SHEAR DRIFTS ESTIMATION OF REINFORCED CONCRETE COLUMNS AT DAMAGE STATES

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A modified truss mechanism was applied to estimate lateral drifts ratio of reinforced concrete columns after shear failure. Strain-stress constitutive law of the struts concrete was modeled based on a modified strain-stress curve for confined concrete by rectangular hoops. Effects of axial loads were considered by multiplying a reduction factor to the lateral drifts obtained from the truss analysis. The reduction factor is computed based on tension steel stress reduction due to effect of applying axial load. Tension bars stresses were obtained by implementing a nonlinear axial-flexural analysis. Lateral drift ratios at the load level, 50% down from the maximum lateral load capacity after shear failure were estimated using the presented process for the twenty one tested columns subjected to static cyclic unidirectional reverse lateral loads and applied axial loads. The analytical outputs were compared with the experimental results.

Key Words : *Axial-shear failure, reinforced concrete columns, damage states, shear drifts*

1. INTRODUCTION

Studies on shear failure mechanism of reinforced concrete members imply the complexity of the phenomena especially when the members are subjected to axial loads. With the new analysis philosophy based on performance of structures, engineers need to understand the actual behavior of structures through whole states of the performance until complete loss of capacity. This object can be achieved by applying the displacement evaluation concepts in analysis process. For this purpose this study carried out to estimate damage states performance of reinforced concrete columns prone to shear failure. A truss mechanism was implemented to estimate damage states lateral drifts of the reinforced concrete columns. Effect of axial-flexural mechanism, was studied by modeling a nonlinear curvature-moment relationship for RC columns.

2. AXIAL-FLEXURAL MECHANISM

Traditionally, moment-curvature diagrams are analytical tools to study flexural mechanisms of beams and columns. This can be achieved by assumption that the plane sections remain plane during loading states. For damage states performance evaluation of RC columns, curvature-moment diagrams must be obtained by considering the nonlinearity of steels and concrete. Bilinear hysteretic models can be applied to implement the inelastic hysteretic behaviors of tension and compression bars. A nonlinear model proposed by Kent and Park[3)], is expressing the inelastic behavior of the confined concrete. The curvature-moment relationship of a reinforced concrete column section (see Fig. 1) for the case where strains are controlled by concrete stress may be found by applying equilibrium equation and by taking moments about tension steel.

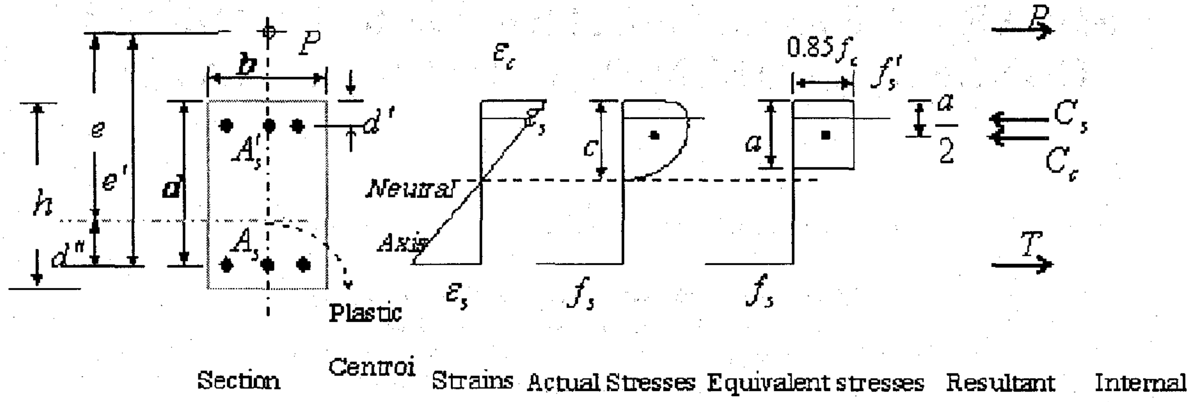


Fig. 1 Reinforced concrete column section, strain-stress relationship

From equilibrium equation,

$$A_s'f_s' + 0.85f_c ab - P = A_s f_s \qquad (1)$$

And from linear strain relationships,

$$f_s' = E_s'\frac{f_c}{E_c a}(a-\beta_1 d'), f_s = E_s\frac{f_c}{E_c a}(\beta_1 d - a) \qquad (2)$$

