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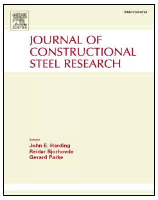

Simplified direct loss measure for seismic isolated steel moment-resisting structures

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ABSTRACT

Seismic base isolation provides an effective means for resilient structures, protects structures from the damaging effect of seismic action and reduces structural vibration, casualties and financial losses. The life cycle costs and advantages of using base isolation can be quantitatively supported by using the FEMA P-58 methodology, but damage and loss estimation using such an approach is time consuming and costly. This study presents a new direct loss measure (LM) for seismic isolated steel moment-resisting structures. Three steel moment-resisting frames of 4, 6 and 8 stories were studied with and without isolation system and 3D nonlinear model of the structures was developed in Opensees. Using common incremental dynamic analysis (IDA) under far-field and near-field records, the expected annual loss (EAL) based on FEMA P-58 approach was estimated. In this regard, LM was introduced for rapid modeling of response based on two main sources of structural damage, that is, interstory drift ratio and peak floor acceleration considering structural and non-structural elements. A good correlation was observed between the EAL and proposed LM. The fixed-base structures were subject to extensive damage and complete failure in the maximum considered earthquakes (MCE), while the base-isolated structures were subject to moderate failure rate in the same situation, indicating the resilience of these structures. The proposed LM can be used for prompt and efficient loss estimation of the base-isolated structures and demonstrate the cost-effective seismic risk management of these systems.

1. Introduction

Residents' safety is of great importance in the design of systems and structures considering earthquakes that result in financial loss, and negatively affect the performance of structures. Due to recent destructive earthquakes, resilient structures have been widely considered since they are capable of exploitation immediately after the earthquake [1]. The design of resilient structures must be based on prevention of destructive effects of earthquakes. It should be noted that it is practically impossible to design a structure that is not vulnerable to earthquakes at all. Simply put, resilient structures are structures that are less damaged as compared to conventional structures in the event of earthquake [2].

Seismic base isolation provides an effective means for resilient structures and protects structures from the damaging effect of seismic action and reduces structural vibration, casualties and financial losses [3–5]. The isolators reduce the frequency of structure and accordingly, reduce the acceleration response of structure. Isolated structures tend to respond like solid mass, and most of the deformations occur in the flexible layer of the isolation system [6,7]. However, high cost of isolation system and uncertainty about future benefits acts as strong obstructions for building clients [8]. Besides, research showed that isolated structures are more susceptible to failure than conventional structures in the case of yield in superstructure due to increased deformation and reduced stiffness. Contrary to the conventional structures, there is no increase in structural frequency in the event of yield and the level of demand forces is not reduced. As a result, the hysteresis energy does not change considerably after yield in the isolated structures [9]. Therefore, isolated structures can be subject to non-elastic deformations and serious damage during great earthquakes like other structures [6,10].

To develop the implementation of base isolation in structures, earthquake experts must be able to demonstrate the above situations so that the base isolation system can be applicable and cost-effective. Several previous studies have attempted to verify the life cycle benefits of base-isolated building. Bruno and Valente [11] compared financial losses in conventional and base-isolated structures by conducting non-linear time history analyses and assessed the expected life cycle benefits of using base isolation to be significant. Goda et al. [10] studied the cost-benefit of isolated structures. They found that the use of isolator could reduce the cost of the lifecycle of the isolated structure by up to 20%,

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but damage and loss estimation were not included in the damage assessment process. Bedrinana and Saito [12] reported that the total life cycle cost of the base isolated structure is 14% lower than the conventional structure after 100 years. Mander [13] proposed and validated four-step closed-form loss estimation methodology that relates hazard to response and thus to losses without the need for classic fragility curves. The study presented loss ratio, which is the ratio of the repair cost to the total replacement cost, and an effective parameter representing structural and nonstructural damage caused by earthquakes. Lashgari [14] evaluated and compared isolated concrete structures and conventional concrete structures with a cost-failure approach and finally indicated the good performance of isolated structures in terms of failure. Chimamphant and Kasai [15] compared the response and performance of isolated steel structures and non-isolated steel structures. Their study was conducted only for the maximum considered earthquake (MCE), in which, the sensitivity of non-structural members to the failure criterion was examined by introducing it as a performance criterion.

