNLESS OTHERWISE SPECIFIED
1. MATERIAL: GLASS REINFORCED NYLON

Enclosure 16

PLASTIC NUT PROTECTOR
NOTES UNLESS OTHERWISE SPECIFIED:
1. MATERIAL: ASTM A36
2. FINISH: GALVANIZED PER ASTM A123
Figure 6. Summary of Results, X-TENuator™ Test # SCC20
General Information

Test Agency: SAFE TECHNOLOGIES, INC.
Test Designation: NCHRP Report 350 3-33
Test No: STI Test #SCC25
Date: 2/11/2010

Test Article
Type: Redirextive, non-gating, crash cushion
Name: X-TENuator Crash Cushion
Dimensions: Length: 7.5 meters (24' 9")
Height: 732 mm (31 19")
Width: 926 mm (36 44")

Test Vehicle
Type: Production Model
Designation: 2000P
Model: 2004 Chevrolet 3/4 ton pickup
Mass (kg): 2168
Curb: 2168
Test Inertial: 2025
Dummy(s): n/a
Gross Static: 2025

Impact Conditions
Speed (km/h): 99
Angle (deg): 15
Impact Severity (kJ): 770.3

Exit Conditions
Speed (km/h): n/a
Angle (deg): n/a
Occupant Risk Values
Impact velocity (m/s)
x-direction: 8
y-direction: 1
Ride-down Acceleration (g's)
x-direction: 12
y-direction: 6

Test Article Deflection (mm)
Dynamic: 2360
Permanent: 2360

Vehicle Damage
Exterior
YDS: FC-2
CDC: 12FCEW2
Interior
OCID: FS0000000

Post-Impact Vehicular behavior (deg - gyro @ c.g)
Maximum Roll Angle: 44
Maximum Pitch angle: 7
Maximum Yaw Angle: 232

Figure 26. Summary of Results, X-TENuator™ Test # SCC25
### General Information

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<td>STI Test # SCC23</td>
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### Test Article

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<tr>
<td>Name</td>
<td>X-TENuator Crash Cushion</td>
</tr>
<tr>
<td>Dimensions</td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>75 meters (24' 9&quot;)</td>
</tr>
<tr>
<td>Height</td>
<td>792 mm (31 1/2&quot;)</td>
</tr>
<tr>
<td>Width</td>
<td>926 mm (36 4/8&quot;)</td>
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### Test Vehicle

<table>
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<td>Designation</td>
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<tr>
<td>Model</td>
<td>1987 Honda CRX</td>
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<tr>
<td>Mass (kg)</td>
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<tr>
<td>Curb</td>
<td>820 S</td>
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<tr>
<td>Dummy(s)</td>
<td>75</td>
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<tr>
<td>Gross Static</td>
<td>807 S</td>
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### Exit Conditions

| Speed (km/h)       | 76                                      |
| Angle (deg)        | 4                                       |

### Occupant Risk Values

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<tr>
<th>Impact velocity (m/s)</th>
<th>x-direction</th>
<th>y-direction</th>
<th>Ridedown Acceleration (g/s)</th>
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<th>y-direction</th>
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<td>3</td>
<td>6</td>
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<td>3</td>
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### Test Article Deflection (mm)

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</thead>
<tbody>
<tr>
<td>Permanent</td>
<td>64</td>
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### Vehicle Damage

**Exterior**
- VDS: FL-2
- CDC: 1FLENN2

**Interior**
- OCDI: FL0000000

### Post-Impact Vehicular Behavior (deg - gyro @ c.g)

- Maximum Roll Angle (before capture) 8°
- Maximum Pitch Angle (before separation) 3°
- Maximum Yaw Angle (at separation) 24.3°

---

**Figure 21. Summary of Results, X-TENuator™ Test # SCC23**
**General Information**
- Test Agency: SAFE TECHNOLOGIES, INC.
- Test Designation: NCHRP Report 350 3-37
- Test No: STI Test # SCC22
- Date: 1/2/2010

**Test Article**
- Type: Redective, non-gating, crash cushion
- Name: X-TENuator Crash Cushion
- Dimensions: Length: 15 meters (24' 9")
- Height: 762 mm (31 1/9")
- Width: 926 mm (36 4/4")

**Test Vehicle**
- Type: Production Model
- Designation: 2000P
- Model: 2003 Chevrolet 34 Tonne Pickup
- Mass (kg): 2191
  - Curb: 2191
  - Test Initial: 2037
  - Dummy(s): 0
  - Gross Static: 2037

**Impact Conditions**
- Speed (km/h): 101
- Angle (deg): 20
- Impact Severity (kJ): 90.3

**Exit Conditions**
- Speed (km/h): 86
- Angle (deg): 11

**Occupant Risk Values**
- Impact velocity (n/s):
  - x-direction: 4
  - y-direction: 5
- Roll Over Acceleration (g/s):
  - x-direction: 10
  - y-direction: 11

