Comparison analysis of expanded polystyrene system (eps) and polyvinyl chloride (pvc) pipe as platform material of floating buildings in the coastal areas of Semarang

***Henny Pratiwi Adi, Slamet Imam Wahyudi, Catur Singgih Sudarmono, Mochammad Caqqul Islam**
Civil Engineering Department, Sultan Agung Islamic University, Jl. Raya Kaligawe Km.4 Semarang, Indonesia

*Corresponding author email: henni@unissula.ac.id

Abstract. The impact of tidal floods in the coastal area of Semarang greatly disrupts people's activities and damages settlements and infrastructure buildings. Floating building is one of the alternative solutions to overcome the rising sea level. This study aims to compare 2 (two) floating housing material platforms, namely EPS (*Expanded Polystyrene*) and PVC (*PolyVinyl Chloride*). The analysis method of floating structure platform was carried out by using various indicators, namely, the uplift generated, the stability and costs. Based on the findings of the analysis, the uplift platform to bear building loads on the water surface showed a value of 0.2 ton / rod for Ø10 inches PVC pipes and 4 meters in length. Then, the uplift capacity of 0.9 tons / sheet was for EPS Styrofoam with dimensions of 2 m x 1 m x 0.5 m. The stability level of floating buildings on water was indicated by the high value of spectrum that was +3.23 m for PVC and +3.61 m for EPS. To support the loads of 54.01 tons, the comparison of material expenses and installation of PVC materials required a cost of IDR. 561,561,350.00; meanwhile EPS material cost IDR. 40,420,000.00.

1. Introduction

Today's climate change is a major issue in the world which becomes a serious problem in several countries. The climate change is characterized by increasing temperature in the atmosphere, rising sea levels, increasing greenhouse gas concentrations and the degree of ocean acidity. Semarang is one of the cities in Indonesia with sea territory, with a coastline in the north along ± 13.6 km [1]. Currently, in the coastal areas of Semarang, there are frequent floods due to rising sea levels. In general, the impact of rising sea levels is the inundation of lowlands, increasing coastal erosion and causing sea water intrusion to mainland. The impacts disturb people's activities, damage residential buildings and infrastructure buildings. The damage of the residential buildings due to rising sea levels requires more innovative building models which are able to adapt to rising sea levels [2]. Floating Building is an alternative solution to overcome rising sea levels because this building will rise when sea water is rising. Floating buildings can also be applied in polder system areas to maintain water storage capacity. There are several materials which can be used as platform materials (floor plates) for floating houses, such as steel plate or hollow concrete, wooden sticks, bamboo, plastic drums, EPS (*Expanded Polystyrene System*) or Styrofoam and PVC pipes. In this study, the comparison between floating house platforms with EPS (*Expanded Polystyrene System*) or Styrofoam and PVC (*PolyVinyl Chloride*) materials was then analyzed.

2. Literarure Review

2.1 Flood due to Rising Sea Levels
Flood is a natural disaster which makes many people suffer. Almost every year, flood hits areas located along the northern coast of Java [3]. Flood occurs due to continuous rain and tunnels can no longer hold water, so it overflows. However, it can also be caused by rising sea levels entering the land, this flood inundation is commonly called '*tidal flood'*. Sea water enters through the river during high tide, and then flows into settlements through drainage tunnels. Naturally, changes in the sea tide elevation cause tidal flood. Meanwhile, the flood caused by human activities, for example, is due to excessive water pumping, dredging of shipping lanes, coastal reclamation and many others [4]. The existence of tidal flood leads to adverse impacts, among others are a decline in the function and the beauty of settlements and offices, quickly damaged flooded-roads, environmental and health degradation as well as dysfunctional agricultural land.

2.2 The Impacts of Rising Sea Levels in Sea Water
There are some losses experienced by communities affected by flood inundation due to high tides [5]. The losses due to high tides are in the form of damages to buildings, infrastructure, costs incurred for repairs, dysfunctions and disadvantages as well as disruption of activities caused by inundation of sea water, flowing to lower land areas. The losses caused by rising tides are different from the ones caused by flood due to rain by assessing the losses of the two disasters, especially in terms of altitude, length and frequency of inundation [6].

2.3 Damaged Houses Caused by Flood
Regarding to the rising sea levels, at present, settlements in coastal areas are often flooded by high tides. The losses on house buildings are calculated based on the losses due to additional costs that must be incurred in conditions where they should not be. For example, a normal house standard has a building age of approximately 25 years. During these 25 years, there are no additional costs to incur, such as raising floors, walls and roofs. Therefore, the costs of raising the floors, walls and roofs are the financial losses that must be incurred, where in a normal condition; this should not occur [2].

