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FEM of a frame structure equipped by friction damper

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ملخص

الأبحاث الخاصة بديناميكا المنشآت دائمة الإستمرار في استكشاف تقنيات جديدة، وأحد هذه التقنيات هو استخدام أجهزة إخماد الطاقة لرفع كفاءة المنشآت في مقاومة الأحمال الجانبية الناتجة من الأحمال الديناميكية. من ضمن هذه الأجهزة هو جهاز الإخماد بالإحتكاك والذي سيتم عرضه في هذا البحث. هذا الجهاز تم تصنيعه محليا في مصر واختبر معمليا في معهد الإنشاءات التابع للمركز القومي لبحوث المياة داخل جمهورية مصر العربية. في هذا البحث تم عمل اختبار معملي لإطار معدني مركب بداخله جهاز الإخماد بالإحتكاك المصنع محليا، وكذلك تم عمل تمثيل رياضي لهذا النموذج المختبر باستخدام برنامج تحليل انشائي يعمل بطريقة العناصر المحددة ومقارنة نتائجه مع النتائج المعملية.

ABSTRACT

The structural dynamics researchers are continuously working for investigating new technologies. The energy dissipation devices are innovative technologies used to increase the structures' lateral capacity against dynamic loads. One of these devices is the rotational friction damper that shall be presented in this paper. This device is manufactured locally and tested in the construction institute, National water Research Center in Egypt. Experimental test of a frame structure equipped with rotating friction damper is carried out. Then, a numerical modeling validation is performed using finite element computer modeling.

KEY WORDS: finite element; time history; natural frequency; friction damper.

Nomenclature	
FDD	Friction Damper Device
FEM	Finite Element Model
FNA	Fast Nonlinear Analysis
LVDT	Linear Variable Displacement Transducer
NWRC	National Water Research Center

1 Introduction

The traditional way to raise the structures' capacity to resist dynamic loads like earthquake, extreme wind, sea waves...etc. was to increase its sections' size and overall indeterminacy. In the recent 40 years, a modern technology for boosting structural dynamic resistance was innovated. That was to equip the structure with energy dissipating devices to absorb the dynamic energy. These structures are named "Smart Structures" [1].

In this paper, a rotating friction damper device innovated by Mualla [2] will be presented. This device is manufactured and tested in the Construction Research Institute, National Water Research Centre in Egypt. The available and simple materials are used for fabricating the friction damper device (FDD). The behavior, properties and efficiency of the damper on the structural dynamic resistance is investigated. Finally, a numerical modeling for the damping system is performed and validated.

2 Friction damper device description and work mechanism

The unit of friction damper device (FDD) is composed of three steel plates, pre-stressed bolt, nut, spring washers, hard washers and filling friction pad disks made from Teflon. The device is fabricated and assembled as shown in Figure (1-a).The steel plates and Teflon friction disks are held together with proper tightening force using the pre-stressed bolt. The purpose of the spring washers is to avoid any relief in bolt tightening force during the dynamic loading. While the hard washers distribute the stresses applied to the side plates from the spring washers. The central plate is connected with the frame girder and the two side plates are linked with chevron bracing made of pre-stressed tie rods as shown in Figure (1-b).

In case the frame girder is exposed to external lateral dynamic loads, the friction damper plates are deformed and rotated relative to each other but with its potential resistance force. The source of this potential force is coming from friction between steel plates and filling friction pads, which is proportional to the bolt tightening force. The required slip force is determined according to the external dynamic loads that need to be resisted.

