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FINITE RESONANCE CURVES OF MULTISTORY R/C AND STEEL PROFILE ENCASED R/C FRAMES WITH SHEAR WALLS -PROPOSAL OF ASEISMIC CAPACITY EVALUATION METHOD OF STRUCTURES-

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SUMMARY

The deformation, fracture and aseismic characteristics of multistory resisting systems, such as reinforced concrete (RC)- and steel profile encased reinforced concrete (SRC)- multistory frames with and without shear walls, are clarified experimentally. Tests on 1/10 scale models of RC and SRC frames with 3-spans and 3-, 6- and 9-stories are carried out under the condition of horizontal alternately repeated loads under constant vertical loads. In order to evaluate the aseismic capacity of structures, besides usual statical and mechanical behaviors, a Finite Resonance Curve method is proposed and applied to these test results.

INTRODUCTION

There are few aseismic design and evaluation methods in which real structural behaviors are taken into account (Ref.1). Though Housner (Ref.2) and Akiyama (Ref.3) proposed a unique aseismic design theory, its correspondence with structural criterion itself is not yet verified. The authors already proposed the "Resonance Capacity Criterion" about RC structures (Refs.4,5,6) in order to evaluate the aseismic capacity of structures. Furthermore, based upon the principle of Finite Resonance Analysis Method proposed by the authors (Ref.5,6), an extended concept of Finite Resonance Curve is able to be introduced in the space composed of the finite resonance velocity capacity, equivalent linear natural period and resonance duration. The purposes of this paper are to illustrate such curves for RC and SRC multistory frames, to make clear the effects of the number of stories and the thickness of cantilever type shear walls and to compose them directly with earthquake information.

TESTS

TESTING METHOD In order to simulate the earthquake responses with the 1st vibration mode of multistory frames, a horizontal force P is loaded at the 2/3 level of the total height of structures (Fig.1). At the same time, vertical forces N are loaded at the top of each column with a constant axial load level ratio 1/3 to the ultimate axial strength N_{oc} of columns. The lateral sway at the loading level is used as controlling deformation. The outlines of test specimens are shown in Fig.2 and test series are shown in Table 1 where, for example, RC-3-30 denotes RC frame - number of stories - thickness of shear walls(in mm).

TEST RESULTS Usual test results of statical and mechanical behaviors of frames are shown in Figs.3(a)(b)(c), and 4(a)(b)(c). Figs.3,4 correspond to SRC and RC frames(Ref.7), and (a),(b),(c) show lateral force(P)-lateral displacement angle(R) relations, ultimate deformation modes and ultimate crack patterns, respectively. Fig.3 shows that the thinner becomes the thickness of cantilever type shear walls, the more predominant shear deformation show SRC frames. Fig.4(Ref.7) implies that all the critical members of RC frames show flexural deformation mode and that the bottoms of cantilever type shear walls finally collapse with combined axial, flexural and shear failure mode. There is no substantial differences between RC and SRC frames except the strength of columns and beams in SRC frames.

EVALUATION OF THE ULTIMATE ASEISMIC CAPACITY BY FINITE RESONANCE CURVES

FINITE RESONANCE CURVES According to the Finite Resonance Response Analysis proposed by the authors(Refs.5,6), the finite resonance velocity capacity C_{rv} of a structure assumed as a one-degree of freedom system(Fig.5) is able to be balanced with the velocity amplitude v_0 of earthquake input waves and given by

$$C_{rv} = \left(\frac{1}{1.2\pi}\cdot\frac{A}{\sqrt{P_a X_a}} + \frac{2}{3\pi}\cdot\sqrt{P_a \cdot X_a}\right)\frac{1}{\sqrt{m}} = (v_0) \qquad -(1)$$

where A, P_a and X_a are the area, loading amplitude and deformation amplitude of a restoring force hysteresis loop of the structure(Fig.6). At resonance, furthermore, equivalent natural period of the structure T_{eq} and equivalent resonance duration t_r are given by

$$T_{eqi} = 2\pi\sqrt{\frac{m}{K_{eqi}}} \quad -(2), \qquad t_r = \sum_i T_{eqi} \quad -(3)$$

where K_{ei} is the equivalent spring constant of i-th hysteresis loop and m is the mass of the structure. Finite Resonance Curve is able to be illustrated in the C_{rv}-T_{eq}-t_r space (Fig.7(a)) and also to be calculated from P-R relationships such as Figs.3(a), 4(a).

