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Effect of Ultra-Lightweight High-Ductility Cementitious Composite in Steel–Concrete–Steel (SCS) Plate to Mitigate Ship Slamming Loads

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Abstract: Bottom slamming loads cause considerable local damage to a ship's body and reduce the ship's structural performance against harsh sea waves. Although extensive studies have worked on stiffening elements to compensate for local damage due to slamming loads, few studies have concentrated on the ship's body itself while using new generations of composite plates. Accordingly, a numerical study is conducted to determine the effect of using ultra-lightweight high-ductility cementitious composite in steel–concrete–steel (SCS) composite plate to mitigate bottom slamming loads. A large-scale model of the ship using SCS composite plates is modelled in Abaqus software, and fluid–solid (FSI) interaction is precisely modelled using the Coupled Eulerian–Lagrangian (CEL) method. The results show that using the CEL method with a large-scale 3D model precisely simulates FSI by providing a 6.5% deviation from the experimental result. Moreover, using an SCS plate when considering ultra-lightweight high-ductility cementitious composite results in a considerable reduction (around 95%) in the maximum strain of the ship body and, accordingly, reduces local damage so that, although about 22% of the strain of the outer layer is transferred to the inner part of the ship body containing only steel plate, almost 0% stress transfer is observed for the SCS-based ship's structure.

Keywords: ship; composite plate; SCS plate; cementitious composite; slamming loads

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1. Introduction

The intense force exerted on ships and offshore structures by rough ocean waves or extreme storm waves, known as slamming load, significantly impacts their structural performance. The effect of the slamming load can cause a large permanent deformation in different regions of the ship's structure [1]. In severe sea states, slamming loads may cause a gradual collapse of structures and threaten human lives. Slamming loads result in the collapse of outer and inner structures, including longitudinal structures, web frames, and side stringers [2]. The main characteristic of slamming load is that the impact duration is short, which can be similar to a local explosion near the ship's structure [3]. Many situations may cause the slamming phenomenon. Violent sea waves cause the ship's structure to experience giant heaves and pitch motions so that a section of the ship's bottom exits and re-enters the water, called the bottom slamming phenomenon.

Different methods have been considered to mitigate the internal damage due to the slamming phenomenon, such as stiffened panels within the ship's structure and using composite plates. In this field, Truong et al. (2021) [4] reported that impact velocity and plate rigidity significantly influenced the slamming response of a stiffened plate. They found that damage to the impacted plates was reduced by increasing the plate stiffness, but they only considered a flat stiffened plate with a numerical study. Khedmati and Pedram (2014) [5] numerically studied the response of initially damaged stiffened aluminium plates exposed to slamming impact loads. They reported that the loading period decreased as the impact velocity increased. Their findings show that increasing the plating thickness and the existence of longitudinal stiffeners enhance structural panel behaviour against slamming loads. They also reported that large slamming loads cause yielding in stiffeners, which is critical for ships travelling long sea distances. Ships should keep their structural buildability after facing slamming loads to prevent sudden progressive damage and save the lives of the ship's crew. A numerical study presented by Luo et al. (2012) [6] showed that the dimensions and arrangement of stiffeners affect the structural performance of stiffened plates against slamming loads. In this context, the experimental results reported by Hosseinzadeh et al. (2023) [7] demonstrated that the peak pressure of a stiffened plate was greater than that of an unstiffened one. However, they only considered two plates on the bottom of the wedge to determine the influence of flexural rigidity on the hydroelastic slamming force. Their experimental results indicated that body mass affects the wedge's structural response, so that the maximum strain reduces by reducing the mass (lighter wedge). Moreover, they reported that the wedge mass affects the structure's natural frequency. Regarding the type of composite plate used for slamming load resistance, Stenius et al. (2013) [8] showed that single-skin glass and foam core panels met the design limit (stiffness) at impact velocities of about 2 m/s and 3 m/s, respectively. However, these composite plates will not be efficient for ships in seas with high violent waves, where impact velocity is at least 10 m/s. In addition, only single plates were used in these studies, without studying large-scale ships. Xue et al. (2011) [9] performed experimental tests to study the effect of composite hull structures against slamming loads with drop tests, including laminated composite, sandwich structure, and hybrid structure. There are previous studies concentrating on this context [10–13]. Although many studies have concentrated on stiffened plates against slamming loads, very few studies have worked on using composite plates instead of only steel plates to alleviate slamming loads. Moreover, current studies have considerable research gaps; for example, only a single plate having been considered in the literature, while no specific study has experimentally or numerically investigated large-scale ship models exposed to various impact velocities.

Steel–concrete–steel composite (SCS) is a composite structure containing two external layers of steel faceplate, mechanical connectors (cohesive materials), and a concrete core. These steel faceplates are anchored to the concrete infill to maintain the composite action using shear connectors (or cohesive materials). Due to its great ultimate strength-to-cost performance [14], SCS shows adaptable potential applications in offshore structures. SCS composites have been used for gravity-based Arctic offshore caisson structures (GBS) [15,16], LNG or oil containers [17], undersea oil production modules [18], immersed tube tunnel construction [19,20], shear walls [21], third-generation nuclear power plants [22,23], offshore decks [18], and bridge decks [18]. The key benefits of SCS composite structure are: (1) steel plates play a role in flexural reinforcement and suggest a lasting formwork that reduces site labour work and improves construction effectiveness [14]; (2) steel plates can be simply cut to any form, and the shear connectors can be quickly connected, reducing the work required for the cutting, bending, and tying of the reinforcement bars; and (3) steel plates are impermeable and benefit impact- and blast-resistant films. The literature has illustrated that SCS composite structures show outstanding structural behaviour in resisting static, impact, and blast loads [18,24]. Hence, wide ranges of force resistivity need to be satisfied by SCS shell members, including static and cyclic loading, bending (flexural) strength, in-plane compressive strength, and durability properties, including low temperature, high temperature, and freeze–thaw resistivity. Additionally, the residual strength of SCS members is important after exploring internal damage, such as pre-cracking in the concrete core or an emerging local pre-buckling phenomenon. To address these characteristics, different SCS members were tested in the literature, including SCS walls, curved SCS shells, SCS beams, and SCS sandwich slabs.

As mentioned in this section, although many industries have used SCS composite plates in different applications, no specific study has concentrated on using this novel composite structure in ships to mitigate the bottom slamming phenomenon. Moreover, considering only a single plate in this type of investigation is inefficient, and so large-scale modelling should be studied. Hence, the following objectives are considered for the present study:

1. How efficient is the CEL method to numerically study FSI in a large-scale ship model in Abaqus software?
2. How much does SCS composite plate mitigate the local damage due to the bottom slamming loads compared to only the common steel plate?
3. Is SCS composite plate useful in damping slamming load energy to impede the transference of local strain from the ship's outer layer to the inner one?
4. Determining the critical parameters that affect the structural performance of ships containing SCS composite plates.

Accordingly, to address these objectives and fill research gaps, a novel large-scale 3D numerical work is conducted in the present study to comprehensively determine the effect of SCS plate containing ultra-lightweight high-ductility cementitious composite on the structural behaviour of ships against slamming loads, compared to conventional steel plate. To achieve this aim, this paper presents a numerical model to consider the three-dimensional slamming impact on the surface of a large-scale ship using the Coupled Eulerian–Lagrangian (CEL) method.

2. Numerical Model

Although both Arbitrary Lagrangian–Eulerian (ALE) and Smoothed Particle Hydrodynamics (SPH) methods have been used for fluid–structure interaction (FSI) problems, the Coupled Eulerian–Lagrangian (CEL) method was used in the present study as the best option for complex FSI studies, such as the bottom slamming phenomenon, to numerically study the structural performance of a ship against slamming bottom loads using steel–concrete–steel (SCS) composite plates. Generally, the Eulerian domain characterises "void + fluid" media, while the Lagrangian domain considers the main ship structure. In the CEL method, the structural domain (composite plate or 3D large-scale ship) and the fluid (water) are modelled by the Lagrangian mesh (considers the structure deformation) and Eulerian mesh (fixed in space and time), respectively [13]. The Eulerian area contains two parts of water and void, considered incompressible and modelled in the present study based on an equation of state (EOS). As the interaction between different Eulerian domains is not applicable, both air and water should be employed in the same domain.

