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Effect of pile dimensions on the behavior of container berth under shipload impact

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Abstract: Container berths are an essential component of the marine wharf that sustains loads from various sources, such as self-weight, operation loads, and environment loads. However, the shipload has more impact on the structure. The container berth in Um Qaser Port is chosen as a case study. This paper numerically investigates the response of container berth structures under the impact of dynamic load. Abaqus software is applied to simulate the components of the structures. The study has dealt with the choice of eight different diameters of the piles, starting from 800 mm to 1500 mm. The study included three cases of pile diameter. The first case is the effect of changing the spacing between the piles. The second case is the effect of the pile depth embedded in the soil. The third case is the change in the thickness of the pile diameter. This study aims to explore the behavior and performance of the pavement structure by changing some parameters, including the diameter of the pile, which is considered the prime and significant portion of the formation of the structure. The changing of pile spacing from 4D to 5D and 6D leads to an increase in deck displacement by ratio between 44% - 76% and between 100% - 349% respectively, while changing the pile depth from 15 to 18 and 21m leads to decrease deck displacement between 0.1% - 2% and between 3% - 10% respectively. Also when it changes the pile thickness from 17 to 20 and 23mm lead to decrease deck displacement range between 9% - 13% and 17% - 24% respectively.

Keywords: container berth, Um Qaser, ship impact, pile diameter, Abaqus.

1. Introduction

Ships are loaded and unloaded onto wharves. The design of berths depends on the kind of vessel that will occupy them. Different terminology is used to describe the most often utilized berth structures. This includes dolphins, piers, quays, jetties, and wharves. Depending on the port, berthing structures are differently classified for different purposes. The size of the berths varies from 5 to 10 m for small boats and exceeds 400 m for larger tankers. Generally, a berth's length should be about 10% longer than the longest vessel parked there. Three types of piles are used to safeguard a wharf from typical wear and tear: fender, mooring, and bearing piles. The pier or wharf's decking and framework are supported by bearing piles. The piles should be straight, and their length should vary based on the water's depth and the state of the bottom. An exposed wharf can be collapsed by the power of a moving ship making direct contact with bearing piles. Fender piles are used to protect and absorb the initial impact. The kinetic energy method is a widely utilized technique in the design of fender systems [1]. Several researches have dealt with the problem of berth structure to the collision of the ship. In 2009 Zhang et, al. [2] examined the load-transfer analytical solution for a single pile in expanding soil. The results demonstrate that while increasing pile length can effectively reduce upward pile movement, doing so also causes the tensile forces of the pile shaft to increase. In expansive soils, piles with a diameter of less than 0.044L (L is the length of pile) can effectively reduce upward pile movements, while piles with a diameter greater than 0.045L contribute little if anything at all. In 2015 Chopra and Patel [3] researched and designed of the piles that serve as the jetty's substructure are included in the study.

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STAAD software was used to model a jetty with piles with diameters of one, two, and four meters. The maximum moment, shear force, and transverse deflection had been extracted from the data. Additionally, design has been completed by creating excel programs and doing cost calculations.
The results showed the most cost-effective combination of pile diameter, depth, and longitudinal and transverse c/c distance between piles. In 2016 Deka [4] used ANSYS software to show a three-dimensional finite element analysis of a pile group foundation under lateral load. The study was done on the effects of pile configuration, diameter, and length within the group. The study changed the length-to-diameter (L/D) ratio and pile spacing. Showed that if the diameter remains constant and the length varies, the increase in the pile's L/D ratio did not result in a corresponding rise in the pile group's lateral load capacity. A pile group's capacity to support a lateral load increases as the pile's diameter rises. In 2016 Kavitha [5] Predicted how piles in berthing structures would behave under lateral load was one of the findings. On a typical ship berthing structure frame, several numerical analyses have been performed in PLAXIS-3D to examine the effects of pile diameter, soil modulus, and bed slope on the piles' structural behavior. In order to comprehend the roles that pile diameter, soil modulus, and bed slope play in predicting the maximum bending moment, pile depth of fixity, and pile top deflection, a set of multivariable regression equations is also established. In 2016, Hasan [6] examined the dolphin structure of Um-Qaser used to study the effect of pile dimensions and soil properties on the structural response under impact loading and elasto-plastic soil state, the result showed that the increasing of pile diameter and pile length decreased the structure response (deck displacement, pile head displacement and pile bending moment) and increased the applied load. In 2017 vremalatha et al. [7] applied finite element software to a group of single frame piles in a sloping marine berth structure. In order to investigate the impact on the load distribution among the piles and the lateral load, the diameter of the piles at various points in a gradient has been altered. Reducing the diameter of the rear piles was found to lessen the structure's deflection significantly. In 2019 Shao and Lee [8] created a dolphin structure while considering offshore load factors as mooring, wind, wave, and current stresses. By choosing the pile structure's diameter, thickness, and arraying direction while keeping the axial compressive pressure-bending moment ratio and total displacement limitations, the design goal is to minimize the pile structure's overall weight. In 2019 Ahemer [9] studied the parametric of dolphin structure by discussing the same thickness for different pile diameters, he found the natural frequency increased with the increase of diameters and for the same diameter there is also increasing in natural frequency with thickness increase. In 2019 Azeez et al. [10] examined how a single pile's embedded length affected its maximum lateral load capacity. Four embedment lengths were chosen (250, 300, 350, and 400 mm) and a 30 mm steel rod pile was employed. Three distinct relative concentrations of sand loose, medium, and dense encased the mound. The findings show that when the embedded ratio (L/D) improves from 8.3 to 13.3, the capacity of a laterally loaded pile can increase by up to 247%, and when the relative density increases from 12% to 85%, the resisting capacity of the pile can increase by up to 599%. In 2020 Azhar et, al. [11] changed the raft thickness, pile diameter, pile length, and pile spacing to examine the behavior and effectiveness of the combination piled raft foundation. This made it easier to comprehend how the raft's total and differential settlement varied, as well as how the raft's maximum moment and pile load sharing worked. Maximum pressure, differential settlement, and settlement are entirely decreased with larger pile diameters.

