NUMERICAL MODELLING OF RC BCJ SHEAR-STRENGTHENED WITH EMBEDDED CFRP BARS

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- Summary of Experimental Work
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Intoduction

- Reinforced concrete (RC) buildings constructed during the 1970s or earlier was vulnerable elements during an earthquake and can undergo sudden brittle failure known as joint shear.
- FRP strengthening system gained interest due to their excellent mechanical and durability properties (Mosallam, 2000; Dirar et. al., 2012)
- Majority numerical (Abbas et.al, 2014; Liang et.al, 2016; Esmaeeli et.al, 2017) and analytical (Pantazopoulou and Bonacci, 1992; Hwang and Lee, 1999) studies focused on the externally wrapped FRP to strengthen RC BJC.
- A novel technique to strengthened RC BCJ using DE method was introduced (Rahman et al., 2018)

Aim and scope of work

- Aim

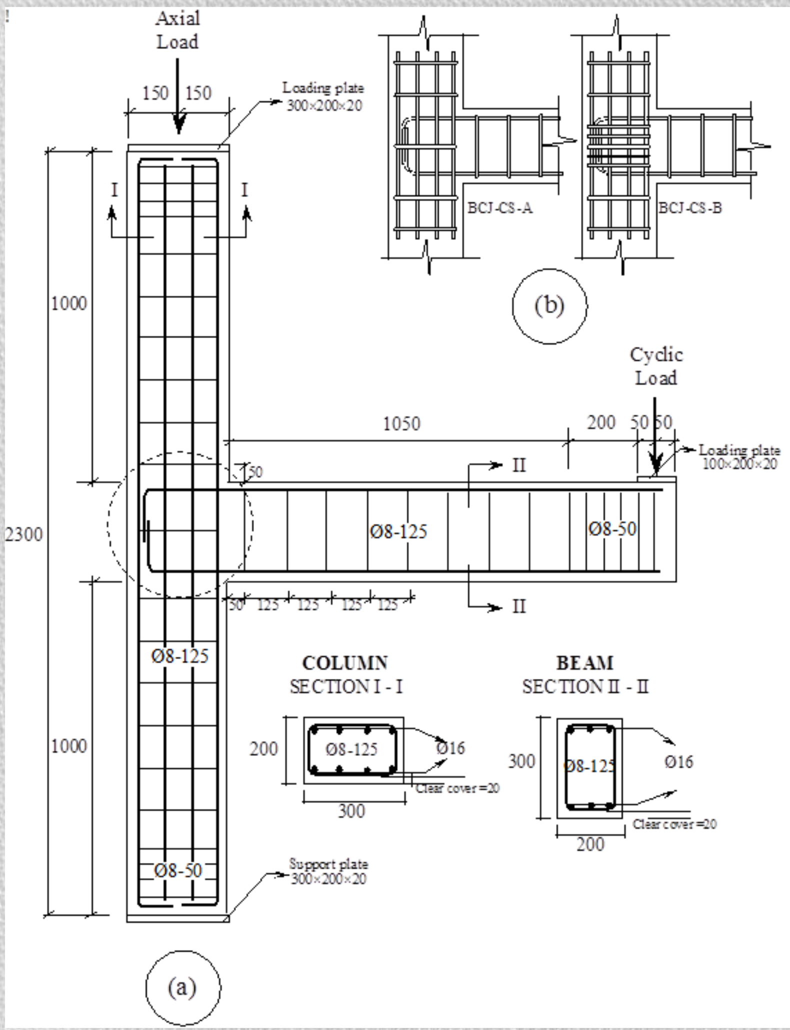
  To develop a nonlinear finite element (FE) model for RC BCJ shear-strengthened with embedded CFRP bars

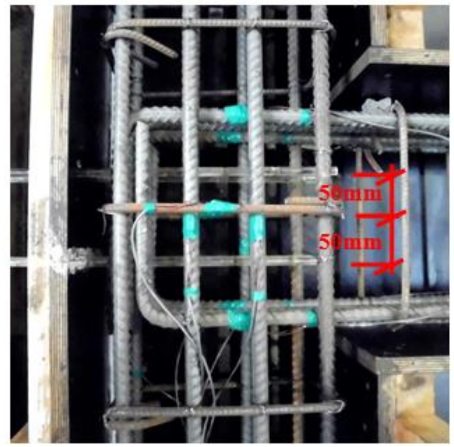
- Scope

  The predictions of the FE model are compared with experimental and analytical results