Figure 1. Settlement damages caused by tidal flood (rob)

2.4 Houses in Coastal Areas
The designs of houses in coastal areas can be divided into several types of buildings. The location of buildings can be on direct lands (landed houses), which are in the forms of stilt and non-stilt houses, and on the medium of water, namely floating houses. The main structures of a house can take forms of wooden structures, concrete structures or bearer-wall structures. Figure 2 below are the forms of house designs in the coastal areas [7].

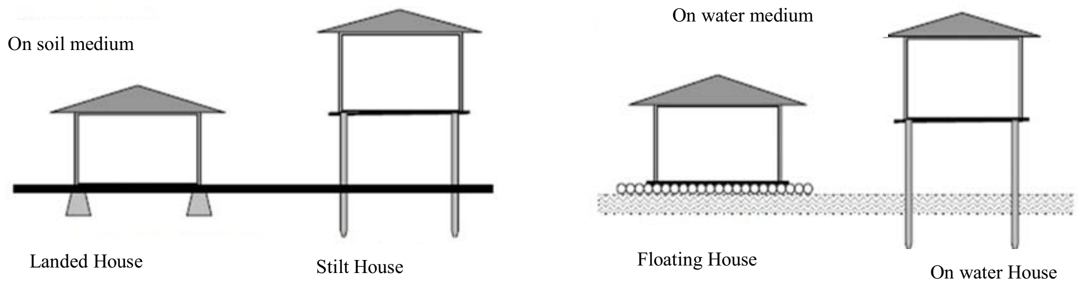

Figure 2. The Designs of Houses in Coastal Areas

2.5 Floating Structure

Floating structure is an innovation developed to deal with problems of limited lands and flood. Floating structures can keep up with changes in water elevation, leaving the building floating above the sea level. Basically, there are two types of *Very Large Floating Structures* (VLFS) which are currently being developed, namely semi-submersible and pontoon types. In general, floating system consists of [8]:

a. Floating pontoon structure, functioning as a foundation.
b. Mooring facility to keep structures floating in place.
c. Bridge access or floating road.
d. Breakwater to reduce wave forces which affect floating structures.

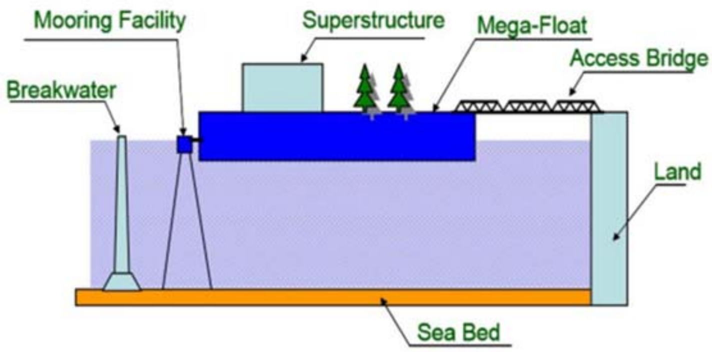

Figure 3 Floating System
(Source: Watanabe. E. et. al 2004)

Floating structure has several advantages compared to ordinary housings [9]. They are :

- The cost is more effective when the water depth is large.
- Environmentally friendly because it does not damage marine ecosystem, and does not interfere with tidal / sea currents.
- Easy and fast to build.
- Can easily be moved.
- Protected from seismic shocks.
- The position is constant to the water surface.
- Its location in coastal waters provides a view of the water surface from its surroundings.

In *Very Large Floating Structure* (VLFSs) design, various loads must be considered, especially in tides, tsunamis, storms and earthquakes. The materials used for floating surfaces are steel, concrete or steel composite concrete and other relevant specifications that must be followed [8].

3. Research Methods

Research method is the main way researchers use to achieve goals and determine the answer to the problem proposed. The stages in this research method were used to determine the desired, qualified, efficient and effective results. The stages of analysis in this study were as follows:

a. Planning the width of the floating building platform and calculating its loads.
b. The liftup analysis was generated by the platform to hold the loads of buildings on the water surface using Achimedes formula:
   Fa = p x g x V
c. Analysis of floating structure stability on water with EPS (*Styrofoam*) materials or with PVC materials (pipes) using the matasentrum formula:

$$BM = \frac{i}{v}$$
$$BG = OG - OB$$
$$GM = BM - BG$$

d. Analysis of material costs and platforms installation by EPS (*Expanded Polystyrene*) and PVC (*PolyVinyl Chloride*) materials.

