Analysis of Structural Strength of Modular Floating Pontoon as the Beam of Floating House

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Abstract: The population density and sea flooding cause the reduction in residential land and land area each year. The way to cope with this condition is by creating a floating house. In constructing a building above water, the shape and strength of the beam must be taken into account by considering strong materials and structure constructions such as ferrocement. This study analyzes the structural and connection strength between pontoon ferrocements sized 120×120×100 with 3 cm thickness and varied connection among the pontoons. The connection variations include the connection of steel plate with a thickness of 3 cm and the connection of round bars with a thickness of 4 cm. The modeling is constructed in the software using finite element method and linear static analysis. The analysis of the two types of connections after given the pressure of seawater and house load shows the stress value of steel plate connection is 107 MPa and the stress value of round bars connection is 50 MPa. The result shows that both connections are considered safe given the fact that based on the Rules of Indonesian Classification Bureau, the allowed stress for steel plate is 235 MPa and for bars is 255 MPa. It means that the structures are safe. The trim pontoon condition resulted from the model creation using Maxsurf and Hydromax Software is trim stern with the height of laden stern is 0.669 m and the height of laden bow is 0.358 m.

Key words: Concrete/ferrocement, finite element, floating house, pontoon, residential, population density

INTRODUCTION

Indonesia is a country with almost the two third of the territory is ocean. The rest of the territory is Islands full of citizens. Currently, the population density has several impacts including flooding. The increase of water area is caused by the sea flooding in the lowland area. This results in the reduction of residential land and land area each year.

The decrease in land area instigates a solution of using sea area for residential use by building floating house. Currently, several countries have developed floating house including the Netherlands, Canada, countries in Europe and America. In addition, in Indonesia, several cities develop resorts comprising floating house.

In constructing floating house, it is a basic requirement that the beam condition should be secure as in the planning a construction of modular floating pontoon (Wang *et al.*, 2006). Previous studies state that the construction concept of floating house is the concept of lightweight structures aiming to reduce the weight of

the floated load (Tran and Kim, 2015). The floater of the floating house depends on the structure integration of floated structure and pontoon (Teoh, 2010).

The planning construction of modular floating pontoon must be able to guarantee a high voltage level structure keeping the structure under the elastic area. Therefore, the construction should have adequate elastic stiffness. Ferrocement is one of the effective materials for the pontoon (Canby, 1969). Ferrocement is a composite material made by giving cement mortar to cane reinforcement through steel (Harsono *et al.*, 1980). Cement mortar functions as the mass and steel wire as the tensile strength and ductility source. Systematically, ferrocement can be referred as a particular form of reinforced concrete in the form of denser concrete. The output of the floating house construction is producing modular floating pontoon with effective and secure structure strength and secure when floating on sea (Kumar, 2005; Rathish, 2010).

Mostly, this study aims to analyze the ideal modular floating pontoon adjusting to the shape of the planned floating house and the structural strength of the modular

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floating pontoon. However, this study only focuses on the construction of planned houses with the material used for the floating house beam is ferrocement. In additions, in this study analyses the strength of modular floating pontoon and connection between pontoons and the calculation is using the linear static analysis.

Theoretically, this study calculates the loading value of the entire modular floating pontoon and that of one pontoon and analyzes the value of displacement and maximum stress of the structure of modular floating pontoon.

Linear static analysis: In linear static analysis, the displacements strain, pressure and reaction force were under the influence of the loaded weight. A series of assumptions relating to linear static analysis is deflection, rotation, material properties and boundary condition. Linear static analysis aims to obtain the structural strength of a model in order to investigate the area with the most critical stress due to loading condition (Anonymous, 2013) (Fig. 1).

