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The Application Modular Floating Pontoon to Support Floods Disaster Evacuation System in Heavy Populated Residential Area

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Abstract *- During floods disaster in the heavy populated residential area, the lack of existing life saving appliances system such as rubber boat and wooden boat were not able to evacuate the disaster victims spontaneously in mass. The condition might be explained since the rubber boat and wooden boat have limited occupant capacity. Based on the conditions, the main objectives of the research are focused on the evaluation of the application of modular floating pontoon as multipurpose floating equipment to support floods disaster evacuation process. The investigation of the modular floating pontoon performance such as hydrostatics characteristics, the equilibrium condition and the intact stability was studied using strip theory and Krylov's method. Furthermore, the strength analysis of the modular floating pontoon structure was calculated using finite element method. The results show that the modular floating pontoon is reliable to support the evacuation process.*

Keywords— *Modular floating pontoon, evacuation system, heavy populated residential area, floods disaster equipment, intact stability, equilibrium condition, strength analysis*

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I. INTRODUCTION

Indonesia has many regions which are very susceptible to floods. In 2013, the Jakarta business center area such as Thamrin and Sudirman Street were also swamped by floods. Based on the data of Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), the average of rainfall in the Jakarta area reach 250-300 millimeters per day in the rainy seasons. It could be three to four times than the typical rainfall, Fig. 1, [1]. The extremely high rainfall may lead to ecological disasters such as: floods, the shutdown of economics activities and crisis of freshwater.

The floods in Jakarta, instead of the heavy rain since December 2012, was caused by the poor drainage systems, the many embankments collapse and the water current volume increased through the 13 rivers across the city. The surrounded regions such as: Bogor, Bekasi, Depok, Tangerang undergo the same circumstances. On January 18th 2013, National Disaster Management Agency declared that the number of casualties recorded were 12 people killed caused by the flood with the details as follow: five persons due to electric shocks, two persons because of the cold, two persons because of the slip or fall, one person was drowning, and two person was found dead at home. Finally, it is confirmed that the total of disaster victims became 20 persons died, and 62.819 persons were relocated, [2].

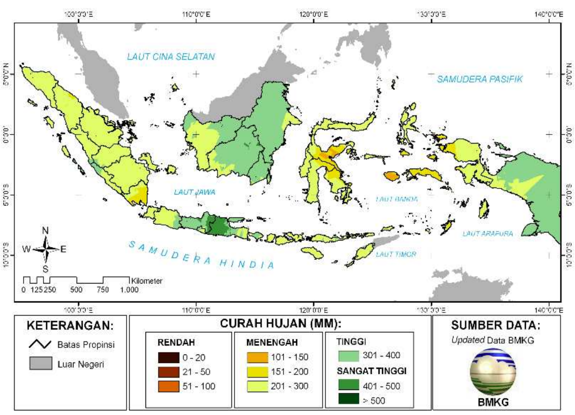


Fig. 1 Rainfall distributions on February 2013, [1]

Many efforts were made to address the various problems that occurred during floods such as: the improvement of river embankment, the establishment of aid center on the disaster location, the relocation of refugees to the save area, and the state enforcement for floods emergency. All of these activities should be supported with adequate equipments, especially for the life saving appliances.

Fig. 2 Rubber boat and outboard engine wooden boat to evacuate floods victims, [3]

Fig. 3 Wheel barrow for the floods evacuation, [3]

The life saving appliances that commonly used to evacuate the disaster victims were rubber boats, wooden boats with an outboard engine and wheel barrows, [3]; see Fig. 2 and Fig. 3. These equipments have advantages for accessing the remote area because of the small size that fit for the gang way and alleys that were swamped by floods. Since the boat carrying capacity was relatively small, therefore it might not able to evacuate concurrently the floods victims in mass. Based on the conditions, the alternative floating equipments that support evacuation process in heavy populated residential area is needed. The characteristics of the alternative evacuation equipments are:

1. Remain stable on a heavy load
2. Represents the multipurpose floating equipment
3. Immediate and simple to deploy
4. Able to operate in the shallow water
5. Able to accommodate disability, food and medical supply
6. Able to provide emergency transportation.

The needs and requirements for adequate equipments to evacuate the floods victims in heavy populated residential area has motivate this research to focused on the application of modular floating pontoon as multipurpose floating equipment to support floods disaster evacuation system. The modular floating pontoons were assembled for the floating walking path that is expected became alternative equipment during spontaneously evacuation of floods victims in mass. The knockdown and modular system was adopted to give the flexibility, adaptability and simplicity for the installation of the pontoons as floating walking path on the disaster area. In the crowded residential area, the evacuation process through the gang way and small alley might be done straightforwardly using the floating walking path equipment.

