EARTHQUAKE RESPONSE ANALYSIS OF MULTI-STORY R.C. FRAMED BUILDINGS

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SUMMARY

In this paper, elasto-plastic response of shear beam type multi-story buildings with various natural periods are computed, inputting various earthquake records and assuming that the yield shear strength on each story is proportional to the max. seismic shear force on the same story in the elastic response. Relations between ductility factor, max. displacement of the story in the elastic response and period, yield shear coefficient (defined as the ratio of yield shear to the max. shear in the elastic response) are given. Results of analysis may be used in the aseismic design of buildings of this type.

INTRODUCTION

Although ductility of structure has been considered in the aseismic code of all countries at present, yet deflection of structure during earthquake is not easy to determine, after considering the plastic deformation of structure. Therefore, it is specified in most of aseismic codes that strength is still a design criterion, but it is not reasonable. The elasto-plastic response of a multi-mass system during earthquake has been analysed by many authors, but not much information derived from the above analysis can be used in structural design for engineers. The elasto-plastic response of the following 8-story buildings of shear beam type (Group A and Group B) is calculated by the direct integration method, giving some data about the displacement response of this type of buildings for the design purpose. Use of these data is not restricted to the calculation of 8-story buildings. In the calculation, it is assumed that the base of the building is fixed on the foundation (1).

1. Group A. Stiffness and mass of each story are equal. The fundamental periods of the buildings are 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.2, 2.4 sec respectively.
2. Group B. Stiffness ratios of the 1st floor to the top floor are 1.0 : 0.9 : 0.8 : 0.7 : 0.6 : 0.5 : 0.4 : 0.3 respectively. Mass of each floor is the same. Fundamental periods of buildings are 0.22, 0.43, 0.65, 0.87, 1.07, 1.29, 1.51, 1.71, 1.93, 2.15, 2.37, 2.58 sec respectively.

Model of restoring force shown in Fig. 1 is used (2). Damping matrix is taken as a linear combination of mass matrix and stiffness matrix. Critical dampings for the 1st and the 2nd mode of the building are all taken as 0.05. Step in calculation is taken as 0.002-0.01 sec, depending on the fundamental period of the building.

It is assumed by the author that, for earthquake load, it is reasonable

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to design based on the assumption that the strength of all floors are equivalent. Therefore, the allowable yielding strength of all floors can be evaluated by the following method. Taking that the allowable yield shear strength is proportional to ~~the max. shear in~~ its elastic response, i.e. $Q_{iy} = q Q_{ie}$. For each building, 4 cases are considered, in which $q =$ 0.3, 0.5, 0.7 and 0.9.

Response of the building is computed for each case mentioned above, using six earthquake records in Table 1 as input. No. 4, 5, 6 records are taken from Ref. (3). Acceleration response spectra of No. 1, 2, 3 record are shown in Fig. 2; those of No. 4, 5, 6 record can be referred to Ref. (3).

Table 1

No.	Location	Date of earthquake	Direction	Max. Ground Accel. (g) (actual)	Max. Ground Accel. (g) (calcul.)	Period of peak-value in Accel. response spectrum(sec)
1	Tianjin	Nov. 9, 1976	N-S	0.148	0.4	0.95
2	Tangshan	Aug. 15, 1976	E-W	0.0224	0.4	0.26
3	Xingtai	Dec. 12, 1967	W16.6 S	0.032	0.4	0.16
4	El-centro	May 18, 1940	SOOE	0.348	0.4	0.46
5	Taft	July 7, 1952	N21E	0.156	0.4	0.36
6	Los Angeles	Sept. 2, 1971	S09W	0.132	0.4	1.70

RESULTS OF COMPUTATION AND THEIR ANALYSIS

Part of the results of computation is given only, owing to the limitation of space of the paper. Max. and average values of shear, distributed along the height of the building, in the elastic response of 6 records for Group A and Group B are given in Fig. 3. It is seen from Fig.3 that distributions of shear in the buildings of both Groups A and B are relatively close to each other. There is not much difference between average shear value and max. shear value; considerable difference exists only in few buildings. It is because that shear in the upper story of few buildings under the action of certain earthquakes is greater than that under the action of the other earthquakes.

