
# Bond-Deteriorated Reinforcement in Concrete Beams Strengthened with CFRP

Riliang Li and Riyad S Aboutaha

Presentation by Riliang Li

Syracuse University

THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE

aci CONCRETE CONVENTION

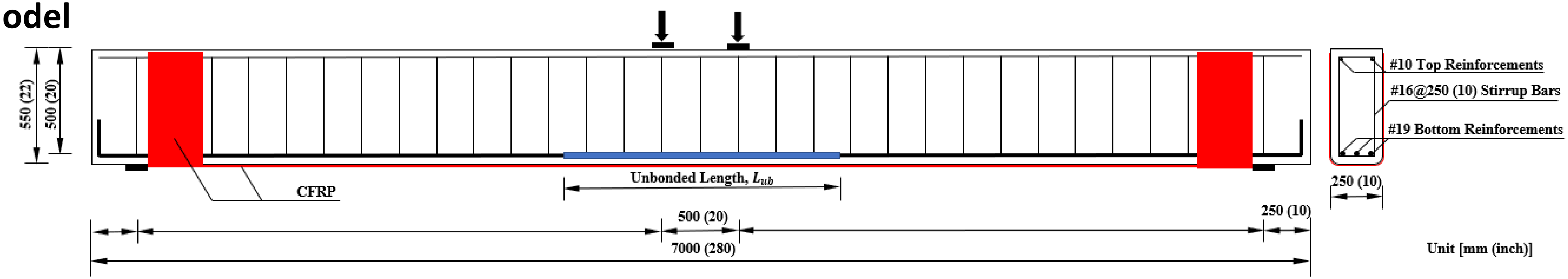
# Introduction

**Corrosion of the reinforcing steel in a bridge beam** (https://www.materialsperformance.com/articles/material-selection-design/2015/12/corrosion-effects-on-the-durability-of-reinforced-concrete-structures)

**Corrosion of reinforcement usually causes:**

- Reduction of cross section
- Spalling of concrete cover
- Deterioration of bond between reinforcement and concrete

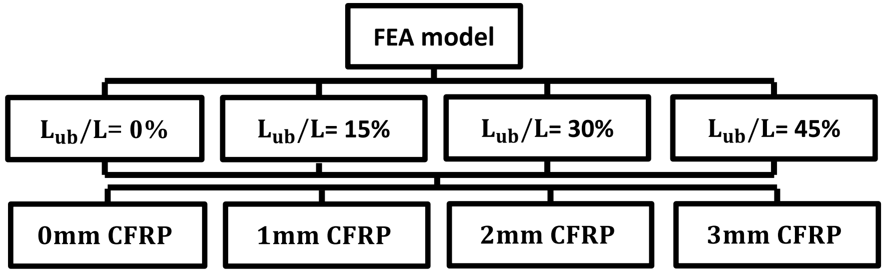
# FEA Model




Details of test specimens

All beams were reinforced with three #19 (19.1 mm in diameter) deformed steel bars as main tensile reinforcement and two #10 (9.5 mm in diameter) deformed steel bars as top reinforcement. The tensile bars were anchored in the test span using a standard hook to prevent anchorage failure. The steel stirrups were also #10 deformed bars with 250 mm spacing. Yield stresses of all steel reinforcing were 414 MPa (Grade 60).

# FEA Model



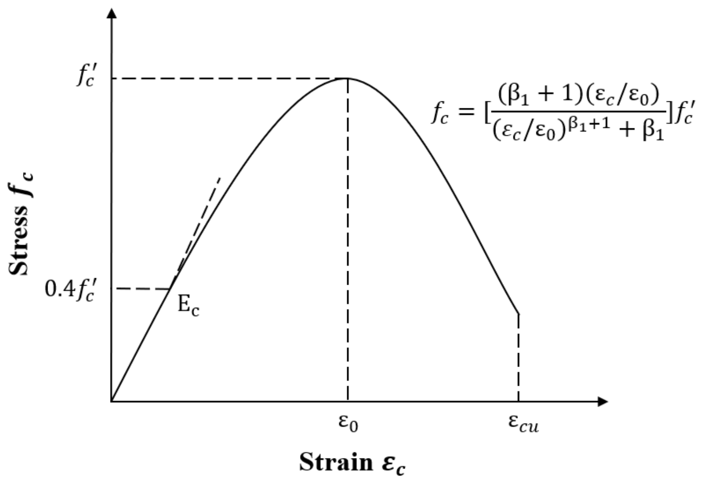

Parameters tree

The specimens were divided into four groups (A, B, C and D) based on the CFRP thickness (0mm, 1mm, 2mm & 3mm); four beams in each group based on the unbonded percentage (0%, 15%, 30% & 45%), a total of 16 specimens.

