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USED ISOLATION SYSTEM TO REDUCE THE RESPONSE OF OFFSHORE STRUCTURE CONSIDERING SOIL STRUCTURE INTERACTION

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Abstract

Fixed offshore platforms are structures of steel or concrete located in the middle of the sea used to export oil, trade, or military. These are designed to withstand all types of weather and dynamic loads. The response was very high under applied these loads. This paper includes a proposal to apply a new isolation system to be placed in different places on the offshore platform to reduce vibrations from high water waves. Three cases that be used, fixed-based (column connect directly to the pile), isolation system in the pile head (isolation between column and pile), and isolation system in the pile head and the middle of columns. The dynamic movements in waves were simulated using ABAQUS programs. More accurate elements and real material properties were used to bring the results closer to reality. The Computational Fluid Dynamics (CFD) method was used to study the effect of water-structure interaction and soil-structure interaction. The results show that the use of the isolation system at the base of the offshore platform has a very significant effect on decreasing the response of the platform to the loads placed on it. Where the isolation system works as a hinge at the pile head and is not allowed to move and rotate for the pile, also the moments are zero. As for the shear force, it is the least that can be compared with the other cases.

Keywords:

Offshore structure;
CFD technique;
Dynamic isolation;
Water wave;
Soil-pile interaction.

1 Introduction

The dynamic isolation system is widely used in buildings, bridges, and many engineering structures. The system is used to absorb impacts and vibrations occurring in the structure and transfer a small part of it to the foundations and then to the soil. Recently, the insulation system was used in building structures at the foundations to resist wind and seismic loads [1-3]. More research in the use of isolation systems has been used for buildings such as, Diana Faella and Elena Meli (2020), [4] studied two real cases of two elastic buildings have isolated between floors under seismic loads. The first building have the superstructure is more rigid than the lower structure, but the second have the superstructure is less rigid than the substructure. It was found that the analysis of sensitivity and frequency reduces the frequency content of the earthquake and increases the strength of the building system and reduces the structure response. The relative displacement and the absolute acceleration are reduced by the filtration in the isolated layer. Liying Xu, Youqin Lin, (2020), [5], conducted many numerical analysis and vibration tests for a seven-storey concrete structure isolated on the lower floor using rubber insolation to study the isolating effect and seismic response. The study shows that the lateral displacement has decreased significantly, and that the displacement and acceleration between floors are clearly reduced, and the study confirmed the use of the isolation method in the ground floor to improve the seismic capacity of the structures. Also, many research was done for computational fluid dynamics (CFD) to study the dynamic movement of water wave to the offshore platform [6-9]. Fernando R. and Roger M. [10] applied CFD techniques for the sunk jacket in the seabed by using ANSYS software and the finite volume method. all data used was real from a Brazilian Navy's meteoceanographic program, with the water depth of 55m. the result shows the generation of an upward current when the overturning of the structures occurs, which increases with the increase in height, and

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the results are high at the back of the platform due to the enormity of the area. Abdulameer Q. [11-13], conducted many numerical studies on the response of fixed offshore steel platforms under the influence of impact loads, water waves, and torsion. The studies focused on soil-pile interaction on the response of offshore platforms, also, estimating the fixed pile depth and the pile fixed moment. The current aims of the research are to apply the Computational Fluid Dynamics (CFD) technique and the dynamic isolation technique using the ABAQUS program to study the response of a fixed offshore steel platform under the influence of water waves, taking into account the soil-pile interaction. Where this research is considered an important step in the real analysis of fixed offshore platforms.

2 The problem

A Steel offshore platform Fig. 1, with dimensions of 20*20 m in the middle of the sea, a height of 36 m above ground level, water is 25 m above ground level, the platform is supported to the soil by 40 m deep steel pipe piles. The platform is exposed to a water wave 11 m above the platform surface. The research includes analysing the response of the platform under the influence of the water wave, then adding isolation to the platform to improve the response.

1 - The first analysis of the platform without isolation (fixed based).
2 - The second analysis of the platform with isolation at the pile head (in the foundations).
3 - The third analysis of the platform with isolation at the pile head and the upper third of the platform.
At each analysis, the response is studied and the improvements resulting from the addition of isolation.

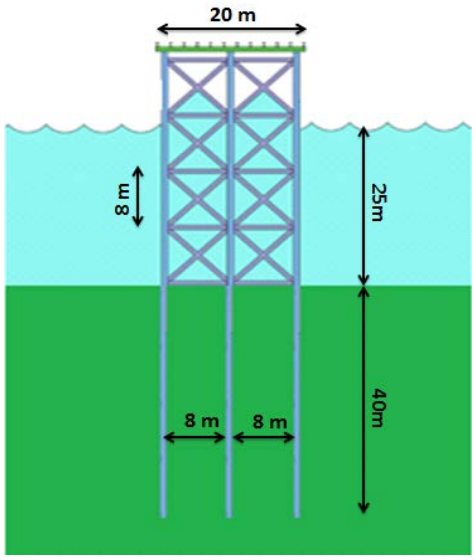


Fig. 1: Structure details used in the study [13].

3 Finite element modeling development

Developing the FEM-CFD model by using ABAQUS software for the platform with an isolation system under applied water wave flow. In this regard, soil-pile interaction and Structure-Fluid-Interaction (SFI) systems were applied in the model. Steel frame with isolation of the platform, soil domain, and water domain represent the three main parts of the model. A coupled simulation was used and the vibration due to water flow, stresses, forces, and moments were calculated in the platform. Base-isolated platform, base and inter-isolated platform, and fixed-base platform were considered. The model details for geometry, loads, and analysis are presented below [14].

