A STUDY ON SHEAR-TYPE STRUCTURAL MODEL FOR ASEISMIC DESIGN

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1. Introduction

The earthquake response analysis of the framed structure has various kinds of purposes, ranging from obtaining the aseismic design data for the preliminary structural design to examining the aseismic safety of the framed structure in a perfect form, and it has been carried out mostly by using a shear-type structural model, in which a mass is concentrated on each floor level and connected with adjacent masses by shear springs having simplified hysteretic characteristics. In such a simulation, however, there remain such problems as whether a shear-type structural model may grasp the comprehensive responses (e.g. relative story displacements or story shear forces) of an actual structure or not, and whether the real aseismic safety of a structure may be guaranteed by the comprehensive appraisal with a shear-type structural model or not.

The study reported in this paper is an attempt to clarify these problems. To examine the accuracy and suitability of a shear-type structural model. The response of this model toward earthquake disturbance is compared with that of the more detailed structural model.

2. Program of Investigation

Structure Considered: In this study is considered an unbraced, single-bay frame of five stories. The assumed working loads on this frame are given in Fig.1, where seismic loads with base shear coefficient 0.2 are obtained from the shear force coefficient distribution proposed by T.Kobori and R.Minai. The load factors are as the values of Table-1. The members are arranged according to the plastic design method based on the minimum weight design[1].

Detailed Structural Model: The detailed structural model used in this study is a general finite element model in which each node has three degrees of freedom. The elasto-plastic stiffness matrix for a member is determined by one-dimensional finite element method[2], where each member is subdivided into five elements along the member axis and a cross-section is simplified in Fig.2. The stress-strain relation of material is assumed to follow a bilinear hysteresis loop in which the strain hardening coefficient is given as 0.01. Besides, the mass matrix for a member is determined by the consistent mass method[3], in which uniform distribution of mass along the beam is assumed.

The damping matrix is derived from the method suggested by Rayleigh, and damping factors in the first two modes are given as 0.01.

Shear-Type Structural Model: In the shear-type structural model the total internal spring force acting on any single floor mass depends only on relative displacements of that floor and two adjacent floors located directly above and below.

The spring constants for linear analysis are determined by the method of least squares to approximate the first some modal properties of the detailed structural model. For further details, the reader may refer to reference[4]. We refer to the shear-type structural model with the stiffnesses determined from the first N modes as Shear Model Nth hereafter.

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For nonlinear analysis, two different types of hysteretic characteristics are considered here. One is a poli-linear type, whose skeleton curve is obtained by approximating the static story shear force-relative story displacement relation. The other is a conventional and very simplified tri-linear type, which is obtained as follows. The stiffness of the Shear Model Nth, which has given the best approximation to the linear responses of the detailed structural model, is selected for the elastic stiffness of the tri-linear type. The strength at elastic limit is given as the story shear force when initial yielding occurs in the same story. After initial yielding, the stiffness ratio is assumed to be 0.3. The ultimate strength is estimated through seismic design load, after which the stiffness becomes zero.

The damping matrix is derived in the same manner as in the detailed structural model.

Hereafter, we call the shear-type structural model with the poli-linear type of hysteretic characteristics Shear Model Poli and the model with the tri-linear type of hysteretic characteristics Shear Model Tri.

Numerical Integration: Numerical integration of the equation of motion is carried out by the Newmark generalized acceleration method and the time interval is given as 0.01sec.

Input Earthquakes: The accelerograms chosen here are the first eight seconds of El Centro, California on May 18, 1940, earthquake N-S component and Taft, California on July 21, 1952, earthquake E-W component. Acceleration amplitude 100gal is used in the linear response analysis, 300gal and 500gal in the nonlinear response analysis.

3. Numerical Results

3-1 Restoring Force Characteristics

The natural periods of shear-type structural models are shown in Table-2, in which the ratios of these results to the natural periods of the detailed structural model are given in parenthesis. As is evident from Table-2, the inclusion of the higher modes leads to the approximate uniformity of relative errors in each natural period, but results in considerably large errors in the fundamental natural period. This indicates that all natural modes of the detailed structural model cannot be approximated by those of a shear-type structural model. Namely, the appropriate stiffness of a shear-type structural model may be considered to be a function of the frequency content of the ground motion.

