Internal Blast Test of a Reinforced Concrete Structure

International Explosives Safety Symposium and Exposition
San Diego, CA

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Overview

Objective:

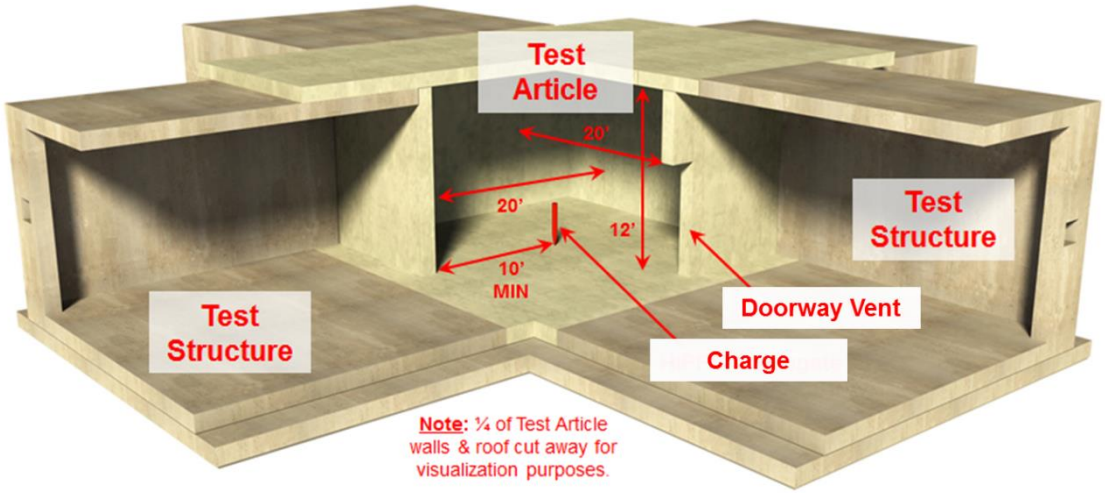
Advance the use of threaded mechanical couplers and headed rebar technology in DoD protective construction.

Goals:

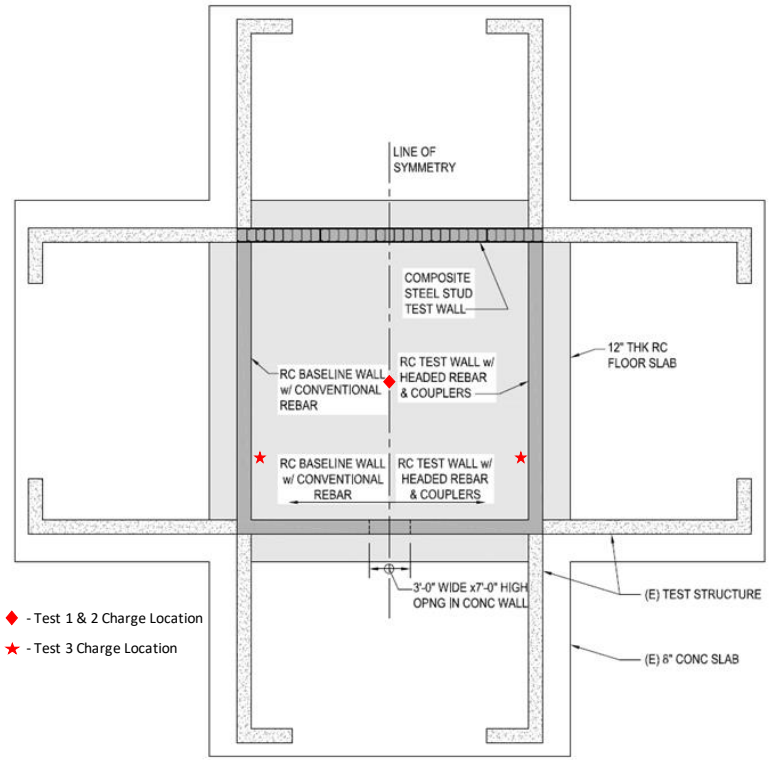
- Demonstrate efficacy of rebar technology at larger support rotations (2-6 degrees)
- Provide equivalent protection as conventional rebar
- Transfer technology to DoD construction via UFC

