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# CONFINING TRANSVERSE REINFORCEMENTS FOR CIRCULAR COMPOSITE HOLLOW RC COLUMN WITH INNER TUBE

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The confining transverse reinforcement has been arranged in plastic hinge region to resist the lateral load, increasing the lateral confining effect in the substructure of the bridge. Columns increased the seismic performance by securing the stiffness and ductility. The calculation method of confining transverse reinforcements is reported in AASHTO-LRFD specification. This specification is only proposed for solid RC columns. In this reason, if this specification is applied to another column as composite column besides solid RC columns, a proper evaluation of the column cannot be done. In particular, composite hollow RC columns have limits for applying this specification. The composite hollow RC column consists of transverse longitudinal reinforcement, cover concrete, core concrete, and an inner tube inserted on hollow face. It increases the ductility, strength, and stiffness of the composite hollow RC column. This paper suggests a modified equation for an economical and rational design through an investigation of displacement ductility when applied to the existing specifications of the composite hollow RC column. Moreover, parametric study is performed for evaluating the detail behavior. Using these results, a calculation method of economic transverse reinforcements is proposed.

*Keywords*: AASHTO, Ductility, Displacement, Hollow ratio, Rebar, Seismic performance.

## 1 INTRODUCTION

Hollow RC columns are used as economical design elements because they use little material amount and are lightweight. However, they have poor ductility due to brittle failure on the inner face of the column. The brittle failure of a hollow RC column originates from the lack of confinement of the core concrete because, generally, the core concrete of a hollow RC column is confined only by the outer transverse reinforcements or both the outer and the inner transverse reinforcements. To prevent this brittle failure, Han et al. (2008) used an inner tube for reinforcing the inner face of a hollow RC column, offering strong and durable confinement because of the reinforcement provided by the inner tube. The column’s strength and ductility are enhanced because of the continuous confining stress provided by the inner tube. A nonlinear concrete model and the compressive performance were analyzed in an experimental study on a composite hollow RC column (Han et al. 2008, 2010). In these studies, the yielding and buckling failure conditions of the inner tube were considered as well.

The confining transverse reinforcement has been arranged in plastic hinge region to resist the lateral load, increasing the lateral confining effect in the substructure of bridge. Columns have increased seismic performance through securing the stiffness and ductility. The calculation method of confining transverse reinforcements is reported in AASHTO-LRFD specification as shown in Eq. (1). This specification is only proposed for solid RC columns. If this specification is applied to another column, such as composite columns besides solid RC columns, proper evaluation of columns cannot be done. In particular, composite hollow RC column (as shown in Figure 1) have limits for applying this specification:

$$\rho_s = larger\left(0.45\left[\frac{A_g}{A_c}-1\right]\frac{f_{ck}}{f_{yh}}, 0.12\frac{f_{ck}}{f_{yh}}\right) \tag{1}$$

where $A_g$ denotes gross area of column, $A_c$ denotes area of core concrete, $f_{ck}$ denotes compressive strength of concrete, and $f_{yh}$ denotes strength of transverse reinforcement.

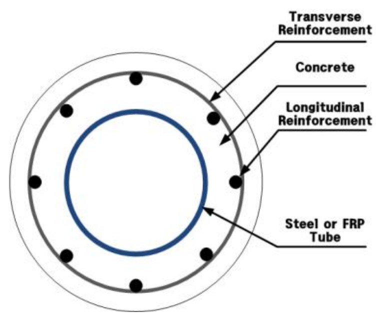


Figure 1. Section of composite hollow RC column.

The composite hollow RC column consists of transverse longitudinal reinforcement, cover concrete, core concrete, and inner tube inserted on hollow face to increase ductility, strength, and stiffness in composite hollow RC column. This paper suggests a modified equation for an economical and rational design through an investigation of displacement ductility when applied to the existing specifications of the composite hollow RC column. Moreover, a parametric study is performed for evaluating the detail behavior. Using these results, a calculation method of economic transverse reinforcements is proposed.

