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Investigation of Bursting Force In I-Section Post-Tensioned Anchorage Zone

M.R. Jain [1], R.N. Khapre [2, *]

[1] Department of Civil Engineering, Research Scholar, Shri Ramdeobaba College of Engineering and Management, Nagpur 440013, India
[2] Department of Civil Engineering, Associate Professor, Shri Ramdeobaba College of Engineering and Management, Nagpur 440013, India

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Abstract

In post tensioned concrete beam the high transverse tensile stress is generated and if proper reinforcement is not given, bursting may occur. To study the effect of these stresses and to find bursting stress in end region the analytical study was carried out. In present work the end block of post-tensioned prestressed concrete beam is modelled in finite element based software with eccentric tendons. The bursting zone of beam is evaluated and parametric study was carried out by varying eccentricity, anchorage ratio and web thickness of girder. The 3D modelling was done and results are compared in terms of bursting force. The results are compared with Indian Standard 1343:2012 and inferences are drawn towards the usability of IS code equation of bursting force for I-section.

Keywords: Post tensioned concrete, transverse stress, bursting stress and end block.

1. Introduction

Post tensioned concrete structures are widely used in civil engineering since they have high tensile capacity and high strength. It is well establish fact that the basic economy of post tensioned concrete lies in its high strength to weight and cost ratio, its resistance to fire and corrosion and its versatility and adaptability. In post tensioned concrete members, stresses are induced during the construction in such a way that they can resist stresses caused by external applied loads. Post tensioned structural member are widely used to achieve high strength at lower self-weight. Prestressed concrete is most suitable for long span structural element like beam and girder.

In post tensioning the load is transferred from the tendon to the concrete. Due to this large concentrated Post tensioning force, high amount of tensile stresses are generated near the end of section which are transverse in nature. These tensile stresses are termed as bursting forces. Hence proper study of bursting force in end block is essential for proper designing of reinforcement.

Many researchers have studied the end block and given numerical, experimental and analytical solutions to computer bursting tensile force. Morsch [1] studied two dimensional load path method models and proposed an equation to calculate the bursting force. Guyan [2] proposed an equation based on elastic stress distribution theory within end block. Douglas [3] has described the theoretical and experimental work on the stress concentration in end block. Both analytical and theoretical models were made and a method is given to solve three dimensional problem of end block mathematically. Iyengar [4] presented two dimensional theories of end block stresses in post-tensioned concrete beam. Literature shows good agreement of presented results with results given by Guyan [2] and Morsch [1]. Som and Ghosh [5] investigated the transverse zone stresses in three axial direction of end block of prestressed concrete beam. The three cases were taken for the study namely central axial prestressing force with single cable, central axial prestressing force with multiple cable arrangement and axial prestressing force with eccentric cable. Transverse stresses have been calculated and compared with the results obtained by Guyan [2].

Stress distribution for multiple and eccentric anchorage on rectangular I-section has been presented by Yetram [6]. Spalling and bursting stresses were studied and results are used for conventional design. Fenwick [7] performed the analytical and experimental work on the post-tensioned concrete beam. Experimental and finite element study on eighteen end block was presented to bursting force developed after formation of first crack in concrete member. Results shows that the magnitude of bursting force used for designing of end block shows significant variation after once a primary crack forms in concrete. Khapre and Gupta [8] efforts are made to reduce the Computational time in the Finite Element Analysis by applying Parallel Computing Technique on Supercomputer PARAM 10000. The problem of End block in Prestressed Post-Tensioned Concrete Beam is investigated using this computer code.

*Corresponding author. Tel: +919960256533; E-mail address: khaprern@rknec.edu

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Gupta and Khapre [9] did the analysis of the end block using Finite Element Method considering the problem as 2-Dimensional Plane Stress. They studied the effect of Poisson's Ratio over the stresses caused by prestressing force (P_k) in the End block. Boye [10], studied 2-dimensional finite element analysis on precast tunnel segments and developed an equation to calculate the bursting force in end block. Three dimensional finite element analysis was conducted on end block by Kwak [11] considering various parameters like tendon angle eccentricity, duct hole and bearing plate size. At the end upgraded design guideline is given by considering duct hole also. Young Lee [12] proposed an equation based on 3D FEM study. Here, an equation is presented considering parameters like eccentricity, shape and cable inclination.

