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SIZE EFFECT IN GFRP REINFORCED CONTINUOUS CONCRETE DEEP BEAMS

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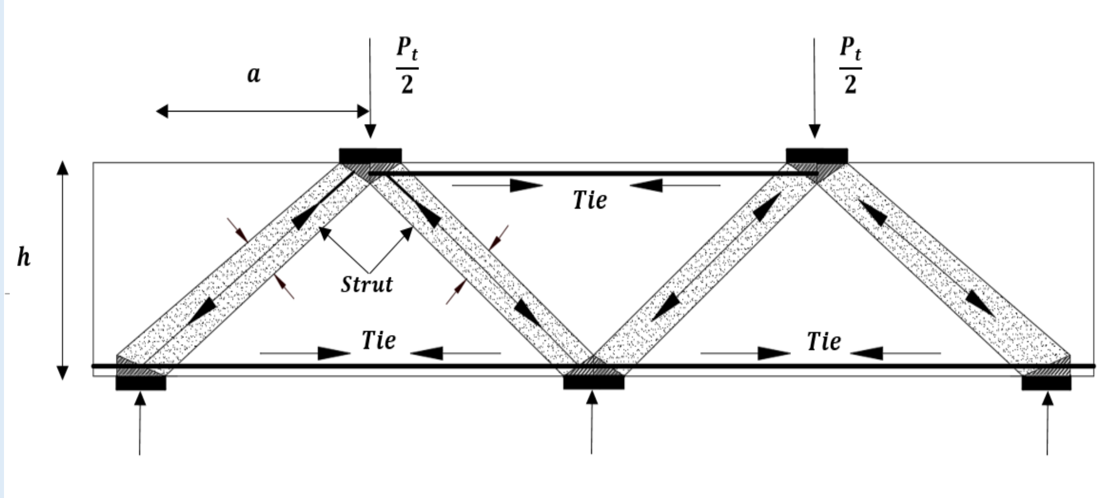
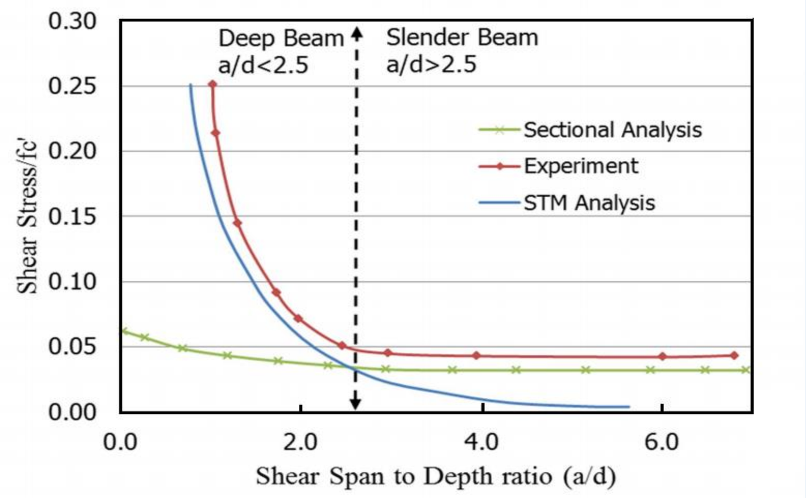
CONTENTS

PROPERTIES OF DEEP BEAMS

- Deep beams are those structural elements designed in a geometrical way so that a considerable part of the applied load is transferred to the supports by the diagonal compression strut
- The strain distribution along the depth of deep beams is non-linear
- The main load transfer element in deep beams is the concrete strut formed between the loading and supporting points.
- The behaviour of concrete deep beams is controlled by shear rather than flexure which results in a brittle behaviour and sudden failure

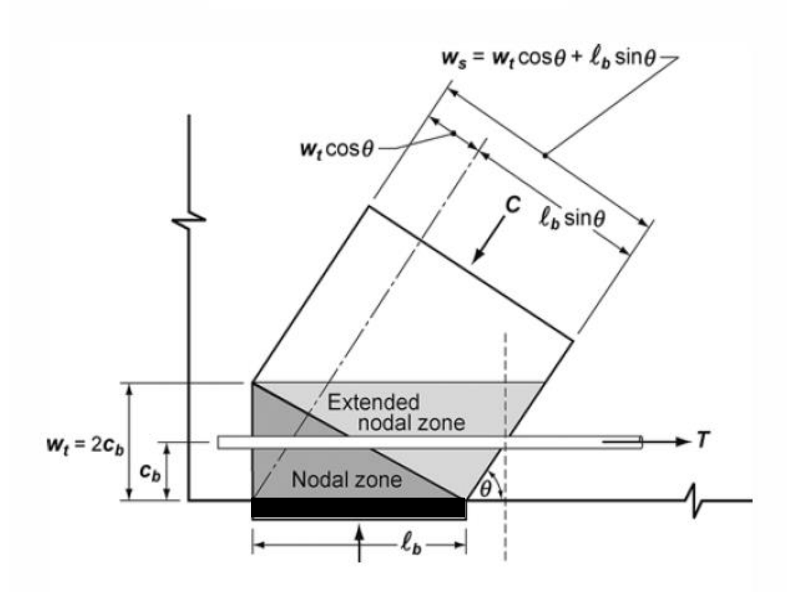


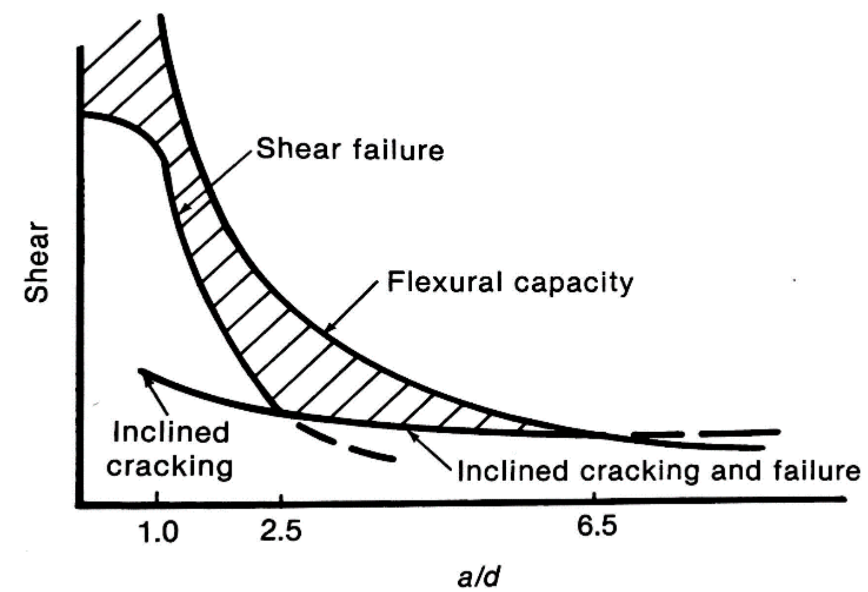


PROPERTIES OF DEEP BEAMS

- Unlike slender members, deep beams have a considerable reserve capacity after the formation of the diagonal crack.