CRITICAL M, Δ, T_G On the other hand, earthquake ground motions are able to be expressed as a trapezoidal spectrum(Ref.5) in the velocity amplitude v_0 - period T - duration t_0 space such as shown in Fig.7(a) which is given by a function of earthquake magnitude M, epicentral distance Δ and predominant ground natural period T_G as follows(Ref.6):

$\Delta \leq \Delta_B$ (within source region): $\qquad$ $\Delta \geq \Delta_B$ (out of source region):

$$T \geq T_C : |z| = Z_0 = (1/4)(T_G/0.15)10^{0.5M-1.30}/\beta \quad -(4), \qquad |z| = Z_0(\Delta_B/\Delta)^2 \quad -(5),$$

$$T_G \leq T \leq T_C : |\dot{z}| = V_0 = (\pi/2)(T_G/0.15)\bar{d}/\beta \quad -(6), \qquad |\dot{z}| = V_0(\Delta_B/\Delta)^2 \quad -(7),$$

$$T \leq T_G : |\ddot{z}| = A_0 = (\pi^2/0.15)\bar{d}/\beta \quad -(8), \qquad |\ddot{z}| = A_0(\Delta_B/\Delta)^2 \quad -(9),$$

$$\log T_C = 0.5M - 1.30 - \log \bar{d} \quad -(10), \qquad \log \Delta_B = 0.5M - 2.1 \quad -(11),$$

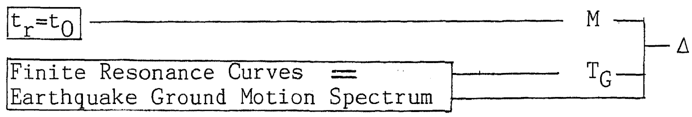
$$\log t_0 = 0.5M - 2.28 \quad -(12), \qquad \beta = 0.6\pi/(0.2\pi + 0.4) \quad -(13),$$

$\bar{d}$ = 15 cm/sec^2 for interplate earthquake,
= 50 cm/sec^2 for intraplate earthquake.

Equating the Finite Resonance Curve until fracture of a structure to an earthquake ground motion spectrum as shown in Fig.7(b), the critical values of M, Δ, T_G are able to be given.

DISCUSSIONS

Figs.8-11 show the Finite Resonance Curves of the P-R relationships given in Figs. 3(a), 4(a). In this report, however, the Finite Resonance Curves are calculated corresponding to the equivalent structures with real size, i.e., with 10 times multiplied scale of test specimens, which enables us to compare them directly to the earthquake ground motion spectrum with real dimensions. After dimension analysis, the cross sectional areas and loads are made 10^2 times and deformation 10 times larger than experimental ones. Figs.8,9 imply that the tests are carried out under pseudo-constant acceleration condition. The effect of the number of stories and the thickness of shear walls upon C_{rv}, T_{eq}, t_r are observed well in Figs.8-11. Tables 2,3 show the critical values of M, Δ, T_G, t_r approximately corresponding to the Finite Resonance Curves shown in Figs.8-11. Here, the calculations are carried out as follows:



It is considered that the test specimens are deformed and collapse after the duration t_r when they are subjected to the earthquake loads with such critical values of M, Δ and T_G. If more number of critical values are plotted about a test specimen, the critical M-Δ-T_G surface will be illustrated experimentally, whereas in Ref.5 the critical M-Δ relations are calculated by analysis. Tables 2,3 show that the tests of frames with smaller number of stories and thicker shear walls are corresponding to assuming the intraplate type earthquake with smaller M and Δ.