Static analysis is carried out by the one-dimensional finite element method. Fig.3 shows the story shear force-story rotation(Q-R) relations of the frame subjected to the proportional lateral loads, whose distribution is shown in Fig.1. It should be noted that story shear strength is influenced by the distribution of lateral loads. For example, in the frame sucjected to uniformly distributed load, the story shear strengths of the lower stories increase by about 10% in comparison, while those of the upper stories decrease by more than 20%. Fig.3 also shows the skeleton curves of hysteretic characteristics of shear-type structural models. In the tri-linear type of hysteretic characteristics, the story shear strength is considerably underestimated.

3-2 Comprehensive Response

Linear Response: Maximum response of story rotation and story shear force obtained from linear response analysis are shown in Fig.4. The difference between response quantities of each shear-type structural model and those of the detailed structural model is difined by the following equation and shown in Table-3.

$$\sqrt{\frac{1}{n}\sum^{n}\left(\frac{DM - SM}{DM}\right)^2}$$

where n is a number of story. SM and DM are the response quantities obtained from the shear-type structural model and the detailed structural model, respectively. Response quantities obtained from Shear Model 1st and 2nd give a good approximation to those of the detailed structural model in comparison with other Shear Models. The difference in fundamental natural period can be considered to have significant effects upon linear responses. Now, the response of Shear Model 2nd against Taft E-W has the best approximation to the response of the detailed structural model. As to the response against El Centro N-S, on the other hand, Shear Model 1st has rather a better approximation than Shear Model 2nd. This example shows the fact that the appropriate shear stiffnesses of a shear-type structural model differ, as described before, according to the disturbance. From this point of view, the stiffnesses of Shear Model 1st and 2nd are selected as those of Shear Model Tri for El Centro N-S and Taft E-W, respectively.

Fig.5 shows an example of the force-deformation relation obtained from the detailed structural model. In this figure, the solid line shows the story shear force-story rotation relation and the broken line shows the relation between story shear force and the shear component of story rotation, which is defined as the remainder of total story rotation from the rotation caused by column shortening and elongation. It can be considered that column shortening and elongation affects the force-deformation relation negligibly, while the stress distribution of adjacent stories has a remarkable effect on the force-deformation relation.

Nonlinear Response: Fig.6 shows the maximum response of story rotation and story shear force obtained from nonlinear response analysis. The responses of Shear Model Poli have a good approximation to those of the detailed structural model.

Fig.7-8 show the time histories of horizontal displacement and of input energy, respectively. As to such responses, Shear Model Poli can also trace the response of the detailed structural model with accuracy.

As is seen in Fig.6, the maximum story shear force of Shear Model Tri are much smaller than those of the detailed structural model. This is caused by restoring force characteristics of Shear Model Tri. Furthermore, the maximum story rotations are also smaller significantly. It should be emphasized that the underestimation for the strength of an actual structure does not always result in the overestimation for the maximum response of displacement.

3-3 Local Response

In order to guarantee the real aseismic safety by using a shear-type structural model, the significant correlations are essential between the comprehensive response and the local response in the structural members. Let us deal with such problems as whether the maximum stress and strain developed in members can be evaluated by the maximum shear force or story rotation of the corresponding story.

Linear Response: Maximum stresses in individual members are obtained by static analysis with the maximum shear force response. These static stress responses σ_{max} are nondimensionalized according to the following equation, and are compared with dynamic stress responses of the detailed structural model in Fig.9.

$$s = \frac{\sigma_{max} - \sigma_o}{\sigma_y - \sigma_o}$$

where σ_y is a yield stress and σ_o is an initial stress by vertical loads.

It should be noted with interest that static stress responses in beams are considerably larger than dynamic stress responses. This is due to the fact that the two maximum story shear forces adjacent to the beam do not always take place simultaneously in dynamic response. On the other hand in columns, it is recognized that static stress responses give a good approximation to dynamic stress responses. Although in the lower stories the former responses are a little larger than the latter; this is due to the overestimation of static analysis for additional axial force caused by overturning moment.