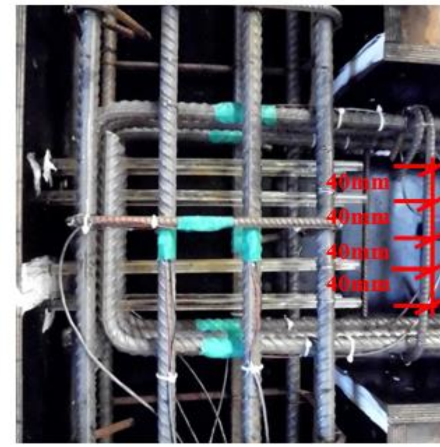
Summary of Experimental Work

- Reinforcement and strengthening configuration

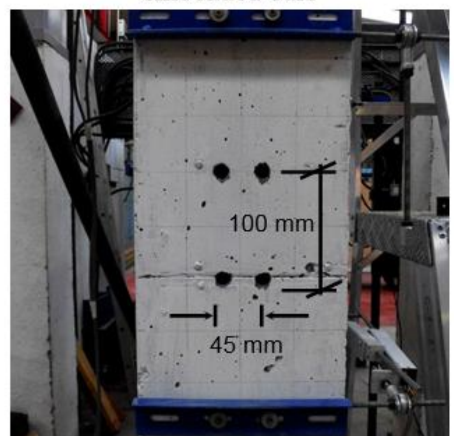




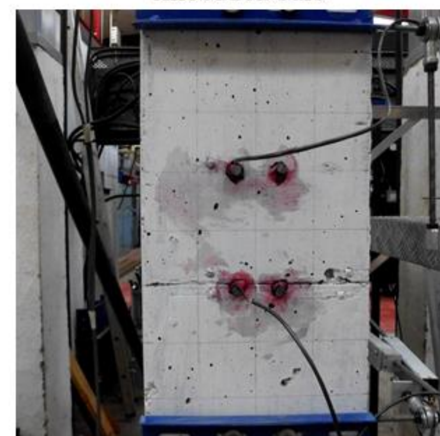
Acrylic rods within specimens with four embedded bars



