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RESEARCH ARTICLE

EVALUATION OF DROP TEST PERFORMANCE OF GLASS FIBER REINFORCED PLASTIC (GFRP) MODULAR PONTOON UNIT USING NUMERICAL ANALYSIS

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ABSTRACT

The main objective of the research was to investigate the structural response of the Glass Fiber Reinforced Plastic modular pontoon unit due to the impact load during the drop test. The impact load was defined as the drop phenomena that might be occurred while GFRP modular pontoon unit is being packaged, stacked and transported. Numerical simulation was performed using nonlinear finite element method to obtain the response characteristics. The maximum effective (Von Mises) stress of the GFRP modular pontoon unit was estimated as a design consideration for the structure strength. The external dynamics parameter which includes as the drop orientation and drop velocity which is equivalent the drop height is being considered on the simulation analysis. According to the simulation result, it can be found that the maximum effective stress is occurred on the corner side drop position. The magnitude of maximum effective stress is larger than the yield strength of the GRFP material. Therefore the plastic deformation is observed on the corner side of the modular pontoon unit. The results of simulation analysis present that the most vulnerable drop position is the corner side position. It is recommended that the corner side of the modular pontoon unit is the important part for design improvement to increase the structure reliability during the drop phenomena.

KEYWORDS

GFRP modular pontoon unit, absorbed ruptured energy, structural response, drop test simulation.

1. INTRODUCTION

Indonesia has many regions that are very vulnerable to flood disaster. In 2013, the central business areas in Jakarta such as Thamrin and Sudirman Street were also flooded. According to the data from the Indonesian Meteorology, Climatology and Geophysics Agency (BMKG), Jakarta area average rainfall may reaches 25-30 centimeters per day during the rainy season. It can be approximately three or four times larger than the normal rainfall, [1]. The very high rainfall may cause natural and social disasters such as floods, the clampdown of economic activities and the lack of clean freshwater.

Figure 1: Rubber boat to evacuate the floods victims, [3]

The floods in Jakarta were caused by the poor drainage systems, the collapse of river dams and the raised of water flow volume on the thirteen rivers throughout the city. The surrounded regions such as Bogor, Bekasi, Depok, Tangerang may experience the same situations. On Januaty 18th 2013, the National Disaster Management Agency stated that the amount of losses reported was twelve people died in the flood with the following

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details: five people caused by electric shock, two people due to cold, and two people due to slipping or fell, one person drowned, and two people were found dead at home. Finally, it was confirmed that the total number of victims of the disaster was 20 people died, and 62,819 people were relocated, [2].

Figure 2: Wheel barrow for the floods evacuation, [3]

Many efforts have been made to address various problems that occur during floods such as: increasing river dams, establishing aid centers at disaster sites, relocating refugees to rescue areas, and enforcing the state for flood emergencies. All of those activities must be supported by qualified equipment, especially for life-saving appliances.

The life-saving equipment such as rubber boats, wooden boats with outboard engines and wheelbarrows are generally used for evacuating the floods victims, [3]; see Figure 1 and Figure 2. This equipment has advantage of accessing remote areas because of its small size which is suitable for flooded gangways and alleys. Because of the carrying capacity of the vessel is relatively small, therefore it may not be able to evacuate the flood victims concurrently. Based on these conditions, the alternative floating equipment that supports the process of evacuation in densely populated residential areas is needed. The alternative evacuation equipment features are:

- Stay stable to withstand the heavy loads
- An adaptable and multipurpose floating gears
- Directly and easy to deploy
- Capable for operation in the narrow and shallow water
- Capable for accommodating disabilities, food and medical supplies
- Capable for providing alternative transportation.

The need and necessities for suitable equipment to evacuate flood victims in highly populated residential areas has motivated the previous study to develop the modular floating submission pontoons as a versatile floating gear to provide flood evacuation systems [4].

During the design development of the modular floating pontoon unit, the efforts to obtain the reliable quality of the pontoon unit were performed. One of the product design requirements is the capability of pontoon unit to withstand the loads that might results product defect or damage. The investigation of structure response during the drop phenomena is the main objective of this study. The drop test of the developed pontoon unit is simulated using the dynamic finite element analysis. The certain drop height and drop position was defined for the simulation model. Therefore the drop phenomena performance can be predicted that the developed pontoon unit has reliable structure integrity to withstand the load during the drop test using the numerical simulation.