3.1 Offshore structure

The offshore frame is consisting of eight main columns with 0.4 m radius and 0.025 m wall thickness. These columns are bounded using a special bracing system, the cylindrical brace members are with 0.3 m radius and 0.0125 m wall thickness as in Fig. 2. These braces are organized in vertical and horizontal plan holding the offshore frame as in Fig. 3. The deck of the offshore frame consists of two types of I-section steel brought from American wide flange Fig. 3. The base beam is the bottom beam while the stand beam is the top beam. Under each column there are a pile that holds the offshore under the soil, these piles are with 0.5 m radius and thickness of 0.032 m. The piles are penetrated into

the soil by 40 m. The soil model is divided into 5 layers each layer has its own properties as in Fig. 4. The piles are contacted with soil using Tie constrain and the properties of contact are illustrated in Table 2 and Fig. 6, [15].

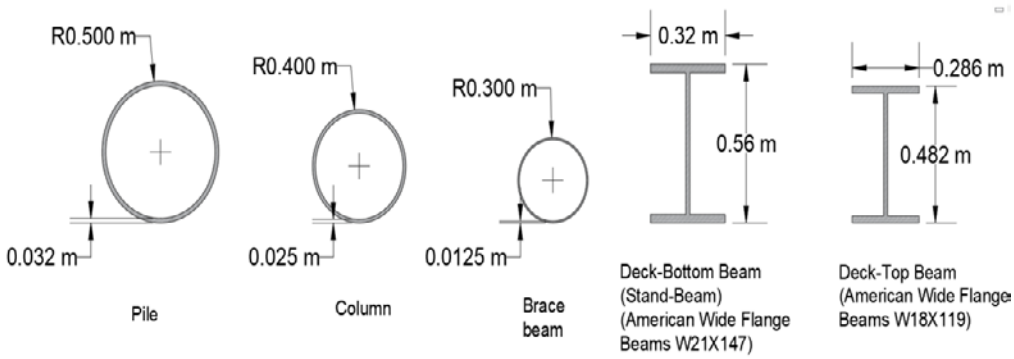


Fig. 2: Section properties for offshore members.

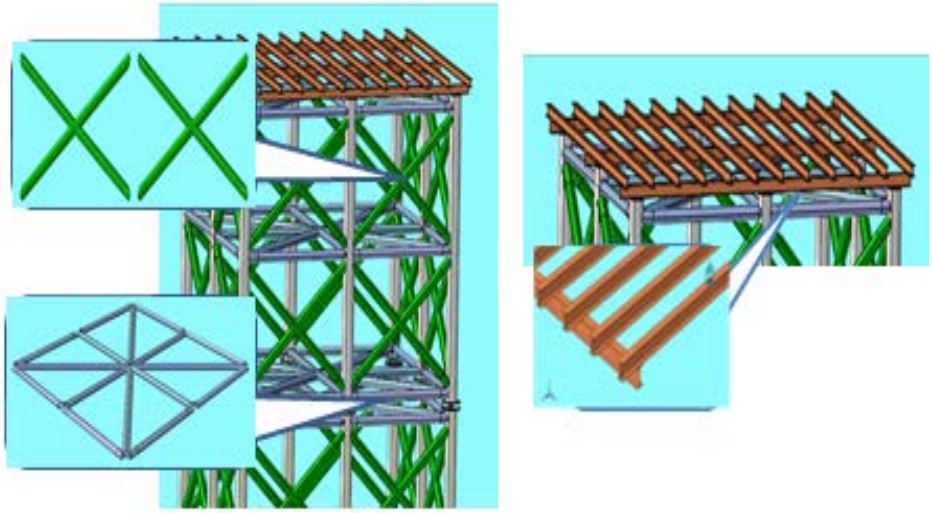


Fig. 3: Brace system and deck details.

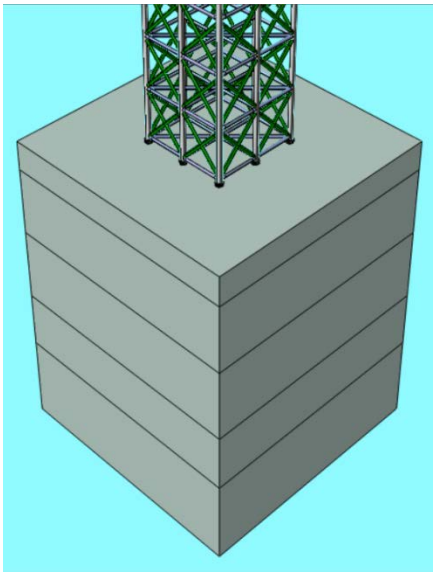


Fig. 4: Soil modeling.

3.2 Isolation system

The isolation system that has been used in this study was from type LRB (Lead Rubber Bearing). There are three models for the offshore regarded to the isolation system; the fixed base offshore, the isolated base offshore, and the offshore with isolated base and middle isolation system Fig. 5 and 6. The isolation device consists of 5 parts (Rubber layers, steel plates, Lead core, Flange plate, and loading plate). All these parts are created using 3D deformable Solid break [16].

