Journal of Engineering Science and Technology
Vol. X, No. Y (Year) PPP - QQQ

A NOVEL NUMERICAL MODEL APPROACH FOR EXAMINING SHIP BERTHING IMPACT ON FLOATING PIERS

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Abstract

This paper presents the results of an investigation into the impact of ship berthing upon floating piers using highly advanced numerical software Abaqus. The ship and floating piers were modeled as solid bodies. For the first time, the effect of soil on the total energy absorption of the system was considered using both elastic and elastic-perfectly plastic soil models. First the results for the elastic soil model were compared to and verified by the existing literature using a spring soil model.

Then a continuum soil model was utilized instead of a spring soil model, with the results showing 27% higher energy absorption compared to the spring model. The investigation also considered a model with soil as an elastic-perfectly plastic material, being more aligned with the soil material's real behavior. With this model the results produced 1% more energy absorption as the soil did not reach plastic failure.

Keywords: Beth impact, Abaqus, Offshore systems, dynamic interaction, soil-pier system

1. Introduction

The idea of floating structures has been gaining increasing interest in recent times. This is exemplified in research into wind turbines [1] and floating pier structures [2, 3, 4]. In addition to this, the application of numerical modeling in marine systems has recently received more attention [5]. There have also been studies conducted into mooring analysis by authors such as Schelfn and Östergaard [6] and Natarajan and Ganapathy [7]. This study focuses on the modeling of the impact of berthing on floating piers. Floating pier systems are widely used around the world and include different elements such as pontoons and mooring piles. When berthing impact occurs, the load is transferred to pontoons in the form of floating impact resistance. The load is then transferred to piles which are intended to laterally support the whole system against berthing impact. The capacity of the piling in this system is obviously important and warrants further investigation. The latest study in this area was conducted by Mostofi and Bargi [4] in which they considered soil as a number of springs. This assumption significantly affected the system's response and as consequence the focus is now on modeling the soil component as accurately as possible. The complete system was modeled and verified against the latest work done by Mostofi and Bargi [4] using Abaqus [8]. Since the actual structural behaviour of pontoon can be represented more closely as a three dimensional structural part, it is decided to simulate the pontoon used in this study as a solid element rather than a "shell" element, as modeled in other recent studies; however, this will have a negligible effects on the pier deflection due to impact energy. The impact effects of ship and pontoon considering interaction effects has been studied by Chegenizadeh, Ghadimi and Nikraz [9]. As continuation of that study in Curtin University, in this study the Abaqus program employed to conduct a finite element simulation of impact.

Figure 1 shows a floating pier system which consists of ships, fenders, pontoons and piles. Historically, approaches have recommended that fenders bear the full berthing impact of the ship. However, a study by Mostofi and Bragi [4] recommended that at every berthing stage, each of the system's components acts in turn as a conveyor of the impact load. In the first stage, the ship load impacts upon the fenders, and ship and fenders act as one in transferring the load to the pontoons. The ship, fenders and pontoons then act in unison as a system, and transfer the load to the piles. As the final bulwark, the stability and capacity of these piles requires thorough investigation, and this is the main concern of this study. A continuous soil medium is used as an alternative to the spring model.

Nomenclatures

M_i	Mass (of pontoon, piers, ship etc.) where i=1,2,3,…
V_i	Velocity (of pontoon, piers, ship etc.) where i=1,2,3,…
E_i	Energy (of pontoon, piers, ship etc.) where i=1,2,3,…
σ_i	Components of stress tensor
c	Cohesion of the soil
f	Flow rule of constitutive model
n	Total number of piles

