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THE EFFECT OF SHEAR REINFORCEMENT RATIO ON PRESTRESSED CONCRETE BEAMS SUBJECTED TO IMPACT LOAD

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Structural elements subjected to impact loads have a different response than those subjected to static loads. This research studied the effect of using shear reinforcement to reduce the local damage occurred when an impact load applied on a prestressed concrete beam. An accurate finite element model was provided for the analysis using the advanced volumetric finite element modeling program (ABAQUS). The concrete material was defined using the built in concrete damage plasticity model (CDP), that considers the nonlinear behavior of concrete when subjected to dynamic loading. All material properties were modified using the dynamic increase factor (DIF) to consider the effect of impact loading. It was realized that the failure was concentrated in the impact zone. However, using shear reinforcement reduced the permanent damage occurred due to impact.

Keywords: Numerical, Damage, Camber.

1 INTRODUCTION

Buildings constructed on steep slope, are vulnerable to rock falling. Rock falling causes impact loading which leads destruction in property. Many researchers have been conducted to study the effect of impact load on Reinforced concrete structures (Chen and May 2009), but very few studies were done on their effect on prestressed concrete beams. Use of prestressed concrete structures is increasingly popular (Kang and Huang 2012), whereas lack basic knowledge of designing prestressed beams subjected to impact loads in international codes exists. Using finite element model give us real results (Joshuva *et al.* 2014). They used 3D finite element model using ANSYS to compare RC beams and prestressed concrete beam. Applying the same load, the prestressed concrete beam failed at 143.6 KN, which is about 22% greater than RC beam of same dimension. Prestressed concrete beam of same dimensions, with approximate same area of reinforcement gave higher flexural capacity and better efficiency. PT increases stiffness of concrete and flexural capacity (Kumar *et al.* 2016). Moreover, researches have worked on modeling of post tension slabs using Abaqus (Kung 2012). The research discussed possible methods of modeling bonded and unbounded post tension beams, and recommended usage of tangential and normal contact conditions for modeling bonded and unbounded cases.

2 AIM AND SCOPE

The aim of this research, is to model prestressed concrete beam subjected to direct impact from a falling object using the commercial finite element program ABAQUS. Then a parametric study will be insured to investigate the effect of shear reinforcement ratio on decreasing damage and deflection. Final conclusions will be drawn at the end of the research.

3 NUMERICAL MODELING

A 300x600mm prestressed concrete beam was modeled with span of five meters, to benefit from cambering effect. The element used was C3D8R "An eight-node linear brick". 3φ14mm were added as minimum reinforcement at TOP and BOTTOM of the beam, and 4φ14mm as shrinkage reinforcement was used at each side, Figure 1. As for stirrups, a ten mm bar size was used. Three different spacings (100mm, 200mm, and 300mm) were used in this study. All these ordinary reinforcements were modeled as rebar elements "Two nodded linear elements". Eight tendons of diameter 12.7mm were added at 100mm height from the bottom face of the beam using the same element used in modeling the concrete body (C3D8R). The falling object in this study is a cubic reinforced concrete block with a dimension of 300x500x500mm with a weight of 187.5kg, and was reinforced by four 10mm stirrups in all directions (Figures 2 and 3).

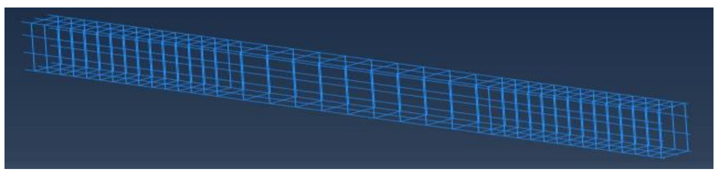

Figure 1. 3D view for all ordinary beam reinforcements.

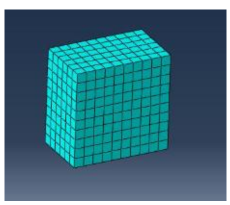

Figure 2. 3D view for falling object.

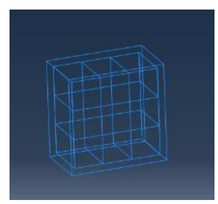

Figure 3. 3D view for Block reinforcements.

