# 論文 Seismic Displacement of Reinforced Concrete Frame with Bedm-yielding Mechanism

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**ABSRACT**: Elastic and inelastic dynamic analysis methods were used to calculate displacement of a 12-story reinforced concrete frame which was designed to form the beam-yielding mechanism under earthquake motions. The results suggested that inelastic maximum displacement and story drift of the beam-yielding frame structure under different intensity earthquake motions can be estimated by an elastic response analysis method.
**KEYWORDS**: reinforced concrete, frame, seismic, displacement, design

## 1. INTRODUCTION

Recently, the concept of displacement based design is studied extensively for earthquake resistant of reinforced concrete structures[1,2]. Inelastic maximum displacement response under different intensity earthquake motions must be estimated to examine design criteria. Although an inelastic response analysis method can be used for this purpose, it takes too much effort for an ordinary structure. Comparing the elastic and inelastic dynamic analysis results of single-degree-freedom systems, Newmark[3] suggested that maximum inelastic displacement can be reasonably estimated by the elastic response; i.e., (1) for a short-period system ($T$<0.5sec), the maximum inelastic displacement can be estimated by the equal energy rule; (2) for a long-period system ($T$>0.5sec), the maximum inelastic displacement can be estimated by the equal displacement rule. This concept may be expanded to estimate maximum inelastic displacement of a multi-story structure. Shibata[4] suggested a method for a shear type multi-story structures. In earthquake resistance design, the beam-yielding mechanism is desired for an RC frame structures[1]. The deformation of this type structure is mainly dominated by the first mode of oscillation. It is suggested to use an equivalent elastic single-degree-freedom system to estimate inelastic displacement for this type of structures[5]. Although this method is simple, the simplification to a single-degree-freedom system is not so simple.

The elastic method is always used in an ordinary structure design, the data can be used directly for an elastic dynamic response analysis. The analysis results of a typical 12-story RC frame structure in this paper suggested that maximum inelastic displacement under different intensity earthquake motions can be estimated by an elastic response for a beam-yielding mechanism structure using the Newmark's rules.

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## 2. EXAMPLE STRUCTURE

### 2.1 OUTLINE OF STRUCTURE

A typical 12-story frame structure, as shown in Fig.1, was used for analysis. The member sections and concrete strength were divided into three groups along the height (Table.1). The average floor weight was assumed to be 11.8kN/m$^2$, the total story weight was $W_i$=16.5MN, and the total structure weight $W$=198MN. Only the response in Y-direction was considered in this paper.

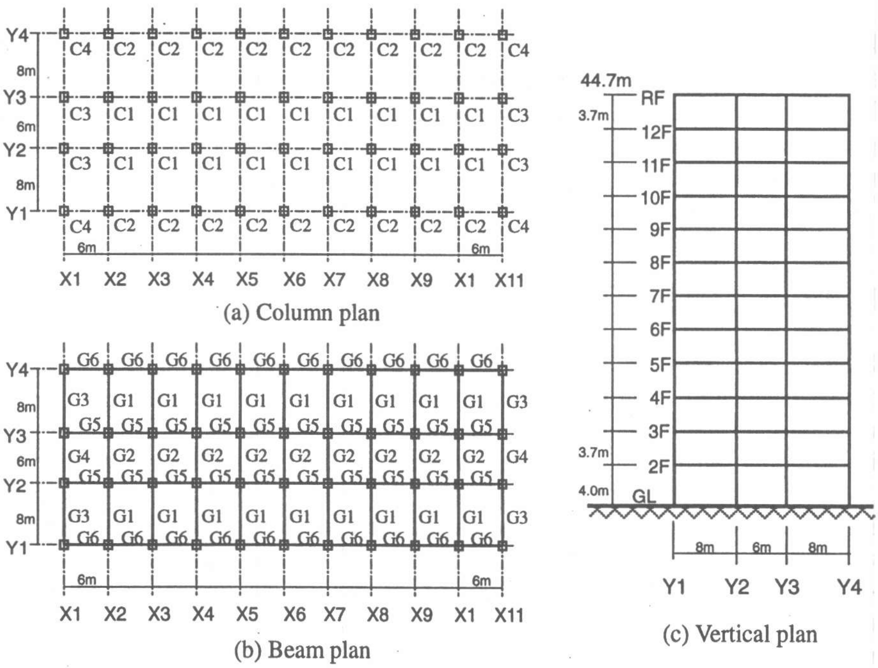



Fig.1 Structure Properties

Table.1 Dimensions of Members and Concrete Strength (Unit of length: cm)

| Floor Story | Column (C1~C4) | Beam (G5,G6) | Beam (G1~G4) | $F_c$ (N/mm$^2$) |
|---|---|---|---|---|
| 11~12 | 85×85 | 45×85 | 50×85 | 30 |
| 6~10 | 90×90 | 55×90 | 60×90 | 33 |
| 1~5 | 95×95 | 60×95 | 65×95 | 36 |