## 2 DUCTILITY RATIO OF CIRCULAR COMPOSITE HOLLOW RC COLUMN ACCORDING TO AASHTO-LRFD SPECIFICATION

In this section, confining transverse reinforcements of composite hollow RC column are calculated by AASHO-LRFD specification, as per as Eq. (1). Here, the core concrete of a composite hollow RC column is confined by inner tube and transverse reinforcements. The material model of this column is the same as hollow RC column, when transverse reinforcement reached failure before yield failure or buckling of inner tube. At this time, the inner tube plays a role as core concrete of hollow RC column. For this reason, gross area ( $A_g$ ) and core concrete area ( $A_c$ ) of composite hollow RC column should be considered a confined area by transverse reinforcements, including the hollow part.

Tables 1 and 2 are dimension of composite hollow RC column for analysis. Table 1 is the common dimension of analysis model. And Table 2 is the section dimension according to hollow ratio. Hollow ratios are considered from 0.0 to 0.9, and the thickness of the inner tube is changed as shown in Table 2.

Table 1. Dimension of column model.

| Spec. | Dimension |
|---|---|
| Diameter | 2,500.0 |
| Thickness of cover concrete | 60.0 |
| Longitudinal rebar ratio | 0.011 |
| Min. transverse rebar ratio | 0.0072 |
| Slenderness ratio | 23.0 |
| Strength of concrete | 21 |
| Yield strength of rebar | 350 |
| Yield strength of internal tube | 235 |
| Elastic modulus of steel | 210,000 |
| Elastic modulus of rebar | 200,000 |
| Elastic modulus of concrete | 26,115 |

Table 2. Section dimension according to hollow ratio.

| Hollow ratio | Diameter of hollow section | Thickness of inner tube |
|---|---|---|
| 0.0 | - | - |
| 0.2 | 473.2 | 1.4 |
| 0.4 | 952.0 | 2.7 |
| 0.5 | 1183.2 | 3.4 |
| 0.6 | 1419.8 | 4.1 |
| 0.7 | 1656.6 | 4.7 |
| 0.8 | 1892.0 | 6.0 |
| 0.9 | 2113.6 | 14.2 |

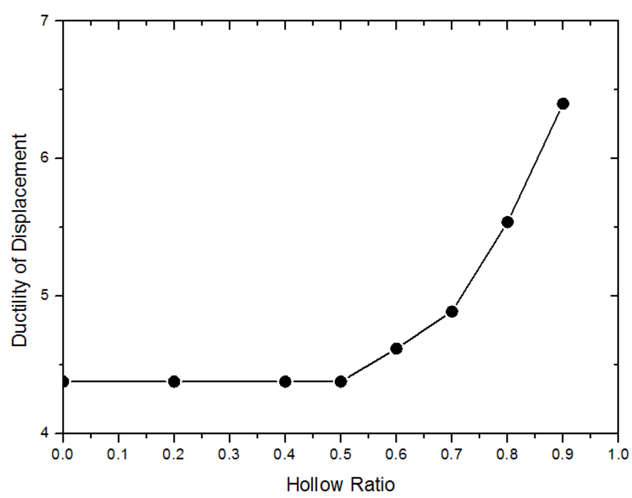


Figure 2. Ductility of displacement by hollow ratio.

Figure 2 shows ductility of displacement by hollow ratio. Ductility of displacement of analysis model has rapidly increased from 0.5 of hollow ratio. When hollow ratio is 0.9, ductility of displacement is about 6.5. Hollow ratios have a decisive effect on the change of ductility with transverse reinforcement ratio.

