Restoring Force Characteristics of Steel Frames of Nuclear Power Station Buildings
(Part 2) - Evaluation of Restoring Force Characteristics Model -

Noriyoshi NAKAMURA
The Tokyo Electric Power CO., Inc. Tokyo, Japan
Hidemasa TOMURA, Mikio YAMAMOTO
Obayashi Corporation, Tokyo, Japan
Masatoshi UEDA, Hajime TANIGUCHI
Takenaka Corporation, Tokyo, Japan
Mitsuru IZUMI, Yuji AIKAWA
Taisei Corporation, Tokyo, Japan

1 INTRODUCTION

In Japan,it is very important to evaluate the nonlinear behavior of nuclear power station building in case of large scale earthquakes.

The purpose of this study is to suggest the evaluation technique of restoring force characteristics of steel frames in nuclear power station buildings.

In part 1 " setting of restoring force characteristics model ",simple restoring force characteristics models for earthquake resistant design of steel frames with X type braces and K type braces were suggested by a series of experiments and investigation of previous studies.

In part 2 " evaluation of restoring force characteristics model",a series of dynamic nonlinear response analyses were carried out,using simple restoring force characteristics models suggested in part 1 and precise models. They were compared with each other,and the applicability of the simple models for the design were verified.

2 RESPONSE ANALYSIS OF THE FRAMES WITH X TYPE BRACES

2.1 Analysis condition

Earthquake response analyses were carried out for plane frames consisted of columns,beams and X type braces in order to evaluate the applicability of the restoring force characteristics of the steel frames with X type braces. The members were chosen on the basis of the investigation of members in real nuclear power plant buildings. The dimensions of the frames are shown in Table 1.

In creating the analytical model,average structural properties of members in real plants (slenderness ratio 60,width-to-thickness ratio of flange 9) and effective buckling length which was obtained through the experiments were used.

Following methods were used in the analyses.

Method A : The frames are converted into lumped mass models,and proposed restoring force characteristics model are given. The skeleton curve of the model is bilinear,and the hysteresis loop is a combined model of perfect elasto-plastic type and pinching type. The models are shown in Fig.1.

Method B : The frames are not converted,and analized directly. Instead, restoring force characteristics are given to each menber. The column-beam joint in the analysis by this method is shown in Fig.2. Restoring force characteristics models proposed by Dr.Wakabayashi et al.(1) were modified in the analysis. Wakabayashi's model is applied to the restoring force characteristics of a brace being subjected to axial load. However, in the model, buckling strength is the strength in steady loop with alternative loading, therefore it is not sufficient to express the strength in initial and early cycles. In the analysis,the modified model was used without change

SMiRT 11 Transactions Vol. K (August 1991) Tokyo, Japan, © 1991

of the fundamental rule. The buckling strength in initial loading and the degradation of the strength in alternative loading are taken into account by modifying the strength curve in the compressive area of this model. The model is shown in Fig.3.
Real behavior of the frames was supposed to be expressed more accurately by method B. Comparing the result by both methods,the applicability of method A was evaluated.
The natural period of each frame was set to 0.3 sec, which is the average value of the natural period of the plants.

Parameters for the analyses were the number of stories and the magmitude of input acceleration. 1.5,2.0,3.0 and 6.0α_0 (α_0 : input accerelation at which response of shear force corresponds to elastic limit of braces) earthquake motion were input for 1,2 and 3 storied building models. Input earthquake motion is an artificial wave which has the same phase as TAFT EW.

Caluculated cases are shown in Table 2.

2.2 Analytical results

Maximum response acceleration and maximum response displacement in each case is shown in Fig.4 and Fig.5. Examples of floor response spectra are shown in Fig.6. The calculated results by both methods of response acceleration and displecement showed similar tendency regardless of number of stories and magnitude of input motion.

3 RESPONSE ANALYSIS OF THE FRAMES WITH K TYPE BRACES

3.1 Analysis condition

Earthquake response analyses were carried out for plane frames consisting of columns,beams and K type braces in order to evaluate the applicability of restoring force characteristics of the steel frames with K type braces. The frames used in the experiments of previous studies (2),(5) were used in the analysis. The dimensions of the frames are shown in Table 3.

