Evaluation and Repair Of Blast Damaged Reinforced Concrete Beams

By

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US Army Corps of Engineers®

Outline

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  - Blast loading and evaluation
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  - Flexural loading
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Purpose and Importance

Purpose

To determine if surface mounted Fiber Reinforced Polymer (FRP) is a viable option for the repair of blast damaged reinforced concrete beams.

Importance

Terrorist attacks and combat operations in Iraq and around the world have caused significant damage to structures

Reconstruction operations in Iraq require the repair of blast damaged structures

The use of FRP may result in reduced time and costs in the repair of these structures

Scope

- 10 beams constructed using standard concrete and A 615 Grade 60 reinforcing steel

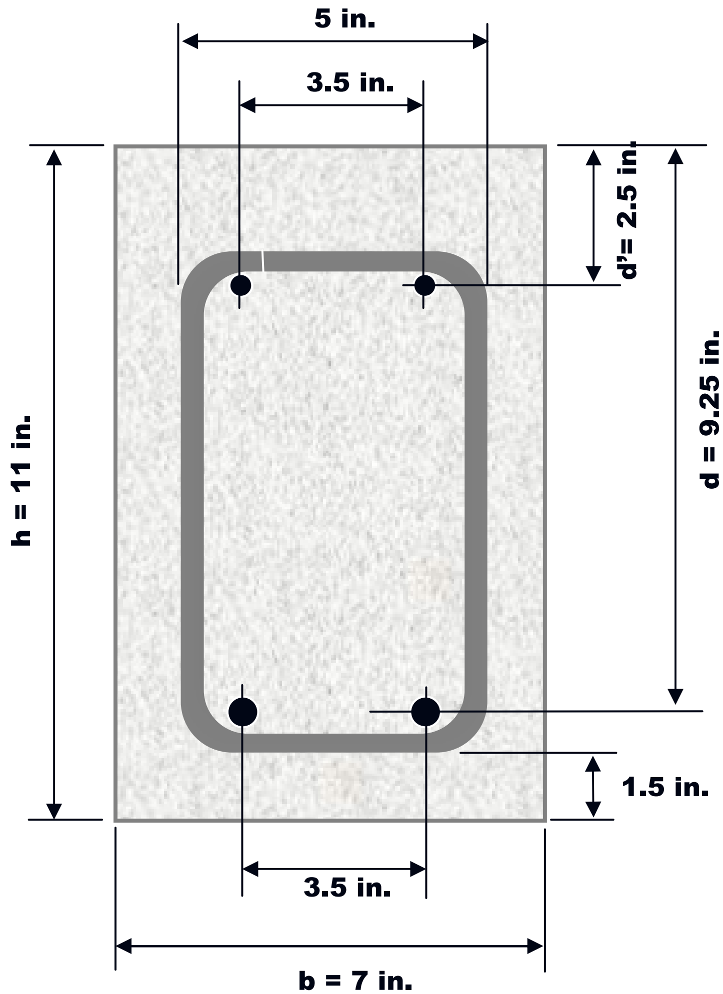
- 8 beams were blast damaged using C-4 high explosives and their damage evaluated

- 2 damaged beams were repaired using FRP

- 6 beams were tested to failure in third point loading (2 unrepaired, 2 repaired, and 2 control beams)

