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The effect of semi-active controller in Sirri jacket seismic vibration control under Kobe earthquake

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ABSTRACT: The Sirri jacket offshore platform was designed and installed in Persian gulf of Iran in 1975 and has been in service since that time. The importance of offshore structure's stability and the failure of this kind of structure during an earthquake in different active zones revealed that earthquake loading has to be considered. In this paper, Magnetorheological (MR) fluid dampers have been proposed as a powerful tool to control seismic vibration of platform. A combination of four MR dampers and six friction pendulum isolators on the joints of cellar deck is applied for dynamic control of an existing steel jacket. In order to accurately evaluate the performance of Sirri jacket with MR dampers under Kobe seismic excitation, the platform numerically modeled in SACS software. The size of generated model with 198 degree-of-freedoms (DOFs) was dynamically reduced so as to be utilized in semi-active control algorithm. To this end, the stiffness, mass and damping matrices of the model has been reduced to the 25 DOFs model by programming in MATLAB software. The algorithm is used in this study for semi-active control of platform was H2/LQG. Comparison between dynamic response of the jacket with and without using semi-active controller showed a great difference in quantity of joints displacement and acceleration. As a consequence, cellar deck joints displacement and acceleration reduced about 50% in average. The results of using semi-active MR dampers showed that the earthquake-induced vibrations can be effectively suppressed by the isolation layer with MR dampers.

Keywords: *Cellar Deck; Dynamic Response Reduction; Kobe Excitation; Persian Gulf*

INTRODUCTION

Production platforms are required to stay on station during its lifetime, which is usually from 20 to 30 years (Chakrabarti, 2005). Offshore platforms are divided into two categories: Fixed platforms and Compliant Platforms. In shallow waters, the most common type of production platforms is the fixed piled structures, commonly known as jackets in the offshore industry. The jacket structures are the most common offshore structures used for drilling and production. Fixed jacket structures consist of tubular members interconnected to form a three-dimensional space frame. These structures usually have four to eight legs battered to achieve stability against toppling in waves. When the water depth exceeds these limits, compliant towers or floating production platforms become more attractive. The principal structural components of the offshore platform are the jacket, the piles and the deck.

Although most of the offshore structures constructed to date have withstood the test of time, there have been several catastrophic failures of offshore structures as well. Weather, blowout, capsizing and human errors have resulted in the loss of a substantial number of fixed and floating structures. The offshore industry requires continued development of new technologies in order to produce oil in seismically active regions.

In this study, a combination of MR dampers and friction pendulum isolators on the joints of cellar deck is used for seismic vibration control of an existing steel jacket in Sirri oil platforms. The platform numerically modeled in SACS software. The size of generated model was dynamically reduced in order to be utilized in semi-active control algorithm.

MATERIALS AND METHODS

Sirri jacket parameters

The existing Sirri oilfield is located in the Iranian territorial water of the Persian Gulf, approximately 100 km from the coast and approximately 32 km South-west of Sire Island. It was developed between 1976 and 1978 and is on stream since October 1978. The Sirri jacket structure is a kind of fixed offshore

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platform. The existing jacket which is located in depth of 60 meters in Persian Gulf is a 6 legs platform. The Gulf in which Sirri platform is built presents a set of complicated and harsh environmental conditions. Dynamic loads including wind, wave, current, and earthquakes dominate the design of offshore platform. In Fig. 1 existing situation of Sirri jacket platform has been illustrated.

Sirri Jacket Platform Modeling

In this study, the Sirri jacket platform has been modeled in SACS (Structural Analysis Computer System) offshore software. SACS is an integrated finite element structural analysis suite of programs that uniquely provides for the design, fabrication, installation, operations, and maintenance of offshore structures, including oil platforms and wind farms. There are four main parameters which are useful in platform modeling. These parameters are:

Working point elevation
Pile connectivity elevation
Mud-line elevation
Jacket legs batter

Loading have been applied in both HAT and LAT elevations and both operating and storm conditions.

