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Seismic damage analysis of a 32-story framed tube building

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ABSTRACT

The results of application of inelastic dynamic time history analysis to a 32-story reinforced concrete framed tube building using two different computer programs (IDARC and DRAIN-2D) are presented and compared. Interpretations with respect to possible damage based on the resulting patterns of plastic hinge formations, damage indices, and lateral drift are suggested.

INTRODUCTION

Due to increasing awareness with respect to the vulnerability of constructed facilities in the event of damaging earthquakes, seismic assessment of existing buildings and possible retrofit designs has become an important component of many consulting activities. Yet, there are not many published results of the application of inelastic dynamic analysis packages to actual buildings. Such results are needed by engineers to help them evaluate the capabilities and differences of existing software for use in practical applications.

Traditionally, ductility factor has been used to evaluate the extent of inelastic response or damage. Recently, models that incorporate hysteretic energy have been introduced, but the application of these models has generally been limited to simple frames and not actual buildings. In this paper, the results of the application of computer programs IDARC (Park et al. 1987) and DRAIN-2D (Kanaan and Powell 1973) for seismic evaluation of an existing 32-story reinforced concrete framed tube building located in Tehran, Iran is presented.

When using DRAIN-2D, damage assessment would be based on comparison of plastic rotation and/or ductility demand with the deformation capacity. More advanced damage models consider the potential of the structure to plastically dissipate the inherent hysteretic energy in addition to ductility. In IDARC, Park and Ang damage model (Park et al. 1985) has been used. In this model, structural damage in an element is expressed as a function of the ductility and the hysteretic energy in the form of a damage index. The damage index for a story and the structure as a whole is obtained by summing component contributions. A damage index less than 0.4 indicates extensive but repairable cracking in concrete. A damage index between 0.4 and 1.0 indicates likelihood of damage beyond repair. The building can be considered partially or totally collapsed for a damage index greater than 1.0.

BUILDING DESCRIPTION

The building has a height of 101.51 m, with three stories below grade and 29 stories above grade, and plan dimensions of 34.5 m in the N-S and 36 m in the E-W directions. Figure 1 shows photograph of the building and Figure 2 shows a typical plan view. The floor system consists of a 6 cm reinforced concrete slab supported by reinforced concrete 11 cm wide by 40 cm deep joists at 50 cm on centers. The slab has increased thickness of 20 cm between lines 3 and 4 along the coridor adjacent to elevator shafts and stair cases. The joists are supported by two E-W direction shallow beams (40 cm deep, 110 cm wide) along column lines 2 and 5, 20 cm thick walls along column lines 3 and 4, and the exterior framing system. Perimeter columns are spaced at 1.5 m and are framed by spandrel beams with a depth of 1.1 m. In the end portions of the N-S direction frames, there are shear walls each spanning five column lines. The foundation consists of a 1.7 m thick solid mat, and 70 cm thick three stories deep perimeter basement (parking garage) walls. The interior frames and walls are gravity bearing systems, leaving essentially the perimeter frames to resist lateral loads by a combination of tube action (Khan and Amin 1973) and frame action. The tube action, which resists overturning tendency, is manifested by the compressive and tensile forces mostly in the columns of perpendicular frames. The frame action, which resists shear due to lateral forces, is brought about by flexure in beams and columns of the parallel frames.

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IDARC ANALYSIS RESULTS

Inelastic dynamic time history analysis (IDTHA) has been performed on analytical models of the building using computer programs IDARC and DRAIN-2D. The input records consists of Tabas (Iran) N 16 W Sept. 16, 1978 (PGA=0.93g), Naghan (Iran) Longitudinal April 16, 1977 (PGA=0.72g), and El Centro N-S May 18, 1940 (PGA=0.32g). Using IDARC, one can perform nonlinear static collapse analysis, IDTHA, and a comprehensive damage analysis of reinforced concrete buildings. In this paper, the results of the latter two are discussed. Due to symmetry, only one half of the building is modeled for N-S direction analysis. The primary lateral load resisting system for the half of the structure is the N-S perimeter frame that along with the two E-W half frames at the north and south ends effectively will behave as a vertical channel and provide resistance to overturning mechanism. The diaphragm in each floor is assumed to be rigid in its own plane. Details of the modeling are described by Rafiee (1995).