Table 3. Material model of columns.

| | Strain at peak stress | Peak axial stress (MPa) | Ultimate Strain |
|---|---|---|---|
| 0.0 | 0.0055 | 28.3428 | 0.0239 |
| 0.2 | 0.0055 | 28.3544 | 0.0239 |
| 0.4 | 0.0055 | 28.3652 | 0.0239 |
| 0.5 | 0.0055 | 28.3710 | 0.0239 |
| 0.6 | 0.0055 | 28.3768 | 0.0239 |
| 0.7 | 0.0055 | 28.3818 | 0.0239 |
| 0.8 | 0.0055 | 28.3877 | 0.0239 |
| 0.9 | 0.0055 | 28.3935 | 0.0239 |

Table 4. Section dimension according to hollow ratio.

| Thickness of inner tube | 5.4 | 6.0 | 6.5 | 7.0 | 7.5 | 8.0 | 8.5 |
|---|---|---|---|---|---|---|---|
| Ductility displacement | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 |

** Dimensions of columns are same hollow ratio 0.8 model.

Table 3 is material model of confined concrete. Strain at peak stress, peak axial stress, and ultimate strain have the same values. This means that parameter exists to affect change of ductility, except for the performance of confining concrete. Table 4 shows ductility of displacement by thickness of inner tube. For these analyses, analysis models are considered the same model with hollow ratio 0.8 models, except that the thickness of the inner tube changes from 5.4 mm to 8.5 mm. Thickness of inner tube does not affect the change of ductility, as shown Table 4.

Table 5. Analysis model by diameter.

| | Hollow ratio | Longitudinal rebar ratio | Transverse rebar ratio | Slenderness ratio |
|---|---|---|---|---|
| D700 | 0.0～0.9 | 0.011 | 0.0072 | 23 |
| D1000 | 0.0～0.9 | 0.011 | 0.0072 | 23 |
| D2000 | 0.0～0.9 | 0.011 | 0.0072 | 23 |
| D2500 | 0.0～0.9 | 0.011 | 0.0072 | 23 |
| D3000 | 0.0～0.9 | 0.011 | 0.0072 | 23 |
| D3500 | 0.0～0.9 | 0.011 | 0.0072 | 23 |

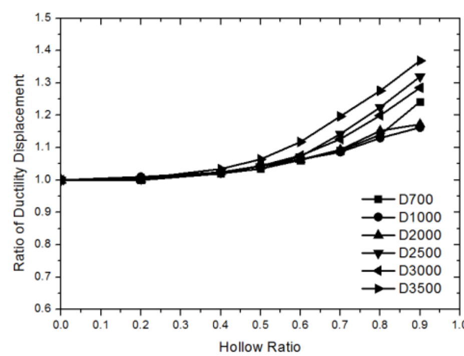


Figure 3. Ratio of ductility of displacement by diameter.

Next, change of ductility investigates by diameter of column. Table 5 shows that as the diameter of the column changes from 700 mm to 3500 mm, the hollow ratio changes from 0.0 to 0.9. Longitudinal reinforcement ratio, transverse reinforcement ratio, and slenderness ratio is the same on all models. Figure 3 shows the ratio of ductility of displacement by diameter of column. When the diameter of column is increased, the ratio of ductility increased. This means that section properties affect the change of ductility. To investigate the effect of parameters, results as shown in Figure 3 compare with radius of gyration as per Eq. (2).

$$r = \sqrt{\frac{0.2E_c I_g + E_s I_s}{0.2E_c A_g + E_s A_s}} \tag{2}$$

where $E_c$ denotes elastic modulus of concrete, $E_s$ denotes elastic modulus of steel tube, $I_s$ denotes moment of inertia of steel tube, $I_c$ denotes moment of inertia of concrete, and $A_s$ denotes area of steel tube.

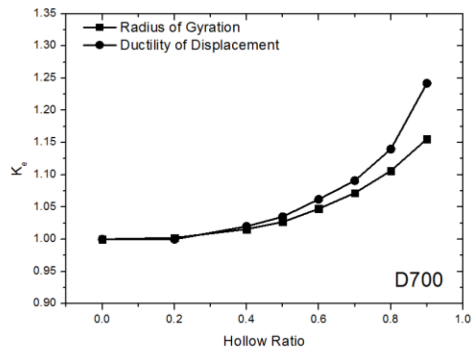


Figure 4. Ratio of ductility and radius of gyration (D700).

