Comparative study of modeling methods used to simulate initial stresses in prestressed beams towards manual analysis

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Abstract. Numerical modeling of the prestressing element that generates prestressed effect in beams has always been considered a big challenge. This research compares two methods of modeling; In the first method we used initial stresses predefined stress and in the second method we used the temperature strain. Concrete damage plasticity model (CDP) was used to model the non-linear behavior of concrete material and an elasto-plastic behavior was applied to ordinary and prestressed reinforcement. Truss elements were used to model ordinary and prestressed reinforcement embedded inside the concrete. As a result, Initial Temperature load method showed less error in bottom and top stresses and cambering of beam in comparison with the basic concept method, than predefined method.

Keywords: Numerical, Stresses, Camber, Prestressed

1 INTRODUCTION

Using prestressed concrete beams is increasing nowadays in residential buildings, commercial, towers and bridges because they are capable of providing high spans with relatively less dimension. Choosing the best method for simulating the pre-compression force in the tendons using finite element models has always been a great challenge. Many researches were conducted to compare between several tendon modeling methods. Kang et al [1] listed 3 modeling techniques to simulate post tensioned beams: tube to tube, multiple spring system and surface to surface contact. They compared these methods with experimental tests and found that using the three methods is acceptable, but the third one is the most reliable. The first two methods gave very accurate results but the computational time is very high in comparison to the surface to surface method.
Kwak et al [2] studies the slip behavior of tendons with concrete surface, where a correlation was done between analytical and experimental studies. It shows the efficient modeling of prestressed concrete beam in ADINA, and very close results have been shown in comparison to experimental results. Analyzing the slip in tendons require nonlinear analysis, where concrete may show nonlinear behavior at anchorage and top face.
Chaudhari,S.V. et al [3] Checked stress strain curves for different mesh size and found that using CDP requires smaller mesh size to get appropriate accuracy.
Using volumetric elements to model prestressed reinforcement requires high computational time, therefore Arab,A., et al [4] compared between two models, one with embedment technique, in which truss elements were used to model prestressed reinforcement and the other is the extrusion technique in which surface to surface method was used. Both techniques were further verified by comparative analysis of the data against the experimental results. In the end of the study they concluded that using the embedded method to simulate prestressed tendons in the concrete beams provides an accurate and numerically efficient alternative in comparison with volumetric method.
Till now very few studies get into prestressing methods of tendons and define the best one to use.

2 AIM AND SCOPE

The aim of this research, is to model prestressed concrete beam using the commercial finite element program ABAQUS. Then a parametric study will be performed to investigate the best method to assign prestressed force in the tendons. 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 generate high camber. The element used was C3D8R "An 8-node linear brick". 3φ14mm were added as minimum reinforcement at TOP and BOTTOM of the beam, and 4φ10mm as shrinkage reinforcement was used at each side (Figure 1). As for stirrups, 10 mm bars size were used in this study at two different spacing (100mm, 200mm) where the spacing of 100mm was used on the first third and the 200mm spacing was used in the middle. Ordinary reinforcements and tendons were modeled as rebar elements "Two nodded linear elements". Eight straight tendons of diameter 12.7mm were added at 100mm height from the bottom face of the beam in order to visualize high top and bottom stresses in addition to high camber.

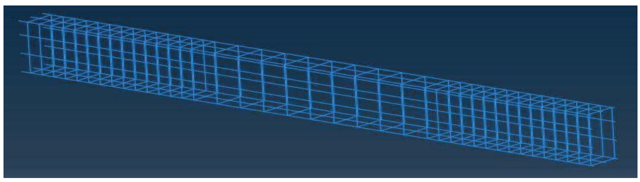

Figure 1. 3D view for all ordinary beam reinforcements

The Concrete Damage Plasticity Model was used to define the behavior of concrete. This model was used by many researchers since it works with both static and dynamic load conditions [5-11]. It was derived by Lubliner [12] and developed by Lee and Fenves [13]. It represents the nonlinear behavior 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 behavior was considered in material definition.

Reinforcing steel can be modeled using several methods. For this simulation we considered the elasto-plastic behavior of reinforcing steel, and assumed a perfect bond between concrete and steel. The same process was used for tendons. Own weight was defined as gravitational load for beam.