Greek Symbols

ϕ	Friction angle of soil
γ	Unit Weight of soil
υ	Poisson Ratio

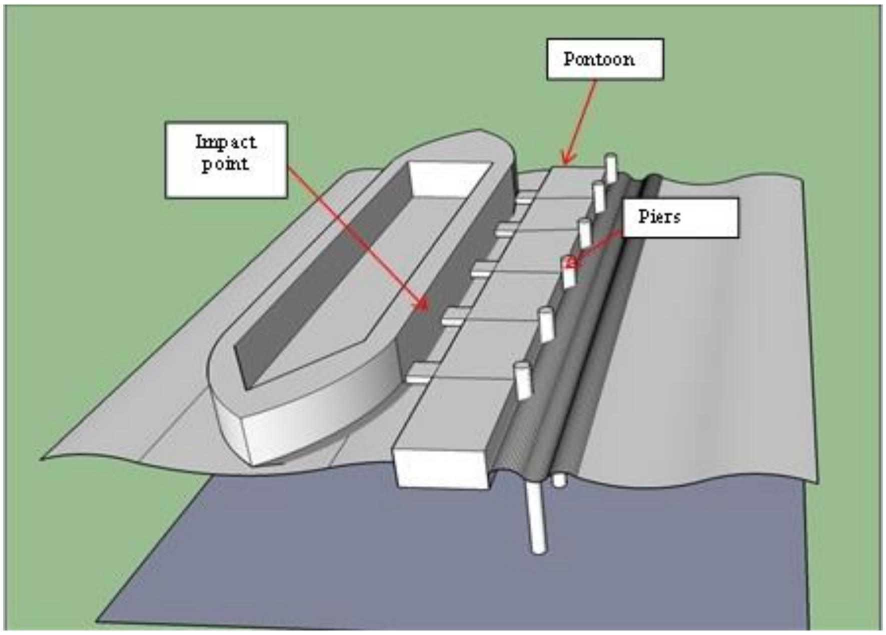

Fig. 1. Schematic Illustration of the Problem.

2. Theoretical Background

The simplified principle of impact, as presented by Mostofi and Bargi [4], is the momentum conservation equation (Chegenizadeh, Ghadimi and Nikraz [9], Mostofi and Bargi [4]):

$$M_1V_1 + M_2 \times 0 = (M_1 + M_2)V_{12} \qquad (1)$$

or

$$V_{12} = M_1V_1/(M_1 + M_2) \qquad (2)$$

M_1 and M_2 indicate total mass of structural systems and ship.

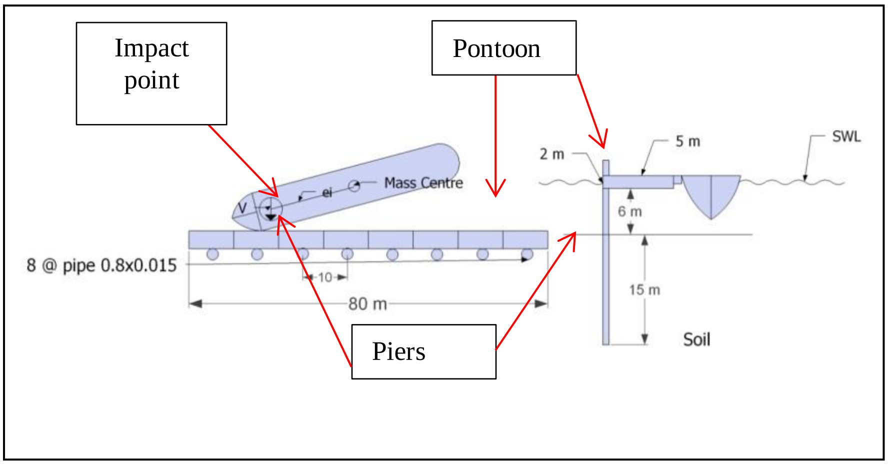

Fig. 2. The Dimension and Assumptions for Numerical Modeling.

Ship impact energy, according to Mostofi and Bargi [4], is considered to be transferred by a one fourth of the ship's longitudinal dimension at the point of contact. The total energy comprises (a) kinetic energy (b) strain energy. In a marine structure, the focus is on strain energy due to its significance which demonstrates how well the structural system can respond to (absorb and deflect) the energy of the impact. In this regard the following equation can be written (Chegenizadeh, Ghadimi and Nikraz [9]):

$$E_{Total} = \int_0^T E_1\,dt + \int_0^T E_2\,dt + \int_0^T E_3\,dt + \sum_1^n \int_0^T E_{P(i)}\,dt \qquad (3)$$

where

E_{Total} = Total induced strain energy of the whole system

E_1 = Strain energy in the ship

E_2 = Strain energy in the soil mass

E_3 = Strain energy in the pontoon

$E_{p(i)}$ = Strain energy induced in the i-th pile

T = Total time of analysis in seconds

n = Total number of piles

This study investigates the effect of soil mass on the ship berthing impact phenomenon. Calculation of the induced strain energy in the whole soil body is a complex task which calls for a new approach, for which the developed Eq. 3 is utilized. Assuming the behavior of a ship to be that of a rigid body, the result of induced strain energy in the ship is zero (E_1 = 0). The strain energy induced in structural parts (E_3 and $E_{p(i)}$) was calculated through a full three-dimensional dynamic analysis (Chegenizadeh, Ghadimi and Nikraz [9]). Therefore, having accounted for the total strain energy (according to the calculations of Mostofi and Bargi [4]), the amount of energy absorbed by soil (E_2) can be evaluated.