Indian Standard 1343:2012 [13] gives directions towards the prestressed concrete design. For calculating the bursting tensile stress only an equation is given based on the work of Zielinki and Raw [14]. It is based on experimental investigation on concrete prismatic prism, empirical relation have been developed by Zielinki and Raw [14] to calculated bursting force. Same equation with little modifications has been adopted by Indian Standard. In this equation, effect of eccentricity and shape of section ignored. Although so many studies were presented related to the bursting force but the eccentricity, anchorage shape, cable curvature are still not considered in IS 1343:2012. An expression given by Indian Standard 1343:2012 is as follows.

$$F_{bst} = P_k\,[0.32-0.3\,y_{po}/y_o] \quad (1)$$

In this paper an attempt is made to understand behaviour of bursting force in rectangular sections and I-section beams on the basis of 3D finite element analysis.3D Modelling and analysis of post tensioned concrete end block was done in ANSYS for different anchorage ratio (ratio of depth of anchorage plate to depth of beam) and eccentric to study their effect on bursting force. The results are compared with the equation available in IS 1343:2012 and conclusions are presented.

2. Finite Element Modelling

The study is categorized in two categories. In the first category, end block having rectangular sections were modelled. Table-1 shows the detailed dimensions of models having rectangular shapes with varying width and anchorage ratio. Models with rectangular sections were modelled in way to understand the effect of reducing width of end block with changing anchorage ratio on bursting force. For comparison with IS 1343:2012, the eccentricity is ignored during the analysis of these models. In the second category, I shape end blocks were modelled with changing parameters like thickness of web, anchorage ratio and eccentricity of prestressing load. The detailed dimensions of the models are shown in Table-2. Total 9 models and 27 models were prepared respectively for rectangular section and I-section end block for through analysis. The depth of the end block is kept constant for all models. Typical 3D models under both categories are shown in Fig. 1 and Fig. 2.

In 3D finite element analysis, material properties of concrete are taken as Modulus of elasticity $E = 3 \times 10^{10}$ N/m² and Poisson's Ratio $\mu = 0.18$. Fine mesh of brick elements (element size 0.01 m) was preferred for discretization for improved accuracy of finite element analysis. External post tensioning force of 1000 N was applied on all models for estimation of bursting force for uniform loading conditions. All the results are compared in terms of dimensionless entity F_{bst}/P_k, as per equation given in IS 1343:2012. As concrete is weak in tension, it will crack before reaching non-linear zone in compression, hence only linear analysis is performed. After successful simulation, the transverse tensile stresses were measured along the centre line path for all models as shown in Fig. 3. These tensile stresses were integrated using computer tool for getting magnitude of bursting force as illustrated in article by Stone [15]. Later, the variation in bursting force was plotted and compared with IS 1343:2012.

Table-1. Dimensions of end block with rectangular cross section

Rectangular model	Depth(d) mm	Width(b) mm	b/d	Anchorage ratio(k)
Model A-1	300	300	1.00	0.1
				0.2
				0.3
Model A-0.75		225	0.75	0.1
				0.2
				0.3
Model A-0.5		150	0.50	0.1
				0.2
				0.3