Summary of specimens

| Group | Group A (CFRP Thickness = 0mm) | | | |
|---|---|---|---|---|
| Specimen | R1T0 | U15T0 | U30T0 | U45T0 |
| Unbonded Percentage | 0% | 15% | 30% | 45% |
| Group | Group B (CFRP Thickness = 1mm) | | | |
| Specimen | R1T1 | U15T1 | U30T1 | U45T1 |
| Unbonded Percentage | 0% | 15% | 30% | 45% |
| Group | Group C (CFRP Thickness = 2mm) | | | |
| Specimen | R1T2 | U15T2 | U30T2 | U45T2 |
| Unbonded Percentage | 0% | 15% | 30% | 45% |
| Group | Group D (CFRP Thickness = 3mm) | | | |
| Specimen | R1T3 | U15T3 | U30T3 | U45T3 |
| Unbonded Percentage | 0% | 15% | 30% | 45% |

## FEA Model




**Compressive behavior of concrete (Yang *et al*., 2014)**

$E_c = A_1(f_c')^a(w_c/w_0)^b$

where $E_c$ = modulus of elasticity; $f_c'$ = compressive strength of concrete; $w_c$ = density of concrete = $2400\mathrm{kg/m^3}$ ; $w_0$ = $2300\mathrm{kg/m^3}$; $A_1$ = 8470; *a* = 1/3; *b* = 1.17.

The nonlinear compressive behavior of concrete can be expressed as follows:

$$f_c = [\frac{(\beta_1+1)\left(\frac{\varepsilon_c}{\varepsilon_0}\right)}{\left(\frac{\varepsilon_c}{\varepsilon_0}\right)^{\beta_1+1}+\beta_1}]f_c'$$

$\varepsilon_0$ is the strain corresponding to the compressive strength of concrete.

$$\varepsilon_0 = 0.0016 \cdot exp[240(\frac{f_c'}{E_c})]$$

$\beta_1$ is the slope of the up and down part of the curve and can be expressed as follow:

$$\beta_1 = \begin{cases} 0.2 \cdot exp(0.73\xi), & for\ \varepsilon_c < \varepsilon_0 \\ 0.41 \cdot exp(0.77\xi), & for\ \varepsilon_c > \varepsilon_0 \end{cases}$$

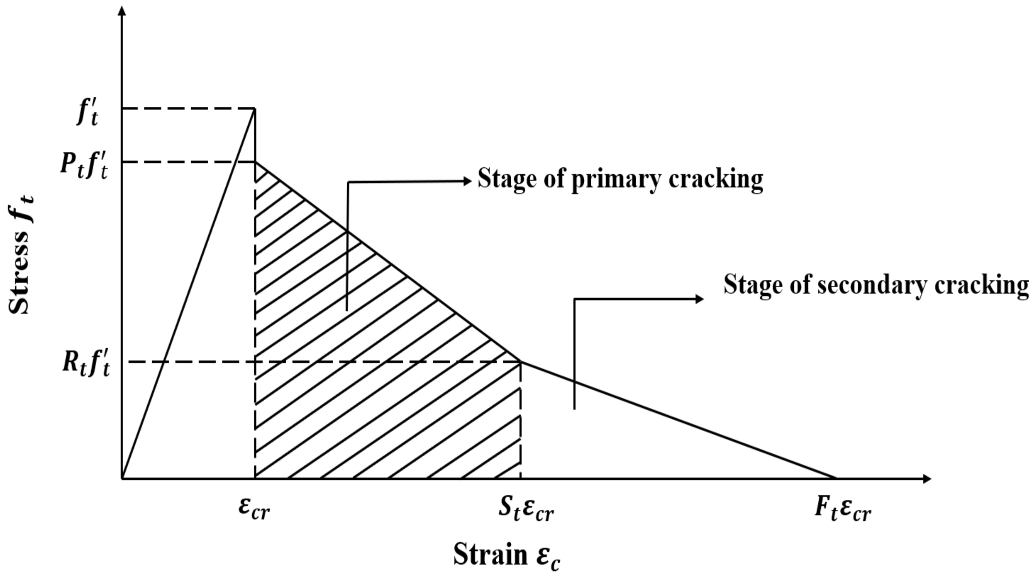
ξ can be expressed as follow:

$$\xi = (\frac{f_c'}{f_0})^{1.17}(\frac{w_0}{w_c})^{1.17}$$

where $f_0$ = 10MPa.

