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Rehabilitation of jacket offshore platforms

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Abstract

Some existing platforms may have some aspects of deficiency in both seismic and fatigue issues. From economic point of view it is preferable to retrofit and continue using of existing jackets in many cases, in comparison to a new installation. In this paper a relatively complete review has been carried out on various methods of rehabilitation. As an example an existing 4-leg service platform placed in the Persian gulf (Ressalat) is considered and the results are presented. Some efficient rehabilitation methods such as Friction Damper Device (FDD) and Buckling Restrained Braces (BRB) are presented and investigated for seismic loads and near-field effects as well. In this paper far and near field earthquakes are considered as possible excitations and the effects of FDD and BRB on the structural behavior are investigated numerically. The results show the high efficiency of both two methods in reduction structural responses and increasing seismic performance level.

Keywords: Jacket Offshore Platform, Rehabilitation, FDD, TMD

1. Introduction

Current methods for upgrading of existing structures can be classified into two major groups: traditional and modern. Ordinary methods aim to increase the strength and/or ductility of the structure by repairing/upgrading members. Modern methods aim is to reduce demands of loads imposed to structure. Use of seismic isolation and energy dissipation for seismic protection of the structures is some examples of this method. Incorporation of energy dissipation systems in a traditional earthquake-resistant structure has been recognized as an effective strategy for seismic protection of structures (Soong and Dargush, [1]). The service life of an offshore structure can be doubled if the dynamic stress amplitude reduces by 15%. Few studies have reported on the effectiveness of the passive control systems using dampers in controlling the response of offshore platforms under a parametric variation studying the influence of important system parameters and comparative performance of dampers. In order to reduce possible damage to jacket offshore platforms in harsh marine environments, the necessity of carrying out further studies on developing efficient and practical vibration control strategies for the suppression of dynamic responses of existing offshore structures should be emphasized.

New vibration control technologies have been applied to offshore structures in the following cases. Vandiver and Mitome [2] used storage tanks as Tuned Liquid Damper (TLD) on a fixed platform to mitigate the vibration of the structure subjected to random wave forces. Kawano and Venkataraman [3] and Kawano [4] studied the application of an active tuned mass damper to reduce the response of platforms due to wave loading. Abdel-Rohman [5] studied the dynamic response of a steel jacket platform with certain active and passive control due to wave-induced loading. Lee [6] used stochastic analysis and demonstrated the efficiency of mechanical dampers for an offshore platform. Suneja and Datta [7] demonstrated the efficiency of an active control system for articulated leg platforms under wave loading. Vincenzo and Roger [8] developed an Active Mass Damper for suppression of vortex- induced vibrations of offshore structures. Ou et al. [9] studied the response reduction of jacket platforms with a viscoelastic damper with respect to ice loads. Wang [10] used Magnetorheological dampers for vibration control of offshore platforms for wave-excited response. Mahadik and Jangid [11] studied the response of offshore jacket platforms with an active tuned mass damper under wave loading. Patil and Janjid [12] studied the behavior of a platform with viscoelastic, viscous and friction damper for wave loads. Lee et al. [13] studied the effectiveness of a Tuned Liquid Column Damper (TLCD), which dissipates energy by water flow between two water columns, for offshore structures and also, Ou et al. [14] studied the application of damping isolation systems for response mitigation of offshore platform structures. Jin et al. [15] studied the effect of Tuned Liquid Dampers (TLD) and found that the larger the ratio of water-mass to platform-mass, the higher the reduction of responses. Golafshani and Gholizad [16] studied the performance of friction dampers for mitigating of wave-induced vibrations and used mathematical formulation to evaluate the response of the model. Yoe et al. [17] used Tuned Mass Damper (TMD) for mitigation of dynamic ice loads.

Chen et al. [18] studied the response of a jacket platform installed with TLD due to earthquake loading. Kumar et al. [19] studied a single-bay ten-storey concentric braced frame with BRB under earthquake loadings and it was observed that BRBs are effective in dissipating energy and controlling inter-storey drift. Tabeshpour and Komachi used Buckling Restrained Brace (BRB) for retrofitting of existing jacket platforms [20].