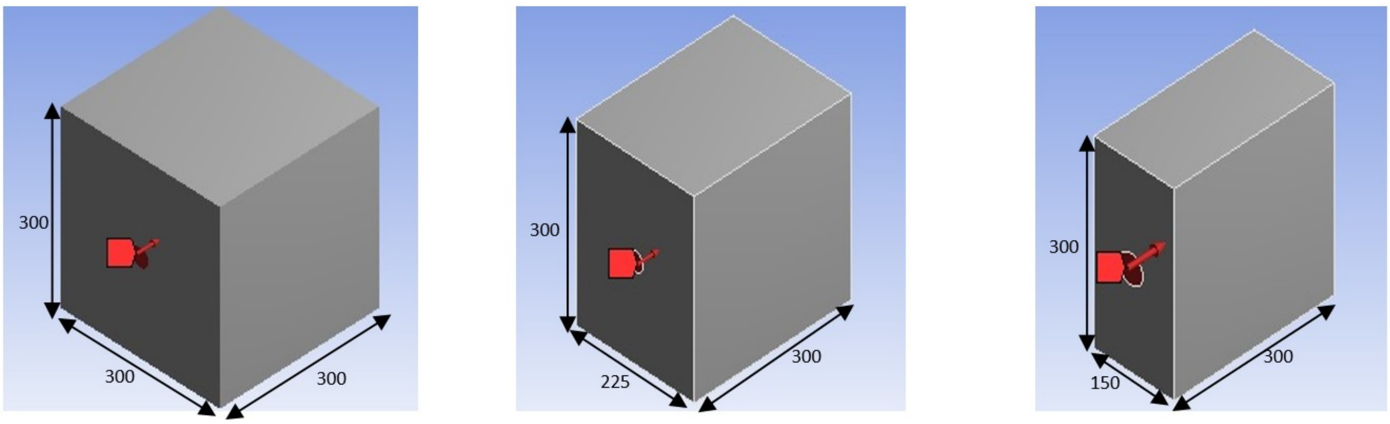

Fig. 1. 3D models of end block with rectangular cross section

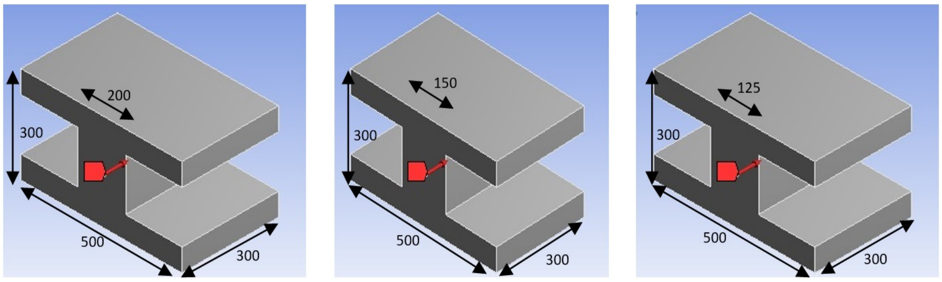

Fig. 2. 3D models of end block with I-cross section

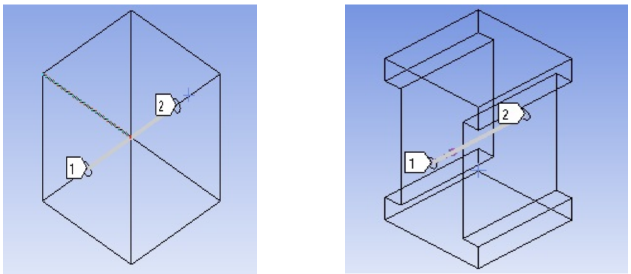

Fig. 3. Centre line path for measurement of transverse tensile stresses in end block models

Table-2. Dimensions of end block with I-cross section

I-section model	Eccentricity(e)	Overall Depth (d) mm	Thickness of web (t) mm	t/d	Anchorage ratio(k)
Model B-0.42	0	300	200	0.42	0.1
					0.25
					0.3
Model B-0.67			150	0.5	0.1
					0.25
					0.3
Model B-0.5			125	0.67	0.1
					0.25
					0.3
Model C-0.42	0.1	300	200	0.42	0.1
					0.25
					0.3
Model C-0.67			150	0.5	0.1
					0.25
					0.3
Model C-0.5			125	0.67	0.1
					0.25
					0.3
Model D-0.42	0.2	300	200	0.42	0.1
					0.25
					0.3
Model D-0.67			150	0.5	0.1
					0.25
					0.3
Model D-0.5			125	0.67	0.1
					0.25
					0.3

3. Results and Discussion:

Nine simulations for each model A, B, C and D were completed and transverse tensile stress distribution is obtained along the centre line path as shown in Fig. 3 for all models. A typical transverse tensile distribution curve is depicted in Fig. 4. Fig.4 (a) show the contour plot for rectangular model with b/t = 0.75 and k = 0.2. Here initial contours are farming as compressive stress trajectories in local zone. These stress contours are showing spalling zone in anchorage zone. Further, as the stress increases from negative to positive as it becomes tensile in nature. Circular red contour is showing the maximum tensile stress at the middle of beam which contributes towards bursting of concrete in this region.

