Bull. ERS, No.15 (1982)

COLLAPSE OF H-SHAPED STEEL COLUMNS TO TWO-DIRECTIONAL EARTHQUAKE MOTIONS

by

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INTRODUCTION

It is important in the earthquake resistant design of structures to know the effect of the coupled lateral response of structures to two-directional earthquake motions. Many researches have been reported on the response of structures to two-directional earthquake motions[1,2,3] and several mathematical models have been used to investigate the inelastic behavior of resisting elements, such as columns, under multi-dimensional forces. However, enough information about the appropriateness of these mathematical models has not been obtained.

In the previous paper,[4] we have reported the some results of the inelastic response of H-shaped steel columns to two-directional earthquake motions analyzed by the computer-actuator on-line system. In the analysis by this system, the responses are computed by using the real restoring forces obtained from the column experiment controlled by the computer, therefore the results by this analysis are available to check the appropriateness of the mathematical model for the restoring force characteristics of H-shaped steel columns under bi-axial bendings.

Here, a mathematical model for the restoring force characteristics of bi-axial bending H-ahaped steel columns is constructed and the results of response analysis to two-directional earthquake motions by this model are compared with those of on-line analysis. Then, using this model, the effect of interaction of two-directional earthquake motions on the maximum response displacements and the response absorbed energy are examined.

MATHEMATICAL MODEL

A lumped mass structural idealization, as shown in Fig.1, is used, and the rotation about the vertical axis and the vertical motion are neglected.

The shear-displacement relation model of column is formulated, extending bi-linear model for one-dimensional hysteretic rule, into two-dimensional one by using Ziegler's kinematic hardening rule.[5] The difference of the post-yield stiffness evaluation in the strong axis bending direction and the weak axis bending direction is taken into consideration, and the corresponding uni-axial shear-displacement relations in each direction are shown in Fig.2. The interaction effect between two orthogonal components of shear force acting on section of column during yielding is taken into an assumed parabolic yield surface as shown in Fig. 3. For numerical integration of the equation of motion, the linear acceleration method was adopted, where the time increment was set 0.001 second.

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COMPARISON WITH ON-LINE ANALYSIS RESULTS

The numerical analyses using this model were conducted on the same columns as used in the on-line analyses. Some results are compared in Fig. 4 and Fig. 5. In each figure, the solid line shows the result by the on-line analysis and the dashed line shows that by the numerical analysis, respectively. The numerical analysis results show the satisfactory results. The large drift of response displacements in the weak axis bending direction, observed in the on-line analysis results in the case, is also observed in the numerical analysis results. It is concluded that the numerical analysis using this model is available for rough estimation of response of H-shaped steel columns to two-directional earthquake motions.

RESPONSES TO TWO-DIRECTIONAL EARTHQUAKE MOTIONS

A series of response analyses of a lumped mass system were carried out to examine the effect of the coupled response to two-directional earthquake motions on the maximum response displacements and on the response absorbed energy. The variables considered were the initial elastic period in the strong axis bending plane, Ty (0.3, 0.4, 0.5, 0.6, 0.8, 1.0, 1.2, 1.5 sec) the ground motion characteristics (EW and NS components of 1968 HACHINOHE, EW and NS components of 1940 EL CENTRO), and the yield acceleration factor, $\alpha = \sqrt{(\ddot{z}_{NS},max)^2 + (\ddot{z}_{EW},max)^2}/\alpha_{pcx}$ ($\ddot{z}_{NS}$,max; the maximum acceleration of NS components of ground motion, $\ddot{z}_{EW}$,max; the maximum acceleration of EW components of ground motion, α_{pcx} = Qpcx/M, Qpcx; Full plastic strength in the weak axis bending plane, M; mass). The properties of a lumped mass system analyzed are listed in Table 1. For each case, the response to each component of ground motion, acting separately (single-component), and the response to both components, acting simultaneously (double-components), were computed.

The ratios of the maximum response displacements to the double-components to those to the single-component, u/u_1 and v/v_1, in the x- and y-directions, are shown in Figs. 6 and 7 for HACHINOHE earthquake and EL CENTRO earthquake, respectively. The response displacements to the double-components often become larger, mainly in the x-direction (the weak axis bending direction), than those to single-component. However, there are the large amount of scatter in the results because of the differnces of the variables considered, the initial elastic period, the ground motion characteristics and the yield acceleration factor.

