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IJIE

http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International
Journal of
Integrated
Engineering

A Numerical Study of Brace-Viscous Damper System of Fixed Offshore Jacket Platforms Under Extreme Environmental Loads

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DOI: https://doi.org/10.30880/ijie.2023.15.02.027
Received 11 January 2023; Accepted 01 May 2023; Available online 13 September 2023

Abstract: The Persian Gulf is one of the most common regions where offshore platforms exist due to the presence of oil and natural gas. Wind, current, and wave loading affect the dynamic response of offshore structures, increasing performance uncertainty and catastrophic failure probability. Thus, this study investigates energy dissipation systems, particularly viscous dampers, to solve design and rehabilitation problems of fixed offshore structures. Viscos dampers improve vibrational behaviour and reduce structural response to optimise platform performance. Thus, eliminating costly structural repairs and strengthening components under extreme environmental loads extends structure lifetime. Thus, different viscous damper system configurations are tested to reduce dynamic response under extreme environmental loads in the Persian Gulf. Diagonal and inverted V-shaped brace viscous dampers with nine different arrangements are compared to find the best configuration. The study found that the brace viscous dampers with only three applied dampers at the top three levels are most efficient at mitigating dynamic response. It reduced displacements from level 1 to level 5 by 52% to 64% and connection stresses by 38% to 54%. Finally, viscous dampers reduce structural vibration and provide uniform and constant structural dynamic response, so the oil and gas industry should use them for offshore structure design and rehabilitation.

Keywords: Offshore structure, viscous dampers, wind loads, Persian Gulf, Rassalat platform

1. Introduction

Steel is the primary material used in the construction of the offshore structure, which is comprised primarily of platforms for installing machinery related to oil or natural gas. The fixed offshore jacket platform is the type of offshore platform that is used the most frequently [1]. All varieties of jacket platforms are subject to severe environmental loads brought on by natural occurrences such as current, wave, wind, and earth movement. Seismic and ice loads may also be present in certain oceanic regions [2]. The continuously repeated forces that occur daily on offshore platforms several times lead to a greater dynamic response under stronger environmental loads, producing higher levels of uncertainty regarding the performance of the platforms and the probability of catastrophic failure [3]. In addition, failure due to fatigue will occur as a result of the transferred energy from the aforementioned loads causing various modes of vibrations and resulting stress concentrations. These stress concentrations have the potential to compromise the capacity of structures to withstand overload. The Persian Gulf water is one of the most common regions where the design experiences of fixed offshore platforms show that the Persian Gulf water had many marine structures that

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**Corresponding author: scchin@ump.edu.my* appeared to be overdesigned and unsafe due to the lack of information regarding wave, wind, and some other environmental characteristics during design. This is because the Persian Gulf water is one of the most common regions where fixed offshore platforms are located. In situations where the safe and cost-effective design of offshore platforms is highly dependent, to a large extent, on the accurate assessment of response demands [4], [5].

It is necessary to increase the stiffness of the structures in offshore platforms in order to reduce the amount of vibration caused by these platforms. The nonlinear behaviour of jacket platforms is dependent on the configuration of bracing systems, and it has been demonstrated that bracing systems that are effectively designed and arranged have a significant impact on the structures in terms of their strength and ductility. The latter two solutions, however, call for additional building materials, which drives up the cost of the project. Because of this, the construction industry has taken to installing energy dissipation systems (EDS) in offshore jacket platforms. Examples of these EDS include viscoelastic, viscous, and friction dampers. These dampers work to reduce the dynamic response of offshore platforms. In addition, an energy dissipation system, also known as an EDS, might be an efficient way to eliminate expensive structural repair operations and strengthen components when they are subjected to loads from the ocean [5], [6].

In recent years, a significant number of researchers have been looking into the significance of various kinds of control mechanisms. In a separate piece of research, the authors [7] compared the performance of a jacket platform with and without viscous dampers and looked into the various conventional configurations of dampers to determine which one provided the best results. The researchers Vaezi et al. [6] investigated the effect of three types of different configurations of brace-viscous damper systems (chevron, toggle, and diagonal) in the mitigation of offshore structure response. They demonstrated that designing the proper arrangement of dampers could change the effectiveness of the dampers. Janbazi Rokni & Tabeshpour [8] found that optimising the configuration of the dampers plays a significant part in extending the fatigue life of the component and lowering the amount of damage it sustains.

