

**EFFECT OF SHEAR ON FLEXURAL BEHAVIOUR OF RC BEAMS
RETROFITTED WITH NEAR SURFACE MOUNTED REINFORCEMENT:
EXPERIMENTAL RESULTS**

VAN HIEN NGUYEN, VAN NAM LE, MAURIZIO GUADAGNINI, KYPROS PILAKOUTAS

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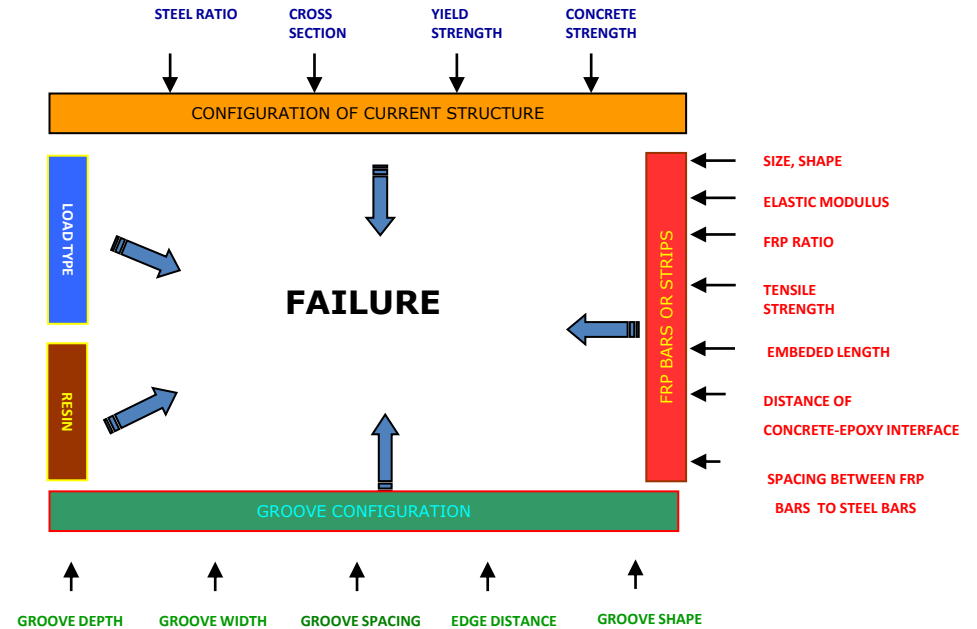
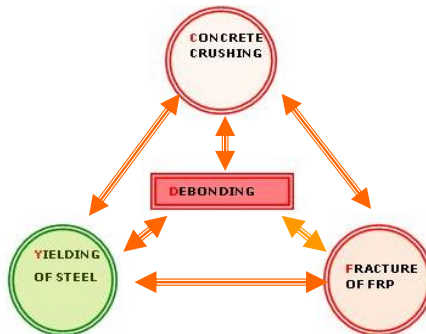
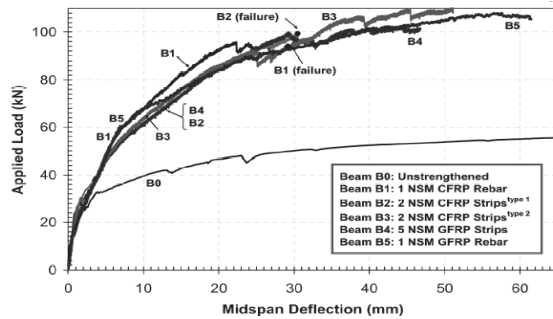
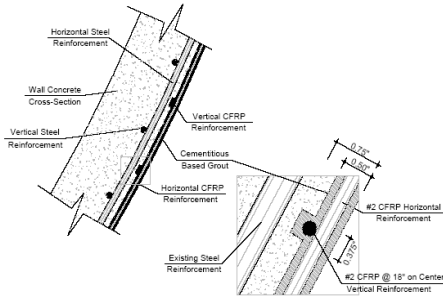
INTRODUCTION

EXPERIMENTAL WORK

EXPERIMENTAL RESULTS AND ANALYSIS

CONCLUSIONS AND FUTURE WORK

INTRODUCTION



INTRODUCTION

f_c

f_y

A_s

E_f

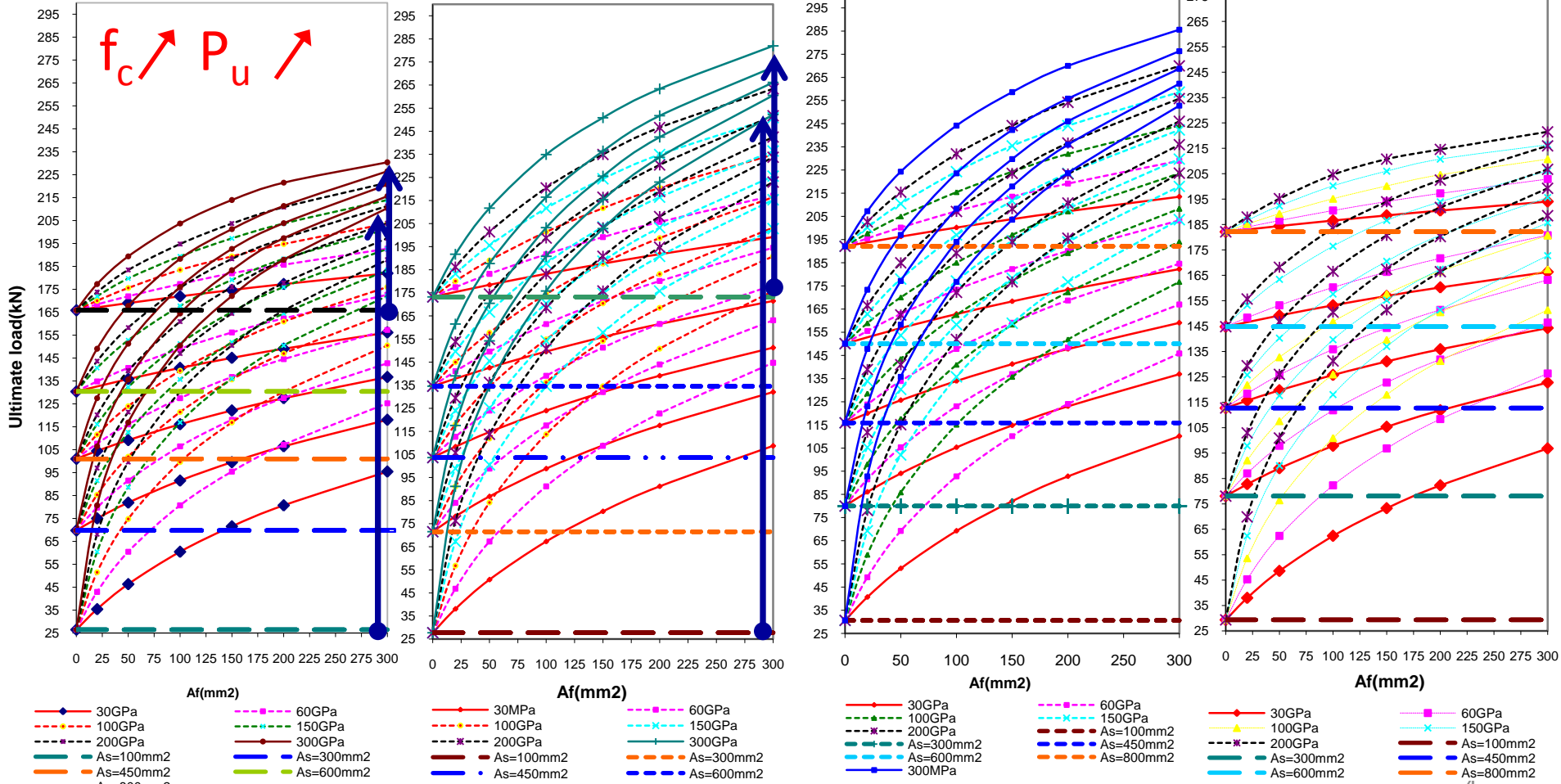
A_f

Ultimate loads vs $f_c = 30\text{MPa}$, $f_y = 460$, $E_f = 30\text{-}200\text{GPa}$
 $A_s = 100 - 800\text{mm}^2$, $A_f = 10 - 300\text{mm}^2$

Ultimate loads vs ($f_c = 40\text{MPa}$), $f_y = 460\text{MPa}$, $E_f = 30\text{-}200\text{GPa}$
 $A_s = 100 - 800\text{mm}^2$, $A_f = 10\text{-}300\text{mm}^2$

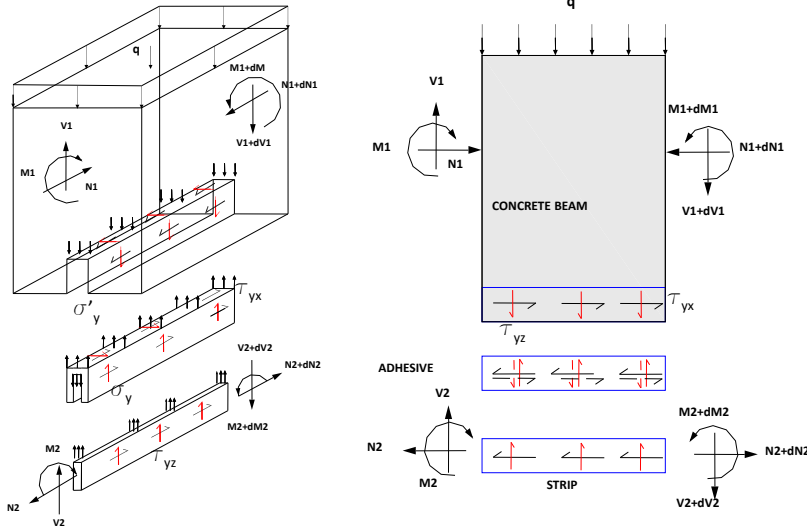
Ultimate load vs $f_c = 40\text{MPa}$, $f_y = 520$, $E_f = 30\text{-}200\text{GPa}$
 $A_s = 100 - 800\text{mm}^2$, $A_f = 10 - 300\text{mm}^2$

