Assessment of the Development Length Equation for GFRP Rebars in tension

UNIVERSITY OF MIAMI

UNIVERSITÉ DE SHERBROOKE

Research group:

Jesús D. Ortiz, *Ph.D. Student*

Zahid Hussain, *Ph.D. Student*

Arman Hosseini, *Ph.D. Student*

Antonio Nanni, *Ph.D., PE.*

Brahim Benmokrane, *Ph.D., PE.*

Fiber-Reinforced Polymer (FRP)

- Carbon fibers
- Glass fibers
- Basalt fibers
- Aramid fibers

→ Fibers

Additives

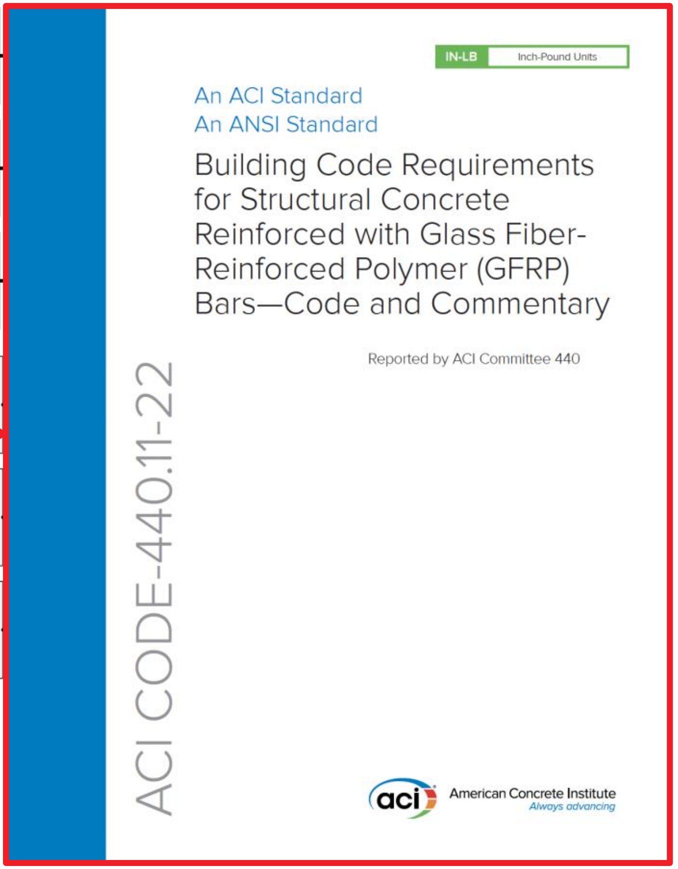
- Thermosetting Resin
- Thermoplastic Resin

→ Polymeric Resin

→ FRP Composites

- CarbonFRP (CFRP)
- GlassFRP (GFRP)
- BasaltFRP (BFRP)
- AramidFRP (AFRP)

- FRP Bars
- FRP Strands
- FRP Mesh
- FRP Plates
- FRP Fabrics
- FRP NSM


IN-LB Inch-Pound Units

An ACI Standard
An ANSI Standard

Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars—Code and Commentary

Reported by ACI Committee 440

ACI CODE-440.11-22

American Concrete Institute
Always advancing

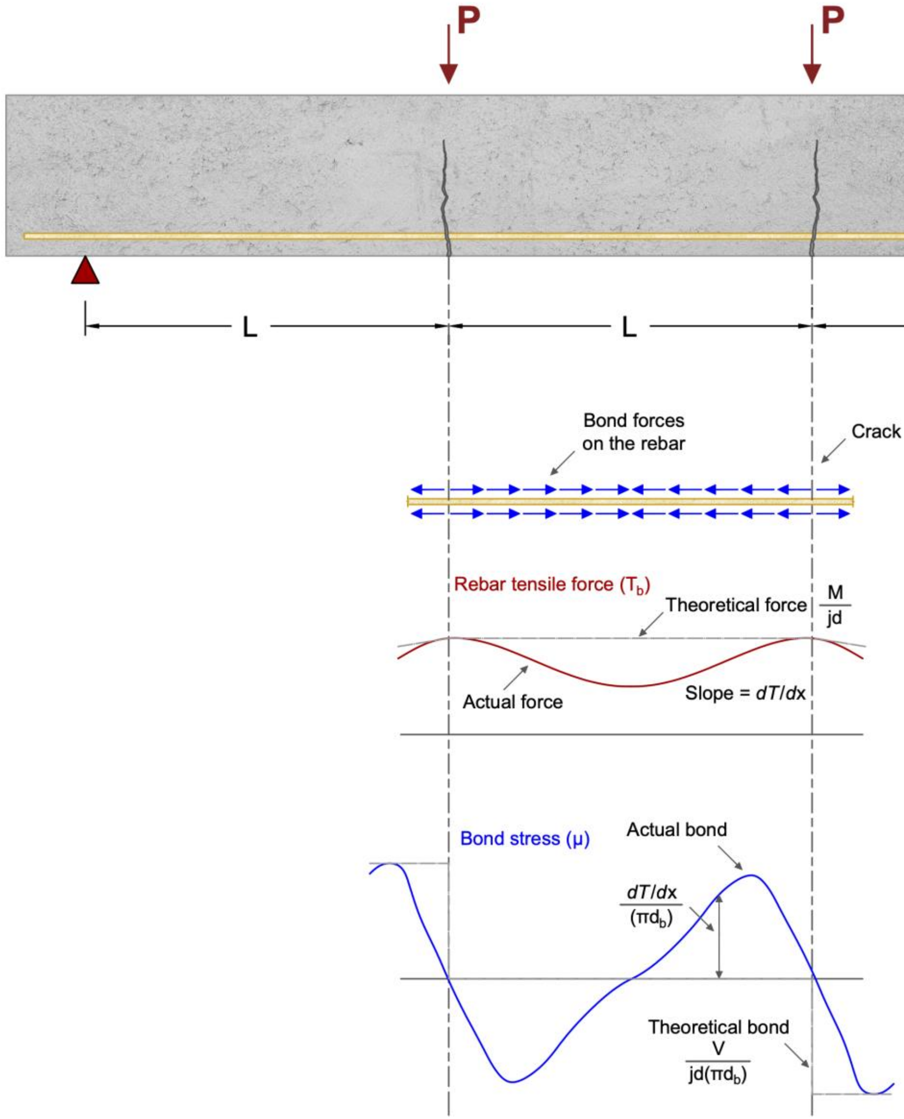
ACI CONCRETE CONVENTION

Fiber-Reinforced Polymer (FRP)

- ☑ **Non-corrosive** (long-term durability).
- ☑ High longitudinal **tensile strength.**
- ☑ **Lightweight** (1/5 of steel)
- ☑ Low thermal and electrical conductivity.

- ☒ **No yielding** before failure.
- ☒ Low **shear strength** and **modulus of elasticity**.
- ☒ *Cannot be **bent in field.***
- ☒ ***Higher initial** cost (lower long-term).*
- ☒ Longer development length.

In-and-Out Bond Stress



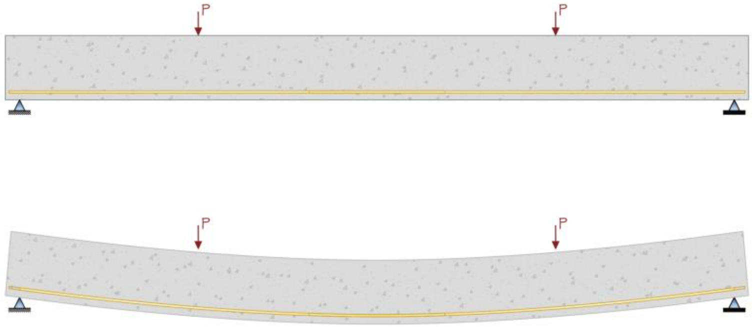
Reinforcement-concrete bond is due to:

- ✓ **Chemical adhesion.**
- ✓ **Friction.**
- ✓ **Bearing** of reinforcement ribs on the concrete.

