Scientific Research and Essays Vol. 7(21), pp. 2002-2009, 7 June, 2012
Available online at http://www.academicjournals.org/SRE
DOI: 10.5897/SRE11.1393
ISSN 1992-2248 ©2012 Academic Journals

Full Length Research Paper

Evaluation of reinforced concrete beam behaviour using finite element analysis by ABAQUS

Hamid Sinaei*, Mahdi Shariati, Amir Hosein Abna, Mohammad Aghaei and Ali Shariati

Faculty of Engineering, Science and Research Branch, Islamic Azad University, Sirjan, Iran.

Accepted 10 January, 2012

In this research, the ABAQUS program is used to model the behaviour of reinforced concrete (RC) beams. The finite element model uses the concrete damaged plasticity approach; this model can help to confirm the theoretical calculations as well as to provide a valuable supplement to the laboratory investigations of behaviour. For validation, a reinforced concrete beam was modelled that had been experimentally tested and reported in previous experimental research. This is followed by a comparison of the finite element with the experimental results for the RC beam element. This paper compares the numerical results with experimental data for the reinforced concrete beam subjected to flexural loading. The results indicate that the displacement, tensile strain for the main reinforcement, compressive strain for concrete and crack patterns obtained from the finite element model (FEM) are well matched with the experimental results.

Key words: ABAQUS, finite element, fiber reinforced polymer, reinforced concrete beam, nonlinear failure.

INTRODUCTION

Reinforced concrete is a complicated material to be modelled within finite element packages. A proper material model in the finite element model should inevitably be capable of representing both the elastic and plastic behaviour of concrete in compression and tension. The complete compressive behaviour should include both elastic and inelastic behaviour of concrete including strain softening regimes. The simulation of proper behaviour under tension should include tension softening, tension stiffening and local bond effects in reinforced concrete elements. Therefore, the development of a finite element model (FEM) may need intensive material testing to incorporate into the material model in any of the finite element (FE) packages available (Sinaei et al., 2011). There are quite a large number of numerical material models available in the literature with the potential to develop complete stress-strain curves of concrete for compression and tension separately based on the experimental results. In this research, the ABAQUS program Hibbitt et al. (1988) is used to model the behaviour of RC beams. The finite element model uses the concrete damaged plasticity approach; this model can help to confirm the theoretical calculations as well as to provide a valuable supplement to the laboratory investigations of behaviour.

For validation, a reinforced concrete beam was modelled which had been experimentally tested and reported by Kachlakev et al. (2001). This is followed by a comparison of the finite element with experimental results on RC beam elements in the following study.

EXPERIMENTAL BEAM

The data of the previous work by Kachlakev et al. (2001) was used as experimental data. One reinforced concrete beam with a span of 5485 mm was subjected to flexural loading. There were two concentrated loads and the distance between loads was1825 mm. The beam was 6095 mm long and the dimensions of the beam section were 770 × 305 mm. The longitudinal reinforcement is shown in the figure. The beam has no shear reinforcement; this reinforced concrete beam was fabricated and tested at Oregon State University. This paper considers the behaviour of the reinforced concrete beam (load-deflection curve, compressive stress of concrete and strain of the steel bars). The beam was tested in the position shown in Figure 1.

*Corresponding author. E-mail: hamid_sinaee@yahoo.com.

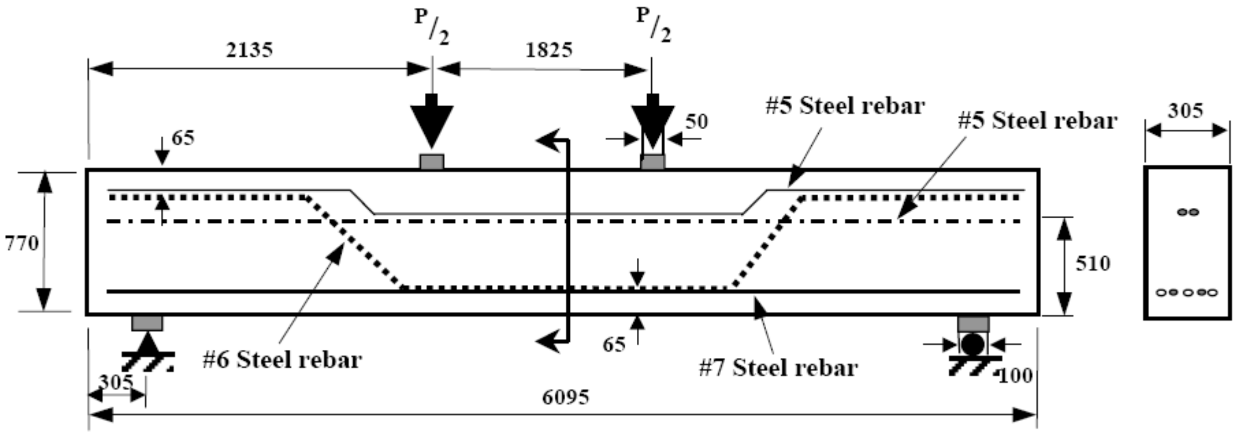

Figure 1. The schematic view of the experimental beam (Dimensions in mm).

