RESPONSE CONTROL OF JACKET PLATFORMS USING MAGNETO-RHEOLOGICAL ELASTOMERIC DAMPER UNDER REGULAR WAVES

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Abstract— Offshore jacket platforms are fixed to the sea bed and installed relatively in shallow water depths. During their service life, unwanted vibrations are induced due to environmental loads like waves, wind, earthquakes, etc. These vibrations may cause fatigue failure and also disturb the functionality of the platform. The present study aims to reduce these unwanted vibrations with the help of a semi-active damper, a Magneto-Rheological Elastomeric (MRE) damper. MRE is an emerging and smart material in the field of vibration reduction, whose mechanical properties can be tuned reversibly using an external magnetic field. A fixed offshore jacket platform considering soil pile interaction is modeled in SACS (Structural Analysis and Computer System) software. The optimum location of the MRE damper is chosen for maximum reduction in the responses of the platform under regular waves, which is at horizontal brace level. To get the responses of the jacket platforms under regular waves, dynamic analysis is carried out on the jacket platform with and without an MRE damper. To know the effect of MRE damper on different wave height, parametric studies are also carried out. The results show that the MRE damper can effectively reduce the vibrations of the jacket platforms. The structural responses of the jacket platforms are improved by decreasing the deflection by 68.50%, velocity by 70.22%, acceleration by 65.89%, and finally base shear by 5.06%. From the parametric studies, as the wave height increases the response reduction effect of MRE damper is marginal for the base shear, deflection, velocity and acceleration. MRE damper can be effectively used to reduce the jacket platforms' excessive vibrations.

Index Terms— Magneto-rheological Elastomeric damper, Offshore Jacket platform, Regular wave, SACS software, Vibration control.

I. INTRODUCTION

The oil and gas exploration in the offshore industry began in the late 19th century. Offshore exploration started in shallow water depth. So many innovations or improvements are happening in the offshore industry, including the discovery of new oil and gas fields in ultradeep water. There has been greater offshore industrial exploration as a result of the depletion of onshore and offshore shallow water reserves. In a while, there are over 12,000 offshore platforms around the world in water depths up to 2450 m. Offshore jacket platforms are the most commonly used production platform worldwide as the concept is proven to be cost-effective at shallow to medium water depths. jacket platform is a framed structure made of tubular steel members called jackets, supported by piles driven into the sea bed with a deck placed on top, providing space for crew quarters, a drilling rig, and production facilities.

During their service life, they are subjected to different type of environmental loadings including wind, waves, earthquakes etc. These loadings may cause unwanted vibrations in the platforms, which may increase fatigue failure and also reduces the performance and productivity of the platforms. The excessive vibration can be reduced by increasing the stiffness, base isolation, or by damping. of the platform can be reduced by increasing the stiffness to shift their natural frequencies away from the resonating frequencies. However, this approach is generally costly requiring excessive construction material. Since the isolation makes the structure oversized and uneconomical and also the base isolation method is not always a practical solution for the vibration control of the jacket platform. An alternative approach is to implement an energy-dissipating mechanism to regulate the structural motion as desired. It includes passive, active, semi-active, and hybrid. Passive control mechanisms do not require external energy but they have an inherent limitation. On the other hand, an active control mechanism can be effective over a wide frequency range with the desired frequency reduction in the dynamic response. Fast response, continuous controlled damping over a wide range, and perhaps low power consumption are features of semi-active control. The semi-active control approach is now of current concern to many researchers and there are several attempts to explore its application to offshore structures.

Magnetorheological elastomer (MRE) is receiving growing attention for vibration reduction in many engineering fields. MRE-based devices may provide a prominent performance of vibration minimization which indicates a significant potential of MRE’s application in vibration control in offshore structures. The working principle of MRE is as follows: after the electromagnetic coil is energized, a uniform magnetic field is generated, and MRE material and magnetic conductor form a closed magnetic circuit. By adjusting the current from an external Direct-current power, the magnetic field strength varies. The modulus of MRE is tunable by varying magnetic field strengths, which determines the controllable stiffness and damping properties. SACS (Structural Analysis Computer System) software is used for modeling and dynamic analysis of the platform. SACS is a collection of integrated finite element structural analysis tools that specifically caters to offshore structure structural analysis and design. This work attempts to study the vibration control of jacket platforms using an MRE damper under the excitation of extreme regular waves. Parametric studies are also conducted to investigate the effectiveness of MRE damper for different wave height.

