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STRONG GROUND MOTION DRIFT
AND
BASE SHEAR COEFFICIENT FOR R/C STRUCTURES

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SUMMARY

Nonlinear displacement response of reinforced concrete structures is investigated by a parametric study of SDOF systems with appropriate hysteresis properties. Strength, stiffness, and the type of ground motion are the main variables considered. It is shown if a system has a certain strength obtained by dimensionless parameters defining the three variables, the nonlinear displacement response will be the same value. The base shear coefficient of the R/C structure for the primary design was investigated using this result. The dynamic response of a 35 story structure designed using the proposed design concept gave satisfactory results.

INTRODUCTION

The progress of computer science enables frame type dynamic response analysis and estimation of the behavior of the reinforced concrete structure members. Much useful information for the evaluation of the earthquake resistant design will be obtained with much work. It is important, however, to estimate earthquake resistant ability of structural systems by a simple method in planning and proportioning.

This paper reports results of a parametric study to investigate the effects of strength, stiffness, and type of ground motion on nonlinear displacement response of SDOF systems. The results showed that nonlinear displacement response is equal to the linear response spectral values if the system has a certain strength which is determined by dimensionless parameters for strength, initial period, and type of ground motion. This paper also investigates the base shear coefficient of R/C structures for the primary design to resist earthquakes.

PARAMETRIC STUDY FOR SDOF SYSTEMS

Displacement Response of SDOF Systems

A parametric study was made using SDOF oscillators with hysteresis properties simulating the behavior of R/C systems. The main variables considered were initial stiffness, strength, and the type of ground motion. Figure 1 shows calculated results for nine various ground motions arranged by using a set of dimensionless parameters defined below.

TR = Initial period (To) / Characteristic period for ground motion (Tg)
(Tg = Intersection of the constant-acceleration and constant-velocity response region on the tripartite response spectra)
SR = Shear strength (Qy) / Elastic resistant response (Qe)
DR = Displacement response (δmax) / Smoothed displacement response spectral value (δe)

These figures show if a system has the same dimensionless parameters, the displacement response given as DR is a similar value. According to the figure of To=1/3Tg, if the system has the value of SR over 0.5, DR is less than 1.0, and if To is greater than Tg, DR is always less than 1.0. From this observation and previous study (Ref. 1), it can be concluded that if TR+SR>1.0 then DR<1.0. In other words, the nonlinear displacement response is less than the elastic displacement response with 2% damping. This means the system satisfies the "Property of Displacement Conservation". In this paper, the shear coefficient satisfied the equation of TR+SR>1 is called "Required Shear Coefficient (Kyo)".

Required Shear Coefficient for SDOF System

According to Newmark(Ref. 2), as the maximum velocity response spectral value is 2 times the maximum velocity of the ground motion for the 2% damping system, the response spectra may be defined as shown in Fig. 2. Shear coefficient spectra are obtained from acceleration response spectra divided by the acceleration of gravity(g) as shown in Fig. 3.

To satisfy the equation of SR+TR>1, the system should be located in the region I of the Fig. 3(a). For To < Tg,

$$\begin{aligned} SR &= Kyo \frac{g \cdot Tg}{12.6 \cdot Vmax} \\ TR &= To/Tg \end{aligned} \qquad (1)$$

Accordingly,

$$Kyo > (1 - To/Tg)\frac{12.6 \cdot Vmax}{g \cdot Tg} \qquad (2)$$

Fig. 3(b) shows the boundary value of Kyo for Tg=0.3, 0.5, and 1.2 second. The envelop curve of this relation can satisfy SR+TR>1 for any ground motion of Tg. Accordingly, the "Required Shear Coefficient" of a SDOF system is defined by the following equation as the envelop curve of equation (2):

$$Kyo > 3.2Vmax/(g \cdot To) \qquad (3)$$

EARTHQUAKE RESISTANT DESIGN FOR R/C STRUCTURES

Required Base Shear Coefficient for R/C Structures

In Japan, the criterion of the earthquake resistant design for super high-rise R/C buildings on the site of soil type II is commonly defined as in Table 1. The "required Shear Coefficient" for the ground motion of 50 cm/sec maximum velocity is

$$Kyo > 0.16/To \qquad (4)$$

Here, To is the initial period of the bilinear system and may be equal to the intermediate value of the initial period(Ti) and the yield period(Ty) of the R/C structure. As the yield stiffness of a R/C member is 1/3 to 1/4 times the initial stiffness, To is about $\sqrt{2}$ times Ti. Accordingly,

