A COMPARATIVE STUDY OF DESIGN TORNADO MISSILES AT SRS

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Structural Mechanics – SRR/SRNS
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**Objective**

A comparison between the prior design tornado missile requirements of DOE-STD-1020 and the new design missile requirements per ANS 2.3 at the Savannah River Site (SRS).

DOE-STD-1020-02 vs. DOE-STD-1020-12 Missile Criteria & The effect on existing missile shield design of frame and grating at SRS.
# Tornado Hazard Criteria Changes

Table- 1  WDC-3 at SRS

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2x4 timber plank 15 lb @ 100 MPH (Horiz) max height 150 ft ; 70 mph (vert)</td>
<td>1.0&quot; dia. Solid steel sphere , 0.147 lb @ 16 MPH (horiz) and 11 MPH (vert)</td>
<td></td>
</tr>
<tr>
<td>3 in dia std steel pipe, 75 lb @ 50 mph (horiz)max height 75 ft; 35 MPH (vert).</td>
<td>6 in dia Sch 40 steel pipe, 15 ft-length, 287 lb @ 64 mph (horiz) and 43 MPH (vert).</td>
<td></td>
</tr>
<tr>
<td>3000 lb automobile @ 19 MPH rolls and tumble</td>
<td>4000 lb automobile @ 48 MPH , 20 ft² contact area, max elevation 30-ft.</td>
<td></td>
</tr>
</tbody>
</table>
**Case Study**

Safety-grade nitrogen system requires protection from missiles. Necessary ventilation was achieved by shielding system with steel grating which would permit ambient airflow which is adequate for proper equipment operation. The structure was built in 2000, with steel column at each corner. 20 ft x 19 ft and @ 12 ft in height and covered by grating on all sides.

*Figure 1 – Shielding Frame – Plan View and Cross Section*
Case Study - SRS

STAAD 3-D model with dead load, live load, tornado load.

Grating
Nitrogen Tank

Bollard

Figure 1 – Shielding Frame – with Bollards around

17 kips per DOE-STD -1020 -2002
83 kips per DOE-STD -1020 -2012
The missile shield is designed for tornado generated missile impact loads for WDC-3 structure as shown below:

Force : \( P = (m)(F) \) where \( P = \) Impact force \( F = \) Acceleration / retardation;

It is assumed that the object decelerates in one hundredth of a second (0.01 second) after impact. In reality the support will deflect, the missile will deform and will reduce the impact forces to great extent.

Results:
- \( P2 \) 17 kips (2002)
- \( P2 \) 83 kips (2012)
Using an equivalent static methodology, significant increase in kinetic energy of pipe and automobile missiles as shown below was obtained:

<table>
<thead>
<tr>
<th>NPH Design Category</th>
<th>DOE-STD-2002</th>
<th>DOE-STD-2012</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 in dia std steel pipe, 75 lb @ 100 mph (horiz)</td>
<td>6 in dia Sch 40 steel pipe, 15 ft-length, 287 lb @ 64 mph (horiz)</td>
<td>%</td>
</tr>
<tr>
<td>Kinetic Energy</td>
<td>KE= 75 kip-in</td>
<td>KE= 417 kip-in</td>
<td>556%</td>
</tr>
<tr>
<td></td>
<td>3000 lb automobile @ 19 MPH rolls and tumble</td>
<td>4000 lb automobile @ 48 MPH, 20 ft^2 contact area, max elevation 30- ft.</td>
<td></td>
</tr>
<tr>
<td>Kinetic Energy</td>
<td>KE= 36 kip-ft</td>
<td>KE= 303 kip-ft</td>
<td>880%</td>
</tr>
</tbody>
</table>
Missile load for WDC-3 Frame – Elasto-Plastic SDOF methodology

Results:

P2 12.3 kips (2002)
P2 39.9 kips (2012)
# Impact from hollow steel pipe

Using the Elasto-Plastic Single Degree of Freedom Analysis method:

<table>
<thead>
<tr>
<th>Missile Type</th>
<th>DOE STD 1020-2002</th>
<th>DOE STD 1020-2012</th>
<th>Impulse</th>
<th>Critical Structure (Tornado Shield)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Pipe</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 in dia std steel pipe, 75 lb @ 50 mph (horiz) max height 75 ft; 35 MPH (vert).</td>
<td></td>
<td>I=170.9 kips-ms Peak force = 33.72 kips</td>
<td>T_d = 10.1 ms P_u=12.3 kips δ_sw=0.491” &lt; 5.53” OK θ= 0.052 ° &lt; 2.0 ° OK</td>
</tr>
<tr>
<td></td>
<td>6 in dia Sch 40 steel pipe, 15 ft-length, 287 lb @ 64 mph (horiz) and 43 MPH (vert).</td>
<td></td>
<td>I=837.6 kips-ms Peak force = 109.5 kips</td>
<td>T_d = 15 ms P_u=39.9 kips δ_sw=1.59” &lt; 5.53” OK θ= 0.20 ° &lt; 2.0 ° OK</td>
</tr>
</tbody>
</table>

F_n = 2.51 Hz T_n = 39.8 ms
Missile load for WDC-3 Frame

Maximum D/C with 2002 criteria was 0.47
With 2012 criteria D/C is 1.73 as shown above for Equivalent static methodology

With 2012 criteria D/C is 0.91 as shown above for Elasto-Plastic SDOF methodology
## Impact from Automobile

Using the Elasto-Plastic Single Degree of Freedom Analysis method:

