Investigation of Structural Response Due to Impact Load on the Small Water Plane Area Twin Hull Autonomous Surface Vehicles (SWATH-ASV)

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Abstract: The main objective of the research was to investigate the structural response of The Small Water Plane Area Twin Hull Autonomous Surface Vehicles (SWATH-ASV) due to the impact load. The impact load was defined as the drop phenomena that might be occurred while SWATH-ASV is being carried and transported. The behavior of the absorbed energy in several drop scenarios also was studied. Numerical simulation was performed using nonlinear finite element method to obtain the numerical simulation data. The size of the damage of the SWATH-ASV was estimated as a design consideration for the structure strength. The external dynamics parameters which include as the contact point location and drop velocity is being considered on the simulation analysis. The internal energy and deformation size which is caused by the drop phenomena will be discussed.

1 INTRODUCTION

Rapid development in the growth of numerical simulation technology, capability of computational speed and relatively large memory capacity makes designers able to create and evaluate of new product designs performance in a virtual world.

Through the finite element method, complex simulations able to provide any valuable information for the design and development of reliable new products like those that have already existed and even better as an improvement on the existing product capabilities. The manufacturer confirmed that this method is very useful, as this method has facilitated them enormously in achieving a better productivity at lower unit costs. This method is also capable for supporting manufacturers to develop engineering components that are easily produced and to create any products that are efficient in terms of material expenditure.

In 2018, an autonomous surface vehicle (ASV) has been developed by Zakki et. al. (2018) which is adopted the Small Water plane Area Twin Hull (SWATH) technology for the hull form. The ASV was developed to support bathymetry survey activities in coastal area. In the development of the SWATH-ASV, the designers attempt to obtain a product that has reliable quality for its hull components. For achieving these quality standards, the SWATH-ASV products must meet the requirements of being able to withstand loads that can result in high stress structures (Ali, et.al, 2011). Therefore this study is focused on the investigation of structural responses that were subjected for impact loading, especially in the drop phenomena. The structure load is the impact load that is occurred when the SWATH-ASV product is dropped from a certain height. Therefore it can be predicted that the developed ASV product has reliable structural integrity when it drops from the certain height during the survey activities.

2 DROP TEST AND FINITE ELEMENT ANALYSIS

2.1 Drop Test

Durability assessment that is important to be conducted for the development of new products is a

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drop test. Drop tests are carried out in the full load conditions and it is dropped from a certain height on a solid floor such as a steel floor or concrete floor. Drop test experiments are costly and require relatively extensive experimental setting times. However with the computational simulation using finite element analysis (FEA), the drop test can be performed without conducting a physical product prototype which is required moulding process and experimental studies. FEA is able to estimate the performance of the response of product structure that is loaded nearly realistic conditions (Abunawas, 2010).

2.2 Finite Element Analysis

Finite Element Analysis is numerical procedure that is accurate and flexible to estimate the performance of a structure, mechanism or process in a loading condition while being operated. FEA is generally associated with the design validation process before the manufacturing process is carried out. Furthermore FEA is also widely used in the initial stages of the design process to try / evaluate new concepts before physical prototypes are made and tested. Some advantages of FEA include:

1. Supporting innovation, as FEA supports designers to think creatively with the accepted risk level.
2. Supporting the process to achieve an optimum design rather than acceptable design, resulting in better performance and lower material costs, as FEA is able to support numerical evaluation processes through evaluation study with multiple scenarios.
3. Understanding and controlling operations in the parametric study of product design, as FEA provides information about detailed performance that cannot be obtained through experimental test.
4. Reducing development research costs and working time, by replacing experimental test into numerical studies, as FEA models are usually faster than creating the physical prototypes and setting up the experimental equipment.

