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Bi-component earthquake tests of model knee braced frames

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ABSTRACT: Knee Bracing System (KBS) is a newly proposed technique for enhancing the overall stiffness and the energy dissipation capacity of steel structures. The framed building incorporating the knee bracing systems rely on the plastic deformations of the knee elements to absorb part of the energy imparted by the earthquake. Symmetric and asymmetric configurations of a 1/12 small scale steel frame were subjected to the action of two horizontal components of a ground motion. A comparison between the superposed responses of the frames under uni-directional excitations and the corresponding responses from bidirectional tests showed that the principle of superposition had been successful in representing the linear and nonlinear response of the symmetric frames as well as the linear response of the asymmetric frames. This principle, however, is no longer valid for the nonlinear response of asymmetric structures. The consequences of these results on the design and analysis of the knee braced frames (KBFs) are discussed.

1 INTRODUCTION

Knee braced frames (KBFs) as proposed by Aristizabal (1986) are steel framed buildings incorporating disposable knee bracing elements (Figure 1). The principle behind the system seeks to concentrate earthquake damage in specially designed and strategically placed knee elements which may be replaced if necessary after damage in an earthquake. The technique is based on the knee elements absorbing plastic work and thereby reducing the energy to do other damage. A comprehensive analytic study has been carried out to provide a qualitative assessment of the dynamic behaviour of the KBS (Bourahla & Blakeborough (1990)). To corroborate the analytical findings, a small scale model of a building was tested on a six axis shaking table. Three extensive series of tests covered the energy dissipation capacity aspect of the frames, the performance of different bracing arrangements in medium-rise buildings under wide range of earthquake types (Bourahla & Blakeborough (1990)), and the torsional coupling behaviour of space KBFs. Part of the results of the last series which examined the response of the frames to bicomponents earthquake motions will be presented in this paper.

Large number of studies have investigated the reduction of the lateral response of buildings by structural yielding. However little research has been carried out into the manner the energy is dissipated in each of the two horizontal directions. Although several studies concentrated on the torsional behaviour of simple nonlinear asymmetric model (see Hejal and Chopra (1989), and Syamal and Pekau (1985)), most of the attention has focused on the effect of dynamic and geometric characteristics on the conventional structural response parameters and the ductility demand. Nigam and Housner (1969), howver, showed that the energy input in each of the 2 horizontal directions is not necessarily dissipated or stored in that direction because of yield interaction. In the same trend, analysis of earthquake behaviour of torsionally coupled buildings with nonlinear resisting elements done by Yamada, Kawamura and Tani (1988), revealed that the energy absorption was constant despite an increasing eccentricity ratio.

Recognizing the importance of these phenomena, an attempt is made to investigate experimentally the fundamental properties of knee braced frames under two horizontal components of ground motion. Typical responses from uni-directional and bidirectional tests were superposed in order to detect any yield interaction of the knee elements and its influence on the overall behaviour of the frames. Results show that the yield interaction of the knee elements is insignificant, the latter are only active in their plane.

2 TEST FRAMES AND INSTRUMENTATION

A ten storey frame of those used in commercial office buildings was initially taken as a prototype for a one twelfth scale model. The model was not designed to duplicate a particular structure, but to simulate the behaviour of a range of typical multi-storey frames. The most important features of the model design is the relatively easy mounting of many building configurations, the removable bracing systems and the easy replacement of damaged knee elements. A detailed description of the design procedure with the implication of imperfect similitude are presented by Bourahla (1990). In this paper, however, two configurations of the lower four storey frame with

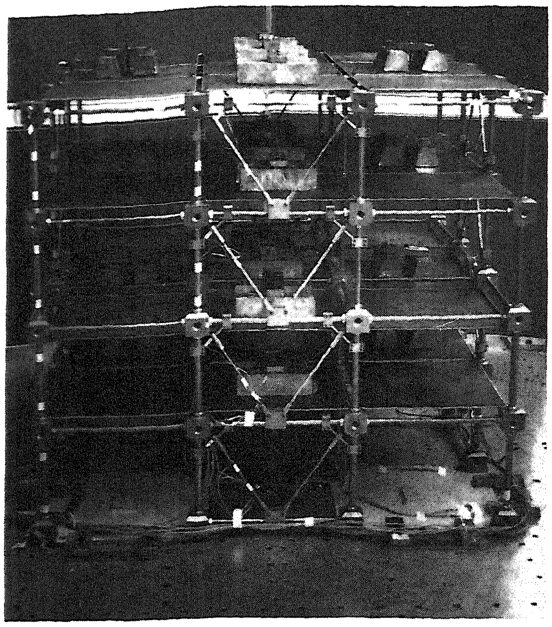
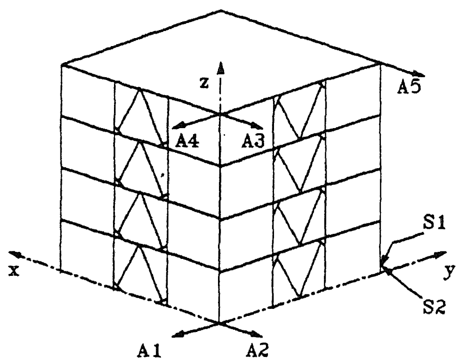