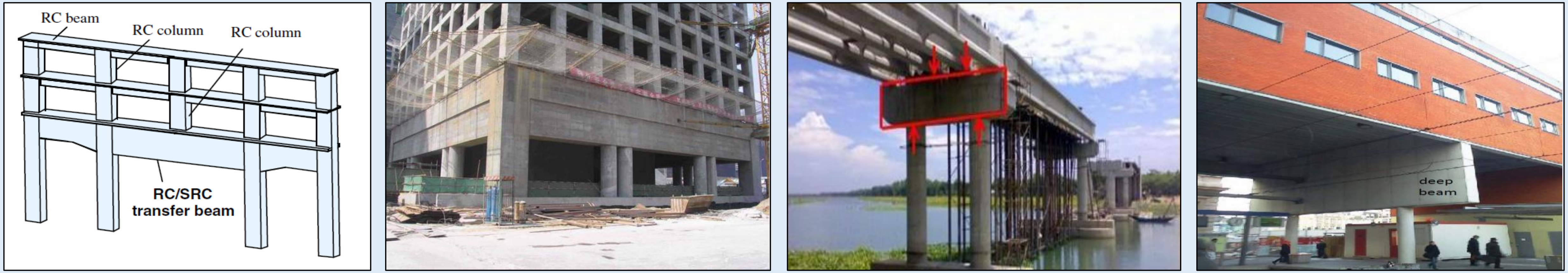
- Unlike slender beams, the shear capacity of deep members is highly dependent on the boundary conditions of the strut; namely the size of the load and support plates.





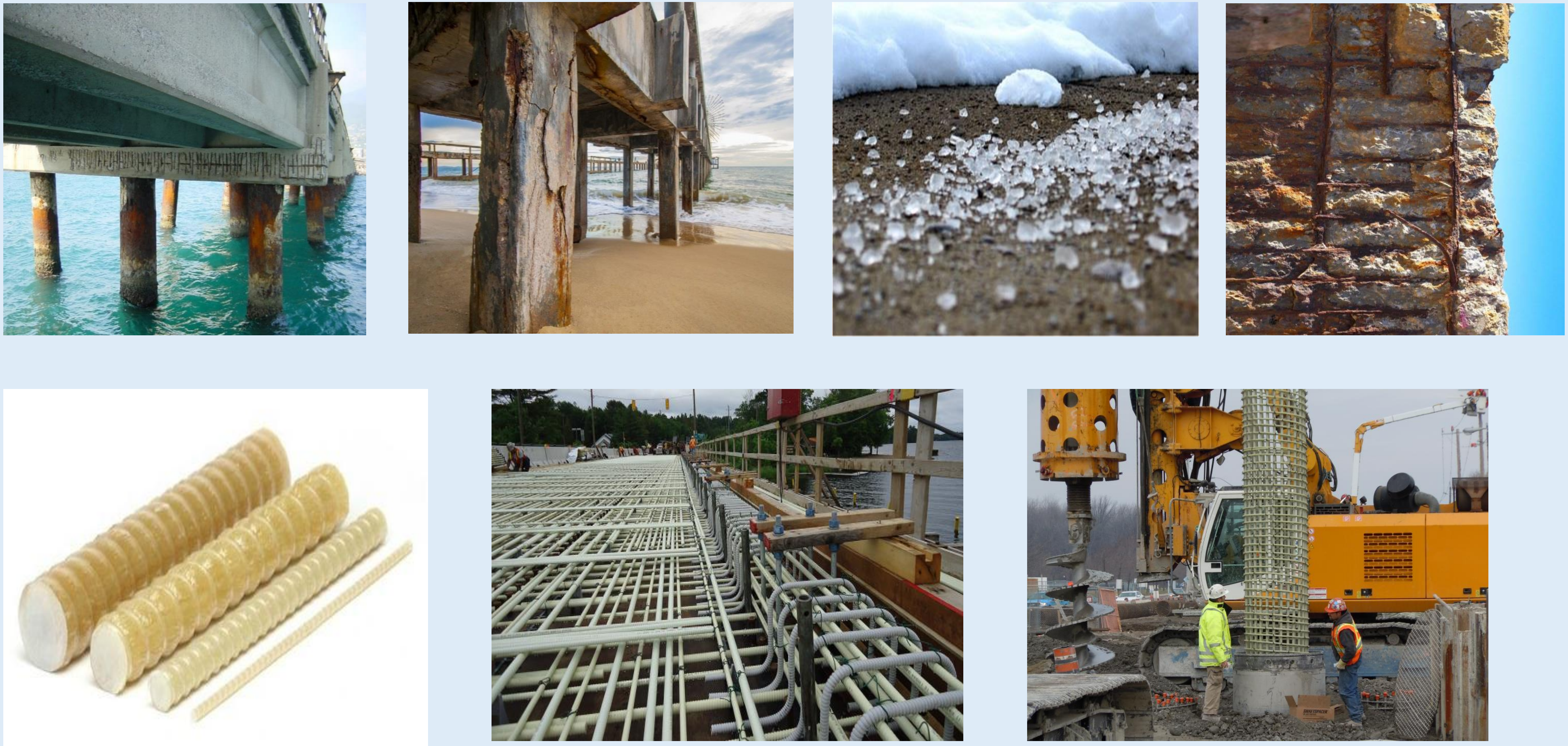
APPLICATIONS OF CONCRETE DEEP BEAMS

- Transfer girder (bridges and multi-storey buildings)
- Offshore structures, pile caps
- Shear walls
- Bunker walls