$$Kyo > 0.11/Ti \quad (5)$$

There is difference between the shear coefficient of SDOF system (Kyo) and the base shear coefficient of MDOF system (C_{B0}). If the response of a MDOF system dominated by one mode shape, the MDOF system can reduced to a SDOF system. The ratio of Kyo/C_{B0} is depending on mode shape and load vector shape. On the assumption of linear distribution of both, the ratio is

$$Kyo/C_{B0} = 2(2n+1)/3(n+1) = 1 - 1.33 \quad (n = 1 - \infty \text{ :number of story}) \quad (6)$$

Accordingly, the "Required Base Shear Coefficient(C_{B0})" becomes

$$C_{B0} > (\ 0.11 - 0.07\ )/Ti \quad (n = 1 - \infty\ ) \quad (7)$$

Base Shear Coefficient for a Primary Design

As the R/C structure having the base shear coefficient obtained by equation (7) satisfies the "Property of Displacement Conservation", the value of SR larger than 1/2 is enough to satisfy the criterion of story ductility ($\mu<2$) for the ground motion of level II. According to Fig. 4(a),

$$\begin{aligned} Ky &> 0.32/To \quad (To>Tg) \\ &> 0.32/Tg \quad (To<Tg) \end{aligned} \quad (8)$$

The base shear coefficient of the multi-story R/C structure,

$$C_{By} > (\ 0.22 - 0.15\ )/Ti \quad (n = 1 - \infty\ ) \quad (9)$$

Equation (9) shows a high-rise structure needs less base shear coefficient even if the initial period is the same value. The high rise structure, however, may need some safety factors. Further, the base shear capacity of the primary design needs about two thirds the value of equation (9) for the frame type structure. Accordingly, the base shear coefficient for the primary design is approximately

$$C_{Bp} > 0.20/Ti \quad (10)$$

This value is compared with the values of existing buildings and Japanese "New Aseismic Code (Soil Type II)" in Fig. 4.

Displacement Response

If a R/C structure has the base shear coefficient satisfying equation (10), the nonlinear displacement response is always less than the spectral value, because equation (10) is larger than equation (7). According to Fig. 2(c), the displacement spectral value of a SDOF system for 50cm/sec ground motion is,

$$q(cm) = 16\ To \quad (To > Tg) \quad (11)$$

The initial period for the R/C structure may be obtained by

$$Ti = 0.02\ h \quad (h \text{ : hight of structure in meter}) \quad (12)$$

Displacement of the structure.at top is participation vector value, βu (1.0 - 1.5 : n = 1 - ∞) times q. Accordingly,

$$\delta top\ (cm) = (0.0045 - 0.0070)\ h \quad (n = 1 - \infty) \quad (13)$$

This value always satisfies the criterion shown in Table 1 even if the story drift becomes 20 to 30% larger than the value of equation (13) because of nonlinear distribution for displacement.

Dynamic Response Analysis for a R/C Building

Dynamic response analyses were made on the 35 story structure shown in Fig. 5. The members was designed using the "working stress method" (Ti = 1.7 sec. then C_{Bp} = 0.20/1.7 = 0.11). Frame type dynamic analysis was used. The hysteresis properties of members were assumed to be simulated by the Takeda model. The damping factor was assumed to have an initial value of 0.02 and varied linearly with the stiffness.

The story drift calculated is shown in Fig. 6 for El Centro 1940 NS and Hachinohe 1968 NS ground motions. Table 2 summarizes the maximum response values of members and stories. The calculated values are satisfactory results.

CONCLUSION

The base shear coefficient of the R/C structure for primary design was investigated using results of a parametric study for SDOF systems. The dynamic response of a 35 story structure designed by the proposed concept showed satisfactory results.

