모멘트에 의한 베이스판의 변형을 고려한 앵커볼트의 설계방법에 관한 연구
A Study on Anchor Bolt Design Considering Moment due to Base Plate Deformation

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ABSTRACT

강재기둥으로부터 전달되어 내려오는 모멘트 하중에 의한 베이스판의 변형을 고려한 앵커볼트의 설계방법에 대해 소개하였다. 기둥-베이스판 접합부의 설계를 위해 간략해석 모델 (Simple Beam Model) 이 개발되었으며 인장력과 모멘트 하중에 동시에 저항하는 앵커볼트의 설계를 위해 국부 메카니즘 개념이 도입되었다. 제안된 새로운 설계법을 적용하여 앵커볼트와 베이스판 사이의 최대지압력을 계산할 수 있었으며 이를 바탕으로 앵커볼트의 사이즈를 결정할 수 있었다. 본 논문에서는 상기 간략히 소개된 앵커볼트 설계법을 보다 상세히 기술하였다.

1. Introduction

In order to understand complex force flow and actual stress distribution in the column-base plate connection under large lateral column deformation, an organized study was conducted at the University of Michigan (Fhamy, 1999; Lee and Goel, 2001) The Michigan researchers evaluated the Drake and Elkin's design method (Drake and Elkin, 1999), which is the current design practice for the column-base in the US, for both the strong and weak axis column bending and developed a new design method that is more realistically estimate the actual behavior of the connection under weak axis column bending. In the proposed new design method (Lee and Goel, 2001), a method for the calculation of minimum base plate thickness which can prevent undesirable anchor bolt failure before the connection reaches its ultimate state is provided. Also provided is an anchor bolt design procedure considering moment due to base plate deformation. This methodology for the design of anchor bolt is introduced in this paper.

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2. Simplified Analysis Model

For the design of anchor bolt, a simplified analysis model (simple beam model) is developed (Figure 1). In this figure, Mp_plate means ultimate strength of the base plate and Wu is ideally distributed force developed by column flange forces. And, h indicates distance between the maximum base plate moment location (i.e., plastic hinge location) and the anchor bolts on the tension side.

As shown in Figure 1, the anchor bolts on the tension side are assumed as a hinge condition in the simplified analysis model. This assumption, based on the global mechanism of the connection, may be satisfactory for the design of the base plate thickness. However, due to its simplicity, the analysis model (i.e., simple beam model) cannot properly explain the actual force flow around the anchor bolts on the tension side. Thus, based on the numerical analysis (Lee and Goel, 2001), the actual force flow around the anchor bolts is investigated in depth and finally, a representative local mechanism on the tension side of the connection is developed. This local mechanism is presented in Figure 2.

Portion of only one anchor bolt is considered in the local mechanism for the purpose of design convenience. For this reason, Wu and Mp_plate are divided by the number of anchor bolts on the tension side (i.e., #t). In addition, the actual reaction forces, developed by the contact between nut and base plate, are simplified as two force components (i.e., P1 and P2) located at two different distances (i.e., d1 and d2) from the center of the anchor bolt. These four variables will be replaced by more convenient expressions later in this paper.

3. α and β

For more convenient expressions, the two reaction forces (i.e., P1 and P2), presented in Figure 2, are replaced by,

$$P_1 = \alpha \cdot P \tag{1}$$

$$P_2 = P \tag{2}$$

In Equation (1), α is the ratio between P1 and P2. Based on the numerical parametric study (Lee and Goel, 2001), the value of α shows a variation between 0.65 and 0.70 when strong anchor bolts and flexible base plates are used. In this study, α = 0.7 is adopted because larger value results in a more conservative design criteria for the design of the base plate. In addition, d1 shows a little large value as compared with d2 for both bolt type connections (i.e., 6-bolt type and 4-bolt type). However, the amount is very small and ignorable. Thus, in the proposed local mechanism, d1 and d2 are assumed to have the same distance β, i.e.,

$$d_1 = d_2 = \beta \tag{3}$$

Further, a simple expression is proposed for β based on the numerical analysis results, i.e.,

$$\beta = \frac{3 \cdot d_b + \left(\dfrac{d_h + W}{2} \right)}{8} \tag{4}$$

where:

db = diameter of each anchor bolt including threaded part, in.

dh = diameter of oversized bolt hole, in.

W = nut width across flats, in.

In Equation (4), the value of β (i.e., the location of P1 or P2 from the center of anchor bolt) is highly dependent on the size of anchor bolt. Now, for a given detail around the anchor bolt, shown in Figure 3, the location of P1 or P2 can be easily given by Equation (4).