The overall (structure) damage indices based on IDARC analysis are 0.27, 0.68, and 0.94 for El Centro, naghan, and Tabas records, respectively. According to these indices, the building would be at the threshold of collapse, would sustain damage beyond repair, and would have repairable damage if it were to experience, respectively, Tabas, Naghan, and El Centro earthquakes. The resulting failure modes showing the pattern of plastic hinge formation under each record is shown in Figure 3. As can be seen in this Figure, the extent of plastic hinge formation is more critical for the case of Tabas record than the other two.

In order to compare the results from damage indices with the more conventional rule of thumb based on relative story displacement or drift ratio, we can look at the resulting distribution of story displacements due to the three records, as shown in Figure 4. The average drift ratio due to El Centro, Naghan, and Tabas is, respectively, 0.2%, 0.4%, and 0.7%. The drift ratio for Tabas is much less than 2% which is usually considered as the threshold of extensive damage in most buildings. Considering the possibility of extensive plastic hinge formation due to Tabas record, one can expect that the structure will sustain considerable structural damage were it subjected to this earthquake. Such a possibility is not readily obvious from the drift ratio of 0.7% which would mean the possibility of nonstructural damage in a conventional frame building. Given that the damage indices can provide a more accurate measure of damage than the 2% rule of thumb, it is possible to relate the drift ratios due to the three earthquake records to the overall structure damage indices, so as to have a better interpretation of the drift ratio values for this type of building. Figure 5 shows the possibility of serious structural damage to this kind of building construction at drift ratios much less than the code allowable values.

COMPARISON OF RESULTS OBTAINED BY IDARC AND DRAIN-2D ANALYSES

Due to symmetry, again, only one half of the building is modeled for DRAIN-2D analysis. Beam-column elements with concentrated plasticity at the ends and strain hardening characteristics are used for column and wall members. Reinforced concrete beam element with strength deterioration in addition to strain hardening is used for beams. Details of DRAIN-2D modeling are discussed by Motlagh (1993). As a comparison for column plastic hinge formation, we consider the criterion in DRAIN-2D first. Accordingly, a plastic hinge forms in a beam-column when the demand moment-axial load (M, P) falls on or outside the boundary of the failure surface. For a beam element without axial load, plastic hinge forms at the yield moment. Figure 6 shows the plastic hinge formation in selected columns determined by DRAIN-2D and IDARC due to the three earthquake records. Plastic hinge formation in DRAIN-2D occurs in beam elements when moment is larger than the yield moment and in column elements when the moment-axial load (M, P) point falls outside of the failure surface. Plastic hinge formation in IDARC occurs when the moment is greater than the yield value. IDARC does not consider P-M interaction while DRAIN-2D considers that in an approximate sense for beam-column element. The agreement is good for Tabas, fair for Naghan, and poor for El Centro records. Apparently, the larger the PGA, the better the agreement between the two programs. However, it should be noted that the plot indicates the columns that have yielded. In other words, for portions that there seems to be inconsistency, the actual values of the rotations or moments could be close to, but not quite exceeding, the yield value.

In yet another comparison, story displacement diagrams resulting from DRAIN-2D and IDARC analysis under the action of El Centro record are plotted in Figure 7. Distributions of the displacements over the height are the same up to the mid-height of the building. Beyond that, IDARC displacements are slightly larger, with the maximum difference of 10% at the top. While in IDARC strength deterioration, pinching effect and stiffness degradation are considered, in DRAIN-2D model, which is based on the modified Takeda, the pinching effect is absent and stiffness degradation is not considered for beam column elements.