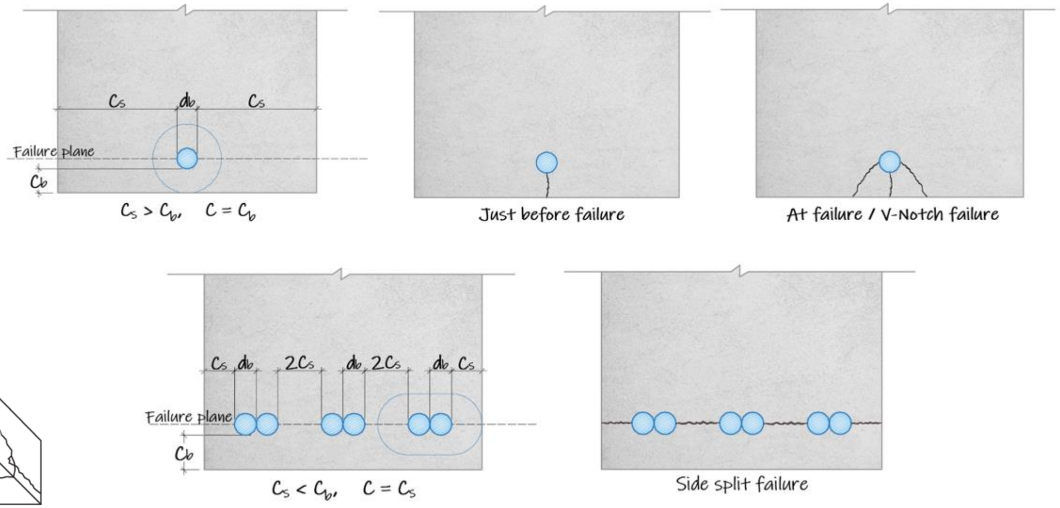
a. Sand-coated
b. Grooved
c. Ribbed
d. Helically wrapped

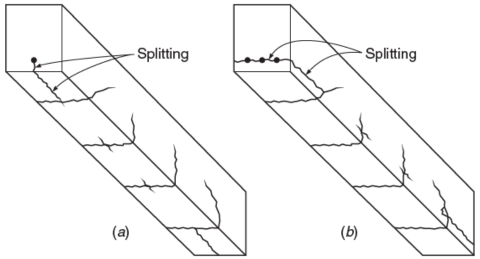
Failure Modes

Pull-out or **Slippage** Failure



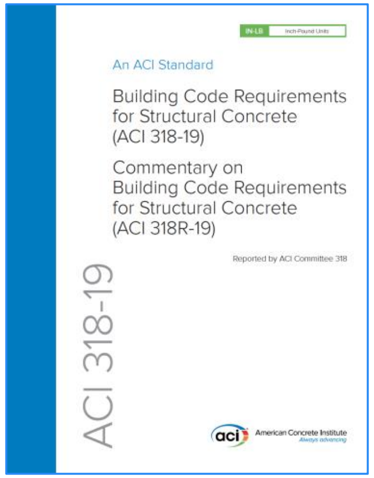
Splitting Failure





Tensile Failure

ACI 440.11-22


IN-LB Inch-Pound Units

An ACI Standard

Building Code Requirements for Structural Concrete (ACI 318-19)

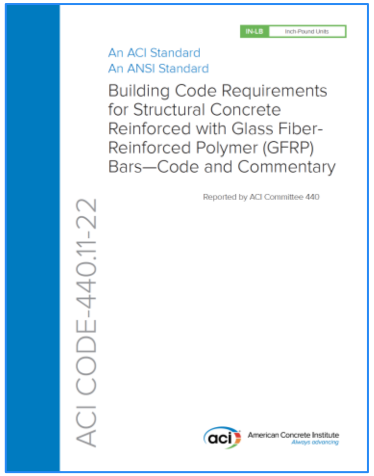
Commentary on Building Code Requirements for Structural Concrete (ACI 318R-19)

Reported by ACI Committee 318

ACI 318-19

aci American Concrete Institute Always advancing

$$\ell_d = \left(\frac{3}{40} \frac{f_y}{\lambda \sqrt{f_c'}} \frac{\Psi_t \Psi_e \Psi_s \Psi_g}{\left(\frac{c_b + K_{tr}}{d_b} \right)} \right) d_b$$


IN-LB Inch-Pound Units

An ACI Standard

An ANSI Standard

Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars—Code and Commentary

Reported by ACI Committee 440

ACI CODE-440.11-22

aci American Concrete Institute Always advancing

$$\ell_d = \frac{d_b \left(\frac{f_{fr}}{\sqrt{f_c'}} - 340 \right) \Psi_t}{13.6 + \frac{c_b}{d_b}}$$

Equation based on the test data conducted **over two decades ago** using FRP bars primarily with **surface deformations** from either a helical lug pattern or a spiral wrap of fibers.

Conservative assumptions were made due to the lack of available data in embedment or splice length, and the effects of some parameters were **disregarded** (i.e., confinement effect).

There have been significant improvements in **FRP material properties** and production methods.

Development length

Parameter		ACI 440	CSA 806-12	JPCI 2021	In this study
Embedment length	l_d	x	x	x	x
Concrete strength	f'_c	x	x	x	x
Bar diameter	d_b	x	x	x	x
Spacing or cover dimension	c	x	x	x	x
Top bar factor	α, k_1	x	x		
Concrete density factor	λ, k_2		x		
Area shear reinforcement	A_t			x	x*
Stirrups spacing	s			x	x*
# of bars being developed	n				x*
Mod. of elasticity trans rebar	E_t			x	
Mod. of elasticity long rebar	E_f				
Bar size factor	k_3		x		
Fiber factor	k_4		x		
Surface profile factor	k_5		x		x**

