Strength Predictions of RC Beam with Various Percentages of Tension Reinforcements

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ABSTRACT: Evolution of computing technology has led to aggressive application of finite element analysis (FEA) framework. Large parametric arrays involved has led to laborious experimental set-up and costly to perform in reinforced concrete beam test. This paper aims to develop a strength prediction framework of RC beam series with variation of tension reinforcement percentages following experimental series by Hussein & Poluraju. Two constitutive models were adopted, i.e., Extended Finite Element Method (XFEM) and Concrete Damage Plasticity (CDP) embedded within ABAQUS CAE 2017. The CDP datasets was captured from similar concrete mixture and reinforcement size reported in Lee *et.al*. Moreover, Maximum Principal Stress (MAXPS) damage criterion based on traction-separation relationship used in the XFEM technique. The post-processing was then validated with the experimental datasets. Overall, good predictions were obtained where CDP showed less discrepancies than XFEM counterparts.

Keywords: *Concrete Beam*; *FEA; CDP; XFEM*

1. INTRODUCTION

Booming demand in housing and infrastructures leading to drastic construction works that requires increased usage of structural reinforced concrete beam and requirement of optimum structural design with different percentages of reinforcement. Presence of large arrays of reinforcement percentage in Reinforced concrete (RC) beam resulting to costly and laborious method to perform an experimental set up. Hence, it is beneficial to conduct FEA modelling to evaluate the RC beams with different percentage of reinforcement. Optimization of reinforcement size and configurations are required to produce a cost-effective and loading resistance design.

FEA is used to investigate structures behavior in reinforced concrete due to external loading based on real problems. Development of modelling framework as a numerical tool is beneficial to study structural response and perform strength prediction of RC beams subjected to four-points bending test. The model used independent material properties embedded within constitutive model available in ABAQUS CAE 2017 to provide a reliable and accurate solutions. These models can be further extended by future researchers to other structures arrays such as different loading conditions and presence of discontinuities such as notches. It is inevitably true that FEA able to facilitate structures engineers to perform optimum design with good precisions. Here, a series of 3D FEA model of concrete beam were developed using ABAQUS CAE 2017 and described in the subsequent sections.

2. FEA MODELLING

Hussain & Poluraju [1] investigated experimentally six reinforced concrete (RC) beam series under four-point bending test with variation of tension reinforcement bar (rebar) area and rebar configurations. The beam size of 2200 × 150 × 300 mm^3 and effective span of 2 m of concrete grade of 30 N/mm^2 and concrete cover of 25 mm. Additional information includes constant 6 mm diameter stirrup with 300 mm spacing.

The beam series were modelled using first-order brick element with eight nodes and incompatible mode (element designation as C3D8I). Moreover, a deformable solid part was used as roller and punch. As for the rebar and stirrups, it was model by using deformable wire. Figure 1 shows all modelling part in tested RC beam. In this study, finer mesh was made at the vicinity of mid-span (associated with large bending moment) region. The displacement is applied at the reference control points by coupling to surface of steel punch by applying traction downward. The supports were assigned as pin and roller supports at left and right supports, respectively.

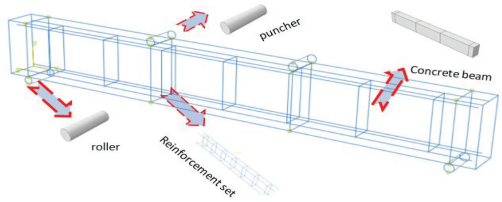

Figure 1 Components parts involved as seen in a tested RC beam

The fracture energy of the concrete beam investigated was determined from three-point bending test. The fracture energy was recorded as 147 N/m and Young's modulus of concrete was measured as 26.5 GPa. High strength deformable bars with yield strength of 500 N/mm² were used as flexural reinforcement of two different rebar size of 8 mm and 10 mm diameters. A constant 6 mm diameter bars were used as stirrup.