Ultimate loads vs $f_c = 30\text{MPa}$, $f_y = 520\text{MPa}$, $E_f = 30\text{-}200\text{GPa}$
 $A_s = 100\text{-}800\text{mm}^2$, $A_f = 10\text{-}300\text{mm}^2$



INTRODUCTION-AN ANALYTICAL MODEL

INTERFACIAL BASED MODEL



$$\left\{ \begin{aligned} \frac{d\tau_{yx}^2(x)}{dx} - \frac{G_a 2nh_f}{t_a} \left[\frac{(y_{eff} - \frac{h_f}{2})^2}{E_c I_{eff} + E_f I_f} + \frac{1}{E_c A_{eff}} + \frac{1}{E_f A_f} \right] \tau_{yx}(x) \\ = \frac{G_a}{t_a} \frac{(y_{eff} - \frac{h_f}{2})}{E_c I_{eff} + E_f I_f} V_T(x) - \frac{G_a (y_{eff} - h_f) dq}{t_a G_c A_{eff}} + 2nh \left(\frac{y_{eff} - h_f}{G_c A_{eff}} + \frac{h_f b}{2G_f A_f} \right) \frac{d\tau_{yz}(x)}{dx} \\ \frac{d^4 \tau_{yz}(x)}{dx^4} - \frac{2G_a nh_f}{t_a} \left(\frac{1}{G_c A_{eff}} + \frac{1}{G_f A_f} \right) \frac{d^2 \tau_{yz}(x)}{dx^2} + \frac{G_a 2nh_f}{t_a} \left(\frac{1}{E_c A_{eff}} + \frac{1}{E_f A_f} \right) \tau_{yz}(x) \\ = \frac{G_a 2nh_f}{t_a E_c I_{eff}} \left(y_{eff} - \frac{h_f}{2} \right) \frac{\tau_{yx}(x)}{dx} + \frac{G_a b}{t_a G_1 A_{eff}} \frac{d^2 q}{dx^2} - \frac{G_a q}{t_a E_c I_{eff}} \end{aligned} \right.$$

- Solutions(for the four point bending case)

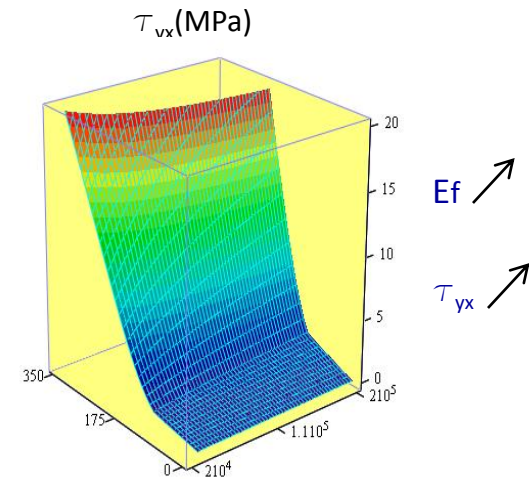
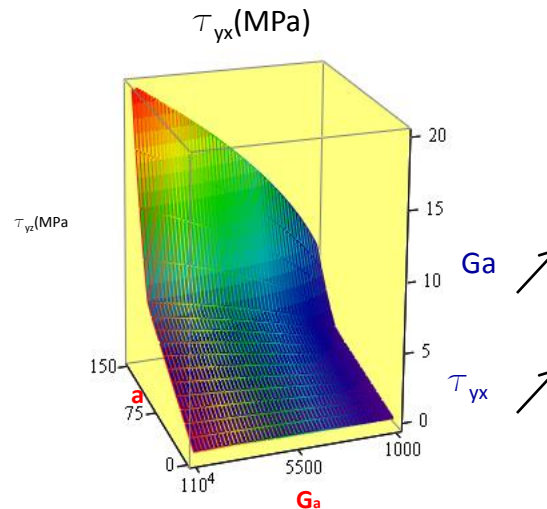
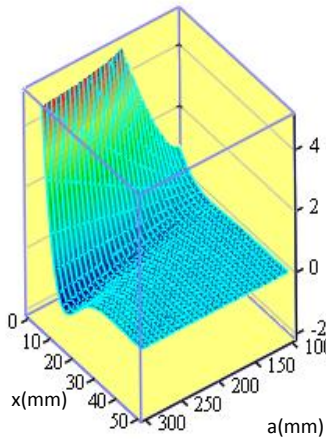
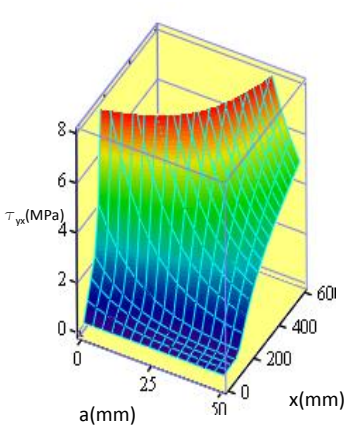
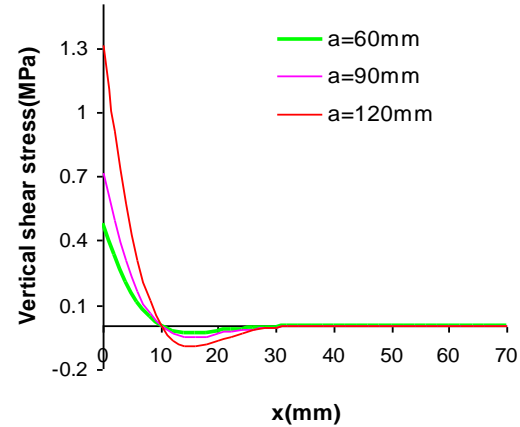
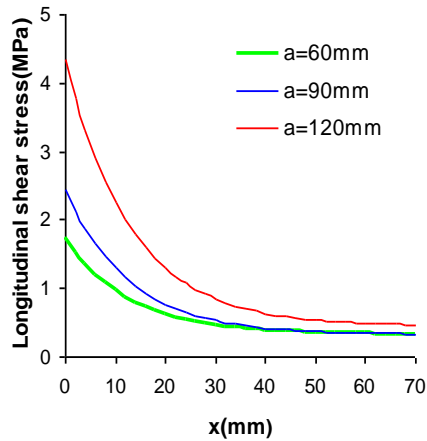
$$\left\{ \begin{aligned} \tau_{yx}(x) &= \frac{\alpha}{\beta} P a e^{-\beta x} + \gamma P \\ \tau_{yz}(x) &= e^{-\omega x} [A \cos(\omega x) + B \sin(\omega x)] \end{aligned} \right.$$

$$\alpha = \frac{G_a}{t_a \beta^2} \frac{y_{eff} - \frac{h_f}{2}}{E_c I_{eff} + E_f I_f} \quad \gamma = \frac{G_a}{t_a} \frac{y_{eff}}{E_c I_{eff}} \quad \beta = \sqrt{\frac{2G_a A_f}{t_a t_f} \left[\frac{(y_{eff} - \frac{h_f}{2})^2}{E_c I_{eff} + E_f I_f} + \frac{1}{E_c A_{eff}} + \frac{1}{E_f A_f} \right]}$$

$$\omega = \sqrt{\frac{G_a nh_f}{2t_a} \left[\frac{1}{E_f I_f} + \frac{1}{E_c I_{eff}} \right]} \quad A = \frac{G_a P}{2E_c I_{eff} \omega^2 t_a} \left[1 + \omega a - 2nh_f \left(\frac{\alpha}{\beta} a + \gamma \right) (y_{eff} - h_f) \right] \quad B = -\frac{G_a P a}{2\omega^2 t_a E_c I_{eff}}$$

LONGITUDINAL SHEAR STRESS τ_{yx}
 VERTICAL SHEAR STRESS τ_{yz}
 NORMAL STRESS σ'_y

INTRODUCTION - ANALYTICAL MODEL



Van Hien Nguyen, Maurizio Guadagnini, Kypros Pilakoutas, Van Nam Le, *Stress Concentration in Cut-Off Zones of RC Beams Retrofitted with Near Surface Mounted Reinforcement: An Analytical Approach*, FRPRCS 9 Proceeding, Sydney, Australia, 2009, page 217

