SOFTWARE FOR ANALYSIS + DESIGN OF GFRP RC – STRUCTURES

Matthew Sauer

Altair-at-a-Glance

$613M
FY23 Revenue

79 Offices
In 28 Countries

3,000+
Engineers, Scientists, and Creative Thinkers

150+
Altair and Partner Software Products

16,000+
Customers Globally

ALTAIR

79 Offices in 28 Countries

ALTAIR

16,000+ Customers Worldwide

Automotive

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Life & Earth Sciences

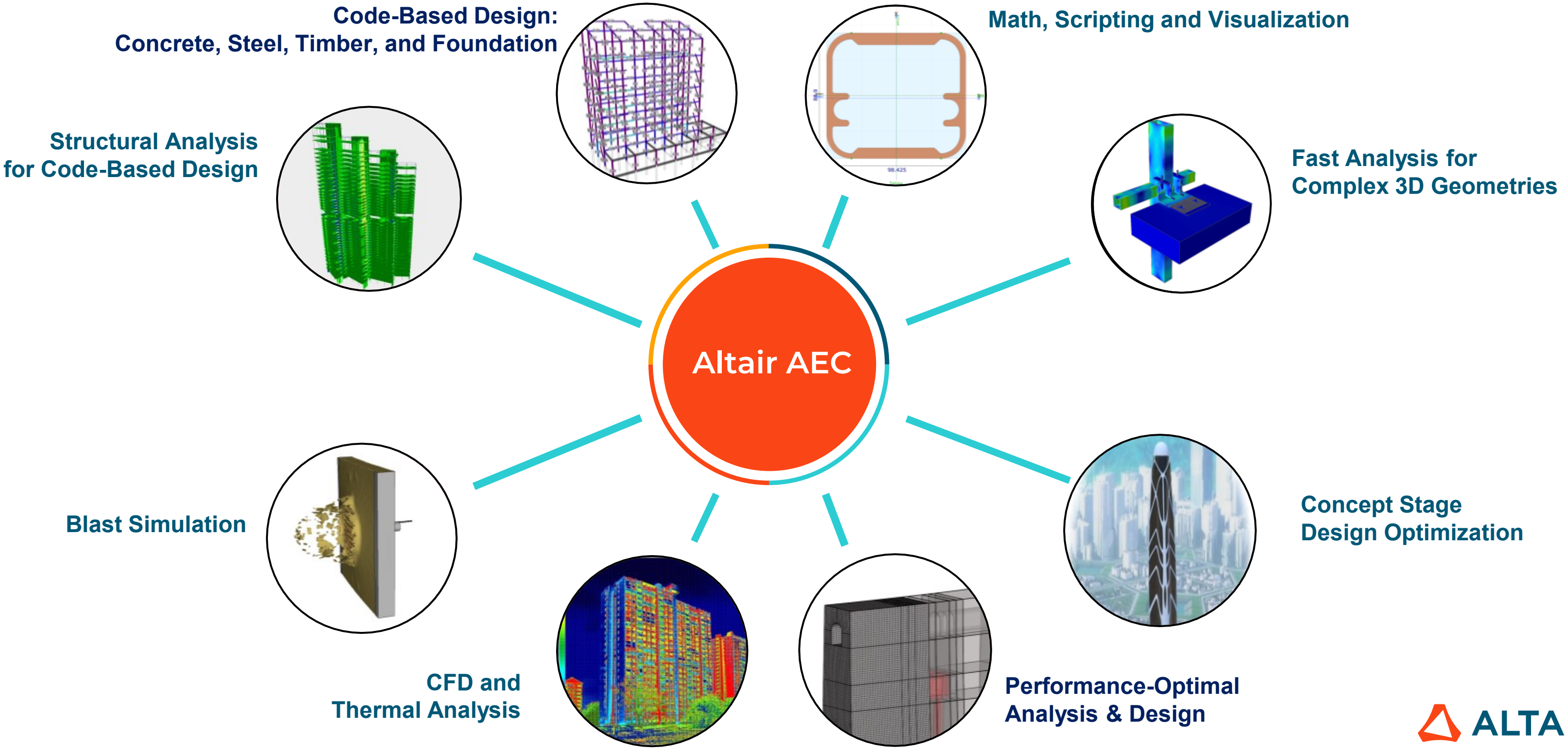
Education

Material Suppliers

Altair S-FRAME Customers – Worldwide

More than half of **The Top 150 Global Design Firms** choose to use S-FRAME structural engineering solutions.
Out of the top 10 global design firms, 7 use some of our software.

Altair Solutions for AEC



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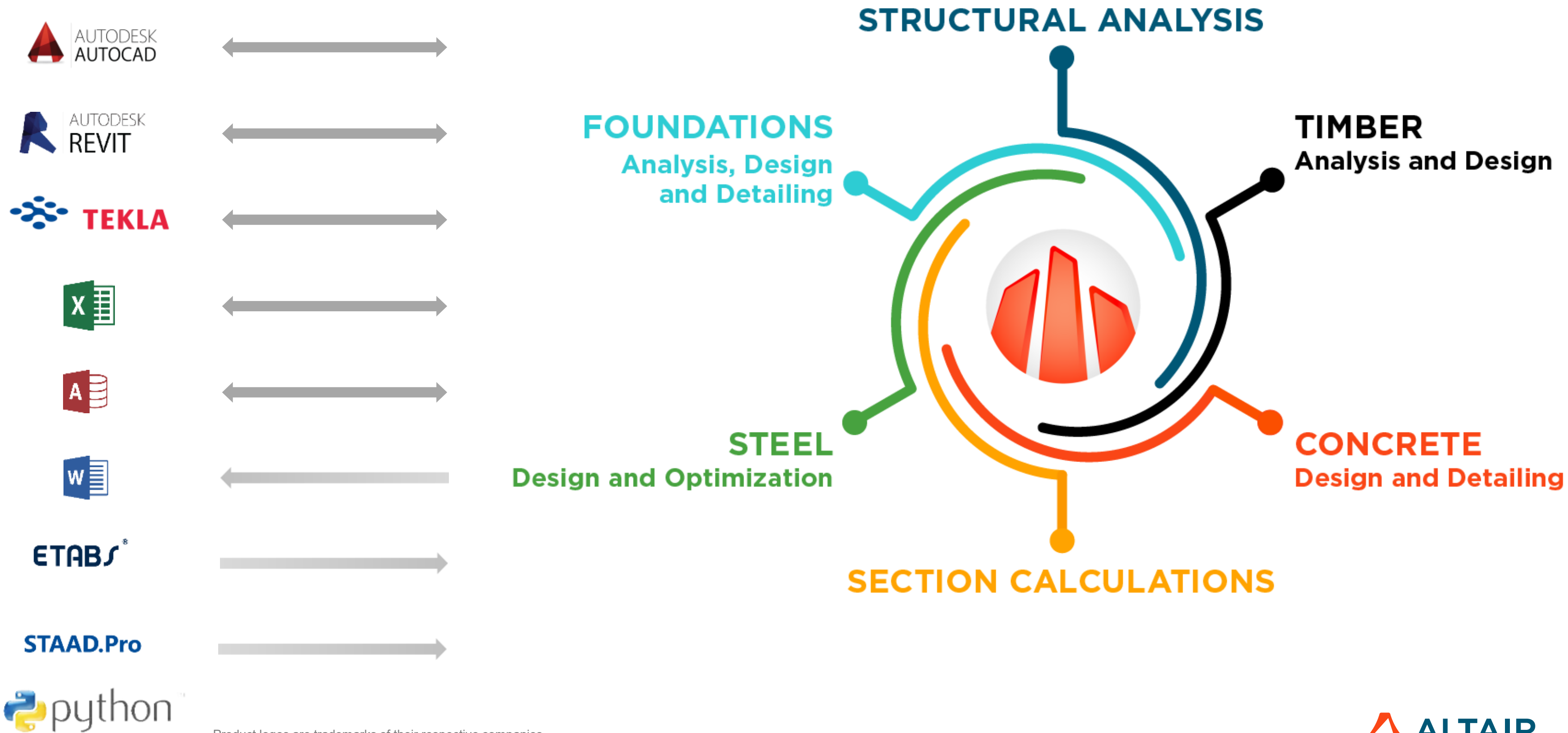
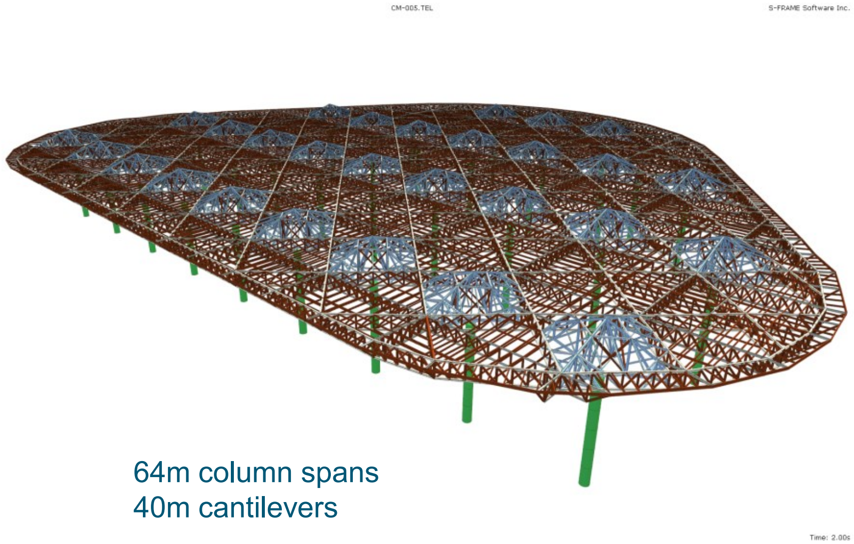
Code-Based Analysis & Design



Product logos are trademarks of their respective companies.

Steel Structures – Mumbai Airport – Skidmore, Owings & Merrill



64m column spans
40m cantilevers

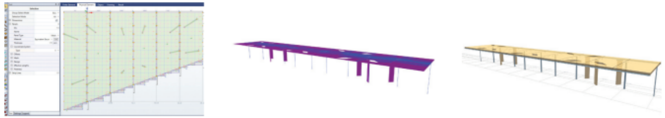
Timber Structures – BCIT Walkway – Bush Bohlman & Partners

CUSTOMER STORY

DESIGNING FOR SUSTAINABILITY

REDUCING THE CARBON FOOTPRINT WITH EMBEDDED

"Structures can account for up to 80% of a building's embodied carbon footprint; our early collaborative design approach helps us develop options that reduce this footprint and even lead



LEFT: Top view of CLT panels with grids and strip line view. **CENTER:** CLT stress contour results from S-TIMBER. **RIGHT:** Final model view in S-TIMBER.

Their Challenge

Bush Bohlman was required to perform the structural analysis and timber design for the British Columbia Institute of Technology, (BCIT), student plaza, a pedestrian and public transport user gateway for the institute. The structure needed to establish a strong campus identity with a biophilic design and demonstrable support for sustainable building practices while ensuring structural safety according to local design codes. The hybrid mass timber structure consists of a Cross-Laminated Timber (CLT) canopy, CLT columns, and steel columns.

The pedestrian comfort walkway needed to meet sustainability, reliability, and structural design requirements. For the structural engineering design team, these projects are unique and fluid. New structural models must be developed and modified for the project's life as the requirements are updated by project stakeholders. This structure involved a pitched roof, skylight openings in the roof CLT panels, and supporting columns constructed from CLT and hollow structural steel. In addition to maintaining a current structural model, the engineers needed to apply local timber design codes to analyze the complex two-way bending behaviour of the cantilevering roof panels and irregular column layout.

Our Solution

The engineer opted to use S-TIMBER to model and analyze the 3D structure. Altair collaborated with Bush Bohlman to ensure the correct modeling parameters were applied while simulating the structure.

S-TIMBER was able to perform a hybrid analysis of the timber and steel elements in one operation and code-check the timber elements for code compliance. Using S-TIMBER's built- in and customizable material databases allowed for a quick definition of the materials conforming to the proprietary CLT required. Modeling automation allowed for easier responses to structural changes resulting from design revisions.

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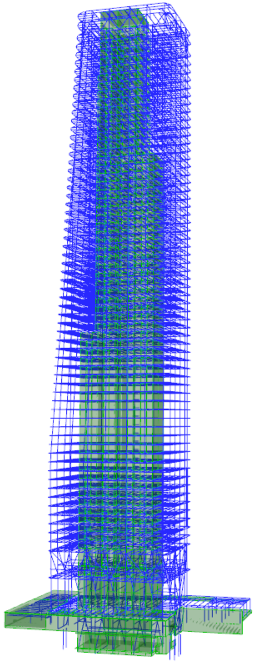
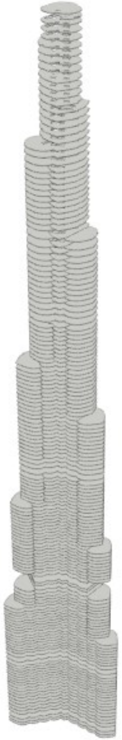
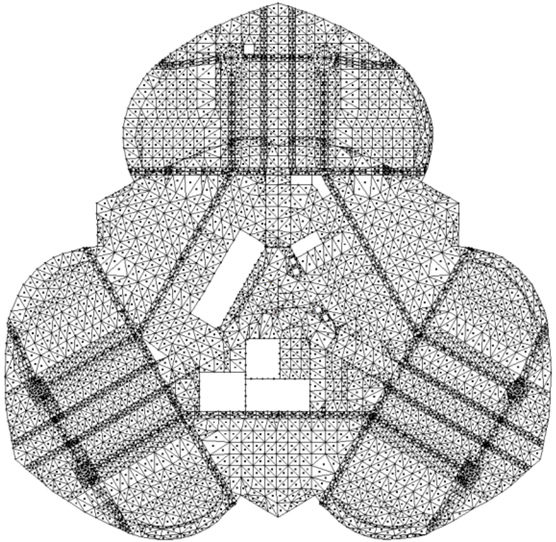
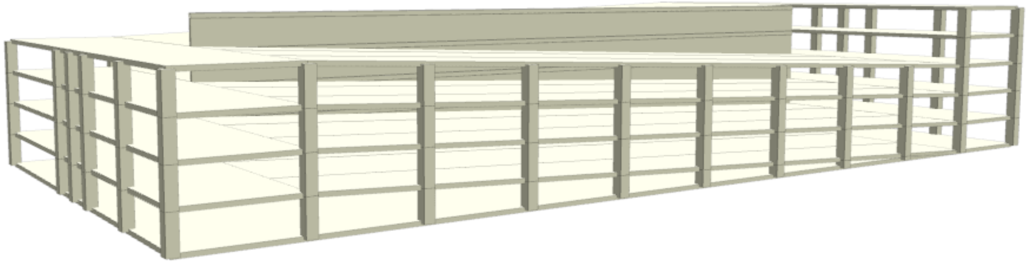
Concrete Structures…





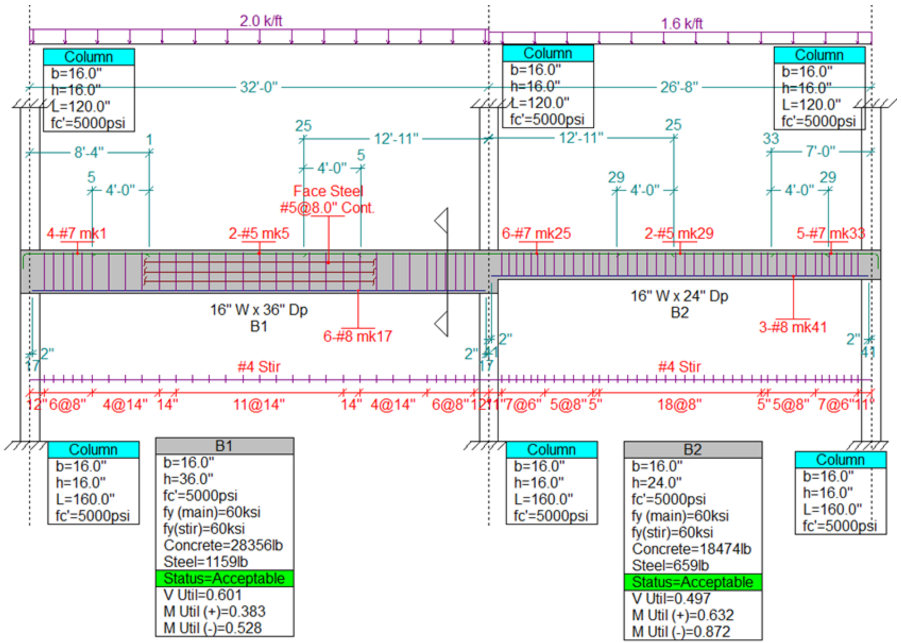




Continuous Concrete Beam Design

Simple/Continuous Concrete Beam Analysis, Design + Reinforcement Layout

- Member Design
- Reinforcement Layout
- Detailed Engineer Design Reports
- Complete design/code check along span
- Deflection checks (short/long)
- ACI 318, CSA A23, **ACI 440 (GFRP)**, BS, CP65



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S-LINE - C:\USERS\MATTHEWS\ONEDRIVE - ALTAIR ENGINEERING, INC\WEBINARS\S-LINE GFRP\2022-01-09_ACI 440_PROB_1.BLN

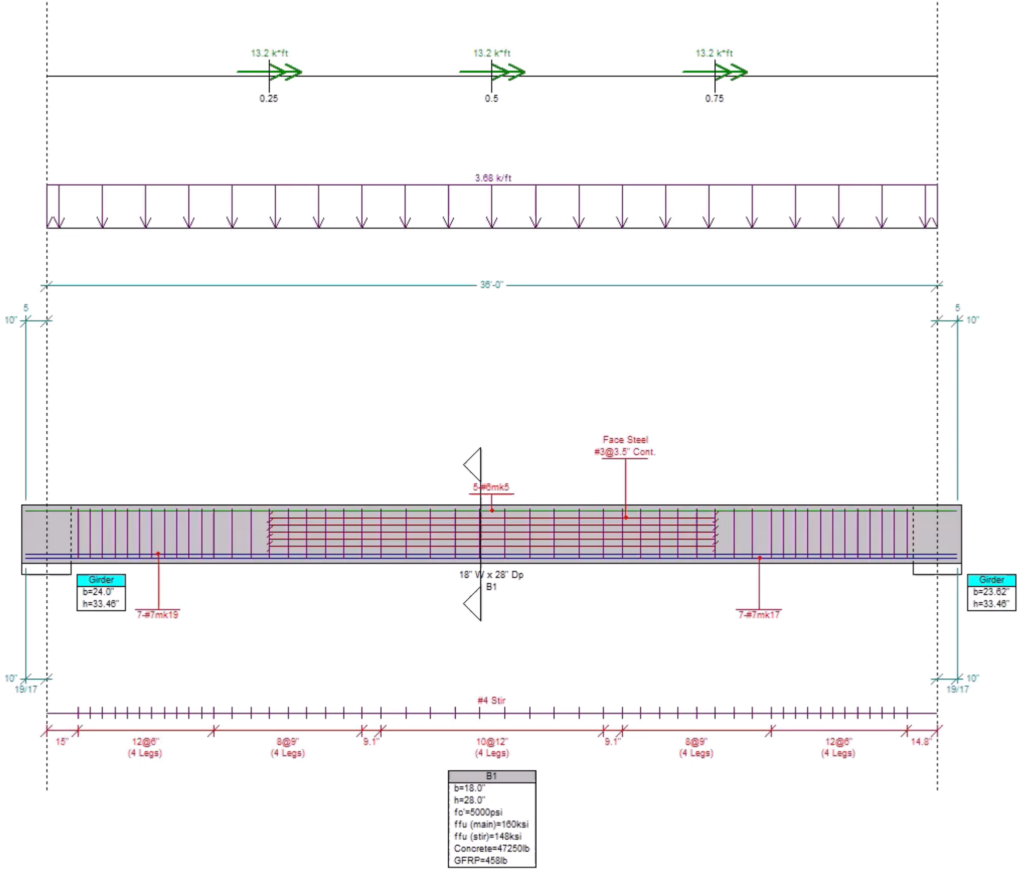
File Edit View Run Results Help Examples

8. 1.20xD + 1.60xL ☑ Visual Editor ☑ Load Combination ☑ Title/Job No/LC ☑ Reinforcing Zoom Percentage 10 %

LC #8: 1.20xD + 1.60xL

ACI 440.11-22

Job #Problem#1

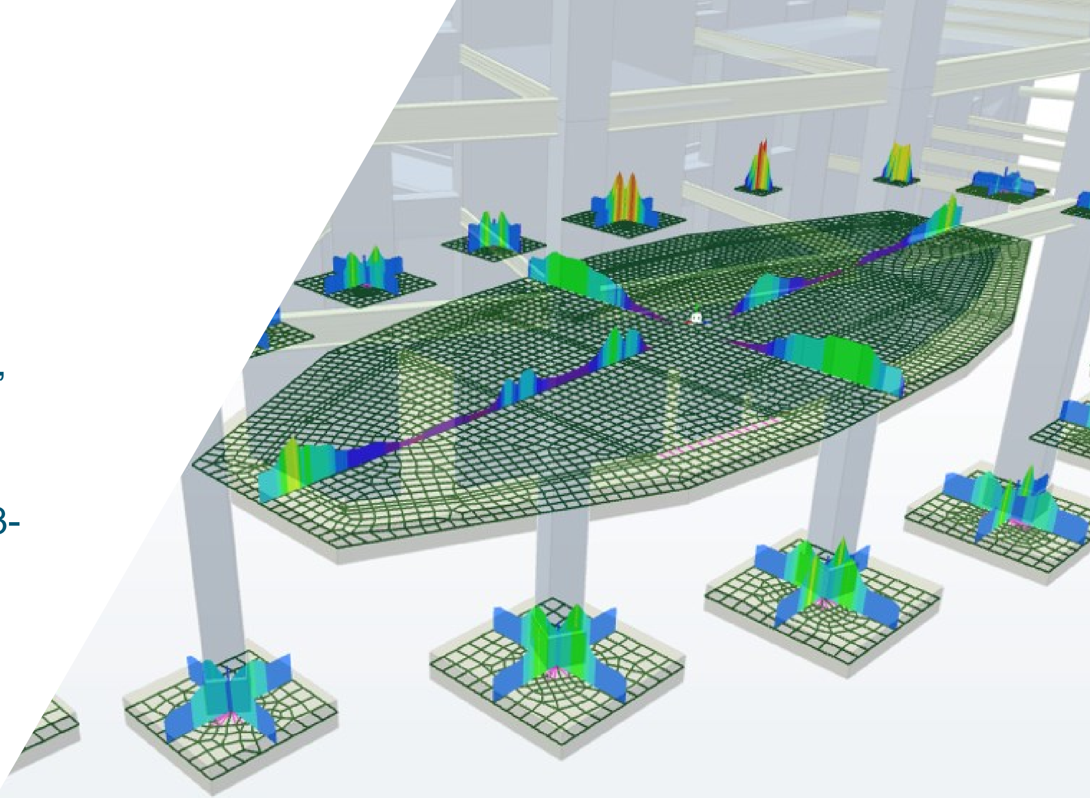


Status = Not Checked | Shear Util = -- N/A -- | Pos Moment Util = -- N/A -- | Neg Moment Util = -- N/A --

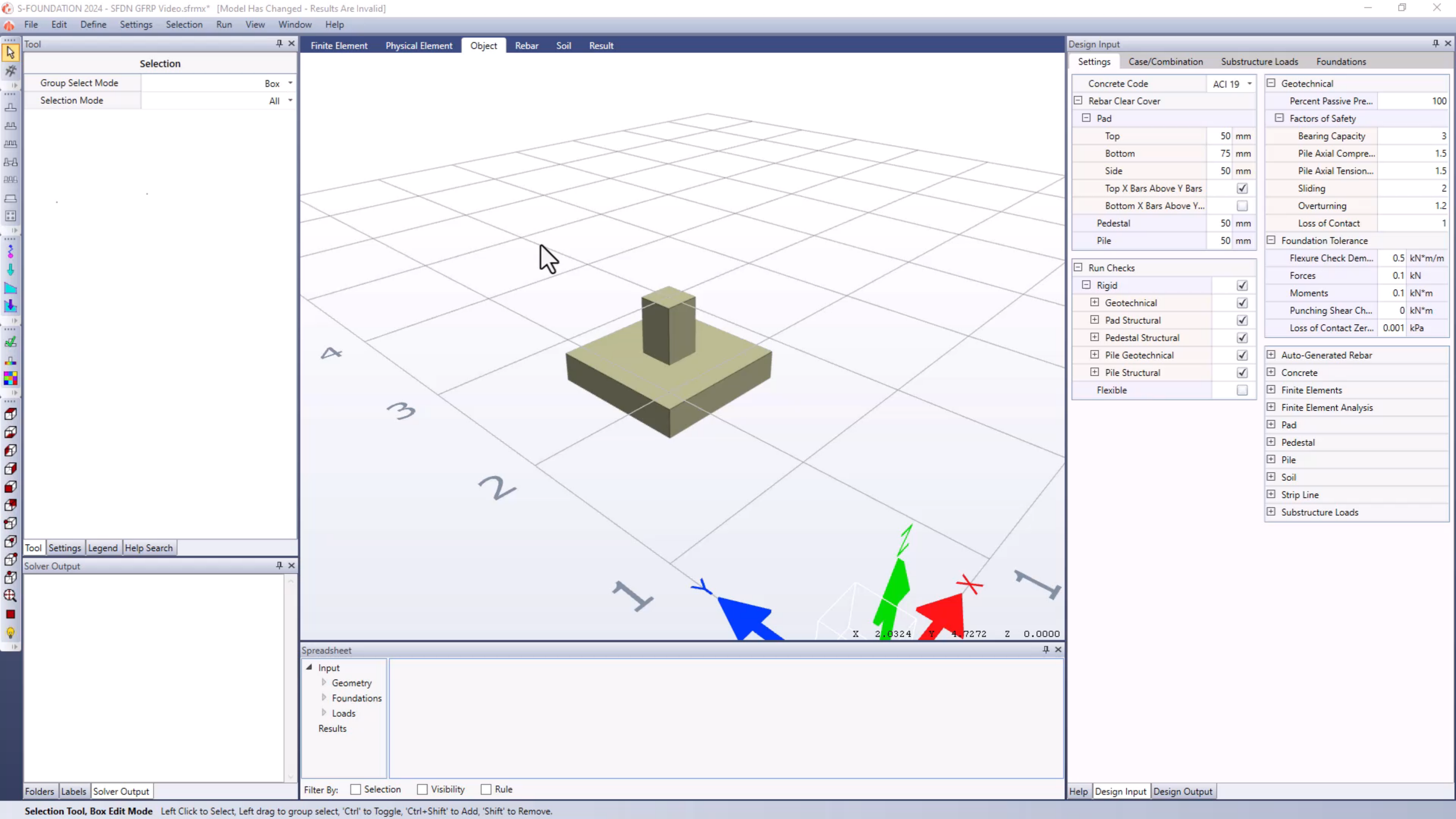
FOUNDATION DESIGN

Parametric Modeling, Analysis + Design

- Deep and Shallow Foundations
- Import from ETABS, STAAD, S-FRAME, and more via CSV files
- Structural and Geotechnical Checks (ACI 318-19, **ACI 440-11.22**, CSA A23.3-19, EC2)
- Automated Design
- Integrated Python Scripting Interface
    - Automation
    - Customization

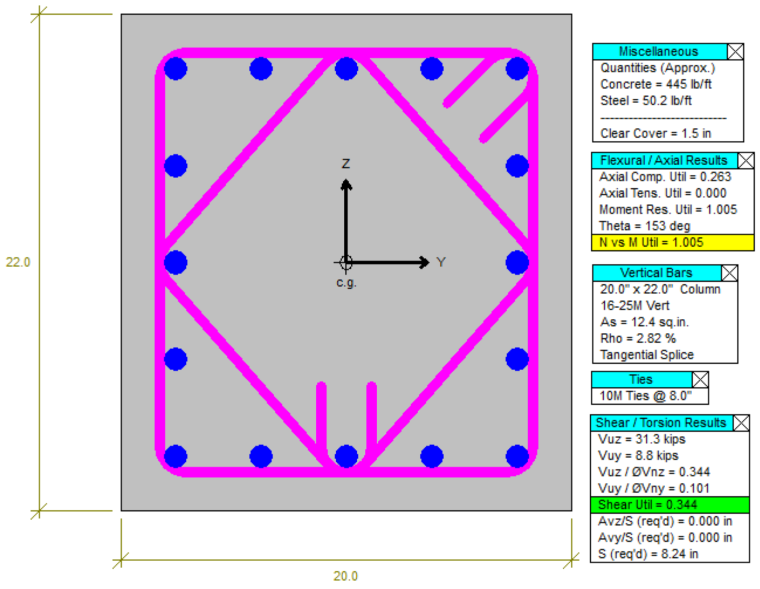


ALTAIR


S-FOUNDATION 2024 - SFDN GFRP Video.sfrmx* [Model Has Changed - Results Are Invalid]
File Edit Define Settings Selection Run View Window Help
Tool
Selection
Group Select Mode Box
Selection Mode All
Tool Settings Legend Help Search
Solver Output
Folders Labels Solver Output
Finite Element Physical Element Object Rebar Soil Result
X 2.0324 Y 4.7272 Z 0.0000
Spreadsheet
Input
Geometry
Foundations
Loads
Results
Filter By: Selection Visibility Rule
Design Input
Settings Case/Combination Substructure Loads Foundations
Concrete Code ACI 19
Rebar Clear Cover
Pad
Top 50 mm
Bottom 75 mm
Side 50 mm
Top X Bars Above Y Bars
Bottom X Bars Above Y...
Pedestal 50 mm
Pile 50 mm
Run Checks
Rigid
Geotechnical
Pad Structural
Pedestal Structural
Pile Geotechnical
Pile Structural
Flexible
Geotechnical
Percent Passive Pre... 100
Factors of Safety
Bearing Capacity 3
Pile Axial Compre... 1.5
Pile Axial Tension... 1.5
Sliding 2
Overturning 1.2
Loss of Contact 1
Foundation Tolerance
Flexure Check Dem... 0.5 kN*m/m
Forces 0.1 kN
Moments 0.1 kN*m
Punching Shear Ch... 0 kN*m
Loss of Contact Zer... 0.001 kPa
Auto-Generated Rebar
Concrete
Finite Elements
Finite Element Analysis
Pad
Pedestal
Pile
Soil
Strip Line
Substructure Loads
Help Design Input Design Output
Selection Tool, Box Edit Mode Left Click to Select, Left drag to group select, 'Ctrl' to Toggle, 'Ctrl+Shift' to Add, 'Shift' to Remove.

Concrete Section Design

Beam, Column and Wall Section Code Checks and Design



- Code checking, and design reinforced concrete **sections**
- ACI 318-19, CSA 19, EC2
- Support for GFRP Design to **ACI 440.11-22**
- Integrated with ETABS, S-FRAME and more…
- Batch Processing

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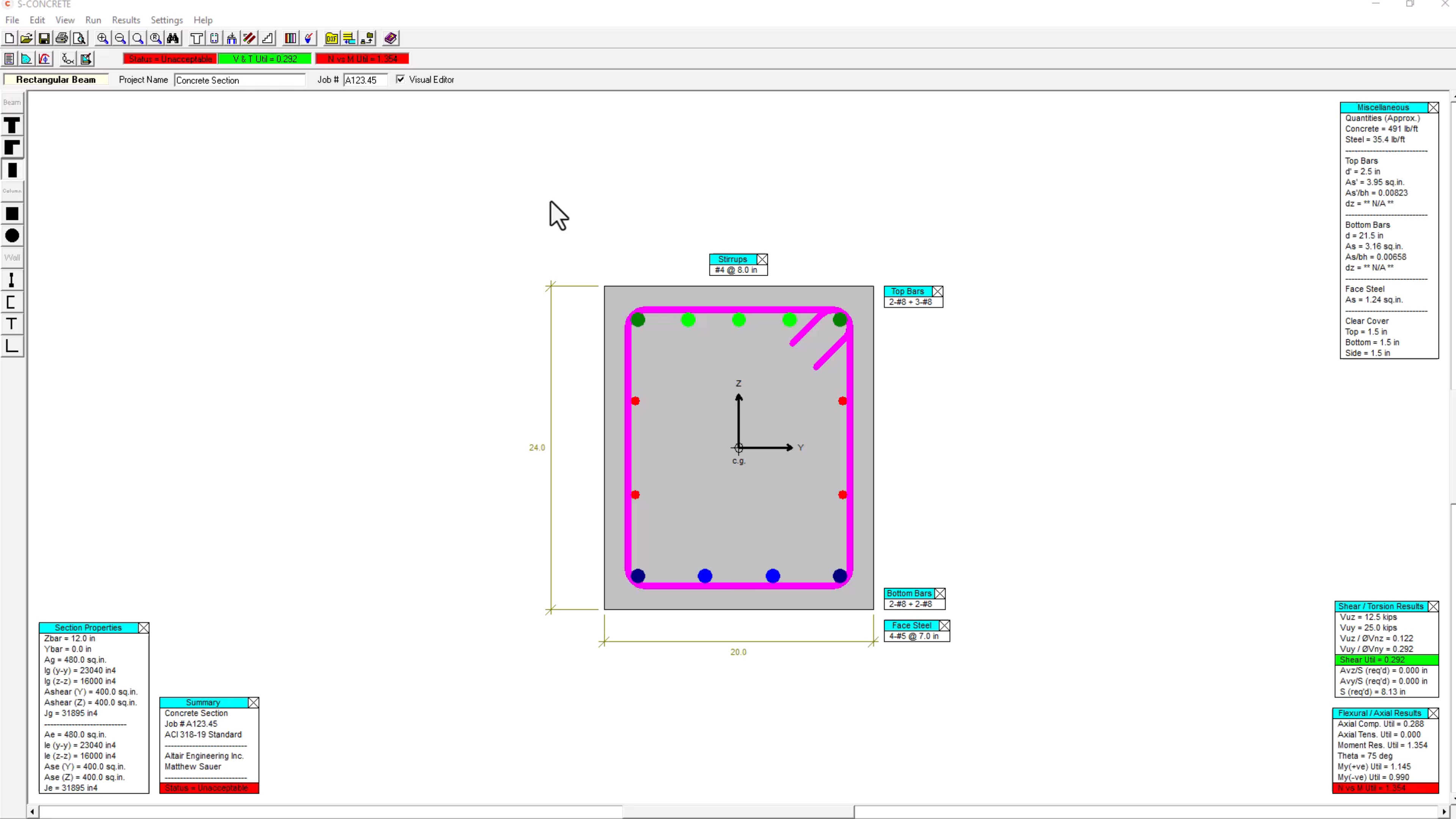
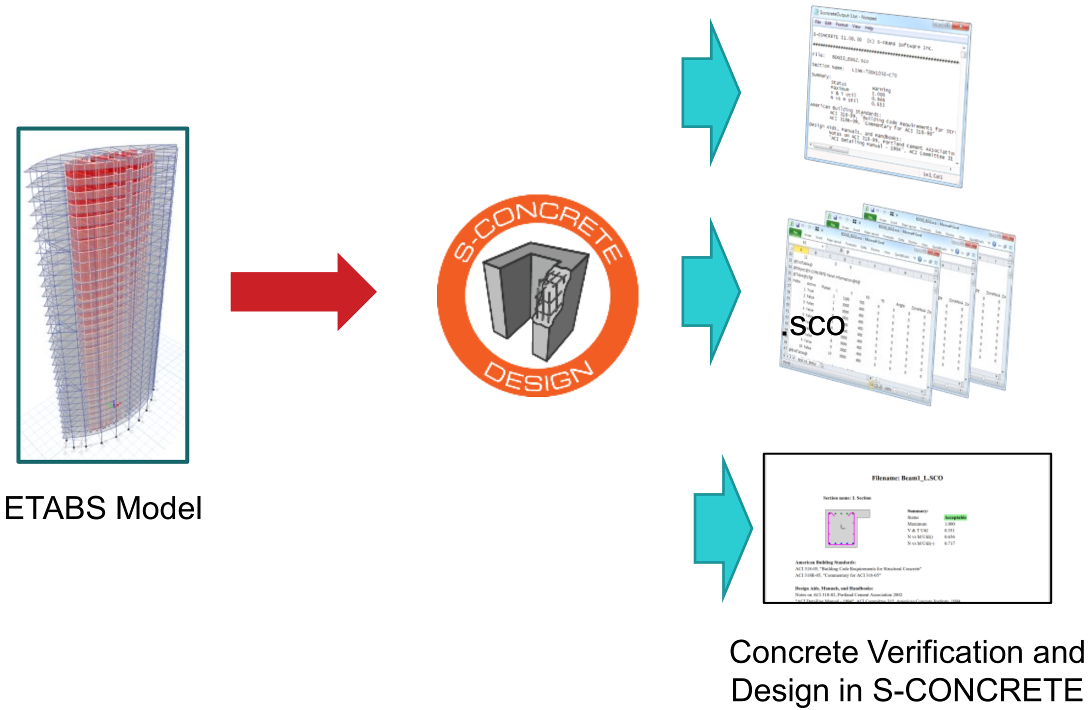

