EVALUATION OF INELASTIC RESPONSE FOR HIGH RISE BUILDINGS BY EQUAL SEISMIC DISPLACEMENT PRINCIPLE

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ABSTRACT:

The evaluation of inelastic response for high rise buildings is the one of key problems in the study of earthquake resistance of buildings. In this paper the main problems in modeling inelastic seismic response of high rise buildings are briefly summarized. The feasibility of using equal seismic displacement principle (seismic displacement responses are nearly equal between long period elastic and inelastic systems) to evaluate displacement response of inelastic system is described based on the summarization of the research results concerning the relation between elastic and inelastic responses of SDF system. And then the relationship between the elastic and inelastic seismic displacement responses of high rise buildings is studied by elastic and inelastic time history response analyses respectively. The results show that the average top drifts of inelastic response under different earthquake excitations are nearly equal to those of elastic responses and basically follow the equal seismic displacement principle. The situation is the same for average inter story drifts of inelastic response in weak and middle nonlinear stages, but in large nonlinear stage they are larger than those of elastic responses and modified formula is provided for evaluation of inelastic inter story drifts based on elastic inter story drifts.

KEYWORDS: equal seismic displacement principle, high rise building, inelastic seismic response, long period

1. INTRODUCTION

Earthquake response analysis is very important for structural seismic research and design. At present, the elastic analysis has been well developed and widely used in engineering practice. But inelastic analysis has always been being a difficult problem puzzling us and has paid great efforts to develop it.

Inelastic seismic response analysis can be divided into two classes: static inelastic analysis and time history analysis. And the former is generally referred to pushover analysis.

Main steps to conduct pushover analysis are as follows: a certain lateral load pattern is first supposed, then perform a static analysis to the structural model under this load pattern until a pre-determined target displacement is reached and thus obtain the relationship between base shear and roof displacement, transfer relationship curve and demanded spectrum curve into the same coordinate system and response value is obtained by finding the intersection of two curves. Study results show that this method is effective to middle and low story shear type buildings, but ineffective to high rise buildings. Generally speaking, the reason can be attributed to fail to consider influence on higher order modes. Therefore, Chintanapakdee and Chopra developed a kind of mode pushover analysis method for high rise building pushover analysis (Chintanapakdee and Chopra,2003). The author had already pointed out the reason is not only failure to take the high order mode effect into consideration, but also the capacity curve of high rise building can not be correctly estimated (Sun ,2003). For example, the capacity curves of two high rise buildings excited by different ground motions and lateral load distributions are given in Fig.1. It can be seen that the curves under various lateral load patterns are much different from those under ground motions no matter shape or values, especially the curve from commonly used inverted triangular load pattern excitation. Therefore, pushover analysis for high rise buildings still need to be studied further.

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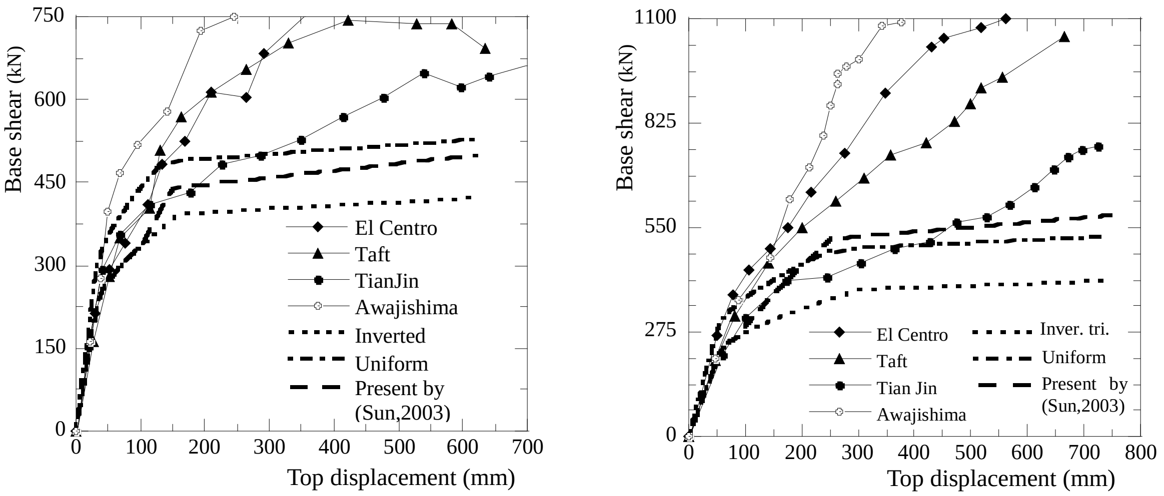


