2-D ANALYSIS METHODS FOR 2007 BLIND ANALYSIS CONTEST

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ABSTRACT :

A blind analysis contest has been conducted in conjunction with the full-scale experiment of total collapse of a four-story moment frame in September 2007 at the E-Defense shake-table facility. The purpose of the contest is to stimulate development of computational methods and efficient modeling techniques for collapse analysis. In this report, the methods of modeling and simulation, and the results of nonlinear time-history analysis of the two winner of the category of two-dimensional analysis are presented.

KEYWORDS: Blind analysis contest, Two-dimensional analysis, Seismic response, Steel frame

1. INTRUDUCTION

A shake-table test of total collapse of a four-story moment frame was carried out in September 2007 at the E-Defense shake-table facility. A blind analysis contest has been carried out in conjunction with the test to stimulate development of computational methods and efficient modeling techniques for collapse analysis of steel frame buildings. See Ohsaki *et al.* (2008) for details of contest rules and results. The contest has two categories of 2D-analysis and 3D-analysis, which are further divided to the categories of researchers and practicing engineers by the types of the participants. In this study, the results of the award-winning groups in the categories of 2D-analsysis are reported.

2. AWARD WINNING RESULTS BY RESEARCHER

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2.1 Analysis model

A two-dimensional elasto-plastic dynamic analysis program has been developed with MATLAB Ver. 5.3 and Simulink Version 3.0. The 2D frame model used for analysis consists of line elements, hinge elements, and panel-zone elements as shown in Figure 1. A line element represents the initial stiffness of a beam or column member. A hinge element represents the hysteretic characteristics between the bending moment and the rotation angle at a member end, and has rigid initial stiffness. To simulate collapse behavior accurately, the following properties are especially taken into consideration:

a) *P-Δ* effect due to overturning moment and vertical response.
b) Beam model and column model that can have negative stiffness caused by local buckling.
c) Asymmetrical hysteresis model for beams with reinforced concrete slabs.
d) Modeling of stiffness and strength of the column bases.
e) Neglect non-structural components because of large excitations.

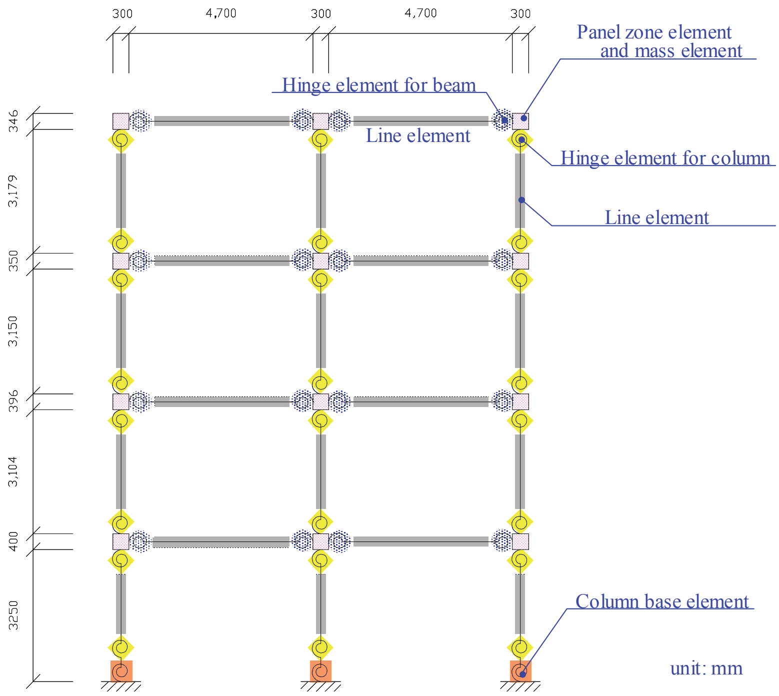

Figure 1 Elevation of the frame model.

