JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Fatigue Behaviour of Rinforced Concrete Under Variable Amplitude Loading: ABAQUS Modelling

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Abstract: Concrete is one of the most versatile and commonly used construction material around the world. With advancement in the engineering fields there is a need for development of concrete with enhanced strength and performance characteristics. Due to this high strength and high performance concrete types were developed which could resist considerably more stresses and offer other performance benefits as well. As the fatigue life performance of reinforced concrete may affect the overall resistance of structures against cyclic loading or seismic activities, investigation regarding the fatigue performance of these reinforced concrete elements is required. Among all the parameters affecting fatigue life this paper focuses on effect of shape on fatigue behaviour of element. The results show that square beam was able to resist more loading cycles as compared to the equivalent area circular beam. Furthermore, square beam exhibited lesser deflection as compared to the circular beam. Results show that square shape act in a more ductile way as compared to the circular shape.

Keywords: Reinforced Concrete, ABAQUS, Finite element analysis, Variable amplitude load

1. Introduction

Knowledge about fatigue is very important both from an economic point of view and from aspect of safety of the structures. Modern structures have become lighter and slender which leads to higher concentrations of stresses and to higher percentage of varying loads in comparison to the total loads. Examples of concrete structures that are exposed for cyclic loading, which causes fatigue, are roads, airfields and bridges. Another type of structures that are subjected to risk from fatigue is the modern energy-producing installations, e.g. wind power plants, offshore structures and different types of machinery foundations. Damage due to fatigue may be divided into different categories dependent of the loading conditions as well as other e.g. environmental conditions. Structures subjected to dynamic stresses are generally prone to fatigue damage. Some of these structures are identified in Table 1

Table 1- Fatigue cycles spectrum with corresponding structures

Low-Cycle Fatigue ($0 – 10^3$ cycles)	High-Cycle Fatigue ($10^3 – 10^7$ cycles)	Super-High-Cycle Fatigue ($10^7 – 5 \times 10^8$ cycles)
• Structures subjected to earthquakes • Structures subjected to storm	• Bridges • Airport pavement • Wind power plants • Highway pavement • Concrete railroad ties	• Mass rapid transit structures • Sea structures • Machine foundations

2. Fatigue Life of Concrete

The fatigue behaviour of concrete is influenced by various factors such as stress level, stress ratio, eccentricity of loading, frequency, shape of the waveform, and stress reversals amongst others. There are different hypotheses concerning the crack initiation and propagation, e.g. according to Murdock & Kessler (1960) [1] failure is caused by the deterioration of the bond between the coarse aggregate and the binding matrix. Several studies have found frequency to be irrelevant for fatigue performance. Arthur et al. [3] exposed concrete beams to frequencies (f_q) from 0.17 to 5 Hz, with no noticeable effect on fatigue life. This result corresponds well with the results obtained by Murdock, which indicated that frequencies in the interval 1.16-15 Hz have little influence on fatigue life given a stress level below 75% of static strength. Raithby and Galloway[4]were also unable to find any frequency effect on fully saturated beams when comparing a sinusoidal load of 4 Hz with 20 Hz. Significantly higher frequencies were investigated by Assimacopoulos et al. for $S_{max} < 0.75$, without any noticeable frequency effect. However, the number of specimens was limited and Assimacopoulos et al. [5] emphasized the need of further tests in order to gain more reliable results. The general tendency of the size effect in monotonic load application is that an increase in specimen size results in a decrease in strength. "Strength" might refer to several stress states, including compression, tension and modulus of rupture. An intuitive explanation for this effect is provided by Neville [11]. As concrete consists of several components with variable strength, the likelihood of a specimen containing elements of extreme low strength increases with specimen volume. The study by Zhang et al. [12], which established a model for fatigue life prediction of cracked concrete beams. This model assumes that a crack has formed in the section. It is the further crack propagation that is relevant for the model. This sort of model is therefore highly relevant for predictions of remnant fatigue life.

3. Fatigue Life of Steel Reinforcement

The fatigue life of steel reinforcing bars is commonly estimated using stress-life models. As previously discussed, this involves a plot of the stress range against the numbers of cycles resulting 7 in failure. Various models have been proposed and used in different codes for estimating the number of cycles to failure for steel reinforcing bars under fatigue loading (Tilly, 1979; JSCE, 1986; Chinese Code, GB 50010-2002; CEB-FIP Model Code 1990; AASHTO (Specified in ACI217R-74); EN 1992-1-1: 6.8). The model proposed by AASHTO considers the influence of the stress range, the diameter of the bar, and the ratio of the radius at the root and the height of the reinforcement rib (r/h).

