SEISMIC BEHAVIOR OF MULTISTORY K-BRACED FRAMES UNDER COMBINED HORIZONTAL AND VERTICAL GROUND MOTION

by

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SYNOPSIS

Effect of vertical component of ground motion on the earthquake response of two 6-story braced steel frames is studied. One frame has K-pattern bracing and the other an X-pattern in 2-story modules. The accelerograms are 1.5 times the intensity of El Centro 1940 earthquake. The results show that inclusion of vertical component of ground motion can cause significant increases in the ductility requirements of frame members among which the columns are most affected particularly in terms of axial forces.

INTRODUCTION

Current design practice of earthquake resistant structures is mostly based on consideration of horizontal component of ground motion. Very few studies have been made to date to study the effects of vertical component of ground acceleration on the response of structures (1). Braced frames of different types are frequently used for multistory steel structures in seismic areas because of their greater stiffness and lower costs over unbraced frames. Since the bracing members and columns in most braced frames are required to resist combined vertical and horizontal forces the effect of vertical ground motion can be quite significant on some of these members. In some earlier studies of the response of K-braced frames due to horizontal component of ground motion only (2,3) it was noticed that the points of connection of bracing members with beams showed significant vertical displacements and inelastic deformation of those members. It is reasonable to expect that such location in a structure would be quite vulnerable to the added influence of vertical inertia forces. An attempt is made in this paper to evaluate the effect of vertical component of ground motion on the earthquake response of multistory K-braced steel frames.

SELECTION OF STRUCTURE AND GROUND MOTION

The structure selected for this study represents a 6-story, three-bay interior frame of a symmetrical building with K-bracing in the middle bay and simple beam-to-column connections in the exterior bays, Figure 1. For response computation this structure is represented by a single bay model as shown in Figure 2. The member sizes are similar to those in the upper 6 stories of a 10-story frame that was designed according to Uniform Building Code by Nilforoushan for his study (2) and also used by the author in an earlier study (3). The dead and live loads for the floor were 132 and 96 kips, respectively. The steel is A36 and the design was performed by a conventional procedure by treating the bracing as secondary members designed to resist full lateral forces.

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A variation of the basic K-braced model is obtained by reversing the K-pattern to V-pattern in alternate stories which produces an X-pattern in 2-story modules, Figure 3. The member sizes are kept identical in the two models. In his earlier study (3) the author found that inelastic activity in beams and bracing members was smaller with this X-pattern bracing as compared to the corresponding K-braced model (response due to horizontal ground motion only).

The North-South and vertical components of the May, 1940 El Centro earthquake are used to study the response of the above two structures. The ground accelerations are multiplied by a factor of 1.5 which results in peak horizontal and vertical accelerations of 0.5g and 0.4g, respectively.

METHOD OF ANALYSIS

Assumptions

The DRAIN-2D program (4) which was originally developed at the University of California, Berkeley, was expanded to include a realistic model for the hysteresis behavior of bracing members. This expanded program was used to compute the dynamic response of the structures. Mathematical modeling of structures is based on the following assumptions:

1. Each floor level has seven degrees of freedom which include one horizontal displacement, three joint rotations and three vertical displacements.
2. Masses equivalent to full dead weight (132 kips) for horizontal inertia force and two thirds of that for vertical inertia force are lumped at the ends and mid-span of each floor girder equally. It is thought that the remaining one-third of the total vertical mass will be resisted by the exterior columns, thus, not effecting the interior braced bay.
3. P-Δ effect of axial force in columns due to the dead loads is included.
4. Inelastic hysteresis behavior of frame members is the only source of energy dissipation in the structure.
5. An elasto-plastic type hysteresis behavior in bending is assumed for girders and columns with the plastic moment for columns modified due to axial force. A strain-hardening stiffness equal to 5 percent of the elastic stiffness is assumed for girders.
6. Bracing members are treated as axially-loaded members. The hysteresis model for these members is shown in Figure 4. It considers their energy dissipative character in tension yielding as well as post-buckling range. Derivation of this model which is based on results of recent theoretical and experimental studies is described elsewhere in the Proceedings of this conference by Singh and Goel (5).

