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Fixed Offshore Platform Rehabilitation with Friction Damper

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Abstract: *This work presents a study for a fixed offshore platform to show the value of applying friction damper in increasing the lateral resistance under wind, waves and currents. It is considered an extendable work for previous published research which investigated the ability of the rotating friction damper by an experimental test and consequently simulated this damper with a suitable mathematical method through finite element software. Then get good benefit for equipping the friction damper to fixed offshore platforms. Here, a prototype for fixed platform shall be presented and analyzed under environmental loads with and without applying friction damper to the platform, then comparable results were discussed.*

Keywords: *dynamic, environmental loads, friction damper, offshore platform, rehabilitation.*

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I. Introduction

Fixed offshore platforms need mitigation actions due to any modifications occurred through their life time or because a deterioration may affect their integrity. The famous modification examples applied on the platform are inserting additional conductors for increasing oil pulling or constructing extensions to accommodate extra equipment or for access purpose. Because of the ageing of the platform, deterioration is usually happened to the structure members and this may cause loss of its integrity.

However, specific offshore platforms may be sensitive for the above mentioned modifications or deterioration such as conductor support platforms and bridge supports because of their low stiffness and light weight. The conductor support type is consisting of half jacket platform with low topside facilities as shown in Fig. 1. In the complexes stations the platforms are connected together by bridges and usually the flare tip must be far from the complex to satisfy hazard safe distance. Fig. 2 shows bridge support for a flare tip, which usually being lite type structure.

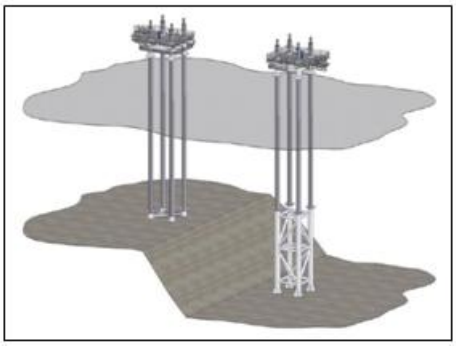

Fig. 1: Conductor support platform

Fig. 2: Bridge support

The incompetence of traditional techniques for increasing the structures lateral resistance, directed the researchers to use the pioneered damping systems technology in 1960s [1]. They have progressively gained recognition as talented method to shield the structures against dynamic loads in addition to their practical and ease implementation [2 to 11]. In this technology, the structure capacity against dynamic loads is raised due to applying devices to it. The structure dynamic resistance depends on its strength and the installed damping devices to scatter dynamic energy. Damping system technology is a smart substitution to improve structural safety and serviceability as it can greatly raise the structure’s efficiency against dynamic loads. When rehabilitating an existing platform, the use of damping systems can save construction cost and reduce materials' weight.

In this study, the rehabilitation that shall be focused on is regarding the platform retrofitting against the environmental loading through a numerical example for a fixed offshore platform prototype. The mitigation method will be described in this study by using friction damping device [12, 13]. This paper presents a full analysis description for a sample of jacket platform installed in 47 meters water depth subjected to wave, current and wind loads. This analysis shall be performed with and without applying friction damper device to illustrate the friction damper ability in increasing platform lateral resistance against environmental loading.

II. Platform Prototype Description

The studied platform is a four legs platform with a cross section 30" in diameter and 0.75" in wall thickness. The jacket part is consisting of six levels at (+) 3.0, (-) 7.0, (-) 17.0, (-) 27.0, (-) 37.0 and (-) 47.0 meter at mudline. Each level has a diamond bracing shape while the jacket legs are braced together by N-bracing system. The vertical bracing member's cross section is 12.75" in diameter and 0.5" in wall thickness while the horizontal bracing is 10.75" in diameter and 0.5" in wall thickness. The distance between jacket legs working points is 12 meters in both directions and the jacket is assumed to be supported by a skirt piles at the mudline elevation. The topside is consisting of helideck, main deck, cellar deck and below cellar deck at elevations (+) 29.0, (+) 23.0, (+) 15.5 and (+) 8.0 meter respectively. The below cellar deck dimensions are 12×6 meters, the main and cellar decks dimensions are 36×23 meters, while Helideck is 12×12 meters. The platform is handling six conductors laterally restrained at cellar deck elevation and three levels at jacket, (+) 3.0, (-) 17.0 and (-) 37.0. While at mudline the conductors are fully restrained. The attached appurtenances to the Jacket are boat landing and two barge bumpers. The platform geometry is illustrated in Fig. 3.