Wave forces acting on the structure are generated by SACS program using Morison equation, based on wave apparent period and in accordance to API RP-2A. In Fig. 2 complete model of Sirri jacket platform in SACS software is shown. The model of jacket platform was statically analyzed under In-place loading. In addition, dynamic analysis was carried out to derive mass and stiffness matrices of the model.

The Position of Control Devices

In this study, six FPS bearings (spring) were considered to insert in the joint of cellar deck elevation. The isolators in X and Y direction were assumed so that to provide natural period of vibration equal to 3 seconds. Furthermore, 12 sensors are used in the location of 6 joints in the cellar deck elevation. Four MR dampers are set in the location of isolators in cellar deck elevation. Fig. 3 shows the location of isolator and MR dampers in joint of jacket and cellar deck.

Model order reduction

The size of mass and stiffness matrices of 198 DOFs model which have been derived from SACS program was dynamically reduced so as to be utilized in semi active control algorithm. To this end, the stiffness, mass and damping matrices of the model has been reduced with modal coordinate in the finite time and frequency intervals to the 25 DOFs model by programming in MATLAB software. The reduction procedure can be set up alternatively, either by first applying frequency and then time transformation of grammians, or by first applying time and then frequency transformation. Hankel singular values are computed by using these two grammians. Fig. 4 shows Hankel singular values based on matrix ranks which are obtained by MATLAB programming. Small quantities of Hankel singular values are omitted for obtaining sub model with 25 DOFs.