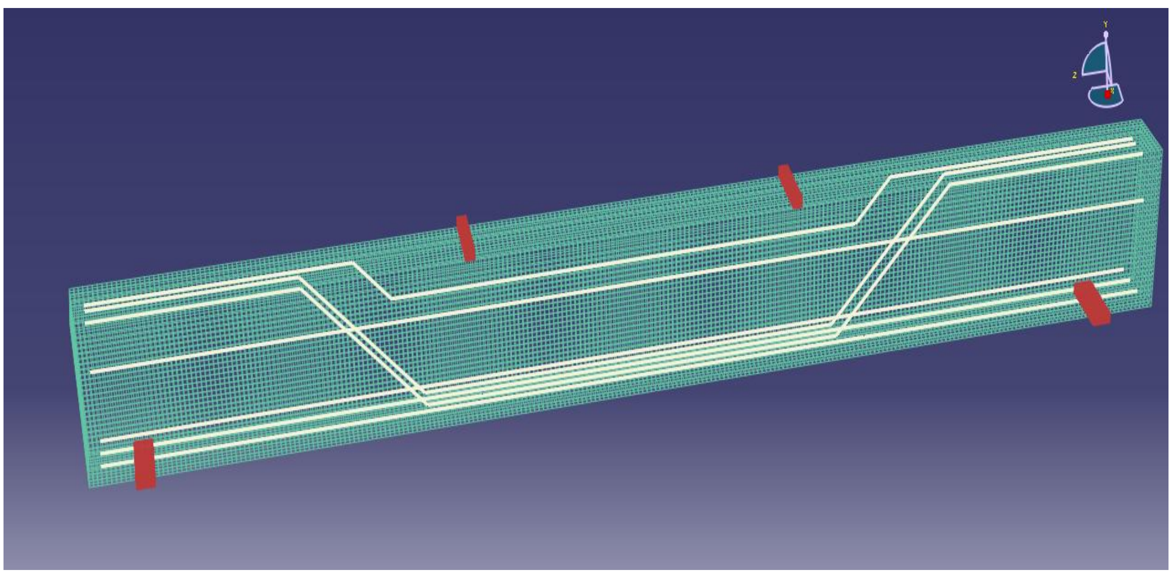

Figure 2. Finite element modeling parts in ABAQUS.

Finite element model

Material properties

In this specimen, concrete, steel bar and steel plate have been used (Figure 2). The properties of the materials are thus explained.

Steel reinforcing bar

An elastic, perfectly plastic material was used for the steel bar with an equal behaviour in tension and compression (Li et al., 2006). The steel bar was treated as a uniaxial material throughout the element section (Figure 3). We can define the rebars as one-dimensional strain elements that can be singly or embedded in the concrete. Their behaviour is the same as an elastic-plastic material. The rebars and concrete cracking behaviour were considered independently (Hu and Liang, 2000). The transfer of load across the concrete cracks through the rebars can be defined by introducing some "tension stiffening" into the concrete cracking model (Hu et al., 2010) The steel bars used in the reinforced concrete beam were assumed to have the yielding stress:

$$\sigma_y = 400MPa$$

While its elastic modulus was assumed to be:

$$E_S = 200GPa$$

The steel reinforcement was assigned with a Poisson's ratio of 0.3, and full bond contact between the steel reinforcement and concrete was presumed. The embedded element option was used for connecting the reinforcement element to the concrete element, steel reinforcement was used as the embedded element and the