by substituting (2)in equation (1) a: depth of the equivalent rectangular stress block, is obtained

$$a = \sqrt{\left(\frac{\rho_s dE_s + \rho_s' dE_s'}{1.7E_c} - \frac{d\sigma_0}{1.7f_c}\right)^2 + \left(\frac{\rho_s' E_s' d\beta_1 d' + \beta_1 d^2 \rho_s E_s}{0.85E_c}\right)} - \left(\frac{\rho_s dE_s + \rho_s' dE_s'}{1.7E_c} - \frac{d\sigma_0}{1.7f_c}\right) \qquad (3)$$

Where, A_s= area of tension bars, A_s'= area of compression bars, E_c,E_s and E_s'= modulus of elasticity of concrete, tension and compression steel bars at the load states in the hysteretic model, b= width of section, d= effective depth of tension steel, d'=distance from extreme compression fiber to centroid of compression steel, f_s = tension bars stresses, f_s' = compression bars stresses, f_c= concrete stresses obtained based on a strain-stress relationship (constitutive law), P= column axial load, β_1= rectangular block stress coefficient which is equal to 0.85 for f_c <280 kg/cm^2, β_1 is reduced continuously by 0.05 for each 70 kg/cm^2, and σ_0=P/bd, ρ_s=A_s/bd, and ρ_s'=A_s'/bd. The expression obtained from taking moments about the tension steel is

$$Pe' = 0.85f_c ab(d - \frac{a}{2}) + A_s' f_s'(d - d') \qquad (4)$$

where

$$e' = e + d''$$

$$, e = \frac{M}{P} = \frac{VL}{2P} \qquad (5)$$

$$d'' = \frac{0.85f_c'bh(d-0.5h) + A_s' f_y(d-d')}{0.85f_c'bh + (A_s' + A_s)f_y}$$

where e' is the eccentricity of axial load P from the centroid of the tension steel and d'' is the distance from the plastic centroid to the centroid of tension steel of the column when eccentrically loaded. The stress-strain relationship of concrete confined by rectangular hoops can be illustrated by a curve proposed by Kent and Park[3)].

Parameters of the model are obtained as following (see Fig. 2):

$$f_c = f_c'\left[\frac{2\varepsilon_c}{0.002} - \left(\frac{\varepsilon_c}{0.002}\right)^2\right] \quad when\ \varepsilon_c \le 0.002$$

$$f_c = f_c'(1 - Z(\varepsilon_c - 0.002)) \quad when\ 0.002 \le \varepsilon_c \le \varepsilon_{20c} \qquad (6)$$

