OPEN ACCESS

International Journal Of Modern Engineering Research (IJMER)

Stress Analysis of Precast Prestressed Concrete Beams during Lifting

V. M. Gaykar[1], J. G. Solanki[2]

[1]M.tech Student, Structural Engineering Department, Veermata Jijabai Technological Institute, India
[2]Asst. Professor, Structural Engineering Department, Veermata Jijabai Technological Institute, India

Abstract: *The use of long span prestressed beams in bridge construction is very common. Even if the sections are economical the erection of the beam still poses a challenge in construction. Not much work has been done in the analysis of stress and deflection at erection stage. This paper deals with the behavior of precast prestressed beams during lifting. Since the spans of these beams are large, it may fail due to cracking during erection. In this paper a detailed 3-dimensional Finite Element Analysis of 2 prestressed beam sections was done with incorporating the effect of initial imperfections and prestress. Results were obtained for both prestressed beam and non-prestressed beam and were compared with Moen's formulae. To include the effect of prestressing cables in the beam new additional formulae were introduced and used in combination with the Moen's. The results obtained were approximately validated with the Finite Element Analysis results. It is seen that the prestressing cables have a significant effect on the behavior of a beam during lifting. For a prestressed beam the overhang length should be kept minimum for safe erection which is opposite in the case of a normal beam.*

Keywords: *Deflection, Finite Element Analysis, Initial Imperfections, Lifting, Prestressed beam.*

I. INTRODUCTION

The use of precast prestressed beams is wide in bridge construction. These beams are long with imperfections and tend to deflect about both major and minor axis during lifting. Moreover the prestressing cable causes the beam to get highly stressed which in turn results in cracking. Thus for safe erection, it is necessary to study the deflection and stress behavior of the prestressed beam.

Many numerical formulae are available in previous literature for analyzing lateral behavior of the beam at lifting.[1]–[7] Also it is found that the camber due to prestress has a considerable effect on the deflection of the beam. [5], [8]. The previous literature also contains an experimental study on initial imperfection.[9]

In this paper, two beam sections viz. 77in. PCI Bulb Tee and Type IV AASHTO beam [9] are numerically modeled using Abaqus software to study its behavior. This study compares the finite element analysis results with the analytical solutions from previous literature and also studies the difference in the stress behavior and deflection of beams due to prestress. The effect of prestress on the deflection of the beam about both major and minor axis is also studied.

II. NUMERICAL MODELLING

Numerical analysis was carried out on two sections of precast prestressed beams of length 42.36m and 31.7m respectively. The initial imperfection in the beam is considered in the form of a radial curvature with sweep of L/1060 and L/790 respectively. The details of the beams are obtained from 'Lifting Analysis of Precast Prestressed Concrete Beams' [9]. The beams are prestressed using low relaxation strands with 0.6 inch diameter and the strands are harped at 1.524m from mid-span. The compressive strength of concrete for both beams is assumed to be fc= 55 N/mm2 with initial compressive strength of f_{ci} =45N/mm2.

Finite element models of both beams were made with and without considering the prestressing force. A 3D model was preferred to 2D and 1D model, as the prestressing cables were to be included. The FE model consisted of 3 parts viz. beam, prestressing cables and lifting loops. C3D8R (8 node linear brick element, reduced integration) hexahedral element was used for the beam formation and C3D4 (4 node linear tetrahedron) element for loop formation. For prestressing cables T3D2 (2 node truss) element was used. Initial condition of stress was applied to the cables, so as to get the effect of prestress [10]. The interaction between cables and beam and loop and beam is done by embedded constraint. Thus a perfect bond is assumed between the different parts without any bond slippage. Pinned boundary conditions were applied to the hooks to get the effect of hanging from cables under the effect of gravity load. M55 grade concrete was used for beam and modulus of elasticity of prestressing steel was taken as 195GPa. The behavior for both materials was assumed to be linear. Fig.1 and Fig.2 shows the details of 77in. PCI Bulb Tee and Type IV AASHTO beam respectively.