2.1. Validation Procedure

Before numerically studying the large-scale ship, the CEL method used in the Abaqus software was validated in this section using an experimental program conducted by Hassoon et al. (2018) [25]. A flexible glass/epoxy composite wedge panel with a thickness of 3.0 mm, dimensions of 500 mm × 250 mm, and deadrise angle (β = 10) was dropped at various impact velocities within a water tank (3 m in length, 2 m in width, and 2 m in depth) filled up to a level of 1.1 m (Figure 1a). An impact velocity of 6 m/s was selected for the validation model. A numerical model was prepared based on the CEL method in Abaqus software. The hydrodynamic force was measured in Abaqus software and compared with the value reported by the experimental test (Hassoon et al. (2018) [25]). As shown in Figure 2, the trend of hydrodynamic force modelled in Abaqus was very close to the experimental results, so that the first and second peaks shown in the numerical model were followed by the experimental results. Additionally, the value of hydrodynamic force obtained in the Abaqus model had a 6.5% difference from the maximum experimental result, which shows the high accuracy of the numerical model obtained in Abaqus (Figure 2). Along with the validation purpose, six different points were selected at the bottom of this flexible glass/epoxy composite wedge panel to check the accuracy of the CEL method used in Abaqus software (Figure 3a). The results indicate that point 1 (P1), located at the side edge of the composite wedge panel, had the highest reaction force after impact slamming load (Figure 3a). A parametric study was also considered for this section. As shown in Figure 3b, reducing the weight of the composite wedge panel caused a 44.5% reduction in the reaction force. Moreover, the parametric results demonstrate that increasing the impact velocity resulted in a significantly higher reaction force on the composite wedge panel (Figure 3c). These results are in good agreement with the literature reviewed in the introduction section, showing the accuracy of the numerical model.

(a) (b)

Figure 1. Validation of the numerical study: (**a**) experimental specimen tested by Hassoon et al. (2018) [25]; (**b**) numerical model in the present study.

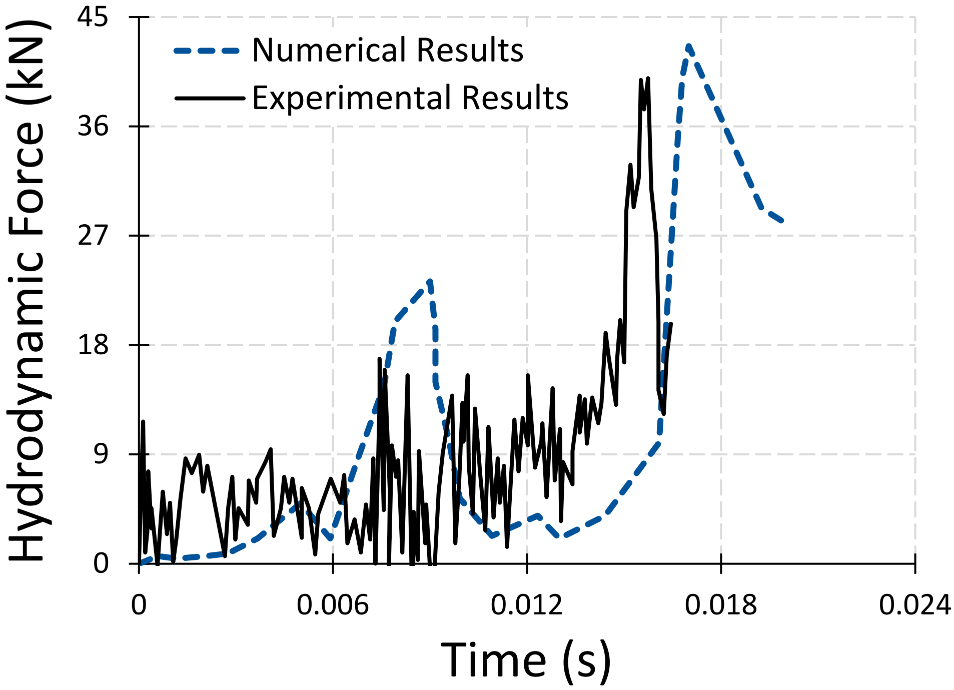


Figure 2. Verification results between the experimental results (Hassoon et al. (2018) [25]) and the numerical model in the present study.

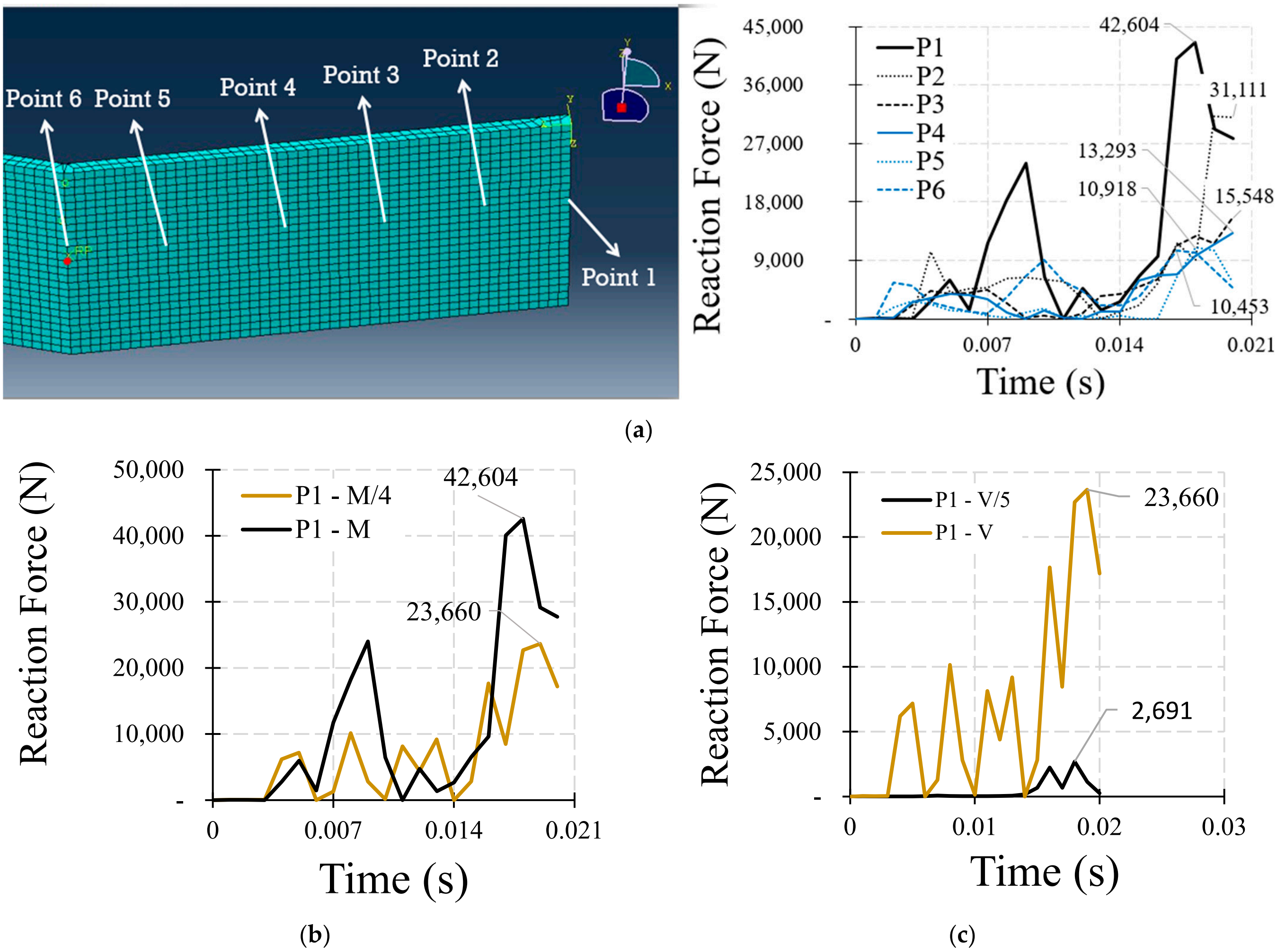


Figure 3. Parametric study of the wedge-shaped structure: (**a**) finding critical point; (**b**) effect of the weight of the structure; (**c**) effect of impact velocity.