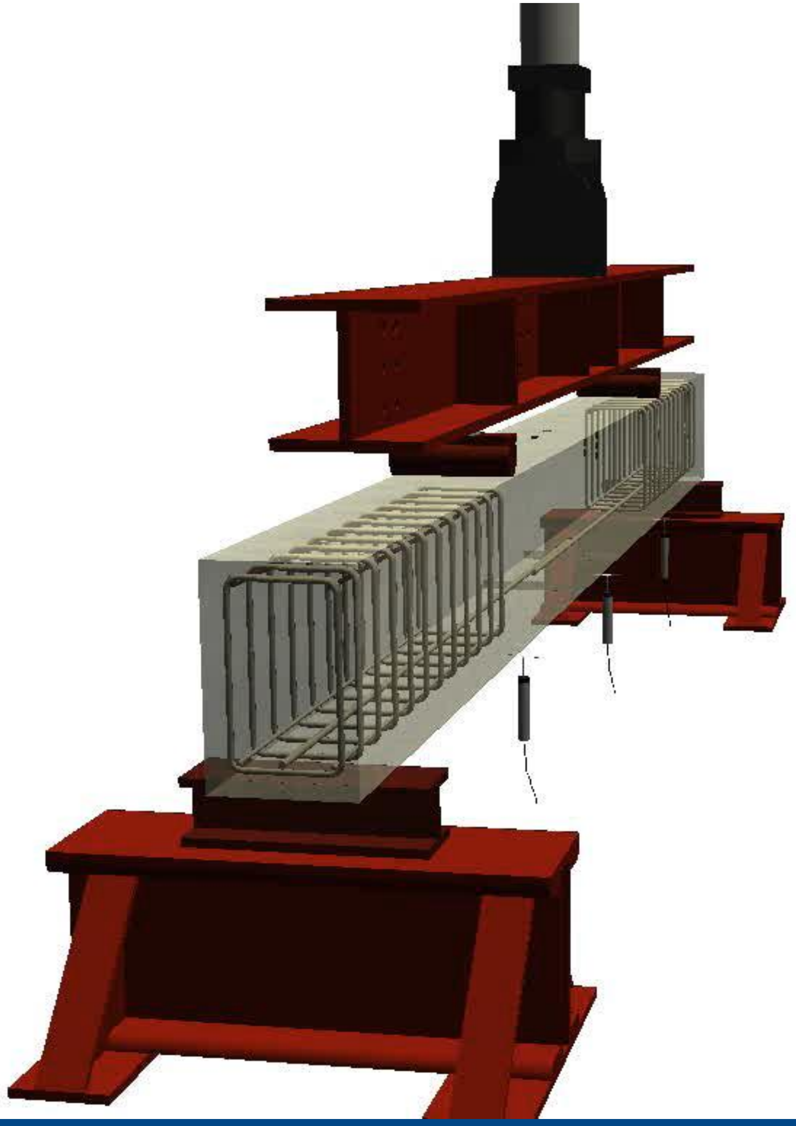
*implicit in the confinement parameter

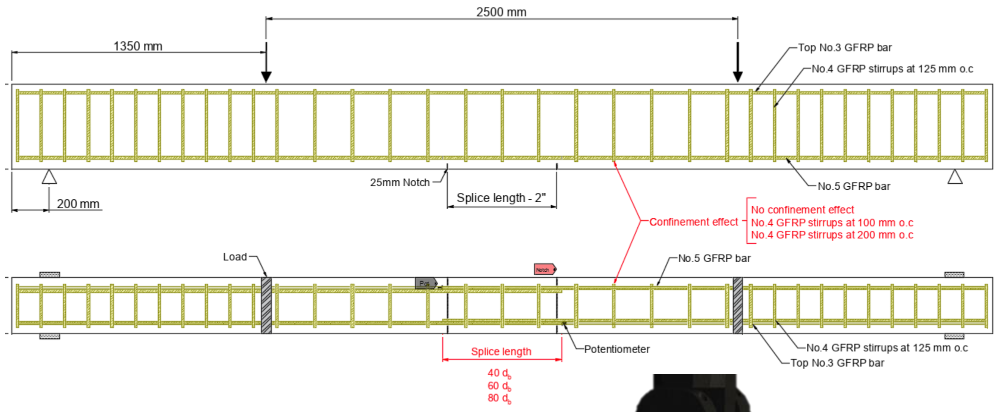
** in the next phase with the k_b

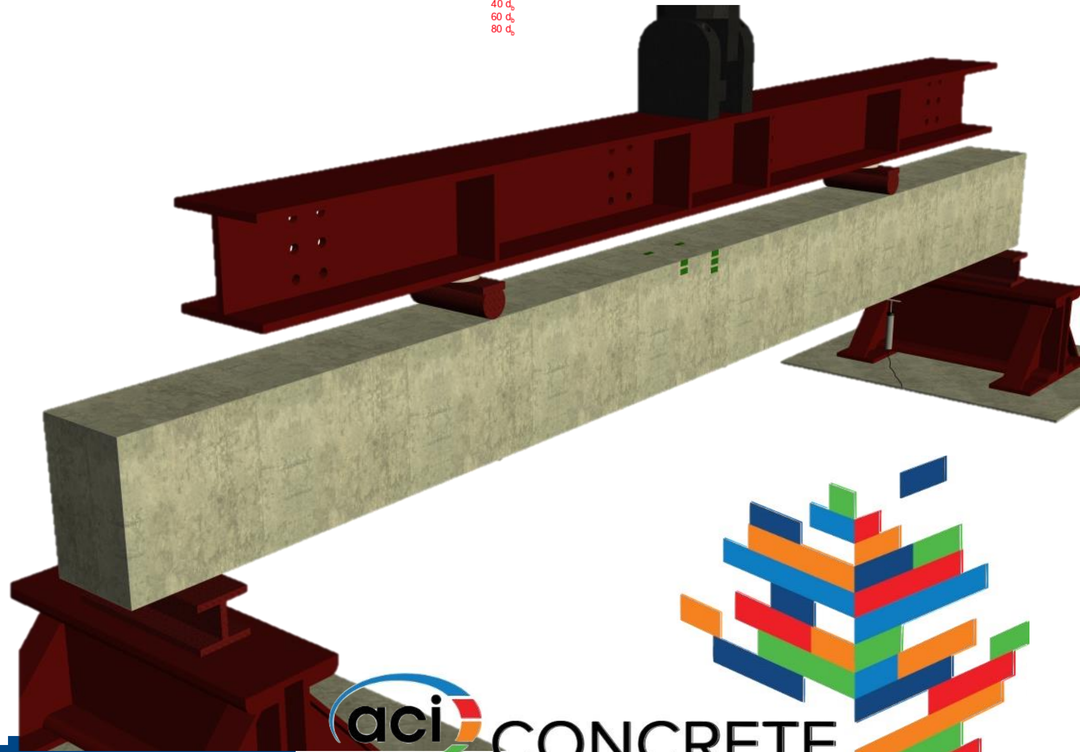
Research Objectives

- To determine the **development length** of sand-coated GFRP bars in 300 x 450 mm reinforced concrete beams (*classifying their failure mode as Splitting, Pull-out or Tensile Failure*)
- To assess **the effect** of bar diameter, clear cover, confinement and concrete compressive strength on the development length of sand-coated GFRP bars in tension.
- To verify the required development length when the stress to be developed is less than the guaranteed tensile strength (**compression-controlled sections**).
- To validate the **current development length equation** in ACI 440 code and propose updates.
- To assess the potential influence of different **surface treatments** through experimental results on bond coefficient.