Acrylic rods within specimens with eight embedded bars



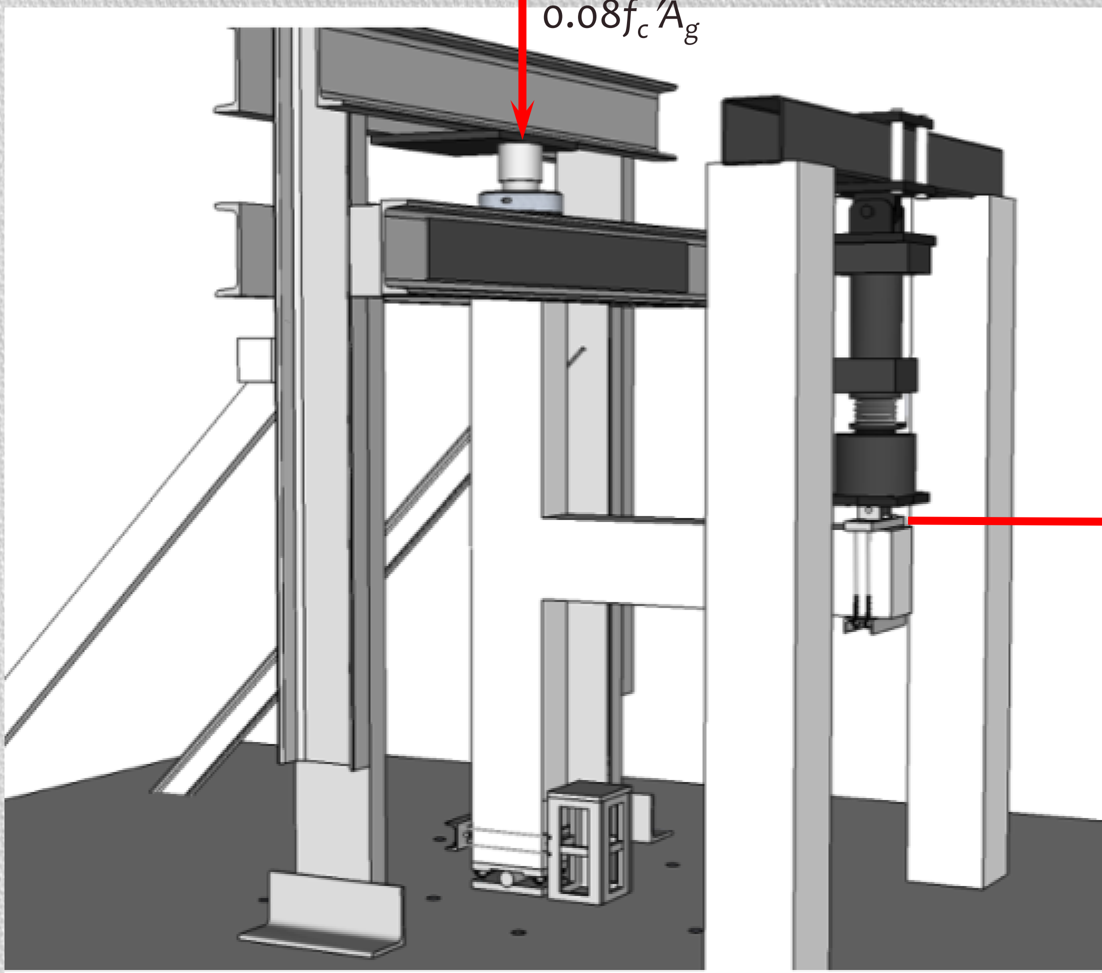
Holes prepared for embedded bars

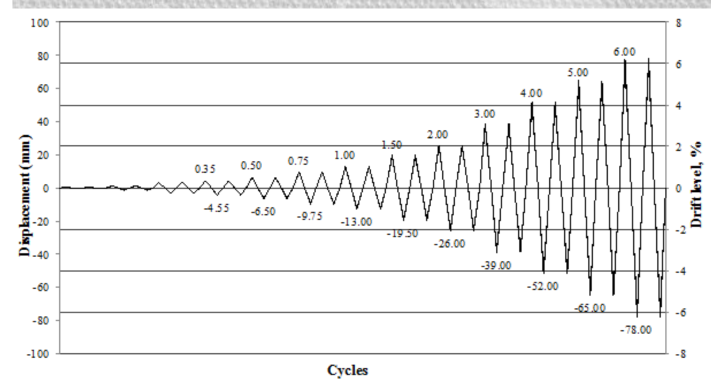


Application of embedded bars

- Experimental setup

Axial load
$0.08 f_c' A_g$





Cyclic load

Material

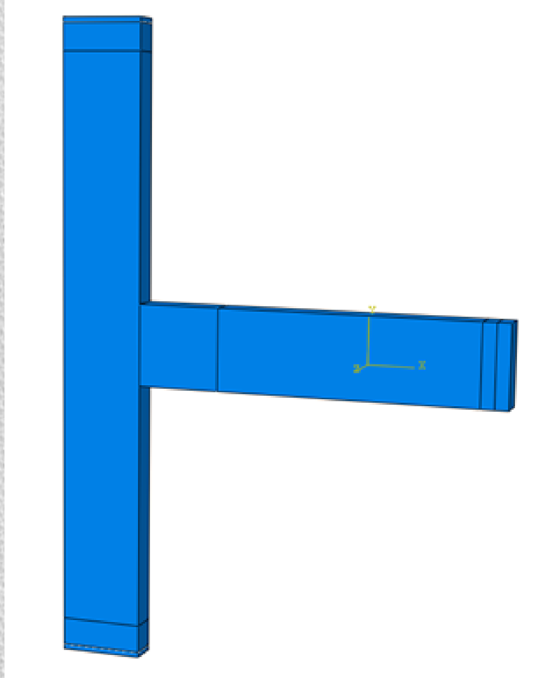
- The concrete cylinder compressive strength on testing day was 32 MPa
- Reinforcement bars:

Diameter (mm)	F_y (MPa)	F_u (MPa)	E_s (MPa)
8	580	672	198.7
16	512	671	200

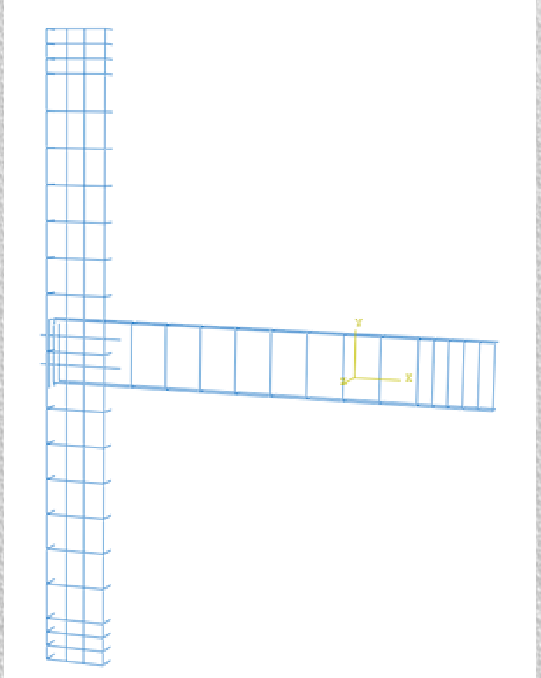
- The CFRP bars had a tensile strength and elastic modulus of 2300 MPa and 130 GPa, respectively.