ACKNOWLEDGMENTS

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REFERENCE

1) Shimazaki, K. and M. A. Sozen, "Seismic Drift of Reinforced Concrete Structures," Technical Research Report of Hazama-Gumi, Ltd., 1984, pp145-166

2) Newmark, N. M. and W. J. Hall, "Earthquake Spectra and Design," Earthquake Engineering Research Institute, 1982

Table 1 Criterion of Earthquake Resistant Design

Level	Maximum Velocity of Ground Motion (cm/sec)	Criterion of Design		
		Story		Member
		Drift	Ductility Factor	Ductility Factor
I	25	1/200	1	1
II	50	1/100	2	4

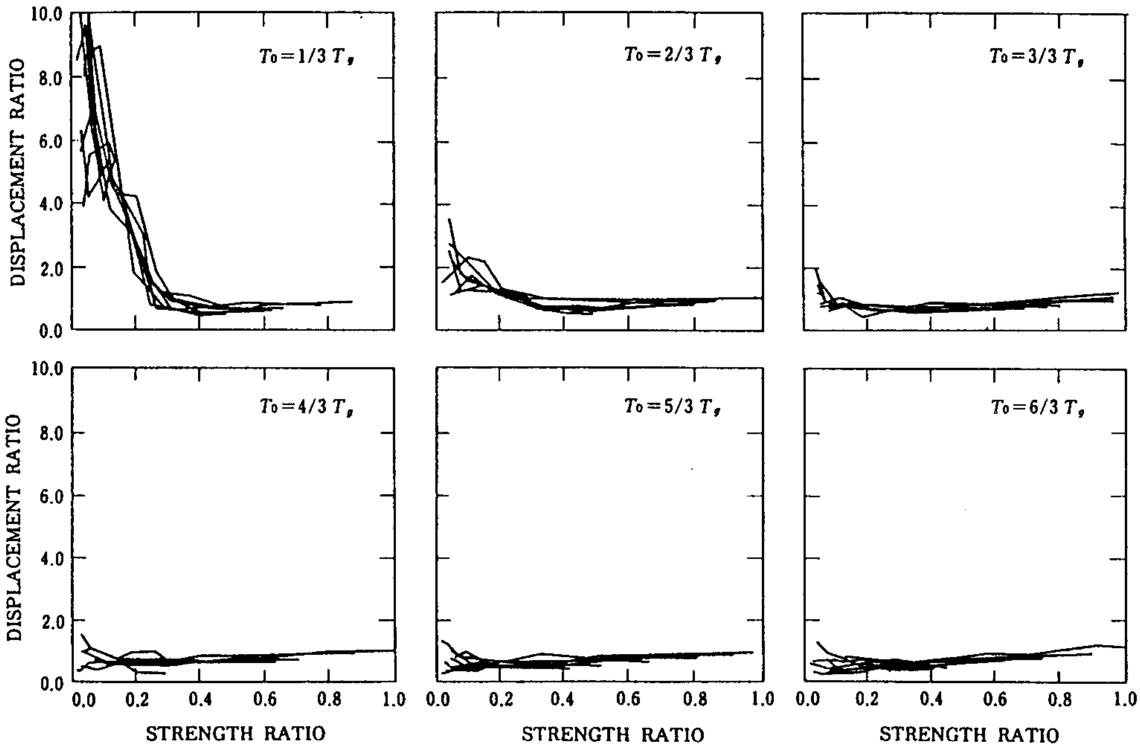
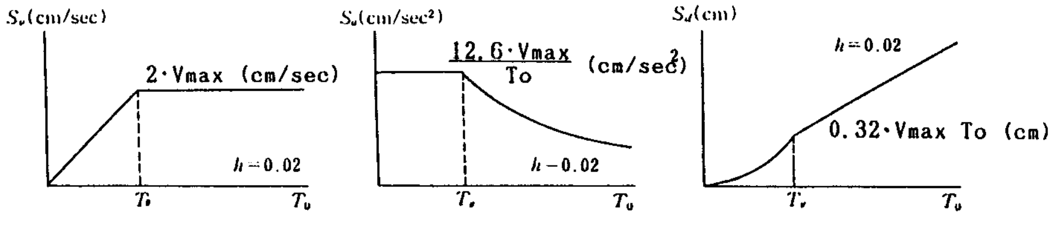
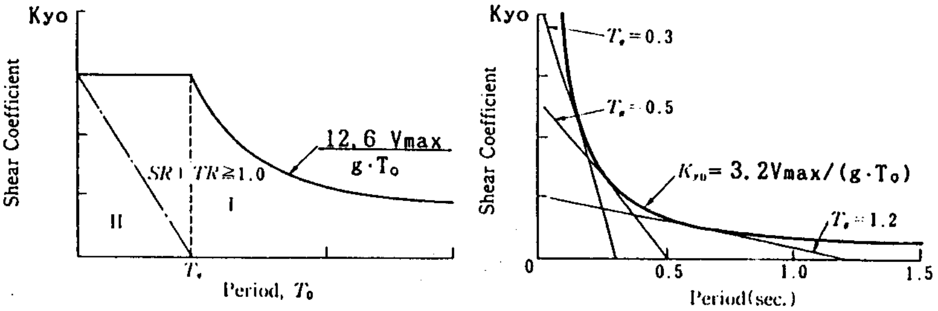