Hysteresis loops of the moment-rotation relation of beam and column were developed particularly for this contest. Figures 2 and 3 show the loops for the hinge model of beam and for the total (i.e. hinge and line) model of column, respectively. These are modeled to simulate the experimental results of component tests of beam and column that were conducted by the organizer of the contest. The positive rotation in Figure 2 corresponds to the slab in compression. Accordingly, M_{p1} and M_{p2} in Figure 2 denote the plastic moment of beam only and the combined plastic moment of beam and slab, respectively. M_p in Figure 3 denotes the plastic moment of column.

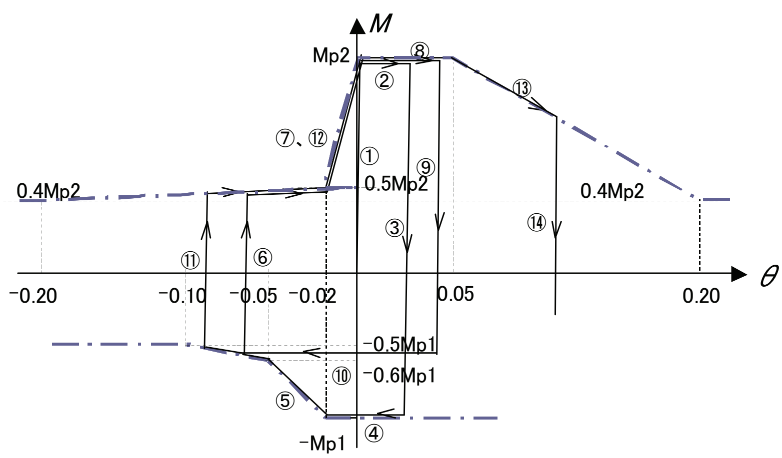

Figure 2 Hysteresis loop for plastic hinge of beam.

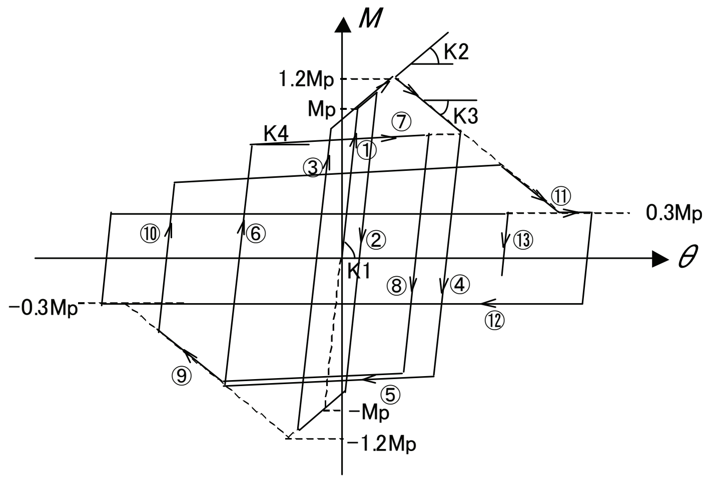

Figure 3 Hysteresis loop for column element (hinge + line).

Column base element is modeled as shown in Figure 4 (Akiyama et al., 1984) as a bilinear slip model, where M_n and M_y represent the lift up moment and the yielding moment, respectively, of the column base. Although the panel zone element was modeled with bilinear elasto-plastic constitutive model, all the panel elements remained in elastic range as a result of time-history analysis. The assumption of rigid floor is not used. *M-N* interaction is also taken into consideration. However, the effect of vertical force *N* turned out to be negligibly small. Mass elements are located at panel zones. The number of elements is 75, and the number of degrees of freedom is 91. The damping matrix is proportional to the stiffness matrix of the line elements only, and the damping factor for the 1st mode is 0.01. The periods (sec.) of the four lowest modes of this model are 0.758, 0.248, 0.139 and 0.099.