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



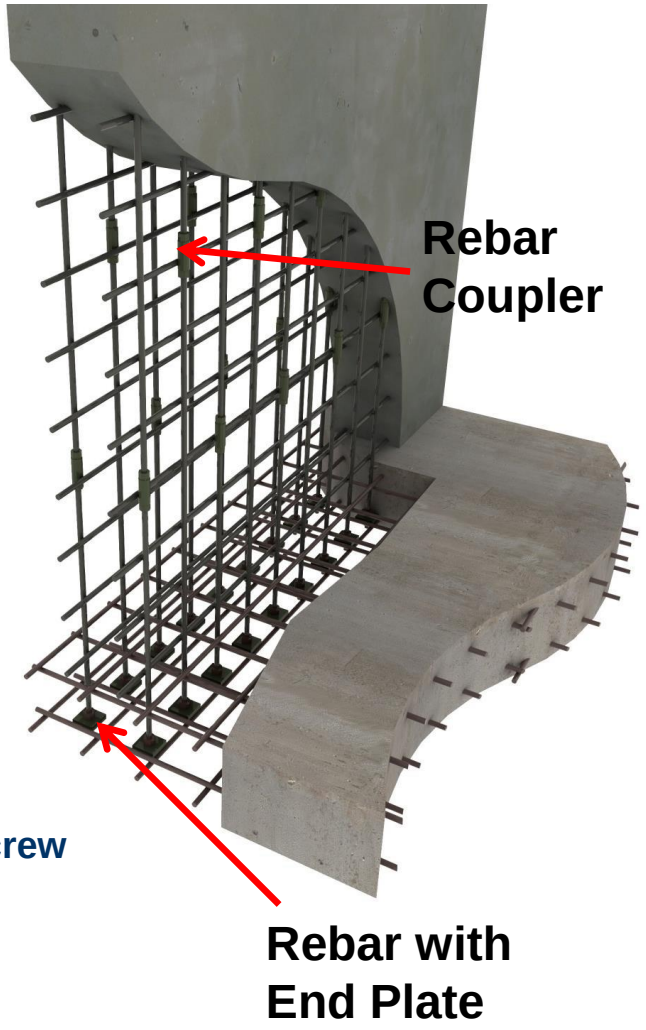
Isometric View



Plan View

Reinforced Concrete with Couplers and Rebar with End Plates

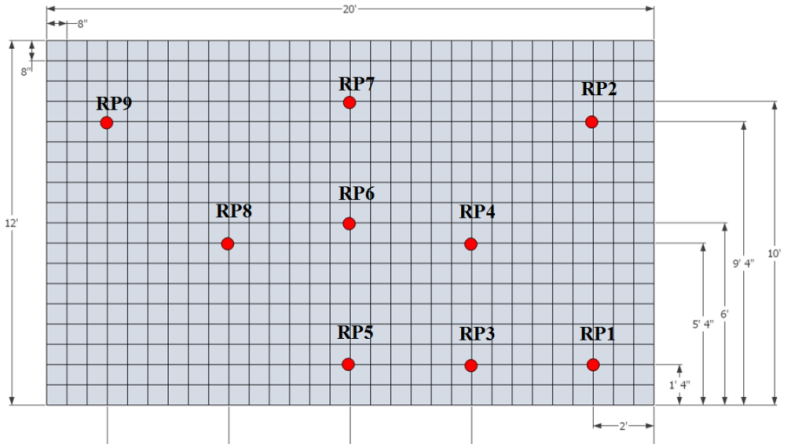
- **Reinforced Concrete for Blast-Resistant Design:**
  - Mass, strength, ductility, and penetration resistance
  - Cost, Constructability, and Maintainability
- **Advantages of Couplers and End Plates:**
  - Improved constructability
  - Enhanced concrete quality
  - Simplified rebar detailing
  - Efficient 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.