Description of the FE Model

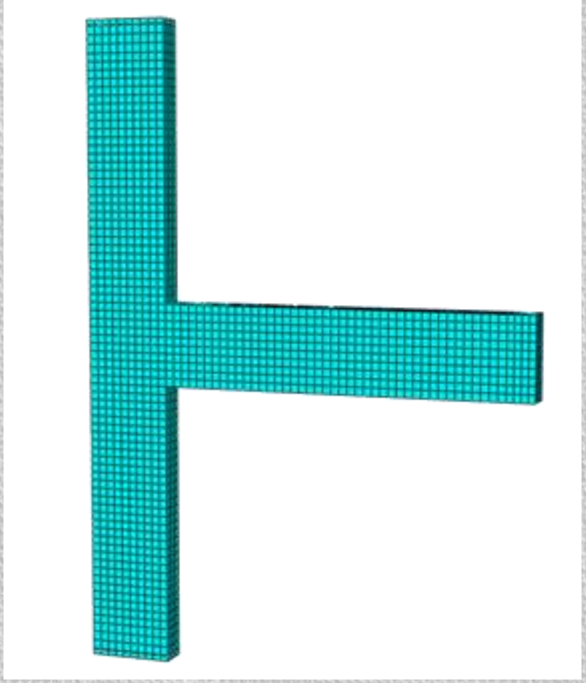
Geometric model and mesh



Geometric model for concrete

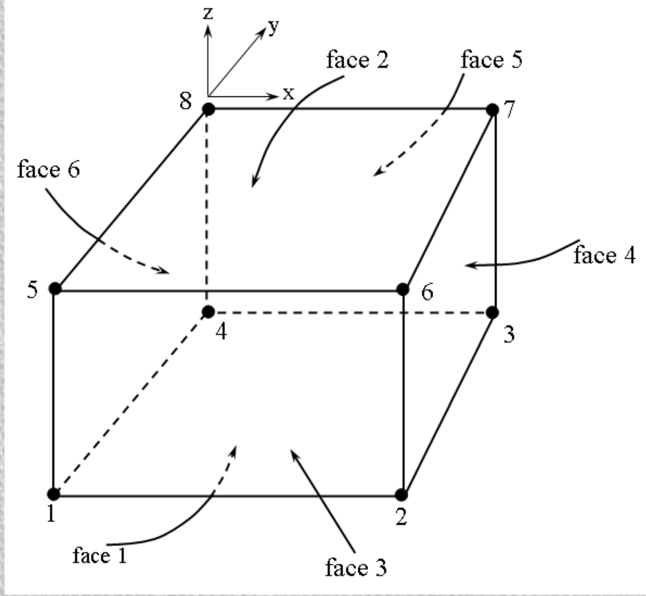


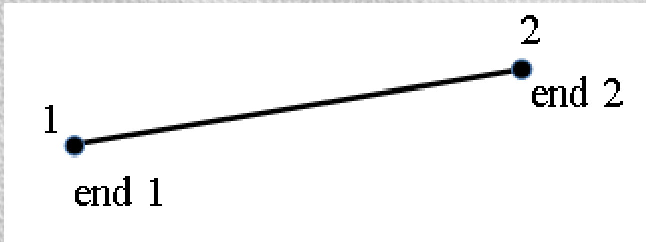
Geometric model for reinf. bars



Finite Element Mesh

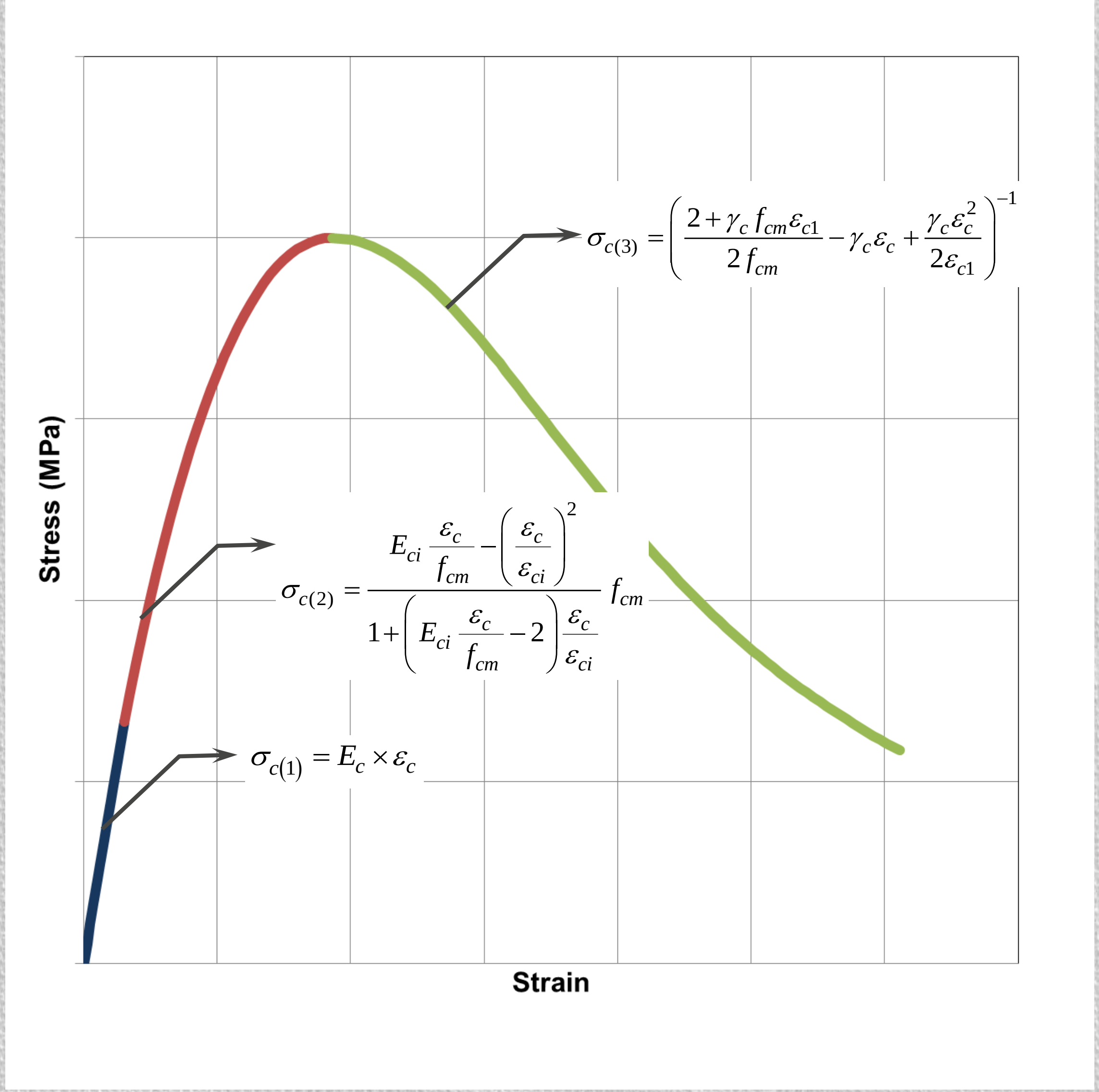
- Three-dimensional, eight-node, linear brick elements with reduced integration (C3D8R) were used to model the concrete, since it was suitable to model RC members subjected cyclic loading (Danesh et al., 2008; Gebreyohaness, 2013)
- One dimensional, two-node truss elements (T3D2) were used to model the steel reinforcement and CFRP bars. Other one-dimensional element types in ABAQUS (e.g. B31 and B32) showed no significant effect on the accuracy of the results and resulted in higher computational cost (Gebreyohaness, 2013)



