Parametric study on prestressed concrete beam subjected to elevated temperature

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ABSTRACT

Prestressed concrete members are used for various applications in the recent days and uncertainties during its service life can lead to deterioration of prestressed members. One of the uncertainties that can damage the structure is fire accident. The elevated temperature can result in cracking and spalling of the concrete elements. In this study, prestressed concrete beam is exposed to high temperature and its behaviour is studied analytically using ABAQUS. Prestressed beams are analysed using coupled – temperature displacement analysis and its behaviour under elevated temperature are investigated. The parametric study is carried out by varying the level of prestressing and span by depth ratio. These parameters are analytically studied and it is that observed that the behaviour of prestressed beams is highly influenced by these parameters when the beams are exposed to high temperature.

Keywords: Coupled - temperature analysis, level of prestress, span by depth ratio.

1. INTRODUCTION

Prestressing is the process of tensioning the steel tendons or strands so that they can withstand the external live loads and avoid failures. The tensile nature of steel helps in improving the behaviour of concrete specimens and avoid it from early cracks and failures. These tendons are made up of steel components which have high strength [1]. The prestressing members allows smaller thickness and longer spans. Usually, the concrete specimens can withstand fire for 30 minutes [2] after that the surface gets damaged and it results in cracks over the surface of structural elements which can eventually result in exposure of reinforcement to fire and cause failure. Compared to reinforced concrete members, prestressed concrete members are more vulnerable to elevated temperature and hence, study on fire response behaviour of prestressed beam is required. This study helps in understanding the behaviour of prestressed beam which is exposed to high temperatures. Parameters like level of prestress, Span by Depth ratio is studied in this work.

2. ANALYTICAL INVESTIGATION

The analytical work is carried out using ABAQUS and the model of prestressed beam is validated with experimental results taken from Ankith M.K et al., (2018). Beam subjected to external load of 1000 kN/m^2 and the beam is provided with tendon and nominal reinforcement [4]. Static analysis is performed and the obtained maximum displacement is 0.58 mm at the load value of 1000 kN. The value obtained from the Ankith M.K et al., (2018) is equal to 0.6 mm and the result is satisfactory.

3. FINITE ELEMENT ANALYSIS

The dimensions of the beam taken for the present study are 2500 mm × 250 mm × 400 mm. Simply supported beam subjected to a live load of 3 kN/m^2 is modelled and three number of tendons are provided in the beam [6]. The bottom portion of the beam is exposed to temperature of 600°C for the duration of 4 hours. The required properties for the analysis are calculated from Eurocode [8] and provided as input for the analysis. Hexagonal mesh element type is assigned for all the modelled elements with the auto generated mesh pattern [3]. Table 1 shows the properties of materials used as input during analysis.

TABLE 1: Properties of the material

Description	Concrete	Steel
Modulus of elasticity	31000 N/mm^2 *	205000 N/mm^2
Poisson's ratio	0.16	0.33
Density	2400 kg/m^3	8050 kg/m^3
Specific heat	1100 J/kg°C	767.55 J/kg°C
Conductivity	0.9152 W/mK	31.3 W/mK

*Value varies with temperature

4. IMPACT OF PARAMETERS

The impact of prestressing level and span by depth ratio on the prestressed beam is studied by performing the coupled temperature - displacement analysis in ABAQUS. Beams are subjected to loading and temperature simultaneously.

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4.1 Prestressing force

It is a process of inducing stress into steel strands or wires as this helps in compensating the tensile stresses acting on the concrete member [5]. Hence this makes the concrete to be in compression state and show a good performance. The prestressing level is varied and the performance of the prestressed concrete beam is studied. The prestressing force of 200 kN, 300 kN, 400 kN were induced into 3 different models and the effect of prestressing is studied. Coupled temperature displacement analysis is performed on the beams for 4 hours with 600°C. The obtained results are shown in Table 2.

