ANALYSIS OF STRESS IN ANCHORAGE ZONE USING ANSYS

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Abstract— **Three dimensional stress analysis of anchorage zone in prestressed post-tensioned concrete beam is presented in this paper. Finite element method is used for the present analysis that was carried out using commercial software ANSYS. A case study is performed in which the loaded area ratio (*k*) is varied for beam subjected to concentric loading & eccentric loading and various stress distribution are obtained. The obtained results are compared with the results available in the literature and presented. Effect of eccentricity on spalling zone stress is also discussed.**

***Index Terms*— Spalling zone, Finite element analysis, ANSYS**

I. INTRODUCTION

In prestressed concrete members, stresses are induced during the construction in such a way that they can resist stresses caused by externally applied loads. Prestressed concrete structural members are widely used to achieve high strength at lower self-weight. Prestressed concrete is most suitable for long span structural elements like beams and girders, where larger bending moment results in greater depth of beam or girder [1], [2]. Broadly there are two methods of prestressing namely Pre-tensioning and Post-tensioning. In Pre-tensioning, the prestressing tendons are tensioned before the concrete is placed while in Post-tensioning hardened concrete is stressed by applying external forces.

In the post-tensioned concrete beams, a duct is formed inside the beam and prestressing cable is kept inside this duct. Once the concrete gets harden, prestressing cable is stressed and anchored at the end of beam that induces internal stresses in the concrete beam. The stress distribution inside the post-tensioned concrete beam is very complex, especially near the end of beam where prestressing cable is anchored. This zone is called as Anchorage Zone [1].

In the past, few researchers attempted to analyze stress distribution in anchorage zone in post tensioned concrete beam using different techniques, which include analytical techniques [3]-[6], experimental methods [7]-[10] and numerical methods [11], [12].

Guyon [3] analyzed the anchorage zone using elasticity equations assuming the beam as end-loaded-semi-infinite strip as two-dimensional problem. The length of anchorage zone was considered equal to the depth of the beam. Som and Ghosh [4] made a similar attempt by treating it as a two-dimensional plane stress boundary value problem. Authors used the Airy's function for their analysis and the stress function was expressed in the form of Fourier series. The obtained results were quite similar to the findings of the Guyon [3]. Iyengar and his other associates [5], [6] analyzed the problem of anchorage zone using the equations of elasticity considering problem as two-dimensional and three-dimensional. Authors carried out the analysis for concentric as well as eccentric prestressing forces and compared the results with the available literature.

Some researchers also carried out experimental investigation of the anchorage zone. Christodoulides [7], [8] conducted actual tests on the concrete block along with two-dimensional and three-dimensional experimental studies using photoelastic bench. Zielinski and Rowe [9] presented results of surface strains measured on the concrete end block subjected to concentric prestressing forces. On the basis of their results, authors gave an expression to calculate the magnitude of the bursting tensile force (F_{bst}) for different values of *k* (ratio of loaded area and cross-sectional area of the beam). The modified version of this expression, by introducing factor of safety, was adopted in the Indian Standard Code IS: 1343-1980 [10]. The effect of Poisson's ratio (ν) and eccentricity (e) of prestressing forces (P_k) over F_{bst} was not included in the given expression.

Yettram and Robbins [11] investigated anchorage zone stresses considering it as a three-dimensional problem. Authors used finite element analysis to determine the anchorage zone stresses. Their investigation did not prove the occurrence of spalling zone. Recently, Byung-Wan Jo et al. [12] investigated the anchorage zone stresses by considering effects of various parameters namely cable inclination, position of anchor plate, and the modeling methods

Authors also carried out their analysis using finite element method considering the problem as two-dimensional as well as three-dimensional and found that the three-dimensional analysis gives slightly smaller values of stresses as compared to their two-dimensional analysis. Authors suggested to adopt the results of two-dimensional analysis to ensure the safety in the design.

Gupta and Khapre [13] did the analysis of the Anchorage Zone using Finite Element Method considering the problem as 2-Dimensional Plane Stress. They carried out their study with the help of a computer code developed on the platform of Unix. They studied the effect of Poisson's Ratio over the stresses caused by prestressing force (P_k) in the Anchorage Zone. The results obtained were compared with the results available in the literature and it was found that they match well. They also developed an equation to calculate bursting tensile force and compared it with the equation available in British Code BS: 8110-1985, Indian Standard Code IS: 1343-1980.