2. Research Methodology

ABAQUS finite element program was used to simulate the problem. The details of the analysis model of container berth or flowchart illustrating the research are shown in Fig. 1. To do the modeling, one unit of pavement was chosen with dimensions (46 x 25 x 0.7) m containing (40) piles arranged in eight columns with a distance of (6m) and five lines in a row with a distance of (5.5 m). The concrete deck slab was modeled by used 3D-structural thick shell-4node (S4R). and soil were modeled using eight-node brick elements (C3D8R) so that each node has three degrees of freedom representing the translation motion in three global coordinates. The piles (steel pipes) and steel beams section were modeled by used pipe section and I-section respectively for 2-node beam element (B31). A mesh size of 0.5m*0.5m have been used through this study. Fig. 2 shows the three-dimensional modeling of the structure with soil dimensions.

Appropriate establishment of the soil mass dimensions is necessary to minimize the impact of borders on the outcomes boundary condition. It includes all soil domains that are regarded as fixed, except for the top, which is regarded as free. The distance between piles and the soil boundary's borders is equal to 10D (D: pile diameter), also the distance from the ends of the piles to the bottom of the soil boundary equals 10D.

Using the Mohr-Coulomb model, nonlinear behavior is modeled. One way to express the Coulomb criteria of failure is as Naylor et al. [12] equation, as follows:

$$|\tau| \leq \sigma n \tan\emptyset + c \tag{1}$$

Where; τ- shear stress, σn-normal effective stress, c- cohesion, $\emptyset$- internal angle of shearing friction.
The relationship between soil and piles is represented by the term embedded region. The damping ratio that is utilized in the current study's analysis has a value of (0.05).
The berth structure is subjected to load combinations; [dead load + current load + berthing load] [13].
Dead loads include the self-weight of a structure calculated by the program and the roof load (Compacted sand and Asphalt paving). Usually, the ship berths parallel to the current. The following equation can be used to determine the pressure intensity on piles that are parallel to the direction of the water current [14]:

$$F_C = C_c \times Ac \times \gamma V^2/2g \tag{2}$$

Where,
F_C = current force,
γ = Unit weight of water (1.025t/m^3),
V = velocity of the current .
C_c = factor for calculation of the transverse and longitudinal force.
Ac = area of the ship's submerged section projected onto a plane that is parallel to the current's direction (m^2).

The details of the properties of seawater collected from the information related to the Arabian Gulf for the past 100 years showing the maximum wave [15].

Based on the vessel's dead weight tonnage (50,000), the reaction force on the fender, which corresponds to the above tonnage, is approximately 200 tons as shows in table 1 [16]. Mooring point loads for general cargo vessels and bulk carriers the value of which were based on the table from the Reference [17]. The time history method is used in ABAQUS program for berth port analysis. Table 2 includes all material properties used in the current problem study. The soil is modeled as an elasto-plastic model by using Mohr-Coulomb method, steel is simulated by the perfect elasto-plastic model and the Concrete damaged plasticity (CDP) model in the present study the parameters are detailed in table 3.

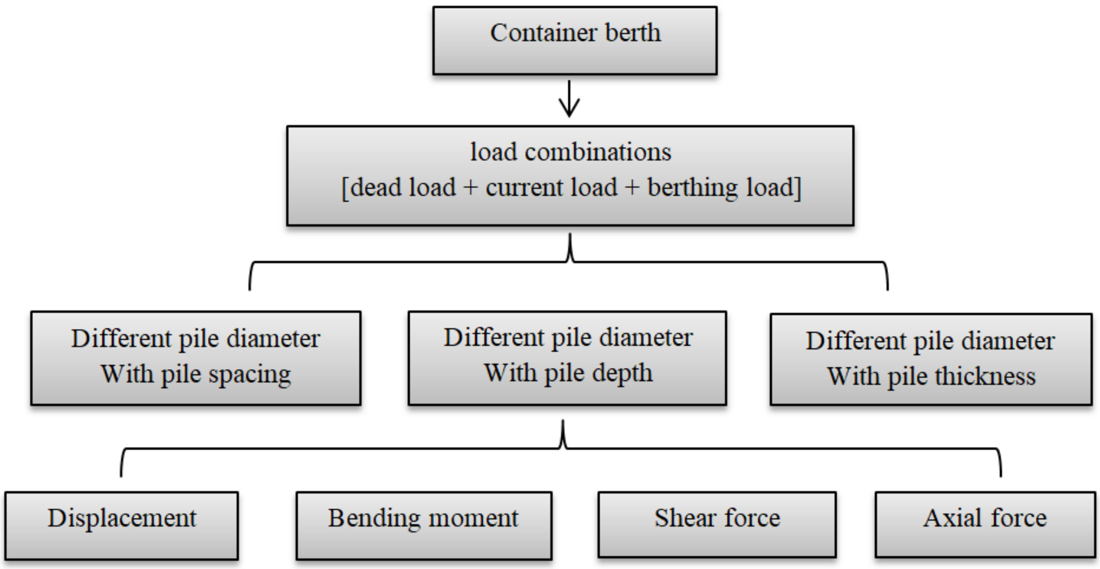

Fig. 1. Flowchart illustrating the research.