2. MATERIAL AND METHODS

2.1 Literature Review

Many articles can be found that reporting results on the drop test and simulation in the recent years. A study the assessment of the reliability of drop performance of four different component boards [5]. It is observed that the temperature has influence on the drop reliability of the component boards significantly. A study on the drop test of FR-4 test board according to the JEDEC standard [6]. The ANSYS/LS-DYNA is adopted to perform the drop simulation of the test board under JESD22-B111 standard. A group researchers conduct the crashworthiness of a civil airplane fuselage section [7]. The relation of speed load and ultimate shear were modeled by logarithmic function. The result shows that the numerical simulation has a good agreement with the experimental drop test.

Other researchers performed the series of drop experiment to investigate the hydrodynamic loads which is experienced by a generic wave piercing catamaran hullform during slamming phenomena [8]. The experiment is focused on the characteristic of unsteady slam loads on the arched wetdeck. The servo hydraulic slam testing system was adopted. It is observed that the slam force peak magnitude have strong relationship with impact velocity.

Other group researchers investigated the mechanical performance of packaging system for the low and intermediate level wastes (LILW) transportation due to the horizontal drop test [9]. It can be found that the localized stress is obtained on the flange and the bottom packaging system. The study shows that the maximum stress is lower than the permissible stress and the package structural integrity was confirmed and reliable.

A studies the effectiveness of simulation method to simulate the electronic control unit (ECU) drop test [10]. The explicit and implicit method is adopted. The results show that explicit method is conditionally stable while the implicit method is unconditionally stable. In this study the ECU is simplified as bare printed circuit board (PCB). The in-plane strain and displacement are obtained at the one meter drop height on the rigid floor.

Some researchers present the performance of hybrid composites of Kenaf and Kevlar due to a low velocity impact load [11]. The result shows that the seven layer laminate able to withstand the impact energy below 30 Joules. The hybrid composites have better mechanical properties compare with the full Kenaf composite.

Other researchers conduct the finite element simulation for the drop test of F-28 fuselage section to investigate the performance of aircraft due to realistic crash conditions [12]. The impact velocity was defined of 346.8 in/s on to soil. The models were executed to find the airframe responses which are compared with the experimental data.

A group researchers investigated the 3D impact problem of generic vessels through the experimental free drop test series [13]. The results show that the 2D numerical simulation is 25% larger than the experimental result. It is also obtained that the 3D effect is prominent in the region of the bow part. The complex fluid form which is including the flow separation and air cavity depended on the impact velocity.

Figure 3: GFRP Modular Pontoon Unit

2.2 Modeling of the Pontoon Unit Drop Test

Durability assessment that is important for developing new products is the drop performance test. Drop tests are conducted due to the operational load conditions and dropped from a certain height on to rigid floors such as steel floors or concrete floors. Drop test experiments are expensive and require relatively extensive experimental settings. Otherwise the numerical simulations using finite element analysis (FEA) able to simulate a drop test can be carried out without making a physical product prototype that is needed for the experimental test. FEA is able to

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estimate the performance of product structure responses that contain almost realistic conditions.

The finite element (FE) model was created from the pre-processor program. The model of pontoon unit was made from the data dimension and specification of the developed pontoon unit, Figure 3. The total weight of the GFRP modular pontoon unit is 7.82 *kg*. The FE model is consisted of 3702 shell elements, 2211 nodes and 2 parts (rigid floor and pontoon component). The boundary conditions of the model was defined as fix support on the rigid floor, furthermore the initial velocity was defined as a representation the free fall velocity before the pontoon hit the rigid floor.

Table 1: FE Model mechanical properties

Properties Item	Material of FE Model
Density (kg/mm3)	1.522 ×10-06
Poisson Ratio	0.30
Long. Young Modulus (GPa)	67.28
Trans. Young Modulus (GPa)	14.25
Long. Tensile Strength (GPa)	1.05
Trans. Tensile Strength (GPa)	0.43
Strain Rate Model	Cowper-Symmonds C= 100 and P=10

The material properties was provided as the representation the glass fiber reinforced plastic (GFRP) material, however the material was assumed as an isotropic material and piecewise linear plastic model. The isotropic material was selected in the mean of to simplify the material modeling process. The influence of the strain rate was defined using the Cowper-Symonds equation, Table 1. Although the simplification was made, however it would not influence the accuracy of computational result significantly.