Finite Element Method (FEM): The basic concept of FEM is solving a problem by dividing the analyzed objects into small finite parts (Jei and Lee, 1988). The small elements are analyzed and the results of the analysis are then assembled to acquire equations for the entire problem (Bae *et al.*, 2016; Phongthanapanich and Dechaumphai, 2009). Finite Element Method (FEM) or the finite element method is one method used to analyze a construction or structure (Zakki *et al.*, 2017; Prabowo *et al.*, 2016). These methods, along with other methods are now widely used in the construction
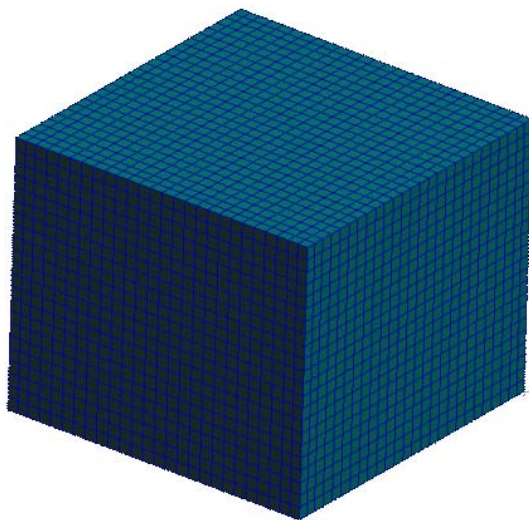
of boats and coastal structures and offshore (Altair University, 2012; Prabowo *et al.*, 2017a-d; Yudo *et al.*, 2017; Chrismianto *et al.*, 2015; Zakki *et al.*, 2016). Finite element method is a method used to analyze a construction or structure. This method is widely used in ship construction, beach buildings or offshore. Basic formula:

$$[K] \{U\} = \{F\}$$

Structural modeling: The model of floating pontoon structure resembles the shape of cube in Fig. 1.

MATERIALS AND METHODS

This study used element-based Software MSC Nastran and MSC Patran 2005 to analyze the data. The material specification in this study is.

Pontoon: This study used element-based Software MSC Nastran and MSC Patran 2005 to analyze the data. The material specification in this study is:

- Material: concrete/ferrocement
- Young's modulus: 48 GPa = 4.8×1010 N/m²
- Density: 2.5 mg/m³ = 2500 kg/m³
- Shear modulus: 20 GPa
- Poisson ratio: 0.20
- Yield stress: 25 MPa
- Size: 120×120×100 cm
- Thickness: 3 cm

Steel plate connection (Type A):
- Size: 20×20 cm
- Thickness: 3 cm
- Material: Steel high strength, grade D
- Young's modulus: 210 GPa = 2.1×1011 N/m²
- Density: 7.8 mg/m³ = 7800 kg/m³
- Shear modulus: 76 GPa
- Poisson ratio: 0.28
- Yield stress: 235 MPa (Rules BKI) (Fig. 2)

Round bars connection (Type B):
- Size: 16 and 22.6 cm
- Thickness: 4 cm
- Material: round bars, grade R410
- Young's modulus: 211 GPa = 2.1×10^{11} N/m²
- Density: 7.874 mg/m³ = 7874 kg/m³
- Shear modulus: 82 GPa
- Poisson ratio: 0.29
- Yield stress: 255 MPa (Fig. 3)

Loading variation: The load on pontoon structure is only from the pressure of seawater and the pressure of both