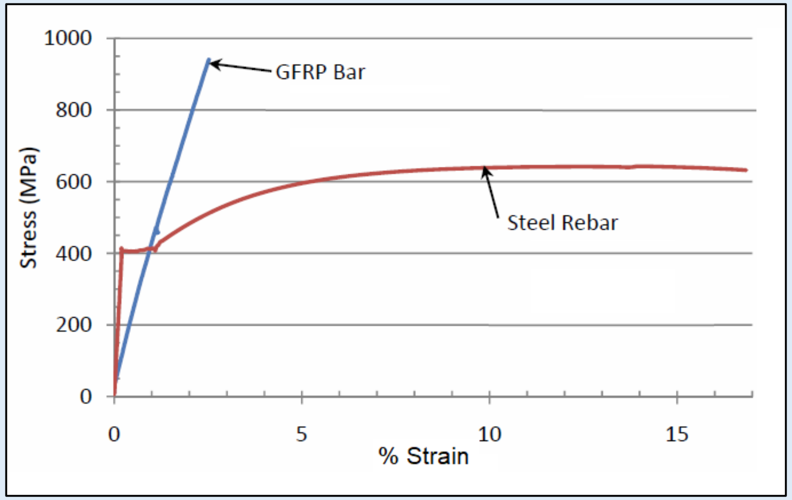
Deep beams as transfer girder

WHY FRP BARS (ADVANTAGES)?



DISADVANTAGES OF FRP BARS

- Brittle behaviour (linear elastic behaviour up to rupture)
- Low elastic modulus
- Low bond
- Anisotropic material
- Low dowel action



RESEARCH SIGNIFICANCE

- Extensive studies were conducted for size effect in steel reinforced concrete deep beams; however, research available to investigate the size effect in FRP reinforced concrete deep beams are very limited
- The size effect is a more fundamental issue in FRP RC beams than the same elements reinforced with steel bars as a result of the insufficient contribution of shear transfer mechanisms.
- The current research focuses on continuous deep beams due to the fact that continuous deep beams are more common in practice and behave differently from simply supported ones due to the coexistence of the high moment and high shear regions within the interior concrete strut that transfers a considerable part of the applied load to the supports.
- The only code provision that addressed the design of FRP RC deep members, namely CSA-S806-12, ignored the influences of web reinforcement and the section size on the shear strength. Therefore, this study focused on those two parameters.
- The results of this study can be applied to validate and develop the design guidelines available and will enable design engineers to achieve a better understanding for the behaviour of continuous concrete deep beams reinforced with FRP bars.

SIZE EFFECT

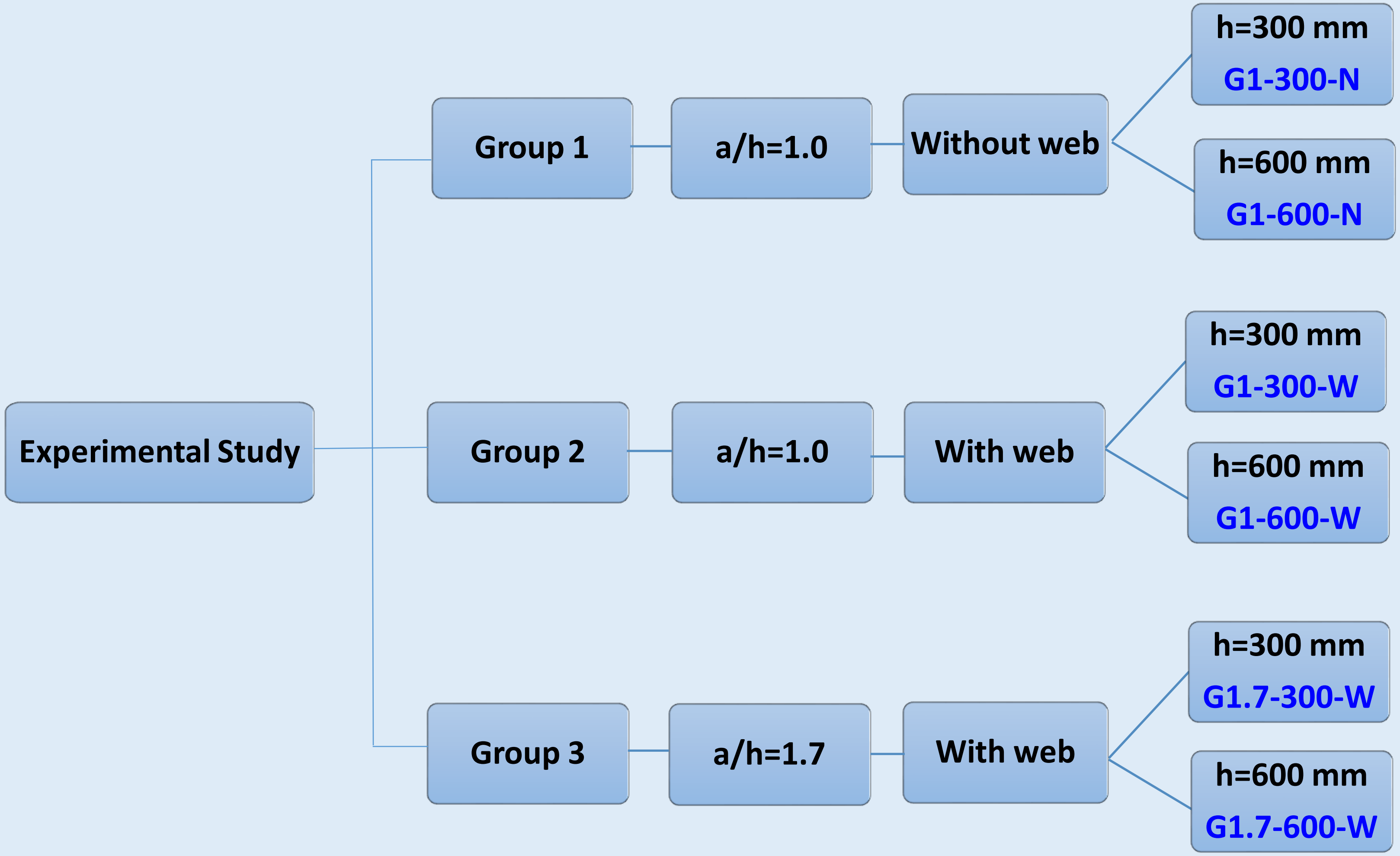
Size effect can be defined as a reduction in shear strength due to an increase in section depth.

The specimen size in the laboratory is usually smaller than its actual size in the real life. Therefore, studying the behavior of structural members while increasing in member size is important.

Size effect can be measured by normalising the shear strength with the member size (V/bh).