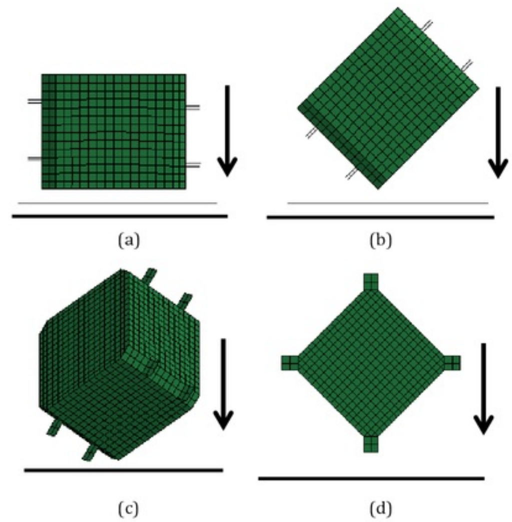

Figure 4: Drop test orientation: (a) Flat Position; (b) 45 degree X-axis rotation; (c) Corner side; (d) Connector side drop

Table 2: Drop test simulation scenario

Drop Scenario	Drop Orientation	Drop Height	Equivalent Initial velocity
Scenario 1	Flat	2 meter	6.26 m/s
Scenario 2	45° X-axis		
Scenario 3	Corner side		
Scenario 4	Connector side		
Scenario 5	Flat	4 meter	8.86 m/s
Scenario 6	45° X-axis		
Scenario 7	Corner side		
Scenario 8	Connector side		

The drop test scenario is determined as the drop orientations and the free fall height. The drop orientations are included as the flat position, 45 degree X-axis rotation, Corner side rotation and Connector side drop, see Figure 4. The free fall height is determined as 2 m and 4 m. the detail of the simulation scenario might be seen in Table 2.

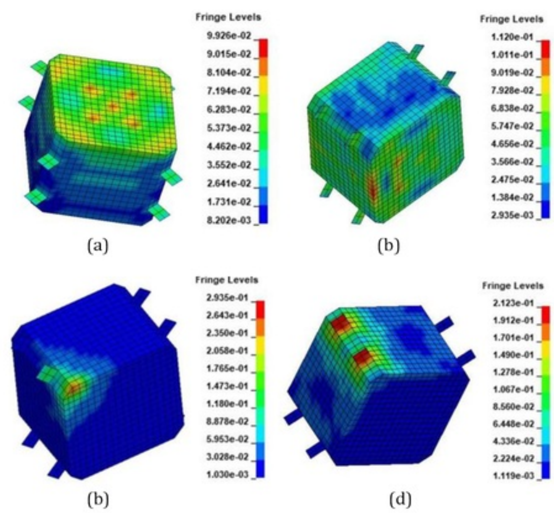

Figure 5: Effective (Von Mises) stress distribution on the 2 m drop height: (a) Flat Position; (b) 45-degree X-axis rotation; (c) Corner side rotation; (d) Connector side drop

3. RESULTS AND DISCUSSIONS

3.1 Maximum effective (Von Mises) stress

The simulation result of maximum effective (Von Mises) stress distribution of the modular pontoon unit structure is shown in Figure 5-Figure 6. The Flat position drop introduces the smallest maximum stress compare with the other drop position. The magnitude of maximum effective stress is 99.2 MPa and 150 MPa for the drop height 2m and 4m, respectively. Based on the obtained maximum effective stress, the structural damage was not occurred in the flat position drop.

The largest maximum effective stress was observed on the corner side drop position. The magnitudes of the maximum effective stresses are 293 MPa and 348 MPa for the 2 m and 4 m drop height, respectively. Since the yield stress limit of the GFRP material is 175 MPa, it is indicated that the damage was occurred on the corner side drop position. Furthermore it also can be seen that the damage was obtained at the connector side position on the 2m drop height. However, the damage do not occurred in the flat drop position in the both drop position, it can be explained that the pontoon unit structure able to transmit the impact load effectively on the flat drop position.

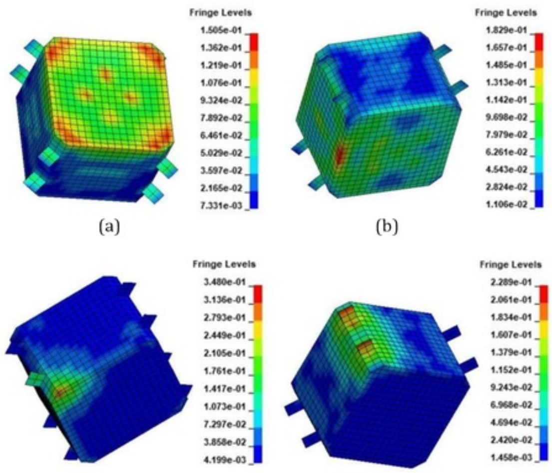

Figure 6: Effective (Von Mises) stress distribution on the 4 m drop height: (a) Flat Position; (b) 45-degree X-axis rotation; (c) Corner side rotation; (d) Connector side drop

