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Investigation of Bursting Forces in Post Tensioned Anchorage Zone

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ABSTRACT

Three dimensional (3D) finite element (FE) analyses for post-tensioned anchorage zone were conducted to calculated bursting stress and bursting force. The structural behavior was investigated through the linear elastic finite element analyses with various design parameters such as the bearing plate size, the eccentricity, and the tendon inclination. Also effect of duct hole to bursting stress and bursting force was analysed with various diameter. Parametric analyses were followed to evaluate the relative contribution of all design parameters in determining the bursting force. Since the bursting force in AASHTO-LRFD is based on two dimensional anchorage model without duct hole, comparisons with the results and AASHTO-LRFD were conducted. Finally, an improved design guideline which considers the effect of the duct hole is suggested.

1. INTRODUCTION

In post tensioned prestressed concrete (PSC) beams with mechanical anchorages, the prestressing force is applied through tendons and load concentration occurs at the anchorages. On the basis of St Venant principle, uniformly distributed stress is occurred at concrete section far away from the anchorage. Closer to the anchorage, however, the distribution of stress in the concrete is more complex. The dispersion of the high local stress under the anchorage causes transvers tensile stress, which may crack the concrete. Accordingly, this transverse tensile stresses referred as bursting stresses have to be determined to arrange proper reinforcements.

With the understanding of the stress distribution in the anchorage zone, considerable efforts have been dedicated in evaluating the tensile force for the placement of reinforcements (Guyon 1953, Burdet 1990, He and Liu 2011) on the basis of many mechanical concepts such as the theory of elasticity, the finite element (FE) analysis,

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and the strut-and-tie method as well as experimental approaches. Related comprehensive reviews on previous research can be found elsewhere (Breen et al. 1994, Rogowsky and Marti 1996, Songwut 2004, Callaghan and Bayrak 2008, Zhou el al. 2015). Moreover, many experimental and numerical studies have allowed the obtained results to be implemented in many design codes (Schlaich et al. 1987, Burdet 1990, Wollman 1992, Sanders and Breen 1997).

In particular, the design formula mentioned in the AASHTO-LRFD design guidelines (AASHTO-LRFD 2012), which was introduced through extensive finite element analyses by Burdet (1990) to provide guidance for designing the anchorage zone, is popularly used in the design practice and evaluation of the bursting force of the design code is introduced as shown in Eq. (1)

$$T_{burst} = 0.25 \sum P \left(1 - \frac{a}{h}\right) + 0.5 \left| \sum \left(P \sin\alpha\right) \right| \quad (1)$$

,where P is the applied anchor load, a is the width of the bearing plate, h is the height of the anchorage block, and α is the inclination of the duct tube.

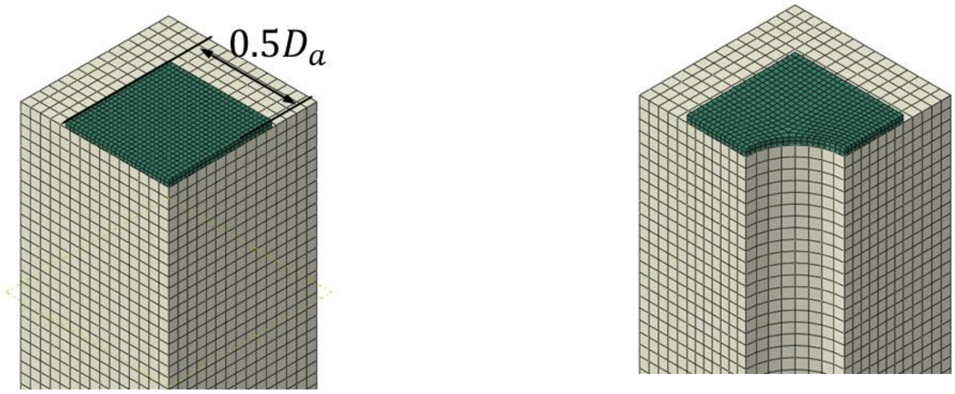
Since the design code was suggested basically on the basis of two dimensional (2D) FE analyses which can't consider three dimensional (3D) effect of duct hole, this equation usually gives conservative results in most cases. As is well known from the elastic theory, the hole within the elastic body causes a stress concentration. When an infinite plate with a circular hole is subjected to uniform stress on two parallel edges far removed from the hole, then the developed maximum stress will be three times the applied stress. This means that the duct hole may cause not only the stress concentration but also the change in a stress distribution around the hole.