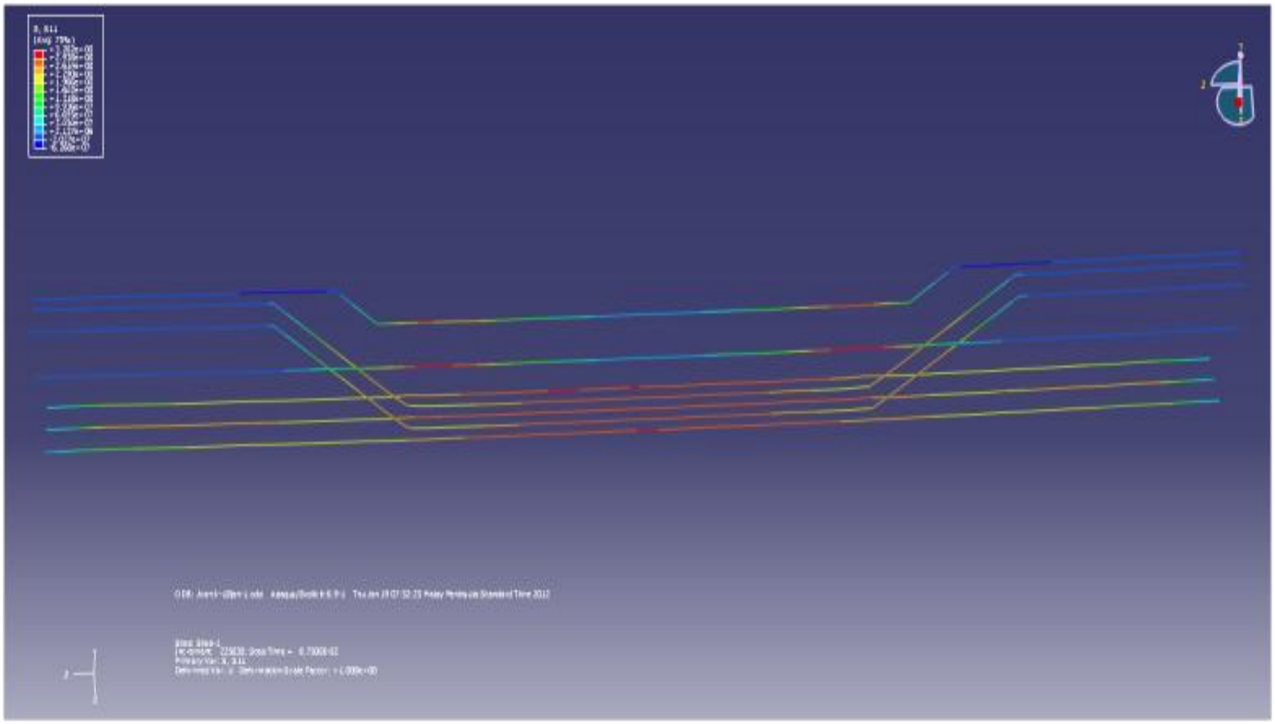

Figure 3. Steel bar stresses.

concrete was designated as the host element.

Concrete

The uniaxial compressive strength of concrete f_c' selected as:

$$f_c' = 168\text{MPa}$$

The strain of concrete ε_0 corresponding to f_c' can be between 0.002 and 0.003. A value of $\varepsilon_0 = 0.003$ is suggested and was used in the analysis. The Poisson rate of concrete V_C is taken as:

$V_C = 0.2$

The tensile strength of concrete f_t' in this paper has been calculated from:

$$f_t' = 0.61\sqrt{f_c'}$$

The modulus of elasticity Ec and the compressive strength of the concrete are dependent on each other and Ec can be considered to have the following value:

$$E_C = 4700\sqrt{f_c'}$$

The concrete failure strength is different under multiaxial combinations and those occurring under uniaxial status (Figure 5). It seems that the load path not be effective, the maximum strength of concrete under multiaxial loading. In ABAQUS, the failure surface of the concrete was modelled using a type of Mohr-Coulomb type compression surface together with a crack detection surface. The concrete response was modelled using the elastic-plastic theory, in which the principal stress components of the concrete are mainly compressive, and the concrete was modelled with an isotropic hardening rule and an associated flow (Figure 5). The orientation of the crack is stored once the crack is defined as occurring in tension. A certain parameter is needed to guide the yield surface expansion when plastic deformation occurs. A proper approach is to use the effective stress σ_c and effective strain ε_c such that the equivalent uniaxial stress-strain curve can correlate all the results obtained following different paths of loading.

Saenz (1964) proposed a stress-strain relationship which can be used as the uniaxial stress-strain curve for concrete as follows:

$$\sigma_c = \frac{E_c \varepsilon_c}{1 + (R + R_E - 2)\left(\frac{\varepsilon_c}{\varepsilon_o}\right) - (2R - 1)\left(\frac{\varepsilon_c}{\varepsilon_o}\right)^2 + R\left(\frac{\varepsilon_c}{\varepsilon_o}\right)^3}$$

Where:

$$R = \frac{R_E(R_\sigma - 1)}{(R_\varepsilon - 1)^2} - \frac{1}{R_\varepsilon}, \quad R_E = \frac{E_c}{E_o}, \quad E_o = \frac{f_c'}{\varepsilon_o}$$

Where $R_E = 4$ and $R_\sigma = 4$ can be used.

