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A Proposal of Shear Design Equation for Reinforced Concrete Circular Section Column without Transverse Reinforcement

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1. Research Background

The current JSCE shear design equation for linear member without web reinforcement was originally formulated from the experimental results of reinforced concrete (RC) beam without web reinforcement. This equation is used both for beam and column members. For the case of RC column with circular cross section, there are three differences in comparing to RC rectangular section beam. The first difference is contribution of side reinforcements in the case of column member. The second difference is effect of section shape. For the case of circular section, the current JSCE specifications use the concept of equivalent section to transform circular section into equivalent square section and treat equivalent section as typical section. By this concept of equivalent section, the JSCE specification define effective depth as the depth to centroil of longitudinal reinforcement arranged in the portion of 90-degree (one-fourth of total longitudinal reinforcement). The effective longitudinal reinforcements are defined as reinforcement in 90-degree portion. The third difference is the source of axial load. The axial load for column members are directly came from self-weigh of structure and live load in gravitational direction, while the one for beam member are came from prestressed force.

2. Statement of Problems

By collecting experimental results of RC circular column without transverse reinforcement, it was found that the ratio of experimental shear strength (Vexp) to calculated shear strength (Vcal) using the current JSCE specification with including a/d effect is average Vexp/Vcal=1.43 with coefficient of variation 17.1% (see Figure 1.1). Therefore it reveals that research to treat shear strength of RC column with circular section is useful and still necessary. Moreover the other major design codes and empirical formulas are still not cover the effect of side reinforcement and section shape simultaneously and precisely.

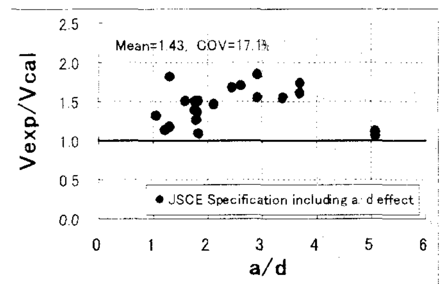

Fig.1 Comparison of shear strength calculated by the current JSCE specification

3. Designation of Parameter in Analysis

The current JSCE shear design equation is shown in Equation (1). This form of equation is still keeping in analysis, since it was already accurate for the case of rectangular beam.

$$V_c = 0.20\sqrt[3]{f'_c} \cdot \beta_d \cdot \beta_p \cdot \beta_n \cdot b_w d \qquad (1)$$

$$\beta_d = \sqrt[4]{1/d} \ \ (\mathrm{d:m}) \quad \le 1.5 \qquad (2)$$

$$\beta_p = \sqrt[3]{100P_w} \quad \le 1.5 \qquad (3)$$

$$\beta_n = 1 + M_o / M_d \quad \le 2.0 \text{ in compression} \qquad (4)$$

where P_w=A_s/bd, M_o is decompression moment to cancel axial stress at extreme fiber, M_d is design moment.
For analysis purpose, $\beta_n = 1 + 2M_o / M_u \le 2.0$ in compression , where M_u is ultimate moment.

Parameter 1: Effective Concrete Area

The upper limit of effective concrete is fully gross area. Typically effective concrete area is defined as area over the effective depth. The definition of effective depth according to the JSCE specification for equivalent square section is seems too small comparing to full depth. Therefore the author proposes another effective depth between this two ranges and defined effective depth up to lowest tensile reinforcement. The parameters of effective concrete area have three cases as hereafter:

Case A: Gross sectional area
Case B: Effective Concrete area up to lowest tensile bar
Case C: Effective concrete area according to the JSCE specification

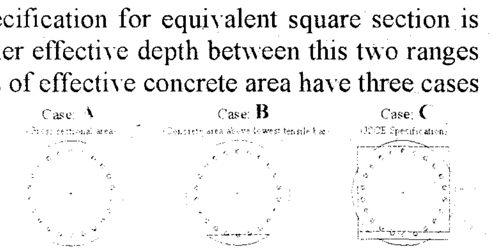

Fig.2 Parameter for effective concrete area

Parameter 2: Definition of Effective Depth for a/d Function

For analysis purpose, the effect of shear span-to-depth ratio (a/d) is included. Okamura and Higai (1980) had proposed a precise equation to describe effect of slenderness for slender member at cracking load as shown in Equation (5). For short shear span range, the equation as proposed by JSCE Committee (1997) is adopted in this analysis, Equation (6).

$$\beta_a = 0.75 + 1.4(a/d)^{-1} \quad > 2.0 \qquad (5)$$

$$\beta_a = 3(a/d)^{-1} \quad \le 2.0 \qquad (6)$$

The upper limit for effective depth should be full section depth and lower limit should be effective depth according to the JSCE specification based on transform section concept. Between these two ranges, the author proposed another the effect depth as the distance from compression face to lowest layer of tensile reinforcement. Therefore, there are three cases of definition of effective depth as follows:

Case I: Using full depth, D

Case II: The depth up to lowest tensile bar, d'

Case III: Effective depth according to the JSCE specification based on transform section, d

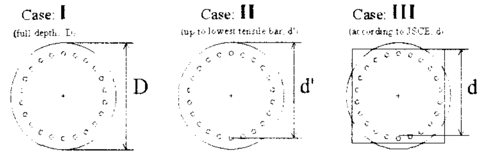

Fig.3 Effective depth for a/d function

Parameter 3: Definition of Effective Depth for Size Effect Function

Consequently from three definitions of effective depth as explained previously, there are three cases for those effective depths using in size effect as follows:

Case r: Using full depth, D

Case s: The depth up to lowest tensile bar, d'

Case t: Effective depth according to the JSCE specification based on transform section, d

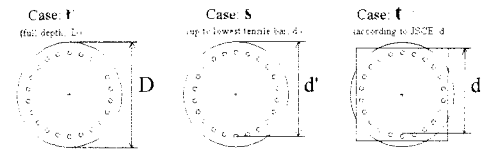

Fig.4 Effective depth for size effect function

Parameter 4: Effective Longitudinal Reinforcement

Ishibashi et al. (1985) had conducted the experiment of RC beams with multi-layer of longitudinal reinforcement and proposed the effect of reinforcement for all layers in summation form by multiplying each layer of reinforcement with distance from compression fact to that layer and normalize by distance to lowest layer of tensile bar:

$$A_s = \sum (A_i d_i / d) \quad (7)$$

By considering the current JSCE specification, which account tensile bar arranging in 90-degree portion, in this analysis the effective dowel bar is expanded to 120, 150, and 180-degree. The method as proposed by Ishibashi et al. (1985) is also included.

Case 1: Longitudinal bar in 90-degree portion

Case 2: Longitudinal bar in 120-degree portion

Case 3: Longitudinal bar in 150-degree portion

Case 4: Longitudinal bar in 180-degree portion

Case 5: Longitudinal bar in summation form as proposed by Ishibashi et al. (1985)

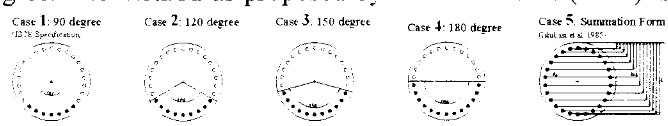

Fig.5 Parameter for effective reinforcement

4. Analytical Results

From four parameters, there are totally 3*3*3*5=135 combination cases. The coefficient of variation (COV) for Vexp/Vcal for all combination cases are shown in Figure 6. From 135 combination cases, there are four cases with low COV. Among these four cases, the lowest average Vexp/Vcal is case number 90, which use effective concrete area up to lowest layer of tensile reinforcement, effective reinforcement in summation form as proposed by Ishibashi et al. (1985), and effective depth as define for equivalent square section.

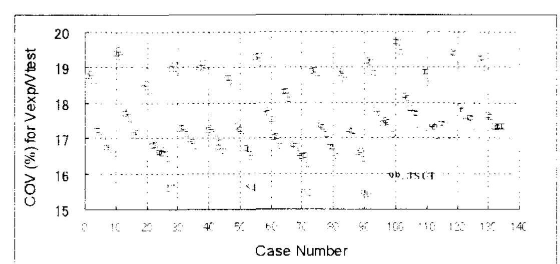

Fig.6 Analytical results for all combination cases

5. Proposal of Shear Design Equation for Circular RC Columns

By considering the consistency of parameter and simplicity in practice, the author propose that the effective concrete area is area above lowest tensile reinforcement, effective reinforcement is half of total longitudinal reinforcement, and effective depth is define as the distance up to lowest layer of tensile reinforcement and use both in size effect and a/d function. The verification of proposal is shown in Figure 7 with average Vexp/Vcal=1.03.

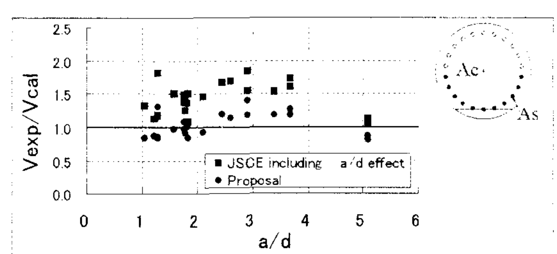

Fig.7 Verification of proposal for circular RC columns

5. Conclusions

1) The current JSCE shear design equation for linear member with using circular cross section based on equivalent square section show conservative results with average Vexp/Vcal=1.43.

2) The author propose the shear design equation for reinforced concrete circular section column by keeping the current form of JSCE shear design equation and changing the details in three items:

i) The effective concrete area is defined as the area above lowest tensile reinforcement.

ii) The effective depth is defined as the distance from compression face to lowest level of tensile reinforcement.

iii) The effective reinforcement effect is defined as the half of total longitudinal reinforcement.