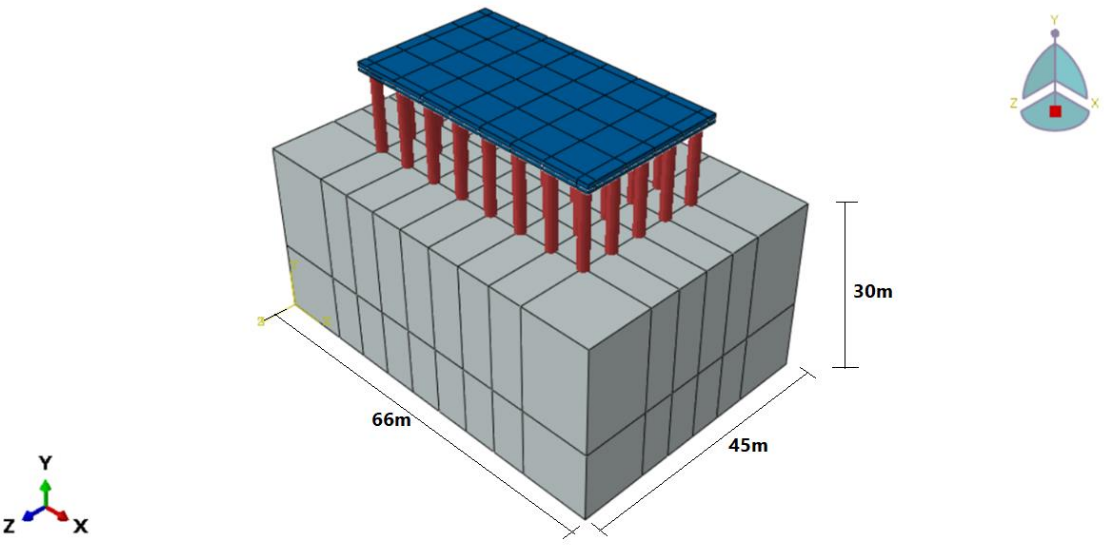

Fig. 2. 3D modeling of Um-Qaser container berth with Abaqus.

Table 1. Fender types with their ranges of application based on dead weight tonnage [16].

Dead weight tonnage (ton)	Type of fender	Approximate energy (ton·m)	Approximate reaction ton)
10,000	Arch or M type	20 – 30	50 – 100
50,000	Cylinder cell or cone	75 – 100	100 – 200
100,000	cell or cone	150 – 200	200 - 300

250,000	Pneumatic / cone	400	300 - 400

Table 2. Details of the Material

Material	Elastic Modulus (MPa)	Poisson´s ratio	cohesion(kPa)	Density (kg/m^3)
Steel	200000	0.3	-	7800
Concrete	25000	0.2	-	2400
Soil	57	0.35	5	2000

$E_c = 4734\sqrt{fc'}$ (ACI 318 2008)

Table 3. relevant parameters of concrete

Dilation angle	Eccentricity	fb0/fc0	K	viscosity parameter
31°	0.1	1.16	0.6667	0

3. Results and Discussion

For this study, the container berth in Um Qaser Port is chosen to analysis under ship impact (berthing load) with dead load (self-weight) and current load. The behavior of contact junctions between the enclosing soil and the structural element considerably impacts the response of structure-foundation systems to static or dynamic loads. These junctions represent the interaction between the soil–structure response, which transmits the load and the deformations as shown in Fig. 3.

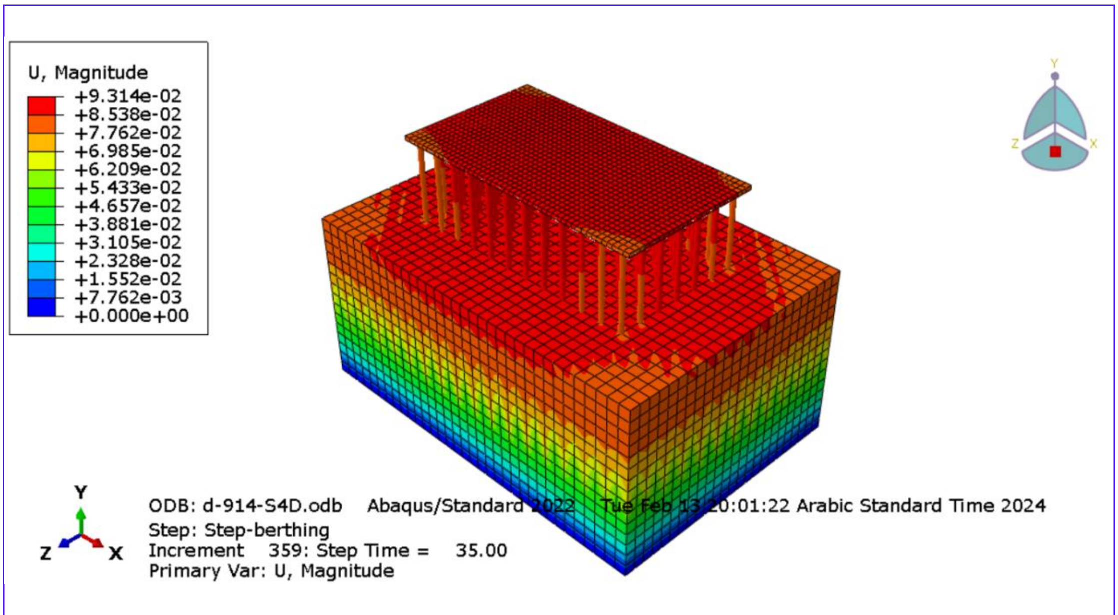

Fig. 3. Deformation of the structure under the influence of loads.