a) 20 story frame shear-wall building

b) 16 story shear-wall building

Fig.1 Capacity curves under the excitations of different ground motions and lateral load patterns

The more accurate and reliable method to estimate inelastic response of high rise building is, no doubt, inelastic time history analysis. But so far, only two-dimensional analysis method has been well developed, and been frequently used with confidence. Now the problem is that most high rise buildings are comparatively complicated, it is difficult to simplify them into two-dimensional analytical model, if we barely do this, the larger analytical errors will be resulted just from initial analytical model simplification stage.

Three dimensional inelastic seismic response analysis has always been being a difficult problem to be solved. The main difficulty is that the hysteretic relationship of structural component under three dimensional forces is extremely complicated, at present, we are unable to sum up the hysteretic relationship which can be widely accepted and used in practical structural analysis. Although analytical programs such as SAP2000, ETABS and MIDAS et al. have the primary ability to carry out three dimensional inelastic seismic response, generally speaking, these still can not be used to model complicated high rise buildings.

In short, many inelastic seismic response analytical methods have been presented, but they are imperfect for various issues, thus none of them is widely accepted.

Newmark and Hall pointed out in 1969 that the maximum acceleration response is nearly a constant for high frequency system and equal to the one of ground for even higher system, comparably, maximal displacement response is close to a constant and slightly enlarges the ground displacement for low frequency system, and equal to the ground displacement for extremely low frequency system (Newmark and Hall,1969). In other words, no matter the structure is in inelastic or elastic state, its displacement is equal to ground displacement, this is called equal seismic displacement principle.

Many researchers suggest that for long period structures such as high rise buildings, above mentioned principle can be used, namely, we can evaluate inelastic displacement response by elastic displacement response. This is a better way to solve the problem of three dimensional inelastic response of high rise buildings and it can also be easily conduct. The problem is that this method has been mentioned more in papers but less in detailed studies.

In this paper, evaluation of inelastic displacement responses of high rise buildings based on equal displacement principle is studied and discussed. Through summarizing the research results concerned the elastic and inelastic seismic displacement response relationship of long period SDF system;we show the possibility to use this method to evaluate high rise building inelastic responses. By four high rise building examples, the maximum seismic displacement responses of elastic and inelastic are studied, and the method of evaluating inelastic displacement responses by elastic analytical results is suggested.

2. THE SEISMIC RESPONSE RELATIONSHIP OF ELASTIC AND INELASTIC FOR LONG PERIOD SDF SYSTEM

the elastic and inelastic seismic response relationship of long period SDF system can be obtained from the results of inelastic response spectrum study.

In the inelastic response spectrum, we define ductility coefficient$\mu = u_n / u_y$, in which u_n stands for inelastic displacement, u_y denotes yield displacement, and the strength reduced coefficient $R_\mu = F_y(\mu=1) / F_y(\mu=\mu_i)$, in which $F_y(\mu=1)$ is elastic yield strength, $F_y(\mu=\mu_i)$ is yield strength to keep the system elastic. The relationship of above parameters is shown in Fig.2.