SUMMARY AND CONCLUSIONS

1. The numerical values of overall damage indices show consistency with the interpretation of the extent and pattern of plastic hinge formation.
2. The drift ratio for Tabas record with PGA of 0.93 g and damage index of 0.94 is 0.7% , which is much smaller than the conventionally accepted 2% as the threshold of extensive damage for most buildings.
3. The patterns of plastic hinge formation are somewhat different according to DRAIN-2D and IDARC for the developed models of this building, with better agreement for larger PGA.
4. The pattern of plastic hinge formation for Tabas and Naghan records indicate extensive column failures, with Tabas pattern showing a near soft story situation.
5. IDARC analysis resulted in 10% larger displacement at the top compared to DRAIN-2D result for El Centro record.

ACKNOWLEDGMENT

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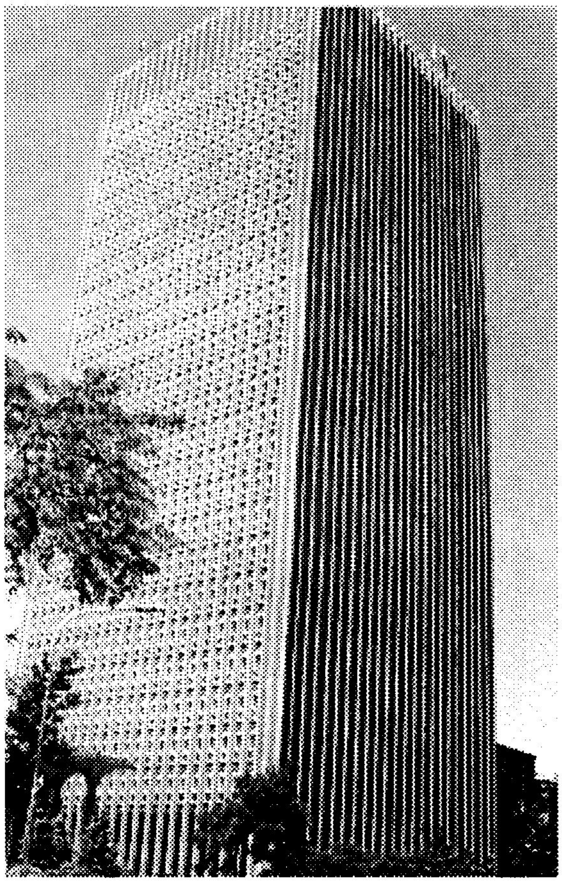


Figure 1. A photograph of the building

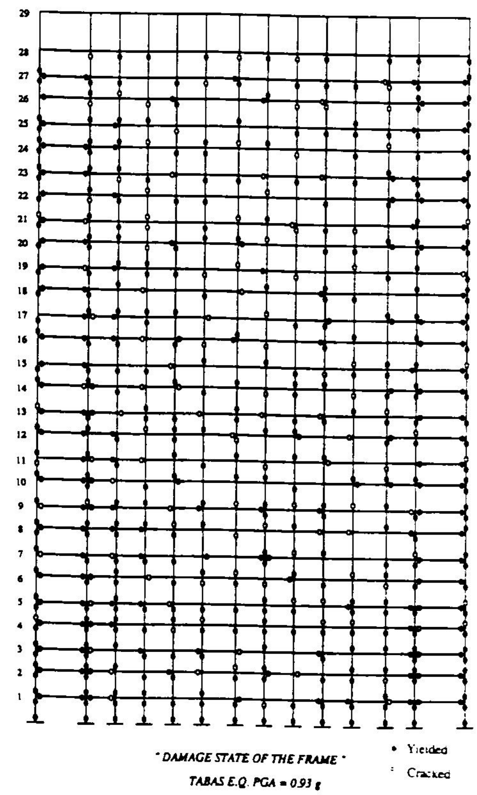
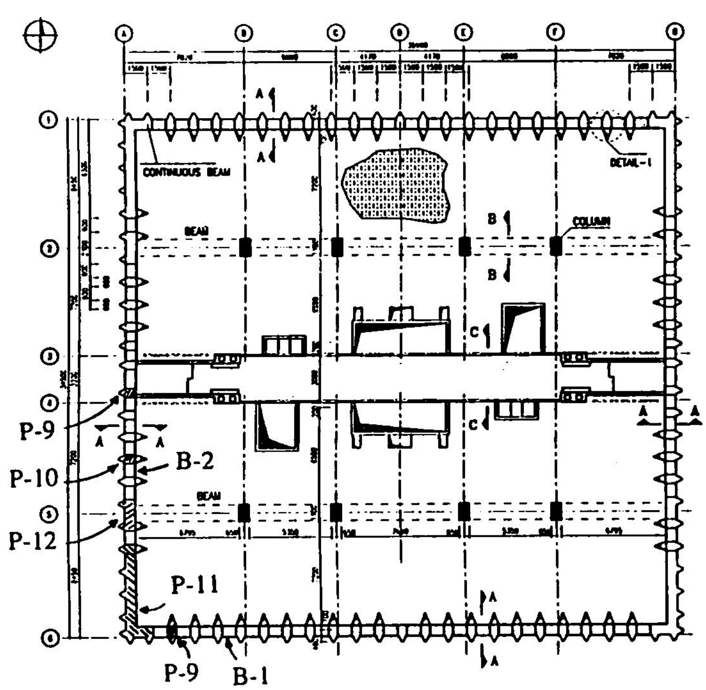


