Mathematical analysis and experimental testing of floating building platform prototypes made from expanded polystyrene system (Styrofoam) and lightweight concrete

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Abstract. Floating building is one of the solutions to anticipate residential areas against Tidal floods which have been occurring on the North Coast of Central Java. This floating building can adjust its buoyancy to the effect of rising sea level and land subsidence. This building can be applied in sea tidal flood areas and retention ponds in polder systems. The main materials used as the floating building platform are styrofoam and lightweight concrete. This study aims to determine the stability, capacity and buoyancy of the prototype platform using styrofoam and lightweight concrete. This study uses mathematical analysis methods and prototype testing with laboratory experiments. Based on the analysis result for the styrofoam material platform with dimensions of 2 x 2 x 0.62 m, a buoyancy force of 2.73 tons was obtained with the Safety Factor (SF) of 1.25. A lightweight concrete weight of 0.97 tons, the load that can be supported by the prototype is 1.2 tons. The prototype of the styrofoam material platform with a lightweight concrete cover has a stable condition with a value of m>0, namely the center of object weight (B0) is +0.74 meters and the metacentric value is +0.9 meters.

1. Introduction
Semarang is a coastal area that often experiences flooding due to rising sea levels. The increase in seawater causes inundation, increases in coastal erosion, and seawater intrusion into the land. The impact can disrupt community activities, damage residential buildings, and other infrastructure buildings [1]. The floating structure is one of the innovations that can be applied to areas that often experience flooding due to rising sea levels. This floating building is suitable to be developed as a residence [2]. The floating platform is a substitute material for the foundation structure which is used as a medium to support buildings that float on water. The use of floating platforms is to anticipate tides so that the position of the building can follow the water level [3].

In Indonesia, the materials that are often used as floating building materials are wood and bamboo [4]. However, nowadays expanded polystyrene system (EPS) or styrofoam material is also starting to be developed as a buoyancy structure material because of the high buoyancy and durability of this material [5]. This research aims to make a prototype of a floating platform made from styrofoam and to test the stability, capacity of the platform, and the buoyancy of the platform.
2. Literature Review

2.1. Definition of the floating structure

The floating structure is a building with a construction that rests on a floating platform by relying on the buoyancy of the platform as a structure that holds the load above it. Floating technology solves the problem of the impact of coastal reclamation. Researchers take a green or environmentally friendly approach so as not to damage the underwater ecosystem. In general, the concept of floating structures is different when compared to land structures in the construction process. This is what distinguishes the work method, the use of technology in the development process [6]. Floating construction is a building structure with the construction that rests on a floating platform by relying on the buoyancy of the platform as a structure that holds the loads above it. In the case of buoyancy construction, the role of the platform (stage) is the main one, the material used must have high buoyancy so that the buoyancy can support the structure built on it. Platform dimensions must be determined based on the load that the platform will later bear [7].

2.2. Floating platform stability

Stability is a science that discusses the ability of a floating object to return to its original position after being exposed to external forces, these forces include wind, water conditions or waves and collisions with other objects [8]. Structural stability control is used in floating buildings to determine whether the floating building can float after adding loads to the building.

2.3. Styrofoam material platform

The styrofoam platform is a construction designed using the styrofoam material of the floor plate. Styrofoam is considered to be more environmentally friendly when used as a building material due to the use of Styrofoam in the long term. Polystyrene foam from Styrofoam has the characteristics of lightweight and water resistance. Therefore, this material is suitable for use as a floating building platform material [9]. According to Halim [10], the floating platform is a place to place the mass of the building where part of the floating platform is the cover layer, the plate frame, and the buoy. The shape of the floating plate will affect the configuration of the buoy used. Styrofoam material can be applied as a platform material to be used for floating construction in this study, with dimensions that will be calculated based on the load above. The greater the load to be borne by the platform, the greater the dimensions of the platform that will be made. After knowing the required platform dimensions, an analysis of the material and its economic value is then carried out.

3. Research Method

The 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. Creating a prototype design of a floating building platform from styrofoam and analyzing the load capacity of the floating platform.

b. Analysis of the buoyancy of the styrofoam material platform using the Archimedes formula

\[
F_a = p \times l \times t \times \rho \times g
\]

(1)

c. The stability analysis of the floating platform made from styrofoam uses the metacentric height formula:

\[
m = \frac{I_0}{V} - A_0 B_0
\]

(2)

d. The design realization of the prototype for a floating building platform made from styrofoam.

e. Loading test platform prototype floating building made of styrofoam.

4. Finding and Discussion

4.1. Buoyancy Analysis (FA)
If the buoyancy force of Styrofoam (Fa) is greater than the gravitational force of Styrofoam (g), the object will float. The following is the calculation of the buoyancy force of a Styrofoam panel with a size of 2 x 1 x 0.62 m (Fa).