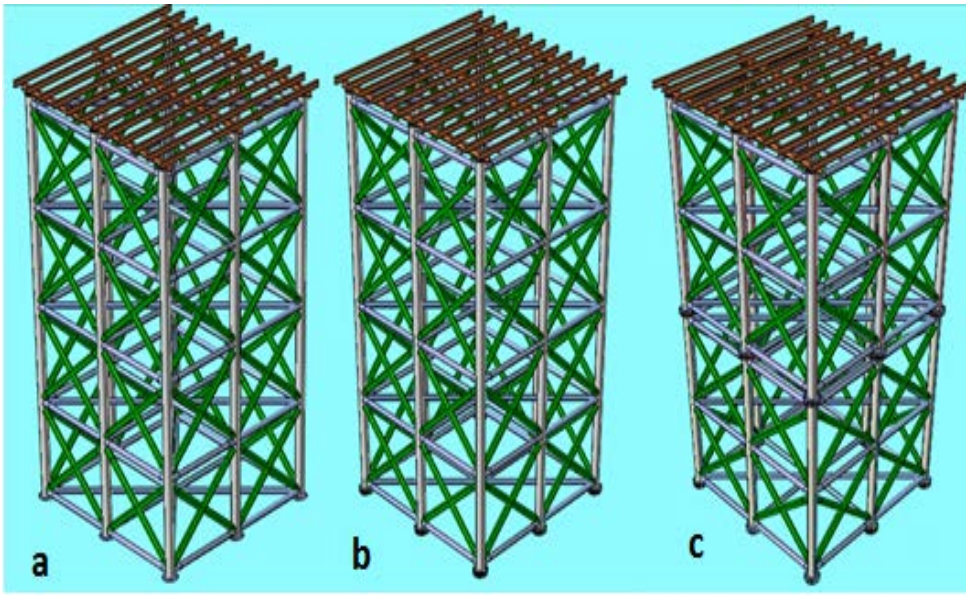


Fig. 5: Three offshore models a) fixed, b) base isolation and c) base & middle isolation.

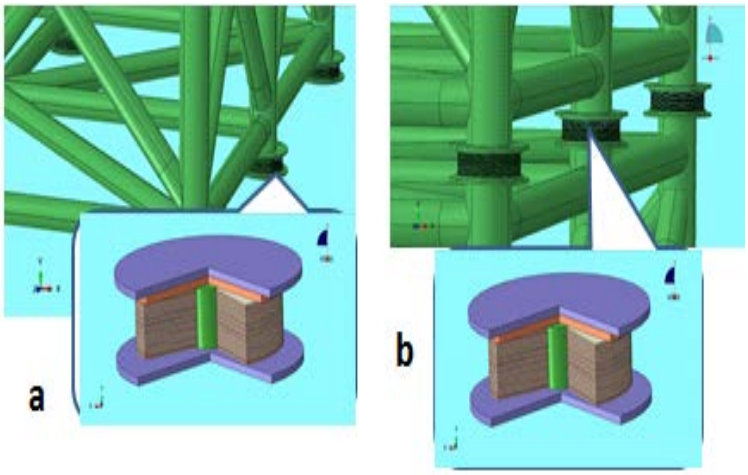


Fig. 6: Isolation details a) base isolation, b) inter-story isolation.

3.3 Water domain

The water domain is created using 3D-Eulerian part, and its dimension is 256 length, 160 width, and 29 m for height as in Fig. 7. The way that we formed the sea wave in the water is to create a huge amount of water that falling from a distance with relatively high acceleration reach 29 m/s^2 to form a wave as in Fig. 8. A predefined field is set to separate the void volume from water volume as in Fig. 8, [17].

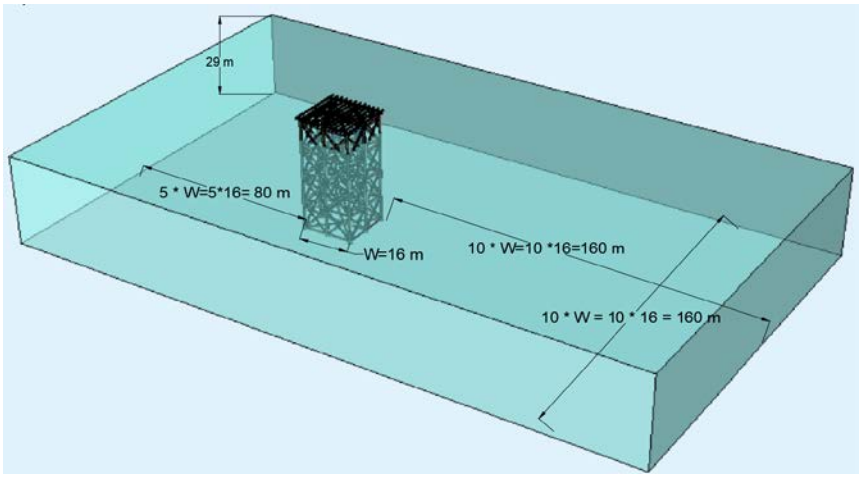


Fig. 7: Range of water.

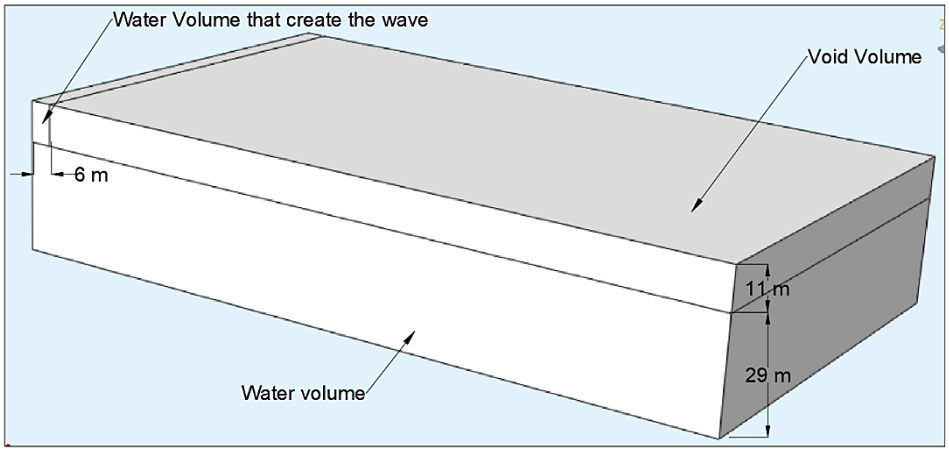


Fig. 8: Water wave represent.

