Application of Lead Rubber Isolation Systems in the Offshore Structures

Habib Saeed Monir, Hiva Nomani.

Abstract: In this paper, lead-rubber isolation system is developed for vibration control of steel jacket offshore platform structures. This isolation system is proposed for vibration mitigation of jacket platform located in Persian Gulf. Effects of the parameters of lead rubber isolation system on the vibration mitigation of offshore structure are studied in detail. For investigating the vibration control effectiveness of this isolation system on the jacket platform, a complete numerical study is carried out. The results show that the lead rubber isolation system is an effective solution for mitigation of the dynamic responses of offshore platforms under earthquake excitations.

Index Terms—**Offshore Structures, Passive Damping, Isolators, Seismic Loading, Lead rubber systems.**

I. Introduction

The steel jacket structure, which originally came from Persian Gulf and then spread worldwide, is a typical type of fixed offshore platform. It is suitable to be built in water depth from a few meters to more than 300 m. Major structural components of such an offshore platform are its jacket, piles, and deck. A jacket structure which serves as bracing for the piles against lateral loads is fixed by piles driven through the inside of the legs of the jacket structure and into soil for many tens of meters. The deck structure is fixed upon the jacket structure [1].

The main purpose of seismic isolation systems is to separate the building structure from its supporting ground for preventing the transmission of the damaging components of earthquake excitations. In other words, isolation system prohibits the superstructure of the building from absorbing the earthquake energy. The whole superstructure should be supported on the discrete isolators whose dynamic characteristics are chosen to decouple the ground motion. Some isolators can also add substantial damping. Displacement and yielding are concentrated at the level of the isolation devices, and the superstructure behaves very similar to that of a rigid body.

Oceans, in which offshore platforms are built, experience very complicated and harsh environmental conditions. Dynamic forces including wind, wave, current, and earthquake influence the design of offshore structures. In seismic zone, such as Iran, earthquakes may generate significant dynamic loads on offshore platforms. The dynamic

loads affect not only the regular operation of an offshore platform such as drilling and production activities, but also the safety and serviceability of the structure. It is crucial to reduce the overall response of a jacket platform subjected to strong dynamic loads. In general, the reduction of dynamic stress amplitude of an offshore structure by 15% can extend the service life over two times, and can result in decreasing the expenditure on the maintenance and inspection of the structure [1].

Vibration control technologies, which have achieved significant success in mitigating vibrations of land-based structures under strong wind or earthquake actions over the past two decades, have rarely been applied to offshore platforms except in the following several cases [2]. Vandiver and Mitome [3] utilized storage tanks on a fixed platform as tuned liquid dampers (TLD) to suppress wave-induced structural vibration response. Lee [4] inserted viscoelastic materials in jacket legs to mitigate the vibration of an offshore structure subjected to random wave forces. Vincenzo and Roger [5] developed an adaptive control technique (Active Mass Damper) for suppression of vortex-induced vibrations of offshore structures.

Since 1997, aiming at mitigating the ice-induced vibration of offshore platforms in Bohai Sea, Ou et al. [6] numerically investigated the ice-induced structural vibrations using insitu measured ice force data, and also conducted numerical and experimental studies on ice-induced vibration control of offshore structures by adding viscoelastic and viscous dampers, respectively [7,8]. Their results showed that due to the limitations on the placement positions of the dampers and relatively low vibration amplitude of the platforms, the damping ratios added by the dampers were relatively small, and the effectiveness of adding the dampers to the offshore structures for the purpose of reducing their vibration responses was not remarkable [1].

In order to reduce possible damages to jacket offshore platforms in harsh marine environments, the necessity of carrying out further studies on developing efficient and practical vibration control strategies for suppression of dynamic responses of offshore structures should be stressed. In this study, lead rubber isolation system is developed to mitigate the vibration of fixed jacket offshore platforms. This isolation system is composed of eight lead rubber bearings as isolators. The contents of this study mainly include: (1) the investigation on the influence of isolation system parameters on vibration control of offshore platforms under the actions of earthquake excitations, (2) finding of the optimized specifications for lead rubber bearings.

