Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Seismic coefficient distribution of high-rise reinforced concrete buildings

K.Shimazaki
Technical Research Institute, Hazama Corporation, Tsukuba, Japan

ABSTRACT : The story shear distribution of high-rise reinforced concrete buildings was investigated for purpose of the earthquake resistant design. The time-invariable oscillatory mode shape of the buildings designed with the appropriate shear distribution was investigated and revealed approximately the same elastic stiffness mode shape. This results show that the seismic coefficient obtained by the SRSS method using the elastic stiffness is the best and this higher mode effect can not be ignored. The seismic coefficient distribution proposed previously was compared with the SRSS distribution. The result shows the inverted triangular shape + top concentrated load type was superior. The investigation of story over turning moment showed that the axial load of the first story column could be reduced from the value obtained by the seismic load used in the design which considered higher mode effects.

1 INTRODUCTION

The story drift of a reinforced concrete structure caused by strong ground motion is an important factor in earthquake-resistant designs. This story drift is affected by the base shear coefficient and the seismic coefficient distribution. For SDOF systems, it was shown at the last conference*[1]*, that if the system had a certain strength, the nonlinear displacement response would be close to the elastic response. The base shear coefficient desired for the design was also proposed.

For a multi-story building, total drift of the building can be estimated as an equivalent SDOF system. The story drift may be also estimated from that value using mode shapes if they are steady during response.

Many shapes of the design seismic coefficient distribution were proposed to avoid story drift concentration. Most of them, however, were investigated only for the elastic response results. These seismic coefficient distributions and their investigations are summarized in refference*[2]*

It is easy to evaluate the elastic stiffness of a building in the first stage of the design. It is also useful to know the nonlinear response from the elastic stiffness. The object of this paper is to investigate the relation between the story drift of elastic and nonlinear response for MDOF systems, and to evaluate the most suitable distribution shape of the seismic coefficient for an earthquake-resistant design.

2 NONLINEAR RESPONSE OF WELL-DESIGNED BUILDINGS

2.1 *Buildings and ground motions*

Two buildings shown in Figure 1 have been investigated in this paper. One is a 35 story building designed with a suitable base shear and shear distribution*[1]*. The other one is a roughly designed 60 story building. These members were designed under the weak-beam strong-column concept. The elastic eigen periods obtained from the frame analysis model are listed in Table 1.

Table 1. Elastic eigen periods

Building	Period (sec) 1st	2nd	3rd
35 story	1.60	0.54	0.30
60 story	3.49	1.11	0.61

The ground motions used are ;