3.1. Impact of pile diameter and spacing

In this case, eight diameters of the pile were selected, starting from 800 mm to 1500 mm. Pile spacing is varied from 4D, 5D, to 6D from center to center in both directions for all pile diameters where D is the diameter of the pile. Fig. 4. represents the relationship between pile diameter and deck displacement for the three pile spacing. From the figures it is clear that the displacement decreases with increasing pile diameter at spacing 4D, while in pile spacing 5D and 6D the displacement decreased in small diameter then increased by increasing diameter of pile, The spacing between the piles increases with increase in the diameter of the pile, and when the spacing increases, the number of piles decreases, which leads to a redistribution of the load on the group of piles. When the pile spacing increase from 4D to 5D and 6D the deck displacement increased range from approximately between 44% - 76% and between 100% - 349% respectively.

Fig. 5 to 7 represent the relationship between the pile diameter and bending moment, shear force and axial force of piles with three pile spacing. The bending moment, shear force and axial force increase with increasing pile diameter for all pile spacing this effect due to increase in sectional area, moment of inertia and stiffness of the pile. As the diameter of the piles increased, it will lead to an increase in the distance between the piles, so their number will decrease and the stresses placed on them will increase. Bending moment for pile diameter from 800mm to 1500mm at change spacing from 4D to 5D and 6D ratio increased approximately between 29% - 44% and 67% - 80% respectively, while the Shear force increased range from approximately between 2% - 16% and between 21% and 25% respectively. The axial force for pile spacing increase from 4D to 5D and 6D its increased between 2% - 6% and between 21% - 63% respectively. As pile spacing increases, there is a minor increase in the reduction in load carrying capacity. As the distance between piles grows, the capacity in each pile decreases. This is because there is less group interaction and each pile acts more like an isolated single pile at bigger spacing.

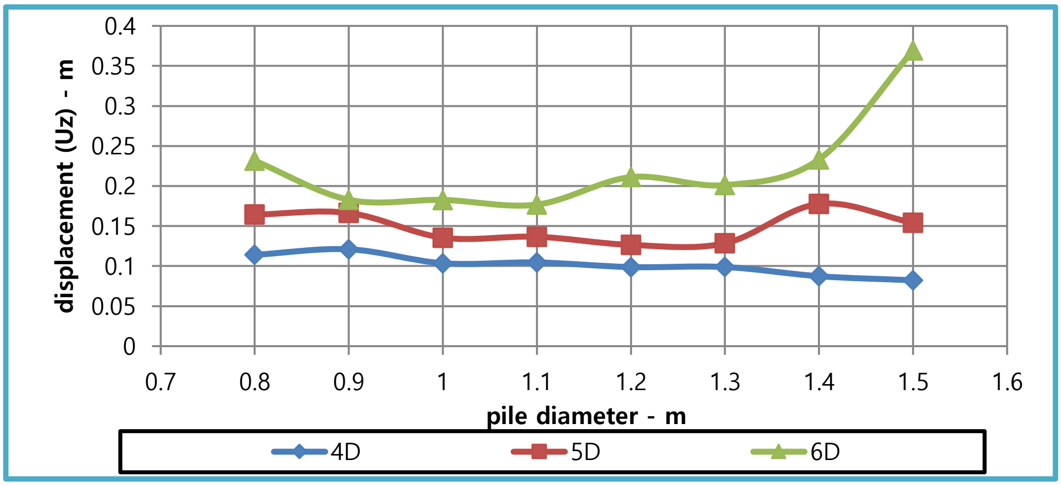

Fig. 4. deck displacement with pile diameter for different spacing of piles.

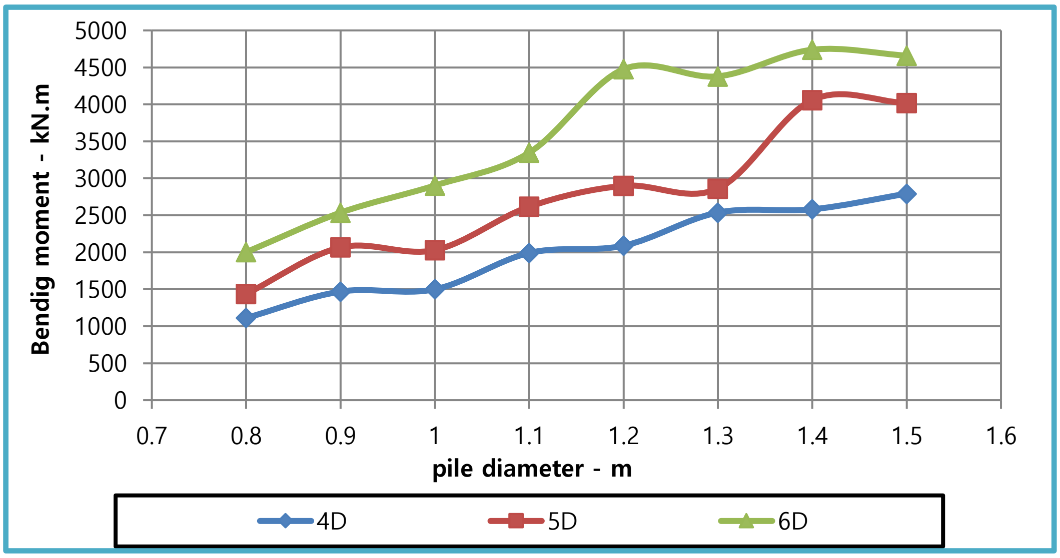

Fig. 5. Bending moment with pile diameter for different spacing of piles.