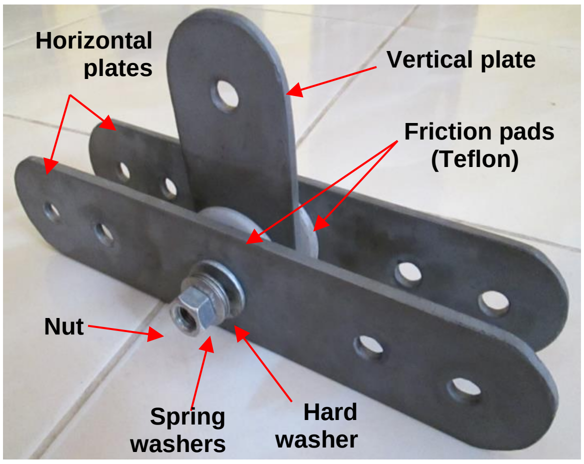

Figure (1-a): Friction damper components

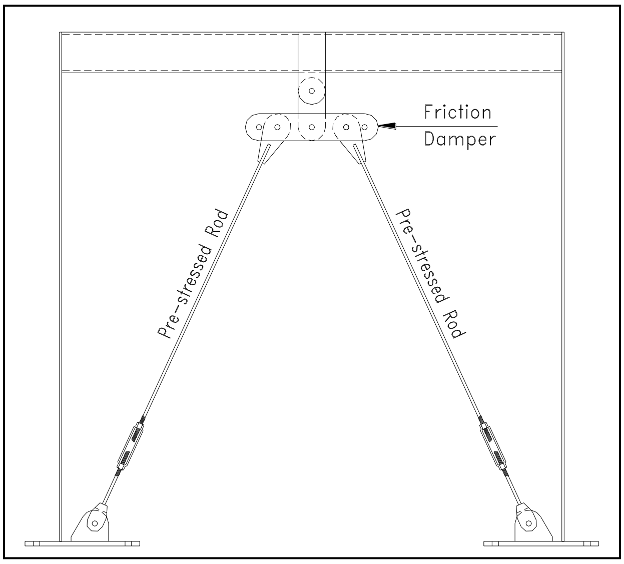

Figure (1-b): Frame equipped with FDD

3 Friction damper behavior and properties

The basic concept of the friction damper is to transform the kinetic energy to heat, same as the car breaks do. The friction damper starts to work and dissipates energy when it is exposed to forces up to its slip load value. In general, the friction damper works in two phases: sticking phase and sliding phase. The first is within forces between zero and the sliding force that makes the device start to rotate. The second is after exceeding the slip force which makes the damper behaves in a hysteresis loop. The device displacement is increased proportional with external force increasing. Figures (2-a) and (2-b) illustrate the acting forces on the device and its hysteresis relation, respectively. As shown in Figure (2-b) the damper may be deformed in two behaviors. The behavior number (2) may eliminate the energy dissipation in the damping system [3].

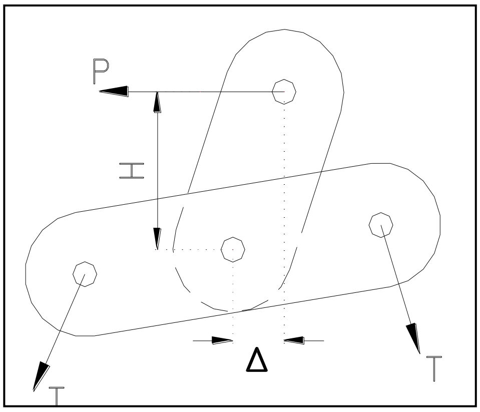

Figure (2-a): Friction damper device acting forces

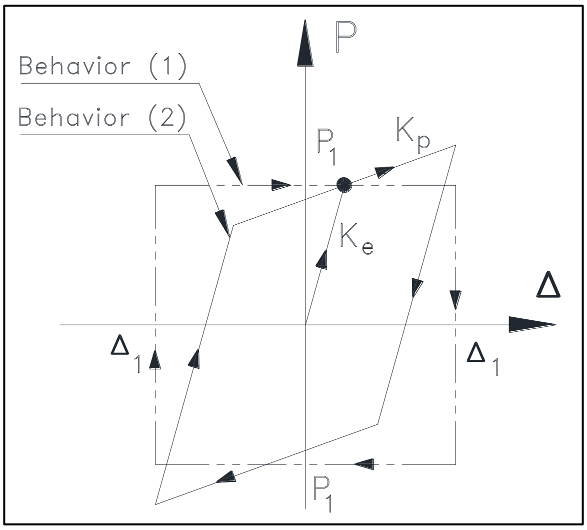

Figure (2-b): Friction damper device hysteresis relation

The FDD is characterized as a frequency-independent type [4], which means that its displacement response is not affected by the rate of the applied force. In addition, the FDD has resistance stability during dynamic forces history; this shall be illustrated in the experimental work section in this paper. Because the hysteresis loop has rectangular or trapezoidal shapes as shown in Figure (2-b), it can absorb high energy compared with the other damper types.

4 Experimental work

4.1 Test preparation

The tested frame is one bay frame; its overall dimensions are 1125 mm high and 1100 mm span. The frame legs are steel bars with 50x5 mm rectangular section. The frame girder is 90x50x3 mm box steel section and is welded to the frame legs by all-around full penetration weld. Frame legs' bases are fixed on shaking table by four bolts 14 mm diameter, each. The shaking table is a unidirectional type and has dimensions of 1.25x1.25 m. Its maximum excitation frequency is 4.29 Hz. this frame resembles the frame tested by Mualla [4].