Several articles have been reviewed to support the development of the modular floating pontoon design. These articles generally relate to the pontoon bridge or very large floating structure (VLFS) characteristics. Wu and Shih, [4], studied the elastic vibration of the floating bridge with a moving load. Pontoons regarded as slender beams were placed on an elastic foundation.

Hydroelastic response analysis of a pontoon bridge in the frequency domain wave conditions, have been carried out by Ueda, [5-7], Oka, [8] and Ikegami, [9]. The numerical solution of large-scale elastic model test was verified by Ikegami. Pontoon bridge structure was modeled using the finite element method and the influence of the fluid was determined using the boundary element method in the scope of the linear theory.

For the time domain, Watanabe, [10], have analyzed the hydroelastic behavior and the calculation of memory effect due to the wave damping. Ertekin analyzed the hydroelastic response of mechanically connected pontoon bridge with moving and static loads, current loads and other external loads, [11].

Based on the articles review, the investigation of the modular floating pontoon performances such as the hydrostatics characteristics, the equilibrium conditions, the intact stability, and the strength of the modular floating pontoon structure is studied using similar procedure as floating bridge structures. The similarity of floating bridge structure with the floating walking path might present reliable results in the numerical analysis.

II. Materials and Methods

The research method has two main steps during the evaluation of modular floating pontoon performances. At first, the geometric form of modular floating pontoon was developed and evaluated to obtain the characteristics of hydrostatics, equilibrium conditions, and intact stability. The strip theory and Krylov's method was adopted for the numerical analysis. Secondly, the strength analysis of modular floating pontoon structure was studied using finite element method. The detail of research method is illustrated in the Fig. 4.

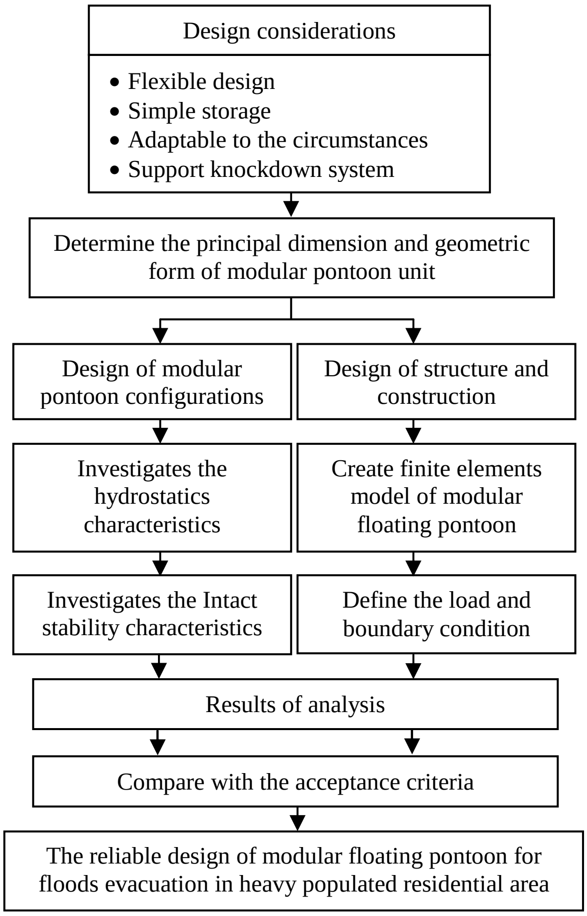


Fig. 4 The flowchart of research method

2.1 Principal Dimension and Pontoon Configurations

The development of modular floating pontoon system started with determining the pontoon unit principal dimensions. The principal dimensions are the length, the width and the height of pontoon unit. The length was determined with regards to the simple handling and storage, when the pontoons were dismantled. Considering the condition, the length of the pontoon unit was created similar with the width, which was 50 cm × 50 cm square plane. By the freeboard and the draught of loaded pontoon, the pontoon height was determined as high as 40 cm.

Since the principal dimensions of modular floating pontoon unit was made, then the configuration of pontoons that would be used for the evacuation process is determined. The size of the gang way, alley and the flooded road and the pontoon stability was considered for the minimum configuration of modular floating pontoon. Regarding the various size of the flooded area, the possibility of the minimum configuration of the modular floating pontoon was determine as large as 4 x 8 pontoons. The detail particulars of pontoons configuration are presented in Fig. 5.

