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Seismic collapse performance of special moment steel frames with torsional irregularities

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ABSTRACT

Many building structures exhibit torsional irregularity, which is a type of horizontal irregularity. It is difficult to estimate the inelastic response of torsionally irregular structures subjected to earthquake ground motions using numerical analyses because torsionally irregular structures experience both lateral displacement and floor rotation. This study evaluates the collapse performance of multi-story model structures with various degrees of torsional irregularity via nonlinear response history analyses. This study also proposes a procedure for computing design story drift demands, which allows torsionally irregular structures to have uniform collapse risk irrespective of the degree of torsional irregularity.

1. Introduction

Torsional irregularities are a type of horizontal irregularity (Table 12.3-1, ASCE 7-10 [1]) that are induced by an asymmetric distribution of mass, stiffness and (or) strength. Since torsionally irregular structures experience both lateral displacement and floor rotation during an earthquake, they sustain greater member forces and drifts compared to regular structures. Without careful design consideration, torsionally irregular structures may be more vulnerable to earthquakes than regular structures. To reduce the vulnerability of torsionally irregular structures, current seismic codes specify more stringent requirements for torsionally irregular structures than regular structures; in other words, torsionally irregular structures must be designed to satisfy the design requirements for regular structures as well as additional requirements for torsionally irregular structures.

Many studies have been conducted to investigate the effect of torsional irregularity on the seismic response of single-story torsionally irregular structures designed according to seismic design provisions (Chopra and Goel [2]; Tso and Wong [3]; Humar and Kumar [4]; Dutta and Das [5]; Aziminejad and Moghadam [6]; Herrera and Soberon [7]). Although it is convenient to draw insight about the effect of torsional irregularity by analyzing simple single-story structures, there are limitations when it comes to extrapolate the results from single-story structures to multi-story torsionally irregular structures (Stathopoulos and Anagnostopoulos [8]).

Recently, due to the development of high-performance computers and software, the seismic behavior of multi-story structures with torsional irregularity has been investigated by conducting nonlinear response analyses (Jeong and Elnashai [9]; Stathopoulos and Anagnostopoulos [10]; Reyes and Quintero [11]). De-la-Colina [12] investigated the seismic behavior of multi-story torsionally irregular structures, and proposed design recommendations to control the ductility demands. DeBock et al. [13] investigated the seismic collapse performance of multi-story reinforced concrete frame structures using sophisticated plastic models that accounted for cyclic and in-cyclic deterioration in order to evaluate the design recommendations related to accidental torsion.

The objective of this study is to evaluate the seismic collapse performance of multi-story structures with various degrees of torsional irregularity, which are designed according to current seismic design provisions. For this purpose, three- and nine-story model structures with various degrees of torsional irregularity are designed according to ASCE 7-10 [1], AISC 341-10 [14] and AISC 360-10 [15], in which special moment steel frames are used as seismic force resisting systems. Incremental dynamic analyses are conducted for the model structures with repeated nonlinear response history analyses using a three-dimensional inelastic analytical model. Based on the analysis results, this study evaluates the collapse performance of the model structures, and proposes a

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procedure for computing the design story drift demand in an attempt to allow torsionally irregular structures to have uniform collapse risk. In order to monitor the change in member sections of torsionally irregular structures according to the design stages, this study also estimates the total steel weight of the moment frames in model structures at each design stage.

2. Summary of design process for torsionally irregular structures

In ASCE 7-10 (Table 12.3-1), when the maximum story drift at one end of the structure is more than 1.2 times the average story drift at both ends of the structure, the structure is classified as being torsionally irregular. When the drift ratio is greater than 1.4, the structure is considered to have extreme torsional irregularity.

When a structure has torsional irregularity, the structure should be designed to satisfy the design requirements for regular structures as well as additional requirements for torsionally irregular structures, as specified in ASCE 7-10 [1]. The seismic design process for torsionally irregular structures is similar to that of regular structures. In this study, the design process for torsionally irregular structures is separated into three stages: (1) strength design stage, (2) drift (stiffness) checking stage, and (3) stability ($P-\Delta$effect) checking stage. Fig. 1 illustrates the schematic flow of the seismic design process for torsionally irregular structures that is used in this study.

The additional requirements specified in ASCE 7-10 are: (1) increases in forces due to irregularities for SDC D, E and F (12.3.3.4), (2) 3-D modeling for structures having torsional irregularity type 1a, 1b, 4, or 5 of Table 12.3-1 in ASCE 7-10 (12.7.3), (3) amplification of accidental torsion for structures assigned to SDC C through F (12.8.4.3), (6) analysis procedure selection for torsionally irregular structures (12.6), and (7) story drift calculation using the largest difference of the deflections of vertically aligned points at the top and bottom of the story along any edges of the structure (12.8.6). The numbers in parentheses are the section numbers of ASCE 7-10 [1] for each of the additional requirements.

