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Extreme modeling of triple friction pendulum isolator and its effect on the behavior of superstructure

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ABSTRACT: Sliding articulated isolators are well-known types of seismic control tools, that extensive observations have shown their effective role in reducing seismic damages in structures. Although this tool significantly improves the performance of the structure at different seismic levels, but the existence of uncertainties in the limited behavior of this isolator in earthquakes with long return periods has attracted the attention of researchers in recent years to model their ultimate behavior. When the isolator reaches its displacement capacity, the sliding parts strike the side edge of the sliding surfaces and the performance of the structure affects by this special condition. In this study, after implementing the equations governing the behavior of these isolators, we proceed to mathematically model their ultimate behavior and study its effects on the dynamic response of the superstructure. So, by designing and modeling a sample structure, we examine the superstructure dynamic response at different scales of several earthquake records. The results show that the average ground acceleration at the beginning of the contact behavior under the studied records, is about 1.25MCE, the elastic base shear is about 0.48 superstructure weight and the maximum elastic drift of the superstructure is about 0.0038. By increasing the level of acceleration, the amount of base shear increases to the levels that the superstructure shows the nonlinear behavior. Also, by performing analysis on models with and without ultimate behavior, converting ratio are presented for different PGA levels.

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1- Introduction

Triple Friction Pendulum isolators (TFPs) that a sample section cut of them is shown in Figure 1 are well-known types of isolators and have adaptive behavior, as shown in Figure 2. Sliding isolators have a specific displacement capacity. In rare earthquakes, which may have a severity beyond the MCE level, the displacement demand of the friction isolator can exceed its capacity and the isolator components can strike each other. This contact can make the structure resemble a fixed base structure and extremely increase the responses of the superstructure in comparison to the pre-strike stage. A few numerical models of the behavior of these isolators are presented by Fenz and Constantinou [1], Becker and Mahin [2], Dao et al.[3] and Sarlis and Constantinou[4]. In a study with experimentally modeling an isolated structure, Becker et al. [5] studied the TFP isolator's failure modes, the average earthquake severity at the moment of contact and increased responses of the structure. Also, Tomek et al. [6] provided a simple way to model the ultimate contact behavior of sliding isolators in LS-DYNA software.

Due to limited studies, uncertainties and the extent of the ultimate behavior issues and its effects on the forces and deformations of superstructures, this field is still under discussion and needs further studies.

2- Methodology

The most comprehensive and accepted model for modeling sliding isolators has been introduced by Sarlis and Constantinou [4], which models the ultimate contact behavior. This model, by simultaneously solving the differential equations, provides the ability to calculate displacements, rotations and velocities of each particular part of friction isolators. By writing the differential equilibrium equations of these parts and using them in state space Equation 1. This equation, along with the differential equations governing the behavior of the superstructure can be solved in MATLAB software. The superstructure model of this study includes a three-story bracing structure in accordance with Chapter 12 of FEMA P-751.

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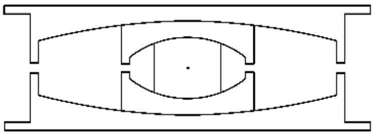

Fig. 1. Sample Section Cut of a TFP

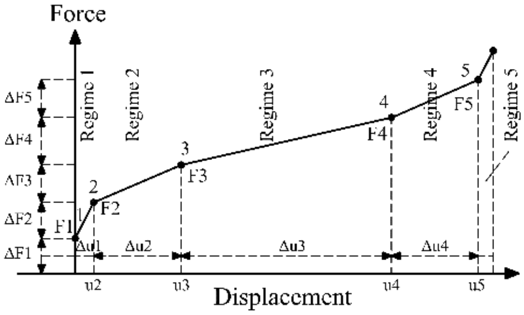

Fig. 2. Adaptive Behavior of a TFP

$$\frac{dQ}{dt}=\frac{d}{dt}\begin{Bmatrix}\theta\\ \dot{\theta}\\ Z\end{Bmatrix}=\begin{Bmatrix}\dot{\theta}\\ -M^{-1}K\theta-M^{-1}S-M^{-1}F\\ \dot{Z}\end{Bmatrix} \tag{1}$$

In this study, to investigate the effect of ultimate contact behavior of isolator on superstructure, it is analyzed by two ultimate and non-ultimate bearings model. Figure 3 shows the difference in the hysteretic behavior of isolators in these two models.

The structural models of the study are examined under the records presented in Table 1 in accordance with FEMA P695. The maximum acceleration of records is scaled to 0.8MCE and then their scale ratio incrementally increased to reach 1.7MCE. Later their responses are studied before and after contact in both ultimate and non-ultimate models.