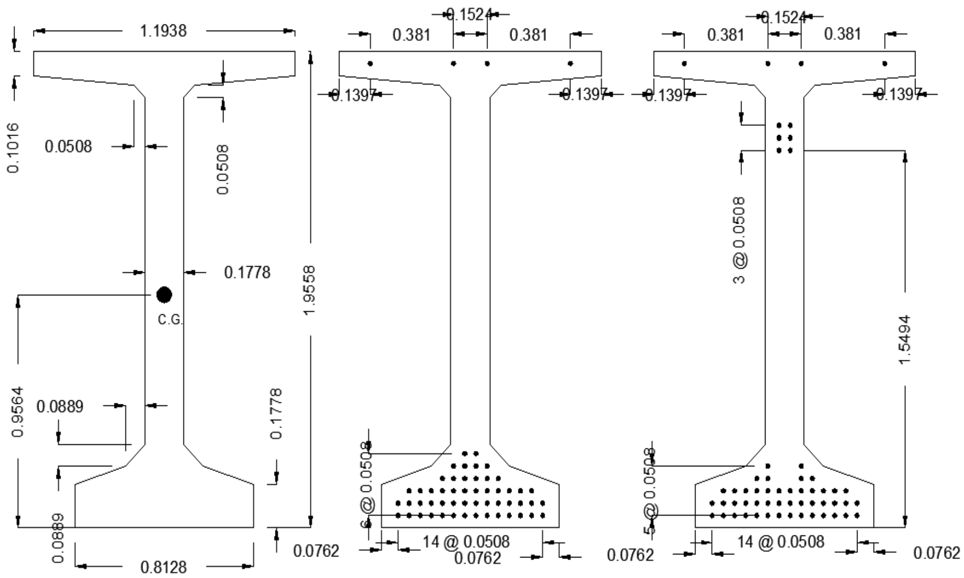


Fig. 1 Beam details of 77in. PCI Bulb Tee

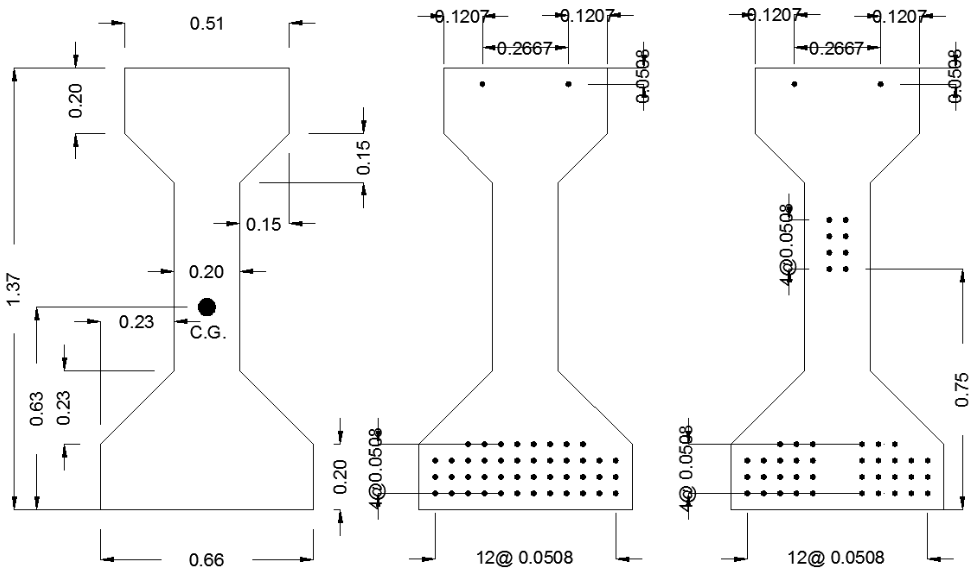


Fig. 2 Beam details of Type IV AASHTO beam

III. Results And Discussions

The Numerical modelling was done as explained above. To verify the prestressing condition, first the beams were analysed as simply supported and convergence study was carried out. The results so obtained were compared with the manual analysis. Thus, similar analysis for hanging condition was carried out with pinned boundary conditions for the lifting loops. Only self-weight was considered under static condition for analysis. Also, analysis was carried out both conditions i.e. by considering and not considering the effect of prestressing cables. Fig.3 shows an isometric view of FE model for both beams.