Manuscript received Dec 08, 2010; revised January 07, 2011.
Habib Saeed Monir, Civil Eng. Department, Islamic Azad University-Maragheh Branch, Iran
Hiva Nomani, MSc Student, Civil Engineering Department, Urmia University, Iran

II. Isolation System of Jacket Offshore Platform

The proposed strategy for vibration suppression of a jacket offshore platform is that an isolation system is placed between the bottom of the deck and above the jacket structure; such a location is called the isolation level in this paper, as shown in Fig. 1. Isolation level can reduce vibration response of the platform effectively. Unlike traditional isolation strategies, which aim at shifting the fundamental natural frequency of a structure away from the dominant frequencies of seismic excitations, the present isolation system aims at dissipating the vibration energy at the isolation level.

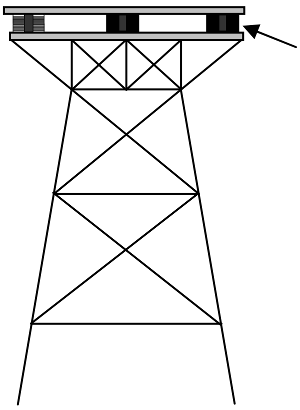

Fig. 1. Isolation system for jacket offshore platforms.

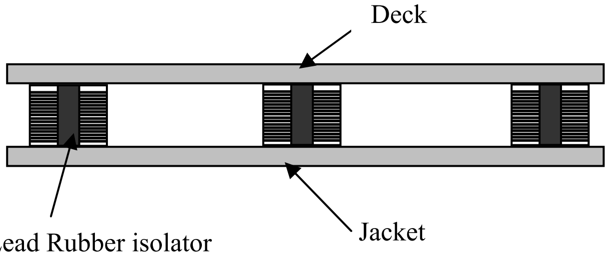

Fig. 2. Detail of the isolation system.

As mentioned previously, the isolation system is composed of eight isolators, as shown in Fig. 2. Lead Rubber bearing is regarded as one of the most popular isolators used in structural control. Stiffness and yield force are important parameters for designing an isolation system. These parameters can be determined according to the vibration control objectives.

III. Description of the Jacket Platform

The platform is located in Persian Gulf. The peak acceleration of the design earthquake excitation for the offshore structure is 0.35g, and the waterdepth considered in the design is 15.5 m [9]. The offshore structure is a four-legs jacket platform. It consists of two main components: substructure and superstructure. The superstructure is supported on a deck, which is fixed on the substructure. Under sea level, jacket has two level units at EL. −15.5 m and EL. −3.5 m, respectively. There are diagonal brace members in both vertical and horizontal planes in the units to enhance the structural stiffness. Above sea level, the jacket also has two level units at EL. 5.85 m and EL. 10 m, respectively. The elevation view of the platform in the longitudinal (X) direction is shown in Fig. 3.

Considering the effective length, effective cross-sectional area and effective moment of inertia of piles due to nonelastics oil–pile interaction, the dynamic characteristics of platform were analyzed using Finite Element method. The computational results are summarized in Table 1.

Table 1: Calculated natural frequencies of platform

Mode number	1	2	3	4	5	6
Frequencies (Hz)	0.76	0.76	0.94	2.64	2.87	2.87

In this paper a numerical study on the earthquacke induced vibrations of the platform is performed. The mass values of the superstructure and of the jacket and pile are 2545 ton and 750 ton respectively. The fundamental natural frequency and damping ratio in the longitudinal (X) direction are 0.725 Hz and 5%, respectively. By having the mass, the fundamental natural frequency and the damping ratio, the system's stiffness k , yeild force of the base isolation and the bace isolation's stiffness can be determined accordingly.