Figure 3. IDARC result: plastic hinge formation



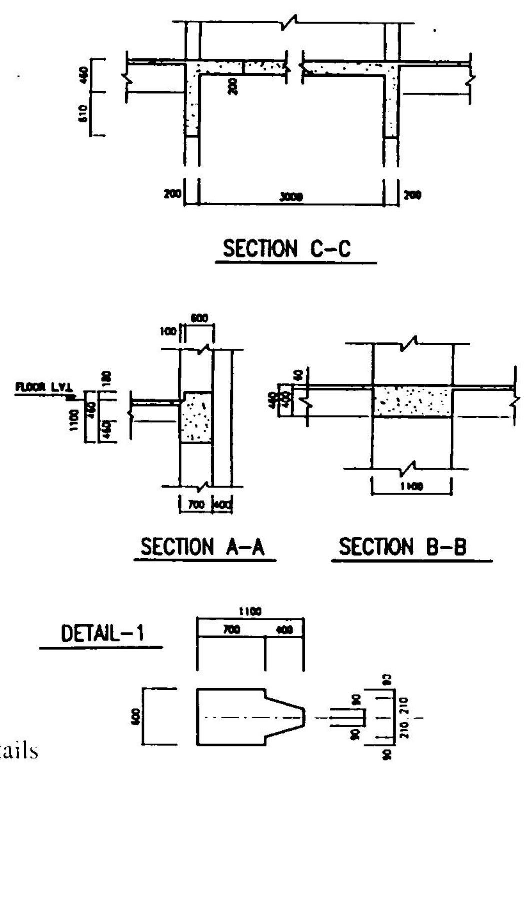


Figure 2. Building plan and some details

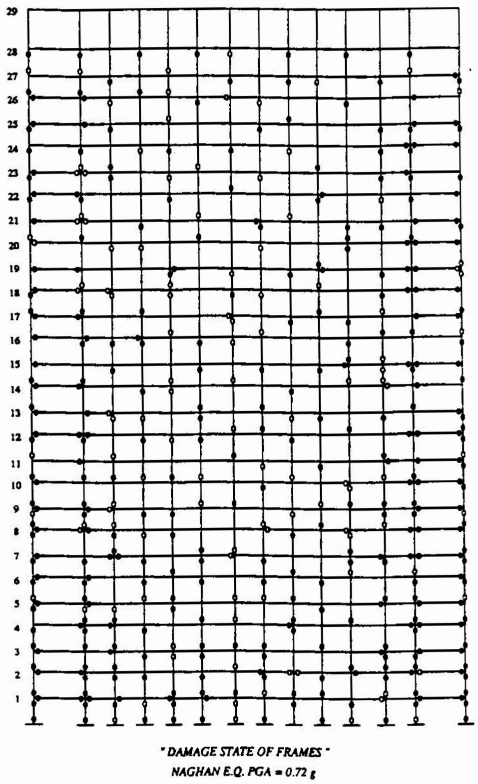
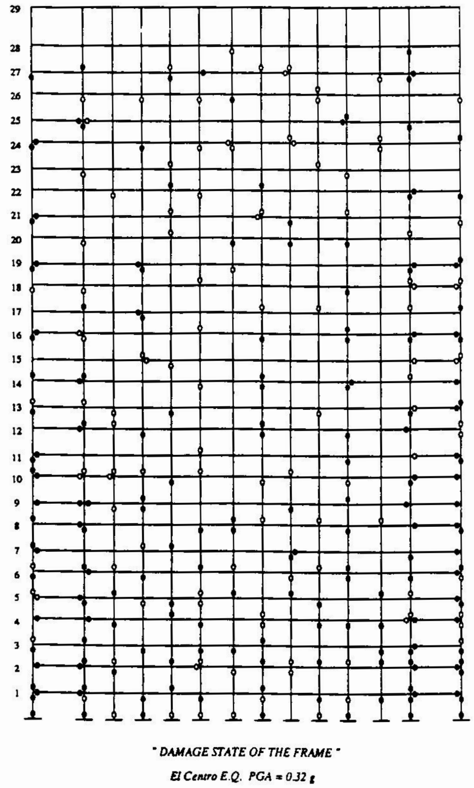


Figure 3. (continued)



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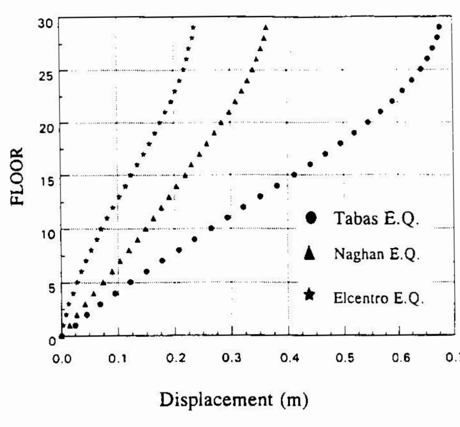