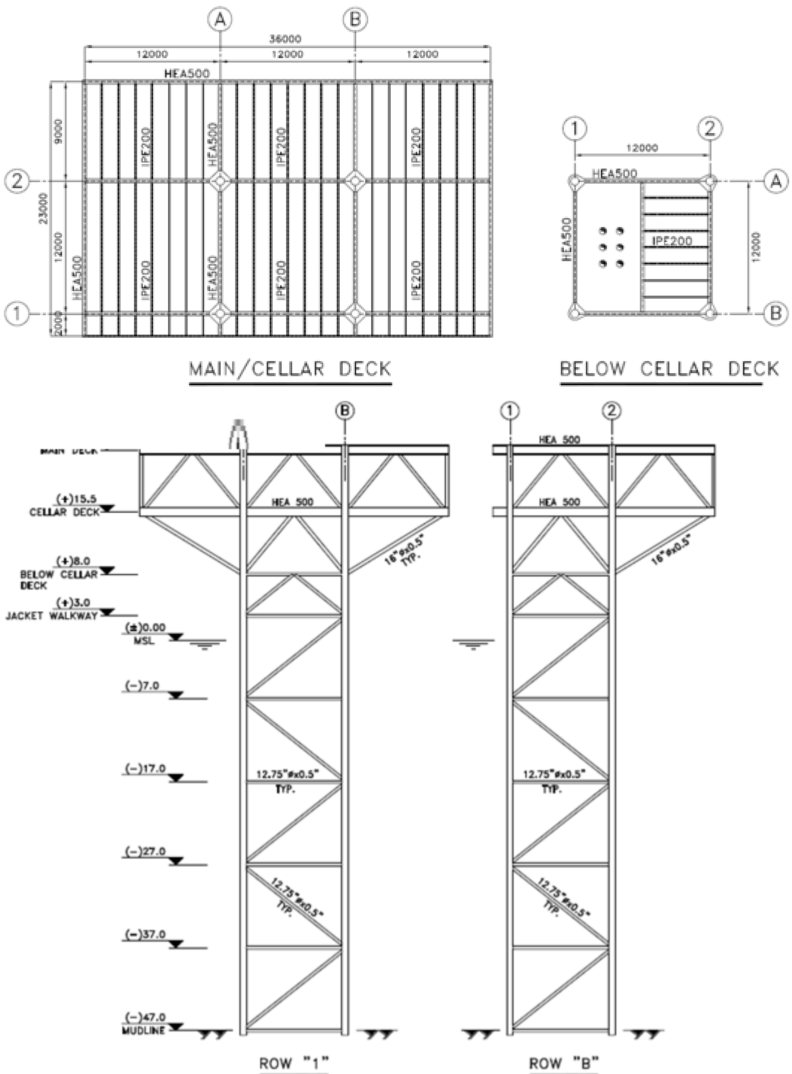

Fig. 3: detailed sketch for the studied platform

III. Environmental data

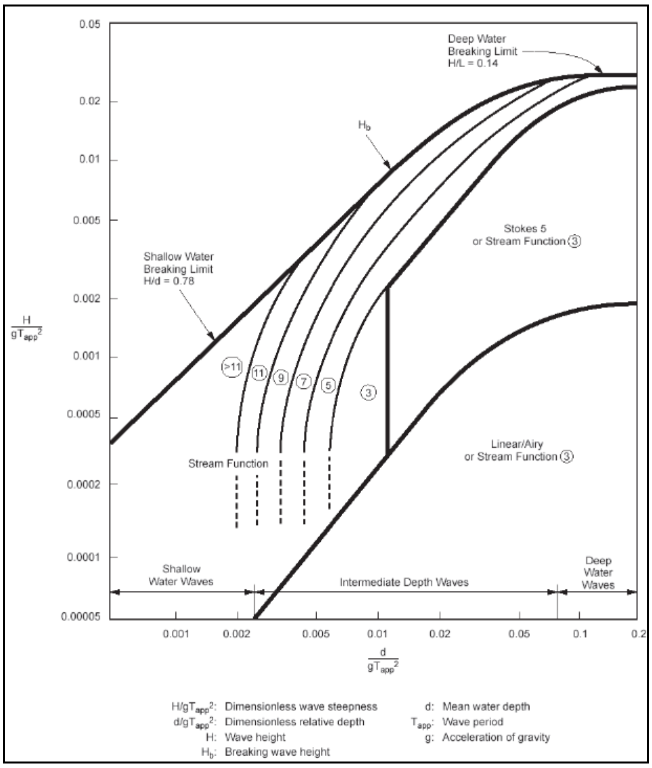

Fig. 4: Regions of wave theories Applicability

Wind forces are applied upon exposed areas of the structure above water level and on any equipment or modules that are located on the topside decks. Generally, wind data was adjusted to 33 ft (10 m) above mean water level as a standard elevation with a specified averaging time equal to 1 hour and the mean wind speed is 30 m/s.

The tidal variations are resulted from the rotational and gravitational interaction between the earth, sun and moon and are regular predictable. The tidal is considered 1.0 meter.

The wind actions are considered the major source of wave forces on the offshore platforms. These waves are irregular in shape and properties and may attack a platform from one or more directions concurrently. Therefore, the determination of the applied wave forces and their distribution is difficult. The specialists of meteorology and oceanography fields and hydrodynamics science are usually consulted to obtain the metocean data of a specific area.

However, wave forces can be calculated based on a chosen wave theory according to obtained metocean data. The wave theory was determined from wave period, wave height and water depth [14]. Fig. 4 shows the regions of wave theory applicability regarding the wave properties. In order to consider the wave directional spreading and irregularity, a wave kinematic factor is chosen from range 0.85 to 1.00 [14]. The considered wave height, wave period and water depth are 10.5 meter, 6 seconds and 49 meter respectively.

