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# Numerical study of the effect of Base Isolated (neoprene) on the dynamic response of the installed module on the FPSO deck

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**ABSTRACT**

Significant advantages of FPSO in the ability to transfer and extract from offshore wells have led to their widespread applications. Kind of different modules is installed on the top of these platforms, where one of the major engineering concerns is choosing the location of these modules on the FPSO platform deck in order to reduce the effects of environmental forces. Typically, these modules are analyzed and designed based on the maximum linear acceleration extracted from the ship's spectral analysis, using a quasi-static method. The main purpose of this research is the analytical study of these modules response under dynamic excitation due to the wave effect. This research has been done in two parts. First, the dynamic response of different parts of the ship's deck has been analyzed under the effect of wave force and proper location for these modules is recommended. For this purpose, first with modeling and analysis performed in MAXSURF software, the ship's dynamic responses at different points of the deck have been calculated. Then these modules have been analyzed against the deck response considering base isolation at the module bases in the second part. The obtained response has been applied to two modules as a case study in Sap2000 software. The result shows that base shear and displacement have a verity response in the function of base isolation stiffness. Due to the extension of the ship's deck and the serious differences in the acceleration spectrum at different locations of the deck, in order to select the optimal stiffness, the locations of the desired module must also be considered.

## 1. Introduction

In addition to the conventional uses of maritime transportations, vessels are also intended to use for extracting oil and gas from offshore wells. These floating platforms are similar to onshore oil refineries, with different equipment and modules located in different parts of the ship's deck. The design of these modules is one of the interest topics for researchers due to the type of operation loads and environmental effects. In general, naval vessels are commonly exposed to the forces of wind, waves, and currents. So, in addition to the usual loads that are applied, also in analyses and design, these modules shall tolerate the forces caused by environmental loads. Generally In ships and similar facilities, , due to the width of the deck and geometric shape of the hull, the modules installed in different locations of the deck and therefore these modules are faced with different dynamic responses from the ship movement under waves effect. The structural design and analysis of the installed modules on the deck of ships are mainly consider with using a maximum of linear acceleration resulting from the spectral analysis wave applied to the hull of the ship. In the quasi-static analysis, the normal practice of design is only considering the maximum acceleration to the structure, therefore, complete details of the structure response are not obtained. The main purpose of this research is analytical study of these modules response under dynamic excitation due to wave effect. This research has been done in two parts. First, the dynamic response of different parts of the ship's deck has been analyzed under the effect of wave force and

proper location for these modules is recommended. Then these modules have been analyzed against the deck response considering base isolation at the module bases at the second part.
In this study, the dynamic response of a module on the deck of an FPSO platform is assumed to be based on that fact the ship is stationary as the worst case when the wave hits the hull. In this research, first, the dynamic response of different locations of the ship's deck under the effect of wave force is investigated and appropriate suggestions are presented. Then in the second part, the numerical study of dynamic response of the base isolated installed module (neoprene provided at its supports) on the designated location on the deck is studied.

## 2. Introducing the FPSO

Usually, tankers and containers ships have a flat deck which are not equipped with structures on top of the deck, but in FPSO platforms, depending on their operation purpose, there are various installed equipment, and structures on top of deck.
In summary, each FPSO has the following parts:

1. Space related to anchoring equipment
2. Topside Deck
3. Main Deck
4. Accommodation
5. Powerhouse
6. Storage Tankers
7. Cargo Unloading Area

Topside equipment are generally divided into two categories according to their performance. One part of equipment are hydrocarbons container and the other part is service equipment.
The main area of hydrocarbon includes:

- Flares
- Compression equipment
- Separation equipment

The main area related to service equipment includes:

- Industrial equipment
- Electrical and energy power equipment
- Structures and modules on the Topside

According to safety rules, it is better to positions of the hydrocarbon equipment area at the farther distance from the accommodation, and service equipment will be placed between this area and the accommodation. In general, on the deck of these platforms are different installed modules including power generators, HP / LP separators, gas purification, and compression modules which are located at the other side of the ship water injection, dewatering, accommodation and etc. are installed. In addition, the design should include a number of safety facilities such as lifeboats, temporary shelters, escape routes, and fire water pumps. The general view of the equipment locations is shown in Figure 1. In the hydrocarbon process area, separate modules are design. The supports of the modules are installed on short columns mounted on the deck of the ship. This method allows the modules to be fabricated on shore and installed on the deck of the ship as a complete modules.