Figure 1 Test frame with knee bracing systems



Ai: accelerometer Si: strain guage

Figure 2 Sensors locations on the test frame

three bays wide and three bays deep are examined (figure 1). Knee bracing systems were incorporated in the central bay of each side. The asymmetric configuration, however, was created by removing the bracing from one side of the model. Figure 2 shows the location of the relevant sensors on the test model. Five accelerometers recorded the table and the top floor accelerations in the two horizontal directions, and two of the strain gauges were used to monitor the bending strain at the base of a corner column in the x and y-directions.

The frames were subjected to the S16E and the S74W horizontal components of San Fernando earthquake at two level of intensity. These tests were conducted in three phases. The frames were excited by the S16E component along the x-axis, then by S74W component along the y-direction, and finally they were subjected to both of them simultaneously. Forced vibration tests were also conducted to measure the initial dynamic characteristics of the models before testing with the earthquakes.

3 EXPERIMENTAL RESULTS

The effect of the bicomponent earthquake excitation is examined through a comparison between the superposed responses of the frame to uni-directional excitations and the corresponding response from the bidirectional tests.

3.1 Linear and nonlinear response of the symmetric frame

The time-history of the relative displacement of the top floor of the symmetric KBF along the y-direction is plotted in figure 3 (continuous line) together with the corresponding response to the two components of the earthquake when applied simultaneously (dashed line). The beginning of the time-histories have been adjusted by changing the origin of the time axis. As illustrated in this figure, the responses to the uni-directional and bidirectional excitations were identical. It should be noted that for the symmetric structure only the nonlinear responses in one direction were plotted since the response along the perpendicular direction and those in the linear range exhibited the same behaviour.

Two important points can be deduced from such a behaviour. The first one is that the displacement along the two components of ground motion of these frames were resisted independently by a set of elastic structural elements (columns) and a set of mutually perpendicular knee bracing systems, this means that there is little or no effect on the yield of the knee elements caused by out-of-plan deformation of the bays, thus provided that only the knee elements that undergo plastic deformation, the response of the KBFs can be obtained independently for each components. If, however, the columns were to reach the yield limit, the behaviour must then be examined under the simultaneous action of the two components. The second point which concerns the reliability of this dynamic testing is the repeatability feature of the tests. As can be seen from figure 3 the same results can be obtained from repetitive tests in normal circumstances.

3.2 Linear response of the asymmetric frame

The linear response of the asymmetric frame to the components of the earthquake are shown in figure 4, the curves with dashed line represents the measured bending strain at the base of the column during the bidirectional test, and the continuous line is the sum of the responses derived from the uni-directional tests. Except a few perturbations at low amplitudes the two curves matched very closely. The peaks were less than 2% different.

This behaviour confirms the observations made during the study of the response of the symmetric