4. Anchor Bolt Contact Force, P

Using the two variables, α and β, the proposed local mechanism is re-configured in Figure 4. In this figure, bf is column flange width and Ls means distance between Tu and Ru. Based on the simplified local mechanism, shown in Figure 4, the moment M at the plastic hinge location can be determined as follows:

$$\begin{aligned} M &= \alpha \cdot P \cdot (h + \beta) + P \cdot (h - \beta) - \left(\frac{W_u}{\#_t} \right) \cdot \left(\frac{b_f^{\,2}}{4 \cdot L_s} \right) \cdot \frac{1}{2} \cdot \left(\frac{b_f^{\,2}}{4 \cdot L_s} \right) \\ &= \{ \alpha \cdot (h + \beta) + (h - \beta) \} \cdot P - \left(\frac{W_u}{\#_t} \right) \cdot \frac{b_f^{\,4}}{32 \cdot L_s^{\,2}} \end{aligned} \tag{5}$$

And, plastic moment of the base plate for the portion of each anchor bolt is,

$$\left(\frac{M_{p\_plate}}{\#_t}\right) = \phi_{bp} \cdot F_{y\_plate} \cdot \frac{N \cdot (t_p)^2}{4 \cdot \#_t} \tag{6}$$

In Equation (6), Φbp, N, tp are resistance factor for flexure in base plate, base plate width, and base plate thickness, respectively.

By letting the moment M equal to the value of (Mp_plate / #t), the anchor bolt contact force P can be easily calculated.

5. Anchor Bolt Diameter, db_eff

In order to explain how to design the size of the anchor bolt, the force and moment resisting mechanisms in the anchor bolt are introduced in Figure 5. The tensile force and moment developed by external P and αP are resisted by Teach and Meach internally in the anchor bolt. Using the defined two variables, α and β, the two internal forces (i.e., Teach and Meach) can be expressed by,

$$T_{each} = (1+\alpha) \cdot P \tag{7}$$

$$M_{each} = (1-\alpha) \cdot \beta \cdot P \tag{8}$$

Referencing to Figure 6, the maximum tensile stresses due to the tensile force (Teach) and the moment (Meach) in the anchor bolt can be written by,

$$\sigma_1 = \frac{T_{each}}{A_{b\_eff}} = \frac{(1+\alpha) \cdot P}{A_{b\_eff}} \tag{9}$$

$$\sigma_2 = \frac{M_{each} \cdot \left(\frac{d_{b\_eff}}{2}\right)}{I_{b\_eff}} = \frac{(1-\alpha) \cdot \beta \cdot P \cdot \left(\frac{d_{b\_eff}}{2}\right)}{I_{b\_eff}} \tag{10}$$

where:

Ab_eff = effective area of each anchor bolt = $0.75 \cdot \frac{\pi \cdot d_b^{\ 2}}{4}$, in.^{2}

db_eff = effective diameter of each anchor bolt = $\sqrt{\frac{4 \cdot A_{b\_eff}}{\pi}}$, in.

Ib_eff = effective moment of inertia of each anchor bolt = $\frac{\pi \cdot \left(\frac{d_{b\_eff}}{2}\right)^4}{4}$, in.[4]

In order to prevent anchor bolt yielding at its outer surface, the summation of σ1 and σ2 should be smaller than or equal to the specified yield stress of the anchor bolt, i.e.,

$$\sigma_1 + \sigma_2 = \left\{ \frac{(1+\alpha)}{A_{b\_eff}} + \frac{(1-\alpha) \cdot \beta \cdot \left(\frac{d_{b\_eff}}{2}\right)}{I_{b\_eff}} \right\} \cdot P \leq F_{y\_bolt} \tag{11}$$

By solving the above equation, db_eff can be provided.

6. Summary and Conclusions

An anchor bolt design procedure considering moment due to base plate deformation is introduced in this paper. Simplified analysis model (so called, simple beam model) is developed for the design of column-base plate connection and local mechanism is configured for the design of anchor bolt on the tension side. Using the two variables, α and β, the method how to calculate the anchor bolt contact force P and anchor bolt diameter db_eff is presented in this paper.