Currents are being considered as a steady flow field and the velocity is only the varying parameter with depth. The variation of current directions and speeds through the water depth can be determined for the field area of the platform according to the metocean data. The current speed through and around the platform should be modified by a blockage factor because the platform presence causes divergence to the current flow. The blockage factor depends on the platform type and hitting direction. As much as the platform jacket members are dense the blockage will be larger and vice versa. The API-RP-2A [14] provides approximate values for the current blockage factor for the famous platform types and it was used in this prototype. Table 1 gives a supposed current speed profile with water depth and the current blockage factors shall be considered to the platform according to API-RP-2A. Marine growth upsurges the structure mass and consequently influences the platform dynamic response. Establishing marine growth thickness can be obtained by site specific studies. Marine growth thickness is varying with depth and cause increase for the drag coefficient due to the increase of jacket member's dimensions and roughness. The marine growth profile was considered in this application is shown in Table 2.

Table 1. Current speed profile

Distance from surface (m)	0.0	-2.35	-4.7	-7.05	-9.4	-18.8	-23.5	-28.2	-32.9
Current speed (m/s)	1.1	1.1	1.09	1.05	1.02	0.95	0.90	0.80	0.75

Table 2. Marine Growth Profile

Increase of radius	Marine Growth Distribution
75 mm	From El. (±) 0.00 m to El. (-) 5.00 m
50 mm	From El. (-) 5.00 m to El. (-) 10.00 m
40 mm	From El. (-) 10.00 m to Mudline