Concrete compressive strength can be used to normalise the shear strength if the strengths of concrete are varied.

EXPERIMENTAL PROGRAMME

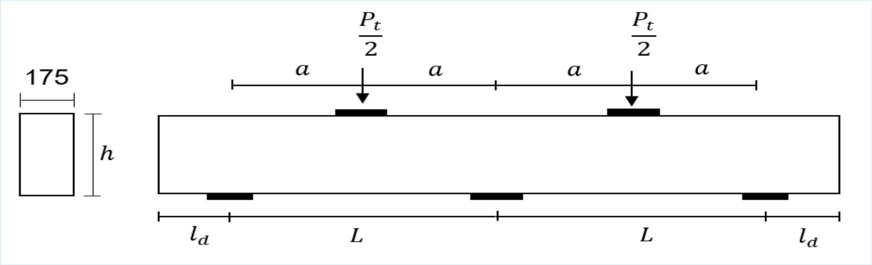


Experimental Study

Group 1 — a/h=1.0 — Without web
- h=300 mm G1-300-N
- h=600 mm G1-600-N

Group 2 — a/h=1.0 — With web
- h=300 mm G1-300-W
- h=600 mm G1-600-W

Group 3 — a/h=1.7 — With web
- h=300 mm G1.7-300-W
- h=600 mm G1.7-600-W



Constant values

b=175 mm

Longitudinal reinforcement=1.2%

Development length=400 mm

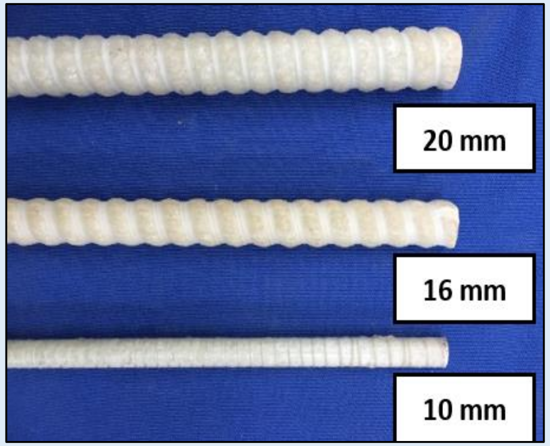