Figure 4. IDARC result: story displacements

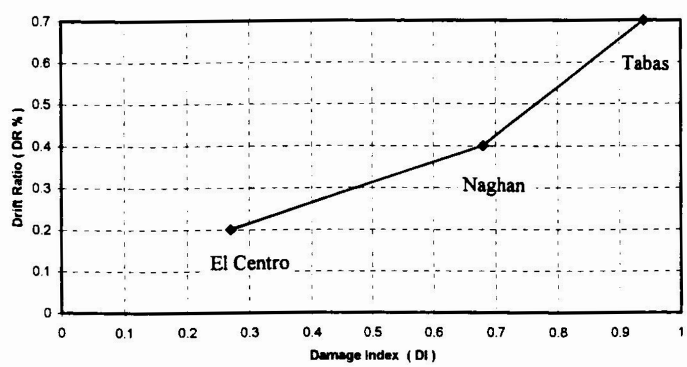


Figure 5. Drift ratio – damage index relation

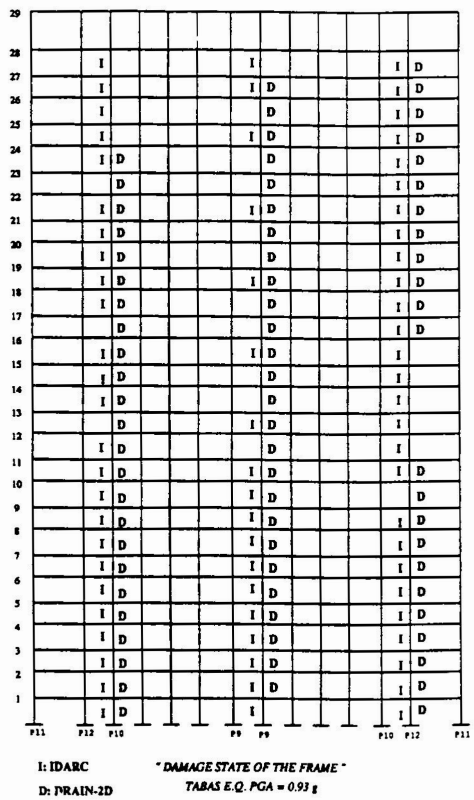


Figure 6. IDARC and DRAIN-2D plastic hinge formations