The Concrete Damage Plasticity Model will be used to define the behaviour of concrete. This model works with static and dynamic load conditions. It was derived by Lubliner (1989) and developed by Lee and Fenves (1998). It represents the nonlinear behaviour of concrete using different input parameters such as: inelastic strain, cracking strain, stiffness degradation and recovery and other parameters. (Figures 4 and 5). As for steel reinforcement and tendons, the plastic behaviour was considered in material definition. Moreover, the effect of impact conditions on all material used in this analysis was considered by using the dynamic increase factor (DIF); since both steel reinforcement and concrete will behave stiffer when subjecting to an impact load conditions (Temsah *et al*. 2017a, 2017b). A trial run was done to find the DIF when subjecting the beam to the falling object. The strain rate was found to 4.45 s^{-1}, and the corresponding DIF will be equal to 1.46.

Reinforcing steel can be modelled using several methods. For this simulation we will consider the elasto-plastic behaviour of reinforcing steel, and we will assume a perfect bond between concrete and steel. Whereas for the concrete - tendon interaction there were some differences (Kung 2012). A tangential and normal behaviour has been added allowing bit of slip. A predefined field condition was used to define the initial stresses in tendons, and gravity was defined for the block so it fell by the earth gravity.

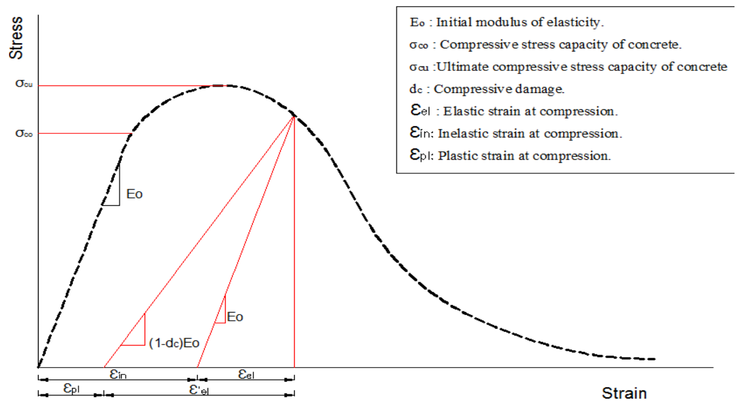

Figure 4. Compressive behaviour of concrete (CDP).

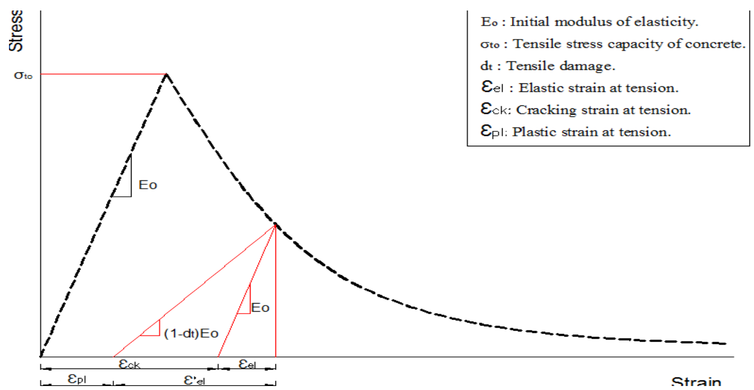

Figure 5. Tensile behaviour of concrete (CDP).

4 ANALYSIS RESULTS

4.1 Beam Camber

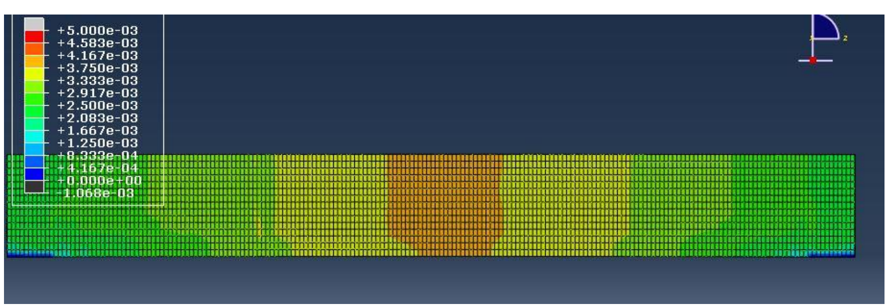

Figure 6. The effect of cambering on beam.