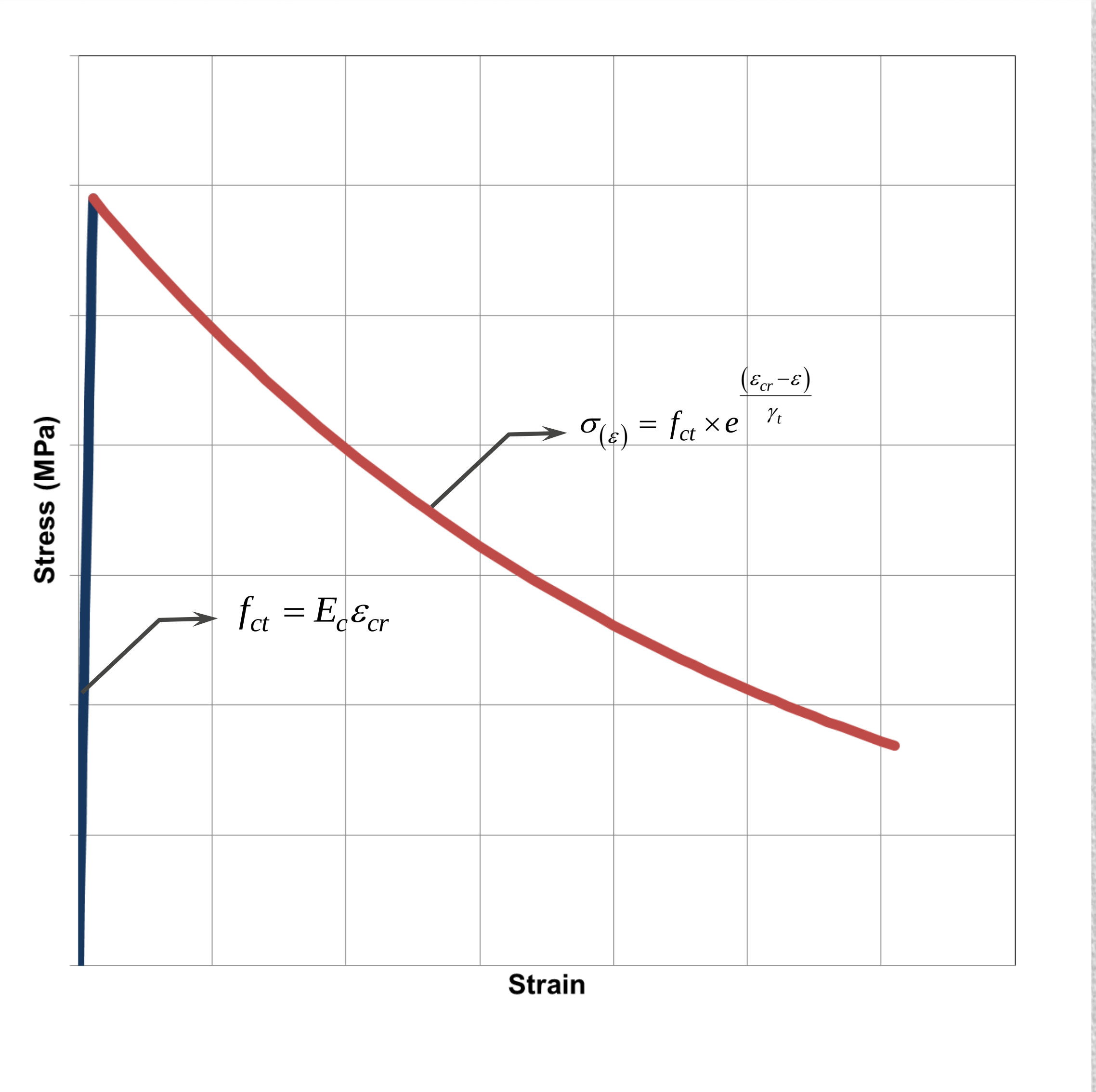


Concrete Damage Plasticity model

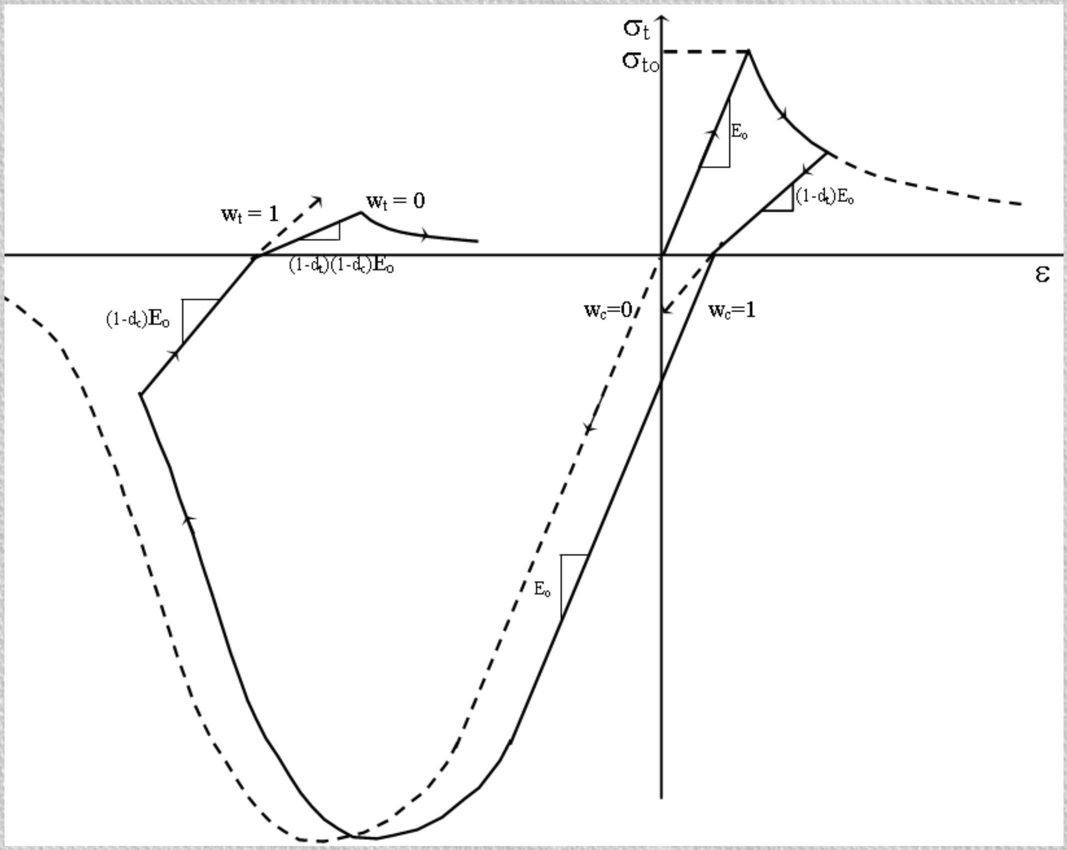
- Model for concrete in compression



- Model for concrete in tension



- During reversed cyclic loading, the elastic stiffness of concrete is weakened by the damage accumulated during loading and unloading.
- The elastic stiffness degradation is defined by two damage variables, d_t and d_c ($0 \leq d_t, d_c \leq 1$). The partial recovery of elastic stiffness as the load changes sign during cyclic loading is considered.