Table.2 Stiffness Reduction Factor of Members by Cracking

| Member | | Flexure | Shear | Axial |
|---|---|---|---|---|
| Column | 1st story | 0.7 | 1.0 | 1.0 |
| | Other | 1.0 | 1.0 | 1.0 |
| Beam | All story | 0.5 | 1.0 | 1.0 |

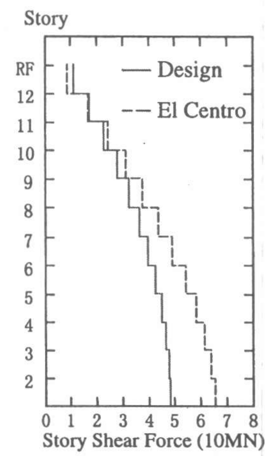



Fig.2 Story Shears for Design and Serviceability Limit Earthquake Motion

### 2.2 DESIGN EARTHQUAKE FORCE

The design earthquake force was calculated according to 'Design Guidelines for Earthquake Resistant Reinforced Concrete Building Based on Inelastic Displacement Concept (Draft)'[1] with the standard base shear coefficient of $C_B$=0.25. The lateral force distribution was assumed to be of inverted-triangular shape. An additional concentric force $P_t$, 10% of total base shear force, was assumed to act at the roof floor. The story shear force under the design earthquake force is shown in Fig.2.

### 2.3 DESIGN UNDER VERTICAL LOAD AND EARTHQUAKE FORCE

An elastic analysis method was used to calculate the design moments under combined vertical loads and earthquake force. The reduced stiffness of members due to cracking was considered in the analysis; the reduction factor was shown in Table.2. The contribution of slab to the beam stiffness was considered by factor $\phi$ ($\phi$ =1.5 for one side slab, $\phi$ =2.0 for two sided slab).

To ensure the formation of the beam-yielding mechanism, an elastic dynamic analysis under El Centro (NS) earthquake motion, normalized to maximum ground velocity $V_{max}$=25(cm/sec), which corresponds to the serviceability limit state, was conducted. The story shear force response is shown in Fig.2.

The flexural strength of beam end sections was determined to satisfy the above two analysis results. For convenience in real construction, the same flexural strength was assumed for each member group by taking the average moment from the two analyses.

To ensure forming the beam-yielding mechanism, the column flexural strength was determined using an enhancement coefficient of 1.7 to consider (a)enlargement of beam strength, (b)dynamic effect, and (c)contribution of two direction ground motion. The same flexural strength of columns was taken for each group. For the bottom section of first story columns, the flexural strength was taken the maximum of the two analyses.

In the following inelastic analysis, the shear strength of member was assumed to be large enough to prevent shear failure.

## 3. INELASTIC DYNAMIC ANALYSIS

### 3.1 HYSTERESIS MODEL

The inelastic dynamic analysis method was used to calculate the displacement response of the example structure under different intensity earthquake motions. Tri-linear Takeda model was used as the moment-curvature relation for element end section. The skeleton curve of the model was shown in Fig.3. The cracking moment $M_c$ was calculated using the following formula,

$$M_c = 0.56\sqrt{F_c}Z + ND/6 \tag{1}$$

here, $F_c$: strength of concrete (N/mm$^2$); $D$: height of section;

$Z$: section modulus;

$N$: axial force acting on members due to vertical load, $N$=0 for beam.

The flexural strength was used as the yield moment $M_y$. The yield stiffness reduction factor $\alpha_y$ was calculated using the following experimental formula,

$$\alpha_y = (0.043 + 1.64np_t + 0.043a/D + 0.33\eta)(d/D)^2 \tag{2}$$

where, $n$: elastic modulus ratio of reinforcement and concrete;

$p_t$: tensile reinforcement ratio, $p_t = A_s/bd$;

$a$: shear span;
$b$: width of section;
$d$: effective height of section;
$\eta$: axial force ratio, $\eta = N_L/F_c bD$;
$N_L$: axial force under service vertical load.

The stiffness after yield was $\alpha_3 K_0$, $\alpha_3$=0.01. The unloading stiffness parameter $\alpha$ = 0.4. The response point during reloading moves toward a peak of an immediately outer hysteresis loop.