3. Finite Element Modelling

3.1 Description of the model

Reinforced concrete elements of two commonly used shapes (circular and square) are used. The cross-sectional area of these two types is kept equal to each other. In order to keep the cross-sectional area same, 150 mm was selected as the diameter of circular element while 133 mm was selected as the dimension for square element. These dimensions provided an area of 17,680 mm^2 . The total length of each column was 1.6 meters and these columns were reinforced with twelve grade Fe250 steel rebars of 6 mm diameter. 3 mm plain bars were used as shear stirrups provided at 30 mm centre to centre distance. The grade of concrete is M40. The elements are modelled under the four point loading. The fatigue loading was applied as step wise increasing cyclic loading after specific intervals as shown in figure 2

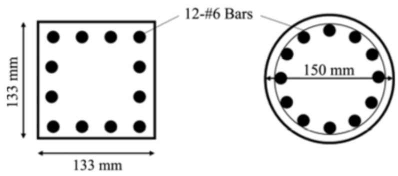


Figure 1. Cross-Sectional Details of Circular and Square element

3.2 Modelling of the Specimen

Position constraints were utilized to assemble the whole model. For the simulation of the interface between steel and concrete, the contact properties used are normal contact behaviour, the default option for ‘‘surface to surface contact”. For tangential contact behaviour, the friction between support plate and concrete was considered as 0.01.The loading pattern is shown in figure 2.

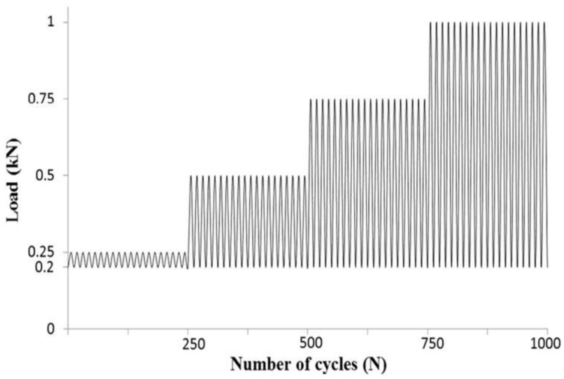


Figure 2. Variable amplitude loading pattern

To increase the accuracy of results partitioning was done at every interval of 20mm each part of assembly with the fine meshing. A ‘linear eight nodded brick element’ type of meshing was provided as shown in figure 3.

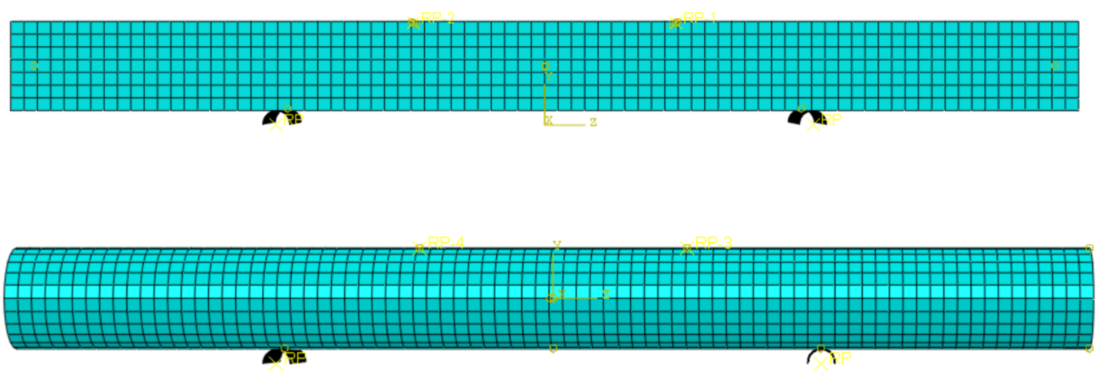


Figure 3 Model after meshing of circular and square element.

4 Analysis

Many analysis methods have been described below and explained.

