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Investigation of ship collision with floating pier structures

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Abstract. This study investigated the collision of ships withfloating pier structures. The nature of the collision phenomenon is complex, and the understanding of it has developed through the modelling of offshore structures. ABAQUS software was used to investigate the collision phenomenon. The interaction between the ship and structural system was modelled, and the stress distribution both at thetime of collision and afterwardswasobserved and modelled. The strain energy absorption by different structural partswas calculated and comparisonswere made.

Keywords: ship; collision; floating; pier; interaction; ABAQUS

1. Introduction

Offshore structure systems have always been subject to collision with ships and other sea vessels. According to the literature (Ryder 1884, Wicks *et al*. 1992, Amdahl and Eberg 1993, Haris and Amdahl 2012, Sivaprasad and Nandakumar 2013), the probability of collision with offshore systems is approximately 0.15 per year.Historically,the impact phenomenonhas proven to be a complex issue. Some researchers have considered ship-ship collisionmechanisms (Ringsberg 2010, Tabri 2012, Harisand Amdahl 2012, Mohammad *et al.* 2013),whilst others have appliedthe finite element method to investigate this important phenomenon (Pilland Tabri 2011, Wu *et al*. 2013).Themechanism of collision has been researched by Hongand Amdahl (2008), whilst the analytical and numerical approach was used by Tavakoli *et al*. (2012). However, with regard to civil engineering and specifically, offshore structure modelling, impact modelling is still in its early stages and hasnot been studied in great depth. This study differs from studies of berthing impact between ship and offshore structures in that it models the direct collision of ships with floating piers and examines stress distribution in thecollision in offshore structure systems by calculating the energy of the system.

This study focuses on ship collision as it relates to floating piers. Fig. 1 shows the floating pier elements in detail and Fig. 2 shows the geometrical details of the problem. Application of numerical software in modelling ship impact is quite complex, and as a consequence some assumptions were applied to simplify the problem. In this study, ABAQUS was used to investigate

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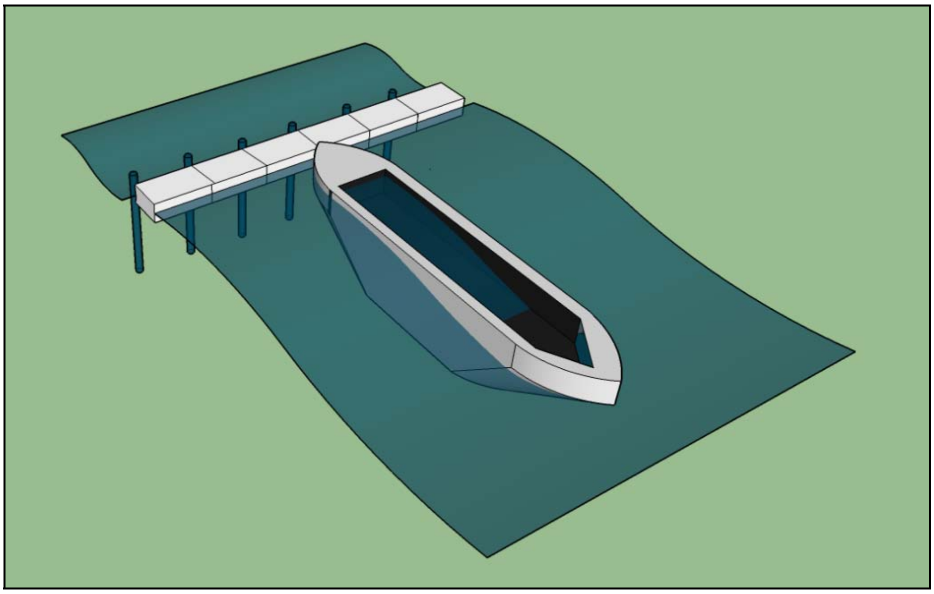