The ratios of the absorbed energy to the double-components to those to the single-component, E_{px}/E^1_{px} and E_{py}/E^1_{py}, in the x- and y-directions and Et/Et^1 ($Et = Epx + Epy$, $Et^1 = Ep^1x + Ep^1y$) are shown in Fig. 8. The ratios Epx/Ep^1x, Epy/Ep^1y and Et/Et^1 result in approximately 1.0 in calculated cases. This fact means that the absorbed energy responses to the single-component are available to estimate those to the double-components.

CONCLUDING REMARKS

1) The proposed mathematical model for the restoring force characteristics of the bi-axial bending H-shaped column is available to predict the responses of such columns to two-directional earthquake motions.
2) The response displacements to two-directional earthquake motions become larger than those to one-directional earthquake motion, but no clear correlation between the results to double-components and those to single-component is observed.

3) The response absorbed energy to single component will give a rough estimate of the response absorbed energy to double components.

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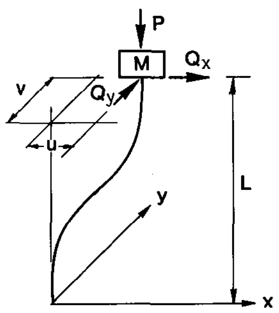


Fig. 1 A lumped mass model

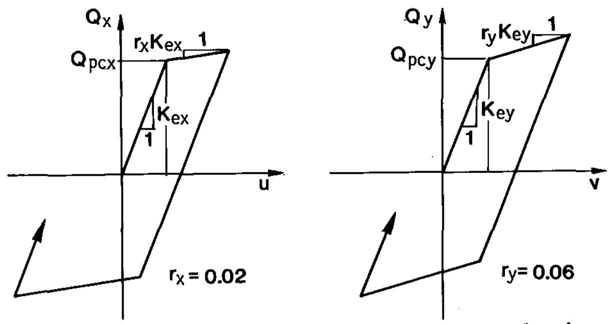
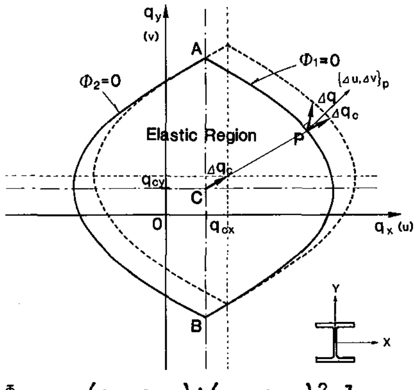


Fig. 2 Uniaxial shear-displacement relation in each direction



$$\Phi_1 = (q_x - q_{cx}) + (q_y - q_{cy})^2 - 1$$
$$\Phi_2 = -(q_x - q_{cx}) + (q_y - q_{cy})^2 - 1$$
$q_x = Q_x/Q_{pcx}$, $q_{cx} = Q_{cx}/Q_{pcx}$
$q_y = Q_y/Q_{pcy}$, $q_{cy} = Q_{cy}/Q_{pcy}$
Q_{pcx}, Q_{pcy};Full plastic strength of column

Fig. 3 Parabolic yield surface

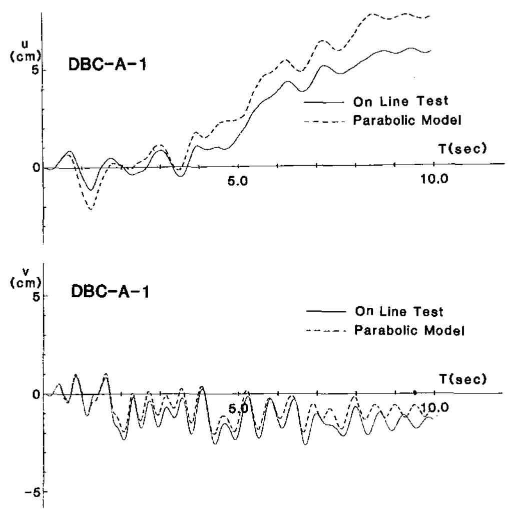


Fig. 4 Time histories of response displacements (DBC-A-1)