2.2 Hydrostatics Calculations

The hydrostatics data were calculated at discrete intervals, as functions of pontoon draught, for constant trim and heel. These data were plotted in hydrostatics curves that allow interpolation. The hydrostatics curves might be grouped into two categories based on the function of hydrostatics data for vessel performance analysis. The first group was the curves that indicating modular floating pontoon geometry coefficients. These coefficients reflect the characteristics of the hull geometry, such as: *Cb* (Block Coefficient), *Cm*

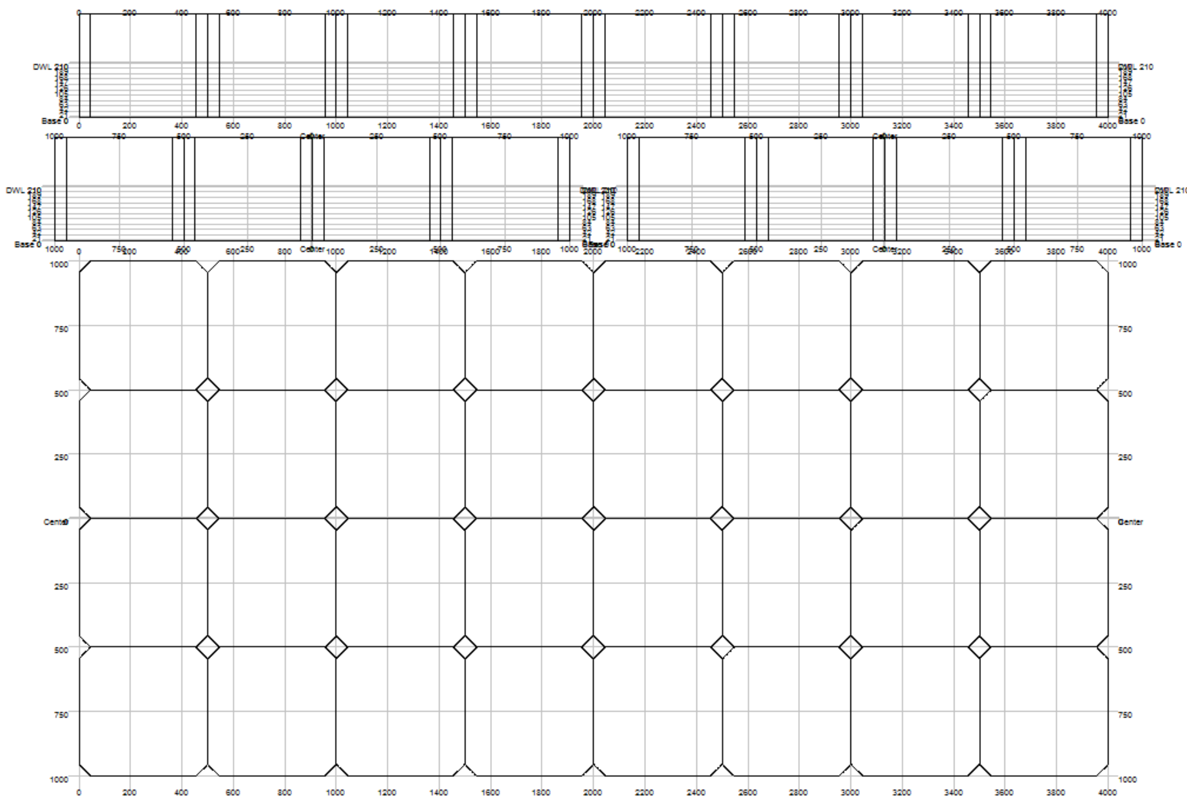


Fig. 5 The minimum configuration of the modular floating pontoon

(Midship Coefficient), *Cw* (Water Line Coefficient), *Cp* (prismatic Coefficient). The second group was the curves that indicating substantially constants that used to determine the characteristics of initial stability and the equilibrium condition of the modular floating pontoon, such as: *W* (Displacement), *WPA* (Water Plan Area), *TPC* (Ton per Centimeter Immersion) and *MTC* (Moment to change trim one centimeter). These curves were part of the documentation that must present the characteristics of the pontoons and were used in calculations related to the operation of the modular floating pontoon. The results of the hydrostatics calculation of the 4×8 modular floating pontoon configuration are shown in the Fig. 6.