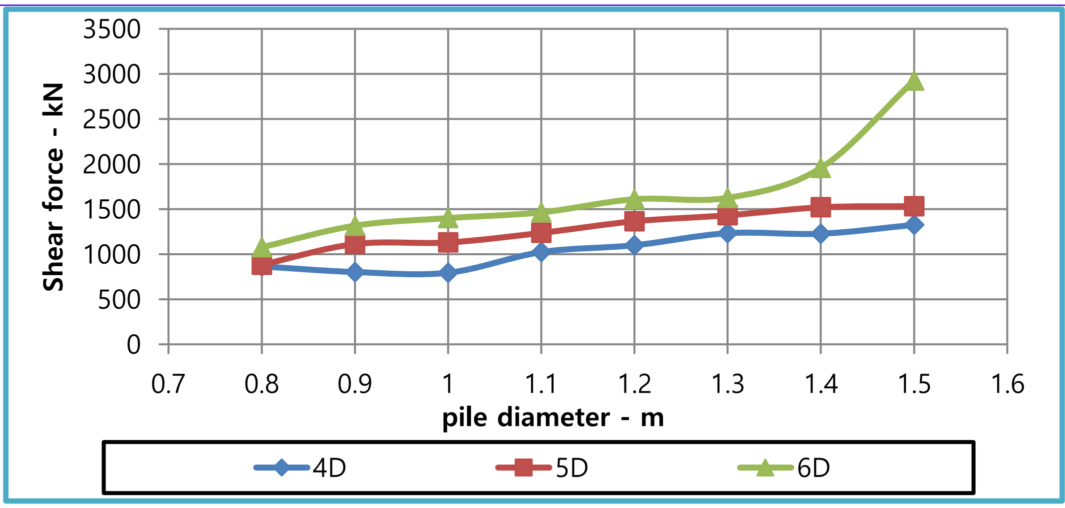

Fig. 6. Shear force with pile diameter for different spacing of piles.

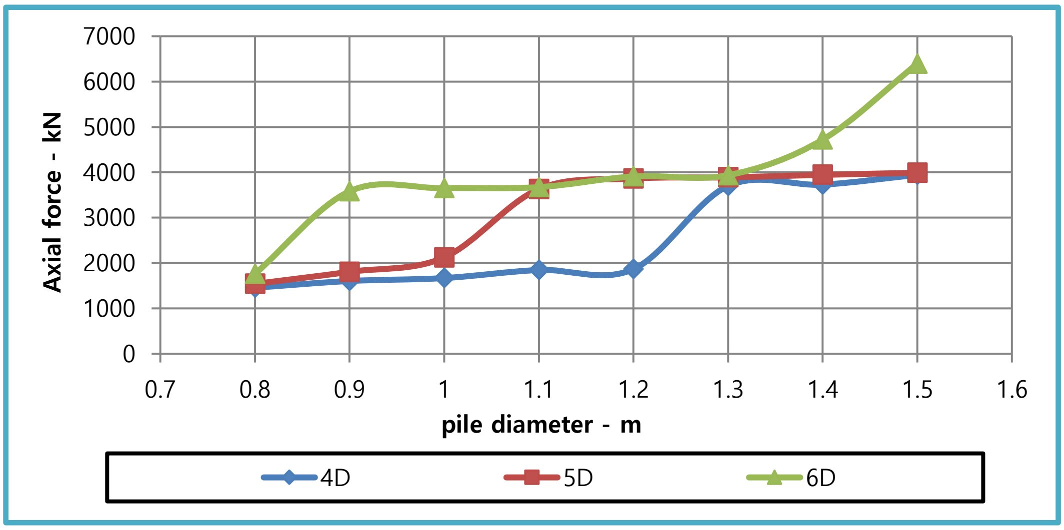

Fig. 7. Axial force with pile diameter for different spacing of piles.

3.2. Behavior of pile diameter with the depth

In this case also eight diameters of the pile selected are starting from 800mm to 1500mm. The thickness of piles in all models are kept constant at 14 mm. the results of this case are shown in figures 8 to 11. The deck displacement as shown in figure 8 represent the relationship between it and the pile diameter for different pile depth 15m, 18m and 21m. The displacement decrease with increasing in pile diameter for all pile depth but the displacement is very small decrease with increasing pile depth as the depth change from 15m to 18m and 21m the reduction range from approximately between 0.1% - 2% and between 3% - 10% respectively.

Fig. 9 represent the relationship between the pile diameter with bending moment. The bending moment decrease with increasing the diameter of the pile for all pile depth and decrease with increasing the pile depth. This behavior is due to increasing in the depth of fixity and increase in the relative stiffens of the soil-pile system due to increase in the embedded length of the pile. Rates of decreased in bending moment with depth for all pile diameter at depth increase from 15m to 18m and 21m by 2% - 3% respectively.

The shear force as shown in Fig. 10 increase with increasing pile length. The length of a pile can affect its shear force in various ways, Increase in shear force with pile length where the longer piles, especially in ocean engineering, are considered frictional piles where lateral friction significantly affects the pile's bearing capacity. Increasing the pile length can lead to an increase in shear force due to the significant effect of lateral friction on the pile's ability to resist shear. The shear force profiles of piles show that increased pile depth leads to higher lateral shear forces acting on the pile. For piles in cohesive soils, the skin friction capacity (which contributes to shear resistance) is calculated as a function of the pile surface area and the average soil cohesion, which increases with depth. In summary, deeper piles generally experience higher shear forces due to the increased soil resistance and frictional forces acting on the pile shaft. The shear force increases up to a critical depth, beyond which it remains relatively constant. Increasing the pile length can impact factors like bending moment and shear force, influencing the overall stability and safety of the structure.

The axial force as shown in Fig. 11 increase almost linearly with increasing the diameter of pile and with increasing pile depth due to increase in weight of the pile. The axial force for pile diameter increase at pile depth increasing from 15m to 18m and 21m between 27% -28% and between 63% - 65% respectively.

