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BRIEF NOTE

BEHAVIOR OF BOLTED JOINTS IN EARTHQUAKE EXCITATION

By

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1. Introduction

The system for the response analysis of non-linear structures was developed recently. It is named "The Computer-Actuator On-line System." The details of the system has been already described in the previous paper[1)].

The main objectives of research by this system can be summarized as the followings:

(1) To check the appropriateness of mathematical expressions for the restoring force characteristics of structures or structural elements.

(2) To obtain directly the response of structures or structural elements which have too complicated restoring force characteristics to be expressed in mathematical functions.

As an example of the analyses along the first objective, the analysis of a frame with a weak beam and strong columns can be taken. The beam is expected to respond plastically to the large earthquake excitations while the columns are considered to remain elastic. A part of the results were reported in the previous paper[2)].

In this paper the response analysis of a frame with the bolted joints is discussed. It is considered an example of the analyses along the second objective.

2. Description of Procedure

The principal procedure is shown schematically in Fig. 1. The response values are obtained through the integrating manipulation of the equation of motion in the computer for the input data of the recorded ground accelerations. In a non-linear structure, however, the restoring force must be considered a time-depending variable. Then, it is required to adopt the value which the structure has at the moment. So it resembles "an adaptive control" in control engi-

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neering. In the system the value of the restoring force is provided instantaneously by the experiment of structural models which is also controlled simultaneously by the computer.

The manipulation of integration and the precise measurement of forces and displacements are the keypoints in the analysis. Here the open type finite difference method is adopted for the integration, according to the preliminary discussion by one of the authors[3].

It brings a great advantage for these types of analyses, since no knowledge at the further steps of the calculations is required in the step by step integrations. Such a method of calculation is inevitably required, because all informations of restoring characteristics are given by the experimental procedures on the structural models, which is, of course, irreversible in the inelastic range of the models.

The direct use of the restoring force values measured in the tests brings the another advantage. It can reduce the laborious work in the measurement, since the restoring force itself is less sensitive to the preciseness of measurement than the tangent stiffness of the structural model which must be used in the other method of integration such as the linear acceleration method.

3. Analyzed Frames and Test Beams

The portal frames with the H-shaped steel beams and the rigid columns as shown in Fig. 2 are taken for analysis. Here the columns are assumed rigid for simplicity, since the columns are usually designed stronger than the beams and the investigation is focussed mainly on the inelastic behavior of the joints in the beams. In table 1, the specific properties of the analyzed frames are summarized. Each frame has the specified bolted joints in spite that the same size of the H-shaped section is used for the beam. Each joint is identified by two figures following BJG in Table 1. The figures in the upper order shows the number of bolts in a flange. The figure in the lower order distinguishes the size of holes. Namely, BJG-61 means 6 bolts in the standard sized holes recommended by AIJ Recommendation and BJG-64 means 6 bolts in the over-sized holes. BJG-0 stands for the beam with no joint which was tested for comparison.

4. Results of Analysis

Some results of Frame J-1 and J-3 are taken to show the different types of response in Figs. 4 to 7.

The frames treated in the analysis are supposed to deform in such a mode as shown in Fig. 3. The response displacement X and the restoring force F were recorded. The time histories of these values are displayed with the input data of the recorded earthquake acceleration in Figs. 4 and 5. The change of restoring force characteristics due to yielding in the beam and slippage at the bolted joint is easily recognized in Figs. 6 and 7. Compared Fig. 7 with Fig. 6, the slippage at the joint causes the sudden change in the restoring force characteristics and then the smooth hysteresis curve change into the zigzag one. The considerable drop in the magnitude of restoring force and the looseness at the joint make the frame flexible. It can be apparantly recognized in the time history of Frame J-3 in Fig. 5.

Fourier spectrum analysis gives more clear evidence of this fact. The Fourier spectrum of Frame J-1 and J-3 are shown in Figs. 8 and 9. The shift of the dominant period can be seen especially in the spectrum of Frame J-3.

5. Concluding Remarks

1) Reliability of "The Computer-Actuator On-line System" was approved. It can be adapted to the analysis of frames with very complicated restoring force characteristics, if some contrivance is provided in the technique of numerical integration.

2) The slippage of bolted joints causes the sudden change in the dynamic features of frames. It gives rise to the large response displacement with longer period, in spite that no damage is observed in the joints.

3) Further research should be required to establish the design criteria of bolted joints under cyclic loads. The criteria involving whether the slippage of bolted joints might be allowed must be discussed, considering damage of non-structural members and loud noise at slippage. The breakdown of non-structural members and the loud noise might initiate panic during earthquakes.

