Available online at www.sciencedirect.com
ScienceDirect
Journal of Constructional Steel Research 63 (2007) 412–421
JOURNAL OF CONSTRUCTIONAL STEEL RESEARCH
www.elsevier.com/locate/jcsr

Shaking table tests of a two-story unbraced steel frame

Seung-Eock Kim*, Dong-Ho Lee, Cuong Ngo-Huu

Department of Civil and Environmental Engineering/Construction Tech. Research Institute, Sejong University, Seoul 143-747, South Korea

Received 19 September 2005; accepted 11 April 2006

Abstract

This paper presents some shaking table tests for a one-bay, two-story steel frame under simulated earthquake loading. The test frame was designed to be capable of showing the second-order inelastic behavior under the earthquake loads and to avoid lateral torsional buckling of a single member. The descriptions of test specimen, instruments, set-up procedures, and results are presented. A comparison of the results obtained from experiment and numerical analysis using beam element model of the ABAQUS program is provided. The experiment aims to clarify the inelastic behavior of steel frames subjected to earthquake load and its results can be used to verify the validity of second-order inelastic dynamic analysis techniques of steel frames.

Keywords: Shaking table test; Steel frames; Earthquake loading; Plastic deformation

1. Introduction

In the past many experiments were conducted for steel frames subjected to static loads to provide experimental results for the verification of second-order inelastic static analysis techniques. In the early work of Harrison [1], an equilateral triangular space steel frame subjected to proportional loads was tested. Yarimci [2] tested a full-size two-dimensional, two-bay, three-story steel frame in which all members were bent about the strong axis. Wakabayashi and Matsui [3] tested two two-dimensional, one-bay, one- and two-story steel frames of quarter-scale subjected to proportional loads. Kanchanalai [4] tested a two-dimensional, two-bay, two-story steel frame of large scale to verify his plastic-zone analysis technique. Avery and Mahendran [5,6] performed large-scale testing of a two-dimensional, one-bay, one-story steel frame comprising non-compact sections subjected to proportional loads. Recently, Kim and Kang [7] and Kim et al. [8] performed some ultimate strength large-scale testing for three-dimensional, one-bay, two-story steel frames subjected to non-proportional and proportional loads, respectively. Kim and Kang [9] performed an ultimate strength large-scale testing to account for local buckling of a three-dimensional, one-bay, two-story steel frame subjected to proportional loads.

Compared to the numerous static tests as presented above, dynamic tests investigating second-order inelastic behavior of steel frames are few, although information on how steel frames behave under dynamic loadings is very necessary. Uang and Bertero [10] performed earthquake simulation tests and associated studies of a 0.3-scale model of a six-story concentrically braced steel structure. Nader and Astaneh-Asl [11] performed shaking table tests of a one-story, one-bay steel frame whose connections could be changed from flexible to rigid.

Recently, many second-order inelastic dynamic analysis methods of steel frames have been employed to design steel frames resisting earthquake loading and hence experimental data is required to check the accuracy of these methods [12–16]. The purpose of this study is to provide the experimental data to verify the validity of second-order inelastic dynamic analysis techniques of steel frames and to investigate the inelastic behavior of steel frames under seismic loading. Some shaking table tests for a one-bay, two-story steel frame under earthquake loads were conducted. A comparison of the results obtained from experiment and numerical analysis using the ABAQUS program is also provided.

2. Test frames and instruments

Three identical frames were manufactured for testing, in which one was used for a pre-test, and the two remaining ones

* Corresponding author. Tel.: +82 2 3408 3291; fax: +82 2 3408 3332.
E-mail address: sekim@sejong.ac.kr (S.-E. Kim).

0143-974X/$ - see front matter
doi:10.1016/j.jcsr.2006.04.009

Table 1
Dimensions and properties of section H-125 × 125 × 6.5 × 9

H (mm)	B (mm)	t_f (mm)	t_w (mm)	r_1 (mm)	A_g (mm^2)	I_X (10^6 mm^4)	I_Y (10^6 mm^4)
125	125	9	6.5	10	3031	8.47	2.92