Response Parameters

The parameters selected to study the earthquake response of the structures are: the maximum horizontal displacement of floors relative to ground, the maximum absolute values of the story displacement and story shears, the maximum vertical displacement at midspan of girders, the maximum column axial force ratios, and the maximum ductility ratios for the various frame members.

The column axial force ratio is defined as the maximum axial force in a column divided by its yield force. The ductility ratio for the bracing members is defined as the maximum elongation or shortening divided by the yield elongation. The ductility ratio for girders and columns is defined as the ratio of maximum end rotation to yield rotation for the member having equal end rotations and no joint translation.

DISCUSSION OF RESULTS

In order to study the effect of vertical ground motion the response of the two structures due to combined horizontal and vertical ground motion (HV) is compared with that due to horizontal ground motion (H) only, Figure 5(a)-(k) for K-braced frame and 6(a)-(k) for the frame with X-pattern of bracing. It should be mentioned that the response is due to the first seven seconds of ground motion.

Figures 5(a), (b), (d) and (e) show that lateral displacements, story shears and column ductility ratios are not significantly affected by vertical ground motion, however, column axial forces are significantly increased both in tension and compression, Figure 5(c). At midspan, the point of connection of bracing with girders, the vertical displacements increase slightly, Figure 5(f)-(g). Consequently, it results in generally slight increase in the ductility ratio of girders and bracing members, Figure 5(h)-(k).

Response of the frame with X-pattern of bracing also shows similar trends as observed in K-braced frame, Figure 6(a)-(k). Horizontal displacements and story shears are not much affected. However, the column axial forces and ductility ratios increase up to 2 to 3 times. A similar increase is noticed in the vertical displacements at midspan of girders, Figure 6(f)-(g). Figure 6(g) is most interesting in that the midspan of an unbraced girder, which does not show any appreciable vertical displacement under horizontal ground shaking only, oscillates quite rapidly with extreme displacement up to 0.5 inch in each direction. Ductility ratio for girders increases significantly and that for bracing members also increases somewhat.

A cross-comparison between the response of these two frames would show that under same conditions the behavior is generally similar. The X-braced frame shows smaller ductility demand on girders but greater axial forces and ductility ratios for columns specially due to combined horizontal and vertical ground motion.

CONCLUSIONS

No general conclusions should be drawn from a limited study such as presented in this paper. Nevertheless, the results do indicate that the vertical component of ground motion increases the ductility requirements for columns quite significantly and also for beams and bracing members to a smaller degree. The response of individual structural members is also influenced strongly by structure geometry. The lateral floor displacements and story drifts on the other hand remain rather insensitive to the above two factors. Thus, for an accurate evaluation of ductility requirements of critical structural members vertical ground motion should also be included in the analysis. These conclusions very well agree with those derived by Anderson and Bertero in their study of unbraced frames (1).

ACKNOWLEDGMENT

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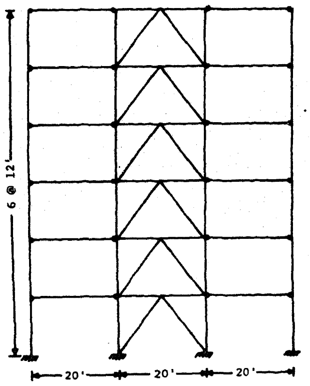