In this paper, many parametric studies to evaluate the relative contribution of all design parameters in determining the bursting force have been conducted on the basis of 3D FE analyses with ABAQUS, and then an improved formula to evaluate the bursting force in the post-tensioned anchorage zones is suggested.

2. Geometric and Structural Properties

Since the numerical analyses conducted in this paper are based on a linear elastic analysis, the stress-strain relations of concrete and steel do not need to be defined. Only the modulus of elasticity and Poisson's ratio for concrete and steel are required. The elastic modulus of concrete and steel is defined according to the formulas $\boldsymbol{E_c = 8,500\sqrt[3]{f'_c} = 35,000\mathrm{MPa}}$ and $\boldsymbol{E_s = 210\mathrm{GPa}}$ defined in the KCI design code (2009), respectively, and the Poisson's ratios **for concrete and steel** have values of $\boldsymbol{\nu_c = 0.18}$ and $\boldsymbol{\nu_s = 0.33}$.

Two different anchorage blocks, (1) the anchorage block without duct hole (see Fig. 1(a)), and (2) the anchorage block with anchorage duct hole (see Fig. 1(b)) are considered to analysis the bursting stress distribution.



(a) anchorage block without duct hole (b) anchorage block with duct hole

Fig. 1. Anchorage block model

To verify the reliability of the constructed FE model, the numerical results were compared to those obtained by Burdet (1990), because Burdet's numerical results obtained from the linear elastic stress analyses were based on the construction of Eq. (1). Fig. 2 shows a typical example for the comparison of the bursting stress (σ_T) along the length (x-direction in Fig. 2) between the Burdet's results and the numerical results obtained by the FE idealization used in Fig. 1, where the ratio of the bearing plate size (D_a) to the concrete block width (h) was assumed to be 0.3 and σ_0 in Fig. 2 means the uniform average normal stress developed by the application of a concentrated load to the anchorage head. As shown in this figure, the bursting stress distributions obtained by the constructed FE idealization of the anchorage block is almost the same as that obtained by Burdet, even though the maximum bursting stress shows a slight difference of $0.014\sigma_o$, which is still negligibly small. This means that the slightly modified FE idealization can effectively be used in the linear elastic analyses of anchorage blocks.

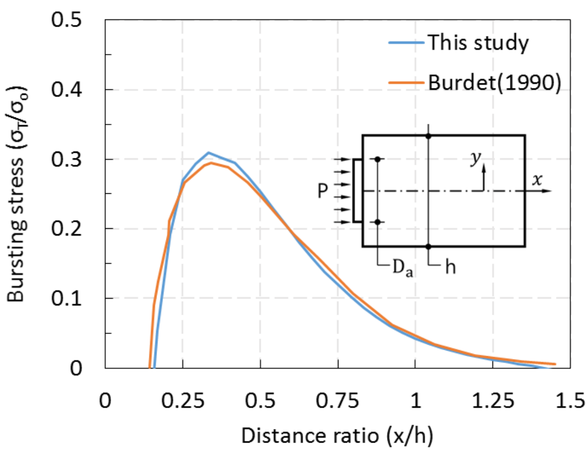


Fig. 2. Comparison of bursting stress in an anchorage block

3. Numerical analyses of anchorage block

Fig. 3 shows the section view of a test specimen with *h*=360mm and *a*=0.69*h*=250mm. Since three dimensional FE analyses were carried out, two transverse stresses across the central axis (the radial bursting stress σ_y and the tangential bursting stress σ_z) were evaluated. Figs. 4 and 5 represent the stress contour lines and the stress distributions along the central axis for the corresponding bursting stresses, respectively, where $\sigma_o = \mathrm{P}/h^2$ denotes the uniformly distributed basic stress. As expected, Fig. 5 shows that both stresses have the same values along the central axis because of the symmetric condition. On the other hand, as shown in Fig. 4, the tangential bursting stress shows the maximum value on the outer surface but a uniform distribution across the depth, in contrast with the radial bursting stress (σ_y), which has the maximum value at the very interior center point.

