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EARTHQUAKE RESPONSE ANALYSIS OF A 1-BAY 2-STORY STEEL FRAME BY COMPUTER-ACTUATOR ON-LINE SYSTEM

by

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1. Introduction

Several examples of the recent earthquake response analyses done by the "Computer-Actuator On-line System" have been reported[1)2)3)]. These frames analyzed were the most simple structures, say, portal frames. They have only one degree of freedom as the first step of so-called "On-line" analysis. So eager desire has been maintained to extend our system into wider fields of analyses involving the non-linear response of the structures with multi-degrees of freedom.

This brief note describes an initial attempt of the application of the "On-line System" to the two degrees of freedom system, that is, a 2-story steel frame.

2. Description of Procedure

The principal procedure is shown schematically in Fig. 1.

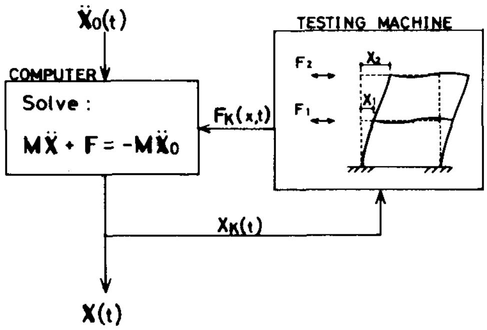

Fig.1. Block Diagram of On-line System

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The response values of the k-th story can be known by integrating the equation of motion;

$$M_k \ddot{X}_k + F_k = M \ddot{X}_0 \qquad (1)$$

in the computer for the given acceleration of a ground motion $\ddot{X}_0$, where M_k, X_k and F_k are the mass, the story displacement and the restoring force of the k-th story, respectively. In general, the restoring force is a non-linear function of the story displacement X and time t. Then, the direct use of the measured restoring forces at the simultaneously running test can provide the real response of non-linear structures.

The advantage of the "On-line System" is the possibility of analysis on any kind of structures, even though such a structure shows the extremely complicated restoring force characteristics.

An incremental calculation for integration of Eq. (1) was adopted. The simplest central difference method gives the following expression for the acceleration of the k-th story, $\ddot{X}_k$:

$$\ddot{X}_k^i = (X_k^{i+1} - 2X_k^i + X_k^{i-1}) / (\Delta t)^2 \qquad (2)$$

where Δt denotes the time interval and the superscript i means the variables at the time, $t = i\Delta t$. As an example, to solve Eq. (1) at the time, $t = i\Delta t$, is now considered. Eq. (1) can be solved approximately and X_k^{i+1} can be calculated by use of Eq. (2) since F_k^i, X_k^{i-1} and X_k^i are already known. The response value at $t = (i+1)\Delta t$, X_k^{i+1} , is the input to the controller of the testing machine. The test frame will be deformed by this response displacement X_k^{i+1} at the k-th floor level. The reaction forces for these displacements are sensed by the load cells and converted into the restoring force F_k^{i+1}. Then, all jobs at $t = i\Delta t$ are completed. This procedure is continued successively.

At each step of calculation, the calculated response displacements must be applied to the test frame as accurately as possible. The preciseness in measuring the restoring forces, that is, the accurateness of the response analysis depends mainly on this accurate application of the specified displacements. That needs some techniques in controlling the machine.

3. An Analyzed Frame

A frame analyzed is 1-bay and 2-story, as shown in Fig. 2. It consists of H-shape columns of H-150x150x7x10(SM50 steel) and H-shaped beams of H-200x100x5.5x8(SS41 steel), which are connected by welding. A set of two same frames apart by 70 cm, parallel with each other, prevents the out-of-plane buckling failure. The displacement of each floor level is given by the loading beams pinned at the centers of the beams.

The static load test was carried out to evaluate the initial stiffness of the frame, previous to the on-line analysis. The result is expressed in a matrix form as follows:

$$\begin{bmatrix} F_1 \\ F_2 \end{bmatrix} = \begin{bmatrix} 31.37 & -14.76 \\ -14.76 & 10.84 \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} \tag{3}$$

where F_1 (ton) and F_2 (ton) are the restoring forces at the lower and upper floor levels, respectively. X_1 (cm) and X_2 (cm) are the horizontal displacements.

The mass of the analyzed frame can be assumed arbitrarily. In fact, there is no weight on the frame analyzed. In this example, the equal amount of masses at the both levels is calculated from the weight which would exist on the floors if the members of the frame were designed according to a traditional allowable stress design method. The masses of the lower and upper levels, denoted by M_1 and M_2, respectively, are both 0.01463 ton sec^2/cm.

The 1st and 2nd natural periods are T_1 of 0.428 sec and T_2 of 0.121 sec, respectively.