FIGURE 1 THREE BAY K-BRACED FRAME

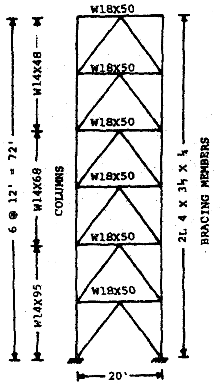


FIGURE 2. SINGLE BAY K-BRACED MODEL

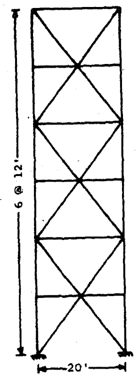


FIGURE 3. SINGLE BAY X-BRACED MODEL

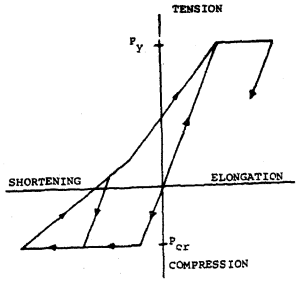
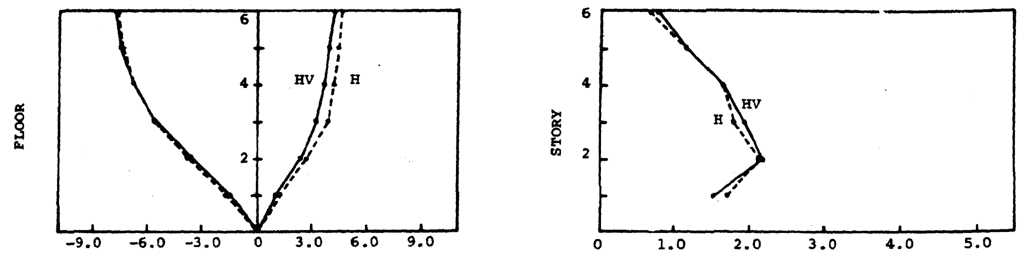
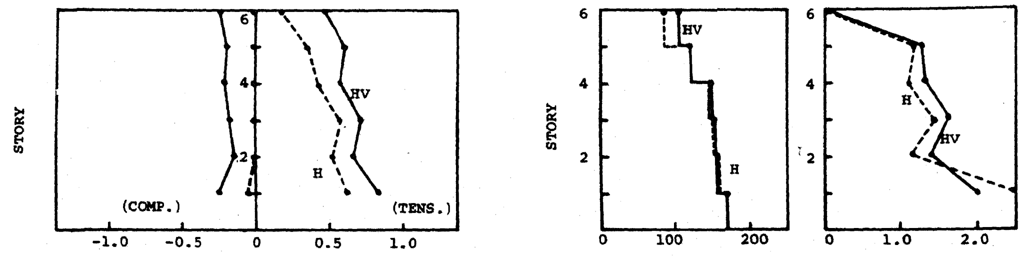