In spite of the fact that a number of recent studies have been conducted on energy dissipation systems, there has not been an assessment performed on the Persian Gulf region's offshore jacket platforms to determine how well they hold up under the combined effects of wind and wave loads. In addition to this, there has been no research conducted that analyses the dynamic response of an offshore structure that is fitted with viscous dampers in terms of displacements, vibrations, and stresses. As a result, the purpose of this research is to carry out an investigation with the objective of better controlling the response of fixed offshore jacket platforms to environmental loads by enhancing the bracing system that is equipped with viscous dampers. This study's primary objective was to evaluate the performance of several distinct configurations of viscous dampers that had been installed on the jacket platform of the Rassalat offshore structure located in the Persian Gulf. A comparison will be made between the dynamic response of the offshore jacket platform with and without viscous dampers, as well as the effectiveness of various configurations of viscous dampers on the vibration, stresses, and displacements of each level of the structure.

In this study, Persian Gulf Water was selected because it is one of the most populated areas with offshore structures. This selection was made because recent studies of the region provided the foundation for the relevant data, which includes information on extreme environmental loads and the characteristics of the water. Abaqus software was used to analyse a 2D model of the Rassalat offshore jacket platform using the finite element method and verify the validity of the simulation work by comparing that with related previous works. The modelling and simulation work is the primary method of this study.

1.1 Viscous Damper System

The previous studies have provided useful information regarding the application of passive control devices to regulate the dynamic response. Some examples of these devices include viscous dampers. As a result of this, the viscous damper system has been chosen for the purpose of evaluating the efficacy of various viscous damper arrangements in terms of improving fatigue life and reducing the stresses on offshore members. Because of their ability to reduce displacement, acceleration, and story drifts, which ultimately results in less stress being placed on the structure members, viscous dampers are the type of energy dissipaters that are recommended for use in offshore structures rather than any of the other types. In addition to this, viscous dampers are typically very simple in terms of installation, operation, and monitoring in comparison to other types of devices. The lifespan of the damper is extended thanks to the unique characteristics of this system, such as the internal fluid reservoirs. Finally, the installation of viscous dampers within a structure can frequently be a cost-effective solution to a preventive maintenance strategy for the long term [8]. The viscous damper's specifics are depicted in Fig. 1. Nevertheless, a damping coefficient of 50 MN s/m is taken into consideration for each and every damper in this investigation. The shapes of the applied brace-viscous dampers are V-shapes that have been inverted as well as diagonal shapes. The effectiveness of the various configurations of these dampers is evaluated by adding these two common shapes to the structure in a variety of shapes and arrangements.

2. Methodology

The description of the research methodology, analysis approaches, type of work, designs, and other related processes are explained in this section of the paper.

2.1 Rassalat Jacket Platforms

The research is being carried out on the Rassalat jacket platform, which can be found in the Persian Gulf approximately 80 km to the south of Lavan Island. The Rassalat jacket structure is comprised of four legs, each of which is installed in water that is approximately 67 m deep. This structure is connected to the production platform by means of an existing bridge. The offshore structure includes a flare tripod, as well as a drilling platform, a service platform, and a production platform. In addition, there is a flare tripod. In addition, the platform is anticipated to have a service life of 25 years. The steel material used in the construction of the jacket structure has a modulus of elasticity of 2.1 x 1011 N/m^2 and yield stress of 3.55 x 108 N/m^2 [9]. The height of the jacket structure is 70,104 m. Fig. 2 and Table 1 show, respectively, the steel bar sizes that were taken into consideration for the Rassalat jacket structure, and its respective material properties.

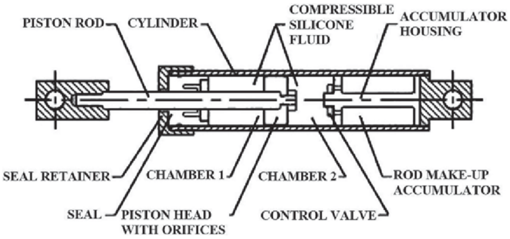

Fig. 1 - Viscous damper details [5]

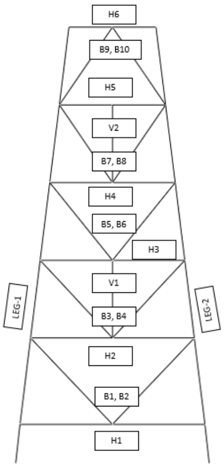

Fig. 2 - Reference of structural elements for the considered specifications of the Rassalat platform structure [9]