CDP model requires concrete plasticity datasets input to explicitly incorporates concrete plasticity due to crushing and cracking. Current study adopted CDP datasets, comprised of tensile and compression yielding datasets of the concrete beam were taken from the literature reported in Lee *et.al* [2]. Extended Finite Element Method (XFEM) has the advantage to track visually crack propagations without requirement of mesh refinements [9]. XFEM incorporates traction-separation law by using Maximum Principal Stress (MaxPS) damage criterion. If the maximum principal stress has reaches to a certain value, fracture is demonstrated in STATUSXFEM field output.

3. RESULTS AND DISCUSSION

3.1 Sensitivity Study

A consistence of mesh refinements and damage stabilization coefficients were incorporated to give a reliable strength prediction in all models under investigations. As the mesh density increases requires more computational time and cost to necessitate a balance between accuracy and computational efforts to provide a practical but yet sensible numerical model. The cohesive damage stabilization was used to improve convergence of finite element calculation by employing damage tolerances. As the damage stabilization coefficient reached 1x 10^{-6} the strength prediction has started to show consistence peak load.

3.2 Validation of strength predictions with experimental datasets

Table 1 showed the modelling discrepancies of strength prediction from both XFEM and CDP models with experimental datasets. It is regarded as good agreements if the discrepancies between strength prediction and experimental datasets were less than 20%.

Table 1 Comparison of strength predictions results of XFEM and CDP models with experimental datasets after Hussain and Poluraju [1].

Series Designations	P_{exp} (kN)	P_{XFEM} (kN)	Disc (%)	P_{CPD} (kN)	Disc (%)
RC-8-0.25	43	40	6.9	38	11.6
RC-8-0.37	62	55	11.3	53	14.5
RC-8-0.50	80	72	10.0	70	12.5
RC-10-0.39	75	70	6.7	65	13.3
RC-10-0.59	105	94	10.5	90	14.3
RC-10-0.79	140	124	11.4	120	14.3

*Disc = Discrepancies

Overall, good agreements were found in both modelling framework. However, less good agreement were seen in XFEM modelling due to several reasons. Firstly, the reinforcement plasticity datasets assigned in XFEM model was calibrated and taken from other literatures as it was not readily available in original Hussein & Poluraju [1]. Secondly, the slippage interactions between reinforcement and concrete are not well-defined and resulting to less good friction behaviour within the concrete matrix and steel reinforcement. Expansive computational costs and efforts are required to be idealized as explicit finite sliding. Current modelling approach assigned self-contact interaction between two interacting surface parts may not exhibits contributions of tensile stress transfer from steel reinforcement and leading to under-predictions.

Dilation angle is one of the most important parameters in CDP constitutive model as it influences the amount of plastic volume deformation. Additionally, CDP model is optimized to match the uniaxial compressive and tensile behavior of comparable concrete studies. The plasticity dataset comprised of yield associated with plastic stress and strain (on both tension and compression) are regarded as material properties that must be determined independently. Moreover, measured plasticity datasets of concrete in both tension and compression were not available leading to less good agreements. These associated fracturing phase were defined by a combination of non-associated multi-hardening plasticity and scalar (isotropic) damaged elasticity.

Good predictions in CDP models (to less extent within XFEM models) enables the simulation of concrete and other quasi-brittle materials as a homogeneous body. However, much better strength prediction can be obtained if these plasticity datasets input were independently determined. Limitation in employing XFEM model is inavailability to explicitly inlcudes proper slippage interactions due to limited computation resources. The absence of properly model explicit slip deformation beween rebar and concrete leading to unavailability of proper stress transfer between contact surfaces of rebar and concrete beam.

4. CONCLUSION

Less good predictions in XFEM modelling but better predictions were expected if the slip behavior between concrete beam and rebar were properly defined and captured. However, CPD requires a comprehensive determination of material parameters and plasticity datasets (suggested to be independently determined) and implemented as a homogenous body, therefore better prediction in CPD models is perhaps not surprising.

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