Fig. 1 Normalized Nonlinear Displacement Response



(a)Velocity (b)Acceleration (c)Displacement

Fig. 2 Idealized Response Spectra

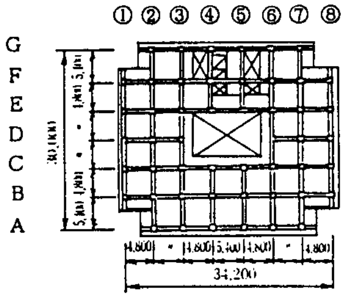


(a)Shear Coefficient (b)Shear Coefficient Required

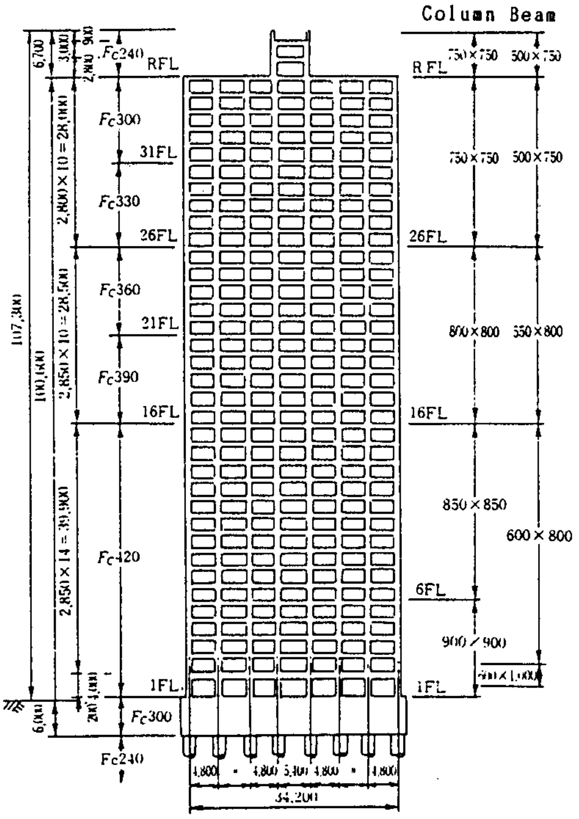
Fig. 3 Shear Coefficient

Table 2 Maximum Response Values

Ground Motions	Story		Member	
	Drift	Ductility	Column	Beam
Hachinohe	1/120	1.4	1.0	2.0
El Centro	1/115	1.6	1.1	2.0



(a) Plan



(b) Elevation

Fig. 5 35 Story Structure

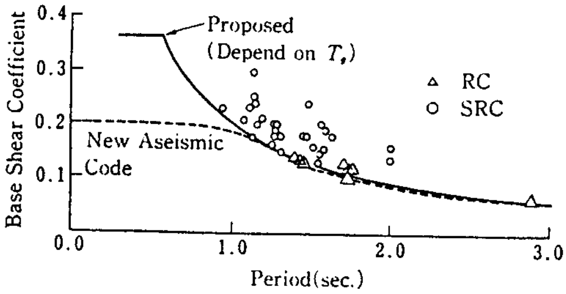


Fig. 4 Base Shear Coefficient

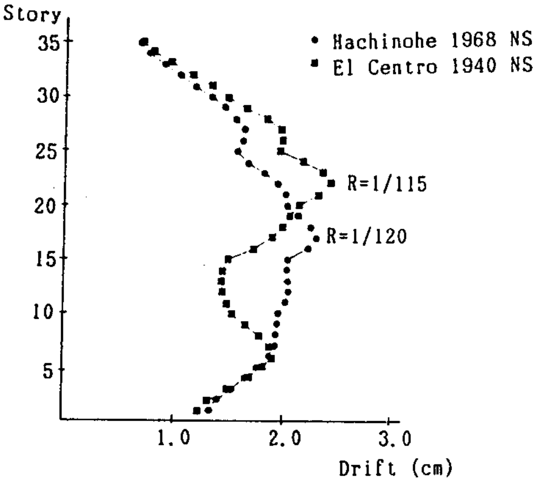


Fig. 6 Story Drift