3.4 Material

The materials used in the problem consist of steel for beams, column, piles and isolation plate that can show in Table 1, soil consist of four layers with different type Table 2 and the piles are contacted with soil using Tie constrain and the properties of contact are illustrated in Table 3, rubber material used to represent the isolation rubber plate Table 4, and water material as shown in Table 5.

Table 1: Steel properties [18].

Member	density [kg/m^3]	Elasticity [Pa]	Poisson ratio	Yeild stress [Pa]
Frame steel	7866	2.05E+11	0.3	308000000
ISOLATION steel	8000	1.66E+11	0.3	245000000
Lead core	12000	5.2E+11	0.45	520000000

Table 2: Soil properties [19].

	soil layers	distance	friction angle	density [kg/m^3]	dilation angle	Elasticity [Pa]	Poisson ratio	cohesive [Pa]	Yield stress [kPa]
1	poorly graded	0-5.2	31	1972	2	75000000	0.31	12500	-
2	soft silty clay stone	5.2-17.2	34	1760	5	1.26E+08	0.24	25000	-
3	silty clay	17.2-30	28	1880	10	90000000	0.35	50000	-
4	stiff clay	30-40	32	2000	16	1E+08	0.42	100000	-
5	Stiff soil	40-55	-	1600	-	2E+11	0.2	-	250000

Table 3: Soil Interaction properties [19].

	Soil layers	Friction coefficient	Friction angle
1	poorly graded	0.401	31
2	soft silty clay stone	0.45	34
3	silty clay	0.354	28
4	stiff clay	0.418	32
5	-	-	-

Table 4: Rubber properties [20].

Material	density [kg/m^3]	Hyperplastic		
		mu	lambda m	D
Rubber	1000	516000	6	1.7E-09

3.5 Modeling of the structure elements

The whole model is divided into two different types; the first model is offshore platform, isolation system, soil layers, and the piles are of type (3D-Deformable-solid element) but the other is the water domain which is of type (3D-Eulerian-Solid element).

3.5.1 Offshore modeling

All offshore parts (columns, brace systema, and Deck beams) beside soil layers, piles, and isolation system are created using 3D-Defromable solid part. For the mesh type the (Structured-Hex) type with (Explicit-Element) class and from 3D-Stress Family of code (C3D8R: An 8-node linear brick, reduced integration) is used for each one of (columns, brace system, Deck beams, piles, and isolation system) see Fig. 9, 10 and 11. But for soil layers meshing the (Sweep-Hex) type with (Explicit-Element) class and from 3D-Stress family of code (C3D8R: An 8-node linear brick, reduced integration). The mesh size is illustrated in Table 6.

Table 5: Water properties [21].

	density [kg/m^3]	Eos			Viscosity
		c0	s	Gamma 0	
Water	1000	1450	0	0	0.001

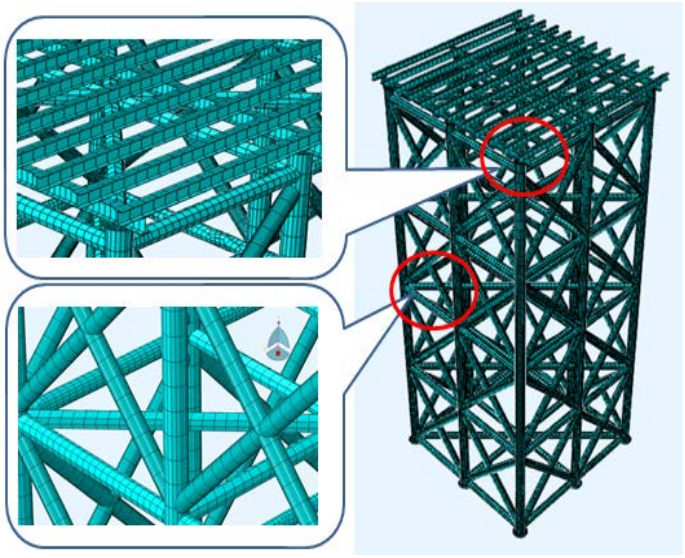


Fig. 9: Offshore mesh.

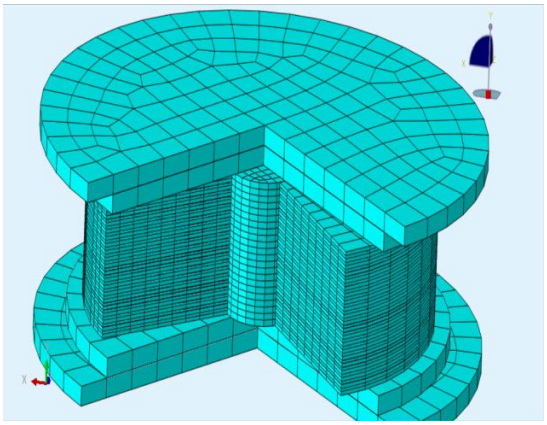


Fig. 10: Mesh detail for isolation system.