Ratios of base shear obtained by direct integration to those based on the calculation of single-mass system, α , are intimately close for buildings of both groups under the action of the same earthquake. Fig. 4 shows the average values of the shear ratio. It is seen from Fig. 4 that variation of α with period for few earthquakes is considerable great.

Max. relative displacements (max. ground acceleration is equal to 0.4 g) and their averages between stories in the elastic response of 6 *records for buildings of Groups A and B are given in Fig. 5. There is* much difference between the average value and the max. value. That is because that the responses of the building, the natual period of which is above 0.6 sec., to No. 1 and No. 6 earthquakes are greater than those to other earthquakes, while the responses of most buildings to No. 3 earthquake are considerable less than those to other earthquakes. Relative displacement of stories of A group buildings is greater in lower stories and smaller in upper stories, similar to the distribution of shear. For buildings of B group, the periods of which are the same as buildings of A group, relative displacement of stories is greater than that of A group generally. Distribution of relative displacement along the height of building is greater in middle stories and smaller both in upper and lower stories.

Relative displacement of stories of both buildings in A and B groups almost increases with the period of building.

Fig. 6 gives the ductility factors of A group buildings, whose period is 0.8 sec for different yield shear coefficient (q) for 6 earthquakes. The greatest of ductility factors in Fig. 6 is 10, those over 10 are also drawn as 10.

The ductility factors of A and B group buildings for No. 1 and No.4 record respectively are given in Fig. 7 and Fig. 8 for different q values.

Allowable yield strength between stories in building is determined by the above computing method. For some buildings, all stories enter the plastic stage for the above 6 earthquakes, except in the case $q=0.9$, in which some stories do not enter the plastic stage for individual earthquakes. When q is not less than 0.7, ductility factors of all stories are close to each other (see Figs. 6, 7, and 8), while the max. relative displacement between stories approaches to the max. displacement in the elastic response. But there is also the case that ductility factors of individual stories in some buildings are larger than usual. In the short period buildings, such case often occurs in the lower stories; but in the upper stories of the long-period buildings, when q is less than 0.5, it is possible for all stories to have larger ductility factor. Therefore, allowable yield strength, taken in computation, cannot be too small. For the same earthquake, distributions of ductility factors along the height of building are similar for different q values (Fig. 6,7,and 8), but not for different earthquakes.

The greatest ductility factors of A group buildings for 6 earthquakes are given in Fig. 9 for different q values.

CONCLUSIONS

During earthquake, if the structure is allowed to enter the plastic stage, and q value of all stories is taken as constant in design, the function of rod members in stories will bring into play, thus failure only occurred in a certain story will be avoided, then no serious damage will occur also. Data given in the paper provide a simplified design process for the above philosophy. Steps of the process are as follows:

1) Find out the max. shear in the structural elastic response first according to the preliminary design.

2) Determine the required q value based on the safety requirement of the structure; find out allowable yield shear of each story, and then determine the cross section of the structural member.

3) Based on the fundamental period of the structure and the selected q value, find out the max. ductility factor possibly occurred from Fig. 9 and thus decide whether the selected q value is reasonable. Ductility factors shown in Fig. 9 are overestimated generally. Practically, average displacement shown in Fig. 5 can be used as a criterion for evaluation of q.

REFERENCES

1. Yin Zhiqian and Li Shuzhen et al, 1978, "Response Analysis of Multi-Story Buildings under the Action of Earthquake", Institute of Engineering Mechanics, Chinese Academy of Sciences, No. 78-02.
2. F. A. Imbeault and N. N. Nielsen, 1973, "Effect of Degrading Stiffness on the Response of Multi-Story Frames Subjected to Earthquakes", WCEE-V.
3. Analysis of Strong Motion Earthquake Accelerograms, Vol II, III California Institute of Technology Earthquake Engineering Research Laboratory, 1971-1974.

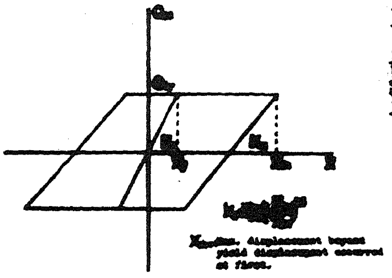


Fig.1 Force-displacement curve.