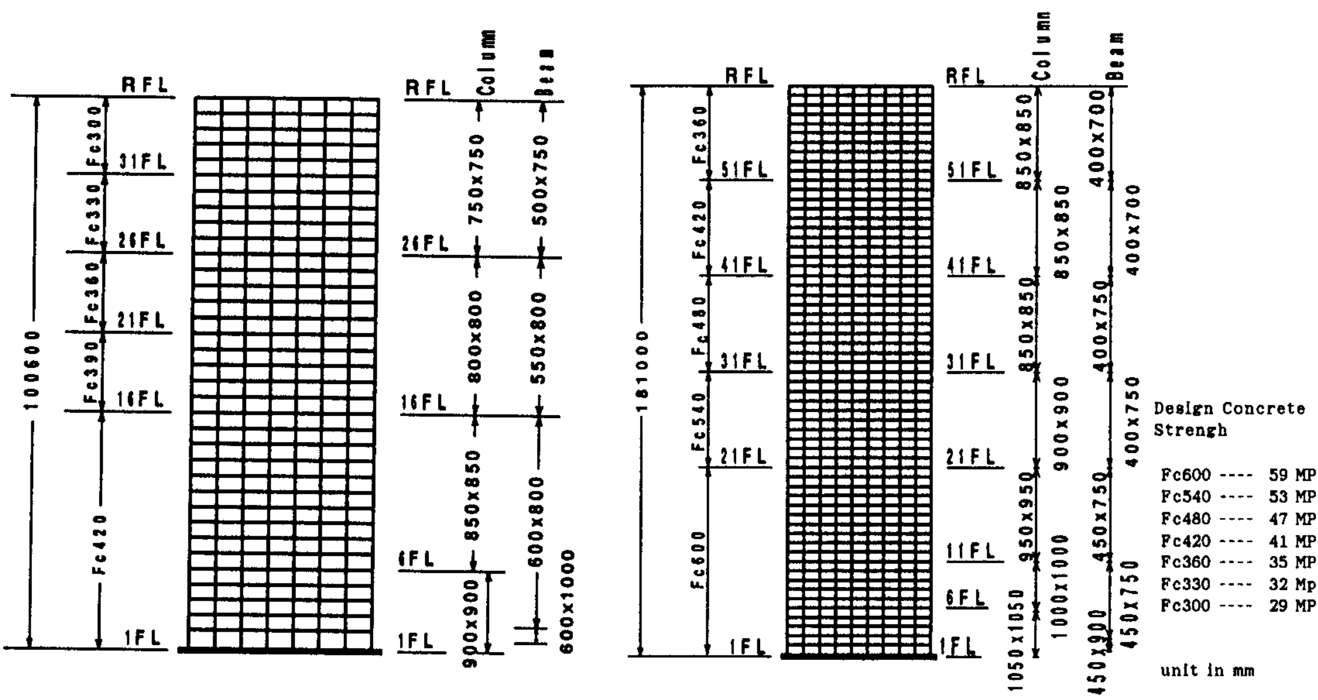
i) El Centro 1940 NS,
ii) Hachinohe 1968 NS,
iii) Tohoku Univ. 1972 NS,
iv) RT2.TFT.

The ground motions labeled RT2.TFT is a synthetic motion which has Japanese standard response spectrum and Taft 1952 EW phase. Response spectrum of these four ground motions were shown in Figure 2. The ground motion records are scaled with 50 cm/sec as the maximum velocity.

2.2 *Mode shapes of buildings*

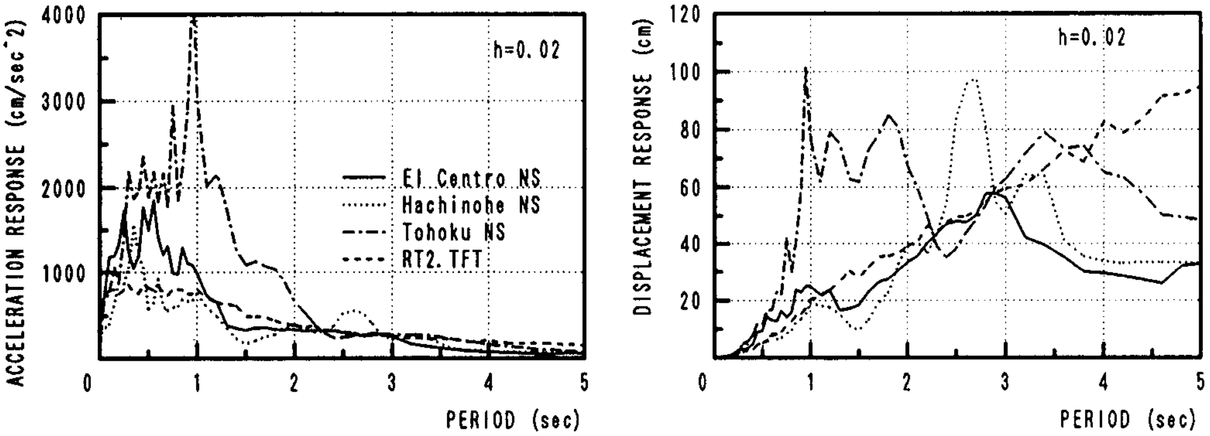
The 35 story building was analyzed for nonlinear dynamic response of three ground motions. Frame response analysis was conducted using Takeda hysteresis models in Giberson type beam models*[3]* and assumed the tangent-stiffness-proportional damping to be 3% for the elastic stiffness.