2.3 Equilibrium conditions and intact stability analysis

The Archimedes principle states that a body immersed in a fluid experiences an up thrust equal to the weight of the fluid displaced. Since the modular floating pontoon is a floating body, the pontoon floating freely in still water experiences a downward force due to gravity is known as the weight. The floating pontoon is in equilibrium, while the weight has the same magnitude and the same line action with the buoyancy force. Otherwise the pontoon would move until the equilibrium position achieved.

The pontoon might be inclined in any direction. Any inclination might be considered as made up of an inclination in the transverse plane and inclination in the longitudinal plane. In equilibrium and stability calculations the transverse inclination is known as heel, and the longitudinal inclination, called trim. The equilibrium position and intact stability characteristics of the modular floating pontoon were estimated, considering the loading conditions that describe the operational conditions of the pontoon.

The loading conditions of the modular floating pontoon were determined based on the number of occupants and the configuration of the occupant positions during the evacuation process. Therefore, the loading conditions in the equilibrium and intact stability calculations are:

a. Condition I: Transversely unbalanced load (TCG =0.415 m from centerline)
b. Condition II: Longitudinally unbalanced load (LCG =0.78 m from AP)
c. Condition III: Full load (12 occupants uniformly distributed)
d. Condition IV: Empty load (no occupant)

The intact stability calculations have been made using Krylov's method, considering the same load case with the loading condition that was used for the equilibrium calculations. No free surfaces in pontoon units were considered. The center of gravity for the lightweight/empty condition was considered at midship. For the cases of the calculations using the loading conditions, the center gravity was adapted following the weights distribution of the occupant positions.

2.4 Structure design and analysis

Through the design geometry that had been obtained, furthermore the pontoon structure was determined to withstand a given load. The pontoon unit structure was designed as a hollow box that was intended to reduce the weight of the pontoon unit. Additionally, the bolted clevis was adopted for the interconnection system between the pontoon units. Prior to supporting an evacuation process, an evaluation of the modular floating pontoon structure strength must be established and confirmed. The estimation of structural response behavior due to operational loads is important for a reliable design. The strength assessment of modular floating pontoon was focused on the investigation of the strength of pontoon unit and the interconnection system structure using finite element method. The finite element (FE) model was developed for the pontoon structure analysis. The requirements that should be followed by the developed FE model are:

1. All main structural members are to be presented in the FE model
2. Bolts are to be modeled by bar element having axial stiffness
3. Pontoons are to be modeled by shell element having out-