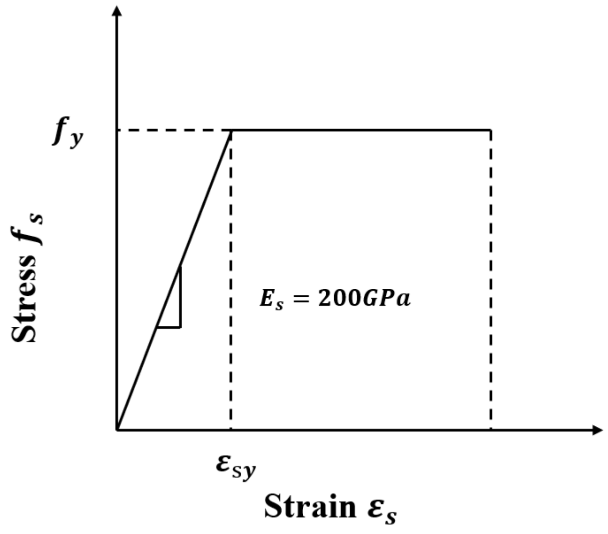
## FEA Model

Tensile behavior of concrete before cracking was assumed to be a linear ascending line until the stress reaches the concrete modulus of rupture. After rupture, the process of cracking generation is divided into two stages, stage of primary cracking and stage of secondary cracking respectively. The best set of parameters selected to match the experiment is $R_t$ = 0.45, $P_t$ = 0.8, $S_t$ = 4, $F_t$ = 10.




**Tensile behavior of concrete (Nayal and Rasheed, 2006)**

## FEA Model




**Stress-strain relationship of reinforcement (CEB-*fib*, 2010)**

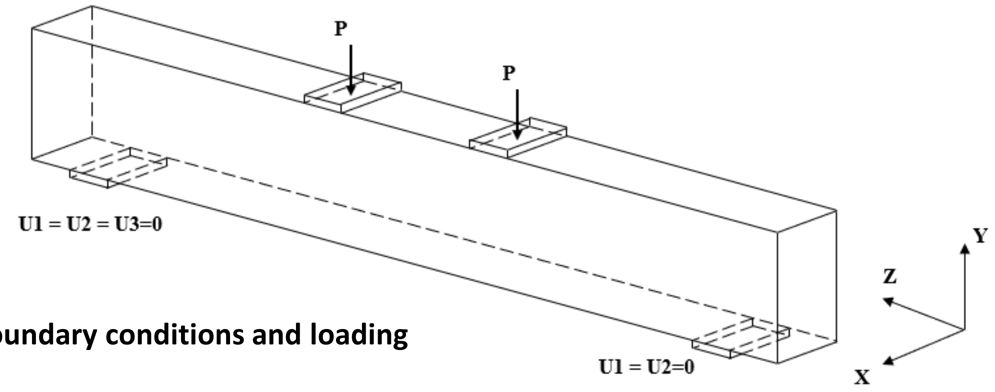
According to CEB-*fib* model code (2010), the actual stress-strain diagrams can be simplified by an idealized characteristic diagram.

# FEA Model

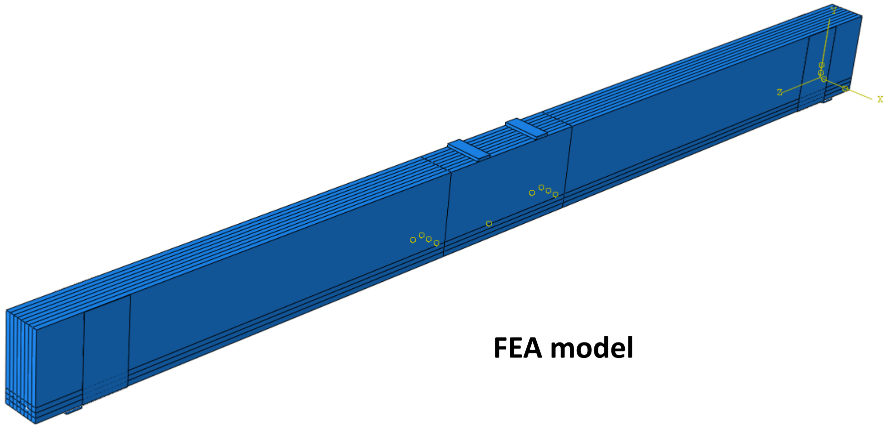
Material properties using in ABAQUS (ABAQUS Analysis User's Manual (v6.6))

| Material | Concrete | Stirrup & Top Reinforcement | CFRP | Bottom Reinforcement | Epoxy Resin |
|---|---|---|---|---|---|
| **Element Type** | C3D8R | T3D2 | C3D8R | C3D8R | COH3D8 |
| **E (MPa)** | 24,511 | 200,000 | 164,785 | 200,000 | 4,500 |
| **Strength (MPa)** | 21 | 414 | 2,800 | 414 | 30 |

