論 文
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[2223] Prediction of Response in Ultimate Stage for Multistory Concrete Frames with Soft-First-Story Subjected to Ground Motions

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1. INTRODUCTION

The soft-story-structure (thereafter, referred to as S.S.S.) system has been gradually attracting the attention of structural designers since M. Fintel et al proposed it in 1969[1]. The basic concept used in the system is insulating the upper stories from high intensity ground motions, by introducing a soft(deformable) story in the lower part of the building.

To realize the mechanism, it is required that the strength or/and stiffness of the soft story is intentionally degraded under the precondition that the story is capable of sustaining a large deformation. Thus, it is very important to estimate amount of deformations on the upper and soft stories of the S.S.S.. Unfortunately, this is nearly impossible at present unless a laborious calculation supported by high-power computer is carried out step by step.

The objective of this study is to give simple and practical method to predict the response of deformations(expressed through accumulated and maximum ductilities herein) for the multistory concrete frames with a soft-first-story (thereafter, referred to as s.f.s.) when subjected to a severe earthquake.

2. MECHANICAL FEATURES OF S.S.S. SYSTEM

To make a comparison with the S.S.S, a standard building (thereafter, referred to as S.B.) having an optimal distribution of both yield shear force coefficient and stiffness[2]-[4], is designated(Figs.1a-c).

The yield shear force coefficient of the s.f.s is degraded from that of the S.B., while those on the upper stories are equal to the S.B.(Fig.1a).i.e.

$$\alpha_i=\overline{\alpha_i}\times\alpha_b^o \quad (1a)$$

$$\alpha_s=\gamma_a\times\alpha_b^o \quad (1b)$$

where, α_i: yield shear force coefficient for the ith story, $\overline{\alpha}_i$: optimal distribution parameter of yield shear force coefficient for the ith story[4],

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α_b^o: base yield shear force coefficient of the S.B., γ_a:strength degrading factor for the s.f.s.($0<\gamma_a<=1.0$).

The yield stiffness of the s.f.s is made smaller than that of the S.B. while those on the other stories are same with the S.B.(Fig.1(b)). i.e.:

$$K_{yi}=\overline{k_i}\times K_{y1}^o \tag{2a}$$

$$K_{ys}=\gamma_k\times K_{y1}^o \tag{2b}$$

where, K_{yi} is yield stiffness for the ith story, $\overline{k_i}$ is optimal distribution parameter of yield stiffness for the ith story(see Eq.3)([2], pp.250), K_{y1}^o is yield stiffness at the base story of the S.B., γ_k is stiffness degrading factor for the s.f.s.($0<\gamma_k<=1.0$).

$$\overline{k_i}=\overline{\alpha_i}\times(\Sigma w_j/W) \tag{3}$$

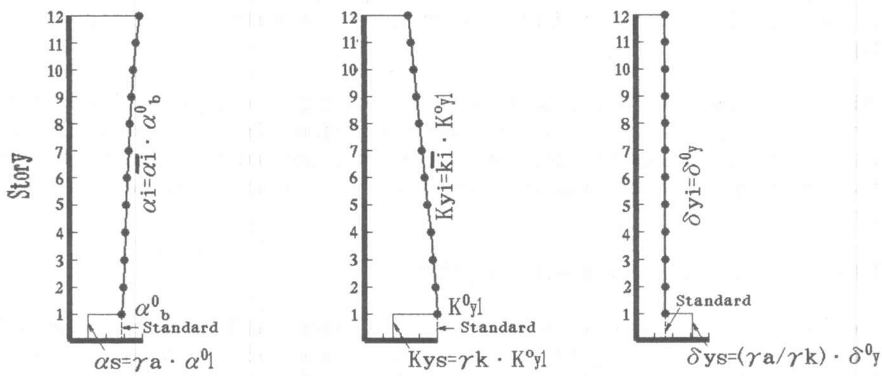
where, Σwj: the sum of weight of the ith and beyond the ith story as well, W: total weight of the building.

Therefore, the yield displacement of the s.f.s. and upper stories of the S.S.S., δ_{ys}, and δ_{yu}, if that of the S.B is δ_y^o, are

$$\delta_{yi}=\delta_y^o \tag{4a}$$

$$\delta_{ys}=(\gamma_a/\gamma_k)\times\delta_y^o \tag{4b}$$

Naturally, $\alpha_s=\alpha_b^o$, $K_{ys}=K_{y1}^o$ and $\delta_{ys}=\delta_y^o$, if $\gamma_a=\gamma_k=1$(S.B.)(Fig.1(c)).