In the last four decades, finite element method becomes a well-known numerical method, since computer applications are widely implemented on the manufacture industries. Versatility and flexibility have been offered by FEA and it is applicable for solving the complex boundary problems. FEA commonly used for the structure analysis in the static and dynamic characteristics. Instead of structure analysis, FEA might be applied for solving the heat conduction, fluid mechanics, electromagnetic and the other continuity problems (Zakki and Windyandari, 2016; Windyandari and Zakki,, 2018; Windyandari, et.al, 2018; Yudo, et.al, 2017; Prabowo, et.al, 2018). There are many commercial finite element analysis software that already support the manufacture industries such as: ANSYS, MSC NASTRAN/PATRAN, SOLIDWORK, LS-DYNA, HYPERWORKS, and many others.

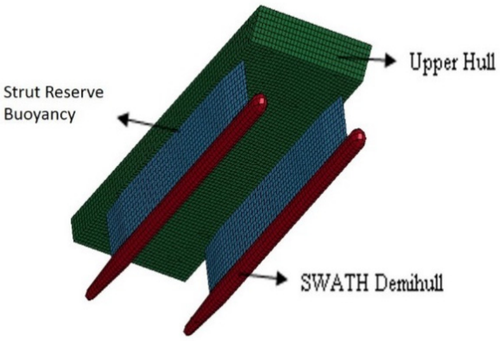


Figure 1: Finite Element Model of SWATH-ASV.

3 DROP TEST SIMULATION MODELLING

The finite element analysis model of the SWATH-ASV is described in the Fig. 1. The meshing process of the SWATH-ASV model is carried out using LS-PREPOST (LSTC, 2009). All of the plate/shell of the SWATH-ASV structures was modelled using 2D elements which is 4 nodded bilinear Belytchko-Tsay shell element is adopted. The finite element model of SWATH-ASV consists of 11706 numbers of nodes and 11674 numbers of shell elements.

In the case of material modelling, Cowper-Symonds strain rate material model is adopted to capture the material behaviour, since the impact problem such as drop test is a high strain rate loading condition. The equation of Cowper-Symonds is defined as follow:

$$\frac{\sigma_d}{\sigma_s} = 1 + (\frac{\dot{\varepsilon}}{C})^{\frac{1}{P}} \quad (1)$$

Where is dynamic yield stress, is static stress, is strain rate, C is material constant which is defined as 100, P is material constant which is defined as 10. The mechanical properties of the FE model can be seen on the Table 1.

Table 1: FE Model mechanical properties.

Properties Item	Material of FE Model
Density (kg/mm^3)	1.522×10^{-06}
Poisson Ratio	0.30
Longitudinal Young Modulus (GPa)	67.28
Transverse Young Modulus (GPa)	14.25
Longitudinal Tensile Strength (GPa)	1.05
Transverse Tensile Strength (GPa)	0.43
Strain Rate Model	Cowper-Symmonds C= 100 and P=10

The boundary condition of the simulation has been defined as the drop orientations which are considered for the numerical analysis. The drop orientations are consist of even keel, 45 degrees heel, 90 degrees heel, 45 degrees trim by stern, 90 degrees trim by stern, 45 degrees trim by bow and 90 degrees trim by bow, see Fig. 2. The floor material is considered as an infinite planer rigid material. For the numerical simulation, the SWATH-ASV is given an initial velocity of 6.26 m/s that is equivalent with the 2m drop velocity before striking the rigid floor. The type of contact algorithm used is node to surface contact with the contact thickness of 0.0001 m for the analysis. Non friction contact is adopted for the SWATH-ASV and the rigid floor.

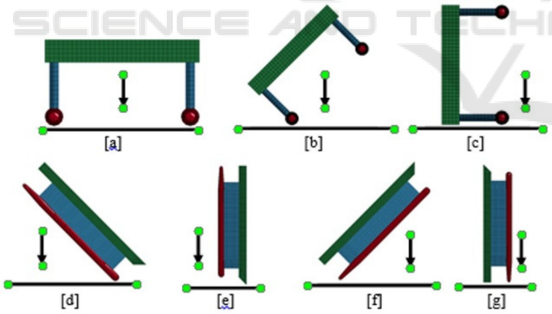


Figure 2: Drop test orientation: [a] even keel; [b] heel 45º; [c] heel 90º; [d] trim by bow 45º; [e] trim by bow 90º; [f] trim by stern 45º; [g] trim by stern 90º.

