Comparison of Conventional and Energy-Based Methods in Fragility Assessment of Steel Moment-Resisting Frames

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ABSTRACT

Methods for generating fragility curves in buildings are generally based on the maximum inter-story drift. Moradi and Abdolmohammadi (2020) proposed an energy-based method. They stated that by considering the plastic strain energy in high-rise structures as an engineering demand parameter, fragility can also be derived. The aim of this study is to compare the maximum inter-story drift-based method and the energy-based method in 4-, 8-, and 12-story steel buildings. For this purpose, after initial design, the structures were modeled nonlinearly in PERFORM-3D software and subjected to 20 near-fault ground motion records. Incremental Dynamic Analysis (IDA) curves were extracted using both the energy and maximum drift methods and compared with each other. Finally, by calculating the energy limit states at two performance levels—Life Safety (LS) and Collapse Prevention (CP)—the fragility curves at these two levels, along with the elastic level, were computed and compared with the maximum drift-based method. The results showed that in low- and mid-rise structures, the maximum drift-based method provides a more conservative fragility estimation compared to the energy-based method. For example, the probability of exceeding 50% of the LS level in the energy-based method for 4-, 8-, and 12-story buildings occurs at peak accelerations of 1g, 1.25g, and 1.45g, respectively, while in the conventional method this occurs at peak accelerations of 0.65g, 0.9g, and 1g, respectively.

KEYWORDS

Fragility, Energy-based method, Drift-based method, Incremental Dynamic Analysis (IDA) curves, Steel moment-resisting frame

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1. Introduction

Earthquakes are among the most destructive natural disasters, potentially causing severe damage to the physical environment, disruption of economic and social activities, and resulting in thousands of fatalities, injuries, and displaced individuals. Although such high-impact events are relatively rare compared to other natural hazards and are characterized by low occurrence probabilities, their consequences are catastrophic and can affect large regions for extended periods of time [1-3].

Moradi and Abdolmohammadi (2020) stated that, since an earthquake is defined as the release of energy within the Earth, a structure maintains its stability during seismic events when the total internal energy in the structure is in equilibrium with the input energy from the earthquake. Therefore, plastic strain energy can be employed as an Engineering Demand Parameter (EDP) in fragility assessment of structures [4]. They were the first to develop Incremental Dynamic Analysis (IDA) curves based on the dissipated strain energy rather than maximum drift. Subsequently, they defined the Collapse Prevention (CP) and Life Safety (LS) performance levels in terms of plastic strain energy and developed corresponding fragility curves. In their study, energy-based fragility was defined as the probability that the plastic strain energy demand in the structure exceeds the energy-based performance levels under varying seismic intensities [5, 6].

Based on previous studies, it has been demonstrated that the energy-based approach proposed by Moradi and Abdolmohammadi can serve as an effective method for assessing the seismic fragility of structures. However, their investigations were primarily conducted on high-rise steel and reinforced concrete buildings. In this study, the applicability of the energy-based method for evaluating the fragility of low- and mid-rise steel structures is examined and compared with the conventional (drift-based) approach. For this purpose, three buildings with 4, 8, and 12 stories were designed and modeled nonlinearly. First, the dynamic behavior and performance of the structures were analyzed. Subsequently, Incremental Dynamic Analysis (IDA) curves were developed based on both maximum drift and dissipated strain energy, and the results were compared. Finally, fragility curves derived from the two approaches—energy-based and drift-based—were computed and compared. The following sections present the numerical modeling and research methodology.

2. Structural Model Description

In this study, 4-, 8-, and 12-story regular-plan steel structures were selected for analysis. Each bay length was considered to be 6 meters, and the story height was set to 3 meters. The structures were designed for a high-seismicity region and soil type III, employing a special moment-resisting frame system with residential occupancy, in accordance with the Iranian Seismic Code Standard No. 2800 (4th edition). The steel material used was ST37 with a yield strength of 2400 kg/cm², a Young's modulus of 2,000,000 kg/cm², and a unit weight of 7.85 ton/m³. The floor system consisted of steel decking with a dead load of 560 kg/m² and a live load of 200 kg/m². Floor loads were distributed in a checkerboard pattern. For exterior spans, wall loads of 700 kg/m and parapet loads of 300 kg/m were considered. The structures were modeled and loaded in ETABS and designed based on strength adequacy and maximum allowable drift criteria.