CONCLUSIONS

In this paper, Finite Resonance Curve Method are applied to the experimental results of RC and SRC frames with cantilever type shear walls in order to evaluate the ultimate aseismic safety of structures. Comparing the Finite Resonance Curves with earthquake ground motion spectra, the follows are concluded:

(1) Finite Resonance Curves show the seismic meanings of cyclic loading test and seismic effects of testing parameters.

(2) The tests in this report are proved to be carried out assuming intraplate type earthquakes and to produce pseudo-constant acceleration resonance of test specimen.

(3) By using many Finite Resonance Curves about a test specimen, its critical M-Δ-T_G surface is able to be composed experimentally.

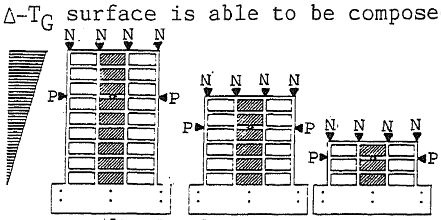


Fig.1 Test Series

Table1 Mechnical Properties of Materials

Test Specimen	Concrete Fc kg/cm²	Concrete Ft kg/cm²	Reinforcement σy kg/cm²	Reinforcement σmax kg/cm²	Steel Profile σy kg/cm²	Steel Profile σmax kg/cm²	$N=\frac{1}{3}N_{oc}$
RC-9-30	380	28.0	2480	3460	----	----	7.00
RC-6-30	367	29.0	2480	3460	----	----	6.80
RC-3-30	305	29.0	2480	3460	----	----	5.80
SRC-9-40	398	34.0	2510	3300	2960	3810	9.90
SRC-9-30	275	21.0	2500	3200	3900	5000	9.20
SRC-9-20	307	21.0	2460	3260	2810	3730	8.20
SRC-9-0	272	23.0	2470	3160	3640	4740	8.50