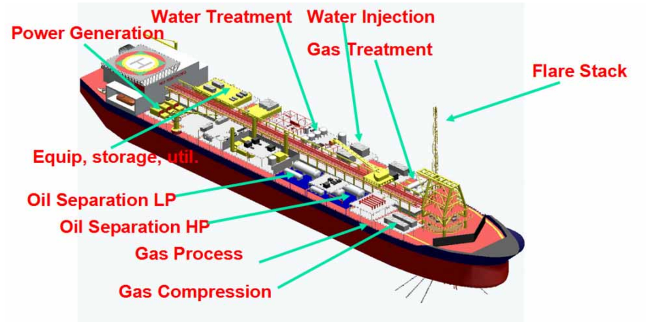



**Figure 1 - Example of equipment installed on the main deck of the FPSO**

The dimensions of different modules are estimated and selected according to various parameters, including the following:

- The size of the largest piece of equipment, for example separators
- Predicting the maximum load capacity of the crane in that area (in terms of weight and height)
- Predict the largest dimensions required for commuting areas such as the interior doors of the accommodation

Surface of the hydrocarbon container is coated to protect area against the penetration of these materials into the deck and corrosion.
The presence of different modules on the deck of this type of ship shape platform has caused sensitivity to the acceleration and the dynamic response of these modules to the forces. In this study, this response has been investigated in two different type of module support.

## 3. Literature review

Vessels and offshore structures are exposed to irregular waves at the sea conditions. Wave effect on these structures are studied in the science of random vibrations that convert each irregular wave into a set of several regular waves using the Fourier transform (figure 2). These calculations were discussed by Journey in detail at the field of marine structures [1].
Journey used these calculations to convert time domain into frequency domain. The Fourier transform is used to convert an irregular wave to a set of regular waves and finally to calculate the wave spectrum.
Kamphuis performed extensive statistical calculations in the field of sea waves and used the wave spectra obtained from Fourier transforms to derive the main wave parameters [2].
This issue was previously raised in 2007 by Holthuijsen et al. In the field of marine engineering [3].

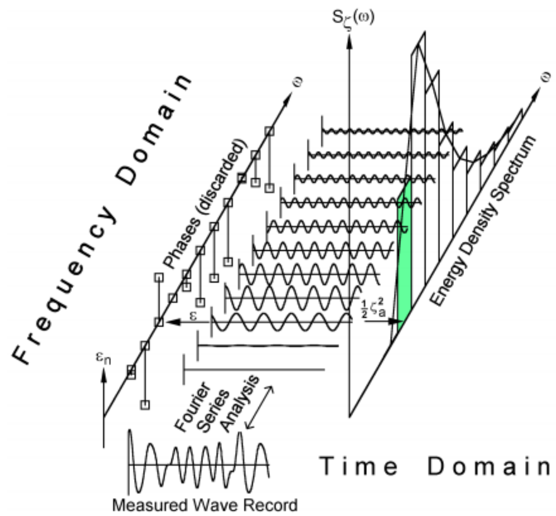



**Figure 2 - Convert an irregular wave to a set of regular waves**

Equation (1) is one of the most important equations in the field of random vibrations. This relationship was presented by Newland in 1993 and 2012 [4].

$$S_y(\omega) = |H(\omega)|^2 S_x(\omega) \tag{1}$$

In this equation $S_y(\omega)$ is response spectral density, $|H(\omega)|$ is system spectral density and $S_x(\omega)$ is excitation spectral density.

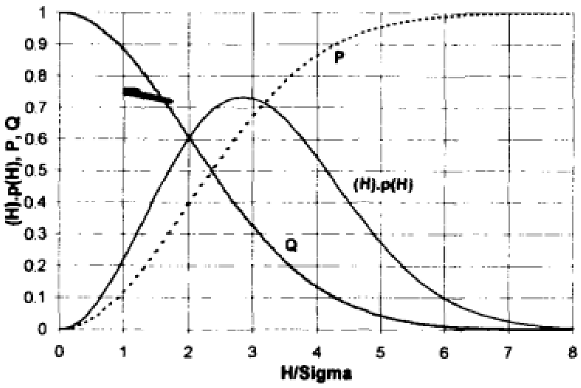



**Figure 3 - Riley wave height distribution**

It should be noted that in marine engineering field, the response amplitude operator (RAO) is used instead of the frequency response function. RAO of a degree of freedom is the response of that degree of freedom to the force of a wave with a unit height. Is that be shown as below formula:

$$S_y(\omega) = |RAO|^2 S_x(\omega) \tag{2}$$

Up to this stage of studies, the convert from the time domain to the frequency domain was briefly discussed. Sometimes in calculations, it is necessary to convert frequency domain to time series function. In other words, using the inverse Fourier from the frequency domain to the time domain for time history analysis. This topic was thoroughly discussed in the field of random vibrations in 1999 [5] and then 2001 [6] by Frigaard.