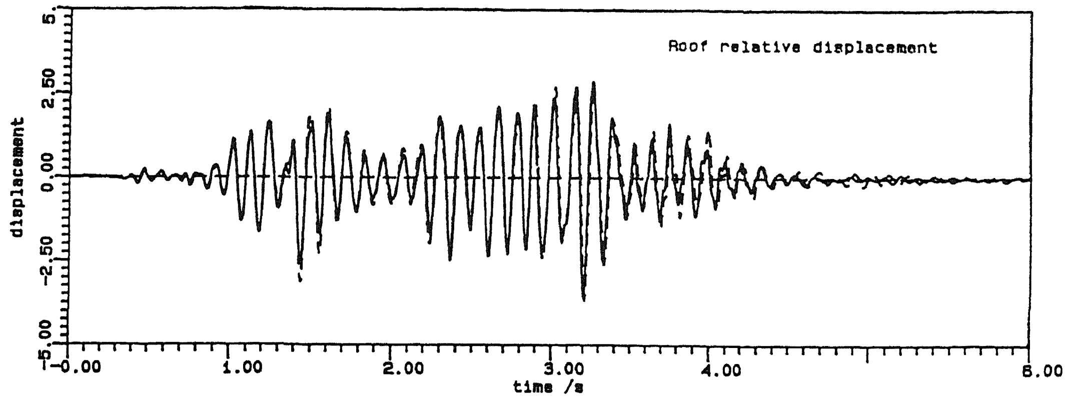


Figure 3 Nonlinear response of the symmetric frame

frame, moreover the torsional-translational coupling initiated by one earthquake component is not altered by the perpendicular one when applied simultaneously. In other words the geometric variations does not affect the initial eccentricity ratio.

3.3 Nonlinear response of the asymmetric frame

The principle of the superposition of bicomponent responses that had been successful in representing the elastic response of symmetric and asymmetric frames as well as the inelastic response of symmetric frames is no longer valid for the nonlinear response of the

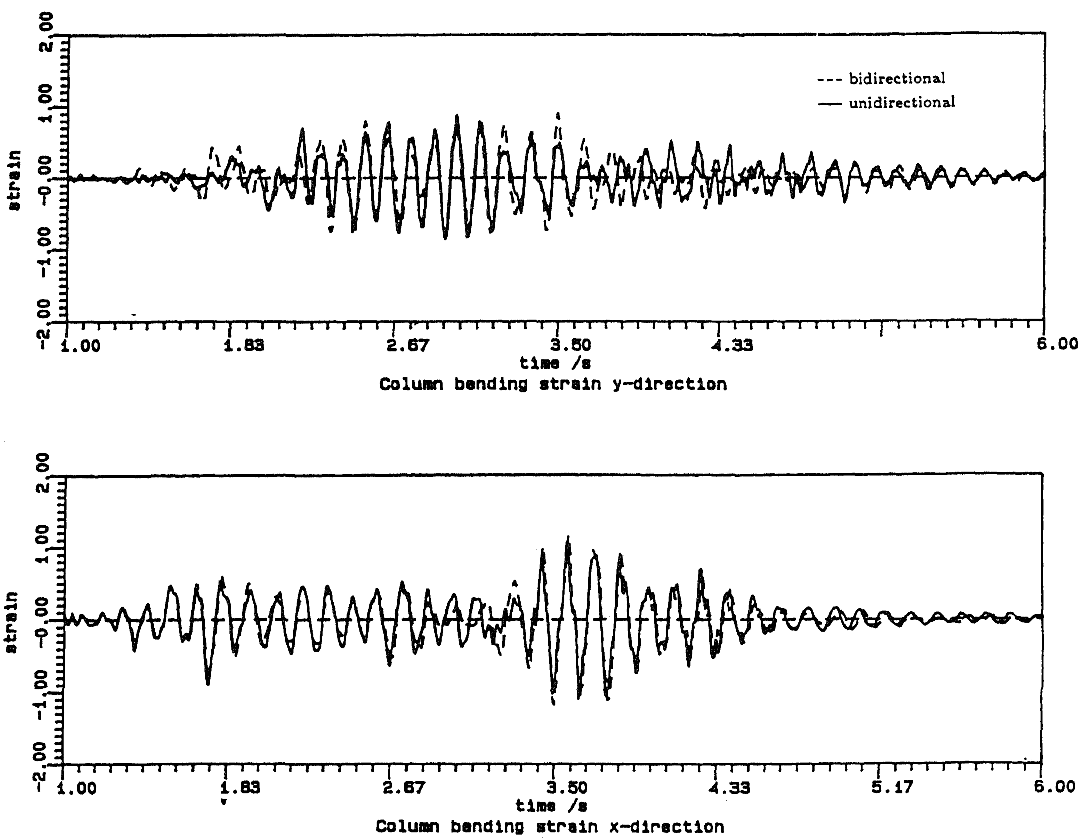


Figure 4 Linear response of the asymmetric frame

asymmetric structure. Although the overall wave pattern of the response of the frame to the uni-directional and bidirectional inputs were quite similar (figure 5), a discrepancy in phase and amplitude can be noticed during the strongest part of the response along the x-direction, which disturbed the response in the perpendicular y-direction. The disagreement between the combined uni-directional and bidirectional responses is mainly attributed to the mutually dependence of the torsional-translational coupling and the eccentricity ratio which vary with time because of an uneven knee elements yield in the asymmetric structure. The effect of the bicomponent excitation on the torsional response of the KBFs is qualitatively assessed from the tests results.