4. Results and Discussion

4.1 The Calculation of Buoyancy

Structural loads consist of *dead load, live load* and *wind load*. Dead load is a burden originating from a component or attribute of a non-movable building. Live load is in the form of people or goods that can move. Wind load is a burden that occurs due to pressures based on the wind speed in the area [10]. The analysis of loads received by the structure of a floating house can be divided into two, namely, loadings on the upper structures which consist of dead load, live load and wind load and the ones on the platform structures which consist of dead load and live load derived from weight platform frames, connecting tools and materials (*PVC* and or *Styrofoam pipe*s). The loadings make use of SNI 3449: 2002 reference [10] for simple houses of 1 (one) floor with a size of 8 m x 8 m, with the following calculations:

qu = qD x 1,2 + qL x 1,6

Description:

qu = Ultimate load
qD = Dead load
qL = Life expenses

The Assumptions of dead load and live load on a simple house with 1 (one) floor:

- Dead loads of wall = weight of walls per meter x wall volume x amount of wall
  = 0,8 T/m3 x (4,5m x 0,15m x 8m) x 4
  = 17,28 T
- Dead loads of roof = 0,1 T x 8m x 8m
  = 6,4 Tm
- Live loads = 0,25 T x 8m x 8m
  = 16 T

Substituted by the formula of SNI 3449:2002

qu = qD x 1,2 + qL x 1,6
= (17,28 + 6,4) x 1,2 + (16x 1,6)
= 54.01 T

4.1.1 PVC Pipe Buoyancy. PVC (Polyvinyl Chloride) Pipe is the third order thermoplastic polymer in terms of the world's usage, right after polyethylene and polypropylene. PVC pipe is generally used as drainage in a project of housing, building or road etc. This PVC pipe is hard, light and strong. In analyzing a floating house platform, the size of Ø10 inches is determined by a pipe with 4 meters in length. The following is the analysis of PVC pipe buoyancy to bear a house of 54.01 T in weight:

PVC buoyancy force:

PVC size (d) = Ø10 " = 0.267 meters
PVC weight (q) = 4,848 kg
PVC uplift force (Fb) = (ρair (1/4 x Π x d2 x t) - q) x g
= (1025 (1/4 x 3,14 x 0,2672) x 4) x 9,81
= 2203,28 N
= 2,203 kN
= 0,2 T

In order for objects to float the amount of PVC needed (n) is:

n = Fg/Fb
= 54,01/0,2
= 270,05 pieces ≈300 pieces

Based on the size of the house planned to be 8 meters x 8 meters with a PVC pipe of 0.267 in diameter and a pipe of 4 meters in length, the dimensions of PVC platforms are 30 pipes with axis (X), 2 pipes with axis (Z), and 5 layers of pipes with axis (Y). The following is the 3D sketch with the Ø10 Inches PVC platform in figure 4.

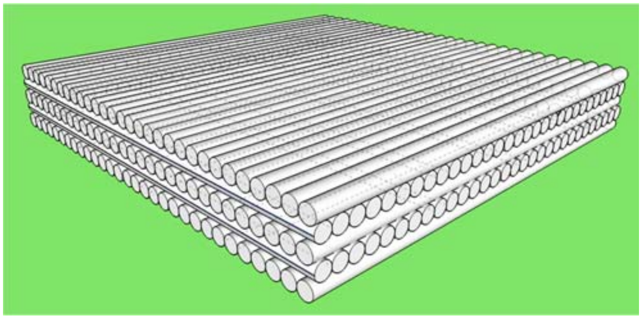

Figure 4. The 3D Sketch of PVC platform

4.1.2. EPS Buoyancy. Styrofoam or EPS (Expanded Polystyrene) which is lightweight and practical, is included in plastic types. Styrofoam is made from styrene monomers through compressive suspense polymerization and a certain temperature, and then it is heated to soften the resin and evaporate the rest of the blowing agent. The basic ingredients used are 90-95% polystyrene and 5-10% gas such as n-butane or n-pentane. Typically polystyrene is light, rigid, translucent, brittle and inexpensive. The material better known as cork is indeed practical, lightweight, relatively leak resistant [9]. From the light and leak resistant properties, the platforms can then be developed. The following buoyancy analysis is shown below:

EPS buoyancy style:

EPS size = 2 meters x 1 meter x 0.5 meters
EPS (q) weight = 9 kg
Uplift force EPS (Fb) = ((ρair (L x B x H) - q) x g
= ((1025 (2 x 1 x 0,5) – 9) x 9,81
= 9966,96 N
= 9,966 kN
= 0,9 T

In order for objects to float the amount of EPS needed (n) is:

n = Fg/Fb
= 54,01/0,9
= 60,01 pieces ≈64 pieces

Based on the size of the house planned to be 8 meters x 8 meters with dimensions of Styrofoam of 2 meters x 1 meter x 0.5 meters, the EPS platform dimensions are 8 pieces on axis (X), 4 pieces on axis (Z), and 2 layers on axis (Y). The following is the 3D sketch with EPS platform in **figure 5**.

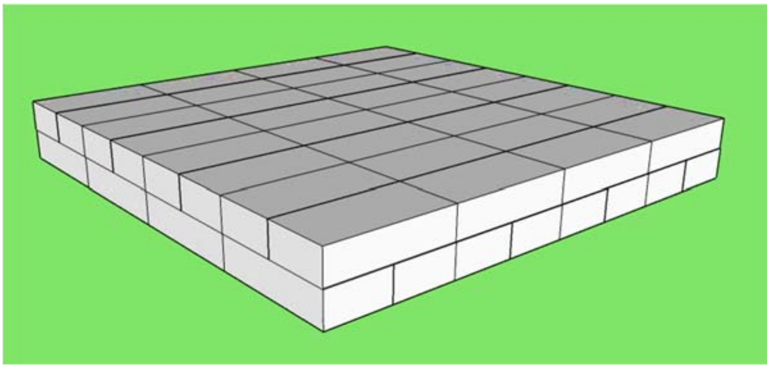

Figure 5. The 3D Sketch of EPS Platform

4.2 The Stability Calculation
The stability of a floating building is seen from the value of metacenter. If it is worth more than 0 (zero), the building is stable or balanced, otherwise if the value is less than 0 (zero), the building is unstable or unbalanced. The following is the calculation of pontoon stability with metacenter Formula [10].

4.2.1 The Stability of PVC Platforms
The calculation results of the PVC platform analysis which are used with pontoon with 0.53 m in thickness can be seen in figure 6 which shows the midpoints to take into account the stability of the building. The following is the calculation of pontoon stability with a PVC platform.

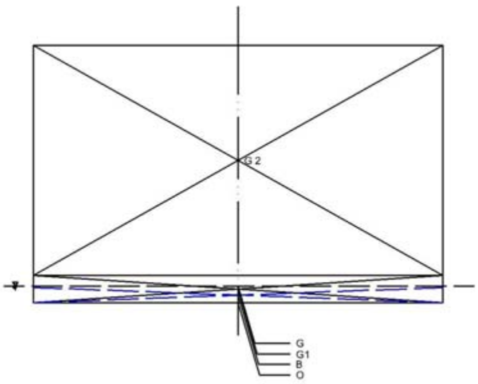

Figure 6. PVC Platform Stability

Description (**Figure 6**):
G1 = Platform midpoint
G2 = House midpoint
B = Dipped platform midpoint
Known:
W1 (PVC) : 0,14 kN
W2 (House) : 540 kN

ρ1 (water)	:	1025 kg/m3
L	:	8 m
B	:	8 m
H	:	1,33 m

- PVC buoyancy

FB = L x B x d x ρ1 x g
= 8 x 8 x 1025 x 9,81
= 643536 d N = 643,5 kN

Wtot = W1 + W2
= 0,14 + 540
= 540,14 kN

- In floating condition (d = dipped pontoon draft)

W = FB
540,14 = 643,5 d
d = 540,14
643,5 = 0,83 m

- The distance between the floating center and the base of pontoon

$$OB = \frac{d}{2} = \frac{0{,}83}{2} = 0{,}4 \text{ m}$$

- The distance between the weight of combined objects and the base of pontoon was calculated by the static moment on the basis of

$$OG = \frac{W1 \times OG1 + W2 \times OG2}{W1 + W2}$$
$$= \frac{0{,}14\ x\ 0{,}66 + 540\ x\ 3{,}58}{0{,}14 + 540}$$
$$= \frac{0{,}092 + 1933{,}2}{540{,}14}$$
$$= 3{,}57\ m$$