INTRODUCTION

PROBLEMS

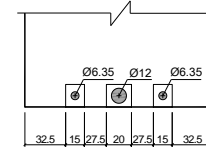
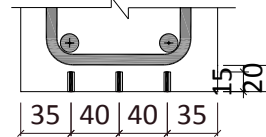
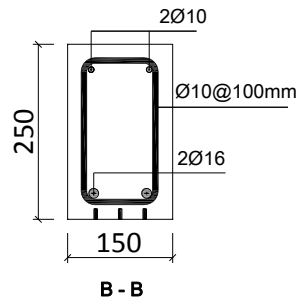
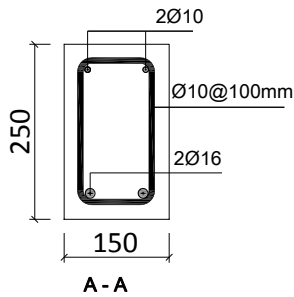
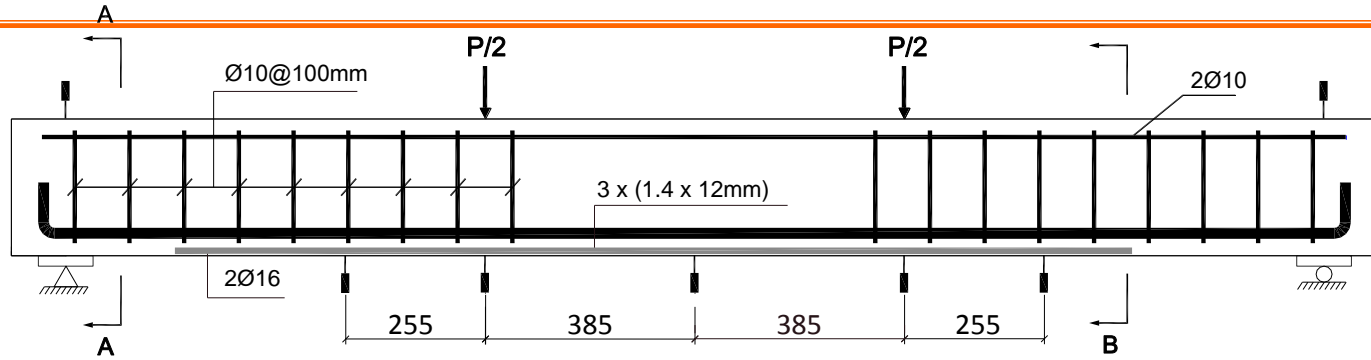
- ❑ DEBONDING IS STILL A CRUCIAL ISSUE, UNDERSTANDING ABOUT DEBONDING FAILURES OF RC STRUCTURES WITH NSMR ARE VERY VAGUE

- ❑ INFLUENCES OF SHEAR ON DEBONDING BEHAVIOUR HAVE BEEN IGNORED IN ALMOST PREVIOUS RESEARCH
 - INFLUENCES OF SHEAR CRACKS ON STRAIN AND STRESS DISTRIBUTION ALONG STEEL AND FRP STRIPS

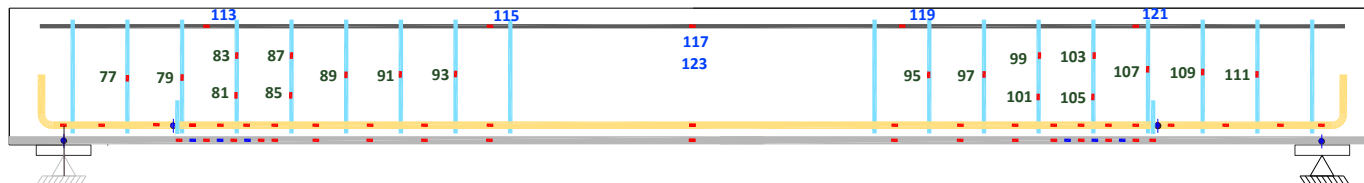
 - INFLUENCES OF SHEAR LINK LOCATIONS ON STRAIN AND STRESS DISTRIBUTION ALONG STEEL AND FRP STRIPS

 - NEEDS OF RELIABLE MODELS TO PREDICT BOND STRESS AND FAILURE LOAD OF RC STRUCTURE RETROFITTED NSMR

EXPERIMENTAL WORK

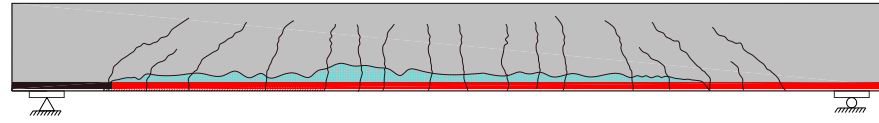
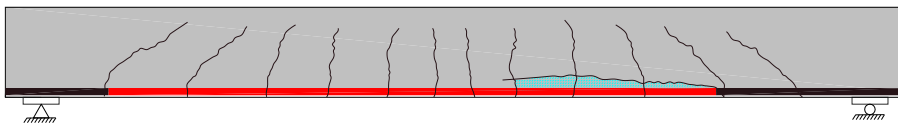
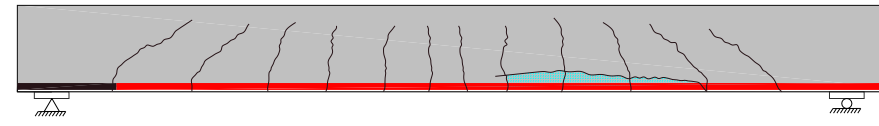
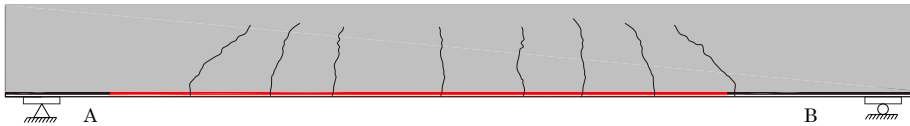
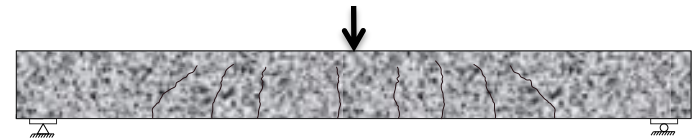


EXAMPLE OF STRAIN GAUGE ARRANGEMENT



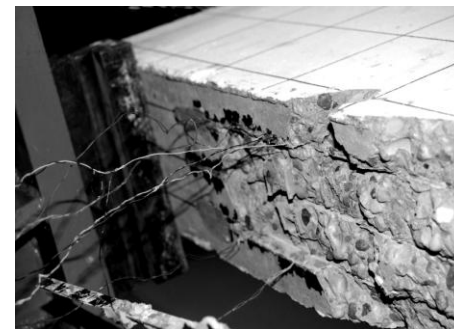
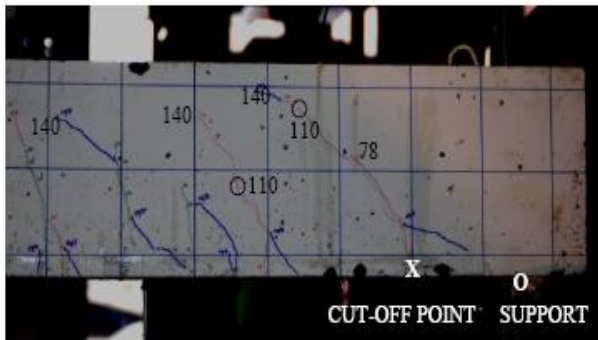
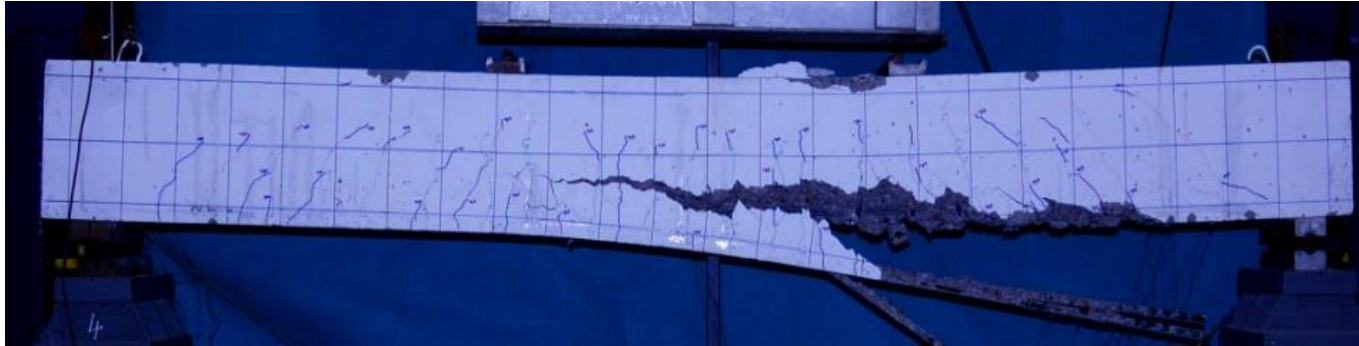
EXPERIMENTAL WORK

No.	Beam	Strengthening technique	FRP	FRP modulus (GPa)	Concrete Comp. strength (MPa)	A	B	Testing method
1	REF-B-1	Control beam			30			4P
2	NSM-CB-2/100/150	NSMR	Carbon round bar	133	30	150	150	4P
3	NSM-CS-3/100/0/150	NSMR	Carbon strip	214	30	0	150	4P
4	NSM-CS-4/100/200/300	NSMR	Carbon strip	214	50	200	300	4P
5	NSM-BS-5/100/350/450	NSMR	Basalt strip	57.1	30	350	450	3P
6	NSM-CS-6/150/350/450	NSMR	Carbon strip	214	30	350	450	4P
7	NSM-BS-7/100/450/550	NSMR	Basalt strip	57.1	30	450	550	3P
8	NSM-CS-8/150/450/550	NSMR	Carbon strip	214	30	450	550	4P
9	NSM-CS-9/100/350/450	NSMR	Carbon strip	214	30 <td 350	450	4P	
10	REF-B-2	Control beam			30			4P