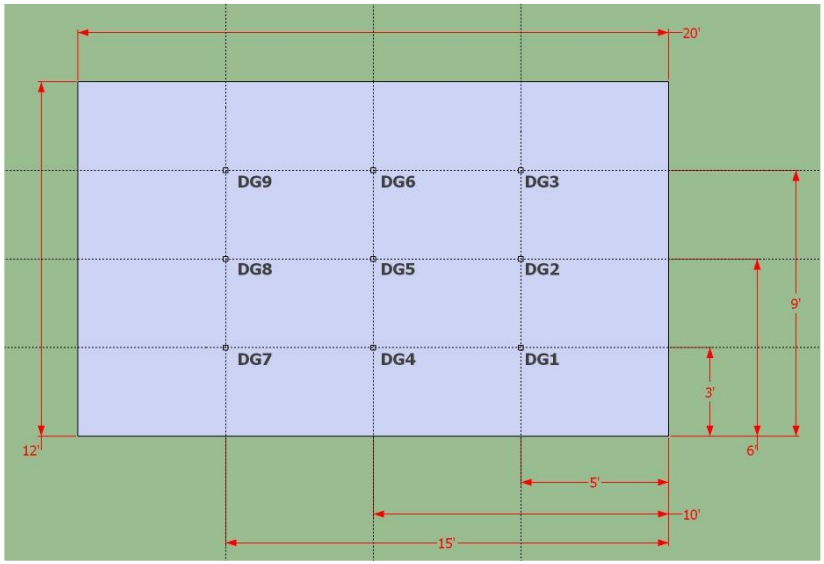
Instrumentation

- **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**

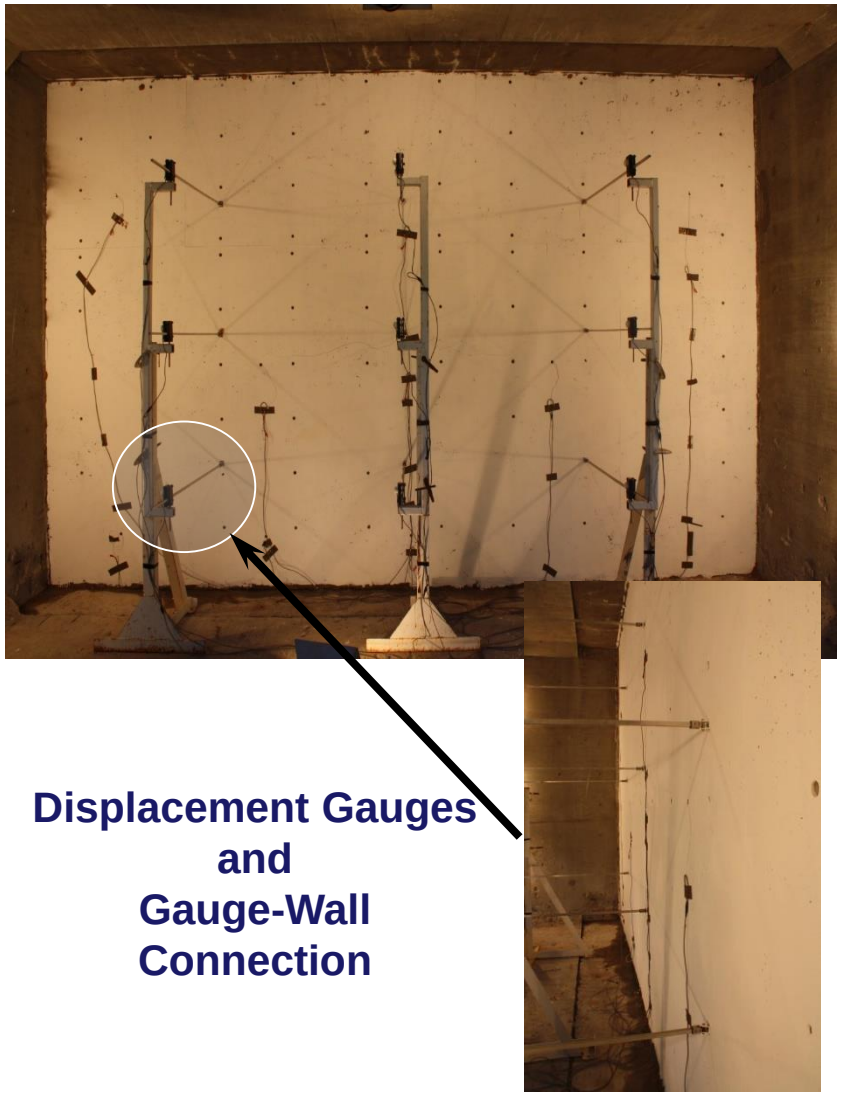
Pressure Gauges



Displacement Gauges



Instrumentation