3. Fragility

Figure 1 presents the fragility curves of the 4-story structure obtained using both the conventional and energy-based methods. As previously discussed, the energy-based approach enables the estimation of fragility at the elastic, Life Safety (LS), and Collapse Prevention (CP) levels, whereas the conventional method can be used to derive fragility for different damage states or performance levels such as Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP). In this study, the conventional method was applied to evaluate fragility at three performance levels: IO, LS, and CP. The results for the 4-story structure indicate that, as expected, the elastic state occurs at lower peak ground accelerations (PGAs) compared with the IO level, and its probability of exceedance reaches unity within a narrower acceleration range. Specifically, there is a 50% probability of exceeding the elastic level at a PGA of 0.15g, while the same probability for the IO level occurs at 0.25g. The 50% exceedance probability for the LS level in the energy-based method occurs at a PGA of 1.0g, compared with 0.65g in the conventional method. Similarly, the 50% probability of exceeding the CP level for the 4-story structure is observed at 1.2g in the energy-based method and at 1.0g in the conventional approach.

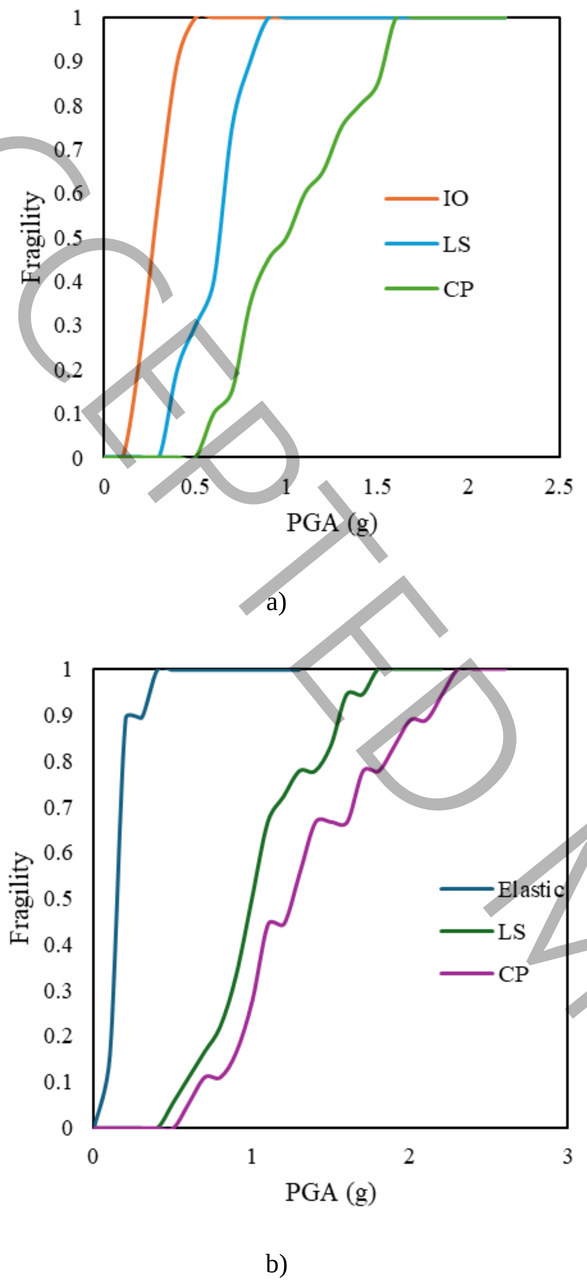

Figure 1. Fragility curves of the 4-story structure using (a) conventional method and (b) energy-based method.

For 8 Stories structure, the 50% probability of exceeding the elastic level occurs at a peak ground acceleration (PGA) of 0.25g, indicating that the 8-story structure remains elastic under higher acceleration levels compared with the 4-story building. The 50% exceedance probability for the IO level occurs at 0.45g. For the LS performance level, the corresponding PGAs are 1.25g and 0.9g for the energy-based and conventional methods, respectively. Similarly, the 50% probability of exceeding the CP level occurs at a PGA of 1.7g for the energy-based method and 1.5g for the conventional approach.

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