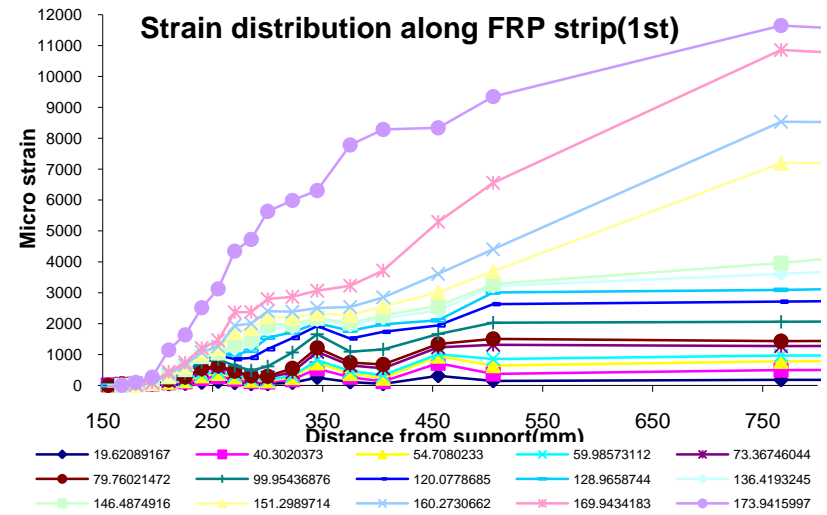
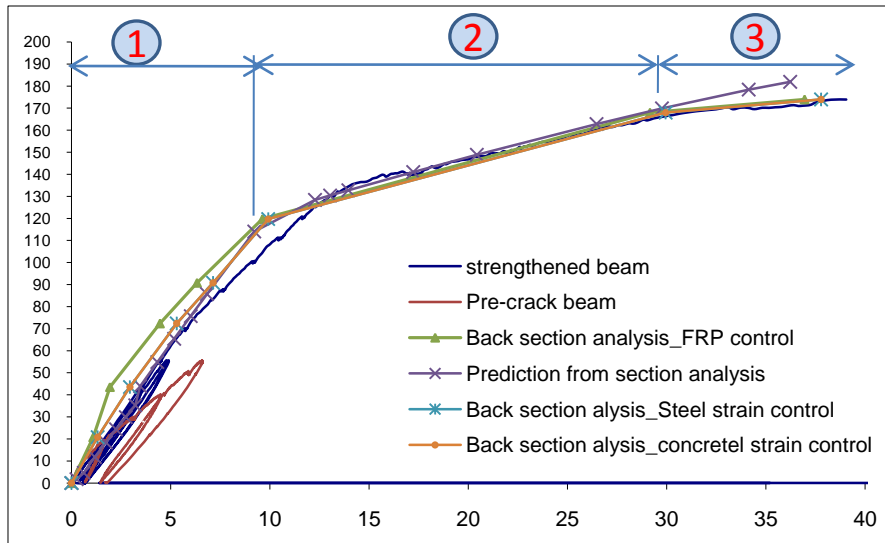


EXPERIMENTAL WORK - RESULTS



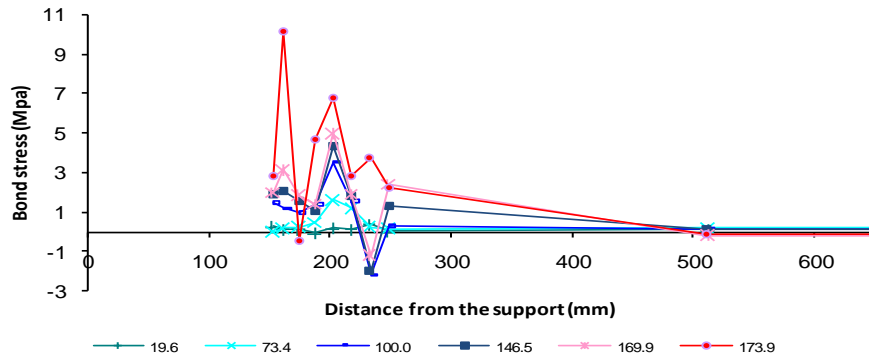
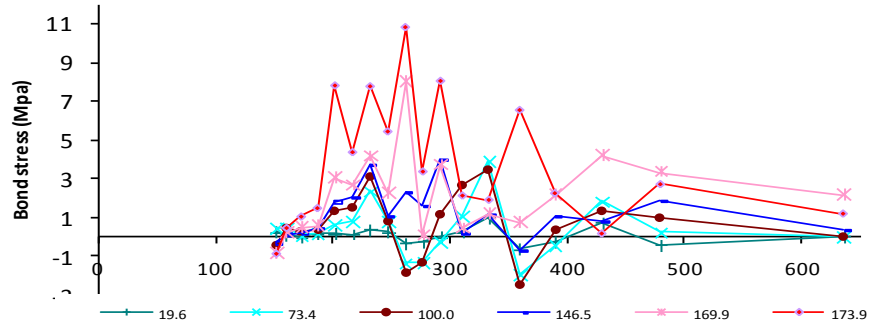
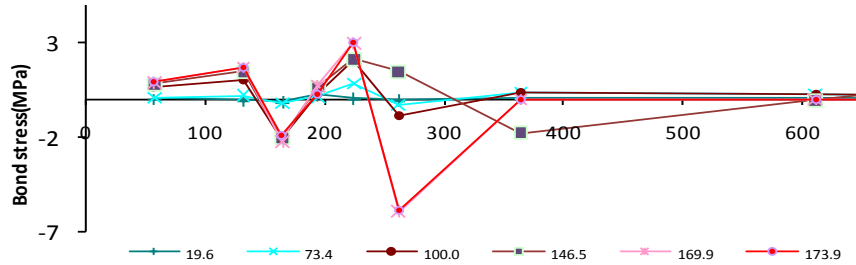
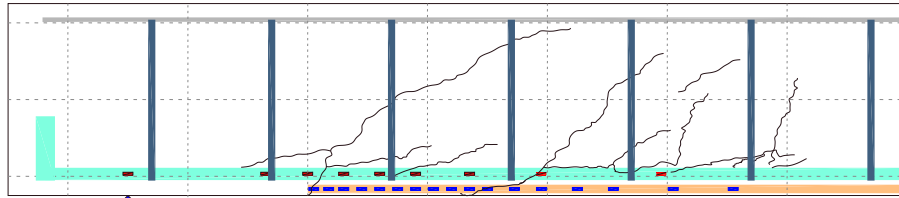
EXPERIMENTAL WORK - RESULTS

DEFLECTION





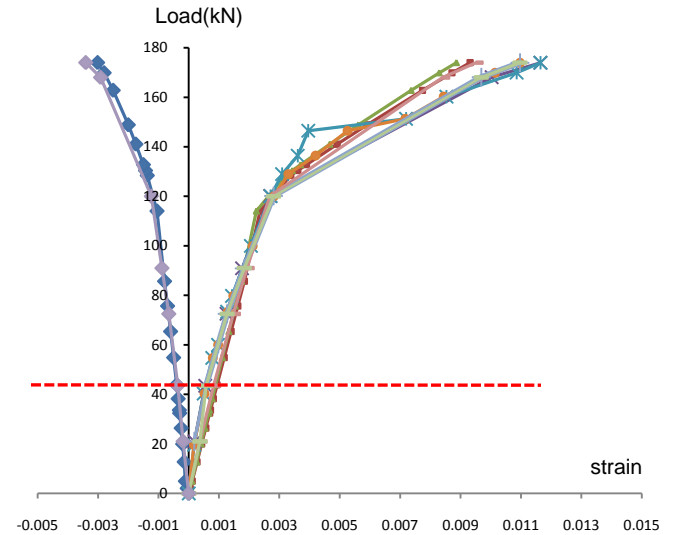
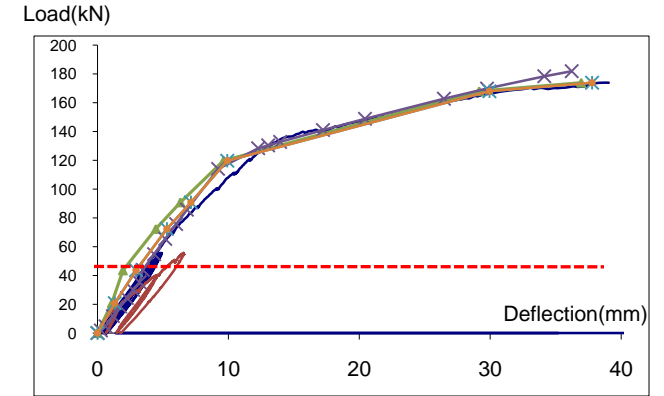
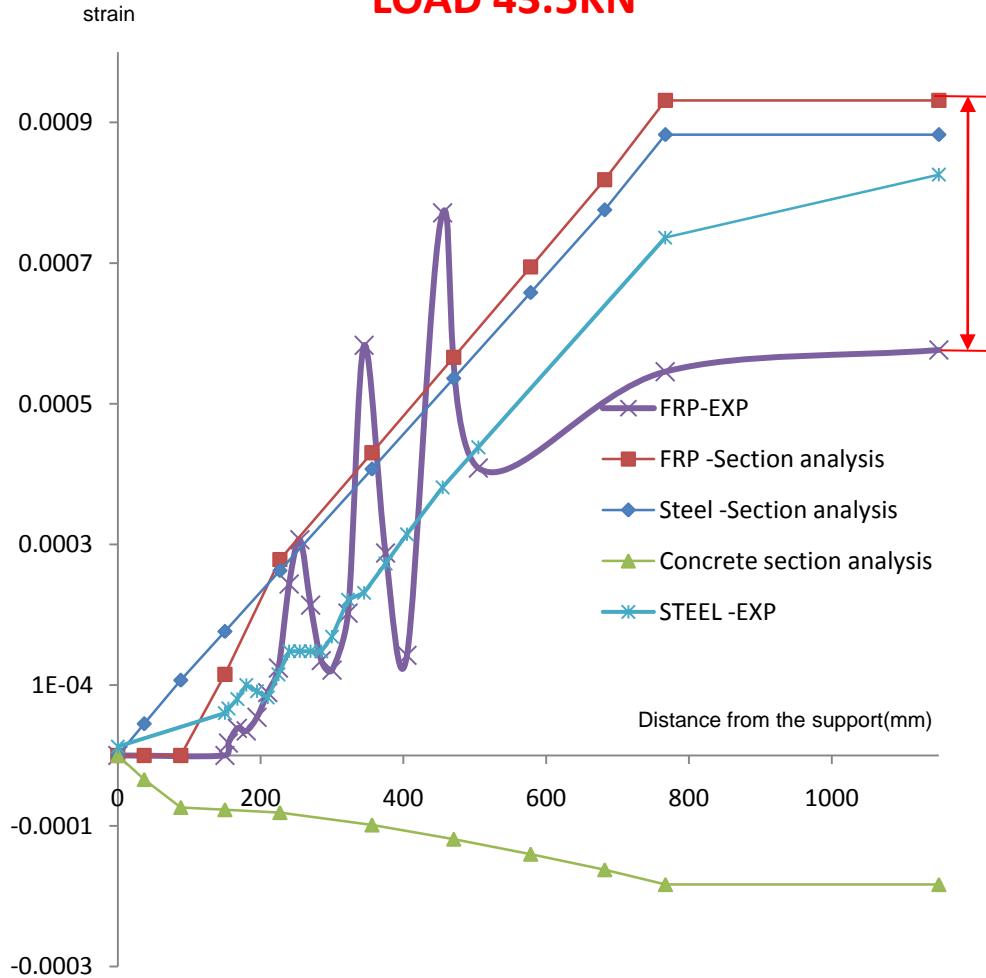
TEST RESULTS AND ANALYSIS