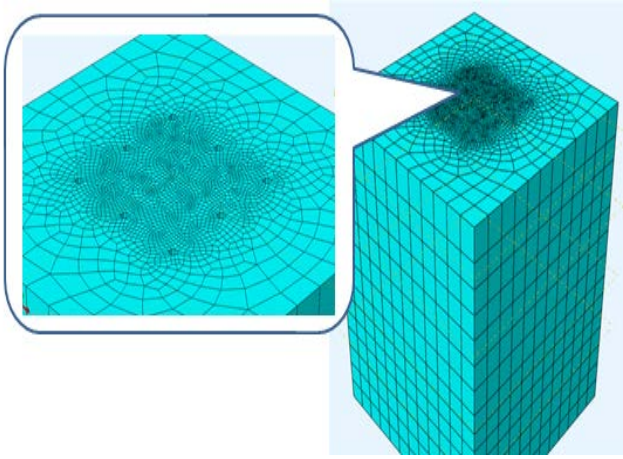


Fig. 11: Mesh detail for soil layers.

Table 6: Mesh size.

Model type	Member name	Largest mesh size [m]	Smallest mesh size [m]
Offshore frame	Columns	0.75	0.025
	Piles	0.75	0.032
	Deck beams	0.5	0.02
	Vertical brace system	0.5	0.0125
	Horizontal brace system	0.3	0.0125
Soil	Soil layers	2	0.15
Isolation system	Rubber layers	0.05	0.008
	Steel plates	0.05	0.006
	Lead core	0.03	0.025
	Loading plate	0.1	0.032
	Flange plate	0.1	0.032
Water	Water domain	0.3	0.3

3.5.2 Water modeling

The water domain created using 3D-Eulerian solid part. And the mesh type used was (Structured-Hex) with (Explicit-Element) type (Eulerian) Family with code (EC3D8R: An 8-node linear Eulerian brick, reduced integration, hourglass control) [21].

3.6 Model assembly

For the column and bracing system, they have been bounded using (Tie-Constrain) Feature. and for the Deck beams they are combined with each other using the (Geometry-Merge) Feature and then the whole Deck is bounded with the Off-shore frame using (Tie-Constrain) through a Circular thick plate with 0.025 m thickness as a Co-binder member see Fig. 12a. The piles are the same as previous bounded with the Off-shore frame using (Tie-Constrain) and also through a Circular thick plate with 0.025 m thickness as a Co-binder member see Fig. 12b.

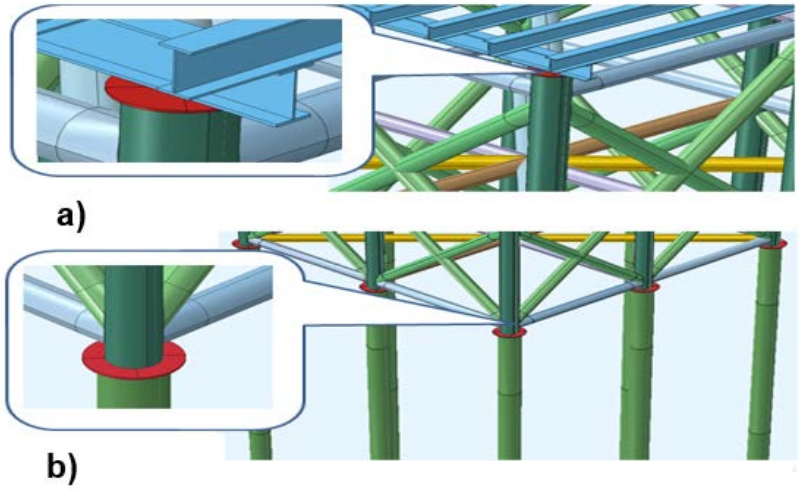


Fig. 12: Represents the connection between off shore members a) connection of the Deck with the Columns, b) connection of the Piles with the Columns.

3.7 Interaction surfaces

Two kinds of Interactions have been used in this model, one for whole model with water domain, and the second for the piles contact with soil layers. As illustrated in following.

3.7.1 Water-offshore Interaction

The interaction type used between the model and water was (General contact Explicit). And for the Contact properties the normal aspects have been set.

3.7.2 Piles and soil layers interaction

Soil part are divided into five different layers represents different soil layer properties each layer has its own contact properties with the pile surface. The interaction type that used was (Tie-Constrain) with specific contact properties for each layer as In Table 2, [22].

3.8 Analysis type

A Dynamic Explicit type analysis is used with total time of 50 second. Based on the time increment equation for the explicit analysis below, the less time increment will be $7.53*10^{-7}$ and this time increment is calculated for the Lead core of isolation system. This small-time increment will increase the analysis time to a higher value, so in order to increase this time increment we use the (Mass-Scaling) method that is available in the dynamic Explicit:

$$\Delta t = L * \sqrt{(m/E)} \quad (1)$$

where:
Δt - Time increment [s],
L - smallest mesh size [m],
m - mass of the element [kg],
E - Young modulus [Pa].

4 Results and discussion

4.1 water pressure distribution around the offshore platform

Water pressure around the offshore platform is showed in Fig. 13 for the three different models. It is notice that water pressure is in its maximum level at the bottom of the platform and it decreases as it goes high until it reaches the top surface where the wave hits the deck of the platform, and here it is notice a turbulence happens in an unorganized way because of water impact with the platform structure. Also, the pressure for all three models is nearly the same in each one of the three models, and this is probably because the shape of the platform doesn't change in the models, the only change is the existence of isolation system in different location within the platform.