Using the aforementioned equivalent and finding several points uniaxial stress-strain curve for concrete can be approximated by several linear segments as shown in Figure 6. When concrete cracking occurs, the crack behaviour is represented and used to define a damaged plasticity model. After cracking, concrete still has

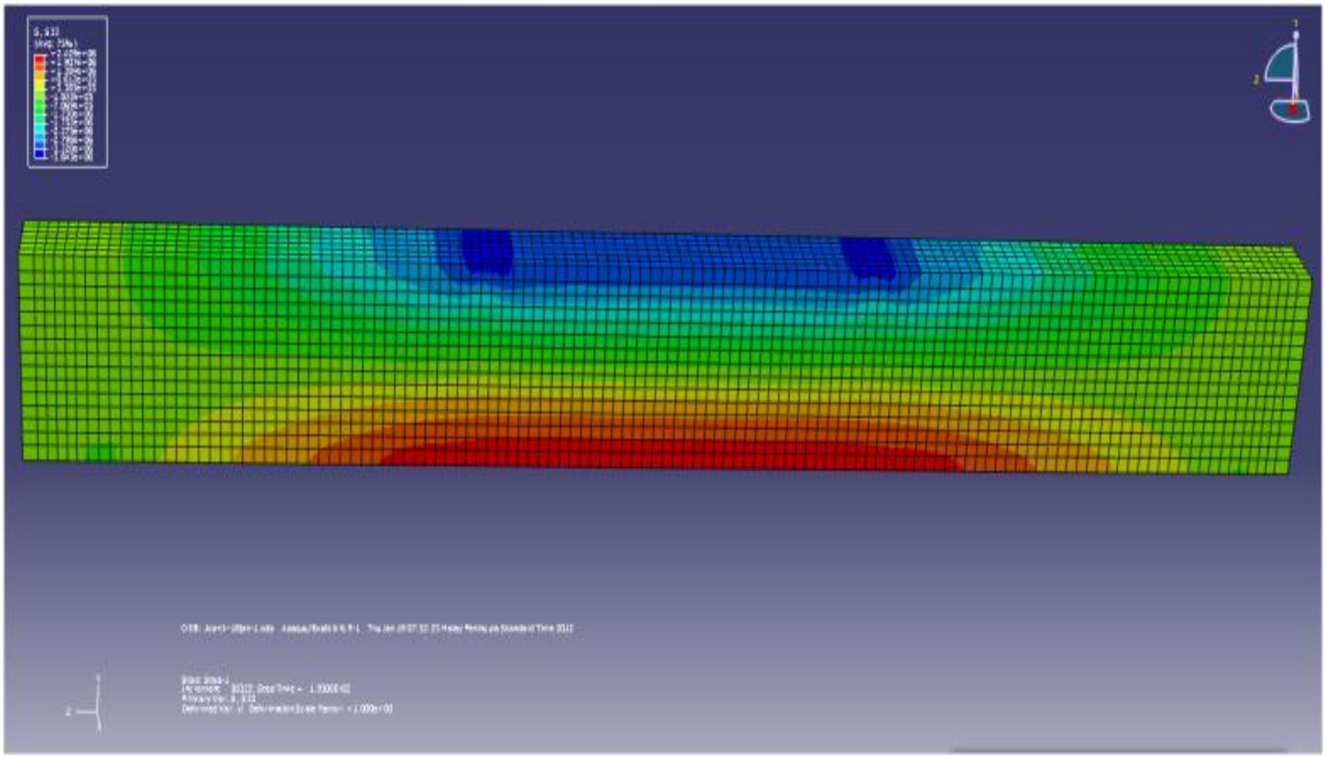

Figure 4. Concrete stresses.