Process

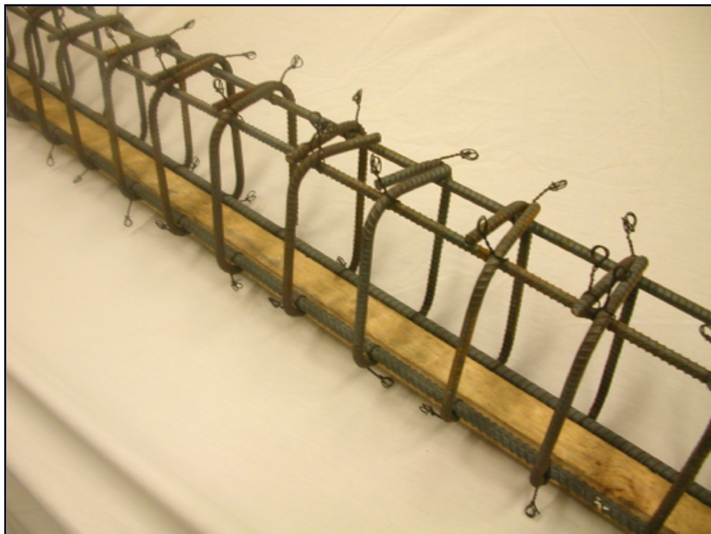
Beam Design



- Based on ACI 318 design requirements
- Longitudinal and transverse reinforcement was the same in all beams
- Smallest, reasonably sized beam given available materials and resources
- Beam weight ~ 580 lbs.
- Beam length was 7 ft – 4 in.
- 22 stirrups at 4 in. on center

Process

Beam Construction



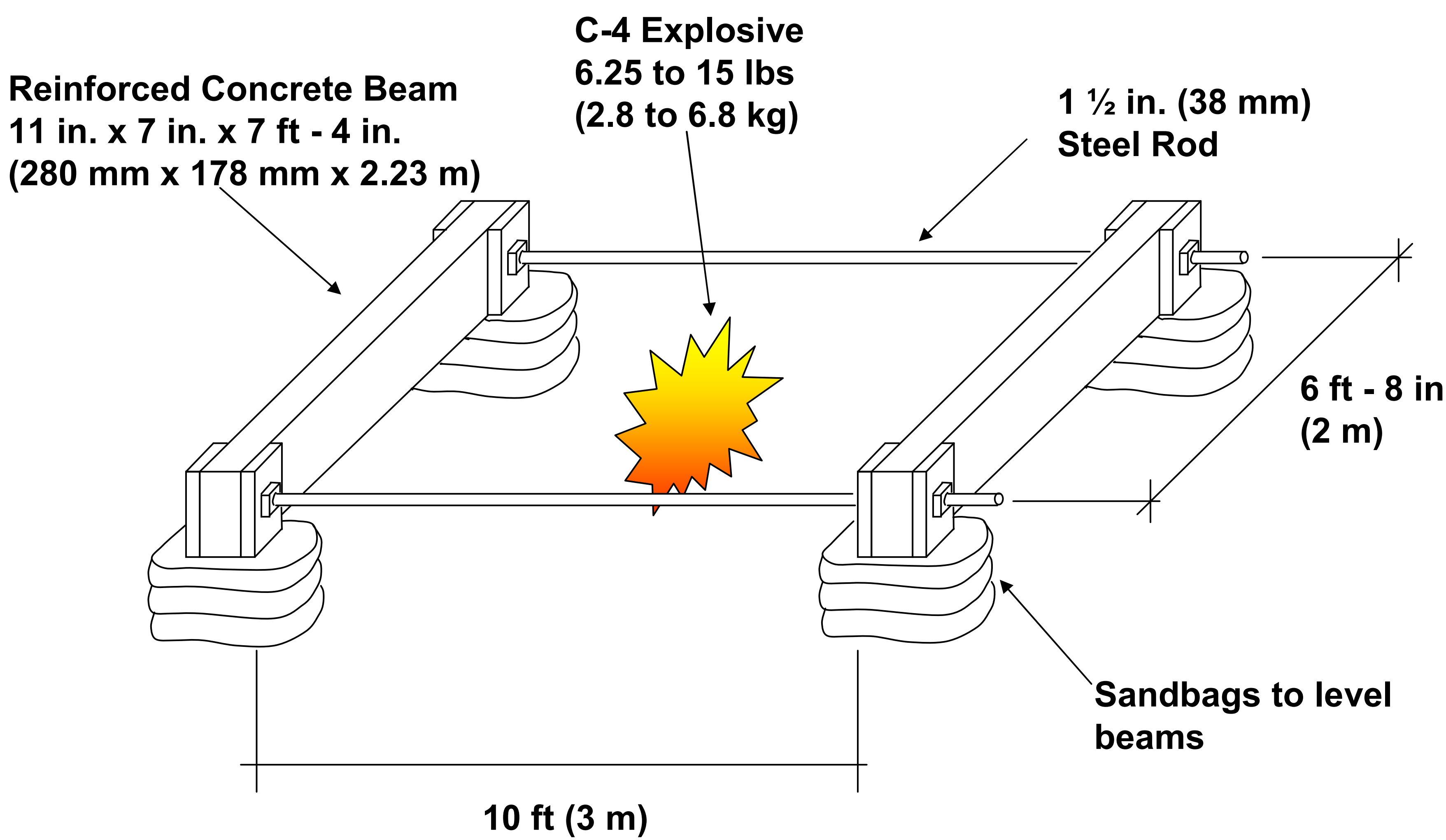
- All beams were cast from the same batch of concrete.