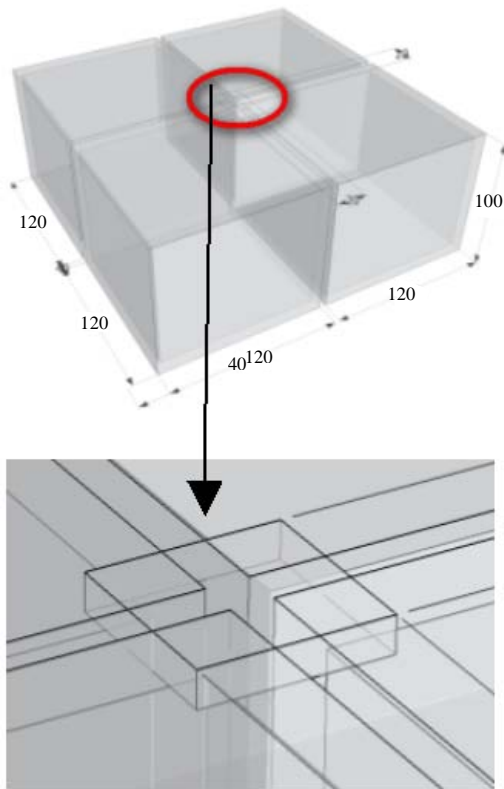Fig. 1: Floating pontoon

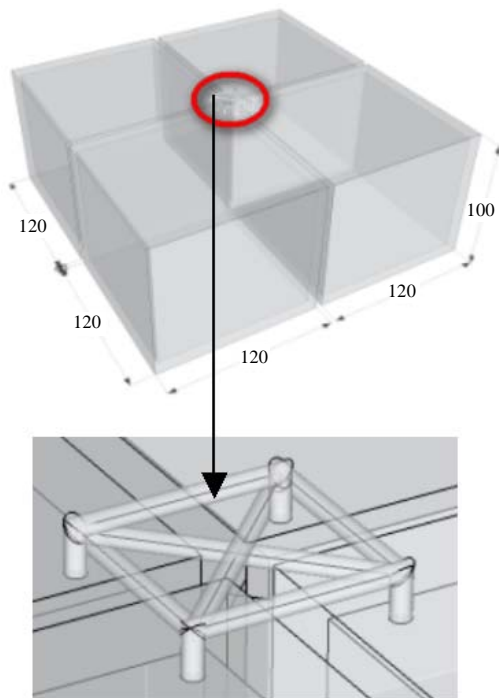Fig. 2: Steel plate connection

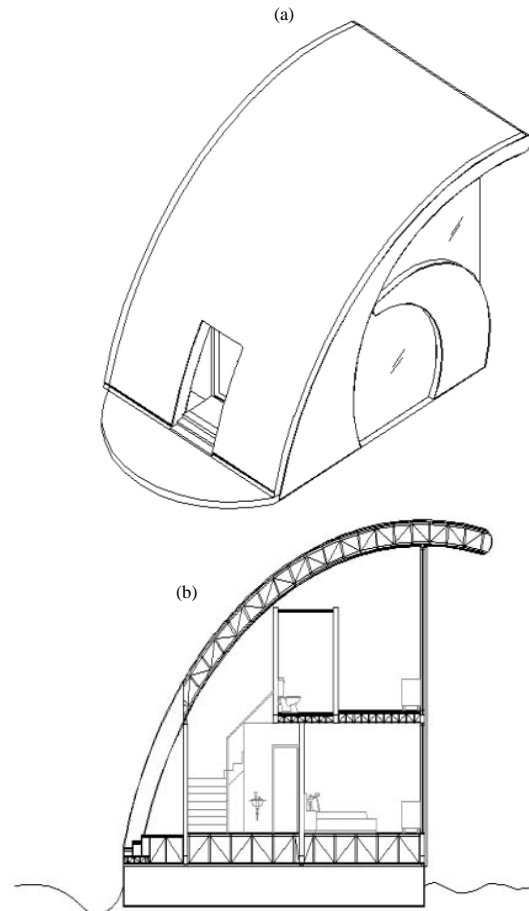Fig. 3: Round bars connection

Fig. 4: a, b) Floating house design

seawater and mass/weight of the house. The applied pressure will push the elements existing on the surface of the pontoon (Fig. 4). The pressure calculation using physics approach is:

- $P = \rho \times g \times h$
- P: Pressure (N/m^2)
- ρ: Density (kg/m^3)
- G: Gravitational acceleration = 9.8 m/sec
- h: Depth of surface (m)

