



Response Modification Factor of Steel Structures Equipped with Cylindrical Frictional Dampers

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ABSTRACT: Frictional dampers are widely used in civil engineering structures as means of passive controller in order to dissipate the energy created by earthquake. One of the frictional dampers that have been recently introduced is called Cylindrical Frictional Damper (CFD). Several researches in the area of the energy absorption capacity of the CFD, meaning hysteretic behavior, have been performed by the authors.

In this research, response modification factor of steel moment resisting frames equipped with Cylindrical Frictional Dampers is evaluated. Utilizing this factor, the standard seismic design code procedure can be applied to the frames equipped with CFDs. In order to achieve this task, Static pushover analysis, nonlinear incremental dynamic analysis and linear dynamic analysis of various structures have been performed.

The results show that the response modification factor of steel frames equipped with frictional dampers is greater than that of conventional steel frames which in turns reduce the seismic forces and leads to a lighter structure. Finally, values of 11 and 16 have been suggested for ultimate limit state and allowable stress design methods respectively.

Review History:

Received: 10 March 2015

Revised: 14 November 2015

Accepted: 9 March 2016

Available Online: 5 November 2016

Keywords:

Frictional Damper

Response Modification Factor

Incremental Dynamic Analysis

Over Strength Factor

1- Introduction

Frictional devices dissipate energy through friction caused by two solid bodies sliding relative to each other. The idea of using frictional dampers was first proposed by Pall and Marsh. Since then many other types of frictional devices have been proposed. Most of frictional dampers are made of a set of steel plates with certain friction coefficient that are forced by bolt pretension in order to induce the friction between the involved elements. Using pre-tensioned bolts to induce friction, makes the behavior of frictional dampers unpredictable. The relaxation or loosening of the link elements such as spring or bolts helps this unpredictably and may lead to decay of slippage load. Recently, Mirtaheri et al. proposed an innovative type of frictional damper called cylindrical friction damper (CFD). In contrast with other frictional dampers, the CFDs do not use high-strength bolts to induce friction between contact surfaces. This reduces construction costs, simplifies design computations and increase reliability in comparison with other types of frictional dampers. Kyung-Won Min et al. proposed a simple design procedure of a friction damper for reducing seismic responses of a single-story structure. Seong and Min proposed a simple design process to determine desired control force of a friction damper to satisfy a given target performance of a SDF system subjected to an earthquake ground excitation. Lee et al.

suggested a design methodology of friction damper-brace systems, to determine the quantity and slippage load of the frictional damper and the brace stiffness systematically for an elastic multistory building structure based on the story shear forces. Fu and Cherry studied the application of a quasi-static design procedure for a friction damped system. They normalized the seismic response of the friction-damped system with respect to the response of its corresponding linear system by an approach that incorporates a credible equivalent linearization method, a damping reduction rule and the algebraic specification of the design spectrum. The resulting closed-form solutions obtained for the normalized response are then used to define a force modification factor for friction-damped systems. This force modification factor, together with the condensation procedure for multi-degree-of-freedom structures, enables the establishment of a quasi-static design procedure for friction-damped structures.

In this investigation, response modification factor of steel moment resisting frames equipped with frictional dampers was evaluated. Utilizing this response modification factor, the standard seismic code design procedure can be applied to friction damped frames, specifically, those equipped with cylindrical frictional dampers. To do so, static pushover analysis, non-linear dynamic analysis and linear dynamic analysis of various structures have been performed using ABAQUS software.

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2- Response Modification Factor

Seismic codes reduce design loads utilizing a factor namely response modification factor. This factor is intended to account for both inelastic performance of structure and over-strength of the members which is partly material-dependent and partly system-dependent.

The non-linear force-displacement relationship between base shear and roof displacement of a structure is usually replaced with an idealized bilinear elastic perfectly-plastic relationship. As it is shown in Figure 1, the yield force of the structure is demonstrated by V_y and the corresponding displacement is Δ_y . V_e is the maximum base shear corresponding to the elastic response and the corresponding displacement is Δ_e . In the other words V_y and V_e are the maximum base shears in the elastic-perfectly plastic behavior and elastic behavior respectively.