II. OBJECTIVES

The main objective of the study is to compare the dynamic responses of the steel jacket offshore structure with and without a Magnetorheological elastomeric (MRE) damper under extreme regular waves. And also, to investigate the effectiveness of MRE damper for different wave height.

III. DESCRIPTION OF THE MODEL

The jacket platform considered for the study is a typical four-legged jacket platform with battered legs located in the Mumbai High region at a water depth of 79m. The jacket platform is selected from the published literature [16]. The major deck framing is 9.76 (m) in plan and the legs are battered at one to eight in broadside and end on framing. The jacket subdivides into 3 bays. The Platform consists of two-level deck structures with the Main Deck with a top of steel elevation at (+) 22.88 (m)., and a Cellar Deck with top of steel elevation at (+) 15.25 (m). The geometrical and mechanical specifications of the members are given in the Tables. I to III. A pile-soil interaction (PSI) input file is obtained for the Mumbai High region to include the effect of the pile below mud level. The T-Z and P-Y curves are shown in Fig .2 and 3 respectively.

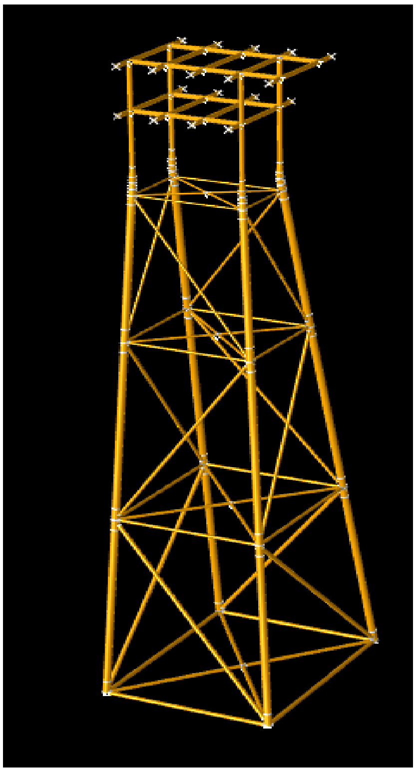

Fig.1 Configuration of the platform (SACS model)

Table. I Dimensions of structural members

Member	Outer diameter (cm)	Wall thickness (cm)
Jacket leg	106.7	3.5
Pile	92.5	2.5
Braces	41-66	1.6-2.5

Table. II Material properties

Density	ρ = 7850 kg/m^3
Young's modulus	E = 2.1$\times$10^{11}Pa
Poisson's ratio	ϑ= 0.3
Thermal expansion coefficient	α= 1.2$\times$10^{-5} / °C
Yield strength	420 MPa