IV. Computer model

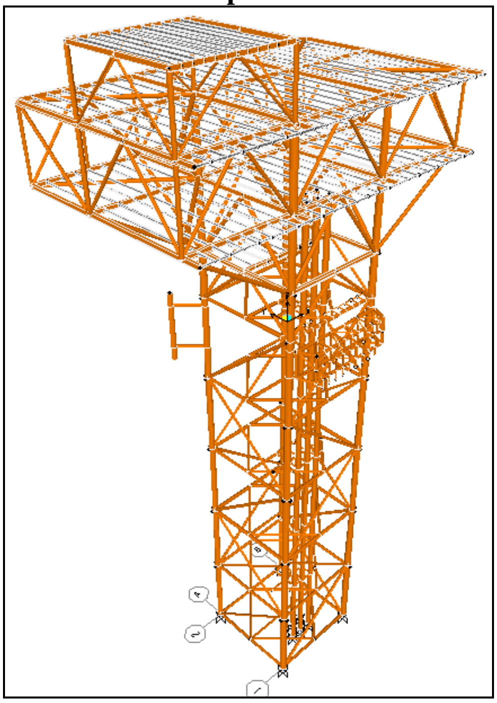

Fig. 5: platform 3D model

A 3D model using SAP2000 software is utilized to simulate the platform including jacket and deck for performing In-place analysis under environmental loads. All members were modeled as 3D frame elements that are rigidly connected to each other. Proper releases were applied to members connected with conductors to consider the laterally restraining condition. Deck plating was modeled as plate elements to simulate its participation in the lateral stability. Jacket appurtenances; boat landing, barge bumpers and conductors were included in the structural model. This is to consider their associated loads (weight, buoyancy and environmental loads) to the jacket members. However their participation in the stiffness of the structure was eliminated by proper releases. The coordinate system is the right hand Cartesian system with the origin at the center of the deck legs and lies at the MSL elevation, with (+)ve Z-axis vertically upward. The model isometric is shown in Fig. 5.

4.1 Hydrodynamics

The provisions and requirements of API-RP-2A [14] are applied in the computer model. A rough type marine growth is supposed in the analysis regarding to the profile described previously in section 5.0. The density of the marine growth is input as 1300 kg/m^3. This approach is derived by the fact that SAP2000 considers marine growth as part of the structural weight, thus the application of a contingency on the structural weight will affect marine growth weight as well. Drag and inertia coefficients for tubular members are taken for the smooth surface as Cd = 0.65, Cm = 1.60 while for the rough surface are taken as Cd = 1.05, Cm = 1.20.

4.2 Structure material and loading

Properties of the structural steel were taken as presented in Table 3. All gravity loads on the topside including dead, equipment and live loads are to be applied as blanket loads. The load intensity at each elevation is summarized in Table 4.

Table 3. Steel Material Properties

Property	Value
Density	7.85 t/m3
Young's Modulus	200000 N/mm2
Shear Modulus	77200 N/mm2
Poisson's Ratio	0.30
Coefficient of Thermal Expansion	0.000117/ °C
Material Yield Strength	2.40 t/cm2

Table 4. Gravity loads on topside decks

Deck	Blanket load (kg/m2)
Below cellar deck	500
Cellar deck	800
Main deck	800
Helideck	100

The environmental loading is considered to be as the follows: wind, wave and current are assumed to act concurrently in the same direction and eight loading directions were considered as shown in Fig. 6. Two end-on directions 0° & 180°. Two broadside directions 90° & 270°. Four perpendicular to jacket diagonal directions 45°, 135°, 225° &315°.

Wave and current loads shall be calculated regarding to the directional wave parameters, wave height and wave period, were considered as presented in clause 4. Two-dimensional wave kinematics was determined from the stoke-5 wave theory for the specified wave height, wave period and water depth. Wave Kinematics factor was taken equal to 0.90 and an Omni directional current profile was considered as presented in Table 1. Current blockage factors were taken to be 0.8 for end-on or broadside directions, and 0.85 for diagonal directions. Increase in forces on the structure because of its dynamic response to the environmental loading was accounted for by applying the appropriate DAF on wave basic load cases based on the results of the platform dynamic properties. The procedure considered for the dynamic analysis as well as the DAF calculations are presented in clause 5.4 of this paper. The wind loads were taken also in Omni directional one hour wind speed. Fig. 7 shows the generated environmental loads by the software analysis program regarding the above presented parameters and wave theory.