4 RESULT AND DISCUSSIONS

The drop phenomena for seven different orientations of SWATH-ASV have been simulated. The integrity of the SWATH-ASV structure was analysed to study the various essential parameters such as Von Misses Stress and crash energy absorbed by the SWATH-ASV components.

4.1 Maximum Effective Stress

In the event keel drop condition, the maximum Von-Mises stress obtained on the bottom part of demihull and the connection between strut and upper hull, see Fig 3a. It can be explained that the bottom part of the demihull is exerted the impact force and distributed the load to the ASV structure. Since the maximum Von-Mises of 201 MPa is below the tensile strength, therefore the ASV is not expected to be failed during the event keel drop.

The maximum Von–Misses stress on the connection between strut and upper hull also can be found on the other drop conditions such as heel 45º, heel 90º, trim by bow 45º and trim by stern 45º, see Fig. 3. It is indicated that the connection of strut and upper hull is a vulnerable area that might be failure if the ASV has experiencing the higher drop height. The tendency can be explained since the connection design have a sharp geometry that could be identified as a stress concentrator. Therefore the rounded joint design should be considered to reduce the maximum stress that might be occurred.

According to the result of numerical simulation, it is shown that the maximum Von-Misses stress obtained on the heel 45 degrees condition is 241 MPa. Failure of the connection of strut and the upper hull can lead the leakage of the hull structure. However the Von Misses stress of the connection area is below the tensile strength of 1.05 GPa. Therefore the connection of strut and upper hull is expected not failed under 2 m drop.

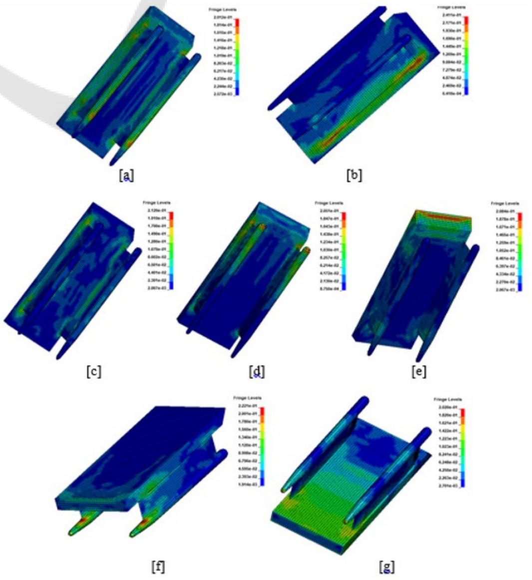
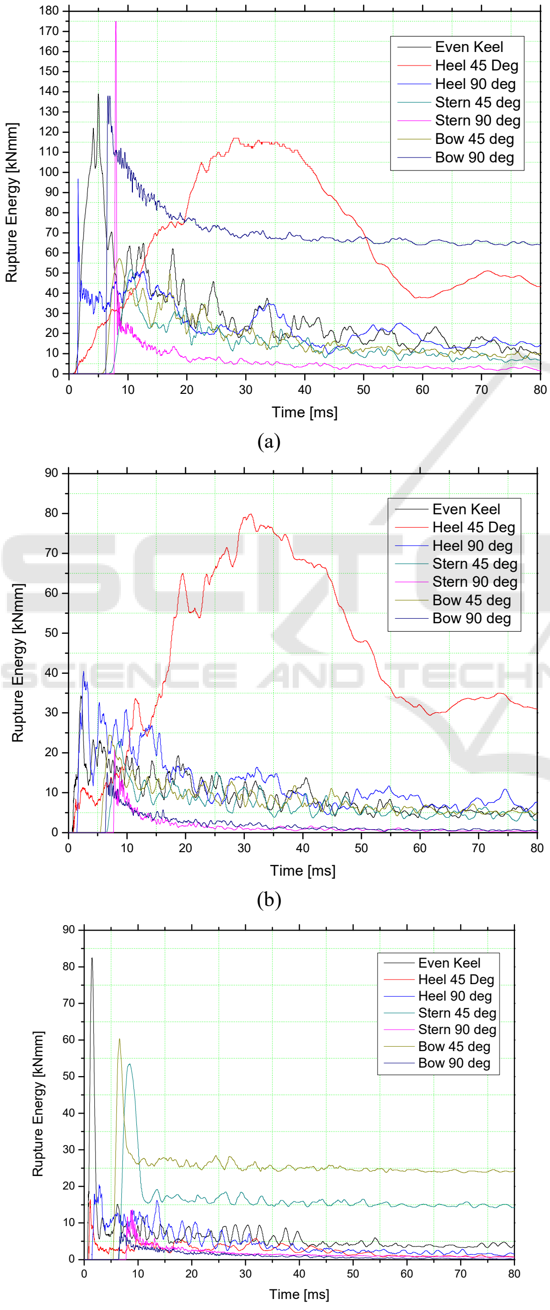