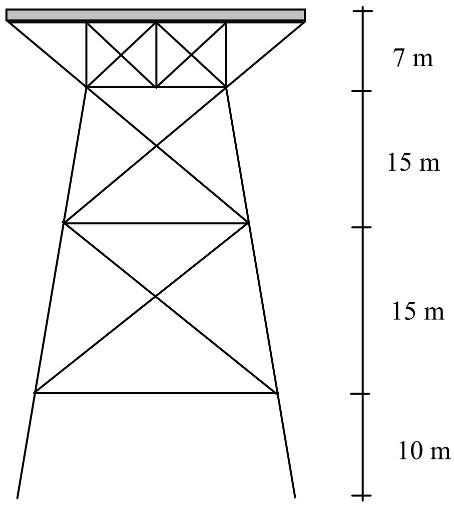

Fig. 3. Longitudinal view of the platform

Load cases

Earthquake load governs the design of all main structural members of jacket platforms in Persian Gulf. Time history analysis of the seismic responses of the platform was performed using the El-Centro (1940) and Kobe (1995) and Tabas (1979) earthquake ground motion records. The peak acceleration in the accelerograms was scaled to 0.35g for the seismic analysis according to the seismic design codes of IRAN. Figure 4 shows the considered excitation record.

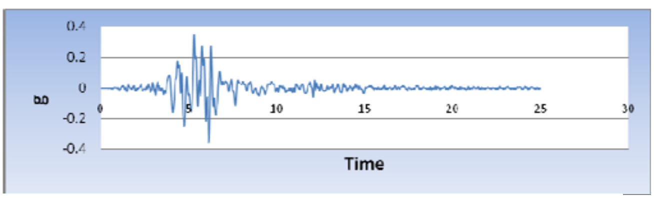

Fig4. Kobe (1995) earthquake acceleration records

ISBN: 978-988-19251-2-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

IV. THE EFFECT OF THE PARAMETERS OF THE ISOLATION SYSTEM ON INTER-STORY DRIFT

Large inter-story drift of the isolation level is not allowed for the jacket platform to satisfy the drilling and production requirements. The yeild force of the isolator and the isolator's stiffness are major effective parameters on the inter-story drift of the isolation level. A normal period ratio γ_t is defined as follows:

$$\gamma_t = \frac{T_d}{T_u}$$

$$T_u = \frac{2\pi}{\sqrt{\dfrac{K_1}{m_1 + m_2}}} \quad \text{and} \quad T_u = \frac{2\pi}{\sqrt{\dfrac{K_2}{m_2}}}$$

K_1 **:** the substructure's stiffness

K_2 **:** the isolaitor's stiffness

m_1 **:** the substructure's mass

m_1 **:** the superstructure's mass

T_u is the fundamental period of the structure without the isolation arrangements,

T_d is the period of the structure above the isolation level. **t** is used to reflect the effect of stiffness of the isolation level on the inter-story drift.

Figurse 5, 6, 7 show the effects of yeild force of isolaitor and γ_t on the maximum inter-story drift of the isolation level under three earthquake ground motions, respectively. In this figures, x_1 is the maximum inter-story drift of the superstructure level. The results show that x_1 is optimum in γ_t=1.22 and $\frac{yeild\ force}{axial\ \text{force}} = 10$

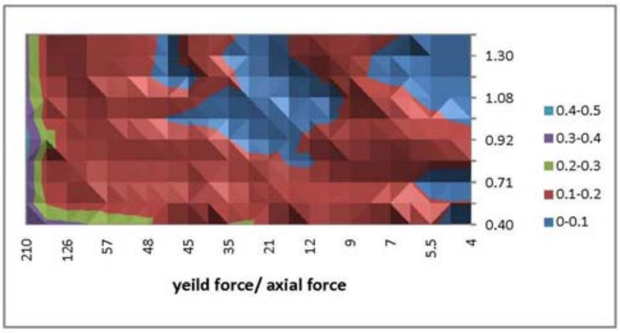

Fig. 5: The variation of interstory drift with the yield force under EL-Centro earthquake (1940, SN)