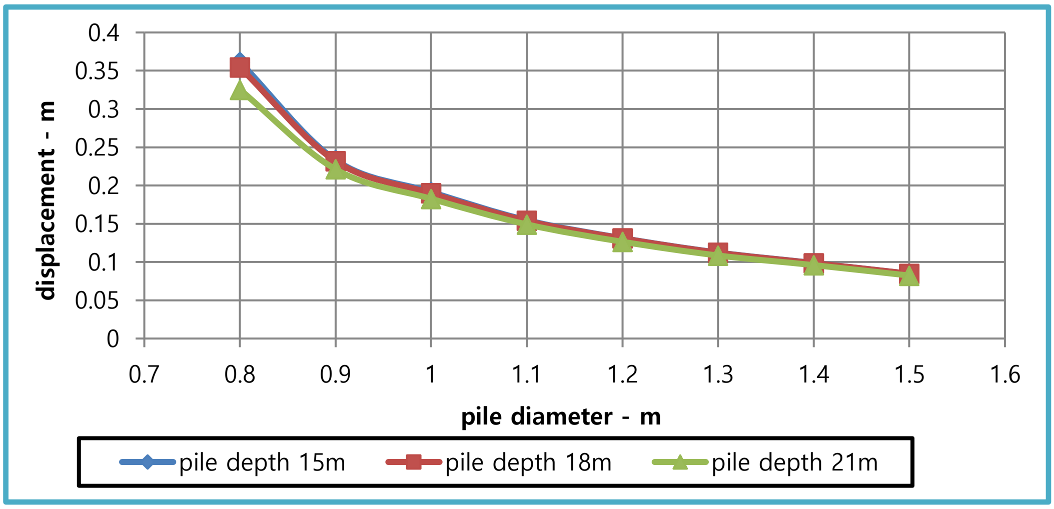

Fig. 8. Deck displacement with pile diameter for different pile depth.

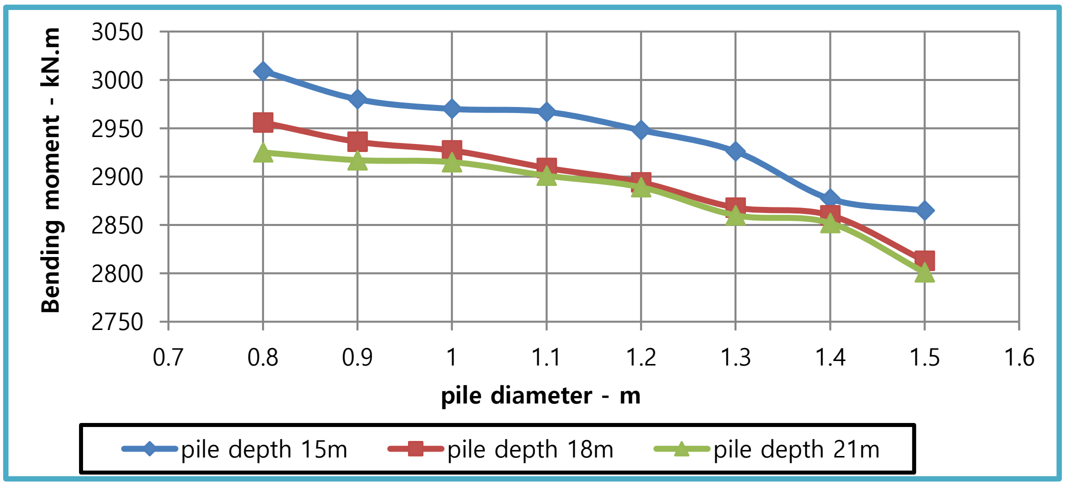

Fig. 9. Bending moment with pile diameter for different pile depth.

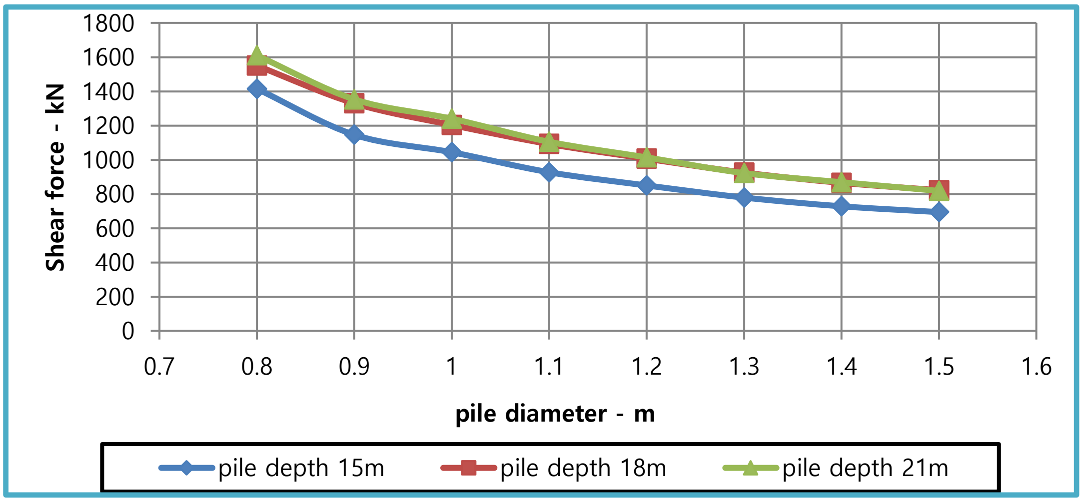

Fig. 10. Shear force with pile diameter for different pile depth.