<table>
<thead>
<tr>
<th>Missile Type</th>
<th>DOE STD 1020-2002</th>
<th>DOE STD 1020-2012</th>
<th>Impulse</th>
<th>Critical Structure (Tornado Shield)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automobile</td>
<td>3000 lbs @ 19 mph (horz.) roll and tumble (i.e. use a frontal contact)</td>
<td>l=2639.4 kips-ms Peak Force = 52.31 kips</td>
<td>T&lt;sub&gt;d&lt;/sub&gt; = 78.5 ms</td>
<td>P&lt;sub&gt;u&lt;/sub&gt;=74.5 kips d&lt;sub&gt;sway&lt;/sub&gt;=3.28&quot; &lt; 5.53&quot; OK q= 1.4 ° &lt; 2.0 ° OK</td>
</tr>
<tr>
<td></td>
<td>4000 lbs @ 48mph (horz.), contact surface=20 ft², max impact ht. is 30 ft.</td>
<td>l=8880.4 kips-ms Peak Force =176 kips</td>
<td>T&lt;sub&gt;d&lt;/sub&gt; = 78.5 ms</td>
<td>P&lt;sub&gt;u&lt;/sub&gt;=74.5 kips d&lt;sub&gt;sway&lt;/sub&gt;=31.04&quot; &gt; 5.53&quot; N.G. q= 12.9 ° &gt; 2.0 ° N.G. (blow away)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>F&lt;sub&gt;n&lt;/sub&gt; = 2.51 Hz T&lt;sub&gt;n&lt;/sub&gt; = 39.8 ms</td>
</tr>
</tbody>
</table>
Impact from Automobile 2002 Criteria

Using the Elasto-Plastic SDOF vs Elastic Dynamic Analysis:

Max. Sway$_{\text{elastic}} = 2.81”$

Max. Sway$_{\text{elasto-plastic}} = 3.48”$

Min. Gap btw Shield and tank = 12”
# Impact from Solid Rod and Plank

Using the Elasto-Plastic Single Degree of Freedom Analysis method:

<table>
<thead>
<tr>
<th>Missile Type</th>
<th>DOE STD 1020-2002</th>
<th>DOE STD 1020-2012</th>
<th>Impulse</th>
<th>Critical Structure (Tornado Shield)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total/Shape</td>
<td>Freq./duration</td>
<td>Response</td>
<td>Freq./Period</td>
</tr>
<tr>
<td>1&quot; Φ solid steel rod</td>
<td>1.0&quot; dia. Solid steel sphere, 0.147 lb @ 16 MPH (horiz) and 11 MPH (vert)</td>
<td>l=0.107 kips-ms</td>
<td>T_d = 0.0023 ms</td>
<td>P_u=0.0045 kips δ_sway=0.00019&quot; &lt; 5.53&quot; OK θ= 0.000077 ° &lt; 2.0 ° OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>F_n = 2.51 Hz T_n = 39.8 ms</td>
</tr>
<tr>
<td>2x4 timber plank</td>
<td>2x4 timber plank</td>
<td>15 lb @ 100 MPH (Horiz) max height 150 ft ; 70 mph (vert)</td>
<td>i=68.35 kips-ms</td>
<td>T_d = 1.406 ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>F_n = 2.51 Hz T_n = 39.8 ms</td>
</tr>
</tbody>
</table>
Discussion

For the rolling/tumbling automobile impact, the impact was taken entirely by the Bollards. But with the new criteria, the bollard are not effective with an impact happening at 30 ft. Though the frame will survive a 2002 automobile criteria impact, it would need to dissipate energy in the inelastic regime.

Weight and Speed of impact have increased for the automobile missile. The 2012 automobile criteria impact will not work even with inelastic energy dissipation. The recommended solution would be to determine the SRS site specific tornado missile speed for automobile.

Using inelastic deformation of the frame to dissipate the impact energy, the acceptance therefore becomes limiting the sway. A sway of L/25 prevents progressive collapse and prevents the frame from impacting the Nitrogen tanks.
Missile load for WDC-3 Frame Grating Analysis

In 2000, tornado missile barrier test was performed on grating at SRS. The intent of testing was to determine size and orientation parameters for shielding design, utilizing grating to stop the DBT missile. The damage to each target was documented by visual inspection after impact, still photos and video of the test results. This test data was used in grating evaluation for the requirements of DOE-STD-1020.
Missile load for WDC-3 Frame (GRATING)

1 inch gap (height)

STAAD Analysis Results – Deflection (max Z= 3.453 inches)
Missile load for WDC-3 Frame Bollard Analysis

The Bollard was designed (in 2000) at SRS to protect the nitrogen tank missile shield from 3000 lbs. rolling and tumbling automobile at 19 MPH.

Each bollard consists of a concrete filled pipe embedded in the ground. The bollards are spread about 3 feet on center and about 3 feet from the face of the tornado missile shield. The bollard resists the tornado missile by absorbing all of the tornado missile's kinetic energy. The energy dissipated by the missile is conservatively neglected in the analysis. Energy absorption of both the composite concrete filled steel pipe and the surrounding soil are considered. A pseudo-static nonlinear pushover analysis of the bollard is performed to determine the total energy absorption capacity of these two interacting mechanisms.

Total Kinetic energy 36.1 ft*kip to 303 ft*kip
DOE-STD-2002 vs DOE-STD-2012
Conclusions

* Adopting the ANS 2.3 2011 Automobile tornado missile criteria will be problematic for the SRS tornado shield design. Recommend site specific Probabilistic wind missile study to predict site specific tornado missile speed.
* If we need to revalidate all tornado missile shielding for the site, we recommend that the inelastic deformation be allowed to dissipate the impact energy.
* Grating testing performed in 2000 at SRS may need to re-visited and retested per DOE-STD-1020-2012.

Questions?