The time-invariable oscillatory mode shape defined by Takizawa*[4]* was calculated as a result of eigen value solution of the correlation matrix of the floor displacement response. These mode shapes were



(a) 35 story building (b) 60 story building

Fig. 1 Outline of buildings



(a) Acceleration response spectra (b) Displacement response spectra

Fig. 2 Response spectra of ground motions used

interpreted to be the mean response mode shapes. These mode shapes have been compared with the elastic oscillatory mode shape in Figure 3a. The mode shapes appear to be very close to each other. The shape of the higher story drift modes shown in Figure 3b was a little different in the lower floors compared with the elastic mode. The same result was obtained for the 60 story building.

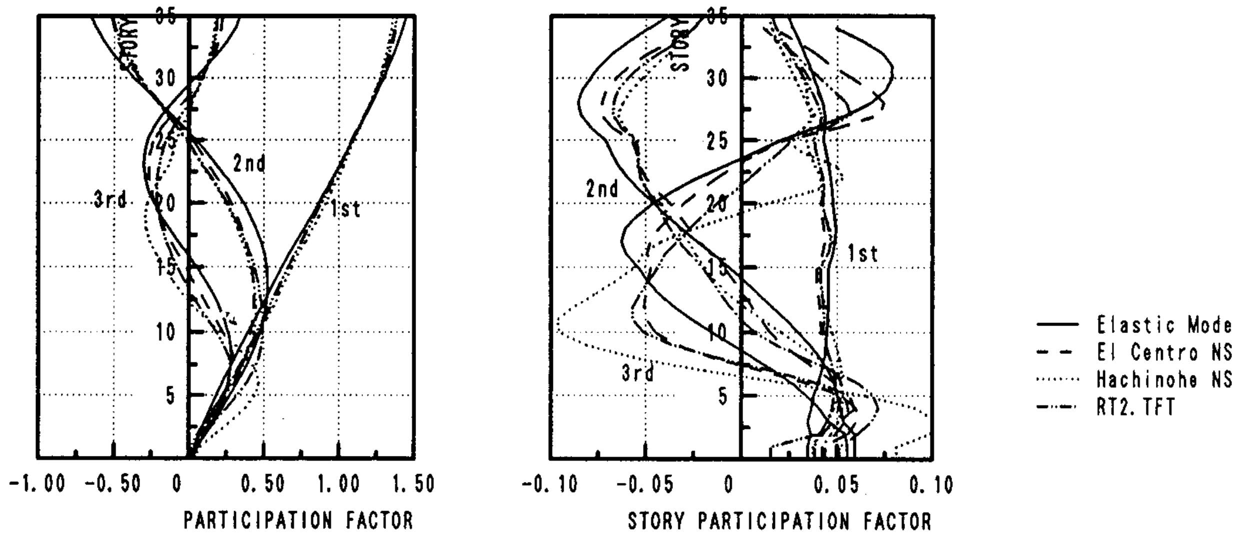
2.3 *Story displacement and story shear response*

Story drifts of the 35 story building obtained from the nonlinear dynamic response analyses have been compared with the value obtained by the SRSS method in Figure 4. The SRSS values were obtained using the root-sum-square formula which uses the lower five elastic story drift modes and a 2% damping response spectrum.

The SRSS values calculated using Hachinohe NS response spectrum were very low because the calculated spectral response curves(Fig. 2b) showed that it had very low response in range 1.4 to 1.6 sec. The lowest period of the 35 story building was just in that range. The values shown as M. Hachinohe in Fig. 4 calculated using smoothed response spectrum, defined as the idealized constant acceleration and constant velocity response spectrum, were showed very close to the nonlinear dynamic response values.

Both values were very close as was expected for El Centro response. In the lower floors, however, a little difference was recognized. The reason of this difference is the difference of the higher story drift modes shown in Figure 3.