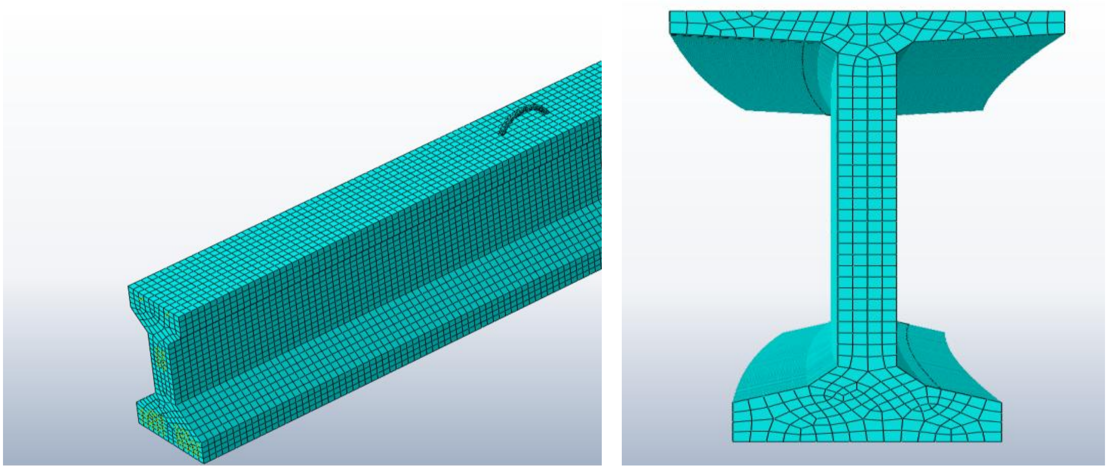


Fig. 3 a) Isometric view of FE model of Type IV AASHTO beam & **b)** side view of FE model of 77in. PCI Bulb Tee

1.1 Finite Element Analysis results

The FEA results for beam without prestressing force shows that as the overhang increases, the tension zone in the beam reduces along with deflection. The stress contours can be seen in Fig.4 and Fig.5 where red zone is tension and blue zone is compression. Fig.4 shows Bulb Tee beam with a/L ratio 0.05 and 0.12 and Fig.5 shows Type IV AASHTO Beam with a/L ratio 0.06 and 0.16. It can be seen that the red zone (tension zone) decreases. This happens because as the overhang increases the internal span reduces which in turn cause a reduction in the self-weight bending moment, thus the flexural stress decreases. Hence the compression stresses at the top and the tension stresses at the bottom also reduces.