Table 1 - Summary of steel bar sizes of Rassalat jacket platform [9], [10]

Element	Cross-Section Drawing (Inch)	Cross-Section Drawing (m)
Leg Size	39 "Dia x 0.500"	0.9906x 0.0127
Joint Can	40 "Dia x 0.500"	1.016x0.0127
H1	24 "dia x 0.375	0.6096x 0.009525
H2	20 "dia x 0.375	0.508x 0.009525
H3	16 "dia x 0.375	0.4064x 0.009525
H4	16 "dia x 0.375	0.4064x 0.009525
H5	12.75 "dia x 0.375	0.32385x 0.009525
H6	16 "dia x 0.375	0.4064x 0.009525
B1, B2	20 "dia x 0.375	0.508x 0.009525
B3, B4	18 "dia x 0.375	0.4572x 0.009525
V1	10.75 "dia x 0.365	0.27305x 0.009271
B5, B6	16 "dia x 0.375	0.4064x 0.009525
B7	16 "dia x 0.375	0.4064x 0.009525
B8	16 "dia x 0.375	0.4064x 0.009525
V2	12.75 "dia x 0.365	0.32385x 0.009271
B9, B10	16 "dia x 0.375	0.4064x 0.009525

2.2 Environmental Loads

In general, all marine structures, including offshore platforms, are highly dependent on external forces and environmental loads such as current and sea surface waves in order to have a precise prediction of the dynamic behaviour of an offshore platform jacket. These loads can be caused by natural phenomena such as volcanoes, earthquakes, and volcanic eruptions. As a result, it is absolutely necessary to identify all the important sources of environmental loads and external forces. In this study, the Rassalat jacket structure is examined to determine how it reacts when subjected to the severe environmental loads that are present in the Persian Gulf region. These loads include current, wind, and wave loads. The properties of the water in the region, which will be used to define the current load in the analysis, include the following: a water density of 1025.0 kg/m^3, a gravity constant of 9.81 m/s^2, a water depth of 67 m, a water velocity at the bottom of the structure of 0 m/s, and a water velocity at the sea level of 1.28 m/s. The investigation conducted by Kamranzad [11] of the Persian region will serve as the basis for the classification and wind characteristics that will be used for the wind load. The wind is produced at the highest point of the structure, which is 67 m in height, at a speed of 5.5 m/s and an air density of 1.255 kg/m^3.

For the purpose of determining the wave load, the linear wave theory, also known as the Airy wave, is utilised. In comparison to other hypotheses, this wave theory is the most straightforward and fruitful one. The Airy wave theory can only be applied in situations in which the wave height, H, is relatively low in comparison to both the wavelength and the water depth. This circumstance makes it possible to linearize the free surface boundary condition. To apply the Airy wave theory, it is necessary to assume that the water is both incompressible and homogeneous, and the wavelength, L, must be at least three metres in length. In addition to this, it is presumed that the water flow is irrotational, which means that there is no shear stress present anywhere. The wave parameters are chosen based on the structure of the region surrounding the Rassalat Platform, which is located in the Persian Gulf and is approximately 80 km away from Lavan Island. The study makes use of a variety of wave parameters, all of which are detailed below in Table 2.

Table 2 - Wave parameters used in the study [5], [10]

Parameter	Value
Jacket height	70.104 m
Wate depth, d	67 m
Wave height, H	5.83 m
Wave Return Period, Tp	7.10 s
Drag coefficient, Cd	0.7
Interia coefficient, Cm	2
Wavelength, L	78.8 m

2.3 Viscous Dampers Properties

Piston steel rods are used to construct the damper, and each rod's head features a hole. The cylinders are then stuffed with a thick, viscous liquid similar to silicone gel. When the damper is subjected to a compressive force, the fluid that is contained within the cylinders is almost incapable of being compressed, and the volume that is contained within the cylinders decreases as a result of the movement of the piston rod area. Because of the fluid orifice, the energy that is generated when the piston moves through the fluid is dissipated, and this makes it possible for the fluid to escape the cylinder when the force of compression is applied. When fluid volume is decreased, a restorative force is produced as a result. The viscous dampers are broken down into their component parts and displayed in Fig. 1. Nevertheless, a damping coefficient of 50 MN. s/m is taken into consideration for each and every damper in this investigation. The diagonal shape and the inverted V-shape are both utilised for brace-viscous damper applications. In order to determine how effective, the various configurations of these dampers are, these two common shapes are added to the structure in a variety of different shapes and arrangements. Fig. 1 provides additional information regarding the viscous dampers.