Fig. 1: Sirri jacket platform in Persian Gulf

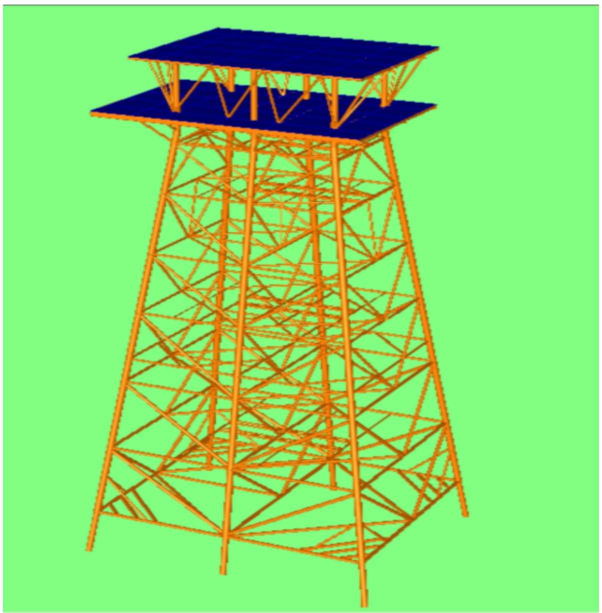


Fig. 2: Model of Sirri jacket platform in SACS program

Fig. 3: Situation and location of Isolator layers and MR dampers

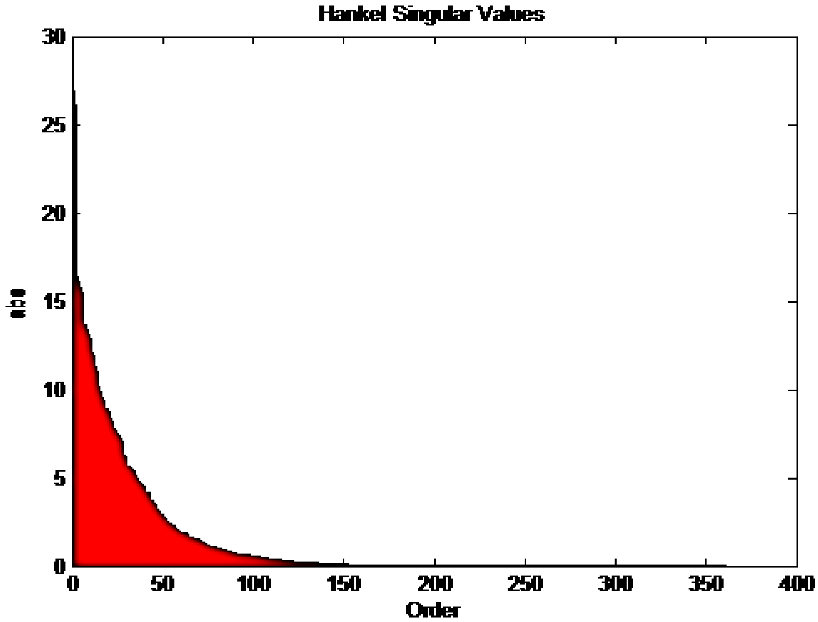


Fig. 4: Diagram of Hankel singular values based on matrix ranks

H2/LQG control algorithm

The control issues, as applied to structures, include precise positioning or tracking. It is expected that the positioning and tracking requirements should be satisfied for structures with natural frequencies within the controller bandwidth and within the disturbance spectra. LQG (Linear system, Quadratic cost, Gaussian noise) controllers can typically meet these conditions and they are often used for tracking and disturbance rejection purposes.

The control inputs are assumed in the LQG controller collocated with the disturbances and consequently with the performance. This assumption imposes significant limits on the LQG controller possibilities and applications. The locations of control inputs do not always coincide with the disturbance locations, and the locations of controlled outputs are not necessarily collocated with the location where the system performance is evaluated.

The H2 controllers address the controller design problem in its general configuration of non-collocated disturbance and control inputs, and non-collocated performance and control outputs. In this study, reduced structure model are controlled by using H2/LQG algorithm. The provided MATLAB Simulink for dynamic systems and control algorithm is displayed in Fig. 5.

Optimal forces and controller voltage are determined in algorithm and transmitted to MR dampers in order to modify the structure responses concurrently. As it described, the data acquisition is performed by using sensors at platform level and recording displacement and acceleration of Sirri jacket responses during seismic excitations.

Seismic Performance of Semi Active Jacket

In this section, displacement and acceleration response time history of cellar deck joints with and without using MR damper are compared. Fig.s 6, 7 and 8 are shown diagrams of 3 cellar deck joints displacement dynamic response under Kobe seismic excitation. More, Fig.s 9, 10 and 11 are shown acceleration dynamic response under Kobe ground motion.

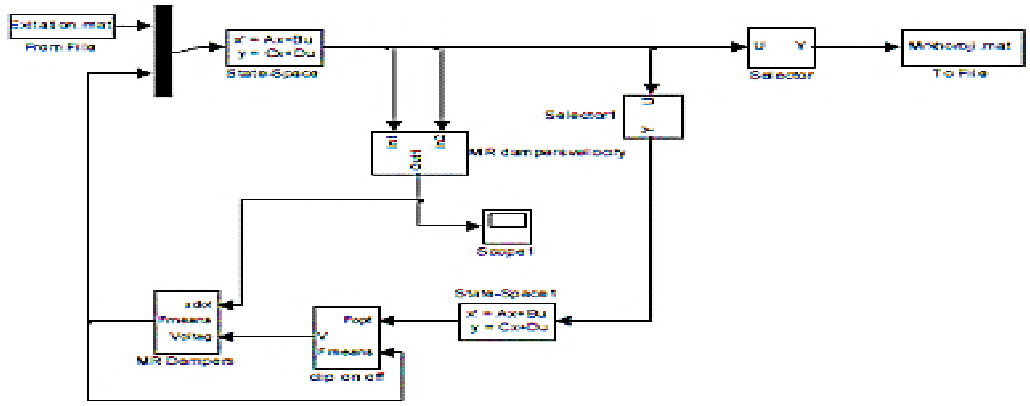


Fig. 5: MATLAB Simulink diagram of Sirri jacket semi-active control using reduced structure matrixes with installing MR dampers