TEST RESULTS AND ANALYSIS

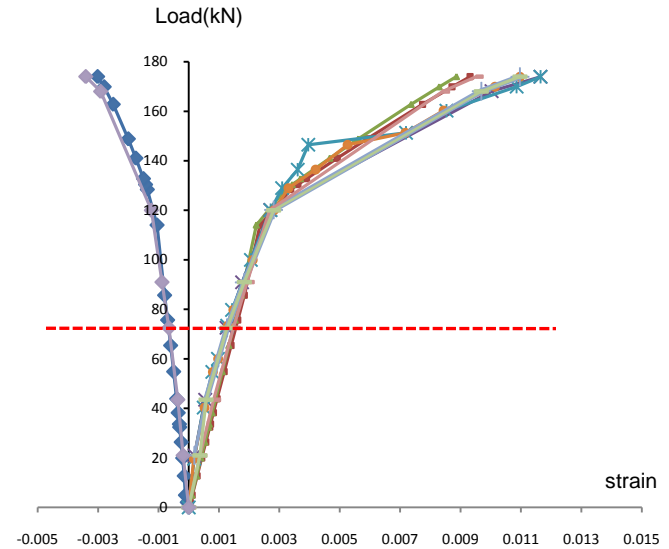
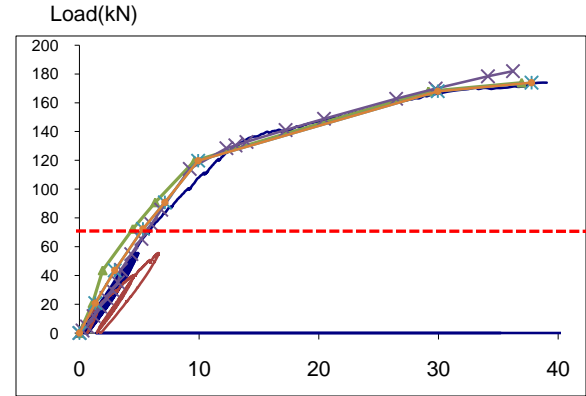
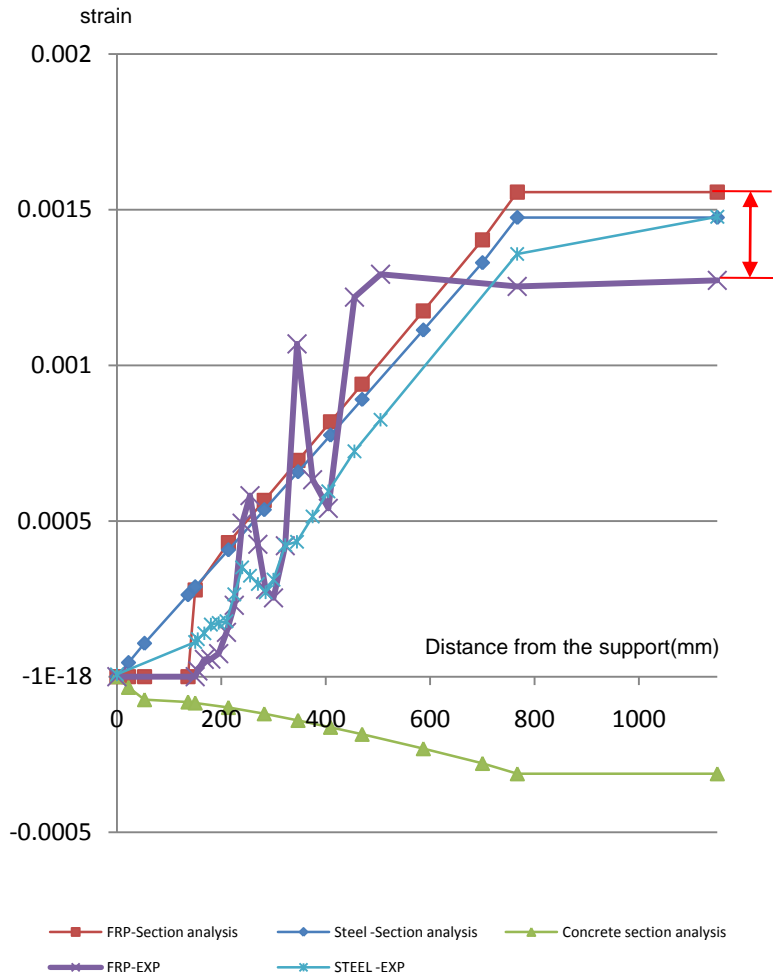
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TEST RESULTS AND ANALYSIS

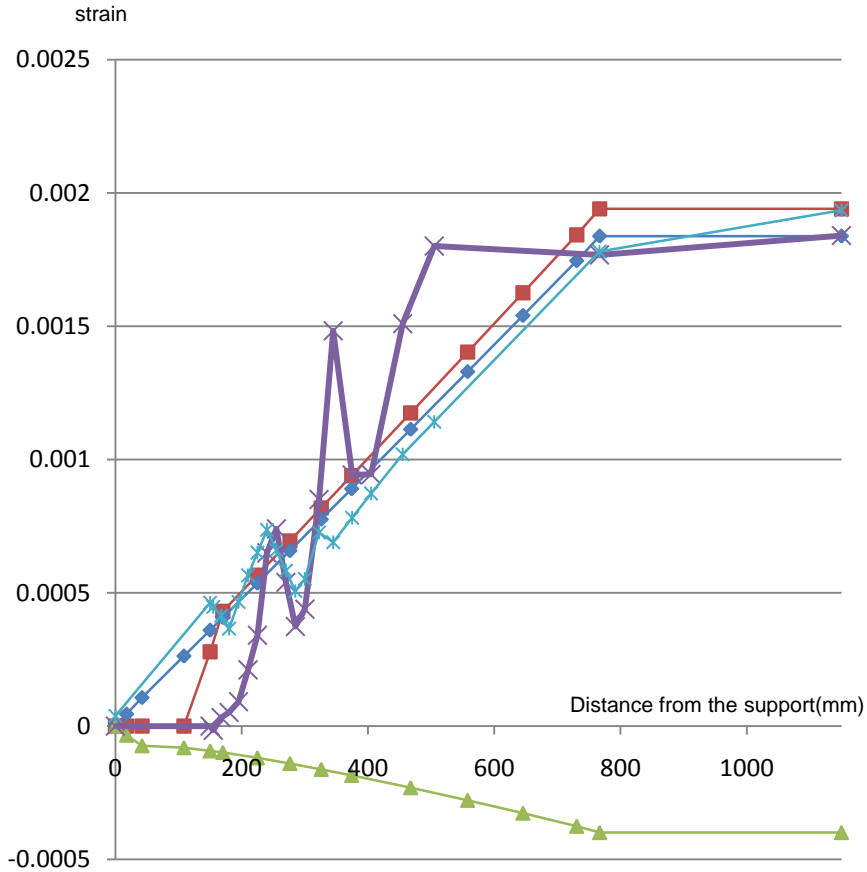
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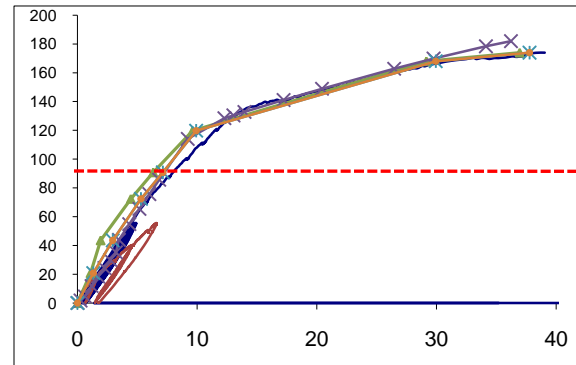