- 4 sets of compression strength tests and one set of split cylinder tests were conducted

- Reinforcement was tested to determine yield and ultimate strength

Process

Blast Loading – Test Configurations



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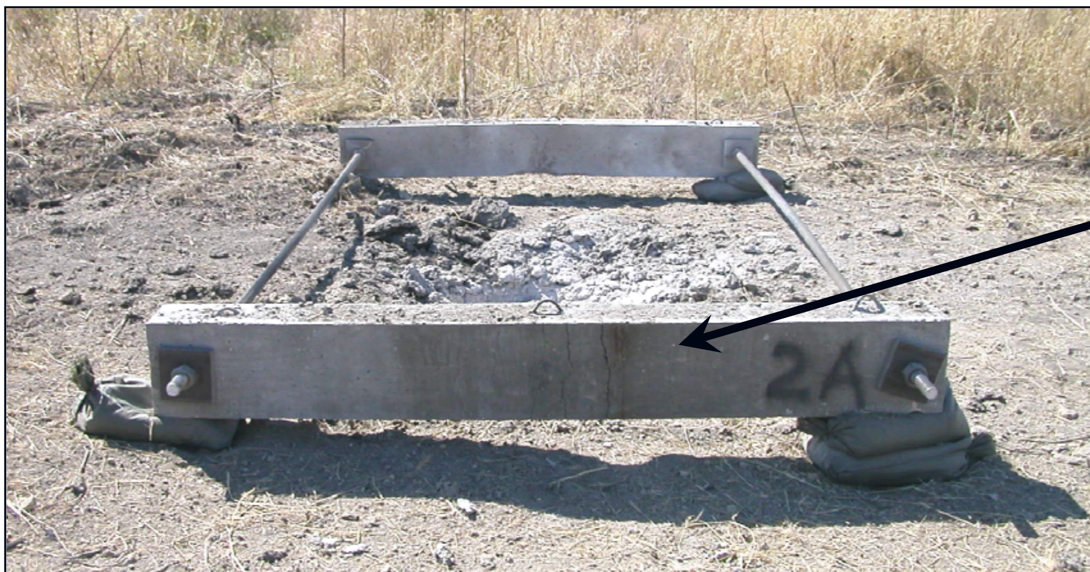
Process