Displacement Gauges and Gauge-Wall Connection

Roof Displacement Gauges

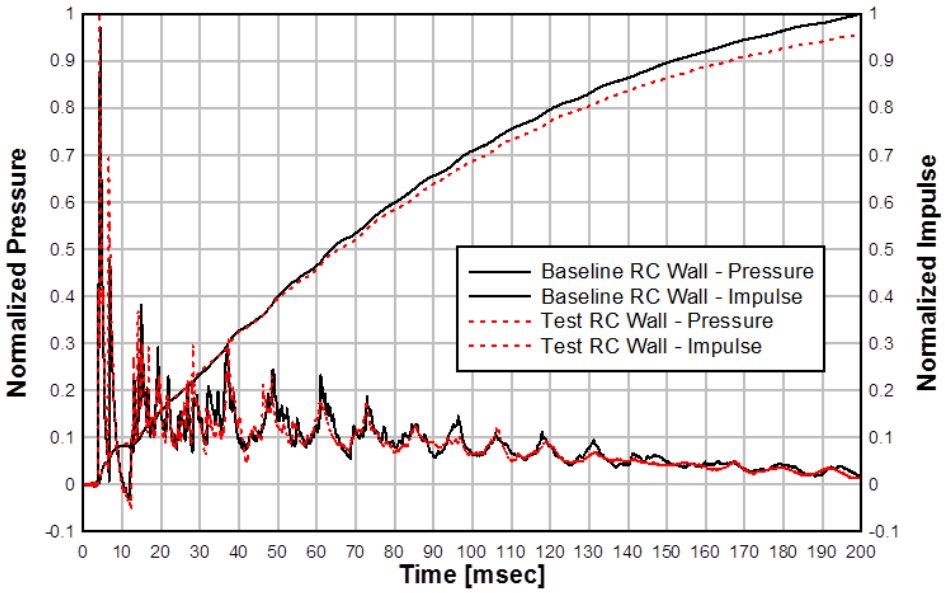
Test 1- Internal Blast Test

Wall	Max. Disp.	Max. Rot.
Conventional	0.90 in.	0.72 deg
Coupler	0.67 in.	0.53 deg
Roof	6.02 in.	2.87 deg