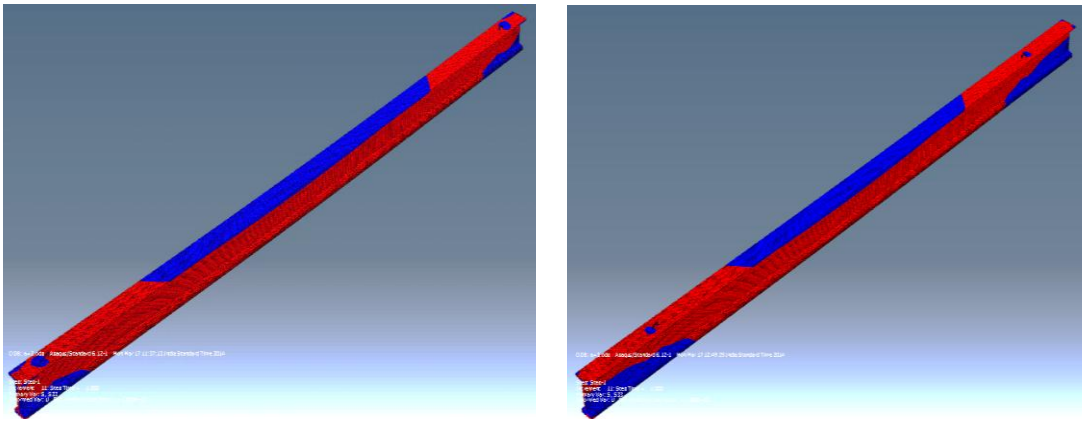


Fig. 4 77in.Bulb Tee Beam at a/L=0.05 & a/L=0.12 respectively

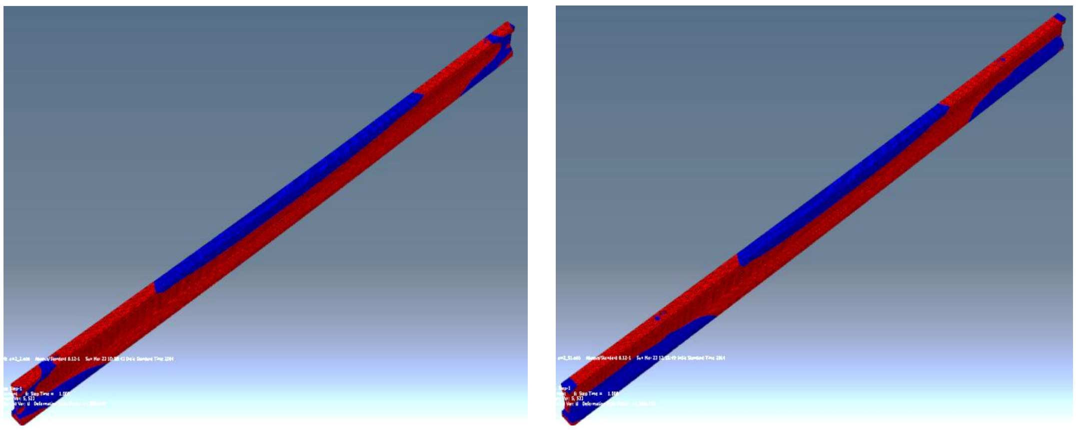


Fig. 5 Type IV AASHTO Beam at a/L=0.06 & a/L=0.16 respectively

For prestressed beam the behaviour seen is opposite. From FEA results the contours in Fig.6 & Fig.7 shows that the red zone increases as the overhang increases. Fig.6 shows Bulb Tee beam at a/L ratio 0.07 and 0.17 and Fig.7 shows Type IV AASHTO Beam at a/L ratio 0.09 and 0.22 respectively. In prestressed beam there is already a negative bending moment due to the prestress, hence there is tension at top and compression at bottom. The stress due to self-weight tries to counteract the stress due to prestress. Thus as the mid-span reduces, the resulting tensile stresses at the top fibre increases and the resulting compression stresses at the bottom fibre increases. This effect is due to the reduction of the bending moment due to self-weight since the mid-span reduces.

1.2 Analytical results

During manual analysis the bending moment in the beam at lifting was calculated using Moens formula [3]. Thus, bending stresses were calculated and then added up to the stress due to prestress. The formulae so obtained and used are given below. Here compression is taken as negative and vice-verse. Also the effect of stress due to lateral bending is neglected.

$$\sigma_{top} = -\frac{P}{A} + \frac{P.e}{Z_t} - \frac{M}{Z_t} \qquad (1)$$

$$\sigma_{bottom} = -\frac{P}{A} - \frac{P.e}{Z_b} + \frac{M}{Z_b} \qquad (2)$$

where,

M = bending moment about strong axis
P = prestressing force
e = eccentricity of the cable
A = cross-sectional area
Z_t , Z_b = Section modulus at top and bottom respectively

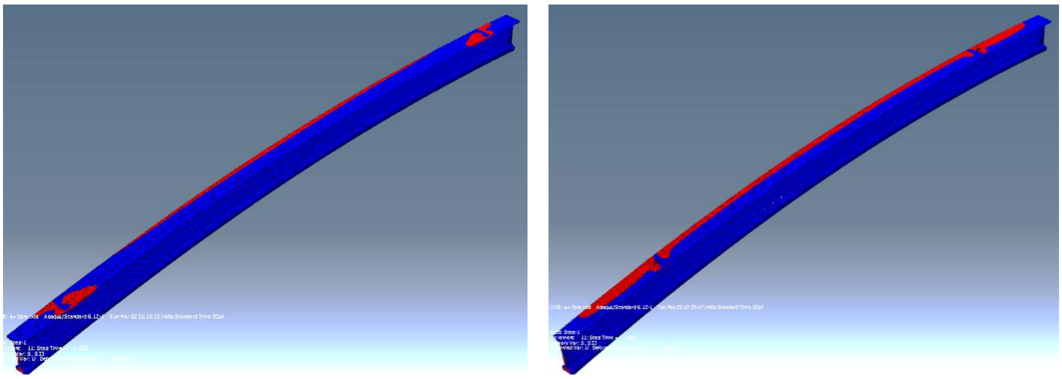


Fig. 6 77in.Bulb Tee Beam (prestressed) at a/L=0.071 & a/L=0.165 respectively

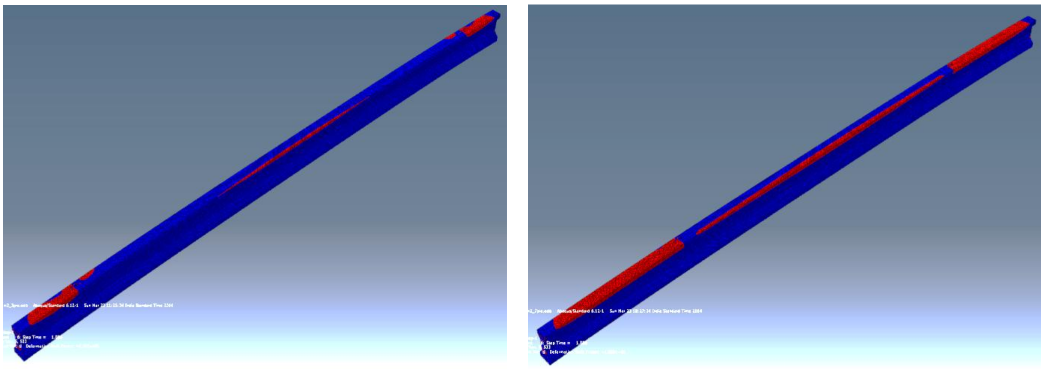


Fig. 7 Type IV AASHTO Beam (prestressed) at a/L=0.09 & a/L=0.22 respectively

Using these formulae stresses were calculated for varying 'a/L'. The analytical results obtained were compared with FEA results for both sections, as shown in Fig.8 The stresses at a particular section goes on increasing as the 'a/L' ratio increases. Also, the values obtained using the given formulae gives conservative results as compared to abaqus. Both compression and tension stresses appears to be higher side. The reason behind this is the assumption differences in calculating the analytical values like not considering the effect of lifting loop and also neglecting the stresses due to lateral bending. Finite element analysis considers the effect of the lifting loops.