3. Developed Numerical Model

All of the pier structures considered in the paper are modeled with Abaqus. All structural and relevant ship properties are presented in Table 1. For the first time, the impact of ship berthing is modeled in Abaqus. Figures 3 and 4 show the ship which is modeled as a solid element, and the complete system including the pontoons and piles. As mentioned earlier, the impact force is modeled as impact acting on one quarter of the ship's length (according to Mostofi and Bargi [4]). The required dynamic analysis, which comprises over 23,184 elements, is time consuming and requires calculation by a large-capacity computer. Therefore, the whole model was analyzed for 4 s. In this 4 s a major part of the impact energy is dissipated. The properties of the soil used in the model are presented in Table 2. To ensure that the soil properties are realistically representative of those in offshore sites, the soil properties used are as documented in Hokmabadi et al. [10].

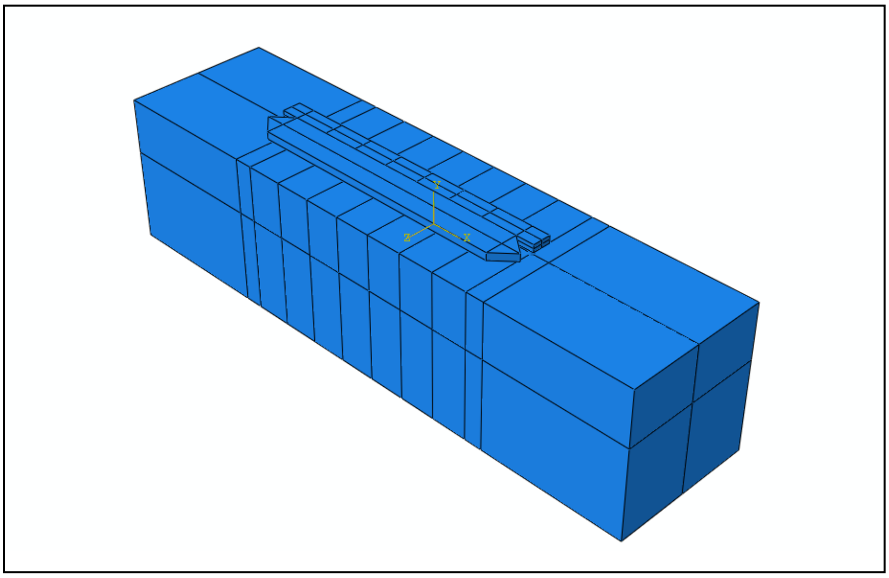

Fig. 3. The Constructed Geometry in Abaqus.

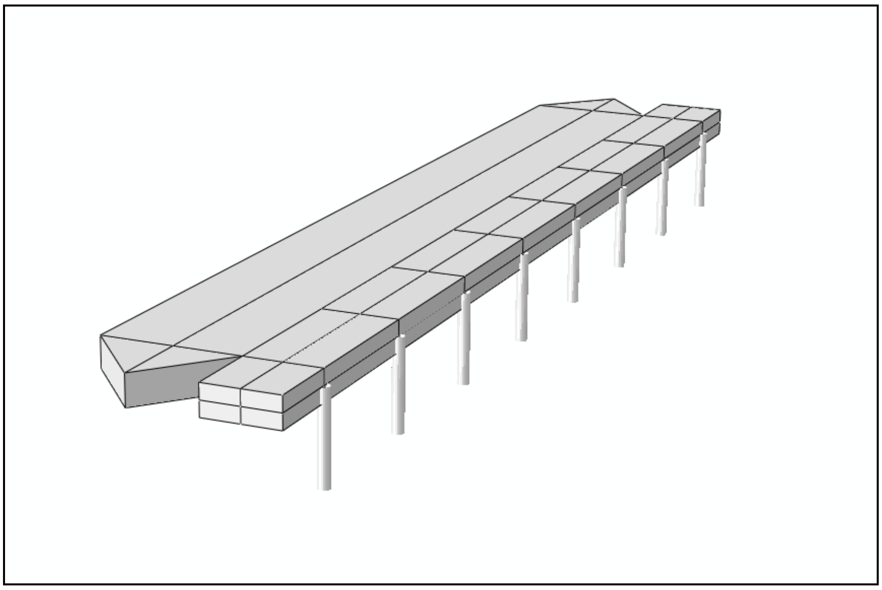

Fig. 4. The Constructed Geometry in Abaqus (Except Soil Medium).