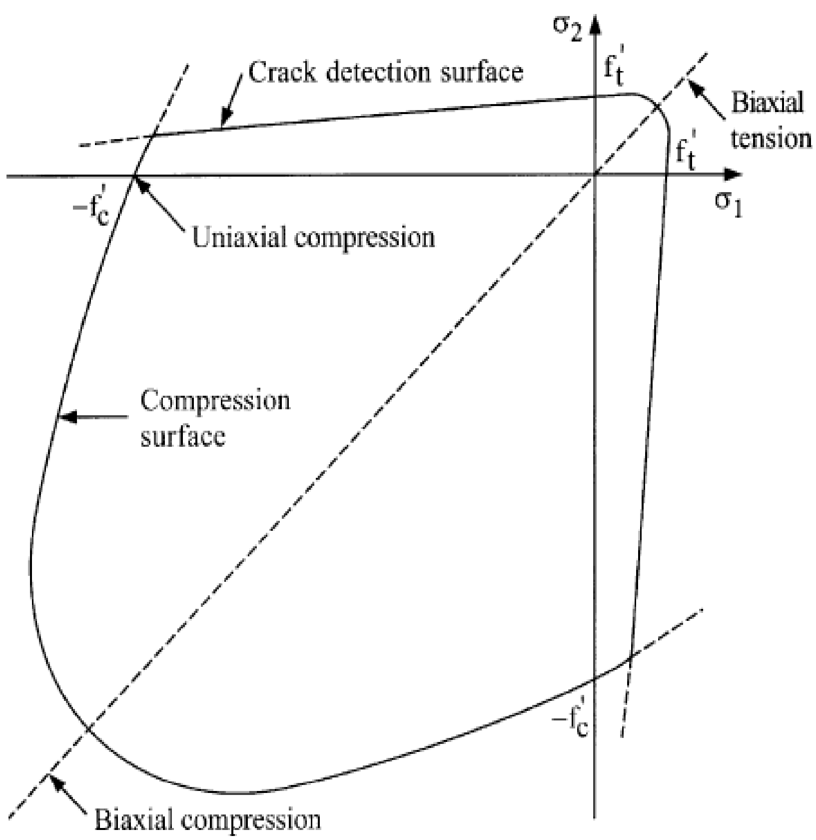

Figure 5. Concrete failure surface in plane stress.

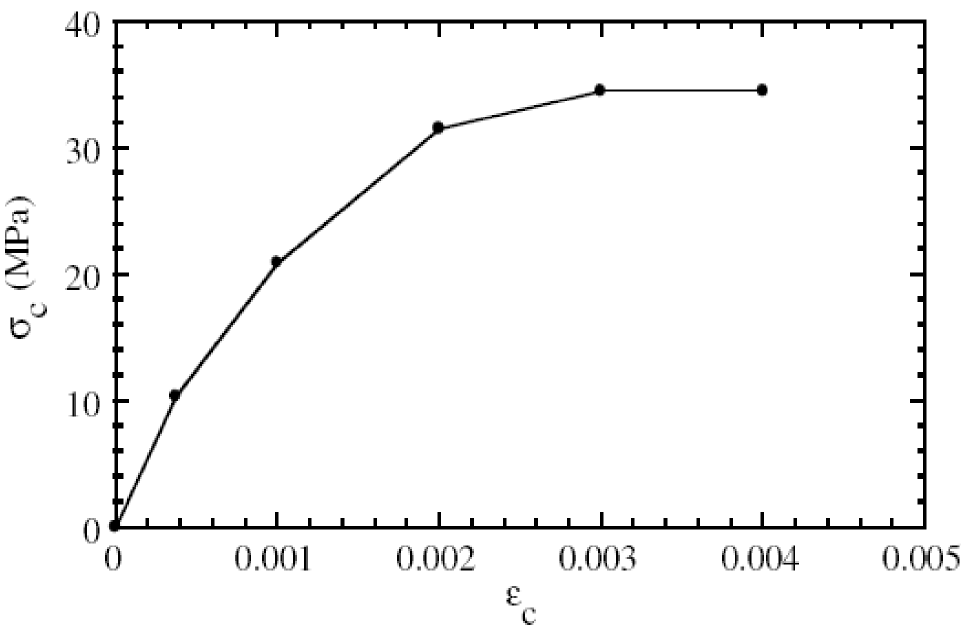

Figure 6. Equivalent uniaxial stress-strain curve for concrete.

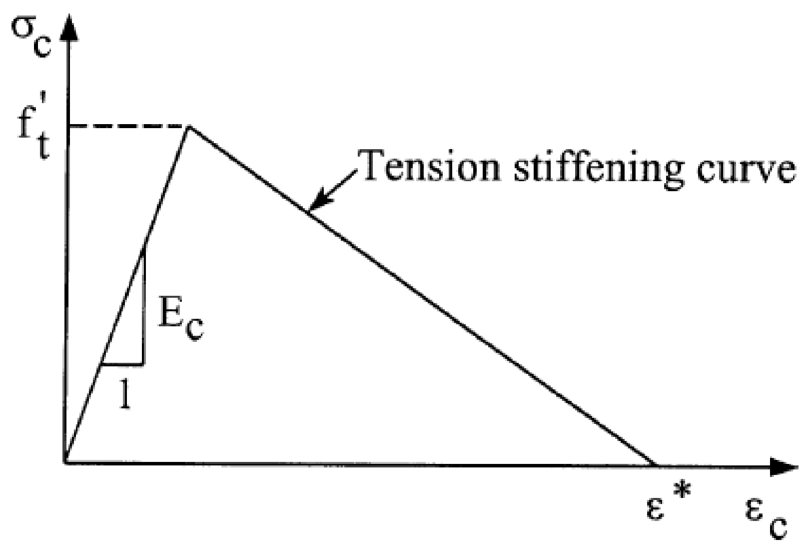

Figure 7. Tension stiffening model.