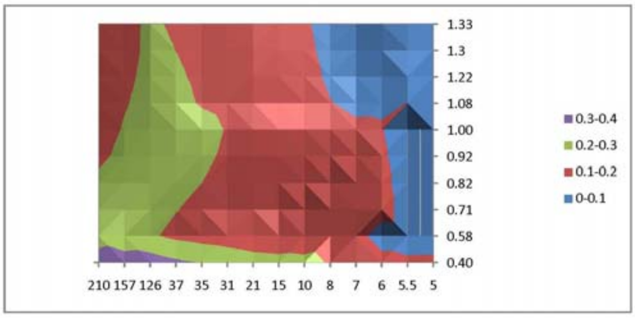

Fig. 6: The variation of inter-story drift with the yield force under Kobe earthquake (1995)

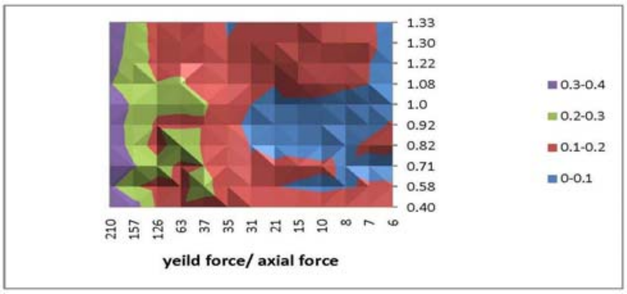

Fig. 7: The variation of inter-story drift with the yield force under Tabas earthquake (1978)

V. THE EFFECT OF THE PARAMETERS OF THE ISOLATION SYSTEM ON THE EFFECTIVENESS OF VIBRATION CONTROL

The (yeild force/axial force) of the structure and the stiffness of the isolator level are two main parameters which affect the vibration control. The maximum acceleration of the deck and the maximum displacement of the jacket cap are particular interests in this study. x_2 is defined as maximum displacement of the structure due to the isolation system . Figurse 8, 9,10 show the effects of γ_t and (yeild force/axial force) on x_2 under three earthquake ground motions, respectively. It can be seen from these figures that x_2 is optimum in γ_t=1.22 and $\frac{yeild\ force}{axial\ \text{force}} = 10$

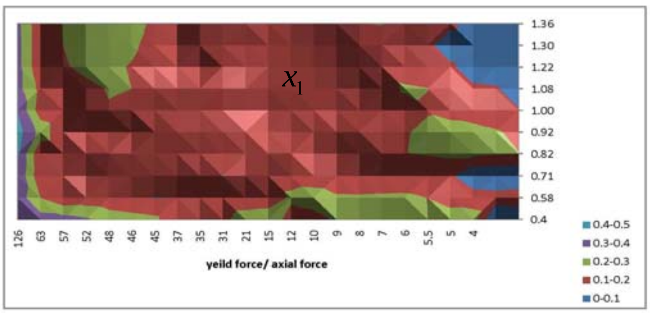

Fig. 8: The variation of acceleration with the yield limit under EL-Centro earthquake (1940, SN)

ISBN: 978-988-19251-2-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

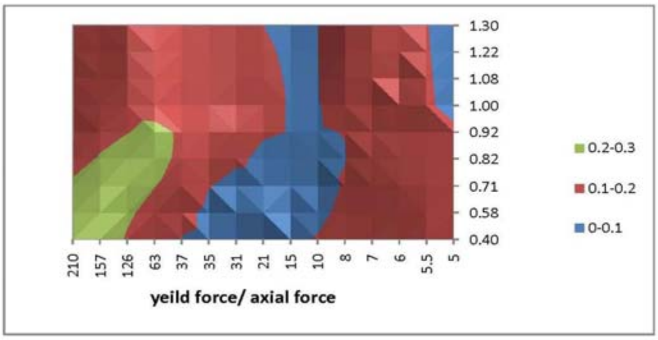

Fig. 9: The variation of acceleration with the yield limit under Kobe earthquake (1995)