FIGURE 4. HYSTERESIS MODEL FOR BRACING MEMBERS



a. MAXIMUM DISPLACEMENT, INCHES

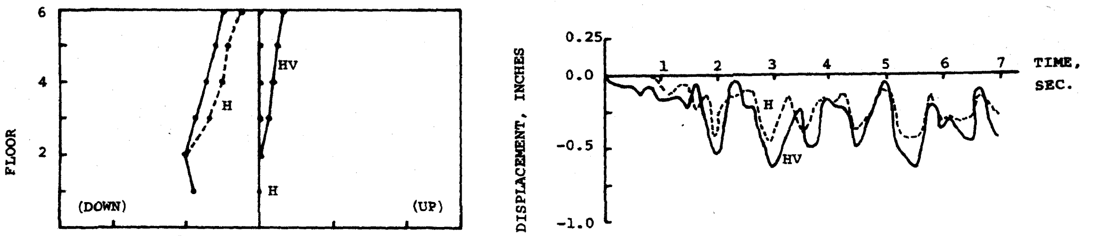
b. STORY DISPLACEMENT, INCHES



c. COLUMN AXIAL FORCE RATIO

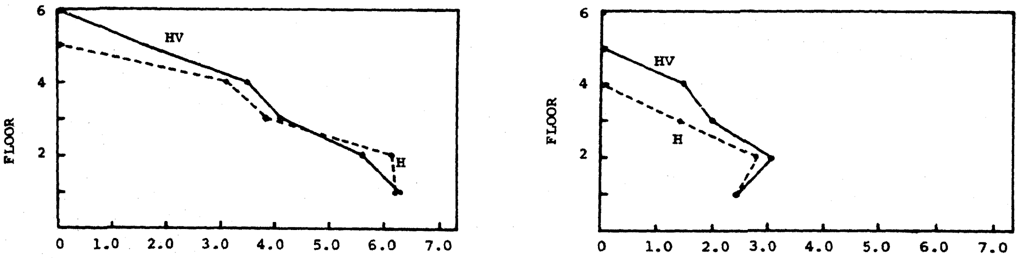
d. STORY SHEAR, KIPS

e. COLUMN DUCTILITY RATIO



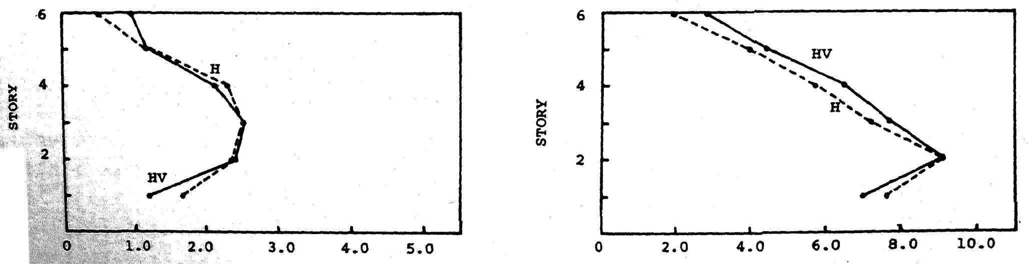
f. VERTICAL DISPLACEMENT AT MIDSPAN OF GIRDERS

g. VERTICAL DISPLACEMENT AT MIDSPAN OF FOURTH FLOOR GIRDER



h. GIRDER DUCTILITY RATIO AT COLUMN FACES

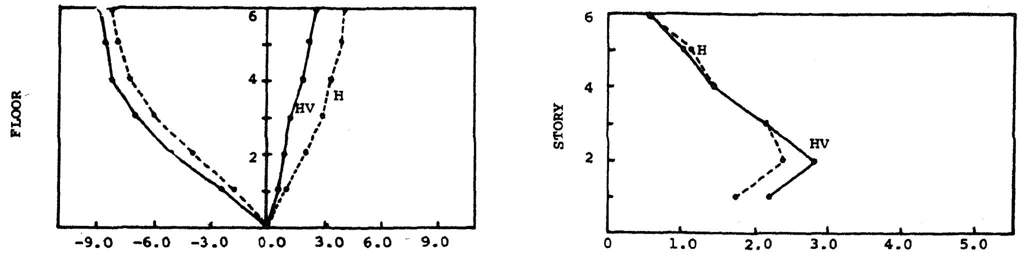
i. GIRDER DUCTILITY RATIO AT MIDSPAN



j. BRACING DUCTILITY RATIO IN TENSION

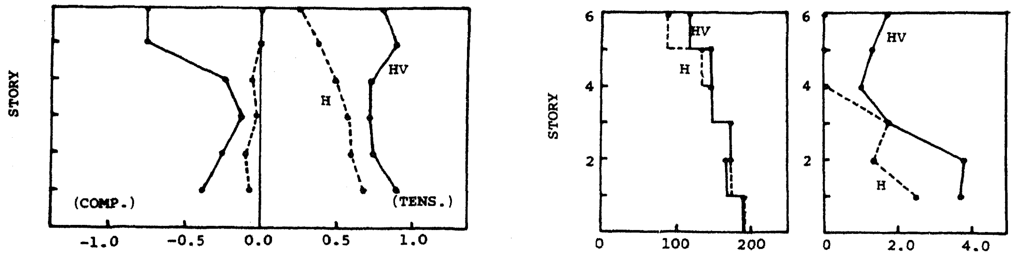
k. BRACING DUCTILITY RATIO IN COMPRESSION