4. Geometry of the Structural System in the Model

The mesh is illustrated in Figure 5. Pontoon, ship and soil are modeled through solid eight-node elements and piles are modeled through a two-point beam element. Boundary conditions are assumed to be rollers at the sides and an encastre at the bottom of the soil body. The soil body is assumed to be a box with the dimensions 40 m x 160 m x40 m.

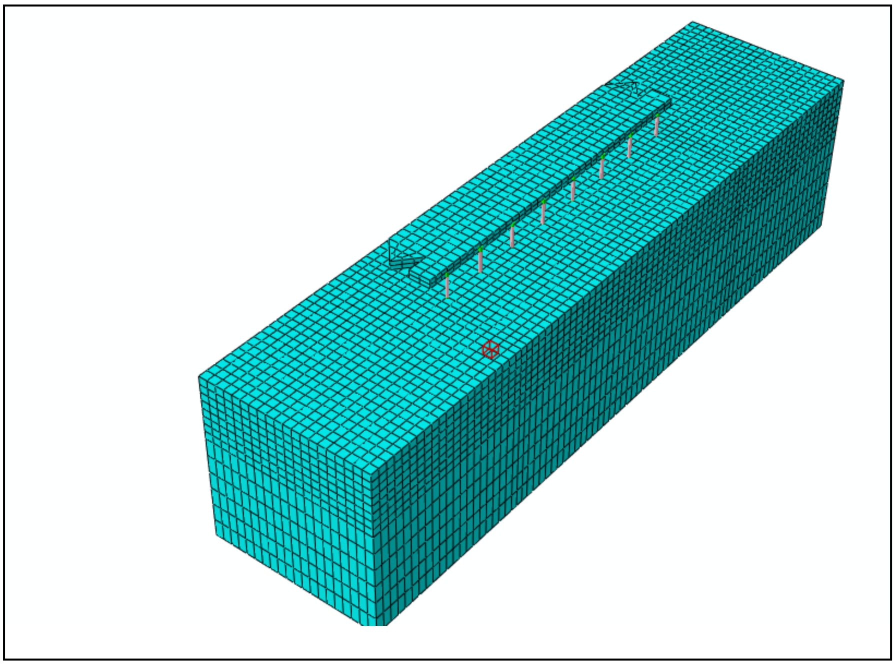

Fig. 5. Finite Element Mesh in Abaqus 3D Model.

Table 1. Pier Properties.

Largest Design ship	1000 dwt
Mass of ship	1690 ton
Berthing velocity of ship	0.343 m/s
Pier overall length	80 m
Pontoon	8@10*5*2
Pile section	Pipe d= 80 cm , t=1.5 cm
Yield stress of steel for piles	360MPa
Embedded length of pile	15 m
Soil	Sand - refer to Table 2

5. Properties of the Soil Medium in the Model

Here the piles are assumed to be placed inside the soil body. The soil body is assumed to behave as if it is cohesionless (simulating sands). For the purpose of the comparison, two types of behavior are modeled for the soil body: (a) pure elastic behavior (b) elasto-plastic behavior.

The elasto-plastic behavior is assumed to follow the Mohr-Coulomb criterion. According to the Mohr-Coulomb criterion the failure surface f can be defined in terms of principle stresses as follows [11]:

$$f = \sigma_1 - \sigma_3 - (\sigma_1 + \sigma_3) sin\varphi - 2c\ cos\varphi = 0 \tag{4}$$

where

$\sigma 1 > \sigma 2 > \sigma 3$ are the principle stresses

c is the cohesion of the soil

ϕ is the friction angle of soil

The properties of the soil medium are listed in Table 2.

Table 2. Soil Properties.