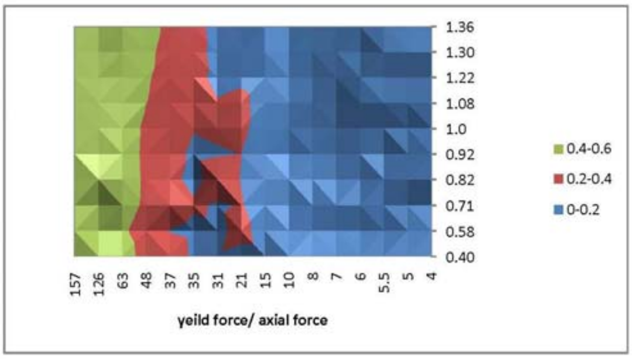

Fig. 10: The variation of acceleration with the yield limit under Tabas earthquake (1978)

VI. Results

The structural models without the isolation systems (called the unisolated structure) and with the lead rubber bearings (called the isolated structure) were studied. The maximum displacement of the jacket cap (EL. +4.300 m), the maximum acceleration of the deck (EL. +4.300 m) and the maximum inter-story drift of the isolate level under the three ground motions are presented in Table 2.

Comparison of the acceleration time history of the deck and the displacement time history of the jacket cap between the unisolated and isolated structures under Kobe earthquake input in optimal parameters of the isolation system are shown in Figures 11 and 12. The results demonstrate significant response reduction when the lead rubber bearings was added to the jacket structure. For the isolated structure case, reductions in the deck acceleration and the jacket cap relative displacement are significant. For the isolated structure under the three earthquake inputs, the maximum deck acceleration reduced by 79% on average and the maximum jacket cap displacement were reduced by 44% on average, and the mean value of the maximum inter-story drift of the isolation level was found to be 33.6 × 10−3 m.

VII. Conclusion

In the present study, lead rubber isolation system was developed to mitigate earthquake induced vibrations of jacket offshore platforms. Taking platform in the Persian Gulf as an example to examine the effectiveness of the proposed vibration control strategy for offshore structures, numerical study carried out. The major conclusions of this study are summarized below:

1. The developed isolation system placed between the deck and the jacket structure is composed of lead rubber bearings. Since the system provides low lateral stiffness relative to that of the superstructure, causing the isolated structure to primarily deform at the isolation level, yielding of isolator were used to dissipate the vibration energy to suppress the dynamic responses of the structure effectively.

2. As the normal period ratio increases, the effects of the vibration reduction in the maximum relative displacement of the jacket cap and the maximum acceleration of the deck increase, but the reductions are less sensitive to the change of the first mode damping ratio.

3. As the damping ratio of the first mode increases, the maximum inter-story drift of the isolation level decreases. As the normal period ratio increases, the maximum inter-story drift increases.

4. Can be seen from these figures that the optimal parameters of the isolation system in γ_t=1.22 and $\frac{yeild\ force}{axial\ \text{force}} = 10$

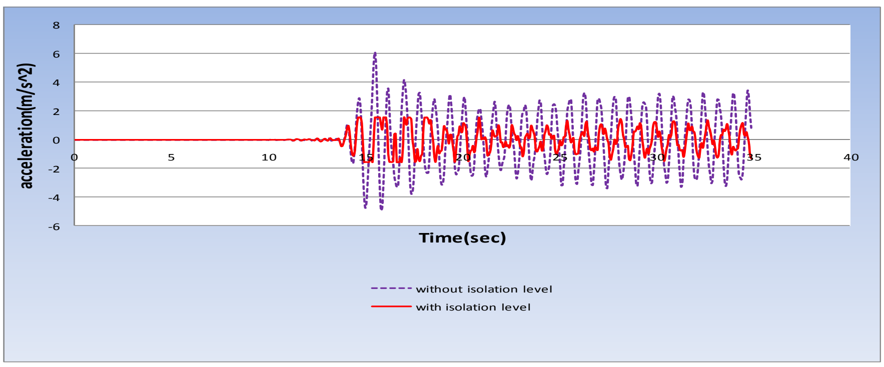

Fig. 11. The time history of displacement of the jacket cap of deck under Kobe earthquake input.