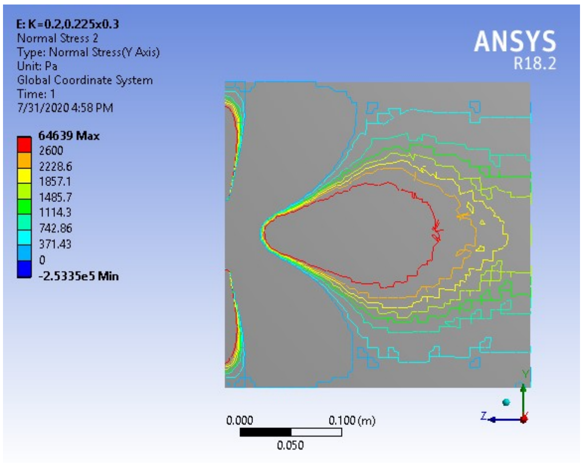

Fig. 4 (a). Rectangular model with b/t = 0.75 and k = 0.2

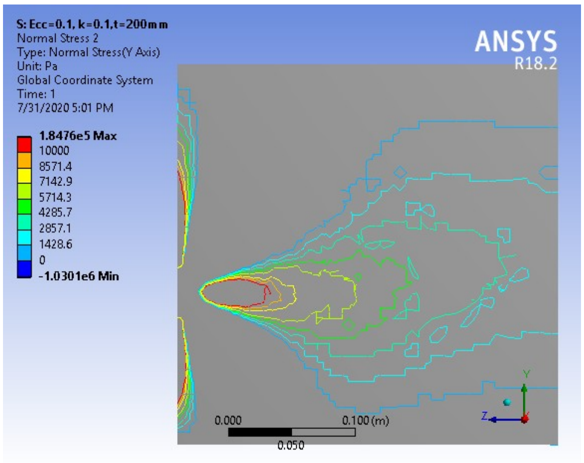

Fig. 4 (b). I-section model with e = 0.1, t/d = 0.42 and k = 0.1

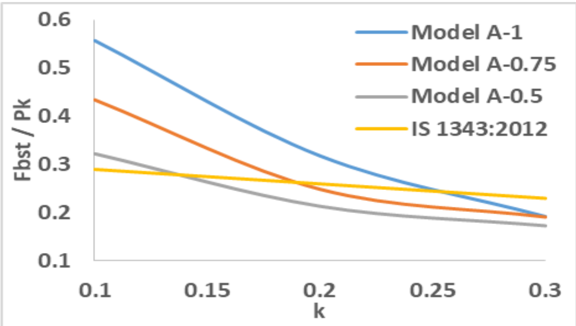

Fig. 5. Variation in F_{bst} for Rectangular model

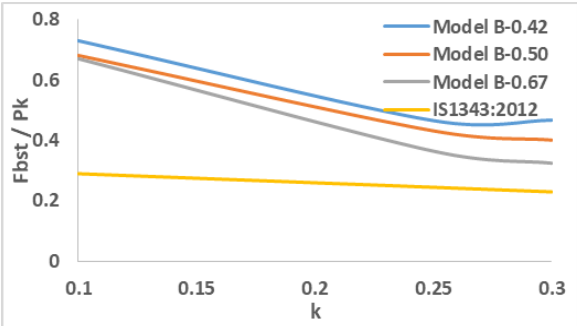

Fig. 6. Variation in F_{bst} for I-Section with e = 0.0

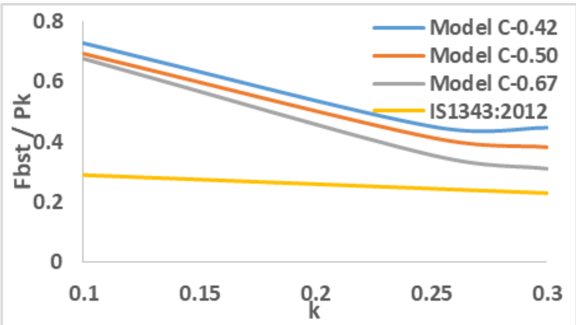

Fig. 7. Variation in F_{bst} for I-Section with e = 0.1

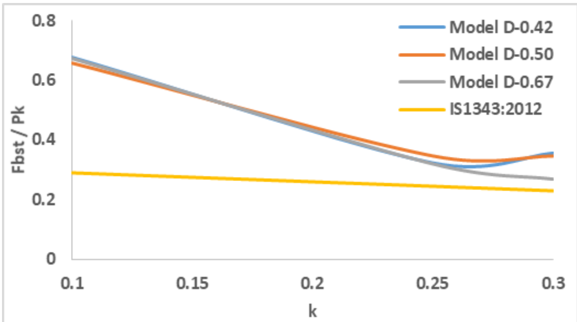

Fig. 8. Variation in F_{bst} for I-Section with e = 0.2

Fig. 4 (b) shows the contour plot for I-section model with e = 0.1, t/d = 0.42 and k = 0.1. As the eccentricity comes is introduced, the magnitude of maximum tensile stress reduces. Figure also shows reduction in zone of compressive stresses. Both figures clearly shows significant amount of tensile stresses developed in the end block due to external post tensioning that will cause bursting of concrete.

After analysing Models A, i.e. rectangular models, the bursting forces are calculated and plotted as shown in Fig. 5. Here comparison is presented on the basis of width to depth ratio of section. The width to depth ratio is increasing from 0.5 to 1.0. Fig. 5 also shows bursting force calculated from Indian Standard 1343:2012. From Fig. 5, it is clear that as the value of b/d ratio reduces, the bursting force also reduces. Figure also indicates that, more the slender section, lesser will be the bursting force irrespective of all the anchorage ratios. Equation to calculate bursting force available in IS 1343:2012 do not have provision of for b/d ratio, hence for all b/d ratios bursting force will be same as per Indian Standard 1343:2012. Figure indicates that Indian

Standard 1343:2012 gives lesser magnitude of busting force for concentric prestressing for i.e. anchorage ratio values less than 0.2. For anchorage ratios greater than 0.2, forces are over estimated by IS 1343:2012.

Figure 5 clearly shows the b/d ratio affects significantly in magnitude of bursting force. This ratio plays a vital role in post tensioned girders having I type cross sections. Hence to understand this effect in details, 3 sets of models namely Model B, C and D where in the eccentricity is varied from 0.0, 0.1 and 0.2. For every eccentricity case, nine models were analyzed wherein the anchorage ratio is varied from 0.1 to 0.3 and ratio of thickness of web to overall depth of section is varied from 0.42 to 0.67.