Soil Layer	**Unit Weight γ(kN/m^3)**	**Cohesion, C (kN/m^2)**	**Angle of friction ϕ**	**Poisson Ratio υ**	**Modulus of elasticity of soil, E soil (MPa)**
Sand	20	0	38	0.37	60

6. Verification of Elastic Soil

In this section, the latest work done by Mostofi and Bargi [4] was used to verify this research model. The material properties for the structure and ship were selected according to Mostofi and Bargi [4]. Figure 6 illustrates the results of the pile deflection at Pile Number 1, arrived at from current calculations, along with those of Mostofi and Bargi. Although general agreement can be seen, there are differences in the responses of each model. These differences can be attributed to different assumptions regarding pontoons. Mostofi and Bargi have modeled pontoons through shell elements, whereas here, solid elements have been used and soil behavior is assumed as an elastic continuum medium with elastic parameters. This differs from the work of Mostofi and Bargi [4] where the soil component was modeled as a set of springs. The piles in this investigation are numbered from 1 to 8, with Number 8 being the pile at the greatest distance from the point of impact.

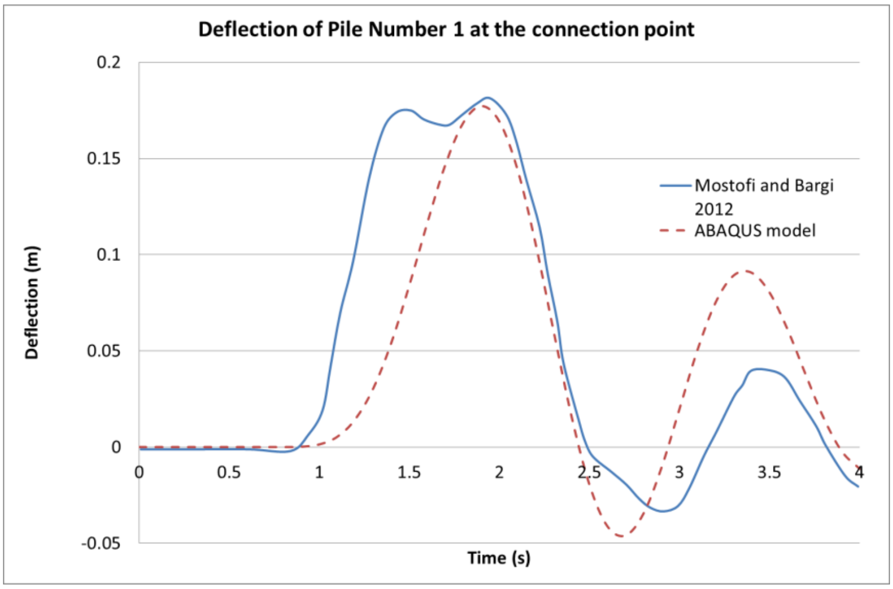

Fig. 6. Response of Pile Number 1 at the Connection Point to the Pontoon.

Figures 7 and 8 demonstrate the time-dependent responses of the piles. Figure 7 represents the time taken for the deflection from each pile (at the connection point to the pontoon). As can be seen from Figure 7, the maximum deflection from piles varies from 0.17 m to 0.08 m. Figure 8 represents the average of the induced strain energy in each pile. The maximum induced strain energy in the piles ranged from15 kN.m to 4 kN.m. It is worth noting that the maximum deflection for all piles did not occur at the same time and that there was a delay (reflecting the system behavior) between maximums. For instance, the maximum deflection of Pile 1 occurs at 1.7 s and the corresponding maximum for Pile 8 occurs at 3.3 s.

