Internal Blast Test of a Reinforced Concrete Structure

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Objective:
Advance the use of threaded mechanical couplers and headed rebar technology in DoD protective construction.

Goals:
• Demonstrate efficacy of rebar technology at larger support rotations (2-6 degrees)
• Provide equivalent protection as conventional rebar
• Transfer technology to DoD construction via UFC
Test Setup

- **3 Tests**
  - Test 1 - Center of room
  - Test 2 - 1.65 x Test 1 – Center of room
  - Test 3 – 2 charges each equal to Test 1 charge – next to walls

- **Doorway sized vent area**
• Reinforced Concrete for Blast-Resistant Design:
  – Mass, strength, ductility, and penetration resistance
  – Cost, Constructability, and Maintainability

• Advantages of Couplers and End Plates:
  – Improved constructability
  – Enhanced concrete quality
  – Simplified rebar detailing
  – Efficient load transfer mechanism
  – Cost

• Previous Testing:
  – HIPPO (2013)
  – Rowell et al (2009) tested several couplers at high strain rates
  – Young et al (2011) performed in-situ testing of two types of taper thread couplers
  – Holland and Wesevich (2012) performed in-situ tests with shear screw couplers using a shock tube.
Instrumentation

- **Incident Pressure Gauges**
  - Four (4) on Ground
  - Five (5) Exit and Witness Rooms

- **Reflected Pressure Gauges**
  - Nine (9) on Conventional RC Wall
  - Nine (9) on RC Wall with Rebar Technologies
  - One (1) on CSSW

- **Displacement Gauges**
  - Nine (9) on Conventional RC Wall
  - Nine (9) on RC Wall with Rebar Technologies
  - One (1) on CSSW
  - Three (3) on Roof Slab

- **High Speed Video**
  - Back Side of Each Wall
  - Multiple Overview Shots

- **Pre- and Post-Test Still Photography**
Instrumentation

Displacement Gauges and Gauge-Wall Connection

Roof Displacement Gauges
## Test 1 - Internal Blast Test

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>0.90 in.</td>
<td>0.72 deg</td>
</tr>
<tr>
<td>Coupler</td>
<td>0.67 in.</td>
<td>0.53 deg</td>
</tr>
<tr>
<td>Roof</td>
<td>6.02 in.</td>
<td>2.87 deg</td>
</tr>
</tbody>
</table>

**Coupler Wall**

**Conventional Wall**
Test 1 - Results

Reflected Pressure and Impulse

Midspan Displacement
# Test 2 - Internal Blast Test

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>2.49 in.</td>
<td>1.98 deg</td>
</tr>
<tr>
<td>Coupler</td>
<td>1.64 in.</td>
<td>1.31 deg</td>
</tr>
<tr>
<td>Roof</td>
<td>10.98 in.</td>
<td>5.22 deg</td>
</tr>
</tbody>
</table>

**Images:**
- **Coupler Wall**
- **Conventional Wall**
Test 2 - Results

Reflected Pressure and Impulse

Midspan Displacement
Test 3 – Location of Charges

- Test 1 & 2 Charge Location
- Test 3 Charge Location
## Test 3- Internal Blast Test

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>8.69 in.</td>
<td>6.88 deg</td>
</tr>
<tr>
<td>Coupler</td>
<td>3.81 in.</td>
<td>3.03 deg</td>
</tr>
<tr>
<td>Roof</td>
<td>~ 4 ft</td>
<td>~38 deg</td>
</tr>
</tbody>
</table>

**Free Edge**

**Coupler Wall**

**Conventional Wall**
Test 3 – Internal Blast Test
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Test 3- Results

Reflected Pressure and Impulse

Normalized Pressure [psi]
Normalized Impulse [psi-msec]

0 50 100 150 200 250 300 350 400 450 500 550 600

Time, msec

6 ft from Ground - 6 ft from Charge
Baseline RC Wall - Pressure
Baseline RC Wall - Impulse
Test RC Wall - Pressure
Test RC Wall - Impulse