# FEA Model



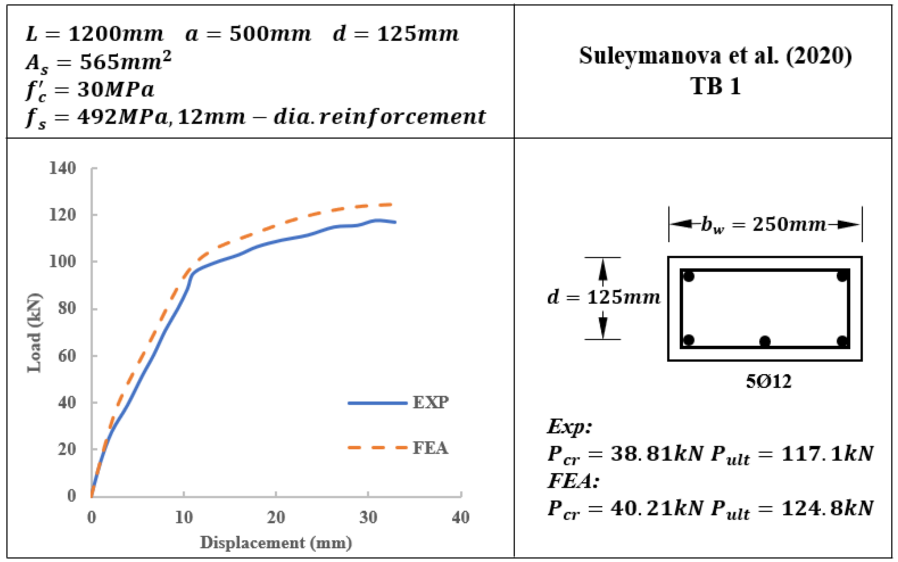

Boundary conditions and loading



FEA model

The composite system was simply supported. Displacement in x, y & z-direction were constrained with pined support (U1 = U2 = U3 = 0). To model the roller support, displacement in x, y-direction were constrained (U1 = U2 = 0)
To avoid load concentration, external loads were applied in y-direction as pressure on a rigid load plate which was tied with the concrete surface.

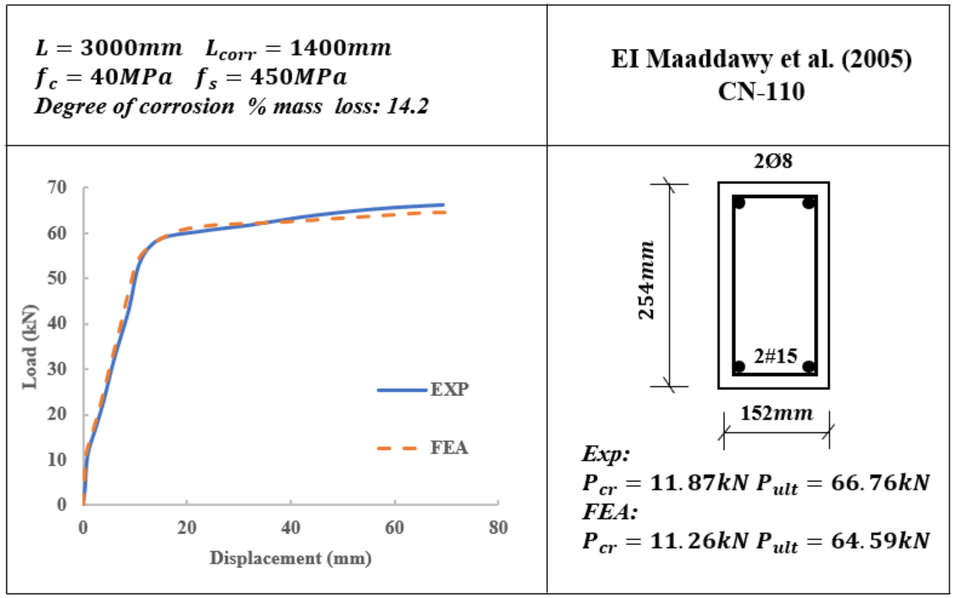
# Verification




Suleymanova et al. (2020) conducted an experimental study to investigate the role of shear-span to depth ratio ($a_v/d$) ratio for the cross-sectional area of RC beam on the defection in RC beams (deep and normal beams), when the value of shear-span to depth ratio equal to (TB-3 = 1.0, TB-2 = 2.0, TB-1 = 4.0, and R.B.= 3.0). In this study, TB-1 was selected to verify the FEA result.