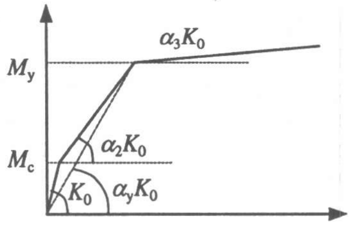


Fig.3 Skeleton of Takada Model

### 3.2 INPUT EARTHQUAKE MOTION

Three earthquake acceleration records were used as input motion:
(1) El Centro 1940 NS
(2) Taft 1952 NS
(3) Hachinohe 1968 NS

The earthquake intensity was determined according to different design limit states of structure. In reference [1], three limit states were suggested for earthquake resistant design, i.e. (a)serviceability limit state, (b)design (restorability) limit state and (c)ultimate (safety) limit state. For the serviceability and design limit states, it is suggested that the maximum velocity of earthquake motion is 25(cm/sec) and 50(cm/sec), respectively; while for the ultimate limit state, the maximum acceleration of earthquake motion is about 800(cm/sec$^2$). The original earthquake records were normalized corresponding to the different limit states, as shown in Table. 3.

Table.3 Input Earthquake Motion Data

| Earthquake | Original data | | Serviceability limit state | | Design limit state | | Ultimate limit state | |
|---|---|---|---|---|---|---|---|---|
| | $A_{max}$ (cm/sec$^2$) | $V_{max}$ (cm/sec) | $A_{max}$ (cm/sec$^2$) | $V_{max}$ (cm/sec) | $A_{max}$ (cm/sec$^2$) | $V_{max}$ (cm/sec) | $A_{max}$ (cm/sec$^2$) | $V_{max}$ (cm/sec) |
| El Centro | 341.7 | 33.4 | 225.8 | 25 | 511.5 | 50 | 800 | 78.2 |
| Taft | 175.9 | 17.7 | 248.4 | 25 | 496.8 | 50 | 800 | 80.5 |
| Hachinohe | 225.0 | 34.1 | 164.6 | 25 | 329.9 | 50 | 800 | 121.2 |

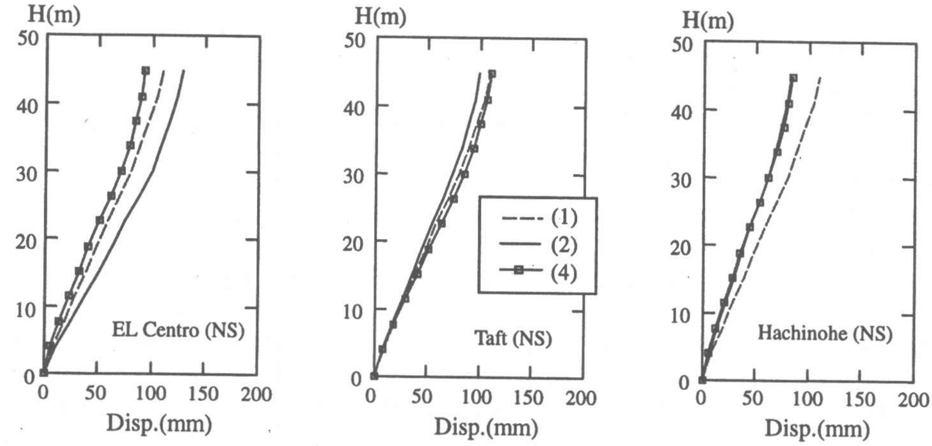
### 3.3 INEASTIC DYNAMIC ANALYSIS METHOD

Newmark $\beta$–method is used in inelastic dynamic analysis with $\beta$= 0.25. The integration time interval is 0.01sec. The damping factor $h$=0.05, proportional to instantaneous stiffness.

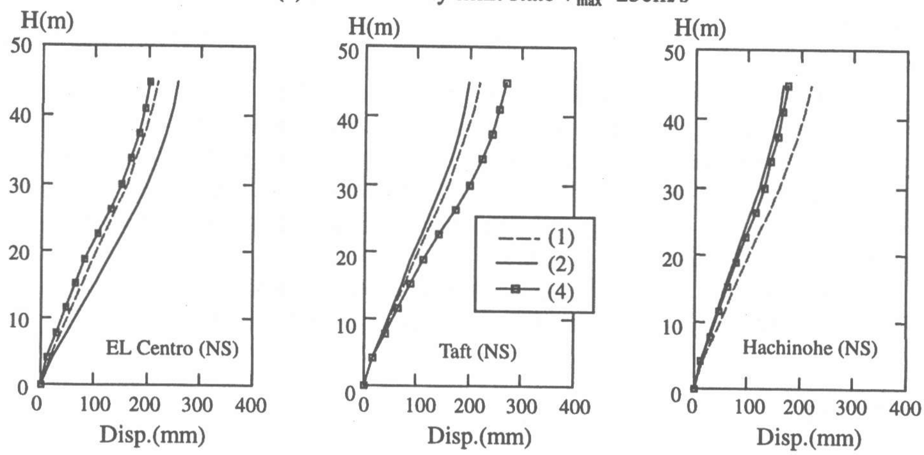
## 4. ANALYSIS RESULTS

The results of four analyses were used for comparison:
(1) Elastic static analysis;
(2) Elastic dynamic analysis;
(3) Elastic dynamic analysis using secant stiffness at yield point;
(4) Inelastic dynamic analysis.

