RESPONSE ANALYSIS OF REINFORCED CONCRETE STRUCTURES UNDER SEISMIC FORCES

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INTRODUCTION

In the response analysis of middle or short height reinforced concrete structures, it is most important to precisely evaluate the stiffness degradation in the hysteresis loops of the restoring force characteristics because of their frequency sensitivity. It is supposed that the shear deformation of reinforced concrete structural elements may act an important role for the stiffness degradations. This study points out that the difficulties exists on the lack of the knowledges to estimate these shear deformations, such as the slippage of the reinforcing bars or shear cracks in both joint regions and members.

The authors proposed a hypothesis that the deformation of the reinforced concrete columns under combined shear and flexure may be considered as the sum of indivisual deformations under respective forces. The results of comprehensive experiments gave a substantial support to this assumption. Employing an analytical model which simply represents the actual deformation mechanisms in the reinforced concrete columns, a semi-empirical method to evaluate the column deformation on the basis of both sectional properties and combined force interaction was established.

Some dynamic responses of reinforced concrete columns subjected to an earthquake excitation are obtained on the basis of the degraded hysteresis rules of the restoring force characteristics proposed.

BASIC EXPERIMENTAL STUDY

Specimens

To obtain the necessary informations the following widely ranged properties were given to the tested columns.

1. Shear span ratio (a/D); 1.0, 2.0 and 3.0.
2. Amount of longitudinal reinforcement Pt; 1.9, 2.54 and 3.80% in gross steel ratio.
3. Amount of lateral shear reinforcement P_V; 0, 0.25, 0.37, 0.75, 1.50%.

Each specimen had a rectangular section BxD =15cmx20cm. The number and the diameters of the longitudinal reinforcements were intentionally chosen so as to yield the same total perimeter Ψ=24cm in both compressive and tensile zones of the column respectively.

Test method

Monotonous loading tests were performed for all kinds of the specimens and reversed repeated loading tests with constant amplitude of the member rotation R=±0.01 rad. were performed only for the specimens with P_t=3.8% in

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each kind of shear-span ratio. For comparison pure flexural tests were also performed. Fig. 1 shows the overall loading devices. Axial load was maintained so as to yield net concrete stress $f_c'/6$ during the test.

The curvature distribution were measured by the dial gages attached to the 6mm dia. bolts buried in the specimen at intervals of 10cm. The relative displacements over the story height 2a between inner loading points were recorded as the story deflection δ or the member rotation. Also the strain distributions of the longitudinal reinforcements were measured by the electric resistance wire strain gages.

Observed deformation mechanisms

Flexural story deflection δ_{fl} may be obtained by the integration of the curvature distributions of the specimens measured by the attached dial gages. Shear story deflection δ_{sh} and shear strain $\gamma(Q)$ are defined by the following equations respectively.

$$\delta_{sh} = \delta - \delta_{fl} \text{ , and } \gamma(Q) = \delta_{sh}/2a$$

In the case of the specimen with small shear span ratio, it was recognized that the experimental curves were well agreed with those calculated by the next equation before the diagonal cracks appeared.

$$\gamma(Q) = 8Q/7Bd \cdot G_c \text{ , } \quad G_c = \frac{E_c}{2(1+\nu)}$$

Fig. 2 shows the results of the separation between flexural and shear deformations for the specimens subjected to the reversed repeated loading. Fig. 3 shows an example of the strain distribution changes of the longitudinal steel, where the strains at the completion of axial load transferring were defined zero.

PROPOSED DEFORMATION MODEL FOR THE ANALYTICAL METHOD

This model shown in Fig. 4 represents the column deformation as the sum of the rigid body rotation for flexure and shear distortion. It may be considered that the reinforced concrete prisms 2dcxB in the compressive and tensile zones of the column may act the moment resisting role in flexure and have the simplified hysteresis rule between the axial force and average strain as shown in Fig. 5. Assuming that the distributions of the forces T_t and T_c are linearly changed and the plane section is remain-ed plane after deformation, the concentrated displacements Δ_{top} and Δ_{bottom} at the centers of the prisms in the critical sections of the column may be obtained by the numerical integration of the strain distributions along the column axis. Increases of the displacements due to the slippage of the reinforcing bars may be considered in future refined analysis.