This frame is loaded by applying 12 Kg of metal wheels equally distributed in both frame girder ends. In order to measure the frame response regarding the applied base excitations, the following measuring devices are used: (1) one LVDT is fixed to frame girder and attached to the FDD to measure its displacements and obtain the force-deflection hysteresis relation for the damper; (2) two accelerometers: the first is side mounted to the frame girder and the second is side mounted to shaking table to measure acceleration through test history. The signals of the accelerometers and LVDT are transferred to a data acquisition system and then analyzed. The frame overall response with and without FDD are measured under base excitation. The test setup of a frame with FDD and an experiment photo are shown in Figures (3-a) and (3-b) respectively.

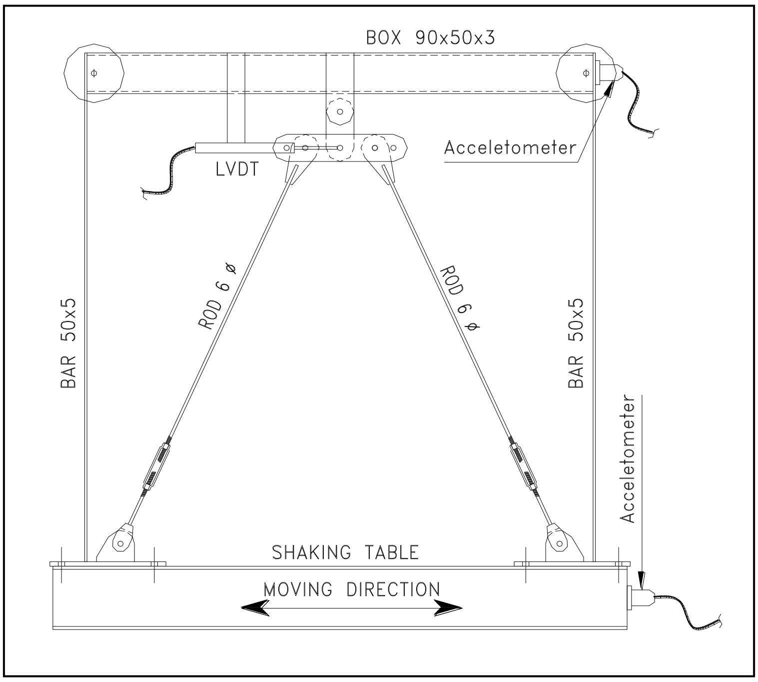

Figure (3-a): Tested frame setup

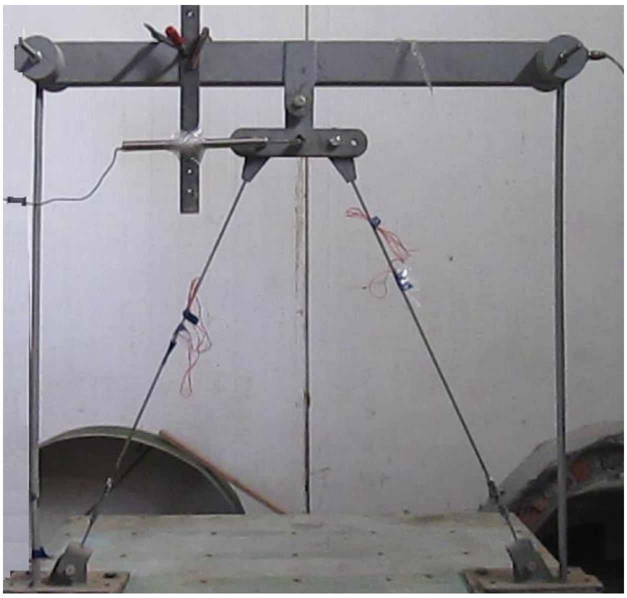

Figure (3-a): Tested frame experiment photo

4.2 Test execution and results

The evaluation of damping system is performed for the FDD stability and for the overall frame behavior after equipping the frame structure with the FDD. The FDD is tested to get the hysteresis relation between acting forces and displacements. This test is performed by fixing the LVDT to the frame girder and attaching its rod to damper center as shown in Figure (3-b), which allows getting the displacement of the FFD separately. The accelerometer is attached to the frame girder to measure the acting acceleration on the FDD. The shaking table is excited by constant harmonic motion with a frequency of 2.86 Hz and hence extracts the hysteresis relation for FDD as shown in Figure (4). Such hysteresis shows almost stable behavior for the FDD with the used Teflon material as a friction pad between the steel plates at the tightening point.