TEST RESULTS AND ANALYSIS

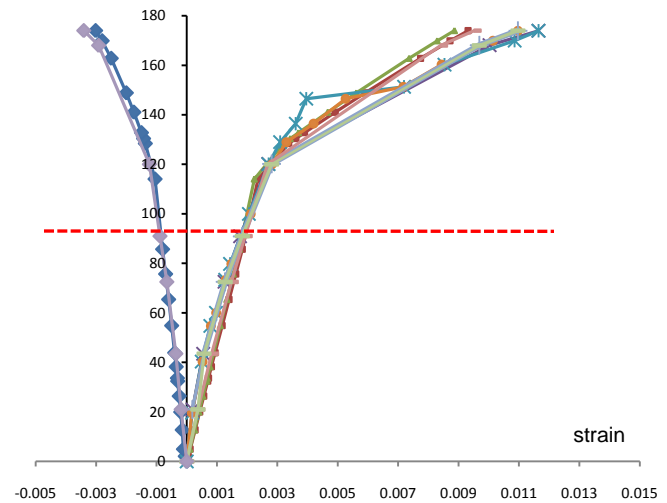
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Load(kN)



Load(kN)

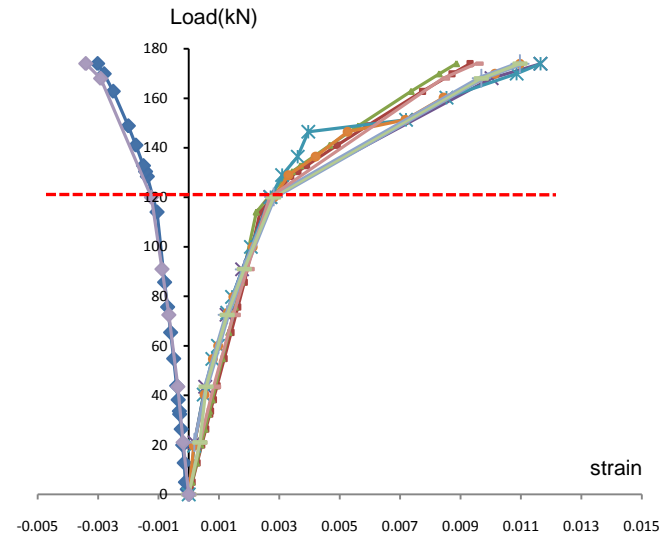
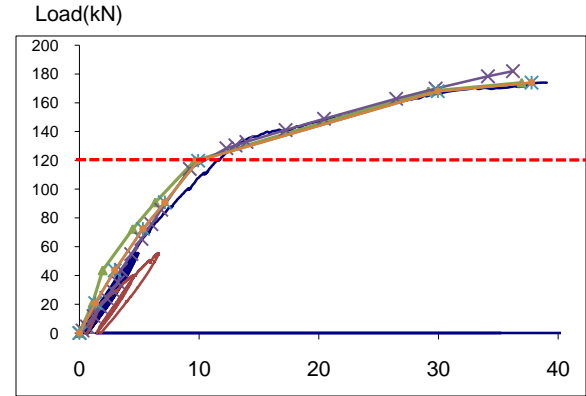
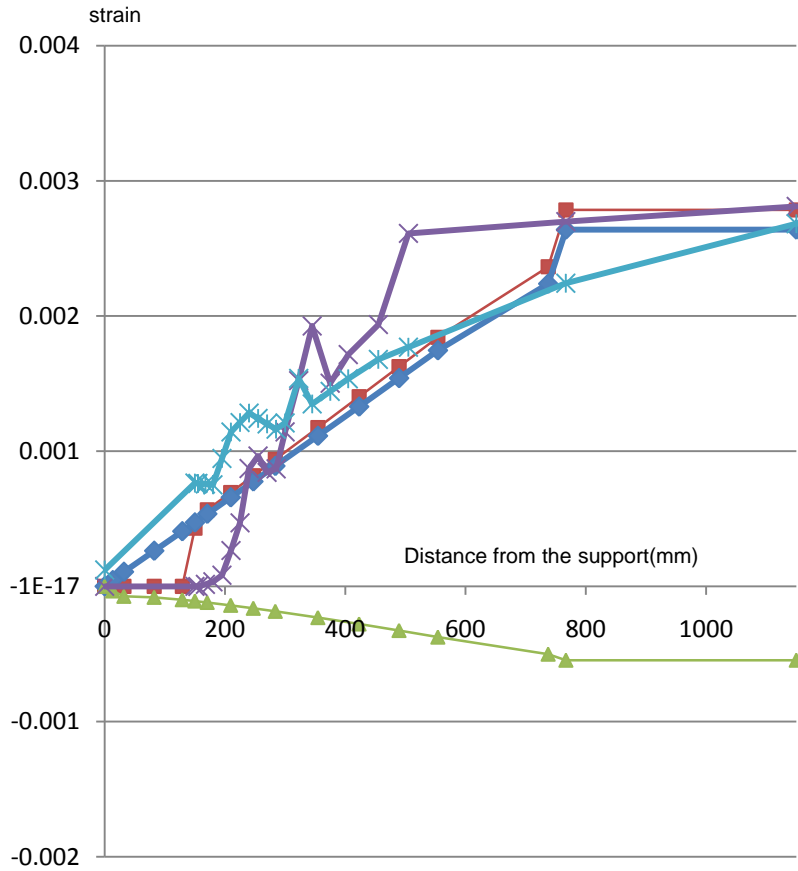


- FRP-Section analysis
- Steel-Section analysis
- Concrete section analysis
- FRP-EXP
- STEEL-EXP



TEST RESULTS AND ANALYSIS

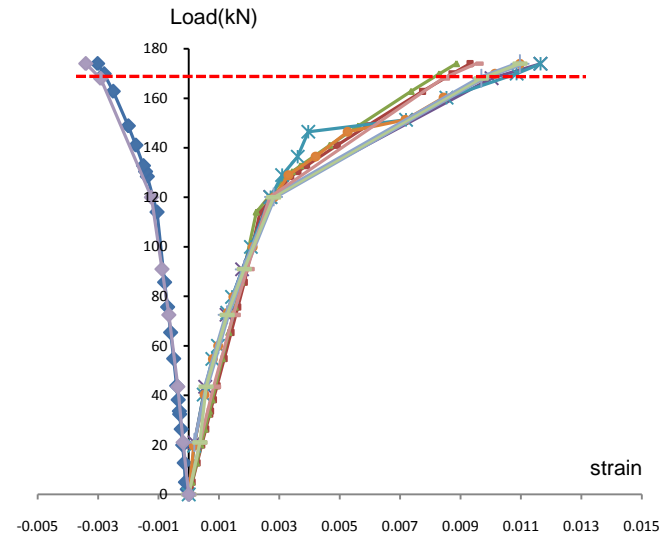
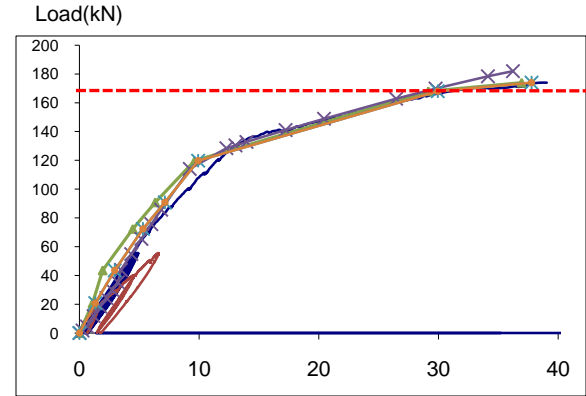
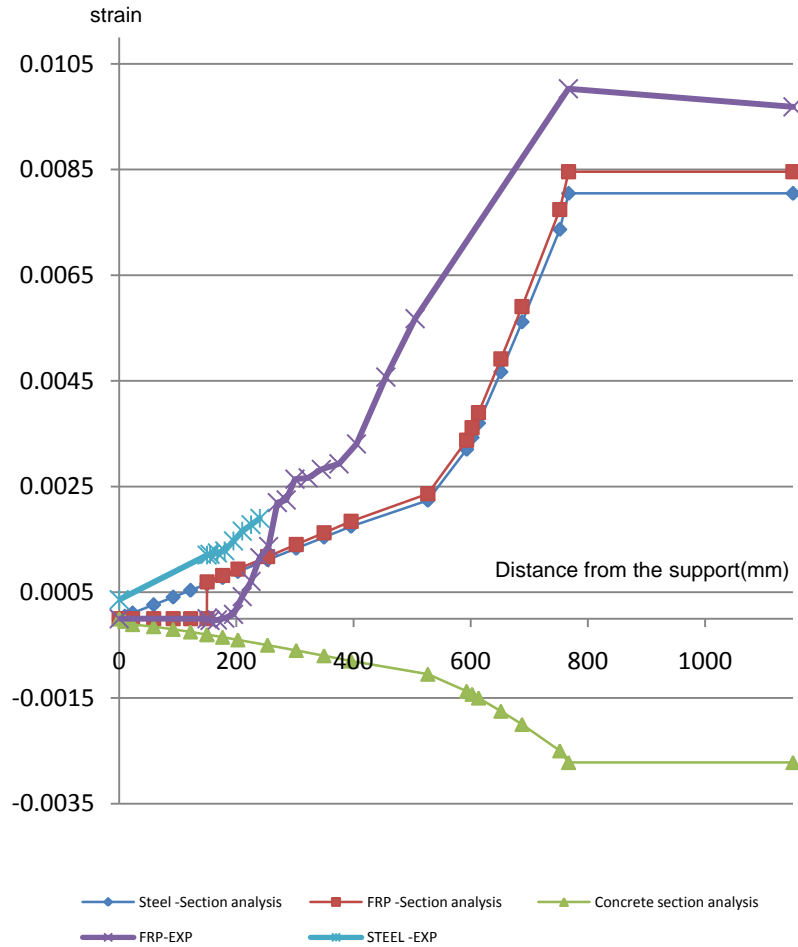
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- FRP-Section analysis
- Steel-Section analysis
- Concrete section analysis
- FRP-EXP
- STEEL-EXP