The prestressing effect was successfully represented. Referring to Figure 6, the camber of the beam was about 4.5 mm. To check this number, a comparison done between the equation of camber calculation and the result from ABAQUS. The following equation was used to calculate the camber:

$$\delta = \frac{P.e}{E.I} \times \frac{L^2}{8} \tag{1}$$

Where "P" is the prestressing force, "e" is the eccentricity, "E" is the modulus of elasticity, "I" is the moment of inertia of the beam, and "L" is the span length of the beam. Applying this equation, the value of cambering was 4.32 mm which is close to the one calculated by finite element modeling.

4.2 Beam Stresses

Top and bottom stresses were checked manually due to own weight and prestressing effect using the following equations (Nawy 2012):

$$F_b = -\frac{P}{Ac} + \frac{P.e.c}{Ig} - \frac{M.c}{Ig} \tag{2}$$

$$F_t = -\frac{P}{Ac} - \frac{P.e.c}{Ig} + \frac{M.c}{Ig} \tag{3}$$

Where "P" is prestressing force, "Ac" is the cross section area of beam, "e" is the distance between c.g of tendons and c.g of beam cross section, "c" is the distance from c.g of beam and the top/bottom face, and "Ig" is the gross moment of inertia.

Table1. Numerical analysis vs. theoretical equations (Nawy 2012).

	Finite Element	(Nawy 2012)	Error
TOP STRESSES	1.52	1.74	12.6%
BOTTOM STRESSES	-7.8	-9.33	16.4%

4.3 Impact Load and Mid Span Deflection

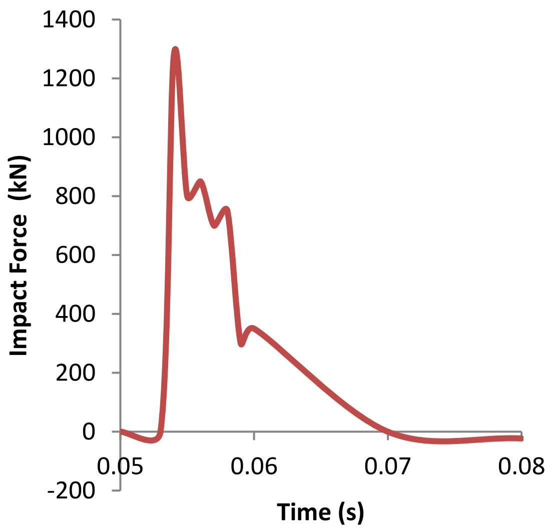

Figure 7. Equivalent impact load.

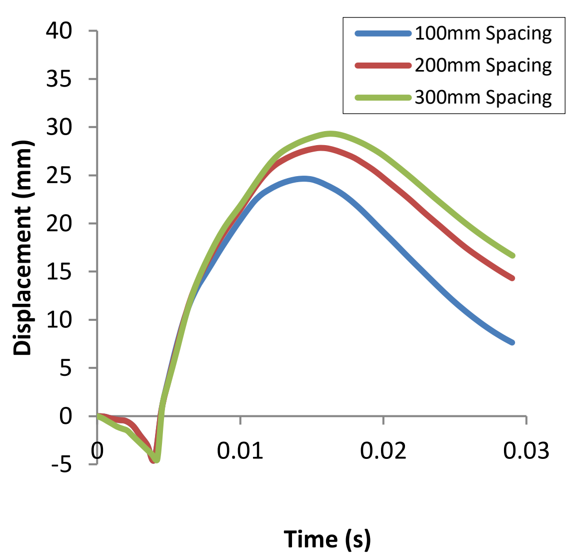

Figure 8. Displacement curve for all cases.

The equivalent peak load of the impact was 1278 KN as shown in Figure 7. As for mid span deflection curves (Figure 8), it can be divided into two zones: the first one is the cambering zone (with negative values) where cables were prestressed and the beam was deflected upwards. Then the test started and the drop weight hit the beam causing the deflection to go to the opposite direction. As can be seen the deflection was improved when using less shear reinforcement spacing (100mm).