ISBN: 978-988-19251-2-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

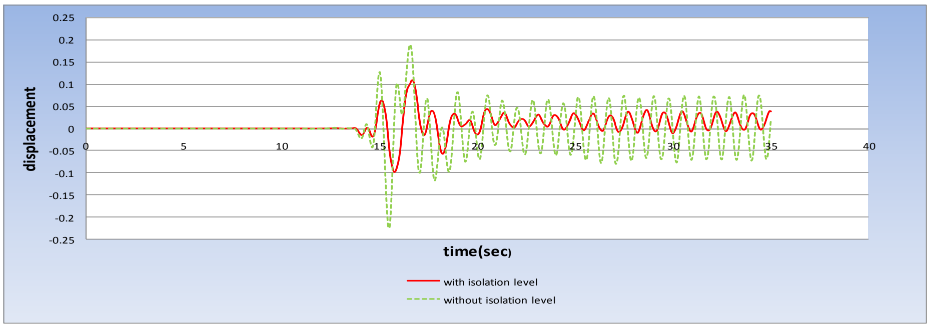

Fig. 12. The time history of acceleration of the jacket cap of deck under Kobe earthquake input.

Table 2: The summary of the results for the jacket model under three earthquake excitations

Earthquake	Peak acceleration		Maximum displacement of jacket cap (m)	Maximum inter-story drift of isolate level (m)	Maximum acceleration of deck (m/s^2)
Kobe	0.35g	Unisolated	0.178	-	5.81
		Isolated	0.092	0.035	1.57
Tabas	0.35g	Unisolated	0.295	-	9.55
		Isolated	0.136	0.034	1.56
El-Centro	0.35g	Unisolated	0.221	-	8.44
		Isolated	0.15	0.032	1.57

REFERENCES

[1] Jinping Oua,_, Xu Longa,b, Q.S. Lic, Y.Q. Xiaod. Vibration control of steel jacket offshore platform structures with damping isolation systems, Engineering Structures, Volume 29, Issue 7, Pages 1525-1538
[2] Housner GW, Bergman LA, Caughey TK, Chassiakos AG, Claus RO, Masri SF. Structural control: Past, present, and future. Journal of Engineering Mechanics ASCE 1997;123:897–908.
[3] Vandiver JK, Mitome S. Effect of liquid storage tanks on the dynamics response of offshore platform. Applied Ocean Research 1979;1:67–74.
[4] Lee HH. Stochastic analysis for offshore structures with added mechanical dampers. Ocean Engineering 1997;24(9):817–34.
[5] Vincenzo G, Roger G. Adaptive control of flow-induced oscillation including vortex effects. International Journal of Non-Linear Mechanics 1999;34:853–68.
[6] Ou JP, Duan ZD, Xiao YQ. Ice-induced vibration analysis of JZ20-2MUQ offshore platform using in-situ ice force histories. The Ocean Engineering 1999;17(2):70–8.
[7] Ou JP, Xiao YQ, Duan ZD, Zou XY, Wu B, Wei JS. Ice-induced vibration control of JZ20-2MUQ platform structure with viscoelastic energy dissipators. The Ocean Engineering 2000;18(3):9–14.
[8] Ding JH. Theoretical and experimental study on structural vibration repressed system using viscous fluid dampers. Ph.D. dissertation. Harbin Institute of Technology; 2001 [in Chinese].

ISBN: 978-988-19251-2-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)