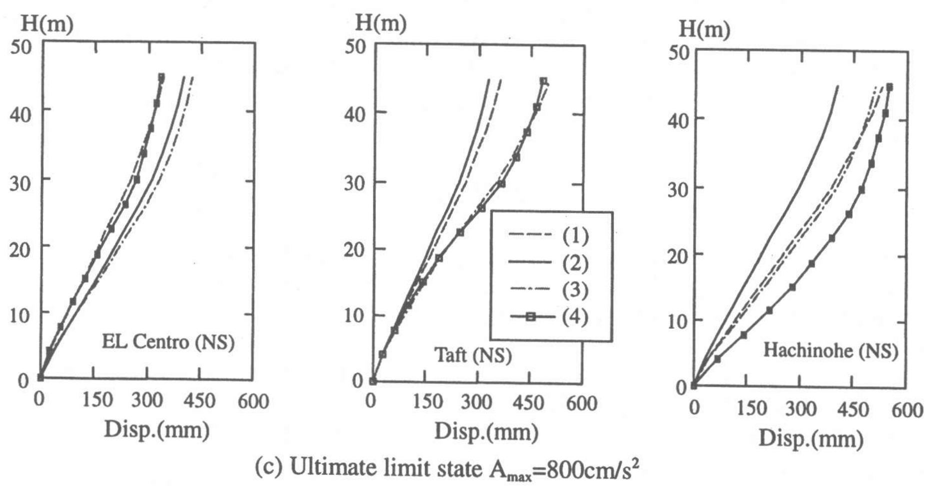
In methods (1) and (2), the stiffness $K_0$ was determined as described in 2.3. In method (3), the secant stiffness $\alpha_y K_0$ at yield point was used. The lateral force distribution in method (1) is same as the design earthquake force in 2.2, the base shear force are taken $Q_1$ and $2Q_1$, corresponding to serviceability and design limit states, and $\zeta Q_1$ for ultimate limit state, where $\zeta$ is as follows;




(a) Serviceability limit state $V_{max}$=25cm/s




(b) Design limit state $V_{max}$=50cm/s




(c) Ultimate limit state $A_{max}$=800cm/s$^2$

Fig.4 Comparison of Floor Displacement of Different Analysis Methods

$$\zeta = \frac{800}{A_{max}|_{V_{max}=25cm/s}} \tag{3}$$

$Q_1$ is design base shear force.

The first natural period of the example structure is 1.02, so the maximum inelastic displacement can be estimated by the Newmark's equal displacement rule. Figure 4 shows the maximum story displacements from different analysis methods.

Under the El Centro earthquake, the displacement of methods (1) and (2) were larger than that of method (4). Method (1) agrees better with method (4) than method (2). Under the Taft earthquake, the displacement of methods (1) and (2) agreed well with that of method (4) for serviceability limit state, but became smaller than that of method (4) as the earthquake intensity increased. For the ultimate limit state under the Taft earthquake, the displacement of method (3) agreed well with that of method (4). Under the Hachinohe earthquake, for the serviceability and design limit states, the displacement of method (2) agreed well with that of method (4), while the displacement of method (1) was larger than that of method (4). The result of method (2) was much smaller than that of method (4) under the ultimate limit state, while the displacement at the top floor of methods (1) and (3) agreed well with that of method (4).

The reason for difference between method (2) and method (4) for the ultimate limit state is due to larger initial stiffness. When taking second stiffness at yielding point (method (3)), the equal displacement rule can also be used. Supposing that small and middle earthquakes happened more than once and the structure is cracked before an extreme earthquake attack, it is reasonable to use the second stiffness at yielding point to calculate the displacement for the ultimate limit state.

The comparison of maximum story drifts of different analysis methods shows that the equal displacement rule can also be used for inelastic story drifts estimation.

## 5. CONCLUSION

From the comparison of different analysis methods, applied for R/C frames of the beam-yielding mechanism, it is suggested that the maximum inelastic displacement and story drift under the serviceability and design limit states can be estimated by static or dynamic elastic method. Under the ultimate limit state, it is reasonable to use the second stiffness in the elastic dynamic method to estimate maximum inelastic displacement and story drift.

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