2.4 Finite Element Modelling

The software package Abaqus/CAE 2021 is utilised in the process of performing a finite element analysis (FEA) on the Rassalat jacket platform. The Abaqus software can be utilised in the following three primary processes: pre-processing, which entails modelling work; processing, which includes simulation and evaluation; and post-processing (visualization). For the purpose of the analysis, Abaqus/CAE offers either Abaqus/Standard or Abaqus/Explicit. A straightforward finite element model can be solved with Abaqus/Standard by making use of an implicit integration scheme, whereas an intricate finite element model can be solved with Abaqus/Explicit by making use of an explicit integration scheme. All three of the procedures described above can be carried out in Abaqus/CAE within their respective modules. Nevertheless, each module defines a logical part of the modelling process. These parts include the part, the property, the assembly, the step, the interaction, the load, the mesh, the optimization, the job, the visualisation, and the sketch. The user builds the finite element model, and Abaqus/CAE creates an input file that the user then submits to the Abaqus/Standard or Abaqus/Explicit analysis product when it is desired to carry a finite element model from one module to another. After all is said and done, the analysis will submit the job so that the progress can be monitored and will write the results to an output database. These results can then be viewed in the Abaqus/CAE Visualization module [12].

3. Results and Discussion

In order to accomplish the goals of the research project, it is necessary to validate the structure models in order to check and make sure that the Abaqus software is applied correctly and without flaws. In order to validate the definition of the environmental loads and the structural analysis, two examples of a riser and a single circular wind turbine are used. As a consequence of this, the top-level displacement of the Rassalat jacket platform has been analysed both without and with a variety of different types and arrangements of viscous dampers in order to select the best possible case for the arrangement of the viscous dampers. The displacements, stresses, and vibrations of all levels of the Rassalat jacket platform have been analysed and compared with the case of the original structure (which did not include viscous dampers) in order to determine how effective, it would be to add viscous dampers to the structure of the jacket. This evaluation was conducted on the basis of the optimum case.

3.1 Validation of Environmental Loads

The model keywords function has to be used for the application of the current, wave, and wind loading in Abaqus/Standard. Based on the SIMULIA Abaqus 6.14 Online Documentation (User Manual) and Example Problems Guide, the definition of the loads was validated. An illustration of a riser that begins at the ocean floor and continues all the way up to the surface of the water, where it is subjected to a variety of loads such as those caused by waves and currents. The standard established by the American Petroleum Institute (API) is used to evaluate and compare the given example to the same conditions that it specifies. On the other hand, Morison's equation is utilised with the following parameters: a coefficient of tangential drag of CT 0.0, a coefficient of transverse inertia of Cm 1.5, and a drag coefficient of Cd 0.7. Both the static step and the dynamic step are utilised in the analysis that is carried out. The outcomes of the demonstration run on Abaqus software have a high degree of congruence with the outcomes of the API standard. These two references, API BULLETIN 2J (1977) and SIMULIA Abaqus 6.14 Online Documentation contain additional information about the example and can be consulted for further details if desired. Nevertheless, the results of this demonstration demonstrated that the model keyword function of the Abaqus software can be used to define current, wave, and wind loads [12].

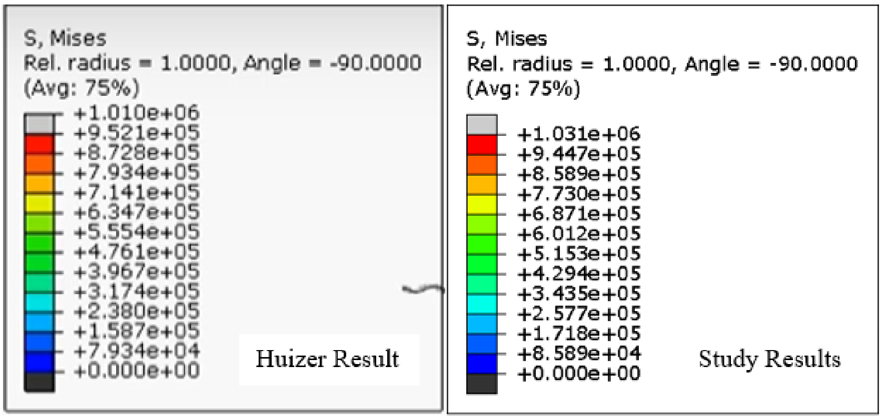

Fig. 3 - The extracted stresses results of the circular beam example provided by Huizer [17] and validation

The keywords AQUA, WAVE=AIRY, and WIND are used to define the current load, the wave load, and the wind load, respectively [13]- [16]. A vertical circular beam with a diameter of 0.2 m and a length of 60 m is simulated and compared with the example that was provided by Huizer [17]. This is done to ensure that the definition of the environmental loads is done correctly in accordance with the instructions provided in the Abaqus user guide.