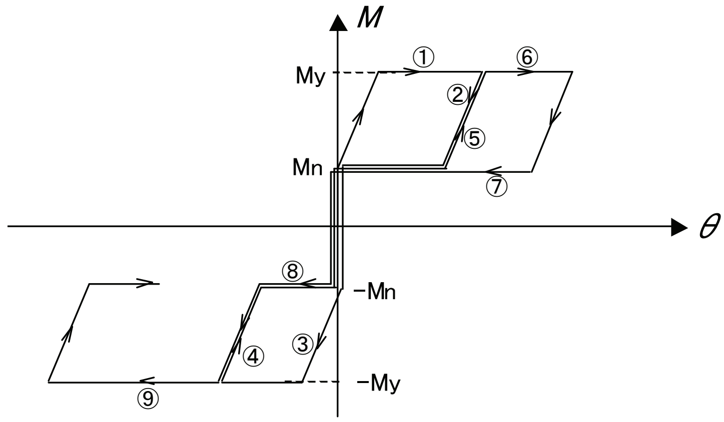

Figure 4 Hysteresis loop for column-base element.

2.2 Analysis results

To compute this complex frame model, a program for the contest was coded on MATLAB/Simulink release 11.1. In the numerical simulation, the acceleration of gravity is necessary to be applied for accurate prediction of *P-Δ* effect and *M-N* interaction. Therefore, the acceleration of gravity is gradually applied in 1 second prior to the time-history analysis. After convergence of the response during 1 second with no additional load, 40% Takatori wave, 60% Takatori wave and 100% Takatori wave are applied in series. Interval time of 10 seconds is also provided between these waves to reduce the response by damped free vibration.

The equation of motion is converted to a 1st-order differential equation based on the conventional state-space equation, and the linear solver ‘ode15s’ of MATLAB (Shampine and Reichelt, 1997), which is suitable for stiff problem of ordinary differential equations, is used for time-history analysis. The step time is variable in this solver. Maximum step time is 0.001 sec., and the maximum tolerance of the error is 0.001. Computation is carried out on a personal workstation with Intel Pentium D 3.2 GHz with 3.5 GB memory. The CPU time is 44 min. for the pretest analysis, and 83 min. for the total of 40%-, 60%- and 100%-Takatori motions that are successively applied in the posttest analysis.

Figure 5 shows the force-displacement relation of the 1st story under target 100% Takatori wave. The curve was able to trace negative stiffness as expected.

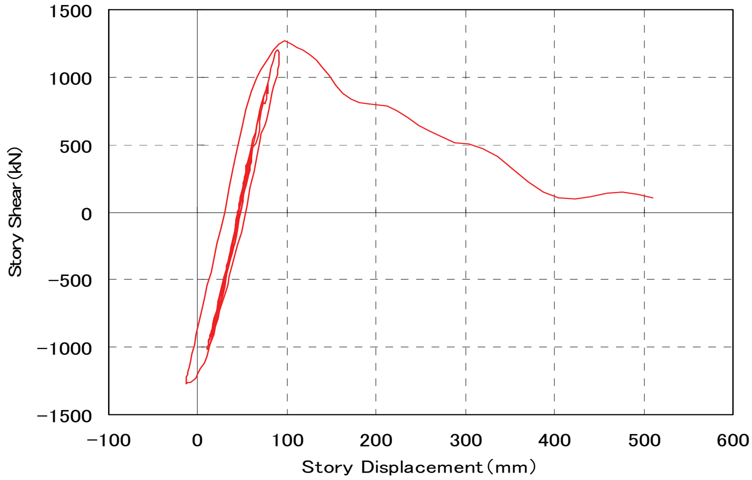

Figure 5 Force-displacement relation of 1st story for target 100% Takatori wave.

Figure 6 shows time history of drift angle of the 1st story under target 60% Takatori wave, where the dashed line is the test result. The computed maximum absolute values of drift angle of the 1st story is 0.0253, which a little overestimates the results 0.019 of experiments. However, the response before reaching the maximum has been accurately simulated. Although the computed residual story drift angle of the 1st story is significantly different from the experimental result, the amplitude and phase of the vibration has been accurately simulated.