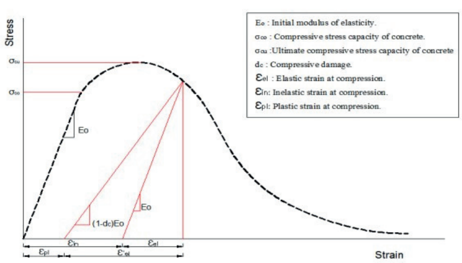

Figure 4. Compressive behaviour of concrete (CDP)

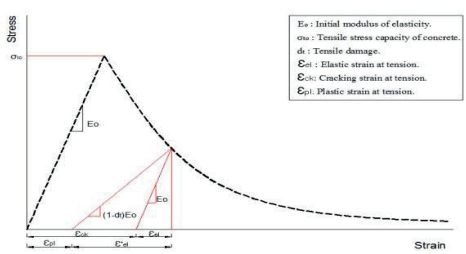

Figure 5. Tensile behaviour of concrete (CDP)

Two methods were used to define the initial stresses in tendons; Predefined field and initial temperature load. In the predefined stresses, we define the intensity of the stresses from the beginning of the analysis till the end. The second method applied is applying initial temperature load.
Using the initial temperature load method, we defined the magnitude of the temperature which is equivalent to the stresses applied to pre-stressed tendon. In order to apply the prestressing force applied, temperature t (C) can be computed using Eq. 1. Ren et al [14]

$$C = -\frac{\mathrm{P}}{c \cdot E \cdot A} \tag{1}$$

C is the coefficient of linear expansion (1.0 x 10^-5 MPa/ C); P is the force applied after long-term losses in prestressed beam took place. E is the modulus of elasticity (MPa) and A is the area in mm2

4 Comparison towards manual analysis:

4.1 Check for stresses

Results were compared with manual calculations and are shown in table 1. Stresses were checked using Basic concept method proposed by Nawi [15]. Moreover, Stresses were compared at two locations; top of the concrete beam face and bottom of the concrete beam face under their own dead load.

$$\text{Fb}= -\frac{P}{AC}+\frac{Pec}{Ig}-\frac{Mc}{Ig} \qquad \text{Ft}= -\frac{P}{AC}-\frac{Pec}{Ig}+\frac{Mc}{Ig} \tag{2}$$

	STRESSES		
	FEM-initial Temperature load(MPa)	Manual Calculation(MPa)	%Error
Top Face of the beam	3.42	3.46	1.15%
Bottom Face of the beam	-10	-10	0%

Table 1Initial temperature load versus hand calculation at top and bottumn faces of the beam

	STRESSES		
	FEM-Predefined Stress(MPa)	Manual Calculation(MPa)	%Error
Top Stresses	3.51	3.46	1.44%
Bottom Stresses	-8.8	-10	12%

Table 2: Predefined stress versus hand calculation at top and bottom faces of the beam