References

1) K. Takanashi, K. Udagawa, M. Seki, T. Okada and H. Tanaka, "Non-linear Earthquake Response Analysis of Structures by a Computer-Actuator On-line System." ERS Bulletin No. 8, Institute of Industrial Science, Univ. of Tokyo,

2) K. Takanashi, K. Udagawa and H. Tanaka, "A Simulation of Earthquake Response of Steel Buildings." Pre-print of 6th World Conference of Earthquake Engineering, Jan. 1977

3) H. Tanaka, "A Computer-Actuator On-line System for Non-linear Earthquake Response Analysis of Structures", SEISAN-KENKYU, Vol. 27 No. 12, Institute of Industrial Science, Univ. of Tokyo, Dec. 1975

Table 1 Analyzed Frames and Maximum Acceleration

Frame	Beam	Ground Motion	Structure				
		$\ddot{X}gmax$ 1)	X_p 2) (cm)	M_p 3) (t cm)	K_e 4) (t/cm)	Mass, M (t sec^2/cm)	T_o 5) (sec)
J-1	BJG-0	$1.67\alpha_y$ 6)	2.06	662.6	3.678	0.02036	0.5
J-2-(1)	BJG-61	$1.67\alpha_y$	2.06	658.4	3.678	0.02036	0.5
J-2-(2)	BJG-61	$2.5\ \alpha_y$	2.06	658.4	3.678	0.02036	0.5
J-3	BJG-64	$2.5\ \alpha_y$	2.06	654.9	3.678	0.02036	0.5
J-4	BJG-81	$2.5\ \alpha_y$	2.06	662.1	3.678	0.02036	0.5

1) Maximum acceleration
2) $X_p=F_p/K_e$
3) Full plastic moment of beam
4) Elastic stiffness of frame
5) Natural period
6) Yield acceleration, $\alpha_y=F_p/M$
$F_p=2M_p/H$
7) h=0.02, C=0.005115 (t sec/cm)