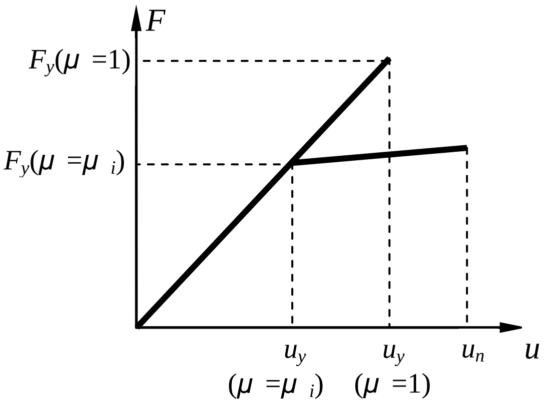


Fig.2 Relationship of strength versus displacement

It can be seen that inelastic displacement is equal to elastic one when the strength reduced coefficient is equal to ductility coefficient. There are many studies on strength reduced coefficient and several evaluation formulas have been proposed [4，5，6，7，8], three of them are illustrated in Fig.3-Fig.5.

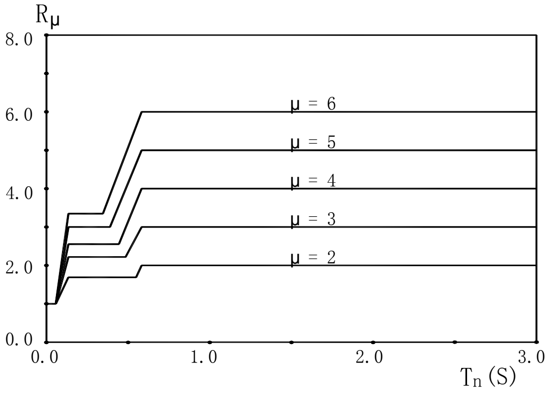


Fig.3 Strength reduced coefficient versus period proposed by Newmark & Hall

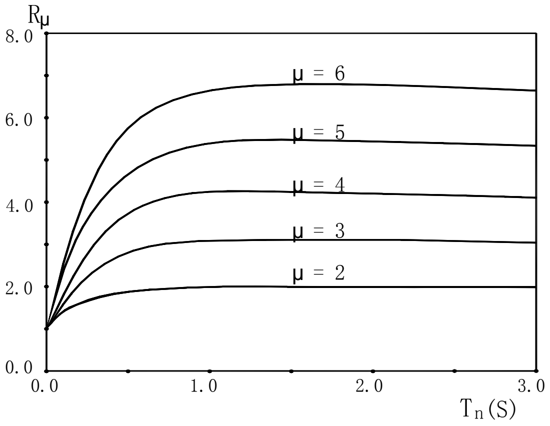


Fig.4 Strength reduced coefficient versus period proposed by Krawinkler & Nassar

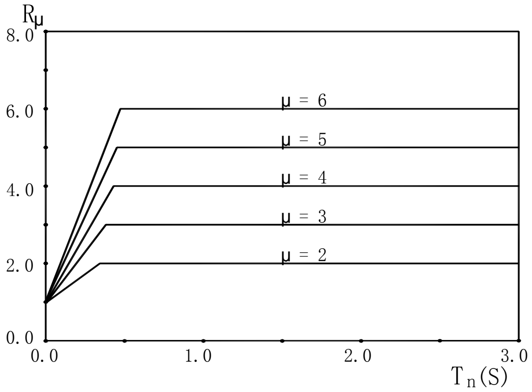


Fig.5 Strength reduced coefficient versus period proposed by Vidic，Fajfar & Fischinger

All above studies show that for long period (longer than about 0.8s) SDF system the R is equal or close to μ and therefore the inelastic displacement response of the system can be evaluated from elastic analytical result.

3. THE SEISMIC DISPLACEMENT RESPONSE RELATIONSHIP OF ELASTIC AND INELASTIC FOR HIGH RISE BUILDINGS

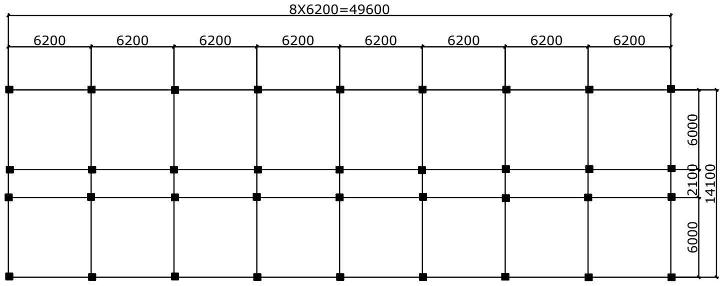
Five reinforced concrete high rise buildings are chosen as analytical examples, twenty earthquake records as excitation input, the peak values from low to high, the elastic and inelastic response analyses are carried out and the results are summarized.