S-CONCRETE
File Edit View Run Results Settings Help
Status = Unacceptable
V & T Util = 0.292
N vs M Util = 1.354
Rectangular Beam
Project Name Concrete Section
Job # A123.45
Visual Editor
Beam
Column
Wall
Stirrups
#4 @ 8.0 in
Top Bars
2-#8 + 3-#8
Z
Y
c.g.
24.0
20.0
Bottom Bars
2-#8 + 2-#8
Face Steel
4-#5 @ 7.0 in
Miscellaneous
Quantities (Approx.)
Concrete = 491 lb/ft
Steel = 35.4 lb/ft
Top Bars
d' = 2.5 in
As' = 3.95 sq.in.
As'/bh = 0.00823
dz = ** N/A **
Bottom Bars
d = 21.5 in
As = 3.16 sq.in.
As/bh = 0.00658
dz = ** N/A **
Face Steel
As = 1.24 sq.in.
Clear Cover
Top = 1.5 in
Bottom = 1.5 in
Side = 1.5 in
Section Properties
Zbar = 12.0 in
Ybar = 0.0 in
Ag = 480.0 sq.in.
Ig (y-y) = 23040 in4
Ig (z-z) = 16000 in4
Ashear (Y) = 400.0 sq.in.
Ashear (Z) = 400.0 sq.in.
Jg = 31895 in4
Ae = 480.0 sq.in.
Ie (y-y) = 23040 in4
Ie (z-z) = 16000 in4
Ase (Y) = 400.0 sq.in.
Ase (Z) = 400.0 sq.in.
Je = 31895 in4
Summary
Concrete Section
Job # A123.45
ACI 318-19 Standard
Altair Engineering Inc.
Matthew Sauer
Status = Unacceptable
Shear / Torsion Results
Vuz = 12.5 kips
Vuy = 25.0 kips
Vuz / ØVnz = 0.122
Vuy / ØVny = 0.292
Shear Util = 0.292
Avz/S (req'd) = 0.000 in
Avy/S (req'd) = 0.000 in
S (req'd) = 8.13 in
Flexural / Axial Results
Axial Comp. Util = 0.288
Axial Tens. Util = 0.000
Moment Res. Util = 1.354
Theta = 75 deg
My(+ve) Util = 1.145
My(-ve) Util = 0.990
N vs M Util = 1.354

Structural Analysis to Concrete Design without hassle



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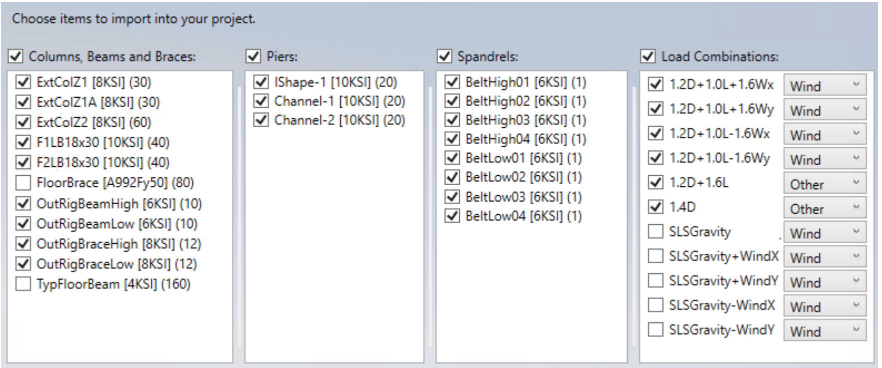
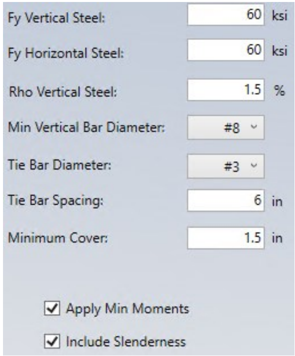
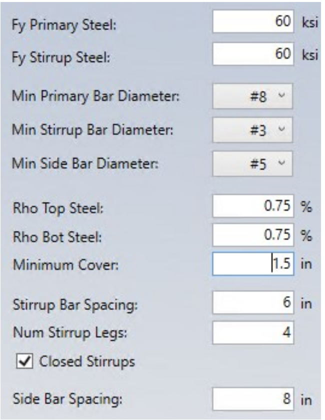
S-CONCRETE Multistory Designer

Import Selected Elements from ETABS Model - Specify Initial Reinforcement by Section Type

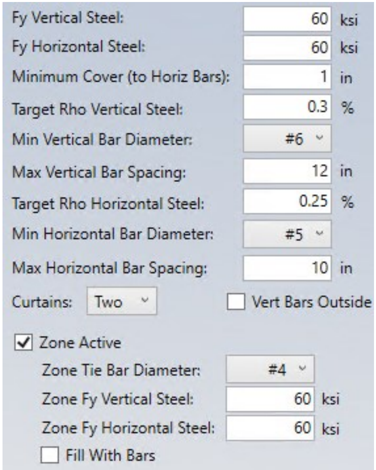




Columns



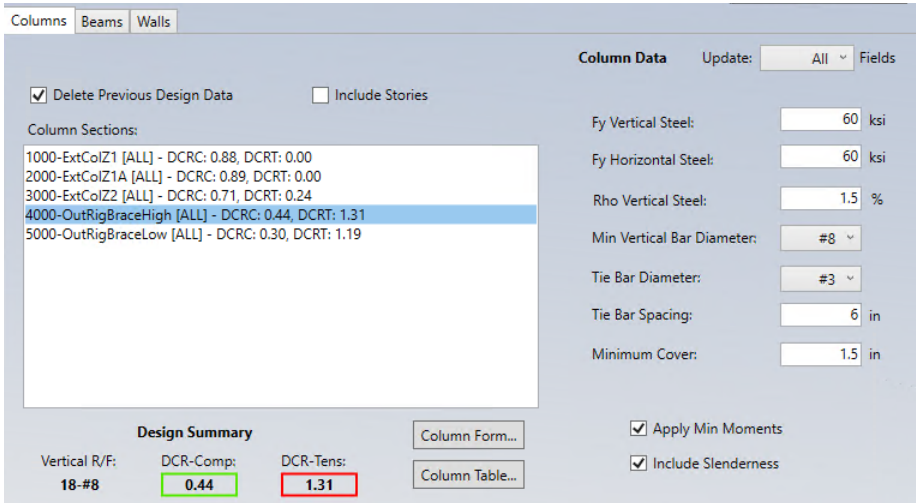
Beams

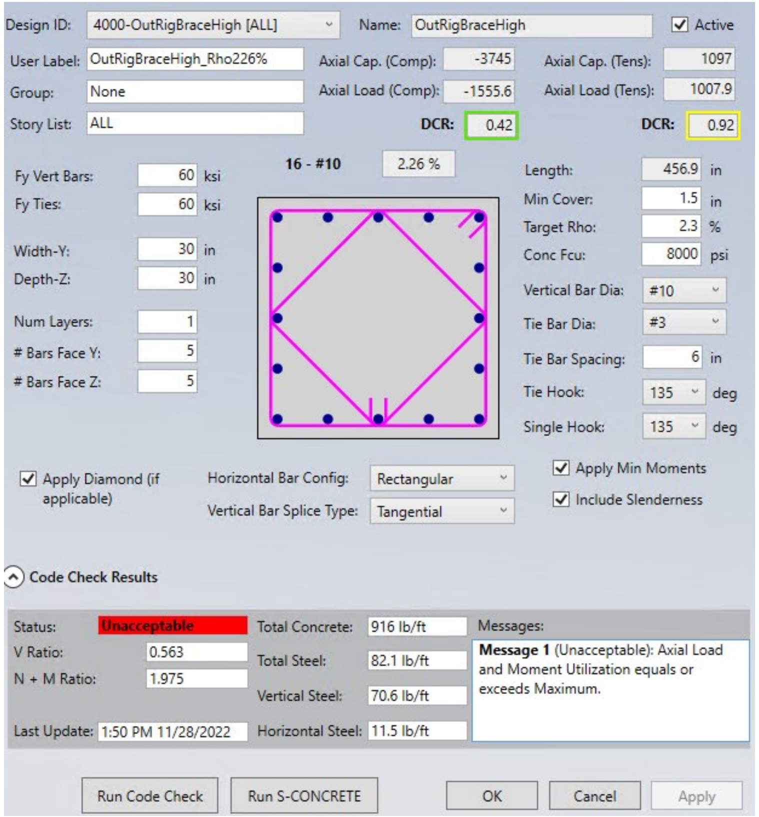


Walls

S-CONCRETE Multistory Designer

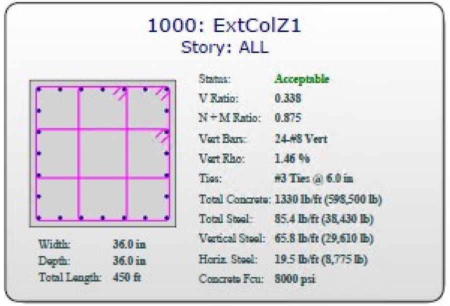
Refine Reinforcement for each Section/Group – Run Preliminary or Full Design Checks

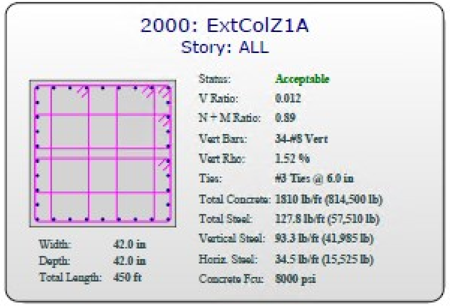




S-CONCRETE Multistory Designer

Generate Input Files, Batch Run, and Generate Result Reports





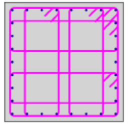
DesignID	SCOFileName	SectName	Story	Status	VT_Ratio	NM_Ratio	SectionType	Width	Depth	fcu	VertBars	VertRho	Ties
1000	1000-ExtColZ1_8000[ALL]	ExtColZ1	ALL	Acceptable	0.338	0.875	Rectangular Column	36.0 in	36.0 in	8000 psi	24-#8 Vert	1.46 %	#3 Ties @ 6.0 in
2000	2000-ExtColZ1A_8000[ALL]	ExtColZ1A	ALL	Acceptable	0.012	0.89	Rectangular Column	42.0 in	42.0 in	8000 psi	34-#8 Vert	1.52 %	#3 Ties @ 6.0 in
3000	3000-ExtColZ2_8000[ALL]	ExtColZ2	ALL	Borderline	1.053	0.76	Circular Column		36.0 in	8000 psi	20-#8 Vert	1.55 %	#3 Ties @ 6.0 in
4000	4000-OutRigBraceHigh_8000[ALL]	OutRigBraceHigh	ALL	Unacceptable	0.563	1.975	Rectangular Column	30.0 in	30.0 in	8000 psi	16-#10 Vert	2.26 %	#3 Ties @ 6.0 in
5000	5000-OutRigBraceLow_8000[ALL]	OutRigBraceLow	ALL	Acceptable	0.341	0.738	Rectangular Column	30.0 in	30.0 in	8000 psi	18-#10 Vert	2.54 %	#3 Ties @ 6.0 in

S-CONCRETE Multistory Designer

Create Design Groups, and Detailed Code Check Reports for Final Documentation

Filename: 1000-ExtColZ1_8000[ALL].sco

Section name: ExtColZ1



Summary:

Status	Acceptable
Maximum	1.000
V & T Util	0.261
N vs M Util	0.904

American Building Standards:

ACI 318-14, "Building Code Requirements for Structural Concrete"

ACI 318R-14, "Commentary for ACI 318-14"

Design Aids, Manuals, and Handbooks (For Reference Only):

The Reinforced Concrete Design Handbook, A Companion to ACI 318-14

"ACI Detailing Manual - 1994", ACI Committee 315, American Concrete Institute, 1994

"Manual of Standard Practice", Concrete Reinforcing Steel Institute, 2003

Section Dimensions:

Rectangular Column

b = 36.0 in

h = 36.0 in

Quantities (approx.):

Concrete = 1336 lb/ft

Steel = 100.5 lb/ft

Primary = 45.8 lb/ft

Secondary = 54.6 lb/ft

Material Properties:

fc' = 8000 psi

fy(vert) = 60.0 ksi

fy(ties) = 60.0 ksi

Wc = 150 pcf

Ws = 500 pcf

Poisson's Ratio = 0.2

hagg = 0.75 in

Es = 29000 ksi

Ec = 5100 ksi

Gc = 1786 ksi

fr = 671 psi

Gross Properties:

Zbar = 0.0 in

Ybar = 0.0 in

Ag = 1296.0 sq.in.

Ig(y-y) = 139968 in4

Ig(z-z) = 139968 in4

Ashear(Y) = 1080.0 sq.in.

Ashear(Z) = 1080.0 sq.in.

Jg = 236120 in4

Effective Properties:

Ae = 1296.0 sq.in.

Ie(y-y) = 139968 in4

Ie(z-z) = 139968 in4

Ase(Y) = 1080.0 sq.in.

Ase(Z) = 1080.0 sq.in.

Je = 236120 in4

Vertical Bars:

36 x 36 in Column

30-#6 Vert

As = 13.2 sq.in.

Rho = 1.02 %

Tangential Splice

Ties:

#4 Ties @ 6.0 in

Legs (Z-Direction) = 6

Legs (Y-Direction) = 6

Miscellaneous:

Clear Cover = 1.5 in

Column Design Summary

Story	ExtCol
L021	Column: ExtColZ2 Status: Borderline DCR:PM 0.58 VT 1.05 RC 36Dia (8000 psi) VertBars: 20-#8 Vert-1.55 % Ties: #3 Ties @ 6.0 in
L020	Column: ExtColZ2 Status: Warning DCR:PM 0.76 VT 0.53 RC 36Dia (8000 psi) VertBars: 20-#8 Vert-1.55 % Ties: #3 Ties @ 6.0 in
L019	Column: ExtColZ2 Status: Acceptable DCR:PM 0.23 VT 0.12 RC 36Dia (8000 psi) VertBars: 20-#8 Vert-1.55 % Ties: #3 Ties @ 6.0 in
L018	Column: ExtColZ2 Status: Acceptable DCR:PM 0.21 VT 0.03 RC 36Dia (8000 psi) VertBars: 20-#8 Vert-1.55 % Ties: #3 Ties @ 6.0 in
L017	Column: ExtColZ2 Status: Acceptable DCR:PM 0.29 VT 0.02 RC 36Dia (8000 psi) VertBars: 20-#8 Vert-1.55 % Ties: #3 Ties @ 6.0 in
L016	Column: ExtColZ2 Status: Acceptable DCR:PM 0.38 VT 0.02 RC 36Dia (8000 psi) VertBars: 20-#8 Vert-1.55 % Ties: #3 Ties @ 6.0 in
L015	Column: ExtColZ2 Status: Acceptable DCR:PM 0.46 VT 0.02 RC 36Dia (8000 psi) VertBars: 20-#8 Vert-1.55 % Ties: #3 Ties @ 6.0 in

Story	ExtCol
L014	Column: ExtColZ2 Status: Acceptable DCR:PM 0.54 VT 0.02 RC 36Dia (8000 psi) VertBars: 20-#8 Vert-1.55 % Ties: #3 Ties @ 6.0 in
L013	Column: ExtColZ2 Status: Acceptable DCR:PM 0.62 VT 0.05 RC 36Dia (8000 psi) VertBars: 20-#8 Vert-1.55 % Ties: #3 Ties @ 6.0 in
L012	Column: ExtColZ2 Status: Acceptable DCR:PM 0.71 VT 0.2 RC 36Dia (8000 psi) VertBars: 20-#8 Vert-1.55 % Ties: #3 Ties @ 6.0 in
L011	Column: ExtColZ1 Status: Acceptable DCR:PM 0.54 VT 0.34 RC 36x36 (8000 psi) VertBars: 24-#8 Vert-1.46 % Ties: #3 Ties @ 6.0 in
L010	Column: ExtColZ1 Status: Acceptable DCR:PM 0.68 VT 0.19 RC 36x36 (8000 psi) VertBars: 24-#8 Vert-1.46 % Ties: #3 Ties @ 6.0 in
L009	Column: ExtColZ1 Status: Acceptable DCR:PM 0.74 VT 0.03 RC 36x36 (8000 psi) VertBars: 24-#8 Vert-1.46 % Ties: #3 Ties @ 6.0 in
L008	Column: ExtColZ1 Status: Acceptable DCR:PM 0.81 VT 0.01 RC 36x36 (8000 psi) VertBars: 24-#8 Vert-1.46 % Ties: #3 Ties @ 6.0 in
L007	Column: ExtColZ1 Status: Acceptable DCR:PM 0.88 VT 0.01 RC 36x36 (8000 psi) VertBars: 24-#8 Vert-1.46 % Ties: #3 Ties @ 6.0 in

ALTAIR

THANK YOU

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#ONLYFORWARD

ALTAIR

FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

DESIGN & REPAIR OF BRIDGE BARRIER WALLS/TRAFFIC RAILING WITH GFRP

Dr. Khaled Sennah, P.Eng., P.E., FCSCE, FEIC, FCAE, FIAAM

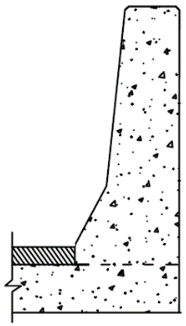
Toronto Metropolitan University

SPONSORED BY:

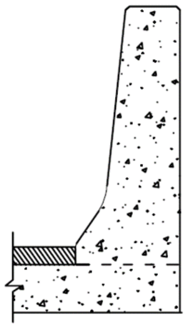
PULTRALL V·ROD FIBERGLASS Innovations ALTAIR MSTBAR MAXIMUM STRENGTH GFRP SFTec ACMA American Composites Manufacturers Association FRP Rebar Manufacturers Council

UNIVERSITÉ DE SHERBROOKE NSERC CRSNG UNIVERSITY OF MIAMI Center for Integration of Composites into Infrastructure FDOT

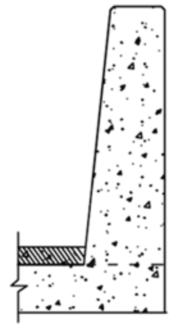
Concrete barrier types and loads



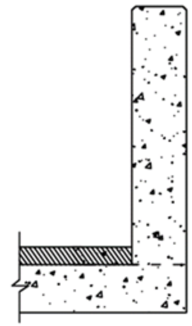
Jersey barrier



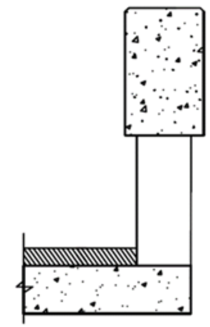
F-shape barrier



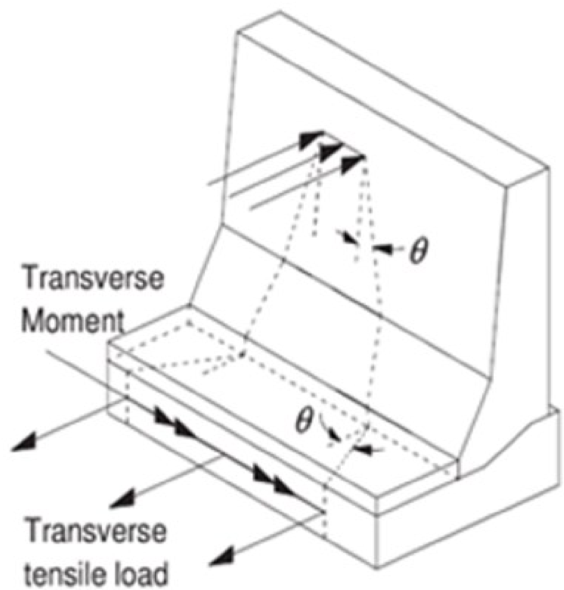
Single-slope barrier



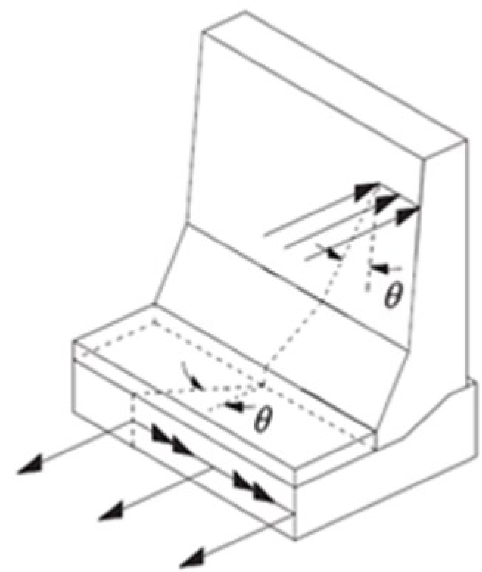
Parapet



Parapet with opening



(a) At the internal location

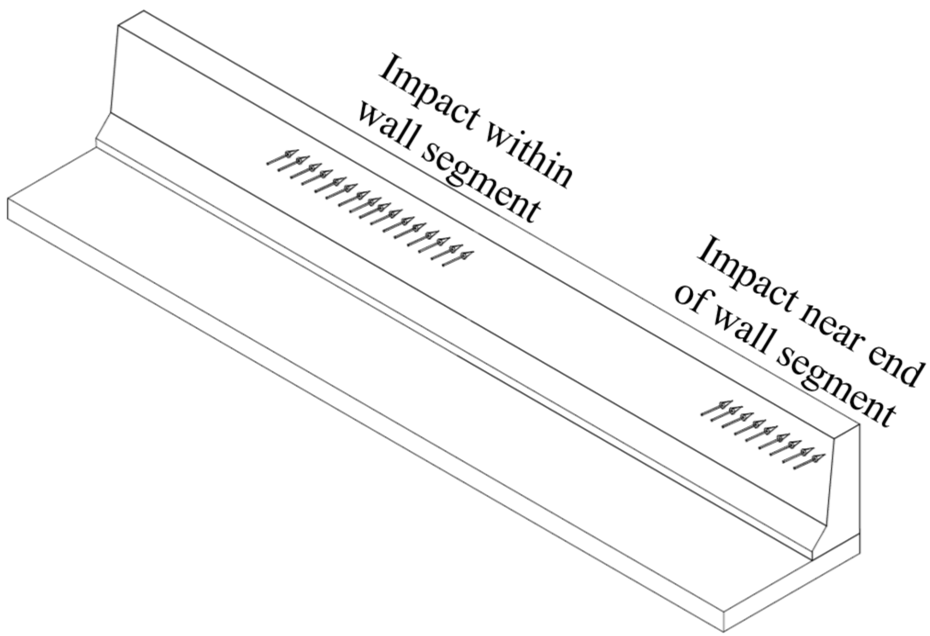


(b) At the end location

AASHTO LRFD design forces for traffic barriers

Design Forces and Designations	Railing Test Levels					
	TL-1	TL-2	TL-3	TL-4	TL-5	TL-6
F_t Transverse (kips)	13.5	27.0	54.0	54.0	124.0	175.0
F_L Longitudinal (kips)	4.5	9.0	18.0	18.0	41.0	58.0
F_v Vertical (kips) Down	4.5	4.5	4.5	18.0	80.0	80.0
L_t and L_L (ft)	4.0	4.0	4.0	3.5	8.0	8.0
L_v (ft)	18.0	18.0	18.0	18.0	40.0	40.0
H_e (min) (in.)	18.0	20.0	24.0	32.0	42.0	56.0
Minimum H Height of Rail (in.)	27.0	27.0	27.0	32.0	42.0	90.0

TL: Test Level



Vehicle Class

Small car

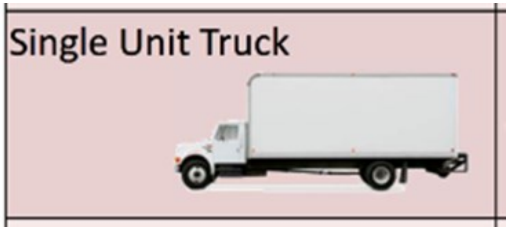
Pickup Truck

Single Unit Truck

Tractor Trailer

Traffic load changes for new MASH TL-4 barrier

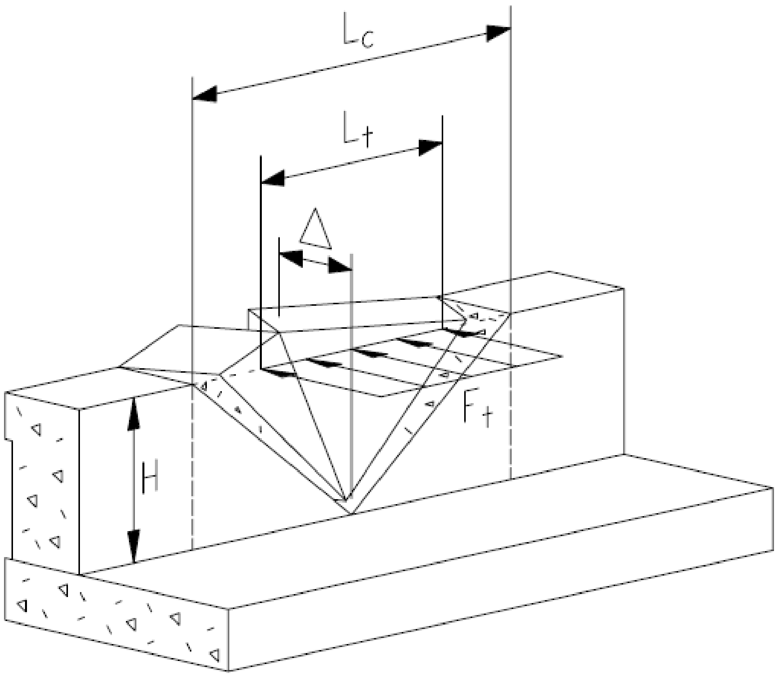
Test Level 4 Criteria	Test Vehicle – Designation and Type	Test Conditions	
		Speed – km/h (mph)	Angle – Degrees
NCHRP Report 350	8000S (Single-Unit Van Truck)	80.0 (50)	15
MASH	10000S (Single-Unit Truck)	90.0 (56)	15



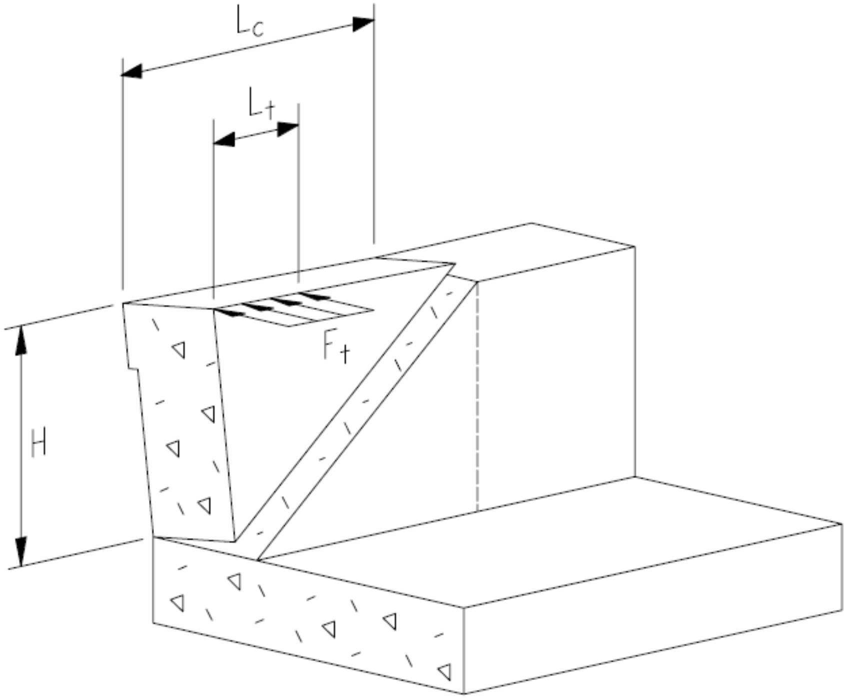
Barrier test level	F_t, kN (kips)	F_L, kN (kips)	F_v, kN (kips)	L_t & L_L, mm (ft)	L_v, mm (ft)	H_e, mm (ft)	H_{min}, mm (ft)
TL-1	60 (13.5)	20 (4.5)	20 (4.5)	1219 (4.0)	5500 (18.0)	457 (18.0)	686 (27.0)
TL-2	120 (27.0)	40 (9.0)	20 (4.5)	1219 (4.0)	5500 (18.0)	508 (20.0)	686 (27.0)
TL-3	240 (54.0)	80 (18.0)	20 (4.5)	1219 (4.0)	5500 (18.0)	607 (24.0)	686 (27.0)
TL-4	240 (54.0)	80 (18.0)	80 (18.0)	1067 (3.5)	5500 (18.0)	813 (32.0)	813 (32.0)
TL-5	551 (124)	182 (41.0)	356 (80.0)	2438 (8.0)	12000 (40)	1067 (42)	1067 (42)
TL-4 (MASH)	**360 (81)**			**1219 (4.0)**		**835 (32.9)**	

AASHTO LRFD design of steel-reinforced barrier

- Triangular yield line failure equations



(a) At the internal location



(b) At the end location

CSA-S6:19 design of steel-reinforced barrier

Flexural resistance for the trapezoidal yield line pattern

a) For barrier loads applied within a wall segment:

$$R_w = \left\{\frac{2}{2L_c - L_t - n^2.L_t}\right\}\left\{8M_b + 8M_w.H + \frac{A}{H}\right\}$$

where the critical yield line length, L_c, is taken as:

$$L_c = 0.5L_t(1+n^2) + \sqrt{\frac{1}{4}L_t^2(1+n^2)^2 + \frac{8M_b H + 8M_w H^2 - B}{M_c}}$$

b) For barrier loads applied at barrier ends:

$$R_w = \left\{\frac{2}{2L_c - L_t - n^2.L_t}\right\}\left\{M_b + M_w.H + \frac{A}{H}\right\}$$

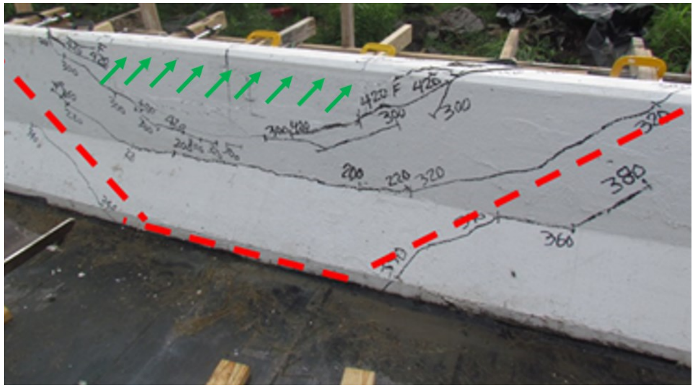
where the critical yield line length occurs, L_c, is taken as:

$$L_c = 0.5L_t(1+n^2) + \sqrt{\frac{1}{4}L_t^2(1+n^2)^2 + \frac{M_b H + M_w H^2 - B}{M_c}}$$

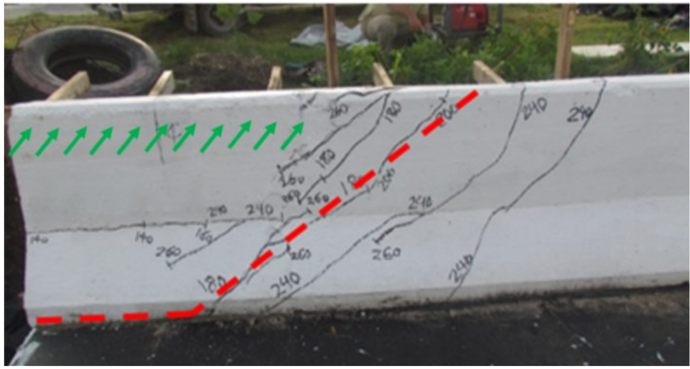
Where:

$$A = M_c\,(L_c - n.L_t)^2 + M_{c,base}(nL_tL_c - n^2L_t^2)$$

$$B = L_t^2\{M_c\,(n - n^2 + n^3) + M_{c,base}(-0.5n + n^2 - 0.5n^3)\}$$



Interior segment

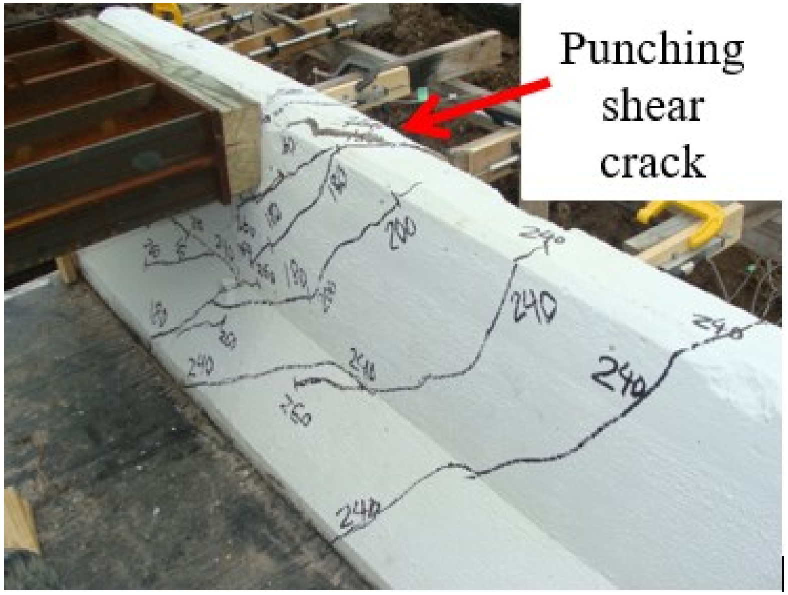


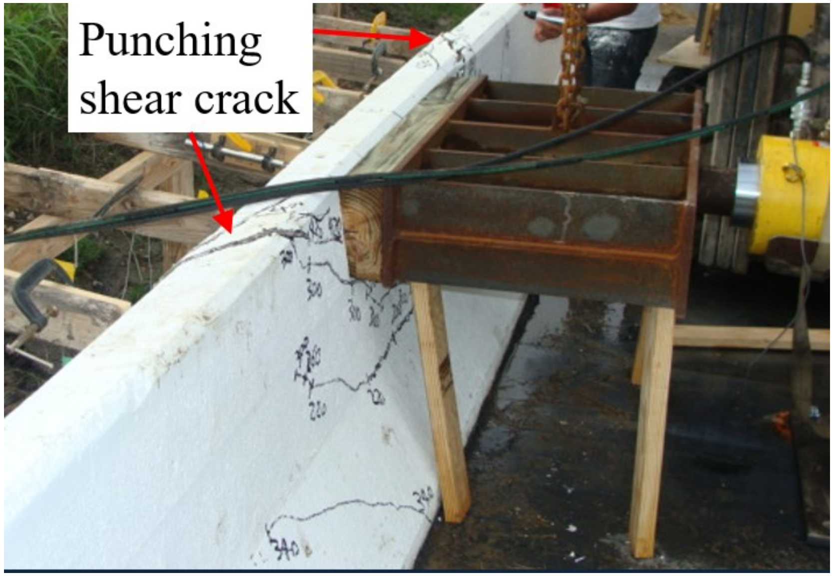
End segment

CSA-S6:25 Commentary - design of steel-reinforced barrier

Factored punching shear resistance:

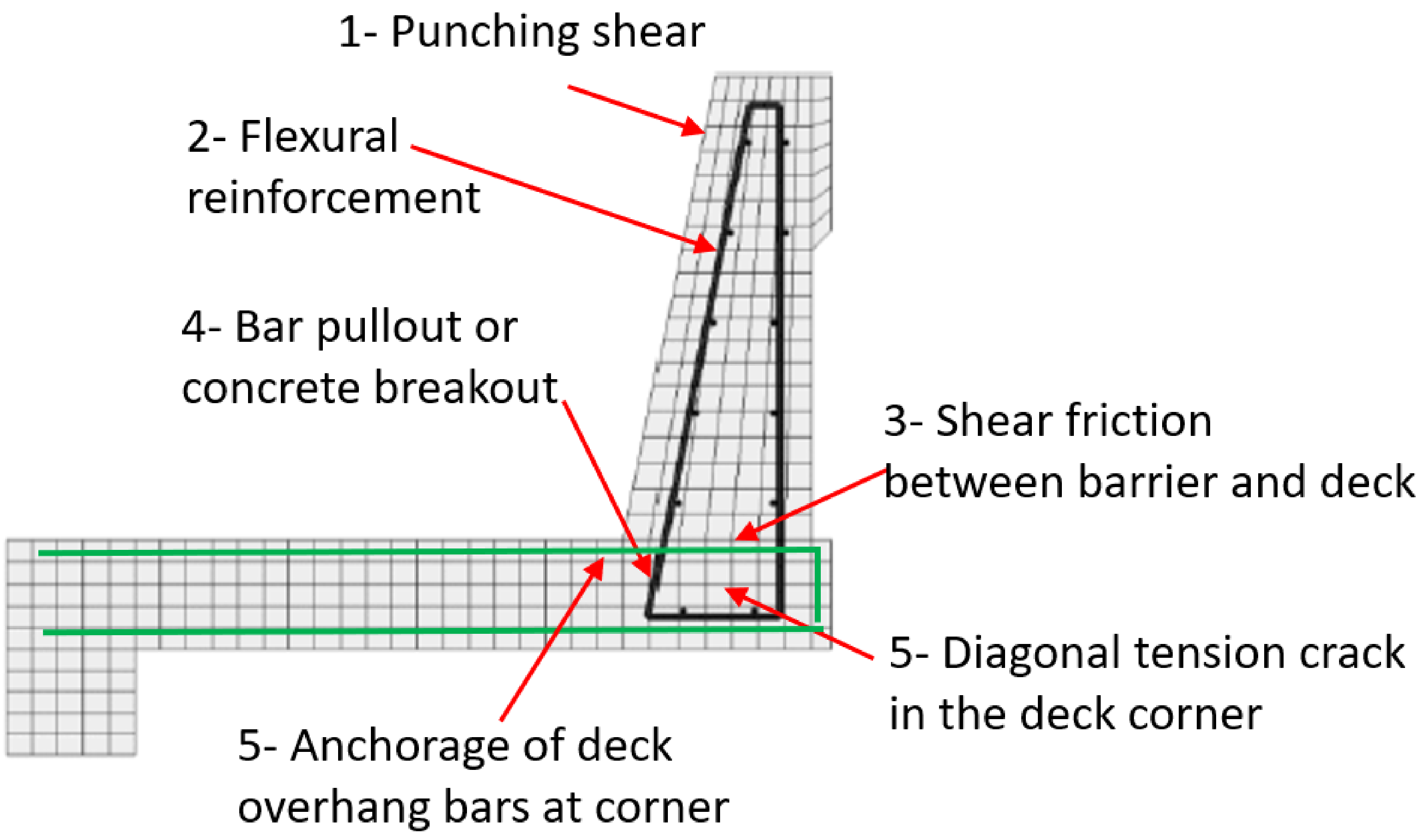
$$V_c = (1 + 2 / \beta_c)\, 0.15\, \lambda\, \varphi_c \sqrt{f'_c}\; b_o . d$$