TABLE 2: Results by varying Prestressing Force

S. No	Prestressing Force (kN)	Maximum Displacement (mm)	Maximum Absolute Stress (N/mm²)	Maximum Absolute Strain
1	200	364	384242	4.3
2	300	376	407128	4.3
3	400	389	429670	4.4

It is observed that, the level of prestressing has a good influence on the residual strength on the member. As the prestress value increases, the stress induced into the member is high and the bearing capacity of the member is increasing gradually. Also, for beams with higher prestressing value, the fire resistance is good and the deterioration is slow. The effect of prestress has less influence on the displacement on the member. The beam with 400 kN of prestressing forces bears 5% and 10% more stress than 300 kN and 200 kN respectively. Load versus displacement graph is shown in Figure 1 and Figure 2 shows the stress versus strain graph obtained. The deflected shapes of beams with 200kN, 300 kN and 400 kN are shown in Figure 3, Figure 4 and Figure 5 respectively.
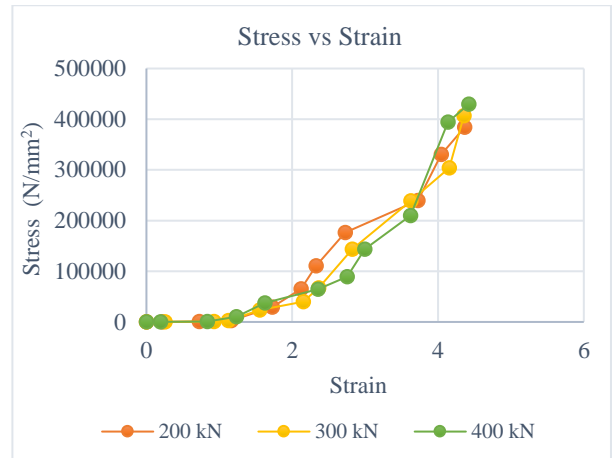

Figure 1: Load vs Displacement
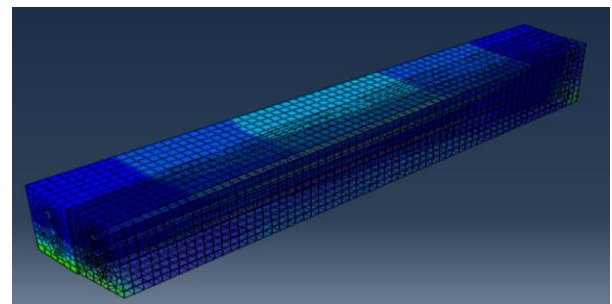

Figure 2: Stress vs Strain graph

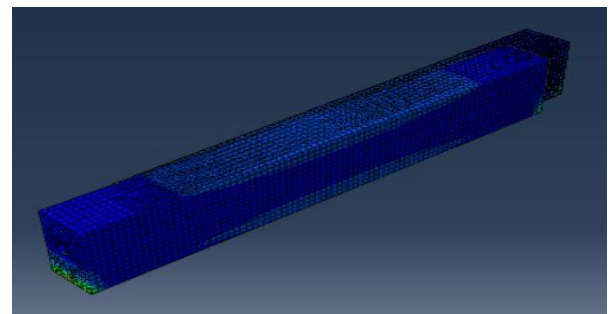**Figure 3: Deflected beam with 200 kN prestress**

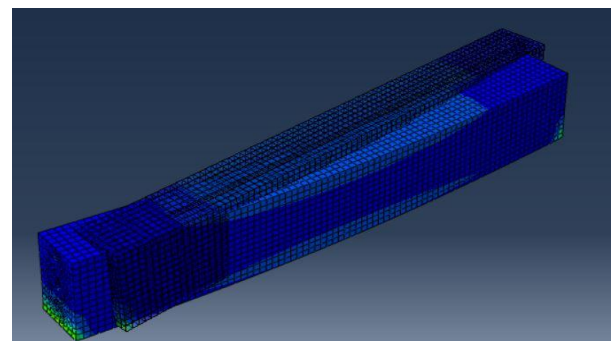**Figure 4: Deflected beam with 300 kN prestress**

Figure 5: Deflected beam with 400 kN prestress

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4.2 Span by Depth ratio

The effect of span by depth ratio on the performance of prestressed beam under high temperature is also studied. The ratio is varied from 100% to 60% and the performance of the beams are studied. The details of span by depth ratio taken for the present study and the dimensions of the beam with varied span by depth ratio are shown in Table 3.