FIGURE 5. RESPONSE OF K-BRACED MODEL



a. MAXIMUM DISPLACEMENT, INCHES

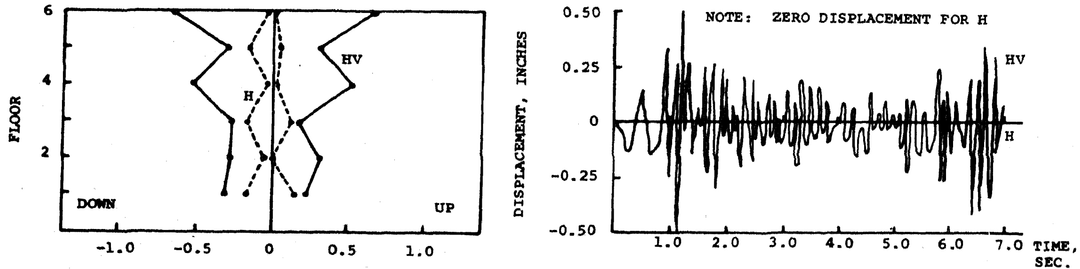
b. STORY DISPLACEMENT, INCHES



c. COLUMN AXIAL FORCE RATIO

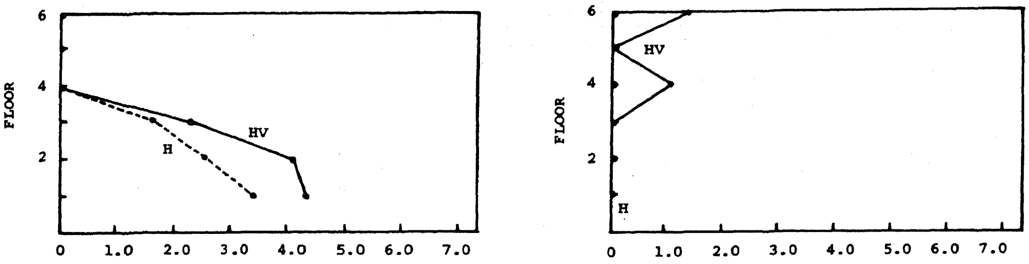
d. STORY SHEAR, KIPS

e. COLUMN DUCTILITY RATIO



f. VERTICAL DISPLACEMENT AT MIDSPAN OF GIRDERS

g. VERTICAL DISPLACEMENT AT MIDSPAN OF FOURTH FLOOR GIRDER



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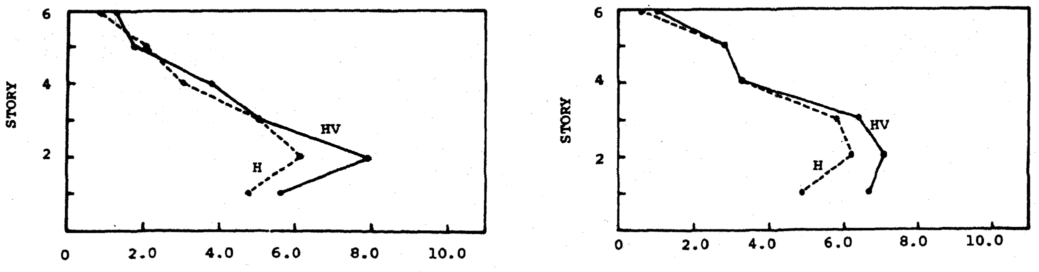

j. BRACING DUCTILITY RATIO IN TENSION

k. BRACING DUCTILITY RATIO IN COMPRESSION

FIGURE 6. RESPONSE OF X-BRACED MODEL