Inertia moment is cut off by the water surface

$$I_0 = \frac{1}{12}\ x\ L\ x\ B^3$$
$$= \frac{1}{12}\ x\ 8\ x\ B^3$$
$$= 341{,}33\ m^4$$

- The volume of moved water

V = L x B x d
= 8 x 8 x 0,83
= 53,12 m

- Metacenter Height

$$BM = \frac{Io}{V}$$
$$= \frac{341{,}33}{53{,}12}$$
$$= 6{,}4\ m$$

- The distance between the floating center and the weight center

BG = OG – OB
= 3,57 – 0,4
= 3,17 m

● Metacenter Height
GM = BM – BG
= 6,4 – 3,17
= 3,23 m

From the metacenter (GM) value which showed a positive result of +3.23, it can be concluded that the object is in a "STABLE" condition. Based on the value of d = 0.83m, it is necessary to anticipate inward runoff, added by a freeboard or height ranged from 0, 5m. Therefore, the thickness for PVC platforms are added 2 layers.

4.2.2 The Stability of EPS Platforms. Based on the results of the EPS platform calculation analysis, pontoon with 0.5 m in thickness was obtained. It can be seen in figure 7 which shows the midpoints to take the building stability into account. The following is the calculation of pontoon stability or EPS platform stability.

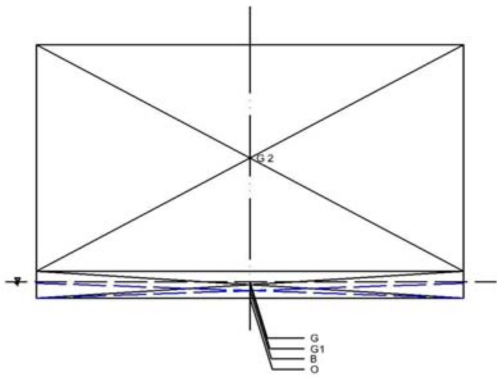

Figure 7. EPS platform stability

Description (Figure 7):
G1 = Platform midpoint
G2 = House midpoint
B = Dipped platform midpoint
Known:
W1 (EPS) : 0,05 kN
W2 (House) : 540 kN
ρ1 (water) : 1025 kg/m3
L : 8 m, B : 8 m, H : 0,5 m

● PVC Buoyancy
FB = L x B x d x ρ1 x g
= 8 x 8 x 1025 x 9,81
= 643.536 d N ☹643,5 kN
Wtot = W1 + W2
= 0,05 + 540
= 540,05 kN
● In floating condition (d = dipped pontoon draft)
$W = FB \; x \; d$

$$540{,}05 = 643{,}5 \; x \; d$$
$$d = \frac{540{,}05}{643{,}5}$$
$$= 0{,}83 \; m$$

The distance between the floating center and the pontoon base

$$OB = \frac{d}{2} = \frac{0,83}{2}$$
$$= 0,41\ m$$

- The distance between the weight of combined objects and the pontoon base was calculated by the static moment on the basis of

$$OG = \frac{W1\ x\ OG1 + W\ \ x\ OG2}{W1 + W2}$$
$$= \frac{0,05\ x\ 0,5 + 540\ x\ 3,25}{0,05 + 540}$$
$$= \frac{1755,025}{540,05}$$
$$= 3,2\ m$$

- Inertia moment is cut off by the water surface

$$I_0 = \frac{1}{12}\ x\ L\ x\ B^3$$
$$= \frac{1}{2}\ x\ 8\ x\ B^3$$
$$= 341,33\ m^4$$

- The volume of moved water

$$V = L\ x\ B\ x\ d$$
$$= 8\ x\ 8\ x\ 0,83$$
$$= 53,12\ m^3$$

- Metacenter height

$$BM = \frac{I_0}{V}$$
$$= \frac{341,33}{53,22}$$
$$= 6,4\ m$$

- The distance of the floating center and the weight center

$$BG = OG - OB$$
$$= 3,2 - 0,41$$
$$= 2,79\ m$$

- Metacenter height

$$GM = BM - BG$$
$$= 6,4 - 2,79$$
$$= 3,61\ m$$

From the metacenter (GM) value which showed positive results of +3.61, it can be concluded that the object is in a "STABLE" condition. Based on the value of d = 0.83 m, it is necessary to anticipate the water runoff entering into, and then it should be added with *freeboard* with 0.5 m in height. Therefore, for the EPS platform, it should be added with 1 layer.