in which

$$Z = \frac{0.5}{\varepsilon_{50u} + \varepsilon_{50h} - 0.002}$$

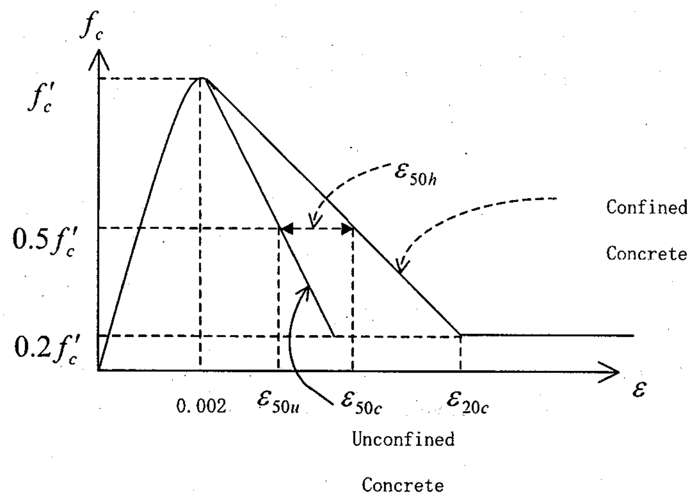
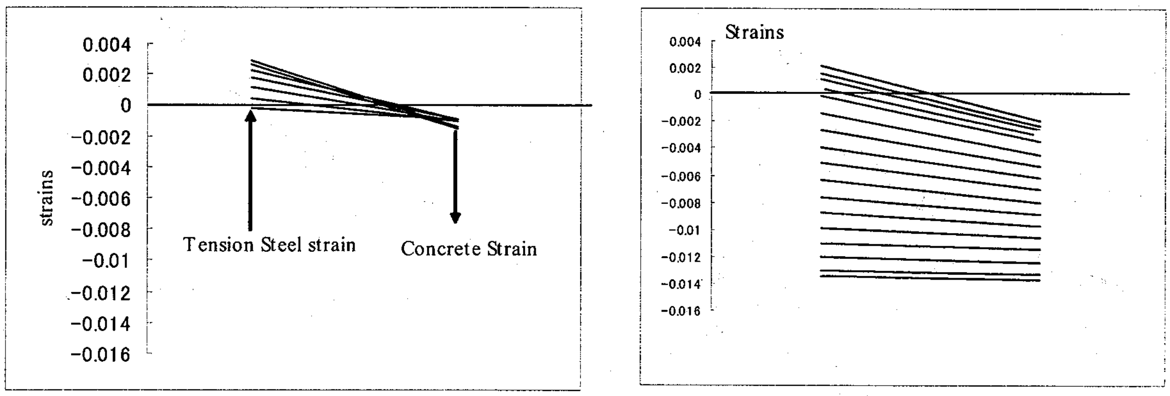


Fig. 2 Stress-strain curve for concrete confined by rectangular hoops, Kent and Park



a) For load ranges from 0 to the maximum lateral load capacity.

b) For load ranges from maximum lateral force capacity to axial-flexural failure

Fig. 3 Strain profiles for specimen[2)] No.5/2002 at maximum moment section

where

$$\varepsilon_{50u} = \frac{0.2109 + 0.002 f'_c}{f'_c - 70.31} \qquad (f'_c : {kgf}/{cm^2}),$$

$$\varepsilon_{50h} = a_w \bar{\rho}_w \left(\frac{\bar{b}}{\bar{s}_w}\right)^{1/b_w}$$

Where $f_c{}'$ = concrete strength in direction of the compression stress kg/cm^2, ρ_w=ratio of volume of transverse reinforcements to volume of concrete core measured to outside of hoops, b^-=width of confined core measured to outside of hoops, s_w = spacing of hoops, bw=2, aw=0.75 (constant factors for the mechanism), and Z= slope of the assumed linear falling branch.

Strain profiles and curvatures of the column section at maximum moment section are shown in Fig.3 for lateral load ranges from 0 to the maximum lateral load capacity up to axial-flexural failure.

From equation (4) and (5), corresponding lateral load V to axial deformations can be obtained. Fig. 4 shows comparison between experimental results and analytical results of lateral force-axial deformation relationship for specimen[2)] No.5/2002. Furthermore, Fig. 5 illustrate correlation between tension steel strain-lateral force measured in test results and tension steel strain-lateral force obtained using the flexural analysis for pecimens[2)]