Design of GFRP-reinforced barrier

Design Considerations:



Design of GFRP-reinforced barrier

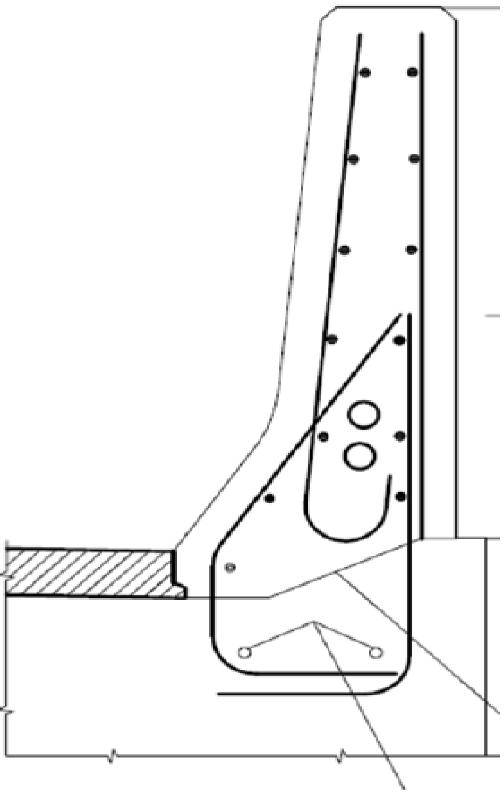
Design methods:

1- Vehicle crash testing

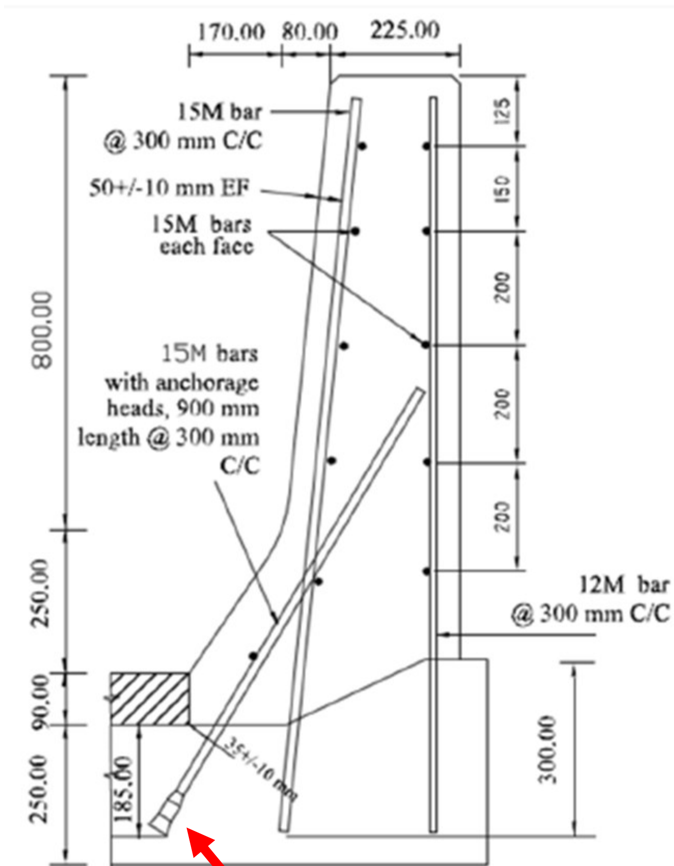
2- Manual calculations using design equations

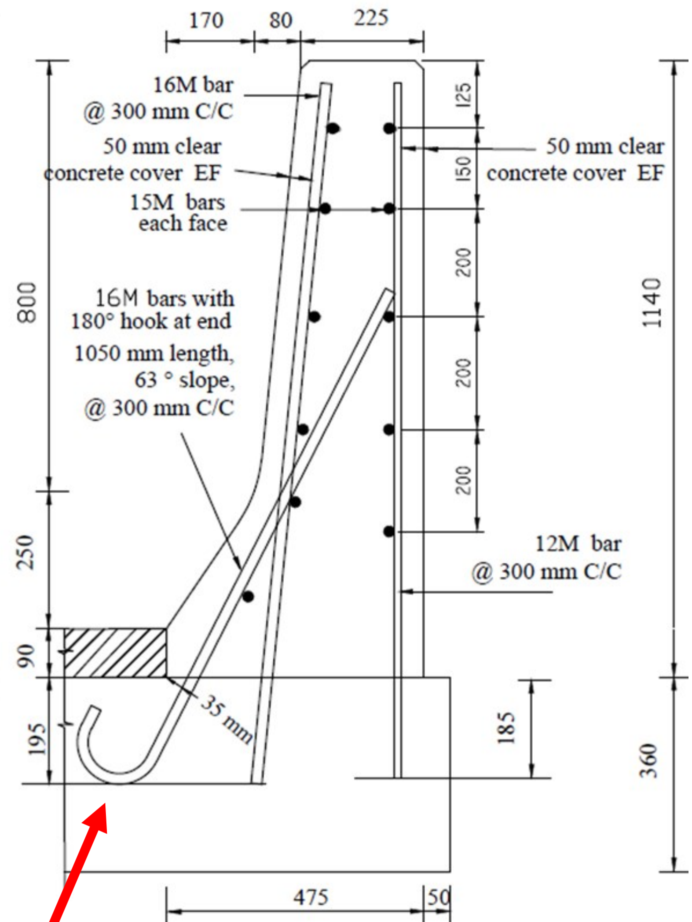
3- Experimental testing on actual-size specimens to verify design

Design of GFRP-reinforced barrier



First generation with Grade I GFRP bars





Headed-end

Hooked-end

Crash-tested barrier with Grade III GFRP bars

1- Vehicle crash testing

Manufacturer # 1:
Ribbed-surface GFRP bars

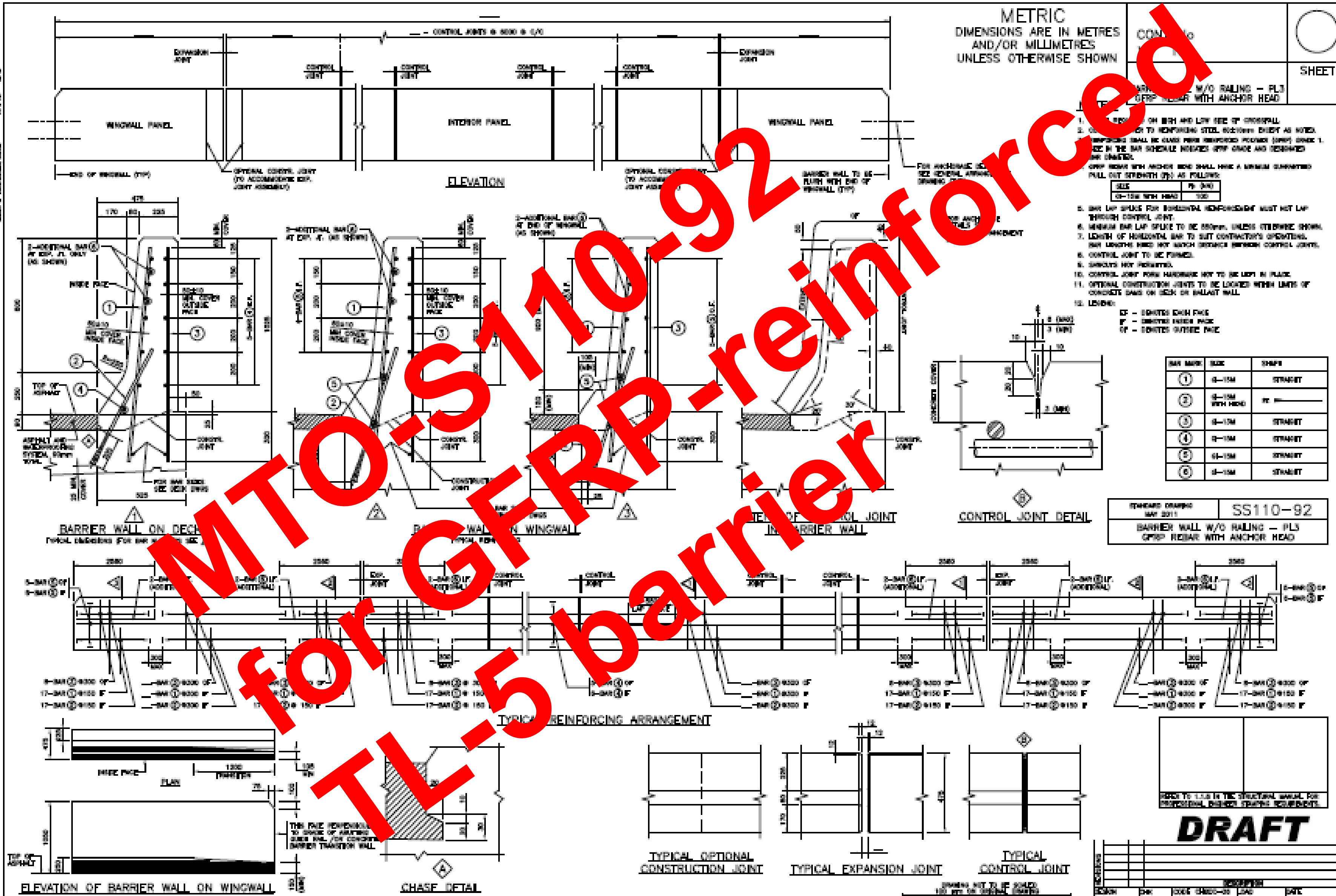
Manufacturer # 2:
Sand-coated GFRP bars

Manufacturer # 3:
Braided-surface GFRP bars

Crash test in 2010

Crash test in 2011

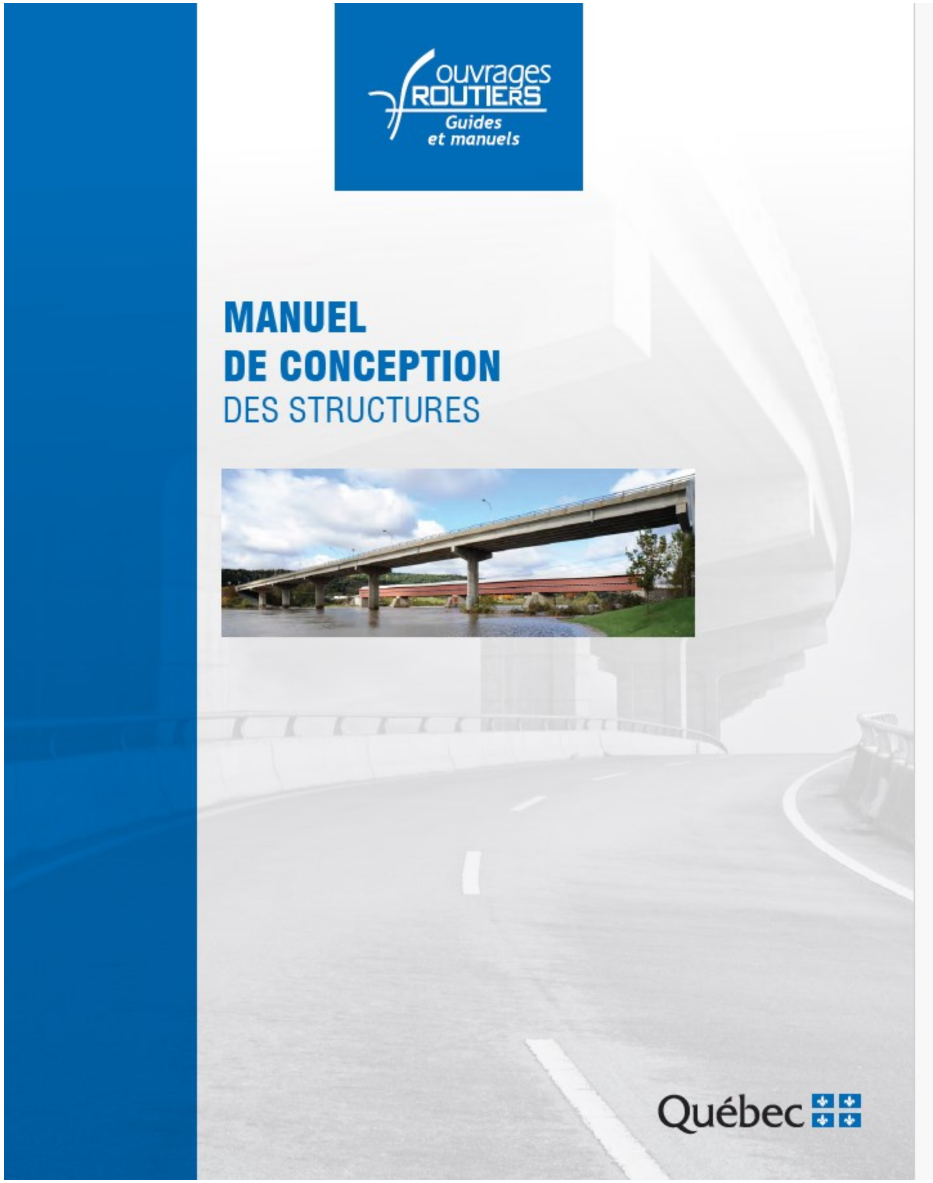
Crash test in 2016



METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN
SHEET
ELEVATION
WINGWALL PANEL
INTERIOR PANEL
BARRIER WALL ON DECK
CONTROL JOINT DETAIL
SS110-92
BARRIER WALL W/O RAILING – PL3 GFRP REBAR WITH ANCHOR HEAD
TYPICAL REINFORCING ARRANGEMENT
ELEVATION OF BARRIER WALL ON WINGWALL
CHASE DETAIL
TYPICAL OPTIONAL CONSTRUCTION JOINT
TYPICAL EXPANSION JOINT
TYPICAL CONTROL JOINT
DRAFT
MTO-S110-92
for GFRP-reinforced
TL-5 barrier

The modified design of the TL-5 barrier-deck system in addition to the identical design for the TL-4 barrier-deck system, was included in the MTQ Structures Manual in 2018.

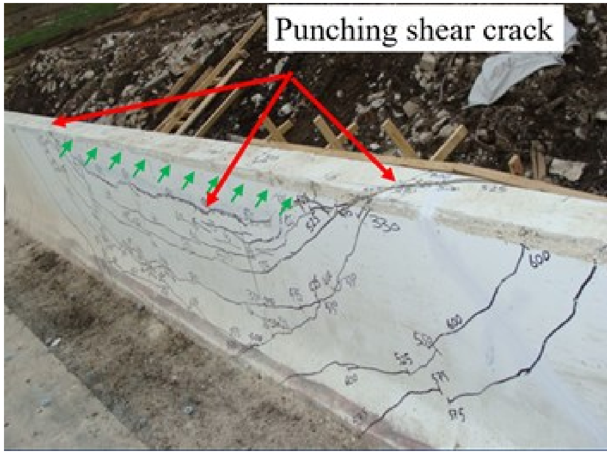
MTQ. 2018. Manuel de conception des structures. Ministry of Transportation of Quebec, Quebec, Canada.



2- Manual calculations using design equations

Test at interior segment

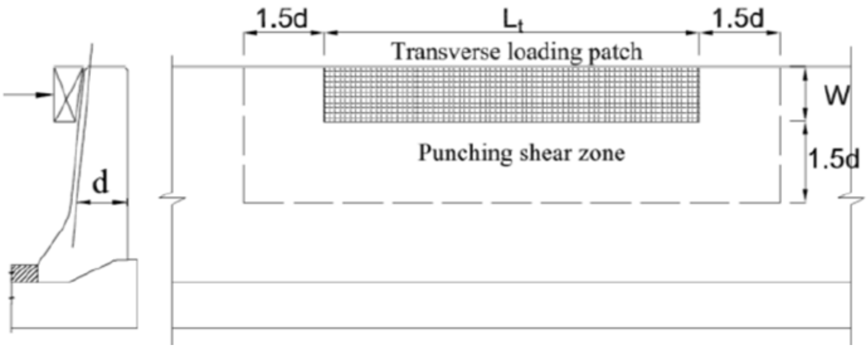
Test at end segment



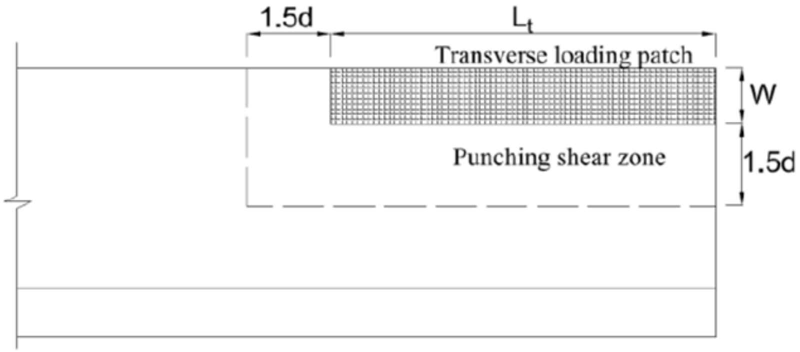
Punching shear failure

Punching shear capacity:

$$V_c = (1 + 2 / \beta_c)\, 0.13\, \lambda\, \varphi_c \frac{\sqrt[3]{\rho_f . E_f . f'_c}}{\sqrt[4]{d}}\, b_{o,1.5d} . d$$



(a) For Impact within a wall segment

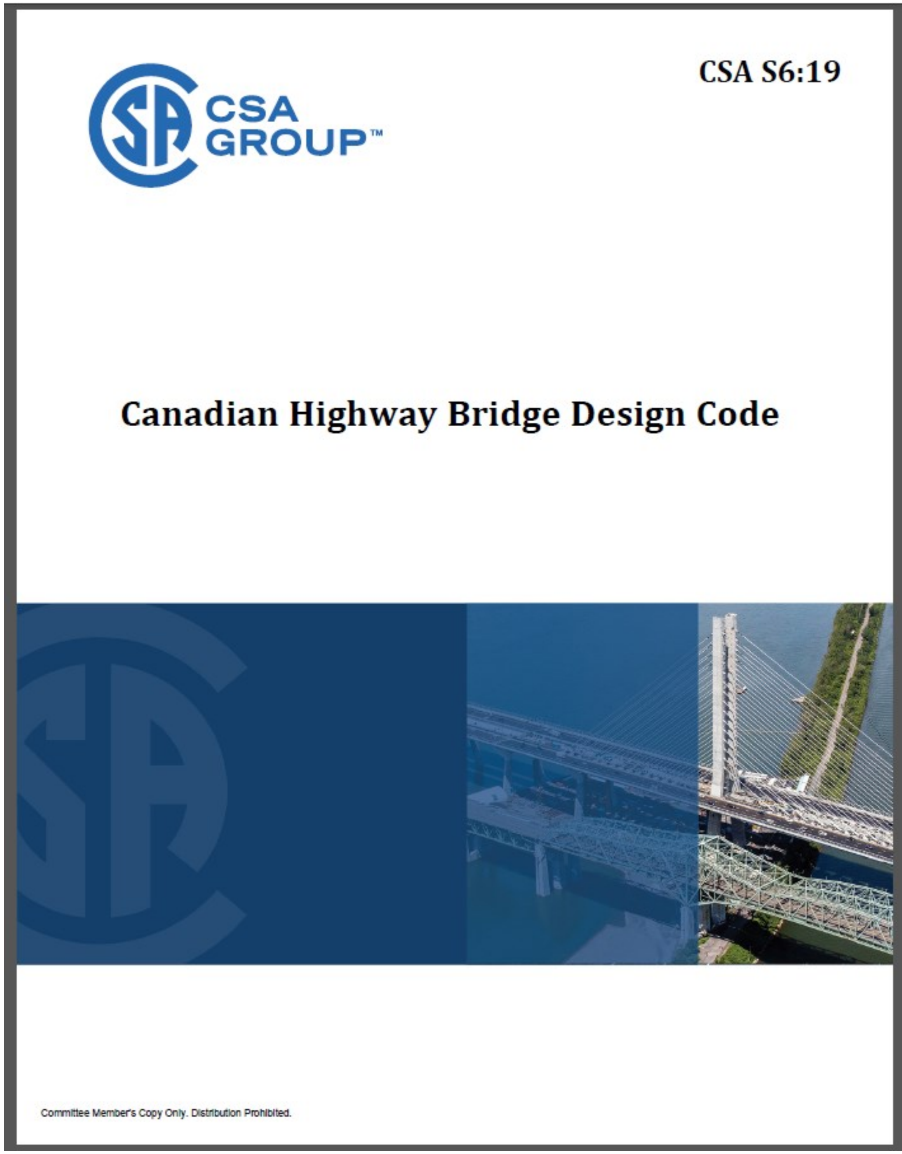


(b) For impact at end of wall or at joint

The design of the TL-5 barrier-deck system in addition to the identical design for the TL-4 barrier-deck system, was included in CSA-S6:19 and CSA-S6.1:19

CSA. 2019. Canadian Highway Bridge Design Code, CSA-S6:19. Canadian Standard Association, Toronto, Canada.

CSA. 2019. Commentary of the Canadian Highway Bridge Design Code, CSA-S6.1:19. Canadian Standard Association, Toronto, Canada.



Barrier end requirement in CSA-S6:19:

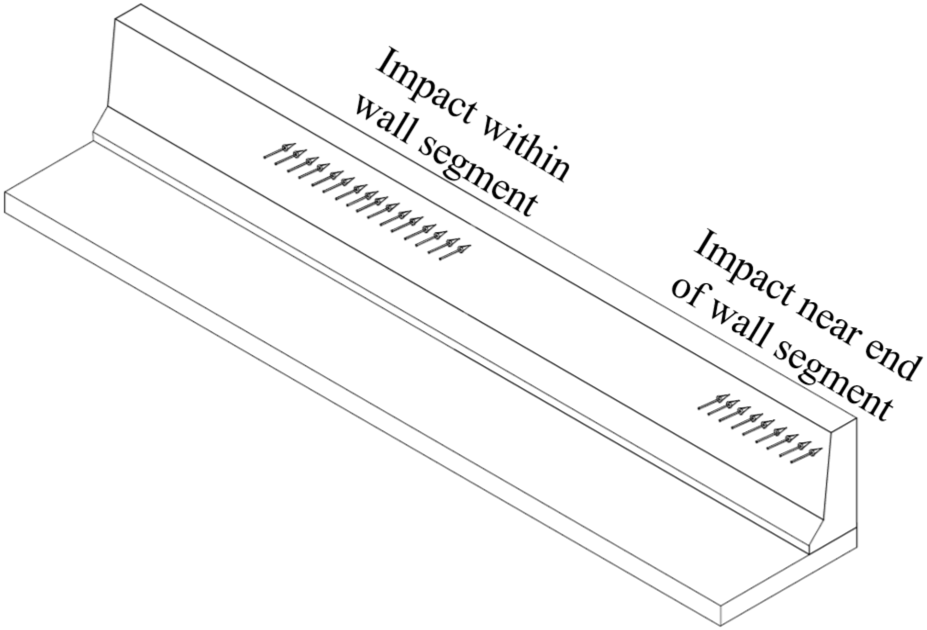
Doubling vertical bars at the traffic side of the barrier end

The spacing of the vertical bars and anchors on the traffic side shall be reduced by half on

a) each side of a joint in the wall;

b) each side of a luminaire embedded in the wall; and

c) from the free vertical edges of the wall for the following lengths of the wall, 1.2 m for barriers meeting crash test requirements for Test Levels 1, 2, and 4; 2.5 m for barriers meeting crash test requirements for Test Level 5.



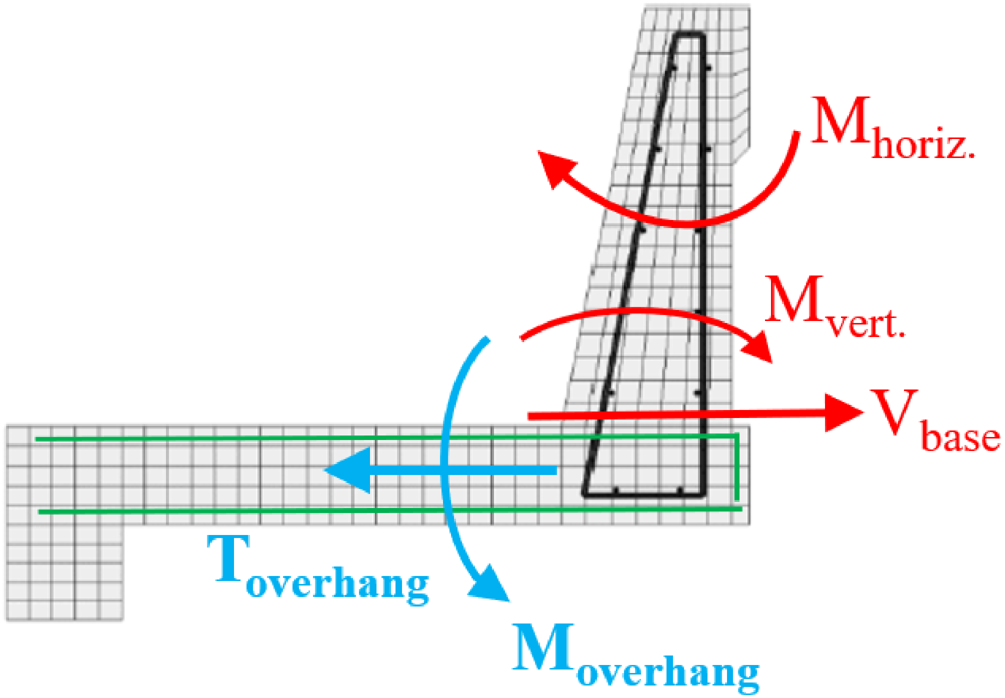
2- Manual calculations using design equations

1- Shear friction resistance at the base (see Clause 16.8.7.3 of CSA-S6:25)

2- Design of vertical and horizontal reinforcement for flexure

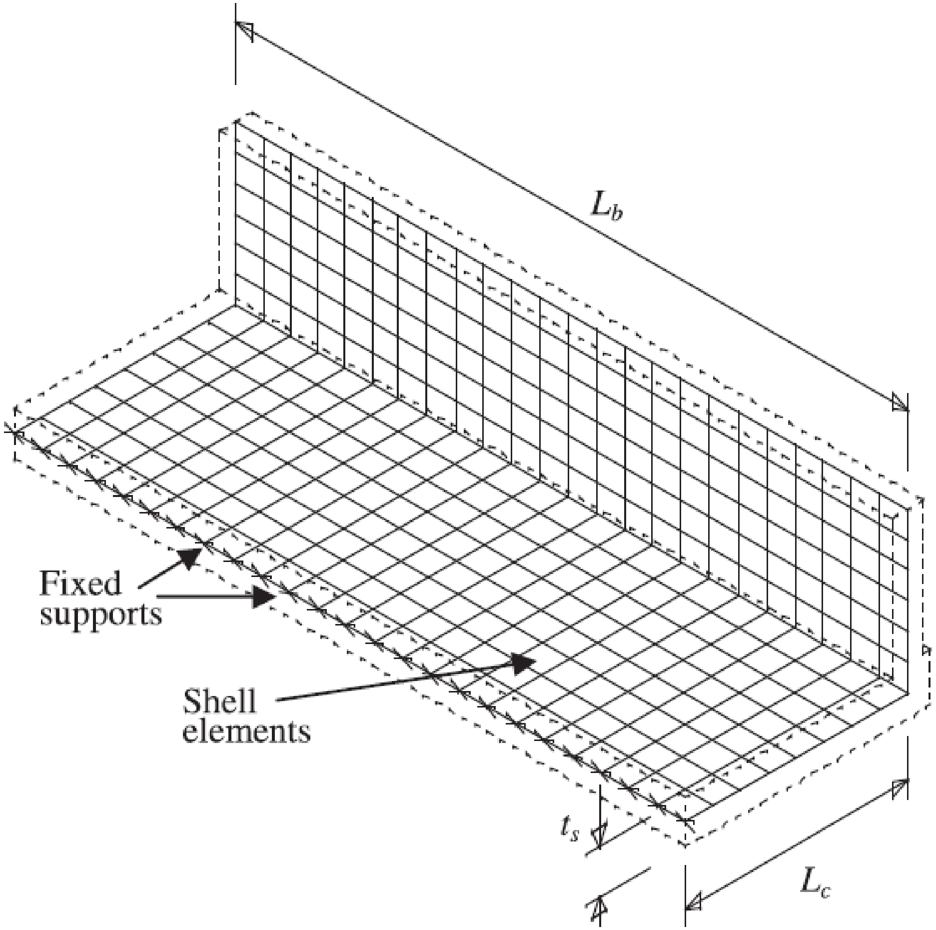
3- Design of barrier thickness due to shear force

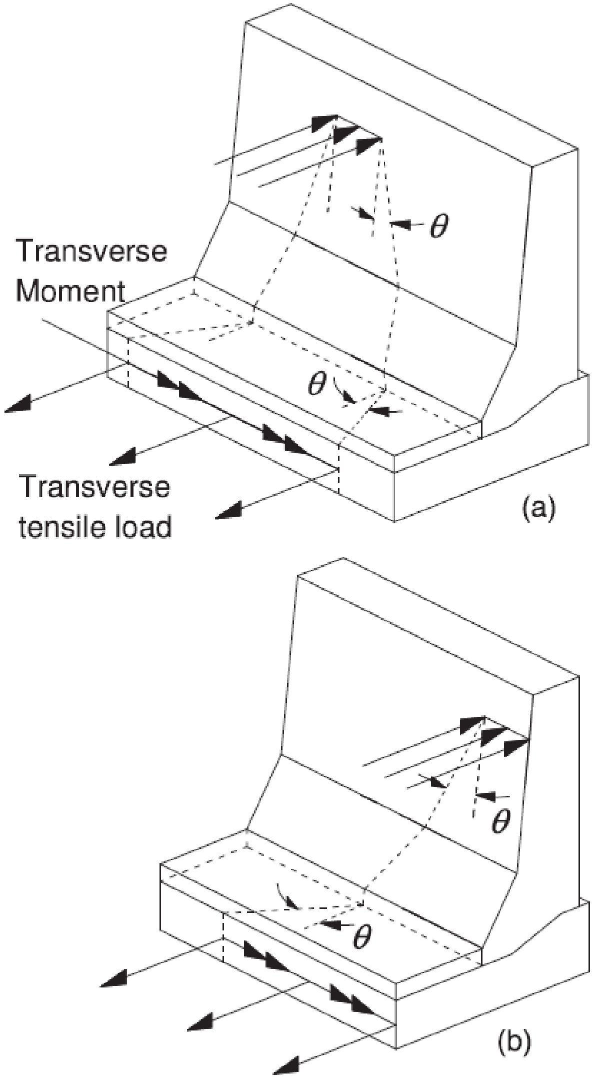
4- Design of deck overhang under combined moment and tensile force



How to obtain applied moment, shear, and tensile forces:

- Finite element analysis of barrier-deck overhang under transverse vehicle impact load





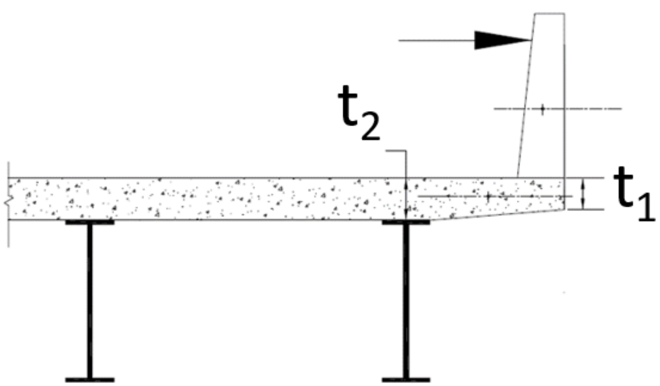
Empirical equations moment and tensile forces for deck overhang design for CSA-S6:25

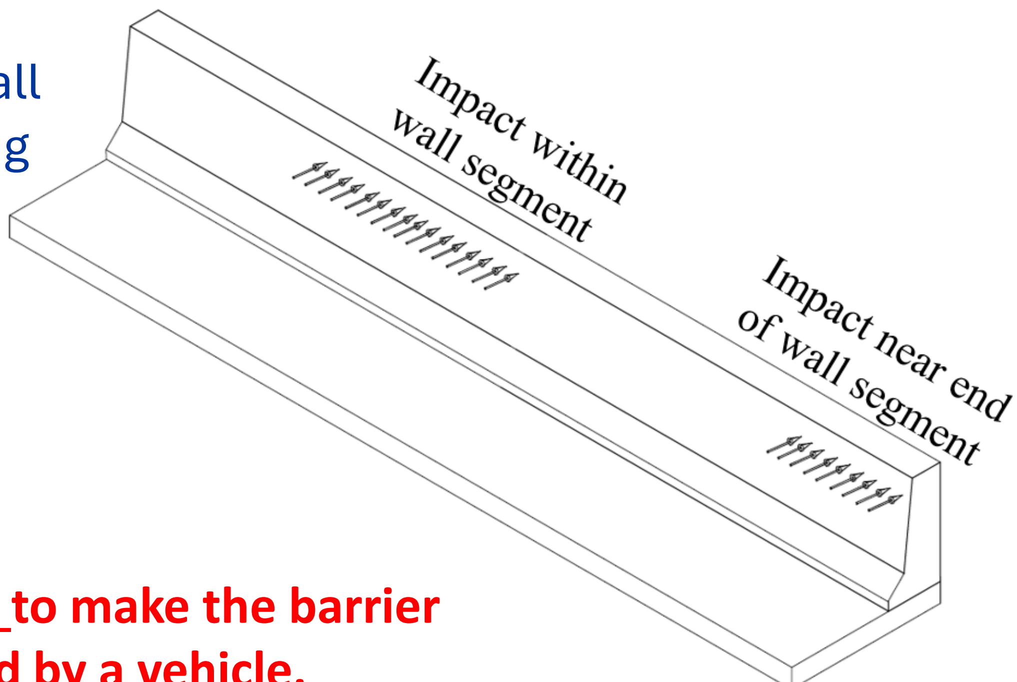
Barrier type		Equations	Limitation of use
TL-2 parapet (constant thickness)	$M_{f,inner}$	$4\,S_p^{-0.1}\,l_b^{-0.43}\,l_s^{0.06}$	$5\ m \leq L_b$
	$T_{f,inner}$	$9\,S_p^{-0.09}\,l_b^{-0.38}\,l_s^{0.04}$	
	$M_{f,end}$	$9\,S_p^{-0.15}\,l_b^{-0.36}\,l_s^{0.08}$	
	$T_{f,end}$	$15\,S_p^{-0.1}\,l_b^{-0.33}\,l_s^{0.04}$	
TL-4 (MASH) parapet (constant thickness)	$M_{f,inner}$	$38\,S_p^{-0.21}\,l_b^{-0.41}\,l_s^{0.14}$	$5\ m \leq L_b$
	$T_{f,inner}$	$100\,S_p^{-0.08}\,l_b^{-0.15}\,l_s^{0.04}$	
	$M_{f,end}$	$51\,S_p^{-0.25}\,l_b^{-0.47}\,l_s^{0.16}$	
	$T_{f,end}$	165	
TL-4 (NCHRP 350) parapet (constant thickness	$M_{f,inner}$	$18\,S_p^{-0.21}\,l_b^{-0.49}\,l_s^{0.15}$	$5\ m \leq L_b$
	$T_{f,inner}$	$52\,S_p^{-0.06}\,l_b^{-0.16}$	
	$M_{f,end}$	$30\,S_p^{-0.24}\,l_b^{-0.47}\,l_s^{0.15}$	
	$T_{f,end}$	110	
TL-4 (MASH) tapered-face barrier	$M_{f,inner}$	$45\,S_p^{-0.27}\,L_b^{-0.18}\,l_b^{-0.47}\,l_s^{0.15}$	$5\ m \leq L_b \leq 8\ m$
	$T_{f,inner}$	$110\,S_p^{-0.18}\,l_b^{-0.21}\,l_s^{0.07}$	
	$M_{f,end}$	$54\,S_p^{-0.49}\,l_b^{-0.64}\,l_s^{0.28}$	
	$T_{f,end}$	$155\,S_p^{-0.07}$	
TL-4 (NCHRP 350) tapered-face barrier	$M_{f,inner}$	$8\,S_p^{-0.29}L_b^{-0.16}\,l_b^{-0.74}\,l_s^{0.17}$	$5\ m \leq L_b \leq 12\ m$
	$T_{f,inner}$	$43\,S_p^{-0.08}\,l_b^{-0.25}\,l_s^{0.03}$	
	$M_{f,end}$	$18\,S_p^{-0.45}\,l_b^{-0.71}\,l_s^{0.27}$	
	$T_{f,end}$	110	
TL-5 tapered-face barrier	$M_{f,inner}$	$60\,S_p^{-0.2}L_b^{-0.19}l_b^{-0.53}\,l_s^{0.12}$	$5\ m \leq L_b \leq 12\ m$
	$T_{f,inner}$	$83\,S_p^{-0.05}\,l_b^{-0.17}$	
	$M_{f,end}$	$125\,L_b^{-0.09}\,S_p^{-0.35}\,l_b^{-0.41}\,l_s^{0.18}$	
	$T_{f,end}$	160	

Empirical equations moment and tensile forces for deck overhang design for CSA-S6:25

TL-5 tapered-face barrier	$M_{f,inner}$	$60\, S_p^{-0.2} L_b^{-0.19} I_b^{-0.53} I_s^{0.12}$	$5\text{ m} \leq L_b \leq 12\text{ m}$
	$T_{f,inner}$	$83\, S_p^{-0.05} I_b^{-0.17}$	
	$M_{f,end}$	$125\, L_b^{-0.09} S_p^{-0.35} I_b^{-0.41} I_s^{0.18}$	
	$T_{f,end}$	160	

S_p = Overhang length
L_b = Barrier length
I_b = Moment of inertia of the barrier wall
I_s = Moment of inertia of deck overhang



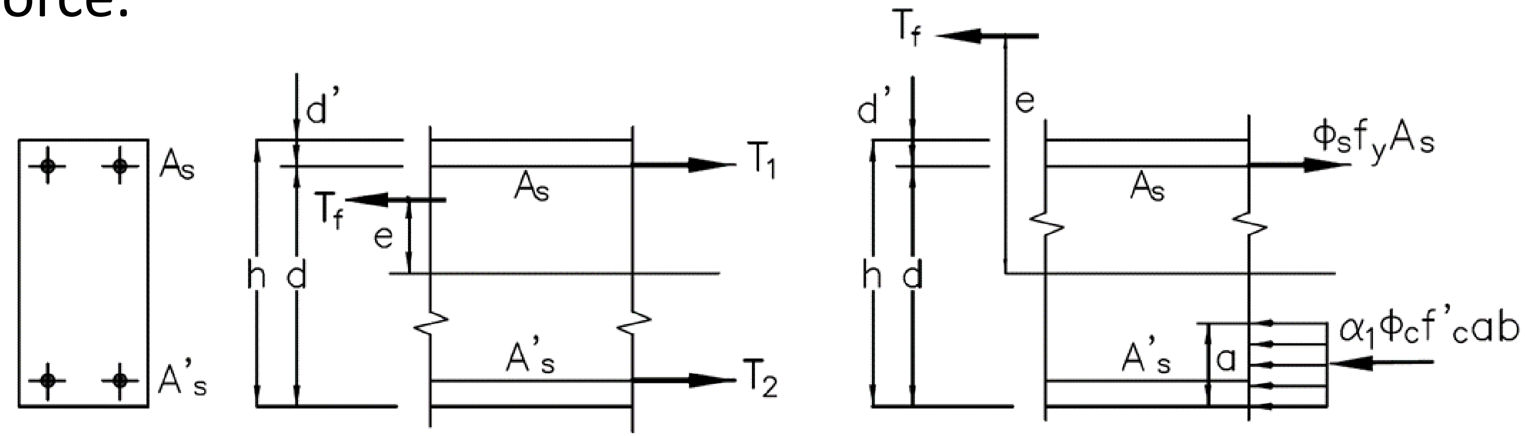


Note: Increase the above values by 20% to make the barrier fail before the overhang when impacted by a vehicle.