2.2. Large-Scale 3D Ship Model Description

In order to numerically study the effect of SCS composite plates on mitigating slamming load in large-scale ships, the model of ships shown in Figure 4a was considered in the present study. This ship model was first imported from SolidWorks software to Abaqus software, with an approximate height and length of 4.0 m and 47.0 m, respectively. The largest width of this ship model was about 6.4 m. This ship model had three different sections, separately meshed in Abaqus software (Figure 4b). Mesh sensitivity analysis for a large-scale 3D ship model in Abaqus was performed in this section. A specific nodal result was selected to check the mesh sensitivity effect. As shown in Figure 5, meshes greater than 0.2 showed imprecise behaviour, while meshes of 0.2 and below could show the same variation, which is desirable. Therefore, in the present study, this mesh was used as a reference mesh for the models. It should be noted that although a mesh smaller than 0.2 can obtain more accurate results, it can cause difficulty due to the higher model processing time and problems in model convergence. As illustrated in Figure 6a, a ship with a deadrise angle was modelled in Abaqus to appropriately simulate the impact of bottom-slamming loads on the ship's structures. Moreover, 10 different points were selected at the bottom of the ship to check the effect of the bottom slamming load on various locations of the ship body (Figure 6b). Point 10 (P10) was the only point selected to determine the amount of damping or energy lost by the outer part of the body. As the difference between the strain of the inner and outer parts increased, the damping role of the ship body increased, showing the performance of the plate defined for the ship body.

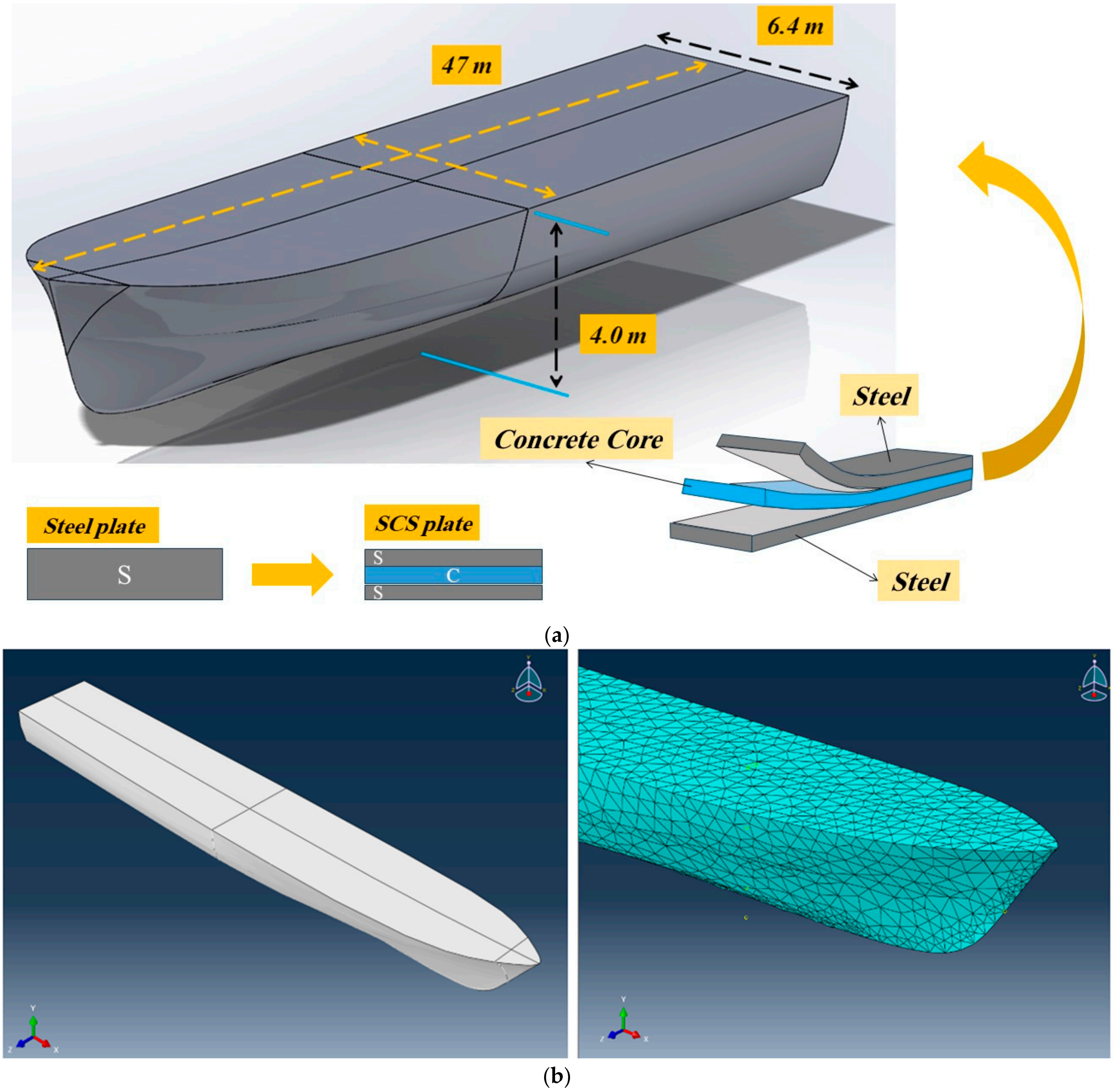


Figure 4. Layout of the present study regarding numerical modelling ship: (**a**) solid model of the ship; (**b**) Abaqus model.

To define concrete in the SCS plate used in this large-scale 3D ship model, with concrete damaged plasticity (CDP) as a continuum, the plasticity-based damage model was used in Abaqus software. The CDP model contains compressive and tensile behaviour, determined distinctly in terms of plasticity and damage parameters in Abaqus [26]. The input parameters for the CDP model used in the present study were dilation angle (ψ) = 35. flow potential eccentricity (ε) = 0.1. σ_{b0}/σ_{c0} = 1.16. K_c = 0.666, and viscosity parameter (μ) = 0.007. Regarding the compressive strength of ultra-lightweight high-ductility cementitious composite, a stress–strain curve measured by Liu et al. (2016) [27] with a maximum stress of 58.7 MPa was used to extract the inelastic strain–damage parameter curve required for the CDP model in Abaqus (Figure 7a). This type of concrete has a Poisson ratio and density of 0.18 and 1305 kg/m^3. As shown in Figure 7b, the cracking strain–damage parameter extracted from the experimental tensile curve from Huang et al. (2021) [28] was used for the CDP model. This concrete has a maximum tensile stress of 3.34 MPa and more than 5.0%

strain capacity. The mix design of ultra-lightweight high-ductility cementitious composite extracted from the literature [27,28] for use in the present numerical study is summarised in Table 1. Novel fibres of polyvinyl alcohol (PVA) and polyethylene (PE) are used in this cementitious composite with volume fractions ranging from 0.5% to 0.7% (by concrete volume) to increase the tensile capacity. Also, as mentioned in Table 1, the unit weight of this cementitious composite is around 1295–1332 kg/m^3, which is considerably lower than normal cementitious composites. These unique features of this type of cementitious composite have caused it to be chosen for use in the SCS composite plate to practically adsorb the slamming energy of rough waves in ships. As a similar mix design was used in experimental studies performed by Liu et al. (2016) [27] and Huang et al. (2021) [28], the stress–strain curves of these experimental works were elected to be defined in the CDP method. Moreover, approximately similar water-to-binder (W/b) ratios (0.32–0.33) were considered in these experimental works (Table 1). Regarding steel in SCS composite plate, common commercial steel properties were used in Abaqus software, including an elastic modulus of 200 GPa and 7850 kg/m^3 density. It is worth mentioning that no slippage was considered in the present study between the concrete and steel layers in the SCS composite plate. Generally, shear connectors are necessary for use in SCS composite plates to control the composite behaviour and impede relative slippage between layers. Although interaction layers in small-scale SCS plates against slamming loads can be studied by future works, defining interfacial elements between layers in a large-scale ship model can cause problems in the convergence of the model and greatly increase the processing time. These issues have been confirmed in the literature for other large-scale steel-concrete composite members [26]. Accordingly, the perfect steel–concrete bond was considered in the present study for the large-scale model of the ship containing SCS composite plates. It is also worth stating that no stiffening elements were considered at the ship's inner part in the present numerical study to precisely investigate the effect of SCS plates compared to only steel plates against slamming loads.