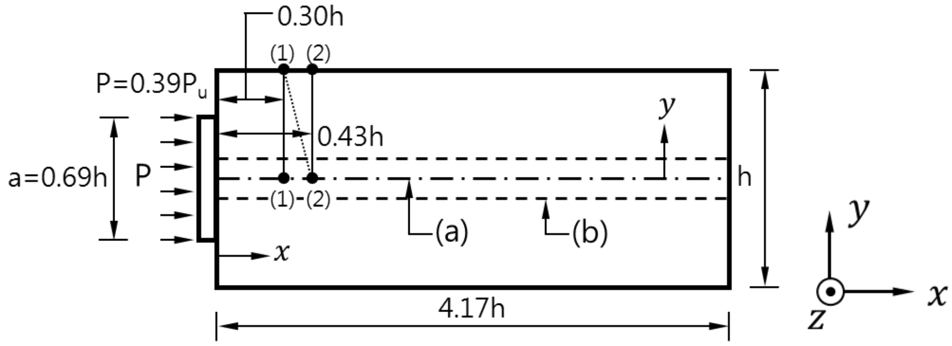
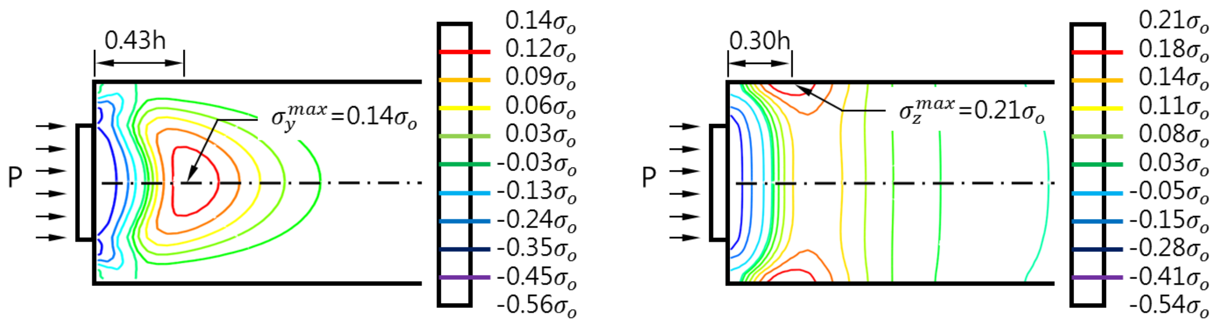


Fig. 3. Section view of the model in Fig. 1(a)



(a) Radial direction (y axis)

(b) Tangential direction (z axis)

Fig. 4. Bursting stress contour developed in the model in Fig. 1(a)

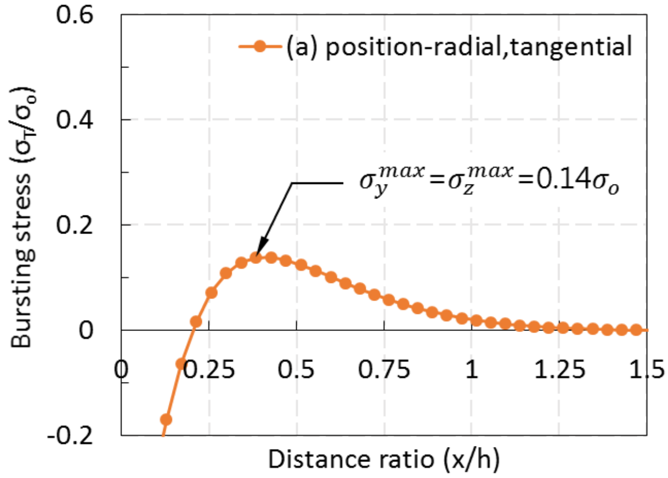


Fig. 5. Bursting stress distribution along (a) position in Fig. 3

Numerical analysis with the specimen in Fig. 1(b) was performed. The diameter of the duct hole(*b*) was assumed to be *b*=0.32*h*=114mm, and sections (c) and (d) correspond to the duct hole surface and the point that produces the maximum radial bursting stress σ_y, respectively (see Fig. 7).