The validation work has a strong agreement, as shown by the extracted stress results of the circular beam example by Huizer [17] and the validation results of this study, which show that the validation work was carried out. Note that there is a negligible difference between the results, which amounts to about 2%, and that this difference may be attributed to the different element mesh used in each analysis. Fig. 3 shows the result comparison of Huizer [17] and research validation. Overall, based on what was covered in the prior conversation, it is appropriate to make use of the Abaqus software to perform an analysis of the Rassalat jacket while it is subjected to severe environmental loads.

3.2 Selection of The Optimum Brace-Viscous Damper Configuration

There are other factors besides the damping coefficient and the total number of viscous dampers that contribute to the effectiveness of the damping system. It is more important to pay attention to the location where the viscous dampers are applied. However, in order to demonstrate that and select the optimal number and configuration of the viscous dampers, it will first be necessary to compare 9 distinct cases of different viscous dampers configurations. In the course of this research, the diagonal shape and the inverted V-shape, both of which are typical for viscous dampers, were chosen. Both of these shapes have a damping coefficient of 50 MN. s/m, as can be seen in Fig. 4. Therefore, in order to choose the most advantageous scenario, the top-level displacements of the Rassalat jacket structure are calculated for each of the possible outcomes and compared to the jacket's initial configuration (without viscous dampers).

According to Table 3, Case 6 offers the greatest reduction in displacement when compared to the other diagonal cases. This case utilises three diagonal viscous dampers that are applied to the fourth, fifth, and sixth levels, respectively (Case 1 to Case 6). In addition, with regard to inverted V-shape dampers, Case 7 exhibits the greatest reduction in top-level displacement. According to the information presented in Table 3, Cases 1, 3, and 5 each contain two diagonal dampers in the jacket structure. These dampers contributed to a 16%, 25%, and 37% decrease in the maximum displacements, respectively. In addition to this, Case 2, Case 4, and Case 6 each have three dampers that have been applied to the structure of the jacket. These dampers reduce the maximum displacements of the top level by approximately 26%, 39%, and 52% respectively. Because of this, it is easy to see that the amount of displacement that is reduced varies from one scenario to the next, despite the fact that the total number of dampers remains the same. In a similar manner, Case 8 and Case 9, both of which have inverted V-shapes, have the same number of dampers, each of which has the potential to reduce displacements by approximately 12.5 and 10.5%, respectively. That is a strong indication to prove that the location of the applied dampers is important, and it must be taken into account during the design phase of the project.

Table 3 - Top-level displacements of all cases

Damper Shape	Reference Case	Applied Dampers Level	Max. Displacement without Dampers (m)	Max. Displacement with Dampers (m)	Reduction Percentage (%)
Diagonal	Case 1	2 & 3	0.002853	0.002395	16.037
	Case 2	2,3,4	0.002853	0.002101	26.349
	Case 3	3,4	0.002853	0.002132	25.264
	Case 4	3,4,5	0.002853	0.001747	38.762
	Case 5	4,5	0.002853	0.001787	37.346
	Case 6	4,5,6	0.002853	0.001375	51.812
Inverted V-Shape	Case 7	2,3	0.002853	0.002127	25.452
	Case 8	2,3,4	0.002853	0.002517	11.785
	Case 9	3,4,5	0.002853	0.002550	10.522

On the other hand, if a comparison is made between Case 2 with three dampers and Case 5 with only two dampers, it can be seen that Case 5 with only two dampers has a higher reduction than Case 5 with three dampers. This is because Case 5 with only two dampers has a lower frequency response than Case 5 with three dampers. Comparing Cases 8 and 9 with Case 7 containing two dampers yields the same results, which are consistent with the inverted V-shape hypothesis. Therefore, increasing the number of viscous dampers that are applied to the structure of the jacket is not required in order to provide the best possible mitigation of the dynamic response. Additionally, the effectiveness and functionality of the viscous dampers may vary depending on the level they are used at. Results from previous investigations [7, 18] both came to the same conclusions after making similar observations.

