COLLAPSE OF MULTI-STORY STEEL-BUILDINGS UNDER SEVER GROUND MOTIONS

O Said Elkholy, Student Member, The University of Tokyo
Kimiro Meguro, Regular Member, The University of Tokyo

1. Introduction

Steel moment resisting frames, which are commonly used as a lateral load resisting system for low- to medium rise buildings, suffered unexpected amount of damage during the 1994 Northridge and 1995 Kobe earthquakes. Studying the failure mechanism of collapse of structures during earthquakes is very important to mitigate casualties due to earthquakes. Using Improved Applied Element Method, a complete collapse process for steel framed buildings during the 1995 Kobe earthquake is presented.

2. Improved Applied Element Method (IAEM)

IAEM is a newly developed method for structural analysis of large scale structural. It can follow total behavior of structures up to complete failure stage with high accuracy in reasonable CPU. In IAEM, each structural member is divided into a proper number of rigid elements connected by pairs of normal and shear springs uniformly distributed on the boundary line between elements. Two major extensions of the AEM[1)] have been implemented in IMEM: The first is improving the element type to use different thickness per each spring to be able to follow change of thickness in non-rectangular cross-sections. The second is using different thicknesses for calculating normal stiffness and shear stiffness in each pair of springs. The sort modifications allow modeling cross sectional geometric parameters of structural members using elements with large size. The value of normal and shear stiffness for each pair of springs can be determined as:

$$K_n^i = \frac{E \cdot d \cdot T_n^i}{a} \qquad \text{And} \qquad K_s^i = \frac{G \cdot d \cdot T_s^i}{a} \tag{1}$$

where: d is the distance between each spring; a is the length of the representative area; E and G are Young's and shear modules, respectively; T_n^i and T_s^i are the thickness represented by the pair of springs "i" for normal and shear cases, respectively.

In dynamic case, the mass matrix and the polar moment of inertia of each element have been idealized as lumped at the element centroid. The lumped mass in each DOF direction can be calculated by summing the effect of small segmental masses represented by each spring considering the change of the springs' thickness. Eq.(2) represents the value of lumped mass in each degree of freedom direction assuming that elements have rectangular shape.

$$\begin{bmatrix} M1 \\ M2 \\ M3 \end{bmatrix} = \begin{bmatrix} \dfrac{a \times b \times \rho}{nsp} \cdot \sum_{i=1}^{i=nsp} t_i^x \\ \dfrac{a \times b \times \rho}{nsp} \cdot \sum_{i=1}^{i=nsp} t_i^y \\ \dfrac{\rho}{nsp} \cdot \sum_{i=1}^{i=nsp} \left(\dfrac{t_i^x \times a^3 \times b}{12 \times nsp} + \dfrac{t_i^y \times a \times b^3}{12 \times nsp} \right) \end{bmatrix} \tag{2}$$

where: a and b are the element dimensions; ρ the density of the material considered.

3. Material modeling

A simplified uniaxial bilinear stress-strain model with kinematic strain hardening is adapted for representing the normal stiffness component of structural steel, as shown in **Fig. 1.** In this model, the plastic range remains constant throughout the various loading stages. Although this is not an

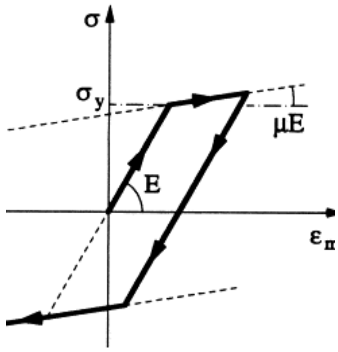
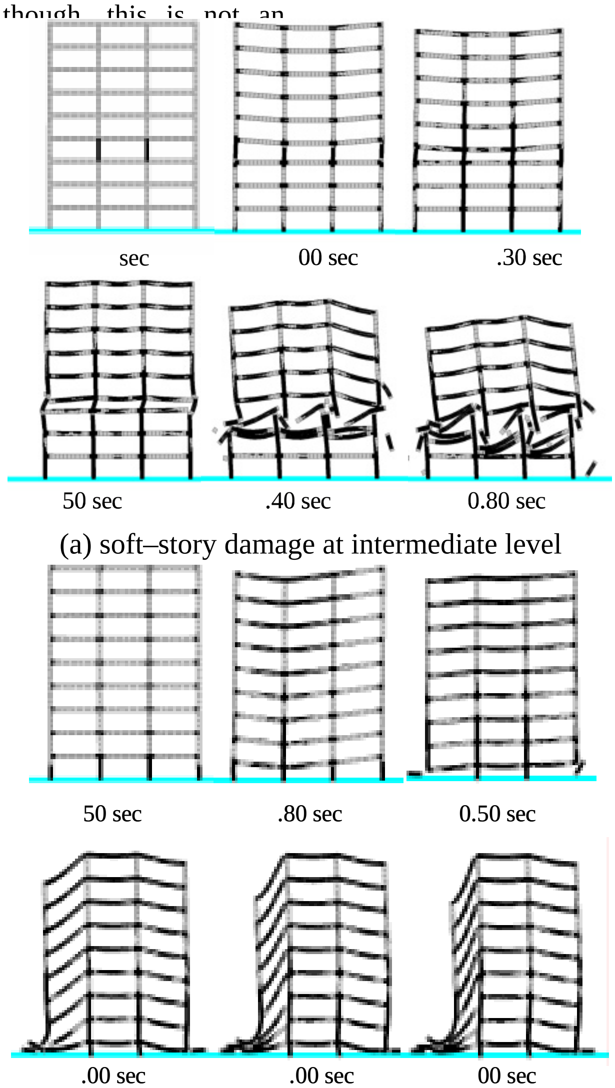