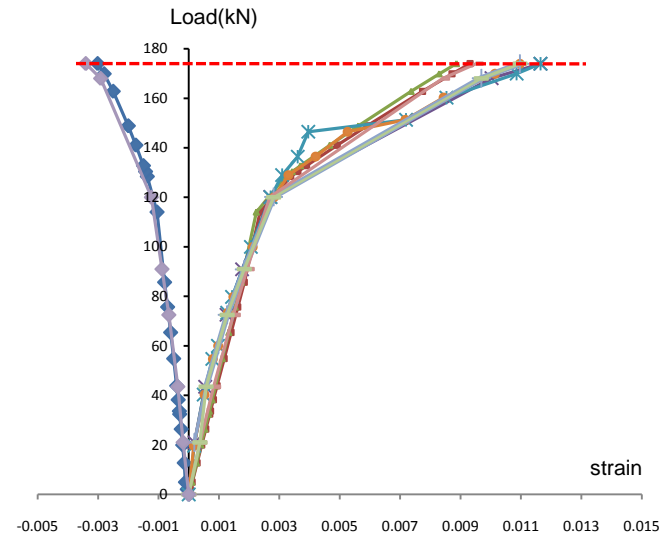
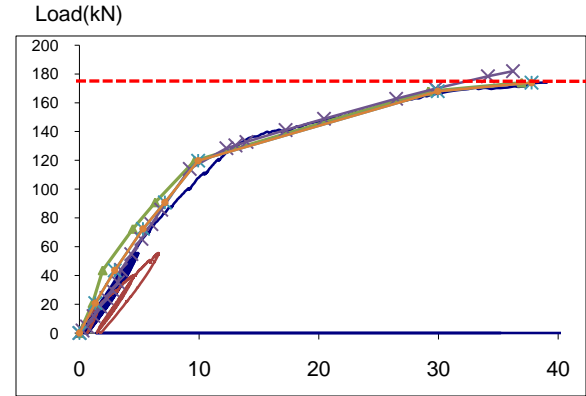
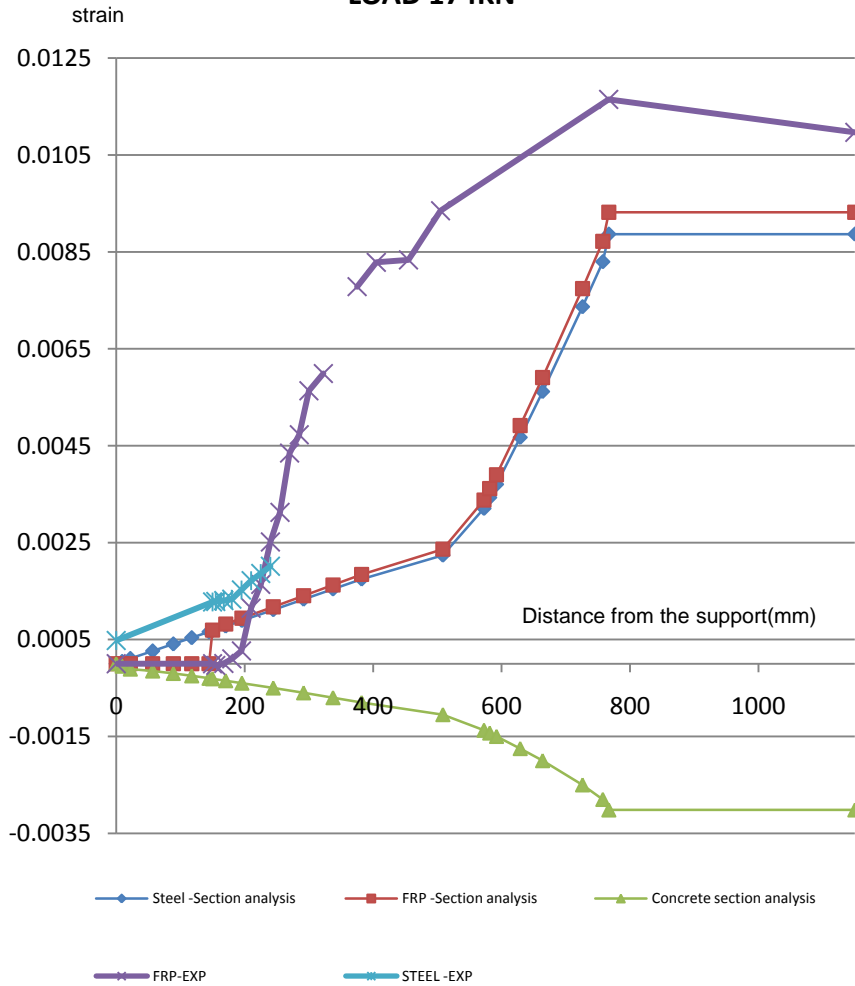
TEST RESULTS AND ANALYSIS





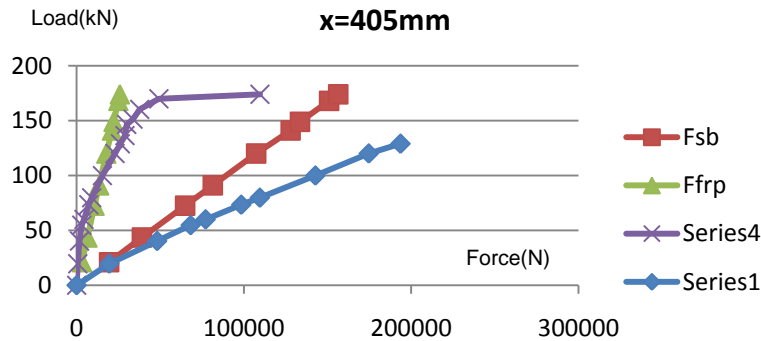
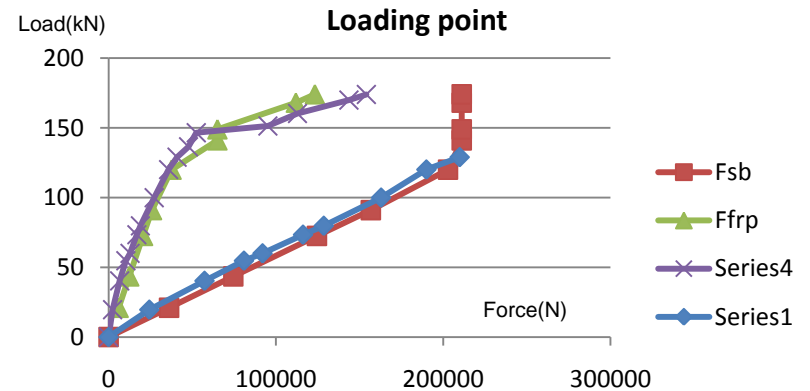
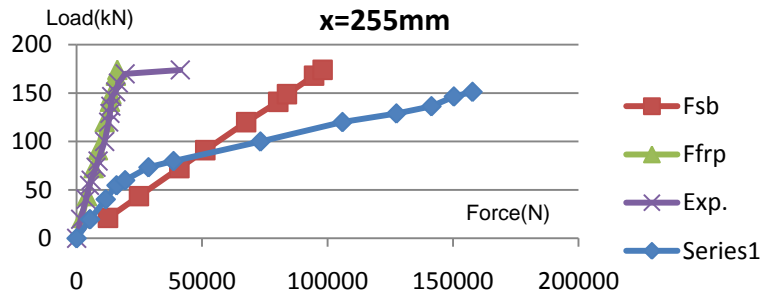
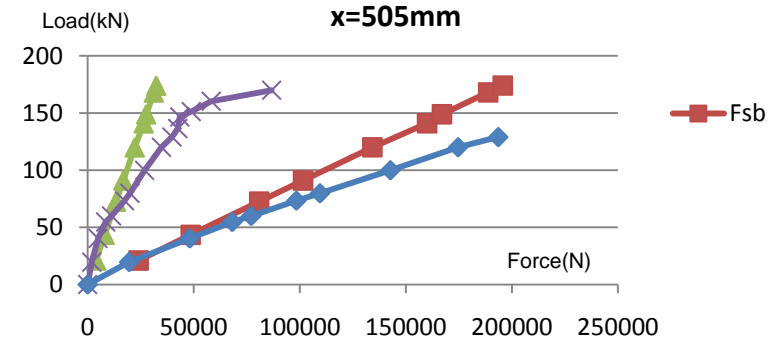
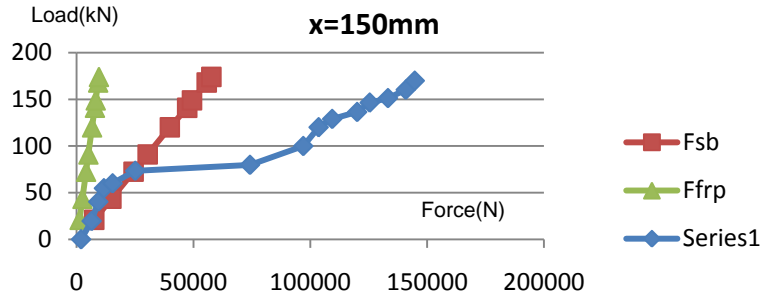
TEST RESULTS AND ANALYSIS