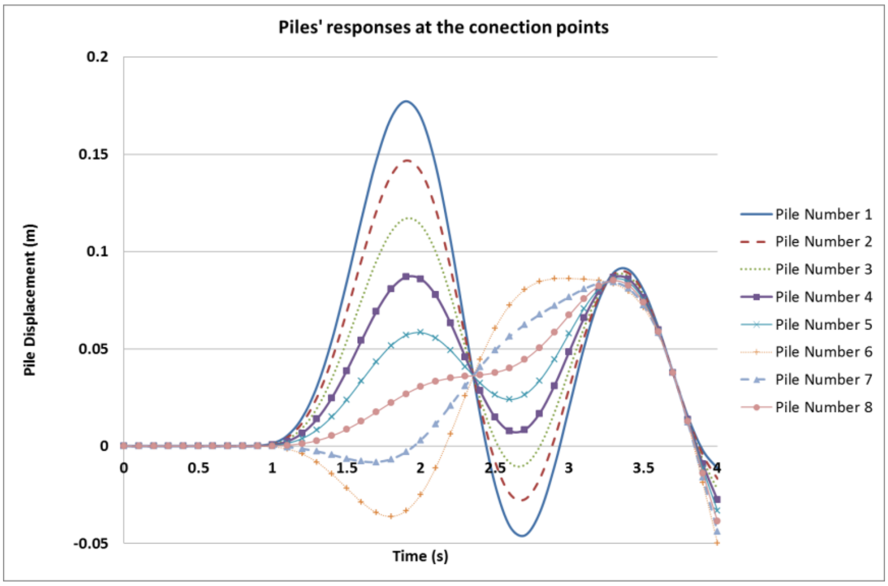

Fig. 7. Deflection of All Piles at the Connection Point to the Pontoon Assuming Elastic Soil.

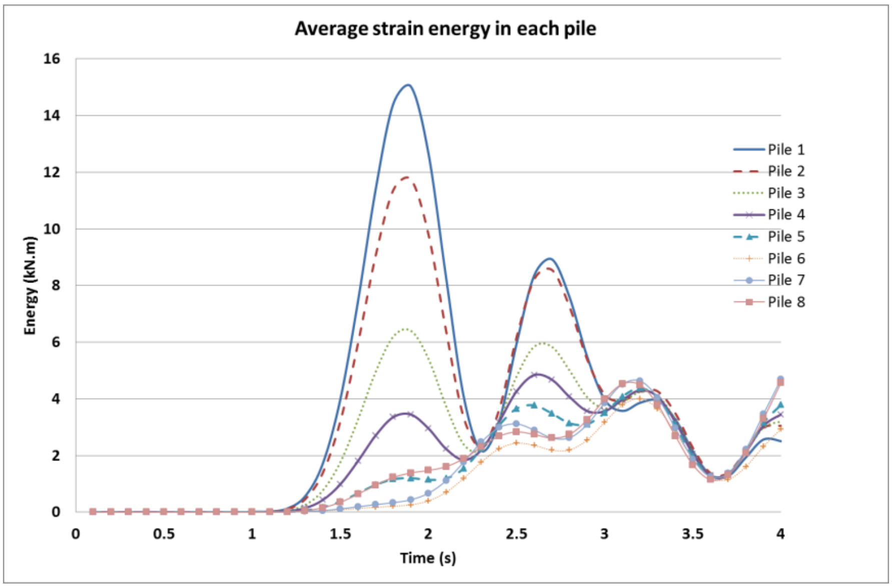

Fig. 8. Average Induced Strain Energy in Each Pile Assuming Elastic Soil.

7. Perfectly Plastic Model of Soil

A unique aspect of this study, apart from the modeling of an elastic zone continuum (rather than the use of a spring model), is mainly the addition of a new type of soil modeling for offshore systems that considers the atypical behavior of soil in offshore structures. As noted previously, soil behavior can produce inexact results if not modeled accurately, and this affects the piling capacity of the system, which relies on accurate soil information. Due to the complexity of soil modeling, no existing literature has been found to address the issue of the accurate modeling of soil behavior. The Geotechnical Research Group at Curtin University has now successfully modeled this behavior. This is the first time that this type of modeling has been carried out. The following section focuses on the results of considering plastic behavior with regard to soil, the behavior producing significant changes in pile responses and the total energy absorbed by the system. The energy absorbed by each component is also presented in Table 3.

As it can be observed from Table 3, the energy absorption has significantly changed when assuming soil as a continuum medium. The main reason for this change can be explained by the fact that the in the case assuming soil as systems of spring, the whole energy of ship impact should be stored in a set of concentrated points (spring) and structural parts. However, having a continuum medium attached to the structural parts, the impact energy will be transferred not only to structural system but also to the continuum body. The energy transferred to this continuum medium is stored in the form of strain energy. Since in the actual construction the system of piers and pontoon are interacting with soil mass, it would be expected that the results of simulation of soil as a continuum media has a better prediction of actual response of the structural system to the impact.

8. Results of the Elasto-plastic (Mohr Coulomb Criterion) for Soil

In the second model, the soil is assumed to behave elastoplastically according to the Mohr-Coulomb criterion. Figures 9 and 10 illustrate the response of each pile to the impact loading of the ship, along with the average strain energy induced in each pile. As observed in these two figures, the assumption of Mohr-Coulomb has a clear impact on the response(s) of the piles. Generally, the system responded more uniformly and there was a decrease in impact energy. The maximum amount of pile deflection reduced from a distance of 0.26 m down to 0.13 m and the strain energy decreased from 13.8 kN.m down to 3.8 kN.m. This shows that the piles' absorption of energy decreased slightly compared to the calculations made for elastic soil.