Methodology

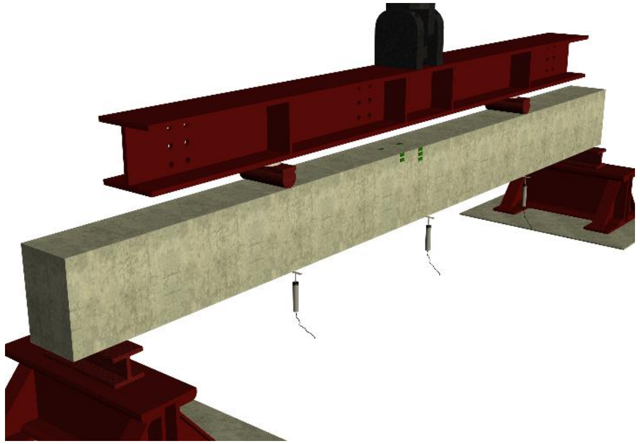






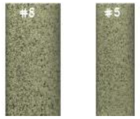
Graphical Abstract

Beam Test
Four-point-bending

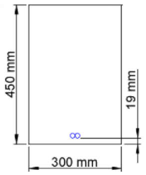


Parameters
That could influence the bond strength

Concrete compressive strength



GFRP bar diameter

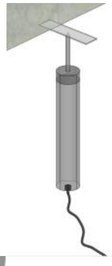


Clear cover

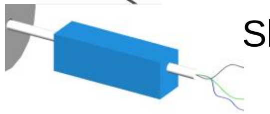
Confinement effect

Splice Length

Data Collection
Information about the structural performance

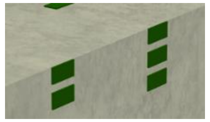


Mid-span Deflection



Slippage

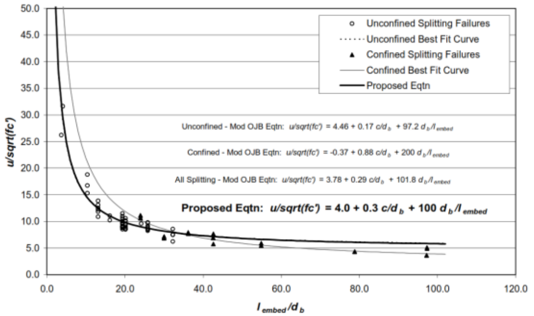
Failure Modes

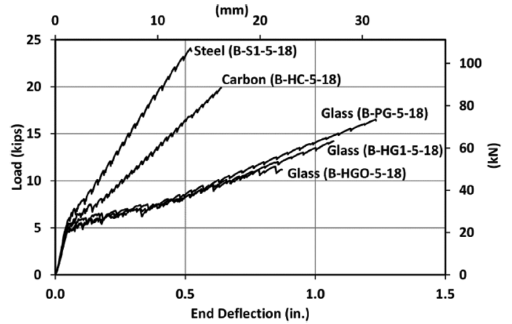


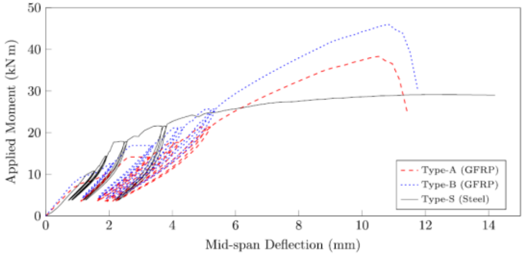
Strain gauges

Peak load

Data Processing
Analysis of the data







Methodology

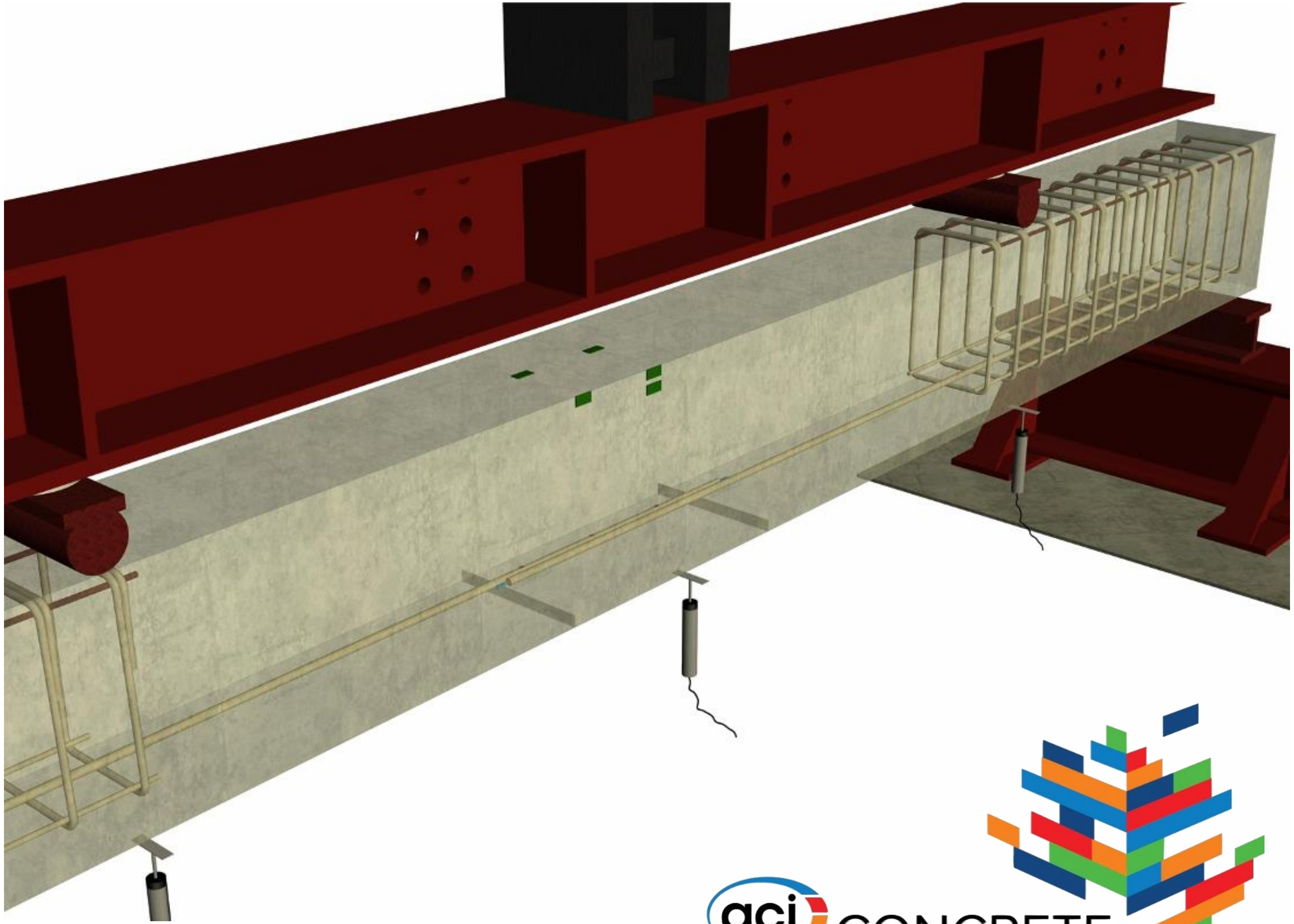
Required development length:

$$l_d = 110\, d_b\ (1700\ \mathrm{mm})$$

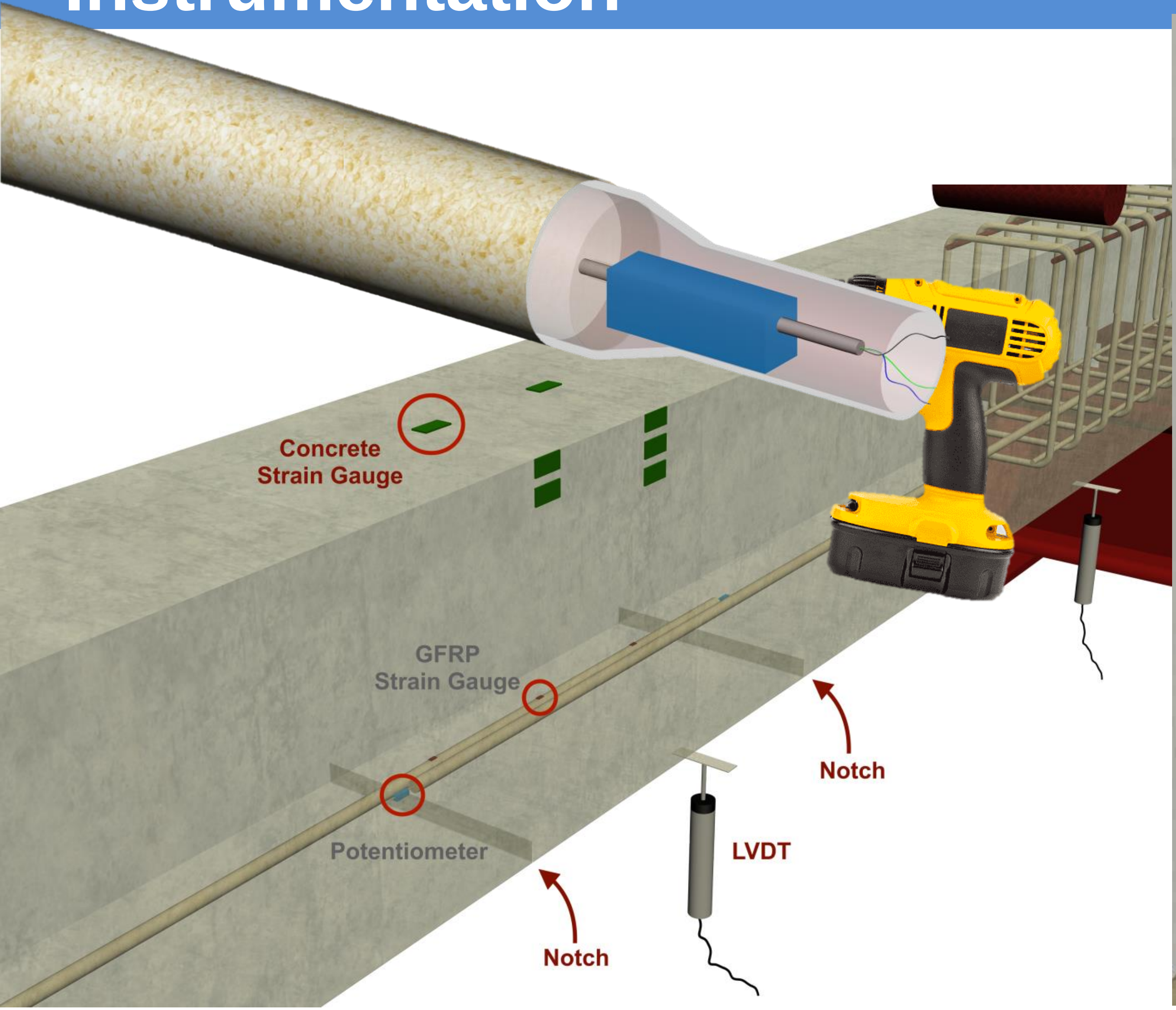
$$l_1 = 40\, d_b\ (630\, mm)$$

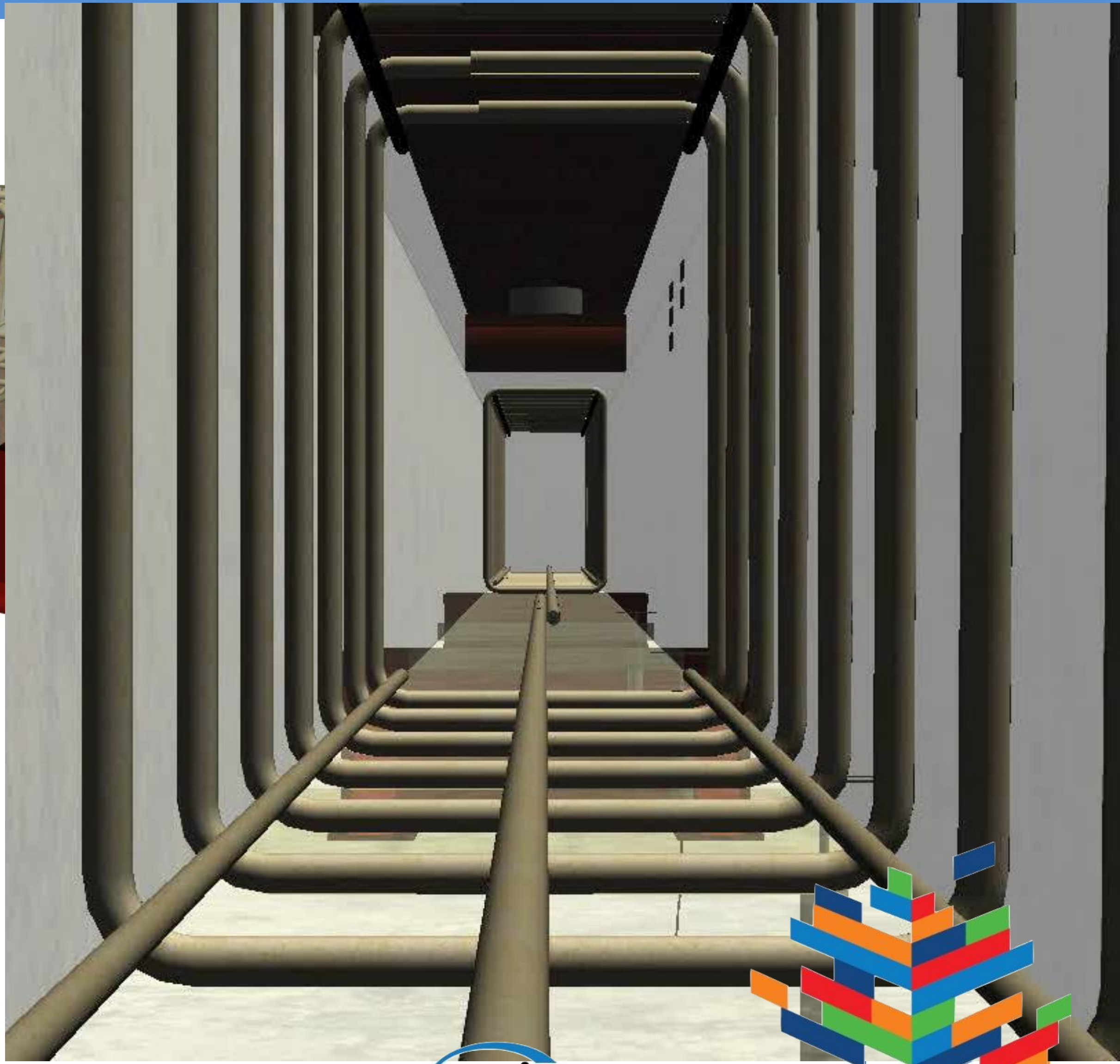
$$l_2 = 60\, d_b\ (950\, mm)$$

$$l_3 = 80\, d_b\ (1260\, mm)$$



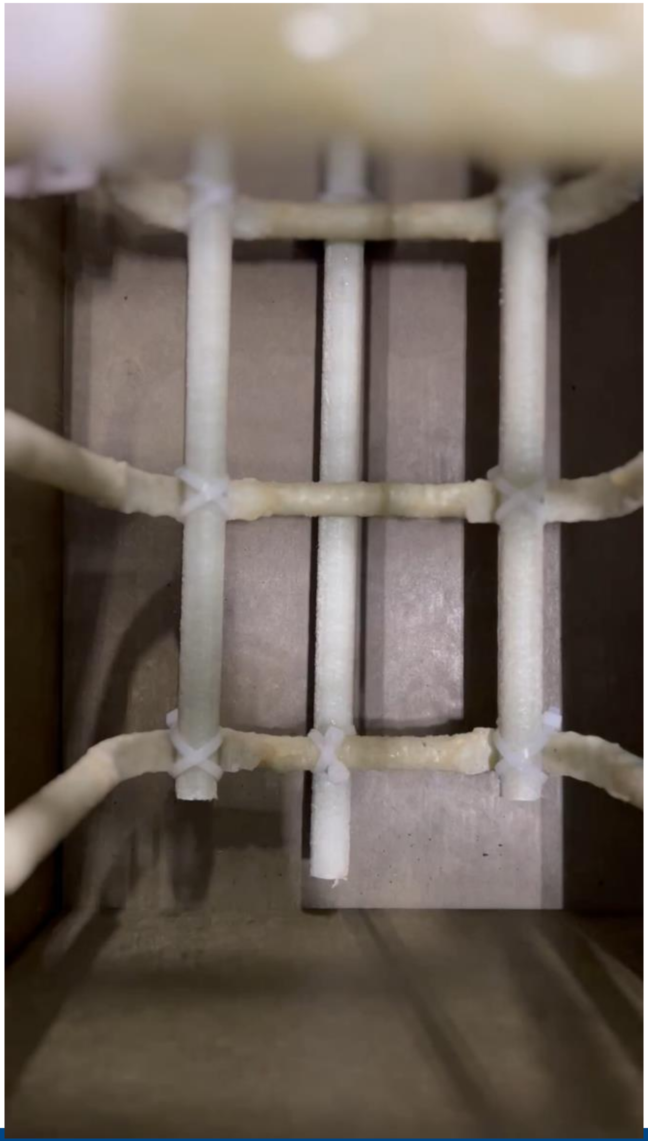
Instrumentation



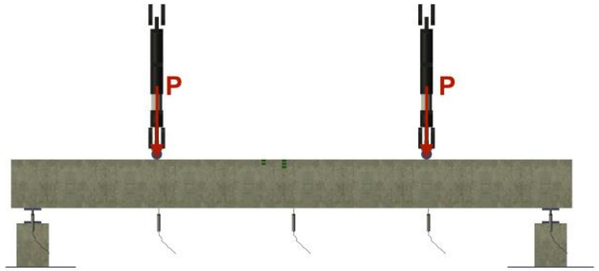


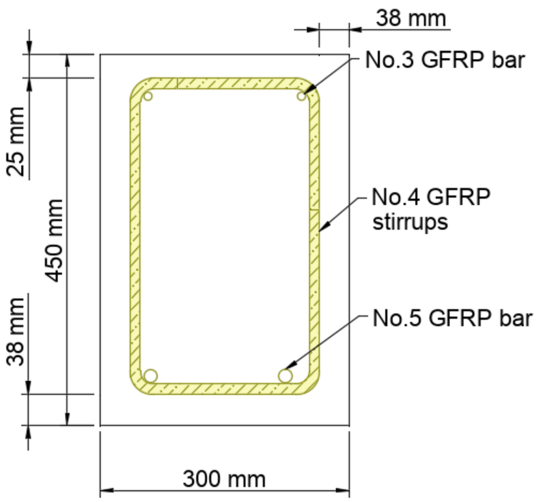
Specimen Fabrication

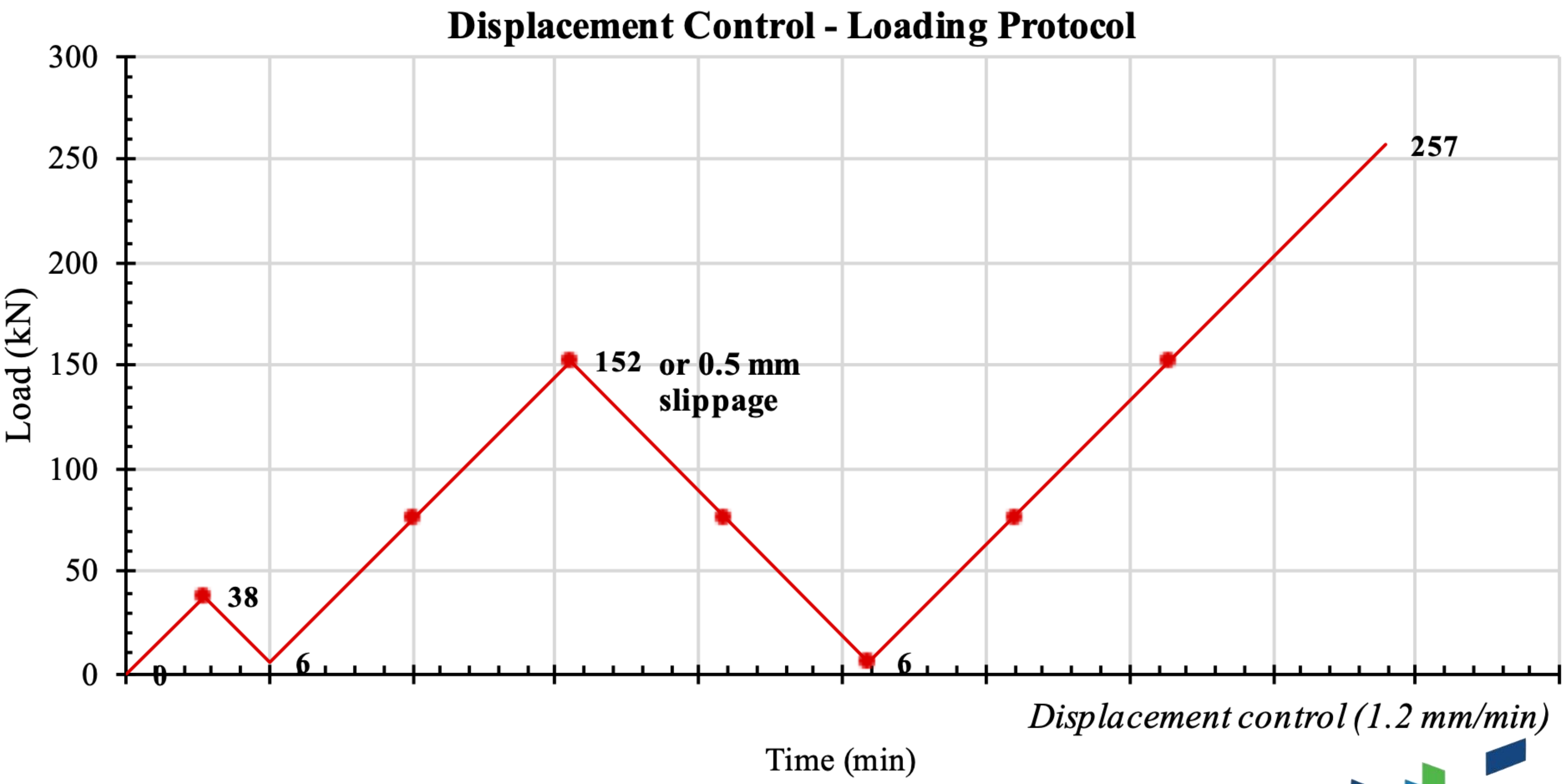
Specimen Fabrication



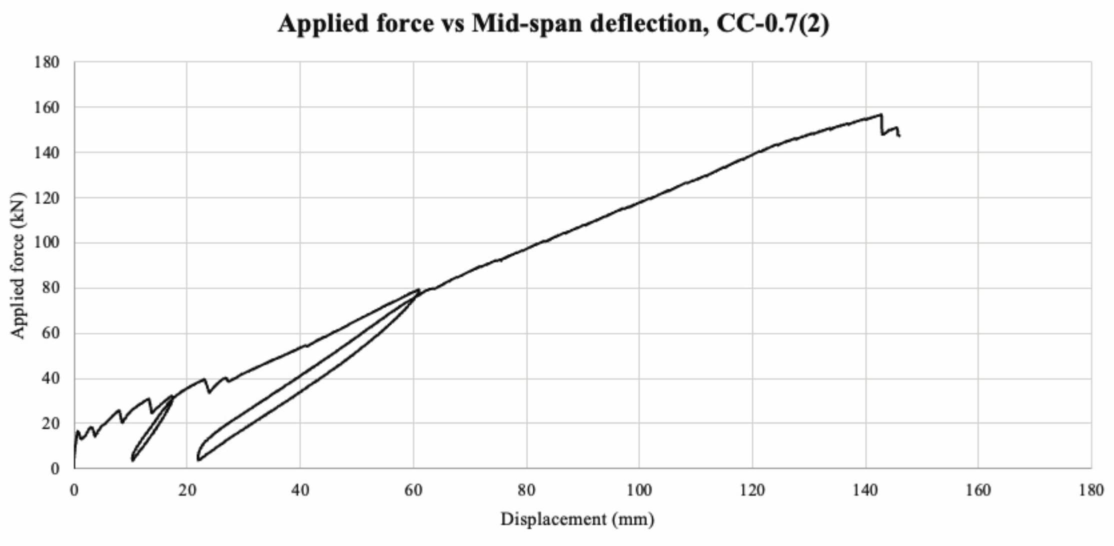