Nonlinear Response: Maximum plastic strains in individual members are obtained by static analysis with the maximum relative story displacement of Shear Model Poli. These static plastic strain responses are compared with dynamic plastic strain responses of the detailed structural model in Fig.10. Static plastic strain responses in beams except the roof beam are considerably larger than dynamic plastic strain responses. This can be explained similarly as mentioned in the linear response. On the contrary, static plastic strain responses are considerably smaller than dynamic plastic strain responses in columns, main cause of which may be considered that plastic strain in columns subjected compressive axial force is accumulated in the compressing direction with repeated bendings[5].

4. Conclusions

The summary of the results is:

1. The elastic stiffness of a shear-type structural model, which gives the best approximation to the linear response of an actual structure, differs according to the frequency content of ground motion. And the story shear strength is affected by the distribution of lateral loads.
2. In order to obtain a good approximation to actual comprehensive responses by using a shear-type structural model, restoring force characteristics have to be simulated to trace the actual load-deformation relation.
3. One has to point out that the correlations cannot be recognized, with any significance, between the comprehensive responses in the shear-type structural model and the local responses.

Reference

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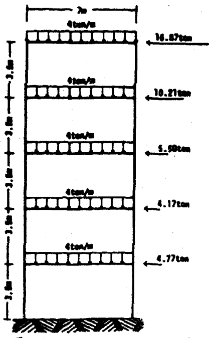

