Seismic Consideration of Reinforced Concrete Wall Section

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ABSTRACT

Seismic capacity of reinforced concrete bearing wall subjected to high axial loading and moment can be attained by improving the deformability of compression zone or by reducing the neutral axis depth. For this two existing options for ductility enhancement were reviewed and improved to conveniently apply to the seismic improvement of compression zone of the wall: (1) end confinement of concrete due to transverse steel and (2) boundary element.

1. Introduction

High-rise apartment buildings have been of typical pattern of dwellings in regions of dense population. In particular, those buildings in Korea consist of thin reinforced concrete (RC) walls supporting slabs without beams and columns. Such a feature may be attributed to the purpose of maximization of service area and efficiency to shorten the construction period. RC bearing walls in those buildings can be characterized by deep rectangular section with high aspect ratio (height/depth ratio), considerably small amount of steel compared to usual columns, unexpectedly low confinement of concrete, and nevertheless, applied high axial loading.

When a bearing wall of high-rise apartment buildings subjected to earthquake–induced deformation, some large flexural-compressive stresses are likely to occur at an end of the wall due to its high aspect ratio, thin thickness and axial loading. This may result in crushing concrete at the compression end and thus limiting ductility of the structural system. In order to secure and further enhance the ductility capacity of the bearing wall system at large deformation demand, the seismic design may employ the following options: (1) confinement of concrete at compression end; and (2) barbell-shaped cross section with boundary elements. For confinement of concrete due to longitudinal and transverse steel, the effect of various design variables, such as material strength, dimension of confined part of walls, bar diameter and spacing, on confinement is investigated. For boundary element option, a methodology to adequately dimension the boundary element is suggested.

2. Determination of Compression Zone

When the compression end of RC bearing wall is reinforced, it is important to appropriately determine the range of compression zone. For this, consider a wall section in ultimate state with linear strain distribution when subjected to axial loading and moment as shown in Fig. 1. It is assumed that the vertical reinforcement uniformly distributed over the section yields either in tension or in compression. Then the neutral axis depth normalized by wall depth, c/L, can be defined from the force equilibrium. That is

$$\frac{c}{L} = \frac{P/f'_c A_g + \rho_t f_y / f'_c}{\alpha\beta + 2\rho_t f_y / f'_c} \tag{1}$$

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where $P / f_c' A_g$ = axial load ratio, f_c' = compressive strength of concrete, f_y = yield strength of steel, A_g = gross section area of RC bearing wall and ρ_l = longitudinal steel ratio.

Using Eq. (1), the compression zone (neutral axis depth ratio) can be plotted in terms of extreme compression fiber strain for various design variables as shown in Fig. 2, in which Tsai's model modified by Chang and Mander (1994) with f_c'=30Mpa and ε_{co}=0.00203 is used for concrete stress-strain relationship. Also plotted is c / L suggested by ACI (2002) from the study of Wallace (1994), where c / L is determined by the expected maximum lateral drift angle. But this approach cannot take the effect of various variables into account. For the maximum drift angle up to 0.02, the range of c / L given by ACI is 0.09~0.25.