Following Fig.8 shows the stress variation at mid-section for both PCI Bulb Tee and Type IV AASHTO beam respectively. It can be seen that from abaqus analysis that the top fiber is in compression, this is possible due to the local effect of top prestress cables in the top flange. Manual analysis does not take this into consideration.

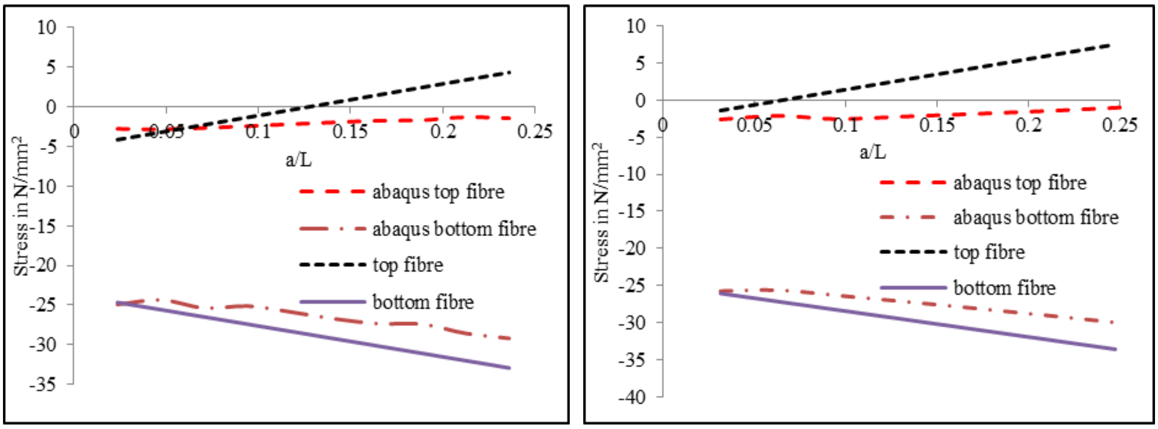
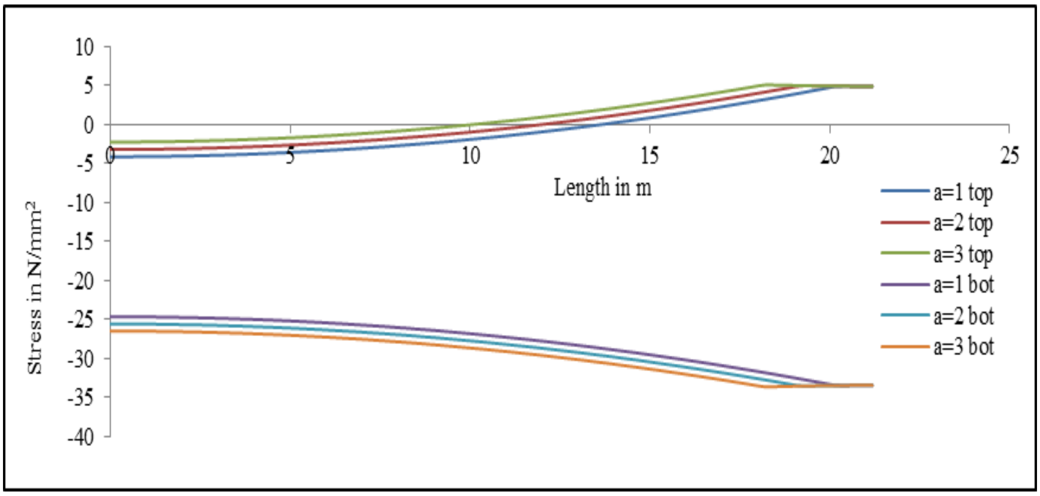


Fig. 8 Stress variation at mid-section (77in. PCI Bulb Tee & Type IV AASHTO Beam respectively)

The stress variation of the both beams along the length is given in Fig.9 & Fig.10. These values are obtained analytically. Here the zero distance indicates mid-span. Thus the distance along X-axis is given from mid-span of the beam. It can be seen that, as the value of 'a' increases (i.e. overhang increases) the stress at both top and bottom fiber increases for all the sections. Maximum tension and compression are obtained at the lifting points.