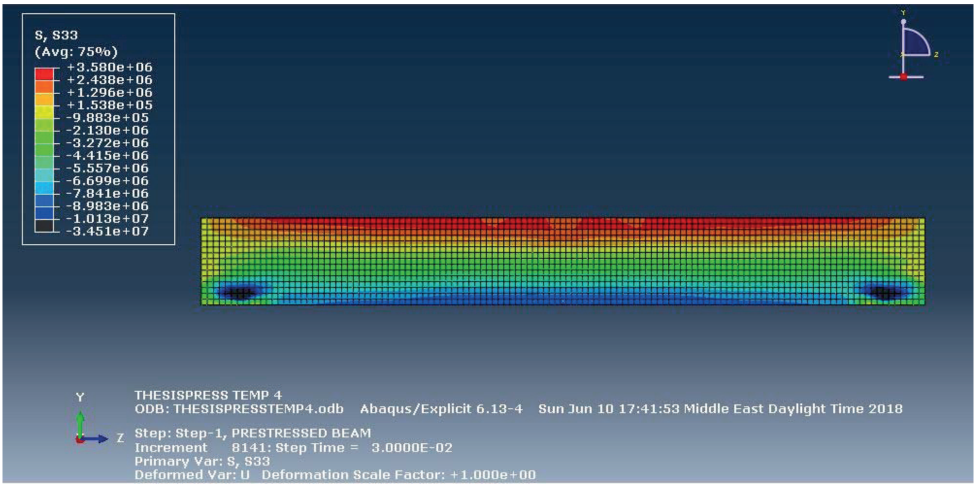

Figure 1:Beam Bottom Stresses For Initial Temperature load

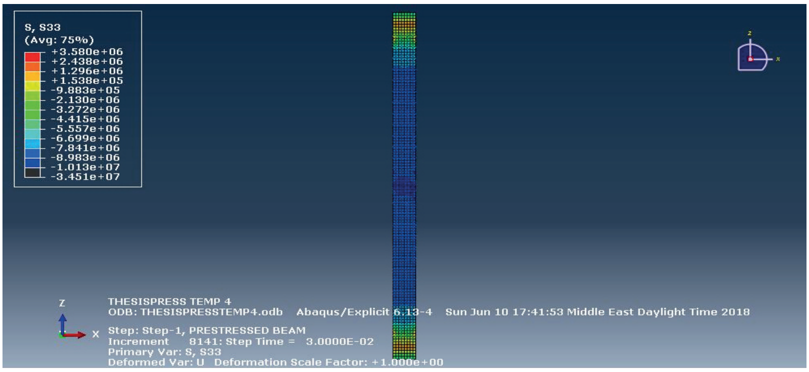

Figure 2: Beam Bottom Stresses For Initial Temperature load

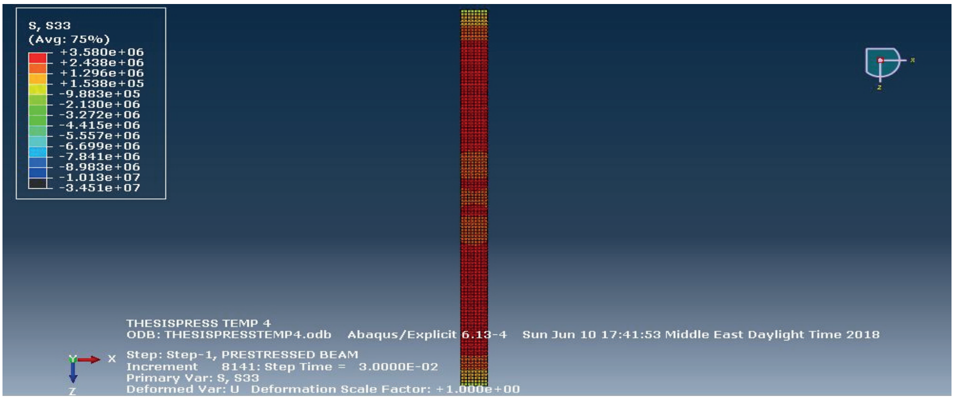

Figure 3: Beam Top Stresses

Using Initial Temperature load, the finite element model showed an error of 1.15% in the top stresses with a decrease of 0.04MPa, but no difference was observed at the bottom face giving zero error. Moreover, using predefined stresses, the finite element model showed higher values for top stresses with an increase of 0.05MPa giving an error of 1.44%. On the other hand, stresses at bottom face showed 8.8MPa, increasing the error to 12%.

4.2 Beam cambering

The prestressing effect was successfully represented in both methods. To check these methods, a comparison was done between the equation of Nawy [12] camber calculation and the result from ABAQUS. The following equation was used to calculate the camber:

$$\delta = \frac{P.e}{E.I} \times \frac{L^2}{8} + \frac{5.w.L^4}{384.E.I} \quad (3)$$

Where "P" is the prestressing force, "e" is the eccentricity, "I" is the moment of inertia of the beam, and "L" is the span length of the beam.

	CAMBERING		
	FEM- Initial Temperature load (mm)	Manual Calculation(mm)	%Error
Cambering	2.2	1.815	17.5%

Table 3: Initial Temperature load versus hand calculation cambering

	CAMBERING		
	FEM-Predefined Stress(mm)	Manual Calculation(mm)	%Error
Cambering	2.23	1.815	18.86%

Table 4: Predefined stress versus hand calculation deflection

Using Initial Temperature load, the finite element model showed a cambering of 2.2 mm compared to 1.815 mm computed using hand calculation, which gives an error of 17.5 %

On the other hand, predefined stress showed a maximum cambering of 2.23mm compared to 1.815mm in the manual calculation, which gives an error of 18.86%

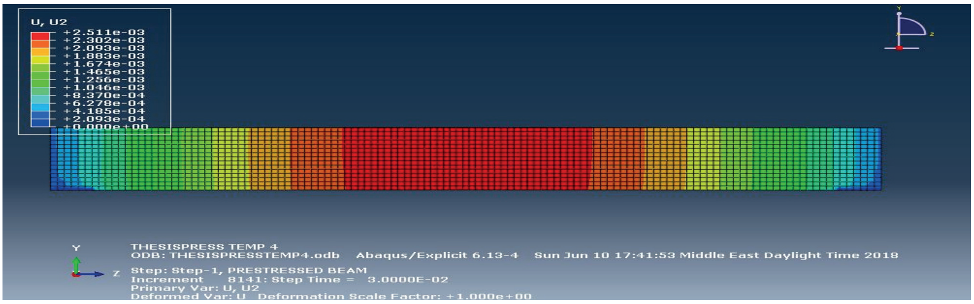

Figure 4: Cambering of prestressed beam using predefined initial stress

5 Analysis and Conclusion:

The Initial Temperature load method showed higher accuracy in both bottom and top stresses than the predefined stress in comparison with manual calculation.

The Initial Temperature load method showed higher accuracy in cambering than the predefined stress in comparison with manual calculation.

As a conclusion, using Initial Temperature load to simulate initial pre-compression in prestressed beams shows more accurate results than using predefined stress.

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