Some modern methods such as Friction Damper Device (FDD) and Buckling Restrained Brace (BRB) were used for rehabilitation of this structure. Results of this study show that selection and use of appropriate system, with respect to loads, is very efficient and can be used for rehabilitation of older jacket platforms.

2. Rehabilitation

Suitable system for rehabilitation of jacket offshore platforms shall be selected with respect to loading conditions. For example seismic excitation can be far-field or near-field. Ocean waves can be deal with as regular or irregular. Wind is consists of two terms of static and fluctuation.

provides proposed relation between rehabilitation methods and excitation types on jacket platforms. Assessment Fig. 1 of existing jacket is performed before rehabilitation. With respect to type of loads, some types of control systems can be used for rehabilitation of jacket offshore platforms. This fig. shows suitable system for various types of excitation. Cases 1 and 2 are studied here.

Fig. 2 shows types of control systems usable for jacket offshore platforms. Control systems are divided into two main categories of passive and active methods. Many researchers have carried out several studies in this area that is shown in this figure.

Viscous and viscoelastic dampers can be used for all types of loading conditions. TMD is useful for wind and wave loads with narrow band excitation. Friction and metallic dampers are suitable systems for seismic rehabilitation. These systems are inactive for low loads. Buckling Restrained Brace (BRB) and deck isolator can also be an appropriate method for seismic rehabilitation. Fig. 2 shows some of studies that is related to some types of rehabilitation systems.

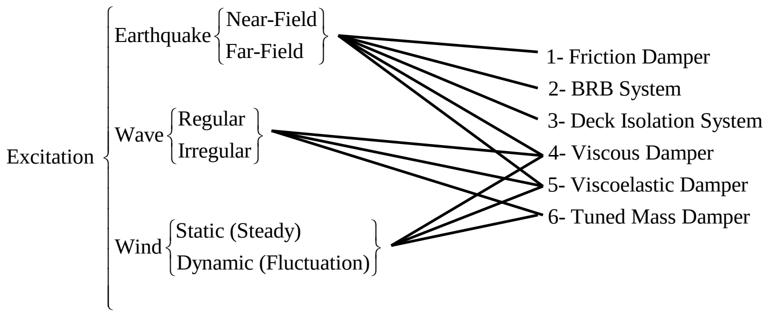


Fig. 1. Rehabilitation studies process for jacket offshore platform[21].

2.1. Friction Damper Devices (FDD)

One of the suitable systems for seismic protection is a novel friction damper device (FDD), which is economical and can be easily manufactured and quickly installed. The damper main parts, behavior, mathematically model and arrangement is shown in Fig. 3. The hinge connection is meant to increase the amount of relative rotation between the central and side plates, which in turn enhances the energy dissipation in the system. The ends of the two side plates are connected to the members of inverted V-brace at a distance r from the FDD center. The bracing makes use of pretension bars in order to avoid compression stresses and subsequent buckling. The bracing bars are pin-connected at both ends to the damper and to the column bases. OpenSees program used for modeling of this system. A simple for design of friction damper was presented with Tabeshpour and Ebrahimian [22].

The equivalent viscous damping of this system is obtained by:

$$\beta_{eff} = \frac{2}{\pi}\frac{FR\left(SR - FR\right)}{\left(SR + FR^{2}\right)}, \quad \frac{FR}{SR} < 1 \tag{3}$$

Which FR and SR are the damper properties in terms of the structure properties are defined as follows:

$$\begin{cases} FR = \dfrac{F_y}{F_e}: \ \text{the ratio of damper yield force to total structure force} \\ SR = \dfrac{K_{bd}}{K_e}: \ \text{the ratio of damper stiffness to total structure stiffness} \end{cases}$$