Loading Protocol

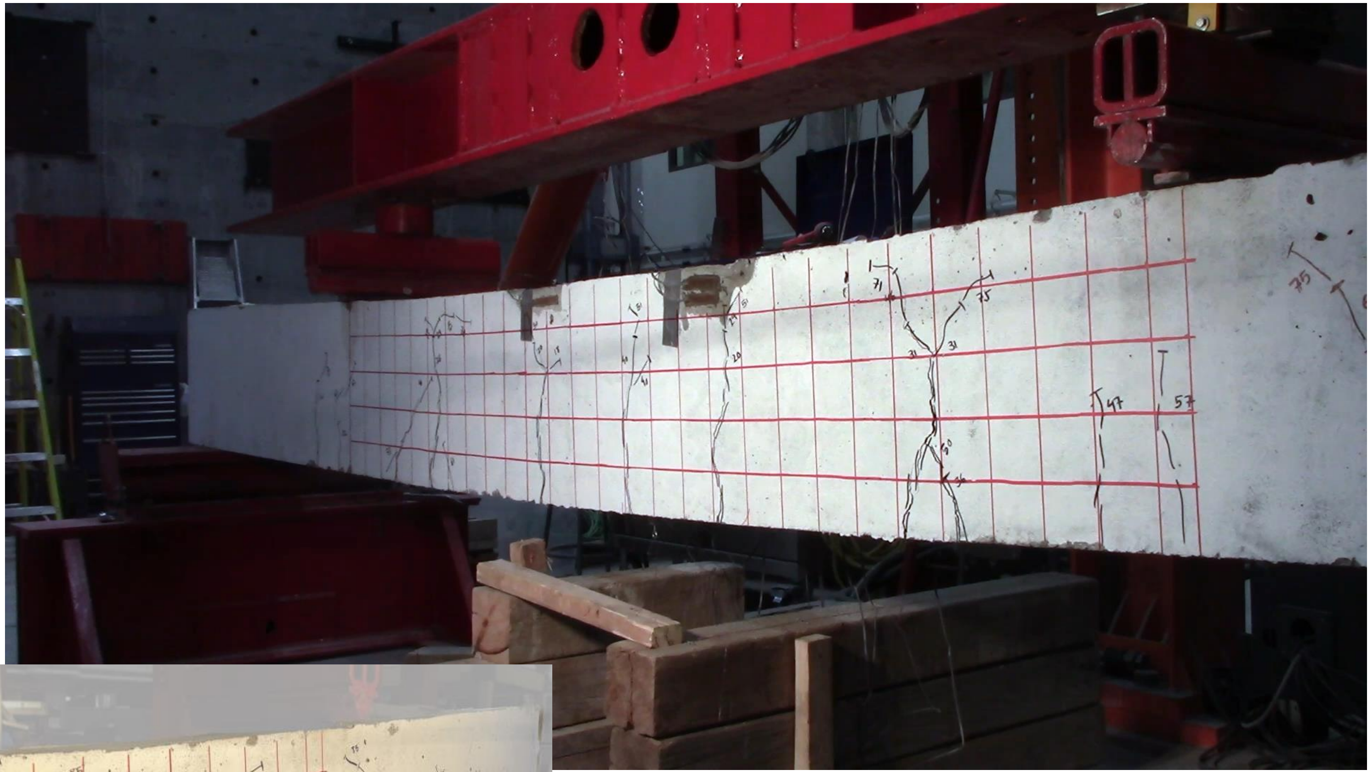


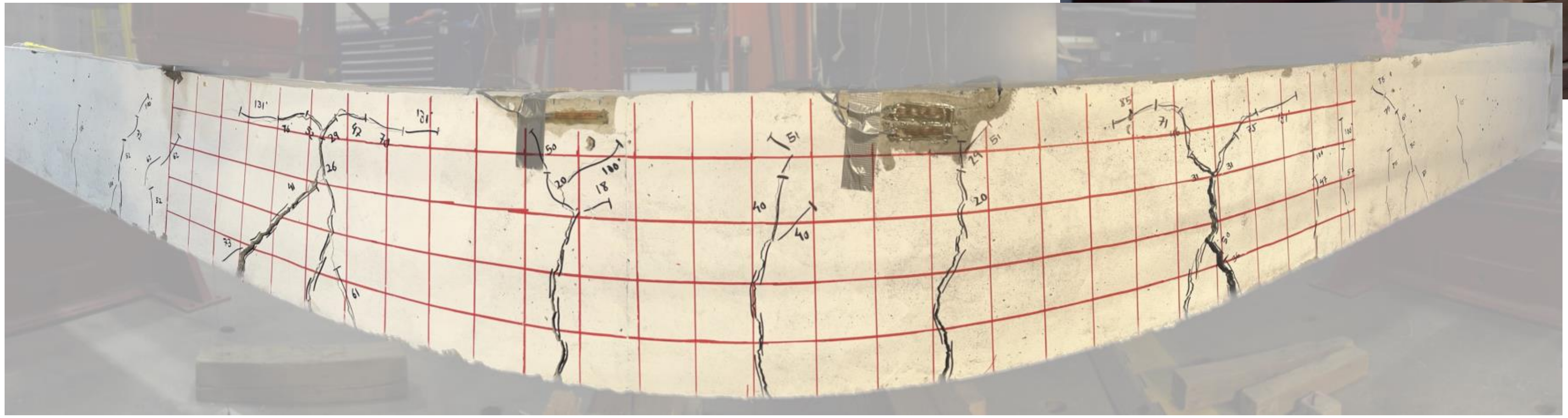




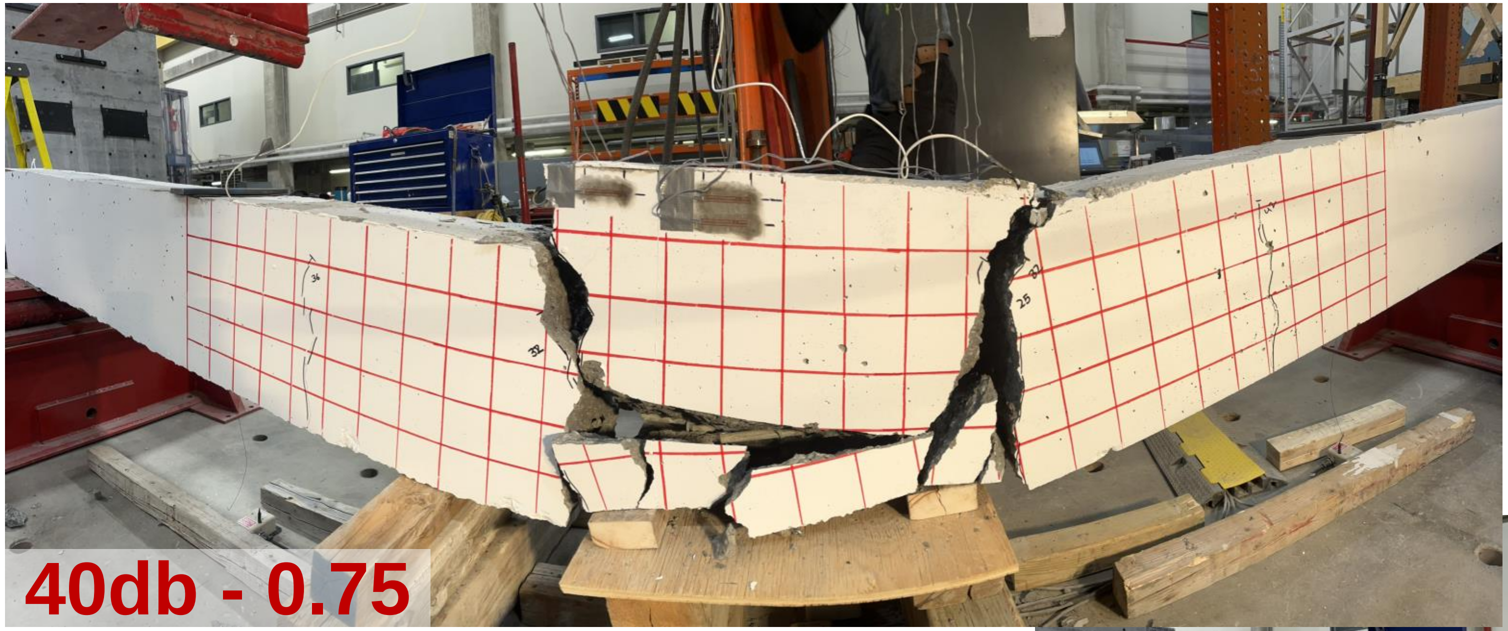
4 Point-Bending Testing

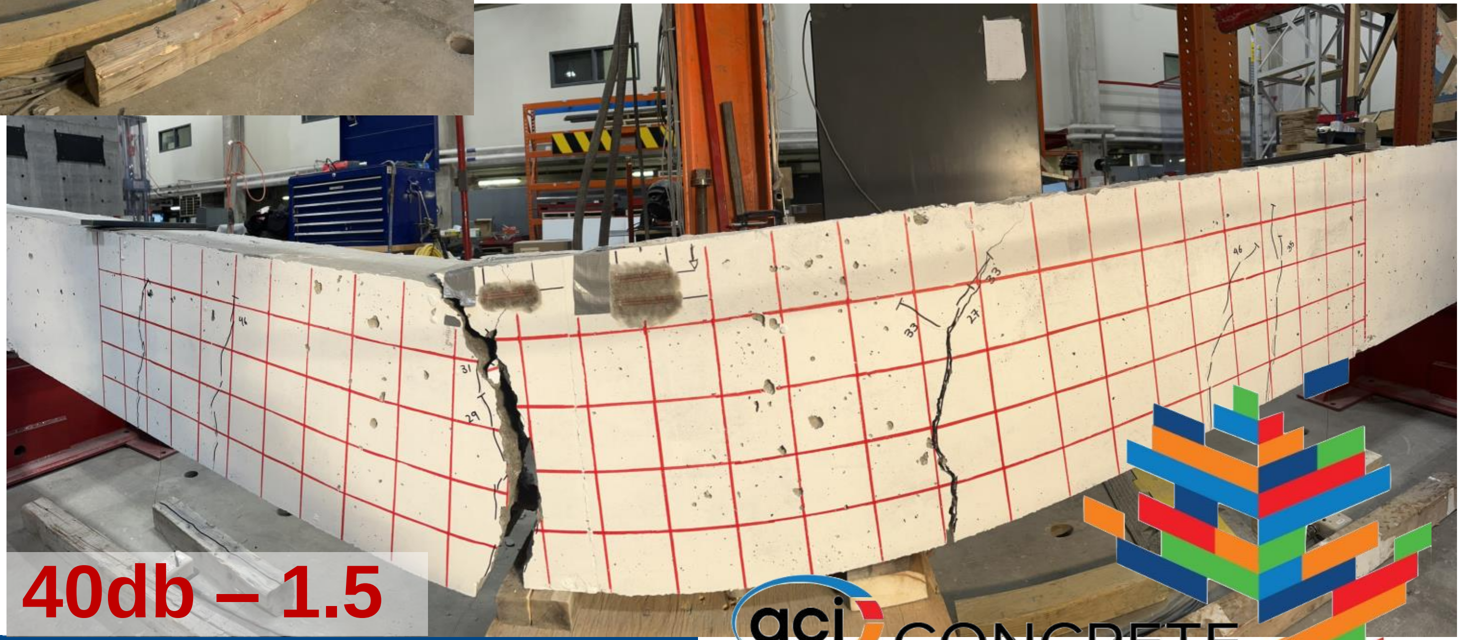




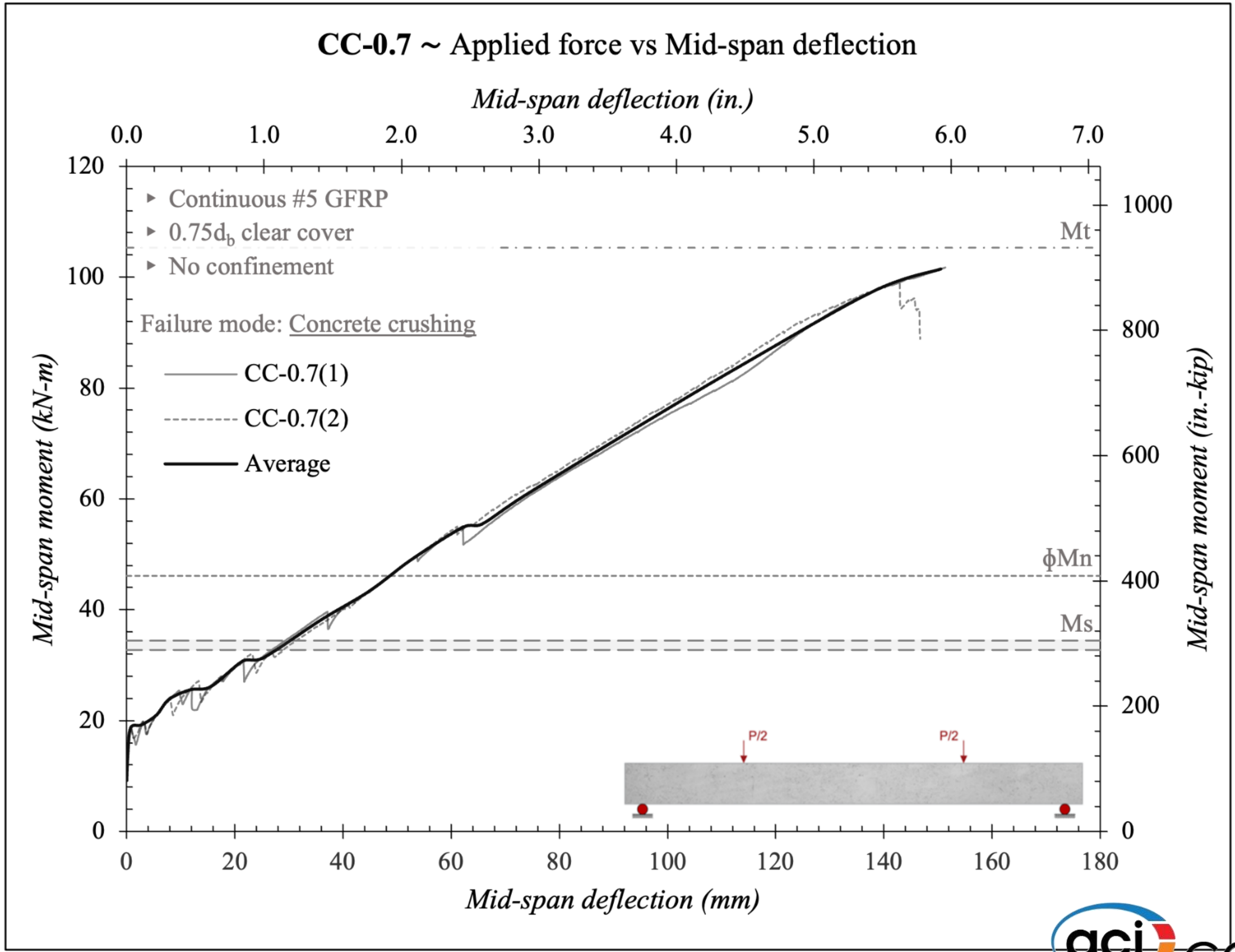


4 Point-Bending Testing

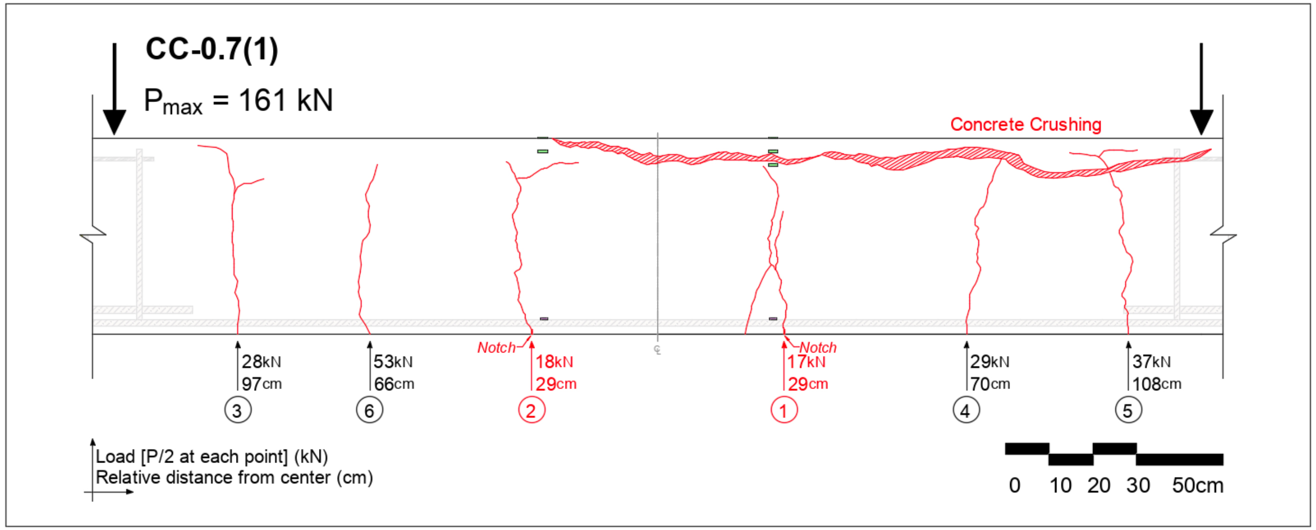


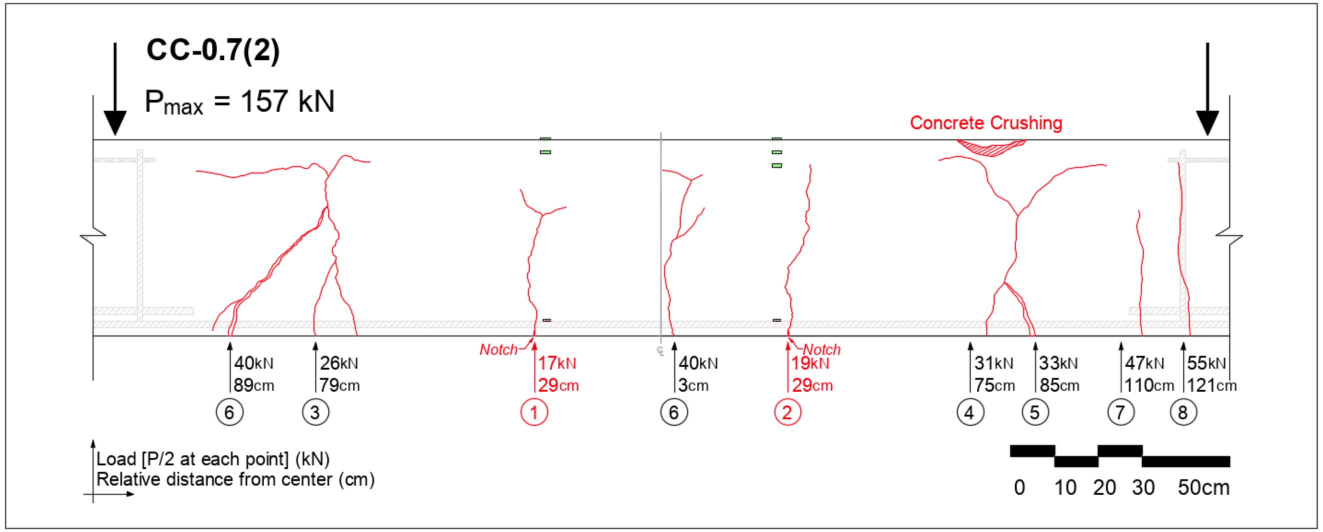


Structural Behavior



What is next?