In the previous study(2),(3),(4),experimental results were simulated by analyses with frames,and adequacy by lumped mass models for evaluating the nonlinear behavior of the frame with K type brace was verified by comparing with the results by the frame models. Afterward the caluculated results were compared by both lumped mass models.

Following methods were used in the analyses.
Method C : The frames are converted into lumped mass models,and proposed restoring force characteristics models are given. The skeleton curve of the model is bilinear,and the hysteresis loop is a combined type of perfect elasto-plastic type and peak-oriented bilinear type. The models are shown in Fig.7.
Method D : The frames are converted into lumped mass models ,and the restoring force characteristic models which simulate experimental results are given. This model is set up so that the unloading gradient and vertex strength at reloading would vary according to the deformation angle with the skeleton curve being bilinear type and hysteresis characteristics being peak-oriented type. This model is shown in Fig.8 with experimental results.

Real behavior of the frames is expected to be expressed more accurately by method D. Comparing the results given by both methods, the applicability of method C was evaluated.

The natural period of each frame was set to 0.3 sec. in the same way as was done with X type brace. Parameter of the analyses were configuration of a frame and magnitude of input acceleration. Earthquake motion 1.5,2.0,3.0 and 6.0α_0 were input for 3 kinds of the frames. Input earthquake motion is the same artificial wave used in the analysis of the frames with X type braces.

Caluculated cases are shown in Table 4.

3.2 Analytical results

Maximum response acceleration and maximum response displacement in each case is shown in Fig.9 and Fig.10. Examples of floor response spectra are shown in Fig.10. The calculated results of response acceleration and displacement by both methods showed similar tendency regardless of configuration and the magnitude of input motion.

4 EVALUATION OF ANALYTICAL RESULTS

In evaluating the nonlinear behavior of the steel frames in the buildings in the event of a large scale earthquake,the frames are confirmed to have enough ductility. Furthermore appropriate floor response spectrum which reflect the behavior of the buildings should be obtained in order to confirm the serviceability of machinery. Therefore the restoring force characteristic model for the design should satisfy the following conditions.

(1) Maximum response displacement is obtained appropriately.

(2) Response acceleration spectra are obtained appropriately.

In the calculated results of maximum response displacement of the frames with X type braces,the ratio of the results by method A to the results by method B varies only from 0.90 to 1.21. Floor response spectrum by method A agreed well with the results by method B in overall configuration and dominant period.

In the caluculated results of maximum response displacement of the frames with K type braces,the ratio of the results by method C to the results by method D varies only from 0.84 to 1.06. Floor response spectrum by method C agreed well with the results by method D in overall configuration and dominant period.

By these analyses,proposed models for the frames with X type brace and K type brace are judged to be effective as models for aseismic design.

5 CONCLUSION

By a series of experiments and investigations of previous studies, simple restoring force characteristic models which are used in aseismic design of steel frames for nuclear power plant buildings are proposed.

The models for the design were verified to be appropriate by comparison with precise models in a series of dynamic nonlinear response analysis.

This study was carried out as a part of joint research study by ten electric power companies in Japan (Tokyo,Hokkaido,Tohoku,Chubu,Hokuriku,Kansai,Chugoku,Shikoku,Kyushu and Japan Atomic) being cooperated by five construction companies(Obayashi,Kajima,Shimizu,Taisei,Takenaka). This work was performed by the guidance of "Committee of Research" chaired by Prof.Ben Kato (The University of Tokyo).The authors wish to acknowledge to the valuable cooperation and suggestions given by the members of the Committee.

Reference

1)Wakabayashi,M.,et al.,(1982),Formularization of hysteresis characteristics of steel braces Part 1 derivation of function.Trans. of Architectural Institute of Japan (AIJ),No.361,pp 18-24

2)Muto,K.,et al.,(1985),A Demonstrative study of aseismic design on a large turbine building with K type braced frame. part 1.Experimental study of elasto-plastic characteristics of K type braced frame,Trans. of AIJ,No.356,pp 66-76.