**Test Article Deflection (mm)**
- Dynamic: 371
- Permanent: 312

**Vehicle Damage**
- Exterior
  - VDS: FL-4
  - CDC: 11LEW4
- Interior
  - ODL: FL0000000

**Post-Impact Vehicle behavior (deg - g)'s @ c.g**
- Maximum Roll Angle (before capture): 16
- Maximum Pitch angle (before capture): 11
- Maximum Yaw Angle (at separation): 35.5 (after capture)

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*Figure 16. Summary of Results, X-TENuator™ Test # SCC22*
Figure 11. Summary of Results, X-TENuator™ Test # SCC21
Figure 31. Summary of Results, X-TENuator™ Test # SCC26
Following certification testing of the X-TENuator Crash Cushion and subsequent submittal to FHWA for acceptance, the “slider panels” were modified to enable easier assembly of the system. The “slider panels” consist of the front W-Beam side panels that attach to the impact heads in the front of the system and wrap around the rear panels at the mid-point of the system. The original slider panel utilized a formed plate that was welded directly to the W-Beam panel and wrapped around the rear panel that is nested inside at the lapped joint (see Figure 1 below). The welded connection was modified to incorporate a bolted connection. The bolt connection allows the rear panel to be nested inside the slider panel and then bolted in place during system assembly (see Figure 2 below). Prior assembly required feeding the entire rear panel through the slider panel.

The bolted connection was designed to be equal to or stronger than the welded connection to ensure equivalent function as was tested and submitted to FHWA for acceptance. The calculations below demonstrate the structural capacity of the bolted joint is greater than the welded connection.

**Slider Panel Analysis:**

**Material Properties:**

\[
\begin{align*}
\sigma_{A36} &= 36000 \text{-psi} \\
\sigma_{g5} &= 120000 \text{-psi} \\
A_0 &= 5 = 0.1416 \text{-in}^2
\end{align*}
\]

**1/2“ Grade 5 Bolt:**

\[
\begin{align*}
A &= 0.1416 \text{-in}^2 \\
A_0 &= 0.1416 \text{-in}^2 \\
F_0 &= 1.699 \times 10^4 \text{lbf}
\end{align*}
\]

**Welded Connection**

\[
\begin{align*}
l_w &= 9.31 \text{-in} \\
w_w &= 0.1875 \text{-in} \\
A_w &= 1.746 \text{-in}^2 \\
F_w &= 6.284 \times 10^4 \text{lbf}
\end{align*}
\]

**Bolted Connection**

\[
\begin{align*}
n &= 4 \\
F_0 &= 1.699 \times 10^4 \text{lbf} \\
F_b &= n \cdot F_0 \\
F_b &= 6.797 \times 10^4 \text{lbf}
\end{align*}
\]
In frontal impacts, the slider panel moves rearward, around the rear panel, and knocks the blockouts and panel connections free. When the end of the slider panel reaches the backstop, it interacts with a ramp on the backstop, forcing the nested panels outward and disengaging the cable from the backstop. Test 3-31 was performed on the system to demonstrate acceptable (and equivalent) function of the modified slider (and other system modifications) in the most severe loading of the effected connection. Other frontal impact tests including tests 3-30, 3-32, and 3-33, are not affected as critically by the slider modification as the system is not stroked far enough to engage many of functions of the component.

During side impacts, the slider panel provides lateral support to the re-direction of the impacting vehicle and transmits the tension to the rear panel. The slider panel also provides the fit to keep the panels nested properly during reverse side impacts. The original slider panel connection was proven adequate for transmitting longitudinal tension in tests 3-36, 3-37, 3-38, and 3-39. The bolted joint is capable of resisting a higher load, therefore, the modification was determined to not affect the performance of the system in these tests. The dimensional characteristics of the slider panel were maintained to ensure consistent gaps and clearances for proper nesting and resistance to snagging in reverse impacts.

In tests 3-36, 3-37, and 3-38, the slider panel connection is not loaded to failure or cause tension loading in excess of the front panel/rear panel joint capacity. While local deformation of the components is evident, the excess strength of the bolted version of the slider panel does not affect the performance of the system or the occupant risk factors. Figures 3 and 4 below illustrate the post impact condition of the slider panel and rear panel for tests 3-37 and 3-38. Test 3-36 shows very minor to no damage to the side panels.

Figure 3: Post Impact 3-37

Figure 4: Post Impact 3-38

In test 3-39, the front panel/rear panel joint is loaded beyond capacity. When excessive longitudinal forces are transmitted across the joint, the "slider bracket" yields and pulls through the slider panel, allowing the panels to separate. The slider bracket consists of a section of angle iron attached to the rearward panel. The welded slider panel was not damaged. Therefore, the excess strength of the bolted version of the slider does not
affect the performance of the system or the occupant risk factors. Figure 5 below illustrates the failure mode of the joint.

Figure 5: Post Impact 3-39

System and component drawings are attached to this document.
NOTES UNLESS OTHERWISE SPECIFIED

1. HOLES TO BE FREE OF WELD SPLATTER
   FINISH TO BE HOT DIPPED GALVANIZED PER ASTM A123
Figure 1. Summary of Results, X-TENuator™ Test # SCC27