#	SPECIMEN	f'c (MPa)	EXPECTED FORCE	M-S DEFLECTION		ULTIMATE FORCE		FORCE RATE
				(mm)	(in.)	(kN)	(kip)	
P1-01	**CC-0.7-(1)**	35.5 MPa	168 kN	151 mm	6.0 in.	161 kN	36 kip	95.8%
P1-02	**CC-0.7-(2)**	35.5 MPa	168 kN	147 mm	5.8 in.	157 kN	35 kip	93.5%
P1-03	**CC-1.5-(1)**	35.5 MPa	159 kN	147 mm	5.8 in.	160 kN	36 kip	100.8%
P1-04	**CC-1.5-(2)**	36.0 MPa	159 kN	130 mm	5.1 in.	152 kN	34 kip	95.3%
P1-05	**40-0.7(1)**	40.0 MPa	168 kN	40 mm	1.6 in.	63 kN	14 kip	37.3%
P1-06	**40-0.7(2)**							
P1-07	**40-1.5(1)**							
P1-08	**40-1.5(2)**							
P1-09	**60-0.7(1)**							
P1-10	**60-0.7(2)**							
P1-11	**60-1.5(1)**							
P1-12	**60-1.5(2)**							
P1-13	**80-0.7(1)**							
P1-14	**80-0.7(2)**							
P1-15	**80-1.5(1)**							
P1-16	**80-1.5(2)**							
P1-17	**S40-1.5-(1)**							
P1-18	**S60-1.5-(2)**							

Thank U

Research group:

Jesús D. Ortiz, *Ph.D. Student*

Zahid Hussain, *Ph.D. Student*

Arman Hosseini, *Ph.D. Student*

Antonio Nanni, *Ph.D., PE.*

Brahim Benmokrane, *Ph.D., PE.*