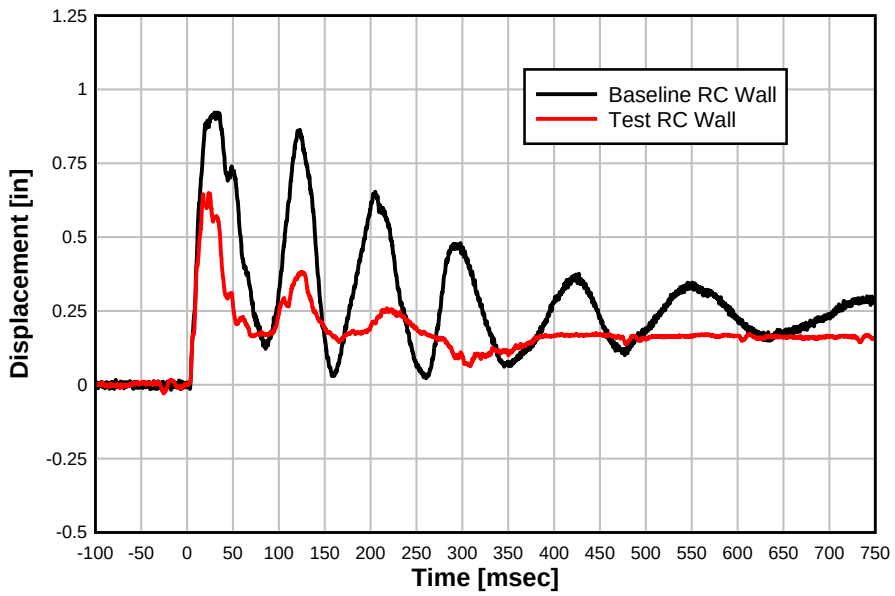
Coupler Wall

Conventional Wall

Test 1- Results



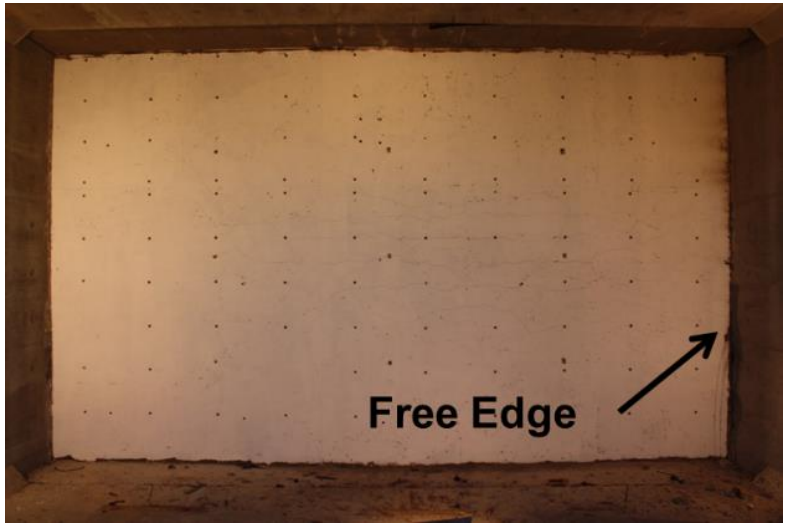
Reflected Pressure and Impulse



Midspan Displacement

Test 2- Internal Blast Test

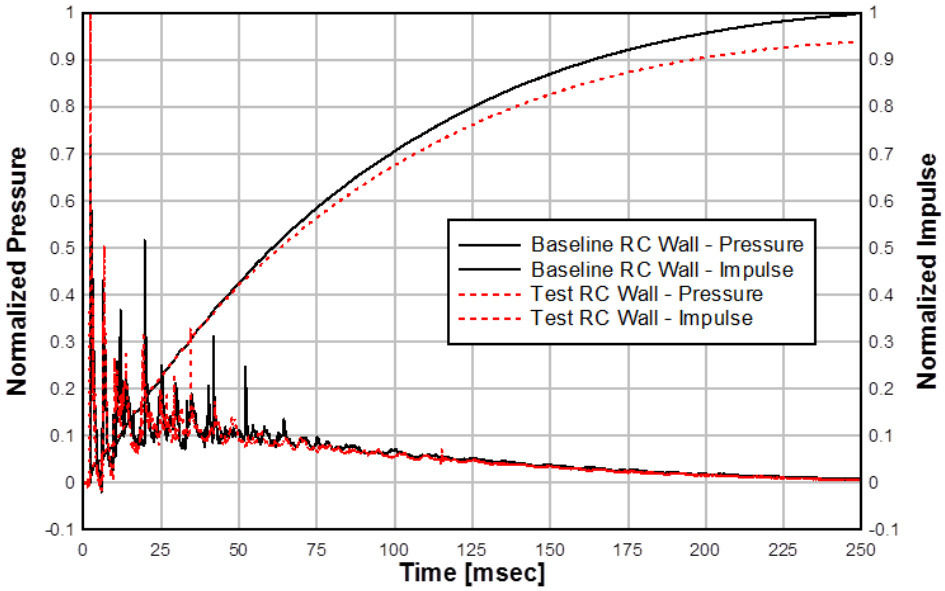
Wall	Max. Disp.	Max. Rot.
Conventional	2.49 in.	1.98 deg
Coupler	1.64 in.	1.31 deg
Roof	10.98 in.	5.22 deg