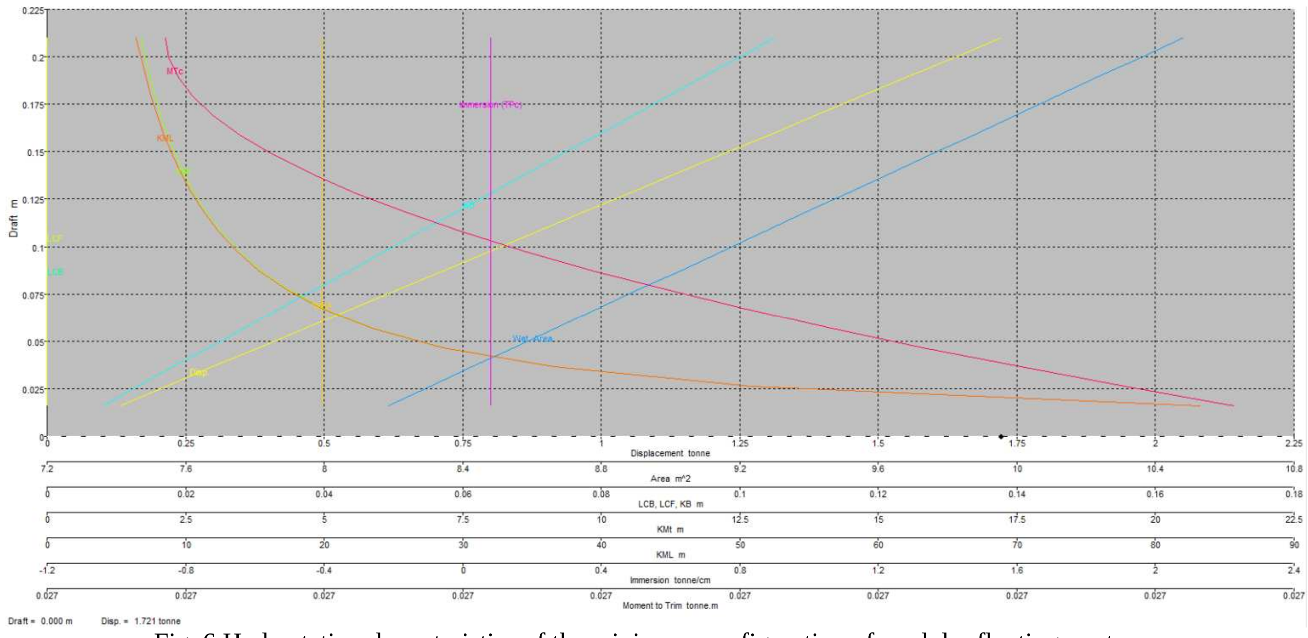


Fig. 6 Hydrostatics characteristics of the minimum configuration of modular floating pontoon

of-plane bending stiffness in addition to bi-axial and in-plane stiffness

Boundary conditions have been defined as simply supported at the both ends of the FE model. The nodes on the clevis at the both end of the modular floating pontoon are to be fixed as presented in the Table 1. The material properties was defined as the properties of fiberglass reinforced plastics (FRP), see Table 2. The loading conditions were used in the analysis including the inertial load, the hydrostatics load and the occupants load.

Table 1. Support conditions of the boundary point

Location of the boundary point	*Translational*			*Rotational*		
	D_x	D_y	D_z	R_x	R_y	R_z
The boundary point on the after end of the model	-	*Fix*	*Fix*	-	-	-
The boundary point on the fore end of the model	*Fix*	*Fix*	*Fix*	*Fix*	-	-

Table 2. Material properties of fiber reinforced plastics (FRP)

Typical Properties	FRP
Density (Ton/mm^3)	2.5 × 10-9
Young Modulus (MPa)	8.7 × 104
Poisson Ratio	0.35
Tensile Strength (MPa)	2.53 × 103

Full conditions load case was selected for the strength analysis, since the condition is the most severe condition for the pontoon structure. The even keel draught should be performed while the modular floating pontoon being operated. Therefore, the strength analysis was made in the equilibrium condition. The illustrations of the FE model, boundary and the loading conditions are described in the Fig.7.

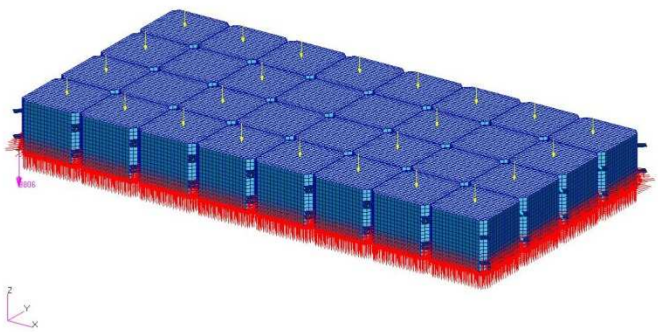
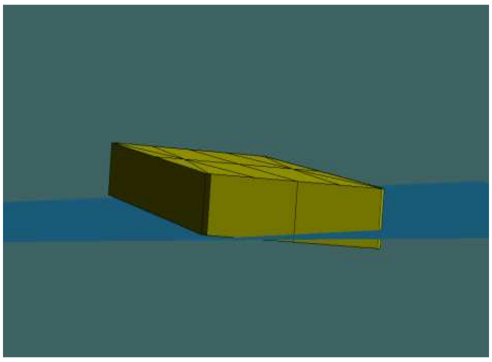


Fig. 7 Boundary and loading conditions of the FE model

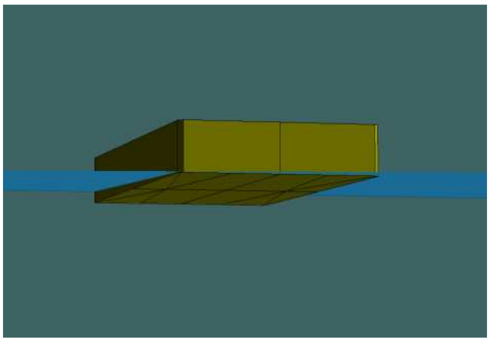
III. RESULT AND DISCUSSION

3.1 Equilibrium and intact stability performance

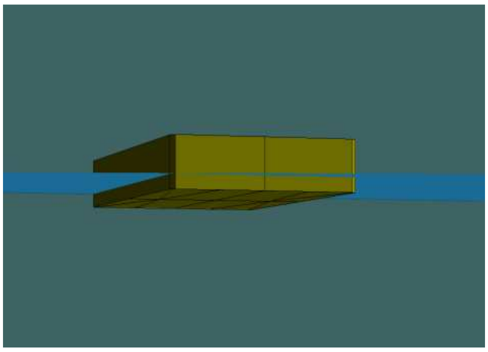
In this section, the results of the equilibrium calculations are presented. Fig. 8 presents the illustration of the equilibrium condition where each loading condition was applied at the modular floating pontoon. As the safely and favorable positions, the small heel angles was shown by the modular floating pontoon in the all of loading conditions.