참고문헌

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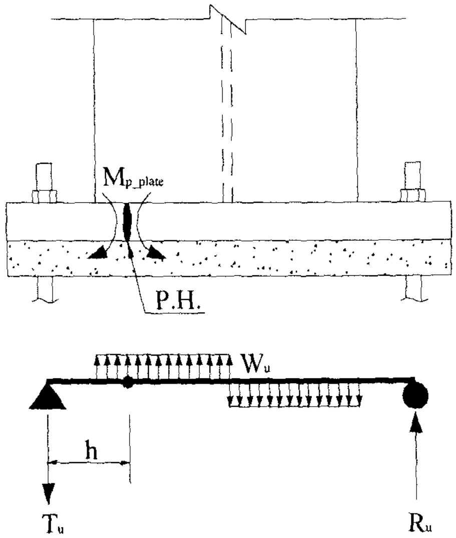

Figure 1. Simplified Analysis Model (Simple Beam Model)

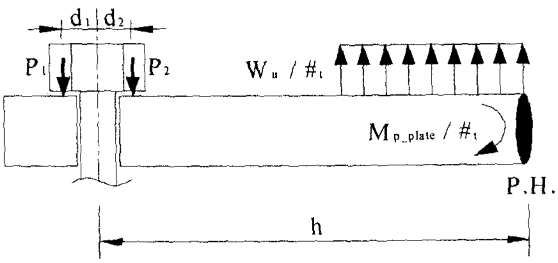

Figure 2. Local Mechanism (For Each Anchor Bolt)

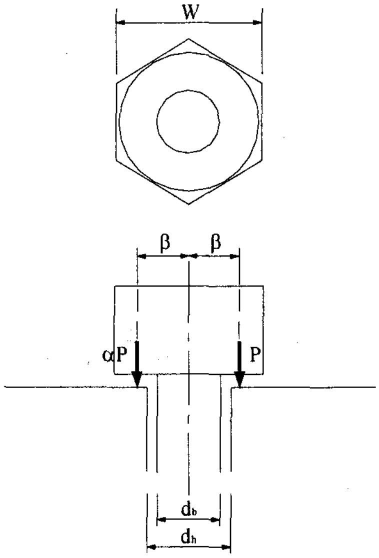

Figure 3. Detail around Anchor Bolt

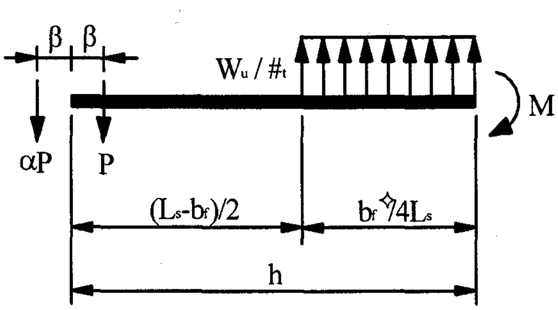

Figure 4. Simplified Local Mechanism

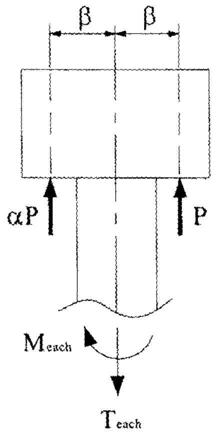

Figure 5. Two Internal Forces in Each Anchor Bolt

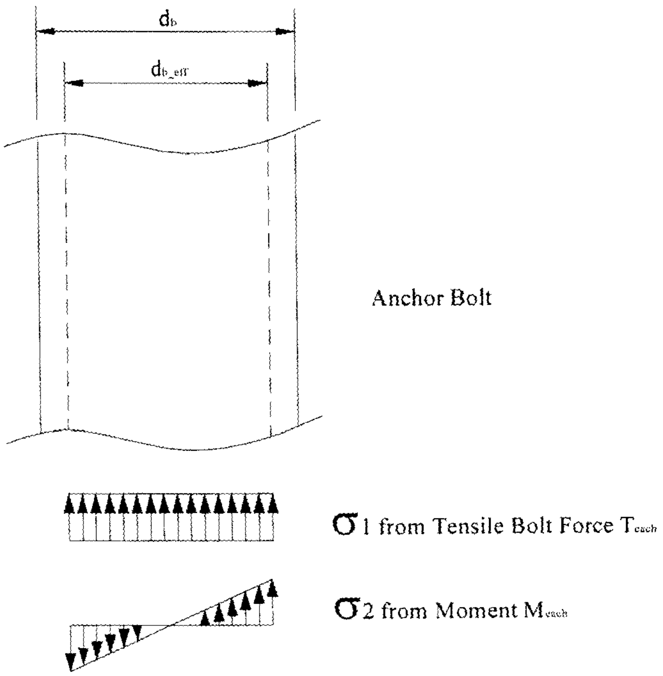

Figure 6. Stress Distribution across Anchor Bolt