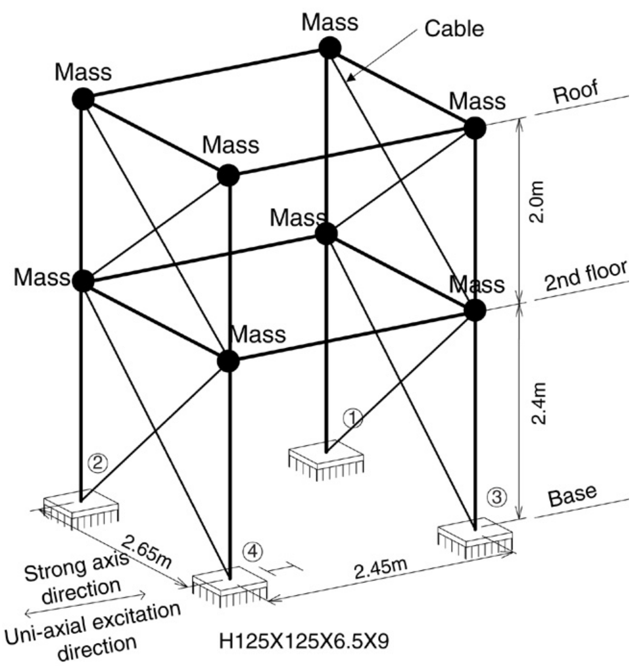

Fig. 1. Dimension and loading conditions of test frame.

were used for formal testing. Their dimensions and loading conditions are illustrated in Fig. 1. Each test frame had a rectangular plan with dimensions of 2.65 m and 2.45 m in weak- and strong-axis bending directions of columns, respectively, and story heights equal to 2.4 m and 2.0 m for the first and the second stories, respectively. The hot-rolled wide flange section of H -125 × 125 × 6.5 × 9 was used for all framed members. The dimensions and properties of the section are listed in Table 1. This section is compact according to AISC [17,18] as shown in the following calculation:

– For flange: $b/t = b_f/(2t_f)$

$$= 6.94 \le \begin{cases} \lambda_p = 0.38\sqrt{E/F_y} = 9.68 \\ \lambda_{ps} = 0.30\sqrt{E/F_y} = 7.64. \end{cases} \quad (1a)$$

– For web: $h/t_w = 16.46 \le \lambda_{ps} = 3.14\sqrt{E/F_y} = 80.00 \quad (1b)$

where E and F_y are Young's modulus and yield stress of material, respectively; b, t, b_f, t_f, h, and t_w are half the full-flange width, thickness of element, full-flange width, thickness of flange, the clear distance between flanges less the fillet or corner radius at each flange, and thickness of web, respectively; λ_p and λ_{ps} are limiting width–thickness ratio (compact) and seismic limiting width–thickness ratio (seismically compact), respectively. Hence the section is not susceptible to local buckling. The material used was grade SS400 steel with a nominal yield stress of 250 MPa. The test frame was designed to be capable of showing the second-order inelastic behavior clearly under earthquake loads and to avoid lateral torsional buckling of a single member. A failure by inelastic lateral torsional buckling of a single member would not be appropriate in investigating global behavior of combined yielding and second-order instability of the frame. The deformations in the weak axis direction were prevented by the cross cables. Two steel plates (2325 × 2125 × 130 mm) simulating the masses of 5 kN were installed in the second floor and roof level. The beam to column connections were fully welded to make rigid connections. Column base connections were made as rigid as possible. The X-stiffeners constructed at the beam–column joints of the test frames were fully welded to prevent panel zone deformation. The test frame was fixed in displacement and rotation at the base level, free to move at the second floor and roof levels. Figs. 2 and 3 show a schematic three-dimensional drawing and a photograph of the test frame, respectively. Fig. 4 shows the connection of the column base. This test frame is a typical sway frame because of its stability involving both P–δ and P–Δ effects, which are the second-order effects at member and frame levels, respectively, while the non-sway frames deal only with the P–δ effect.

The shaking table tests were carried out by using a unidirectional shaking table with dimensions of 5 × 3 m in the Large-Scale Structural Testing Laboratory, Hyundai Institute of Construction Technology, South Korea.

The following procedures were used to set up the test instruments:

(1) Two beam-shape base blocks were positioned and fastened to the shaking table by using twenty M20 bolts.
(2) Four base plates at the bottom of four columns of the test frame were fastened to the beam-shape base block by using thirty-two M24 bolts.
(3) Eight mass supports were fastened at the second floor and roof level by using thirty-two M20 bolts.
(4) Two steel plates were fastened to the mass support at the second floor and roof level by using thirty-two M20 bolts.
(5) Two base plates of two reference columns, which were used to measure the displacements, were fastened to the base block by using eight M24 bolts at the fixed ground outside of the shaking table.
(6) Two accelerometers were installed at the steel plate simulating the mass at the second floor and roof level, as presented in Fig. 5.
(7) Two dynamic LVDTs (linear variable differential transducers) with 200 mm stroke were installed at the mid-length of the beams, which are directed in the strong-axis bending direction of columns (Fig. 6).