4.3 The Comparison of Material Expenses

In the analysis of the platforms using PVC pipes and Styrofoam EPS materials, the calculation of expenses was also carried out on each material. The following tables 1 and 2 show the calculation of material expenses between PVC pipes and EPS Styrofoam:

Table 1. The Calculation of PVC Platform Expenses

	Tools and Materials	Volume	Price IDR	Result IDR
The installation of PVC Platform	10" PVC Pipes (AW)	300	1,698,900	509,670,000
	10" Fitting Socket (AW)	150	128,425	19,263,750
	10" Fitting Cap (AW)	300	98,600	29,580,000
	Foreman	1	100,000	100,000
	Head of Labors	1	90,000	90,000
	Labors	4	75,000	300,000
	Concrete Wire	2700	16,000	4,320,000
	True Glue	6	39,000	237,600
		Total of Expenses		561,561,350

From the table 4., the total expenses of making pontoons or platforms made from PVC is Rp. 561,561,350.00.

Table 2. The Calculation of EPS platform Expenses

	Tools and Materials	Volume	Price IDR	Result IDR
The Installation of EPS Platform	Styrofoam (2x1x0,5)	64	600,000	38,400,000
	Foreman	1	100,000	100,000
	Head of Labors	1	90,000	90,000
	Labor	4	75,000	300,000
	Wire rope / seling wire D = 10 mm	150	10,200	1,530,000
		Total of Cost		**40,420,000**

From the result of the calculation of EPS-based platform or pontoon expenses planning, it cost Rp. 40,420,000.00. It can be concluded that in terms of the comparison of expenses between PVC platforms and EPS usage, the use of EPS is whole lot cheaper. Based on the data above, the comparison of expenses between PVC and EPS materials is far different, seen from the standpoint of the durability of both materials. They have different resistances. The EPS is durable from 15 to 20 years, while the PVC has a resistance of 50 years [10].

5. Conclusion

The buoyancy or uplift force produced from PVC (*Polyvinyl Chloride*) with 4 m in length, 4 inches diameter was 0.2 T per rod, meanwhile the one produed from EPS (*Expanded Polystyrene*) with dimensions of 2 mx 1 mx 0.5 m was 0.9 T per sheet. Based on the calculation results of the uplift forces of each platform to bear a simple house with 54.01 T in weight, the total numbers of 300 rods for PVC are obtained with the dimensions of 30 pipes by axis (x), 2 pipes by axis (z), and 5 pipes by axis (y). Whereas for the EPS, a total of 64 sheets are obtained, with the dimensions of 8 sheets of axis (x), 4 sheets of axis (z), and 2 sheets by axis (y).

The stability of the floating buildings of each platform is in "STABLE" condition with a note that the use of an additional freeboard or height of 0.5 m for each platform.In terms of the comparison of the platform expenses, the EPS materials are more economical compared to PVC. The PVC materials cost IDR. 561,561,360.00, meanwhile the EPS cost IDR 40,420,000.00.mBoth of these platform materials require binders and protectors to anticipate collisions.

6. Acknowledgement
Our gratitude goes to the Directorate of Research and Public Service, Ministry of Research, Technology and Higher Education of Indonesia that has funded this research, as well as all those stakeholders who participated and supported.

References

[1] Sarbidi 2002 *Proseding Puslitbangkim Bandung* pp. 35–41.
[2] Adi H. P. and Wahyudi S. I. 2018 *Tidal Flood Handling through Community Participation in Drainage Management System (A case study of the first water board in Indonesia)* **10** pp. 19–23, 2018.
[3] Wahyudi, S. I., Adi, H.P., and Le Bras 2012 *Proceeding of International Commision Irrigation and Drainage (ICID) 63rd International EC Meeting & 7th Asian Regional Conference*.
[4] Adi H. P. and B. S. Wahyudi, S. I 2017 *J. Environ. Sci. Eng.* B pp 17–26.
[5] Purwito 2002 *Prosiding Puslitbangkim.*
[6] Wahyudi S I, H, Adi H P, Rochim A, and Marot D 2014 *Int. J. Civ. Environ. Eng. IJCEE/IJENS.*
[7] Dadri A 2012 *Prosiding Puslitbangkim Bandung.*
[8] Watanabe T M, Wang C M 2004 *Centre for Offshore Research and Engineering National University of Singapore.*
[9] Wang C M, Watanabe E, and Utsunomiya T 2008 *Tailor & Fransis,* pp. 1–30.
[10] Ishaque F, Ahamed M S, and Hoque M N 2014 *Design and Estimation of Low Cost Floating House* **7(1)** pp. 49–57.