ACI Foundation Research Fund (2024-2026)

To develop simplified equations for the design of GFRP-reinforced concrete section under a combined moment and tensile force

- ***ACI-313-16: Design Specification for Concrete Silos and Stacking Tubes for Storing Granular Materials*** specifies design procedure for steel-reinforced sections with small or large eccentricity of the tensile force.

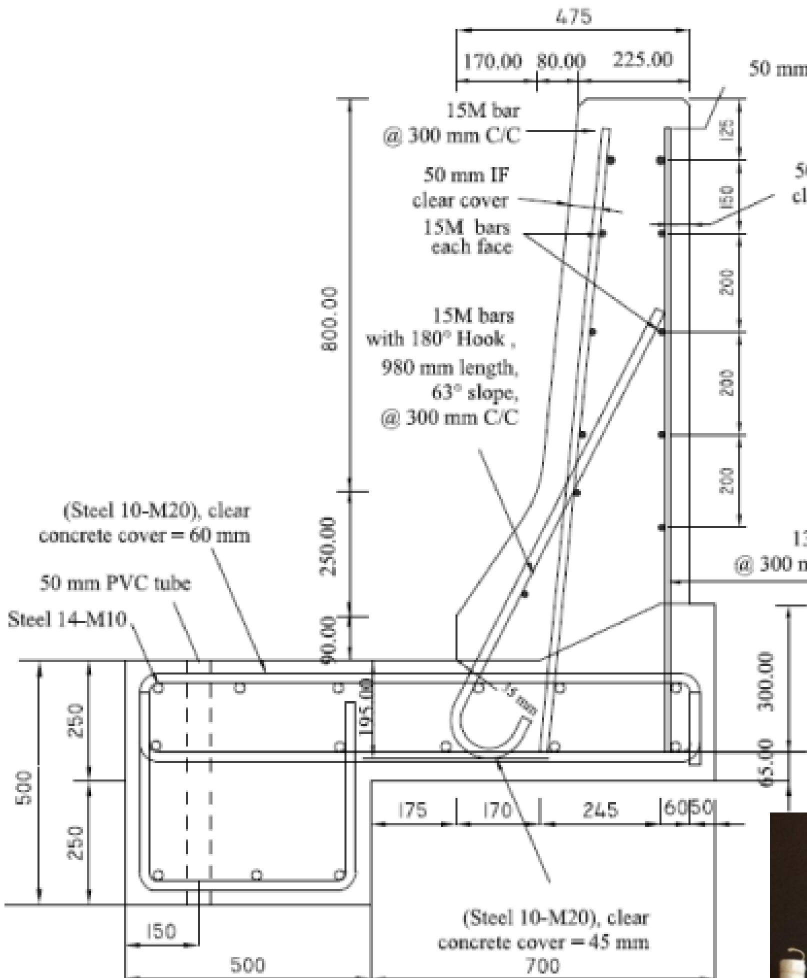


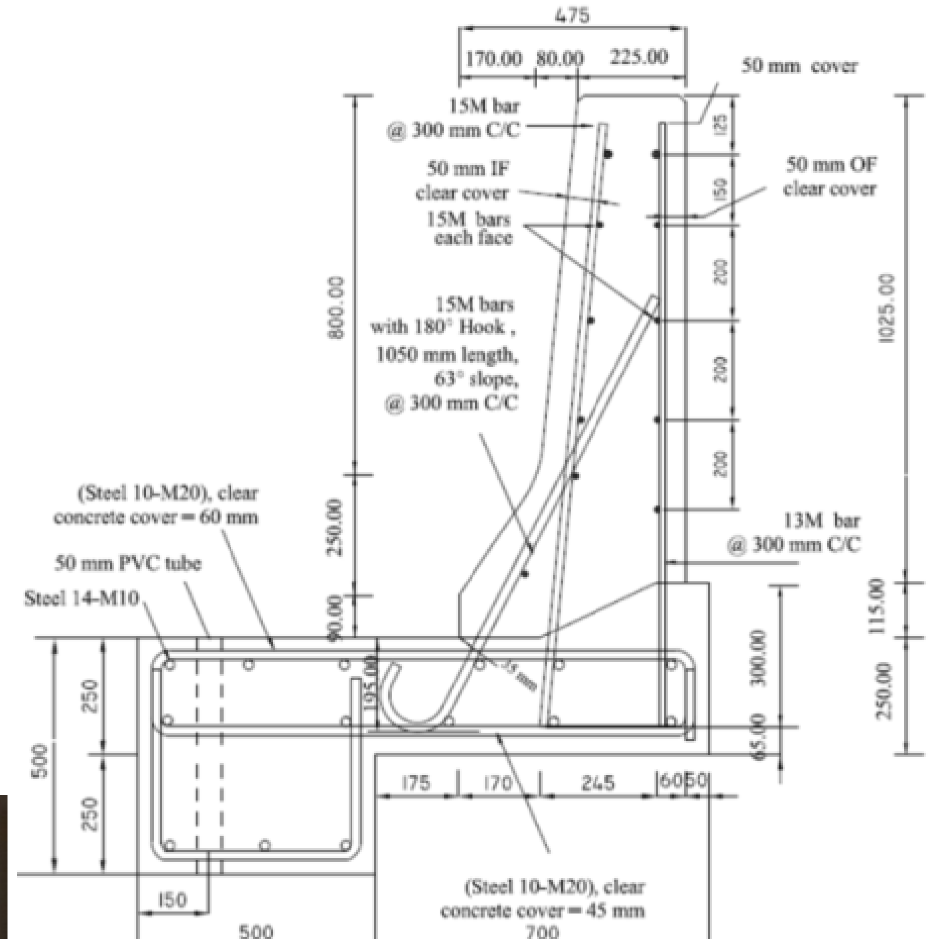
Case 1: Small eccentricity, $e \leq (h/2 - d')$

Case 2: Large eccentricity, $e > (h/2 - d')$

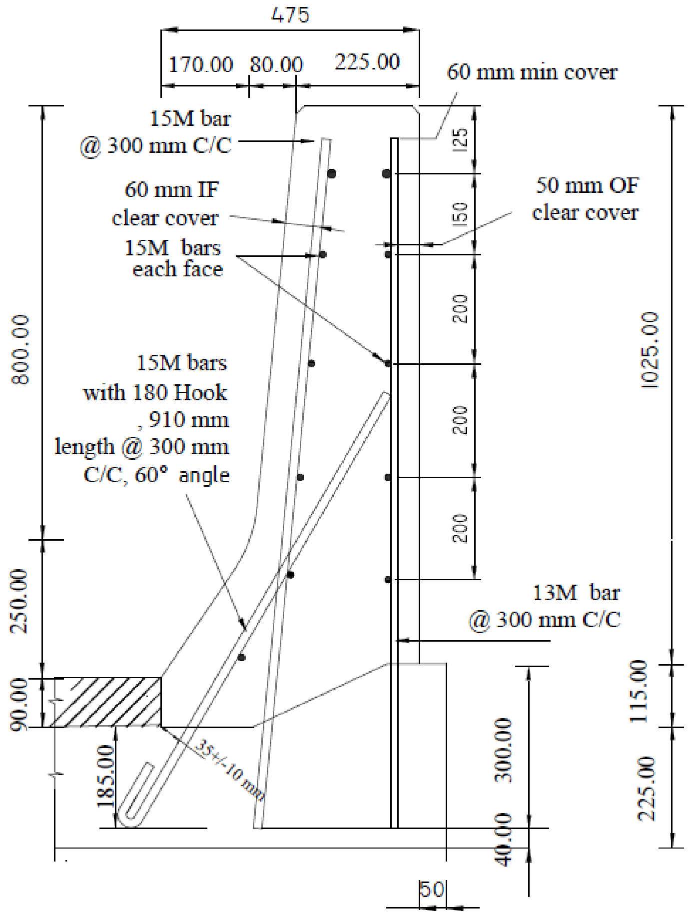
22

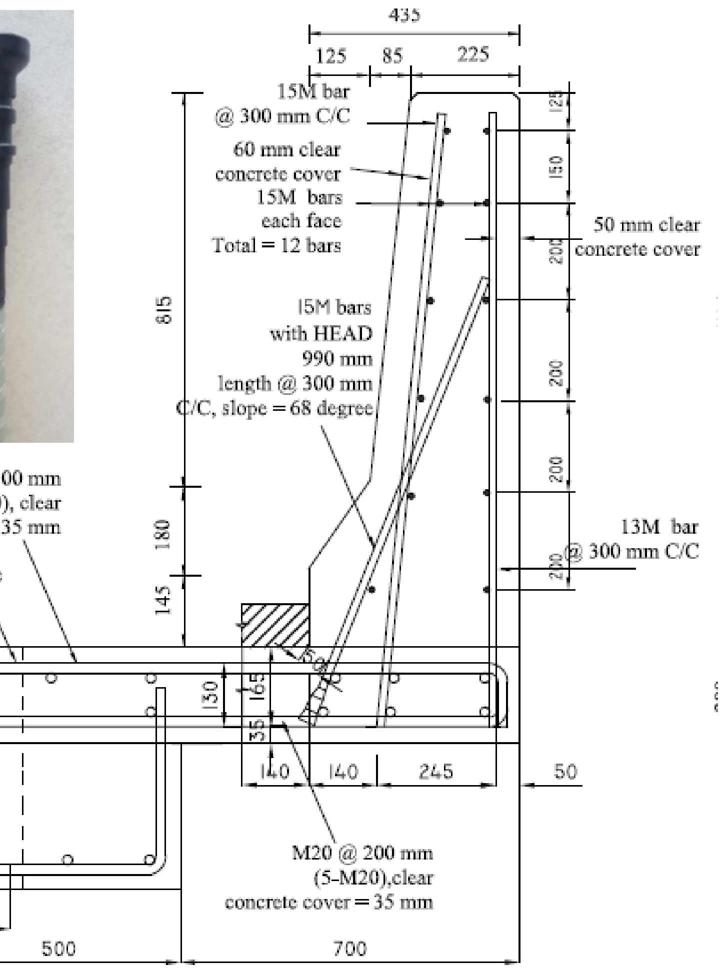
3- Experimental testing on actual-size barriers to verify design

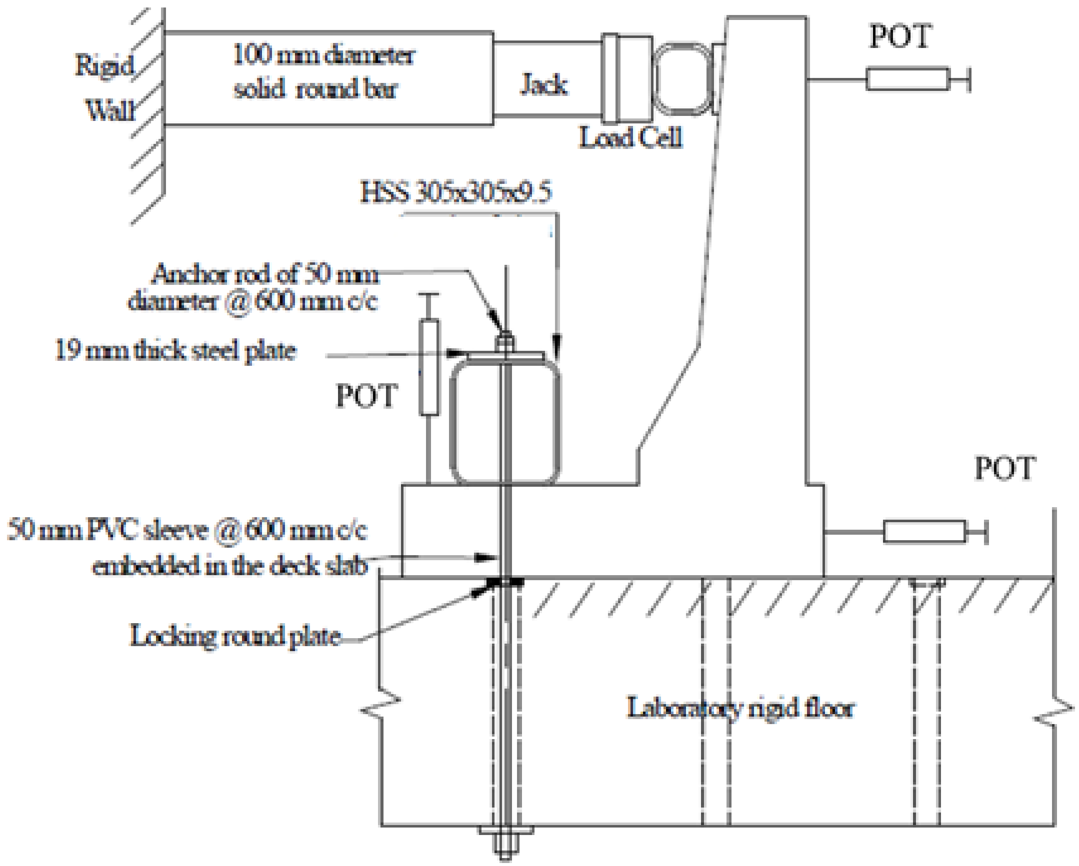




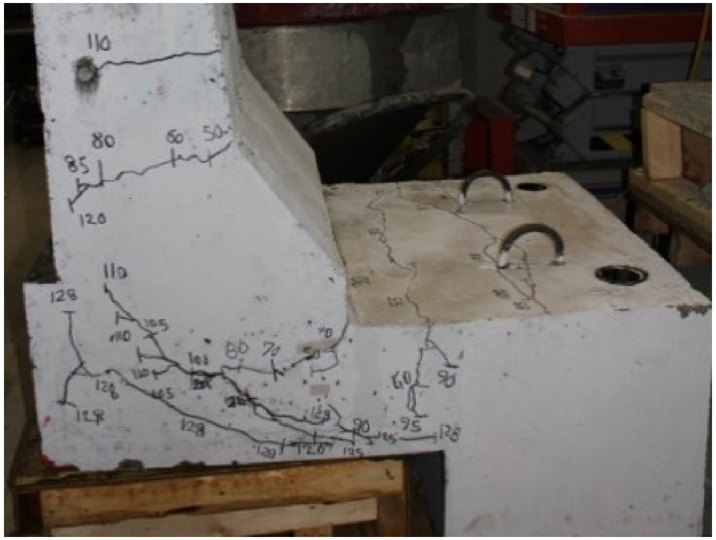
3- Experimental testing on actual-size barriers to verify design



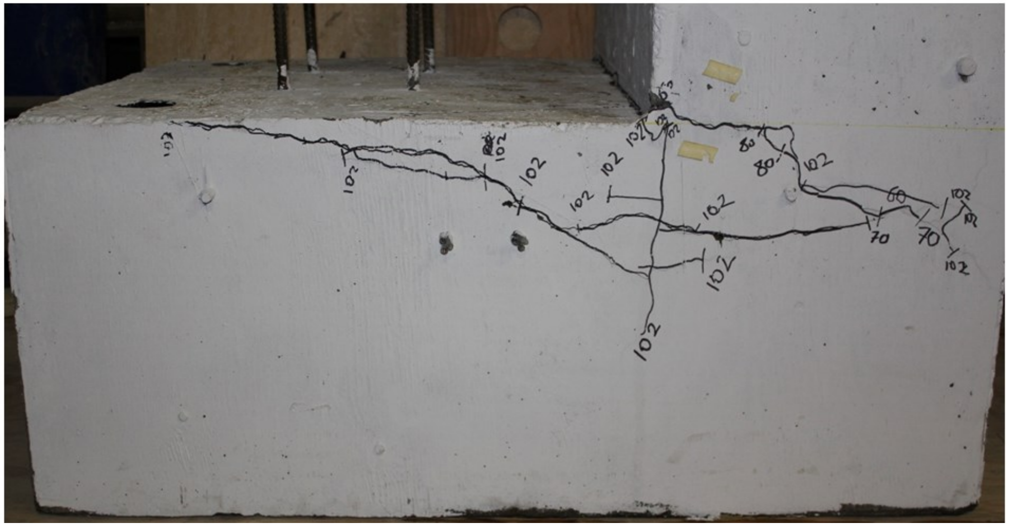



Rigid Wall
100 mm diameter solid round bar
Jack
Load Cell
POT
HSS 305x305x9.5
Anchor rod of 50 mm diameter @ 600 mm c/c
19 mm thick steel plate
POT
POT
50 mm PVC sleeve @ 600 mm c/c embedded in the deck slab
Locking round plate
Laboratory rigid floor

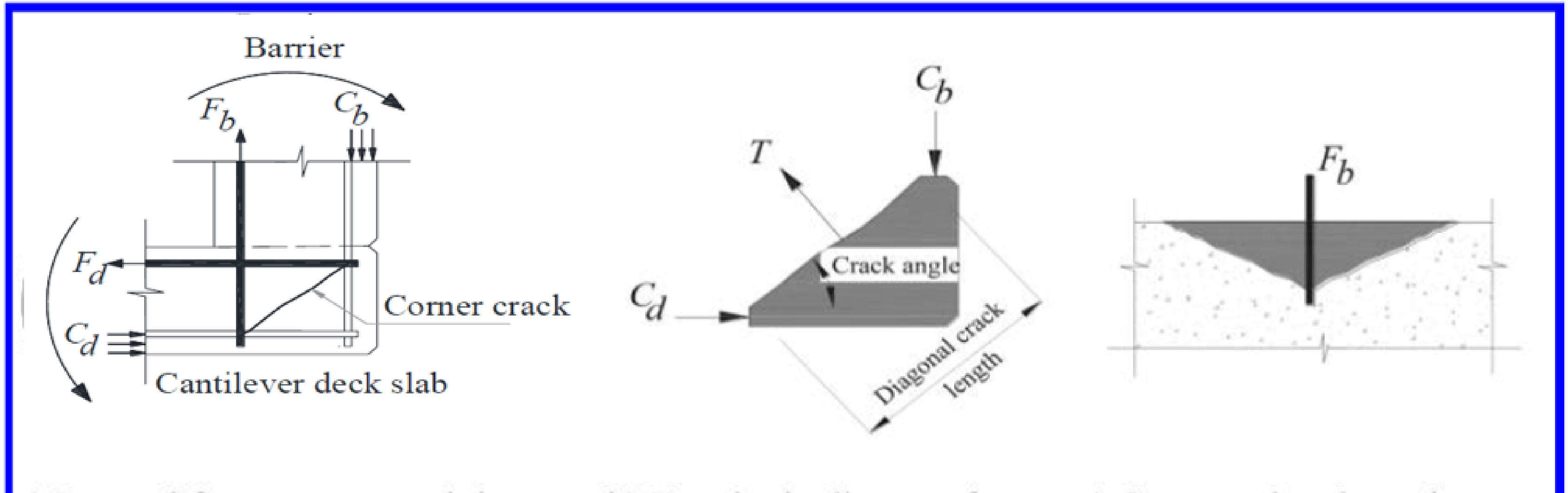
Test setup



Diagonal tension crack at corner



Concrete breakout in thick deck slab



a) Internal forces at corner joint for diagonal tension failure

b) Free-body diagram for diagonal tension failure

c) Concrete breakout due to GFRP tension in the deck slab

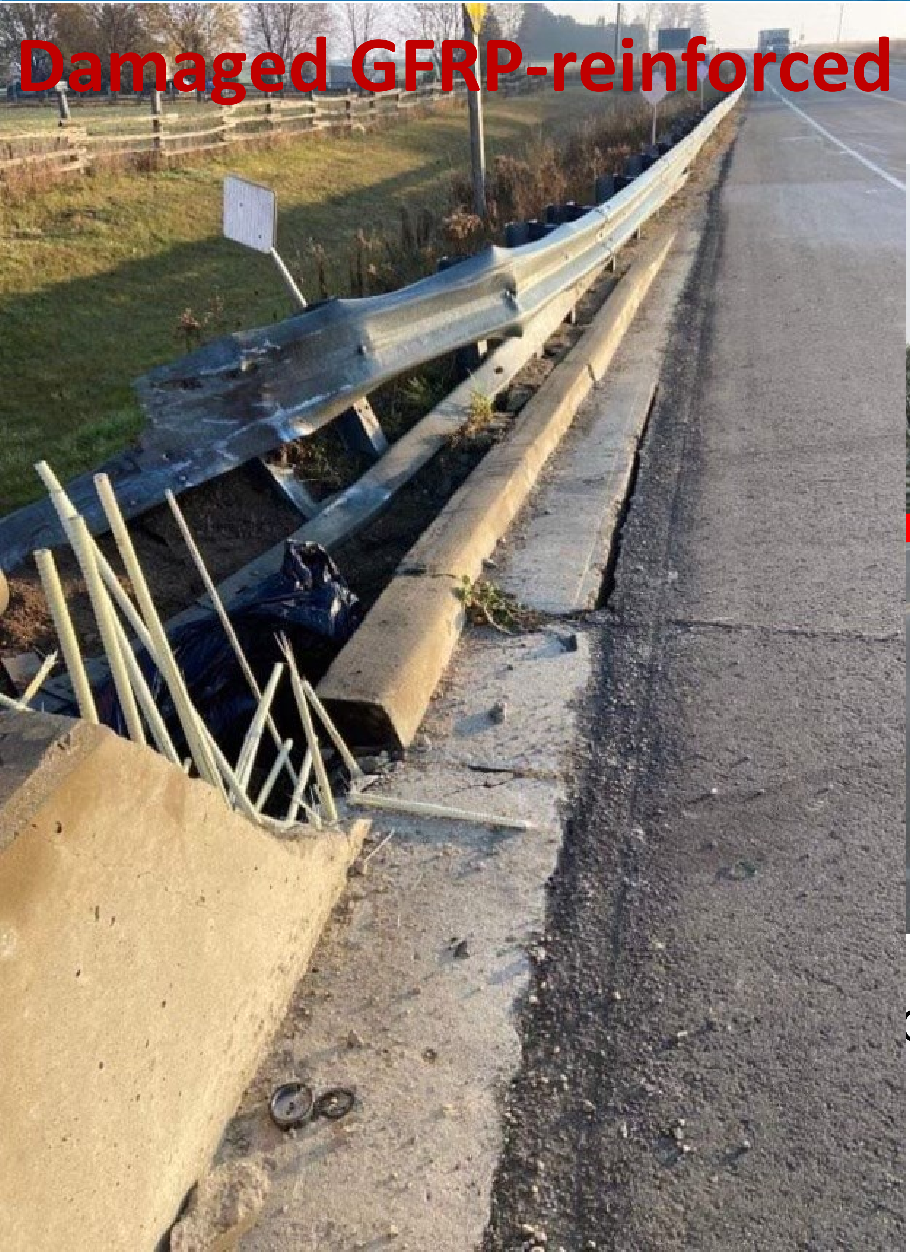
Deteriorated steel-reinforced barrier

Damaged steel-reinforced barrier due to vehicle collision

Damaged steel-reinforced barrier due to vehicle collision

Florida Bridge Railing Failure

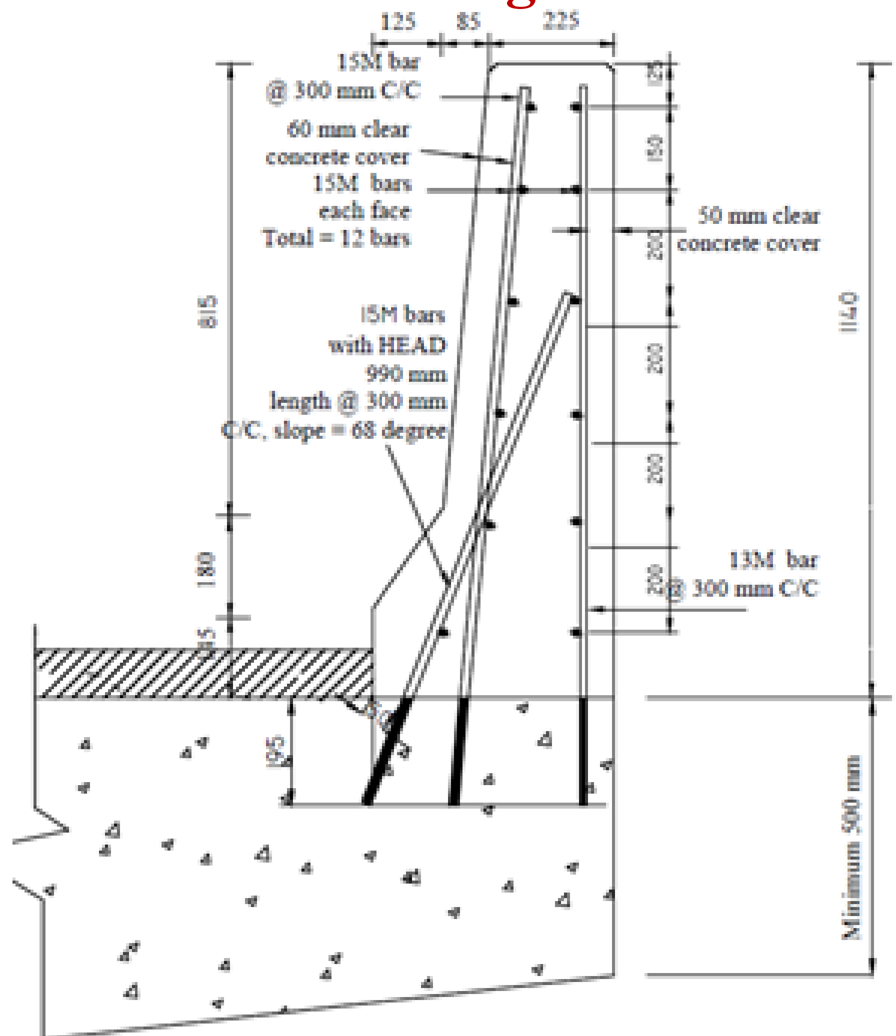
Damaged GFRP-reinforced barrier due to vehicle collision



O wi

Post-installed GFRP bars between barrier and existing deck

Saw-cut the defected segment



Installation of post-installed GFRP bars

Post-installed GFRP bar testing to collapse

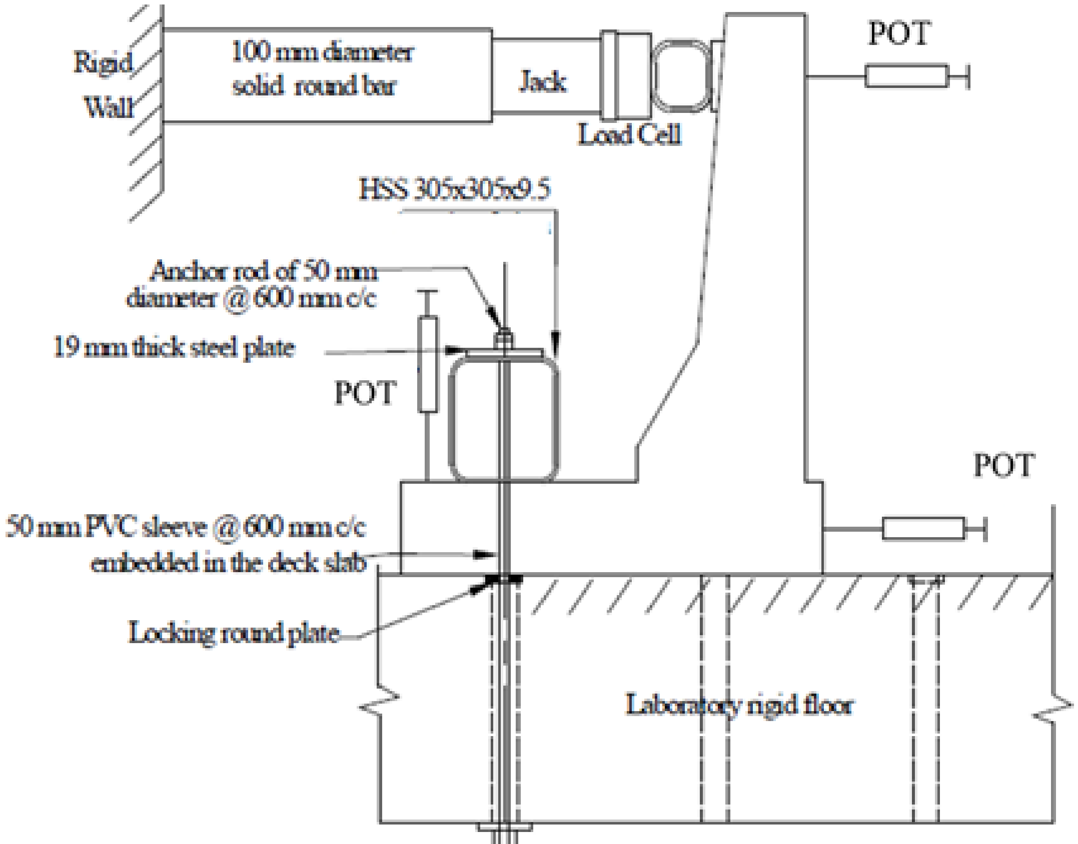
At barrier end

At barrier interior segment

GFRP bar planting

Close-up view

Post-installed GFRP bar testing



Test setup

Concrete breakout in thick deck slab

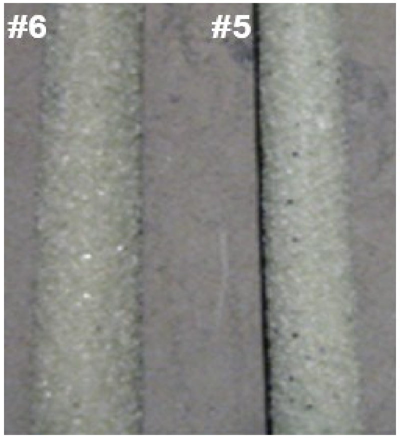
Post-installed GFRP bars exposed to freeze-thaw cycles

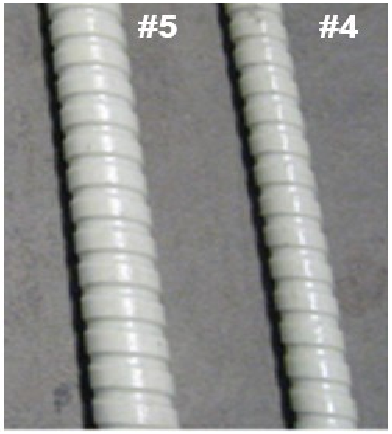
Types of adhesives:

- Type I: HILTI HIT-RE 500-SD Epoxy Adhesive

- Type II & III: Sika CONSTRUCTION
  - Sika AnchorFix-2001
  - Sika AnchorFix-3001

GFRP bar post-installed 200 mm deep in a concrete block

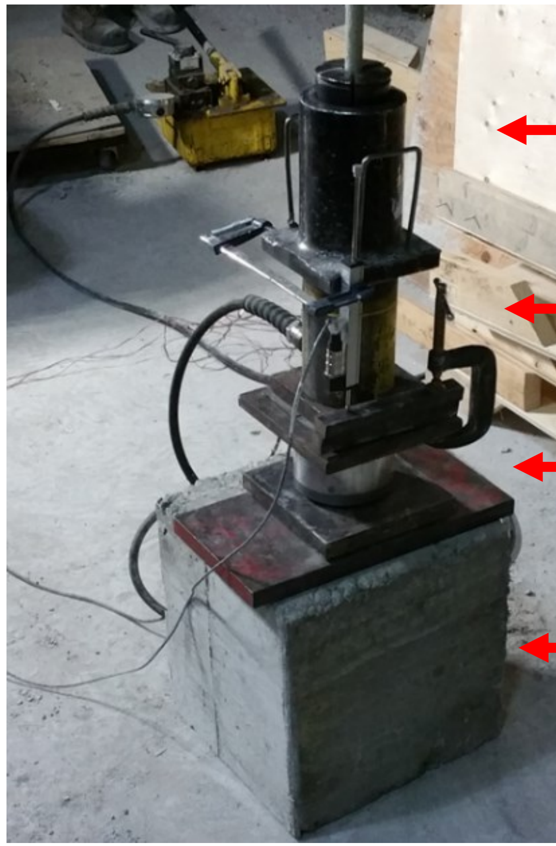




GFRP bars used in this study

Post-installed GFRP bars exposed to freeze-thaw cycles

Concrete block in the environmental chamber



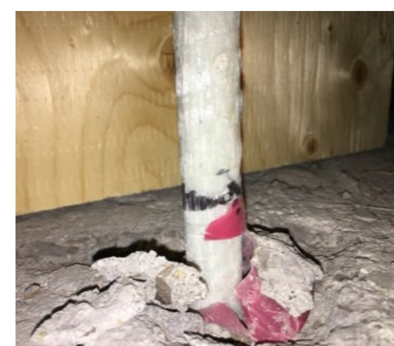
Grip

Jack

Load cell

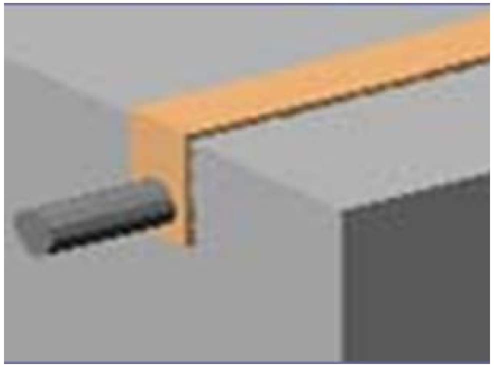
Concrete block

Pullout test

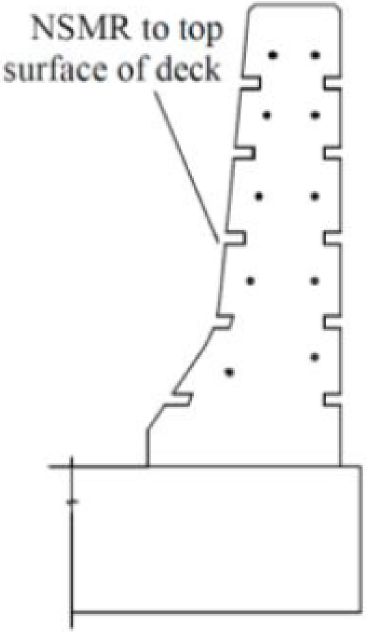


Bar pull-out

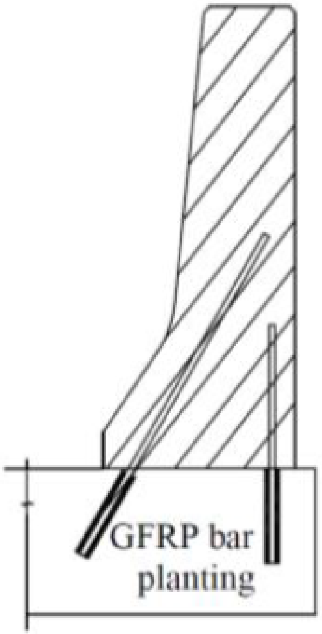
Post-installed GFRP bars between old and new barrier segments and barrier-to-side of existing deck overhang