Blast Loading – Testing

Charge tightly wrapped to minimize voids in charge

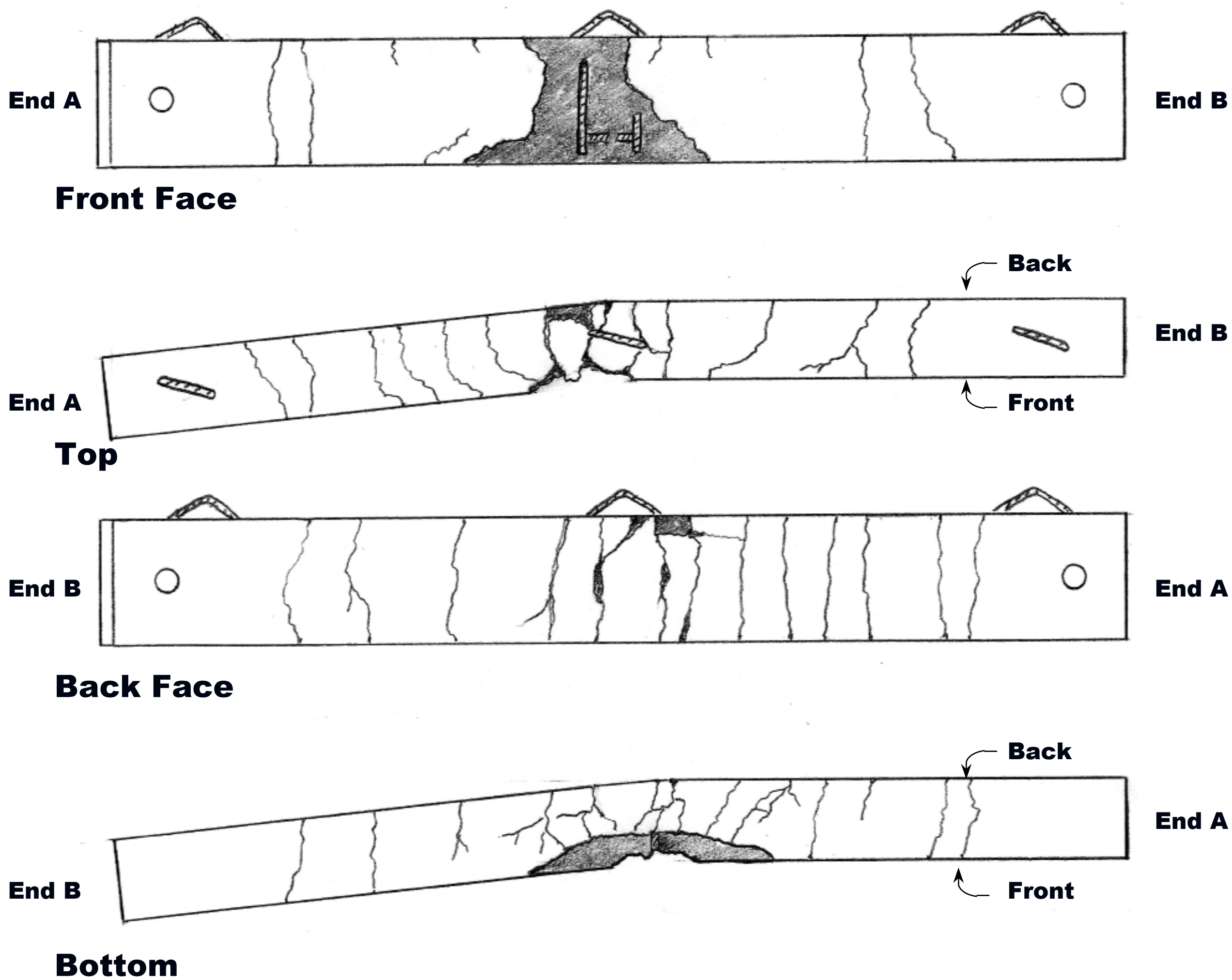
Charges placed on sand bags even with the centerline of the beams



Set 2 after detonation of charge

Process

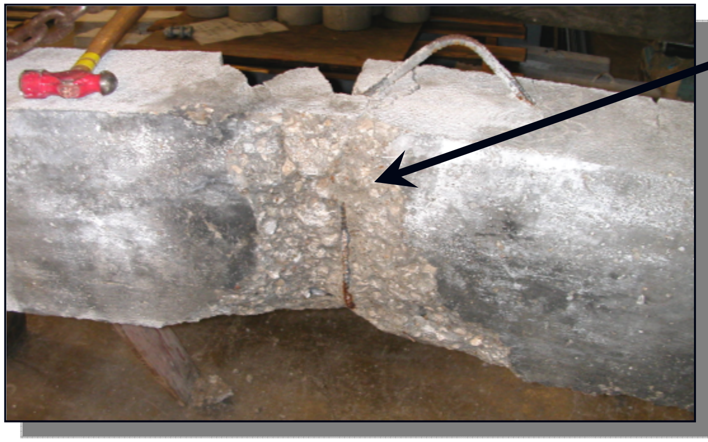
Blast Loading – Evaluation



- Each beam was sketched and all cracking, spalling and exposure of reinforcement was identified
- 2 of the 4 sets were determined to have damage beyond repair
- 3 of the 4 sets experienced permanent horizontal deformations