TABLE 3: Ratio of Span by Depth

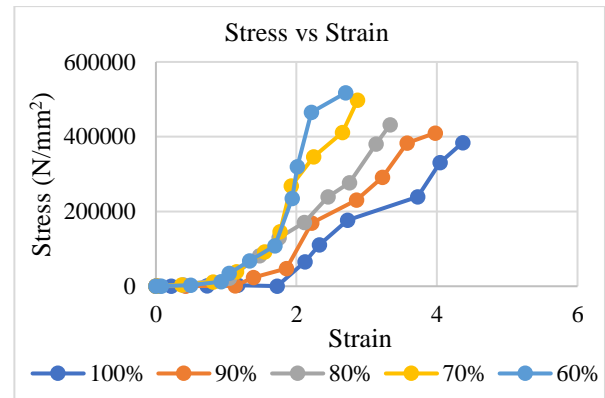| S. No	% of S/D value	Values of Span/Depth	Ratio
1	100	2500/400	6.2
2	90	2000/350	5.6
3	80	2000/400	5.0
4	70	2000/450	4.3
5	60	2000/550	3.7

Beams with different dimensions are modeled in the software. The calculated properties are assigned to the members. Coupled temperature displacement analysis is performed on the beams for 4 hours with 600°C. The obtained results are shown in Table 4.

TABLE 4: Results by varying the Span/ Depth ratio

S. No	% of S/D ratio	Maximum Displacement (mm)	Maximum Absolute Stress (N/mm²)	Maximum Absolute Strain
1	100	364	384248	4.3
2	90	281	409875	3.9
3	80	234	432254	3.3
4	70	183	497655	2.8
5	60	159	517132	2.6

It is observed that, the bearing capacity of the prestressed beams is increasing with the decrease of S/D ratio. Larger the value of S/D ratio, bearing capacity is low. Also, the flexural stiffness is higher in the beams with low S/D ratio, higher the value of S/D ratio, more the displacement is observed. The beam with 60% of S/D ratio bears 2%, 15%, 19%, 24% more stress than the beams with 70%, 80%, 90%, 100% of S/D ratio respectively. Figure 6 shows the load versus displacement graph and Figure 7 shows the stress versus strain graph obtained from analysis.

Figure 6. Load vs Displacement graph

Figure 7. Stress vs Strain graph

The deflected shapes of the beams with 100%, 90%, 80%, 70%, 60% span by depth ratio are shown in Figure 8, Figure 9, Figure 10, Figure 11, Figure 12 respectively.
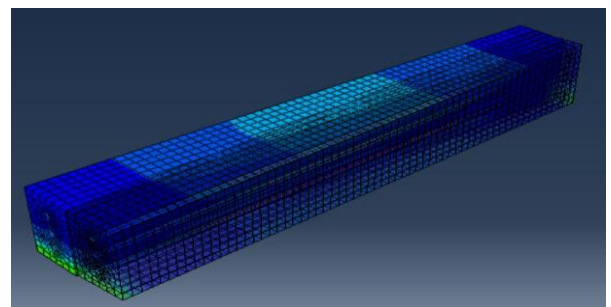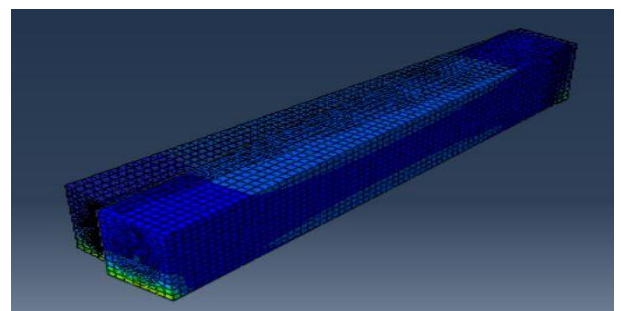