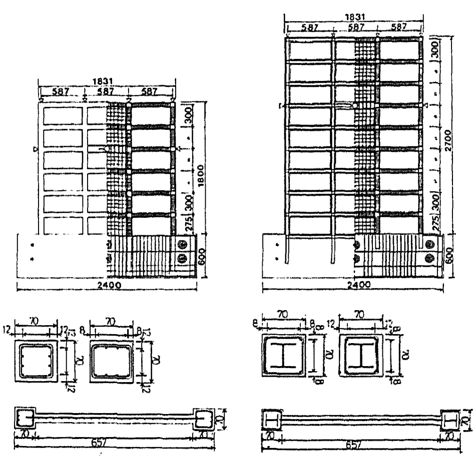


Fig.2 Test Specimens

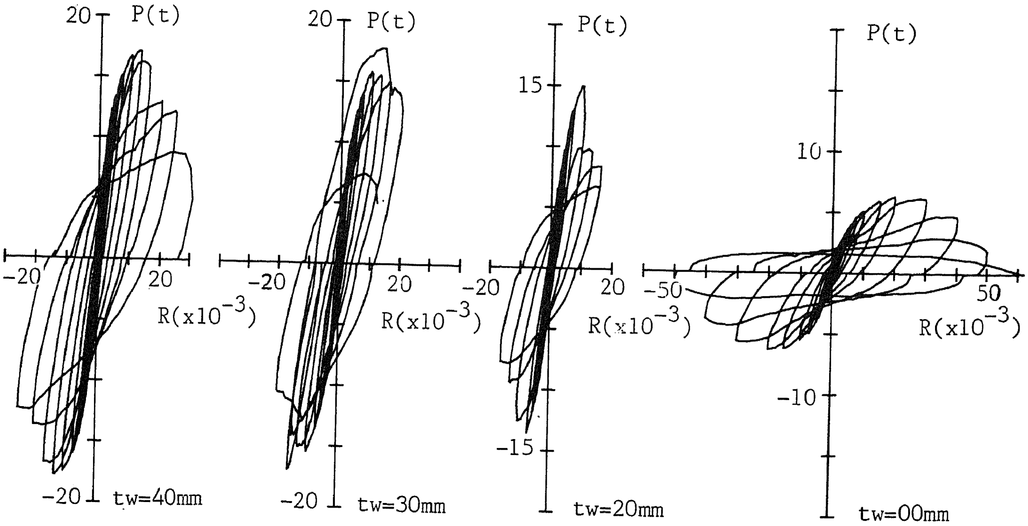


Fig.3(a) P-R Relationships :Steel Profile Encased R/C Frames

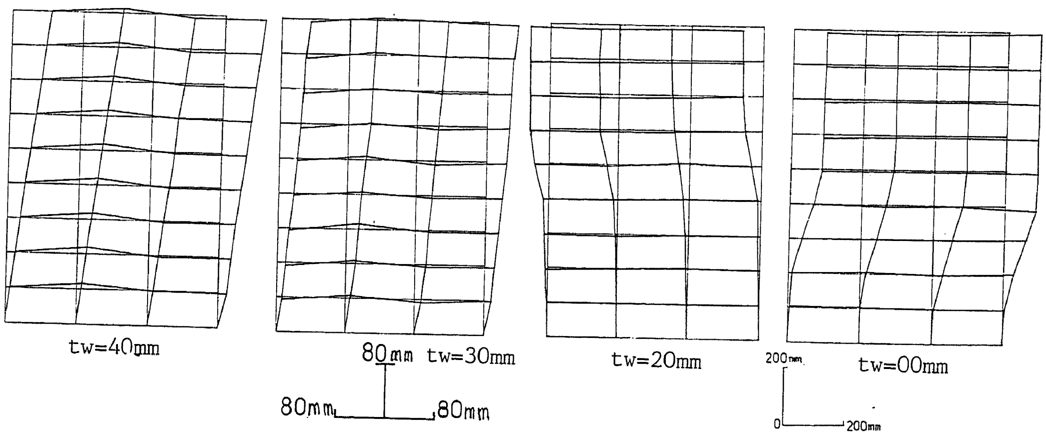


Fig.3(b) Deformation :Steel Profile Encased R/C Frames

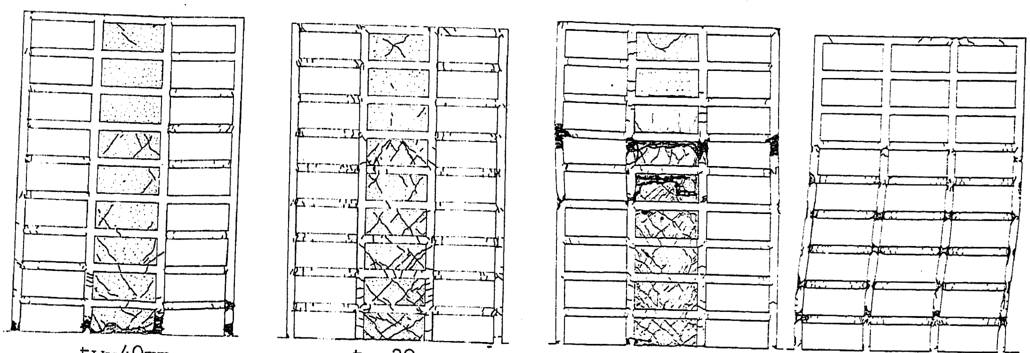
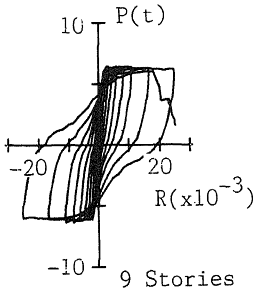