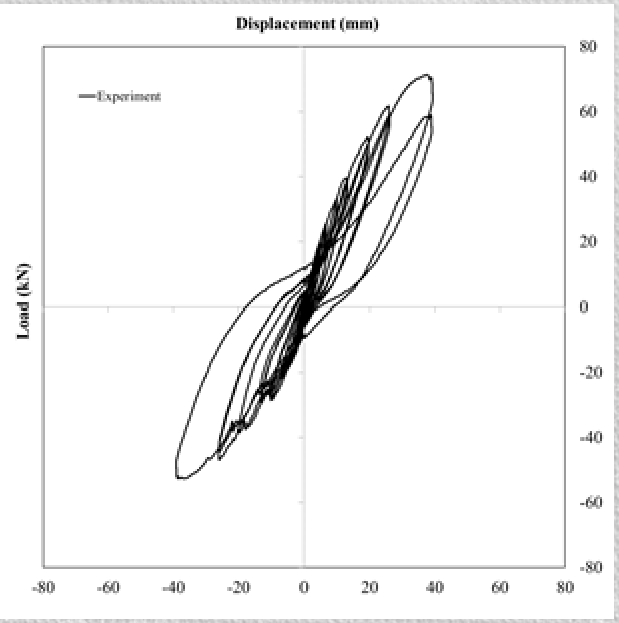
Reinforcement bar material model

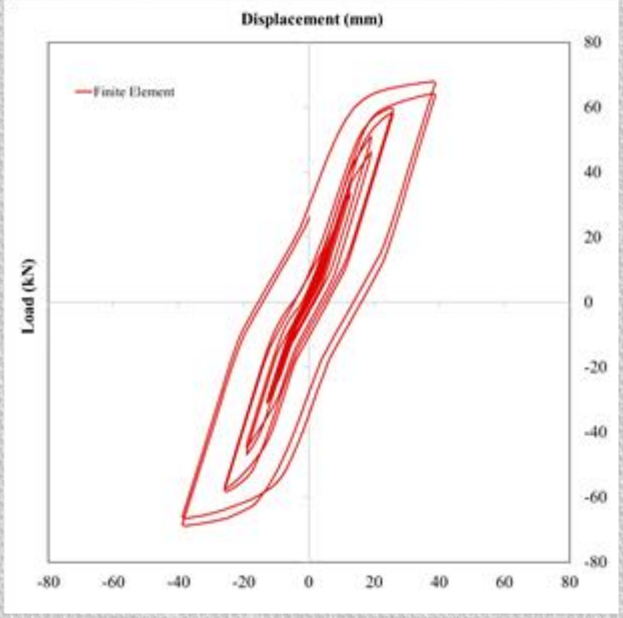
- An elastic-plastic model was used for the steel reinforcement. The elastic modulus, yield strength and ultimate strength values determined by tensile testing were used to define a trilinear elastic-plastic-linear hardening stress-strain curve.
- The CFRP bars were modelled as linear elastic up to failure.