**Load-deflection curve of TB 1 from FEA and Exp. (Suleymanova et al., 2020)**

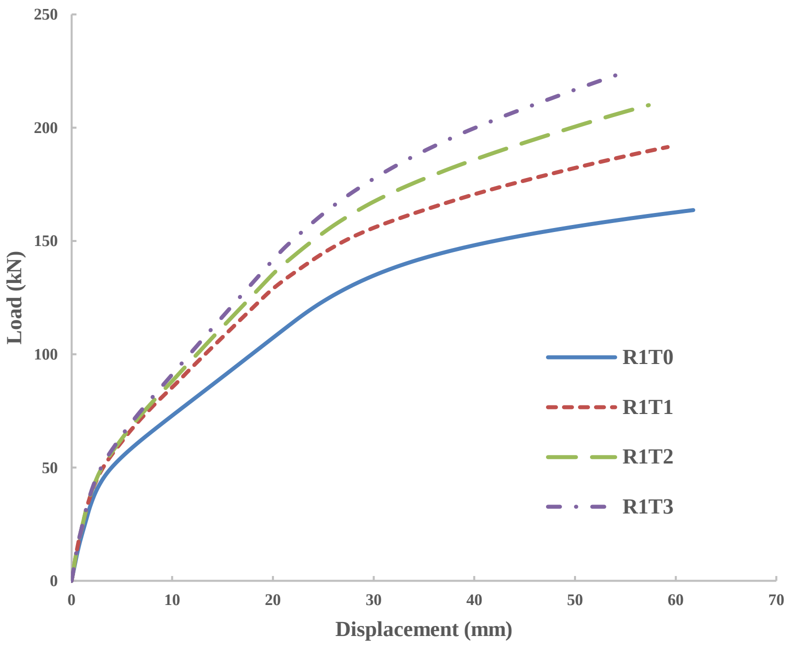
## Verification



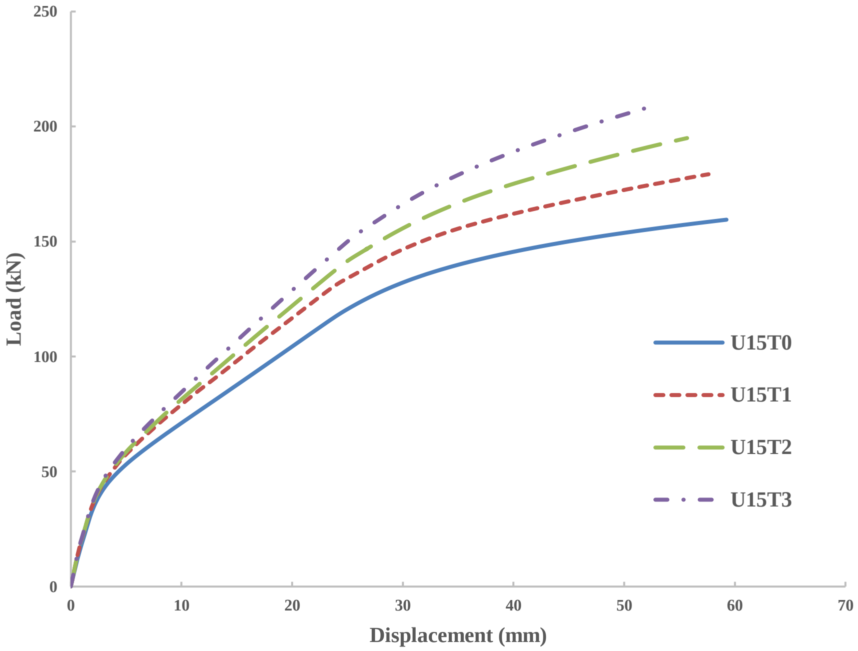

El Maaddawy et al. (2005) performed a test on one control beam and four corroded beams with different corrosion degrees. While the control beam was not exposed to corrosion, the other four specimens CN-50, CN-110, and CN-310 were subjected to 50, 110, 210, and 310 days of corrosion exposure, which resulted in average steel mass losses of approximately 8.9%, 14.2%, 22.2%, and 31.6%, respectively. Specimen CN-110 was selected to validate in this study.

**Load-deflection curve of CN-110 from FEA and Exp. (El Maaddawy et al., 2005)**

## Simulation Results

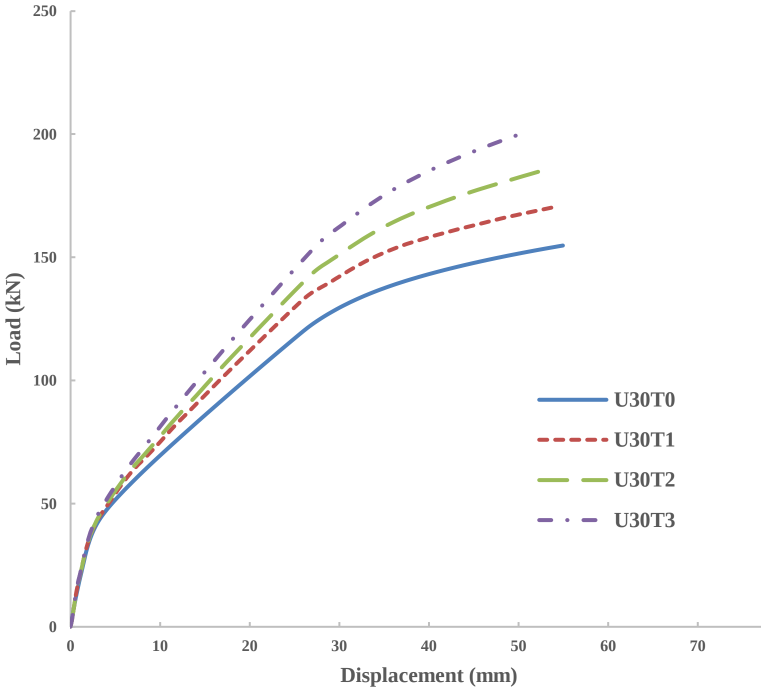



CFRP thickness=0mm, 1mm, 2mm & 3mm ($L_{ub} = 0\%L$ )