On the other hand, to investigate the damper efficiency for increasing frame lateral resistance, the frame base is excited by a frequency of 1.43 Hz, with and without the FDD through 40 seconds. By comparing the frame girder displacements history for both cases, it is found that the damper has the ability to reduce around 83 % of the frame response, and the frame natural frequency is shifted from 1.66 Hz to 23.93 Hz. Figure (5) presents these results.

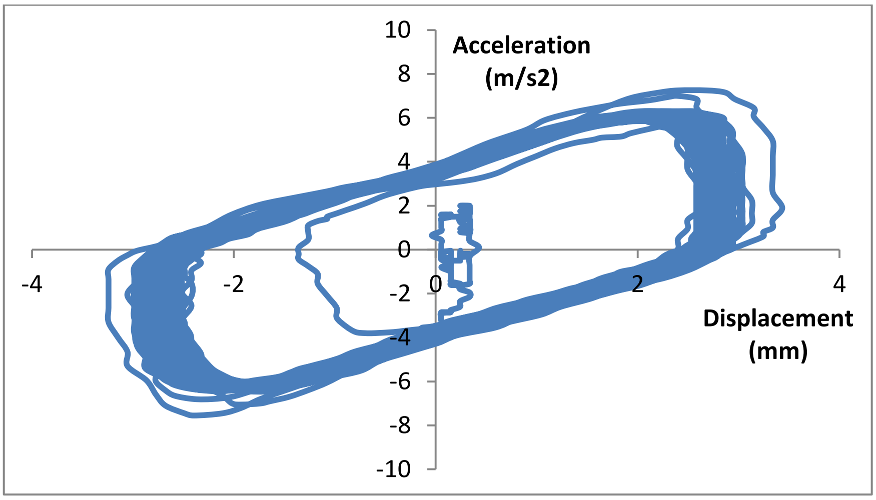

Figure (4): Hysteresis relation of tested FDD

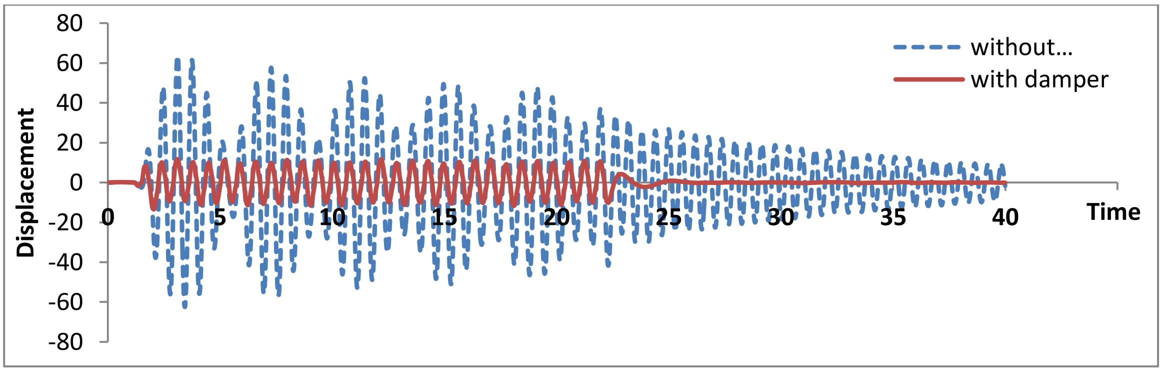

Figure (5): Basic frame response with and without FDD

5 Computer modeling and analysis results

Previous works have been performed in the mathematical modeling for the current friction damper device. Mualla et al [5] use DRAIN-2DX code and model the FDD with non-linear spring with rigid-plastic moment-rotation relationship. Amiri et al [6] use

Wen plastic model in SAP2000 software to model the behavior of the frictional hinge by defining its moment-rotation relationship.

In this study the frame structure with the examined damping system is simulated by SAP 2000 [7] software package. The frame legs and girder are modeled as frame elements and are defined with the cross sections mentioned in section 4.1. The legs restraints are fixed supports. Proper adjustments are applied to consider the beam column connection rigidity of the physical frame model. The damping system consisted of the FDD and the tie rods chevron bracing is modeled as follows: the damper steel plates are modeled as rigid frame elements; the tie rods are modeled as cable elements with an option to use them as straight frame objects, that is because the catenary behavior is not needed in this model. Moment releases are assigned at damper ends where hinges are present. Regarding the friction effect of the damper, it is modeled using Wen non-linear link defined by one joint and is assigned in the damper center. Figure (6) presents the defined FE model.