3.1.outline of buildings and input ground motions

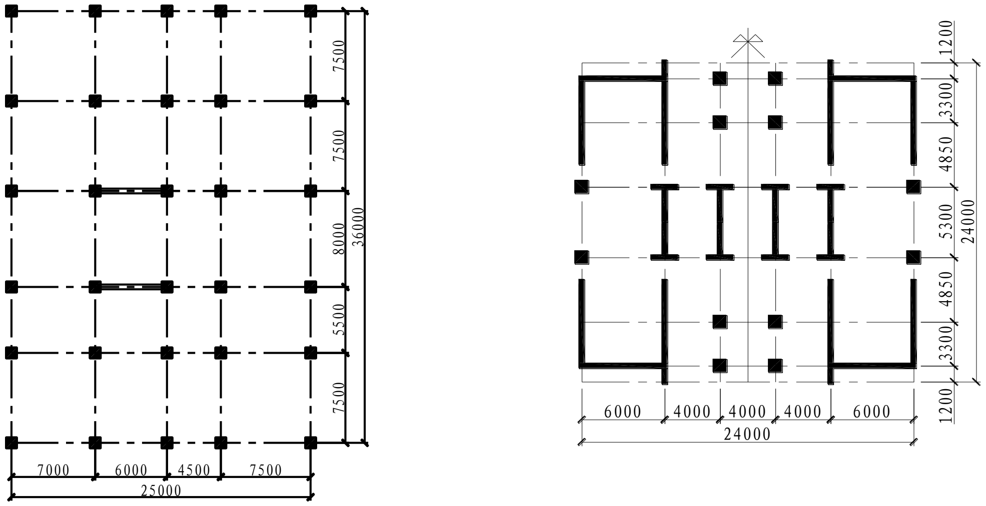
The main parameters and sketch plans of five structures are listed in Table 1 and Fig .6 respectively.

Table 1 Main parameters of five buildings

No.	structural type	stories	height（mm）	Fundamental period (s)
S1	RC frame	13	46.2	1.71
S2	RC frame-shear wall	18	55.1	1.35
S3	RC frame-shear wall	36	105.2	3.65
S4	RC frame-shear wall	22	99.4	2.21
S5	RC frame-shear wall	25	83.7	1.55

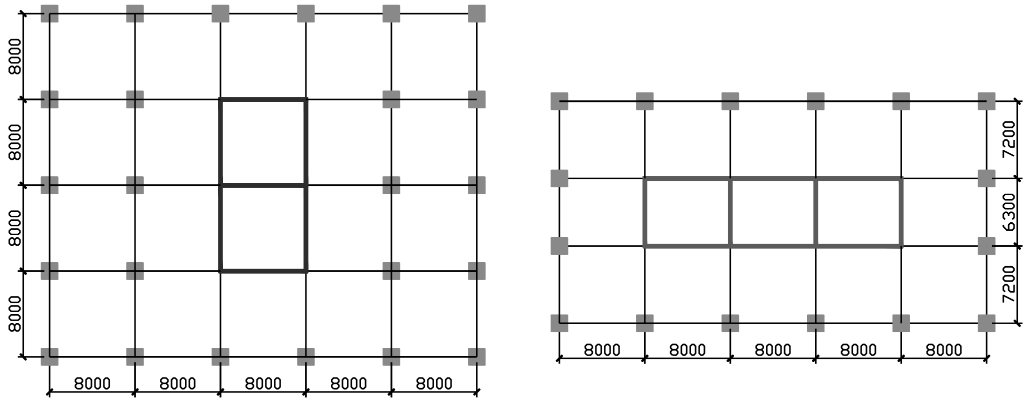


(a) Building S1



(b) Building S2

(c) Building S3



(d) Building S4

(e) Building S5

Fig. 6 Sketch plans of five buildings (Unit: mm)

Twenty earthquake waves are selected as input, among which three are on firm site, thirteen on medium soil site and four on soft soil site.

