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EVALUATION OF REDUNDANCY FACTOR IN STEEL STRUCTURES WITH ECCENTRIC BRACING SYSTEM

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In seismic design of structures, structural redundancy is considered vital to retain the overall integrity and stability. In general, the terms redundancy and alternative load path are being used interchangeably, particularly in random incidents and progressive collapses. In a structure, the importance of redundancy can be underlined when a failed element cannot appropriately redistribute loads to its adjacent element. The redundancy in a structure manifests itself by providing alternative load path through excessive mechanism for load transmission. Structures with inadequate redundancy might collapse immediately due to a local failure (Fang and Fan, 2011). In other words, the role of redundancy in an intact structure is not underlined until some elements fail during an unpredictable incident such as earthquake (Schafer and Bajpai, 2005).

During a strong ground motion, the response of a structure is no longer elastic. Experiencing inelastic behavior, some local failures are inevitable when seismic forces are imposed to a structure. The paucity of adequate redundancy in the structural elements can lead to their undesirable devastation during seismic ground motions. The concept of redundancy factor was first introduced in NEHRP97, UBC 97, and IBC2000 (Godínez and Tena, 2016). Research studies have indicated that decreasing the number of lateral resistant elements (i.e. inadequate redundancy factor) to resist seismic-induced loads in a direction can adversely affect the energy absorption (Marhadi and Venkataraman, 2009) and ductility capacity (Tena and Cortés, 2015) of a structure. To consider this undesirable issue, the design seismic force of such structures will be increased by an incremental redundancy factor. The value of this incremental factor is 1.2 in 2800 standard while FEMA and ASCE-7 (FEMA and ASCE-7 2010 codes) recommend a value of 1.3.

This study focuses on evaluating the redundancy factor in hinged steel structures with eccentric bracing system. Towards this, several three-dimensional structures of five and eight stories were designed with 5 bays of 6 m long as schematically indicated in Figure 1. The structures were divided into regular and irregular structures with link beams of different lengths. The analysis and design of the selected structures were performed using SAP2000. Seismic design of structures was carried out according to the 4th edition of Standard 2800. In such design, the structures were considered to be residential and located in soil type II in a place of very high seismicity (i.e. Tehran).

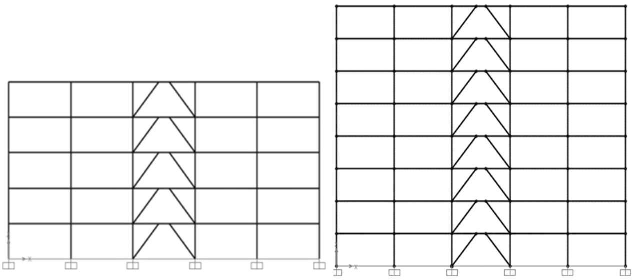

Figure 1. Schematic illustrations of the case study structures.

To evaluate the redundancy factor, the case-study structures were initially designed based on a redundancy factor of 1.0. The structures were then analyzed using nonlinear pushover approach to evaluate their performance level. The redundancy factor was then increased until the target performance level (life safety) is achieved. According to Standard 2800, residential buildings should indicate a life-safety performance level. In other words, none of the assigned plastic hinges to structural members should not pass the life-safety threshold, otherwise the structures should be redesigned with a higher redundancy factor. In this case, the structure would be stronger and less plastic hinges would pass the life-safety performance level. Therefore, to achieve the target performance level and required redundancy factor, the structure should become stronger until no plastic hinges pass the life-safety performance level.

Nonlinear static (pushover) analysis is a common approach in performance evaluation of the existing structures. In this approach, a monotonically increasing load is applied to structures to simulate, albeit approximately, the forces imposed to a structure during seismic ground motions. In addition, the nonlinear behavior of materials and structural element are taking into account during analysis.

The results indicate that the life safety performance level is satisfied with a redundancy of 1.0 in some cases, 1.3 in others unlike the Standard 2800 provision. In addition, it is observed that for structures in which the length of link beam is determined according to Equations 1 and 2, a higher redundancy factor is required to achieve the life safety performance level by increasing and decreasing the length of the link beam, respectively.

$$e \leq \frac{1.6M_{CE}}{V_{CE}} \tag{1}$$

$$e \geq \frac{2.6M_{CE}}{V_{CE}} \tag{2}$$

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