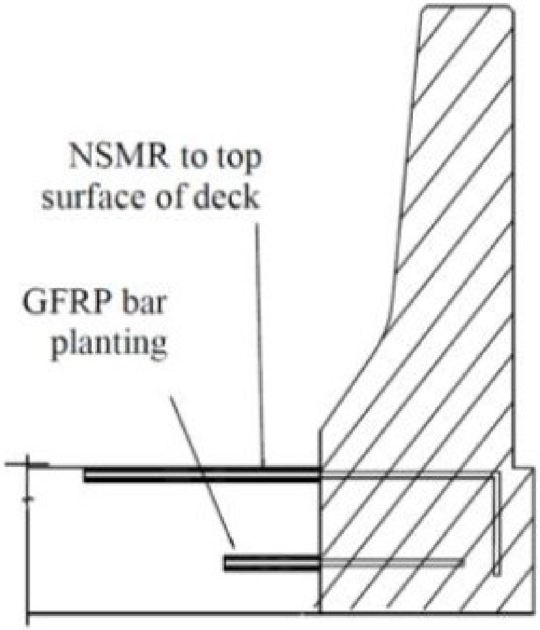
NSMR



NSMR in wall

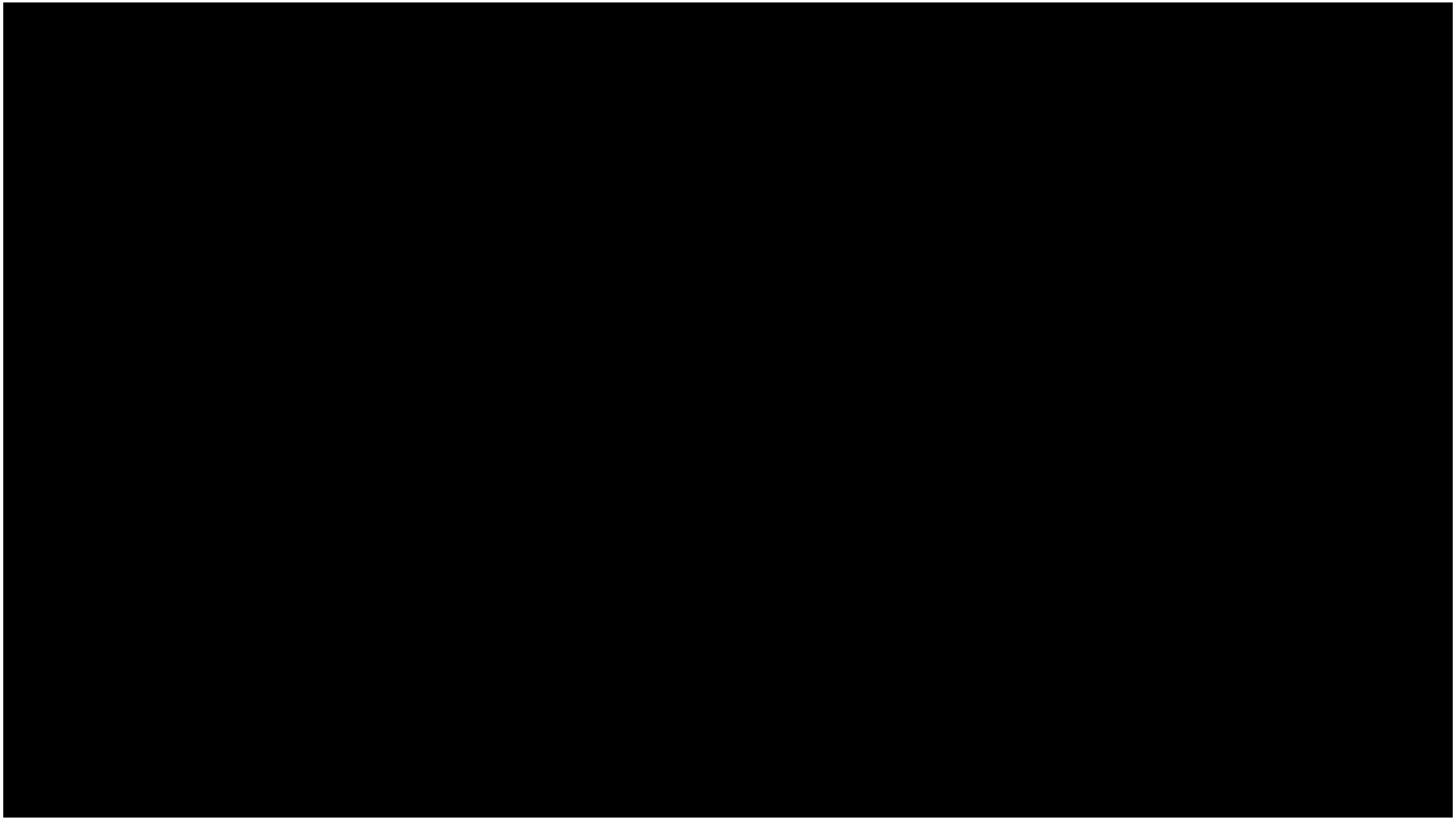


GFRP Planting on deck

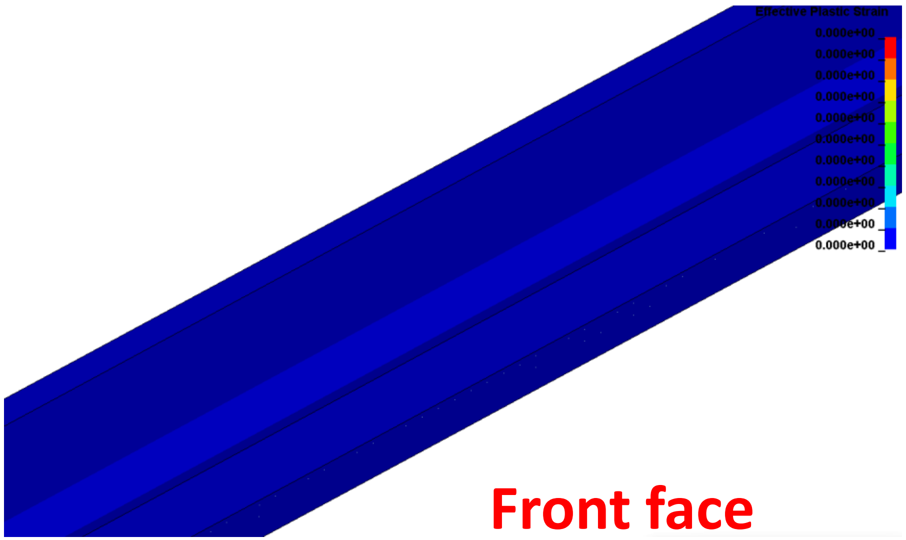


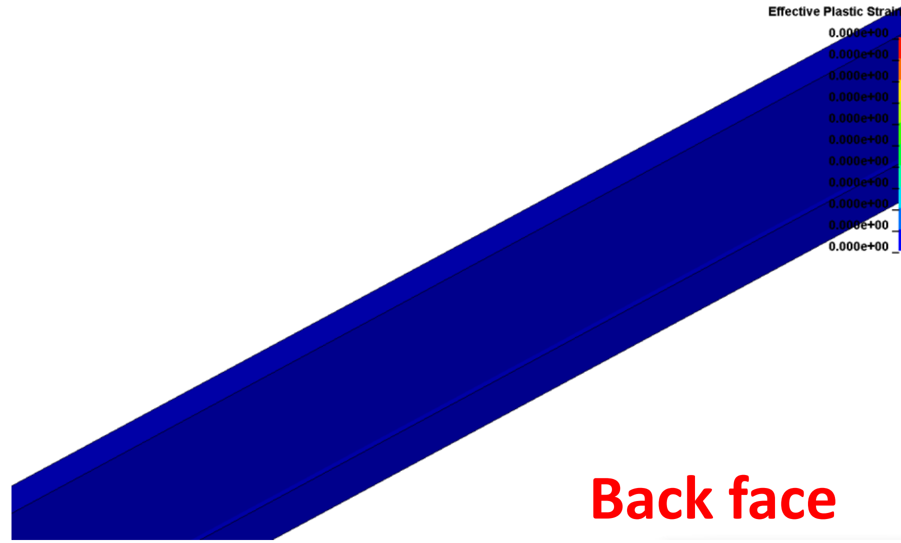
NSMR and planting On side of overhang

LS-DYNA finite element modeling validation

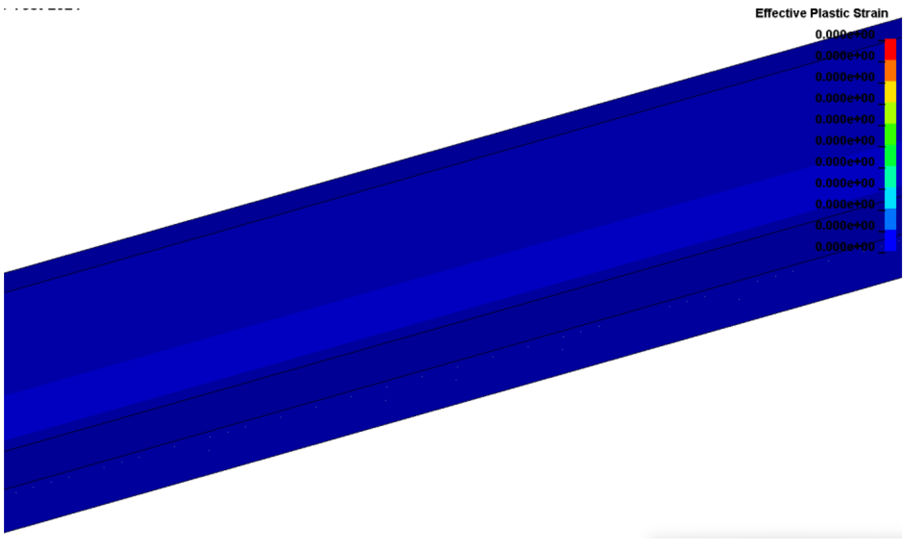


LS-DYNA modelling – static loading to collapse





THANK YOU


Effective Plastic Strain
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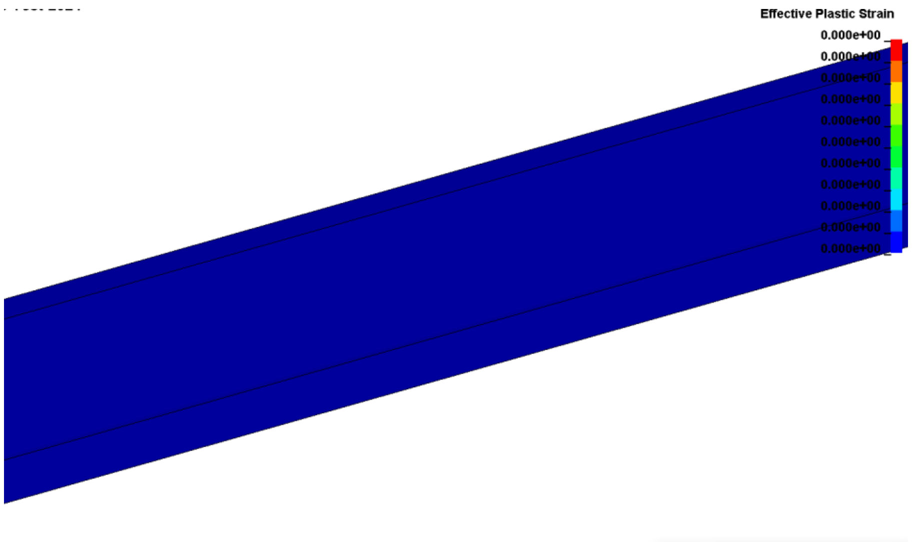
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FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

Performance of RC Columns With Hybrid Reinforcement (GFRP-Steel) under Cyclic Load

Girish Narayan Prajapati

Université de Sherbrooke, QC, Canada

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Content

- Introduction
- GFRP as lateral reinforcement
- GFRP as longitudinal reinforcement
- Hybrid GFRP-steel vertical reinforcement
- Conclusion

Introduction

Columns

Commercial Buildings, Hospitals, etc.

Bridge Piers

Highway Bridges

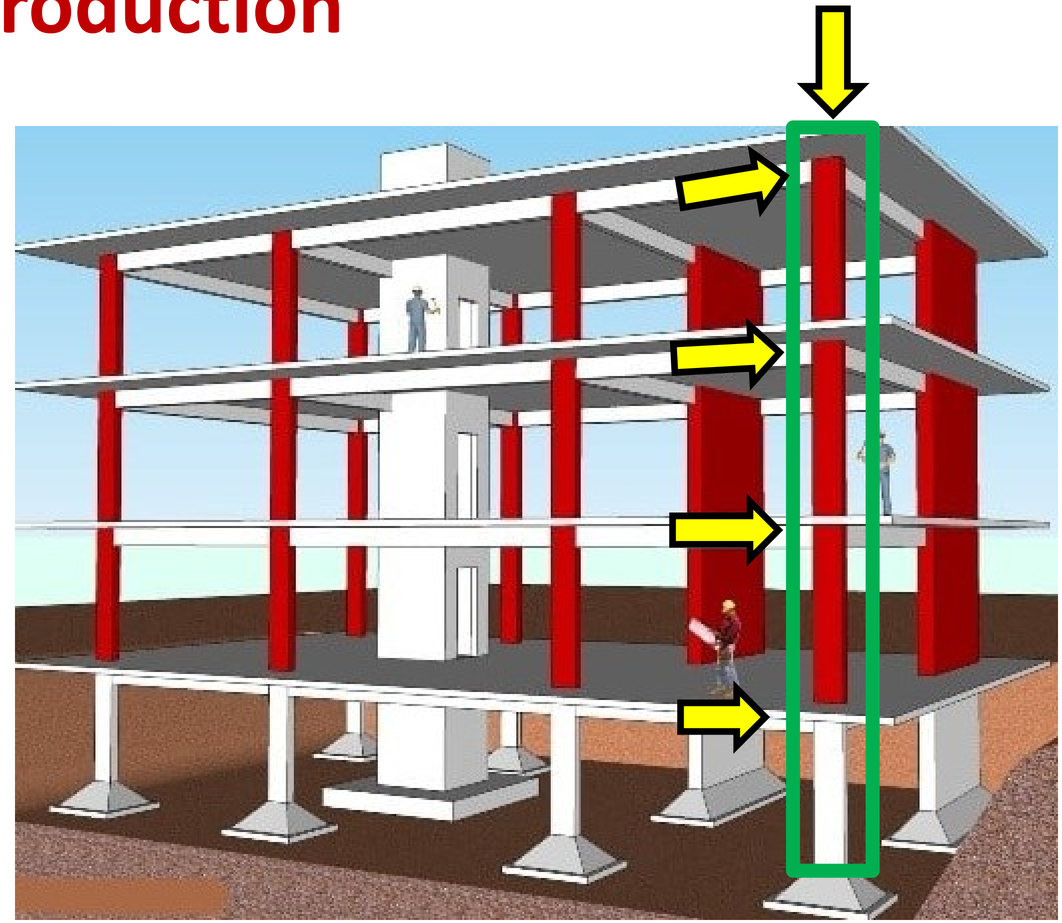
Railway Bridges

Parking Facilities

Introduction

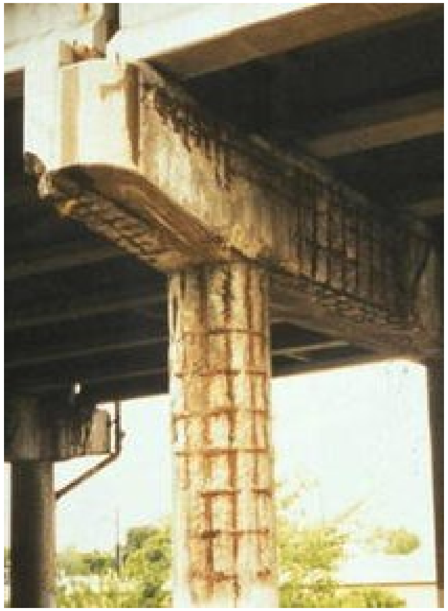
Columns

- Vertical load
- Lateral load
- Provide lateral stiffness to frame
- Control frame lateral drift
- Prevent structural collapse



Introduction

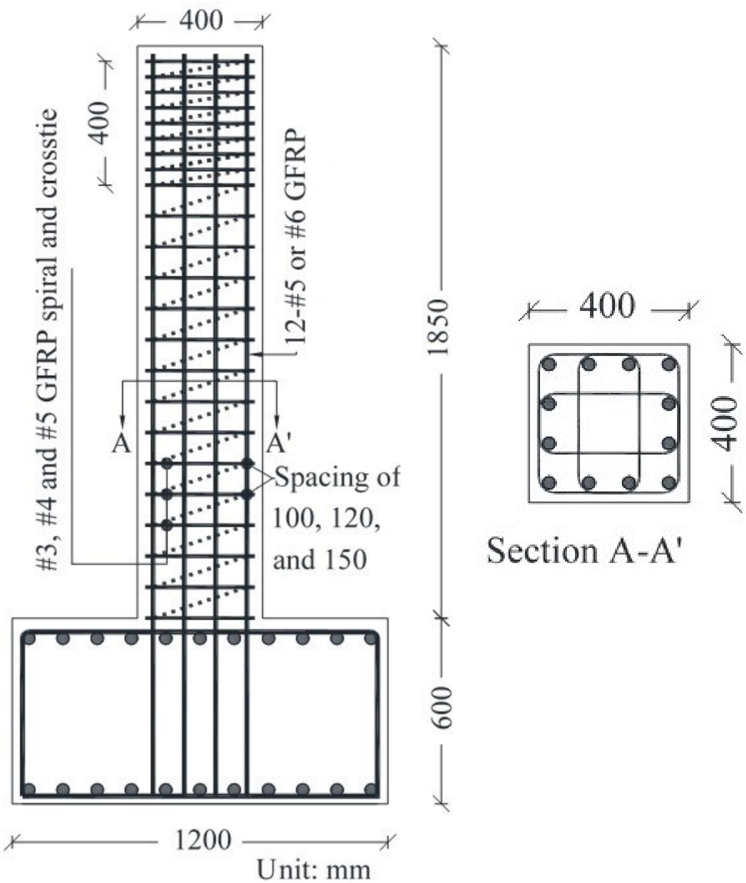
Problem: Corrosion in steel reinforced members

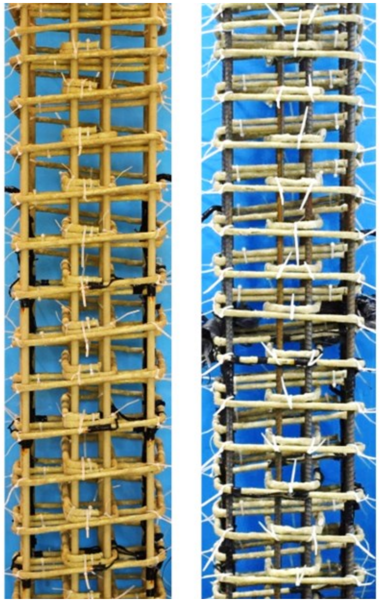




Corrosion Damage to RC Columns

GFRP as lateral reinforcement

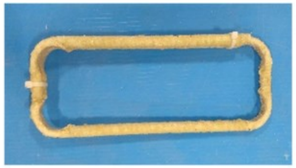
GFRP and hybrid-RC columns





Reinforcement cage

GFRP spiral



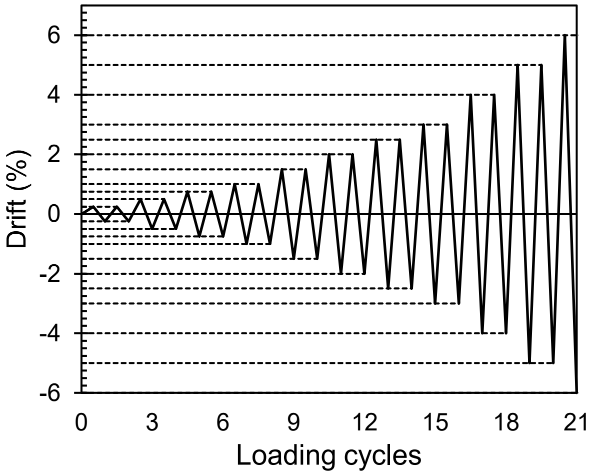
GFRP crosstie

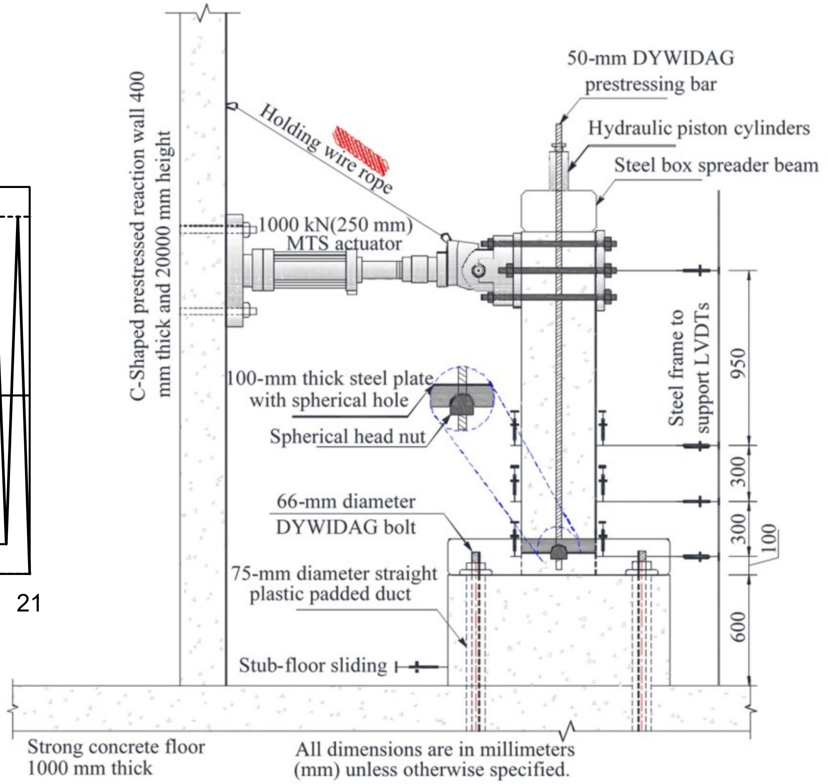
GFRP bar

Steel bar

GFRP as lateral reinforcement

GFRP and hybrid-RC columns



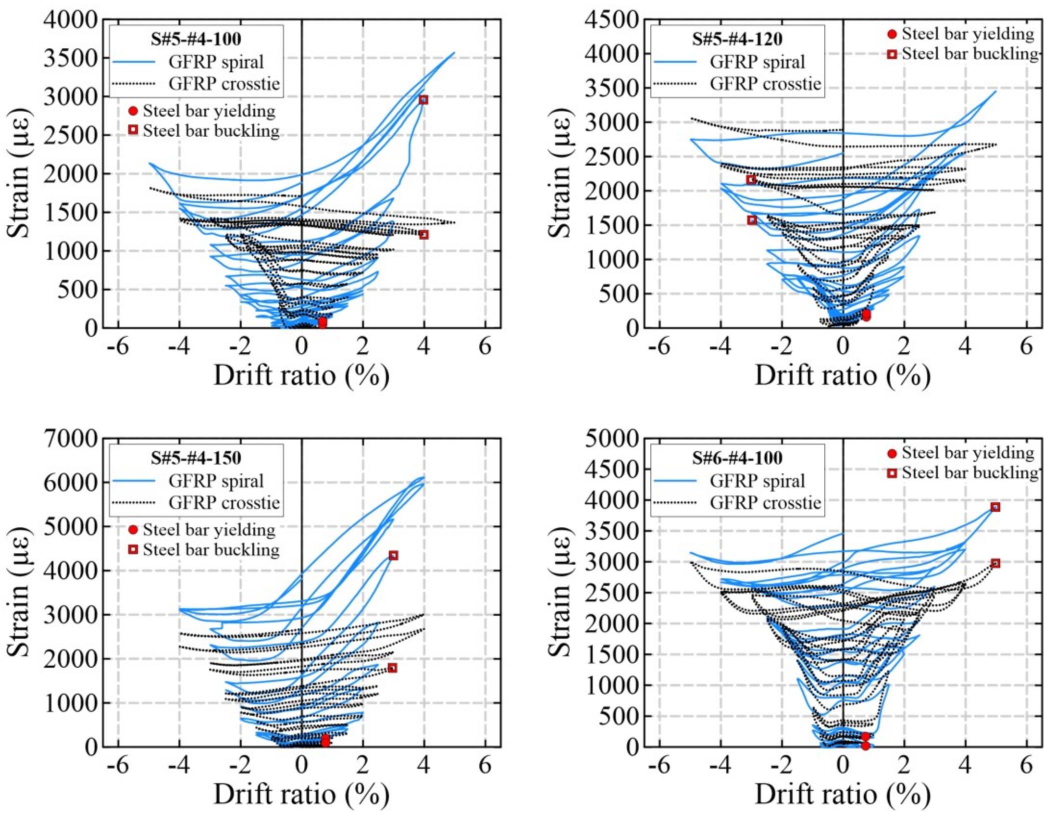


GFRP as lateral reinforcement

GFRP spiral and crossties strain

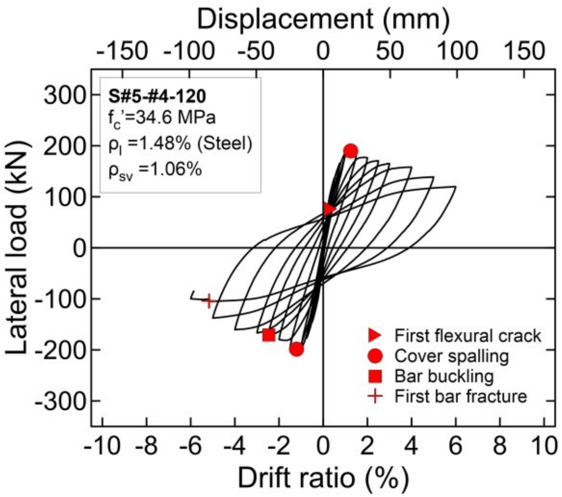
- GFRP spiral and crossties effectively confined the concrete column

- GFRP Strain was higher than steel tie yield strain (0.002), provide continuous confinement until the specimen failure



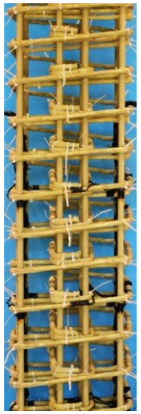
GFRP as longitudinal reinforcement

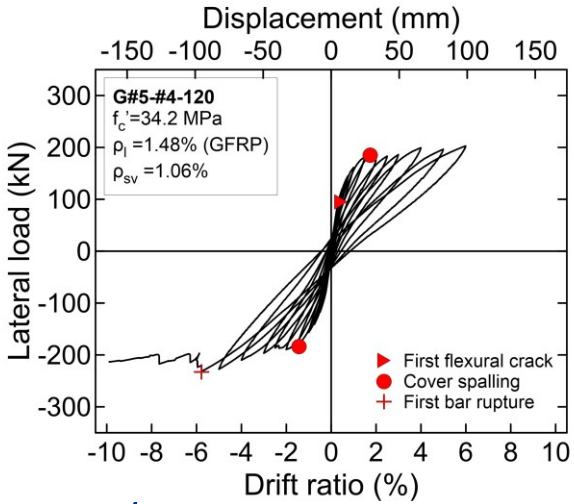
Hysteresis response



Hybrid-RC column

- **The lateral load continues to increase in GFRP-RC column compared with hybrid-RC column**





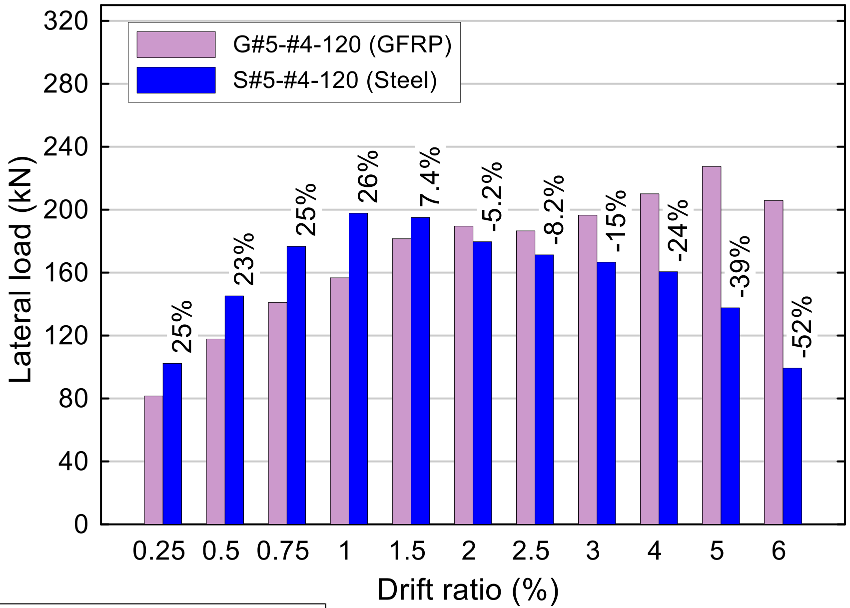
GFRP-RC column

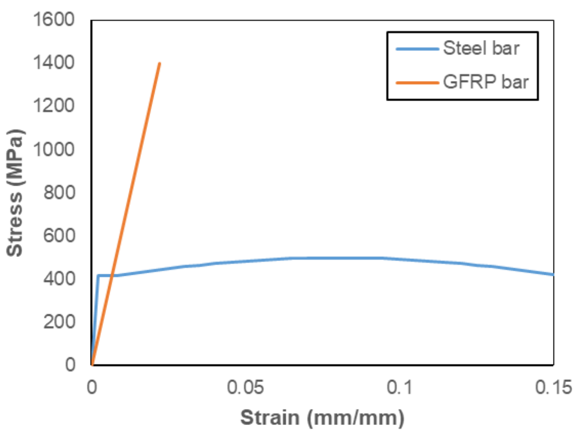
GFRP as longitudinal reinforcement

Hysteresis response

- Due to high stiffness of steel bar than GFRP bar, lateral load was more in initial drift cycles in hybrid-RC column.

- However, after 1.5% drift ratio, it was reversed, and more lateral load was observed in GFRP-RC column.

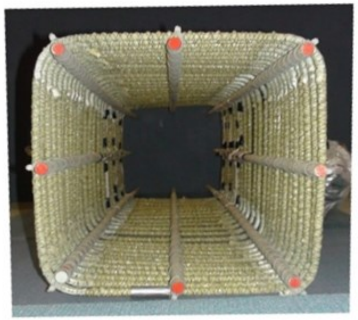




GFRP as longitudinal reinforcement

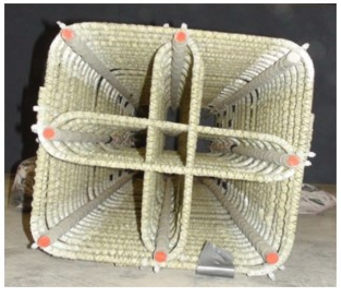
Tie configurations

C1



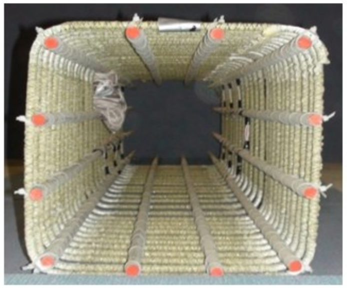
8N4-C1-100

C2



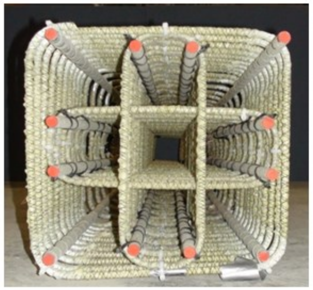
8N4-C2-100

C3



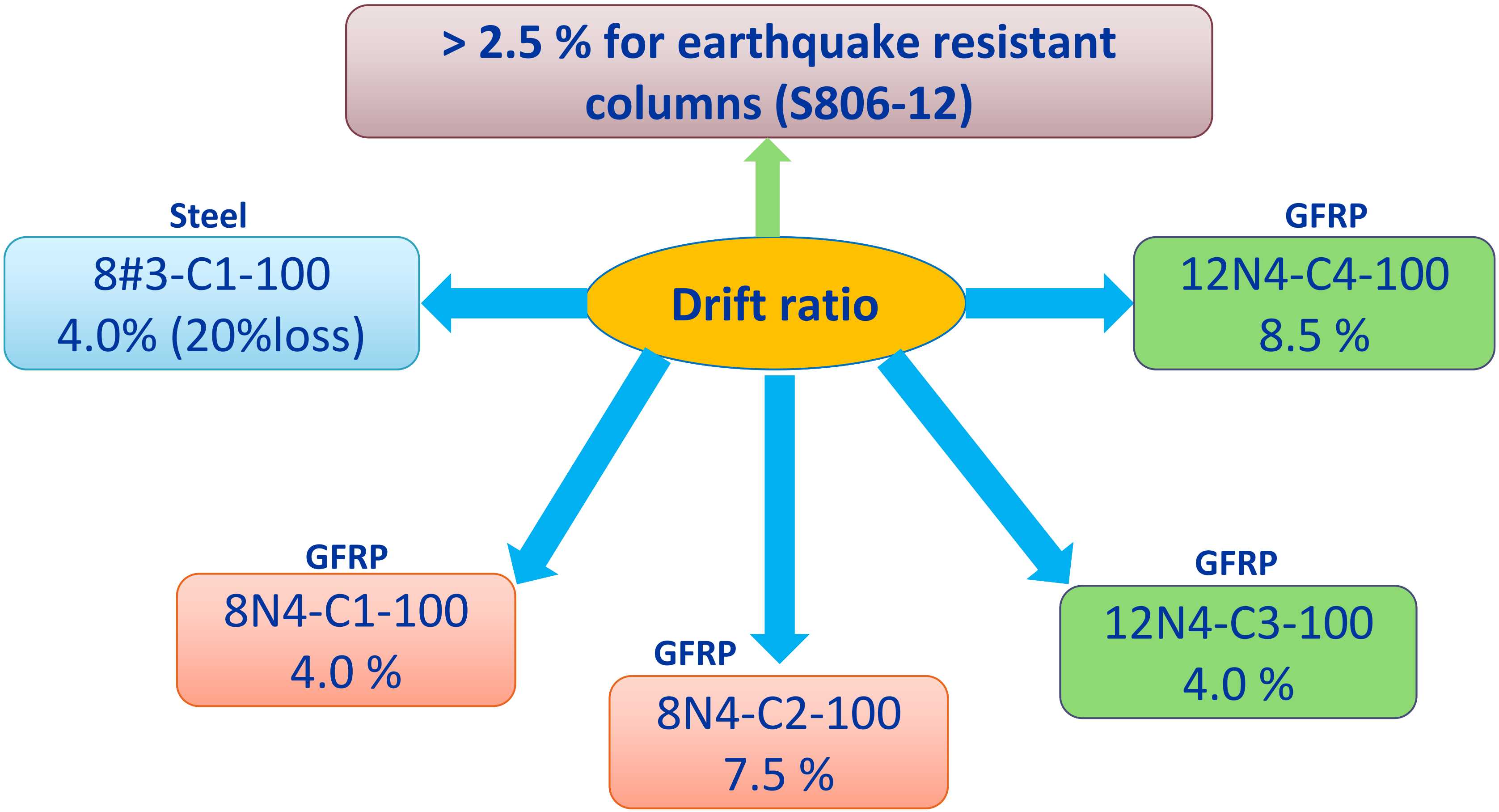
12N4-C3-100

C4



12N4-C4-100

GFRP as longitudinal reinforcement

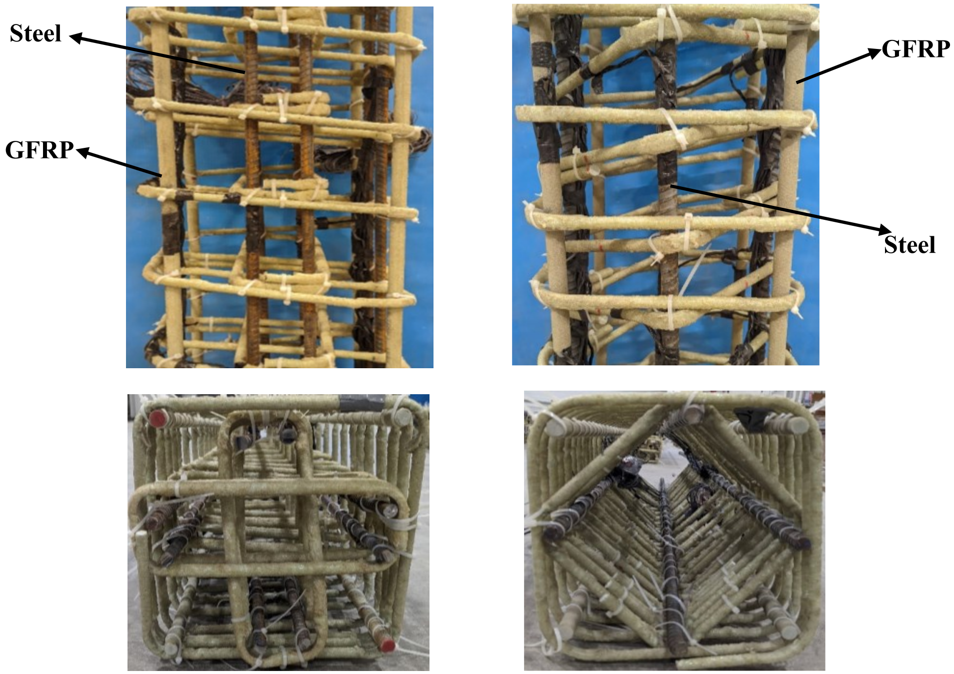


Hybrid GFRP-steel vertical reinforcement

Hybrid (GFRP-steel) longitudinal reinforcement

- To provide a better column with corrosion resistance and improved seismic performance