Results
Hysteresis Response

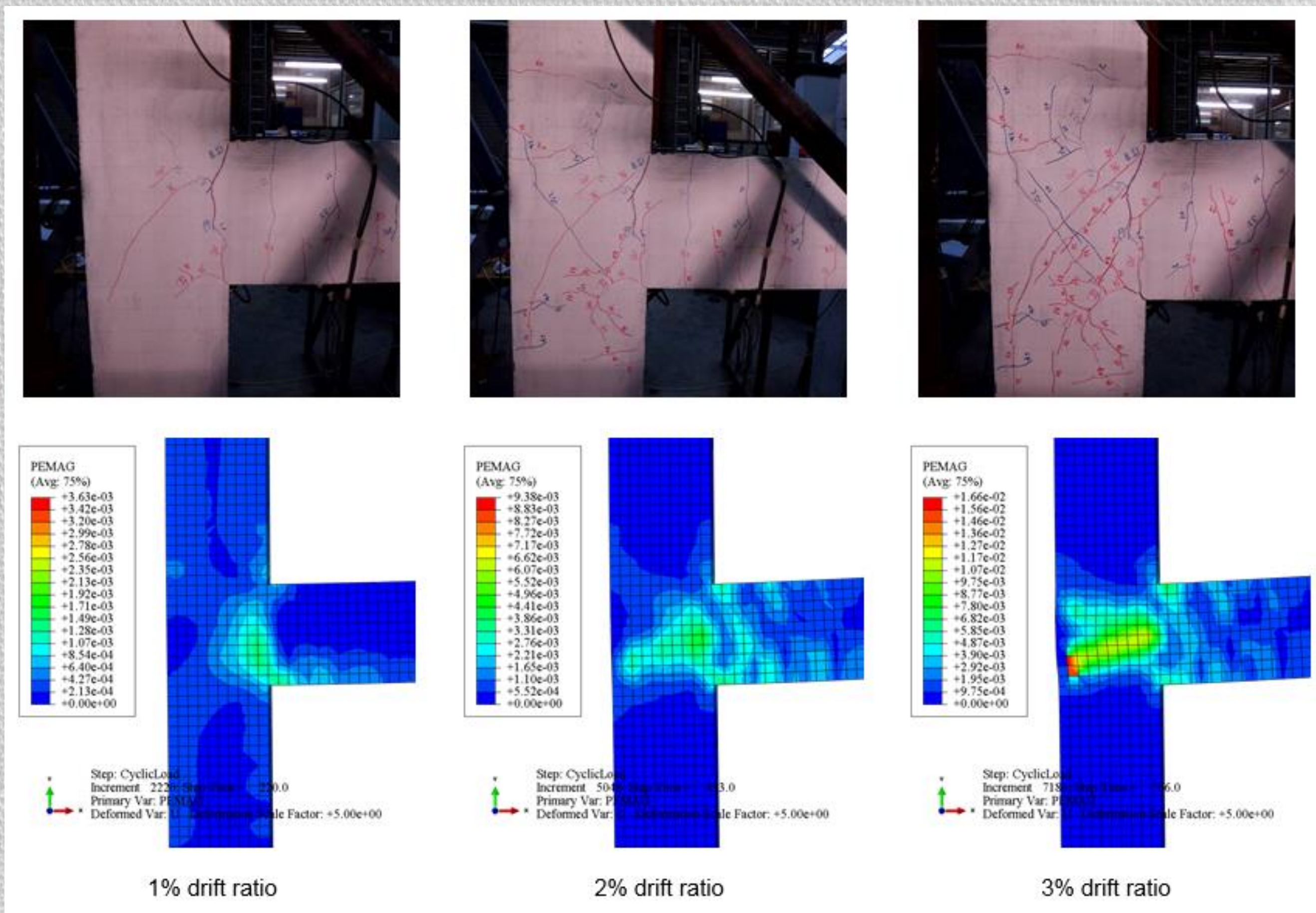
The experimental and FE-predicted hysteresis response up to 3% drift ratio (corresponding to peak load) are presented.

- Both the experimental and numerical results featured a quasi-linear load-displacement response, with limited stiffness degradation, up to peak load.
- The FE predictions showed good agreement with the experimental results in terms of peak-to-peak load-displacement response.
- The FE model predicted the secant stiffness with mean predicted/experimental ratios of 1.00 and 1.24, and standard deviations of 0.12 and 0.11 for upward and downward loading, respectively. Table 1 shows that the predicted/experimental peak load ratios at 1, 2, and 3% drift ratios were 0.85, 0.94 and 0.89 respectively. This demonstrates the accuracy of the FE model.





Results
Damage Evolution



The experimental and FE-predicted damage at 1, 2 and 3% drift ratios are shown.

- The FE model correctly predicted damage accumulation at the beam-column interface at 1% drift ratio. With increased loading, the FE model correctly predicted both the propagation of flexural cracks in the beam and the accumulation of damage in the joint panel. At 3% drift ratio, the FE-predicted damage mainly accumulated in the joint panel whereas the flexural cracks in the beam remained stable.
- This correlates well with the experimental crack pattern at 3% drift ratio where X-shaped diagonal cracks formed within the joint area

Experimental Vs Numerical and Analytical Results

- Rahman et al. (2018) developed an analytical model for RC BCJ strengthened in shear with embedded bars.
- The model is based on those proposed by Pantazopoulou and Bonacci (1992) and Antonopoulos and Triantafillou (2002).
- It covers BCJ response before and after the yielding of the longitudinal and transverse steel reinforcement. Failure is defined as either concrete crushing or debonding of the embedded bars. Further details on the analytical model are available elsewhere (Rahman et al. (2018) .

- The analytical model predicted a shear strength of 6.5 MPa for the tested specimen whereas the FE-predicted shear strength was 5.5 MPa.
- Both values correlate well with the experimental shear strength value of 6.2 MPa, with the FE model providing a conservative lower bound estimate of the joint shear strength.

Conclusions

This paper presents a three-dimensional nonlinear finite element model for reinforced concrete beam-column joints strengthened in shear with embedded CFRP bars.

- The model was used to predict the response of a test specimen. The FE model predicted the hysteresis response, including secant stiffness and peak load, with good accuracy.
- There was also good correlation between the experimental and FE-predicted damage evolution.
- Comparison between experimental, numerical and analytical results showed that the FE model gave a conservative estimate of the joint shear strength.

Thank you