From Fig.9 & Fig.10 it is clear that in prestressed beams, stresses goes on increasing as the overhang distance increases which is opposite to the behavior of normal R.C.C. beam. As the span increases, the tension in the bottom fiber and compression in the top fiber due to self-weight increases. This helps to counteract the stress produced by the prestressing strands, explaining this behavior of the prestressed beam to that of a normal beam. This behavior is verified by both analytical and FEA results.



zFig. 9 Variation of stress along the length (77in. PCI Bulb Tee)

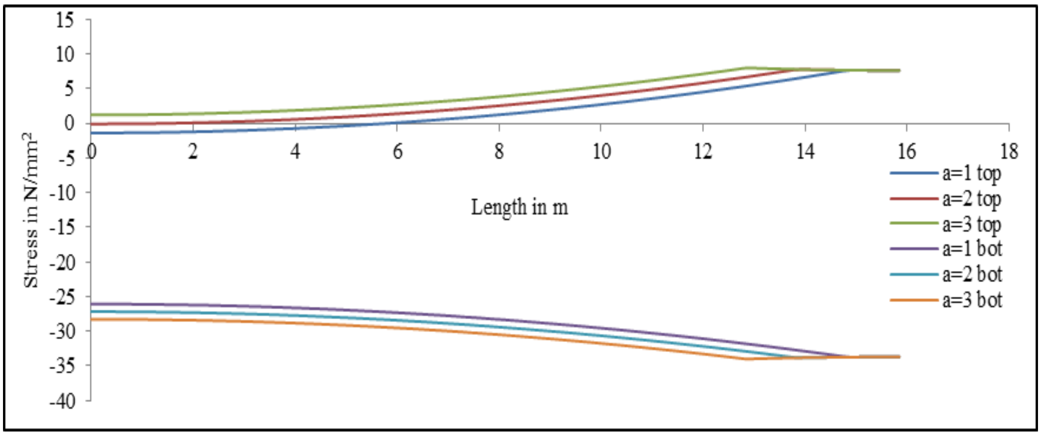


Fig. 10 Variation of stress along the length (Type IV AASHTO Beam)

Along with the stresses the deflections were also compared. Also the observed FEA results of downward deflection are found to be approximately same to the analytical results. Both lateral and downward deflection for both sections reduces at mid-span as the overhang increases. This behaviour is observed for both prestressed and non-prestressed beams.

Fig.11 & Fig.13 shows lateral deflection for both the beams. We can see that the behaviour of lateral deflection is same as analytical but in opposite direction. This difference is due to the downward deflection of the beam, which results in the shift of centroid below the roll axis hence radially inward deflection. From both figures it can be seen that the lateral deflection reduces as the 'a/L' ratio increases. Here positive value means radially outward deflection and vice-verse.

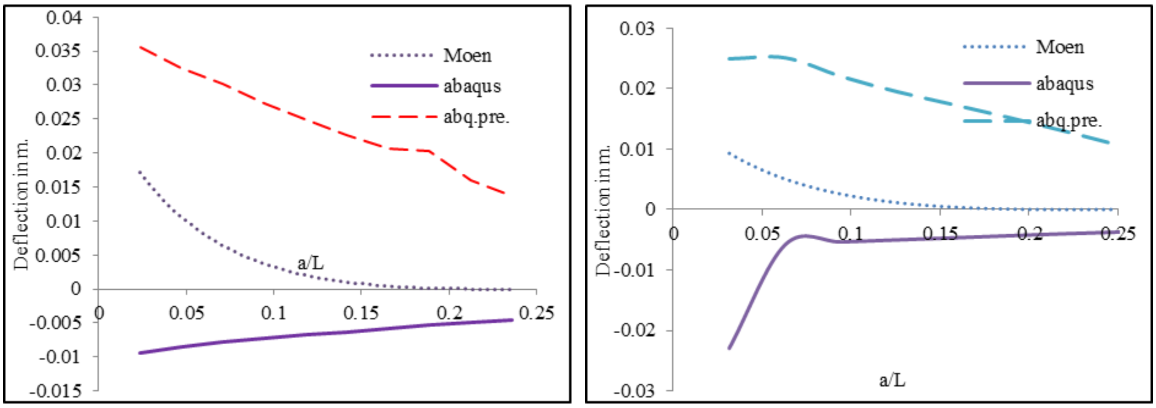


Fig. 11 Lateral Deflection at midsection (77in. PCI Bulb Tee & Type IV AASHTO Beam respectively)

Similar behavior is observed from Fig.12 & Fig.14 for downward deflection for both beams. Here negative value was considered downward deflection and vice-verse. The deflection in prestressed beam was observed to be upward due to the effect of prestress cables. For calculating the net downward deflection due to gravity and prestress following formula was used. This formula gives the deflection due to prestress; this deflection was then added to the deflection due to gravity. The result and behavior obtained were very much similar.