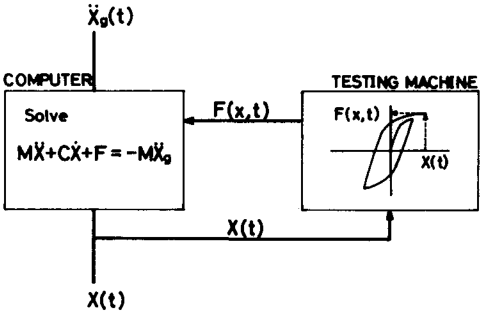

Fig.1 Flow Chart of Simulation

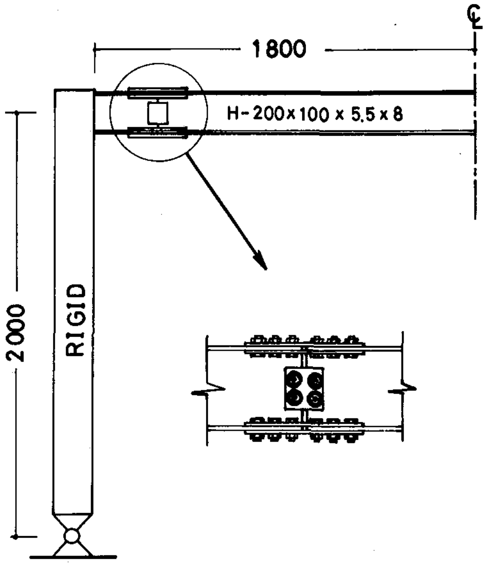

Fig.2 Frame Analyzed

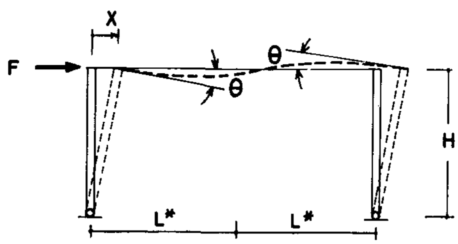

Fig.3 Deformation of Frame

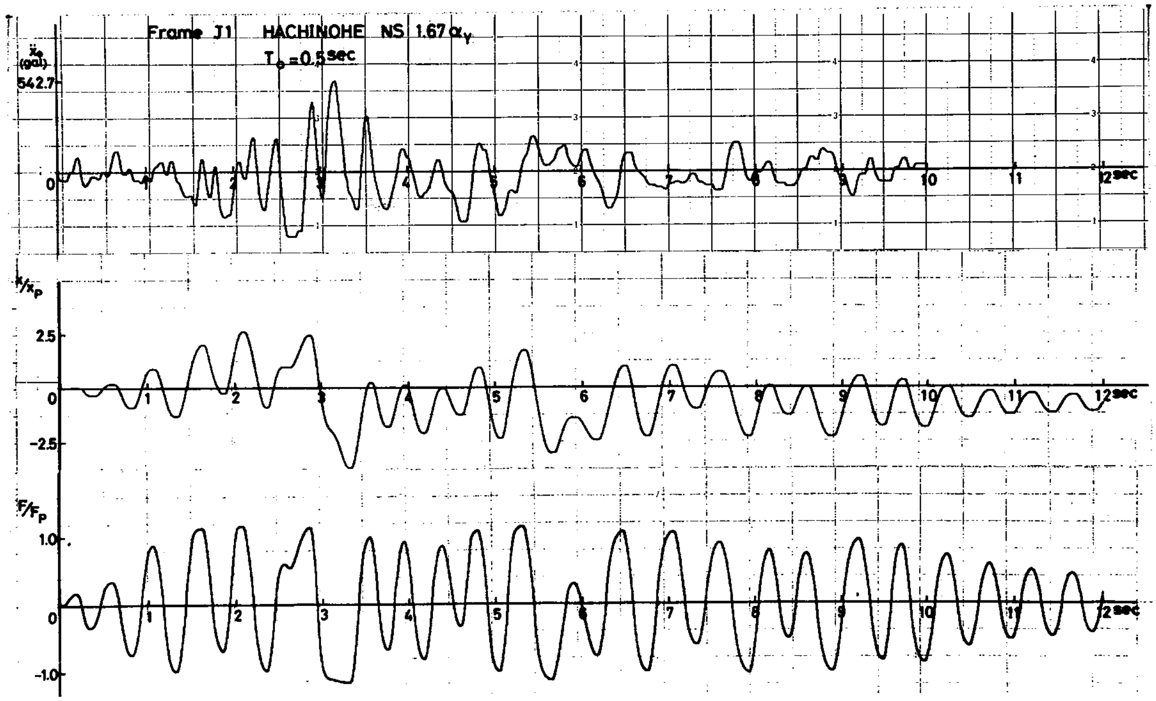

Fig.4 Time Histories of Responses (Frame J-1)

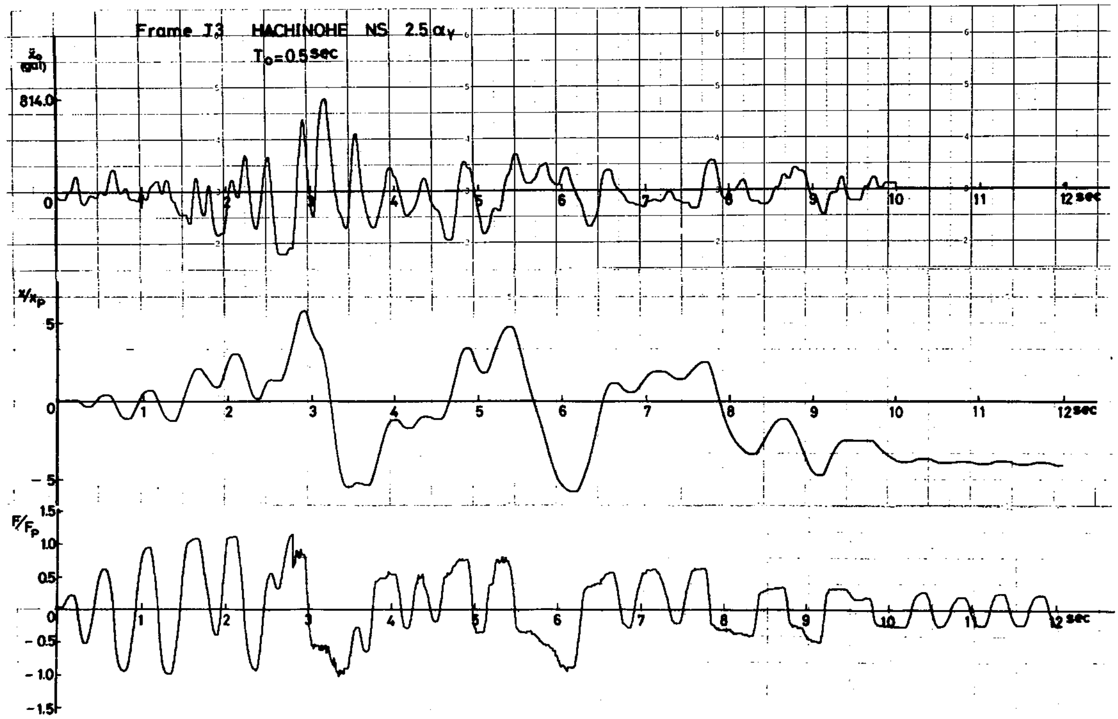

Fig.5 Time Histories of Responses (Frame J-3)