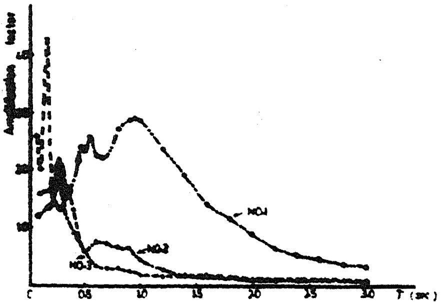
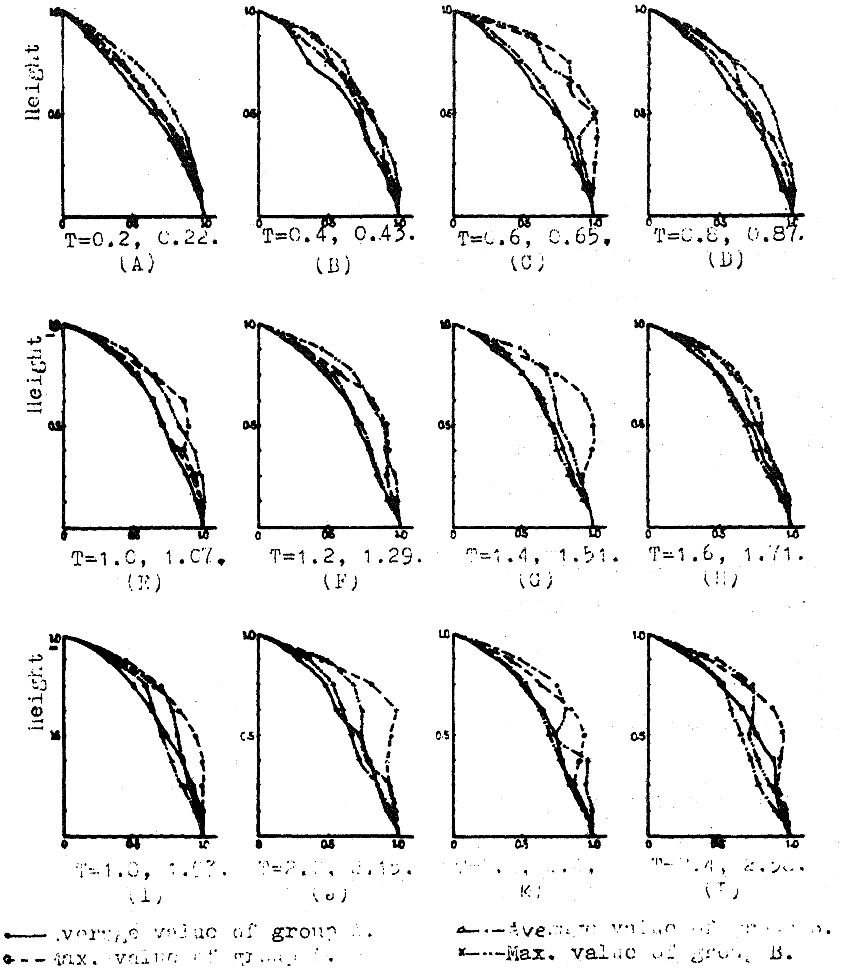


Fig.2 Acceleration response spectra of No. 1.2.3 earthquakes.



T=0.2, 0.22. (A)
T=0.4, 0.43. (B)
T=0.6, 0.65. (C)
T=0.8, 0.87. (D)
T=1.0, 1.07. (E)
T=1.2, 1.29. (F)
T=1.4, 1.51. (G)
T=1.6, 1.71. (H)
T=1.8, 1.[illegible]. (I)
T=2.0, 2.15. (J)
[illegible] (K)
T=[illegible].4, 2.5[illegible]. (L)

Fig. 3 Max. and average shear along the height of building in the elastic response during 6 earthquakes.