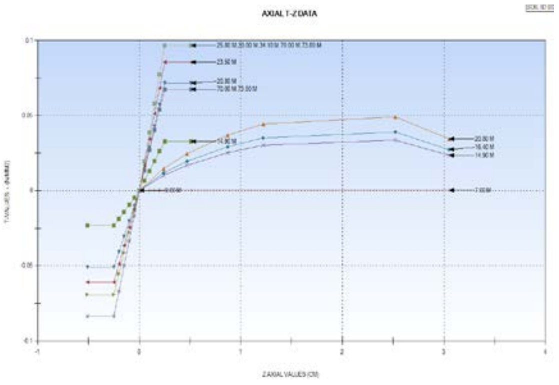

Fig.2 Axial T-Z data

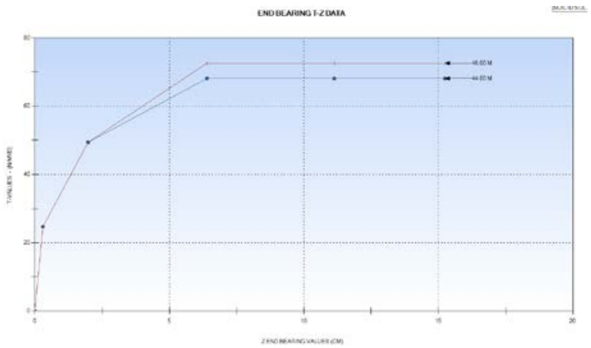

Fig.3 End bearing T-Z data

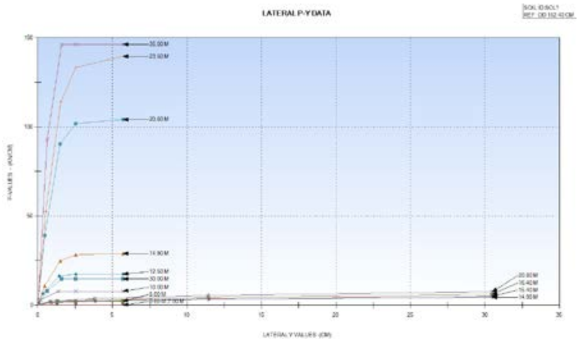

Fig.4 Lateral P-Y data

IV. MODELLING OF JACKET PLATFORM WITH MRE DAMPER

The MRE damper is modeled using dummy members (zero density) with a spring joint to give the effect of the MRE damper. The MRE damper can work with variable stiffness, while the MRF works with variable damping. Since there is no direct provision in SACS to model the MRE damper, the equivalent stiffness of the MRE damper is given to the spring joint. Different position of the MRE damper on jacket platform are tried to obtain the optimum location of the damper. The optimum location of the MRE damper is taken for the configuration with a high reduction in the responses of the platform. MRE damper provided at horizontal brace level give maximum reduction in the responses than MRE damper provided at vertical brace level. Thus, more investigations are done on horizontal brace level. Same values are obtained for dampers at all levels and all levels without damper at lowest brace level; means dampers are not required near seabed. Dampers provided at all horizontal brace levels except at bottom brace level gave minimum responses as depicted in Fig.6 and total number of dampers is 12. Stiffness values of MRE damper are taken from published literature (Dingxin Leng et.al (2021) Ref [5]), and given in Table. III.

Table. III Stiffness value of MRE damper

Current (A)	0	1	2	3
Stiffness (MN/m)	20.2	53.5	83.2	118.8

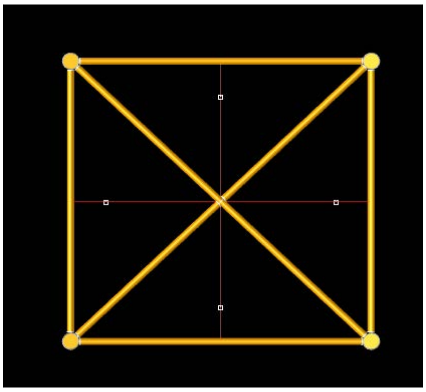

Fig.5 Damper arrangement at horizontal brace level

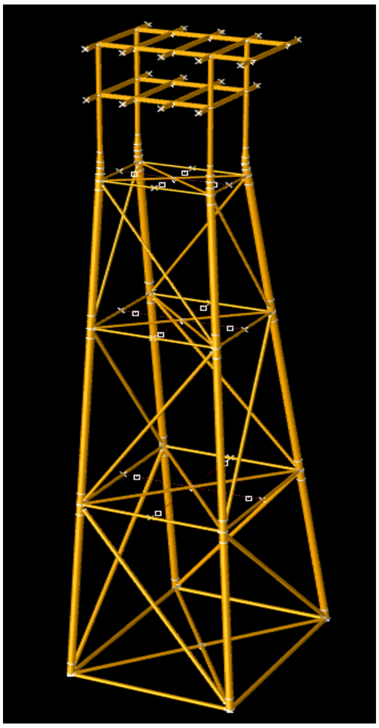

Fig.6 Optimum location of MRE damper in jacket platform

Fig.7 Mumbai High field location.

V. LOADING DATA

The total dead and live load acting on the deck is taken as 2000 tonnes. The environmental data required for the analysis of jacket platform with and without MRE damper is selected from the published literature [12]. The environmental data is for the Mumbai High offshore region. Historically, Mumbai High field Fig.7 has several offshore platforms in the shallow water region of 50m to 80m water depth. Most of these platforms are fixed template type structures with either main or skirt piles. Many of these structures are as old as 20 to 30 years and has been designed as per API-RP-2A guidelines. Effects of current and wind is neglected. For regular waves, a wave height of 12.19m and period of 11s is selected. 5th order stokes theory is used after checking the wave theory validation. The inertia and drag coefficients of the Morison equation (C_M and C_D) were taken as 2.0 and 0.6. For a 4-legged jacket platform, 8 loading directions shall be considered.

VI. RESULTS AND DISCUSSIONS

Dynamic and wave response module of the SACS software is utilized to get the regular wave responses of the 4-legged jacket platform. For the regular waves 8 wave directions are considered, 4 in orthogonal directions i.e., 0, 90, 180, and 270 deg. and 4 in diagonal directions i.e., 45, 135, 225,315 deg. The dynamic analysis of jacket platform without and with MRE damper is carried out for different stiffnesses 20.2, 53.5, 83.2 and 118.8 MN/m corresponding to the current of 0, 1, 2 and 3 A, which is taken from a literature. From dynamic analysis the maximum reduction in the response is obtained for the MRE damper with stiffness 118.8 MN/m. Parametric studies are conducted to investigate the effectiveness of MRE damper with stiffness 118.8 MN/m for different wave height. The wave height is varied from 4 to 10m with the period of 11 sec. The dynamic responses of the jacket platform without and with MRE damper for different stiffness values are tabulated below.