One of the challenges in the field of oil and gas extraction is designed the economical equipment for extraction from shallow and deep water. Lapidaire and et al are the first researcher in these field in the theory of floating platforms in deep water. In 1996, they studied the ship-shaped floating platforms and the effect of waves on them base on their extensive experience in the field of design, installation in fixed platforms [7]. Han and colleagues (2002) examined a specific type of FPSO platform for the extraction and storage of liquefied natural gas. This type of platform is called FSRU. They stated that with the expansion of natural gas demand in many countries, the extraction of these resources from deep water is important and after extensive studies, FSRU as a suitable scientific and economical solution to this challenge [8]. Now, considering popularity of using and designing FPSO platforms was increasing, this issue was faced with the challenge of a lack of sufficient information and data. In this condition, Wang and et al show the lack of appropriate data available for the design of these platforms. In 2003, they focused on providing data from commercial tankers that could be used to design FPSO platforms [9]. As reported by Chakrabarti (2005), in Chapters 7 and 10 of the "Marine Structures Engineering Handbook", reviewed the design of offshore structures as well as the equipment on the deck of these rigs, and finally provided useful information in this area [10]. The issue of forces excreted the hull of the ship is still under debate, with Buchner and et al studied the effects of strong waves in deep water on floating structures (2007). They focused on the response of the structure to the incoming waves by numerical methods [11]. Molland, (2008) in Section 9 of the Marine Engineering Reference Book, discusses the design, construction, and operation of the ship [12]. Henriksen et al (2008). Carefully investigate the structures on the deck of the FPSO platforms under the loads caused by the deformation of the main hull beams, the pressure from the existing tankers, and the inertial force of the structures on the deck [13]. Luo and his colleagues then investigated the FPSO for use in deep water (2014). They reviewed deck structures, hulls, floating systems, anchoring systems, risers, and design concepts in the South China Sea [14]. The expansion of the use of FPSO has led to broader and more complex discussions tailored to the climatic conditions of each region. Watson and his team investigated the effect of the collision of ice cubes (2019) [15] And Davis and colleagues in 2019 discussed the issue of explosion risk analysis in design [16]. In this regard, the issue of comparing the stability of different types of floating platforms in 2019 was on the agenda of Rivera and his team [17]. Due to the importance of the impact of environmental forces in the design of marine structures, this issue has received much attention today. In this regard, Dezvareh intends to examine the effect of wind turbulence on the aero-hydrodynamic behaviour of offshore wind turbines with a monopile platform [18].

## 4. Method Statement

In these study, analytical Modeling has been done in several stages with using three commercial software. MAXSURF software version 8 is used for modeler and motions module. Then spectral outputs are converted to time history using SeismoArtif software version 2020 and finally, time history analysis is performed on the desired module using SAP software version 14.2. The details of each model are discussed separately below.

### 4.1. Modeling in MAXSURF

The ship with a length of 205 meters, a width of 37 meters, a depth of 26.55 meters, and a draft of 10.55 meters is considered in these studies. The basis of this modeling is the use of standard JONSWAP spectrum and waves with a height of 4m and 11m. Total of 6 points on the deck surface of this ship shape platform have been considered for selecting the best locations of module. The location of these points on the deck of the ship have shown in Figure 4.

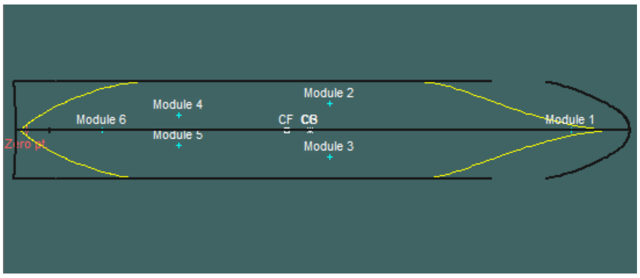



**Figure 4 – Locations of the studied position**

It is assumed that the ship is stationary at the moment of the waves hitting the hull. Also, the wave hitting angles are assumed to be 0 and 90 degrees. It should be noted that the presented results are related to a wave with a height of 4 meters. Initially, the RAO of the three degrees of freedom of the roll, pitch and heave at the center of gravity of the ship to due to waves with angles of 0 and 90 degrees is analyzed. Figure 5 shows the results of the ship's response to a wave with a zero-degree angle of impact.

As shown in Figure 5, according to the angle of impact of the wave on the ship, pitch and then heave degree of freedom (DOF) will have the greatest effect on the response of the ship and the response of the degree of freedom of the roll is near to zero. In the second step, the ship's response is studied under the effect of a wave with an angle of 90 degrees. As shown in Figure 6, the RAO of the roll DOF is far greater than the response values of the pitch and heave.