Fig.1 Frame Dimension

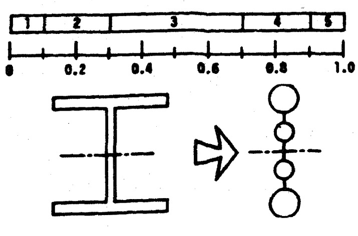

Fig.2 Idealized Model for 1-FEM

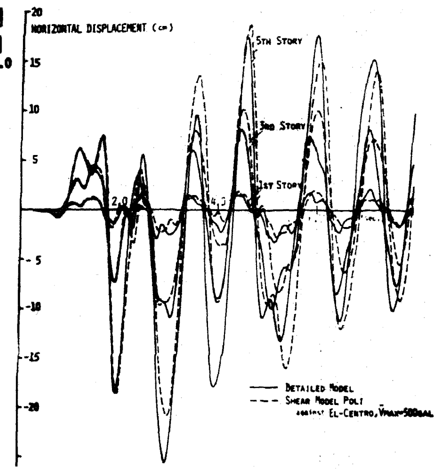

Fig.7 Displacement Time Histories

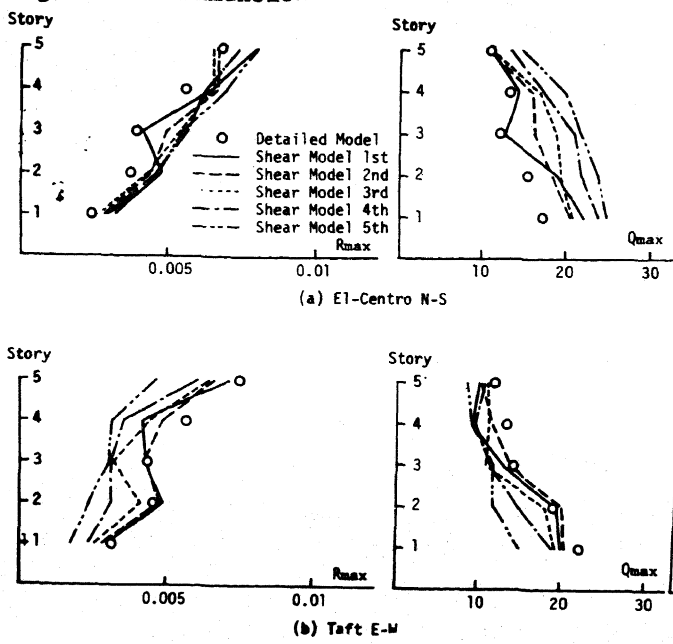

Fig.4 Maximum Responses in Linear Analysis

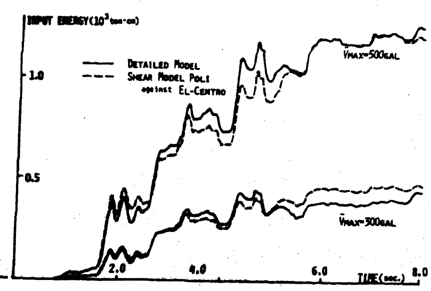

Fig.8 Input Energy Time Histories

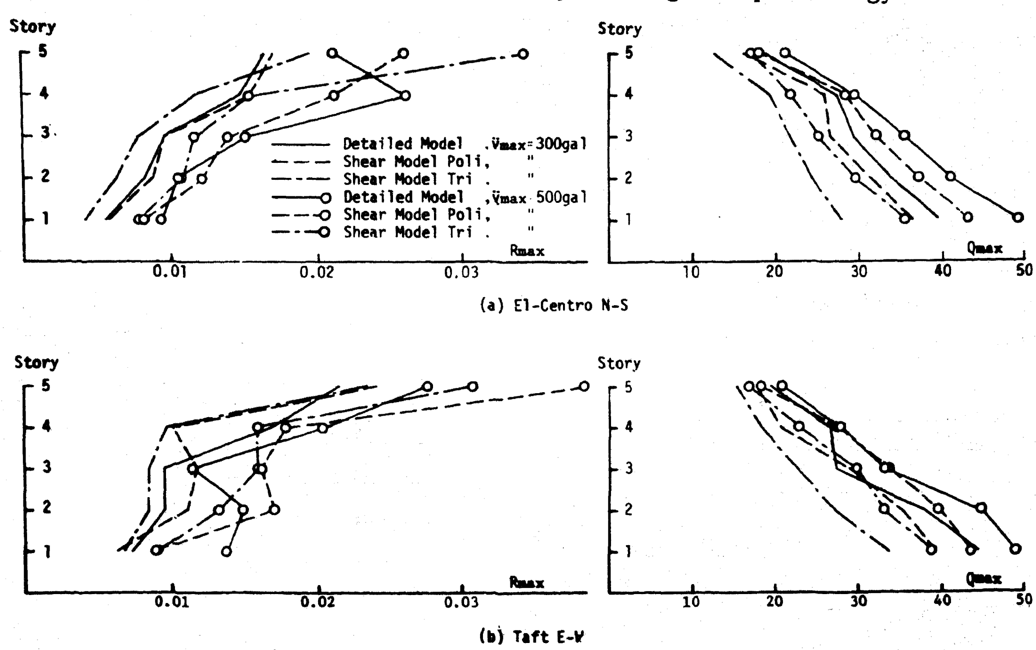

Fig.6 Maximum Responses in Nonlinear Analysis

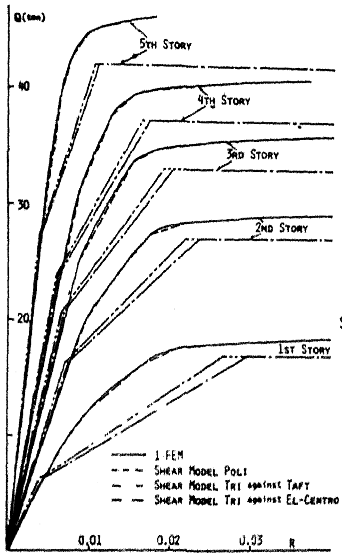

Fig.3 One Way Q-R Relations

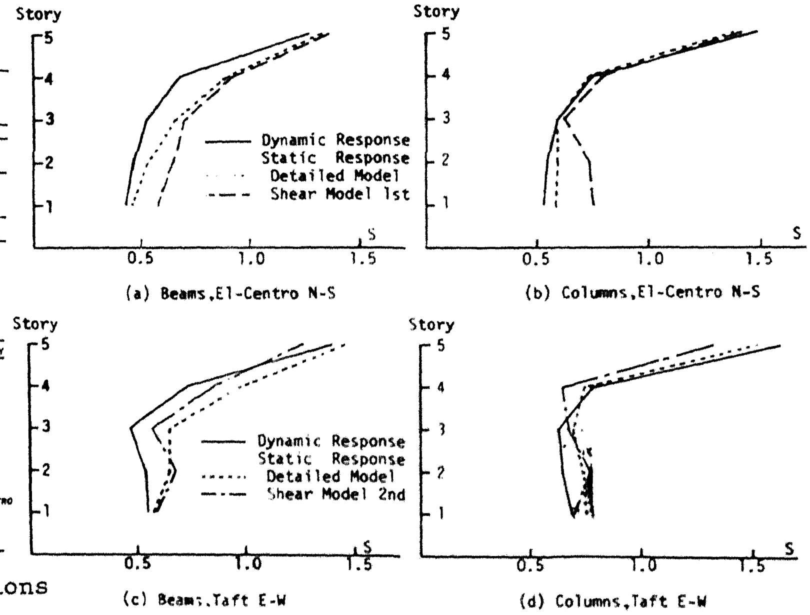

Fig.9 Maximum Stress Responses

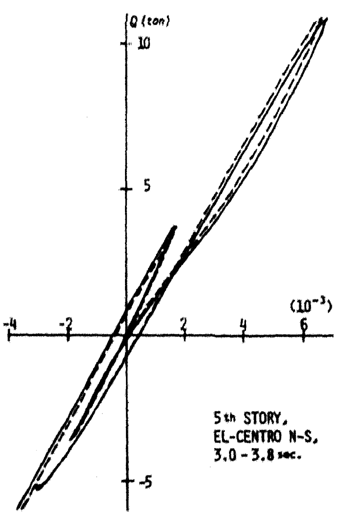

Fig.5 Q-R Relation for El Centro N-S

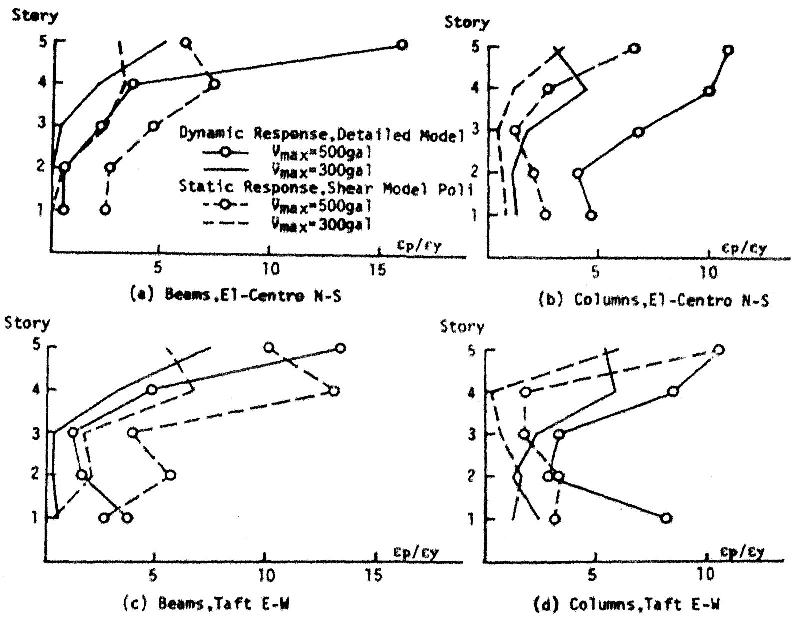

Fig.10 Maximum Plastic Strain Responses

Gravity Load Condition	1.65(G+P)
Combination Load Condition	G+P+1.5K

G:Dead Load, P:Live Load, K:Aseismic Load