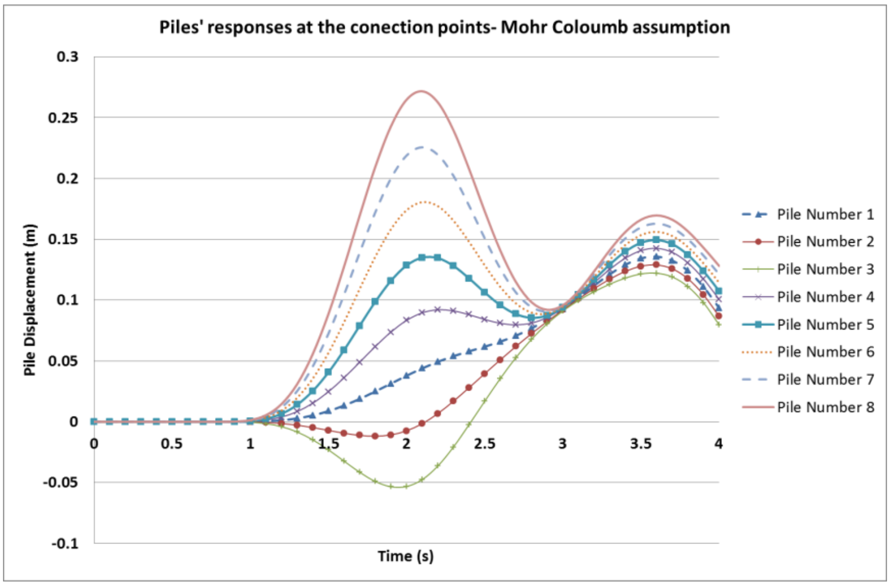

Fig. 9. Deflection of All Piles at the Connection Point to the Pontoon Assuming Mohr-Coulomb Soil.

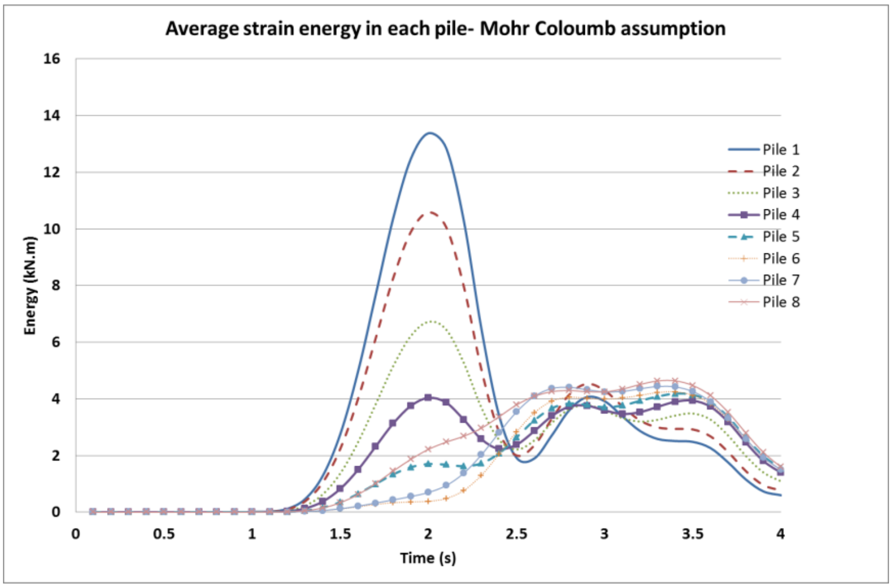

Fig. 10. Average Induced Strain Energy in Each Pile, Assuming Mohr-Coulomb Soil.

Having calculated the energy in both the elastic and Mohr-Coulomb models, the effect of the soil on energy absorption can now be calculated. For this purpose, the total energy of the structural parts (third and fourth integral terms in Eq. 3) is calculated, as presented in Figure 11. In the graph below, the results of the analyses, using two different assumptions (elastic soil and Mohr-Coulomb soil), are presented together for the purposes of comparison.