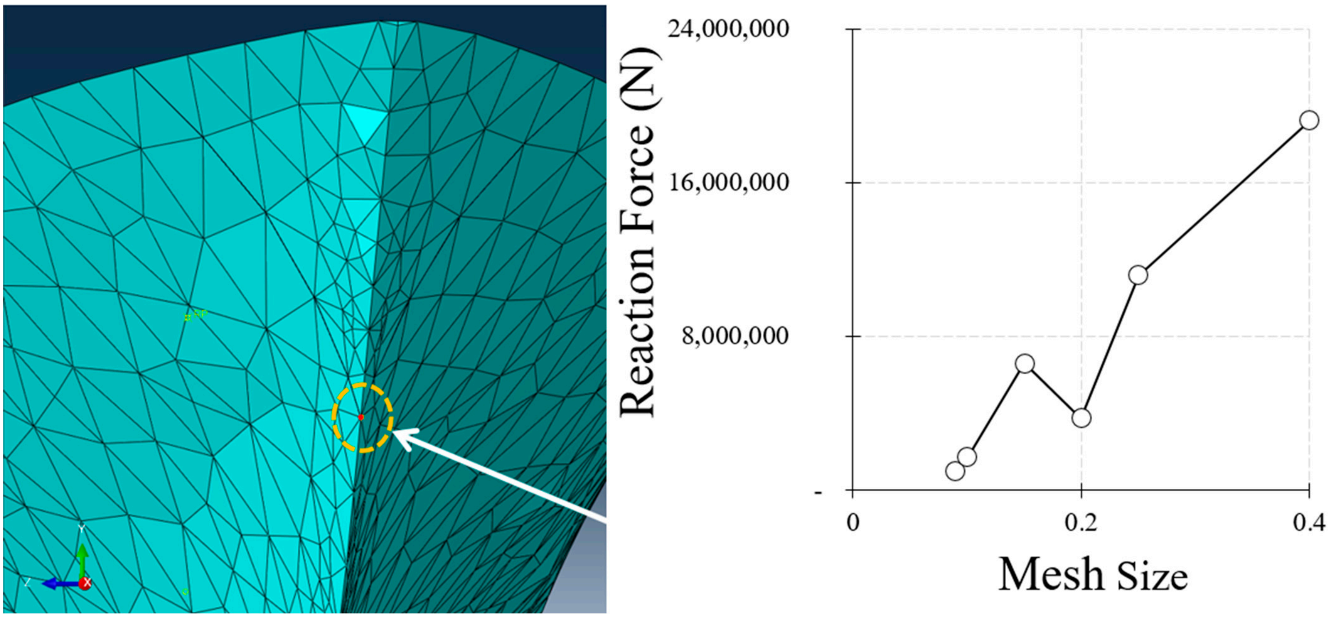
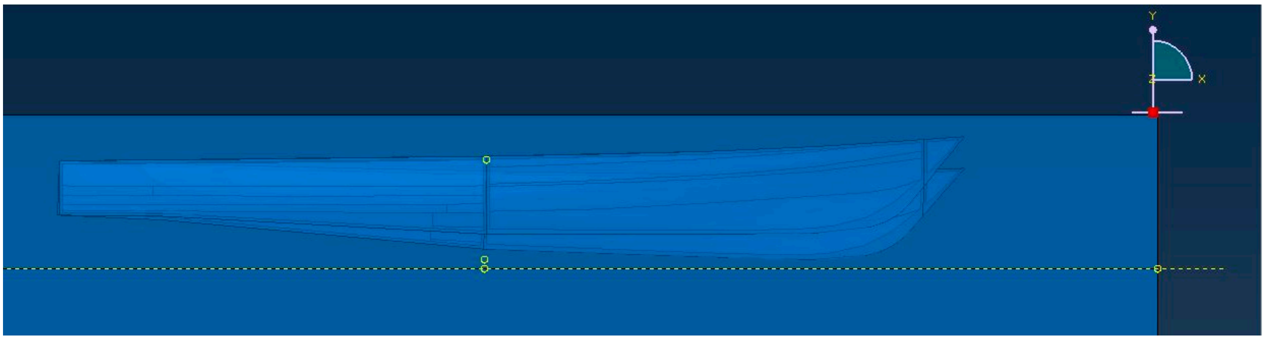


Figure 5. Mesh sensitivity analysis for Abaqus model of ship.



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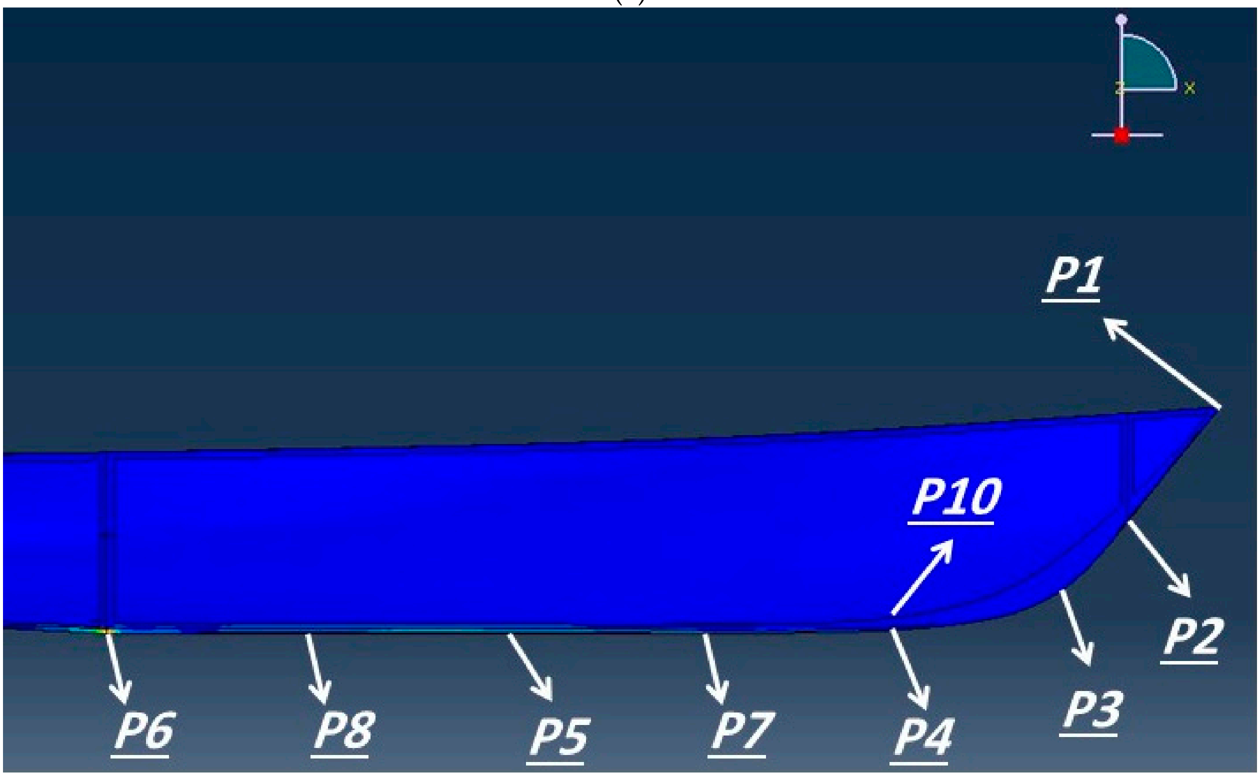


(b)

Figure 6. Location within numerical model: (**a**) placement of ship; (**b**) placement of points at the bottom of the ship model.

Table 1. Mix design of ultra-lightweight high-ductility cementitious composite used in the present numerical study.