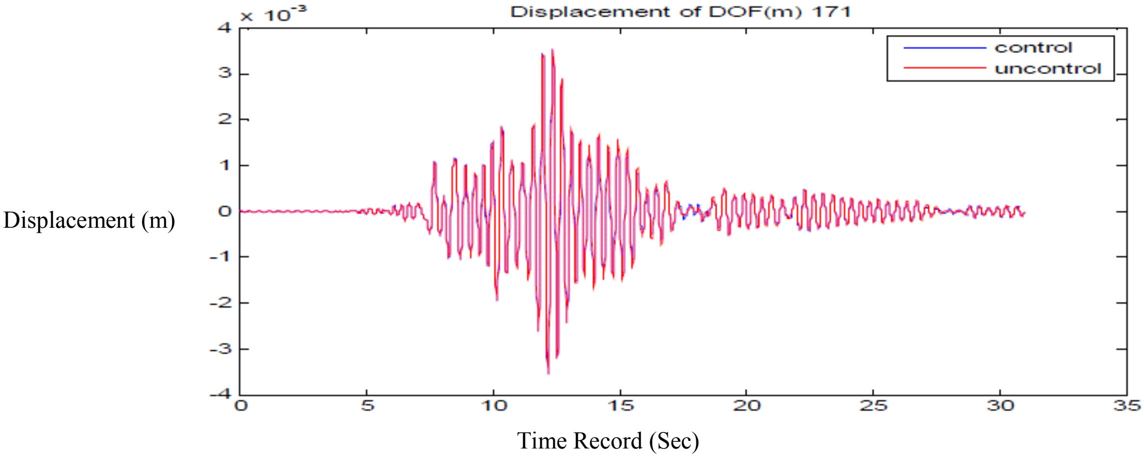


Fig. 6: Displacement of Degree of Freedom No. 171 in Terms of Kobe Earthquake Time Records in Cellar deck Elevation with and without use of MR controllers

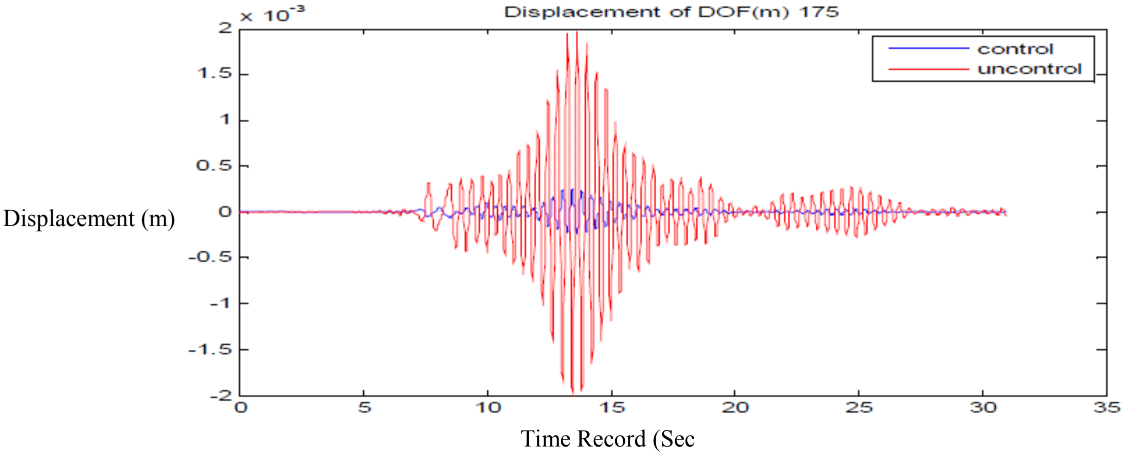


Fig. 7: Displacement of Degree of Freedom No. 175 in Terms of Kobe Earthquake Time Records in Cellar deck Elevation with and without use of MR controllers