However, according to the findings presented, the diagonal shape is more effective than the inverted V-shape in terms of efficiency. This is demonstrated in Table 4, where Case 6 has the potential to reduce the top-level displacement by up to 52%. As a result of this, Case 6 has been chosen as the best possible scenario, and it will be utilised in the process of determining the effectiveness of the viscous dampers in lowering the displacements, connection stresses at all levels, and vibration of the jacket structure.

3.3 Effect of the Viscous Dampers on the Jacket's Displacement

The displacements at all levels under Case 6 are evaluated and then compared to the jacket structure with viscous dampers removed. The analysis is carried out at the left leg joints of the Rassalat jacket structure, as shown in Fig. 4. Case 1, which summarises the maximum displacements at all levels of the Rassalat jacket structure when brace viscous dampers are configured in the optimal way (Case 6). It has been demonstrated that the percentage of displacement that is reduced decreases from a lower level to a higher level, which results in a reduction of approximately 52-64%.

Therefore, using only three diagonal dampers with the same arrangement as shown in Case 6 has a high efficiency to reduce the displacements of the jacket by more than 50%.

Table 4 - Max displacements of all levels, Case 6

Optimal Configuration	**Level**	**Max Dis without dampers**	**Max Dis with dampers**	**Reduction Percentage (%)**
Case 6	Level 1	0.000333	0.000119	64.178
	Level 2	0.000760	0.000288	62.081
	Level 3	0.001239	0.000495	60.080
	Level 4	0.001830	0.000769	57.971
	Level 5	0.002459	0.001128	54.131
	Level 6	0.002853	0.001375	51.812

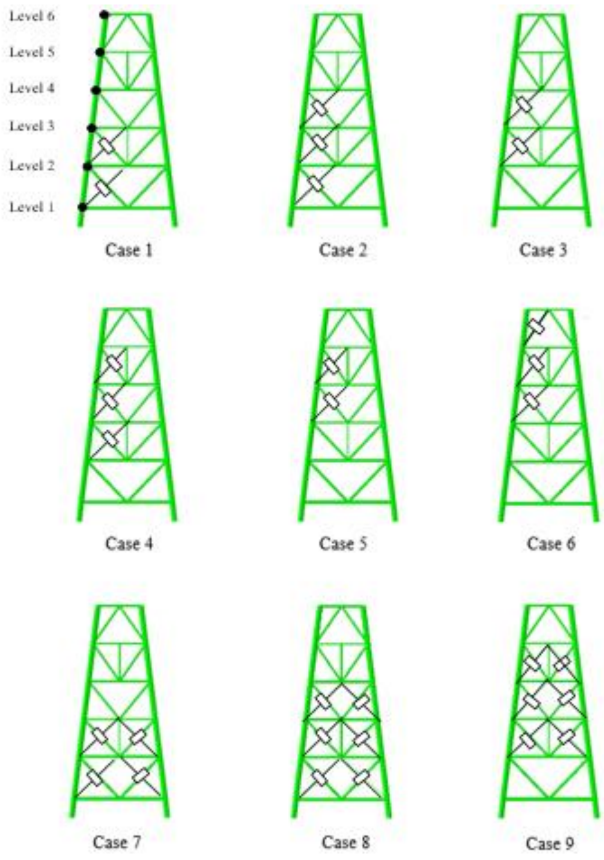

Fig. 4 - The nine cases of brace viscous dampers configurations

3.4 Effect of the Viscous Dampers on the Jacket's Stresses

The maximum connection stresses can be found in Table 5, which covers all levels. On the other hand, it is clear that the dampers have been successful in lowering the maximum stresses at the nodes of all levels, with the exception of the top level. That might refer to the location of the applied loads at which they make a significant impact on the node. The top level is subjected to direct loading from the wave and wind components. Therefore, the dampers begin to reduce the response of the structure by providing a resistance force at the top level, which results in an increase in the stress at the node at the top level. As a result, in order to prevent the failure of the top-level connection after the dampers have been applied, the connection will need to be redesigned, and, if necessary, the connection's stiffness will also need to be increased. In general, the viscous dampers helped reduce the stresses on the other nodes by anywhere from 38-54%, with 38 being the lowest possible reduction and 54 being the highest possible reduction. The reduction of connection stresses helps to lengthen the jacket structure's lifetime, which in turn reduces the risk of cumulative fatigue failure and improves the structure's performance.

