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Collapse prevention seismic performance assessment of new special concentrically braced frames using ASCE 41

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ABSTRACT

This paper presents the results of a seismic performance assessment using ASCE 41-06 for six special concentrically braced frames (SCBFs) designed in accordance with the 2012 *International Building Code*. The correlation between ASCE 7-10 and ASCE 41-06 is investigated to compare the seismic performance anticipated by the two standards. Three archetype buildings (4-, 8-, and 16-story) with SCBFs along one principal direction are designed for seismic effects: (1) once using the equivalent lateral force (ELF) procedure and (2) a second time using the response spectrum analysis (RSA) procedure. Performance assessments are conducted using four analysis procedures, static and dynamic analyses performed under both linear and nonlinear analysis regimes. Linear analysis results indicate minor performance issues in the columns and no performance issues in the braces. In contrast, the nonlinear analysis results indicate that the braces consistently fail to meet the assessment criteria. The contributing factors to the noted performance issues with regards to ASCE 41 are investigated. Recommendations are made on how to alter the performance outcome such as using alternative ground motion selection approaches (e.g., conditional mean spectrum), using higher fidelity brace models, and having acceptance criteria based on cumulative ductility demand or energy dissipation.

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1. Introduction

The popularity of performance-based seismic design (PBSD) as a way to directly achieve a suitable seismic performance level has created the need for more understanding regarding how current PBSD methodologies compare to their established prescriptive counterparts. ASCE/SEI 7-10 [1] (hereafter ASCE 7) allows the use of PBSD for new buildings. However, with no methodology specified to achieve the anticipated performance objective, practitioners often apply the PBSD techniques developed for evaluating existing buildings in ASCE/SEI 41-06 [2] (hereafter ASCE 41). Potential problems arise because ASCE 41 contains a number of conservative assumptions to account for typically large uncertainties in evaluating existing buildings. Limited investigation into the correlation between the performance objectives of the two standards has been performed. NIST GCR 09-917-2 entitled *Research Required to Support Full Implementation of Performance-Based Seismic Design* listed benchmarking ASCE 41 procedures as the top practitioner-oriented need because of perceived conservatism and know inconsistencies [3]. Adams [4] investigated the behavior of an ASCE 7-designed 6-story special concentrically braced frame and found that ASCE 41 procedures give widely varying results, with the nonlinear procedures indicating more performance deficiencies than the linear procedures. Given that some code jurisdictions, particularly on the west coast of the U.S., are allowing the use of ASCE 41 as the basis for new building design, further investigation is warranted. The basic question addressed in this paper is whether the standards for designing new buildings and assessing existing buildings provide consistent levels of performance.

This paper presents the results of a structural seismic performance assessment using ASCE 41 for six new special concentrically braced frames (SCBFs) located in a region of high seismicity. Three SCBFs are designed using both the equivalent lateral force (ELF) and response spectrum analysis (RSA) procedures to provide a range of seismic force-resisting system (SFRS) strengths. Performance assessments are conducted using the linear static and dynamic procedures and the nonlinear static and dynamic procedures as prescribed in ASCE 41. This work is part of a larger investigation examining the correlation between ASCE 7 and ASCE 41 to identify similarities and differences in the seismic performance of buildings designed using these two standards [5–7]. Project results are intended to provide the technical background for provisions that target equivalent seismic performance in new and existing buildings and to spur further development of PBSD.

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Abbreviations	
BSE	Basic Safety Earthquake
BSO	Basic Safety Objective
CP	Collapse Prevention
$DCR_{(N)}$	demand-capacity ratio (normalized)
ELF	equivalent lateral force
EQ	earthquake
IBC	International Building Code
LDP	linear dynamic procedure
LS	Life Safety
LSP	linear static procedure
MCE_R	Maximum Considered Earthquake (risk-targeted)
NDP	nonlinear dynamic procedure
NSP	nonlinear static procedure
PBSD	performance-based seismic design
RSA	response spectrum analysis
SCBF	special concentrically braced frame
SDC	Seismic Design Category
SFRS	seismic force-resisting system
SMF	special moment frame

2. Building design

Six archetype buildings (two at 4-, 8-, and 16-stories) are investigated in this paper. Each building is designed in accordance with the 2012 *International Building Code* (IBC) [8] and its referenced standards (i.e., ASCE 7-10 and AISC 341-10 [9]). Detailed information regarding building properties, materials, and the design process can be found in Harris and Speicher [6]. The SFRS for each building is a three-bay special moment frame in the east-west direction and a two-bay SCBF in the north-south direction. The braced frame bays in the 4- and 8-story buildings are symmetrically located and separated by a collector bay, whereas the two bays in the 16-story building are contiguous. Figs. 1 and 2 show the building floor plans and SCBF elevations, respectively. This paper only discusses the performance of the SCBFs, information regarding the moment frame can be found in Harris and Speicher [5].