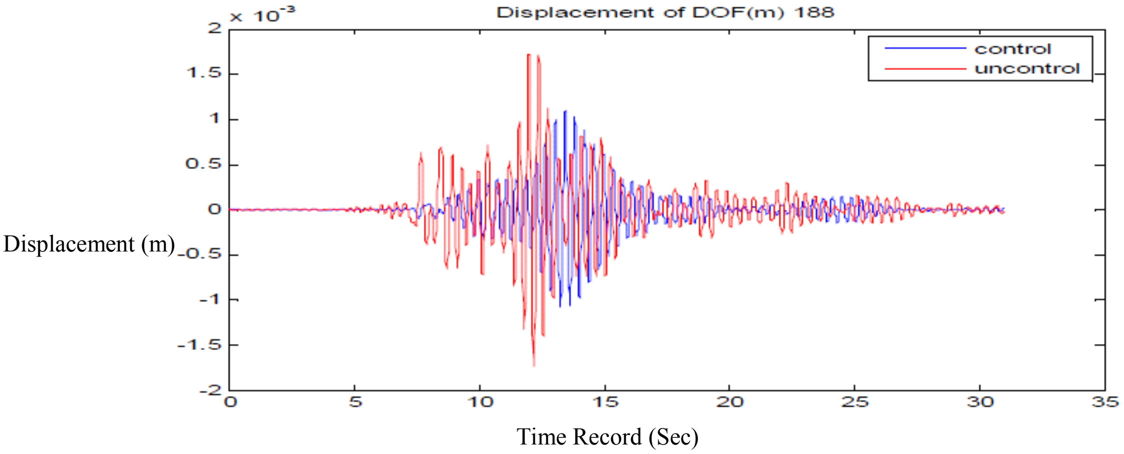


Fig. 8: Displacement of Degree of Freedom No. 188 in Terms of Kobe Earthquake Time Records in Cellar deck Elevation with and without use of MR controllers

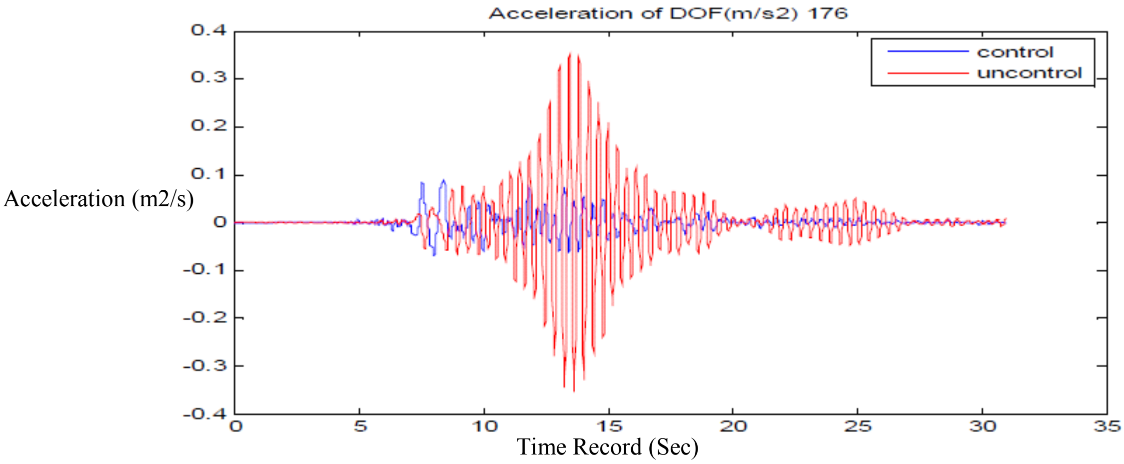


Fig. 9: Acceleration of Degree of Freedom No. 176 in Terms of Kobe Earthquake Time Records in Cellar deck Elevation with and without use of MR controllers