Fig.1: Material Model



(a) soft–story damage at intermediate level

(b) soft–story damage at ground floor level

Fig.4 Failure mechanism of multi-story steel frame

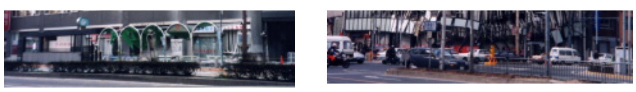


Fig. 5 Collapsed steel structures, Kobe1995

Key words: Earthquake Damage, Improved Applied Element Method, AEM, Collapse, Progressive Failure

Institute of Industrial Science, The University of Tokyo, 4-6-1 Komaba, Meguro-Ku, Tokyo 153-8505, Japan
(Tel: 03-5452-6437, Fax: 03-5452-6438)

capacity of the frame, according the experimental test that was carried out by Hodge[2] was 133.0kN. However, based on IAEM, the maximum frame resistance is reached at load (P) of 136kN which is around 2% higher than the maximum recorded load during the experiment. The load-vertical displacement curve obtained by both IAEM and RBSM are plotted in **Fig. 4** as well as the experimental data.

6. Collapse of a nine-story steel building

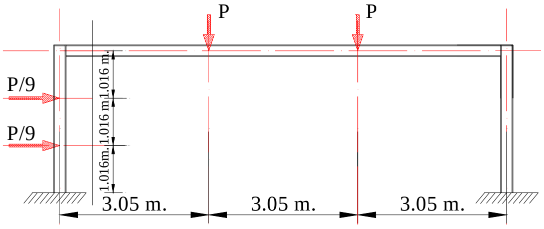


Fig. 2: Analysis Model

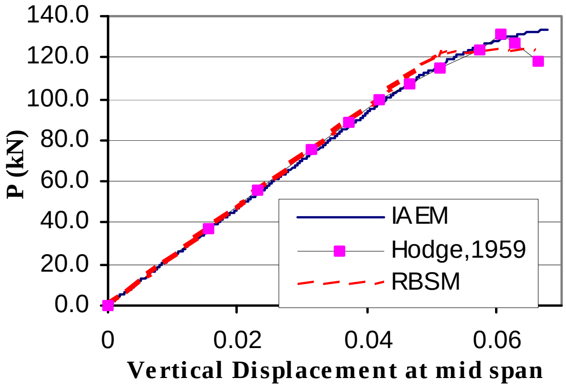


Fig. 3: Ultimate load capacity

IAEM is applied to investigate the validity of the proposed method in simulating progressive failure of steel structural buildings under severe ground motion conditions. The structure considered is a plane nine-story steel frame with three bays of 9.00m long. The typical story height is 3.75m. Using IAEM, only 477 elements are utilized for modeling the whole structure. Two different failure modes are illustrated in **Fig. 4**; the first is intermediate soft-story type failure and the second is soft-story at ground level. A reduction of 40 % of steel strength of the columns and lack of ductility in column-to-beam connections at 4th floor level (case 1) and ground floor level (case 2) were assumed. The intense shaking caused the failure of load bearing columns at the weak floor level and resulted in the formation of plastic zones at several locations (dark color in the figures). From the figure, it can be noted that most of the plastic hinges formed in beams, instated of columns, is due to the strong column-weak beam design philosophy. With the progress of time and formation of enough plastic hinges, the weakness of the strength and the low ductility demand produced columns failure. The end stage of the failure, illustrated in **Fig. 4**, shows a good agreement with recorded collapse cases of multi-story steel buildings due to Kobe (1995) Earthquake (as shown in **Fig. 5)**.

7. Conclusions

The analysis of structural failure of steel framed building due to strong ground acceleration is presented. The good agreement had been reported between the final stage of numerical analysis and the observed damage of many steel structures by the 1995 Kobe earthquake. IAEM can be used for structure vulnerability assessment to evaluate and select the structural configurations that increase the overall structures resistance to extend damage beyond that caused by severs ground motions.

References

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