4.1 Finite Element Method

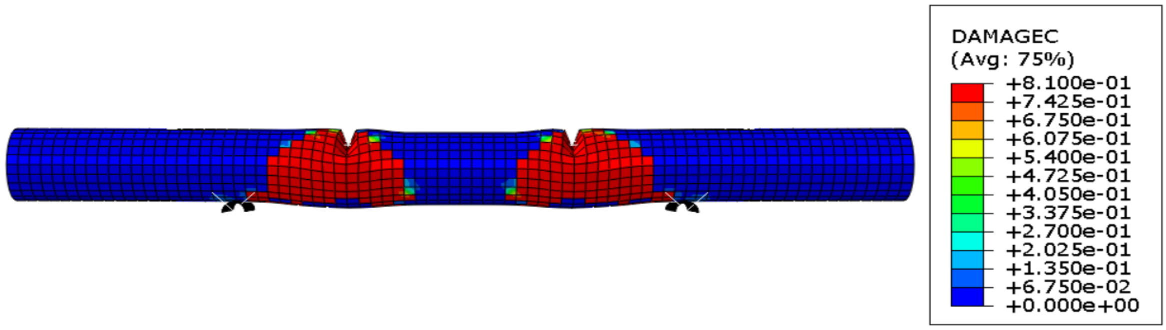
For many engineering problems analytical solutions are not suitable because of the complexity of the material properties, the boundary conditions and the structure itself. The basis of the finite element method is the representation of a body or a structure by an assemblage of subdivisions called finite elements.

4.2 Static analysis

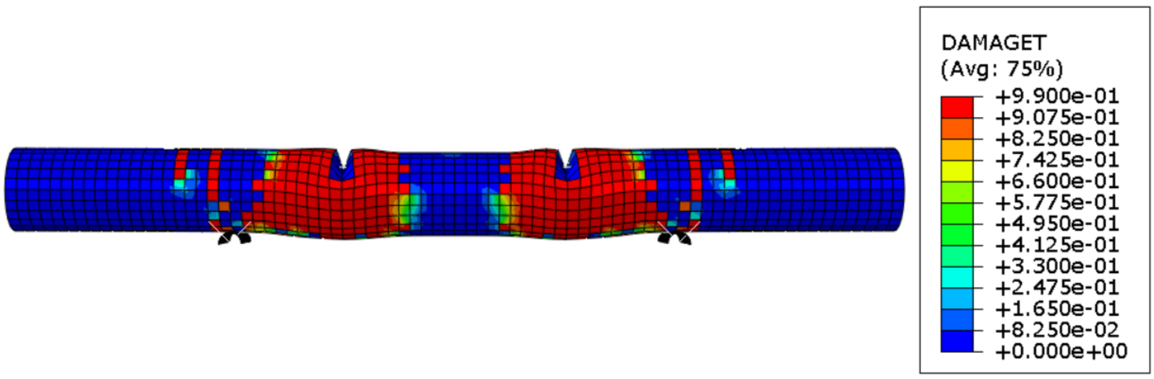
The direct cyclic analysis capability in Abaqus/Standard provides a computationally effective modelling technique to obtain the stabilized response of a structure subjected to periodic loading and is ideally suited to perform low-cycle fatigue calculations on a large structure. The capability uses a combination of Fourier series and time integration of the nonlinear material behaviour to obtain the stabilized response of the structure directly. The response is obtained by evaluating the behaviour of the structure at discrete points along the loading history. The degraded material properties are then used to compute the solution at the next increment in the load history. Therefore, the damage growth rate is updated continually throughout the analysis. The solution at each of these points is used to predict the degradation and evolution of material properties that will take place during the next increment, which spans a number of load cycles.