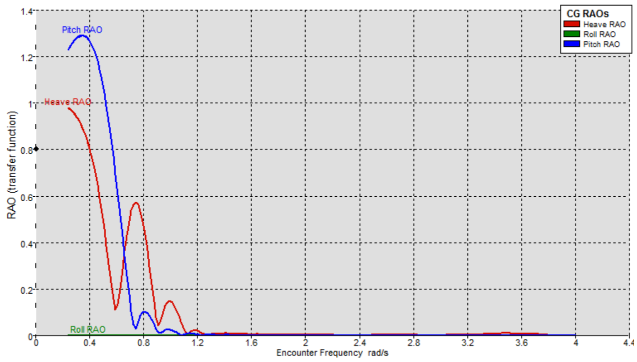



**Figure 5 – RAO of the CG disp, wave impact angle: zero degree**

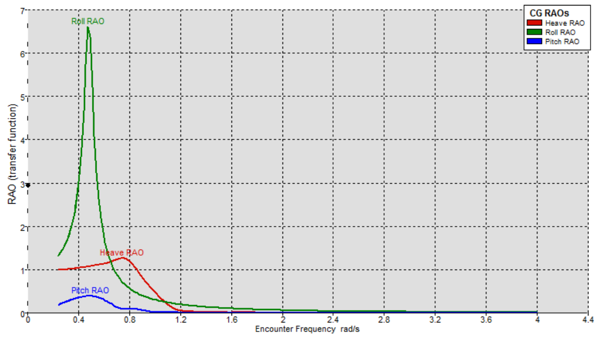



**Figure 6 – RAO of the CG disp , wave impact angle: 90 degree**

In the next step, the RAO is extract at the desired points on the deck of the ship. based on this study, it was found that in general, the response of the module in points 1and 6, 2 and 4, as well as 3 and 5 are similar to each other in pairs. Due to this similarity, the location 1 and 2 have been investigated. The point of 1 and 6 is located in the vessel centerline with zero distance in the transverse direction and far distance in longitudinal direction. So, it is anticipated to have maximum vertical displacement response in wave hitting in zero angles as obtained in results. Figure 7 clearly confirms this.

Wave is hitting in zero angles cause maximum vertical displacement in vessels and so the maximum displacement response of location 2 is much less than location 1 because of this point is closer than ship center of mass.

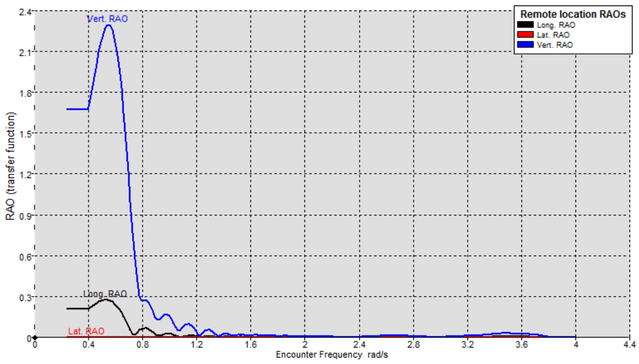



**Figure 7 – RAO of the module 1 disp , wave impact angle: 0 degree**

The response diagram of this position is in accordance with Figure 8.

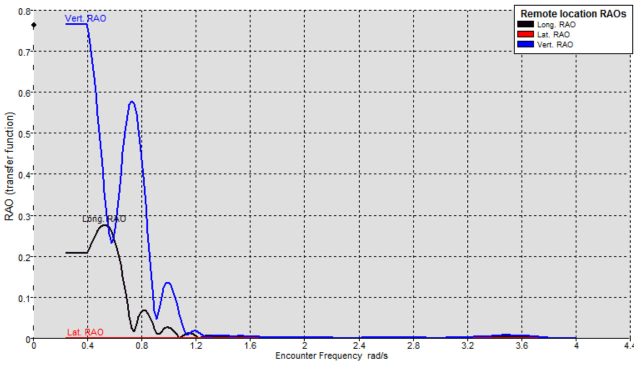



**Figure 8 – RAO of the module 2 disp, wave impact angle: 0 degree**

Then, the response of the module in location 1 due to the impact of the wave with an angle of 90 degrees is investigated. In this case, in addition to the response in the direction of vertical displacement, the response in the transverse direction is also significant according to Figure 9, but the values of longitudinal displacements are close to zero.

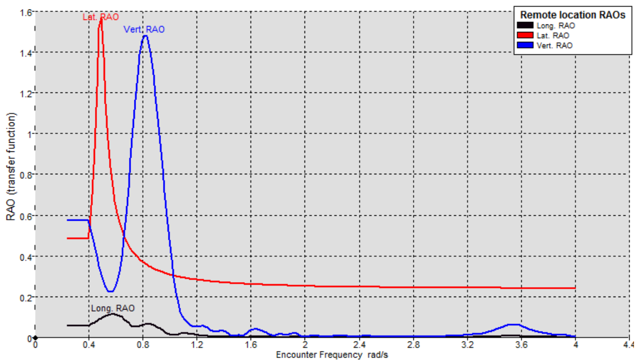



**Figure 9 – RAO of the module 1 disp, wave impact angle: 90 degree**

In position 2, due to the impact of this wave, the amplitude of the transverse displacement response is almost unchanged compared to position 1, but in vertical displacement, it shows a response nearly twice as large as position 1.

