DUCTILITY REQUEST IN SEISMIC ANALYSIS OF NONLINEAR MULTIDEGREE-OF-FREEDOM STRUCTURES

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SYNOPSIS

The dynamic analysis of a ten-story shear-system is performed in this paper to evaluate the influence of the mechanical properties of the structure and the characteristics of the excitation on the relationship between overall and local ductility request. Different stiffness distributions and constitutive laws are considered. Statistics of the response to a set of artificial accelerograms are obtained.

INTRODUCTION

Considerable difficulties are encountered in extending to seismic analysis of multi-d.o.f. structures approximate procedures, based on the ductility factor concept, that hold good for one-d.o.f. systems. Reference is made, in this extension, to a mean ductility parameter but the relationship between overall structural ductility and local values must be established in order to perform a reliable aseismic design. The analysis of the seismic nonlinear response of multi-d.o.f. systems dealt with in this paper is aimed at evaluating the way the relationship is influenced by the mechanical properties of the structure and the characteristics of the excitation. In order to make a reasonably complete analysis of the basic features of the ductility request of multi-d.o.f. structures, a relatively simple model is considered, i.e. a ten-story shear-type system. In a previous study[1,2] different stiffness distributions were examined; only two of them are considered here, S1 constant and S2 linear which show different seismic behaviour. (Fig. 1). The constitutive law assumed is purely elasto perfectly plastic in a first stage and such that the ultimate shear force T_u supported by each story is proportional to its stiffness. A trilateral law is then considered and an analysis is made of the influence of variation in slope of the second elastic branch (Fig. 2).

Since the nonlinear seismic response is highly dependent on the earthquake adopted, the dynamic analysis is run with reference to excitations of two kinds: simple recorded accelerograms having quite different characteristics and a set of ten artificial accelerograms. By using the former, the effect of variations in the excitation intensity and duration on the structural response is analysed; the results obtained through the latter are used to obtain statistics of the response. A non-stationary stochastic model is adopted for the generation of artificial accelerograms; the process is represented by the p.s.d. $S(\omega)$ of the stationary component, which is determined from the knowledge of the average spectral response of the seismic phenomenon adopted by way of reference. In the present case, a set of 12 recorded accelerograms of the Friuli 6.5.1976 earthquake of marked affinity has been adopted.

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INFLUENCE OF STIFFNESS DISTRIBUTION

The results of the numerical investigation are analysed by reference to overall and local structural response values; the values of the maximum ductility of the individual stories are considered, as well as the synthetic parameters mean ductility $\bar{\mu}$ and amplification coefficient a_μ defined as the relationship between the maximum and mean ductility values of the model. In the investigation with the family of artificial earthquakes, reference is made for each response quantity x to the corresponding statistical quantities mean value x, variance $\sigma_x{}^2$ and coefficient of variation (c.o.v.) V_x. Fig. 3 illustrates the μ_j diagrams with the statistical values of μ and a_μ. The most uniform characteristics of the response of S2 already observed in the analysis performed with recorded accelerograms [1, 2] are confirmed. The following points emerge very clearly: (a) μ is greater for S2 but to a smaller extent than required on the basis of the ratio between the total volumes of material of the two models equal to 1.33; (b) $V_{\bar{\mu}}$ is about the same for S1 and S2; (c) $\bar{a}_\mu$ is considerably higher for S1 than for S2 and the variance $\sigma^2_{a_\mu}$ is such that V_{a_μ} is also higher for S1; (d) the c.o.v. 's of the response are generally fairly low. It ensues from the comparison that even when μ is greater the amplification coefficient of local ductility is substantially lower in the linear model, which in turn is less sensitive to the diversities among the realizations of the seismic process. Where local quantities μ_j are concerned, the c.o.v. of the response is higher in the whole than that associated with the overall quantities, with maxima (0.35-0.45) that occur at the lower stories. The variation of that coefficient along the height is more marked for S1 (0.35÷0.10) than for S2. From the structural behaviour aspect, it should be noted that the greatest dispersion of μ_j values occurs in the case of the maximum values. In this sense a ductility distribution with yield concentrations appears unfavourable even as regards statistics of the problem.