Compressive strength≈55 MPa

Web reinforcement

ρ_v and ρ_h=0.4%

EXPERIMENTAL PROGRAMME

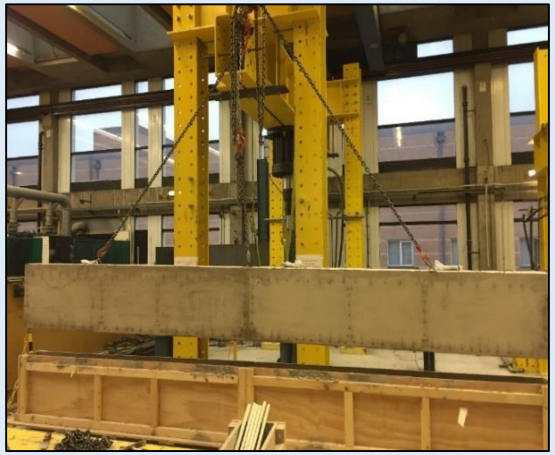
- **Specimens' preparation**



GFRP bars

Formwork

Ready mix concrete

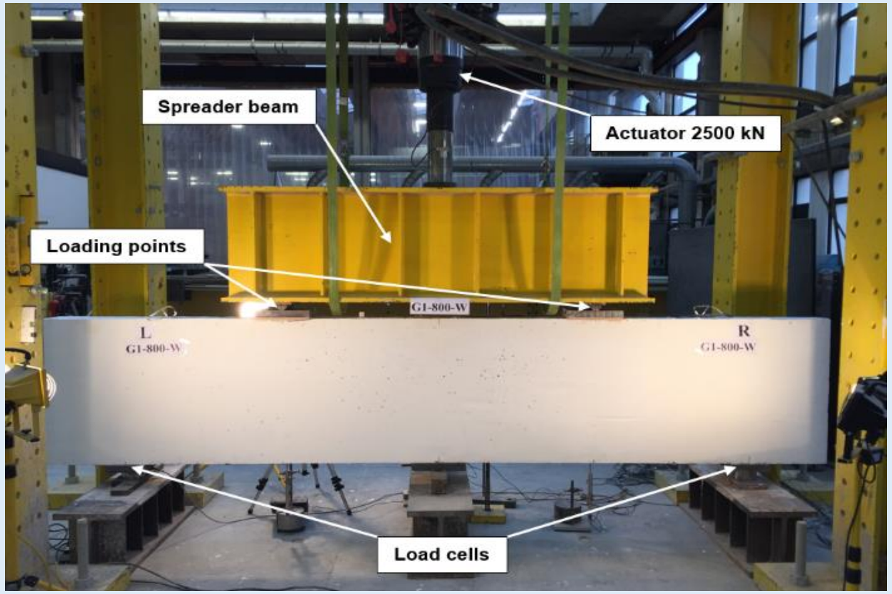


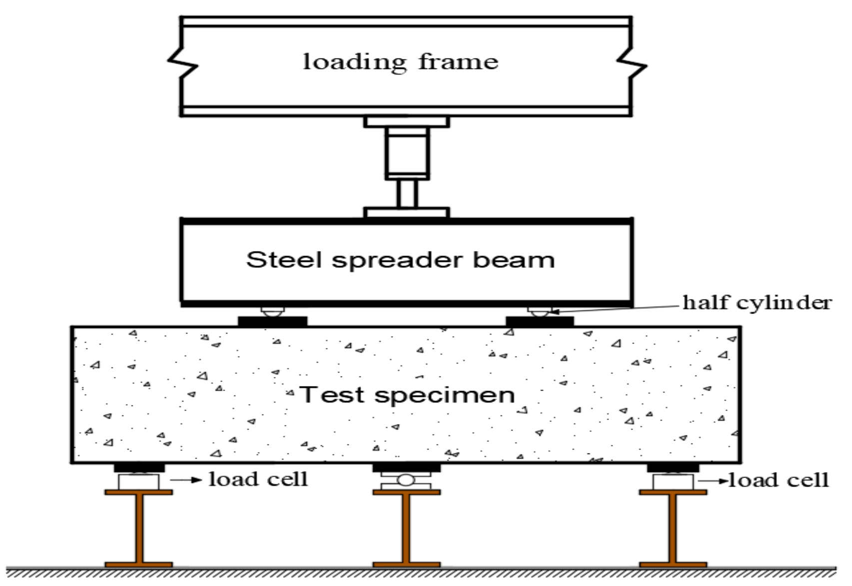
Demoulding

Curing

EXPERIMENTAL PROGRAMME

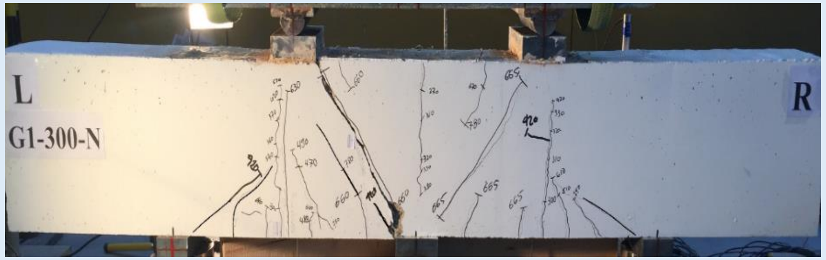
➢ Test Setup



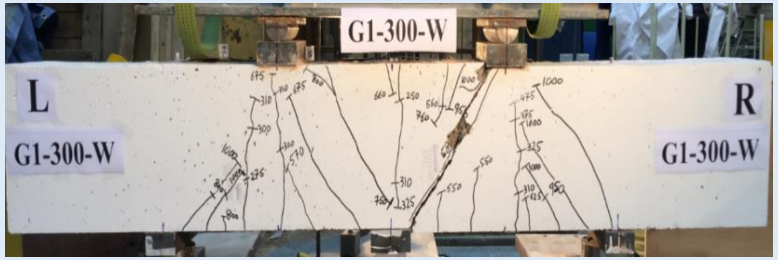


EXPERIMENTAL RESULTS

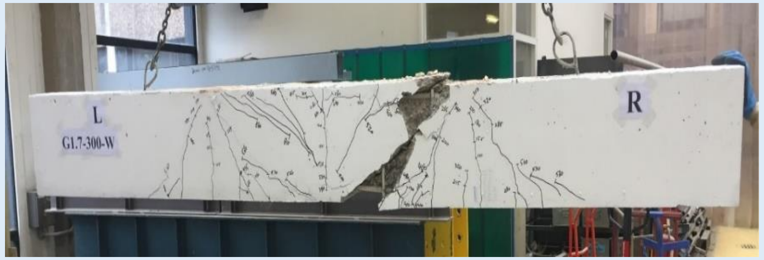
- **Failure mode**



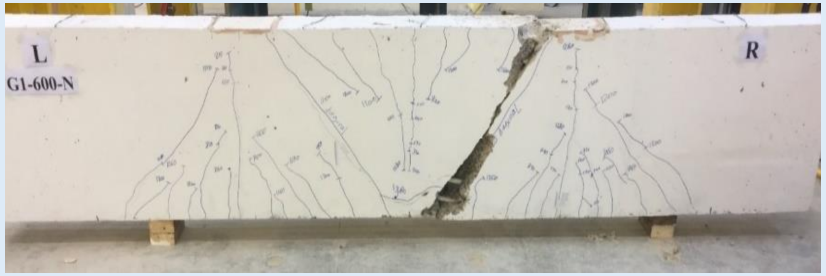
G1-300-N