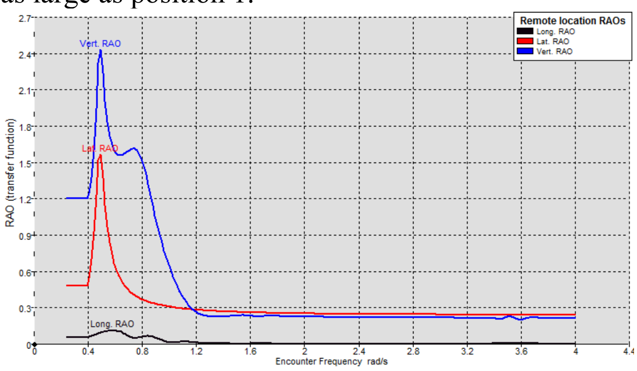



**Figure 10 – RAO of the module 2 disp, wave impact angle: 90 degree**

Because of the extreme impact of transverse displacement on the response spectrum, in this study location 2 has been selected for structural response study. The response acceleration spectrum in this location is presented in both X and Y directions according to Figures 11 and 12, respectively.

## 4.2. Generating Time Series

Response accelerations spectra result from MAXSURF software is presented in Figures 11 and 12. These responses are converted into time series function with using SeismoArtif software.

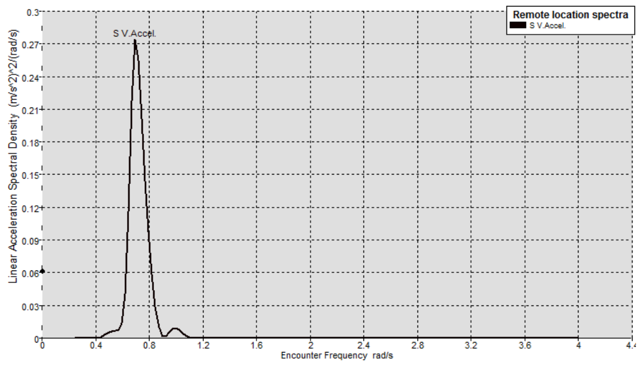



**Figure 11 – The acceleration spectrum in position 2, X Direction (wave height 4 m)**

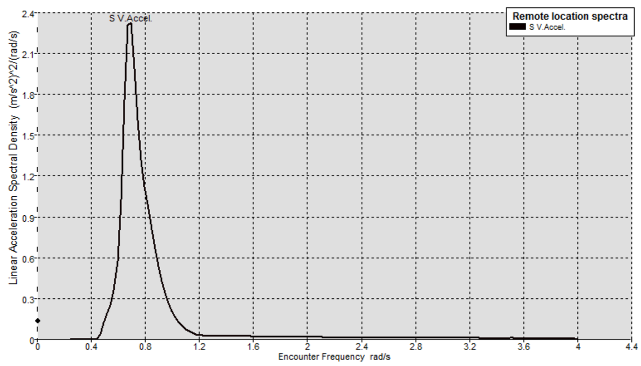



**Figure 12 – The acceleration spectrum in position 2, Y Direction (wave height 4 m)**

Time history records generated in both X and Y directions are shown in Figures 13 and 14, respectively.

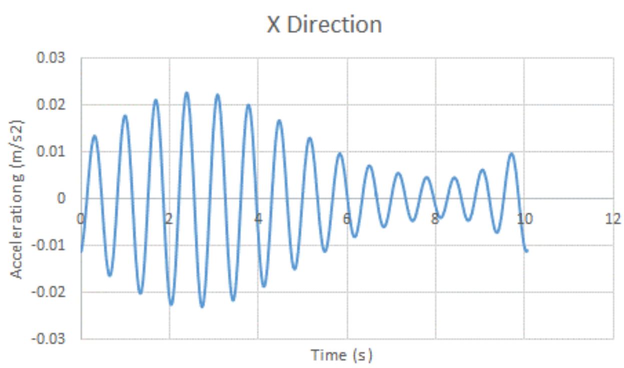



**Figure 13 – Generated Time History – X Direction**

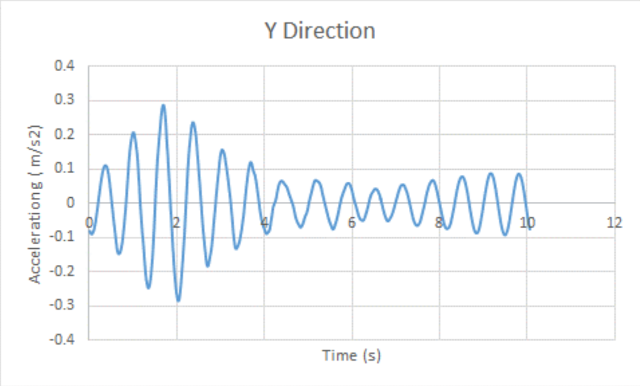



**Figure 14 – Generated Time History – Y Direction**

As seen in the figures that the response of the module in the Y direction is much more critical and nearly 10 times higher than in the X-direction. This can also be predicted from the ship response amplitude operator in Figures 8 and 10.

In the next step, the time history obtained on the installed modules is studied.

## 4.3. Modeling in SAP

The studied module that modeled in SAP software according to Figure 15 has 4 supports at a distance of 6 meters from each other and with an overall height of 7.55 meters.

This module is a sample of a module installed on a FPSO deck and is considered as a real module.

