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Performance Based Plastic Design of Steel Moment Frame and Comparing It with Force Based Design

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ABSTRACT: In conventional seismic design methods the performance of structure has not been considered in base shear estimation and structural drift, as a measure of damage, will be checked at the end of design stages. This weakness of force-based design (FBD) methods causes special attention to performance-based design. Performance-based plastic design (PBPD) is of performance-based design (PBD) in which the desired damage level and plastic mechanism of the structure are predefined at the beginning of the design procedure, to estimate internal forces. It is expected that applying PBPD ends to a structural behavior with more compliance with the desired mechanism. In this paper, the priority of PBPD over FBD has been investigated. The PBPD and FBD methods are applied to the design of four special steel moment frames of 4, 8, 12, and 16 stories. The nonlinear behavior of designed structures has been evaluated by push-over and nonlinear time history analysis. Analysis results show that the PBPD frame has mechanism mode closer to assumed mechanism mode in the design procedure. Another conclusion is that the PBPD frame mechanism in the push-over analysis is more ductile than the FBD frame. Also, it concluded that in the PBPD frame, plastic hinges are approximately distributed uniformly all over the structure. The general reason for PBPD ductility improvement, versus FBD, is the strength of columns which prevent undesirable mechanism.

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1. INTRODUCTION

There are many seismic design methods based on the performance of structures such as the displacement coefficient method [1], the spectral capacity method [2], the N2 method [3], the direct displacement-based method [4], and the performance-based plastic method. In fact in each of these methods a measure of damage is defined. Moreover, it is expected that the damage level to be limited explicitly by applying deformation limitations. The performance-based plastic method is a direct design method in which evaluation of deformation as a measure of damage is not required in the last step of the design procedure, for the reason that it has been considered explicitly for calculation of base shear [5].

Among the variations in performance-based design methods, performance-based plastic design is one of the newest seismic design methods introduced by Goel et al. [6, 7]. In this method, work-energy balance, plastic displacement, and predicted yield mechanism are used to calculate the base shear force of structures [8].

The main objectives of this research are to study the principles of the performance-based plastic design method (PBPD) and to compare the results of method PBPD with force-based design (FBD). To accomplish the above objectives, the design concepts of PBPD will be described. Then four assumed special moment frames of 4, 8, 12, and 16 floors were designed by PBPD and FBD methods according to procedures described in [9,10]. In the next step, nonlinear responses of PBPD and FBD frames were evaluated by nonlinear static and dynamic analysis. A comparison of nonlinear responses of frames designed by two methods indicates that PBPD frames nonlinear responses are closer to the desired performance than the FBD method.

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2. BASIC CONCEPTS IN PERFORMANCE-BASED PLASTIC DESIGN

The performance-based plastic design steps are such that the purpose of the intended operation is first to determine the level of performance (target displacement) for a known hazard level. In PBPD, two performance objectives are the life safety performance for a medium-risk level (probability of occurrence of 10% in 50 years) and the collapse prevention performance for a high-risk level (probability of occurrence of 2% in 50 years) [10]. Notably, the design objective may differ according to the importance of structure. After that, the fundamental period of the building and the spectral acceleration of the design is determined by the existing PBPD provisions [9]. In the next step, the base shear shall be calculated by equivalency of the work required to uniformly push the structure up to the target displacement, and the energy required to reach displacement of an equivalent elastoplastic single degree of freedom system to that of considered structure [11]. Then, obtained base shear shall be distributed on the floor level laterally along with the height of the building [12]. After that, it is time to choose the structural system and determine the desirable yield mechanism. For example, in moment frames, plastic joints should be formed only at the two ends of the beam and the bottom of the base columns. Also, the proper mechanism in other structural systems takes place according to the distribution of structural ductile members and components. In EBFs[1] plastic hinges appear in link beams, in CBFs[2] it is desired to appear axial hinges in brace members and STMFs[3] special. Finally, the design of deformation control and force control members shall be performed as the last stage of PBPD [13].

3. RESEARCH METHOD AND STUDIED MODELS

Four special moment-resistant steel frames of different heights with 4, 8, 12, and 16 stories were studied. Models consist of steel members with a yield stress of 2400 kg/cm^2 are shown in Fig.1. The height of the stories is taken to be 3.2 meters and the frames consist of 3 spans of 4.5 m.

The dead load of all floors beam is assumed to be 24.52 KN/m and the live load of floors beams except the roof is taken equal to 11.97 KN/m and the roof live loading is taken 4.79 KN/m. The validity of the nonlinear static procedure is less than the nonlinear dynamic analysis, but it can relatively give proper average information about priority, distribution, and condition of hinges if there is no irregularity in structure. To take into account the effect of higher modes and irregularities, nonlinear dynamic analysis is inevitable. To execute nonlinear dynamic analysis, a set of seven appropriate earthquake records selected and scaled according to assumed performance objectives. The results of both static and dynamic methods are used to evaluate the nonlinear behavior of frames.

4. CONCLUSION

Design results show that the weight of the PBPD frame, in the same geometry and loading condition, is about 20~30 % more than FBD one. Moreover, the total Weight of beams in both design methods is almost equal. Also, PBPD frame columns weight is approximately 30~40 % more than FBD one, which causes the PBPD frame to have more lateral initial stiffness, ultimate strength, and ductility.

The ductility of PBPD in comparison to FBD makes to have more lateral drift before the collapse, which enables the frame to satisfy the assumed performance at the beginning of the design procedure. Another word nonlinear push-over analysis show that PBPD frames can withstand the lateral deformation more than target displacement, while FBD frames may not pass the deformation criteria in nonlinear analysis.

1 Eccentric Braced Frames
2 Concentric Braced Frames
3 Special Truss Moment Frame

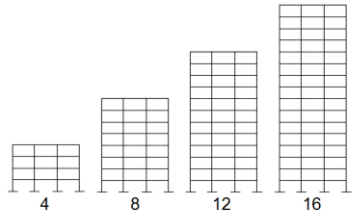

Fig 1. The configuration of the moment steel frames studied.

Both nonlinear static pushover and nonlinear dynamic time-history analysis show that distribution of hinges is more uniform, throughout beams of a frame, in PBPD comparing to FBD. Particularly creation of hinges in top stories could be observed in PBPD frames more than FBD ones.

Nonlinear time-history analysis of frames against several earthquake records show that average story residual drift in PBPD frames is more than FBD ones, for predefined earthquake level. It is an expected result based on the amount and distribution of observed plastic hinges.

The formation of plastic hinges in the desired places makes it possible for the PBPD frames to maintain their stability along with more lateral drift to achieve more ductile behavior. The reason for this appropriate behavior is that the performance criteria, desirable mechanism, and target displacement have been considered in the design procedure. Also, due to the use of two performance objectives in base shear evaluation, it can be considered a more reliable method as a multi-performance objective approach. While, in the conventional method, the base shear calculation is based on the response spectrum and the expected performance is not a predefined design parameter. Control of the displacement as an indicator of the performance is done in the last stage of the design process. In addition, the use of response modification factor R for expressing nonlinear behavior is not accurate.

Finally, the results of this study show that the weakness of the FBD method can be covered, to some extent, by applying the PBPD method.

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