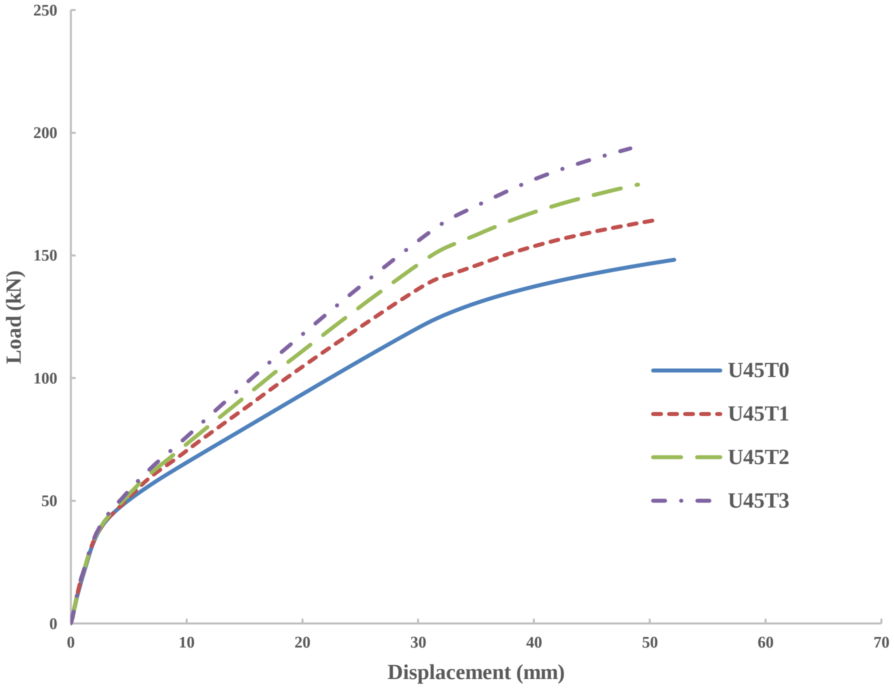



CFRP thickness=0mm, 1mm, 2mm & 3mm ($L_{ub} = 15\%L$ )

# Simulation Results

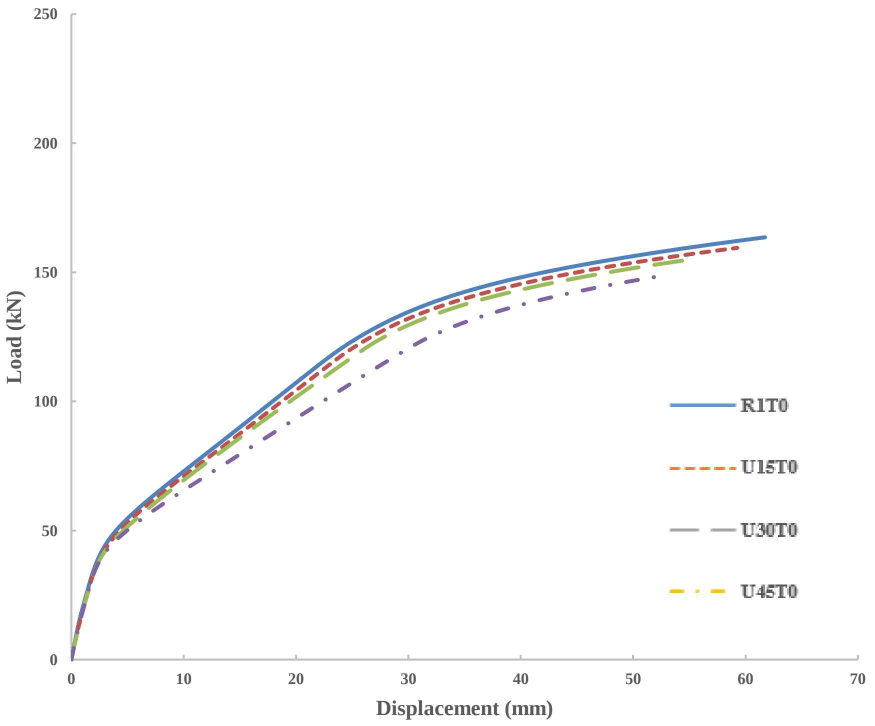



CFRP thickness=0mm, 1mm, 2mm & 3mm ($L_{ub} = 30\%L$ )