3)Muto,K.,et al.,(1986),A Demonstrative study of aseismic sesign on a large turbine building with K type braced frame. part 2.Design of K type braced frame and its ultimate strength, Trans. of AIJ,No.360,pp 44-53.

4)Muto,K.,et al.,(1985),A Demonstrative study of aseismic sesign on a large turbine building with K type braced frame. part 3.Aseismic capability of a large turbine building er severe earthquake,Trans. of AIJ,No.356,pp 66-76.

5)Kato,T.,et al.,(1983),Strength and ductility of K type braced frame,summaries of technical papers of annual meeting of AIJ,pp 1431-1432

Table 1 Dimensions of the frames (X type brace)

Analysis Model		Dimensions
for method B	for method A	
X 0 1 Mass setting location M1 H S S×H=7.5m×7.5m	M1 H	M_1=4950 ton Column : BH-800×400×25×35 Beam : H-458 ×417×30×50 Brace : H-414 ×405×18×28 Joint type: Bracket type
X 0 2 M2	M2 2H	M_2=2110ton
X 0 3, X 0 4 M3 M2 M1	M3 M2 M1 3H	X 0 3 M_1 =M_2 =M_3 =740ton X 0 4 M_1 =M_2 =M_3 =590ton Brace : H-400 ×400 ×13×21 Joint type: Double gusset type

Note) ◦ Damping factor of each menber is h=2%
◦ Dimensions are the same as those of X01 unless otherwise noted

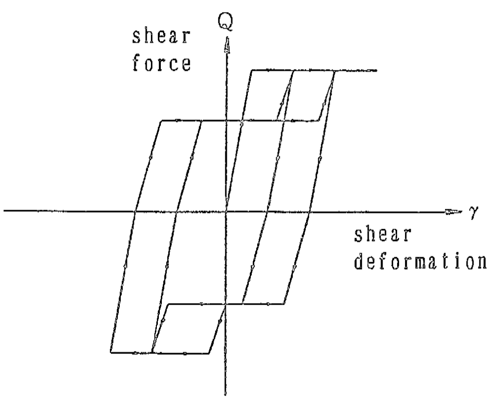


Fig.1 Restoring force characteristics model (X type brace,method A)

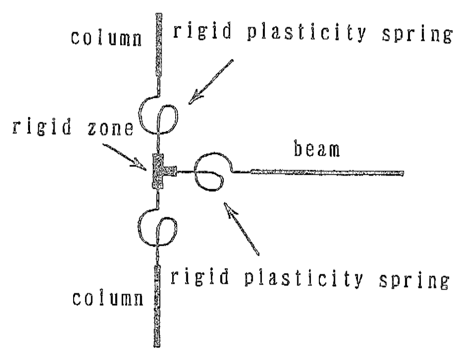


Fig.2 Beam-column joint in the analysis by method B

Table 2 Analysis cases (X type brace)

No.	Model	input acceleration	α_0(gal)
1	X 0 1	1.5 α_0	167.1
2		2.0 α_0	
3		3.0 α_0	
4		6.0 α_0	
5	X 0 2	1.5 α_0	403.4
6		2.0 α_0	
7		3.0 α_0	
8	X 0 3	2.0 α_0	506.8
9	X 0 4	2.0 α_0	550.8

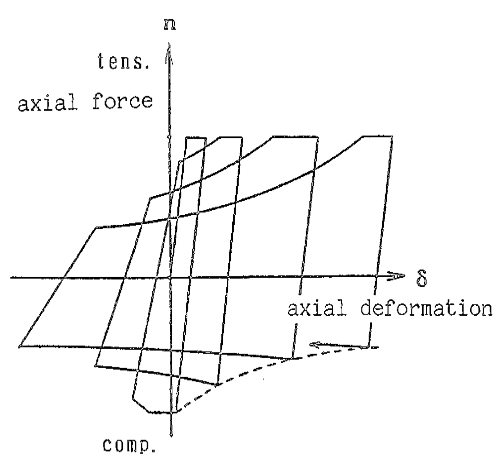


Fig.3 Relationships between axial force(n) and axial deformation (δ) of brace by modified Wakabayashi model