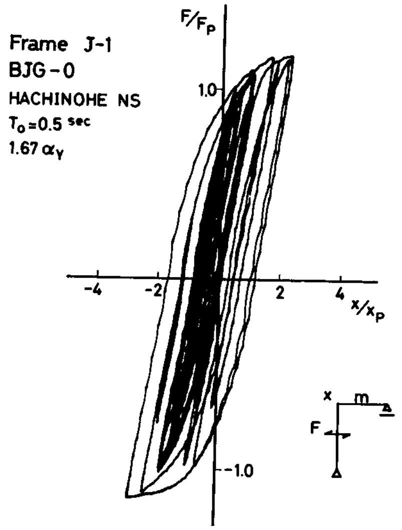

Fig.6 X/X_p vs F/F_p Curve
(Frame J-1)

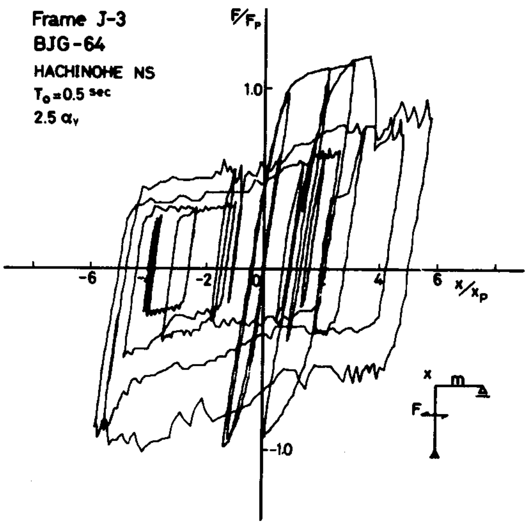

Fig.7 X/X_p vs F/F_p Curve
(Frame J-3)

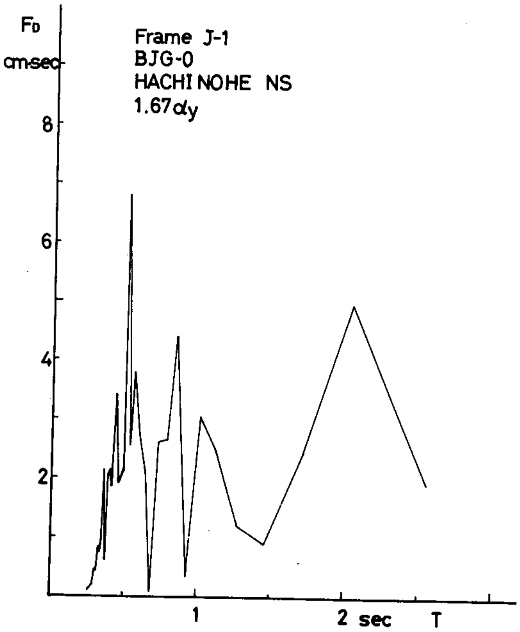

Fig.8 Fourier Spectrum of Response Displacement (Frame J-1)

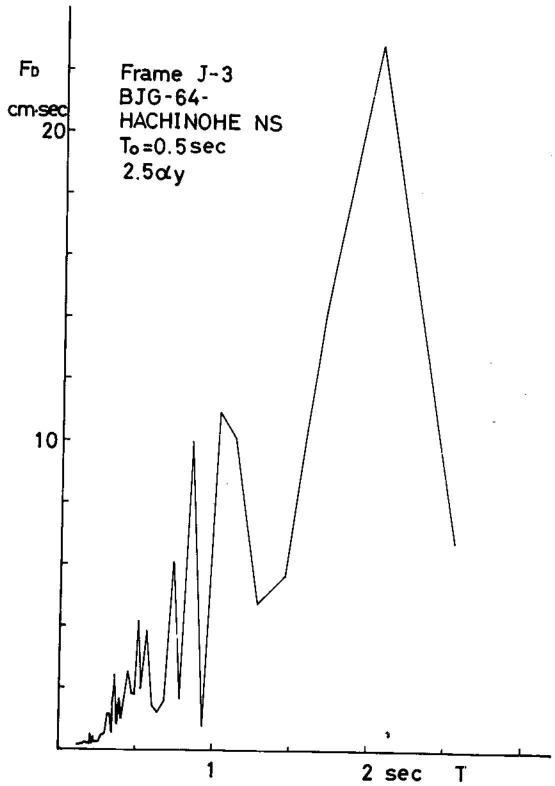

Fig.9 Fourier Spectrum of Response Displacement (Frame J-3)