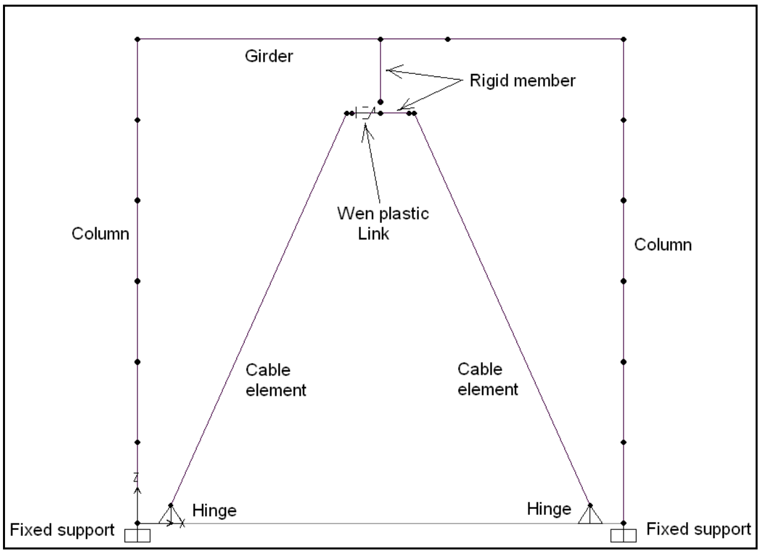

Figure (6): Finite element model for frame with damping system

The link properties are defined according to the hysteresis relation obtained from the experimental test explained in the previous section. Because Wen plasticity property is a non-linear force-deformation relationship [7], the relation shown in Figure (4) is calibrated by multiplying the acceleration values by the contributed mass in the frame. Wen hysteresis relation is defined in the X-direction only. Figure (7) illustrates Wen hysteresis relation defined in the program.

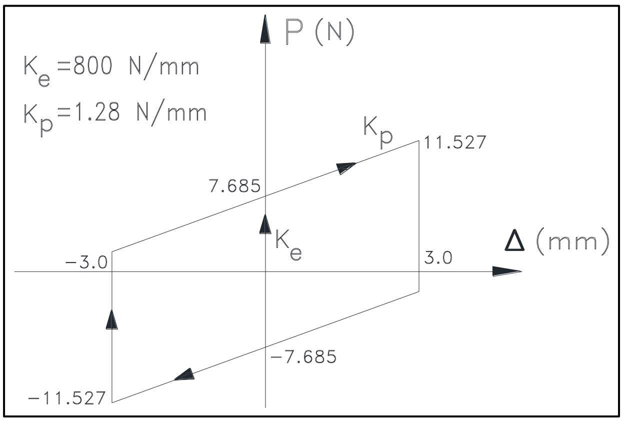

Figure (7): Defined hysteresis relation

The base excitation applied to the frame in the experimental work is assigned in the finite element software using the time history function. The shaking table excitation is recorded using the accelerometer as function of acceleration through time for 40 seconds. These records are filtered using seismosignal software to avoid noises. Two input excitations are performed experimentally; a constant harmonic motion with a frequency of 2.86 Hz and variable frequencies increasing from 0.0 Hz to 2.86 Hz, then decreasing to 0.0 Hz, as shown in Figures (8) and (9) respectively. Both excitations are defined in SAP2000 program as time history function. The analysis is performed using the modal Fast Nonlinear Analysis (FNA), and then the frame response is reported. A comparison between experimental and numerical model for both cases are illustrated in Figures (10) and (11). It is clear that the constant loading case shows good agreement except in the first two seconds. The variable case shows good agreement with slight deviations. Hence, it can be concluded that the numerical simulation for the FDD using Wen link definition is proper. In addition the new natural frequency of the frame is compared with experimental results and is very close.