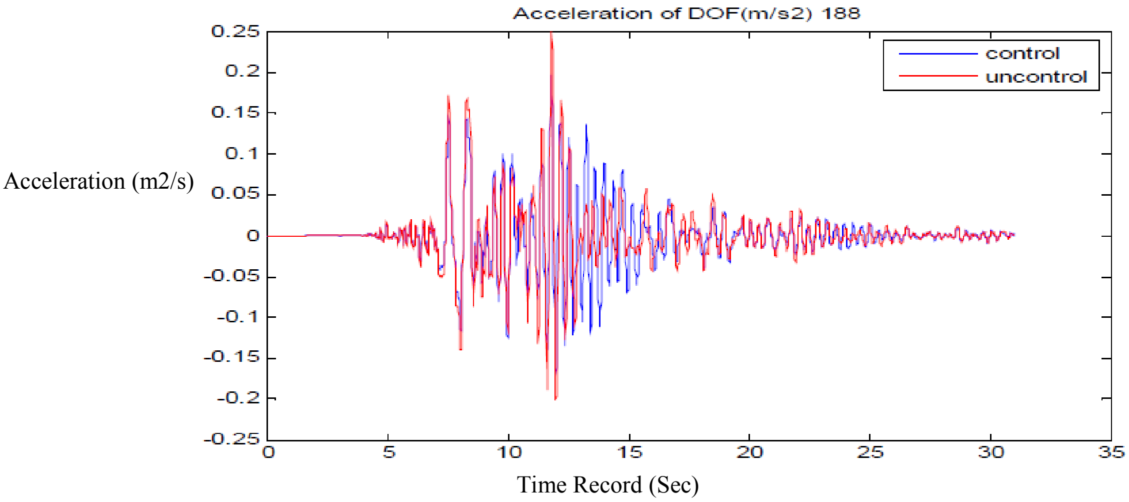


Fig. 10: Acceleration of Degree of Freedom No. 188 in Terms of Kobe Earthquake Time Records in Cellar deck Elevation with and without use of MR controllers