Figure 5 compares the 35 story building's story shear distribution shapes normalized 1.0 at the base. Shear



(a) Mode shapes

(b) In story mode shapes

Fig. 3 Mode shapes of the 35 story building

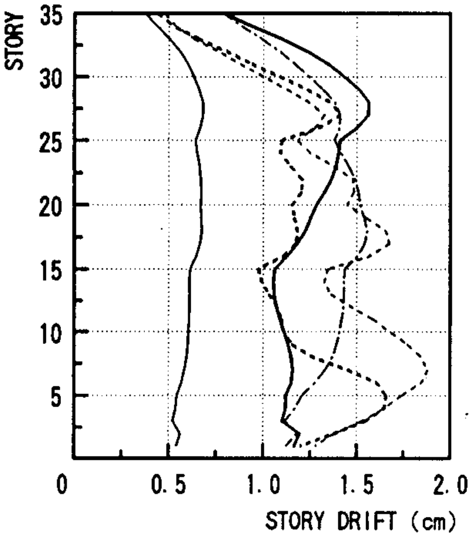


Fig. 4 Displacement response

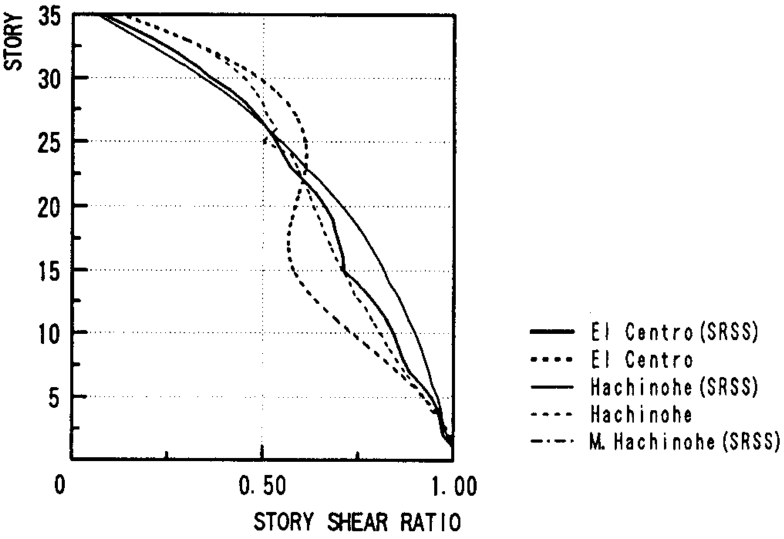


Fig. 5 Shear distribution shape

distribution wave shapes were included in the SRSS results for El Centro ground motion record. It can be said, however, that this is good correlation.

The same results are obtained for the 60 story buildings.

These results indicate the SRSS method is a good method for estimating the nonlinear response for well-designed buildings.

3 SEISMIC COEFFICIENT DISTRIBUTION

3.1 *Seismic shear coefficients*

Seismic shear coefficient distribution was investigated by comparing the previously proposed values with those obtained using the SRSS method. The SRSS values were calculated as the root-sum-square of the lower five mode shear force. The seismic coefficient distribution used was as follows;

i)SRSS distribution using Japanese standard normalized spectrum, (Rt)*[5]*,

ii)Japanese standard type distribution, (Ai)*[5]*,

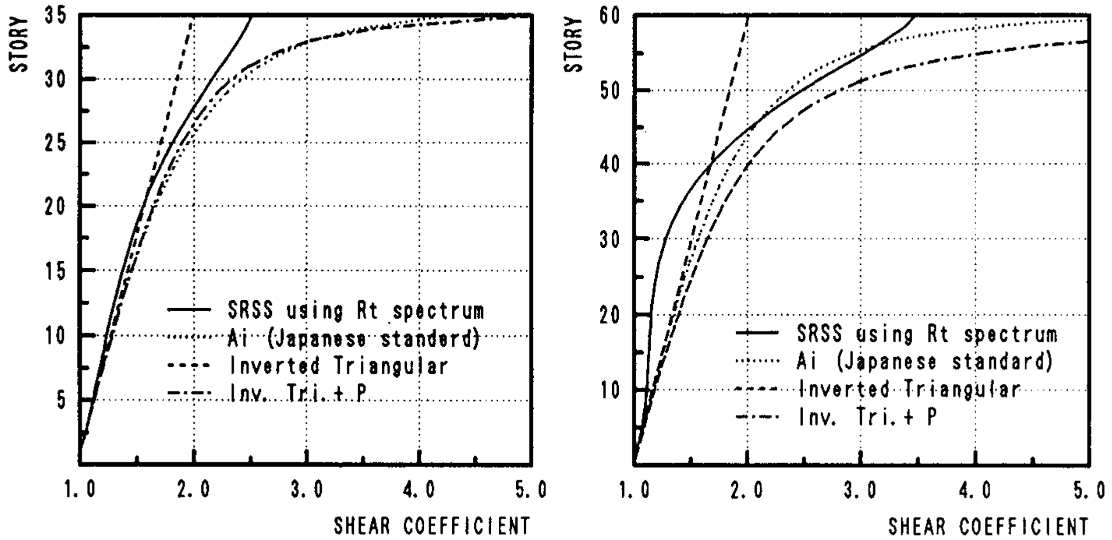
iii)Inverted triangular shaped distribution,