Table 5 - Max stresses of all levels, Case 6

Level	No dampers	With dampers	Reduction %
Level 1	2.813	1.411	49.84%
Level 2	1.608	1.060	34.08%
Level 3	1.788	0.818	54.24%
Level 4	1.899	0.927	51.21%
Level 5	1.838	1.139	38.03%
Level 6	2.122	2.366	-11.50%

3.5 Effect of the Viscous Dampers on the Jacket's Vibration

Accelerations and displacement data of a structure are considered to be great indicators for evaluating structural vibration. In order to determine whether or not the viscous dampers are effective in reducing the vibrations, it is necessary to begin by analysing the accelerations experienced at each level of the jacket structure. Due to the fact that the acceleration of the jacket structure was found to gradually decrease from the top level to the lower level as a result of the findings of the analysis, only two results of the top level and lower level with and without dampers are presented in Fig. 5 and Fig. 6, respectively. Both of these figures demonstrate that the accelerations of the nodes have been significantly slowed down and that the dampers were able to control the change in accelerations in less than six seconds. In order to make the concept clearer, a slow velocity change over time expresses a more stable structure. This indicates that the jacket is responding in a manner that is a uniform and steady mode.

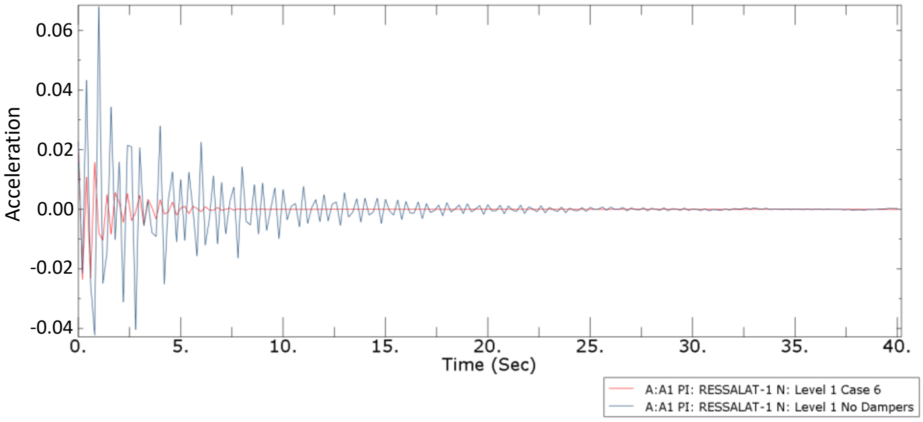

Fig. 5 - Accelerations at first level under Case 6

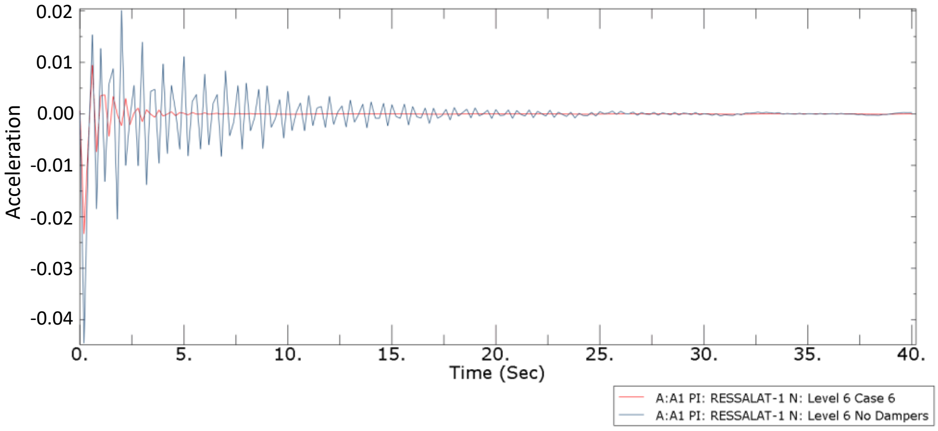

Fig. 6 - Accelerations at a sixth level under Case 6

Regarding the second indicator, Fig. 7 and Fig. 8 display the displacement oscillation of the jacket structure both before and after the addition of dampers, respectively. It can be seen in Fig. 7 that the jacket structure does not have any dampers, and this results in significant oscillation of displacements, which is an indication that the structure is operating in a strong vibration mode. The displacements of the jacket structure are more susceptible to change when dampers are not present than when they are. Fig. 8 demonstrates that the displacement oscillations are becoming increasingly stable and uniform. On the other hand, it has been noticed that viscous dampers make a significant contribution to the overall reduction of structural vibration.