Therefore, the depth of rotation centers of the critical section in the n-th incremental stage may be expressed by the following equation.

$$Y^n = \left(\frac{\Delta^n_{top}}{\Delta^n_{top} - \Delta^n_{bottom}} \right)(D - 2 \cdot d_c) + d_c \tag{1}$$

Neglecting the tensile stress of concrete but considering all the compressive stress of the concrete above y, the equivalence conditions about the axial force N and the moment M of the column are expressed referring to Fig. 6.

a) After crack development in the critical section.

$$N^n = T^n_{u1} + \frac{1}{2}(y - d_c)\cdot B\cdot\sigma^n_t + T^n_{L1} \tag{2}$$

$$M^n = (T_{u1}^{\ n} - T_{L1}^{\ n})\cdot\frac{D-2dc}{2} + \frac{1}{2}(y-dc)\cdot B\cdot\sigma^n_t\cdot\frac{(3D-10d_c-2y)}{6} \tag{3}$$

b) Before crack development in the critical section.

$$N^n = T^n_{u1} + \frac{1}{2}(\sigma^n_t + \sigma^n_b)(D-4d_c)B + T^n_{L1} \tag{2'}$$

$$M^n = (T^n_{u1}-T^n_{L1})\frac{D-2dc}{2} + \frac{1}{2}(\sigma^n_t - \sigma^n_b)(D-4d_c)\cdot B\cdot\frac{1}{6}(D-4d_c) \tag{3'}$$

Shear force equivalence is

$$Q^n = \frac{M^n}{a} = \tau^n\cdot B\cdot y^n + \alpha\cdot\sum \sigma^n_{sv}\cdot A_v \tag{4}$$

α : Effective coefficient of hoops.

Any failure criterion of concrete under combined stresses should be considered.

Total story deflection is as prescribed.

$$\delta^n = \delta^n_{fl} + \delta^n_{sh} = [\frac{\Delta^n_{top} - \Delta^n_{bottom}}{D - 2d_c} + \gamma^n(Q)]\ 2a \tag{5}$$

Succesive incremental calculation to the whole process produces the n+1 -th story deflection $\delta^{n+1} = \delta^n + \Delta\delta^n$.

CALCULATED RESULTS OF RESTORING FORCE CHARACTERISTICS OF A REINFORCED CONCRETE COLUMN AND ITS DYNAMIC RESPONSE

For an example the specific details of the column specimen F2 was given to the numeric calculation. The reinforced concrete prisms in the compressive and tensile zones of the column have the bredth B=15cm and the depth $2d_c$=5.1cm. Both prisms are divided into four equal elements over the half distance of the story height. The reinforcing bars considered are 2-deformed bars of nominal diameter 19mm. The compressive strength f_c' and tensile one f_{sp} of concrete are 329 kg/cm^2 and 26.3 kg/cm^2. The yield stress of the reinforcing bars is $\pm$4600 kg/cm^2. In present example the shear force effects for the column and the failure criterion of concrete under combined stress are dismissed but these factors may be easily considered in the analysis using the experimentally obtained results. Obtained hysteresis loop on the restoring force characteristics of reinforced concrete column is shown in Fig. 7. It is supposed that the difference between the experiment and analysis is caused by omitting the shear force effects.

A calculated result on the dynamic response of the cantilever column with a mass of 22ton at the top is obtained. El centro 1940, N-S component record, scaling twice the time axis, was used as the acceleration input to the fixed base of the column.

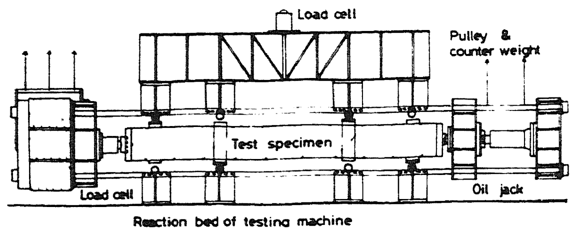
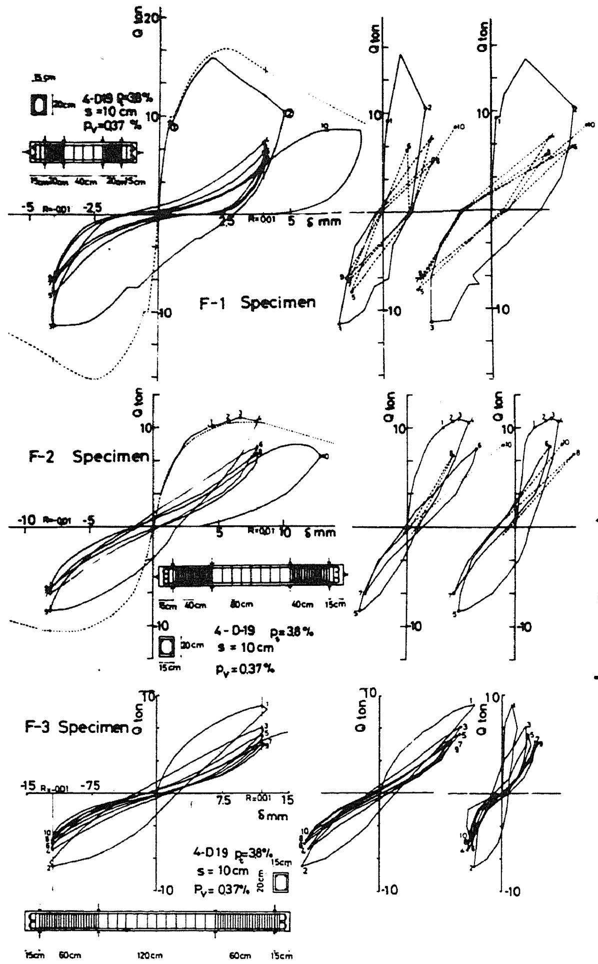