Mix ID	W/b	Water	Cement	Silica Fume	Aggregate	Fibers (%)	Weight (kg/m³)
		kg/m³					
ULCC [27]	0.32	265	775	41	335	PVA (0.5%)	1305
R425-5-0.7 [28]	0.33	259	702	78.0	322.9	PE (0.7%)	1295–1332

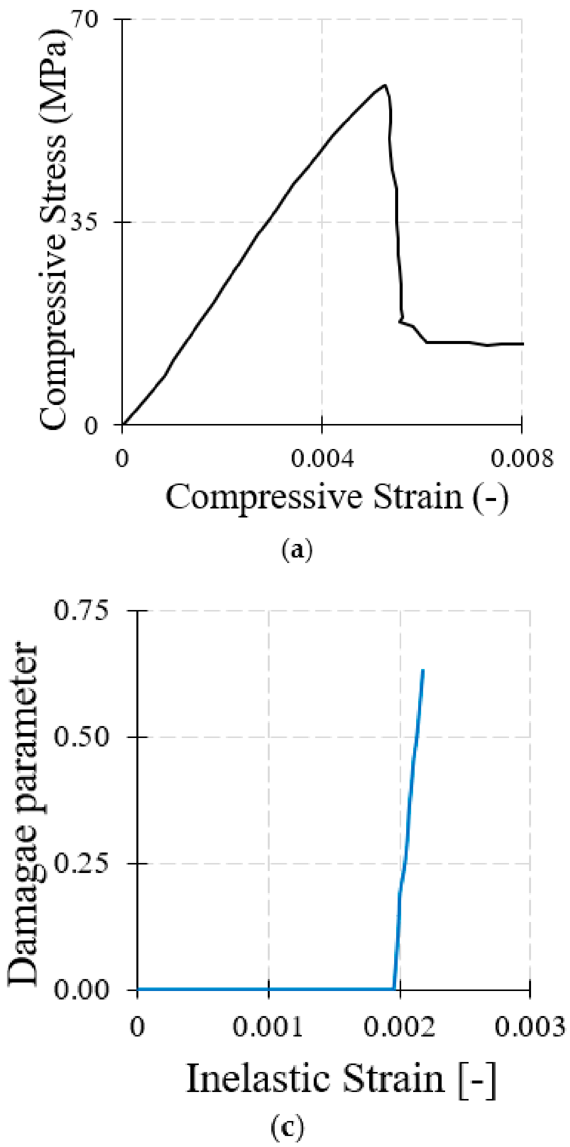


Figure 7. CDP stress–strain curves and damage parameters for ultra-lightweight high-ductility cementitious composite used in the present study: (**a**) compression stress–strain curve extracted from Liu et al. (2016) [27]; (**b**) tension stress–strain curve extracted from Huang et al. (2021) [28]; (**c**) compressive damage parameters; (**d**) tensile damage parameters.

3. Results and Discussion

The LE strain of a ship containing SCS composite plates against bottom slamming loads is illustrated in Figure 8. Various elastic moduli, impact velocities, and thicknesses were considered in these models. Generally, the results indicate that among the nodes selected at the bottom of the ship body (Figure 6b), the strain of point 4 (P4) located at the front part of the ship's structure before the bow of the tip of the hull had the highest value for all model types with various impact velocities, steel elastic moduli, and SCS thicknesses (Figure 8). The results also showed that the highest strain happened sooner for models with high impact velocities as compared to low impact velocities, which was similarly confirmed by the literature. Figure 6 also shows that changing SCS thickness, impact velocity, and steel stiffness considerably affected the strain of the ship body for all selected points, which needs to be considered by ship designers. The ship body should be designed according to the weather conditions and sea location.

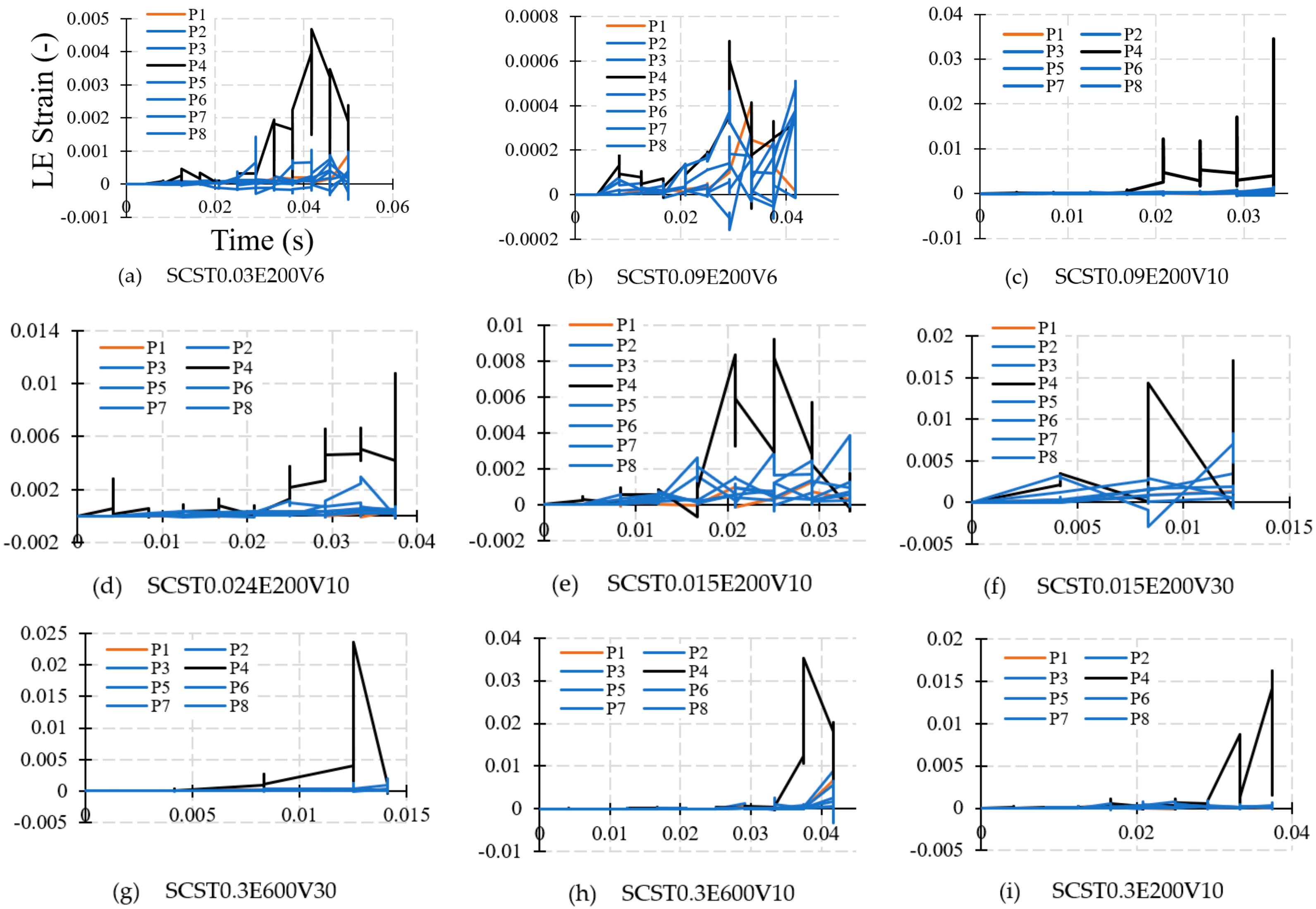


Figure 8. Strain of points located at the external layer of ship model (axis titles of graphs are the same as (**a**) SCST0.03E200V6; (**b**) SCST0.09E200V6; (**c**) SCST0.09E200V10; (**d**) SCST0.024E200V10; (**e**) SCST0.015E200V10; (**f**) SCST0.015E200V30; (**g**) SCST0.3E600V30; (**h**) SCST0.3E600V10; (**i**) SCST0.3E200V10.

The strain of the ship's bottom structure (at point 4) containing SCS composite plates as compared to only steel plates is demonstrated in Figure 9. The results indicate that although a high value of strain (0.78) was reported for the bottom of the ship containing only steel plates (Figure 9b), the SCS-based ship's structure showed the lowest strain (0.01–0.03) for various total plate thicknesses (Figure 9a). This clearly demonstrates that a ship containing SCS composite plates performs better than a ship containing only steel plates to mitigate the slamming load damage. Also, it can be deduced from the numerical results shown in Figure 9b that about 22% of the strain of the outer layer transferred to the inner part of the ship body containing only steel plates due to the low energy adsorption capacity of simple steel plate without using any stiffening elements. However, as shown in Figure 9a, almost zero percent of strain transferred from the outer layer to the inner one in the ship containing SCS composite plates. This clearly shows that the SCS plates have a considerably higher damping ability for slamming loads as compared to steel plates. To put it simply, the results confirmed that using SCS composite plates reduces the required quantity of stiffened elements for the inner part of the ship body. A similar observation was obtained for steel plates with a higher elastic modulus (Figure 10), where the ship containing SCS had a significantly lower LE strain at point 4 (0.035) compared to the body of the ship containing steel (1.08). Additionally, only the body of the ship containing steel (E600) transferred about 14% of the strain from the outer layer to the inner one, while the value reduced to almost 3.0% for the body of the ship containing SCS. The findings also indicated that increasing steel elastic modulus in ships that have steel plates but no stiffened elements does not help prevent internal damage caused by slamming loads. However, incorporating SCS composite plates significantly reduces the requirement for stiffened elements.