As finite element analysis involves several computations that results in large computational time. Efforts are made by Khapre and Gupta [14] to reduce the Computational time in the Finite Element Analysis by applying Parallel Computing Technique on Supercomputer PARAM 10000. They developed a computer code for linear Finite Element Analysis using MPI, which is capable of analyzing two-dimensional problems. The problem of Anchorage Zone in Prestressed Post-Tensioned Concrete Beam was investigated using this computer code. The Computational time variation for increasing number of processors was obtained and it was found that analysis of anchorage zone could be carried out in lesser time by employing more number of processors.

Using the same code, Gupta and Khapre [15] carried out the analysis of spalling zone in prestressed post-tensioned concrete beam subjected to concentric and eccentric loadings. They found that the magnitude of bursting tensile force reduces with the increase in the eccentricity of prestressing forces. They also found that the magnitude of maximum transverse tensile force along the loaded face is greater than the magnitude of maximum transverse tensile force along the axis of loading which clearly concludes the existence of spalling zone. The details of work carried out by Gupta and Khapre [13]-[15] is summarized in paper [16]. As supercomputer is expensive device for achieving quicker solutions, it cheaper alternative can be created in from of PC Cluster. A PC Cluster and a program on it were developed by Gupta and Khapre and analyzed Anchorage zone stresses as a case study problem. [17].

Most of the work presented in the literature uses two-dimensional analysis. In order to investigate anchorage zone stresses in details, an attempt has been made by Uchibagale and Khapre [18]. They used commercial software ANSYS for the three dimensional analysis of the anchorage zone stresses. They modeled the anchorage zone as a cubical block with circular shape anchorage place. They used tetrahedron elements for the discretization with cartesian as well as cylindrical co-ordinate system. They obtained the transverse/radial stress variation along the axis of loading for different values of *k* varying from 0.1 to 0.7 and compared their results with the results available in the literature. Their results match well with the literature and also found that the magnitude of maximum transverse tensile stress is along the loaded face is more than the maximum of transverse tensile stress along the axis of loading, which clearly depicts the existence of Spalling zone in the post tensioned prestressed concrete beam which was not observed in study presented by Yettram and Robbins [11].

Present study is the continuation of work done by Uchibagale and Khapre [18]. Here, anchorage zone stresses are investigated subjected to eccentric loading as eccentric loading is used widely applied in the field. Comparison of stresses induced in anchorage zone subjected to concentric load is made with the stresses induced due to eccentric loading and presented.

II. METHODOLOGY

In the present study, the problem of anchorage zone is idealized as three-dimensional problem. Cubical block with side *d* is adopted to represent the end portion of prestressed post-tensioned concrete beam. This block is discretized using 35705 tetrahedral elements with 57228 nodes for performing finite element analysis. Default material properties of concrete available in ANSYS are used in the present analysis. To get accurate results, the mesh is kept advance fine with relevance center. Circular shape anchorage plate is considered during the analysis. The diameter of this plate is adjusted such that value of *k* varies from 0.1 to 0.7 for concentric loading (see Fig. 1 (a)) and 0.1 to 0.5 for eccentric loading (see Fig. 1 (b)), then the analysis of anchorage zone is carried out for different values of *k*. Displacement support is provided at the back face of loaded face such that displacement along the axis of loading is restricted. Cylindrical co-ordinate system is used instead of cartesian co-ordinate system so that stresses in radial and circumferential direction can be obtained.

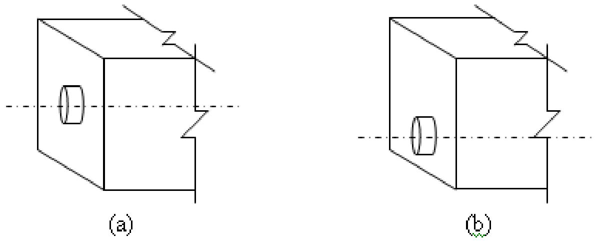


Fig. 1. Idealization of Anchorage zone block in prestressed post-tensioned concrete beam subjected to (a) concentric loading (b) eccentric loading

Figure 2 shows the transverse tensile stress variation in anchorage zone subjected to concentric loading i.e. e = 0.0. Figure 2(a) shows a typical transverse tensile stress variation for k = 0.1. Figure 2(b) shows the vertically cut portion of anchorage zone that shows development of transverse tensile along the axis of loading.