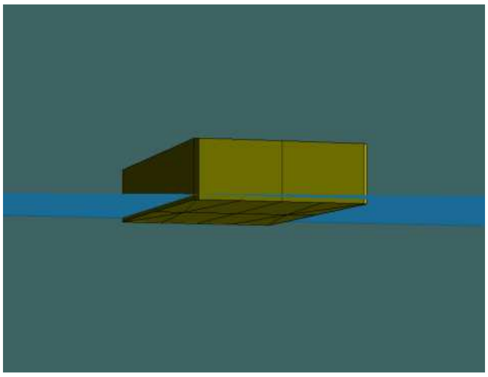
[a]



[b]



[c]



[d]

Fig. 8 The pontoon equilibrium conditions: [a] transversely unbalanced load; [b] longitudinally unbalanced load; [c] full load; [d] empty load

The maximum heel angle is 5.5 degrees at the transversely unbalanced load condition. Although the heel angle is relatively high, however the condition still acceptable because the pontoon still have the positive transversal metacentric height (MGT =2.321 m). It may be explained that the pontoon has positive initial stability which is able to turn in the right position while the occupant is stepping in the side of pontoon deck. The maximum trim is 1.7 degrees have been shown by the longitudinally unbalanced condition. The detail results of the equilibrium calculations can be seen in the Table 3.

Table 3. Equilibrium for each loading conditions

Item Name	Loading Conditions			
	I	II	III	IV
Displacement [tons]	0.568	0.498	1.128	0.288
Heel to starboard [degrees]	-5.500	0.000	0.000	0.000
Trim by stern [deg]	0.000	1.700	0.000	0.000
Draft at FP [m]	0.067	0.001	0.138	0.035
Draft at AP [m]	0.067	0.120	0.138	0.035
MG_T corrected [m]	2.321	4.880	1.507	9.295
MG_L corrected [m]	15.745	21.348	8.766	37.727
Righting Moment at 1 deg [tons.m]	0.023	0.042	0.030	0.047
KB	0.014	0.040	0.069	0.018
KG	0.178	0.643	0.982	0.200

The stability curves of the 4×8 modular floating pontoon configuration studied are presented in Fig. 9. Comparison of stability curves of the pontoon in each of loading conditions have been plotted jointly. Regarding the stability curves calculated for each loading conditions, all conditions have positive GZ. It is indicated that the positive intact stability was conducted by the pontoon minimum configurations.

In almost case, all the case studies fulfilled all applicable IMO stability criteria, Table 4. However, the unfavorable results were shown by the full condition on the criteria of Area 30^0 to 40^0 and GZ at 30^0 or greater. Since the positive stability of the full condition has the short range, the area of stability curve is smaller than the other load case. It is indicated that the increase of the number of occupants generates the KG escalation. The increases of KG give a negative influence to the pontoon stability.

Although the full conditions not passed the IMO criteria, however the intact stability characteristics is still acceptable, because the modular floating pontoon is not used as a seagoing vehicle such as boat and ship. Otherwise, the problems solution also may be achieved by rearranged the configuration of the modular floating as large as needed. The flexibility of knockdown and modular system provide the possibility to adjust the pontoons configuration to fulfill the IMO requirement.

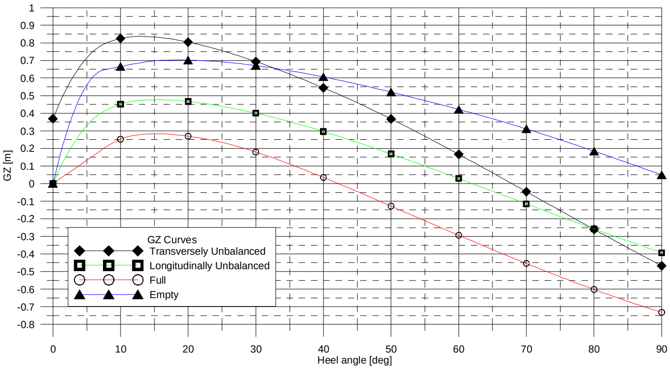


Fig.9 The stability curves of the 4×8 modular floating pontoon

3.2 The strength of modular floating pontoon

The FE model that has been defined with the loading and boundary condition was analyzed using finite element method. The linear static analysis was chosen to solve the problem case. The structure of the 4×8 modular floating pontoon was modeled using 99380 shell elements and 165 bar elements. The shell elements were mixed using quadrilateral and triangular elements. Computing time required for the analysis is 35 minutes on an AMD V120 Processor 2.2 GHz with 2 GB RAM running Windows 7. The illustration of the results of numerical analysis might be seen in Figs.10-14.