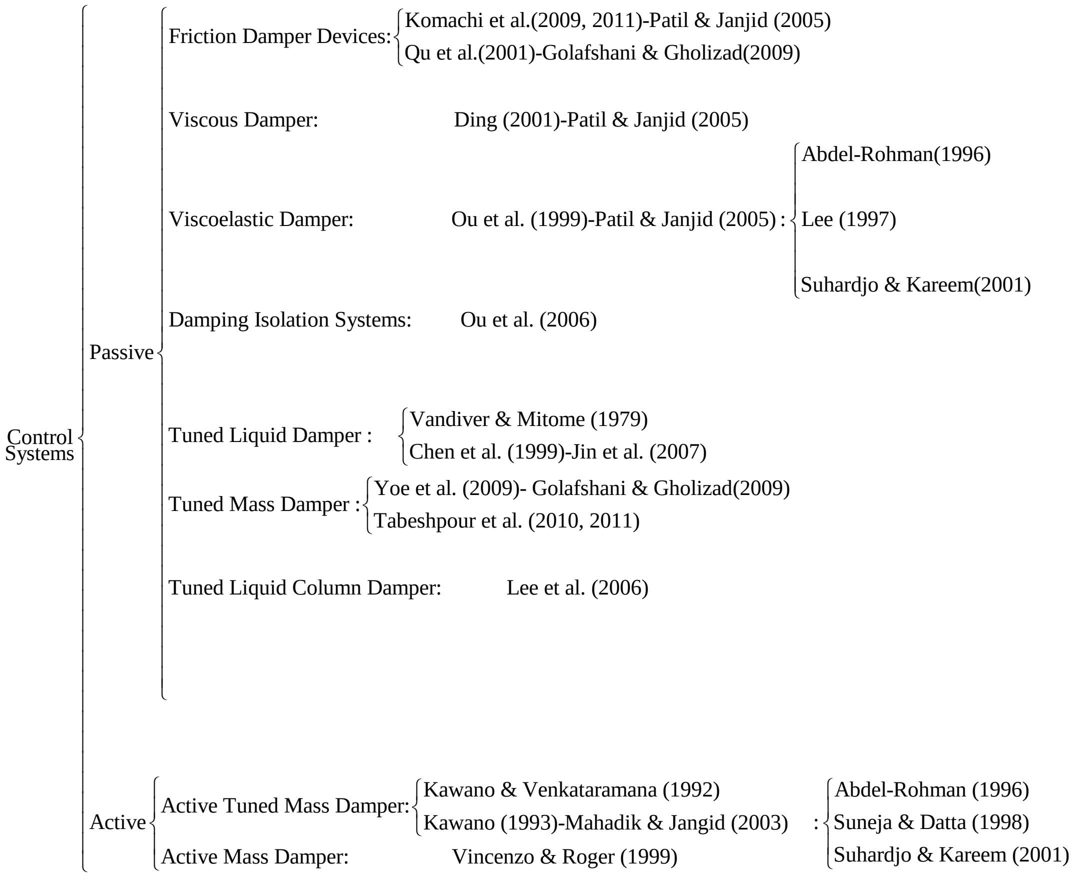
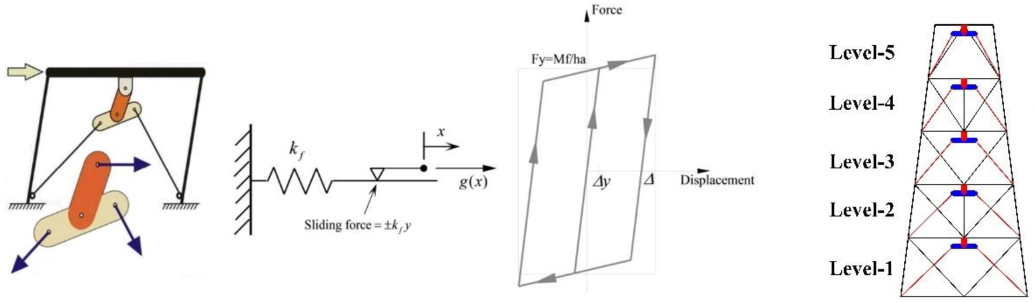


Fig. 2. Types of control systems used for jacket offshore platforms [21].



(a) (b) (c) (d)

Fig. 3. a) Configuration of friction damper, b) Mathematical model, c) Hysteresis behavior, d) Arrangement of FDD.

2.2. BRB System

Another system that is suitable for seismic rehabilitation is BRB. The brace is composed of a ductile steel core, which is designed to yield in both tension and compression. To preclude global buckling in compression, the steel core is first placed inside a steel casing (usually a hollow structure shape) before the casing is filled with mortar or concrete. prior to casing mortar, an unbonding material or a very small air gap between the steel core and mortar is provided to minimize, or eliminate if possible, the transfer of axial force from the steel core to and the hollow structural section (HSS).