4.4 Beam Damage

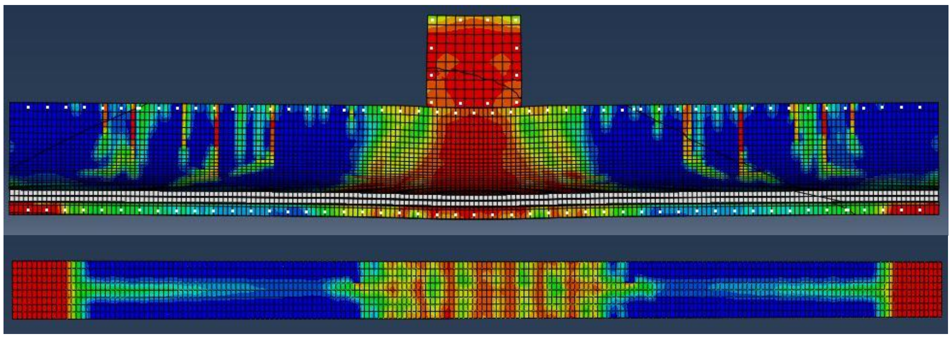

Figure 9. Tensile damage for 100mm spacing.

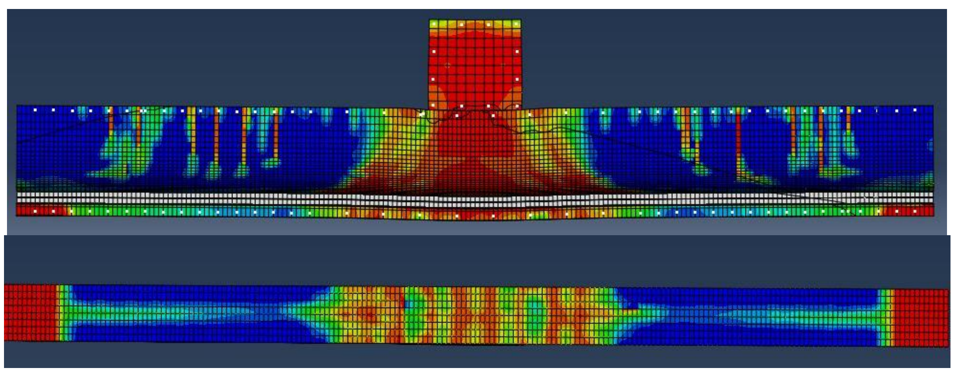

Figure 10. Tensile damage for 200mm spacing.

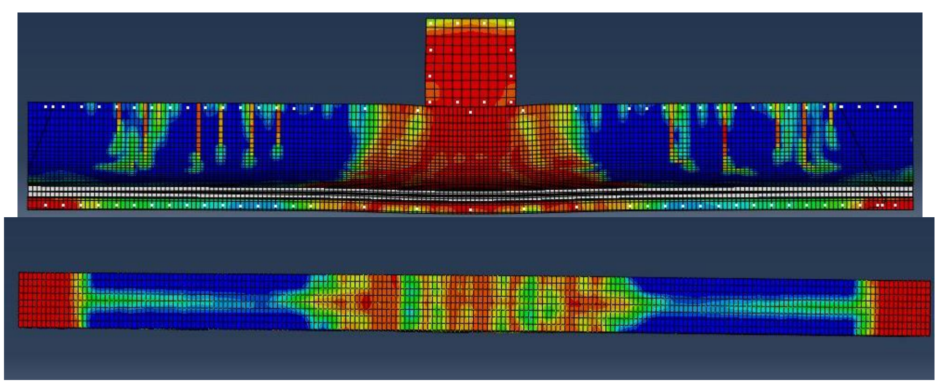

Figure 11. Tensile damage for 300mm spacing.

Table 2. Tensile damage zone length.

	Tensile Damage Zone		
Stirrups spacing (mm)	100	200	300
Zone length (m)	1.35	1.6	1.9

The Damage mode was local and concentrated at the impact point as can be seen from Figures 9 to 11, and a local punching occurred. As shown, using stirrups reduced the tensile damage in prestressed concrete beam which indicates that these reinforcements have a great role in resisting local punching.

5 CONCLUSION

The following conclusions can be drawn from the current investigation:

(i) Finite element modelling can successfully simulate prestressed concrete structures with all its stages starting from prestressing stage till load application stage. This type of simulations must consider the nonlinearity of materials in order to reach acceptable results, and to take into consideration the effect of impact loads on the mechanical properties of materials.

(ii) The analysis showed that prestressed concrete beams subjected to impact loads due to drop weight are likely to be damaged locally at the impact point in both tension and compression zones. However, by using shear reinforcement the local damage decreased, and that was shown in terms of tensile damage and mid-span deflections.

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