Figure 16 shows the general assembly and installed equipment's on selected module.

Two separate models of this module have been prepared in SAP software V.14.2, all modeling parameters in both models are the same except the support constraints.

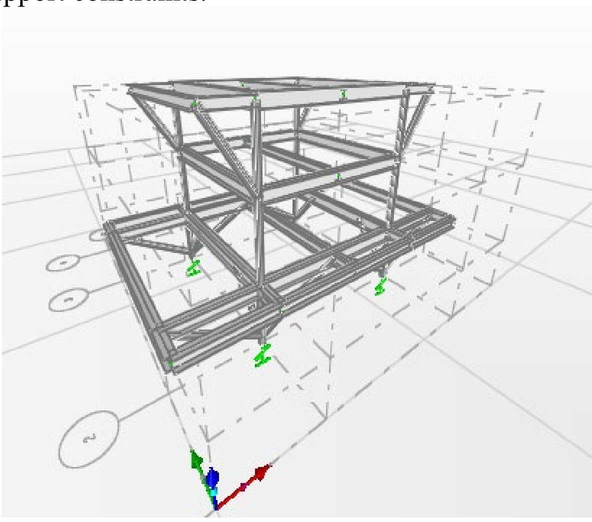


**Figure 15 – Extruded view in SAP**

In the first model, the fixed support is used according to Figure 17. In the second model, neoprene is used as support constraints according to Figure 18.

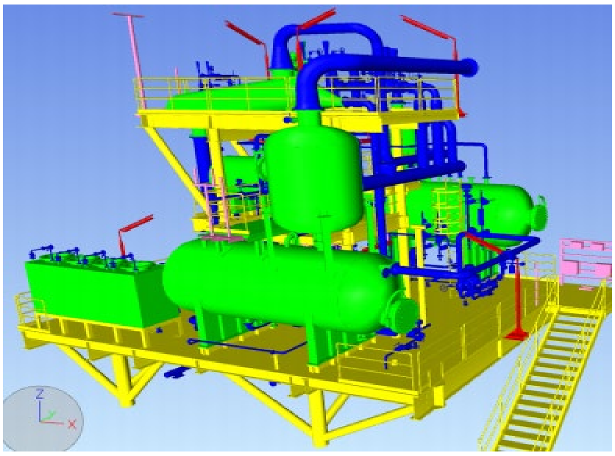


**Figure 16 – Equipment installed on the module**

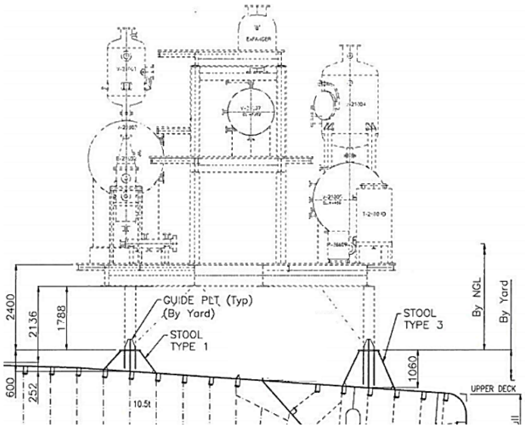



**Figure 17– the connection of the fixed support to the ship deck**

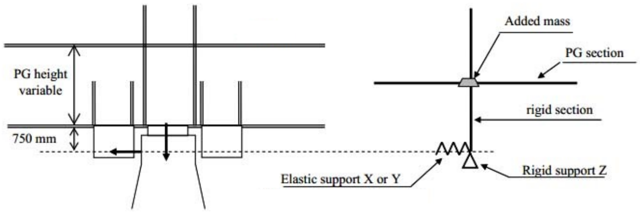
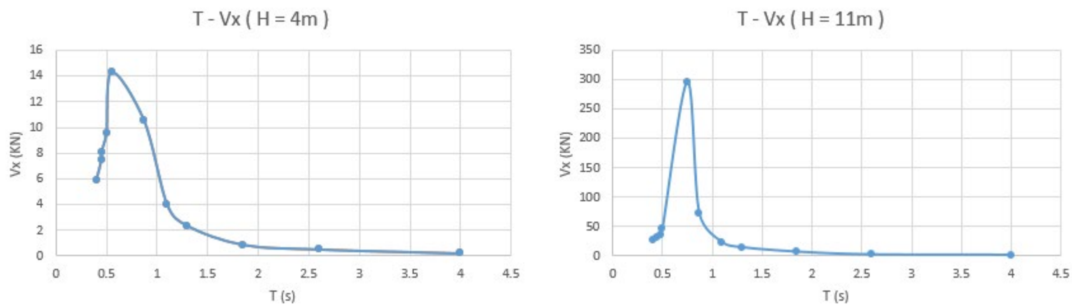