Fig. 4 shows a comparison of the behavior of a BRB and a conventional brace. Conventional braces are expected to buckle, but BRB systems buckle in higher modes and therefore compressive capacity increase.

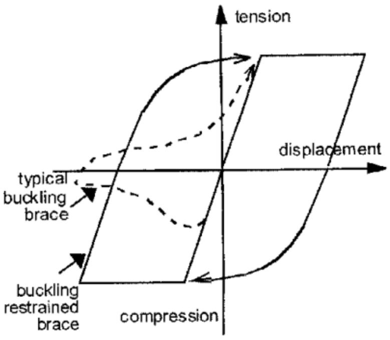


Fig. 4. Behavior of conventional brace versus BRB **Error! Reference source not found.**.

3. Case study

In this section, results of rehabilitation of existing jacket offshore platform with TMD, FDD, and BRB is mentioned. Here the service platform of the existing offshore complex is considered that consists of a four leg battered jacket and topside located in 67.40 m water depth which is connected to production platform by means of one existing bridge was used for case study. The service life of the platform is 25 years.

3.1. Structural model

Analytical models were created using the open source finite element program, OpenSees [22]. This program is useful for modeling of jacket platform structures because of its capability of modeling the post-buckling behavior of tubular members, soil-pile-structure interaction, friction damper behavior modeling and etc. A two-dimensional model of a single frame is developed for the structure. A force-based nonlinear beam-column element (utilizing a layered fiber section) is used to model all components of the frame. Steel material is modeled using a bilinear stress-strain curve with 3% post-yield hardening.

The mathematical model of the pile-soil system consists of the following sets of elements:

1. Pile elements, modeled by a number of nonlinear beam-column elements.
2. Far-field soil model representing the free-field motion of the soil column, vertically and horizontally that is unaffected by the pile motions. The soil is modeled using elastic quad elements. The nodes that are at the same depth are constrained.
3. Near-field elements that connect the piles to the soil, vertically and horizontally.

For time history analysis, a typical record Chi-Chi (Taiwan, 1999) record with PGA=0.353g (CHY101W) was used.

3.2. Seismic protection with FDD

Time history of base shear and deck displacement of jacket for CHY101W record show in the Fig 5 and Fig 6 respectively. It can be seen that use of FDD reduce deck displacement, and also base shear remain constant. Base shear of the structure vs. deck displacement (hysteresis loops) for CHY101W record is presented in Fig. 7 for cases of with and without FDD. Fig. 8 shows the combination of structure and damper behavior (Stiffness and Strength). This fig provide that use of FDD not only increase stiffness of structure, but also improve strength and stability.

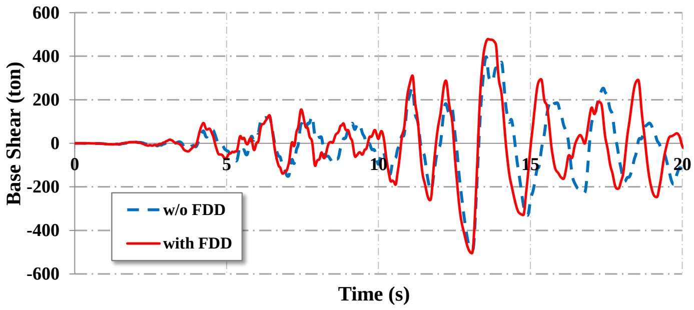


Fig 5. Base shear of structure for CHY101W record.

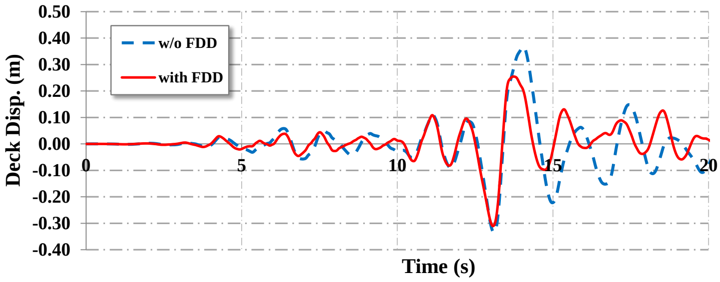


Fig 6. Deck Displacement of structure for CHY101W record.