The bidirectional response was much more damped because the knee elements underwent larger inelastic deformations which was reflected by a pronounced period elongation characterising the bidirectional response. The maximum bending strain in x-direction corresponding to the bidirectional response was about 18 % lower than that reached by the uni-directional response. The asymmetric KBF tend to dissipate more energy under two-dimensional input. The same phenomenon was noticed by Hoener (1971) in symmetric structures resisted by structural elements the yield interaction has the effect of reducing the energy input to the frame.

It should be noted however that the difference between the responses to the bicomponent and the combined uni-directional excitation seemed generally to be minor regarding the high degree of eccentricity of the model (estimated values of the eccentricity ratio e/L varied from 15% in the lower storeys to 26% in the upper storeys).

4 CONCLUSION

The experimental results obtained in this investigation show for the first time certain features of the KBSs behaviour in space frames which are essential for the analysis and the design of this kind of frames.
Based on the results presented here, the Knee Bracing System behaves as a one directional resisting and energy dissipator element which means that space symmetric KBFs can be analysed as 2-D models when only the knee elements are expected to yield.

The effect of the two horizontal components of an earthquake should be considered for an elastic asymmetric KBF individually or simultaneously to estimate the true margin of safety against yielding,

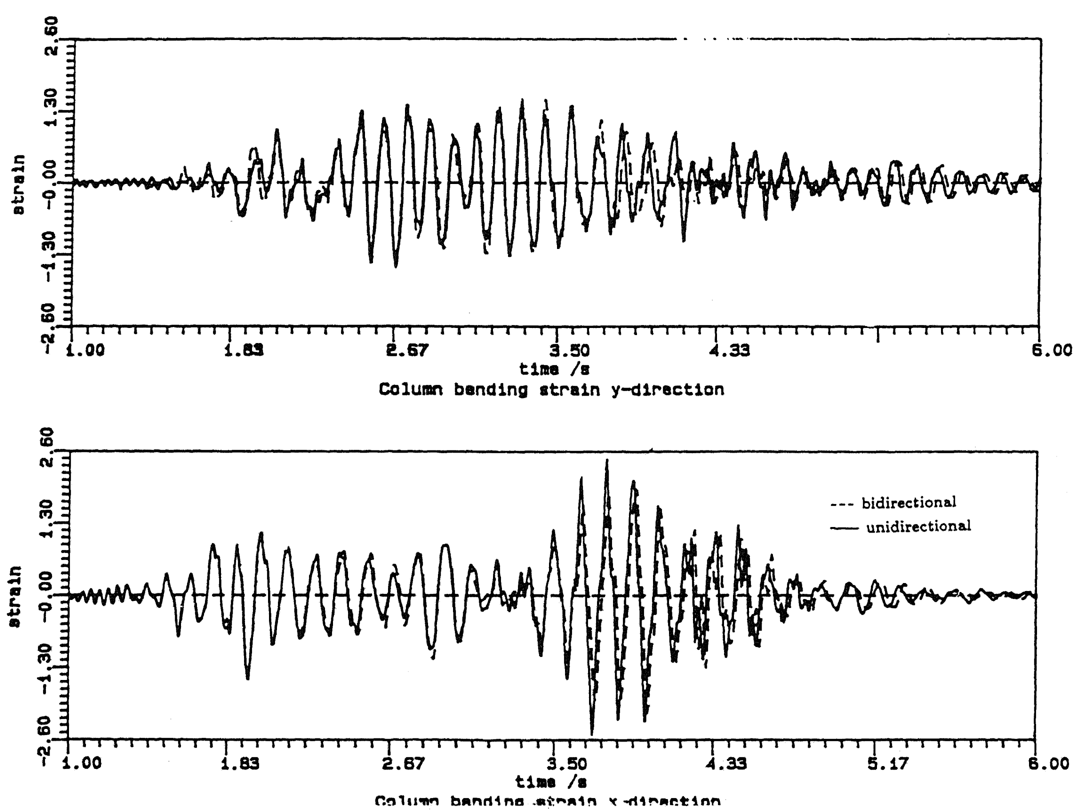


Figure 5 Nonlinear response of the asymmetric frame

however the simultaneous action should be considered in the nonlinear analysis. Although the asymmetric KBFs tend to dissipate better the energy imparted by the bi-component earthquake motion, the degree of the initial eccentricity still has a minor effect.

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