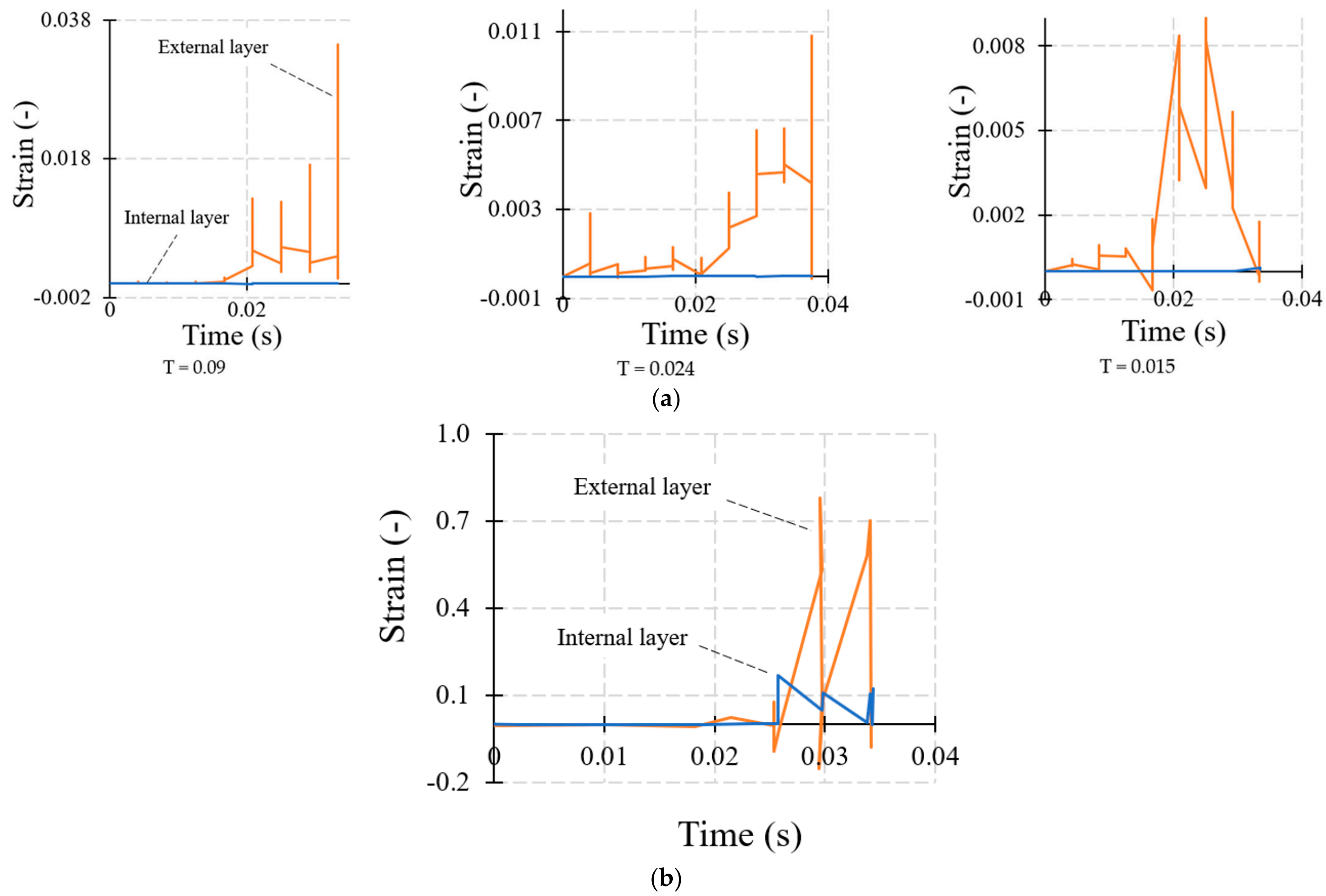


Figure 9. Strain of the bottom structure of the ship: (**a**) SCS composites with E200V10; (**b**) only steel plate with E200V10.

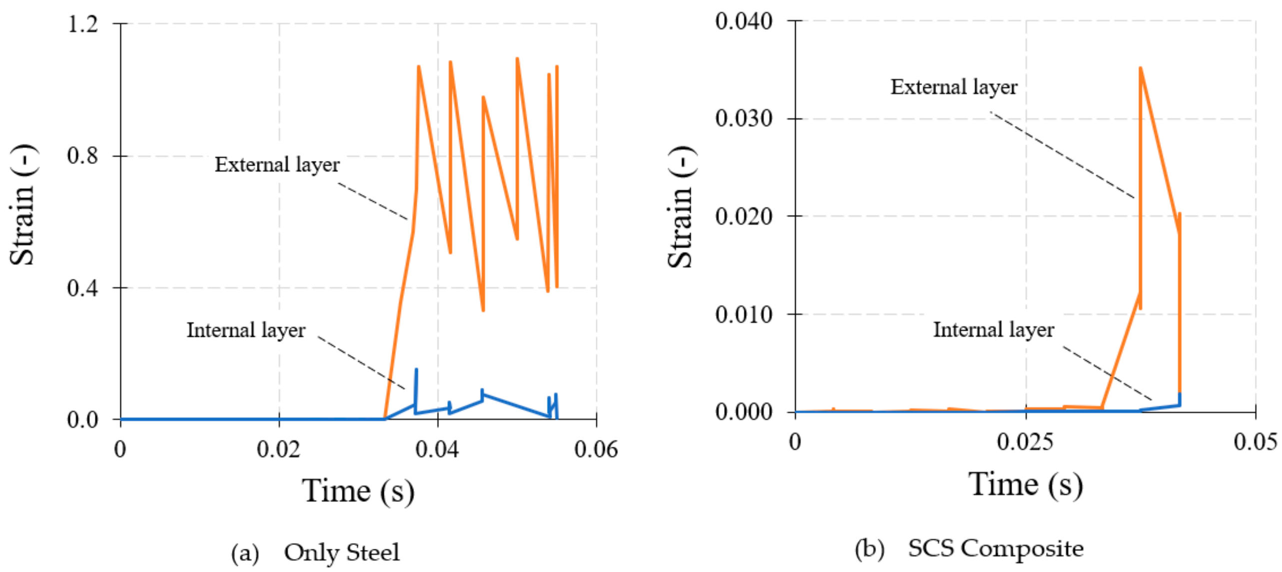


Figure 10. The strain of the bottom structure of the ship: (**a**) SCS composites with E600V10; (**b**) only steel plate with E600V10.

Stress concentration in both the steel- and SCS-containing ship bodies is illustrated in Figure 11. The findings indicate that constructing a ship body solely using steel plates, without incorporating stiffening elements, can lead to harmful local damage in areas close to the bow of the ship. This damage may not be compensated and relieved even with the use of stiffening elements (Figure 11a). However, no local damage was observed in the SCS-containing ship body (Figure 11b). Additionally, controlled stress spreading was observed instead of stress concentration. On the other hand, the results suggest that implementing SCS composite plates leads to a significant decrease in the number of stiffening components needed in the ship's structure. A parametric study was also conducted on the large-scale ship model to distinguish the critical parameters. According to the results shown in Figure 12a, when the thickness of SCS composite plates was increased, there was a reduction of 14.7% in the maximum strain for a small impact velocity of 6 m/s. The results also show that increasing impact velocity from 6 m/s to 10 m/s resulted in a considerable increase in the strain of the ship body; a reduction in time of this maximum strain (Figure 12b).

It is worth mentioning that the current promising numerical results obtained by the present study can be extended by future experimental works. For instance, more novel and sustainable concrete mixtures can be used instead of ultra-lightweight high-ductility cementitious composite [29,30]. Additionally, one of the main assumptions in the present study was the perfect interaction between concrete and steel layers in SCS composite with no slippage. Accordingly, a specific study is necessary for future works to determine the effect of steel–concrete slippage on the performance of SCS composite in ship structures. Moreover, as previous studies showed that concrete composition has a critical impact on the steel–concrete interface, using other types of concrete composition can improve the interface between the layers. Also, other types of composite plates can be used in the ship's structure through the CEL method in Abaqus software to reduce the weight along with decreasing the bottom slamming damage [31].