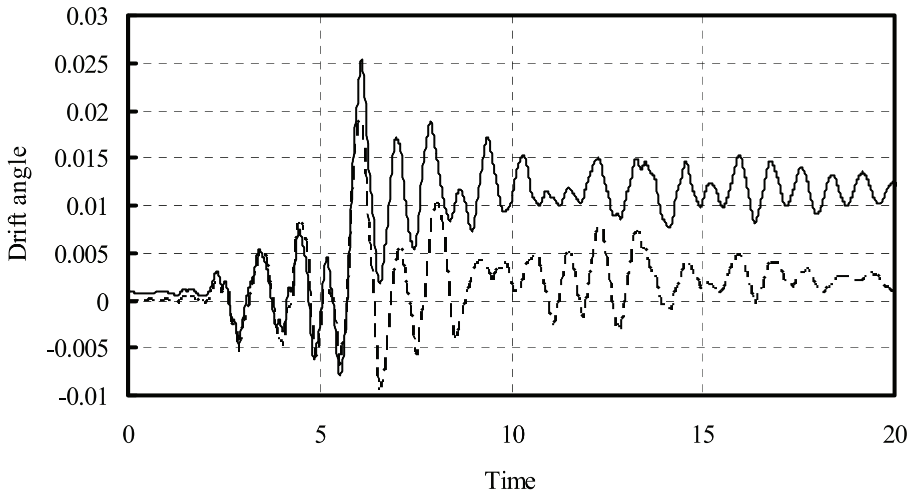

Figure 6 Time history of drift angle of 1st story for target 60% Takatori wave.

3. AWARD WINNING RESULTS BY PRACTICING ENGINEER

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3.1 Analysis model

The self-made program code is used for simulating the collapse behavior of the frame. The relation between the interstory drift angle and the story shear (skeleton curve) is first obtained by static pushover analysis for the steel frame model. Beams and columns are connected directly without panel zone or rigid region. The nominal values are used for the mechanical properties of the beam, and the stiffness of the beam is amplified by 1.25 due to the composite action between beam and slab, which is estimated from the preliminary experimental result of a beam. Plastic hinges are located at the member ends, and the members are assumed to remain in the elastic range. Bilinear moment-rotation relation is used for columns using the yield stress of 330 N/mm^2 obtained from the coupon test.

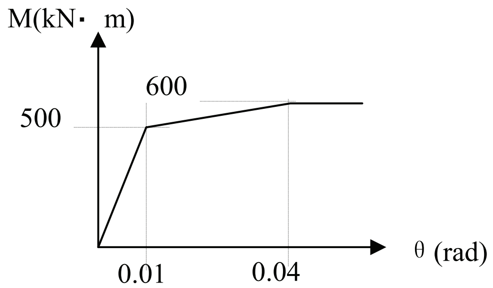

Figure 7 Moment-rotation relation of plastic hinges at beam ends.

The tri-linear moment-rotation relation of a hinge is obtained from the preliminary test results. Figure 7 shows the moment-rotation relation of plastic hinge at beam end, which is given for all beams. A bi-linear moment-rotation relation is used for each plastic hinge at column ends. Column base is fixed. The skeleton curve is obtained from the static pushover analysis, where the load factor is used as the path parameter, and geometrical nonlinearity is not considered. Figure 8 shows the results of pushover analysis. A PC with x86 Family 15 Model 4 Stepping 10 GenuineIntel "3400 Mhz".