Fig. 1 Schematic illustration of the floating pier system

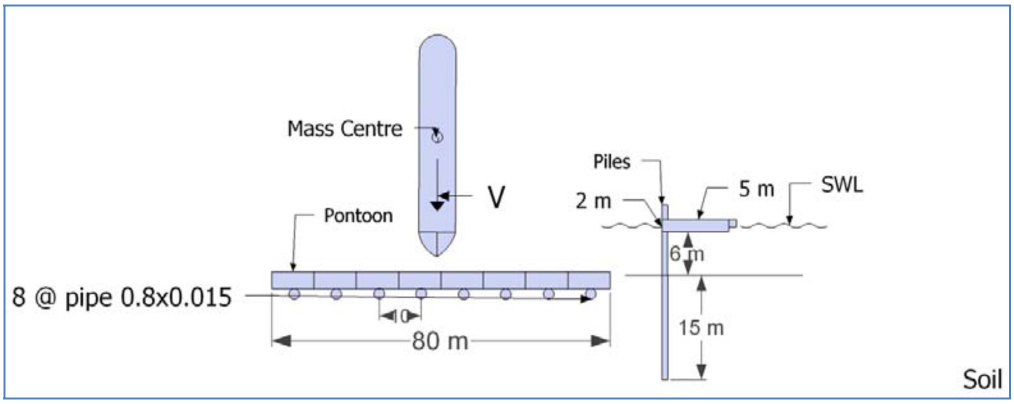

Fig. 2 The dimensions and assumptions for numerical modelling

ship impact withstress distribution modelled around the time of impact.

The first partof the study models the ship collision with thepontoon. The shipand pontoons behave in unison and transfer the load to the piles. As the final bulwark, the stability and capacity of these pilesis fundamental to the management of the stresses caused by thecollision.The pile is assumed to have a burden length in soil medium.

2. Theoretical background of impact

The momentum conservation equation can provide a clearer understanding of this complex phenomenon. Mostofi and Bargi (2012) expressed the principle of impact as follows

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

or

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

where M_1 is the mass of the ship and M_2 the mass of the pontoons

The total energy of thiscollision impact can be divided into(a) kinetic energy and (b) strain energy. Strain energy is an important part of the energy in any offshore structure system. It represents the efficiency of the structural system to absorb and deflect the energy of impact. Given this, the total strain energy of the system can be expressed as follows

$$E_{Total} = \frac{1}{T}\left(\int_0^T E_1 dt + \int_0^T E_2 dt + \int_0^T E_3 dt + \sum_1^n \int_0^T E_{(i)} dt\right) \tag{3}$$

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 paper investigates the collisionimpact phenomenon using the advanced numerical software, ABAQUS. Stress distribution in the soil part of the pontoon or pier structure will not be examined as this requires a separate investigation.There are some assumptions involved in this study: firstly the ship is consideredto bea rigid body and as a consequence the strain energy in the ship is negligible ($E_1 = 0$). The soil mass is modelled as an elastic medium. The strain energy of induced in the structural parts (E_3 and $E_{p(i)}$) is calculated through a full three-dimensional dynamic analysis in implicit scheme**.**

Table 1 The properties of the structural parts

Ship type	1000 dwt
Mass of ship	1000 ton
Impact velocity of ship	5 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 piles	15 m

Table 2 The properties of the soil medium

Soil layer	Unit weight γ(kN/m3)	Poisson ratio υ	Modulus of elasticity of soil, E soil (MPa)
Sand	20	0.37	60

3. Numerical simulation and results

The collision was modelled through 1s analysis, in which 0.55 s of the analysis was conducted before the impact, impact occurred at 0.55 s, and the remainder of the analysis continueduntil 1s (0.45 s after impact). The reasons for 1s analysis are that firstly, the run time of the dynamic impact is time consuming and having convergence in a numerical study requires a very small time step, which intensifies time consumption in computation. Secondly, the major part of the distributed stress will almost vanish during this 1 s.