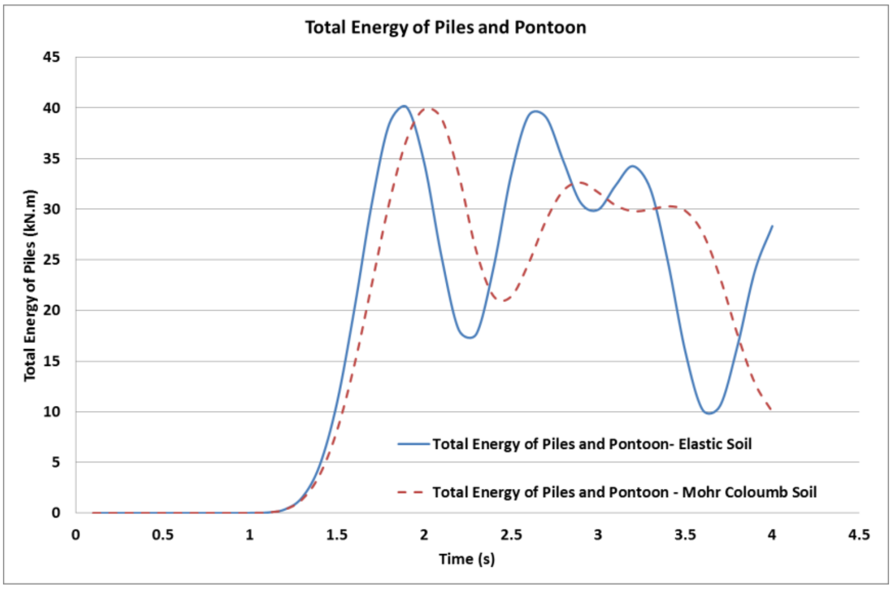

Fig. 11. Total Induced Strain Energy in the Structural Parts Using Two Models.

Mostofi and Bargi [4] calculated the induced strain energy in the structural parts of the system. They did not include any soil mass in their modeling. Therefore, the total strain energy is absorbed purely by the piles and pontoons (total impact energy is assumed to be 95.06 kN.m). In Table 3, a comparison of strain energy absorption in each model is summarized.

Table 3. Comparison of Absorbed Strain Energy Using Different Assumptions.

Model Assumption	**Energy Absorbed by Structural Parts (kN.m)**	**Energy Absorbed by Soil Mass (percentage from the total induced strain energy)**
Mostofi and Bargi 2012	95.06	0%
Elastic Soil	68.83	27%
Mohr-Coulomb Soil	68.54	28%

It can be seen that by assuming the soil mass, a significant effect on the absorbed strain energy in the structural parts is created. In fact, assuming a spring model as opposed to a soil continuum model leads to conservative design (all of the energy should be borne by the piles and pontoon). According to the principles of virtual work, the total energy assumed by the soil should be the same in both cases. In this instance, the difference between the Mohr-Coulomb and the elastic soil was less than 1%. This difference occurred due to the dissipation of energy through the plasticity of soils (which in this model was not considerable). However, the most visible difference can be understood in terms of the time history of the absorbed energy (Figure 11). Here, assuming Mohr-Coulomb behavior for the soil results in more uniform energy absorption for the structural system. This can be related the softer behavior of the soil medium under the assumption of plastic Mohr-Coulomb rather than purely elastic soil.

Based on this simulation, the modeling of soil as springs was found to ignore 27% of energy absorption through the soil medium. Moreover, the resulting changes from considering soil as an elasto-plastic material compared with elastic material were found to be marginal by 1% in terms of total absorbed energy. However, the change of the material behavior affected the time history of the energy absorption responded. The reason for the slight changes in the soil can be related to the impact load which was not great enough to move the soil into the plastic zone, and the soil behaved mainly as an elastic material. However, the expectation is that an increase in impact load will lead the soil to produce a plastic response, and the results will change significantly.

9. Conclusion

This paper investigated the impact of ship berthing upon a floating pier system. In the study, a highly advanced finite element software program, Abaqus, was used. The study has improved upon current research in this area via two means:

- By the use of an elastic soil model which considered soil as a continuum space, followed by verification and comparison of the outcomes through considering soil as a spring model.
- By simulation of an elasto-plastic soil model and considering interaction effects of ship-pontoon collision.

Comparison of the simulation’s results confirmed that the assumption of soil as “springs” has a significant difference to simulation of soil as a frictional elastoplastic materials.

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