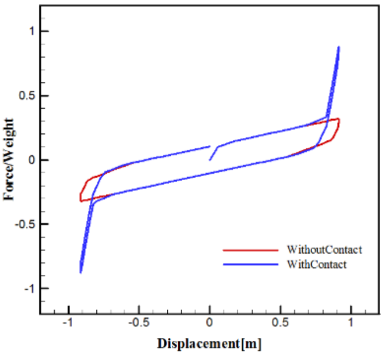

Fig. 3. Ultimate and Non-Ultimate Models for TFP

Table 1. Selected Accelerometers in This Study

Earthquake	Station	Year
Imperial Valley	El Centro	1979
Landers	Coolwater	1992
Northridge	Beverly Hills	1994
Manjil	Abbar	1990
Friuli	Tolmezzo	1976
Kobe	Nishi-Akashi	1995
San Fernando	LA - Hollywood	1971

3- Results and Discussion

The average ground acceleration in the moment of ultimate contact under the introduced records was observed about 1.25MCE, which is equivalent to 0.65g. The most important superstructure results at before and after the ultimate contact event are presented as follows.

3- 1- Base Shear Transferred to the Superstructure

The average base shear at the moment of ultimate contact, is about 0.48 superstructure weight. Figure 4 shows the maximum base shear transferred to the superstructure for both models. The results show a sharp increase in values after the contact occurrence in the ultimate model. But in the non-ultimate model, no change in the response process because of approaching superstructure to a fixed base structure can be seen. This behavior indicates the shortcomings of the commonly used models in true contact modeling.

3- 2- Maximum drift Recorded in the Superstructure

The average maximum superstructure drifts at the moment of ultimate contact is about 0.0038. As in the previous section, the process of results after the ultimate contact in the non-ultimate model in Figure 5 shows the shortcomings of this model.

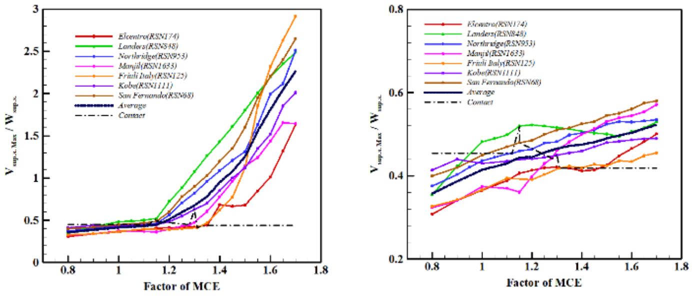

Fig. 4. Maximum Superstructure Base Shear (Left) Ultimate Model (Right) Non-Ultimate Model

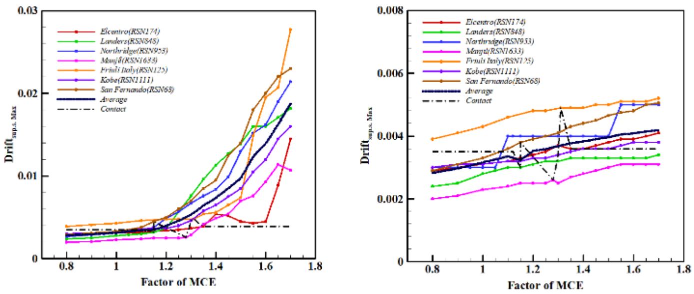

Fig. 5. Maximum Superstructure Drift (Left) Ultimate Model (Right) Non-Ultimate Model

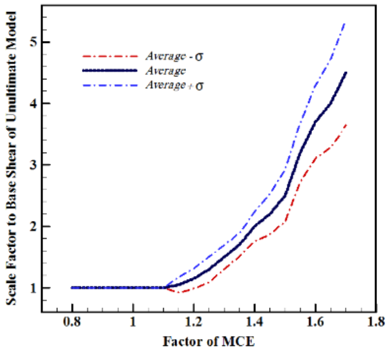

Fig. 6. The Proposed Conversion Coefficients for Non-Ultimate Model Base Shear

3- 3- Conversion Coefficients for Non-Ultimate analysis

The results of the ultimate model have a behavior close to reality and there is large difference between the results of the non-ultimate model and the ultimate model. To this end, it is necessary to correct the results of non-ultimate models. Figure 6 presents the proposed coefficients in this study for converting base shear from the non-ultimate model to the ultimate model.

4- Conclusion

The main results of this study are summarized below.

The average ground acceleration value of 1.25MCE indicates the need for a very high acceleration for the ultimate contact to occur.

The values of superstructure responses increase significantly after the ultimate contact occurs, which indicates the need to consider the minimum ductility for superstructure.

For structural analysis under rare earthquakes, it is better to use the ultimate model directly, and if a non-ultimate model is used, the responses should be adjusted by converting coefficients.

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