2.1. Strength design

In the strength design stage, seismic design forces are calculated to determine the member section. Three different analysis procedures are permitted in ASCE-7-10 [1]: (1) equivalent lateral force analysis, (2) modal response spectrum analysis, and (3) response history analysis. A three-dimensional analytical model is required for the analysis of torsionally irregular structures assigned to all levels of SDCs, with the exception of SDC A. For torsionally irregular structures assigned to SDCs D, E, and F, the equivalent lateral force analysis procedure is not permitted. In this study, a modal response spectrum analysis method that has no limitations according to the level of SDCs is used.For torsionally irregular structures, both inherent and accidental torsions should be properly accounted for when calculating the member forces and drifts. The inherent torsion results from an asymmetric distribution of mass, stiffness, and strength, whereas accidental torsion is induced by uncertainties in the distribution of mass, stiffness, and strength. The accidental torsional moment is calculated using

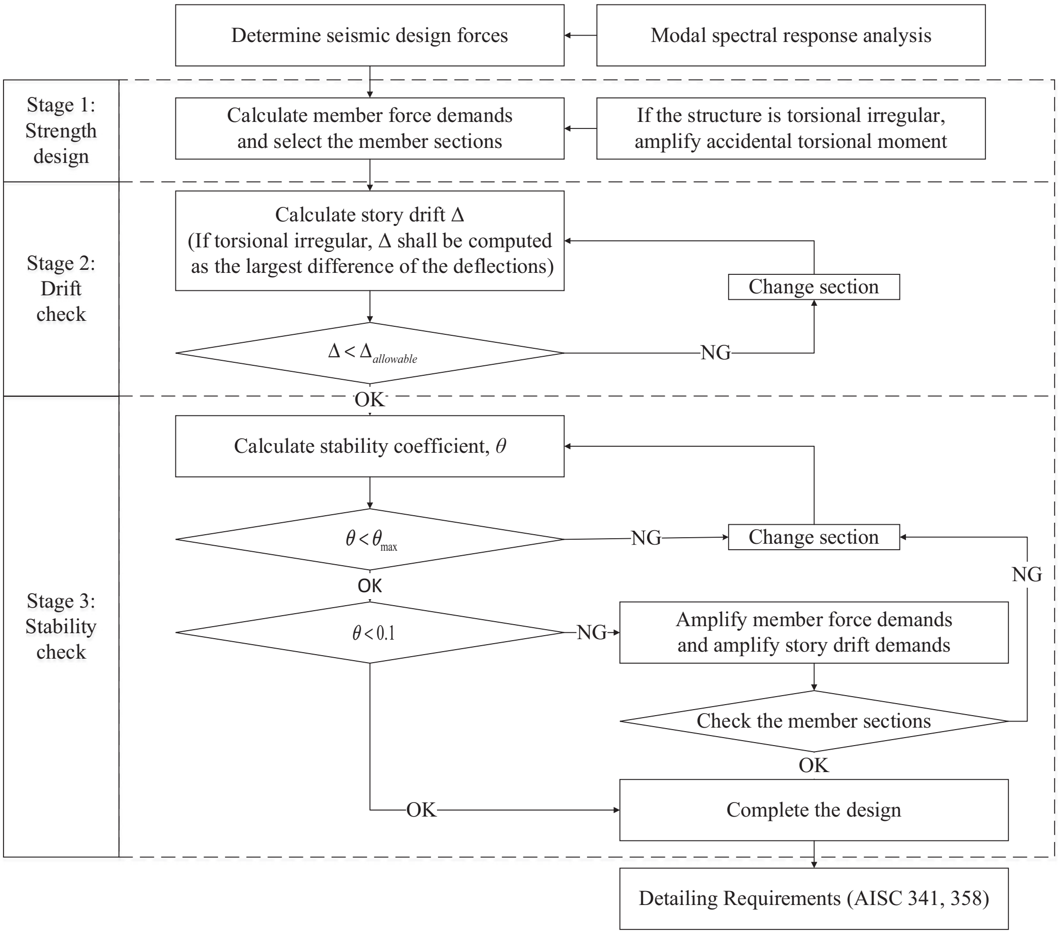

Fig. 1. Seismic design process for torsion-irregular structures.