Fig.3(c) Fracture Mode :Steel Profile Encased R/C Frames



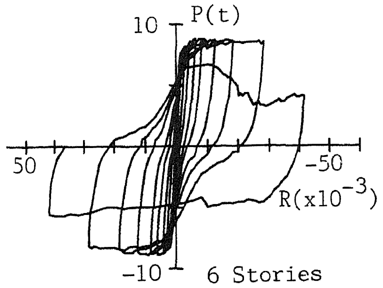
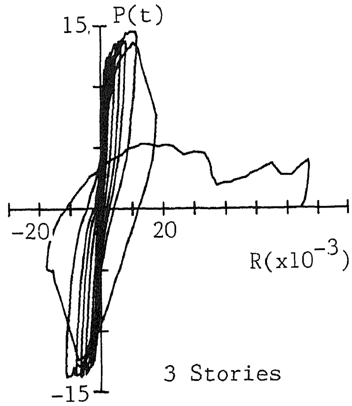


Fig.4(a) P-R Relationships :R/C Frames



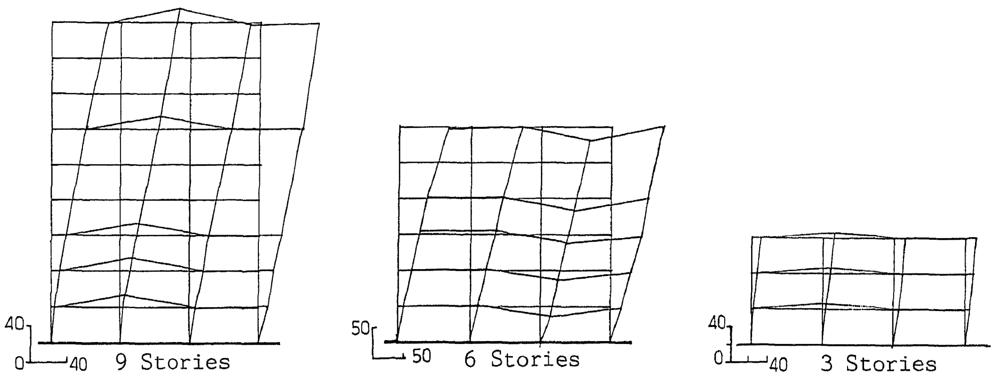


Fig.4(b) Deformation :R/C Frames

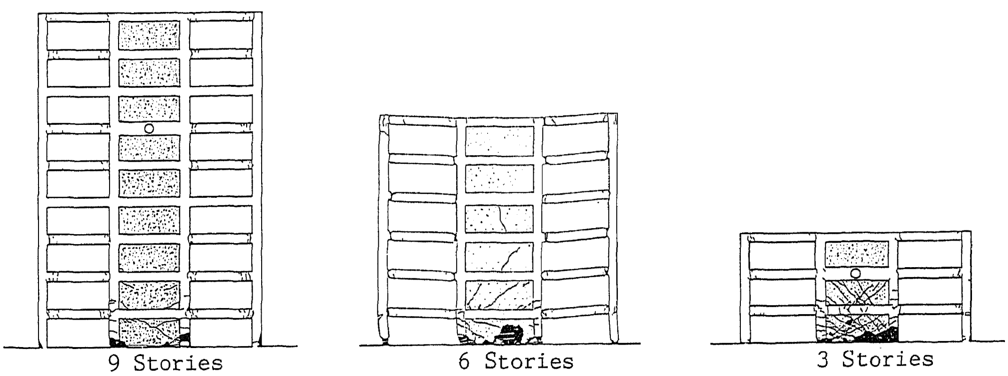


Fig.4(c) Fracture Mode :R/C Frames

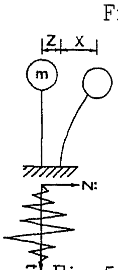


Fig.5 One Mass Oscillator

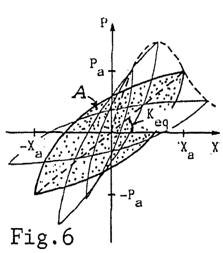


Fig.6 Restoring force Characteristics

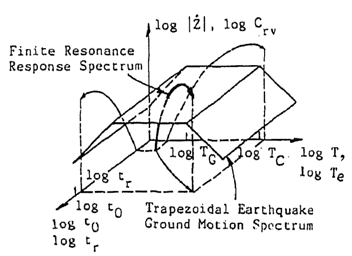


Fig.7(a) Finite Resonance Response Space

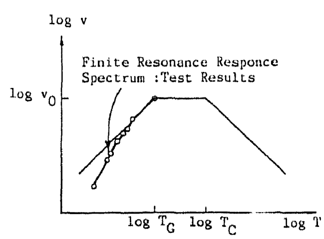


Fig.7(b) Estimation of Critical Values of M, Δ, T_G using Test Results

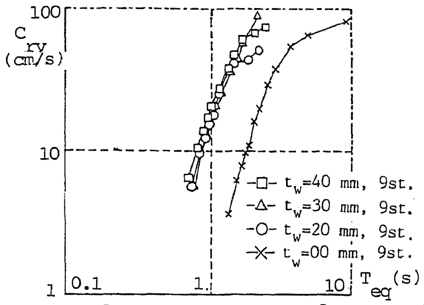


Fig.8 Finite Resonance Curves, C_{rv}-T_{eq} Relationship for SRC Frames

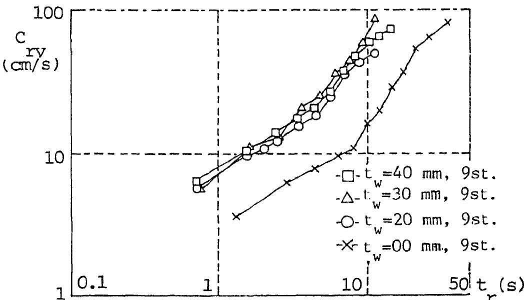