4. Analysis by Computer-Actuator On-line System

The computer-actuator on-line analysis was carried out on the test frame. The ground acceleration used in the analysis is a part of the recorded one at Hachinohe in the 1968 Tokachi-oki earthquake, which includes the maximum value of acceleration $\ddot{X}_{omax}$. Its duration time is 8 sec. The analysis comprises three cessions: Run A-1, Run A-2 and Run A-3. Only one difference exists in the absolute values of accelerations. The maximum accelerations A_1, A_2, A_3 in the cessions are listed below:

$$\begin{aligned} &\text{Run A-1} \quad A_1 = 0.25\,\ddot{X}_0\,\max = 0.18\ \alpha_Y \\ &\text{Run A-2} \quad A_2 = 1.0\ \ddot{X}_0\,\max = 0.72\ \alpha_Y \\ &\text{Run A-3} \quad A_3 = 1.5\ \ddot{X}_0\,\max = 1.1\ \ \alpha_Y \end{aligned} \tag{4}$$

where α_Y denotes the yield acceleration which is defined as (base shear/total mass) of the statically deformed frame in the same mode as the 1st mode of vibration.

The time interval $\triangle t$ of 0.01 sec in the numerical integration of Eq. (1) was used. At each time station, the calculated response values of displacements, valocities, accelerations and the measured restoring forces were stored in the magnetic tapes.

5. Results of Analysis

A part of the results obtained are shown in Fig. 3 and 7. The time histories for Run A-1 of response displacements at the lower and upper floor levels X_1, X_2 are shown in Fig. 3, and the base shear (the sum of the restoring forces at the lower and upper floor levels) in Fig. 4. The time histories for Run A-3 of the same kinds of responses are shown in Fig. 5 and 6. The frame was observed to remain elastic during Run A-1, but some parts of the frame got into inelastic range during Run A-3. By the hysteresis loops of the endmoment vs. endrotation relationship at the lower floor beam end shown in Fig. 7, the maximum ductility $\theta\,max/\,\theta_p$ is 2.6 approximately, where θ_p is the elastic rotation at the level of the full plastic moment M_p of the beam. However, no local and lateral buckling were not observed.

The Fourier spectrum of the displacement response at the lower level in Fig. 8 shows the shift of the peak of the curve for Run A-3 due to the yielding.

The time history of response displacement at the lower level in Fig. 9 is the calculated result based on the initial stiffness of Eq. (3). The ground acceleration used was the same as used in the on-line analysis. Then, this history can be directly compared to the history in Fig. 3a.

The agreement between them is quite good up to 6 sec. However, the response obtained by the on-line analysis becomes a little smaller than the calculated response. The reason is left unfound for further analysis.

6. Concluding Remarks

1) Possibility of application of the computer-actuator on-line analysis to 2 degrees of freedom systems was approved.

2) Further research should be carried out to obtain the higher level control techniques of the testing machine. The improved system will be applicable to more complicated frame structures such as braced frames and frames with bolted connections.

References

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2) K. Takanashi et al., "A Simulation of Earthquake Response of Steel Buildings," Pre-print of 6WCEE, New Delhi, Jan. 1977

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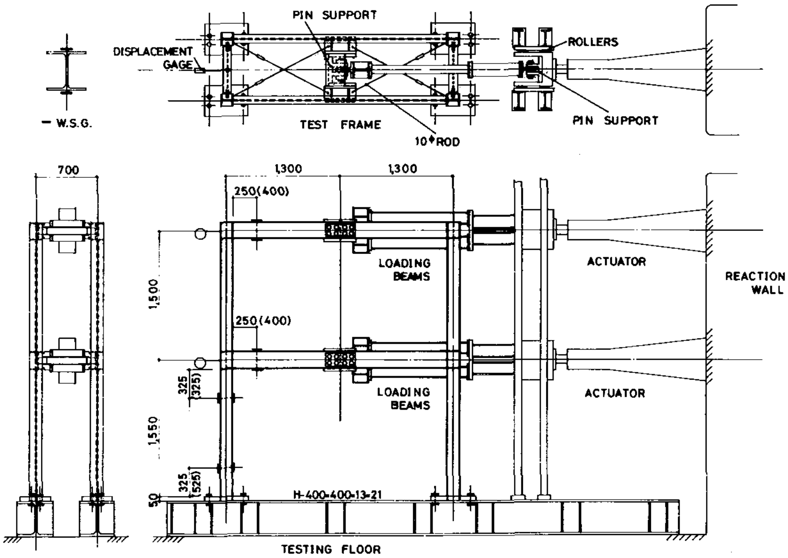