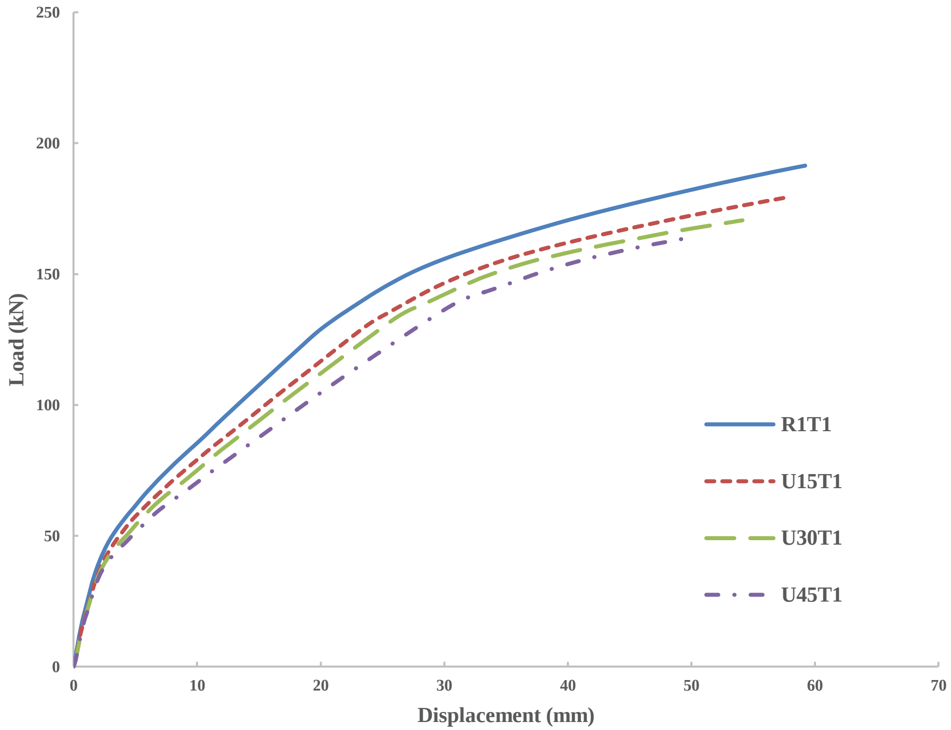



CFRP thickness=0mm, 1mm, 2mm & 3mm ($L_{ub} = 45\%L$ )

## Simulation Results

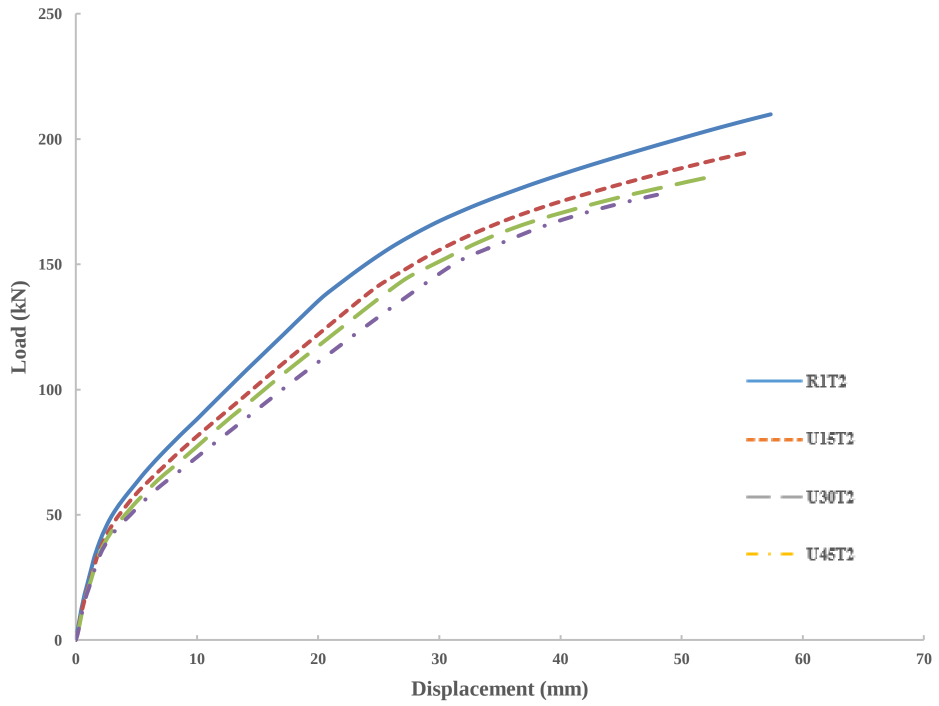



$L_{ub} = \underline{0\%}L, 15\%L, 30\%L\ and\ 45\%L$ (0mm CFRP)