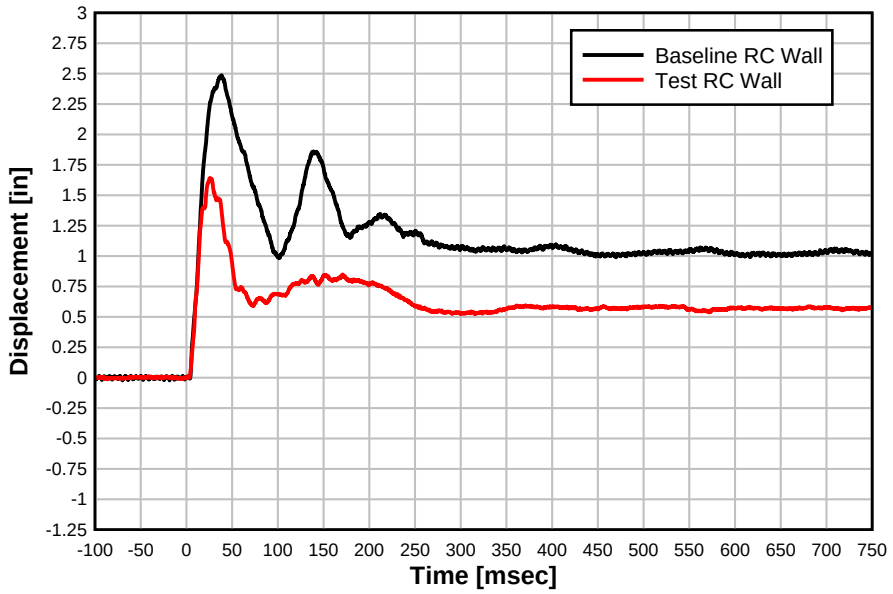
Coupler Wall

Conventional Wall

Test 2- Results

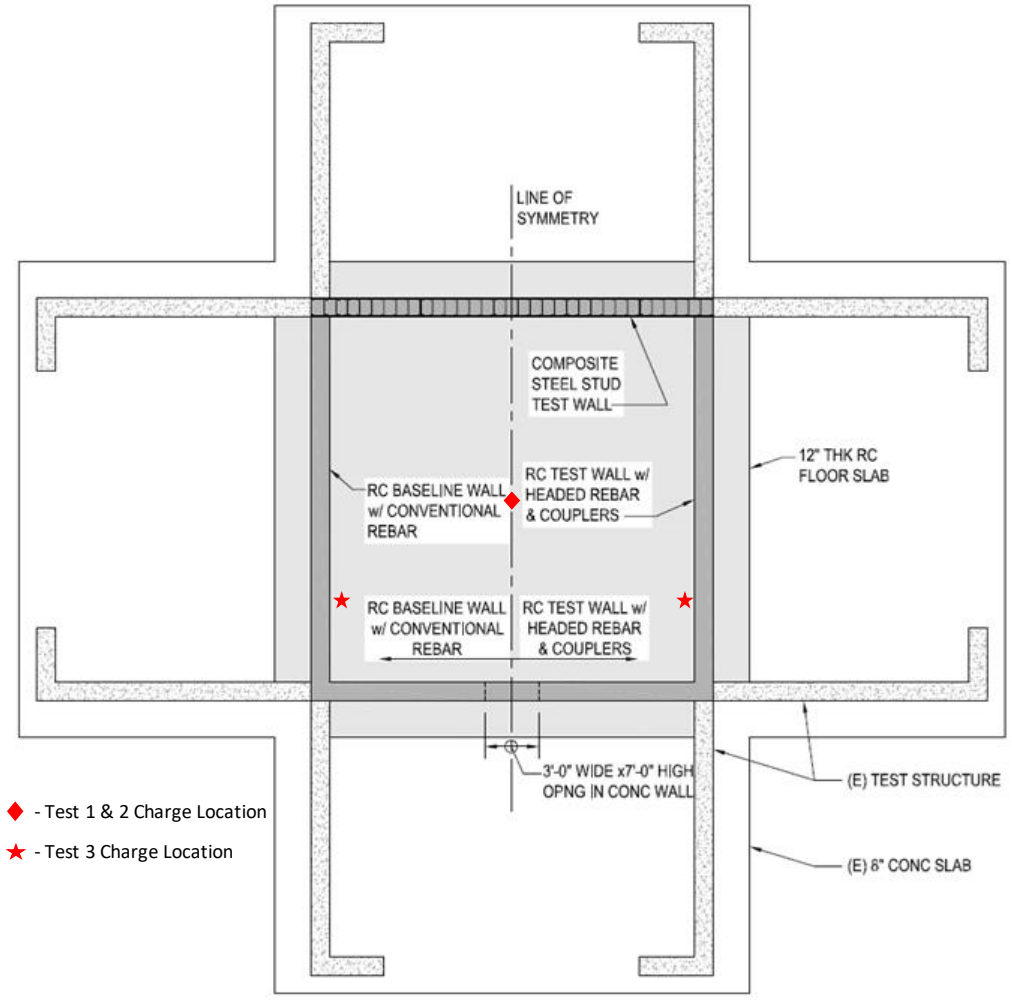


Reflected Pressure and Impulse



Midspan Displacement

Test 3 – Location of Charges



Test 3- Internal Blast Test

Wall	Max. Disp.	Max. Rot.
Conventional	8.69 in.	6.88 deg
Coupler	3.81 in.	3.03 deg
Roof	~ 4 ft	~38 deg