Tables 1-2 listthe properties of the structural parts and the soil medium in this simulation. The ship is assumed to behave almost rigidly (to avoid energy absorption by the ship’s body). Pontoons, ship and soil are modelled through 8-noded solid elements. Pilesare assumed to have a pipe cross-section andaremodelled through a 2-noded beam element. Fig. 3 illustrates the total mesh of the model.

Series of analyses are conducted to identify the impact of mesh size on the results and it is found to be the finer mesh size could not have meaningful impact on the results of stress and displacement.

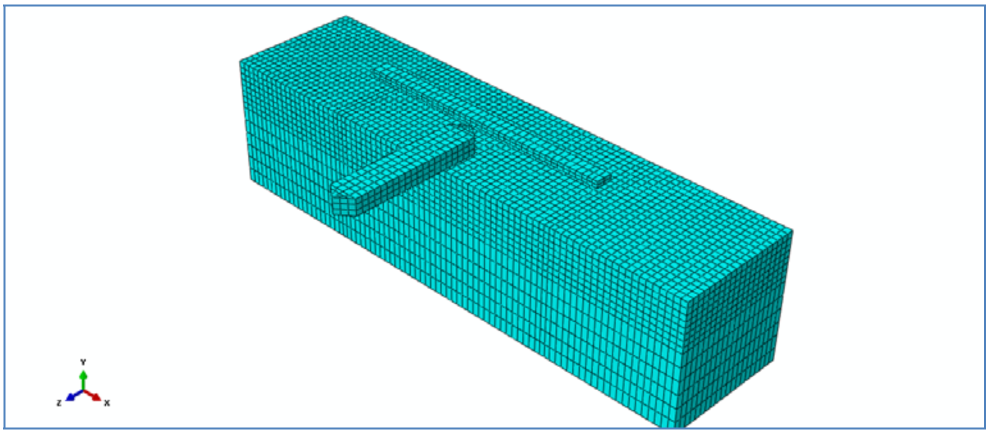

Fig. 3 Finite element mesh of the whole model

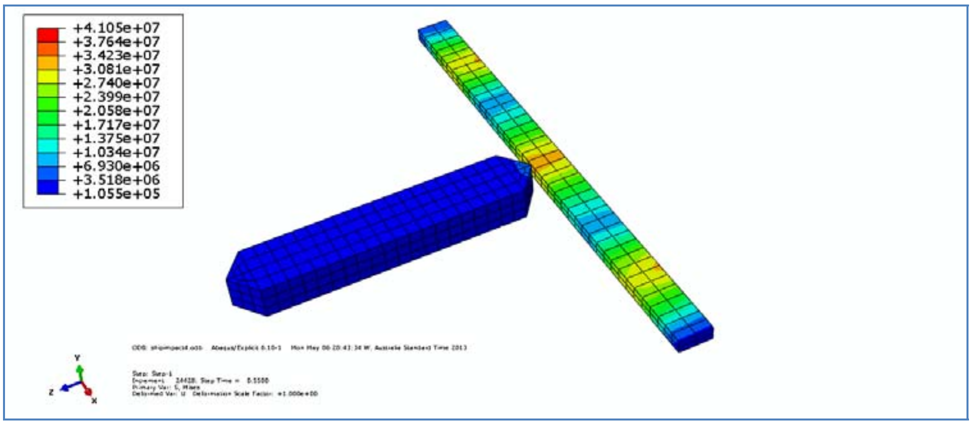

Fig. 4 Mises stress distribution at time of impact (0.55 s)