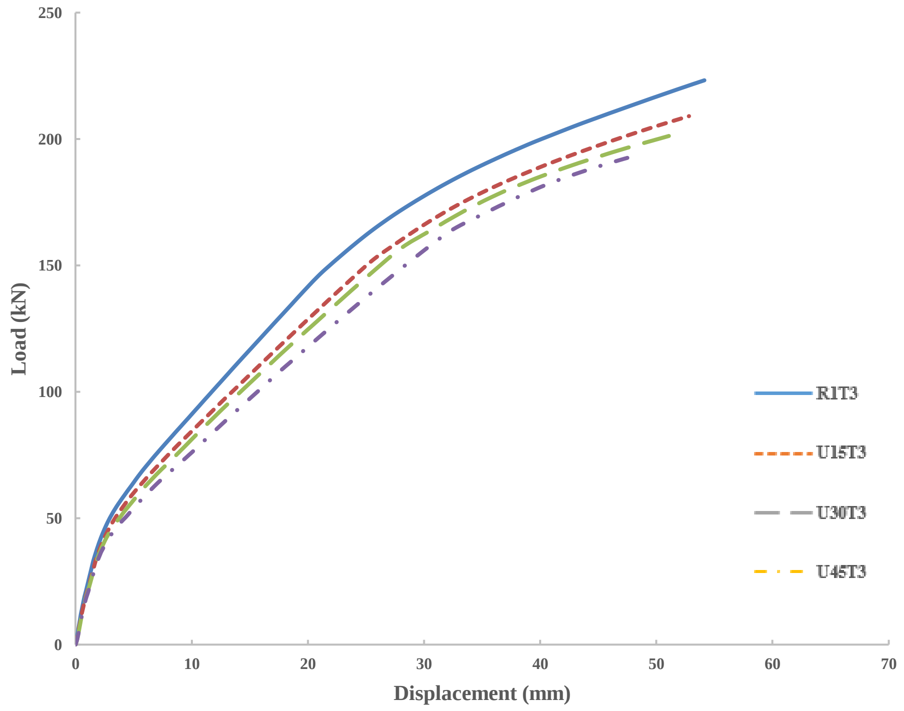



$L_{ub} = \underline{0\%}L, 15\%L, 30\%L\ and\ 45\%L$ (1mm CFRP)

## Simulation Results




$L_{ub} = \underline{0\%}L, 15\%L, 30\%L\ and\ 45\%L$ (2mm CFRP)




$L_{ub} = \underline{0\%}L, 15\%L, 30\%L\ and\ 45\%L$ (3mm CFRP)

# Conclusions

Based on the results of the role of unbonded length ($L_{ub}$) and CFRP thickness conducted throughout this study, the following conclusions could be drawn:

- Unbonded length of main reinforcement has a significant impact on the behavior of flexure dominated RC beams
- For flexure dominated RC beams, the lack of bond between concrete reinforcement greatly affects the stiffness, ductility, and ultimate strength. All decrease as the unbonded length increases.
- CFRP is an effective rehabilitation material for RC beams with different unbonded lengths.
- With increase of CFRP thickness, the stiffness and ultimate strength were all significantly increased but the ductility decreased.

# REFERENCES

[1] Al-Rifaie, W. N., Ismaeel, N. N., and Riyad, H., 2017, "Rehabilitation of damaged reinforced concrete beams", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 14(3), 58-70.
[2] Jnaid, F. and Aboutaha, R. S., 2014, "Residual flexural strength of reinforced concrete beams with unbonded reinforcement", ACI Structural Journal, 111(6), 1419-1430.
[3] Zhao, Y. and Lin, H., 2018, "The bond behavior between concrete and corroded reinforcement: state of the art", Sixth International Conference on Durability of Concrete Structures, KN05, 63-73.
[4] Dhand, V., Mittal, G., Rhee, K.Y., Park, S.-J and Hui, D., 2015. "A short review on basalt fiber reinforced polymer composites", Composites Part B: Engineering, 73, 166-180.
[5] Yang, K. H. et al, 2014. "Stress-strain model for various unconfined concretes in compression", ACI Structural Journal, 111(4), 819-826.
[6] Nayal, R. and Rasheed, H. A., 2006. "Tension stiffening model for concrete beams reinforced with steel and FRP bars", Journal of Materials in Civil Engineering, 18(6), 831-841.
[7] CEB-fib, 2010. "Design input data", International Federation for Structural Concrete Bulletin, No.55.
[8] Suleymanova, L. et al., 2020. "The role of shear span to effective depth ratio (a/d) on the deflection in deep and normal reinforced concrete beams when this ratio is (1, 2, 3, and 4)", IOP Conference Series Materials Science and Engineering, 890(1), 012044.
[9] El Maaddawy T. et al, 2005. "Long-term performance of corrosion-damaged reinforced concrete beams", ACI Struct J, 105(5), 649-56.

# Thank you !