Fig. 6 shows variation in bursting force for I-section with concentric loading. Fig. 6 shows that the bursting force reduces with the increase in t/d ratio and anchorage ratio (k). When the results are compared with the Indian Standard 1343:2012 results, it shows that Indian Standard 1343:2012 computes lesser magnitude of bursting force irrespective of anchorage ratio and t/d ratio. Fig. 7 and Fig. 8 shows similar pattern when eccentricity of post tensioning forces are simulated.

From Fig. 7 to Fig 8, it can be seen that eccentric play an insignificant role in computation of bursting tensile force. Meager reduction in bursting force is observed with increase in eccentric. However the shape of section, especially I-section, makes huge difference in magnitude of bursting force computed in present study and using equation available in IS 1343:2012.

4. Conclusions

In present study, a finite element analysis was performed on post tensioned concrete rectangular and I-shape beam. Here eccentricity and anchorage ratio were considered as a variable to study their effect on bursting tensile force. From results of Finite element analysis it is clear that anchorage ratio influences the bursting force. For both the models, i.e. rectangular and I-section as the value of anchorage ratio increase the bursting force reduces. Also the position of zero stress moves away from the origin. The results of rectangular model shows that for higher values of anchorage ratio, Indian Standard 1343:2012 is giving higher magnitude of bursting force, but as the anchorage ratio reduces from 0.2 and less, Indian Standard 1343:2012 gives lesser magnitude of bursting force.

For the rectangular section, as the section become slender i.e. as the b/d ratio reduces the bursting force also reduces, hence lower the width of section lower will be the bursting force. For an I-section, it is observed that as the thickness of web reduces, the magnitude of bursting force increases. The increase in magnitude of bursting force with increase in thickness of web is observed to be meager.

Analytical results shows that for I-section model, present analysis is giving higher magnitude of bursting force when compared with IS 1343:2012. Hence revision in code is advised. As eccentricity increases for I-section model the bursting force is reducing insignificantly irrespective of t/d ratio. Web thickness and eccentricity both the parameter are influencing the bursting force magnitude. Hence further study should be needed for improvement in IS code equations.

Disclosures

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