Table. IV Regular wave response of jacket platform for different stiffness for regular wave (H=12.19 (m) and T= 11 (sec))

	Maximum Base shear (kN)	**Maximum Deflection (cm)**	**Maximum Velocity (cm/s)**	**Maximum Acceleration (cm/s^2)**
Without MRE damper	1176.54	4.489	3.664	3.592
With MRE damper				
20.2 (MN/m)	1140.06	2.025	1.569	1.669
% Reduction	3.10	54.89	57.18	53.54
53.5 (MN/m)	1129.45	1.594	1.230	1.356
% Reduction	4.02	64.49	66.43	62.25
83.2 (MN/m)	1122.07	1.479	1.142	1.273
% Reduction	4.63	67.05	68.83	64.56
118.8 (MN/m)	1117.01	1.414	1.091	1.225
% Reduction	5.06	68.50	70.22	65.89

From the results, maximum % reduction of responses is obtained for MRE damper with 118.8 (MN/m) stiffness as expected. Maximum response reduction is obtained when approaches at 135 degrees. For maximum deck deflection the reduction is 68.50 %, for maximum base shear the reduction is 5.06%. In the case of maximum velocity and maximum acceleration the reduction is 70.22 % and 65.89 % respectively. The minimum stiffness value of 20.2 (MN/m) also showed a reduction in the response above of 50 %. Base shear has less % reduction in the response, below 10%.

Table. V Effectiveness of MRE damper with stiffness 118.8 MN/m for different wave height

Wave height (m)		4	6	8	10
Base shear (kN)	Without damper	266.98	430.62	638.42	878.57
	With damper	271.00	420.45	611.45	835.07
	% Reduction	-1.51	2.36	4.22	4.95
Deflection (cm)	Without damper	0.825	1.413	2.167	3.102
	With damper	0.246	0.431	0.673	0.969
	% Reduction	70.18	69.97	68.94	68.76
Velocity	Without damper	0.570	1.039	1.663	2.499

(cm/s)	With damper	0.159	0.291	0.474	0.722
	% Reduction	72.11	71.99	71.49	71.11
Acceleration (cm/s^2)	Without damper	0.415	0.856	1.413	2.252
	With damper	0.125	0.259	0.445	0.730
	% Reduction	69.88	68.78	68.51	67.58

The Table.V shows the variation of responses for with and without MRE damper due to regular waves with respect to wave heights 4 to 10m and period 11sec. As the wave height increases the response reduction effect of MRE damper is marginal for base shear, deflection, velocity and acceleration.

VII. SUMMARY AND CONCLUSION

In this study, the effectiveness of MRE damper in controlling the wave induced vibrations of a 4-legged jacket platform are investigated. For that a typical 4-legged jacket platform in the Mumbai High field of Indian offshore region is selected from a published literature [16]. The analysis is carried out using SACS software and MRE damper is introduced in to the structure using spring joints and dummy members. Since there is no direct provision in the SACS software to model the MRE damper, equivalent stiffness value of MRE damper provided at various horizontal bracing levels is given to the spring joint. By the trial-and-error method, the optimum location of the MRE damper is taken for the configuration with a high reduction in the responses of the platform. The optimum location of the MRE damper is taken at all horizontal brace levels without damper at lowest brace level. Wave response analysis of the 4-legged jacket platform accounting Soil Pile Interaction (PSI) under regular waves is carried out. Parametric studies are also conducted to investigate the effectiveness of MRE damper with stiffness 118.8 (MN/m) under different wave height (4 to 10 m). The obtained responses of the jacket platform for regular waves are as follows,

- For regular waves, by comparing the results of jacket platform with and without MRE damper, the MRE damper is effective in controlling the vibrations of the platform.
- As expected, the % reduction in the responses increases with increases in stiffness of MRE damper and the maximum response reduction is obtained for 118.8 (MN/m).
- There is a reduction of maximum deflection by 68.50%, velocity by 70.22%, acceleration by 65.89 % and finally the base shear by 5.02%.
- The minimum stiffness value 20.2 (MN/m) also showed a considerable reduction in the responses of jacket platform above 50%.
- From parametric studies, as the wave height increases the response reduction effect of MRE damper is marginal for base shear, deflection, velocity and acceleration.

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