(a)yield shear force coefficient (b)yield stiffness (c)yield displacement

Fig.1 Distribution to each story

3.EXPRESSIONS PREDICTING DUCTILITY IN ULTIMATE STAGE

3.1 FOR ELASTO-PLASTIC FORCE-DEFLECTION RELATIONSHIP

The equations of the energy balance during an earthquake are, for the S.B. and S.S.S respectively, as follows:

$$W_e^o+W_p^o=E_d^o \tag{5a}$$

$$W_e^s+W_p^s=E_d^s \tag{5b}$$

where, W_e^o, $W_{e e}^s$ are the sum of kinetic energy and elastic strain energy at the end of the ground motion, W_p^o, W_p^s are the sum of hysteretic energy accumulated during the ground motion and E_d^o, E_d^s are the energy input contributing to the damage of structure defined by Akiyama et al while the superscripts o and s denote the S.B. and S.S.S. respectively. E_d^o, E_d^s become constant when the natural period of the buildings is equal to or longer than the predominant period of the ground motion(ranging from 0.4 to 1.0 sec.)([2],pp.149).

In addition, the inelastic energy absorbed in the s.f.s., W_{ps}^s can be written as:

$$W_{ps}^s = p_w \times W_p^s \tag{6}$$

where, Pw is the ratio of the inelastic energy absorbed by the s.f.s.(%).

The amount of Pw, is varied when the strength and stiffness of the s.f.s. are changed relatively to the upper story. Akiyama has obtained the Pw's expression for the strength-degraded S.S.S. from a statistical computation of dynamically analyzed results([2],pp.76). i.e.

$$p_w = \frac{1}{1+\gamma_a^{12} \times (\Sigma \bar{k}_i - 1)} \tag{7}$$

Eq.(7) is modified by the authors for both strength- and stiffness-degraded S.S.S.. i.e.:

$$p_w = \frac{1}{1+\gamma_k \times \gamma_a^{12} \times (\Sigma \bar{k}_i - 1)} \tag{7'}$$

Assuming a uniform accumulated ductilities, μ_c^o all over the stories of S.B. as well as μ_{cu} over the upper stories of S.S.S. and μ_{cs} of the ductility of s.f.s., find the energies above and solve Esq.(5a),(5b) and (6), then

$$\mu_c^o = \frac{1}{4} \times [(\frac{\alpha_e^o}{\alpha_b^o})^2 - 1] \tag{8a}$$

$$\mu_{cu} = (\frac{1-p_w}{\Sigma \bar{k}_i - 1}) \times [(\mu_c^o - 1)\Sigma \bar{k}_i - \frac{1}{4}(\frac{\gamma_a^2}{\gamma_k} - 1)] \tag{8b}$$

$$\mu_{cs} = \frac{\gamma_k}{\gamma_a^2} p_w \times [(\mu_c^o - 1)\Sigma \bar{k}_i - \frac{1}{4}(\frac{\gamma_a^2}{\gamma_k} - 1)] \tag{8c}$$

where, α_e^o is the base shear force coefficient of elastic limit for the S.B.([2],pp.214) and $\Sigma \bar{k}_i$ is the sum of $\bar{k}_i$ from the 1st to the top story.

After getting the accumulated ductilities, the maximum ductilities of corresponding story, μ_{ms} and μ_{mu} can be determined by [5]:

$$\mu_{mu} = \frac{1}{6}(\mu_{cu} + 5) \tag{9a}$$

$$\mu_{ms} = \frac{1}{6}(\mu_{cs} + 5) \tag{9b}$$

3.2 For General Force-Deflection Relationship

In concrete structures, it is rare that the structural members behaves perfectly in the elasto-plastic hysteresis. In this study, a force-deflection relationship constituted by simply superposing elastic(braces) and PRC model[6](columns) is employed for the s.f.s.(Fig.2) and PRC model for each upper story.

