Determining the Optimal Slip Load Pattern of Pall Friction Dampers considering Soil-Structure interaction

Farnaz Rafie[1], Hamed Hamidi[2*], Javad Vaseghi Amiri[3]

[1] Master of Structural Engineering, Babol Noshirvani University of Technology
[2] Assistant Professor, Babol Noshirvani University of Technology
[3] Professor, Babol Noshirvani University of Technology

ABSTRACT

In engineering designs, structural analysis is generally performed assuming a rigid base. While introducing the effect of structural substrate flexibility on the response and dynamic properties of structures is important. Introducing different solutions to reduce the response of the structure against dynamic forces is another important issue in engineering designs. In this paper, the passive Pall friction damper system has been used for this purpose. In the researches that have been done so far, various optimization methods have been used for the optimal design of friction dampers, but in most of these methods, the effect of soil-structure interaction has not been considered for friction dampers, while in earthquake soil-structure interactions is important. One of the main objectives of this study is to investigate the effect of soil-structure interaction on the optimization of friction dampers. The actual forces and displacements of a structure due to free-surface seismic movements can be determined by considering the effects of soil-structure interaction. In this regard, in this paper, two-dimensional frames of 4, 8, and 12 floors equipped with dampers were analyzed in nonlinear structural analysis software under seven accelerometers using nonlinear time history method once, considering the effect of soil-structure interaction and introducing 3 Different lateral loading patterns and again without this effect. The results show that considering this issue in terms of cumulative triangular slip load pattern has increased the loss of earthquake input energy. Also, depending on the type of load pattern, the applied record and the height of the structure, a decrease has been observed, which is mentioned in the results section.

KEYWORDS

Pall Friction Damper, Soil-Structure Interaction, Optimal Slip Load Pattern, Winkler Method, Nonlinear Dynamic Analysis.

[*] Corresponding Author; Email: h.hamidi@nit.ac.ir

1. Introduction

Structures must be able to withstand variable loads during their useful life. That is, in addition to conventional lateral bearing systems such as shear walls, braces and their combination, other methods have been proposed and used in the past few decades [1]. Today, the loss of energy applied to the structure due to earthquakes has led to the use of active, semi-active and passive structural control devices [2]. The most commonly used are passive dampers that have different types such as metal dampers, friction dampers, viscous dampers, etc. In this research, Pall friction dampers, which are passive control devices, have been investigated.

The use of damper allows the structure to remain elastic until a more severe earthquake occurs [3]. Vaseghi et al. (2009) investigated the behavior of eccentric braced steel frames equipped with friction dampers. According to the results, friction damper reduced the story drift, base shear and axial force of the columns in both structures [4]. Miguel et al. (2014) proposed robust design optimization of friction dampers to control the structural response to earthquakes. The results showed that the proposed method was able to reduce the mean of maximum displacement by about 70% and the variance of maximum displacement by about 99% with only three dampers [5]. Jarrahi et al. (2020) proposed an optimal design for a rotational friction damper (RFD) to control the seismic vibration of a single–story steel moment–resisting frame (SMRF) [6].

As mentioned, in recent decades, different optimization methods have been used for the optimal design of energy dissipation devices, but in most of these methods, especially for friction dampers, the effect of soil-structure interaction has not been considered. In this paper, slip load patterns were first defined using this method. Then the 4-, 8-, and 12-story frames were analyzed by nonlinear time history analysis once in terms of soil-structure interaction and again without it under 7 accelerometers in PERFORM-3D software. The aim of this study was to determine the effect of soil-structure interaction on determining the optimal slip load of Pall friction dampers.

2. Methodology

2.1. Slip load patterns of friction damper

In 2002, Mualla introduced an index called the SPI index, which is a combination of other performance indicators, which ultimately determines the slip load that minimizes this index as the optimal slip load. In Equation (1), the values of R_d, R_f and R_e are the ratio of maximum displacement of the roof, base shear and dissipated energy of the structure with friction damper to the initial structure without damper, respectively [7].

$$SPI = \sqrt{R_d^2 + R_f^2 + R_e^2} \tag{1}$$

In this research, three load patterns have been used that have been scaled in such a way that they create similar base shear in the first mode response of the structure [8]. "Figure 1" shows an example of load patterns for a 4-story structure.

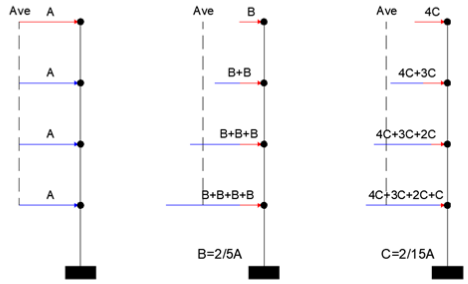

Figure 1. Left load pattern: uniform - middle: cumulative uniform - right: cumulative triangular

For each structure, damper slip force was applied from 5 KN to 280 KN and in each case, nonlinear time history analysis was performed and SPI index was obtained.

2.2. The effect of soil-structure interaction

In this paper, Winkler method is used to model the soil-structure interaction. In this model, ("Figure 3") the structure is mounted on foundation rested on distributed dampers and springs.