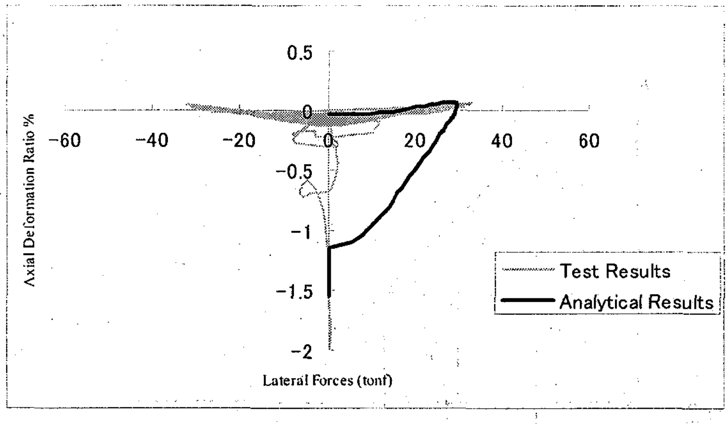
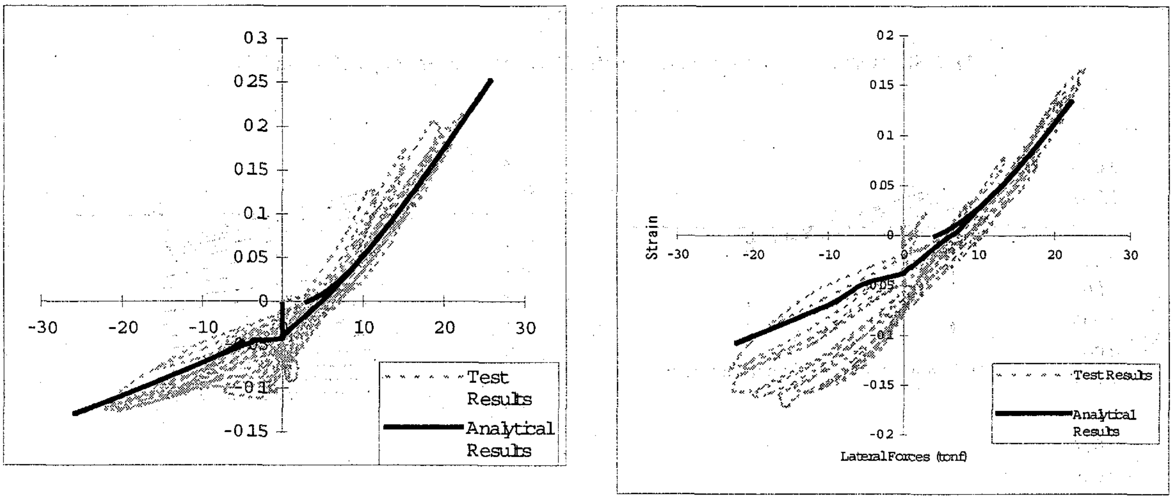


Fig. 4 Axial deformation ratio – lateral force relationship, comparison between experimental and analytical results of specimen[2] No.5/2002.



a) Specimen[2] No.12/2001.

b) Specimen[2] No.8/2001.

Fig. 5 Correlation between tension steel strain-lateral force measured from test results and those obtained using the analytical approach

No.8/2001 and No.12/2001 which implies acceptable agreement.

Axial deformations ware estimated based on the axial-flexural mechanism using nonlinear curvature-moment relationship for the tested reinforced concrete columns. Correlation between the experimental outputs and analytical results of axial deformations ratios for tested columns[1)2)] were depicted in Fig 6. The study shows that the nonlinear curvature-moment diagram approach may give reliable results for estimation of axial deformations. The more reliable confined concrete strain-stress constitutive law applies to the analysis, the more verified results can be achieved. By assuming a constitutive law for concrete we may estimate the tension steel at each load levels after shear failure which will be applied to the obtained reduction factor for the truss mechanism analysis drifts results.