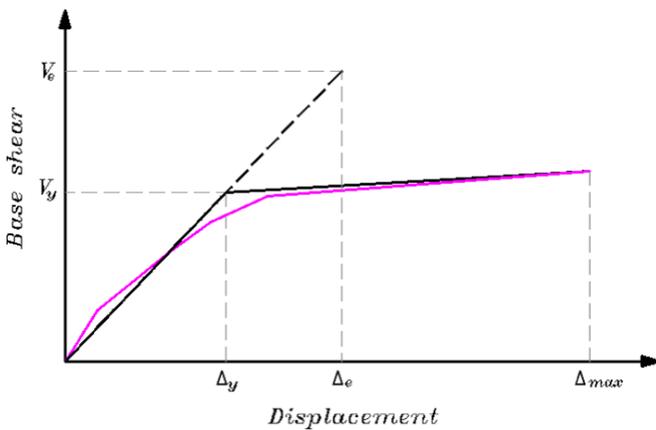


Figure 1. Actual and idealized response of the structure

The response modification factor is determined as follows:

$$R = R_\mu \cdot R_s \quad (1)$$

where R_μ is the ductility factor and is defined as the ratio of V_e over V_y , that is:

$$R_\mu = \frac{V_e}{V_y} \quad (2)$$

and R_s is the over-strength factor and is calculated as:

$$R_s = R_{SO} \cdot F_1 \cdot F_2 \dots F_n \quad (3)$$

Where

$$R_{SO} = \frac{V}{V_s} \quad (4)$$

V_s is the base shear which corresponds to the first significant yield in the structure. F_1 is used to account for the difference between actual static yield strength and nominal static yield

strength. For structural steel, a statistical study shows that the value of F_1 may be taken as 1.05. Coefficient F_2 may be used to consider the increase in yield stress as a result of strain rate effect during an earthquake excitation. A value of 1.1, a 10% increase to account for the strain rate effect, could be used. Other coefficients account for parameters such as nonstructural component contributions, variation of lateral force pattern, etc. When reliable data is available, these coefficients can also be included. In this paper, coefficients F_1 and F_2 are assumed to be 1.05 and 1.1 respectively. In other words:

$$R_s = 1.15 R_{SO} = 1.15 \frac{V}{V_s} \quad (5)$$

In allowable stress design method, V_s is replaced by the design base shear V_d which is calculated as follows:

$$V_d = \frac{V}{Y} \quad (6)$$

where Y is the allowable stress factor. For wide flange sections, this factor is about 1.4 to 1.5. In the current study allowable stress factor is considered as 1.44.

3- Results and Discussion

Static pushover analysis, linear dynamic analysis and incremental nonlinear dynamic analysis were performed to evaluate the over-strength, ductility and response modification factors of steel frames equipped with frictional dampers. Based on the results provided by the analyses, the following conclusions may be reached:

1. The over-strength factor of 4, 6, 8, 10 and 12-story frames are 1.490, 1.409, 1.445, 1.512 and 1.599 respectively.
2. The ductility factor of 4, 6, 8, 10 and 12-story frames are 5.636, 8.765, 10.197, 8.911 and 5.509 respectively.
3. Response modification factor of 4, 6, 8, 10 and 12-story frames in allowable design method are 12.167, 15.646, 21.169, 19.183 and 12.707 respectively.
4. Response modification factor of 4, 6, 8, 10 and 12-story frames in Limit state design method are 8.449, 10.539, 14.701, 13.322 and 8.824 respectively.
5. Average of response modification factors is 11.167 in limit state design method and 16.174 in allowable stress design method. Therefore, values of 11 and 16 are suggested for ultimate limit state and allowable stress design methods respectively. Utilizing the new response factor obtained by hundreds of analyses clearly reduce the seismic loads in the structures. This will lead to more economical structures.

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Please cite this article using:

H. Mirzaeefard, M. Mirtaheri, H. Rahmani Samani, "Response modification factor of steel structures equipped with cylindrical frictional dampers", *Amirkabir J. Civil Eng.*, 49(3) (2017) 453-462.

DOI: 10.22060/ceej.2016.689