Figure 3: The Maximum Von-Misses stress: [a] even keel; [b] heel 45º; [c] heel 90º; [d] trim by bow 45º; [e] trim by bow 90º; [f] trim by stern 45º; [g] trim by stern 90º.

4.2 Absorbed Rupture Energy

The rupture energy absorbed by all of the components of SWATH-ASV structure after 2m drop is shown in the Fig. 4. It can be seen that the maximum energy which is absorbed by the upper hull is observed in the trim by stern 90º. It might be explained that the upper hull is experiencing the impact energy while the ASV was striking the rigid floor. Although the upper hull absorbed most of the impact energy, however the maximum stress is occurred on the stern peak structure because the stern peak have a narrow shape hull form as the stress concentrator.



(a)

(b)

(c)

Figure 4: The rupture energy absorbed: [a] by upper hull; [b] by strut; [c] by demihull.

On the strut part of the structure, the maximum rupture energy is occurred on the heel 45º condition. It can be explained that during the collision period the strut was experiencing the collision energy and the maximum effective stress have shown in the connection between strut and upper hull as the structure response. Otherwise the design geometry of the connection between strut and upper hull have a sharp shaped that would concentrate the stress in the area. Therefore the connection area is the vulnerableregion that should be improved by providing the smooth connection such as rounded joint and hull haunch.

Finally, the demihull part was shown a maximum absorbed energy on the even keel drop condition. The rupture energy was absorbed when the demihull strike the rigid floor and then the energy was distributed to the upper hull through the strut structure. Therefore the upper hull part has shown larger absorbed rupture energy, especially in the connection between strut and upper hull. According to the numerical simulation result, it can be concluded that the connection between strut and upper hull is critical region that should be modified to improve the drop performance of the SWATH-ASV.

5 CONCLUSIONS

The investigation of SWATH-ASV structural response was made due to the impact load on the 2m drop phenomena. It was obtained that the maximum effective stress (Von –Misses stress) was occurred on the Heel 45º condition. The maximum effective stress of 241 MPa is smaller than the tensile strength of the SWATH-ASV material. Therefore it could be concluded that the SWATH-ASV structure is able to withstand the impact load during the 2m drop test.

In the case of absorbed rupture energy that might influence the strength integrity of the SWATH-ASV structure, the maximum absorbed rupture energy is occurred on the trim by stern 90º, it is indicated that the upper hull have absorbed most of the impact energy. Although the maximum rupture energy was shown by the trim by stern 90º, However the most critical region of the SWATH-ASV structure is the connection between strut and upper hull, since the area have a sharp shaped that might become as stress concentrator. Therefore it can be concluded that the connection between strut and upper hull is vulnerable region that should be modified to provide smooth connection for eliminating the stress concentration that might be increased the effective stress.

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