3. TRUSS MECHANISM

Truss mechanism is an old concept for estimation of shear deformation of RC beams. It can be applied for reinforced concrete columns by considering the effects of axial loads. Fig.7 shows how this mechanism can be depicted for columns. The shear distortions, in the web of reinforced concrete columns, can be approximated by using an analogous truss presented in Fig. 7. Horizontal

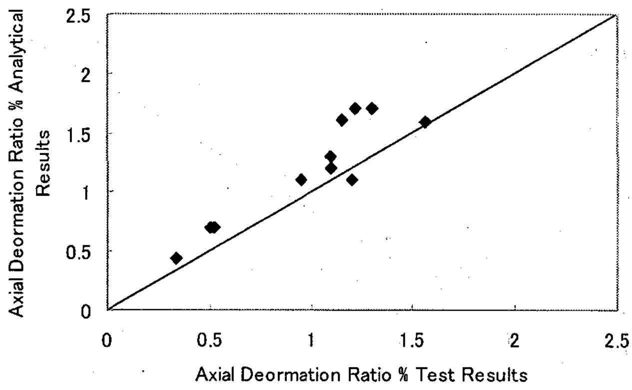


Fig. 6 Comparison between experimental and analytical results of axial deformation ratios

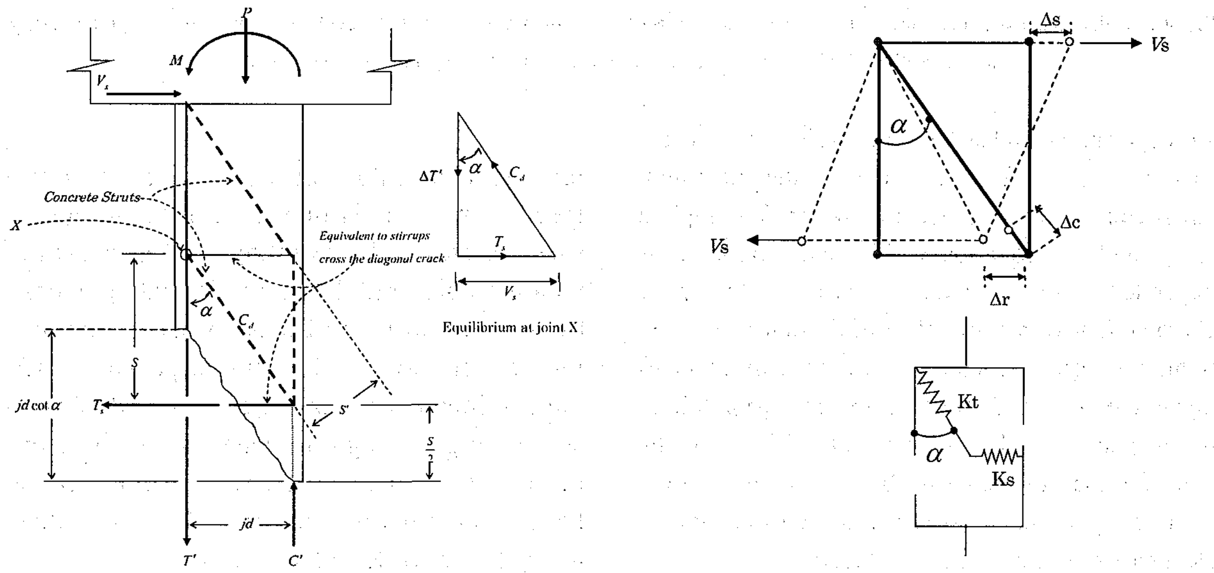


Fig. 7 Shear distortions in the web of a reinforced concrete column, and the analogous truss.

stirrups and α degree diagonal concrete struts are assumed to form the web members. The inclination of the diagonal compression struts , is assumed equal to an angle α to the vertical direction. The stress-strain constitutive law of the strut concrete, vector C_d in Fig.7 running parallel to diagonal cracks, is express by the same constitutive law as Fig.2 but with maximum compression strength equal to $\nu f'_c$. Parameter ν is efficient factor for compression strength in direction of the strut obtained from AIJ code of Japan.