iv)Inverted triangular + concentrated top load distribution*[6]*.

The four shear coefficient distribution shown in Figure 6 is for the 35 and 60 story buildings. Figure 7 shows the ratio of these coefficient values to the SRSS value.

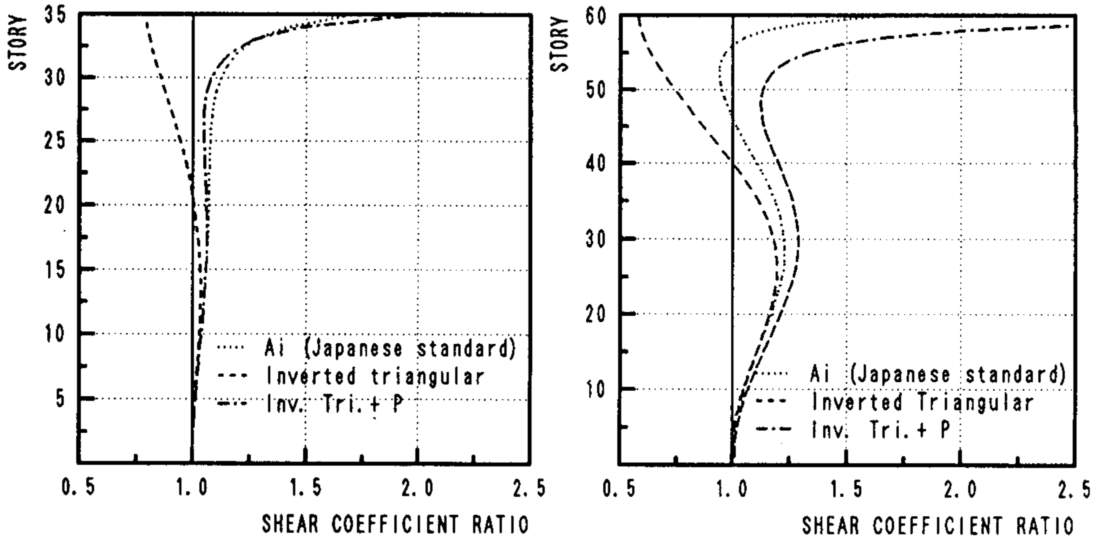
The results show that the values of the inverted triangular + concentrated top load were always greater than the SRSS value. The Ai distribution values were less than the SRSS values for the floors between 45th and 55th story, and the inverted triangular shape values were less in the floors above 40th story in the 60 story building. All values except the inverted triangular value in the floors above 20th story are larger than the SRSS values in the 35 story building.