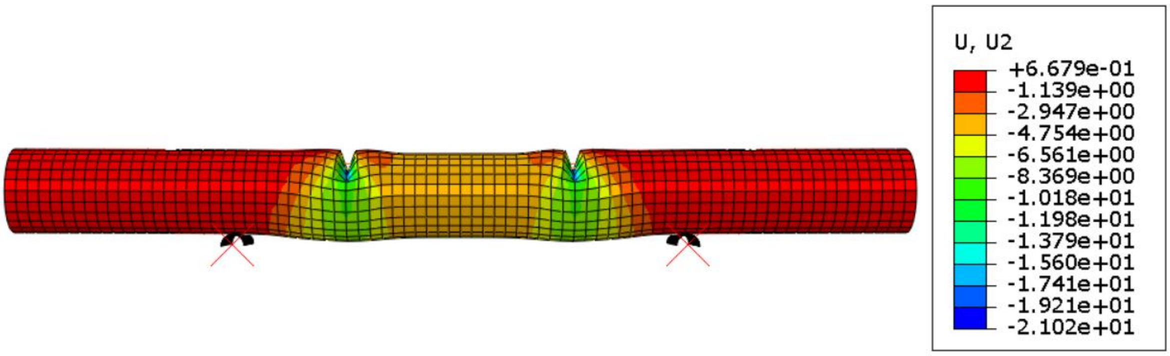
5. Results

Circular and square elements under variable amplitude load starting from 0.2 kN to 5 kN is applied for 50 second in ABAQUS under static analysis. The following figure 4 and figure 5 shows the tension damage, compressive damage and displacement in Y direction in cylindrical and square element.



a)

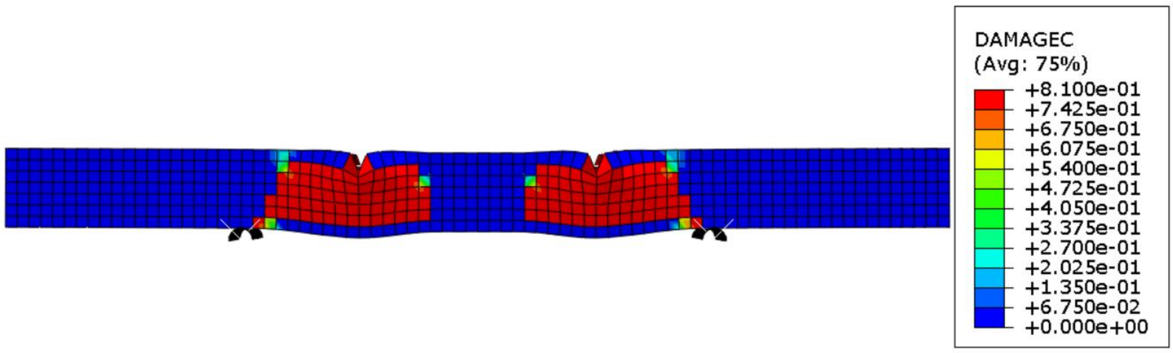




b)

c)

Figure 4. The results of the analysis on reinforced concrete cylinder (a) damage in compression, (b) damage in compression and (c) displacement distribution (mm)



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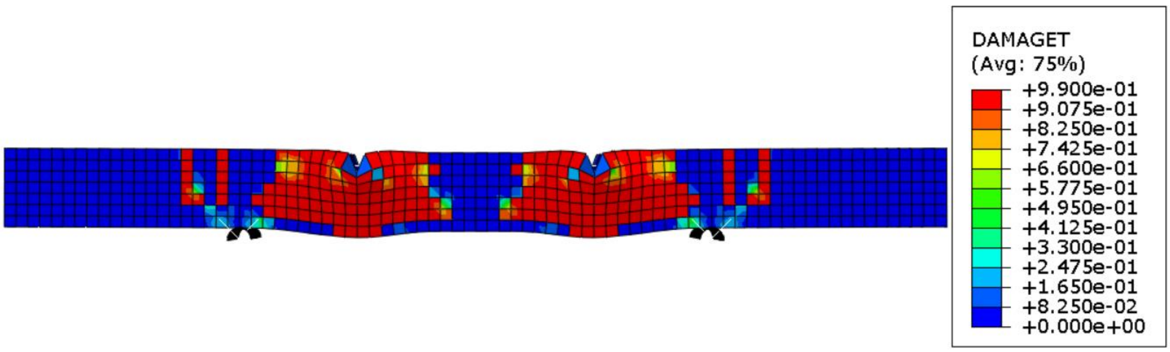