G1-300-W



G1.7-300-W



G1-600-N

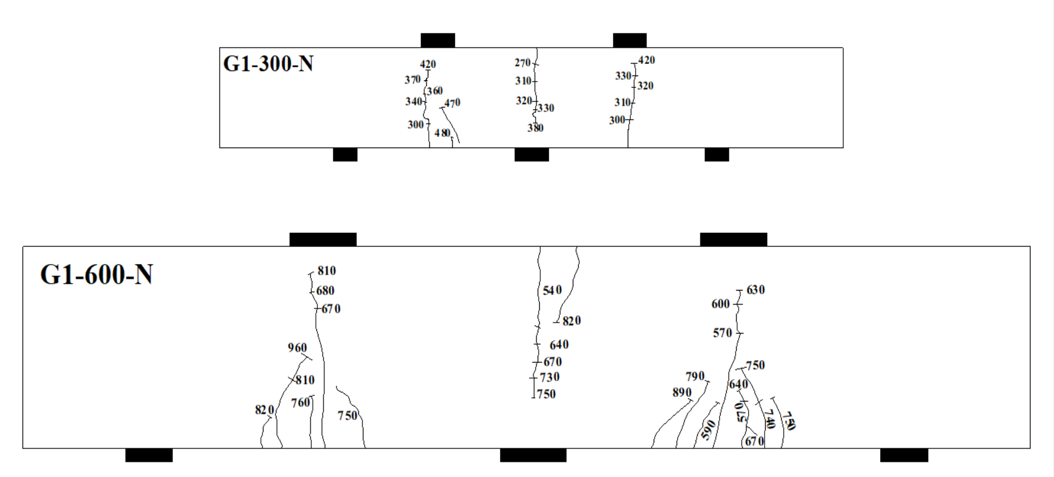
G1-600-W

G1.7-600-W

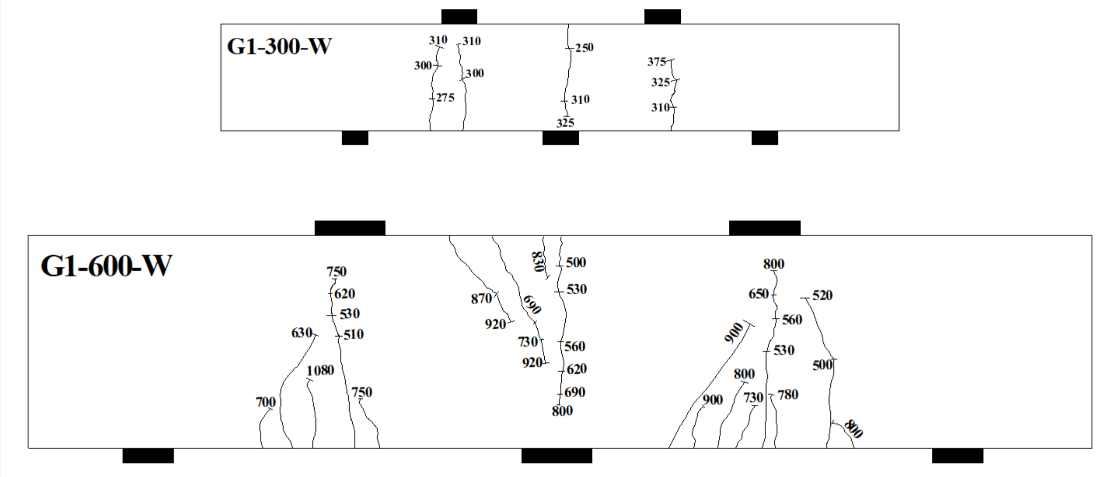
EXPERIMENTAL RESULTS

➢ Crack propagation

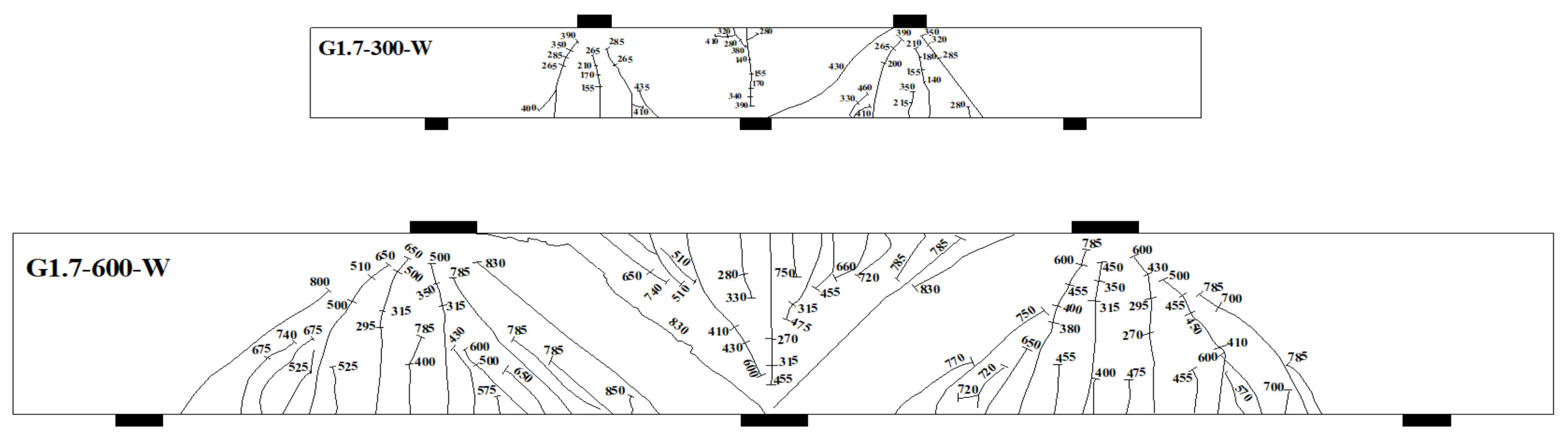
$P/f'_c\,bh$ = 0.16



Group 1



Group 2

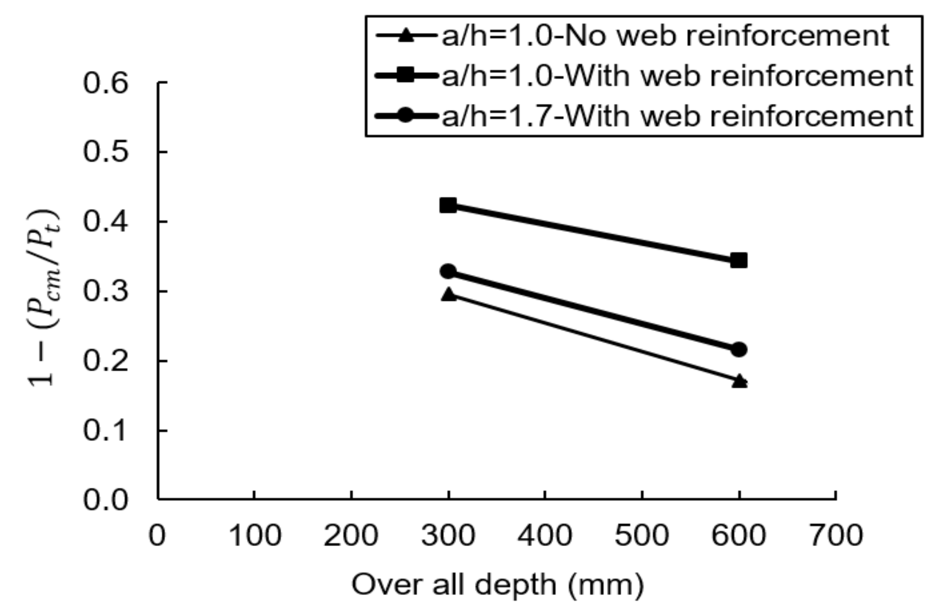


Group 3

Crack patterns at the same normalised load of $P/f'_c\,bh$ = 0.16

EXPERIMENTAL RESULTS

- **Reserve capacity =** $1 - \frac{P_c}{P_t}$



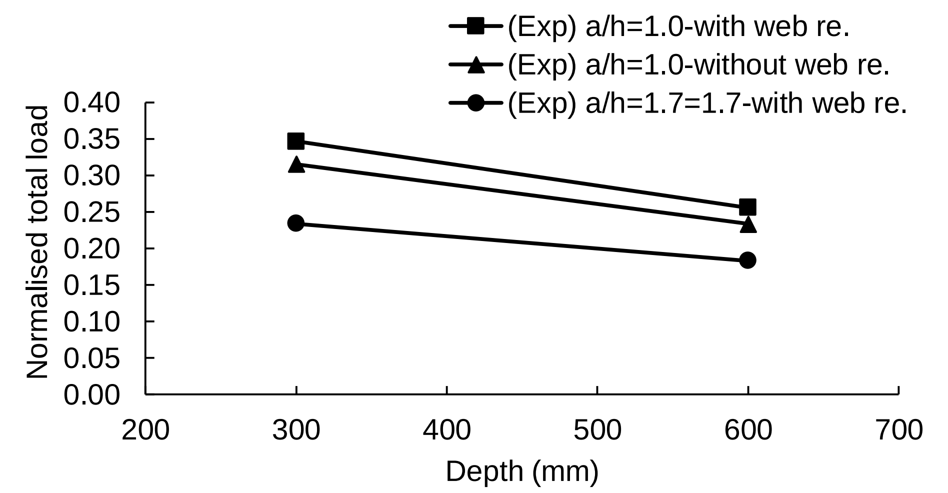
Reserve capacity after the formation of the main diagonal crack