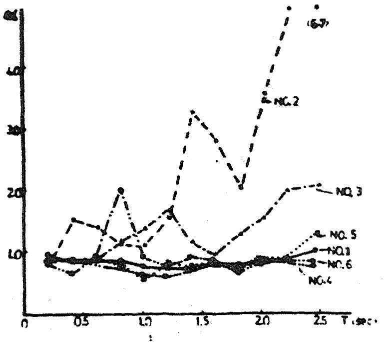
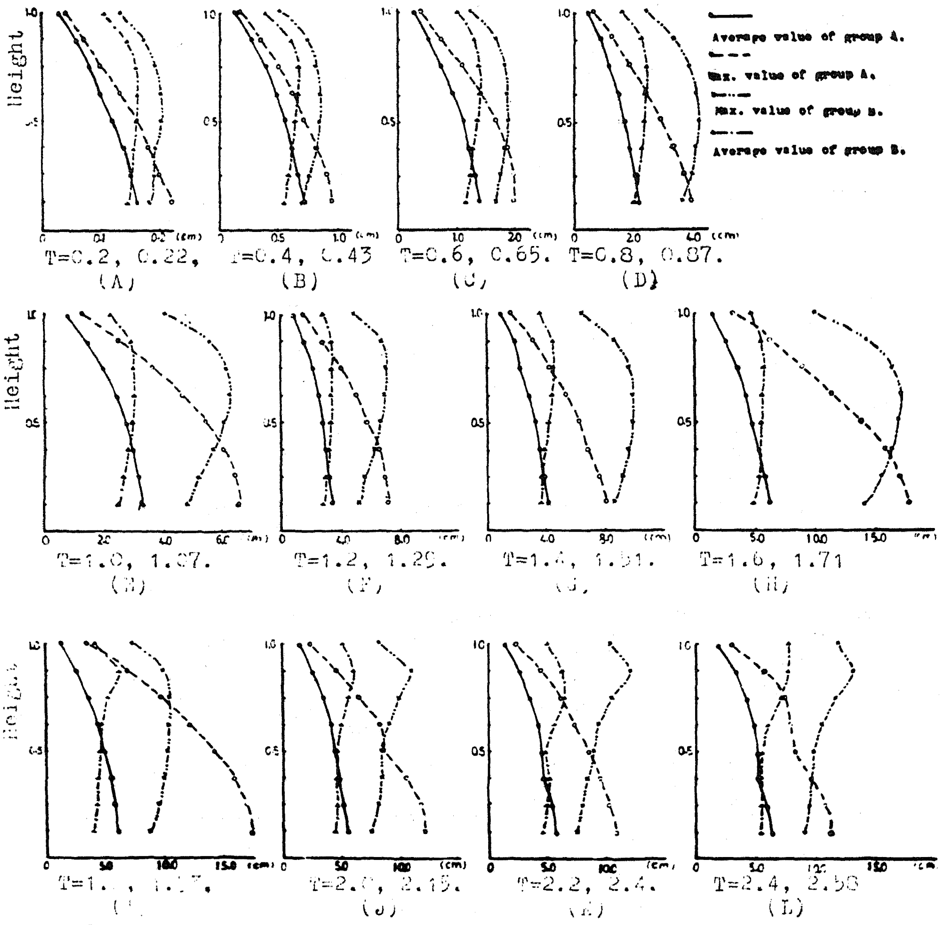


Fig. 4 Base shear ratios for 6 earthquakes.

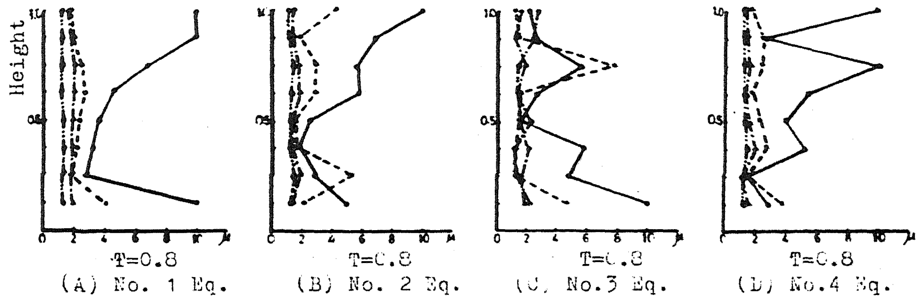


T=0.2, 0.22, (A) T=0.4, 0.43 (B) T=0.6, 0.65. (C) T=0.8, 0.87. (D)

T=1.0, 1.07. (E) T=1.2, 1.29. (F) T=1.4, 1.51. (G) T=1.6, 1.71 (H)

T=1.8, 1.87. (I) T=2.0, 2.15. (J) T=2.2, 2.4. (K) T=2.4, 2.58 (L)

Fig. 5 Max. relative displacements between stories and their averages in the elastic response for buildings of group A and B during 6 earthquakes.