Fig.9 Finite Resonance Curves, C_{rv}-t_r Relationship for SRC Frames

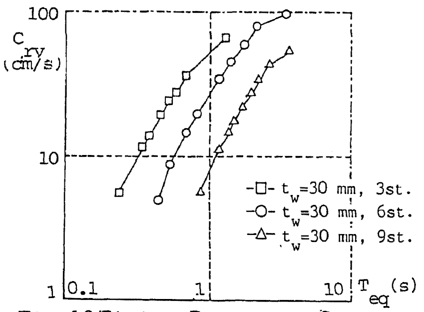


Fig.10 Finite Resonance Curves, C_{rv}-T_{eq} Relationship for R/C Frames.

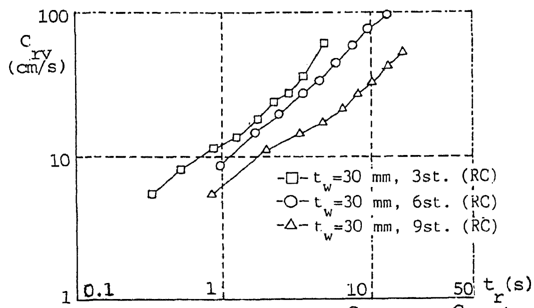


Fig.11 Finite Resonance Curves, C_{rv}-t_r Relationship for R/C Frames.

Table2

Critical Values of M,Δ,TG (SRC Frames)

SRC	tr=ΣTeq (sec)	TG(s)	Vo (sec)	M	Δ(km) *1
SRC-9-00	35.4	3.6	30	7.7	127 / 232
SRC-9-20	11.1	1.5	23	6.7	29 / 53
SRC-9-30	11.5	2.2	49	6.7	25 / 46
SRC-9-40	14.5	1.7	34	6.9	33 / 61

Table3

Critical Values of M,Δ,TG (RC Frames)

RC	tr=ΣTeq (sec)	TG(s)	Vo (sec)	M	Δ(km) *1
RC-3-30	4.8	0.7	32	5.9	6 / 17
RC-6-60	13.3	2.2	43	6.8	31 / 56
RC-9-30	16.8	2.6	24	7.0	57 / 103

*1 upper :Intraplate Earthquake ; $\bar{d}$ = 50 (cm/sec)
lower :Interplate Earthquake ; $\bar{d}$ = 15 (cm/sec)

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