For determining seismic loads, the buildings are assigned to the upper limit of Seismic Design Category (SDC) D with spectral accelerations at 0.2 s (S_S) and 1.0 s (S_1) equal to 1.5 g and 0.6 g, respectively (though S_1 is treated to be just less than 0.6 g to avoid additional requirements in ASCE 7). For each building height, two designs are produced: one design using demands determined by the ELF procedure and a second design using demands determined by the RSA procedure. Two designs are produced to provide a common range of potential system strengths for the selected SDC, and to a lesser extent, to compare results obtained from the two design methodologies. The seismic analysis and design parameters for each archetype building are summarized in Table 1.

The frames are designed for wind in accordance with IBC requirements. For determining wind loads, the basic wind speeds are set to 177 km/h (110 mph) for the 700-year (strength) and 116 km/h (72 mph) for the 10-year wind (drift). Though wind is considered, seismic loads control the design of the braces, even for the 16-story frame as indicated by the wind-to-seismic story shear comparisons shown in Fig. 3(a) and (b). To compare the story demand to story strength (capacity), an approximate story strength, V_{story}, is calculated by assuming the frame acts as a truss with pinned connections:

$$V_{story} = \frac{x(\phi_c P_n)L}{\sqrt{h^2 + L^2/4}} \quad (1)$$

where x is the number of braced bays per story, $\phi_c P_n$ is the brace compression strength, L is the bay width, and h is the story height. Note, Eq. (1) works well when the brace bays are separated, but when the brace bays are contiguous the global flexural action in the frame causes unequal load sharing in the braces at a particular floor. This approximation of the story shear strength is less accurate for this situation.

Regarding the SCBF designs, a chevron bracing configuration is used in the 4-story building and two-story X-bracing is used in the 8- and 16-story buildings. For the latter, brace sizes are maintained over the two-story pair. For the 4- and 8-story buildings, the braced bay width is 6.10 m (20 ft.). For the 16-story building, the braced bay width is increased to 9.14 m (30 ft.) and the braced bays are placed adjacent to each other to increase frame stiffness, thus limiting drift and allowing for strength controlled braces.

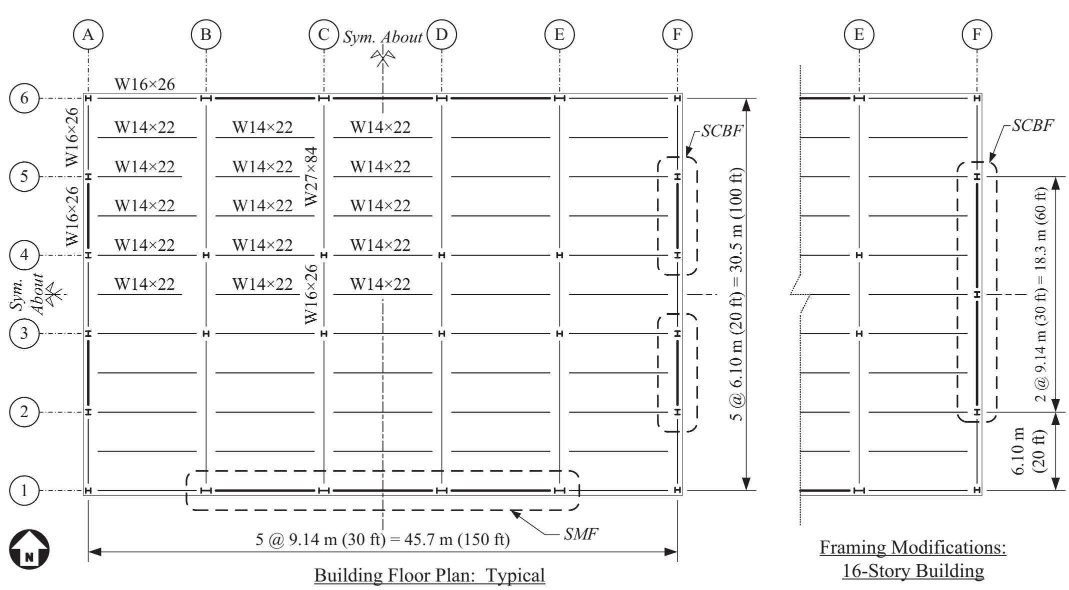

Fig. 1. Typical floor plan for the buildings.