RESULTS AND DISCUSSION

Type A and B applying the load from seawater with the depth 35 cm are experiencing pressure:

- $P = 1025 \ kg/m^3 \times 9.8 \ m/sec \times 0.35 \ m$
- $= 3515.75 \ N/m^2$ (Pascal)
- $= 3.51 \times 10^3$ Pascal

Therefore, the maximum load received by the pontoon structure in seawater is 3.51×10^3 Pascal (Fig. 5). Type A
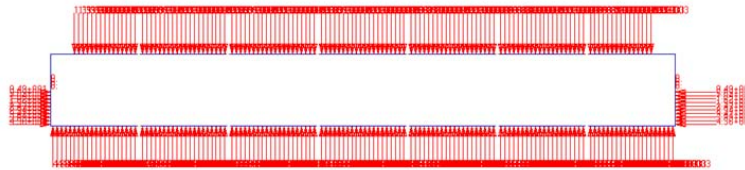
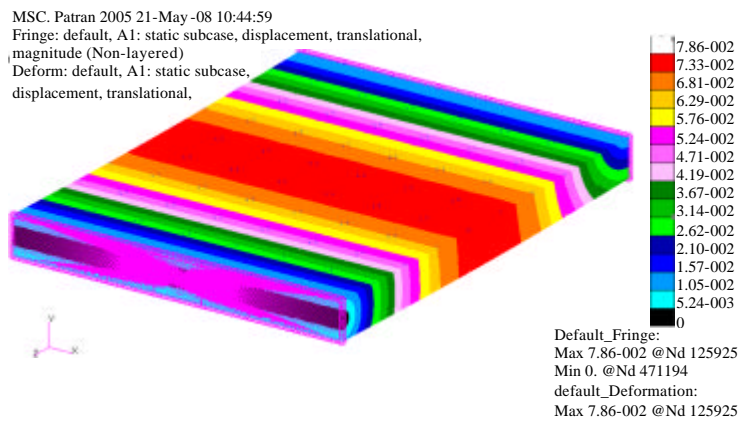Fig. 5: Seawater pressure

Fig. 6: Seawater and house pressure

MSC. Patran 2005 21-May-08 10:44:59
Fringe: default, A1: static subcase, displacement, translational, magnitude (Non-layered)
Deform: default, A1: static subcase, displacement, translational,

Default_Fringe:
Max 7.86-002 @Nd 125925
Min 0. @Nd 471194
default_Deformation:
Max 7.86-002 @Nd 125925

Fig. 7: Deformation type A (seawater pressure)

Table 1: The weight of the house

Mass	Weight (kg)
House weight	9,975.89
Outfit weight	32
Alternative weight	101.28
Person weight	320
Freshwater weight	1,200
Food weight	36
Equipment and supplies weight	2000
Total house weight	13,665.17

and B applying the load from seawater and (Fig. 6) mass/weight of the house with the depth 50 cm are experiencing pressure:

- Pseawater = 1025 kg/m^3×9.8 m/sec×0.458 m
- = 4600.61 N/m^2 (Pascal)
- = 4.6×10^3 Pascal

To calculate the pressure from the house sized 10×8 m, measure the mass/weight of the house and divide with the volume of the house (Table 1). The pressure calculation using physics approach is:

- P = F/A
- = (13665.17×9.8)/39.41

- = 3398.09 N/m^2 (Pascal)
- = 3.39×10^2 Pascal

Type A (seawater pressure): In this condition, deformation occurred with the largest displacement value of 7.86×10^{-2} m or 7.86 cm at node 125,925 and the smallest displacement value 0 m at node 471,194. The maximum stress occurred with the value 1.27×10^{-8} Pascal at node 904,661 and the smallest stress value is 5.90×10^{-3} at node 9,490. The maximum stress was in the central part of the floating pontoon connection. This condition occurred because the central part of modular floating pontoon was located at the farthest from the pedestal flops given to the model (Fig. 7 and 8).