The accumulated and maximum ductilities for this general situation can be derived, based on the principle of deformation energy conservation; i.e., from equalizing the energy dissipated by the hysteretic loop of this general case to that of the elasto-plastic relationship described in the previous section. If the inelastic energy accumulated prior to the yield of the story is neglected, the accumulated and maximum ductility of the s.f.s., $\bar{\mu}_{cs}$ and $\bar{\mu}_{ms}$ are as follows:

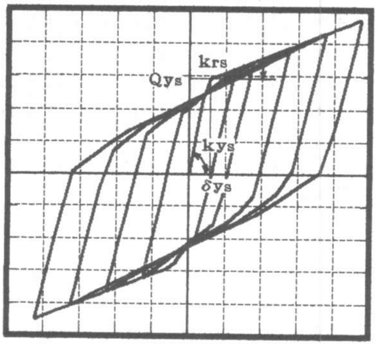


Fig.2 Restoring force-deflection curve for soft-first-story

$$\bar{\mu}_{cs}=\left(\frac{1-\gamma_b}{\gamma_s-\gamma_b}\right)\left[\sqrt{1+\frac{2(\gamma_s-\gamma_b)}{(1-\gamma_b)(1-\gamma_s)}(\mu_{cs}-1)}-1\right]$$

$$\bar{\mu}_{ms}=\frac{1}{\gamma_s}\left[\sqrt{1+2\gamma_s(\mu_{ms}-1)}-1\right]+1 \qquad (10a),(10b)$$

where, γ_s is the strain hardening ratio of the s.f.s($=K_{rs}/K_{ys}$) and γ_b is the brace stiffness ratio($={}_bK_s/K_{ys}$).

Similarly, when P-Δ effect is to be considered,

$$\bar{\mu}'_{cs}=\left(\frac{1-\gamma'_b}{\gamma'_s-\gamma'_b}\right)\left[\sqrt{1+\frac{2(\gamma'_s-\gamma'_b)}{(1-\gamma'_b)(1-\gamma'_s)}(\mu_{cs}-1)}-1\right] \qquad (11a)$$

$$\bar{\mu}'_{ms}=\frac{1}{\gamma'_s}\left[\sqrt{1+\frac{2\gamma'_s}{(1-\theta_{es})}(\mu_{ms}-1)}-1\right]+1 \qquad (11b)$$

where, $\gamma'_s=(\gamma_s-\theta_e)/(1-\theta_e)$, $\gamma'_b=(\gamma_b-\theta_e)/(1-\theta_e)$ and θ_e is the stability coefficient of the s.f.s. at elastic stage.

As for the accumulated and maximum ductility of the upper stories, we can easily derive them in same way by setting $\gamma_b=\gamma'_b=0$ in Eqs.10a-11b.

4.Comparison with Numerical analysis

4.1 Analytical Model

Fig.3 shows a typical MDOF shear model of a S.S.S.having braces and columns on the s.f.s.

The parameters concerned in the analysis are set as follows:

(1)The total number of stories NF, is equal to 12 while the weight and height of each story are constant, 450(ton) and 300(cm) respectively;

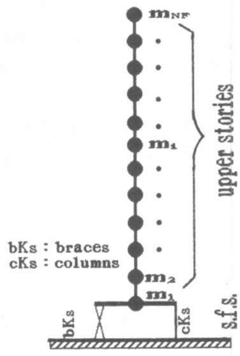


Fig.3 Analytical Model

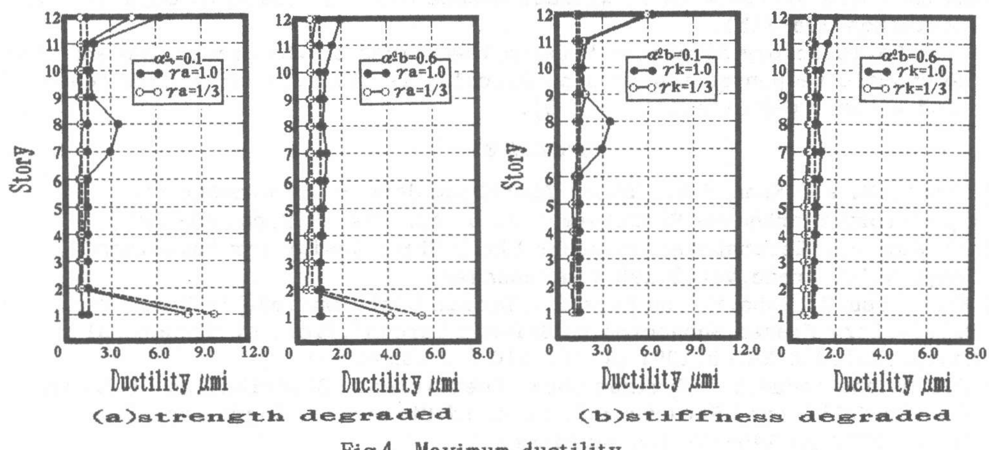
(2)The base yield shear force coefficient of the S.B., α_b^o, is arranged for two cases: 0.1 and 0.6 while δ_y^o,the yield displacement of the S.B.is considered one case, 3.0(cm) on all stories;

(3)Two cases, 1.0 and 1/3 are considered for the strength and stiffness degrading factors, γ_a and γ_k while the strain hardening ratio, γ_s, is ranging from 2.5% (when $\gamma_b=0$ ***and*** θ_e=1.67%) to 35%(when $\gamma_b=34.2\%$ ***and*** θ_e=30%).