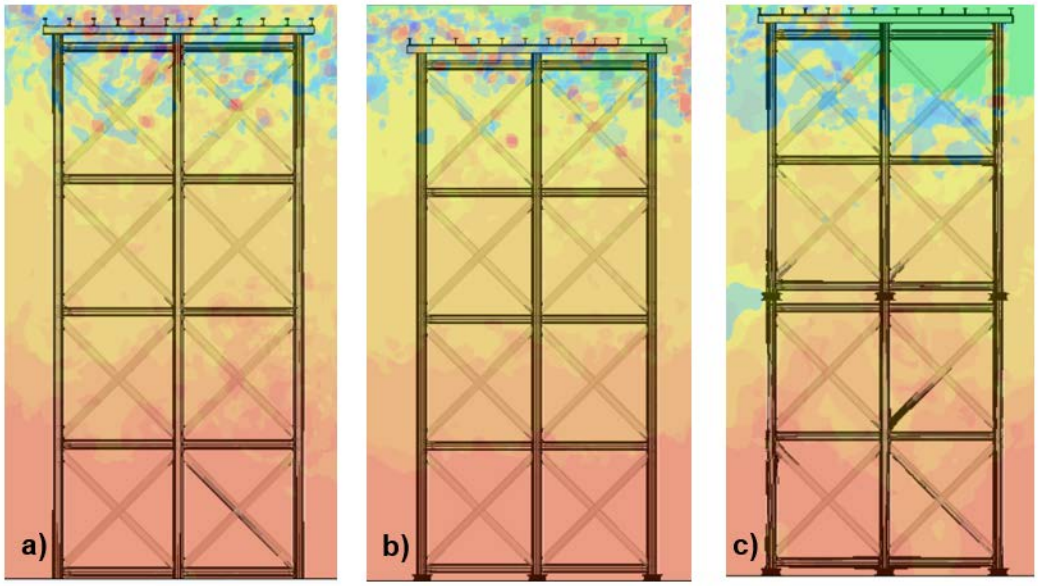


Fig. 13: Water pressure distribution in water domain for three different platform models a) Fixed base, b) Isolated base, c) Isolated base and middle at column middle level.

4.2 Displacement of the platform at the base level

The displacement at the platform base is very important during the wave because of the poor soil layer at the bottom of the sea and it causes damage to the piles. Fig. 14 shows the displacement in the water wave direction (*X*-direction) at the base of the platforms including soil first layer and isolation system. It is notice that in the fixed base case the front and middle row part of the base is displaced in the positive direction to high level about 1.2 cm while the back row of base part is displaced in the negative direction. While in the other two cases that all rows are nearly displaced in a normal level.

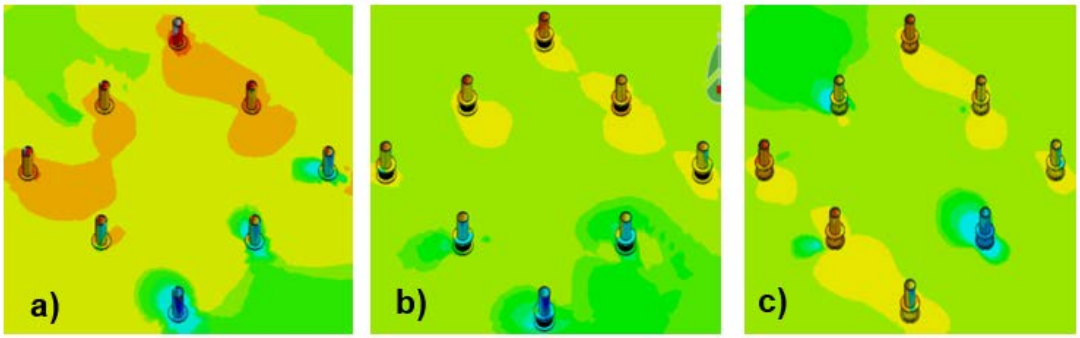


Fig. 14: Displacement at the base level for all three cases a) Fixed base, b) Isolated base, c) Isolated base and middle at column middle level.

4.3 Deck displacement of the platform

The maximum displacement that occurred in the offshore platform deck was studied for the three cases, where only the maximum part was drawn because the curves would be clear. Through Fig. 15, the displacement value in the isolated base is less than the other cases, as it decreases by 26 % from the fixed base by 51 % when the isolated in the base and middle of columns. This indicator is very important because it also shows the effect of the movement of the isolated on the parts of the platform. The phase of the displacement curve when the isolate is at the base and middle of the columns is completely different from the other cases because of the freedom of movement that occurs in the isolate.

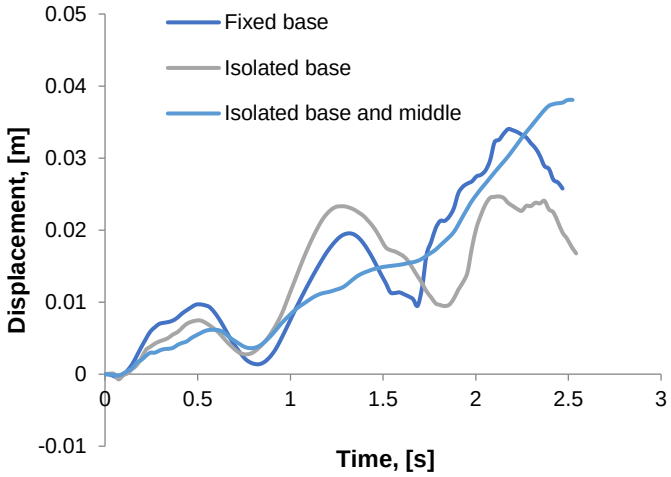


Fig. 15: Deck displacement of platform for three offshore platform case.