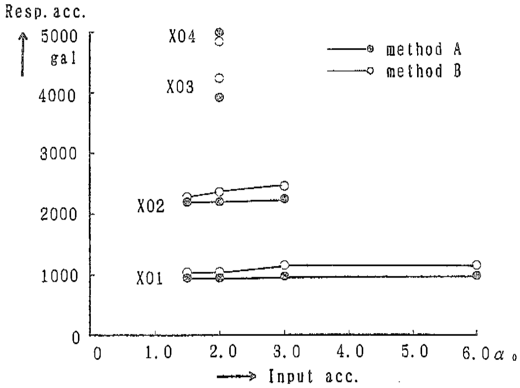


Fig.4 Relations between input acceleration and response acceleration

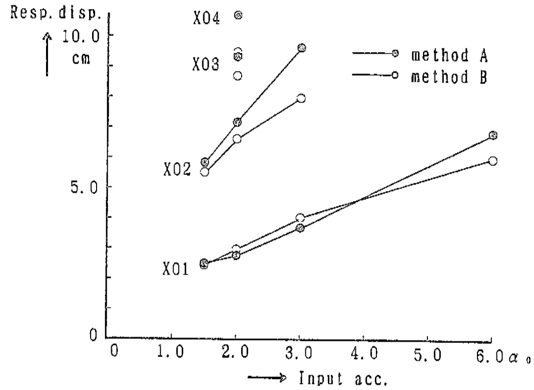


Fig.5 Relations between input acceleration and response displacement

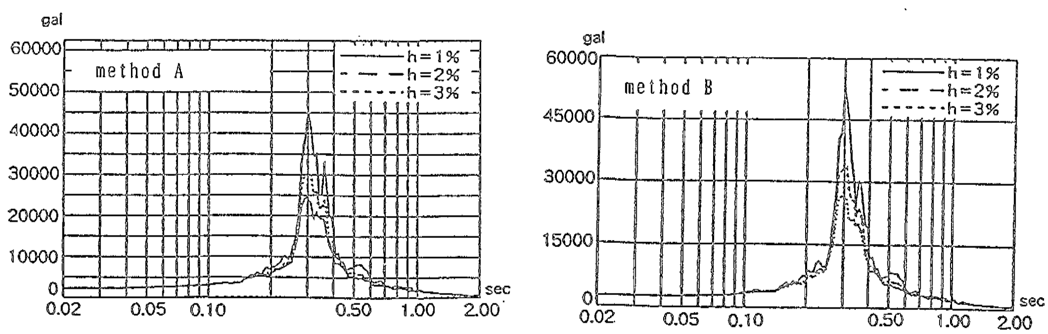
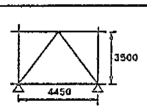
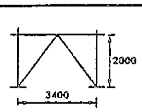
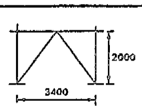


Fig.6 Floor response spectrum for acceleration (X01,3.0 α_0)

Table 3 Dimensions of the frames (K type brace)

Analysis Model			Dimensions
frame		for method C, D	
M 0 1			M=310 ton Column : H-200×200×14×28 Beam : H-456×150× 9×16 Brace : H-175×175× 6×10 Joint type: Gusset plate type
K 0 1			M=224 ton Column : H-175×175×7.5×11 Beam : H-250×125×6×9 Brace : H- 80× 80×6×6 Joint type: Double gusset type
K 0 2			M=559 ton Column : H-175×175×7.5×11 Beam : H-350×175×7×11 Brace : H-160×160×6×9 Joint type: Double gusset type

Note) ◦Damping factor of each menber is h=2%

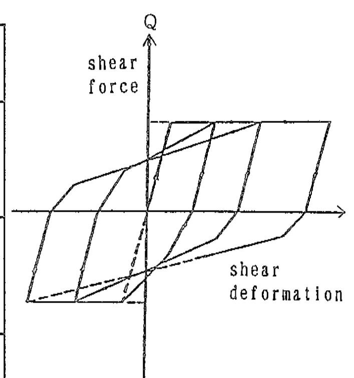


Fig.7 Restoring force characteristics model(K type brace ,method C)