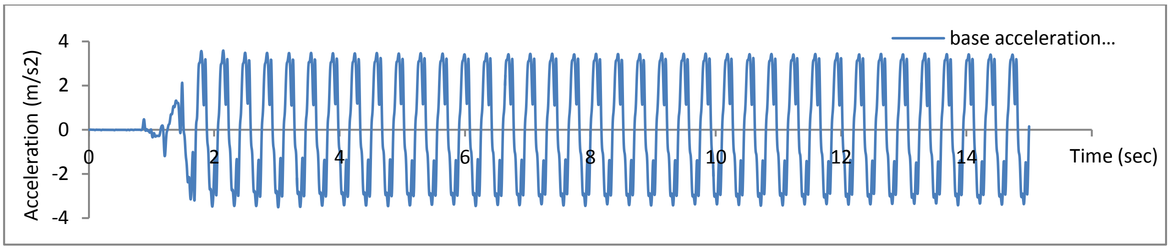

Figure (8): Input base acceleration for constant excitation

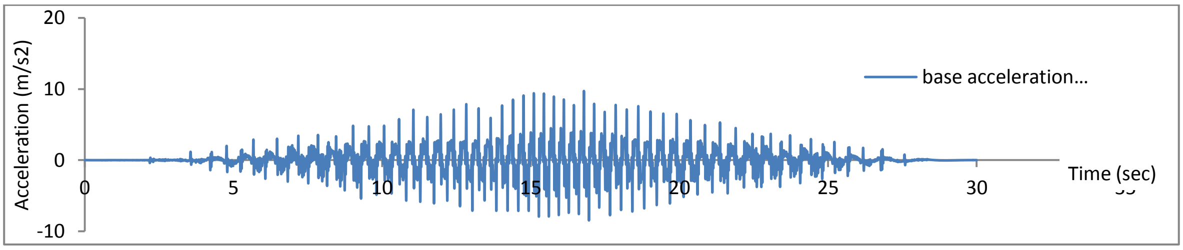

Figure (9): Input base acceleration for variable excitation

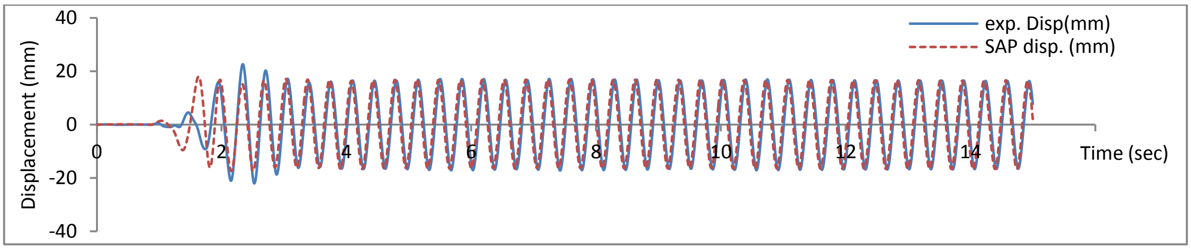

Figure (10): Comparable response for constant excitation

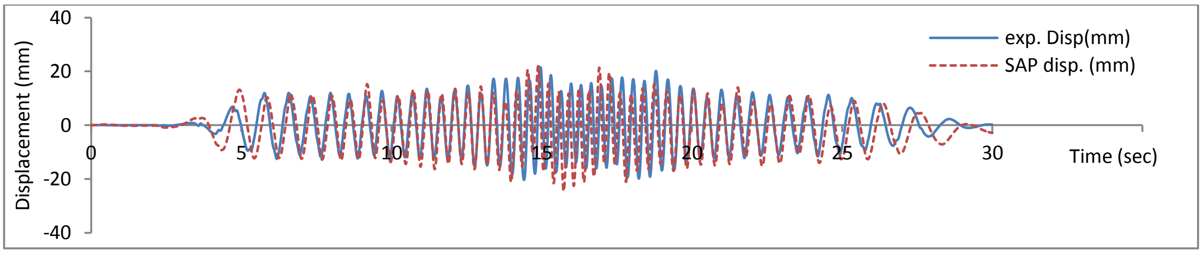

Figure (11): Comparable response for variable excitation

6 Conclusions

Based on the experimental results and its comparison with the numerical simulation technique, the following can be concluded:

- The rotational friction damper device can be fabricated in Egypt. The device is manufactured and assembled using the simple materials in the local market in Egypt. The friction pad material is made from Teflon.
- The hysteresis relation of the FDD device is extracted experimentally.
- The frame structure resistance against shaking table excitation is highly increased with FDD.
- The finite element model for the FDD using Wen relationship gives very good results compared with experimental results.
- The finite element simulation technique for the FDD is an easy and powerful tool that can be used to analyze many types of frames with different location of the FDD.

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