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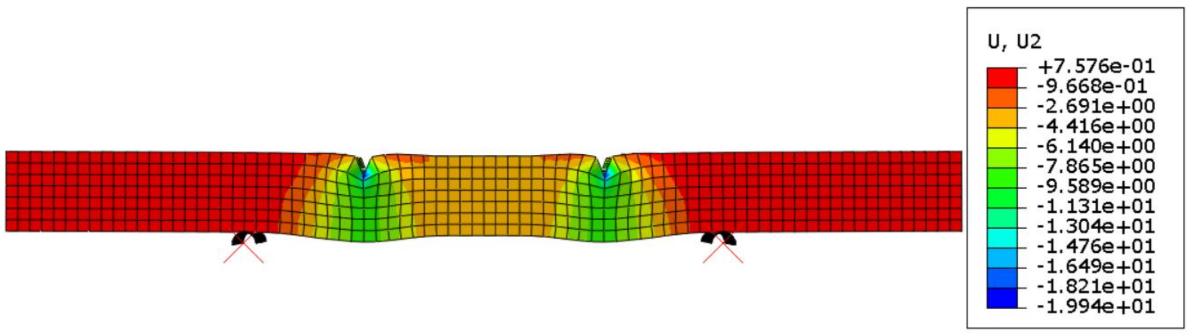

c)

Figure 4 The results of the analysis on reinforced concrete square (a) damage in compression, (b) damage in compression and (c) displacement distribution (mm)

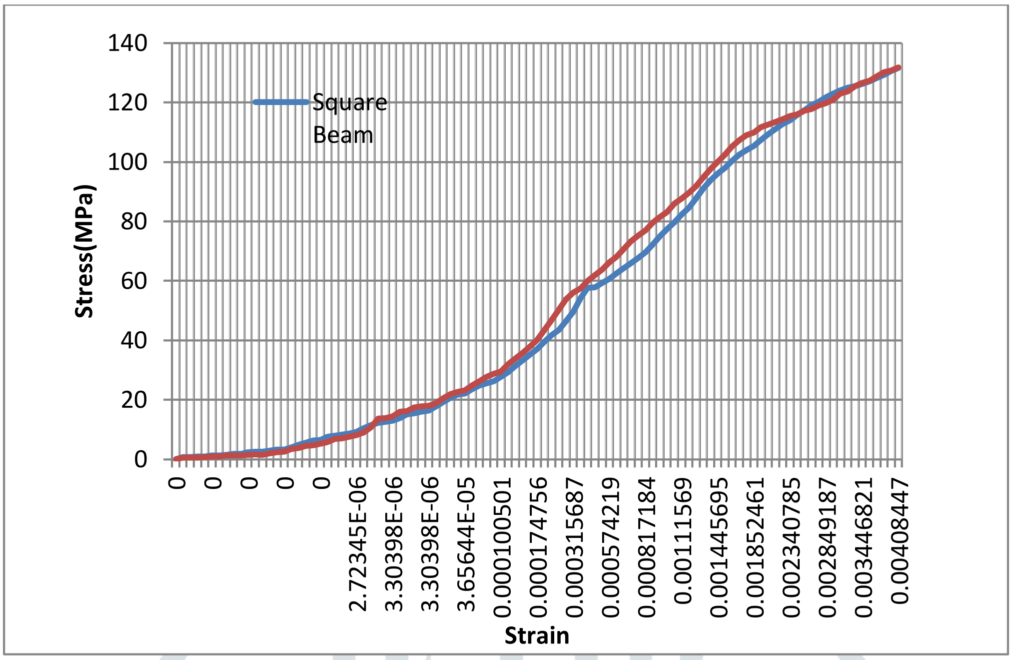

Figure 6 Comparison of stress strain curve of reinforced elements from ABAQUS model.

6. Conclusions

In this work behaviour of reinforced square and circular elements has been elaborately done by FE analysis and general conclusions are drawn of the following. Square member exhibited lesser deflection as compared to the circular member. Square member could resist more load as compared to the circular member. In four point loading only loading points shows downward displacement while whole element bend upward in negative Y direction.

From the above analysis, geometric parameters like shape of reinforced element, it has been observed that strength of reinforced concrete has been affected.

Stress ratio significantly affects the fatigue properties of concrete. Loading frequency influences the fatigue life of concrete for higher stress ratio displacement with respect to time is higher. The non-linear behaviour of both types of members is comparable with an exception to the failure mechanism which favours the circular shape.

7 FUTURE SCOPE

The mechanical behaviour of a concrete material under biaxial or triaxial loading has not been widely attempted. Since many concrete structures in practice may be subjected to multi-axial stress fields, one also needs to extend the existing principles to 3-D problem

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