Table 4 Analysis cases (K type brace)

No.	Model	input acceleration	α_0(gal)
1	M 0 1	1.5 α_0	58.40
2		2.0 α_0	
3		3.0 α_0	
4		6.0 α_0	
5	K 0 1	1.5 α_0	49.68
6		2.0 α_0	
7		3.0 α_0	
8		6.0 α_0	
9	K 0 2	1.5 α_0	46.90
10		2.0 α_0	
11		3.0 α_0	
12		6.0 α_0	

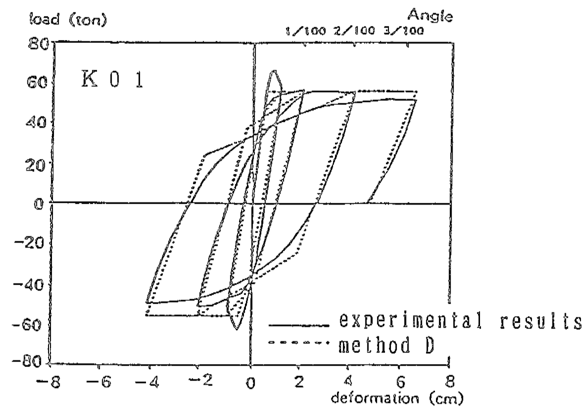


Fig.8 Restoring force characteristics model (K type brace, method D) and experimental result

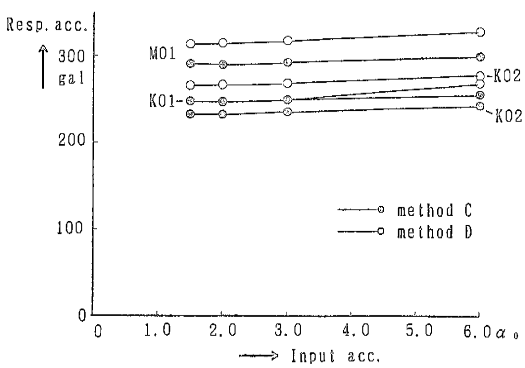


Fig.9 Relations between input acceleration and response acceleration

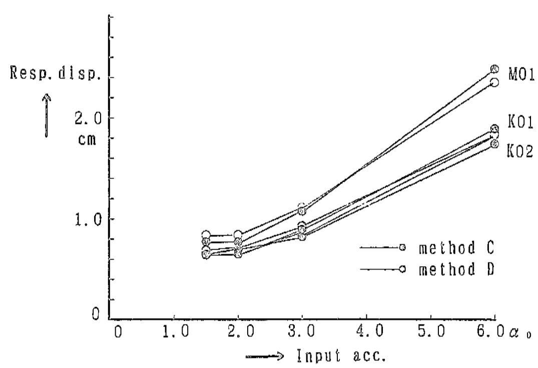


Fig.10 Relations between input acceleration and response displacement

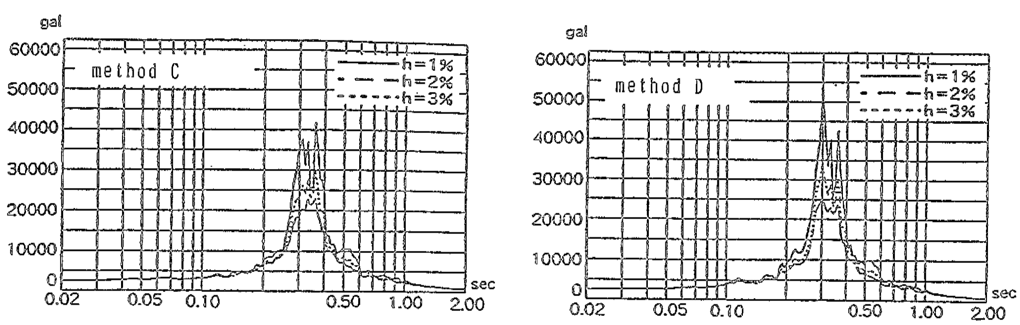


Fig.11 Floor response spectrum for acceleration (K01, 3.0 α_0)