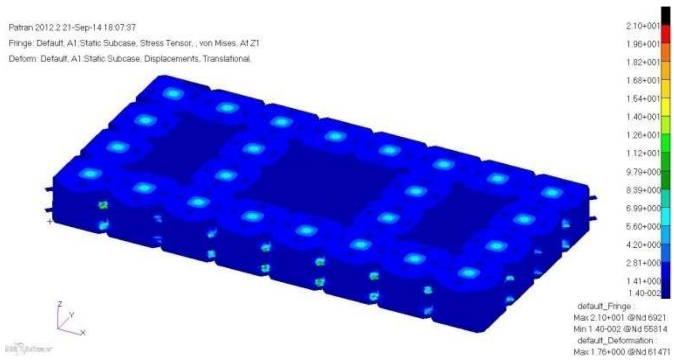


Fig.10 The stress distribution of the 4×8 modular floating pontoon

Table 4 Intact stability calculation results and IMO criteria

No	Rule	*Criteria*	*Required*	*Load Condition*			
				I	II	III	IV
1	IMO.A.749(18) Ch.3.1.2.1	*Area 0º to 30º*	3.15 *m.deg*	22.545	12.022	6.380	18.613
2	IMO.A.749(18) Ch.3.1.2.1	*Area 0º to 40º. or Down flooding point*	5.16 *m.deg*	28.758	15.530	7.477	25.019
3	IMO.A.749(18) Ch.3.1.2.1	*Area 30º to 40º. or Down flooding point*	1.719 *m.deg*	6.213	3.508	1.097	6.406
4	IMO.A.749(18) Ch.3.1.2.2	*GZ at 30º. or greater*	0.2 *m*	0.694	0.401	0.179	0.671