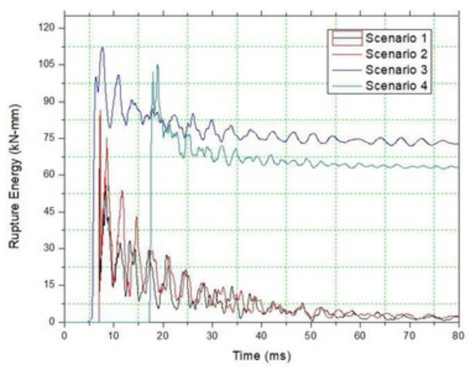

Figure 7: The absorbed rupture energy of modular pontoon unit on 2m height drop

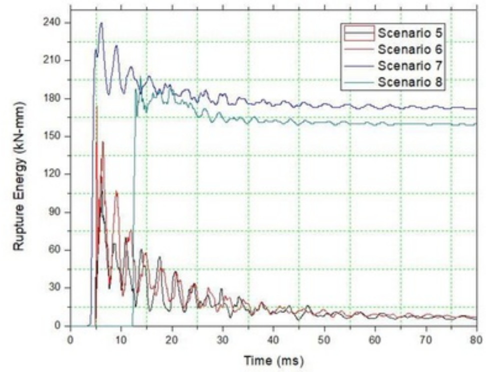

Figure 8: The absorbed rupture energy of modular pontoon unit on 4m height drop

3.2 The Absorbed Rupture Energy on the Drop Test

In the case of absorbed rupture energy, the simulation results show that the modular pontoon units have absorbed the impact energy at all of the drop scenarios, see Figure 7 and Figure 8. It can be seen that the larger drop height has increased the rupture energy which is absorbed by the structure of pontoon unit while crashing the rigid floor. The larger drop height has increased the gravitational potential energy which has proportionally linear relation with the height of the dropped object. The maximum absorbed rupture energy can be found on the Table 3. According to the Table 3, the range of the percent of change of the absorbed rupture energy is 87.48%-114.04%. It shows that the simulation has a good tendency in describing the effect of height drop on the absorbed rupture energy.

Table 3: The increased of maximum absorbed rupture energy

Drop Orientation	2m (kN-mm)	4m (kN-mm)	Percent of change (%)
Flat	73.86	144.71	95.92
45° X-axis	86.48	173.84	101.02
Corner side	112.34	240.45	114.04
Connector side	105.41	197.62	87.48

Otherwise the absorbed rupture energy is influenced by the drop orientation. According to the simulation result, the corner side has shown the largest absorbed rupture energy compare with the other drop orientation. The increments of the absorbed rupture energy of the corner side compare with flat drop position are 52.1% and 66.16% for 2m and 4m drop height, respectively.

Therefore, it can be concluded that the corner side drop orientation is the most vulnerable drop position that might increase the absorption of the rupture energy which may cause the damage on the structure of modular pontoon unit. The range of the percent of change of the absorbed rupture energy because of the drop orientation is 17.09%-52.1% and 20.13%-66.16% for 2m and 4m drop height, respectively.

4. CONCLUSION

The drop test simulations have been conducted to investigate the structural response of the GFRP modular pontoon unit due to the impact load on the 2m and 4m drop height condition. It was observed that the maximum effective (Von Mises) stress is happened on the corner side drop position. The maximum effective stress of 293 MPa and 348 MPa are larger than the yield stress limit of the GFRP material. Therefore, it is indicated that the plastic deformation can be found on the structure of modular pontoon unit during the corner drop position.

The result of the simulation presented that the most vulnerable drop position is the corner side position. The corner side position has increased the maximum effective stress and the absorbed rupture energy significantly compare with the flat drop position. Therefore, the corner side part of the modular pontoon unit is the important part for the design consideration, especially to improve the drop performance test.

The numerical simulation shows that the increase of the drop height has significant increment on the maximum effective stress and the absorbed rupture energy. The similar increment trend also can be found while the drop orientation is changed. Therefore, it can be concluded that the drop height and orientation have significant influence on the drop performance test of the modular pontoon unit.

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