some tensile strength in the normal direction to the crack which is termed tension stiffening. In this paper, the tension stiffening phenomenon was modelled as linear (Figure 7). The concrete damaged plasticity model (CDP) was used for defining the concrete material behaviour in the inelastic range. Lee and Han (1998) developed this model. The tensile cracking and the compressive crushing are the main failure mechanisms of the concrete in the concrete damaged plasticity model. The program computes the concrete compressive stress-strain curve based on the input of stress versus inelastic strain. The concrete behaviour under axial tension is assumed to be linear until the formation of the initial cracking at the peak stress known as the failure stress.

Post failure stress is defined in the program in terms of stress versus cracking strain. This behaviour allows for the effect of interaction between the concrete and reinforcement rebar through introducing tension stiffening to the softening side of the curve.

The finite element mesh

In order to obtain accurate results from the FE model, all the elements in the model were purposely assigned the same mesh size to ensure that each two different materials share the same node. The type of mesh selected in the model is structured. The

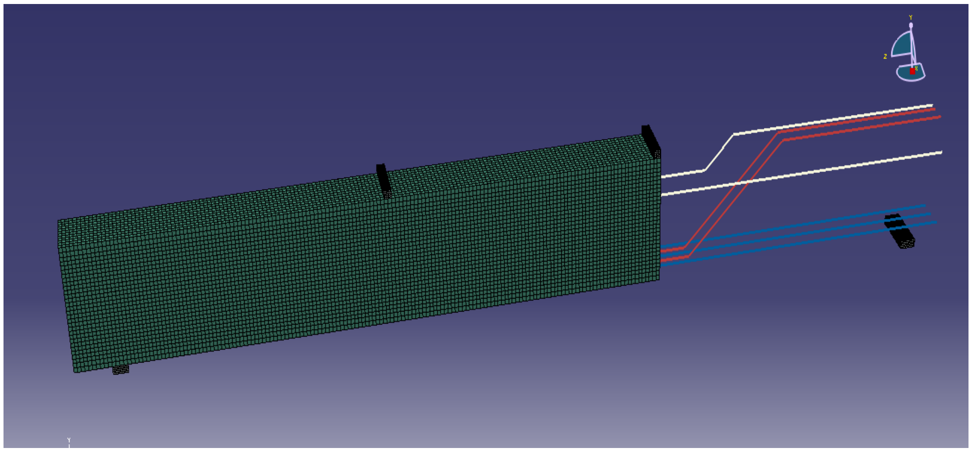

Figure 8. Concrete meshed model in ABAQUS.

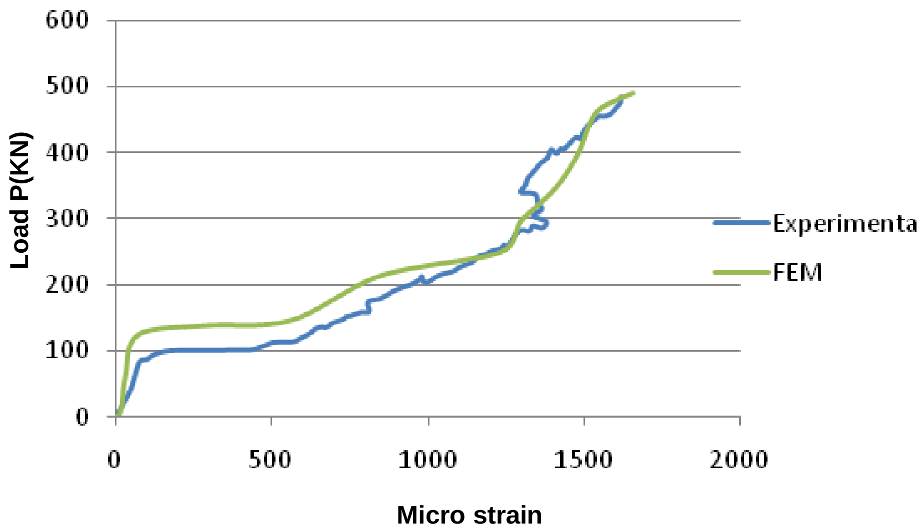

Figure 9. Load-tensile strain plot for main steel rebar.

mesh element for concrete is 3D solid which is called C3D8R and for the rebar it is 2D truss which is called T3D2 (Figure 8).