Type A (seawater and house pressure): In this condition, deformation occurred with the largest displacement value of 9.98×10^{-2} m or 9.98 cm at node 129,510 and the smallest displacement value 0 m at node 471194. The maximum stress occurred with the value 2.03×10^{-8} Pascal at node 904,823 and the smallest stress value is 6.67×10^{-3} at node 999,506 (Fig. 9 and 10). The
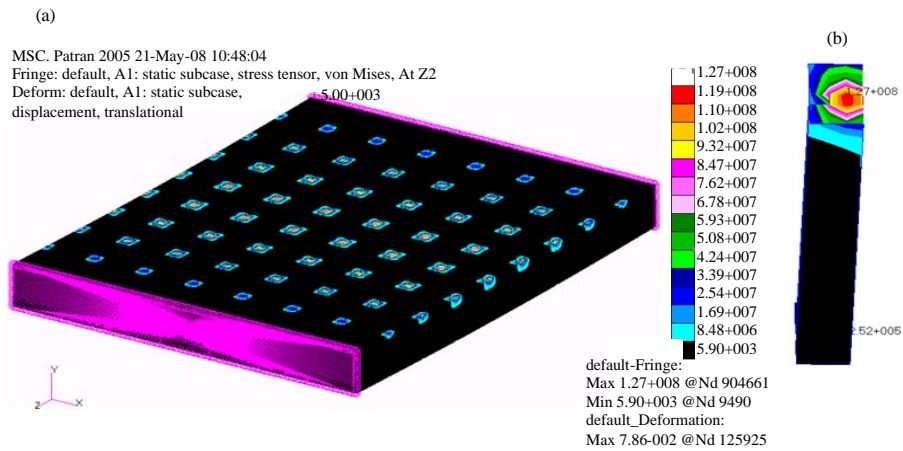
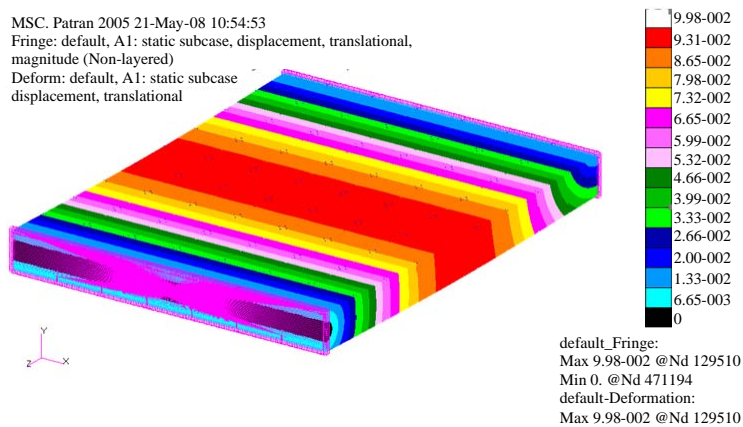Fig. 8: a, b) Stress tipe A (seawater pressure)

Fig. 9: Deformation type A (seawater and house pressure)
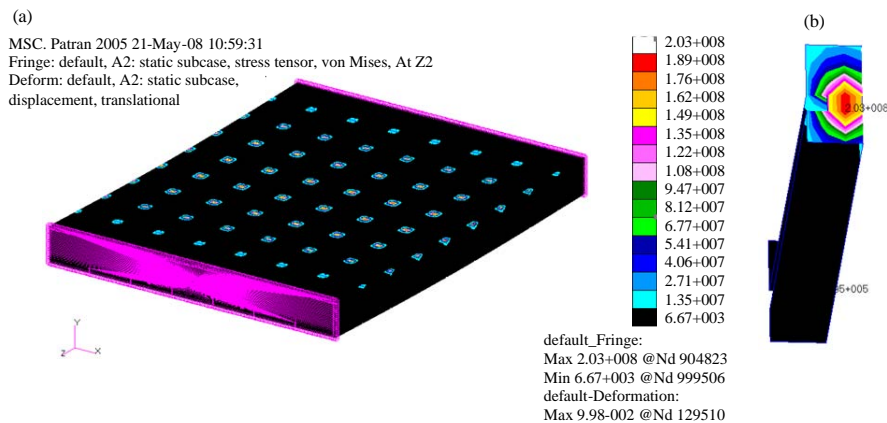