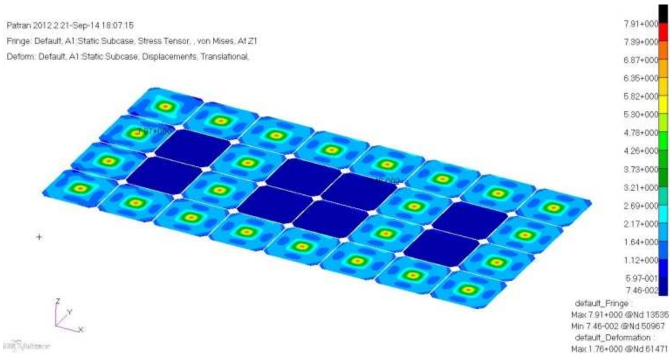


Fig.11 Stresses at the deck structure of the pontoon

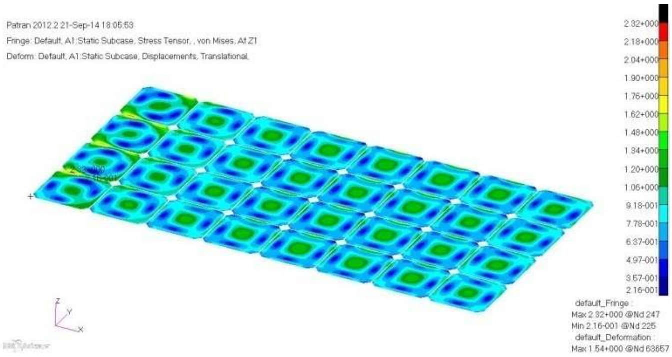


Fig.12 Stresses at the bottom structure of the pontoon

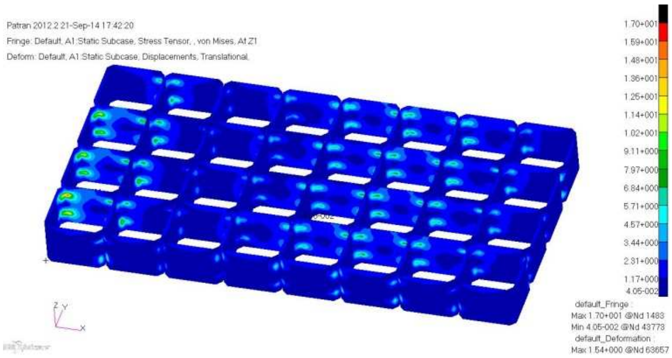


Fig.13 Stresses at the wall structure of the pontoon

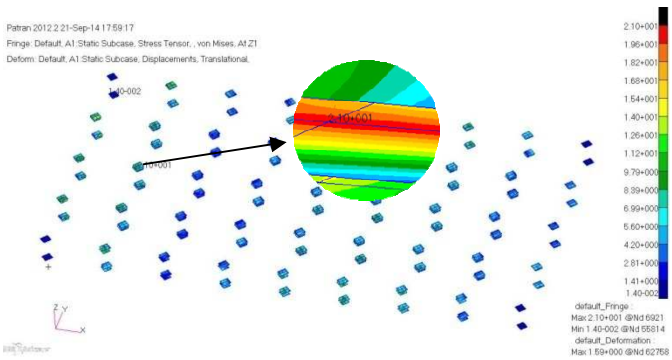


Fig.14 Stresses at the connector structure of the pontoon

The results of the numerical analysis are Von Mises stress plots on the finite elements for particular parts of the structure. The right side of each figure there is a colored scale, which corresponds to the stress levels plotted on the structure sketch. The stress results presented correspond to the layer that exhibits the highest stress. The deformation of the FE model was exaggerated for visualization purposes.

In general, it may be seen that the boundary conditions perform quite well, as there is no visible effect on the stress field. At the pontoon deck the stress distribution is uniform and not affected by the boundary conditions. The nodes which constraint was defined also have shown no stress concentration.

In Figs. 10-11, the small stress was occurred on the deck of the pontoon. It can be explained that the stress was induced by the occupant loads that has been modeled as a concentrated force. These stresses are about 7.91 MPa, significantly smaller than the permissible stress (68.9 MPa). The maximum stress of modular floating pontoon in Fig. 10 is about 21 MPa which was occurred at the connector of the pontoons (bolted clevis). The exact location of the maximum stress can be seen in the Fig. 14. The bottom part of the modular floating pontoon which was loaded by the hydrostatics pressure, the stresses is about 2.32 MPa, slightly smaller than the stress at the pontoon deck. It is indicated that the hydrostatics pressure do not generate the stress concentration since the pressure was uniformly distributed. Finally, the pontoon wall, Fig. 13 shows that the stresses are about 17 MPa, which is slightly higher than the stresses at the deck.

As expected, the results of the strength analysis shows that the structure of modular floating pontoon is reliable to support the maximum load which 12 occupants on the deck of the pontoons. The maximum stress was occurred at the connector of the pontoons, the stresses are about 21 MPa slightly smaller than the permissible stress 68.9 MPa. It is indicated that the structure of the modular floating pontoon are safe and reliable for supporting the evacuation process of floods disaster

IV. CONCLUSIONS

An investigation of modular floating pontoon performances to support floods disaster evacuation system in heavy populated residential area was made, utilizing the simulation and numerical analysis. The minimum configuration of modular floating pontoon for floating walking path was determined and evaluated in order to bring about the equilibrium conditions and intact stability performance at four loading conditions, namely transversely unbalanced load, longitudinally unbalanced load, full load and empty load. The comparison between the pontoons stability characteristics with IMO criteria was taken in order to identify the minimum configurations of modular floating pontoon have fulfilled the IMO acceptance requirements. Hence, the 4×8 pontoons configuration shows acceptable equilibrium conditions, and good stability with all loading conditions. However, it is recommended that the floating walking path employ the configuration as large as possible, following the available of the flooded area, since the better stability would be achieved by the enlargement of the pontoons configuration. The modular floating pontoon with the knockdown system provide the flexibility and adaptability during the implementation of the facilities in the heavy populated residential area

The evaluation of modular floating pontoon strength was calculated using finite element method comprising, to build FE model (meshing), to define the load and boundary conditions, to define the material properties and structure scantlings. Full load condition was selected for the strength analysis, since the condition was the most severe condition for the pontoon structure. Hence, the maximum stress was 21 MPa which was occurred at the connector of the pontoons, slightly smaller than the permissible stress (68.9 MPa). It is concluded that the structure of modular floating pontoon is safe and reliable for floods evacuation equipment.

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