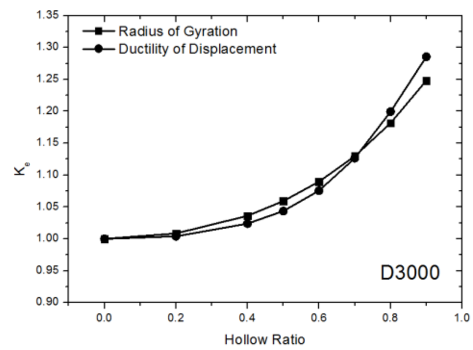


Figure 5. Ratio of ductility and radius of gyration (D3000).

Figures 4 and 5 compare the ratio of ductility and the radius of gyration. It is not a perfect match, but they have similar increasing tendencies. Here $K_e$ denotes ratio based on hollow ratio 0.0.

## 3 MODIFIED EQUATION FOR CONFINING TRANSVERSE REINFORCEMENTS OF CIRCULAR COMPOSITE HOLLOW RC COLUMN

In this section, the modified equation of calculation method for confining transverse reinforcement of composite hollow RC column is suggested using a radius of gyration of column. This modified equation demonstrates that composite hollow RC column shave similar ductility to solid RC columns. This method could produce economic designs of composite hollow RC columns. Here, we impose the reduction coefficient $\gamma$ that can be calculated as Eq. (4).

$$\gamma \cdot \rho_s \tag{3}$$

$$\gamma = \left( \frac{r_s}{r_x} \right)^{\alpha} \tag{4}$$

$$\alpha = 1.108 \ln D - 6.659 \tag{5}$$

where, $\gamma$ denotes reduction coefficient, $r_s$ denotes radius of gyration of solid RC column, $r_x$ denotes radius of gyration of composite hollow RC column, and $D$ denotes diameter of column:

Table 6. Confining transverse reinforcement by modified equation.

| | $\rho_s$ | $\gamma$ | **Thickness of inner tube** |
|---|---|---|---|
| 0.0 | 0.007 | - | - |
| 0.2 | 0.007 | 0.981 | 1.4 |
| 0.4 | 0.006 | 0.921 | 2.6 |
| 0.5 | 0.006 | 0.878 | 3.2 |
| 0.6 | 0.005 | 0.825 | 3.7 |
| 0.7 | 0.005 | 0.765 | 4.2 |
| 0.8 | 0.005 | 0.697 | 4.5 |
| 0.9 | 0.004 | 0.624 | 4.8 |

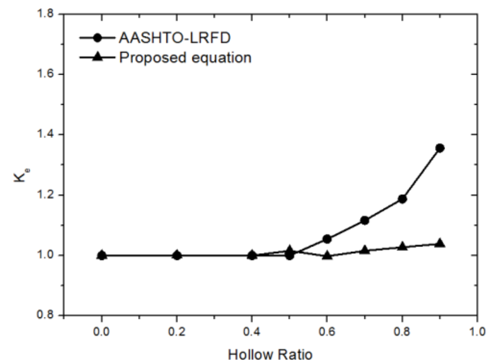


Figure 6. Comparison of displacement ductility ratio and AASHO-LRFD specification.

Table 6 is confining transverse reinforcement ratio by proposed equation. Confining transverse reinforcement ratio decrease from 0.007 to 0.004 at 0.9 of hollow ratio. This results lead to decrease ductility of displacement as shown Figure 6. Ductility of compoiste hollow RC column has a steady value as solid RC column by hollow ratio. Ductility is reduced reasonably. This prevent excessive design of compiste hollow RC column.

## 4 RESULTS AND SUMMARY

This paper investigated confining transverse reinforcement for composite hollow RC columns. Modified equations suggested economical and rational design through investigation of displacement ductility when applied to the existing specifications of composite hollow RC columns. Relation radius of gyration and ductility of column have similar tendencies when dimensions of composite hollow RC column are changed. Using these results, the calculation method of economic transverse reinforcements is proposed. These equations prevent excessive design of composite hollow RC columns.

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