RESULTS AND DISCUSSION

Comparison of results

Tensile strain in rebars

The load-tensile strain plot collected for the tensile steel reinforcement at mid span from the experiment is compared with the results from the finite element analysis in Figure 9. The results from the finite element correlate well with those from the experimental data. The tensile steel rebar at mid span of the beam did not yield at failure in either the experimental results or the finite element analysis.

Compressive strain in concrete

Comparisons of the compressive strain versus load curve from the results of the finite element and the experimental data for concrete at the centre of the top face are shown in Figure 10. There is a good agreement between the finite element analysis and the experimental data for the compressive strain in the concrete.

Load deflection curve at mid span

Deflection was measured at midspan at the centre of the bottom face of the beam. Figure 11 shows the load deflection curve of the beam for both the experimental and numerical data. In general, the load deflection curve for the beam from the numerical results has excellent

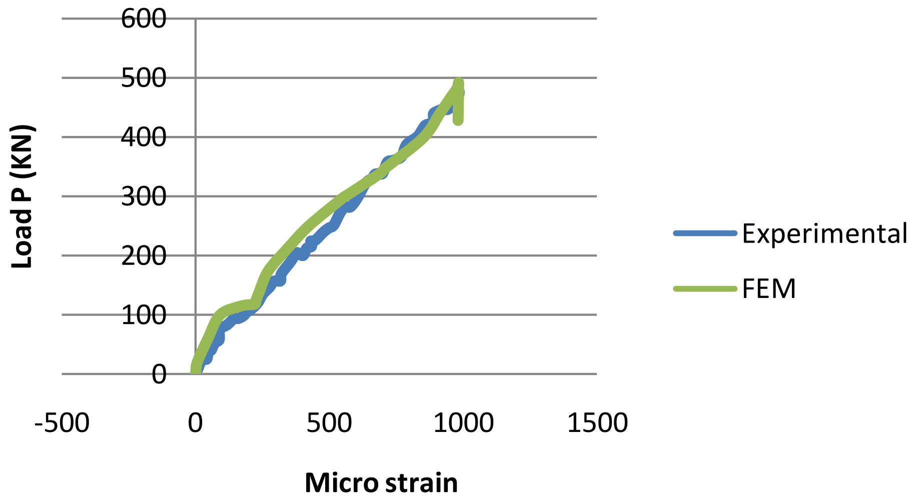

Figure 10. Load-compressive strain plot for concrete.

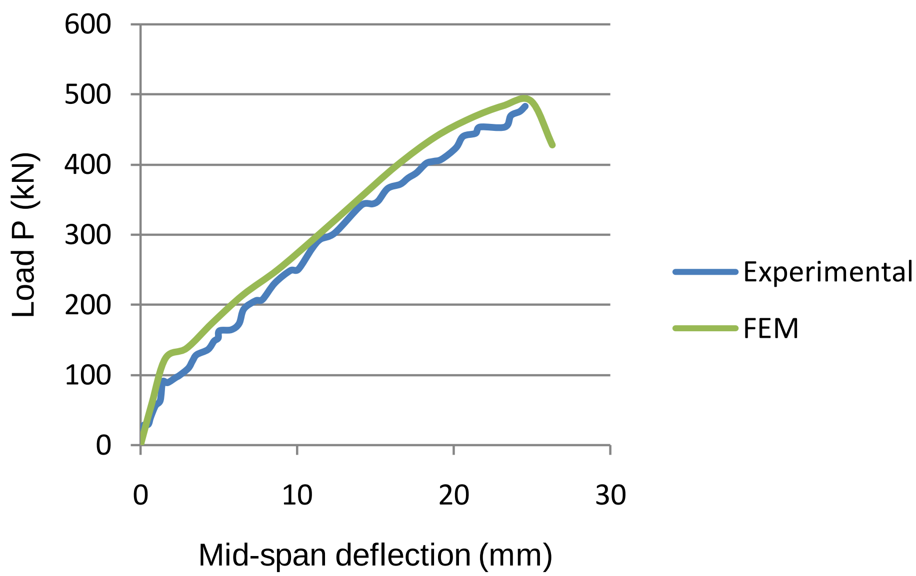

Figure 11. Load-deflection plot for the beam.

agreement with the experimental data.

Evolution of crack patterns for concrete

A comparison of the concrete crack patterns from the numerical results with those observed in the laboratory is shown in Figure 12. In general, flexural cracks occur early at mid span. When the applied loads increase, vertical flexural cracks spread horizontally from the mid span to the support. At a higher applied load, diagonal tensile cracks appear. Increasing the applied loads induces additional diagonal and flexural cracks. There is good agreement between the finite element analysis and the experimental data for the concrete crack patterns.