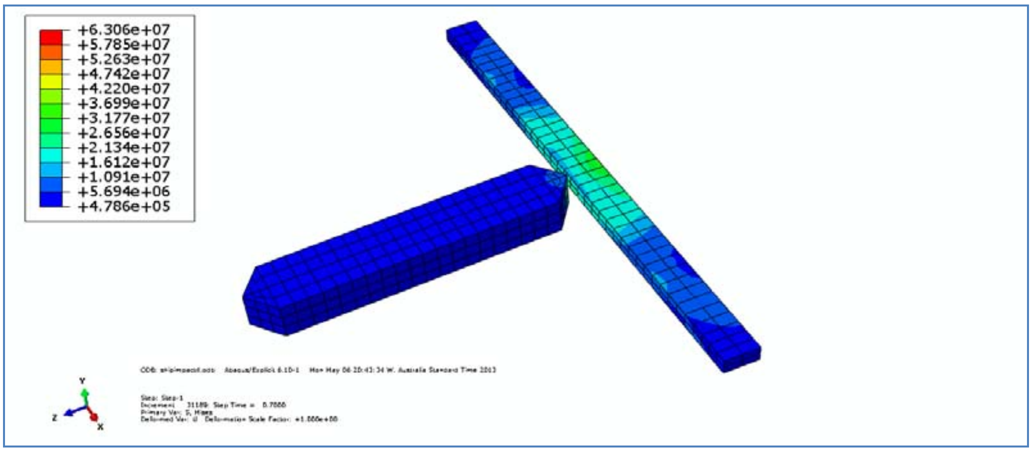

Fig. 5 Mises stress distribution at 0.7 s

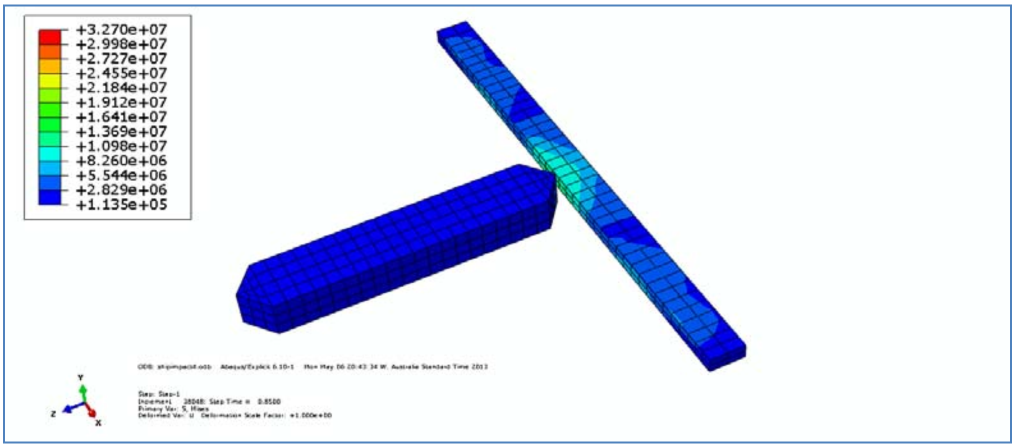

Fig. 6 Mises stress distribution at 0.85 s

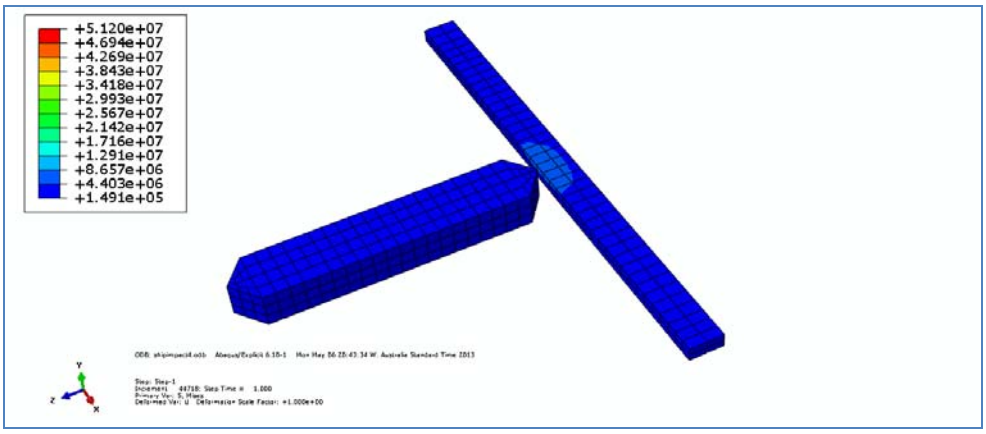

Fig. 7 Mises stress distribution at 1 s

Figs. 4-7 represent theMises stress distribution of the pontoon structure in four different time steps after impact. Fig.4 illustrates the impact instant. At this point, almost all of the pontoon structure has contributed to the impact stress (except the free edge of the pontoon that should physically have zero stress).