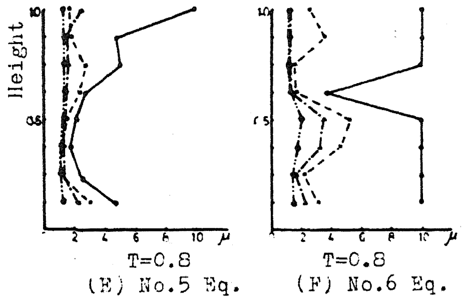
T=0.8
(A) No. 1 Eq.

T=0.8
(B) No. 2 Eq.

T=0.8
(C) No.3 Eq.

T=0.8
(D) No.4 Eq.

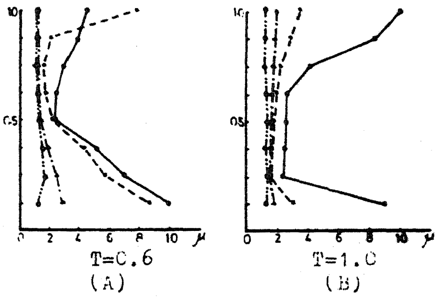
Fig. 6 Ductility factos of A group buildings during 6 earthquakes.



T=0.8
(E) No.5 Eq.

T=0.8
(F) No.6 Eq.

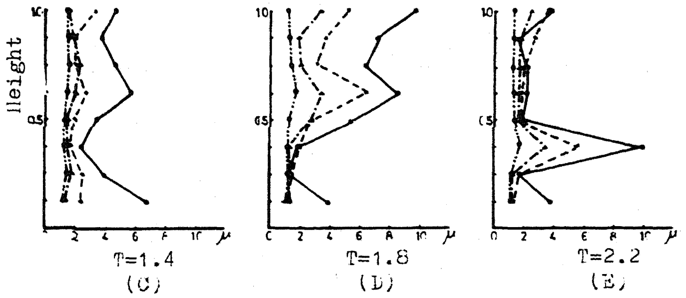
Fig. 6



T=0.6
(A)

T=1.0
(B)

Fig. 7

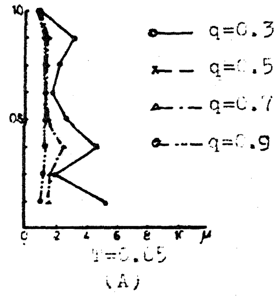


T=1.4
(C)

T=1.8
(D)

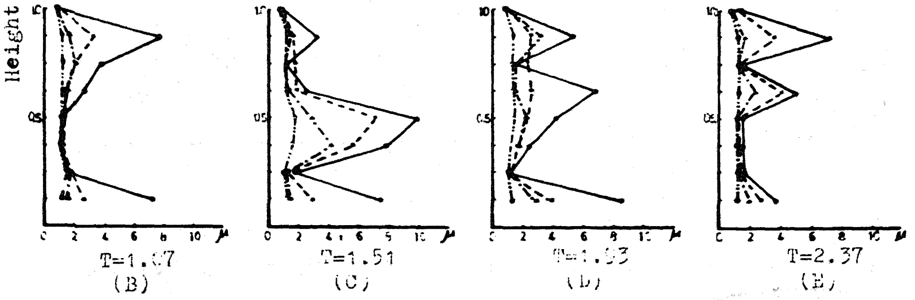
T=2.2
(E)

Fig. 7 Ductility factors of A group buildings in No.1 earthquake.