Figs. 7 and 8 represent the stress contour lines and the stress distributions along the length direction for the corresponding bursting stresses. As shown in Fig. 7, the maximum radial bursting stress σ_y does not occur along the outer surface of the duct hole and its magnitude is also negligibly small. However, the tangential bursting stress σ_z shows the maximum value at the surface of the duct hole and its magnitude is $\sigma_z = 0.23\sigma_o$, which is about 64% larger than the maximum bursting stress obtained at the anchorage block without the duct hole (see Fig. 8). This means that the existence of the duct hole causes a shift in the bursting stress distribution with an increase of the tangential bursting stress and a decrease of the radial bursting stress. This shift in the stress distribution has been maintained along the entire length of the anchorage block, as shown in Fig. 8. Very similar results for the shift of the bursting stress distribution were also obtained by Douglas and Trahair (1960) from their experimental study. Accordingly, the bursting force needs to be evaluated on the basis of the tangential bursting stress even in the case of the anchorage block with a duct hole.

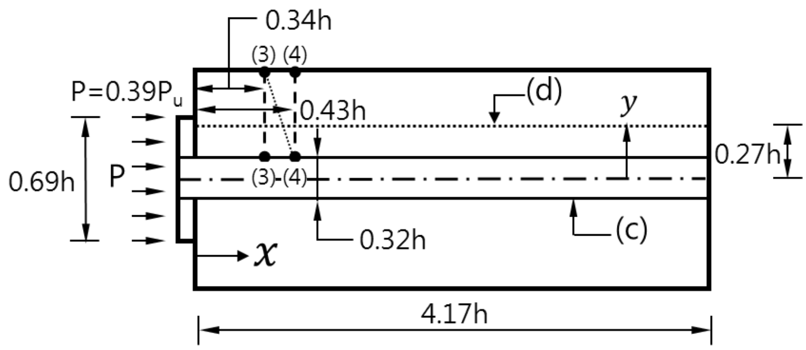
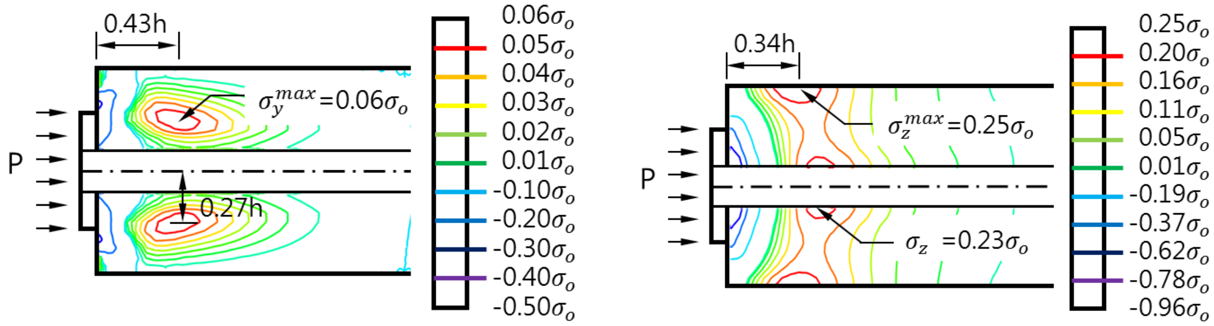
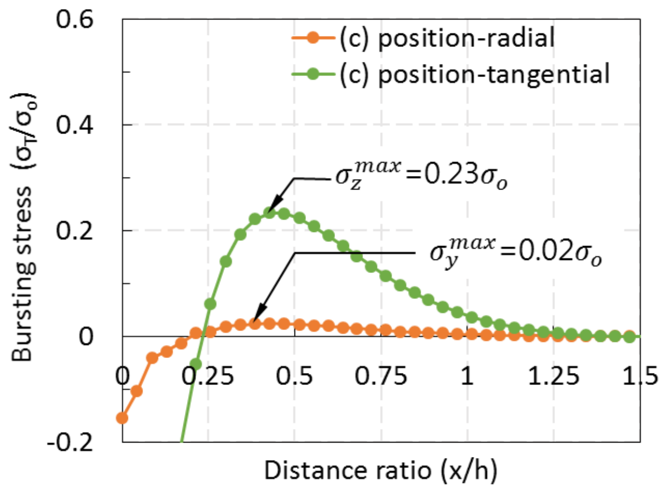


Fig. 6. Section view of the model in Fig. 1(b)