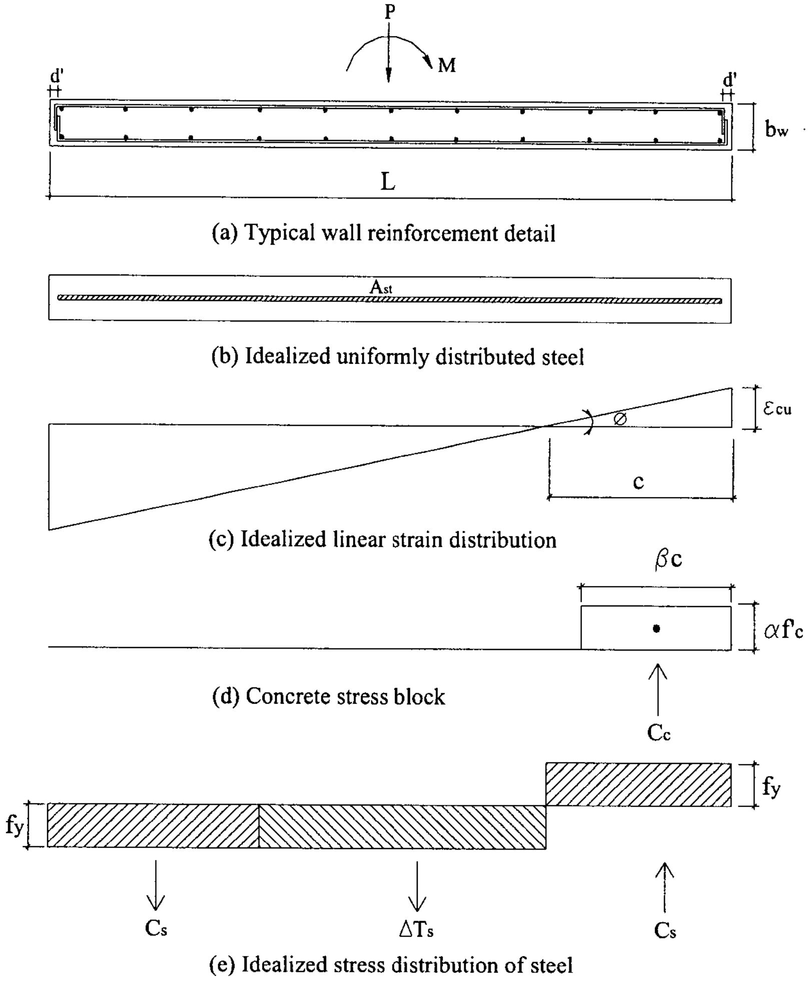

Fig. 1 RC bearing wall section under in-plane flexure at ultimate state

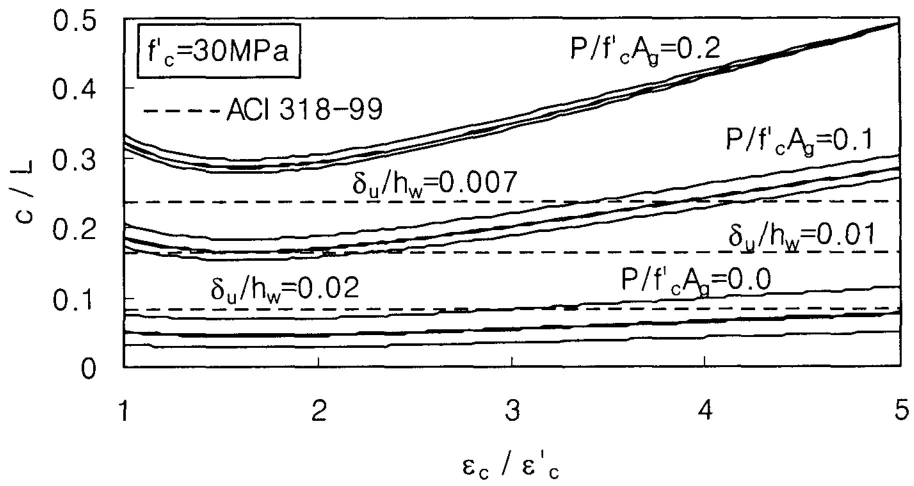

Fig. 2 Compression zone of RC wall subjected to in-plane flexure at ultimate state

3. Confinement of Compression End

Mander, et al. (1988) proposed a theoretical expression to determine the confinement effect due to transverse reinforcement for rectangular and circular columns. In its general form, the confinement effect on the stress-strain curve of concrete can be expressed by

$$K = f'_{cc} / f'_{co} \tag{2}$$

$$\varepsilon_{cc} = \varepsilon_{co}\left[1+5(K-1)\right] \tag{3}$$

where K = factor for confinement effect, $f'_{cc}, \varepsilon_{cc}$ = stress and strain at peak of confined concrete, $f'_{co}, \varepsilon_{co}$ = stress and strain at peak of unconfined concrete. It is noted that with the improved stress-strain curve of concrete due to confinement, the rotational capacity at critical section of the wall can be enhanced, that is $\phi = \varepsilon_{cu} / c$, and so the ductility can. In application of this model to the compression end of bearing walls, a slight modification is required, since no cover concrete will be spalled out from one side of confined part contacting with solid concrete.

Design variables considered to determine K are yield strength of steel, dimensions of confined end, bar diameter and spacing of vertical and horizontal steel. Mathematical expressions to obtain K from design variables are intentionally omitted to avoid repetition, since they are widely spread in use. Fig. 3 presents the factor for confinement effect along with net spacing between vertical bars for various variables. For this, b_c =600mm is assumed. From the figure, it is noted that the most influential parameter on confinement effect is spacing between horizontal steel but becomes less influential with spacing between vertical steel getting greater. For spacing between horizontal steel bars greater than 150mm, significant ductility enhancement due to confinement cannot be expected.