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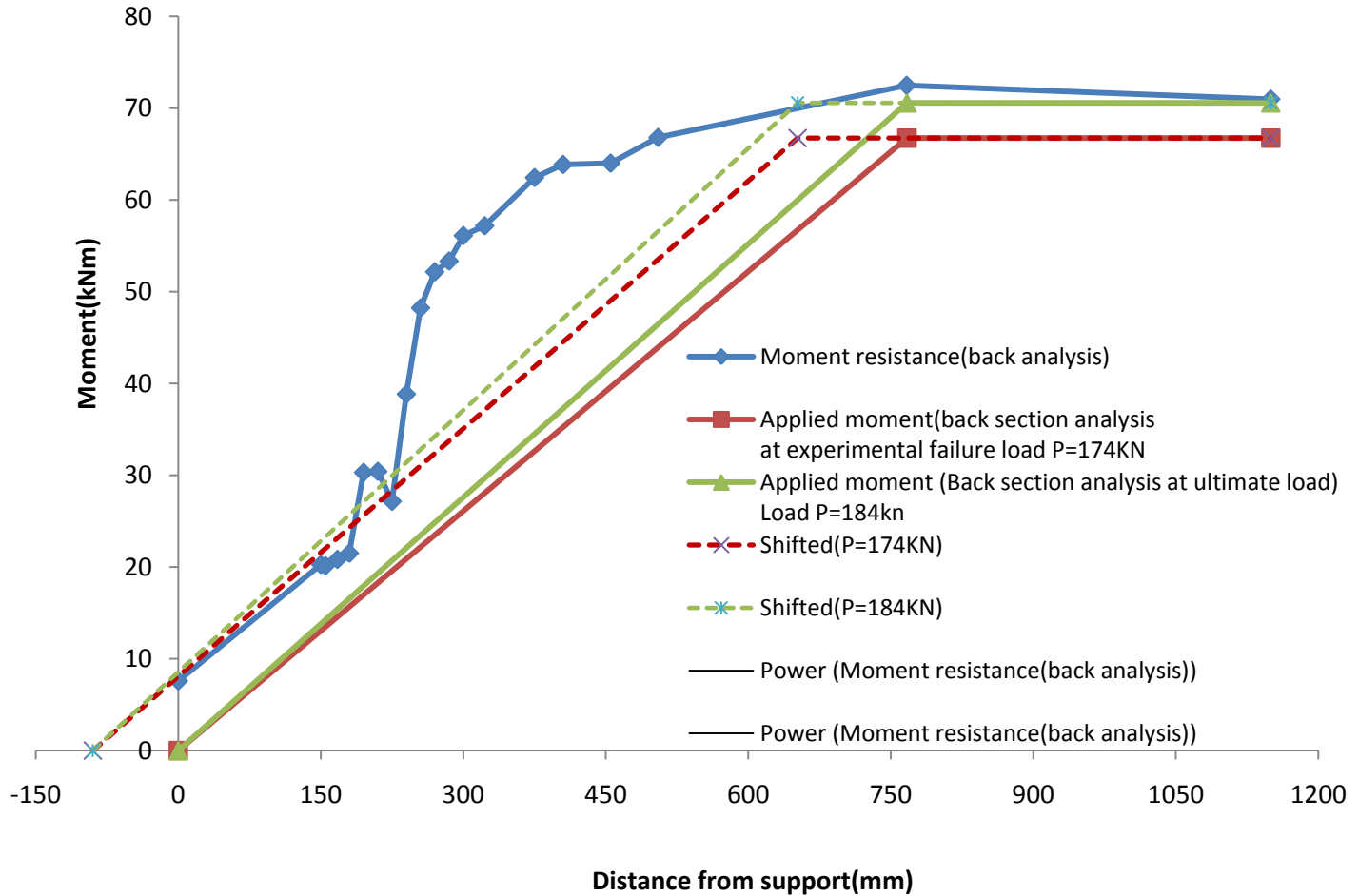
TEST RESULTS AND ANALYSIS





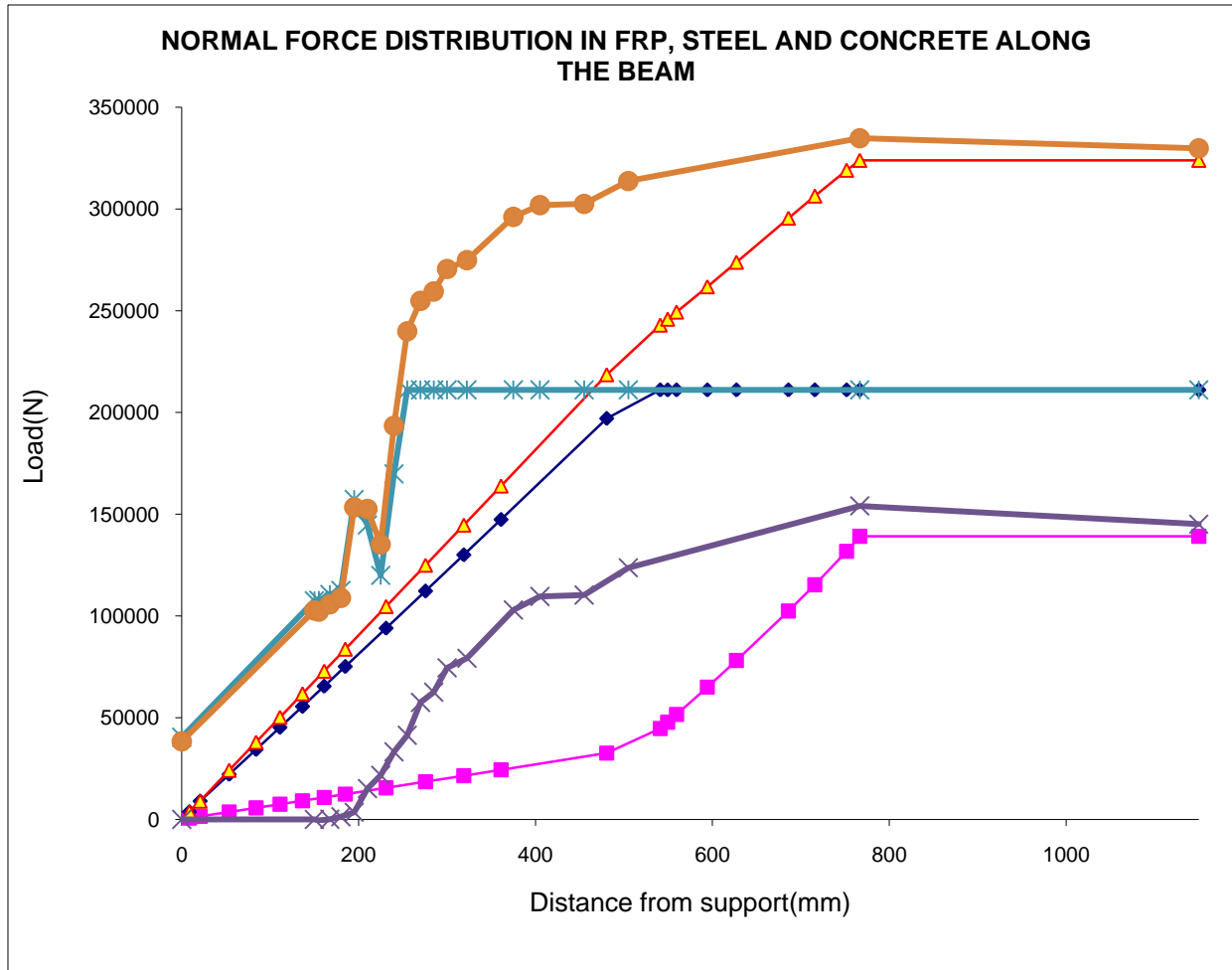
TEST RESULTS AND ANALYSIS

Moment resistance of beam(calculated from test results)





TEST RESULTS AND ANALYSIS



CONCLUSIONS

- ❑ SHEAR EFFECTS ARE SIGNIFICANT ON BOND BEHAVIOUR OF FRP NSMR

- ❑ AT MID-SPAN ZONE, SECTION ANALYSIS CAN BE USED WITH A HIGH RELIABILITY

- ❑ SHEAR CRACKS TEND TO EXTEND THE YIELD ZONE OF STEEL IN RC BEAM RETROFITTED WITH FRP NSMR

- ❑ SHEAR CRACKS PROVOKE AN INTENSIVE INCREASE OF STRAIN AND STRESS IN BOTH STEEL REINFORCEMENT AND FRP NSMR

- ❑ SHEAR EFFECTS ARE POSSIBLY MOST INTENSIVE AROUND MID SHEAR SPAN

FUTURE WORK

- ❑ FAILURE MECHANISM UNDER SHEAR EFFECTS

- ❑ PARAMETRIC STUDY ON SHEAR EFFECTS: STIRRUP SPACINGS, RELATIVE POSITION OF THE CUT-OFF POINT AND SHEAR LINKS

- ❑ PROPOSE RELIABLE MODELS TAKING INTO ACCOUNT THE SHEAR EFFECTS FOR TO PREDICT THE FAILURE LOAD FOR BEAM RETROFITTED WITH FRP NSMR
 - INTERFACIAL STRESS BASE MODEL

 - FAILURE PRISM MODEL

 - TRUSS AND TIE MODEL

ACKNOWLEDGEMENTS

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- MINISTRY OF EDUCATION AND TRAINING OF VIETNAM

THANK
YOU