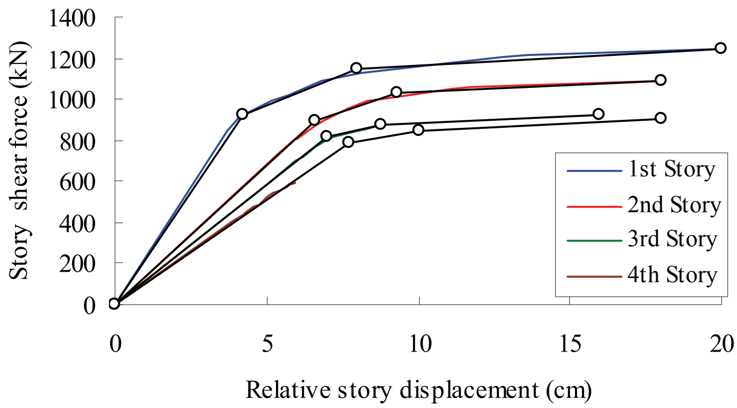

Figure 8 Results of pushover analysis.

Time-history analysis is carried out using the normal tri-linear lumped mass model with rigidly supported base. Since the effect of the stiffness and damping of the nonstructural components cannot be neglect for low-rise steel-framed buildings, the stiffness and damping due to ALC panel and interior dry partition walls (gypsum boards) (Suita et al., 2008), are incorporated in the analysis model, where their properties are estimated from the existing study (Koyama et al., 2003), and the widths are assumed to be 10 m for both of ALC-panel and gypsum board.

The stiffness (frequency) proportional modal damping is used, where $h = 0.02$ for the first mode of the steel frame without nonstructural components. The Newmark-β method with $\beta = 0.25$ is used for time integration, where the time increment is 0.002 sec. The maximum strain of a column is estimated from the maximum overturning moment.

3.2 Analysis results.

The response in Y-direction is computed. The 1st natural period is 1.102 sec. The time history of the drift angle of the 1st story is as shown in solid line in Figure 9 for the target 60% Takatori wave, where the dashed line is the test result. Although the computed value is not close to the measured value after about 9 seconds, the computed maximum absolute values of 1st story drift angles is 0.0177, which is close to the results 0.019 of experiments. The CPU time is about 2 sec.

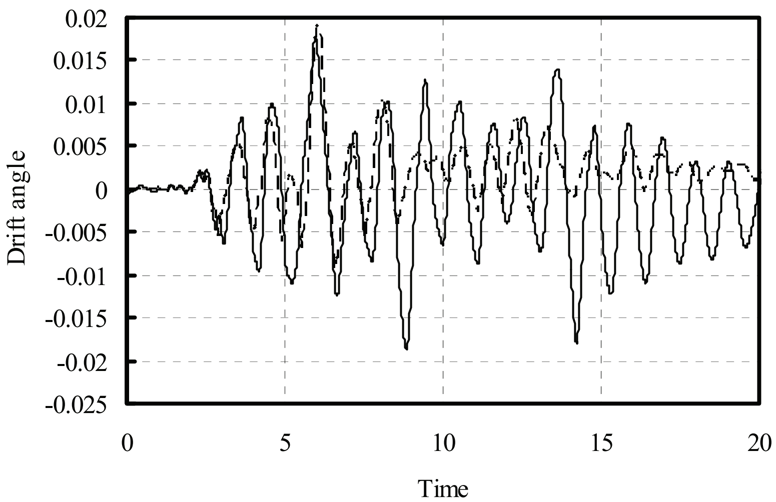

Figure 9 Time history of drift angle of 1st story for target 60% Takatori wave.

4. CONCLUSIONS

The results of award winning groups in the category of 2D-analysis of the blind analysis contest have been reported. Different methods and models were used by the two winners, but the effect of composite beam is incorporated by both winners.

New moment-rotation relations of plastic hinges have been developed by the award winner of the category of researcher to show that the use of accurate degrading relation is very important for prediction of collapse behavior with good accuracy. Although not mentioned in this study, their results showed very good agreement in the maximum responses related to forces such as shear forces and overturning moment.

The award winning results by practicing engineer show that the responses against incipient collapse level motions can be simulated with good accuracy by a lumped-mass model if the hysteresis properties are incorporated accurately by the pushover analysis. Since the effects of geometrical nonlinearity and elastoplastic deformation of column bases are not incorporated in this pushover analysis, the responses to the incipient collapse level motions does not seem to depend strongly on these effects.

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