Three recorded earthquake waves, El Centro 1940 NS (maximum ground acceleration Agmax=341.7gal,duration,td=29s), Taft 1952 EW(Agmax=175.9gal, td=30s) and Hachinohe 1968 NS(Agmax=183.6gal, td=30s) are normalized through a spectrum intensity in the range of the natural period, T=0.5s-5.0s and the results of responses calculated by the Newmark β method (β=1/4) with the time interval, 0.005s, are finally averaged. The normalizing factors for the three waves are 1,1.976 and 1.24 in the order listed above.

4.2 Results of Analysis and Discussion

Figs.4a-b and 5-a-b show the results of maximum ductility obtained from the numerical analysis(solid lines) and rational prediction(broken lines) when the P-Δ effect is ignored and involved respectively. The cases of degrading strength and stiffness of the s.f.s. are shown in a and b respectively, together with the S.B.($\gamma_a=\gamma_k$=1). It can be seen from the analytical results that distribution of maximum ductility, regardless of ignoring or considering the P-Δ effect, is nearly uniform over the stories of the S.B. except the top story of the case, α_b^o=0.1 (this exception may be resulted from imperfectness of optimal strength or stiffness distribution when α_b^o is small). Same appearance can also be observed upon the stiffness-degraded S.S.S.($\gamma_a=1,\gamma_k$=1/3) while the ductility is almost completely concentrated to the s.f.s in the case of strength-degraded S.S.S. ($\gamma_a=1/3,\gamma_k$=1).



(a)strength degraded (b)stiffness degraded

Fig.4 Maximum ductility
(without P-Δ effect;----predicted —— analyzed)

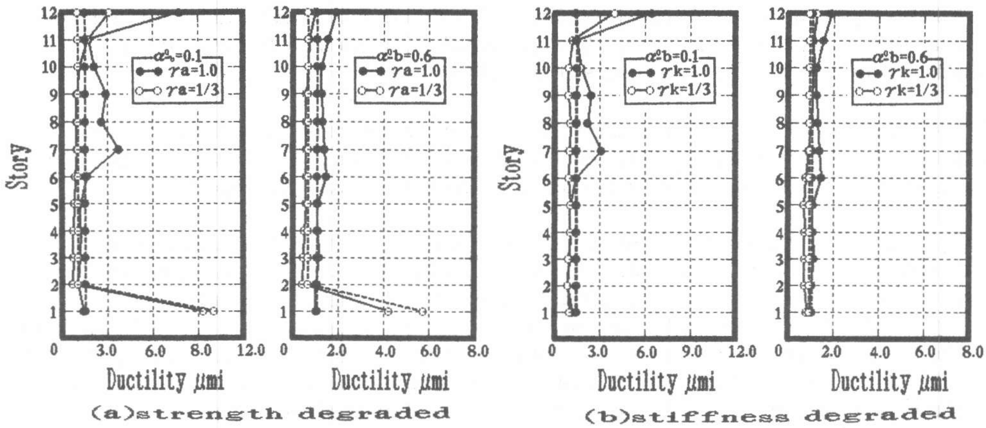


Fig.5 Maximum ductility
(with P-Δ effect;-----predicted —— analyzed)

All these facts are as expected in the theoretical presumption in Sec.3 and another fact is that the broken lines trace the corresponding solid ones quite well, in both cases with and without p-Δ effect, particularly when a_b^o=0.6; this illustrates the agreement between the responses analyzed numerically and the results predicted by the proposed method is satisfactory in a practical range of application.

5.SUMMARY AND CONCLUSIONS

(1) A method to predict the deformations(elastic or inelastic) of the multistory concrete frames with a soft-first-story system subjected to a severe earthquake motion are suggested, based on the energy principle.

(2) The method is available to apply for such frames that have any restoring force system with or without braces and P-Δ effect throughout the structure(**Eqs**.10a-11b).

(3) Satisfactory agreement between the values of the prediction and that of the dynamic responses analyzed numerically is illustrated in both cases with and without p-Δ effect(**Figs**.4-5).

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