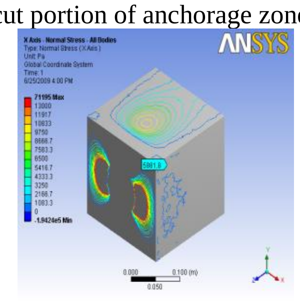
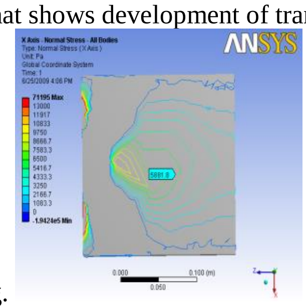


Fig.



(a) (b)

2. Transverse stress variation in anchorage zone subjected

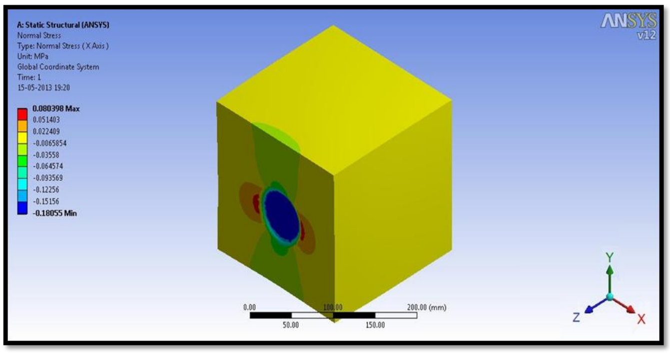


Fig. 3. Transverse stress variation in anchorage zone subjected to eccentric loading

Figure 3 shows the transverse tensile stress variation in anchorage zone subjected to eccentric loading i.e. e = 0.1. Figure 3 shows a typical transverse tensile stress variation for k = 0.1 and e = 0.1.

Figure 4 shows the comparison of distribution of transverse tensile stress (σ_t) along radial direction for value of k = 0.1. It can be observed that the magnitude of maximum transverse tensile stress ($\sigma_{t(max)}$) calculated by Guyon [3] is on extremely higher side. The stress distribution obtained by present investigation fairly matches with the distribution obtained by Iyengar (two-dimensional as well as three-dimensional) [5], [6].

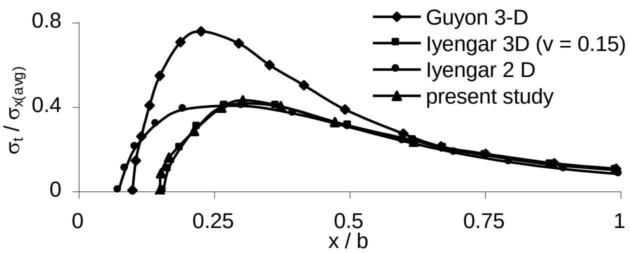


Fig. 4. Comparison of transverse tensile stress distribution along the direction of loading for k = 0.1

For the higher values of k = 0.5 (see Fig. 5), the stress distribution obtained by present investigation matches well with the stress distribution obtained by Iyengar (three-dimensional) [6], whereas the stress distribution in two-dimensional analysis given by Iyengar [5] does not match with the stress distribution obtained by present investigation. The magnitude of maximum transverse tensile stress obtained by Iyengar (two-dimensional) [5] is nearly half of the maximum transverse tensile stress obtained by present investigation for the same value of k = 0.5.