INFLUENCE OF EXCITATION CHARACTERISTICS

There are many excitation characteristics which influence the amount of yielding of a structure (shape, peak acceleration, distribution of peaks, duration, etc.). The way some of these characteristics influence the relationship between overall and local ductility is examined, a check also being run on the validity of the observations made regarding the role played by the stiffness distribution. In Fig. 4 μ and a_μ are plotted against the amplification coefficient α of the peak acceleration of Taft 21.7.1952 NW earthquake. Mean ductility increases almost linearly with α; however, it is interesting to observe that the amplification coefficient also increases. These observations hold good for both models, though the behaviour of S2 is decidedly better. The responses of the two models to an increase in duration of the excitation are compared in Fig. 5. In this case, too, there is an increase in μ - less for S2 -and a simultaneous increase in a_μ. The increase in plastic deformation is concentrated where this already exists; stiffness distribution S1 is thus affected more strongly. Even for a given model, the relationship between maximum local ductility and mean ductility thus varies quite considerably with variation in excitation intensity and duration. It also depends greatly on the shape of the excitation: recorded accelerograms that are quite different from one another but with intensities such as to produce about the same values of μ exhibit considerable differences in a_μ. Indeed, analysis of the values of μ and a_μ (Fig.6) obtained with the individual realizations, of comparable intensity, of the set of artificial accele rograms, reveals maximum differences of the two quantities of up to 35%, which can be ascribed quite reasonably to the different shapes of the excitations.

INFLUENCE OF VARIATIONS OF THE ELASTO PLASTIC LAW

The investigation is conducted using the set of artificial accelerograms. Consideration is given first to the local ductility values reported in Fig.7. Adoption of a trilateral law - albeit with limited differences vis-à-vis the EP law - produces a marked decrease in μ_j values; the improvement induced by that variation tends to diminish for successive increases in the slope of the second branch of the trilateral. The biggest reductions in ductility occur, however, where the yield concentrations with the EP law are the greatest. An improvement is also found as regards the statistical distribution of μ_j values: the variance $\sigma^2_{\mu j}$ is considerably reduced, it being noted that the greater the variances of the EP response the greater the decreases involved. It appears clear from the observations that the improvement in the structural behaviour as a result of the trilateral law is smaller in the case of those models (S2) where plastic deformations -and their variances- are quite limited and uniform already. As regards the c.o.v.'s the differences along the height of the structure observed with the EP law still persist (Fig. 8). If the overall response values are considered, a reduction is observed in mean ductility and its variance for both models; the c.o.v.'s are still law (Tab. 1). The effect of the trilateral law on the amplification coefficient is somewhat different for the two models (Fig. 9); in any case, however, linear distribution of stiffness is still better than constant stiffness. From the results submitted here it emerges that consideration of deviations from the purely EP law provides a response in which the differences of ductility request among the various resisting members are decreased. From this point of view the role played by the type of constitutive law of the members is just as important as that of stiffness distribution.

CONCLUSIONS

Though the numerical investigation that has been made refers to a relatively simple multi d.o.f. system, it does show the importance of defining the response of the structure not only in terms of overall ductility but also as regards the distribution of local values. Indeed, many factors bound up with the characteristics of the structure and the earthquake cause big variations in the relationship between these quantities. An analysis has been made of the influence of the stiffness distribution and of the constitutive law on which action can be taken to reduce the yield concentrations. This would appear to be an interesting objective since systems with uniform ductility distribution are relatively insensitive to the characteristics of the earthquake and support increases in intensity and duration in a uniform manner. It is only for systems of this type that use of the overall ductility parameter might be meaningful. Further studies are under way to make a statistical evaluation of the sensitivity of the response with a set of recorded accelerograms, taking account also of structural damping and second order effects.

ACKNOWLEDGEMENTS

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REFERENCES

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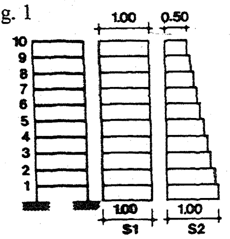
[2] Capecchi, D., Rega, G. and Vestroni, F. "Seismic response of multi-d.o.f. elastoplastic systems", Rep. N. 30, Ist. Scienza delle Costr. Univ. of L'Aquila, 1978 (in Italian).