Higher oscillation mode effects on the shear force distribution shape were investigated using the participative factors in the SRSS method. The factors are defined as the the square value of each mode shear force divided by the sum square value of the lower five



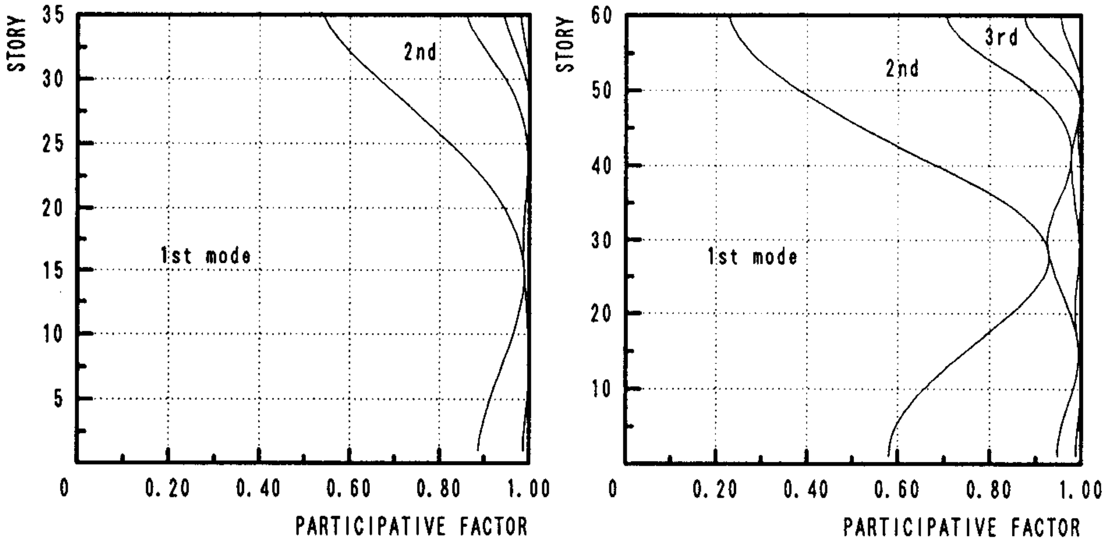
(a) 35 story building (b) 60 story building

Fig. 6 Shear coefficient distribution



(a) 35 story building (b) 60 story building

Fig. 7 Shear coefficient ratio to the SRSS



(a) 35 story building (b) 60 story building

Fig. 8 Participative factors in the SRSS values modes. Figure 8 shows the results. In the upper one third floors, the rate of the lowest mode becomes smaller, and is reduced to almost one half in the 35 story building and one third in the 60 story building at the top. This indicates the higher mode effect should be taken into account in the upper floors.

In the 60 story building, the participative factor of the first mode shear is 0.6 at the bottom. As the rate of the first mode shear to the total shear is root of this value, the first mode base shear is about 0.8 times the total base shear.

In conservative designs, the inverted triangular + concentrated top load type is superior, if the SRSS method was not used.

3.2 *Story over turning moment*

The over turning moment at the first story calculated from the design shear distribution which took into account the effect of higher modes was larger than the actual value. This kind of things can be often observed during the dynamic response analysis. The dynamic response results, however, include many factors. Accordingly, the over turning moment calculated from the design load distribution can not reduce directory using the results of response analysis.

The story over turning moment calculated from the design load described previously was compared with the values calculated by the SRSS method. Under the SRSS method, values are calculated as the root-sum-square of the story over turning moment of each mode. Figure 9a shows the story over turning moment for the 60 story building expressed in the values relative to the SRSS base moment. The value ratio in comparison to the SRSS value were shown in Figure 9b. All values calculated through design load distribution are larger than the SRSS moment values at the lower floor. If figure 9b shows the reduction rate of the over turning moment, it is 0.7 for the inverted triangular + concentrated top distribution design load.

Figure 9c shows the participative factors of the story overturning moment in the SRSS method. This shows that the first story over turning moment can be obtained only by the first mode load. The over turning moment or the axial load of the first story columns, therefore, can be reduced from the value obtained by the design seismic load which took into account the effects of higher mode. The reduction rate can be defined as the over turning moment of the first mode load divided by the over turning moment calculated from the design load distribution.