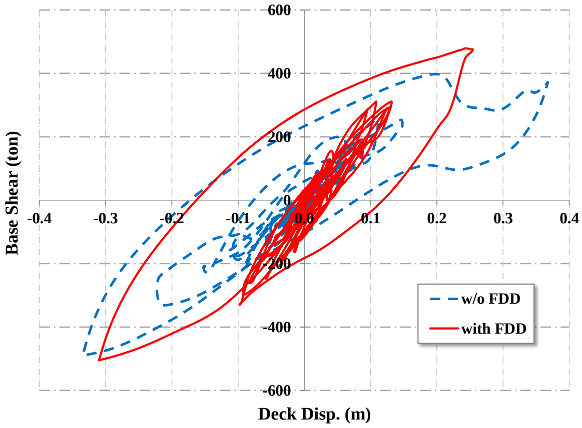
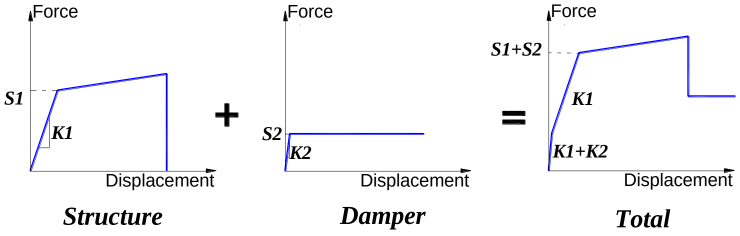


Fig. 7. Hysteresis loops of jacket for CHY101W record.



Structure ***Damper*** ***Total***

Fig. 8. Combination of structure and damper behavior (Stiffness and Strength)

Fig. 9 shows time history of frictional hinge rotation of dampers at 5th level of jacket for CHY101W record. Average rotation of friction damper can be used for as a criteria for performance of device. The greater value of this parameter shows that performance of friction damper is better. This parameter is as follow:

$$\text{Average Rotation} = \frac{\text{Total Froction Work}}{\text{Erthquake Duration}}$$

Performance Factor of damper defined as:

$$\text{Performance Factor} = \frac{\theta_{\text{ave}}}{\theta_{\text{max}}}$$

The nearest of this value to one, the higher performance of FDD. This means that difference of max and mean rotation is lower.

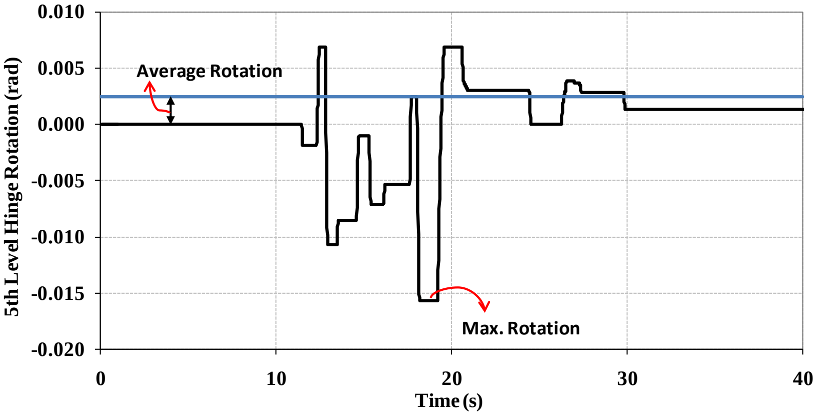


Fig. 9. Time history of 5th level hinge rotation for CHY101W record.

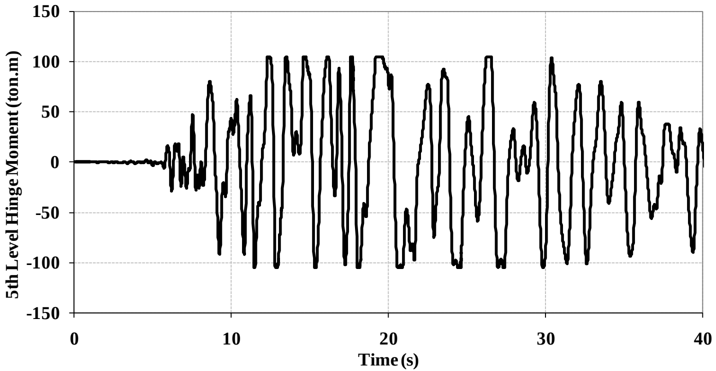


Fig. 10. Time history of 5th level hinge moment for CHY101W record.