Fig.1 Loading devices



a)Q-δ curve b)Q-δ_{fl} curve c)Q-δ_{sh} curve

Fig.2 Restoring force characteristics of columns under repeated reversal loading

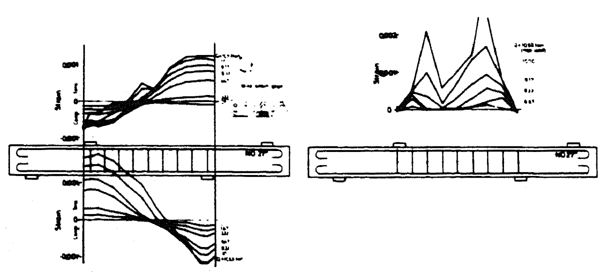


Fig.3 Measured strain distribution of reinforcing bars and hoops

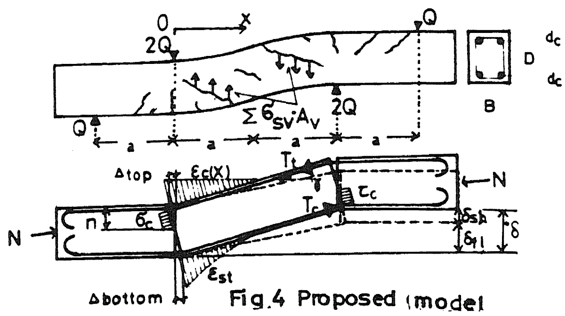


Fig.4 Proposed (model

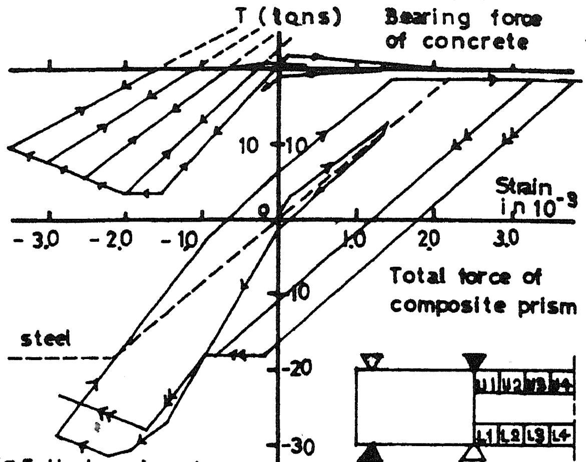


Fig.5 Hysteresis rule

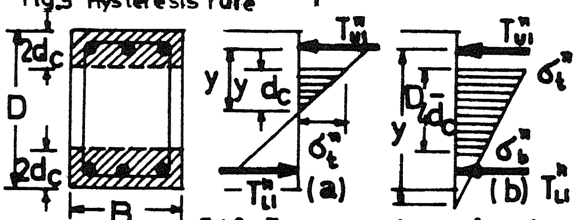


Fig.6 Force equivalence of section

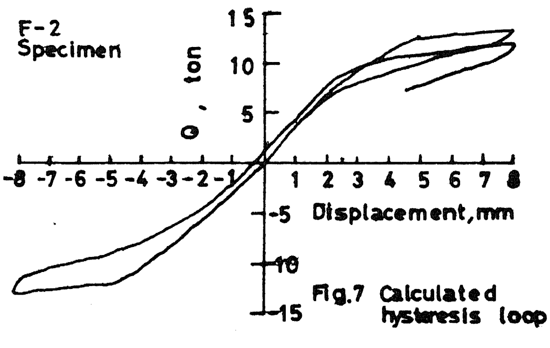


Fig.7 Calculated hysteresis loop