4.4 Column displacement of the platform

The other importance parts are the columns, where the response of the columns under the water wave of three type of the offshore platform has been studied. Fig. 16 shows the distortions that occur in the columns as a result of water waves. In all cases, the displacements along the columns are close, and the displacement in the deck of the platform is little as possible because of the bonding that occurs in the deck of the platform, as well as at the base due to cohesion with the soil. In the case of isolate in the base and the middle of the columns, the upper part of the columns is the largest possible displacement, unlike the lower part, it was the least possible compared to the other cases, and the reason for the presence of insulation led to the dispersion of wave energy in the lower part.

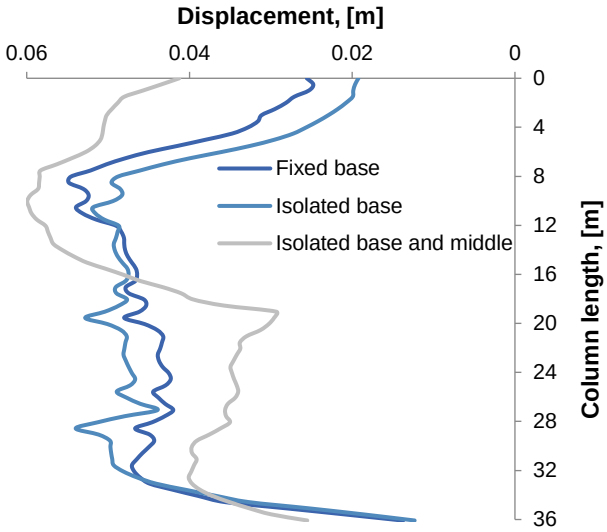


Fig. 16: Displacement along the column length for three offshore platform case.

4.5 Pile displacement of the platform

Fig. 17 shows the maximum displacement along the pile length for the three cases of the offshore platform. The pile with the highest displacement in all cases was taken and compared with the other cases. Through the figure, it was observed that when the base of the platform is fixed, the displacement is greater than the other cases. When the platform contains the isolation system, the displacement of the pile is very small, as the isolation system reduced the amount of displacement by 68 % of the displacement when the platform is in a fixed based. Also, the displacement inflection point differed in the three cases, and this is due to the isolation system used. The change in the pile fixed length cannot be estimated at present study and needs more study of its own. But it can be said that the difference in the pile fixed length is very small.

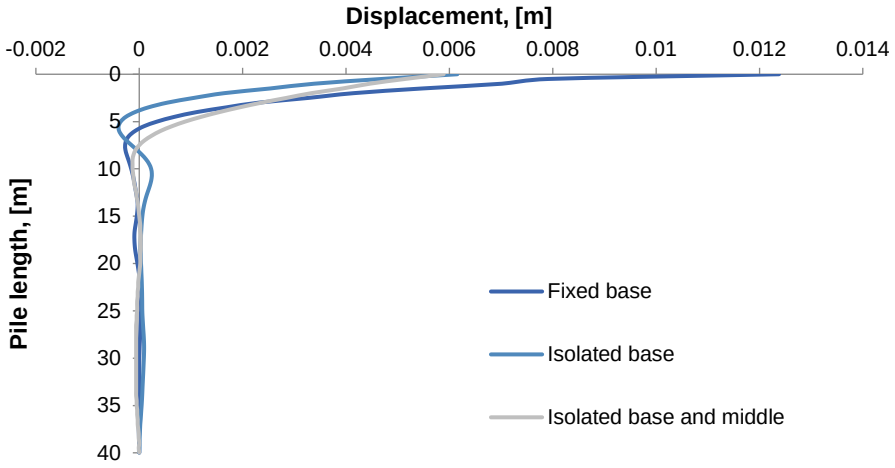


Fig. 17: Maximum displacement along the pile length for three offshore platform case.

4.6 Pile rotation [rad] of the platform

The rotation angle or the twist angle of the pile is an important engineering property that should be calculated and focused on in engineering design. Fig. 18 shows the maximum rotation angle along the piles for the three cases study. It is noted that when the base of the offshore platform is fixed, the twist angle is the maximum that can be reversed in the isolation system used in the other offshore platforms. The angle of rotation has almost vanished in the isolation system, which is an excellent indicator in this case. The figure also shows that the angle rotation of the pile for fixed base platform continued at about 10 m below the soil surface and at a very large angle, unlike in other cases.

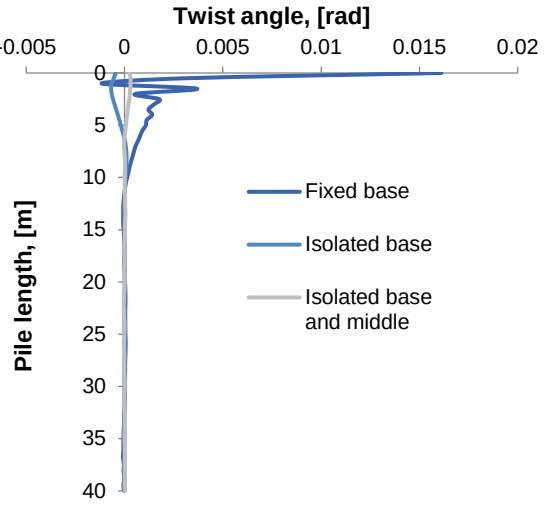


Fig. 18: Shows the maximum rotation angle along the piles for the three cases study.