$$v = -\frac{Pex^2}{2EI} + \frac{PeLx}{2EI} \qquad (3)$$

where,
v = deflection due to prestressing cables
P = total prestressing force in the cables
e = eccentricity of the cables
L = Total length of the beam
x = distance of section from the end
E,I= modulus of elasticity and moment of inertia about strong axis of the section

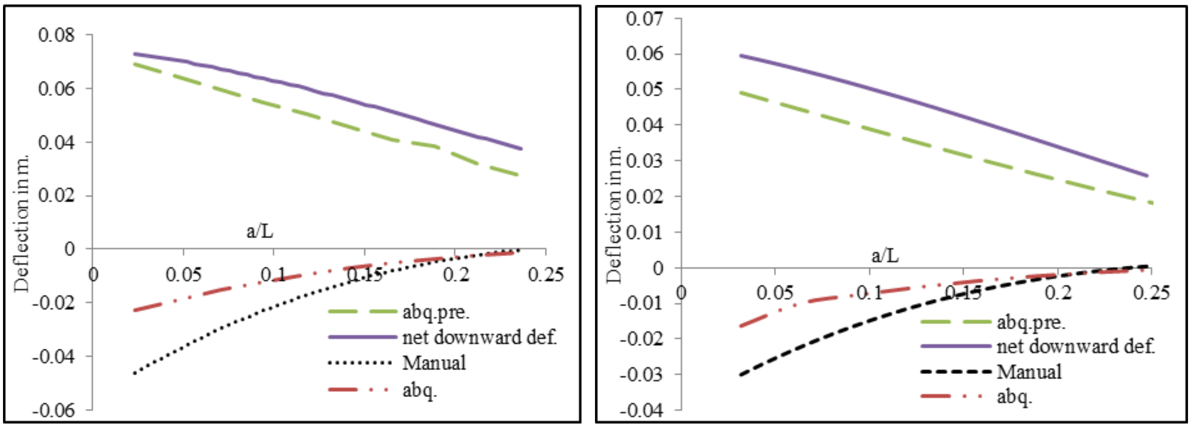


Fig. 12 Downward Deflection at midsection (77in. PCI Bulb Tee & Type IV AASHTO Beam respectively)

Following Fig.13 shows lateral deflection at end-sections. The deflection behaviour for non-prestressed beam is observed to be same, whereas for prestressed beam it goes on increasing as a/L ratio increases. Thus the effect due to prestress observed is significant.

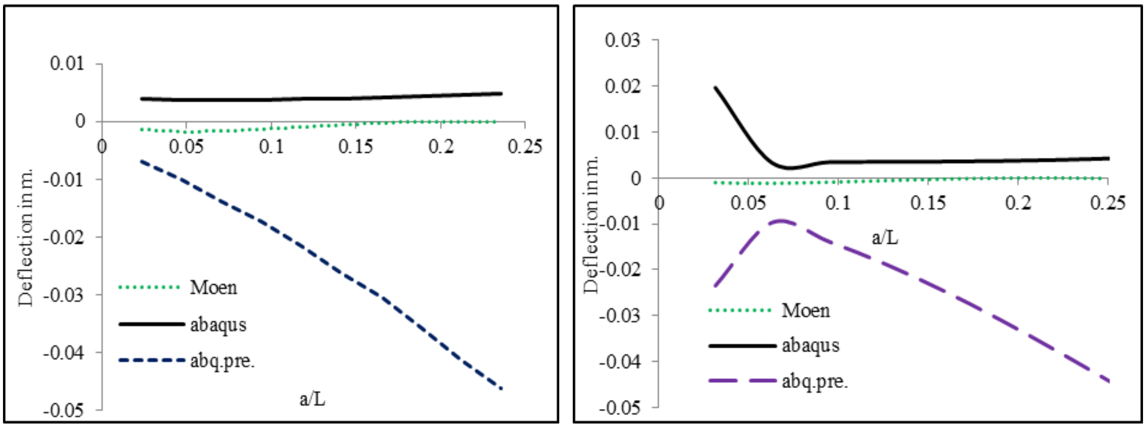


Fig. 13 Lateral Deflection at end section (77in. PCI Bulb Tee & Type IV AASHTO Beam respectively)

Fig.14 shows the downward deflection at end-section for both beams. It is seen that the deflection observed in non prestressed beam is approximately same, but in prestressed beam the deflection observed is in opposite direction and increases drastically as ‘a/L’ ratio increases.