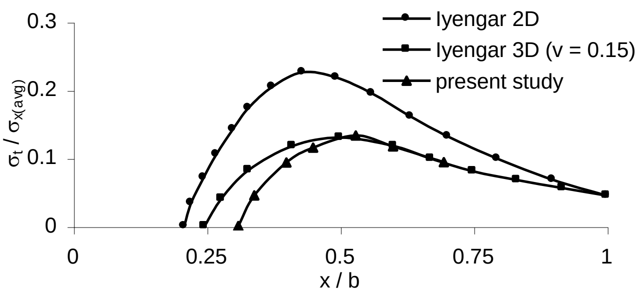


Fig. 5 Comparison of transverse tensile stress distribution along the direction for k = 0.5

Figure 6 shows the comparison of maximum transverse tensile stress along the direction of loading. It can be seen that the magnitude of maximum transverse tensile stress for concentric loading at any value of k is more than that of magnitude of maximum transverse tensile stress for eccentric loading at corresponding values of k. It can also be observed that difference in magnitude of maximum transverse tensile stress at e = 0.0 & e = 0.1 reduces with the increase in value of k. This difference becomes negligible after value of k = 0.5.

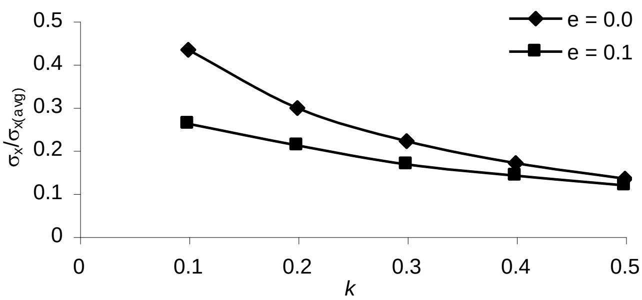


Fig. 6 Comparison of maximum transverse tensile stress along the direction of loading at e = 0.0 and e = 0.1.

Figure 7 shows the comparison of maximum transverse tensile stress along the loaded face. It can be seen that the magnitude of maximum transverse tensile stress for concentric loading at any value of k is more than that of magnitude of maximum transverse tensile stress for eccentric loading at corresponding values of k. It can also be observed that difference in magnitude of maximum transverse tensile stress at e = 0.0 & e = 0.1 reduces with the increase in value of k.

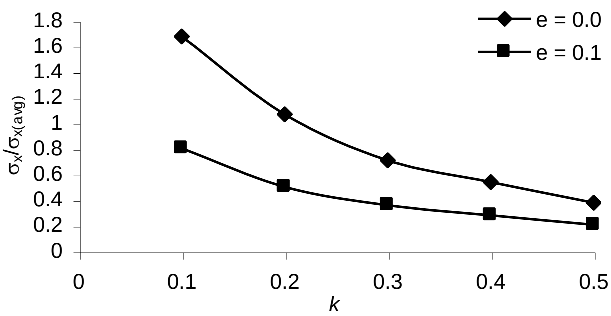


Fig. 7 Comparison of maximum transverse tensile stress along the loaded face at e = 0.0 and e = 0.1.

From Fig. 6 and Fig. 7, one can observe that the magnitude of maximum transverse tensile stress measured along the loaded face is much greater than the magnitude of maximum transverse tensile stress measured along the axis of loading at all values of k and e. This shows the existence of spalling zone in prestressed post-tensioned concrete beams subjected to concentric load as well as eccentric load. One can also observe from Fig. 2(b) and Fig. 3(b) that the area of spalling zone increases with the increase in the eccentricity of prestressing force.

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III DISCUSSION

In the present work, three dimensional finite element analysis of anchorage zone in post-tensioned prestressed concrete be using commercial software ANSYS is presented. The analysis was carried out considering concentric prestressing forces on a three dimensional beam model. Both, concentric and eccentric loading conditions are considered with varying values of *k*. Stress variation was studied and presented for various values of *k* and *e*. It was observed that magnitude of maximum transverse tensile stresses measured along the axis of loading or along the loaded face reduces with the introduction of eccentricity in prestressing forces. From Fig. 2(b) and Fig. 3(b) it can be seen that the area under the anchorage zone reduces with increase in the eccentricity of loads. This directly affects the bursting tensile force and it starts reducing with the increase in eccentricity. Exactly reverse situation can be seen in case of spalling zone. Area under the spalling zone increases with the increase in the eccentricity. Although the area is very less as compared to area of anchorage zone but it may create negative force for higher value of eccentricity that my cause cracks in the concrete in the spalling zone region. Hence it is recommended to analyze spalling zone as well as anchorage zone for prestressed post-tensioned concrete beams subjected to eccentric loading.

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