First flexural and main diagonal cracking loads, and the failure load

Group	Beam	First flexural cracking load, kN		Main diagonal cracking load kN (% Reserve capacity)	Failure load, kN
		Mid-span (% Reserve capacity)	Over middle support (% Reserve capacity)		
Group 1	G1-300-N	300 (68%)	270 (71%)	660 (30%)	937.3
	G1-600-N	570 (59%)	540 (61%)	1150 (17%)	1388
Group 2	G1-300-W	275 (73%)	250 (75%)	580 (42%)	1005.8
	G1-600-W	510 (65%)	500 (65%)	945 (34%)	1439.4
Group 3	G1.7-300-W	140 (78%)	140 (78%)	430 (33%)	639.7
	G1.7-600-W	270 (73%)	270 (73%)	785 (22%)	1000.5

EXPERIMENTAL RESULTS

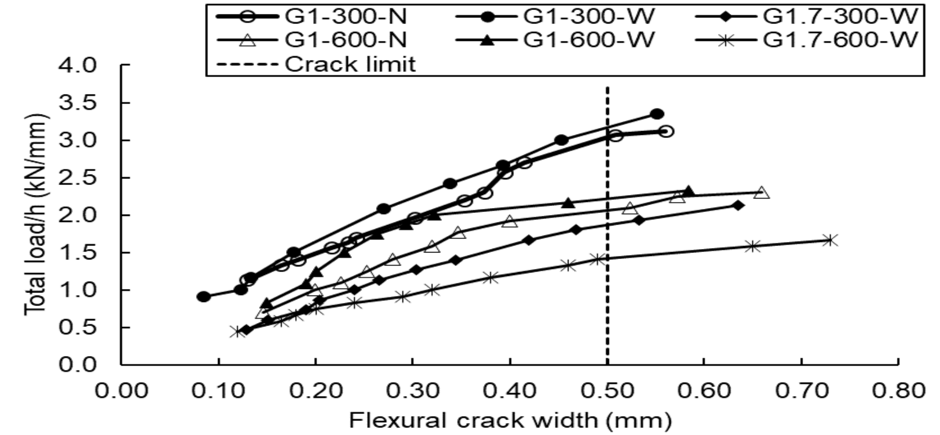
➢ Load capacity



Compressive strengths, failure loads and support reactions of beams tested

Beam	f_c' (MPa)	P_t (kN)	V_E (kN)	V_I (kN)
G1-300-N	56.6	937.3	145.76	322.9
G1-600-N	56.6	1388.0	214.73	479.3
G1-300-W	55.3	1005.8	166.95	335.9
G1-600-W	53.6	1439.4	217.84	501.8
G1.7-300-W	52.1	639.7	105.68	214.2
G1.7-600-W	52.1	1000.5	146.85	353.4