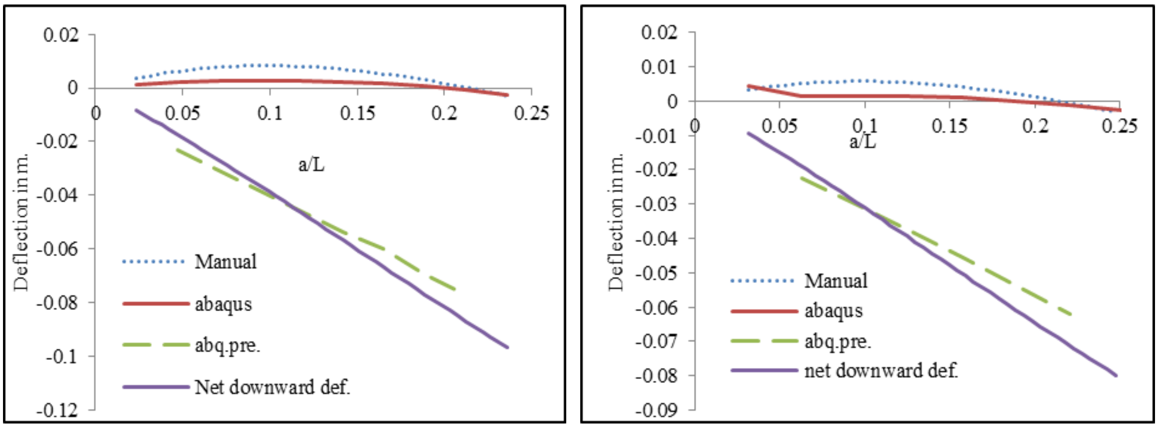


Fig. 14 Downward Deflection at end section (77in. PCI Bulb Tee & Type IV AASHTO Beam respectively)

IV. Conclusions

The Finite Element Analysis results are compared with the analytical equations obtained from Moen [3]. The results verify that the stress behaviour of both prestressed and non prestressed beams between analytical and Finite Element Analysis is same.

It is observed that for a prestressed beam the lifting loops should be far from the mid-section i.e. the 'a/L' ratio should be less than 0.2 to 0.25. Thus the stresses will be under permissible limits. On the contrary a beam without prestressing shows lesser deflection and stresses when the overhang normalized ratio is near by 0.2 to 0.25.

Also the behaviour for lateral and downward deflection shown by the finite element analysis and the formulae are same along the length, except the finite element analysis shows lateral deflection in opposite direction due to the effect of gravity.

The above given formulae combined with Moen's formulae can be used to calculate the deflection and stresses of any precast prestressed as well as non-prestressed beam at any section at hanging stage. Thus the results obtained should be useful in deciding the lift points of the prestressed beam to avoid cracking and collapse.

REFERENCES

[1] R. R. Imper and G. Laszlo, "Handling and shipping of long span bridge beams," PCI J., vol. 32, no. 6, pp. 86–101, 1987.

[2] R. F. Mast, "Lateral stability of long prestressed concrete beams, Part 1," PCI J., vol. 34, no. 1, pp. 34–53, 1989.

[3] R. Plaut and C. Moen, "Analysis of Elastic, Doubly Symmetric, Horizontally Curved Beams during Lifting," J. Struct. Eng., vol. 139, no. 1, pp. 39–46, 2013.

[4] R. Plaut, C. Moen, and R. Cojocaru, "Beam deflections and stresses during lifting," Eng. J., vol. 49, no. 4, p. 187, 2012.

[5] R. V. Southwell, H. P. J. Taylor, C. J. Burgoyne, and T. J. Stratford, "Stability Design of Long Precast Concrete Beams.," Proc. ICE - Struct. Build., vol. 134, no. 2, pp. 155–168, Jan. 1999.

[6] T. J. Stratford, SOUTHWELL, and C. J. Burgoyne, "Lateral Stability of Long Precast Concrete Beams.," Proc. ICE - Struct. Build., vol. 134, no. 2, pp. 169–180, Jan. 1999.

[7] R. Swann and W. Godden, "The lateral buckling of concrete beams lifted by cables," Struct. Eng., vol. 44, no. 1, pp. 21–33, 1966.

[8] W. Peart, E. Rhomberg, and R. James, "Buckling of Suspended Cambered Girders," J. Struct. Eng., vol. 118, no. 2, pp. 505–528, 1992.

[9] R. Cojocaru, "Lifting Analysis of Precast Prestressed Concrete Beams," masters diss., Virginia Polytechnic Institute and State University, Blacksburg, VA, 2012.

[10] P. Riva and F. Minelli, "Numerical modeling of prestressed fiber reinforced high performance concrete beams subjected to shear."