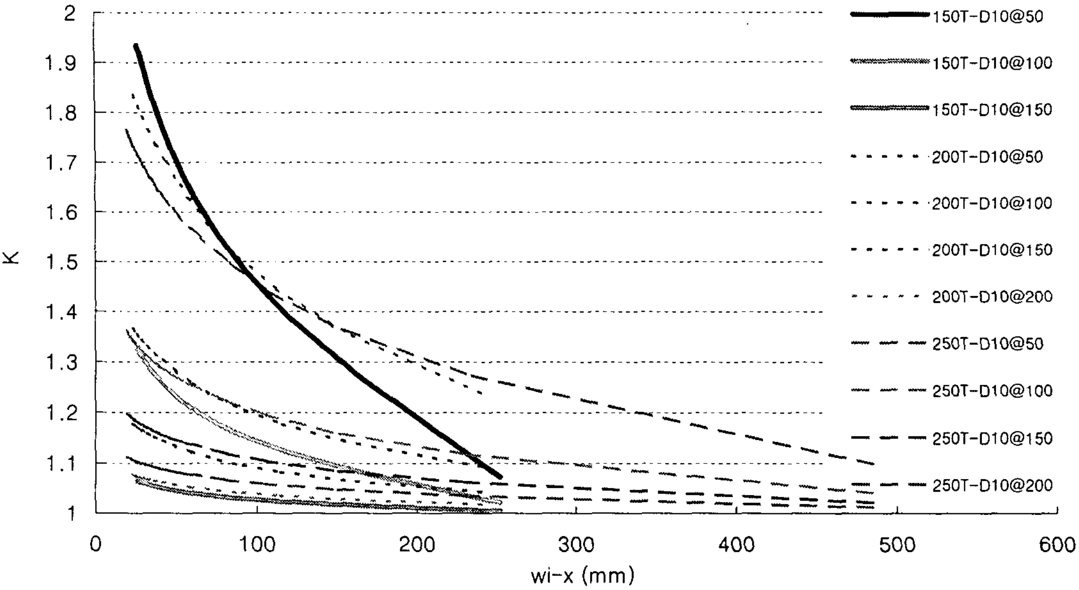

Fig. 3 Confinement effect influenced by various factors

4. Dimensioning Boundary Element

The wall thickness of 150~200mm in typical wall-slab building system in Korean practice may not be spacious enough to accommodate placing confinement steel. Therefore, an alternative way to enhance the ductility capacity of RC walls may be advocated. That is, the neutral axis depth, c, can be reduced by placing boundary element dimensioned by $mc \times kb_w$ for length×thickness at both ends of the wall section. Everything else other than boundary element is the same as those in Fig. 1. The longitudinal steel in boundary elements is not expected to contribute to reduce c because the internal flexural compressive and tensile forces generated in them must be cancelled out each other. In order for the boundary element to be effective in flexural compression, the boundary element should be within the neutral axis depth, that is, within the compression zone. Then the neutral axis depth normalized by the wall depth, c_r / L, can be defined from the equilibrium of forces. That is

$$\frac{c_r}{L} = \frac{P / f'_c A_g + \rho_t f_y / f'_c}{\alpha\beta(1 + mk) + 2\rho_t f_y / f'_c} \tag{4}$$

where m = the ratio of boundary element depth to the rectangular stress block depth and k = the ratio of additional thickness of boundary element exceeding wall thickness to wall thickness. To guarantee the whole section of boundary element located within the compression zone, $m < 1.0$ is required.

Fig. 4 presents the plotted compression zone in terms of mk with various variables. It is noted that as mk increases, c_r / L decreases. This denotes that the compression zone decreases by adding the boundary elements, resulting in ductility enhancement. With appropriate value of mk, c_r / L is readily

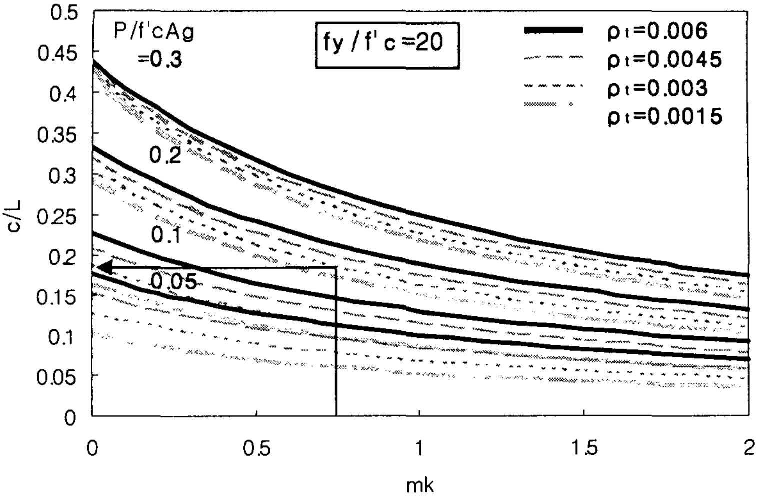

Fig. 4 Compression zone RC wall with boundary elements

determined from the charts. Then, as a final step, mk should be decoupled into m and k in consideration of architectural aspect.

For example, a RC bearing wall with L =6000mm and b_w =200mm for determination of boundary element size. Assume that f_y =400Mpa and f_c' =20Mpa (f_y / f_c' =20). With $P / f_c' A_g$ =0.2 and ρ_t =0.003 (0.3%), select mk =0.75. Then c_r / L =0.19 can be obtained from Fig. 4. This is about 39% of reduction in c_r / L compared to the state without boundary element (mk =0). If m =0.5 is taken, k becomes 1.5. Then the required dimension of boundary element is 480×500mm.

5. CONCLUSIONS

In the present paper, RC bearing walls of wall-slab high-rise apartment building system subjected to in-plane flexure are considered for improvement of seismic capacity. The following conclusions are drawn from the study:

(1) A mathematical expression to determine the compression zone of RC wall at ultimate state was reviewed.

(2) In order for confinement to be effective for ductility enhancement, the spacing between transverse reinforcement should not be greater than 150mm. With the current detailing practice for wall ends in Korea, confinement effect cannot be expected.

(3) A comprehensive methodology for dimensioning boundary elements was proposed as an alternative way in ductility enhancement, in which the size of boundary elements can be determined in consideration of architectural requirement.

ACKNOWLEDGMENTS

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