The FEMA P-58 [16] analysis approach combines ground motion hazard, structural response and component damage predictions so as to make predictions of building performance under seismic loads. The calculation approach generates estimates of repair costs, the number of injuries and fatalities, repair times, and the potential for an unsafe placard to be placed on the building. All results are in the form of probability distributions, reflecting the substantial uncertainty in these estimations. These output metrics were quantified because they facilitate cost-effective risk management decisions when assessing design of new structures or risk management actions for existing structures. A number of recent studies have evaluated the life cycle costs and advantages of using base isolation using the FEMA P-58 methodology. Terzic et al. [17] determined the expected net present value of using base isolation in a steel moment-resisting frame structure considering the effects of business downtime. Their study showed that the isolation system can be economically feasible if the discount rate is between 3.4 and 4.9%. Mayes et al. [18] used the FEMA P-58 approach to evaluate the performance of low-rise steel structure and found that base isolation was by far the most effective method for reducing seismic losses in a design level earthquake. Marrs [19] compared the performance of a conventional and 12-storey isolated-steel office building. The study concluded that the conventional building's expected repair cost was 4.2 times larger than the base isolated building's expected repair cost. Cutfield et al. [20] presented a case study on the effects of moat wall pounding and business interruption using the FEMA P-58 methodology. The study showed that the cost-effectiveness of the isolation was sensitive to the ability of businesses to rearrange promptly and effectively after a severe earthquake. Banazadeh et al. [21] presented a methodology based on FEMA P-58 and utilized performance-based seismic design procedure for evaluation of isolated structures with or without viscous damper considering cost-benefit analysis. They used the cost-benefit analysis to calculate payback period of investment for additional cost of the isolation system. Parvini Sani et al. [22] developed loss estimation procedure based on FEMA P-58 considering repair costs, injuries and fatalities, downtime for isolated low-rise steel structures. The cost-benefit analysis considering discount rate, was used in their study and it was shown that increased construction cost of base-isolated structures can be paid back within 7 to 41 years.

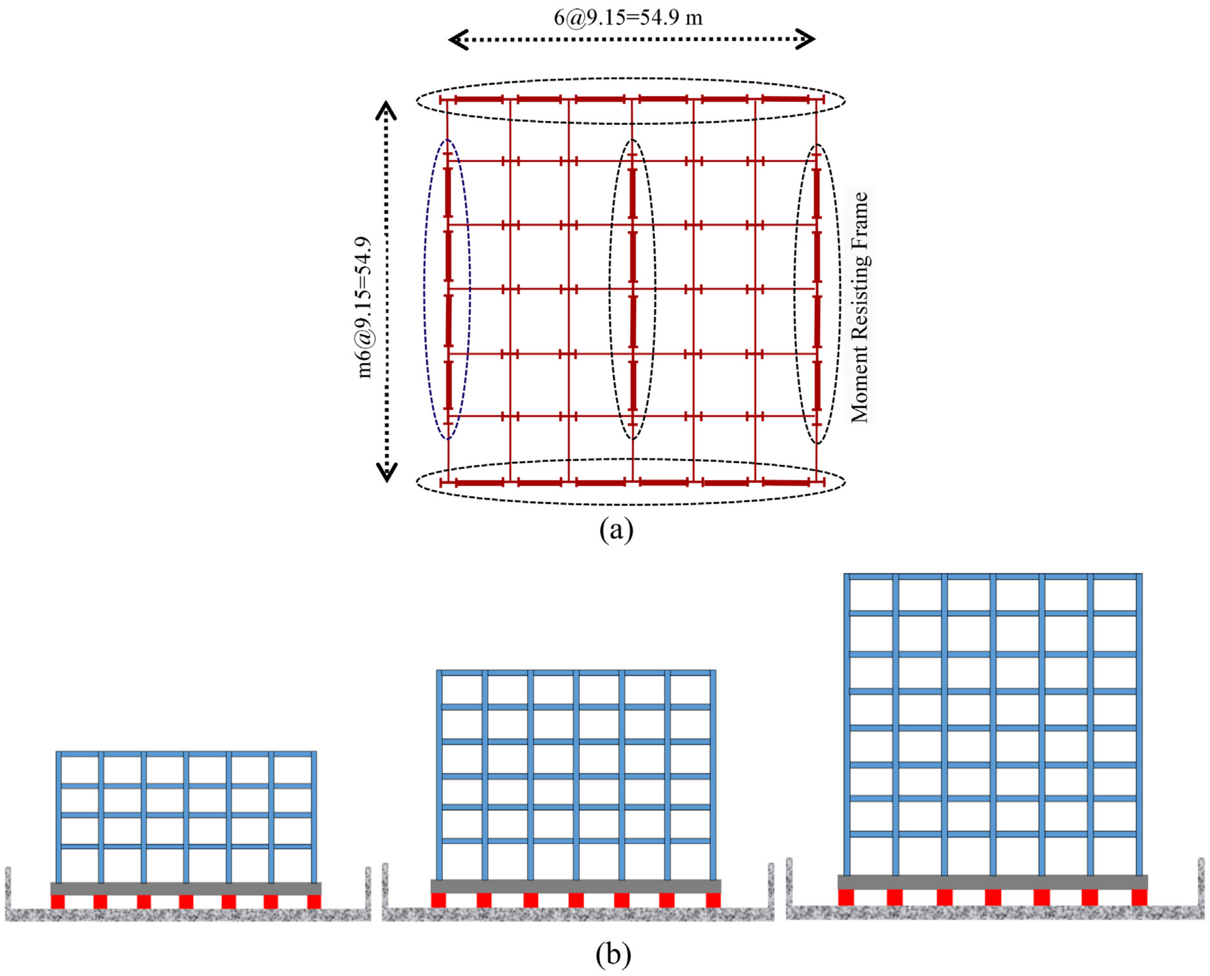

Fig. 1. (a) Plan of the studied structures, (b) elevation view of the structures.