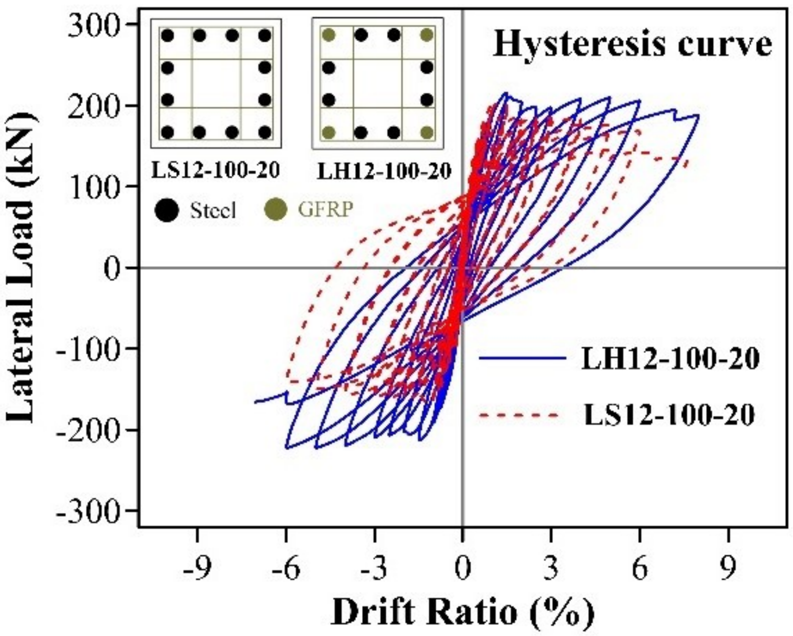
- Replacing some steel longitudinal bars with GFRP bars to improve self-centering capacity of the column



Hybrid GFRP-steel vertical reinforcement

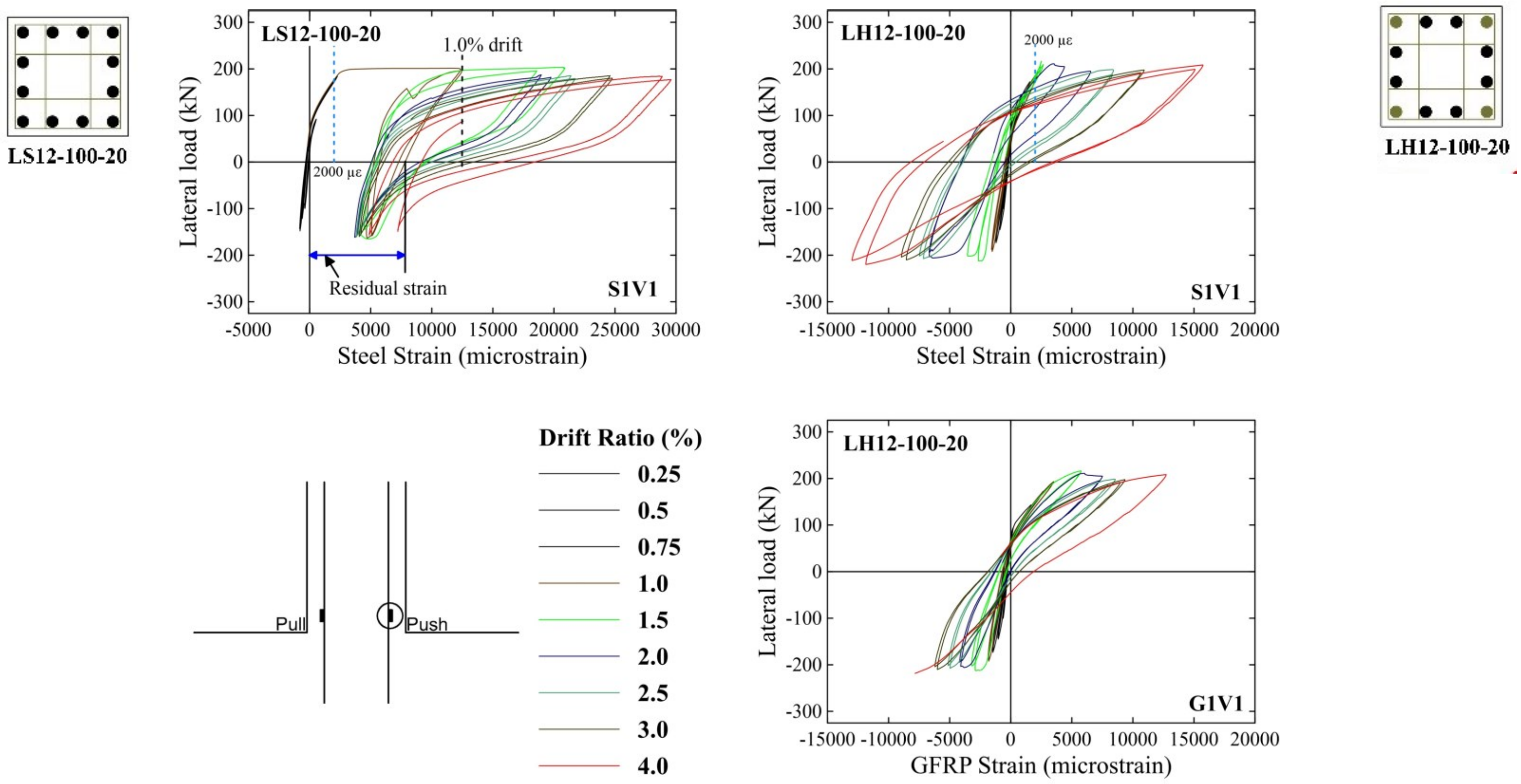
Comparison to steel-RC column

- Concrete column with hybrid longitudinal reinforcement maintained a higher lateral load in contrast to RC column with longitudinal steel bar
- Moreover, the contribution of GFRP longitudinal bars show a narrower response after loading



Hybrid GFRP-steel vertical reinforcement

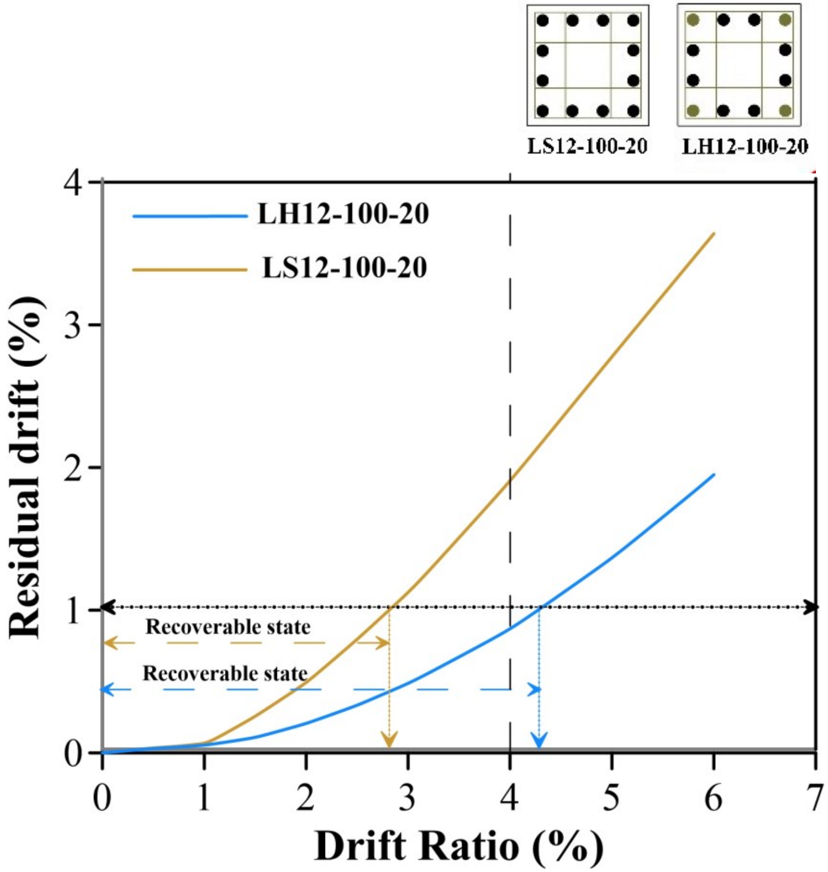
Comparison to steel-RC column



Hybrid GFRP-steel vertical reinforcement

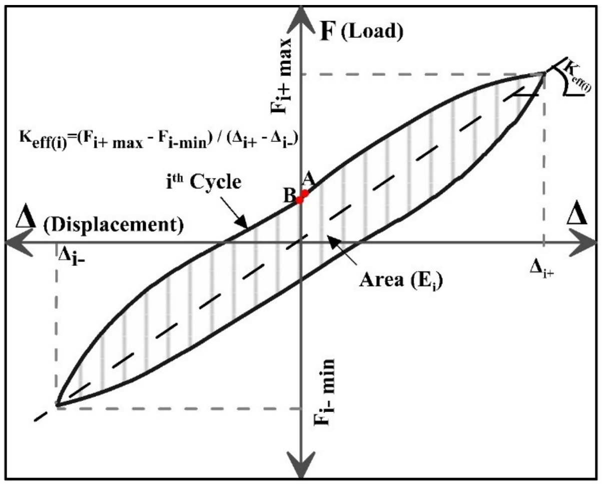
Self-centering ability

- Residual drift ratio is influenced by concrete deterioration and yield of steel bars
- Incorporation of longitudinal GFRP bars led to reduction in residual drift ratio
- Japan's design specification (JRA-2019) recommend recoverable state below 1% residual drift

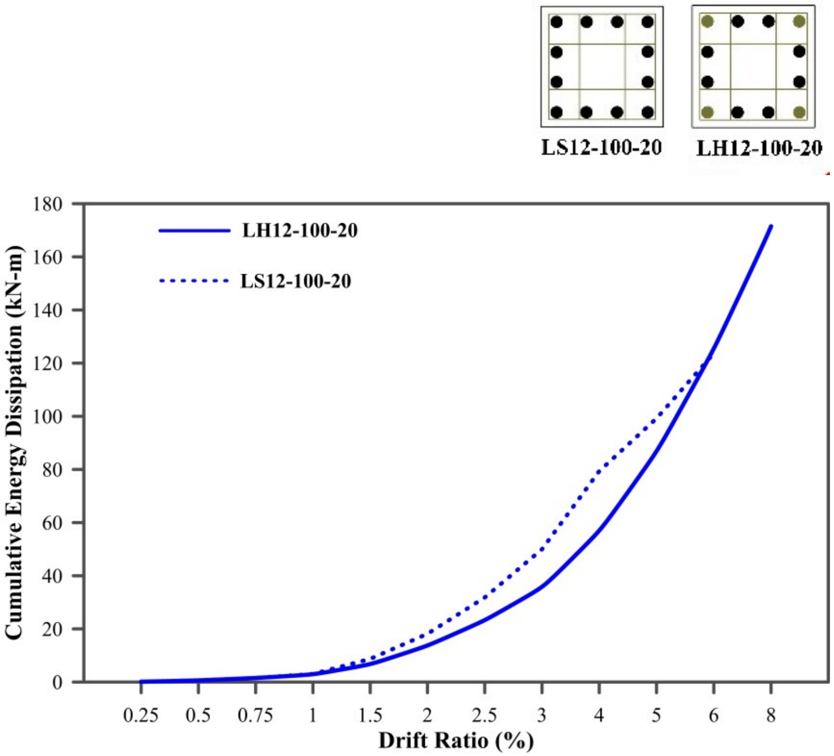


Hybrid GFRP-steel vertical reinforcement

Energy Dissipation



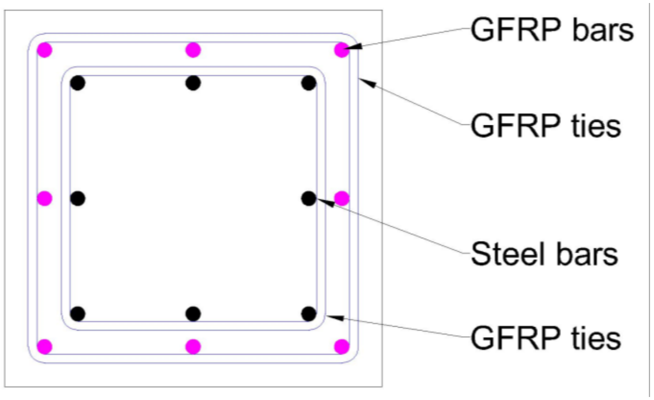
$$E_t = \sum_{1}^{n} E_i$$



Hybrid GFRP-steel vertical reinforcement

Why hybrid (GFRP-steel) longitudinal reinforcement?

- FRP bars have better resistance against corrosion; however, they have a linear elastic stress-strain relationship until the failure
- Steel has good plasticity; however, steel bars corrode under extreme environmental conditions
- Two layers of reinforcement, with outer GFRP and inner longitudinal steel bars, will improve the ductility and service life of concrete columns; they can also be used in high seismic zones



Conclusion

- GFRP-RC column with adequate confinement provided by GFRP ties exhibited stable behavior, achieving drift more than 4.0%
- Strain developed in lateral GFRP reinforcement indicates effective confinement provided by GFRP ties after the steel longitudinal bar yielded
- Incorporation of longitudinal GFRP bars in steel-RC columns demonstrates resilience, enhances their self-centering ability and improves lateral load and drift capacity
- A concrete column entirely reinforced with GFRP could be suitable for low-to-moderate seismic zones, whereas longitudinal steel reinforcement would be required in high seismic zones to achieve energy dissipation

Acknowledgements

Prof. Brahim Benmokrane
Professor of Civil Engineering
Université de Sherbrooke, QC

- **Tier-1 Canada Research Chair in Advanced FRP Composite Materials for Civil Structures**
- **Industrial Research Chair in Innovative FRP Reinforcement for Concrete Structures**
- **Natural Sciences and Engineering Research Council of Canada (NSERC).**
- **Fonds québécois de la recherche sur la nature et les technologies (FQRNT).**
- **Université de Sherbrooke, Department of Civil Engineering.**

Thank You

FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

PERFORMANCE OF RC HYBRID COLUMNS UNDER SIMULATED EARTHQUAKE LOADS

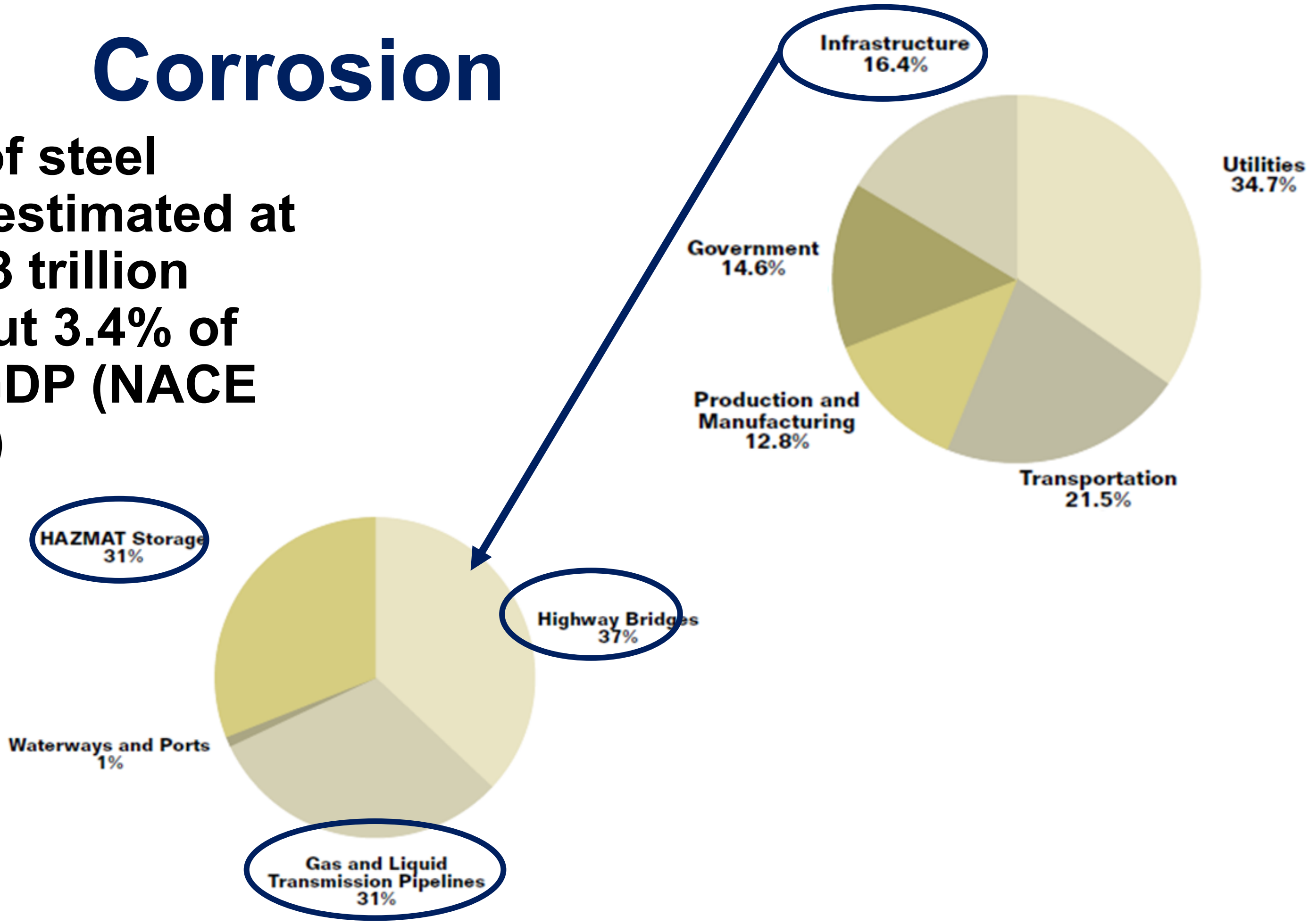
Shamim Sheikh

University of Toronto

SPONSORED BY:

Corrosion

- Global cost of steel corrosion is estimated at about USD $3 trillion which is about 3.4% of the world's GDP (NACE International)



Experimental Program

- **Constituted of three phases.**

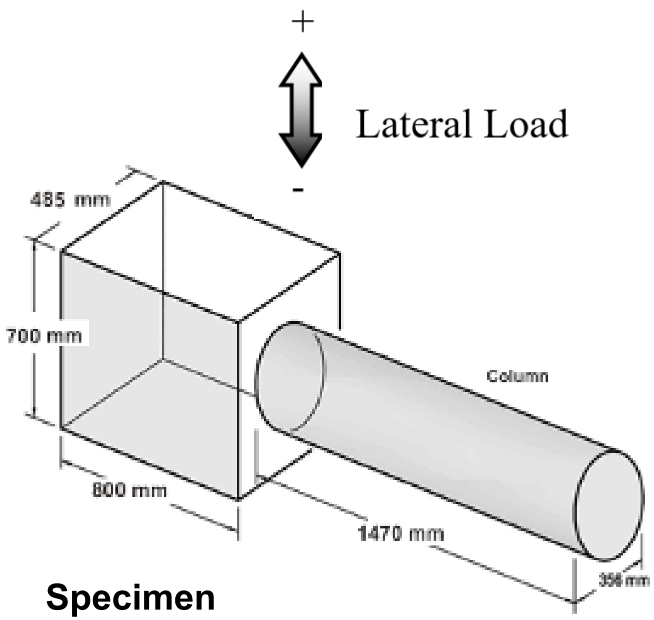
- **Columns reinforced with:**
  1. **GFRP spirals** and **GFRP longitudinal bars;**
  2. **GFRP spirals** and **Steel longitudinal bars; and**
  3. **GFRP ties** and **steel longitudinal bars.**

- Before this program was undertaken hundreds of small and large steel-reinforced columns were tested

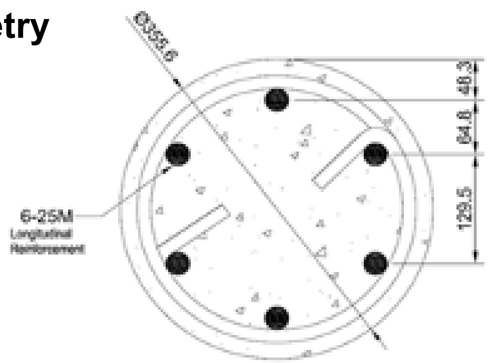
PHASE I: Circular Columns with GFRP Longitudinal Bars and GFRP Spirals

- Nine Circular Columns → GFRP spirals and GFRP longitudinal bars.
- Large-scale columns → 356 mm diameter and 1470 mm length.
- Tested at the University of Toronto → simulated earthquake loading.

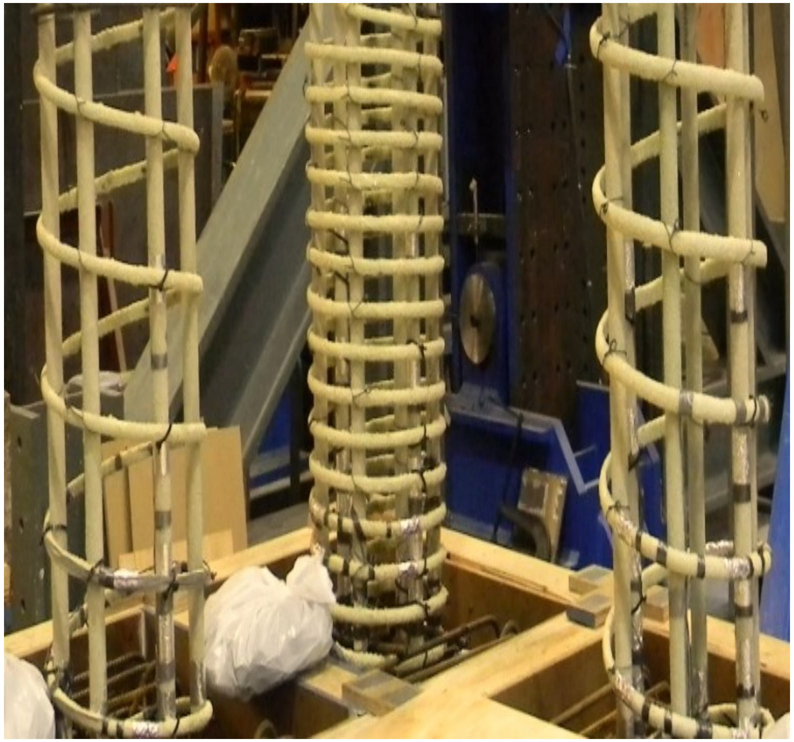
Specimen Details



Specimen Geometry



Specimen Cages

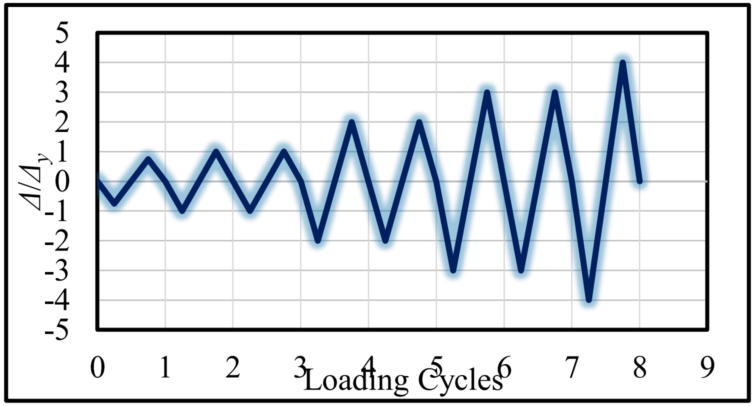


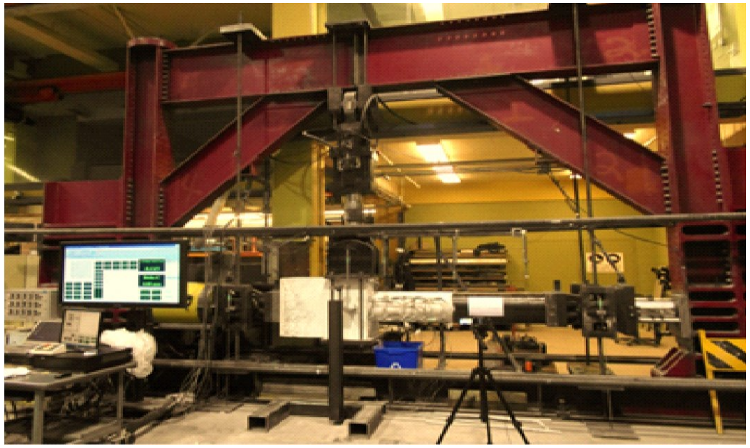
Main Variables

- Axial load level
- Type of reinforcement
- Column cross-section
- Spacing of transverse reinforcement
- Volumetric ratio of transverse reinforcement

Test Set-up

- **Simulated earthquake loading**
  - Constant axial load
  - Cyclic lateral displacement excursions





OBSERVATIONS:
Columns with GFRP Longitudinal Bars and Spirals

Failure Mode → Longitudinal Bar Rupture

- The compressive strength of GFRP bars at failure was approximately 60% of the ultimate coupon tensile strength for both circular and square columns.
- The GFRP spirals and ties were able to provide continuing effective confinement to the core concrete till specimen failure.

Results

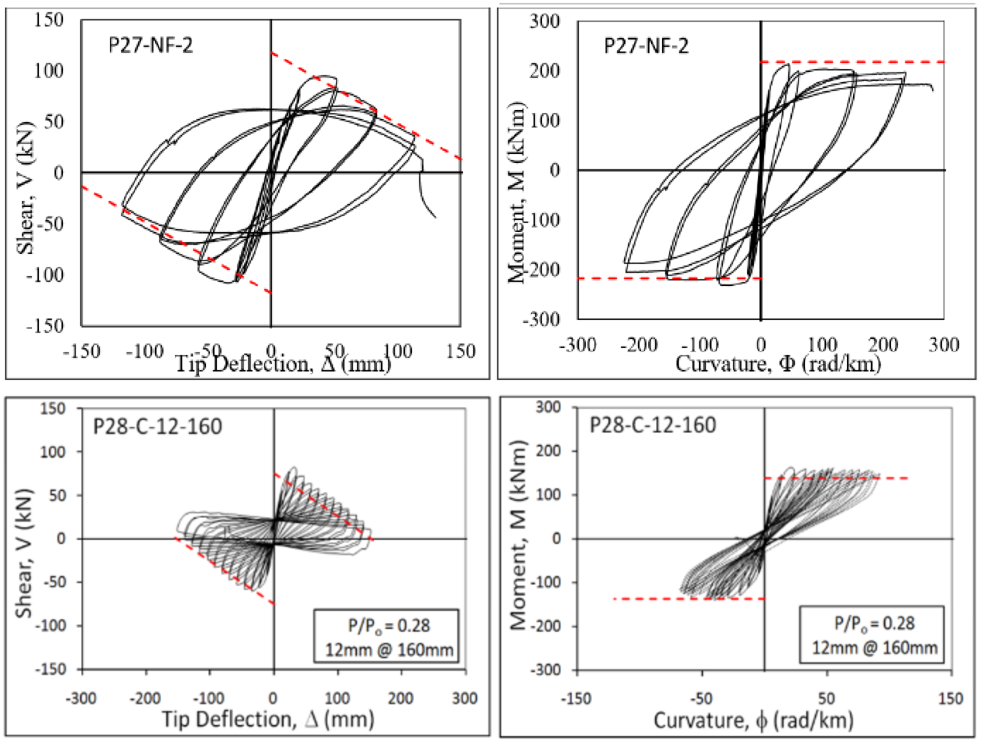
Steel-RC Column

- Steel Longitudinal bars
- Steel spirals
- Axial Load = 0.28Po
- Reinforcement ratio = 0.90%
- Spacing of spirals = 9.5 mm @ 150 mm

GFRP-RC Column

- GFRP Longitudinal bars
- GFRP spirals
- Axial Load = 0.28Po
- Reinforcement ratio = 0.94%
- Spacing of spirals = 12 mm @ 160 mm

Shear vs Tip Deflection | Moment vs Curvature



1. The GFRP reinforced specimens were able to undergo several more cycles than the conventional steel specimens.

2. However, they had lower shear and moment capacities in comparison with conventional steel reinforced columns.

3. The hysteresis loops had significantly lower energy dissipation.

4. They displayed softer response → Due to lower stiffness of longitudinal GFRP bars

PHASE II: Circular Columns with Steel Longitudinal Bars and GFRP Spirals

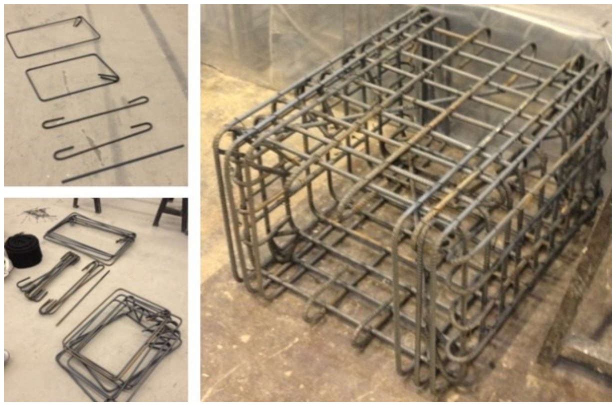
- **Aim :** To maximize the advantages and minimize the disadvantages of GFRP bars.

- Eight Hybrid **Circular** Columns → **GFRP spirals** and **steel longitudinal bars.**
  (f'c = 41 MPa)

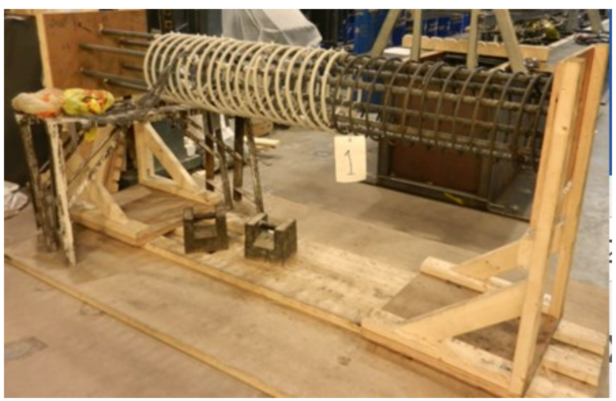
- **Large-scale** columns → same dimensions as columns with GFRP longitudinal bars and spirals, and columns with all steel reinforcement

- Designed according to CSA-S806-12 to achieve various lateral drift ratios.

Construction of Specimens



1. Stub cage

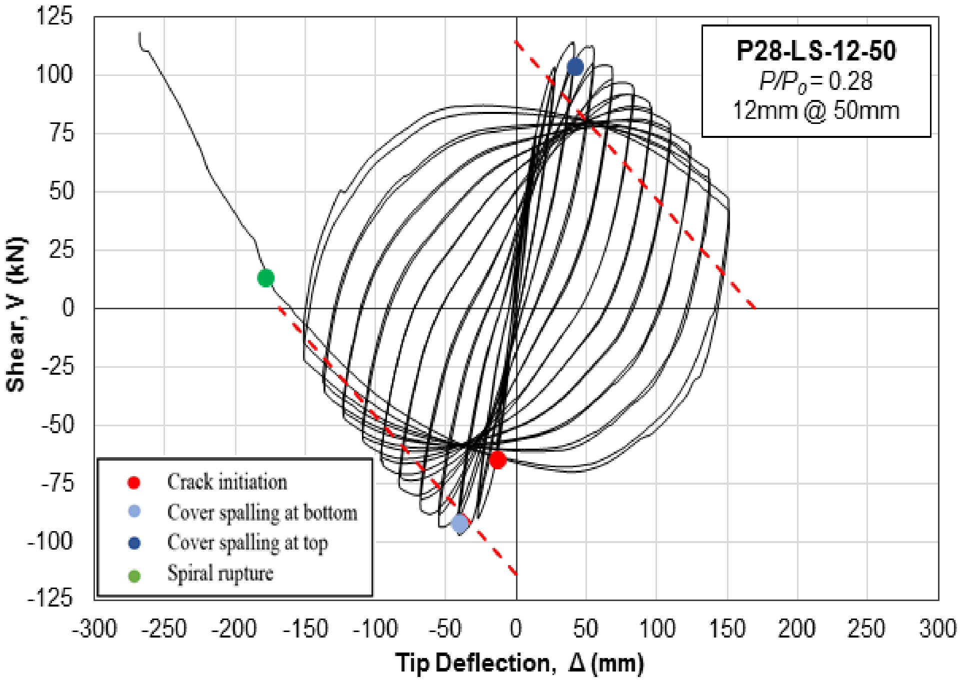


2. Column cage

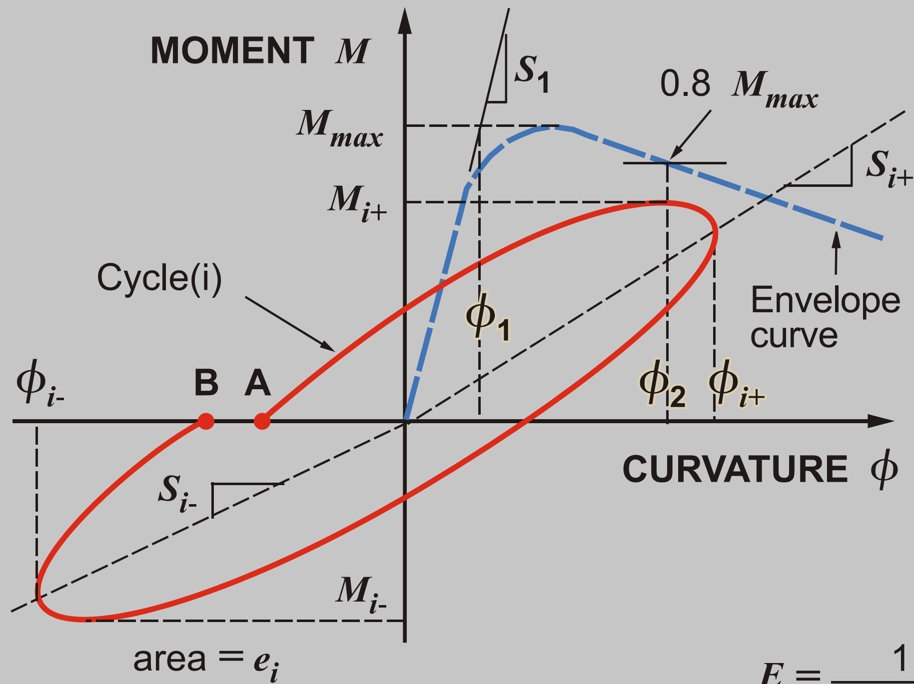
3. Cages Assembled in formwork

Results

- **Columns were able to:**
  - Undergo several displacement cycles
  - Achieve high levels of ductility
  - Dissipate large amount of energy



Ductility Parameters



$$\phi_i = \frac{1}{2}\left(\phi_{i+} + \phi_{i-}\right)$$

$$M_{i,max} = \frac{1}{2}\left(M_{i+} + M_{i-}\right)$$

$$S_i = \frac{1}{2}\left(S_{i+} + S_{i-}\right)$$

$$\mu_\phi = \frac{\phi_2}{\phi_1}$$

$$N_\phi = \sum_{i=1}^{i=m} \frac{\phi_i}{\phi_1}$$

$$E = \frac{1}{M_{max}\,\phi_1} \sum_{i=1}^{i=m} e_i \frac{L_f}{t} \left(\frac{S_i}{S_1}\right) \left(\frac{\phi_i}{\phi_1}\right)^2$$

Sheikh, S.A. and Khoury, S.S. (1997), "A Performance-Based Approach for the Design of Confining Steel in Tied Columns", ACI Str. J, 94-4.