Process

FRP Repair – Surface Preparation



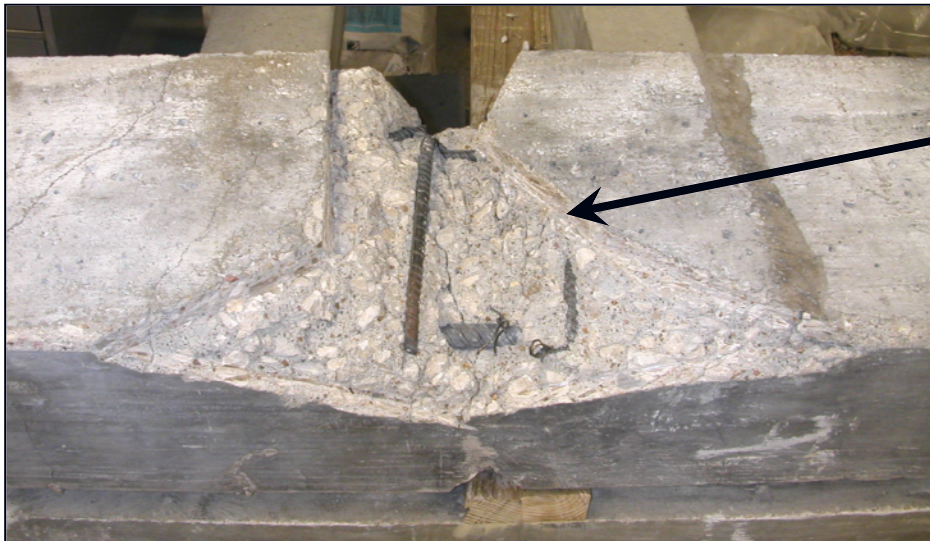
All unsound concrete was removed

Bottom edges were rounded to reduce force concentrations in FRP

Beam 2B was straightened by jacking it against an undamaged beam

Process

FRP Repair – High-strength mortar



The edges around the area in which the high-strength repair mortar was placed were cut ½ in. (13 mm) deep using a masonry blade on a skill saw.

Beam 2B after the repair mortar has cured

Compression strength test was conducted on three mortar cylinders yielding an average strength of 8900 psi

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Process

FRP Repair – Application of FRP

Beams 2B and 4A were sandblasted prior to application of the FRP Primer to remove any surface contaminates

One coat of MBrace Primer was applied to each beam using a short nap roller

The primer cured for approximately 18 hours resulting in a clear, shiny, slightly tacky surface.

Process

FRP Repair – Application of FRP

The MBrace Putty is applied in a thin coating to smooth the surface of the beam.

The MBrace Putty cured for approximately six hours before the saturant was applied.

The MBrace Saturant was applied to each beam using a medium nap roller.

The first layer of carbon fiber fabric was applied running parallel to the beam's primary axis. This layer of fabric provided tensile reinforcement to the beams.

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Process

FRP Repair – Application of FRP

A 2nd layer of saturant was applied on top of the fabric. The saturant was applied generously to ensure that the fabric was fully saturated.

The second layer of carbon fiber fabric was applied on top of the fully saturated longitudinally oriented fabric.

A final layer of saturant was applied to the beams on top of the shear reinforcement fabric.

Process

FRP Repair – Application of FRP

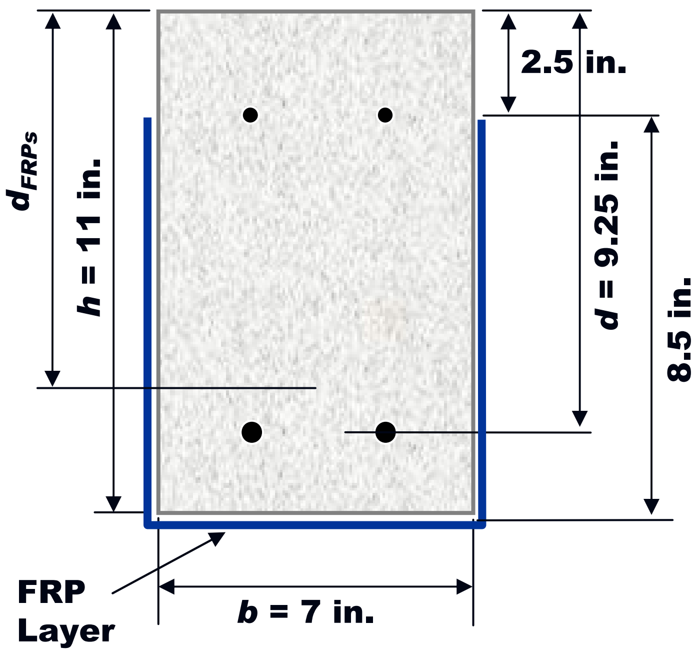
Application of the three layers of saturant and two layers of carbon fiber fabric took approximately 15 to 20 minutes per beam.