3.2.Analytical results

The analytical results show that inelastic displacement responses of high rise buildings are sometimes greater than the elastic ones, sometimes less and dispersion is great. In view of this case, taking more earthquake records to carry out inelastic analysis is necessary. The effect of soil site to the relationship between elastic and inelastic responses is not obvious and thus following presented results no longer distinguish the soil site. This relationship concerned top displacements and inter drifts of five buildings under twenty earthquake and different intensity level excitations is given in Fig.7 and Fig.8 respectively. It can be seen that the average maximum inelastic top displacement response are nearly the same as elastic response and therefore we can use the elastic top displacements to evaluate the inelastic ones (Fig.7), when the maximum inter drift is about less than 1/167, the average maximum inelastic response and elastic response are nearly the same and it is greater than 1/167, the former is greater than latter (Fig.8).

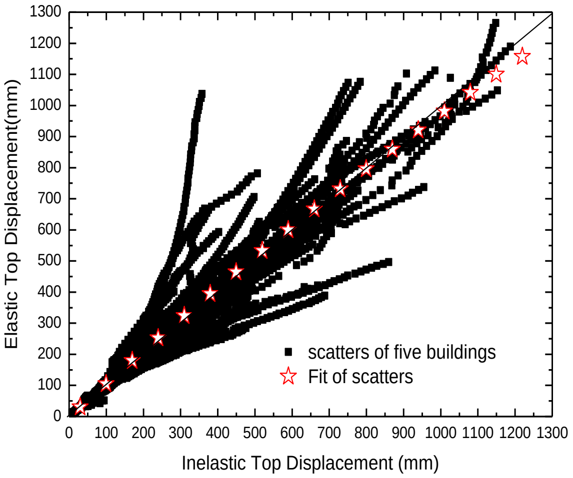


Fig.7 Elastic and inelastic top displacement relationship and fitting curve

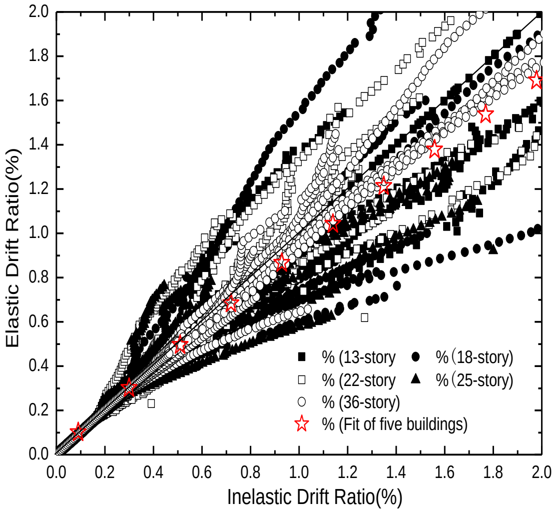


Fig.8 Elastic and inelastic inter drift ratio relationship and fitting curve

By fitting all analytical results in Fig.8 and take structural safety into consideration, the formula (1) is proposed to estimate inelastic inter story drift when it is greater than 1/167, if it is less than the elastic response result it can be directly used as inelastic response value.

$$\alpha_s = 0.42\alpha_e^2 + 0.59\alpha_e + 0.115 \qquad (1)$$

In which, α_s and α_e stand for maximum inelastic and elastic inter story drift, both are expressed in percentage.

4. CONCLUSION

(1) There is much difference of inelastic displacement response for high rise buildings under different earthquake excitations. Sometimes it is greater than elastic response, sometimes less.

(2) The average inelastic maximum top displacement is close to the elastic one for high rise buildings under

different earthquake excitations. So we could estimate the former from the latter value directly.

(3) When inter story drift is less than 1/167, the average maximum inelastic response value and elastic response value is nearly equal to each other, if it is greater than 1/167, inelastic response value can be estimated by formula (1) based elastic result.

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