UNIVERSITY OF TORONTO
Department of Civil Engineering

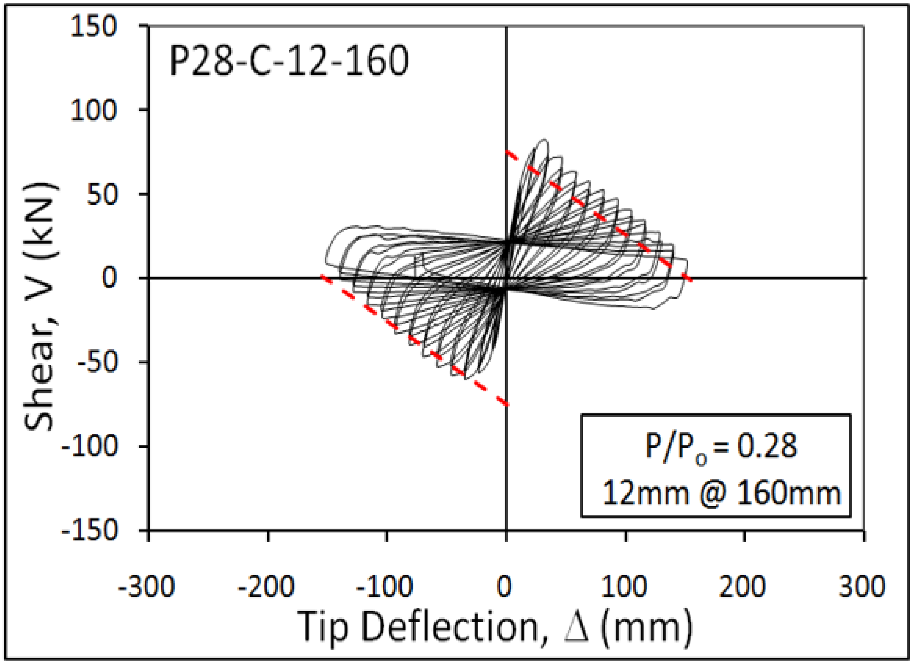
GFRP VS. STEEL AS LONGITUDINAL BARS

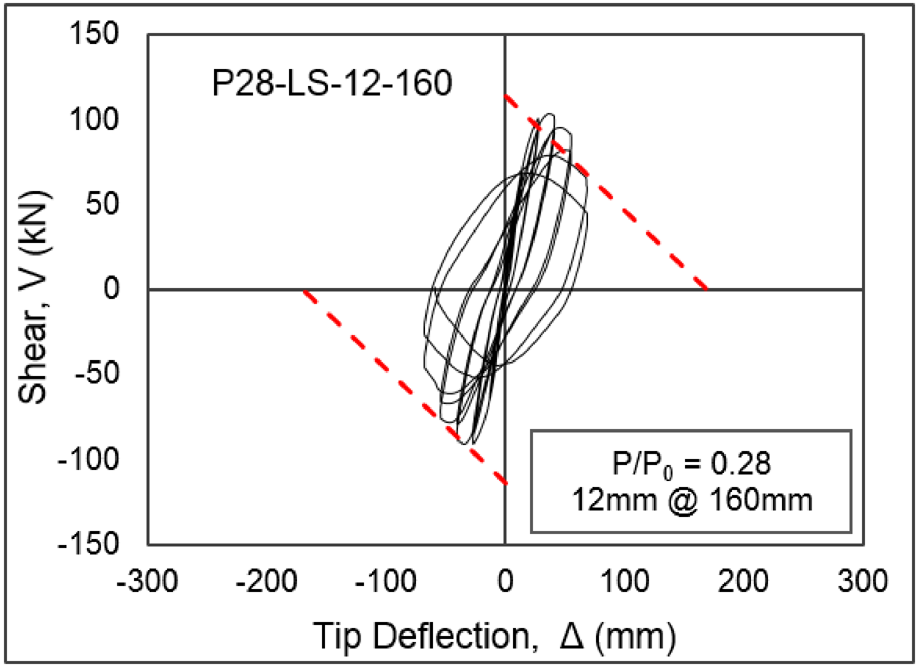
- Two identical columns with the exception of longitudinal bar type were tested under similar loading conditions
- Both columns were reinforced laterally with 12 mm @ 160 mm GFRP spirals

	Maximum Shear, V_{max} (kN)	Moment Capacity, M_{max} (kN.m)	Displacement Ductility Factor, μ_{Δ}	Lateral Drift Ratio, δ (%)	Work Damage Indicator, W_{80}
GFRP P28-C-12-160	71	152	3.2	3.0	22
Steel P28-LS-12-160	98	210	3.1	3.1	19

GFRP Longitudinal Bars

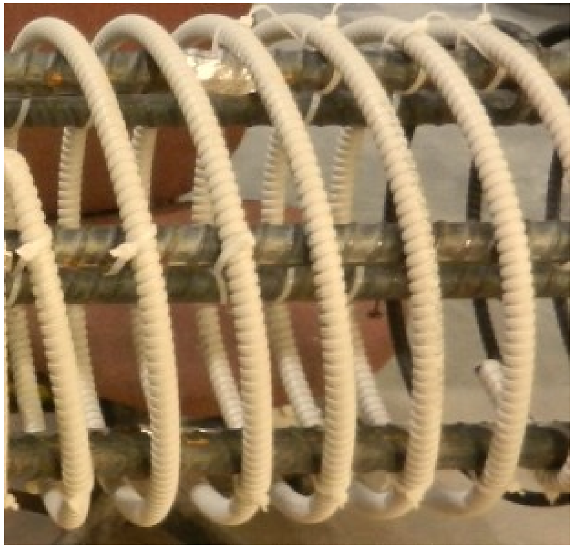
Steel Longitudinal Bars





GFRP VERSUS STEEL SPIRALS

- Results from these tests (long. Steel and GFRP spirals) were compared with the results from conventional all steel-reinforced columns
- Comparable columns had identical properties except the spiral reinforcement
- All columns were tested under similar conditions

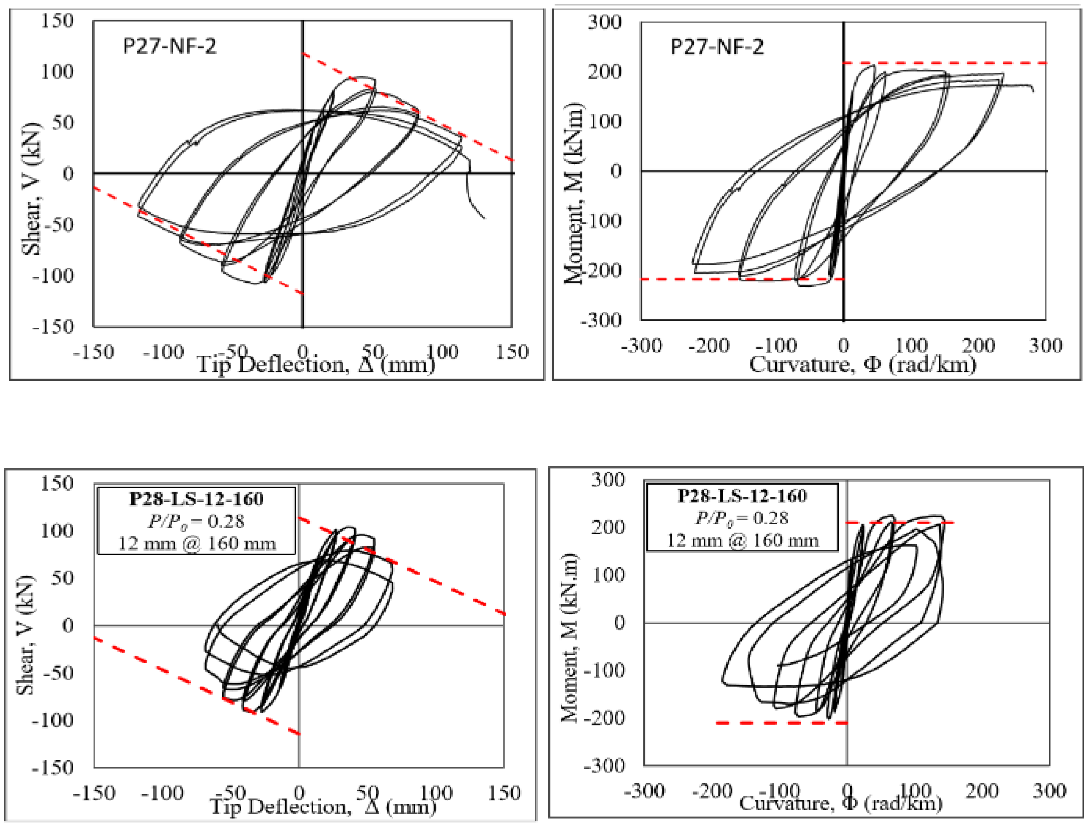


Steel Circular Column

- Steel Longitudinal bars
- Steel spirals
- Axial Load = 0.28Po
- Reinforcement ratio = 0.90%
- Spacing of spirals = 9.5 mm @ 150 mm

Hybrid Circular Column

- Steel Longitudinal bars
- GFRP spirals
- Axial Load = 0.28Po
- Reinforcement ratio = 0.94%
- Spacing of spirals = 12 mm @ 161 mm



Shear vs Tip Deflection

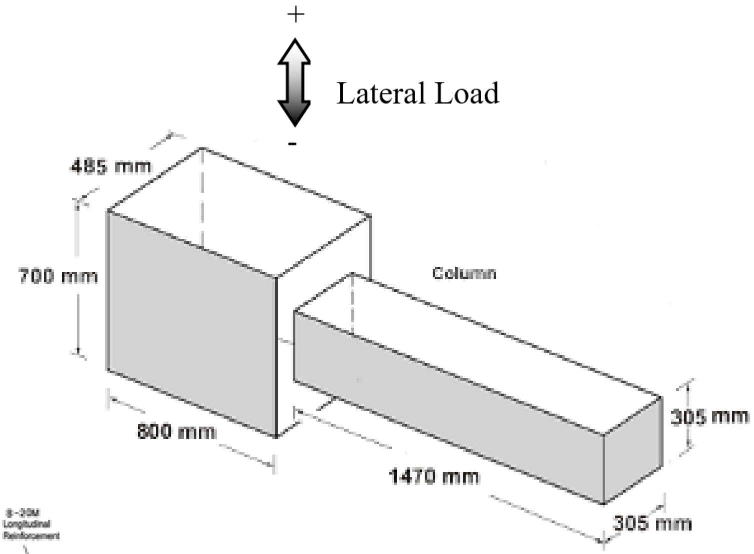
Moment vs Curvature

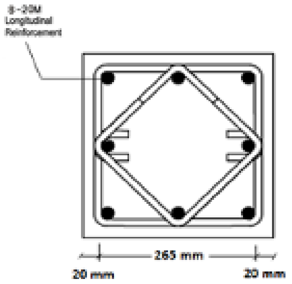
Specimen	Axial load level P/P_o	Transverse confinement		Curvature ductility factor	Displacement ductility factor	V_{max} (kN)	M_{max} (kNm)	Drift ratio, δ (%)
		Designation @ Spacing (mm)	Spiral ratio	μ_Φ	μ_Δ			
Steel P27-NF-1	0.27	#3@150	0.60	12.6	3.4	100	204	3.18
GFRP P28-LS-12-160	0.28	12 @ 160	0.94	11.1	3.1	98	210	3.09
Steel P56-NF-11	0.56	10M@100	1.22	12.8	3.3	95	203	2.22
GFRP P55- LS-12-90	0.55	12 @ 90	1.67	12.7	2.9	104	234	2.15

PHASE III: Square Columns with Steel Longitudinal Bars and GFRP Ties

- Fourteen Hybrid **Square** Columns → **GFRP ties** and **steel longitudinal bars.**
  (f'c = 46 MPa)
- **Large-scale** columns → 305 mm square cross-section with a length of 1470 mm.
- Columns were designed according to CSA-S806-12 to achieve various lateral drift ratios.

Specimen Details





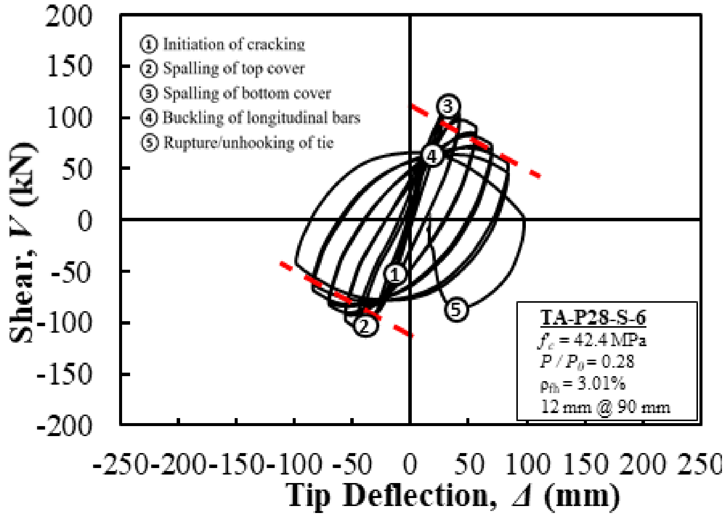
Specimen Geometry

Formwork

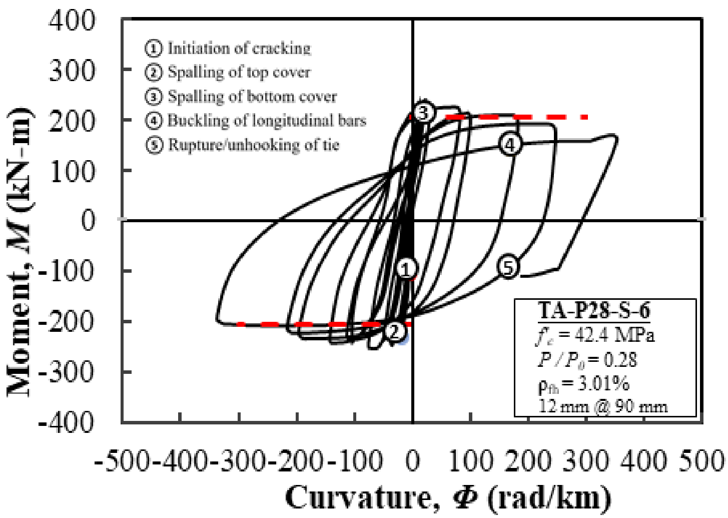
OBSERVATIONS

Failure Mode → GFRP Tie failure/rupture

TEST RESULTS

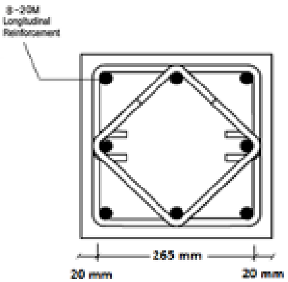


Shear vs Tip Deflection



Moment vs Curvature

- Steel Longitudinal bars
- GFRP Ties 12 mm @ 90 m
- Axial Load = 0.28Po
- Reinforcement ratio = 3.01



Square vs Circular Columns

- **For circular columns - No redundancy after the rupture of GFRP spiral and confinement provided to the core concrete vanished as soon as the spirals ruptured.**

- **For square columns - The loss of confinement was not as sudden; the failure was more prolonged due to the fact that there were two ties at each level in columns with reinforcement Configuration A.**

Square Column

Circular Column

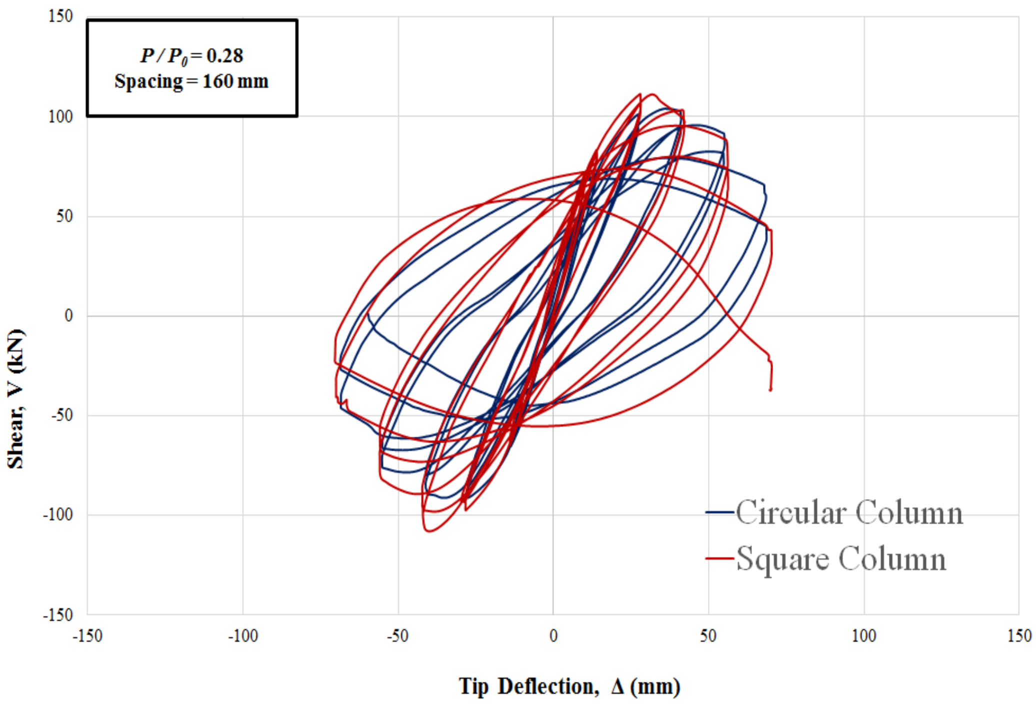
Comparison Of Shear Vs. Deflection Hysteresis

Square Hybrid Column

- Steel Longitudinal bars
- GFRP Ties
- Axial Load = 0.28Po
- Reinforcement ratio = 1.68%
- Spacing of ties = 12 mm @ 160 mm

Circular Hybrid Column

- Steel Longitudinal bars
- GFRP spirals
- Axial Load = 0.28Po
- Reinforcement ratio = 0.94%
- Spacing of spirals = 12 mm @ 161 mm



Ductility Parameters

The drift capacity of the cicular and square hybrid columns ranged between **2.5 and 3.5%**

Thus, meeting the requirements of the North American building codes.

Shape	Specimen	Axial load P/P_o	Ductility Parameters μ_Δ	μ_ϕ	δ (%)
Square	TA-P28-S-10	0.28	2.94	15.6	3.5
Circular	P-28-LS-12-160	0.28	3.10	11.1	3.1

Concluding Remarks

- Columns with GFRP longitudinal bars displayed stable behaviour and achieved high deformability, but the flexural strength and stiffness was found to be lacking.
- The columns with steel longitudinal bars had flexural strength and stiffness comparable to conventional steel-RC columns.
- The optimum solution with respect to column strength and stiffness, ductility and energy dissipation, and corrosion resistance appears to be a hybrid column with steel longitudinal bars and GFRP transverse reinforcement.
- This provides an ideal solution for durable columns with appropriate seismic resistance for resilient structures.

Selected Background Papers

- **Sheikh, S.A. and Kharal, Z., "Full-Scale and Half-Scale GFRP-Confined Concrete Columns for Seismic Loading", Bridge Engineering, Bridge and transport network resilience, ICE, 2024, https://www.icevirtuallibrary.com/doi/10.1680/jbren.21.00104.**
- **Kharal, Z., Carrette, J. and Sheikh, Shamim A., "Large concrete columns internally reinforced with GFRP spirals subjected to seismic loads", ASCE Journal of Composites for Construction, Vol 25, No. 3, June 2021.**
- **Liu, J, Kharal, Zahra and Sheikh, Shamim A. "Steel-Confined Circular Columns under Simulated Seismic Loads", ACI Structural Journal, Vol 118, No. 1, January 2021, pp189-200.**
- **Kharal, Zahra and Sheikh, Shamim A., "Seismic Behavior of Square and Circular Concrete Columns Internally reinforced with GFRP", Journal of Composites for Construction, ASCE , Vol. 24, No. 1, Feb. 2020, Published Online, Nov. 30, 2019.**
- **Kharal, Z. and Sheikh, S. A., "Seismic Performance of Square Concrete Columns Confined with Glass Fiber–Reinforced Polymer Ties", Journal of Composites for Construction, ASCE, Vol 22, Issue 6, Dec. 2018.**
- **Tavassoli, Arsalan and Sheikh, S.A., "Seismic resistance of circular columns reinforced with steel and GFRP", Journal of Composites for Construction, ASCE, Vol 21, No. 4, August 2017.**
- **Tavassoli, Arjang, Liu, J. and Sheikh, S. A., "Glass Fiber-Reinforced Polymer-Reinforced Circular Columns under Simulated Seismic Loads", ACI Structural Journal, Vol. 112, No. 1, Jan-Feb 2015, pp 103-114.**

Acknowledgements

❑ **Financial Support provided by:**

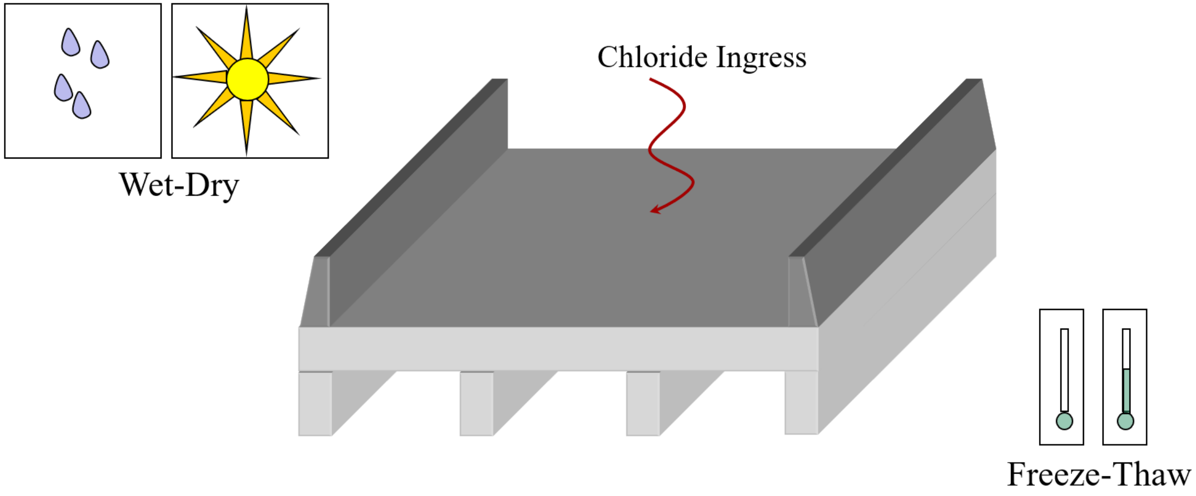
- IC-IMPACTS, NSERC Network of Centres of Excellence
- Natural Sciences and Engineering Research Council of Canada (NSERC)
- Schöck Canada Inc.
- Canadian Association for Earthquake Engineering (CAEE)

❑ **Material and Technical Support provided by:**

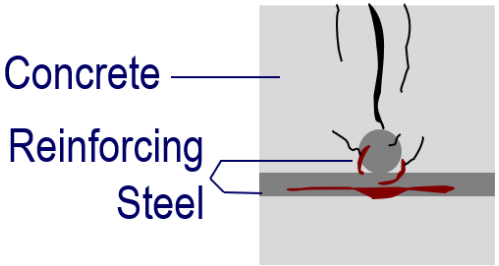
- Dufferin Concrete
- Pultrall Inc.
- Schöck Canada Inc.

CORROSION IN CANADA AND OTHER COUNTRIES

- The effect of corrosion in structures like bridges is worse in countries such as Canada due to aggressive environments.



EFFECT OF CORROSION IN COLUMNS



1. Corrosion products form
2. Volume expansion occurs

Cover Spalling
Highway 401 bridge, Toronto

EFFECT OF COVER SPALLING

- Cover Spalling in columns results in a **reduction** of:

Load carrying capacity	Ductility	Energy Dissipation

GLASS FIBRE REINFORCED POLYMER – A FEASIBLE SOLUTION

Light weight

Easy to install

High Strength

3x steel

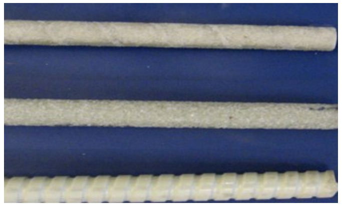
GFRP Bars

Corrosion resistant

Durable structures

Highly versatile

Suits many projects



Various GFRP bars

Use of GFRP in bridge construction
(Floodway Bridge over Red River Winnipeg)

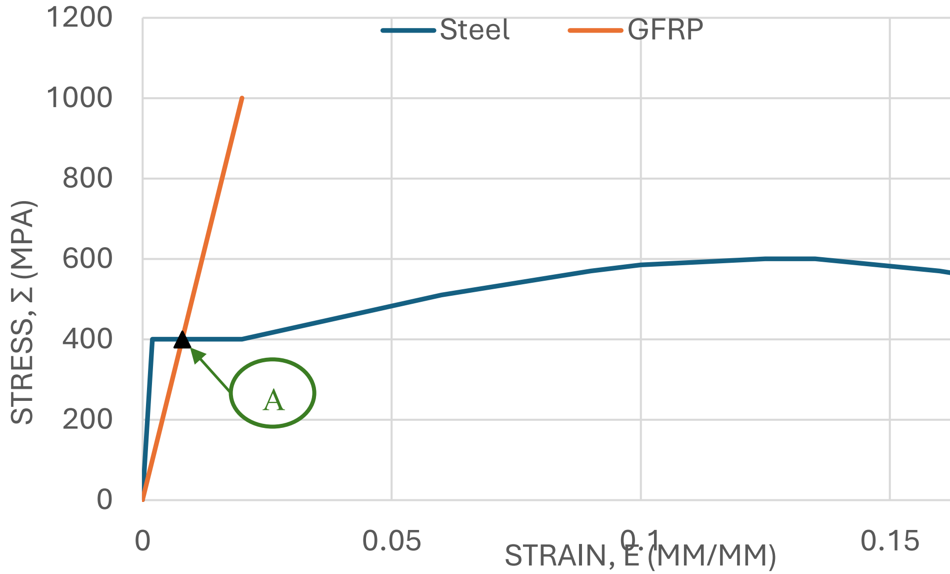
Flexural Strength Enhancement

Up to **30% increase** was observed in the **nominal moment capacity** due to GFRP confinement

Shape	Specimen	Failure Mode		Axial load level P/P_o	V_{max} [kN]	M_{max} [kNm]	M_n [kNm]	$\frac{M_{max}}{M_n}$
		Last Cycle	Max. Disp (mm)					
Square	TA-P28-S-10	11	-22.5	0.28	109	219	206	1.06
Circular	P-28-LS-12-160	12	-28	0.28	98	210	210	1.00

ADVANTAGE OF GFRP SPIRALS

- **Steel is relatively very stiff up to a strain of about 0.002 when it yields**
- **Beyond yield, modulus of elasticity of steel varies from 0 to about 10% of initial stiffness**
- **GFRP behaves elastically linear until rupture at a strain of approximately 0.02**
- **Significant difference in providing an effective confinement beyond Point A**



Internal GFRP Spirals vs. External GFRP Wrap

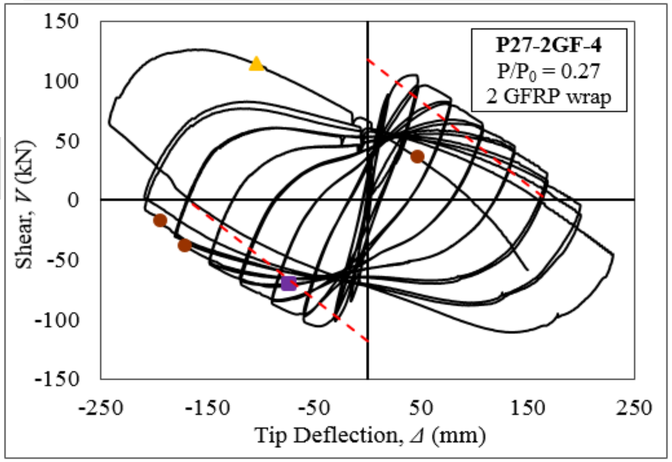
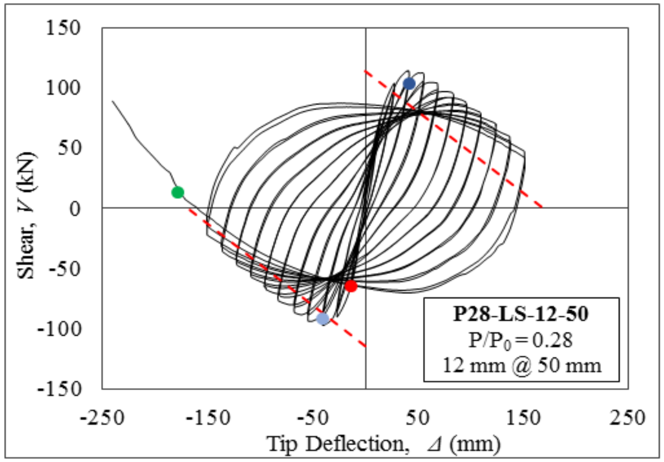
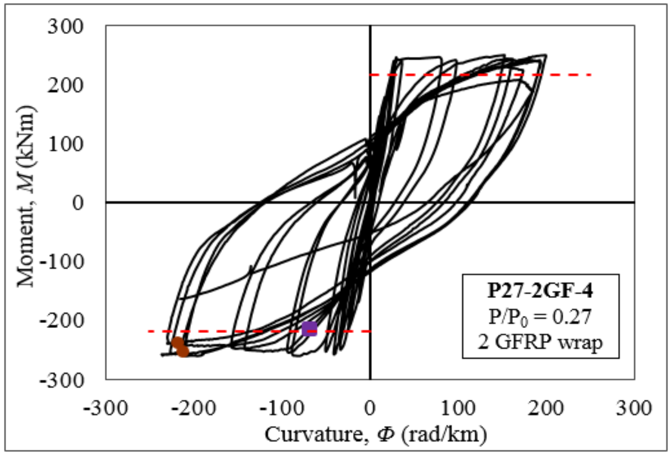
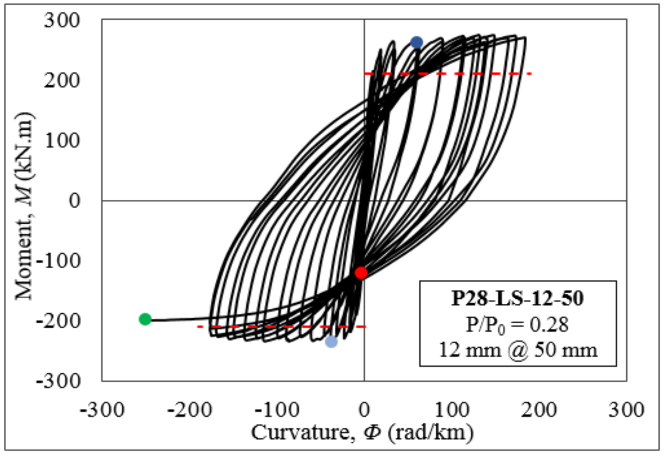
- **Two identical columns with the exception of internal GFRP spirals and external GFRP wrap were tested under similar loading conditions.**

1. **GFRP spiral column = P28-LS-12-50**
   - 12 mm spirals @ 50 mm spacing
2. **GFRP-wrapped column = P27-2GF-4**

   (Liu, 2013)
   - steel spirals = US#3@300 mm &
   - two layers of GFRP wraps.

Failure Modes

Columns after testing: P27-2GF-4 (left) and P28-LS-12-50 (right)

	External GFRP Wrap	GFRP Spirals
Shear vs Tip Deflection		
Moment vs Curvature		

NSERC CRSNG
MIAMI
FDOT

The behaviour of columns well-confined with GFRP spirals was similar to columns externally confined with GFRP wrap.

Specimen name	μ_{Δ}	μ_{Φ}	δ (%)	W_{80}	W	E_{80}	E	V_{max} (kN)	M_{max} (kN.m)
P27-2GF-4	4.9	17.5	4.5	52	330	1272	1272	105	251
P28-LS-12-50	4.7	33.8	4.7	65	239	1768	1768	106	254

NRC·CNRC

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Climate Change Adaptation for Resilient Highway Bridges

Husham Almansour, Ph.D., P.Eng.
National Research Council Canada

Fourth International Workshop on FRP Bars for Concrete Structure

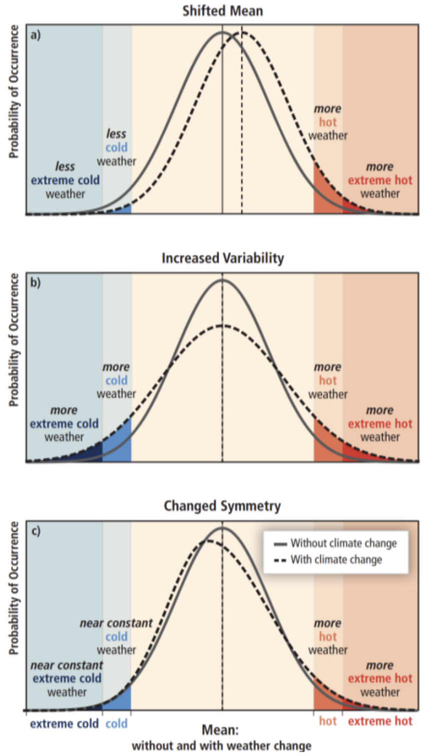
Outline

- Introduction: Climate Change
- Extreme Climate Events
- Climate Resiliency
- Innovative Materials
- FRP and Climate Change Adaptation

Introduction: Climate Change Impact

Climate Change

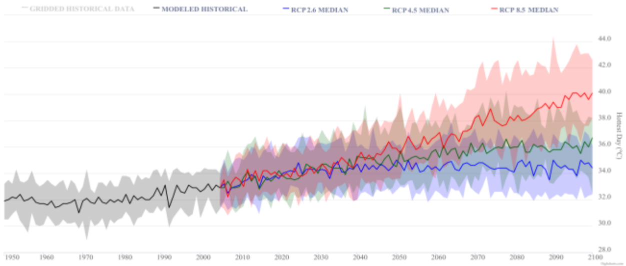
- Bridge performance is highly affected by the weather
- Design stage: assumptions about climate loads are based on historical climate data
- Climate change: While the increase in average temperatures is insignificant, the increases in climate extremes are apparent



Introduction: Climate Change Impact

Climate Change Risks

- Accelerated aging and deterioration;
- Frequency & intensity of extreme events;
- Increasing temperature extremes;
- Freeze-thaw cycles;
- Increased corrosion.



RCP 6.0

Scenario for CHBDC S6:25

Kennedy et al. (2022)

NPS (2020)

Extreme temperatures

Introduction: Climate Change Impact

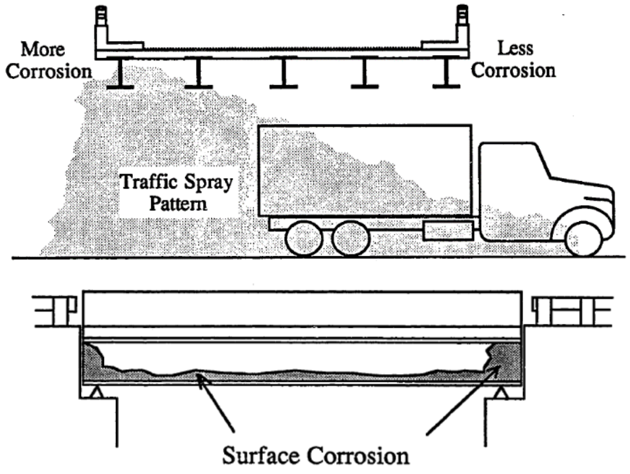
Bridge Infrastructure

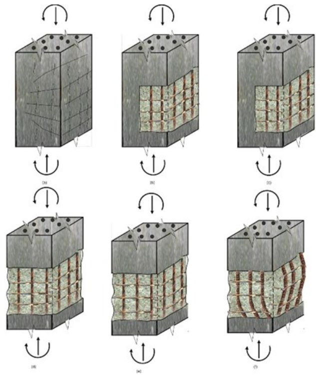
- Aging bridges require maintenance;
- Corrosion damage to steel and concrete bridge elements.