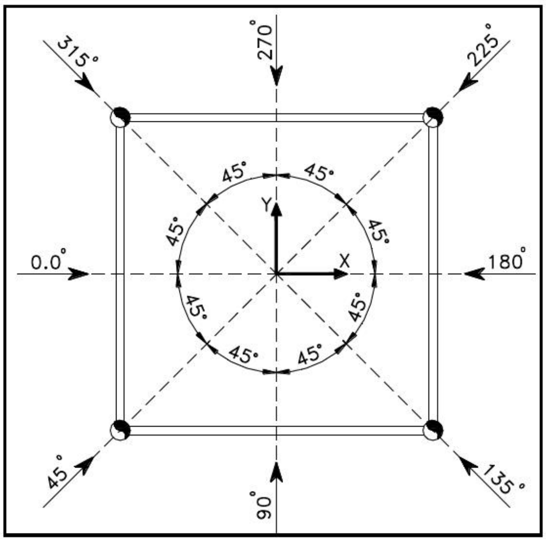

Fig. 6: Environmental loading directions

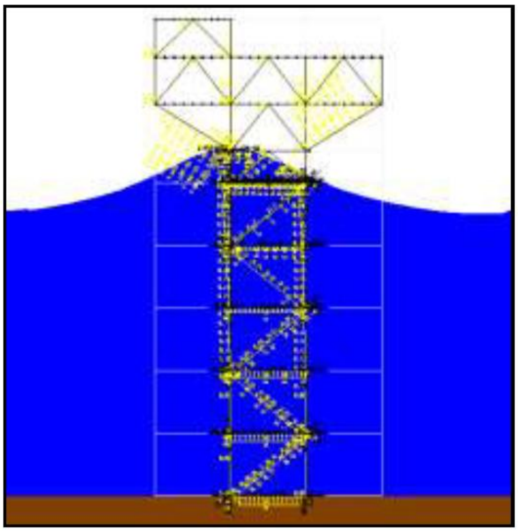

Fig. 7: environmental loads generated by analysis software

4.3 Platform dynamic properties and DAF calculation

Increase in forces on the structure because of its dynamic response to the environmental loading was accounted for, by applying the appropriate DAF on wave basic load cases based on the dynamic analysis results. The procedure considered for the dynamic analysis as well as the DAF calculations are presented hereafter.

In order to obtain the dynamic characteristics of the platform, a modal analysis was performed using SAP2000 package to extract mode periods and mode shapes. The first ten mode shapes are extracted in order to be considered in simulating the dynamic responses of the platform. Masses were simulated from modeled members and applied gravity loads.

Dynamic amplification factor (DAF) was applied to wave loads for each case. It was calculated using the following approximate formula [15]:

$$\mathrm{DAF} = \frac{1}{\sqrt{\left(\left[1-\frac{T_p^2}{T_n^2}\right]^2 + 4\left[\in \frac{T_p}{T_n}\right]^2\right)}}$$

Where,
T_p : Platform natural period
T_n : Wave period
$\in$: Structural damping coefficient (taken as 5%)

DAF calculations considered the larger natural periods for the first two cantilever modes of the platform under the respective loading conditions.

4.4 Basic load cases

The basic load cases considered in the In-place analysis are as detailed in Table 5.

Table 5. Basic load cases

Load type	Load case	Description
Gravity load	global	- Structure modeled and non-modeled items including the Equipment, Piping, Cable trays and Live loads.
Environmental load	W-000	Wind, wave and current loads in direction 0o
	W-045	Wind, wave and current loads in direction 45o
	W-090	Wind, wave and current loads in direction 90o
	W-135	Wind, wave and current loads in direction 135o
	W-180	Wind, wave and current loads in direction 180o
	W-225	Wind, wave and current loads in direction 225o
	W-270	Wind, wave and current loads in direction 270o
	W-315	Wind, wave and current loads in direction 315o

4.5 Modal analysis

Modal analysis was performed considering the gravity loads to get the platform dynamic characteristics and mode shapes. The objective from this analysis was to calculate the dynamic amplification factor (DAF) to structure dynamic represent with the wave loads. The first three modes are representing the global platform dynamic characteristics. Table 6 is presenting the platform time periods and frequencies.