4.7 Shear force along the pile length of the platform

The shear force curve is drawn for the first five meters of the pile for all cases until the shear forces are fully demonstrated over this distance Fig. 19, after which the shear force is zero along the pile length. The shear force is as low as possible in the case of using the isolation system at the base of the offshore platform due to the fading of the force in the isolation system, in the case of the fixed platform the shear force is very large. In the case of a fixed base, the soil works to absorb the shear force from the piles and disperses it to the soil, and whenever the soil is solid the fading is as large as possible, in contrast to the soft soil.

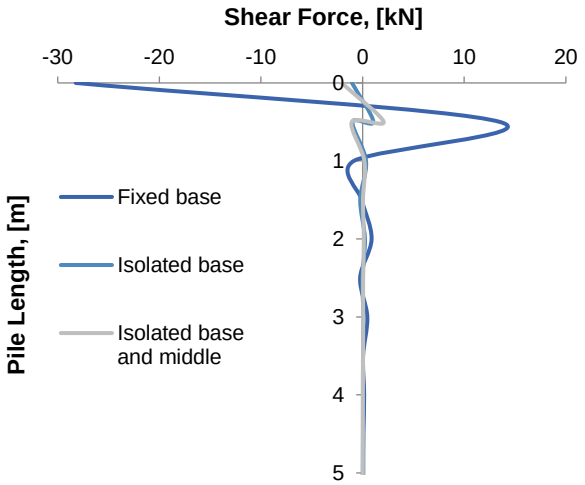


Fig. 19: Shows the maximum shear force along the piles for the three cases study.

4.8 Pile bending moment of the platform

The bending moment curves were drawn for five meters of the pile for all cases so that the bending moments are fully illustrated during this distance, where the bending moment is almost zero along the length of the pile after 2 m, Fig. 20. The moments are zero at the pile head in the case of using the isolation system at the base of the offshore platform, and this indicates that the isolation system works as a hinge work at the pile head, in the case of the fixed platform, the bending moments are very large at the pile head. The fixed moment depth in this case is less than what it is in the normal cases that do not use the isolation system, and this shows the real and engineering effect of the isolation system. Also, the soil has an important role in the case of a fixed base in absorbing the moments from the piles and dispersing them to the soil.

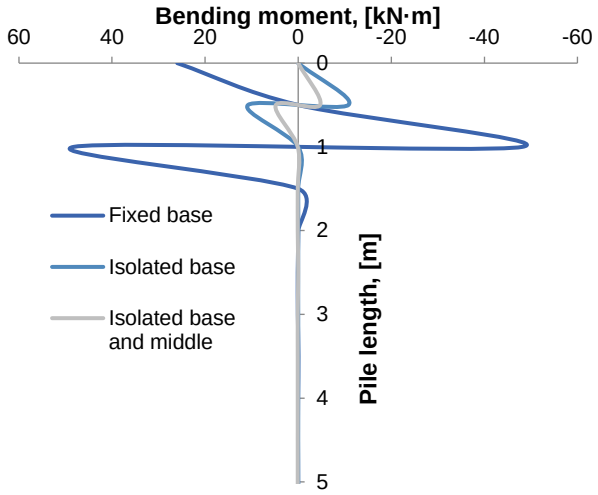


Fig. 20: Shows the maximum bending moment along the piles for the three cases study.

5 Conclusion

By studying the three cases in the research, the study can be summarized through the following points.

1) The current study differed from many previous studies and gave a wonderful model in the real representation of the soil -structure interaction and water - structure interaction, and the analysis method was clear and accurate.

2) Computational Fluid Dynamics analysis should be adopted in all structures that are exposed to water, such as offshore platforms, bridges, etc.

3) Choosing a suitable isolation system in offshore platforms reduces the facilities' response to the loads placed on them, such as water waves, impact loads, earthquakes, etc.

4) Representing materials and elements in a real way gives a clear indication of the response of the facility.

5) The presence of an isolation system at the base of the offshore platform at the pile head generates complete stability for the platform when exposed to high water waves, and this reduces the loads and moments transmitted to the foundations of the platform.

6) The isolation system works as a hinge in transferring loads and moments. Where the bending moments transmitted to the foundations are zero, while the shear strength is as low as possible or vanished.

7) The water pressure on the platform is irregular in all cases, and the maximum amount is at the base of the platform. But the isolation system allows the upper part of the platform to move freely.

8) When the base is fixed, the effect is on the piles in the first line of the wave direction, making it move more than the other piles in the other lines. But the isolation system makes the displacement almost constant at each pile head and in any line it is.

9) The displacement of the offshore platform deck is very small in the case of using an isolation system at the base only, unlike what is present in the case of an isolation system at the base and in the middle of the columns, the displacement is very high, increased 50 %. In the case of the fixed base, the displacement is higher than the isolation system in the base by about 26 %.

10) It is noted that the displacement of the columns in the isolation system at the base only is less than the rest of the cases, and this indicates that the upper part of the platform acts as a block interconnected with each other.

11) The twist angle is almost vanishes and the displacement is reduce by 68 % at the pile head using the isolation system.

12) The pile fixity length and pile fixity moment are reduced by using the isolation system.

13) Choosing the ABAQUS program was very useful for the study and showing the results clearly and in conformity with reality.

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