After 24 hours the beams were still tacky and by 48 hours they were tack free.

The FRP takes seven days to reach its full load carrying capacity.

Process

FRP Repair – Flexural Strength Increase



- Cross sectional area of FRP was 0.1560 in² but only 0.1495 in² was in tension

- Iterative process was used to determine increase in strength in beam due to FRP assuming beam was undamaged

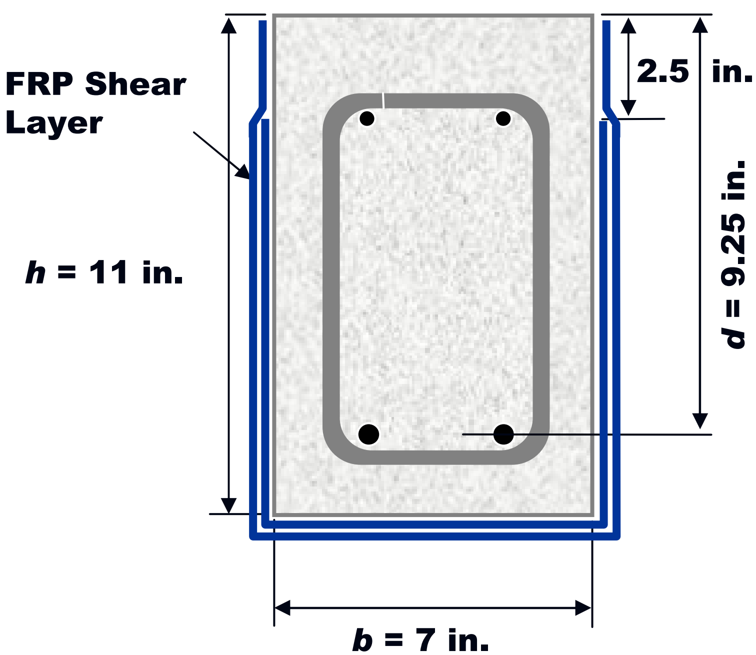
- FRP results in an overreinforced section and provides a 40% increase in moment capacity for an undamaged beam

Material Properties Used in Calculation	f'_c psi	f_y psi	f_{FRPy} psi	c in	M_n ft-kips	Predicted maximum total load lbs	f_{FRPb} at failure psi
Design Properties	3500	60000	550000	3.13	39.9	39940	218700
Actual Material Properties	5160	82000	550000	3.00	50.9	50870	232300

Process

FRP Repair – Shear Strength Increase

- The shear reinforcement was U-wrapped from the top edge on one side to the top edge on the other side

