8th National Congress on Civil Engineering, 7-8 May 2014
BabolNoshirvani University of Technology, Babol, Iran

Performance-based plastic design method For steel concentric braced frames

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Abstract

This paper presents a performance-based plastic design (PBPD) methodology for the design of steel concentric braced frames (CBF). The design base shear is obtained based on energy-work balance equation using pre-selected target drift and yield mechanism. In order to achieve the intended yield mechanism and behavior, plastic design is performed to detail the frame members. Three low-to-medium rise CBF (3-story, 6-story and 9-story) were designed by the proposed methodology and current seismic codes that include provisions to design ductile concentric braced frames called special concentric braced frames (SCBF). Results of inelastic dynamic analyses carried out on example frames designed by the PBPD method showed that the frames met all the intended performance objectives in terms of yield mechanisms and target drift levels. On the other hand, when designed by current code as SCBF the same structures showed very poor response due to premature brace fractures leading to unacceptably large drifts and instability. Finally it should be noted that no iterations were carried out to achieve the performance objectives of CBF in the PBPD method.

Keywords: Performance based plastic design, steel concentric brace frame, nonlinear dynamic analyses and energy-work balance equation.

1. INTRODUCTION

Steel concentrically Braced Frames (CBFs) are very efficient steel structures that are commonly used to resist forces due to wind or earthquakes because they provide complete truss action. Based on research performed during the last twenty years or so (for example, Goel, 1992), current seismic codes (ANSI, 2005) now include provisions to design ductile concentrically braced frames called special concentrically braced frames (SCBFs) [1]. Since the seismic forces are assumed to be entirely resisted by means of truss action, the columns are designed based on axial load demand only, and simple shear connections are used to join the beams and columns [1, 2, 3]. It has been estimated that CBFs comprise about 40 percent of the newly built commercial construction in California during the last decade [4]. This change in the newly designed steel structures can be attributed to the simpler design of CBFs and also their high efficiency in resisting lateral load with reduced deflections compared to other systems such as SMRFs, especially after the 1994 Northridge earthquake. However, CBFs are generally considered less ductile seismic-resistant structures than other systems due to the buckling or fracture of the bracing members under large cyclic deformations. These structures can undergo excessive story drifts after the buckling of bracing members, when designed by conventional elastic design methods [5, 6]. This can lead to early fractures of the bracing members, especially in those that popular rectangular tube sections (HSSs). Nevertheless, structural and nonstructural damage observed in code compliant SCBF buildings due to undesired failure modes have shown the need to develop alternative methodologies to better ensure the desired performance [7]. Since SCBF system has been widely used as part of seismic force-resisting systems, design methodologies and systematic procedures are needed which require no or little iteration after initial design in order to meet the targeted design objectives. Performance-Based Plastic Design (PBPD) method has been recently developed to achieve enhanced performance of earthquake resistant steel structures [8, 9, 10, 11]. In this method pre-selected target drift and yield mechanisms were used as performance-limit states. The design lateral forces are derived by using an energy equation where the energy needed to push the structure up to the target drift is calculated as a fraction of elastic input energy, which is obtained from the selected elastic design spectra. Plastic design is then performed to detail the frame members in order to achieve the intended yield mechanism and behavior. Therefore in the PBPD method, control of drift and yielding is built into the design process from the very start, eliminating or minimizing the need for lengthy iterations to arrive at the final design. This paper presents first time application of the PBPD approach to seismic resistant SCBF system. SCBF structures present special challenge because of their complex and degrading ("pinched") hysteretic behavior. In order to account for the degrading hysteretic behavior the FEMA 440; C2 factor concept was used in developing the process of determining the design base shear for targeted drift and yield mechanism in the PBPD