Coupler Wall

Conventional Wall

Test 3 – Internal Blast Test

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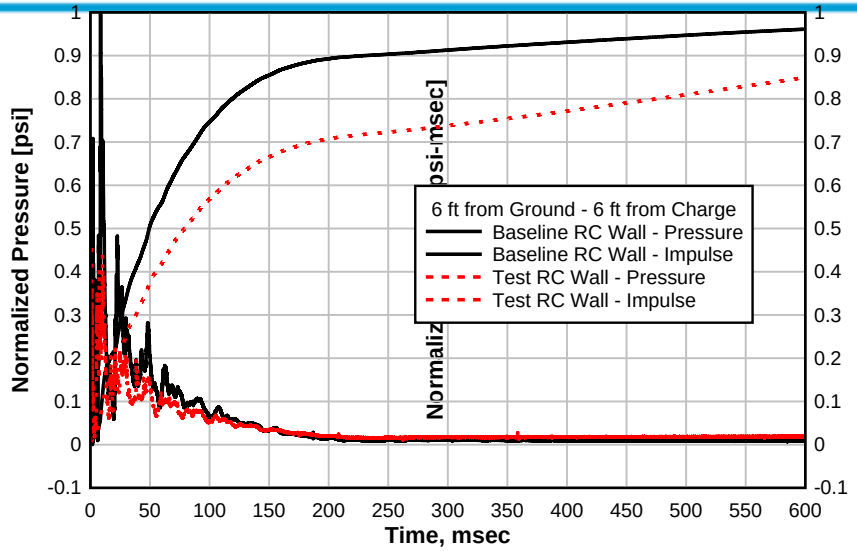
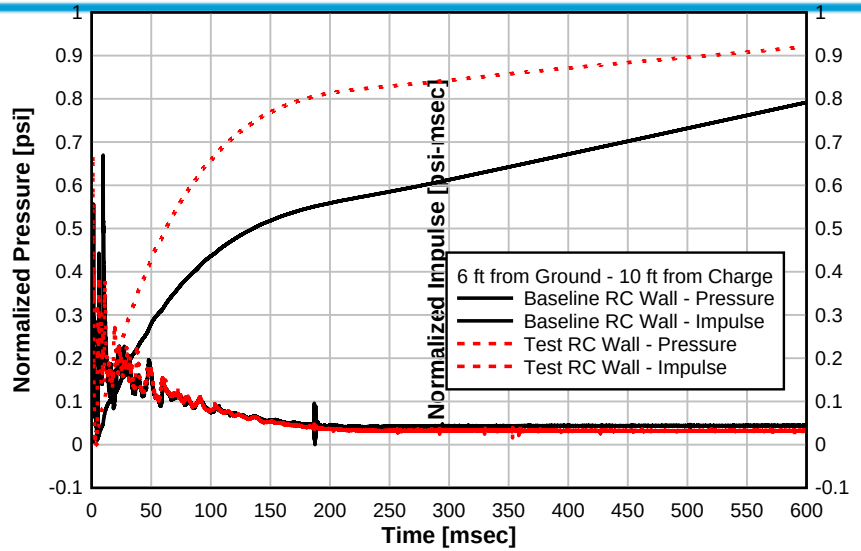
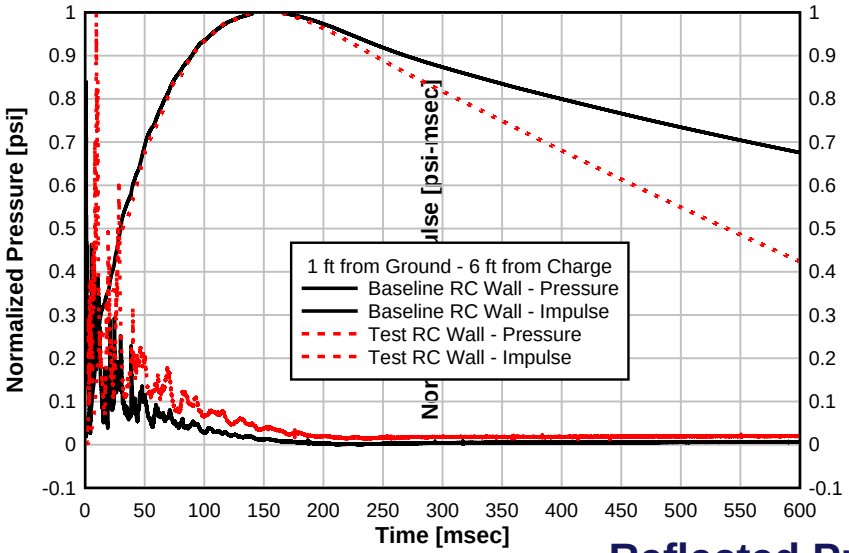
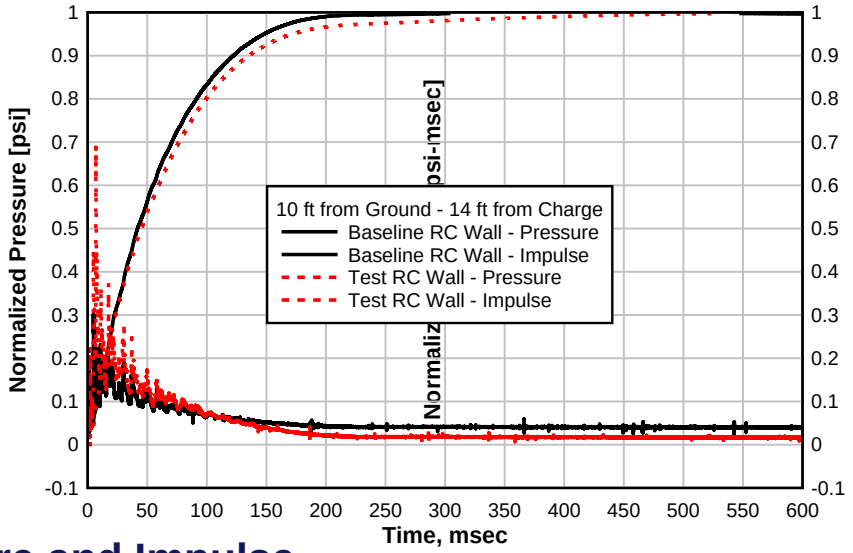
Test 3- Results