Fig. 10: a, b) Stress type A (seawater and house pressure)

maximum stress was in the central part of the floating pontoon connection. This condition occurred because the central part of modular floating pontoon was located at the farthest from the pedestal flops given to the model. In this condition, the stress/tension intensifies because the modular floating pontoon received pressure from above, the house.
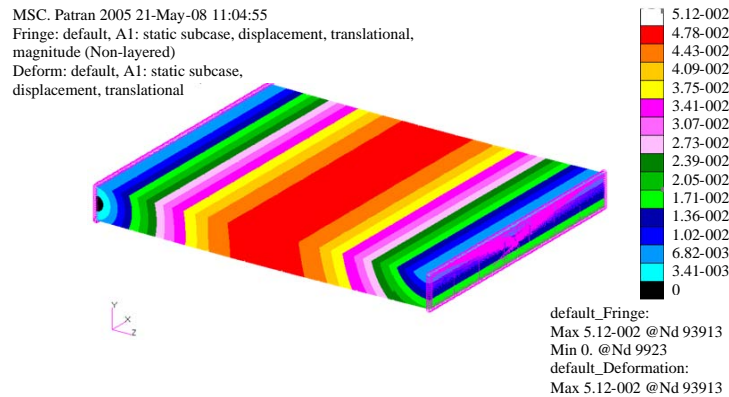
MSC. Patran 2005 21-May-08 11:04:55
Fringe: default, A1: static subcase, displacement, translational, magnitude (Non-layered)
Deform: default, A1: static subcase, displacement, translational

default_Fringe:
Max 5.12-002 @Nd 93913
Min 0. @Nd 9923
default_Deformation:
Max 5.12-002 @Nd 93913

Fig. 11: Deformation type B (seawater pressure)

(a)

MSC. Patran 2005 21-May-08 11:06:52
Fringe: default, A1: static subcase, stress tensor, von Mises, At Z2
Deform: default, A1: static subcase, displacement, translational

(b)

default_Fringe:
Max 3.35+007 @Nd 91310
Min 6.66+003 @Nd 159398
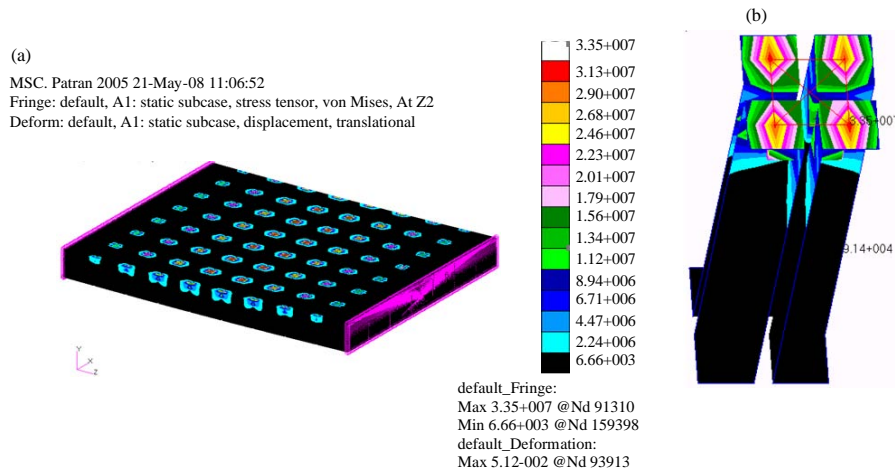default_Deformation:
Max 5.12-002 @Nd 93913