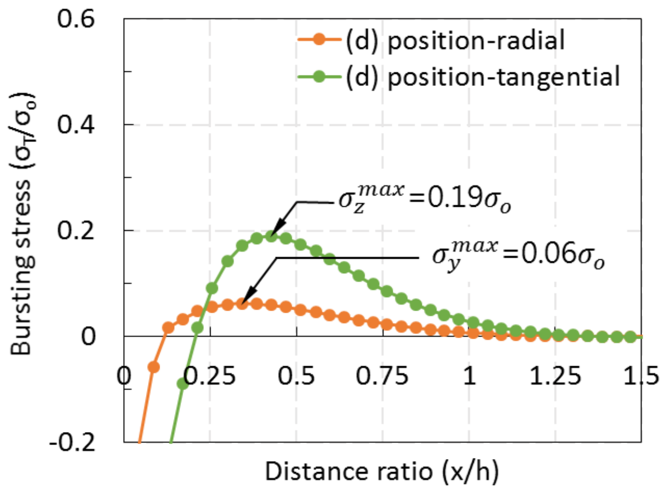


(a) Radial direction (y axis) (b) Tangential direction (z axis)

Fig. 7. Bursting stress contour developed in the model in Fig. 1(b)



(a) Stress distribution along (c) position



(b) Stress distribution along (d) position

Fig. 8. Bursting stress distribution along (c) and (d) positions in Fig. 6

4. Bursting force of anchorage block

Upon the parametric studies with variation in the size of the duct hole, the evaluated bursting forces have been shown in Fig. 9. As shown in this figure, since the existence of the duct hole slightly increases the bursting force together with an increase of the bursting stress, the influence of the duct hole in the anchorage block needs to be considered in the evaluation of the bursting force. However, the relative differences in the bursting force according to the change in the size of duct hole are not as large as expected. This result appears to be induced from characteristic that the maximum tangential bursting stress is not increased in proportion to the size of the duct hole but maintains almost constant values, as shown in Fig. 9, in the case of adopted test specimens with the size of the duct hole ranging from 74mm (equivalent to 0.21h) to 134mm (equivalent to 0.37h). However, since the size of the duct hole in real structures is about 0.2h, the test specimens are sufficient to cover the influence of the duct hole, in a real structure. Accordingly, the design equation in Eq. (1), which does not take into account the influence of the duct hole, needs to be revised to $\mathrm{T}_{burst} = 0.28P\left(1 - \frac{a}{h}\right)$ for an anchorage block with a square bearing plate.

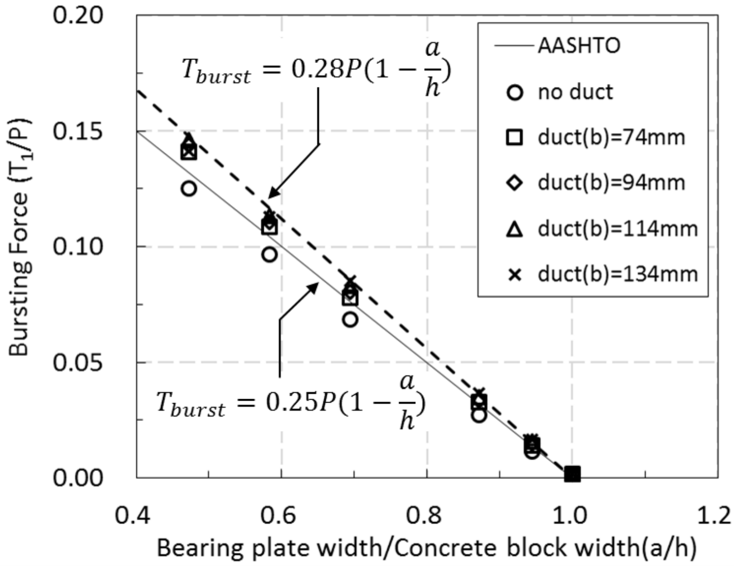


Fig. 9. Bursting force in the anchorage block with a duct hole

5. Conclusion

An improved equation to predict the bursting tensile force in the anchorage block is proposed through parametric studies, and no additional understanding is required in using the introduced equation because it maintains the same form and expression as suggested in AASHTO-LRFD. The introduced equation can effectively be used in the preliminary design stage to determine the amount of anchorage reinforcement and to estimate the safety for cracking in the anchorage zone. Nevertheless, an additional verification process through many experimental tests may be required prior to its use as a standard design equation in practice.

Parametric studies to evaluate the influence of many design variables lead to the following conclusions: (1) Eq. (1) currently used in the design may underestimate the bursting force, which may lead to an unsafe design of the anchorage block; (2) the influence of the duct hole must be considered in the evaluation of the bursting force;

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