Figs. 5-6 show the two next time steps after impact where the Mises stress is mainly concentrated around the impact point (middle of the pontoon).

In Fig. 7 it can be observed that the stress distribution almost disappears after 1s (0.45 s after impact) except for the impact of the front line on the pontoon structure.

To enablea better understanding of the impact mechanism, Fig. 8 presents the horizontal stress distribution in the front line of the pontoon structure. Here it can be seen that at the instant of impact, the whole pontoon responds to the impact while the impact point has the highest stress (-700 kPa). However, at0.7s (0.15s after impact) the direction of the stress changes and the stress is highly concentrated around the middle of the pontoon structure. In this case the highest stress (2600 kPa) is reached at the impact point. In the two following steps the stress distribution drops down from its peak and is more uniform (the impact effect disappears).

Figs. 9-10 demonstrate the pile responses in terms of piledeflection and the absorbed strain energy of each pile. Fig. 9 shows that the deflection of pile number 5 reaches the highest value of 0.37 m. This pile is the closest to the impact point in the middle of the pontoon. The surrounding piles respond similarly and symmetrically according to their respective distances from the impact point.

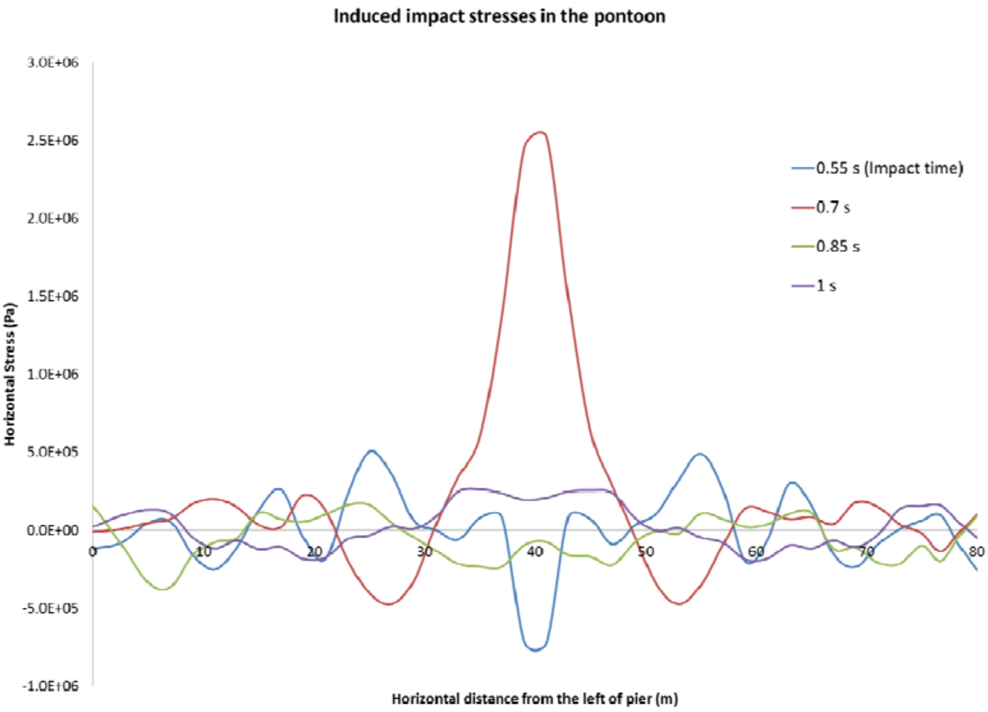

Fig. 8 Stress distribution in the front line of the pontoon at different sequences

Fig. 10 demonstrates the average absorbed strain energy in each pile. The piles again demonstrate symmetrical behaviour. It can be seen that the major portionof the impact energy is absorbed at 0.55 s to 0.85 s (a 0.3 s time span). The peak responses of the piles occur at different times but between 0.6s and 0.7s (0.05 s to 0.1 s after impact).The highest peaks are for pile numbers1 and 8 (the outside piles) with a magnitude of 44 kN.m.