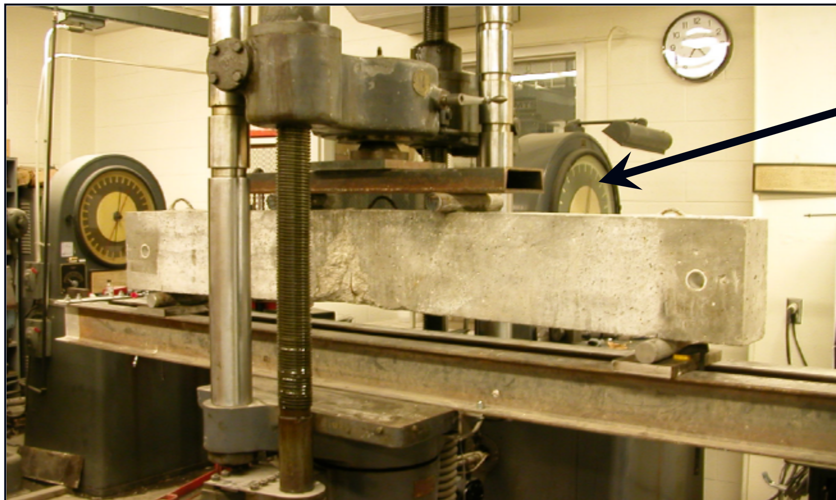


- With a calculated shear strength of 59.0 kips (262 kN), the shear strength did not govern the strength of the beams.

Material Properties Used in Calculation	f'_c psi	f_{fe} psi	f_y psi	A_{fv} in.^{2}	V_f kips	V_u kips
Design Properties	3500	112500	60000	0.99	16.1	53.3
Actual Material Properties	5160	123000	66000	0.99	17.6	59.0

Process

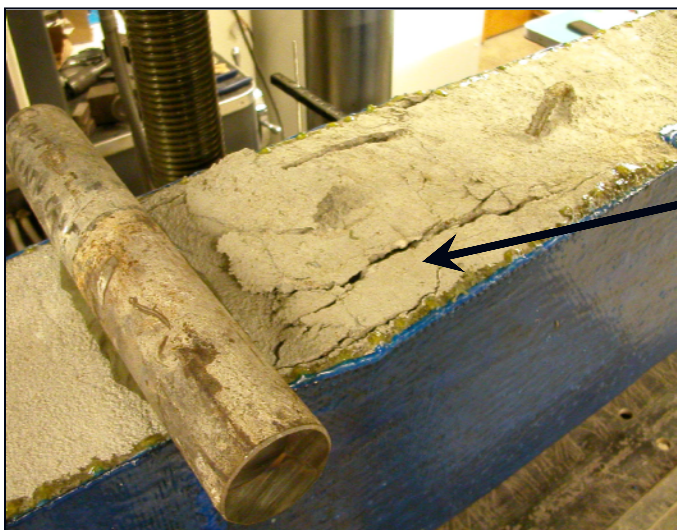
Load Testing



Beams were mounted in the third-point reaction frame on the 120 kip Baldwin Universal Testing Machine.

Displacement transducer measured the deflection of the centerline of the beam.

Compression failure in the concrete of beam 4A after reaching a load of 56,700 lb



Results

Blast Damage Evaluation

- Sets 1 (15 lbs) and 3 (10 lbs) experienced significant damage to the concrete and yielding of the steel with horizontal deflections between 2½ and 3 in.

- Set 2 (11.25) experienced less significant damage to the concrete and yielding of the steel with horizontal deflections of 1½ in. on both beams