Conclusion

This paper presents a finite element model which can be used to analyse the non-linear behaviour of reinforced concrete elements. This finite element model is validated using previous experimental results available in the literature. The result section indicates that displacement, tensile strain for main reinforcement, compressive strain for concrete and crack patterns obtained from FEM are

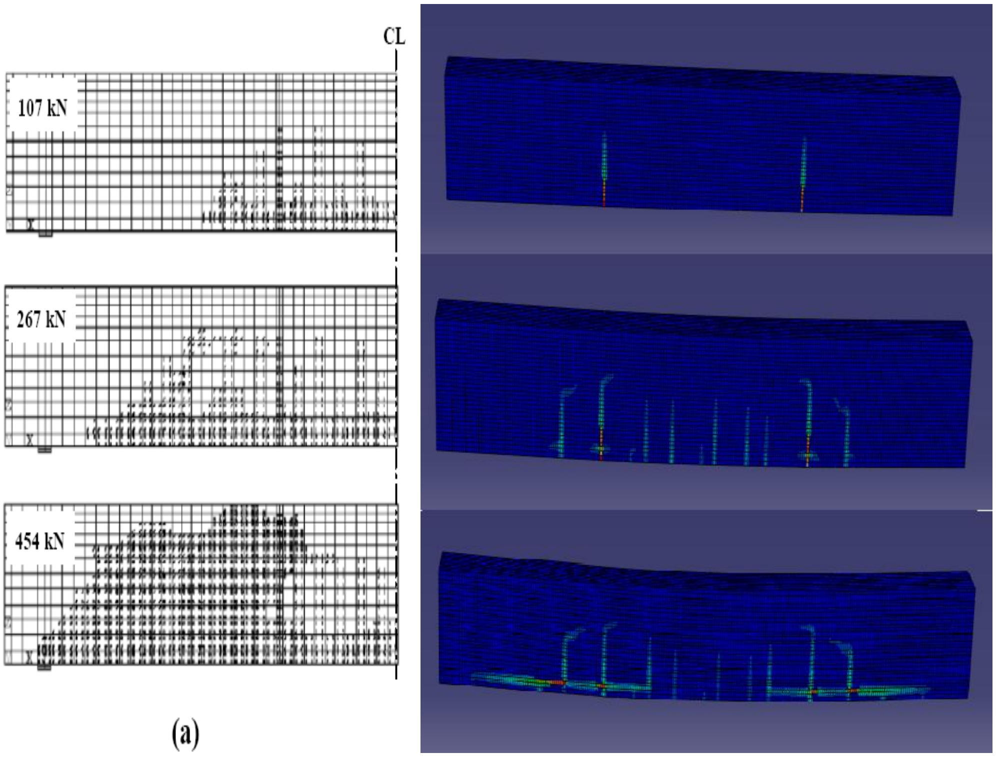

Figure 12. Crack patterns in process of analysis.

well matched with the experimental results. This paper compares the numerical results with the experimental results for the reinforced concrete beam subjected to flexural loading.

REFERENCES

Hibbitt K, Karlsson B, Sorensen P (1988). ABAQUS: User's Manual: Hibbitt, Karlsson & Sorensen.

Hu HT, Liang JI (2000). Ultimate analysis of BWR Mark III reinforced concrete containment subjected to internal pressure. Nuclear Eng. Des., *195:* 1-11.

Hu HT, Lin FM, Liu HT, Huang YF, Pan TC (2010). Constitutive modeling of reinforced concrete and prestressed concrete structures strengthened by fiber-reinforced plastics. Compos. Struct.., 92: 1640-1650.

Kachlakev D, Miller T, Yim S, Chansawat K, Potisuk T (2001). Finite element modeling of concrete structures strengthened with frp laminates. Oregon Department of Transportation and Federal Highway Administration. Report FHWA-OR-RD-01-17.

Lee K, Han J (1998). Fatigue behavior of composite beams with pyramidal shear connectors under repeated loading. KSCE J. Civil Eng., *2 :*119-128.

Li L, Guo Y, Liu F, Bungey J (2006). An experimental and numerical study of the effect of thickness and length of CFRP on performance of repaired reinforced concrete beams. Constr. Build. Mater., *20:* 901-909.

Saenz LP (1964). Discussion of "aquation for the stress-strain curve of concrete" by Desayi and Krishnan. ACI J., 61(9): 1229-1235.

Sinaei H, Jumaat MZ, Shariati M (2011) Numerical investigation on exterior reinforced concrete Beam-Column joint strengthened by composite fiber reinforced polymer (CFRP).