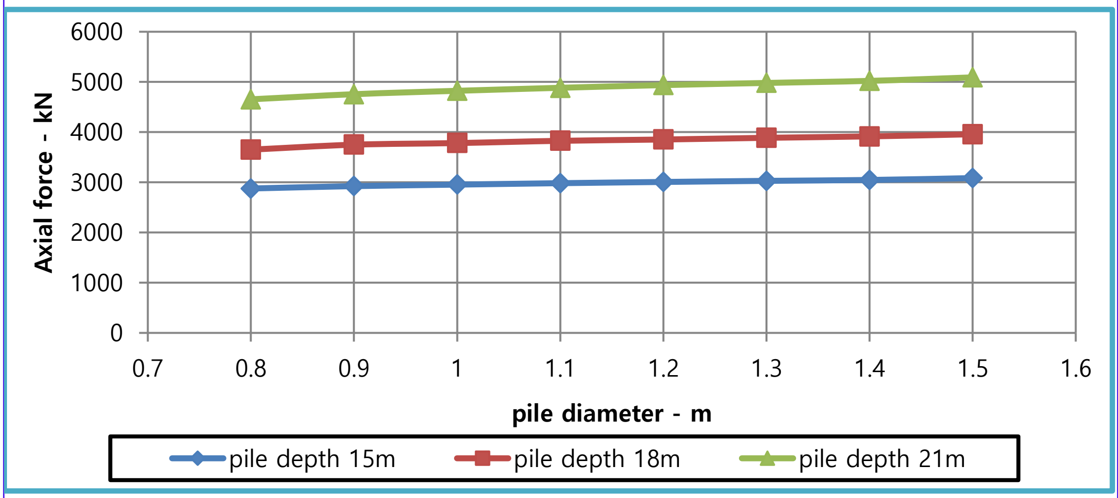

Fig. 11. Axial force with pile diameter for different pile depth.

3.3. Different pile diameter with pile thickness

In this case the results are shown in figures 12 to 15. In this case pile thickness are chosen, 17, 20 and 23mm for varied pile diameter from 800mm to 1500mm. The deck displacement and pile bending moment decrease with increasing pile diameter and with pile thickness this effect due to increase in sectional area, moment of inertia and stiffness of the pile. However the decrease displacement for all pile diameter at depth increase from 17mm to 20m and 23m the reduction range between 9% -13% and 17% - 24% respectively, while the bending moment reduction range between 1% - 3% .

Fig. 14 represent the relationship between the shear force and pile diameter for different thickness of pile. From the figure it is clear that there is a convergence in the shear forces for the three cases of substrate thickness, as the increasing the diameter and thickness of piles can lead to higher load capacity and ultimate shear stress. The thicker the pile, the higher its ability to resist shear forces and bending moment.

Figure 15 represent the relationship between axial force and pile diameter for three pile thickness. The axial force increase with increasing pile diameter and with increasing the pile thickness, whereas the rate increase in axial force varied with thickness from 1% to 2%.

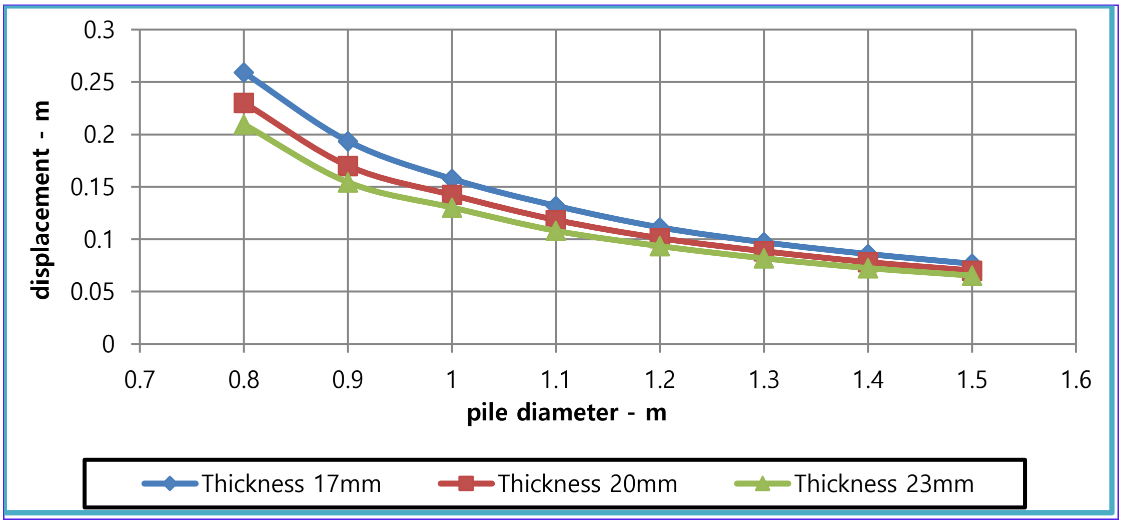

Fig. 12. deck displacement with pile diameter for different thickness of piles.

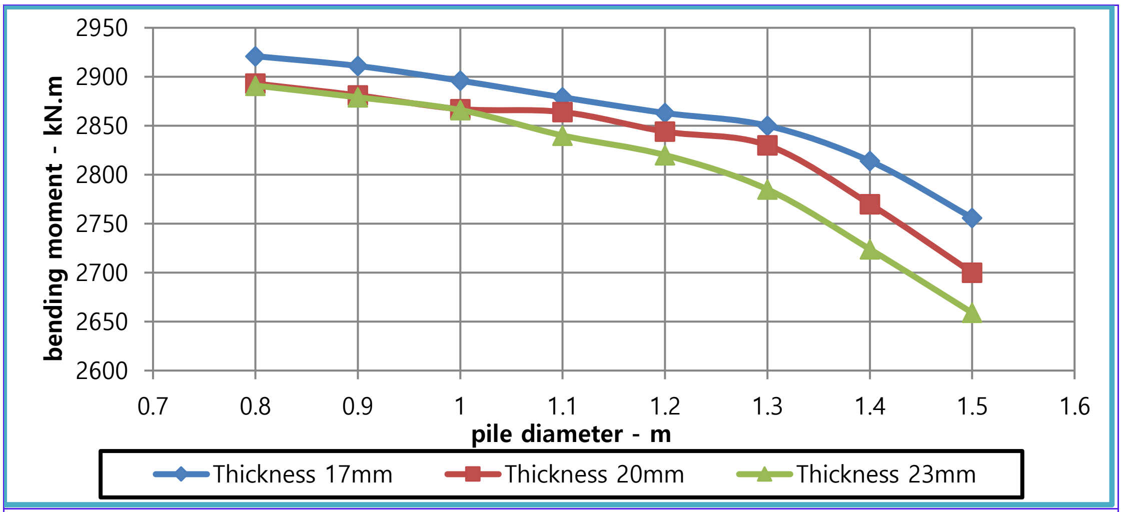

Fig. 13. Bending moment with pile diameter for different thickness of piles.