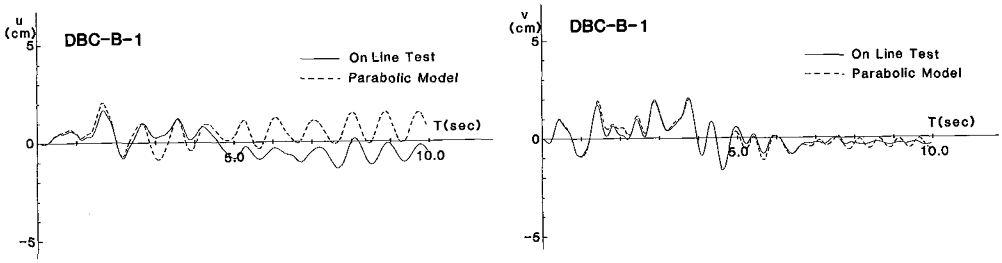
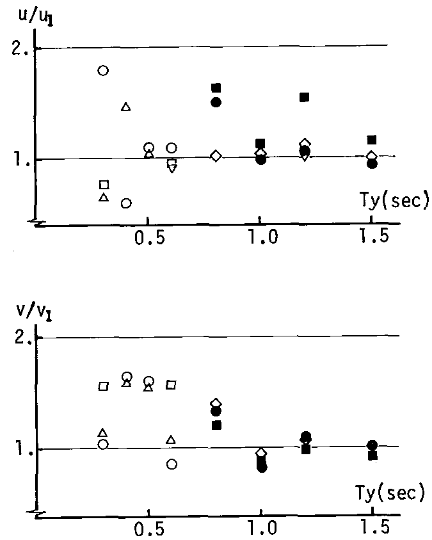
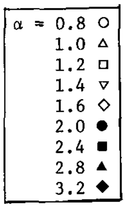


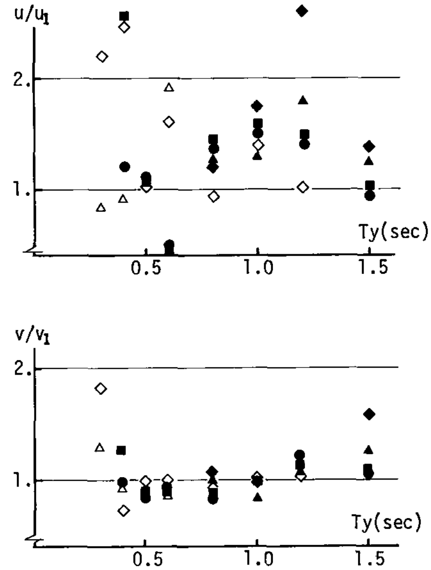
Fig. 5 Time histories of response displacements (DBC-B-1)

Table 1 Properties of a lumped mass system analyzed

Qpcx/Qpcy	Kex/Key	Upc/Vpc	Tx/Ty	rx	ry	P/(Kex·L)	P/(Key·L)
0.5544	0.3583	1.5474	1.67	0.02	0.06	0.1074	0.0385







(x-HACHINOHE EW
y-HACHINOHE NS)

Fig. 6 The ratio u/u_1 and v/v_1

(x-EL CENTRO EW
y-EL CENTRO NS)

Fig. 7 The ratio u/u_1 and v/v_1

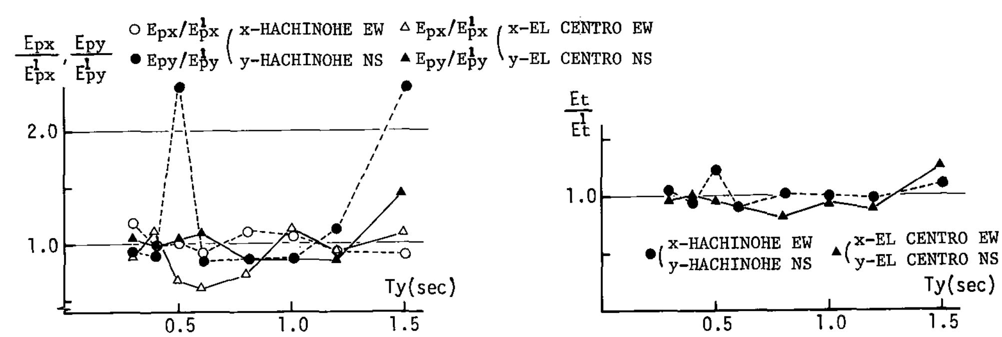


Fig. 8 The ratio of absorbed energy to double-components to those to single-component