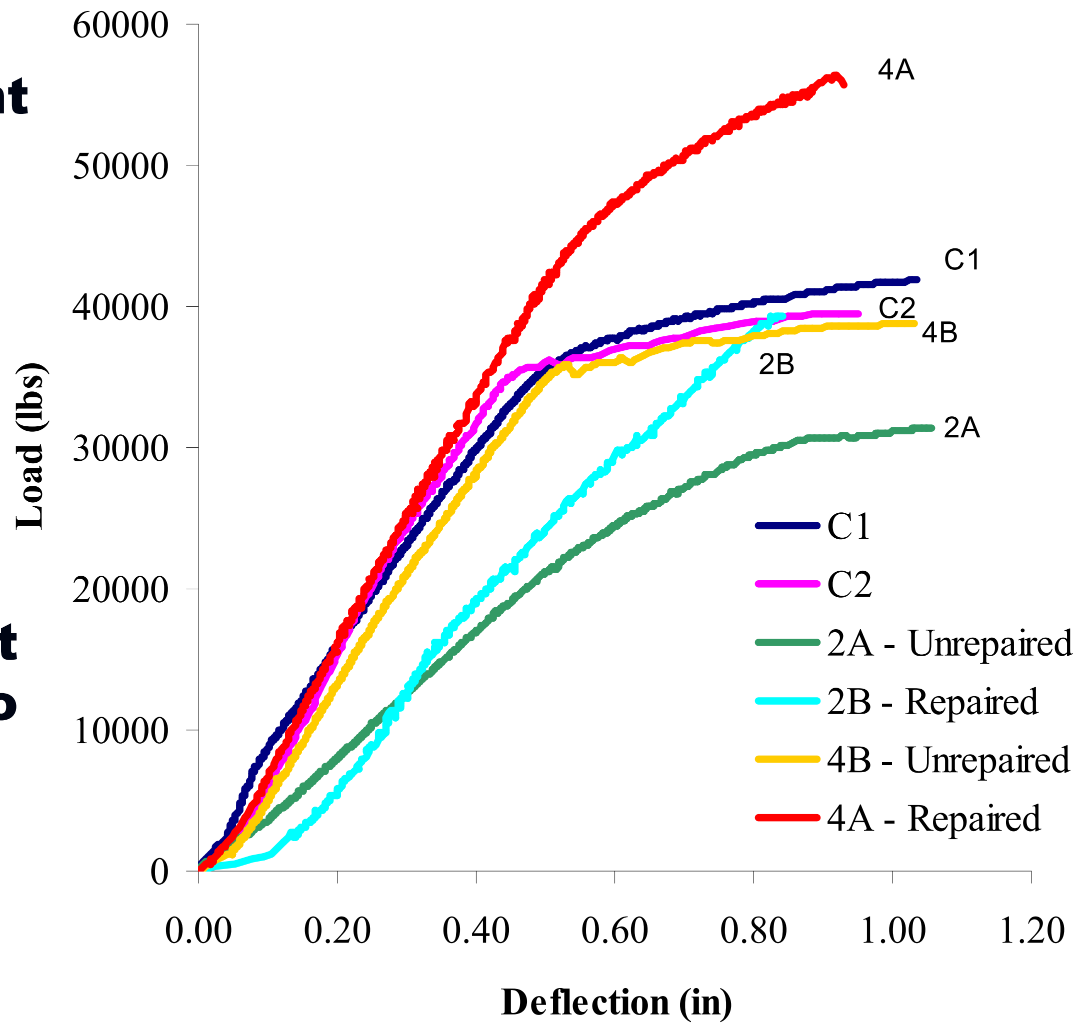
- Set 4 (6.25 lbs) resulted in flexural cracking through the beams at several locations but no apparent yielding of the steel

- Damage inflicted on the 2 beams of each set was similar but not the same

Results

Flexure Test

- Both repaired beams demonstrated a significant improvement in strength
- All 6 beams ultimately failed when the concrete at the top center of the beam crushed
- Beam 2B did not experience any significant nonlinear behavior prior to yielding
- Beam 4B demonstrated very similar behavior to the control beams



Results

Flexure Test

Beam Identifier	Beam type	Predicted maximum total load lbs	Maximum total load lbs	Approx. load at initiation of nonlinear behavior lbs	Deflection at failure in	Change in capacity
C1	C	36400	41900	35000	1.04	N/A
C2	C	36400	41500	35000	0.95	
2A	D	36400	31175	N/A	1.06	126 %
2B	D+R	51220	39350	N/A	0.84	
4A	D+R	51220	56700	46000	0.93	145 %
4B	D	36400	39000	36000	1.03	

Conclusions

- FRP is a viable option for the repair of blast damaged beams. The FRP repaired beams demonstrated a significant improvement in flexural capacity in comparison to their equivalently damaged counterparts.

- Blast damaged beams can be repaired even after experiencing flexural and shear cracking, crushing of concrete, and yielding of reinforcement.

- FRP is a relatively simple and easy repair system to install.

- The addition of FRP to beams can result in an overreinforced section, thereby preventing any significant yielding prior to a brittle fracture of the concrete.

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Cost

- FRP estimated cost of material and labor

Surface prep and 1st layer of FRP	-	$20 per sqft
Each additional layer	-	$15 per sqft

- Material costs are approximately $6-7 per sqft
- The greatest variables in FRP project costs relate to access cost, i.e. removal and replacement of walls/ceilings and scaffolding
- The repaired beams used in this project would have cost approximately $1000 each to repair

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Questions

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