One of the primary considerations when using SCS composite plates instead of steel ones is the total weight of the ship. To check this critical factor, the mass of ships containing various steel and SCS plates were normalised with the biggest value, and are illustrated in Figure 13. Because ultra-lightweight high-ductility cementitious composites have a lower density than steel materials, ships containing SCS composite plates are significantly lighter than those made of steel. Typically, a ship body is made with 12mm steel thickness. However, when it comes to SCS composite plates, thicker values are necessary for the steel and concrete layers. Despite having thicker upper layers, ships that use SCS composite plates had a lower total weight compared to those containing only steel plates, and in some cases, the weight was comparable (Figure 13).

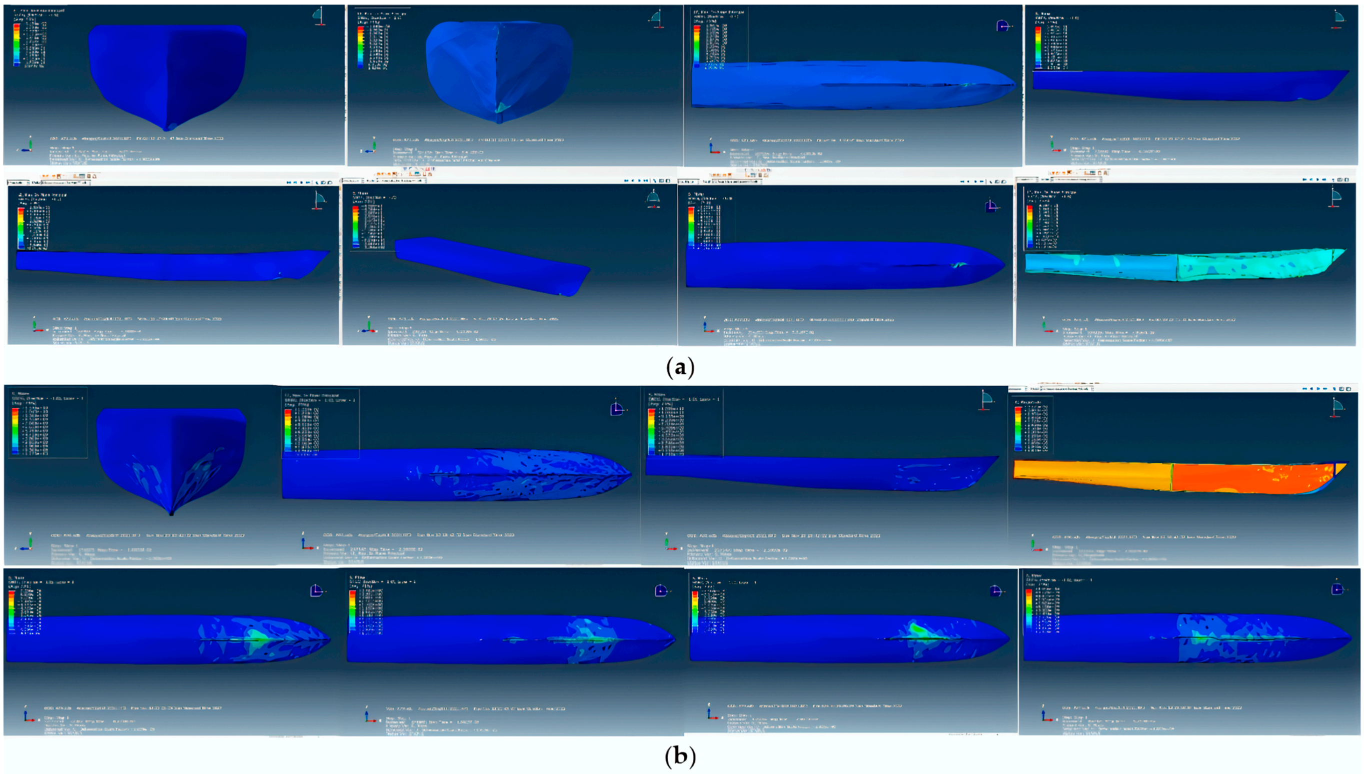
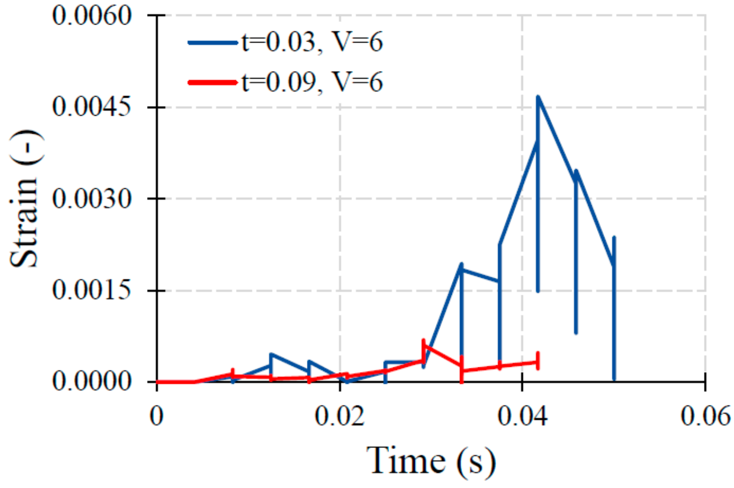


Figure 11. Stress concentration in plates used in the numerical models: (**a**) only steel plates; (**b**) SCS composite plates.

Minitab statistical software was also used in the present study to conduct a statistical analysis on the maximum strain of ships based on the input variables of impact velocities, SCS thickness, and elastic modulus. This can help determine the significance of these parameters (Figure 14). To determine the desired output, the maximum strain at point 4 was considered, located at the bottom of the ship body, as illustrated in Figure 6b. This output variable was then normalised within the software. The research findings suggest that when the thickness of the concrete layer in the SCS plate is increased to a certain level while keeping the total thickness of SCS constant, there is a significant decrease in the strain of the ship body exposed to the slamming loads (Figure 14a). In the case of there being a small thickness of the concrete layer in the SCS composite plate or only steel plate, a high elastic modulus of steel is required to reduce the maximum strain at the bottom of the ship body against slamming loads (Figure 14b). Based on statistical analysis, it has been found that high impact velocity can lead to greater strain on the body of a ship that contains SCS plates. However, the data suggest that increasing the value of the concrete layer's thickness in the SCS composite plate can significantly reduce the destructive effects of high impact velocity on the ship's body (Figure 14c). Moreover, the statistical findings revealed that using a particular type of steel plate (with improved elastic modulus) in the SCS composite plate could slightly decrease the strain level, but not as much as when increasing the concrete thickness within the SCS composite plate (Figure 14d). The impact of concrete thickness on the maximum strain at P4 shows that a thicker concrete layer can help reduce the damage caused by slamming loads up to a certain point. However, going beyond this thickness range can have a negative effect on the ship's behaviour due to the weight of the SCS. Therefore, it is important to control the thickness of the SCS composite plate (Figure 14e).



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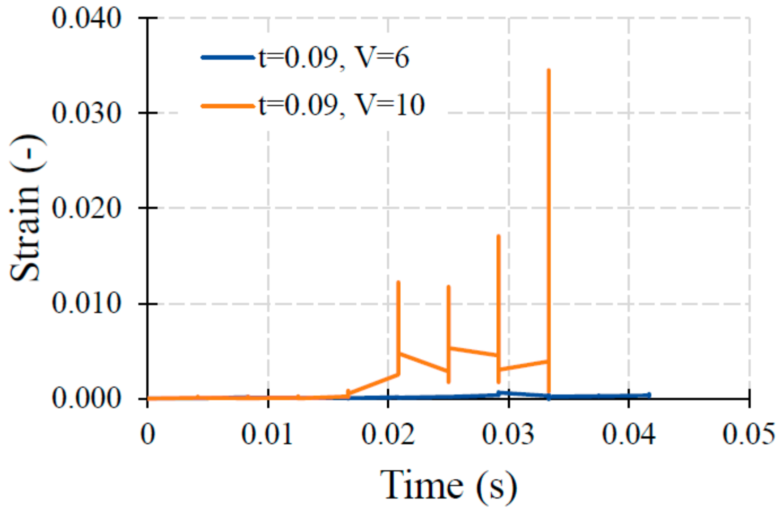

(b)

Figure 12. Effect of crucial parameters on the behaviour of ships containing SCS composite plates: (**a**) effect of layers' thickness for V6; (**b**) effect of drop velocity of the ship.