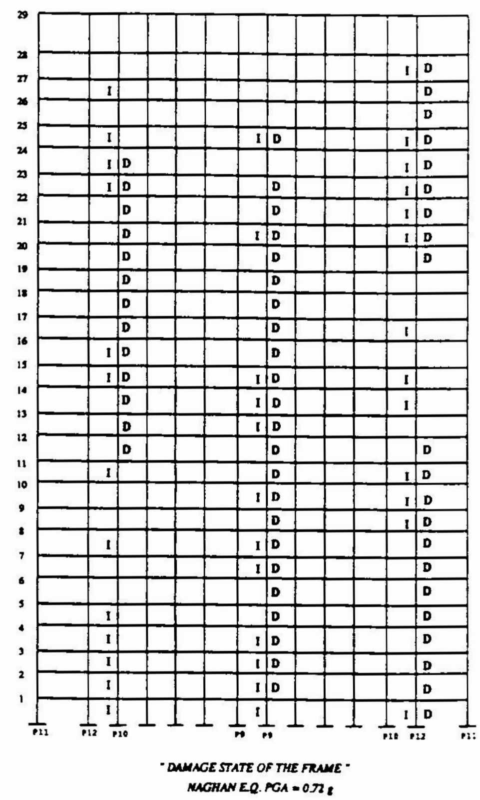
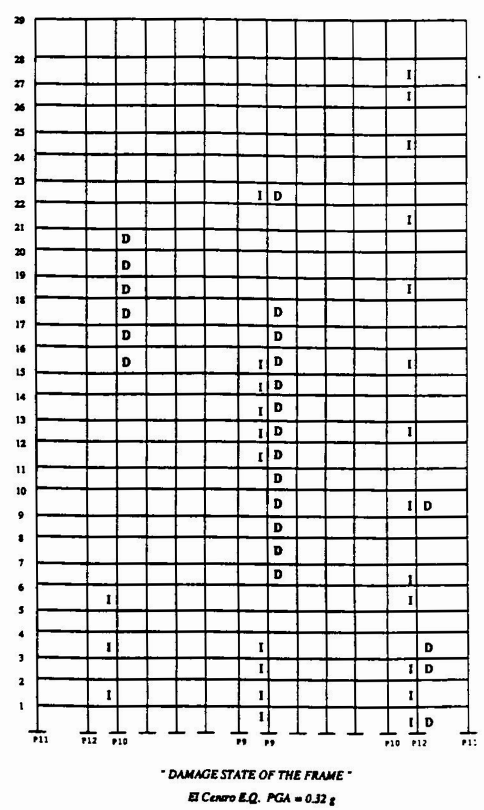


Figure 6. (continued)



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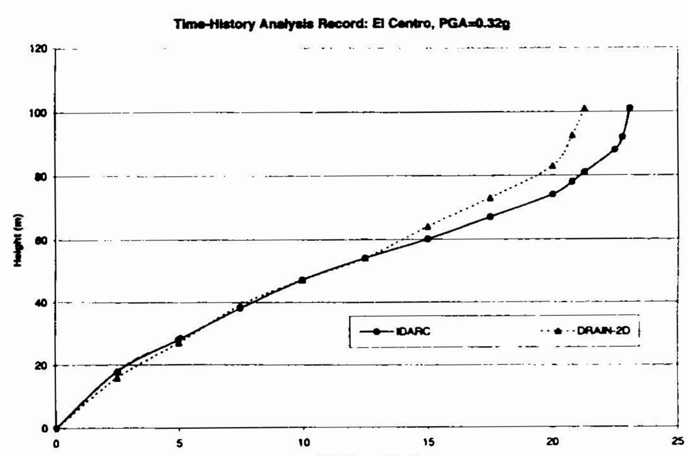

Figure 7. IDARC and DRAIN-2D displacements