Fig.2. 1-Bay 2-Story Frame Analyzed

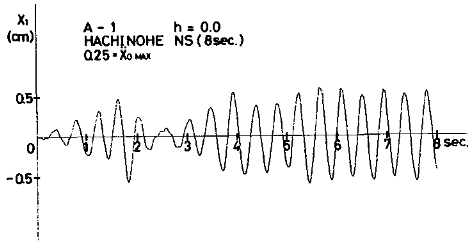

Fig.3a. Response Displacement at Lower Level, X_1 (Run A-1)

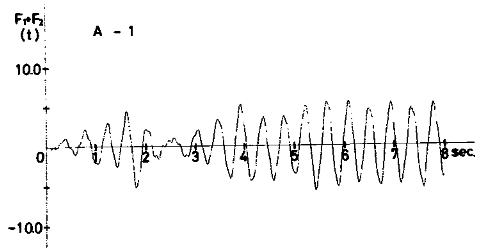

Fig.4. Base Shear, F_1+F_2 (Run A-1)

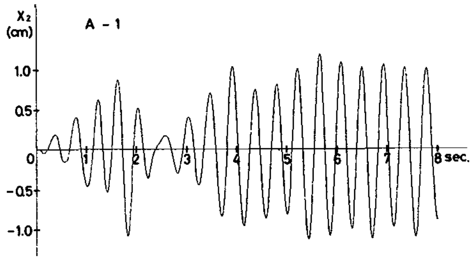

Fig.3b. Response Displacement at Upper Level, X_2 (Run A-1)

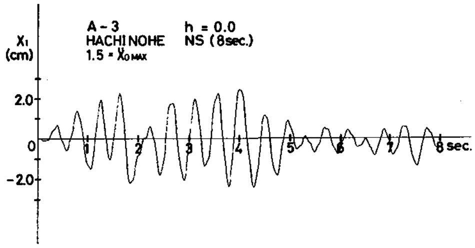

Fig.5a. Response Displacement at Lower Level, X_1 (Run A-3)

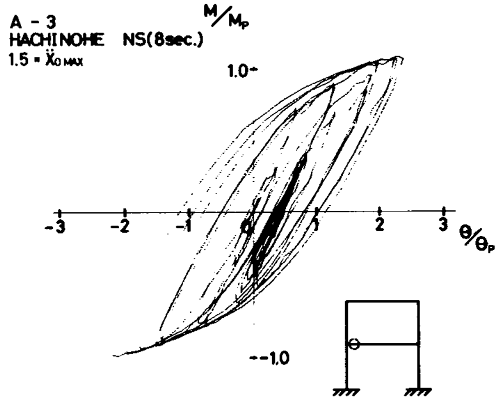

Fig.7. Hysteresis Loops at Lower Beam End (Run A-3)

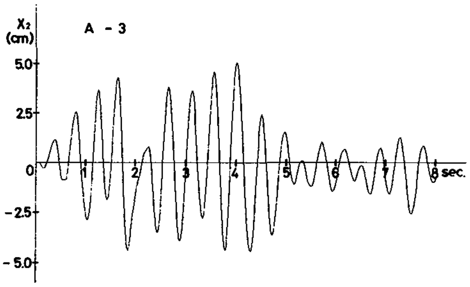

Fig.5b. Response Displacement at Upper Level, X_2 (Run A-3)

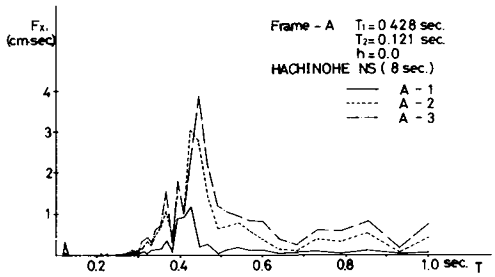

Fig.8. Fourier Spectrum of Response Displacement X_1

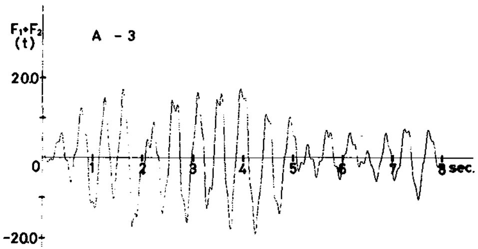

Fig.6. Base Shear, F_1+F_2 (Run A-3)

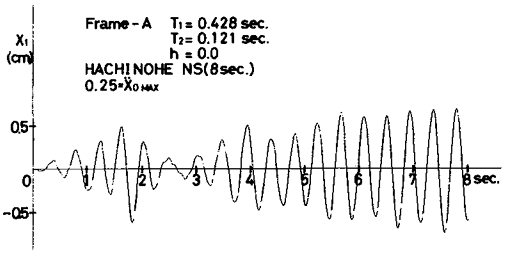

Fig.9. Calculated Response Displacement X_1 based on Initial Stiffness