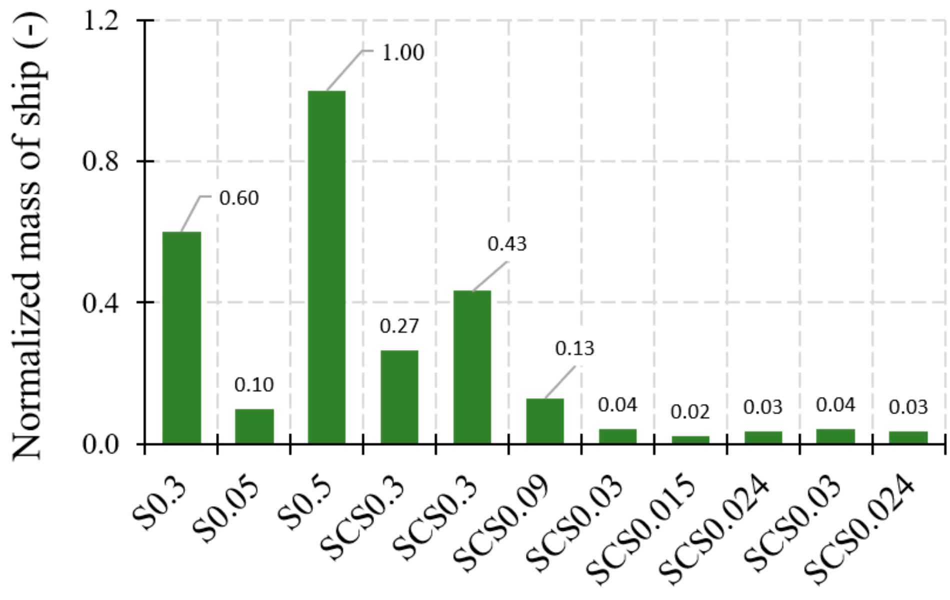

Figure 13. Mass of SCS plates compared to only steel plates (normalised with S0.5).

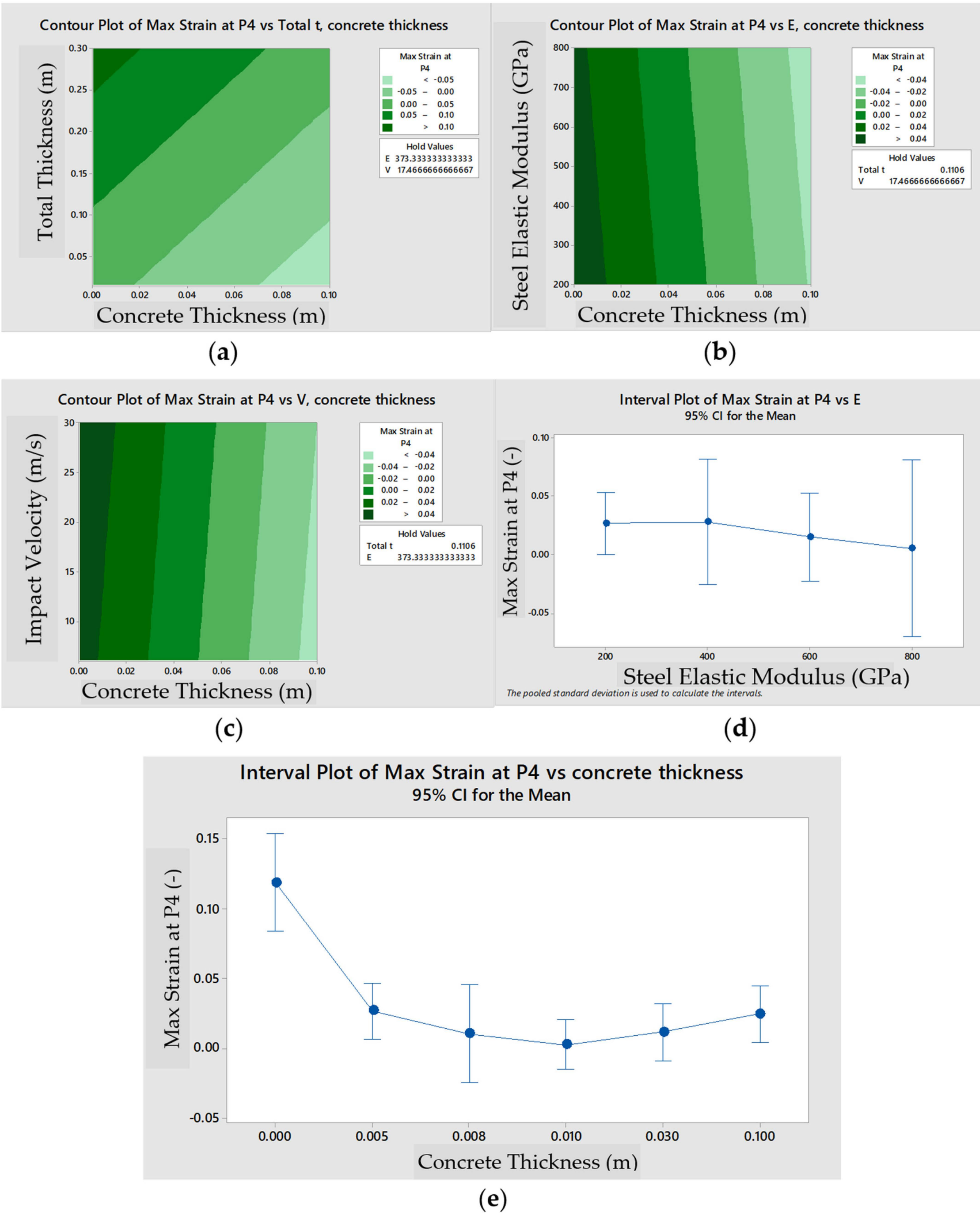

Figure 14. ANOVA analysis to determine the importance of parameters in ships containing SCS composite plate: (**a**) effects of total thickness and concrete thickness on the maximum strain; (**b**) effects of steel elastic modulus and concrete thickness on the maximum strain; (**c**) effects of impact velocity and concrete thickness on the maximum strain; (**d**) one-way effect of steel elastic modulus on the maximum strain; (**e**) one-way effect of concrete thickness on the maximum strain.

4. Conclusions

This paper presents a numerical study to determine the effect of using SCS plates containing a new generation of cementitious composites in mitigating slamming loads in ships. A large-scale model was considered in Abaqus software using the CEL method to employ FSI interaction comprehensively. Impact velocity, steel elastic modulus, concrete thickness, and total SCS thickness were the parameters studied in the present investigation after validating the numerical modelling. Finally, the following conclusions were made based on the present studies' results:

- Using the CEL method in Abaqus was efficient in numerically modelling FSI interaction in the complex slamming loading phenomenon. Moreover, this method was reliable when numerically studying a large-scale ship against bottom impact loading due to the slamming loading phenomenon, so that a minor deviation of 6.5% was found between the numerical model and experimental result.
- The numerical results showed that strain at the front part of the ship's structure before the bow of the tip of the hull had the highest value and therefore should be considered as a critical zone to be strengthened by novel methods.
- It can be deduced from the findings that using an SCS plate containing novel cementitious composite in the ship body considerably reduced the maximum strain value to mitigate the slamming loads.
- The results indicated that SCS composite plates using ultra-lightweight high-ductility cementitious composite causes practical damping in reducing transferring strain from the outer layer to the inner part of the ship body.
- The statistical results in the present study also showed that impact velocity, plate weight, and steel stiffness critically influence the ship body's response to the bottom slamming loads.

It is worth mentioning that small-scale and large-scale experimental studies are required to confirm and extend the present study's findings against various slamming loads. Moreover, novel generations of cementitious composites can be used in SCS plates to mitigate the slamming loads. More experimental works are required for future investigations to concentrate on the ship body itself instead of only using stiffening elements. Moreover, due to the convergence issue in the large-scale ship model, the perfect bond was considered in the present study. Accordingly, future investigation is necessary to determine the effect of steel–concrete layers' relative slippage on the performance of SCS plates within the ship's structure against various slamming loads.

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