Fig. 12: a, b) Type B (seawater pressure)

Type B (seawater pressure): In this condition, deformation occurred with the largest displacement value of 5.12×10^{-2} m or 5.12 cm at node 93913 and the smallest displacement value 0 m at node 9923. The maximum stress occurred with the value 3.35×10^{-7} Pascal at node 91,310 and the smallest stress value is 6.66×10^{-3} at node 159,398. The maximum stress was in the central part of the floating pontoon connection. This condition occurred because the central part of modular floating pontoon was located at the farthest from the pedestal flops given to the model. In this condition, the stress/tension intensifies because the modular floating pontoon received pressure from above, the house (Fig. 11 and 12).

Type B (seawater and house pressure): In this condition, deformation occurred with the largest displacement value of 7.64×10^{-2} m or 7.64 cm at node 93,913 and the smallest displacement value 0 m at node 9,923. The maximum stress occurred with the value 5.00×10^{-7} Pascal at node 91,310 and the smallest stress value is 1.69×10^{-4} at node 162,002.

Table 2: Correction for each condition

Connection types	Pressure	Max stress (Mpa)	Allowed stress (MPa)	Status
Steel plate	Seawater	107	235	Eligible
Steel plate	Seawater and house	203	235	Eligible
Round bars	Seawater	33.5	255	Eligible
Round bars	Seawater and house	50	255	Eligible

The maximum stress was in the central part of the floating pontoon connection. This condition occurred because the central part of modular floating pontoon was located at the farthest from the pedestal flops given to the model. In this condition, the stress/tension intensifies because the modular floating pontoon received pressure from above, the house (Fig. 13-15). The results showed that all the stress/maximum tension occurring in each condition or circumstance met the criteria of allowed stress of each material property corresponding to the Rules of Indonesian Classification Bureau Volume V (Table 2 and 3).

Trim condition of modular floating pontoon: Based on the load distribution and the center of gravity on modular
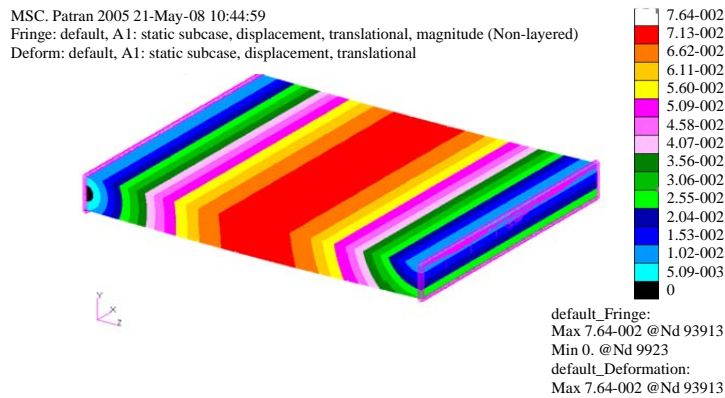
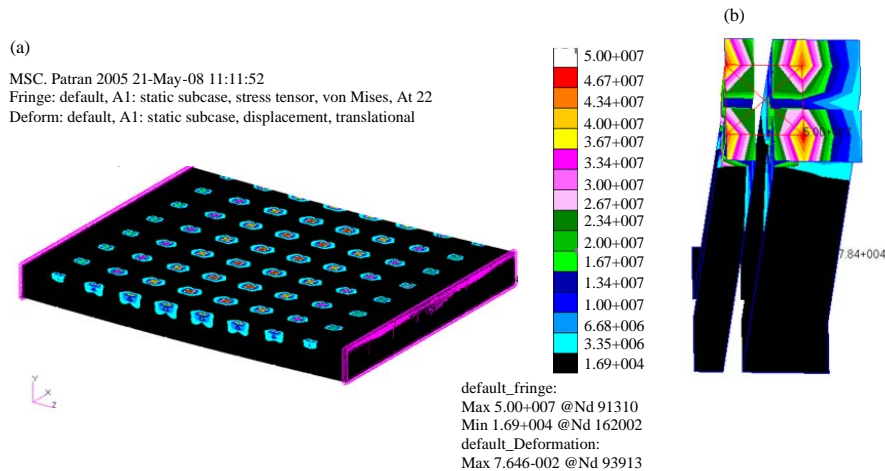Fig. 13: Deformation type B (seawater and house pressure)