Figure 8: Deflected Beam with 100% S/D ratio

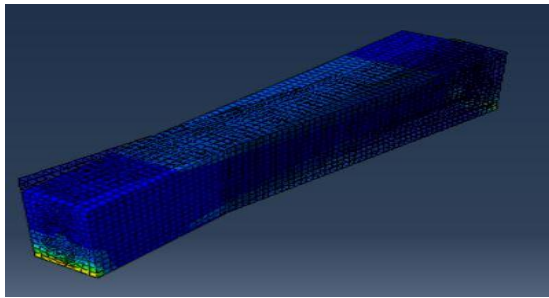**Figure 9: Deflected beam with 90% S/D ratio**

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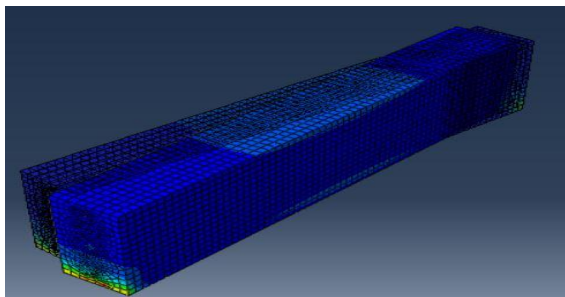**Figure 10: Deflected beam with 80% S/D ratio**

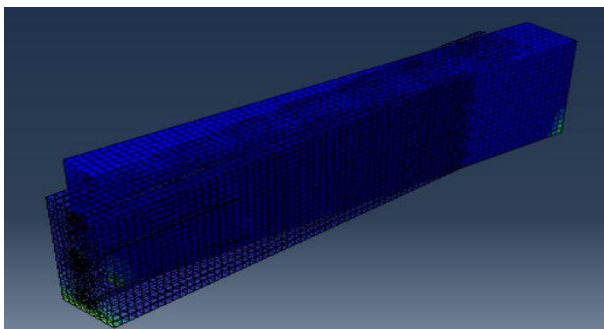
Figure 11: Deflected beam with 70% S/D ratio

Figure12. Deflected beam with 60% S/D ratio

4. Results and Discussion

The post tensioned beam is exposed to elevated temperature and the different parameters that influence the performance of the beam are studied. The parameters include prestressing force and span by depth ratio. The absolute stress is higher in the beam with 400 kN and it is less in the beam with 200 kN. The displacement values are observed to be almost close. It can be noticed that the displacement values are less influenced by varying the prestressing force. By varying the prestressed force, the load bearing capacity of the prestressed beams is increased. Hence higher the prestressing force more the load bearing capacity of prestressed beam. It is also noticed that the span by depth ratio can influence the behaviour of prestressed beam. the beam with 60% span by depth ratio was inducing more stress than the beam with 100% span by depth ratio. The displacement of the beam is gradually reducing from 100% to 60% span by depth ratio. Flexural stiffness is

higher in the beams with low span by depth ratio. The beam with 60% of S/D ratio bears 2%, 15%, 19%, 24% more stress than the beams with 70%, 80%, 90%, 100% of S/D ratio respectively.

5. Conclusions

- It is observed that higher the prestressing force better the performance and also the bearing capacity. The beam with 400 kN induces 5% and 10% more stress than the beams with 300 kN and 200 kN respectively. Minor variations in the displacements are noticed in the beams by varying the level of prestressing force under elevated temperature.

- The beams with lower span by depth ratio has enhanced performance than the beams with higher span by depth ratio. Higher the span by depth ratio lesser the bearing capacity. The beam with 60%

  span by depth ratio induces 25% higher stress and displaces 56% less than the beam with 100% span by depth ratio.

- From this study, it is observed that span by depth ratio is found to be significant parameter affecting behaviour of prestressed beam under elevated temperature.

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