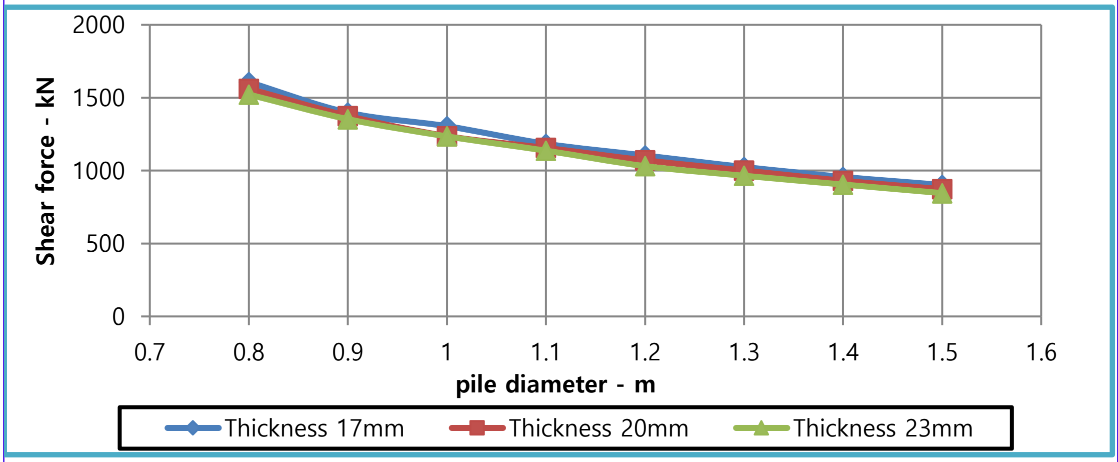

Fig. 14. Shear force with pile diameter for different thickness of piles.

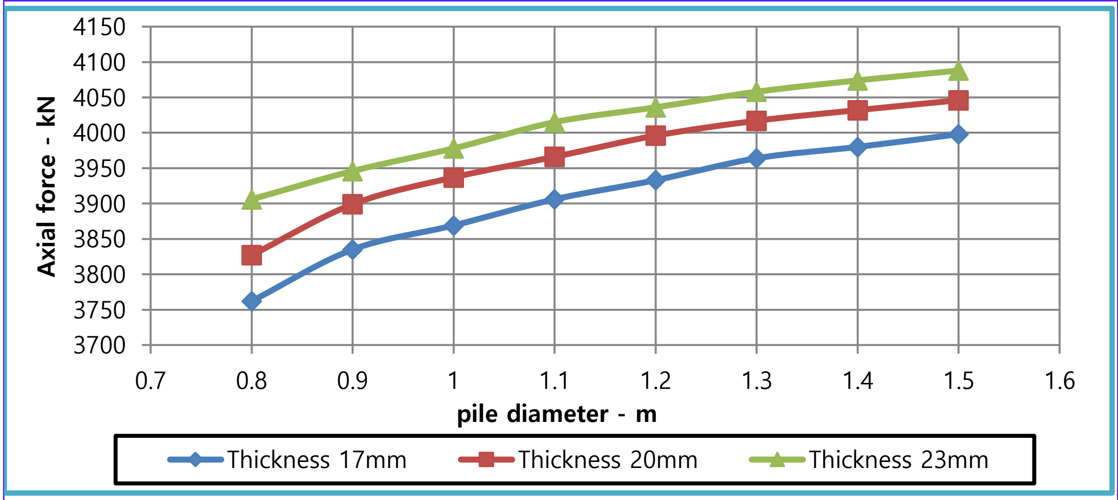

Fig. 15. Axial force with pile diameter for different thickness of piles.

Summary and Conclusions

The study used the elements specified by the Abacus program to analyze the container berth in Um-Qaser Port and determine the structure's behavior under the influence of the ship's impact load. The study dealt with three cases of study, changing the diameter of the pile with each of the distance between the piles, changing the depth of the piles, and changing the thickness of the piles. The results obtained from the analysis showed the effect of these variables on the behavior of the structure.

The conclusion of this study can be given as follows:

1- The deck displacement, bending moment, shear force and axial force increase with increasing pile spacing. Increasing the spaces between the piles with the increase in the diameter of the pile leads to a decrease in the number of piles, which causes increased stress and deformation on the structure.

2- Increasing pile depth in soil embedded its due to decrease deck displacement and bending moment, this was due to the friction was mobilized on increased embedment of pile. The fixity of pile length and critical embedded pile length is not affected by changing pile length. While the shear force and axial force increase with increasing pile depth. Increasing the pile length can lead to an increase in shear force due to the significant effect of lateral friction on the pile's ability to resist shear. The effect of pile length is very important when increasing lateral loads and axial loads.

3- The deck displacement and pile bending moment decrease with increasing pile diameter and with pile thickness this effect due to increase in sectional area, moment of inertia and stiffness of the pile. The thicker the pile, the higher its ability to resist shear forces, while the axial force increase with increasing pile thickness this effect due to increase in weight and sectional area of the pile.

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Conflicts of Interest: The authors declare no conflict of interest

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