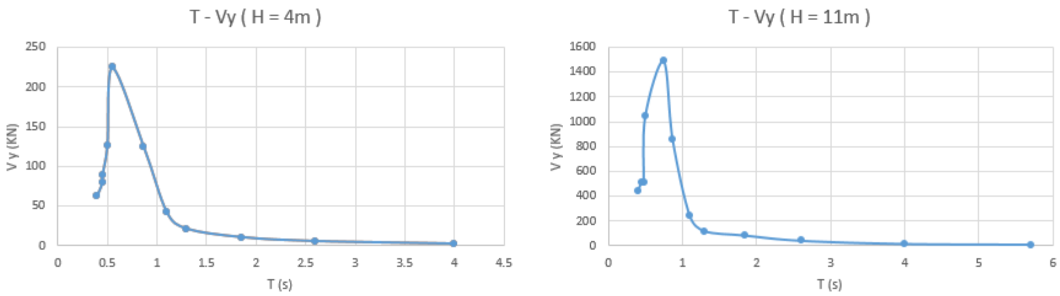

**Figure 18– sample of the support connection with neoprene**

## 5. Results and Discussion

In this modeling, different stiffness has been theoretically assumed for base isolations. Stiffnesses are designed to cover wide range intervals of the natural period of the structure. The natural period of the fixed module is about 0.4. The stiffness of base isolations is selected in such a way that include a module natural period between 0.4 to 4 seconds. In similar conditions, the module was analyzed due to the impact of 11-meter wave height on the ship, and for a more detailed study, this case done with more stiffness conditions so a natural period of module up to 5.7 seconds. Finally, the base shear, displacement, and moment created by the wave impaction are investigated. Figures 19, 20, and 21 show the outputs of the base shear, displacement, and moment created in the support member, respectively.

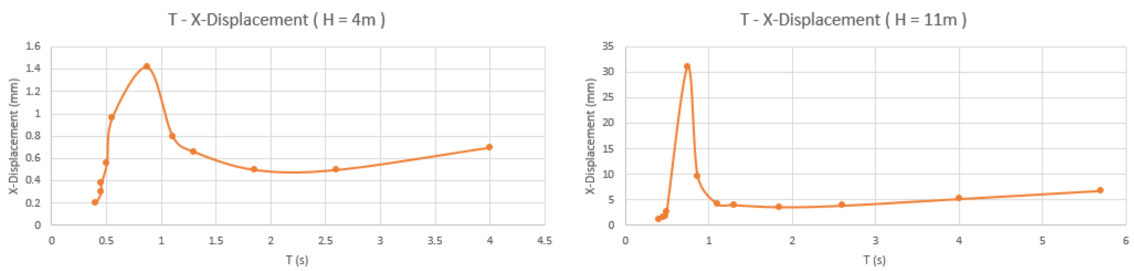



**a) Base shear in X direction**

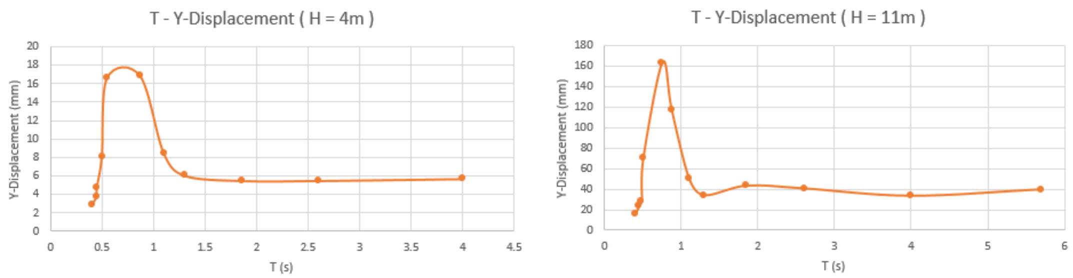



**b) Base shear in Y direction**

**Figure 19 – Base shear on the module**




**a) Displacement in X direction**




**b) Displacement in Y direction**

**Figure 20 – Displacement on the module**

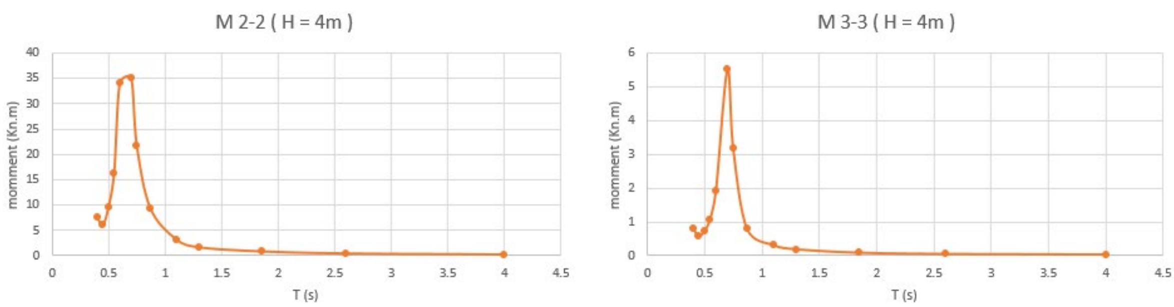



**Figure 21 – the moment created in the support member**

As shown in Figures 13 and 14, due to the narrow band of the acceleration response spectrum, the time history record created is very close to the harmonic condition. So, the excitation period is approximately 0.7 seconds.