1 ft from Ground - 6 ft from Charge
Baseline RC Wall - Pressure
Baseline RC Wall - Impulse
Test RC Wall - Pressure
Test RC Wall - Impulse

10 ft from Ground - 14 ft from Charge
Baseline RC Wall - Pressure
Baseline RC Wall - Impulse
Test RC Wall - Pressure
Test RC Wall - Impulse

NAVFAC EXWC: Technology Driven, Warfighter Focused
Test 3- Results

Midspan Displacement

Baseline RC Wall
Test RC Wall

Displacement [in]
Time [msec]

NAVFAC EXWC: Technology Driven, Warfighter Focused
## Residual and Cumulative Results

<table>
<thead>
<tr>
<th>Test</th>
<th>Measurement</th>
<th>Baseline Wall</th>
<th>Test Wall</th>
<th>Roof</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test 1</strong></td>
<td>Residual Disp.</td>
<td>0.14 in.</td>
<td>0.16 in</td>
<td>2.59 in</td>
</tr>
<tr>
<td></td>
<td>Residual Rot.</td>
<td>0.13 deg</td>
<td>0.12 deg</td>
<td>1.23 deg</td>
</tr>
<tr>
<td><strong>Test 2</strong></td>
<td>Residual Disp.</td>
<td>1.01 in.</td>
<td>0.57 in</td>
<td>2.62 in</td>
</tr>
<tr>
<td></td>
<td>Residual Rot.</td>
<td>0.80 deg</td>
<td>0.45 deg</td>
<td>1.25 deg</td>
</tr>
<tr>
<td><strong>Test 2 – Cumulative</strong></td>
<td>Max Disp.</td>
<td>2.64 in.</td>
<td>1.81 in</td>
<td>13.6 in</td>
</tr>
<tr>
<td></td>
<td>Max Rot.</td>
<td>2.11 deg</td>
<td>1.43 deg</td>
<td>6.45 deg</td>
</tr>
<tr>
<td><strong>Test 3</strong></td>
<td>Residual Disp.</td>
<td>6.95 in.</td>
<td>1.95 in</td>
<td>5.92 in</td>
</tr>
<tr>
<td></td>
<td>Residual Rot.</td>
<td>5.51 deg</td>
<td>1.55 deg</td>
<td>2.82 deg</td>
</tr>
<tr>
<td><strong>Test 3 – Cumulative</strong></td>
<td>Max Disp.</td>
<td>9.7 in.</td>
<td>4.38 in.</td>
<td>~ 4 ft</td>
</tr>
<tr>
<td></td>
<td>Max Rot.</td>
<td>7.68 deg</td>
<td>3.48 deg</td>
<td>~ 38 deg</td>
</tr>
</tbody>
</table>

*Cumulative includes maximums from respective test plus the residuals from the previous test*
Discussion of Results

Baseline RC Wall

- Exceeded 2 degrees support rotation after Test 2
- Max. rotation of 7.7 degrees
- Cumulative displacement of 6.95 in.
- 4 to 5 lap splice connections failed

Test RC Wall

- Exceeded 2 degrees support rotation after Test 3
- Max. rotation of 3.5 degrees
- Cumulative displacement of 1.95 in.
- Fracture of one rebar but outside the coupler region
Discussion of Results
Discussion of Results

Baseline Wall

Test Wall
Discussion of Results

• Couplers performed well in regions of very high strain rates
• Wall with rebar with end plate detail had less overall deformation and connection to roof remained intact under significant joint opening
• Wall with hooked ends had more deformation and under significant joint opening concrete crushed and hooks opened up
• Cost savings of 5 to 10 percent using rebar with end plates and threaded mechanical couplers
  – Reduced volume of required steel
  – Increased worker productivity during installation
  – Reduced likelihood of required repairs due to poor concrete consolidation stemming from rebar congestion
• System promotes constructability
Thank you!

Questions?