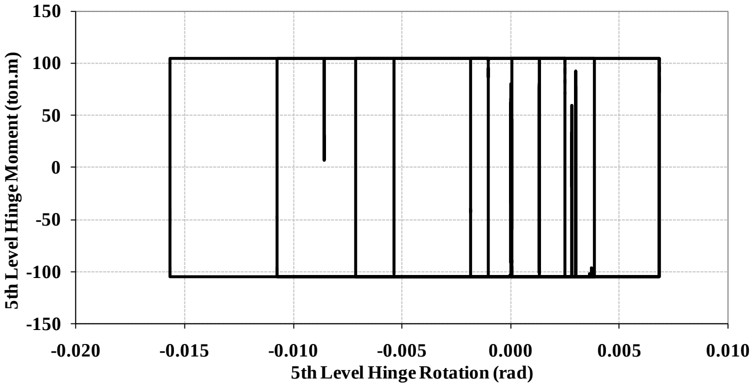


Fig. 11. Hinge rotation vs. hinge moment of friction damper at 5th level of jacket for CHY101W record.

3.3. Performance of Jacket equipped with BRB

Use of BRB system for diagonal members of jacket improve performance of jacket, especially at inelastic behavior. Responses of jacket platform for two cases of with FDD and BRB was compared. Fig. 12 compares the pushover curve of jacket for two cases with existing structure. It can be seen that unlike FDD, BRB system do not increase initial stiffness and only at buckling condition, increase capacity and at this case negative slope do not take place.

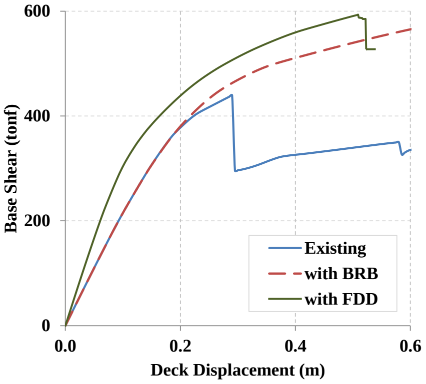


Fig. 12. Pushover curves of jacket platform for cases of Existing, with BRB and with FDD

Nonlinear time history analysis of jacket was performed for two cases. A pulse with following equation was used.

Fig. 13 shows the time history of deck displacement of jacket for two cases. It can be seen that use of BRB system reduces displacement responses up to 50 percent.

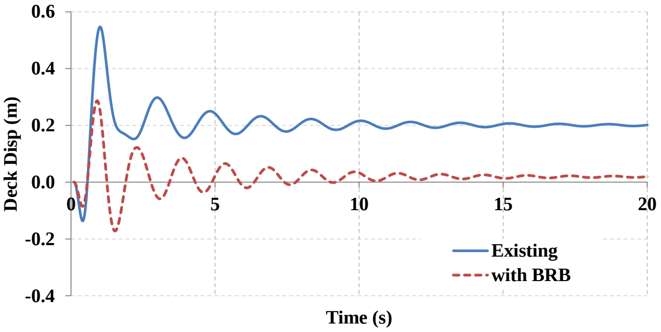


Fig. 13. Time history of deck displacement for two cases

4. Conclusion

Rehabilitation process using FDD, BRB for jacket platform offshore structures presented. Effect of FDD and BRB on the response of jacket offshore platform under the seismic excitation presented. It was shown that FFD is very effective for reduction of jacket responses under the seismic loads. Results were shown that responses of jacket reduce dramatically. Pushover analysis results were shown that use of FDD and BRB system reduce target displacement of the structure and also was shown that a sudden decrease of jacket strength does not occur when this system is installed on the structure. Due to the low redundancy of jacket platform structures, the strength of these structures can decrease suddenly and the use of FDD and BRB systems can be extremely useful. It was observed that for large record accelerations structure behavior becomes highly nonlinear and the performance of the friction damper for response reduction increases. Numerical studies clearly exhibit that these control systems represent a practical alternative for rehabilitation of existing jacket platforms.

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