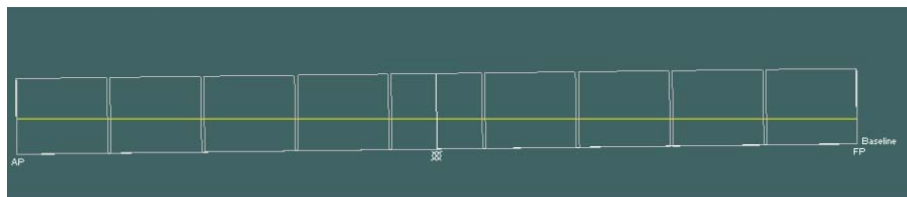Fig. 14: a, b) Stress type B (seawater and house pressure)

Fig. 15: Equilibrium results of modular floating pontoon in Hydromax Software

Table 3: Equilibrium results of modular floating pontoon

Variables	Values
Draft Amidsh (m)	0.513
Displacement tonne	38.870
Heel to starboard degrees	0.000
Draft at FP (m)	0.358
Draft at AP (m)	0.669
Draft at LCF (m)	0.513
Trim (+ve by stern) (m)	0.311
WL Length (m)	11.124
WL Beam (m)	6.640
Wetted area (m²)	92.074
Waterpl. area (m²)	73.866

Table 3: Continue

Variables	Values
Prismatic coeff.	0.768
Block coeff.	0.768
Midship area coeff.	1.000
Waterpl. area coeff.	1.000
LCB from Amidsh. (+ve fwd) (m)	-0.561
LCF from Amidsh. (+ve fwd) (m)	0.000
KB (m)	0.265
KG fluid (m)	1.959
BMt (m)	7.159
BML (m)	20.094
GMt corrected (m)	5.464
GML corrected (m)	18.398
KMt (m)	7.423
KML (m)	20.358
Immersion (TPc) (tonne/cm)	0.757
MTc tonne. (m)	0.643
RM at 1° = Gmt.Disp.sin (1) (tonne.m)	3.706
Max deck inclination (deg)	1.6.00
Trim angle (+ve by stern) (deg)	1.6.00
Draft Amidsh. (m)	0.513

floating pontoon, the running analysis resulted the stern trim condition with the value of the height of laden stern 0.669 m and the height of laden bow 0.358 m (Table 3).

CONCLUSION

The load of the house received by modular floating pontoon can be classified as follows: the height of laden of modular floating pontoon without the house load is 35 cm. The height of laden of the entire modular floating pontoon (63 pontoons) receiving 13665.17 kg house load is 45.8 cm. For each increment load of 60 kg, the height of laden increase by 3 cm, meaning that each pontoon received 216.9 kg load. The result shows the stern trim condition with the value of the height of laden stern 0.669 m and the height of laden bow 0.358 m.

The analysis of the two types of connections (type A and B) given the pressure of seawater and house show that type A (seawater pressure) experiencing stress 107 MPa. Type A (seawater and house pressure) experiencing stress 203 MPa. Type B (seawater pressure) experiencing stress 33.5 MPa. Type B (seawater and house pressure) experiencing stress 50 MPa. Finally, all stresses are considered secure as they do not exceed the allowed stress established by Rules Indonesia Classification Bureau Volume V.

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