Table 6. Platform dynamic characteristics

Mode	Period (sec.)	Frequency (Hz)	direction
1	3.18	0.314	X
2	3.08	0.325	Y
3	2.41	0.415	rotation

The first two modes are cantilever modes and considered the main modes affecting the structure dynamic response with wave loading. Hence, the time period 3.18 seconds shall be used in DAF calculation. The DAF calculation is as below:

$$\mathrm{DAF} = \frac{1}{\sqrt{\left(\left[1-\frac{3.18^2}{6^2}\right]^2 + 4\left[0.05\,\frac{3.18}{6}\right]^2\right)}} = 1.39$$

Therefore, this value shall be multiplied to each environmental load case.

4.6 Load combinations

The combined load cases considered in the In-place analysis are as detailed in Table 7.

Table 7. Load combinations description and factors

Load comb.	Load cases								
	Dead	W_000	W_045	W_090	W_135	W_180	W_225	W_270	W_315
Storm_0	1.0	1.39	-	-	-	-	-	-	-
Storm_45	1.0	-	1.39	-	-	-	-	-	-
Storm_90	1.0	-	-	1.39	-	-	-	-	-

Load comb.	Load cases								
	Dead	W_000	W_045	W_090	W_135	W_180	W_225	W_270	W_315
Storm_135	1.0	-	-	-	1.39		-	-	-
Storm_180	1.0	-	-	-	-	1.39	-	-	-
Storm_225	1.0	-	-	-	-	-	1.39	-	-
Storm_270	1.0	-	-	-	-	-	-	1.39	-
Storm_315	1.0	-	-	-	-	-	-	-	1.39

V. Applying the FDD to the jacket platform

The platform shall be strengthened by applying the FDD. The FDD is provided as shown in Fig. 8 with a distribution through the platform in the analyzed computer model as shown in Fig. 9. The properties of the FDD were chosen to have 80 kN yielding force and 40mm displacement demand. The hysteresis relation of the chosen damper is illustrated in Fig. 10 and because the analysis shall be performed linearly, the FDD was defined in the computer model by a bilinear model, the details of FDD equipping modeling and analysis are explained by Dawood [13,16].

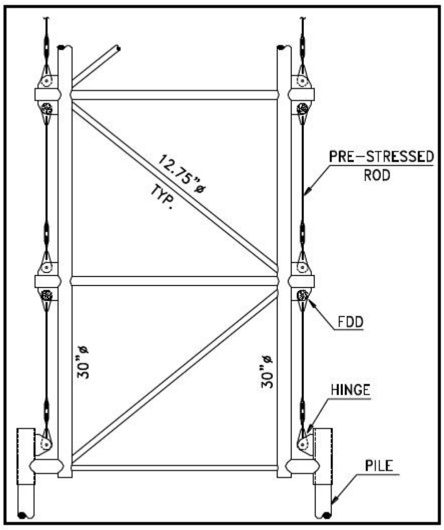

Fig. 8: Friction damper fixation

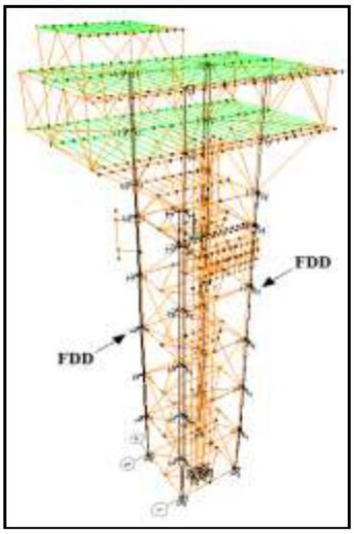

Fig. 9: Friction damper distribution

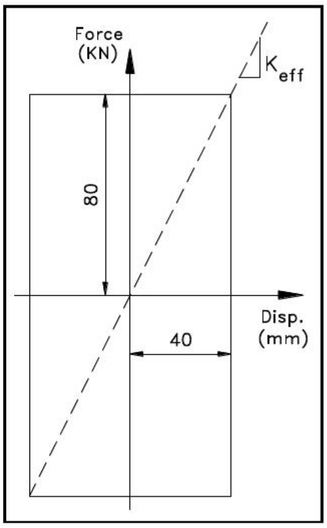

Fig. 10: Chosen friction damper bilinear model

The following is the calculated properties for the defined FDD:

$$K_{\text{eff}} = \frac{80}{40} = 2.0 \text{ kN/mm}$$

$$E_D = 160 \times 80 = 12800 \text{ kN.mm}$$

$$\beta_{\text{eff}} = \frac{12800}{2\pi \times 2 \times 40^2} = 0.6366$$

5.1 Modified dynamic properties

The modal analysis was re-analyzed to the modified platform considering the same gravity loads and then the platform dynamic characteristics and mode shapes were obtained. Table 8 is presenting the platform modified time periods and frequencies.

Table 8. Platform modified dynamic characteristics

Mode	Period (sec.)	Frequency (Hz)	direction
1	1.989	0.503	rotation
2	1.725	0.580	X
3	1.683	0.594	Y

The dynamic amplification factor (DAF) re-calculated and was found to be 1.09 as presented below. This shall reduce the wave forces around 21%.

$$\text{DAF} = \frac{1}{\sqrt{\left(\left[1-\frac{1.725^2}{6^2}\right]^2 + 4\left[0.05\,\frac{1.725}{6}\right]^2\right)}} = 1.09$$

5.2 In-place analysis comparison results and conclusion

The execution for in-place analysis is performed for both models, without damper and with damper, under the previously mentioned loading. A comparison is presented to show the FDD ability to increase the jacket platform lateral resistance against the environmental loading. Tables 9, 10 and 11 present comparable values for lateral displacements, base shear and axial pile reactions respectively.

Table 9. Lateral displacement

Location	Without FDD		With FDD		Reduction Ratio	
	X (mm)	Y (mm)	X (mm)	Y (mm)	X	Y
EL(-) 27.0	268.9	255.8	95.8	60.8	64 %	76 %
EL(-) 7.0	217.9	205.2	79.7	57.7	63 %	72 %
EL(+) 8.0	155.6	145.1	58.7	45.7	62 %	68 %
EL(-) 23.0	63.8	59.4	24.7	21.5	61 %	64 %

Table 10. Base Shear

Comb.	Without FDD (tonne)	With FDD (tonne)	Reduction Ratio
Storm_0	602.0	214.0	64 %
Storm_45	550.0	166.0	70 %
Storm_90	589.0	133.0	77 %
Storm_135	268.0	40.0	85 %
Storm_180	252.0	73.0	71 %
Storm_225	172.0	85.0	51 %
Storm_270	313.0	132.0	58 %
Storm_315	479.0	198.0	59 %

Table 11. Piles axial reaction

Comb.	Without FDD (tonne)		With FDD (tonne)		Reduction Ratio	
	Comp.	Tension	Comp.	Tension	Comp.	Tension
Storm_0	1400	1174	481	228	65 %	80 %
Storm_45	1655	1407	532	259	68 %	81 %
Storm_90	1401	1151	438	163	69 %	86 %
Storm_135	1224	953	404	111	67 %	88 %
Storm_180	1045	756	380	76	64 %	90 %
Storm_225	558	254	247	----	56 %	----
Storm_270	591	322	228	----	61 %	-----
Storm_315	1139	905	388	112	67 %	88 %

The above results show that the FDD can achieve significant effect in platform lateral resistance.

VI. Conclusions

As mentioned previously, some types of the offshore jacket platforms are dynamically sensitive and need mitigations through their life time due to future modifications or members deterioration. FDD ability in controlling the platform lateral resistance was presented in this research and the below points can be concluded:

- Energy dissipation devices are smart solution to control dynamic loads.
- Friction damper device (FDD) is very efficient device to dissipate the dynamic energy.
- The FDD is a good idea to be applied in the fixed offshore platforms and control their dynamic characteristics.

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