The external shear force V_s, is the proportion of shear force resisting by truss mechanism which is equal to the resultant of all stirrup forces across the diagonal crack. $\Delta T'$ is the bond force or difference of tension forces between two truss sections obtain from the axial flexural mechanism. Horizontal displacement component due to truss mechanism can be calculated as:

$$\frac{\Delta_{ht}}{Jd\cot\alpha} \approx \frac{\Delta_s}{\cot\alpha Jd} + \frac{\Delta_c}{Jd\cos\alpha} \qquad (7)$$

where, Δ_s= stirrups deformation, Δ_c= strut deformation, Δ_{ht}=lateral drift ratio. Inelastic shear behavior of truss mechanism can be modeled by introducing two nonlinear springs (see Fig. 7), K_s represents as a transverse reinforcement spring which can be modeled by a normal bilinear hysteretic model and Kc functions as a concrete

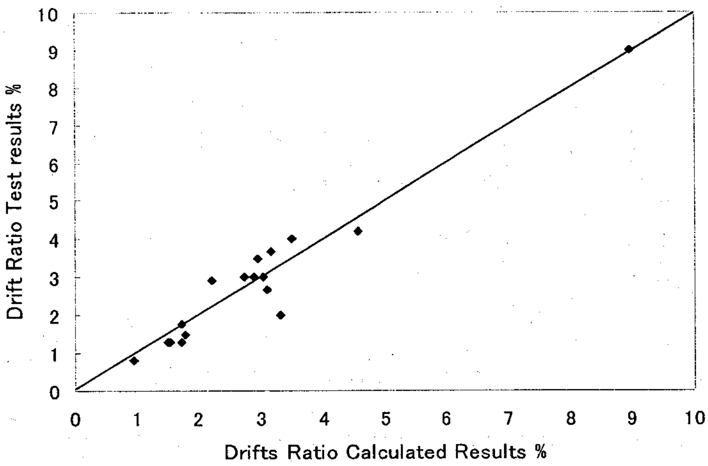


Fig. 8 Correlation between experimental and analytical results of lateral drift ratios at the load level 50% down from maximum lateral load capacity of the columns after shear failure for the twenty one tested columns[1)2)]

strut spring, which has the same skeletal model as Fig. 2 for confined concrete with the maximum stress equal to $\nu f'_c$. A reduction factor is multiplied to ε_{50u} and ε_{50h} (equation 6). The reduction factor is depended on loading type (hysteretic characteristics), mainly effect of tension bars stress reduction (after shear failure at each damage state) due to the axial load effects and compression failure mechanism, which can be obtained from the axial-flexural mechanism. In this study, it was assumed to be equal to reduction tension ratio in steel bars due to applying axial load.

Fig. 8 shows the correlation between experimental results and analytical outputs of lateral drift ratios, at the load level 50% of the maximum lateral load capacity of the columns after shear failure for the twenty one tested columns 2),3) .

4. CONCLUSIONS

By applying a reliable confined concrete strain-stress constitutive law , in truss mechanism analysis and considering the effect of axial load by a nonlinear curvature-moment analysis for reinforced concrete columns, it would be likely to implement a reliable damage states lateral drifts evaluation. It is clear that confinement of columns play a very important role on increasing the deformability of the reinforced concrete columns. Increasing axial load in the RC columns with low transverse reinforcement ratio follows by a brittle failure mechanism. This is due to decreasing tension steel stresses and preventing steel to cross the yielding point and therefore dissipating energy by concrete instead of tension bars which has low capacity to absorb energy especially when the confinement of concrete is not sufficient to sustain large enough ultimate strain. Therefore tension bars and transverse reinforcement ratios have a major effect on lateral drifts ratios values and behavior of RC columns.

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