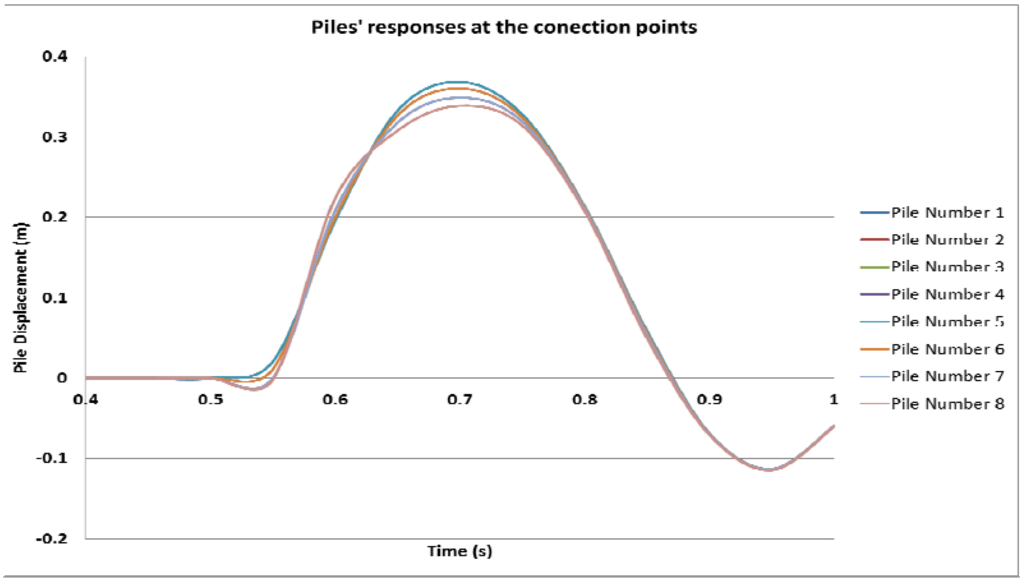

Fig. 9 Deflection of all piles at the connection point to the pontoon

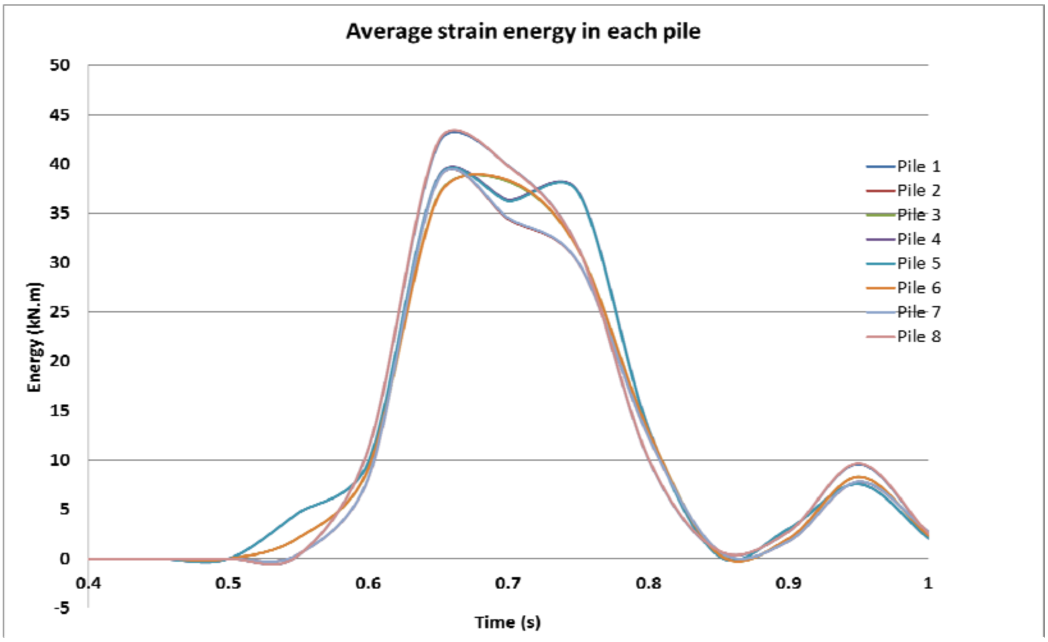

Fig. 10 Average induced strain energy in each pile

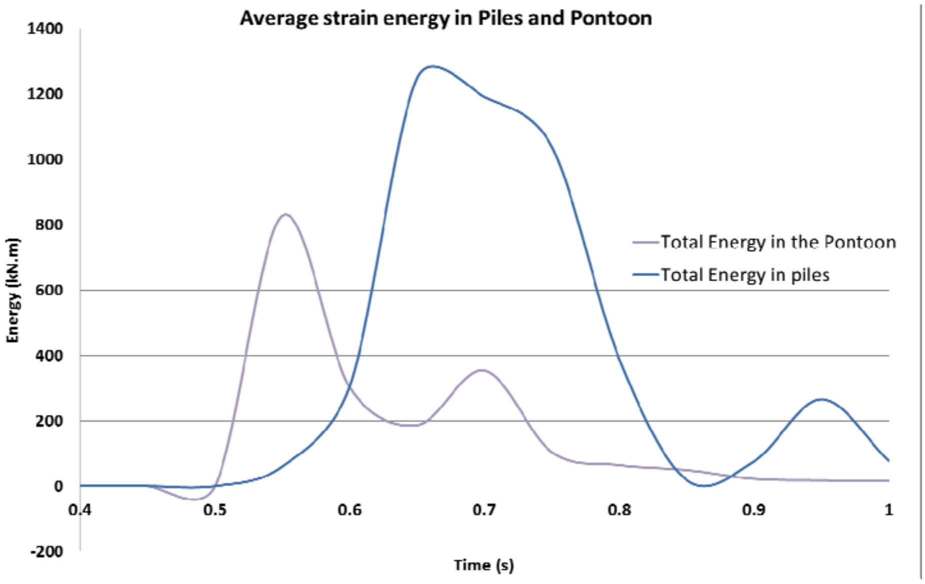

Fig. 11 Total induced strain energy in the pontoon and piles

An in-depth idea of the collision mechanism can be gained by comparingthe absorbed energy of the pontoon and piles system. This is presented in Fig. 11, which illustrates the way in which the energy of impact (in terms of strain energy) is distributed between the piles and the pontoon. The two major points are thatfirstly, the piles have absorbed more energy; therefore they may contribute moretoresisting the impact. The pontoon absorbed 96.7 kN.m while the piles absorbed 231.7 kN.m.Secondly, the peak absorption for the pontoon occurs before thepile responses, which suggests that the pontoonhas amore important role in the stability of the whole structure against the impact. In fact, it is the pontoon that should bear the impact load initially and after a very short time (0.1s) the energy is then transferred to the piles. The rate of energy absorption by the pontoon reaches almost 0 after 1 s (0.45 s after impact).

4. Conclusions

This study has considered the effect of collision and stress distribution on a floating pier structurewith regard to both the time of collision and post-collision.Atdifferent time stages, stress and energy were calculated and presented using theadvanced ABAQUS software.The impact instance was carefully analysed at each 0.15s intervals. The results of this research will make it possible to discuss the different parameters which may help reduce the risk of collapse of offshore structures.

The impact effects (in terms of strain energy and Mises stress) wereseparately analysed for each of the structural parts (piles and pontoon).It was found that the major portion of the pontoon’s energy and stress dissipate in the 0.45 s after the instant of impact. Initially, the major portion of the impact energy is carried through the pontoon, and after 0.1 s the energy is transferred to the piles system.

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