T=0.65
(A)

Fig. 8



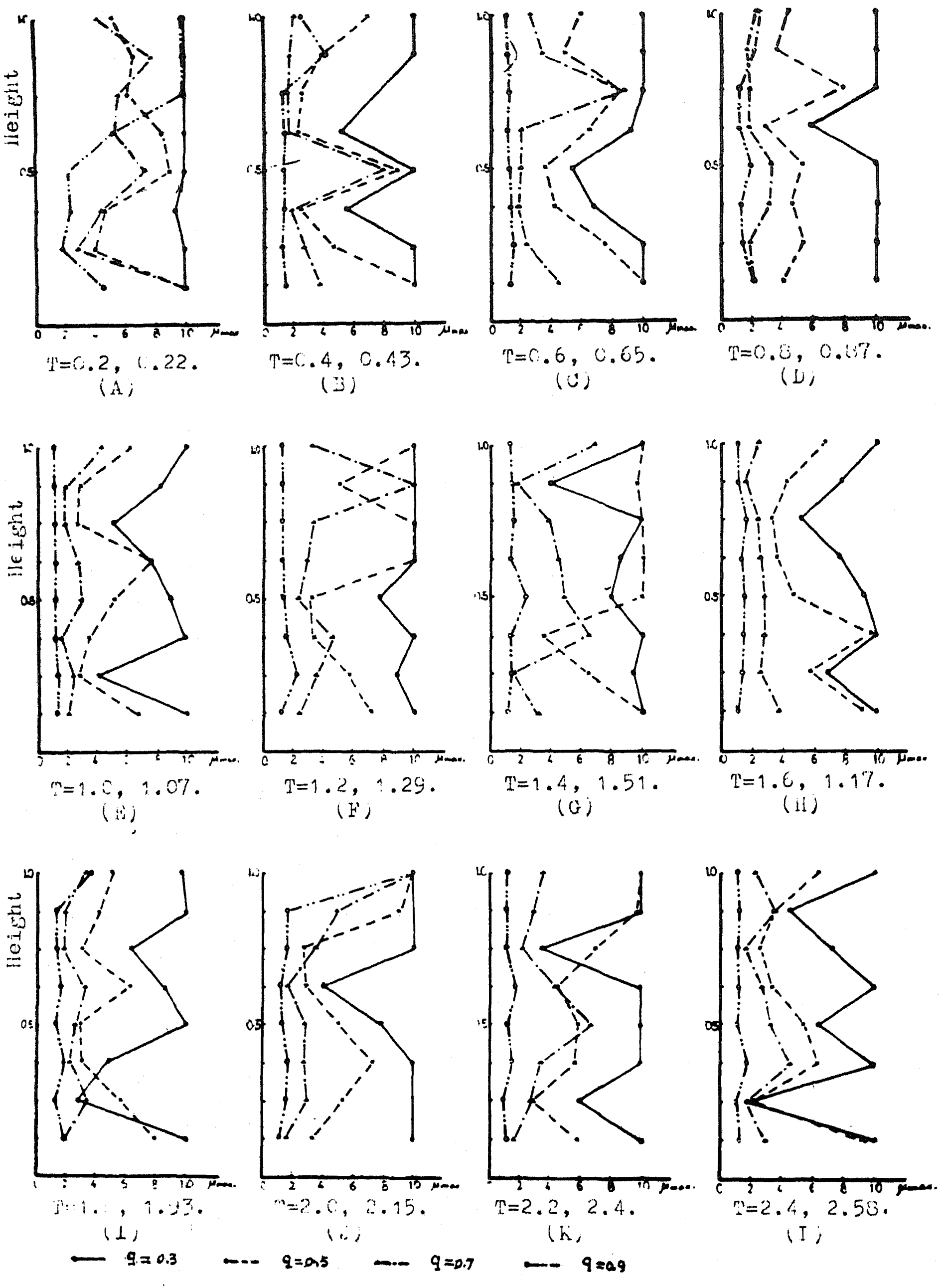
T=1.07
(B)

T=1.51
(C)

T=1.93
(D)

T=2.37
(E)

Fig. 8 Ductility factors of B group buildings in No.4 earthquake.



T=0.2, 0.22. (A)
T=0.4, 0.43. (B)
T=0.6, 0.65. (C)
T=0.8, 0.87. (D)
T=1.0, 1.07. (E)
T=1.2, 1.29. (F)
T=1.4, 1.51. (G)
T=1.6, 1.17. (H)
T=1.8, 1.93. (I)
T=2.0, 2.15. (J)
T=2.2, 2.4. (K)
T=2.4, 2.58. (L)

Fig. 9 Max. ductility factors of A- group buildings during 6 earthquakes.