Fig. 1



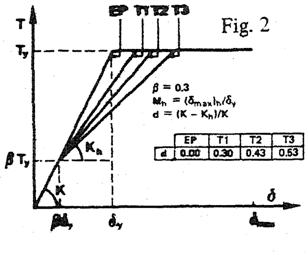


Fig. 2

	EP	T1	T2	T3
d	0.00	0.30	0.43	0.53

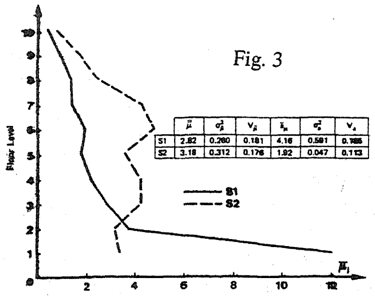


Fig. 3

	$\overline{\mu}$	$\sigma^2_{\overline{\mu}}$	$V_{\overline{\mu}}$	$\overline{a}_{\mu}$	σ^2_a	V_a
S1	2.82	0.260	0.181	4.16	0.581	0.185
S2	3.18	0.312	0.176	1.92	0.047	0.113

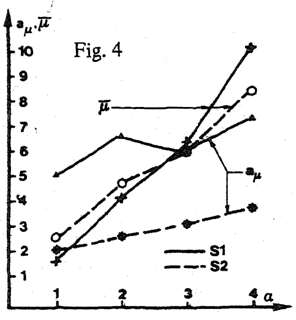


Fig. 4

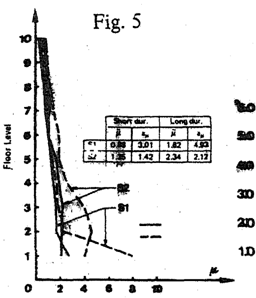


Fig. 5

	Short dur.		Long dur.	
	$\overline{\mu}$	a_μ	$\overline{\mu}$	a_μ
S1	0.88	3.01	1.82	4.93
S2	1.35	1.42	2.34	2.12

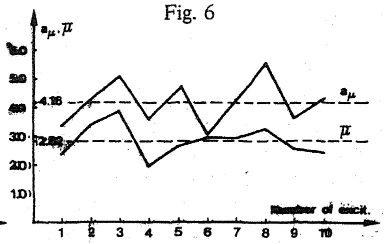


Fig. 6

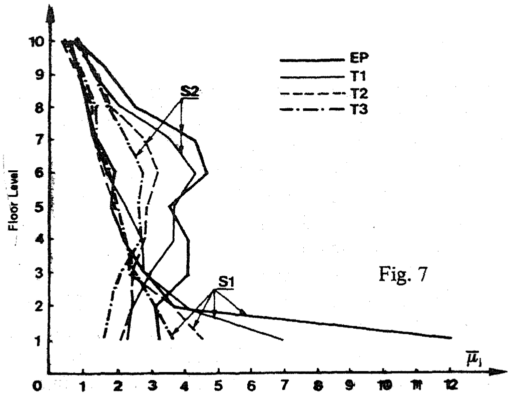


Fig. 7

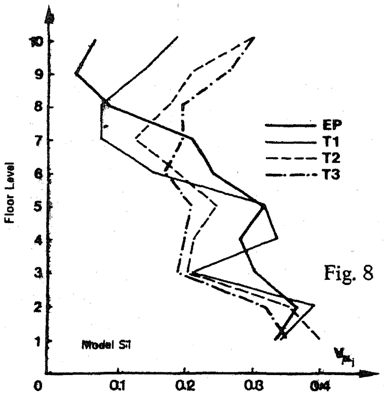
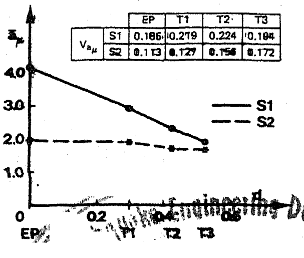


Fig. 8

Tab. 1

	S1			S2		
	$\overline{\overline{\mu}}$	$\sigma^2_{\overline{\mu}}$	$V_{\overline{\mu}}$	$\overline{\overline{\mu}}$	$\sigma^2_{\overline{\mu}}$	$V_{\overline{\mu}}$
EP	2.82	0.260	0.181	3.18	0.312	0.176
T1	2.41	0.125	0.147	2.69	0.276	0.195
T2	1.99	0.190	0.219	2.22	0.240	0.221
T3	1.92	0.166	0.212	1.93	0.180	0.225



		EP	T1	T2	T3
V_{a_μ}	S1	0.186	0.219	0.224	0.194
	S2	0.113	0.127	0.156	0.172

Fig. 9