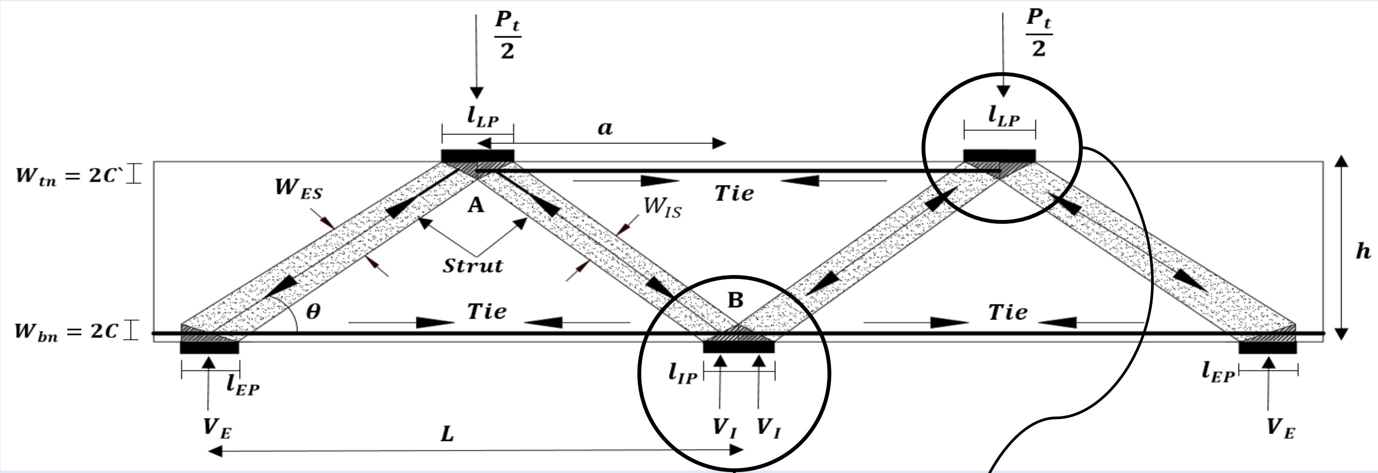
➢ Crack width

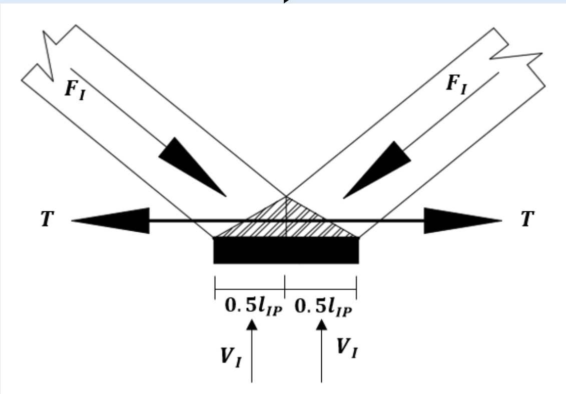


Size effect on the flexural crack widths

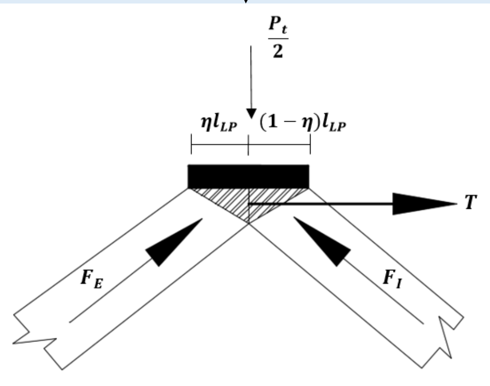
LOAD CAPACITY PREDICTIONS

- **Strut-and-Tie Method (STM)**





Intermediate support



Loading point

Simplified STM

$$F_E = \upsilon\, f_c' b\, W_{ES} \qquad (1)$$

$$V_E = F_E \sin\theta \qquad (2)$$

$$F_I = \upsilon\, f_c'\, b\, W_{IS} \qquad (3)$$

$$V_I = F_I \sin\theta \qquad (4)$$

$$\theta = \tan^{-1}\frac{(h - c - c`)}{a} \qquad (5)$$

$$W_{ES} = \frac{(W_{ES})_t + (W_{ES})_b}{2} \qquad (6)$$

$$W_{IS} = \frac{(W_{IS})_t + (W_{IS})_b}{2} \qquad (7)$$

$$(W_{ES})_t = \eta\, l_{LP} \sin\theta + W_{tn}\cos\theta \qquad (8)$$

$$(W_{ES})_b = l_{EP} \sin\theta + W_{bn}\cos\theta \qquad (9)$$

$$(W_{IS})_t = (1-\eta)\, l_{LP} \sin\theta + W_{tn}\cos\theta \qquad (10)$$

$$(W_{IS})_b = 0.5\, l_{IP} \sin\theta + W_{bn}\cos\theta \qquad (11)$$

$$P_t = min\begin{cases}\dfrac{V_E}{0.15}\\[2ex] \dfrac{V_I}{0.35}\end{cases} \qquad (12)$$

LOAD CAPACITY PREDICTIONS

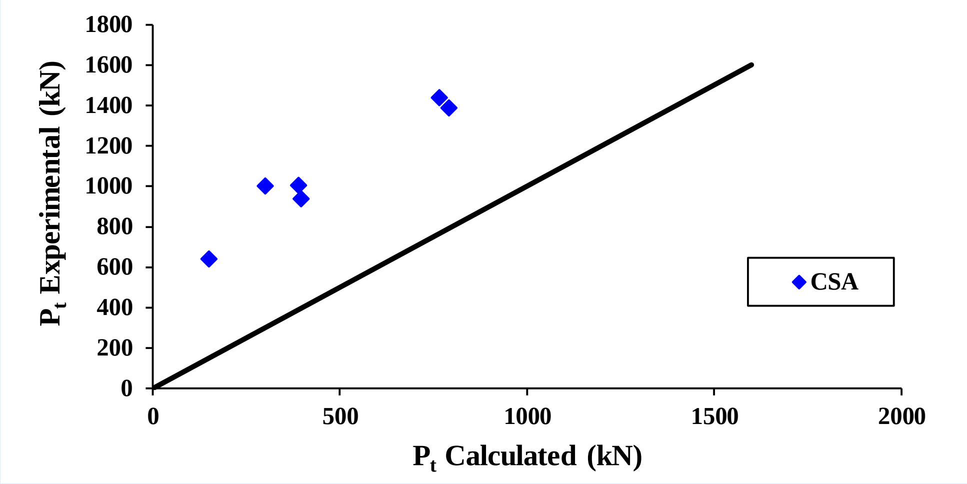
➢ STM of the CSA-S806-12

Strut effectiveness factors according to ACI 318-14, EN 1992-1-1 and CSA-S806-12 codes

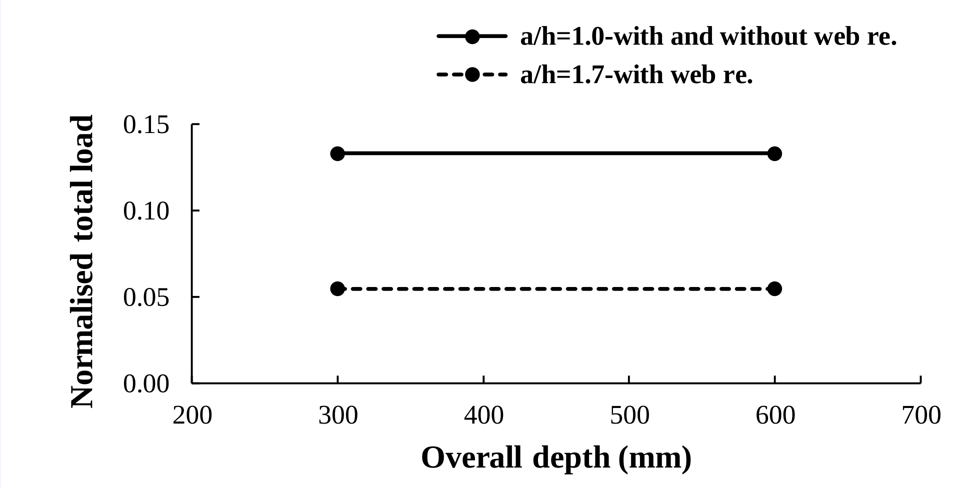
Code	Strut effectiveness factor (υ)
CSA-S806-12	$\frac{1}{0.8+170\varepsilon_1} \le 0.85,\ \varepsilon_1 = [\varepsilon_f + (\varepsilon_f + 0.002)cot^2\theta_f]$, ε_1 is the principal tensile strain and ε_f is the tensile strain in the FRP bar point that intersects with inclined concrete strut and θ_f is the slope of the strut

load capacity predictions using the STM of the Canadian code

Beam	Exp.	CSA	Exp/CSA
G1-300-N	937.29	396.0	2.37
G1-600-N	1388.016	792.1	1.75
G1-300-W	1005.79	390.5	2.58
G1-600-W	1439.361	766.5	1.88
G1.7-300-W	639.68	150.3	4.26
G1.7-600-W	1000.52	300.5	3.33
		Mean	2.69
		STD	0.95
		CoV	0.35



Comparisons between experimental results and predictions of the STM of the Canadian codes



Size effect of the test specimens according to the STM of the Canadian code

MAIN CONCLUSIONS

- This experimental study confirmed the impacts of web reinforcement and member size on the shear strength. However, the STM of the Canadian code did not consider the effect of those two parameters

- Increasing the section size
- Increased the crack propagation rate,
- Reduced the reserve capacity,
- Reduced the shear strength,
- And increased the crack widths

- The existing STM of the Canadian code was unable to estimate the load capacity of the beams tested. Therefore, STM of the Canadian standard needs to be modified.

Thank you for listening