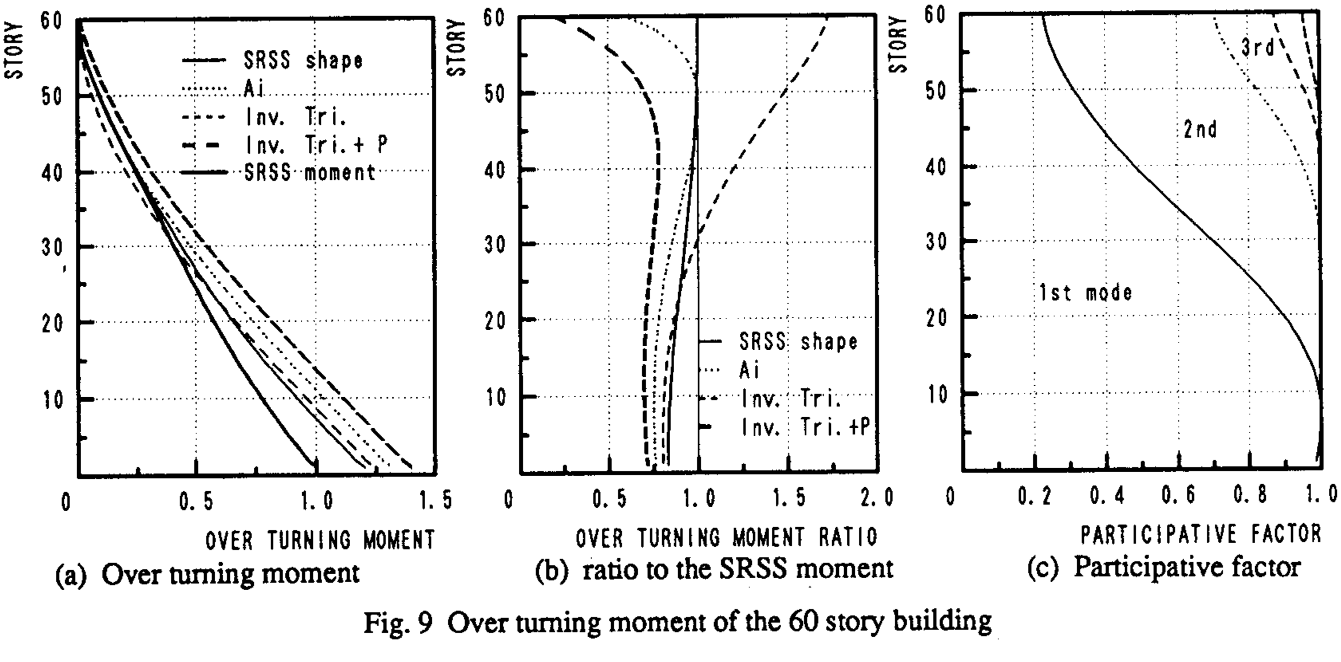
3.3 *Nonlinear dynamic response according to seismic coefficient distribution*

To investigate the effect of the assumed design shear distribution on the story drift, the 35 and 60 story buildings were analyzed for nonlinear dynamic response analyses using Tohoku NS ground motion which have much influence on the higher mode range.

The buildings were designed to have 0.18/Ti (Ti:Initial period) base shear coefficients*[1]*. The strength of each story was determined as the just value calculated using the design base shear coefficient and shear force distribution. The mathematical model used was a lumped mass type bending/shear model. Non-linearlity was considered only for shear deformation. The tri-linear Takeda model is used for the hysteresis model of shear deformation. The first break point was assumed to be one third of the story strength and the second slope was assumed to be 0.45 times the elastic stiffness. Damping was assumed the tangent-stiffness-proportional damping and to be 3% for the elastic stiffness.