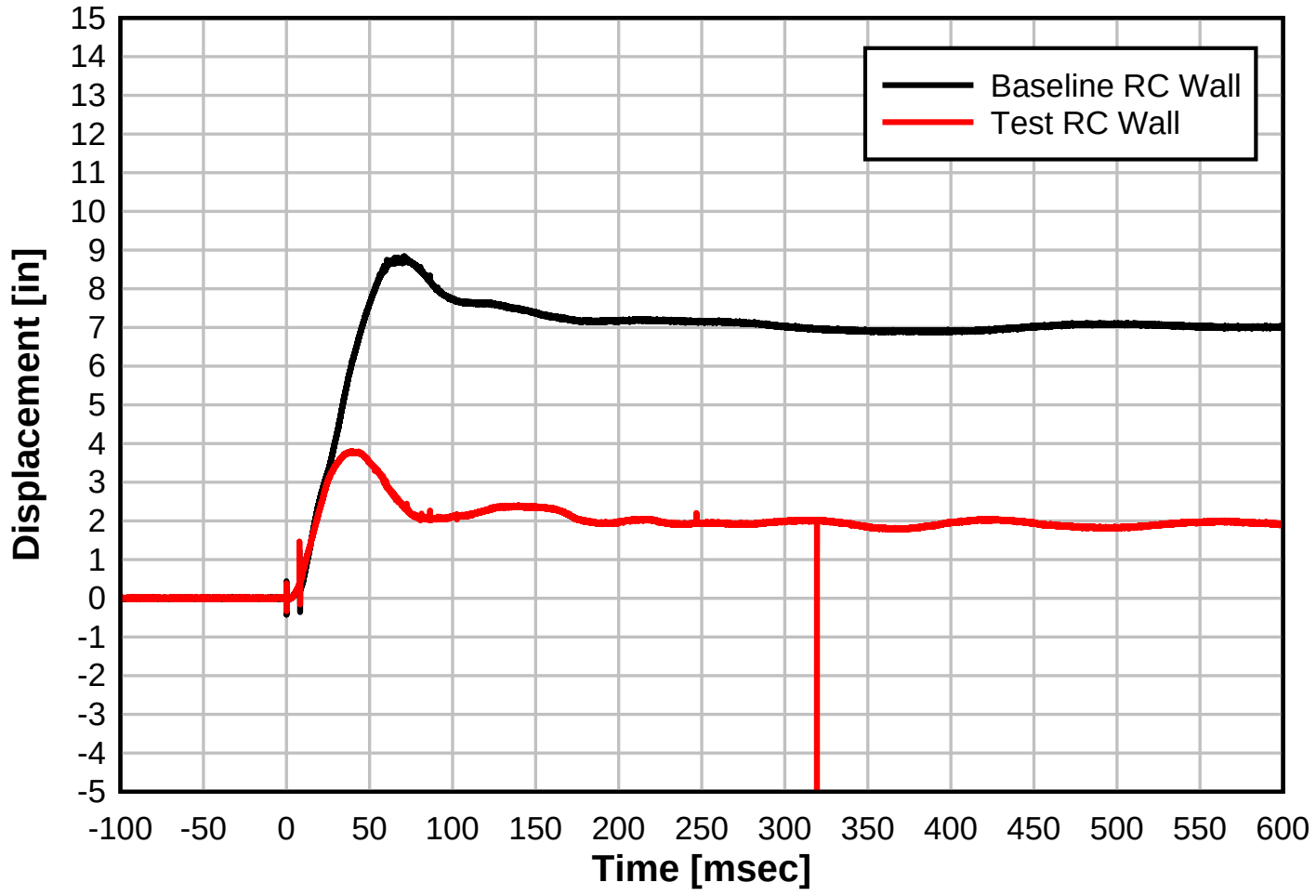






Reflected Pressure and Impulse

Test 3- Results



Midspan Displacement

Residual and Cumulative Results

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

*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?