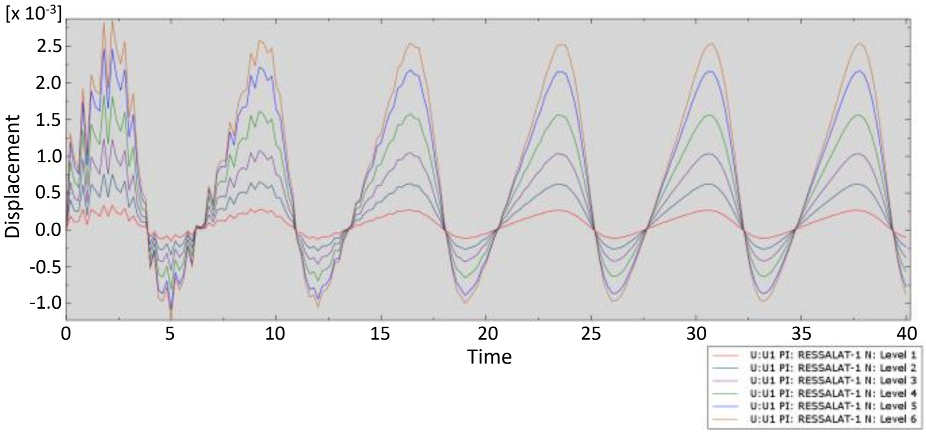

Fig. 7 - Displacements oscillation at all levels without dampers

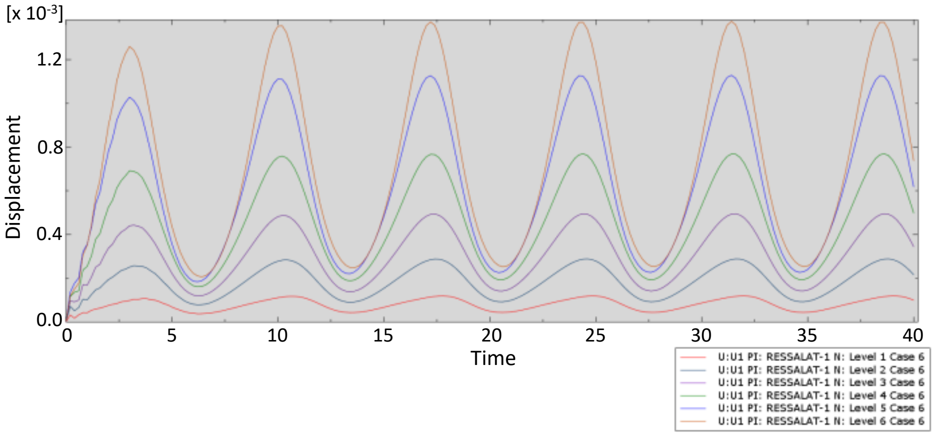

Fig. 8 - Displacements oscillation at all levels with dampers

4. Conclusion

The detailed analysis of the study was able to produce reasonable analytical outcomes. Based on the results obtained, the following conclusions can be drawn:

- All nine cases successfully mitigated the dynamic response, with the diagonal shape being approximately 50% more effective than the inverted V-shape. Case 6 with three diagonal dampers applied at levels 4, 5, and 6 represents the optimal configuration of the brace-viscous damper system on the Rassalat jacket platform among the nine selected cases of the brace-viscous dampers.
- Case 6 has the potential to reduce the maximum displacements at all levels by 52% to 64%, respectively, from the highest level to the lowest level. In addition, the stresses at the connections of the left leg of the jacket structure have been evaluated and compared to the jacket structure without dampers in Case 6.
- The stress results demonstrated that viscous dampers can reduce the maximum stresses at the connections of levels 1 through 5 by a minimum of 38% and a maximum of 54%, excluding the top level. The viscous dampers also have a significant impact on structural vibration mitigation, as they can reduce acceleration and displacement changes by providing uniform and constant structural vibration with a lower frequency.
- In general, all nine cases have successfully attenuated the dynamic response, with the efficiency of the dampers varying according to their various configurations and application locations. Furthermore, an increase in the viscous-damper number applied to the jacket structure is not required for the best mitigation of the dynamic response. In addition to efficiency and performance, viscous dampers may vary between levels.

Acknowledgement

The authors would also like to express their gratitude to the Research and Innovation Department, Universiti Malaysia Pahang for the financial support.

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