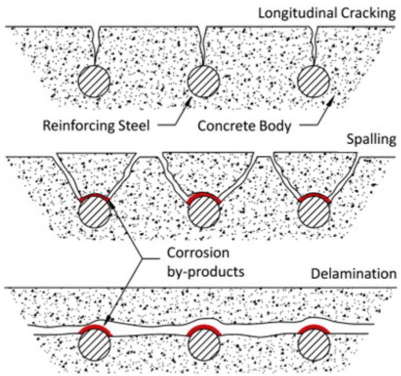
$US 52B / Year

Cost of Corrosion in Canada

AMPP (2021)

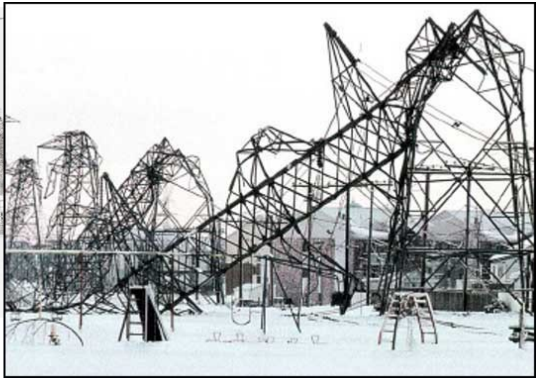






Extreme Climate Events

- Extreme heat and cold waves



RCP 6.0

Scenario for CHBDC S6:25

Kennedy et al. (2022)

NPS (2020)

Extreme temperatures

Extreme Climate Events

- Extreme floods
- Flash Floods

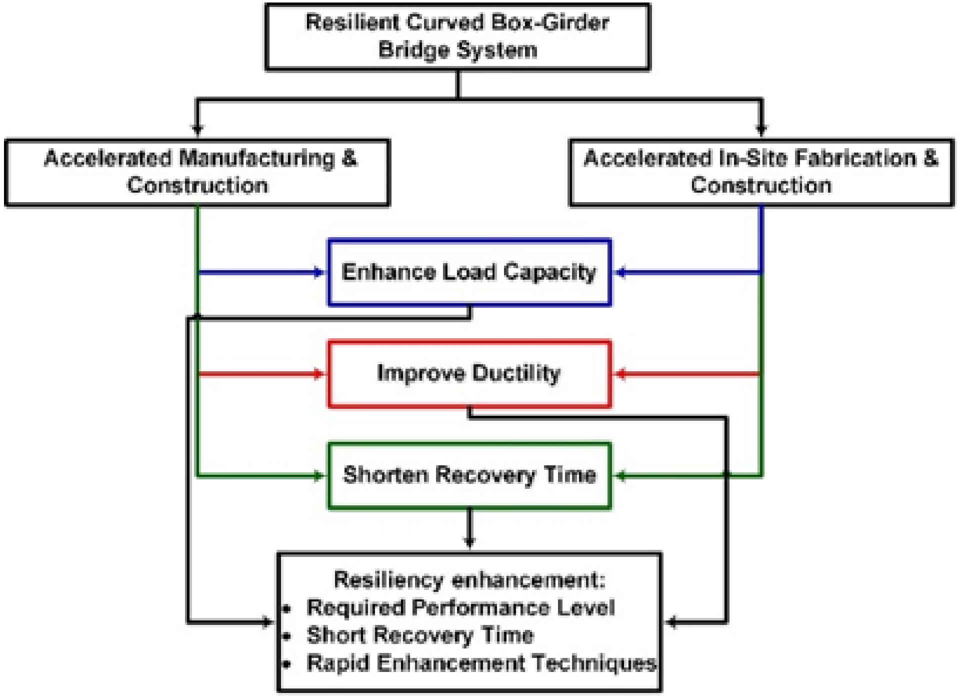
Extreme Climate Events

- WildFire



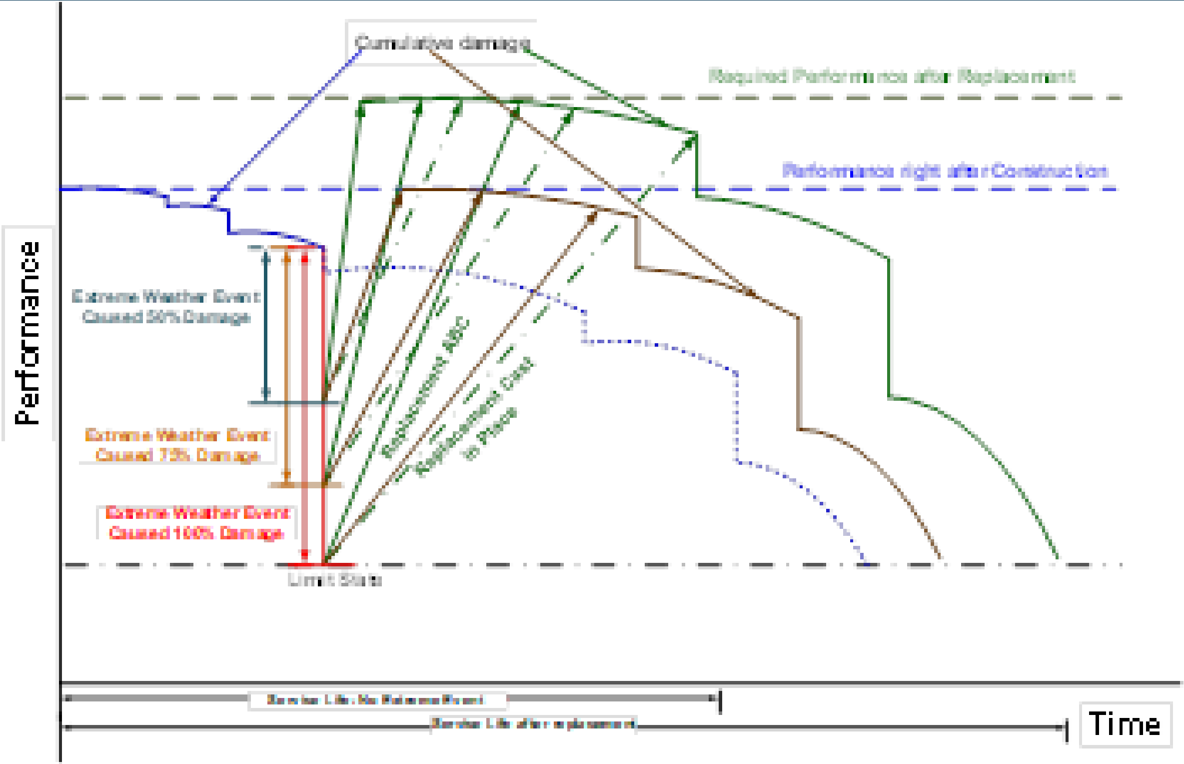
Climate Resiliency

Framework for climate resilient bridges



Climate Resiliency

Schematic representation of resilient curved box-girder bridge systems



Innovative Materials

- FRP Reinforcement
- FRP Strengthening
- UHPFRC
- Stainless Steel
- Impact of Climate loads: more focus on suitable materials
- **Needs for a national database:** improve reliability

FRP for Climate Change Adaptation

Improve Performance in extreme climate events

- New tailored FRP materials
- All FRP Structures
- Hybrid Structural Systems

Performance-Based Design Procedures

- Set Performance criterion
- Standardization of production
- Hybrid Structural Systems

Questions?

Husham Almansour

husham.almansour@nrc-cnrc.gc.ca

FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

NEx: An ACI Center of Excellence for Nonmetallic Building Materials and future collaboration opportunities

Aparna Deshmukh, PhD

Technical Director, NEx

SPONSORED BY:

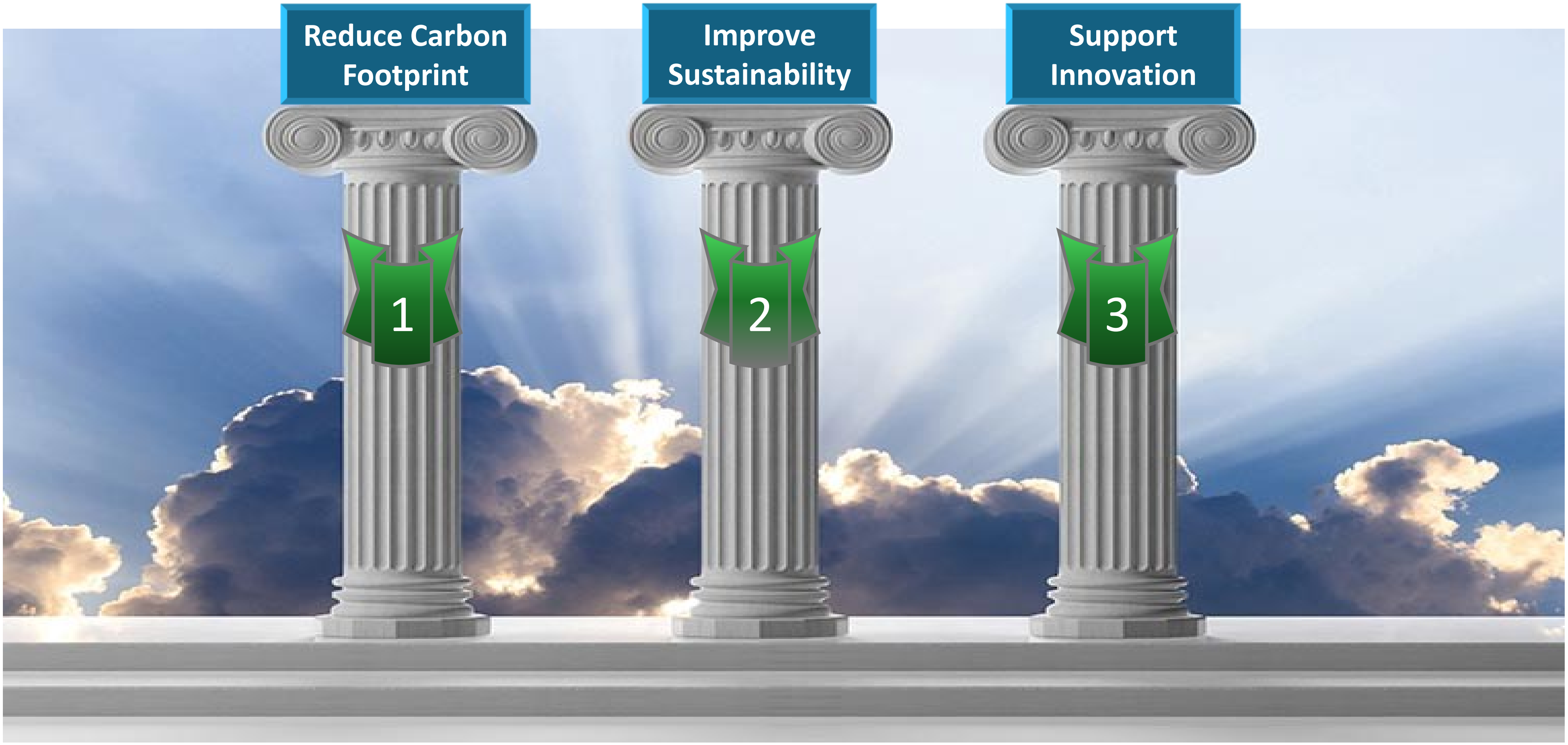
PULTRALL V-ROD FIBERGLASS Innovations ALTAIR MST BAR MAXIMUM STRENGTH GFRP SFTec ACMA American Composites Manufacturers Association FRP Rebar Manufacturers Council

UNIVERSITÉ DE SHERBROOKE NSERC CRSNG UNIVERSITY OF MIAMI Center for Integration of Composites into Infrastructure FDOT

Outline

- Why Nonmetallics in Construction?
- Introduction to NEx
- Our Mission & Scope
- What we do?
- NEx Funded Projects
- Collaboration opportunities
- Concluding Remarks

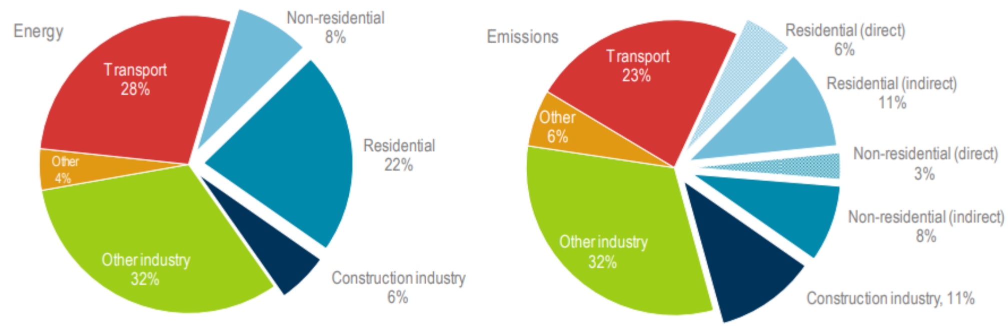
Why Nonmetallics in Construction



Why Nonmetallics in Construction

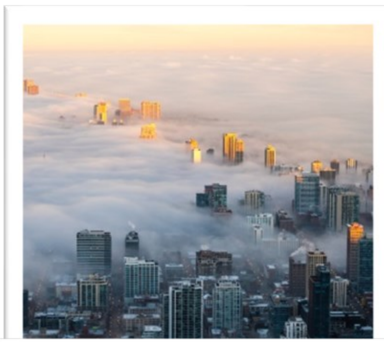
1. Reduce Carbon Footprint

- Construction industry accounts for 38% of CO_2 emissions
- Concrete 2nd largest material used globally and responsible for 6 -10 % of global CO_2 Emission
- Steel accounts for 6.7% of world's total CO_2



Global share of buildings and construction final energy and emissions, 2017, IEA Report

- **Nonmetallic Composite** support reduction of CO_2 emission
- Potential to reduce concrete water curing
- Support recyclability and reusability



NEX An ACI Center of Excellence for Nonmetallic Building Materials

Why Nonmetallics in Construction

2. Improve Sustainability

- Cost of corrosion for highways bridges estimated at **8.3 Billion** annually
- Limited structure life
- Significant increase to **replace or repair** so often due to steel corrosion
- Ineffective material in some environments e.g. coastal and high humidity regions

- Extend service life & reduce maintenance requirement
- Nonmetallic based structure expected to have 5 to 10 times longer service life
- Enhance building efficiency and quality

NSERC CRSNG
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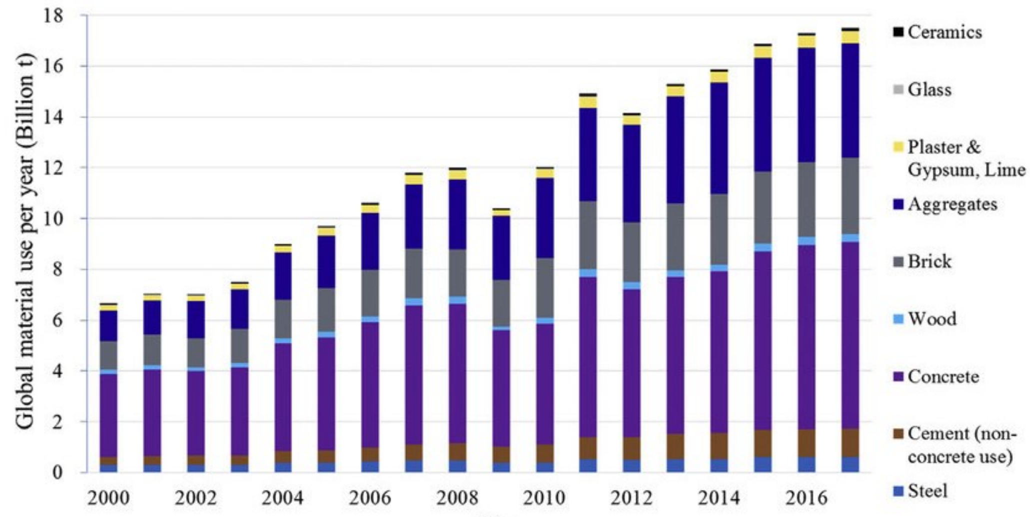
Why Nonmetallics in Construction

3. Support innovation

- Large market and enormous material consumptions size
- Huge opportunities for new technologies and material
- Interest and support from private sector and governments

- Encourage development of new construction material and technologies
- Accelerate deployment of new technologies



Introduction to NEx

- **How NEx came into Existence? …..2021**

Partnership Drives Action

aramco

American Concrete Institute
Always advancing

NEx
An ACI Center of Excellence for Nonmetallic Building Materials

Aramco

- Developing and deploying nonmetallic solutions for more than 20 years
- Offering superior life-cycle cost, efficiency, and environmental advantages
- Use of Nonmetallic advanced polymeric materials in B&C

ACI Organization

- 120 technical committees
- 94 chapters
- 244 student chapters
- 30,000 members spanning over 120 countries

ACI and NEx

aci
American Concrete Institute
Always advancing

Two Independent Organizations

Symbiotic Relationship

NEx
An ACI Center of Excellence for Nonmetallic Building Materials

NEx Mission

Collaborate globally to expand and accelerate the use of nonmetallics in the built environment to drive innovation, research, education, awareness, adoption, and deployment.

Scope

The Center of Excellence will serve as a catalyst for the use of nonmetallics in construction applications, including but not limited to:

- FRP reinforcement
- Polymer concrete
- FRP structural members
- Construction chemicals
- FRP building components and systems
- Soil beneficiation
- Additive manufacturing

NEx Member Companies

Founding and Sustaining Members

Sustaining Members

Gold Members

Bronze Members

NEx Allied Partners

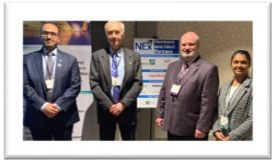
ES ICC EVALUATION SERVICE®

NRMCA

cfa CONCRETE FOUNDATIONS ASSOCIATION

TCA® TILT-UP CONCRETE ASSOCIATION

Center for Integration of Composites into Infrastructure



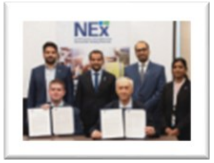
ICFMA INSULATING CONCRETE FORMS MANUFACTURERS ASSOCIATION

사단법인 한국콘크리트학회 Korea Concrete Institute

rilem

THE UNIVERSITY OF ALABAMA®

SCA SLAG CEMENT ASSOCIATION



ATM CIR CENTER FOR Infrastructure Renewal

UNIVERSITY OF NOTRE DAME

UIPE PREPARE FOR THE FUTURE
UGANDA INSTITUTION OF PROFESSIONAL ENGINEERS

IIFC

IRF® GLOBAL

What We Do?

Research and Development	support and facilitate research needed for new technologies in nonmetallics to resolve challenges with effective solutions
Standards and Guidelines	identify and facilitate the development and adoption of design and construction codes and specifications
Professional Development	help the industry in assuring the manufacturing quality of nonmetallics and of the competent installation, testing, and inspection of those products
Technical Advocacy	Facilitate the creation of the knowledge needed for designers, work with material suppliers, manufacturers, designers, owners, government agencies, and standards developers to bring nonmetallics into wider use in construction

How We Do?

NEx is working through collaboration with:

- Academia
- Industrial Partners
- Government Organizations
- Non-Profits
- Member Companies
- Allied Organizations

in the following areas:

- **Standards & Guidelines**
- **Research & Development**
- **Professional Development**
- **Advocacy and Awareness**

NEx Projects - Summary:

Year	Total Projects Funded	NEx Funding
2022	12	>$575,000
2023	20	>$770,000
2024	29	> $1.1 million
Total	**61**	**> 2.45 million**

Full list of projects available at nonmetallic.org/Projects

Standards & Guidelines

Develop design manual for GFRP rebar: "An ACI/NEx Manual: GFRP Reinforced Concrete Design Handbook"

MNL-7(23)

American Concrete Institute
Always advancing

NEx
An ACI Center of Excellence for Nonmetallic Building Materials

GFRP-Reinforced Concrete Design Handbook

This manual for designing GFRP reinforced concrete structures has been made possible in part by the sponsorship of NEx. NEx is a subsidiary of the American Concrete Institute that partners with leading organizations focused on accelerating the use and technolo... products in construction.

The authors would like to thank and recognize NEx and its member companies* for providing insight, guidance, and ...ces for the development of this manual.

*NEx member companies:
Sustaining: Aramco
Gold: ExxonMobil
Bronze: MST Bar, Owens Corning, GatorBar, Dextra, Creative Com... p, Galen Panamerica, IKK Mateenbar, Comp-King, Strongwell, Rochling

Fron... Port Clinton Walkway, Port Clinton, Ohio, ... Inc.)

Back cover photo: GFRP Bars (photo courtesy Galen-Panamerica/...

Owens Corning Infrastructure Solutions
One Owens Corning Parkway, Toledo, OH 43659 www.owenscorning.com/pinkbar+, +1 855-OC-Rebar, email: https://www.owenscorning.com/en-us/contact-us

Design Values – PINKBAR®+ Fiberglas™ Rebar

Property	Test Method	Bar Size No. 2 [M6]	No. 3 [M10]	No. 4 [M13]	No. 5 [M16]	No. 6 [M19]	No. 7 [M22]	No. [M2
Cross Sectional Area, in.² [mm²]	ASTM D7205 11.2.5.1		0.11 [71]	0.20 [129]	0.31 [199]	0.44 [284]	0.60 [387]	0.7 [51
Guaranteed Ultimate Tensile Force, kip [kN]	ASTM D7205		16.0 [71.2]	24.7 [110]	41.8 [186]	57.3 [255]	78.3 [348]	10 [45
Mean Tensile Modulus of Elasticity, ksi [GPa]	ASTM D7205		6,800 [47]	6,800 [47]	8,700 [60]	8,700 [60]	8,700 [60]	8,7 [6
Guaranteed Ultimate Tensile Force of Bent Portion of Bar, kip [kN]	ASTM D7914		N/A	23.2 [103]	36.0 [160]	44.7 [199]	60.9 [271]	80. [35
Guaranteed Transverse Shear Strength, ksi [MPa]	ASTM D7617		22 [152]	22 [152]	22 [152]	22 [152]	22 [152]	2 [15
Guaranteed Bond Strength, psi [MPa]	ASTM D7913		1400 [10.0]	1400 [10.0]	1400 [10.0]	1400 [10.0]	1100 [8.0]	11 [8.

Guaranteed and mean values are as defined in ASTM D7957.

Property	Test Method	Value
Glass Transition Temperature	ASTM E1356	212°F [100°C]
Alkali Resistance	ASTM D7705 Procedure A	>85%
Degree of Cure	ASTM E2160	>75
Moisture Absorption to Saturation	ASTM D570, subsection 7.4	<0.75%

The authors would like to thank and recognize NEx and its member companies* for providing insight, guidance, and resources for the development of this manual.

*NEx member companies:
Sustaining: Aramco
Gold: ExxonMobil
Bronze: MST Bar, Owens Corning, GatorBar, Dextra, Creative Composites Group, Galen Panamerica, IKK Mateenbar, Comp-King, Strongwell, Rochling

Front cover photo: Port Clinton Walkway, ... MST ... Inc.)

Back cover photo: GFRP Bars (pho...

Thank you NEx Members!

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Standards & Guidelines

Develop recommended practice for pre-engineered projects with FRP bars: "Recommended Practice Guidelines for FRP Bars in Pre-Engineered Projects"

MNL-6(23)

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Recommended Practice Guidelines for FRP Bars in Pre-Engineered Projects

This educational document for using FRP reinforcement has been made possible in part by the sponsorship of NEx. NEx is a subsidiary of the American Concrete Institute that partners with leading organizations focused on accelerating the use and technology of nonmetallic materials and products in construction.

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Owens Corning Infrastructure Solutions
One Owens Corning Parkway, Toledo, OH 43659 www.owenscorning.com/pinkbar+, +1 855-OC-Rebar, email: https://www.owenscorning.com/en-us/contact-us

Design Values – PINKBAR®+ Fiberglas™ Rebar

Property	Test Method	Bar Size						
		No. 2 [M6]	No. 3 [M10]	No. 4 [M13]	No. 5 [M16]	No. 6 [M19]	No. 7 [M22]	No. [M2
Cross Sectional Area, in.^{2} [mm^2]	ASTM D7205 11.2.5.1		0.11 [71]	0.20 [129]	0.31 [199]	0.44 [284]	0.60 [387]	0.7 [51
Guaranteed Ultimate Tensile Force, kip [kN]	ASTM D7205		16.0 [71.2]	24.7 [110]	41.8 [186]	57.3 [255]	78.3 [348]	10 [45
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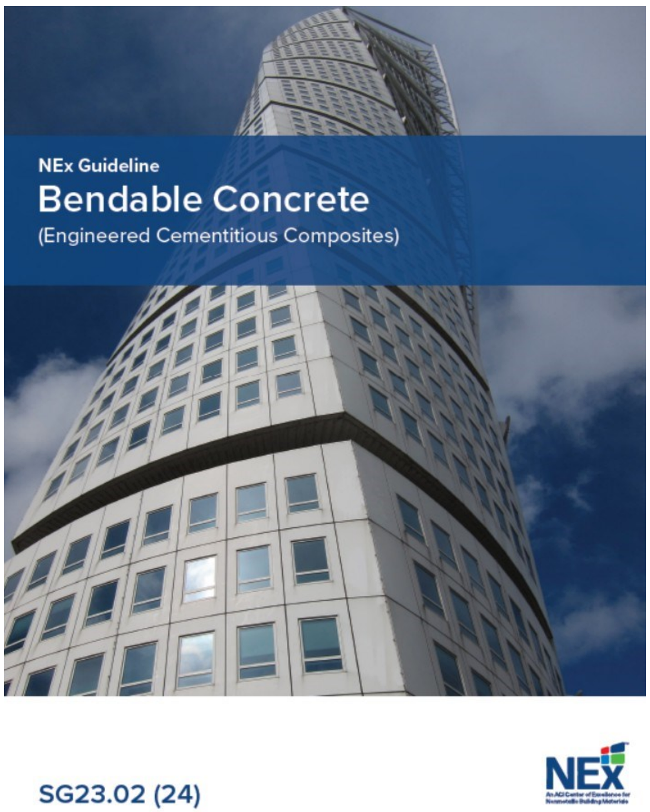
Standards & Guidelines

Guideline: Bendable Concrete (Engineered Cementitious Composites)



Design and Selection Guidelines for FRP Pultruded Structures

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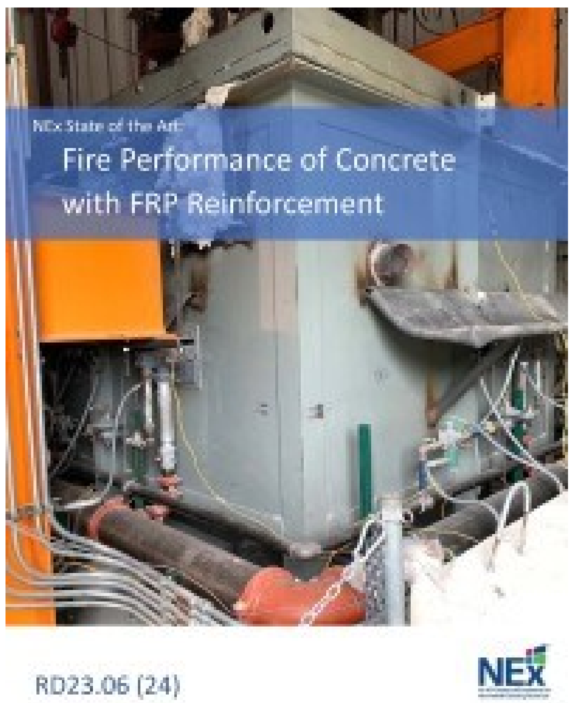
Research and Development

Develop State of the Art: Fire Performance of Concrete with FRP Reinforcement



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Acceptance Criteria for FRP Bar Splices

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ACCEPTANCE CRITERIA FOR MECHANICAL SPLICE SYSTEMS FOR FIBER REINFORCED POLYMER (FRP) BARS

AC552

Approved October 2023

PREFACE

Evaluation reports issued by ICC Evaluation Service, LLC (ICC-ES), are based upon performance features of the International family of codes. (Some reports may also reference older code families such as the BOCA National Codes, the Standard Codes, and the Uniform Codes, or other codes as designated by the ICC-ES president.) Section 104.11 of the *International Building Code®* reads as follows:

> The provisions of this code are not intended to prevent the installation of any materials or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.

This acceptance criteria has been issued to provide interested parties with guidelines for demonstrating compliance with performance features of the codes referenced in the criteria. The criteria was developed through a transparent process involving public hearings of the ICC-ES Evaluation Committee, and/or on-line postings where public comment was solicited.

New acceptance criteria will only have an "approved" date, which is the date the document was approved by the Evaluation Committee. When existing acceptance criteria are revised, the Evaluation Committee will decide whether the revised document should carry only an "approved" date, or an "approved" date combined with a "compliance" date. The compliance date is the date by which relevant evaluation reports must comply with the requirements of the criteria. See the ICC-ES web site for more information on compliance dates.

If this criteria is a revised edition, a solid vertical line (|) in the margin within the criteria indicates a change from the previous edition. A deletion indicator (→) is provided in the margin where any significant wording has been deleted.

ICC-ES may consider alternate criteria for report approval, provided the report applicant submits data demonstrating that the alternate criteria are at least equivalent to the criteria set forth in this document, and otherwise demonstrate compliance with the performance features of the codes. ICC-ES retains the right to refuse to issue or renew any evaluation report, if the applicable product, material, or method of construction is such that either unusual care with its installation or use must be exercised for satisfactory performance, or if malfunctioning is apt to cause injury or unreasonable damage.

Acceptance criteria are developed for use solely by ICC-ES for purposes of issuing ICC-ES evaluation reports.

Acceptance Criteria Published

AC552 available on ICC-ES website: https://icc-es.org/acceptance-criteria/ac552/

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Professional Development

FRP Bar Design Certificate Program

Designing Concrete Structures Reinforced with GFRP Bars Using the ACI CODE-440.11-22 Certificate Program

ACI Certificate Programs are designed to provide concrete professionals with in-depth knowledge about particular topics in concrete materials, design, and/or construction by following a defined course of study. Once a course of study for a certificate program has been completed, the participant can request to receive a certificate through ACI University.

The primary purpose of the **Designing Concrete Structures Reinforced with GFRP Bars Using the ACI CODE-440.11-22** certificate program is to educate attendees on ACI CODE 440.11-22 and the application of Glass Fiber-Reinforced Polymer (GFRP) reinforced concrete in the construction industry. ACI 440.11-22 "Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars" is a newly developed design code for new concrete structures reinforced with GFRP bars. It is based on ACI 318 code requirements for steel-reinforced concrete but modifies ACI 318 code requirements for the specific use of GFRP reinforcing bars as an alternative to steel reinforcing bars. It addresses construction and material requirements, structural systems, members, and strength and serviceability requirements. Among the subjects covered are design and construction for strength, serviceability, and durability; load combinations, load factors, and strength reduction factors; structural analysis methods; deflection limits; development and splicing of reinforcement; construction document information; and field inspection and testing.

This program will provide a basic overview of FRP reinforcing bar properties, where they are commonly used, and how other specifications and standards from ACI and ASTM provide the basic foundation on which the new code has been developed. A discussion on where the code puts limits on the types of structures that can be reinforced with GFRP and where the code does and does not apply will be presented. The program will then provide detailed discussion on the engineering of GFRP reinforced concrete for various member types (including beams, columns, slabs, walls, and connections); determining flexural, shear, torsional, and axial strength of members reinforced with GFRP; and detailing GFRP bars for serviceability and durability. In all presentations, specific differences in designing with GFRP reinforcement versus steel reinforcement will be highlighted.

This is a great opportunity for engineers, owners, contractors, consultants, students, and manufacturers to get familiar with the technical and engineering aspects of the ACI 440.11 code and learn more about designing and detailing with GFRP reinforcement.

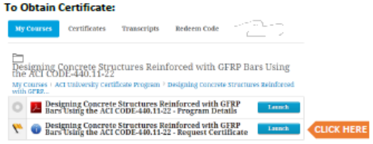
A program certificate is awarded after completion of the following required courses (6 PDHs):

- ACI CODE-440.11-22: Overview of GFRP Reinforced Concrete (1 PDH)
- ACI CODE-440.11-22: Serviceability and Flexural Design of GFRP Reinforced Concrete (1.5 PDH)
- ACI CODE-440.11-22: Shear and Torsion Design of GFRP Reinforced Concrete (1.5 PDH)
- ACI CODE-440.11-22: Requirements for GFRP Reinforced Concrete Columns, Fire, and Structural Analysis (1 PDH)
- ACI SPEC-440.5-22: Handling and Placing of GFRP Reinforcement (1 PDH)

Program Guidelines:

- Completion of each course requires an 80% passing score on the course exam.
- All course completion certificates must be earned within a maximum period of 2 years.
- Courses that are updated will still count toward the certificate program as long as they have been completed within the 2-year timeframe.
- Any course completed outside the 2-year timeframe must be retaken using the current version of the course.
- Courses must be completed by one individual using the same username.
- Access to ACI documents not included with the course may be required.
- Once the course of study has been completed, a program certificate can be requested through ACI University (My Courses tab).
- ACI reserves the right to update courses and change certificate program requirements at any time.
- ACI reserves the right to revoke a certificate or discontinue a certificate program for any reason.

To Obtain Certificate:

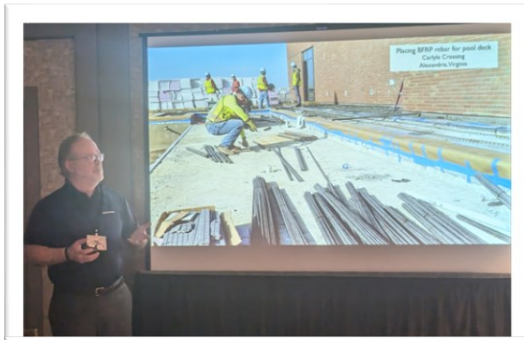


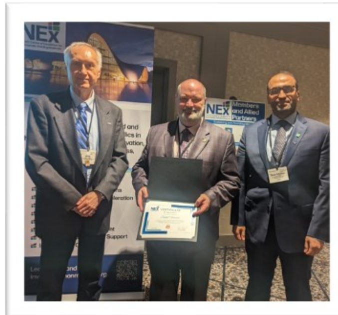
Project Complete

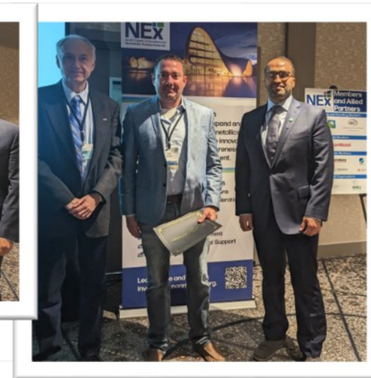
Website: Certificate Program (concrete.org)

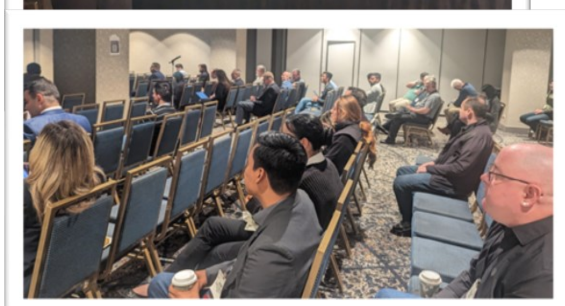
Technical Advocacy

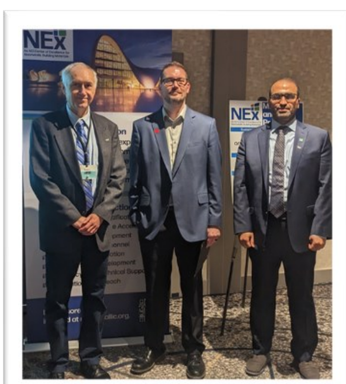
NEx Workshops at ACI Convention

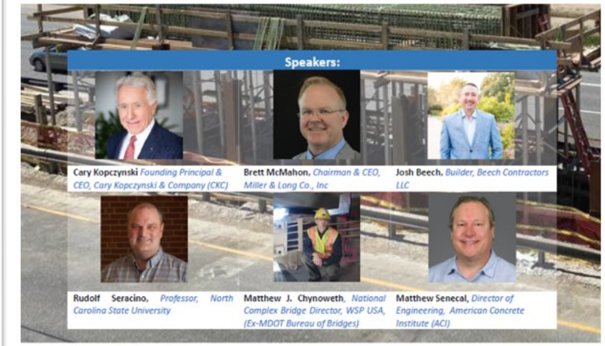












NEx Workshop on FRP Reinforced Concrete: User Experiences and Success Stories

Wednesday, April 5, 2023 • ACI Concrete Convention • San Francisco, CA

Sponsored by

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aci American Concrete Institute *Always advancing*

Overview

Speakers:

Cary Kopczynski *Founding Principal & CEO, Cary Kopczynski & Company (CKC)*

Brett McMahon, *Chairman & CEO, Miller & Long Co., Inc*

Josh Beech, *Builder, Beech Contractors LLC*

Rudolf Seracino, *Professor, North Carolina State University*

Matthew J. Chynoweth, *National Complex Bridge Director, WSP USA, (Ex-MDOT Bureau of Bridges)*

Matthew Senecal, *Director of Engineering, American Concrete Institute (ACI)*

Who Should Attend?

This is a great opportunity for engineers, owners, contractors, consultants, students, and manufacturers to get familiar with the experiences from day-to-day projects using FRP reinforcement. Come and learn real stories how FRP rebar is used in transportation infrastructure, commercial buildings, residential construction, and marine applications.

NEx Members & Partners:

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Farmington Hills, MI
48331-3439 USA
+1.248.848.3170

www.nonmetallic.org

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Recordings are available at www.nonmetallic.org/resources

Technical Advocacy

Upcoming workshop at ACI Convention:

"Building the Future with Nonmetallic Materials and Low-Carbon Concrete for Eco-Friendly Construction"- NEx and NEU joint workshop

Tuesday, November 5, 2024

NEx-Workshop Part 1

9:00 AM - 12:00 PM

NEx-Workshop Part 2

12:00 PM - 5:00 PM

Building the Future with Nonmetallic Materials and Low-Carbon Concrete for Eco-Friendly Construction

This full-day workshop is jointly organized by NEx and NEU. This comprehensive workshop will delve into the forefront of sustainable construction practices, emphasizing the pivotal role of nonmetallic materials and low-carbon concrete in shaping a greener future. The workshop is designed to align with the missions and visions of both centers of excellence. Participants will explore innovative materials and techniques that reduce the environmental footprint of construction projects while enhancing durability and performance. Topics will include the development and application of nonmetallic materials, advancements in low-carbon concrete technology, and their contributions to eco-friendly construction practices.

Register for ACI Fall Convention in Philadelphia to attend this workshop

Collaboration opportunities

Are you?

Manufacturer
Contractor
Academician
Owner
Building Official

- **Become a NEx Member** (Company membership only- visit https://www.nonmetallic.org/become-a-member-or-partner to get more information)
- **Participate in monthly Webinars and Workshops** (recordings available for free on NEx Youtube Channel)
- **Submit Ideas and Proposals for funding** (Request for proposals will be open in mid-August for 2025 funding)
- **Get free access to NEx documents/ publications** (www.nonmetallic.org/resources)

We are just getting started. Join us!

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www.nonmetallic.org

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