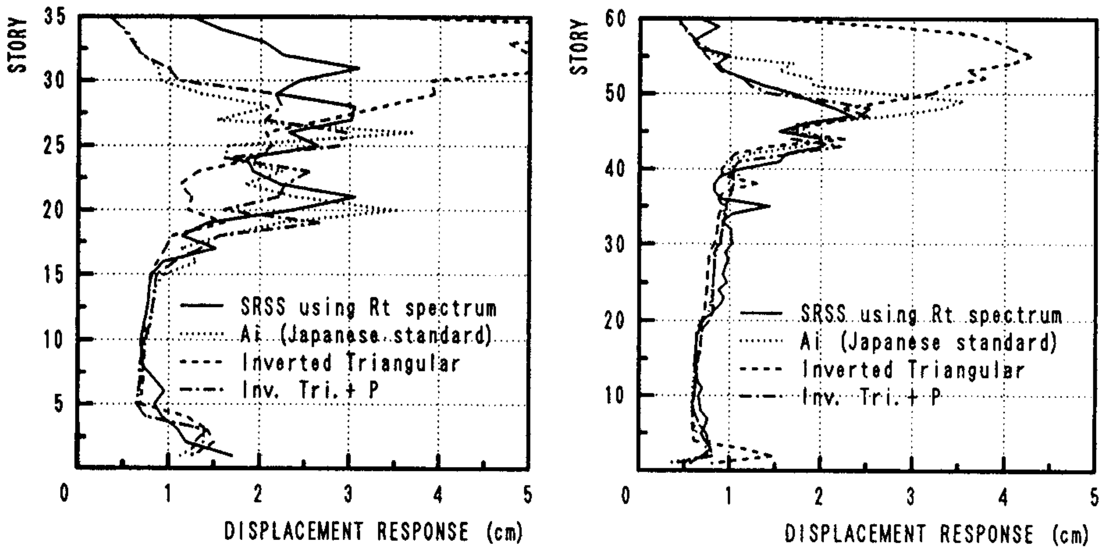
Figure 10 shows the results of the maximum story drift response. For the 60 story building, the story drift were concentrated in the upper floors for the buildings designed by the inverted triangular and Ai shear coefficient. The story drift of the 35 story building designed by inverted triangular shear coefficient were concentrated in the upper floors. These design shear coefficients were smaller than the SRSS value shown in figure 6 and 7.

This shows that the assumed seismic coefficient



(a) Over turning moment (b) ratio to the SRSS moment (c) Participative factor

Fig. 9 Over turning moment of the 60 story building



(a) 35 story building (b) 60 story building

Fig. 10 Displacement response for the Tohoku NS ground motion

distribution affected the amount of story-to-story drift concentration.

4 CONCLUSIONS

1. The seismic coefficient distribution needs consideration with regard to higher-mode effects.
2. The coefficient obtained from the SRSS method was the most suitable, and the inverted triangular shape + concentration top load type was next one for seismic coefficient distribution.
3. The nonlinear response of the buildings which ignored higher mode effects in the design shear load distribution showed that the story drift was concentrated at the upper floors.
4. The axial load of the first story columns can be reduced from the value obtained by the design seismic load which considered the effects of higher mode.

ACKNOWLEDGMENTS

The writer gratefully acknowledges Professor A. WADA of Tokyo Institute of Technology for the valuable suggestion for the SRSS method and Professor M. YOSHIMURA of Tokyo Metropolitan University for the instruction of the time invariable oscillatory mode. Mr. Y. HAYAKAWA of HAZAMA Corp. is thanked for his assistance of drawing figures.

REFERENCE

1) Shimazaki K. 1988. Strong ground motion drift and base shear coefficient for R/C structures. *Proc. 9th WCEE:* V165-170. Tokyo, Japan.
2) AIJ 1987. *Seismic loads--state of the art and future developments*(in Japanese). AIJ. Tokyo, Japan
3) Takeda,T., M.A. Sozen & N.N. Nelson 1970. Reinforced concrete response to simulated earthquakes. *Journal of structural division, ASCE.* Vol. 96. No. ST12: 2557-2573
4) Takizawa, H. 1990. Extraction of the time-invariant oscillatory modes during the kinematic failure of ductile weak-girder and strong-column frames (in Japanese). *Journal of structural engineering.* Vol.36B: 245-258. Tokyo, Japan
5) Ministry of construction 1980. *Commentary on the structural calculation based on the revised enforcement order, Building standard law* (in Japanese). Building Center of Japan.
6) International conference of building officials 1988. *Uniform building code.* California, U.S.A