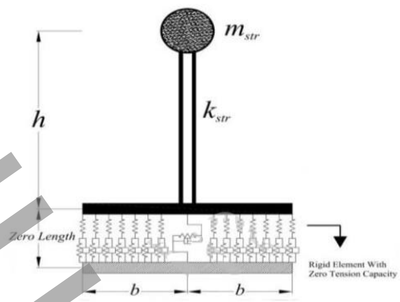

Figure 3. Considered model for soil and structure system [9]

3. Results and Discussion

In this paper, in order to investigate the effect of soil-structure interaction on the optimal slip load pattern of Pall friction dampers, the parameters of lateral roof displacement, maximum drift of the structure and energy dissipation are considered. For better comparison, these parameters have been scaled to structures without dampers. Variables in this study include seismic loading, damping slip load and soil-structure interaction. A concise result for the 8- and 12-story structures is shown in "Figure 4".

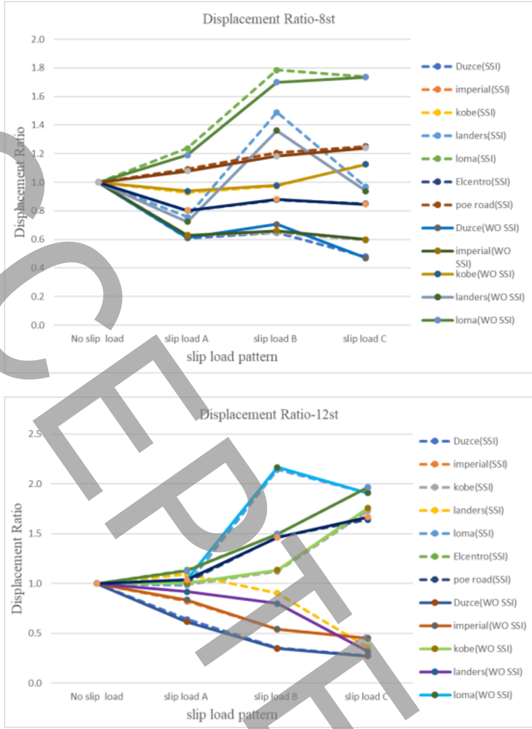

Figure 4. Roof lateral displacement rates of the 8- and 12-story structures

4. Conclusions

By considering the parameters of lateral displacement of the roof, maximum drift of the structure and Energy dissipation, the effect of soil-structure interaction on the optimal slip load pattern of the friction damper were investigated. The summary of the results is as follows:

- Regarding the ratio of roof displacement in a structure equipped with dampers to structures without dampers, the displacement ratio in all groups of structures under load combination A has the lowest ratio.
- With increasing the number of stories, there is a direct effect of soil and structure interaction on increasing the displacement of the roof floor up to 27%.
- In the slip load pattern A with increasing the height of the structure, a kind of stability and proximity of drift ratios in all accelerometers is observed and the dispersion of drift ratio is minimal, which indicates that the structure under this slip load behaves almost identically in different earthquake conditions and will be more predictable.
- Under the C-slip load pattern, 8- and 12-story structures recorded the highest energy dissipation (lowest energy ratio) at 38 and 51%, respectively, indicating that under all records these structures performed well with C-slip load pattern and it is the optimal state for slip force of friction dampers.
- In the case of soil-structure interaction, energy ratios are reduced and naturally due to the flexibility of the structure support in soil-structure interaction state, some of the input energy is lost due to soil-structure interaction in addition to dampers and it helps the seismic capacity of structures.

5. References

[1] B.A. Bolt, Seismic input motions for nonlinear structural analysis, ISET journal of earthquake technology, 41(2) (2004) 223-232.

[2] S. Akhondzade, A.H. Hasaniye, M.R. Mashayekhi, Investigation of active algorithm in structures equipped with tuned mass damper (TMD), in, Pardisan Higher Education Institute, 3282 (In Persian), Babolsar, 1391.

[3] C. Pasquin, N. Leboeuf, R.T. Pall, A. Pall, Friction dampers for seismic rehabilitation of Eaton's building, Montreal, in, 2004, pp. 1-2.

[4] J. Vaseghi, S. Navaei, B. Navayinia, F. Roshantabari, A parametric assessment of friction damper in eccentric braced frame, International Journal of Civil and Environmental Engineering, 3(10) (2009) 361-365.

[5] L.F.F. Miguel, L.F.F. Miguel, R.H. Lopez, Robust design optimization of friction dampers for structural response control, Structural Control and Health Monitoring, 21(9) (2014) 1240-1251.

[6] H. Jarrahi, A. Asadi, M. Khatibinia, S. Etedali, Optimal design of rotational friction dampers for improving seismic performance of inelastic structures, Journal of Building Engineering, 27 (2020) 100960-100960.

[7] I.H. Mualla, Parameters influencing the behavior of a new friction damper device, in, International Society for Optics and Photonics, 2000, pp. 64-74.

[8] N. Nabid, I. Hajirasouliha, M. Petkovski, A practical method for optimum seismic design of friction wall dampers, Earthquake Spectra, 33(3) (2017) 1033-1052.

[9] A.H. Jafarieh, M.A. Ghannad, The Effects of Nonlinear Behavior of Soil and Foundation Uplift on Seismic Response of Inelastic SDOF Structures, Journal of Structural and Construction Engineering, (2019).