Clearly in all the results that when the natural period of the module approaches the excitation period, the module experiences the resonance phenomenon and shows maximum high responses. In this regard, one of

the main principles of choosing the stiffness of neoprene is to pay attention to the excitation period to avoiding resonance. As can be seen in Figure 19, outside the resonance range, the base shear always decreases as the stiffness of the neoprene decreases.
According to Figure 20, it can be noted that the use of neoprene does not have a positive effect on improving the displacement of the module.
In Figure 21, reducing the stiffness of neoprene outside the resonance range always lead to reduce the moment created in the support elements.

## 5. Conclusions

In this study, Analytical investigation has been performed in two sections including determining the ship deck response against wave hitting and structural dynamic analysis of the install module on deck. With regard to obtaining the result and apply assumption following result can be inferred. The section one shows:

- Wave hitting in the most cases, cause a maximum response in the ship location that is located in the far distance from the ship center of mass.
- A formation result shows that it is better to install modules closer to the center of mass. This result also maybe considers for rescue helipad location.

Results in section two shows:

- Install modules excited with harmonic function due to wave hitting.
- With regard to harmonic excitation in selecting base isolation more attention shall be applied in such a way that module frequency shift from harmonic excitation frequency.
- Generally base isolation cause reducing base reaction (shear and moment) of installed modules.
- If install modules are sensitive to displacement more caution shall be applied in base isolation selection.
- With regard to variety of response of deck under wave hitting in difference location
- base isolation stiffness is important parameter in structural design and response resonance.

## 6. References

1- Journee, J. M., & Massie, W. (2001). *Introduction in offshore hydromechanics* (OT3600). TUDelft, Faculty of Marine Technology, Ship Hydromechanics Laboratory, Report No. 1267-K, Lecture Notes.
2- Kamphuis, J. W. (2010). *Introduction to coastal engineering and management* (Vol. 30). World Scientific.
3- Holthuijsen, L. H. (2010). *Waves in oceanic and coastal waters*. Cambridge university press.
4-Newland, D. E. (2012). *An introduction to random vibrations, spectral & wavelet analysis*. Courier Corporation.
5- Liu, Z. and P. Frigaard (1999). *Generation and Analysis of Random Waves*, Aalborg Universitet.
6-Liu, Z., & Frigaard, P. (2001). *Generation and analysis of random waves, cursus*. Aalborg University.
7-Lapidaire, P. J. M., & Leeuw, P. J. (1996, January). *The effect of ship motions on FPSO topsides design*. In Offshore Technology Conference. Offshore Technology Conference.
8- Han, H., Lee, J. H., & Kim, Y. S. (2002, January). *Design development of FSRU from LNG carrier and FPSO construction experiences*. In Offshore Technology Conference. Offshore Technology Conference.
9- Wang, G., & Spong, R. (2003, January). *Experience based data for FPSO's structural design*. In Offshore Technology Conference. Offshore Technology Conference.
10- Chakrabarti, S., Halkyard, J., & Capanoglu, C. (2005). *Historical development of offshore structures*. In Handbook of offshore engineering Elsevier.
11- Buchner, B., & Bunnik, T. (2007, January 1). *Extreme Wave Effects on Deepwater Floating Structures*. Offshore Technology Conference.
12-Molland, A.F. (2008), *Ship design, construction and operation.*
13- Henriksen, L.O., Wang, X., & Liu, D.J. (2008). *Structural Design and Analysis of FPSO Topside Module Supports.*
14- Su, Z., Luo, Y., Qi, X., & Xie, Y. (2014, March 25*). FPSOS for Deepwater Applications*. Offshore Technology Conference.
15- Sayed, M., Watson, D., Islam, S., & Wright, B. (2019, July 15). *The Influence of Floe Size and Ice Concentration on Ice Force Levels for an FPSO in Pack Ice*. International Society of Offshore and Polar Engineers.
16-Davis, S., Marsegan, C., & Botwinick, D. (2019, April). *Inherent Safety-How to Utilize Explosion Hazard Analyses as an Early Tool to Improve FPSO and FLNG Design*. In 2019 Spring Meeting and 15th Global Congress on Process Safety. AIChE
17- Rivera, L. A., Neves, M. A., Cruz, R. E., & Paulo de Tarso, T. E. (2019). *A study on unstable motions of a tension leg platform in close proximity to a large FPSO*. In Contemporary Ideas on Ship Stability (pp. 307-321). Springer, Cham.
18- Dezvareh, Reza. "*Evaluation of turbulence on the dynamics of monopile offshore wind turbine under the wave and wind excitations*." Journal of Applied and Computational Mechanics5, no. 4 (2019): 704-716.