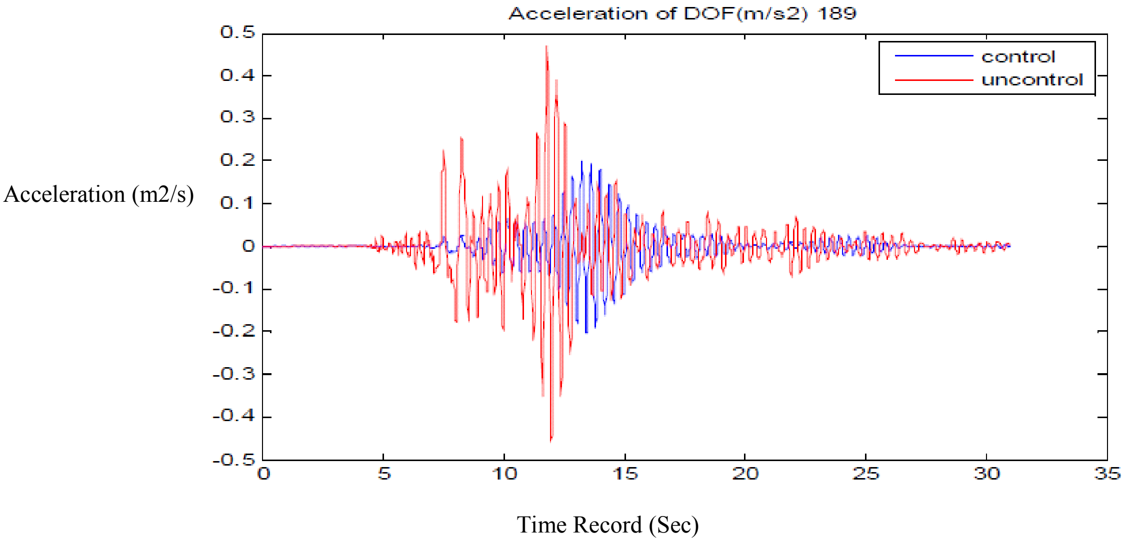


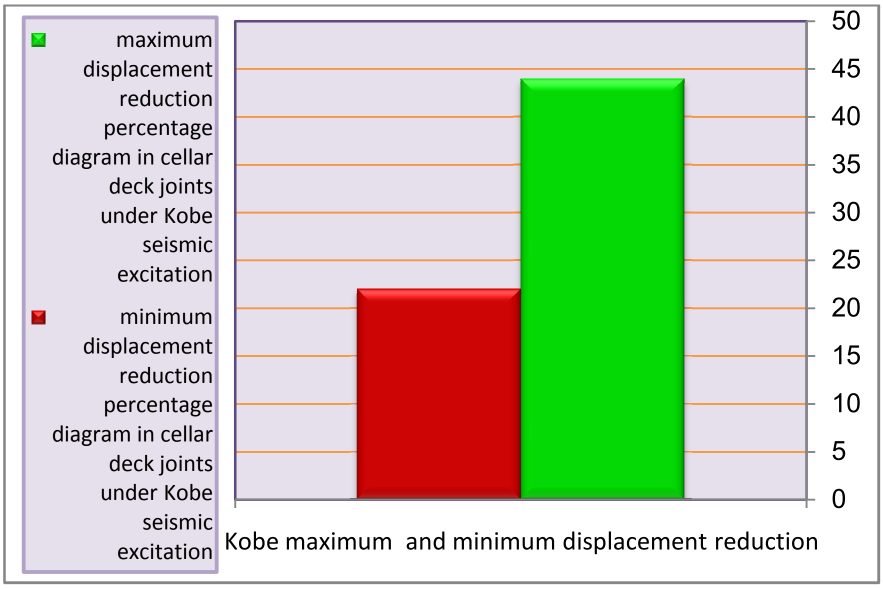
Fig. 11: Acceleration of Degree of Freedom No. 189 in Terms of Kobe Earthquake Time Records in Cellar deck Elevation with and without use of MR controllers

RESULTS AND DISCUSSION

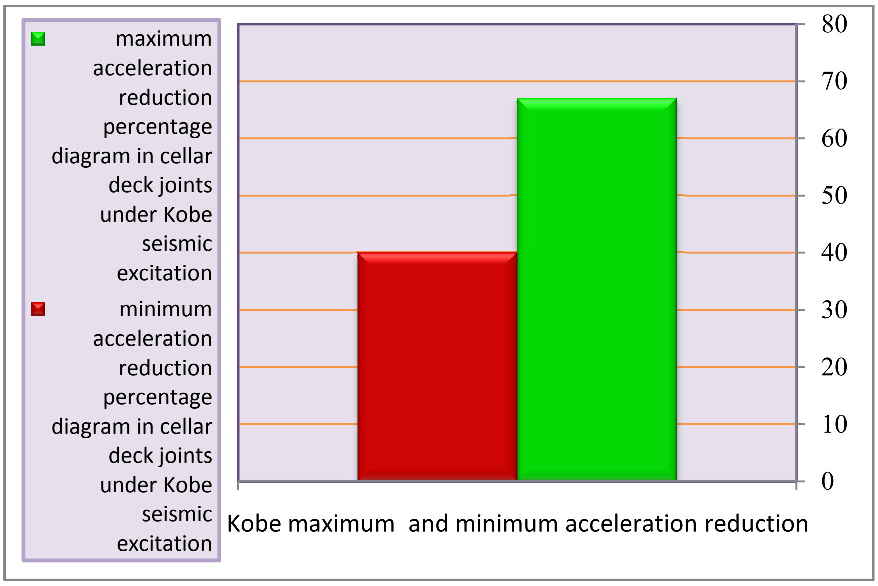
Comparison between dynamic response of the jacket with and without using semi-active controller in Fig.s 6 to 11 shows a great difference in quantity of cellar deck joints displacement and acceleration. Fig. 12 summarized maximum and minimum displacement and acceleration reduction percentage diagrams in 6 cellar deck joints under Kobe seismic excitation. In Fig. 12-a, maximum displacement reductions are about 44% under Kobe ground motion. For minimum displacement reductions this order are 22% for Kobe seismic excitation. In Fig. 12-b, maximum acceleration reductions are 67% under Kobe Earthquake. Also minimum acceleration reductions are 40% under Kobe ground motions.

CONCLUSION

The results of using semi-active MR dampers show that the earthquake-induced vibrations can be effectively suppressed by the isolation bearings with MR dampers. This study reported clearly that semi active control system presents a practical alternative for offshore industry and a powerful tool to control dynamic vibration of platforms caused by seismic excitation. This system by simultaneous reduction of displacement and acceleration of cellar deck protects structural and non-structural components of Sirri jacket under severe earthquakes.



(a)



(b)

Fig. 12 (a, b): (a)maximum and (b)minimum displacement and acceleration reduction percentage diagrams in 6 cellar deck joints under Kobe seismic excitation

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