Table-1 Load Factor

	El-Centro N-S		Taft E-W	
	Qmax	Rmax	Qmax	Rmax
Shear Model 1st	0.162	0.217	0.168	0.129
Shear Model 2nd	0.207	0.186	0.096	0.097
Shear Model 3rd	0.302	0.216	0.145	0.194
Shear Model 4th	0.434	0.252	0.205	0.296
Shear Model 5th	0.536	0.269	0.309	0.418

ıble-3 Difference of Responses

	1st	2nd	3rd	4th	5th
Detailed Model	1.149	0.433	0.249	0.168	0.119
Shear Model 1st	1.149 (1.000)	0.465 (1.075)	0.300 (1.202)	0.222 (1.322)	0.170 (1.426)
Shear Model 2nd	1.114 (0.969)	0.446 (1.031)	0.288 (1.156)	0.216 (1.282)	0.165 (1.390)
Shear Model 3rd	1.080 (0.940)	0.431 (0.997)	0.278 (1.117)	0.209 (1.241)	0.161 (1.352)
Shear Model 4th	1.045 (0.910)	0.419 (0.969)	0.270 (1.084)	0.202 (1.200)	0.156 (1.310)
Shear Model 5th	1.017 (0.885)	0.411 (0.949)	0.264 (1.061)	0.197 (1.170)	0.151 (1.267)

Table-2 Natural Period