**Buoyancy Analysis:**

Styrofoam Size = 2 meters x 1 meter x 0.62 meter
Styrofoam Weight (q) = 30 kg/m³

Buoyancy force of Styrofoam (Fa) = L x B x H x ρ x g

\[ Fa = 2 \text{ m} \times 1 \text{ m} \times 0.62 \text{ m} \times 1000 \text{ kg/m}^3 \times 9.81 \text{N/kg} \]

= 12,164.4 N

Styrofoam Gravity (g) = 30 kg x 1.24 m³ x 9.81 m/s³

= 364.932 Newton

Buoyancy force of Styrofoam (Fa) > EPS Gravity (g), then object will be floating.

\[ 12,164.4 > 364.932 \text{ (Ok)} \]

### 4.2. Load Analysis

The loads working on the structure are dead, live and external loads on the building. In this study, the calculated loads that work on the floating platform are as follows:

- **a. Normal concrete cover**
  - Normal concrete cover load for 2 EPS
  - Type = Normal Concrete
  - Dimension = 2 m x 2 m x 0.62
  - Floor plate Volume = 4 x 0.06
    - = 0.24 m³
  - Side Volume = 2 x 0.62 x 0.06 x 4
    - = 0.2976 m³
  - Total volume of concrete cover = 0.24 + 0.2976
    - = 0.5376 m³
  - Concrete Density = 2,400 kg/m³
  - Concrete weight = Volume x Concrete Density
    - = 0.5376 x 2400
    - = 1,290.24 kg
    - = 12,902.4 N

- **b. Lightweight Concrete Cover**
  - Light weight concrete cover load for 2 styrofoam
  - Type = Lightweight Concrete
  - Dimensions = 2 m x 2 m x 0.62
  - Floor plate Volume = 4 x 0.06
    - = 0.24 m³
  - Side Volume = 2 x 0.62 x 0.06 x 4
    - = 0.2976 m³
  - Total volume of Concrete cover = 0.24 + 0.2976
    - = 0.5376 m³
  - Concrete Density = 1600 kg/m³
  - Concrete weight = Volume x Concrete Density
    - = 0.5376 x 1600
    - = 860.16 kg

- **c. Dead Load**
  - The dead load that is borne by this floating platform made of styrofoam is the burden of the accessories in the middle of the platform. For dead load, the calculation is as follows:
Density of Steel Pipe Ø10 cm = 16.07 kg/m
Pipe Length = 2 m
Pipe Weight = 2 x 16.07 = 32.14 kg
Accessories weight = 3 kg
Table Weight = 4 kg
2 Chairs weight = 3 kg x 2 = 6 kg
Total load = 32.14 + 3 + 4 + 6
= 45.14 kg = 451.4 N
de.

Connection Load
Every 1 m² of Styrofoam requires 1.62 kg of glue for connection, then the glue needs are:
Long side area = 2 x 0.62 = 1.24 m²
Total weight of glue= 1.62 x 1.24 = 2 kg = 20 N
e.

Total Load
The total load that works when using a normal concrete cover is:
Total load = cover load + live load + connection load
= 12,902.4 + 451.4 + 20
= 13,373.8 N
The total load that works when using a lightweight concrete cover is:
Total load = cover load + live load + connection load
= 8,601.6 + 451.4 + 20
= 9,073 N

4.3. Stability Calculation
Buoyancy of 2 pieces of Styrofoam = 2 x 12,164.4
= 24,328.8 Newton

a. Structural stability Control of Floating foundation with normal concrete cover
Total weight of floating load = 13,373.8 N (downward)
SF = 1.2
Upward Buoyancy (Fa) = 24,328.8 N (upward)
Stability Control = Fa/G > 1.2 = 24,328.8 / 13,373.8 > 1.2 = 1.8 > 1.2 (Ok)

This load is only calculated for cover load, dead load and connection load. The following is the calculation of the maximum allowable live load on the styrofoam material platform with normal concrete cover dimensions of 2.06x2.06x0.68 m.
SF = 1.2
Upward buoyancy (Fa) = 24,328.8 N (upward)
Stability Control = Fa/G > 1.2 = 24,328.8 /G > 1.2
To find the load value that can be borne by Styrofoam (G) panels, a divider factor that is higher than the SF value is used. In this analysis, a divider factor of 1.25 is used. So the formula is as follows:
Total Structure Weight = \frac{24,328.8}{1.25}
= 19,463.04 N, so that
Stability Control = Fa/G > 1.2
= 24,328.8 /19,463.04 > 1.2
= 1.25 > 1.2 (Ok)

So the live load that can be maintained by styrofoam material platform is:
Liveload (LL) = 19,463.04 N – 13,373.8 N
= 6,089.24 N
= 608.924 kg

b. Structural stability control of Floating foundation with lightweight concrete cover

Total Weight of Floating Structure = 9,073 N (downward)

SF = 1.2

Upward Buoyancy (Fa) = 24,328.8 N (Upward)
Stability Control = \( \frac{Fa}{G} > 1.2 \)
= \( \frac{24,328.8}{9,073} > 1.2 \)
= 2.68 > 1.2....................(Ok)

From the analysis that has been carried out, the calculation of the load on the prototype platform of a lightweight concrete cover based on the cover, joint weight, and dead load weight with a total of 9,073 N has a high SF value of 2.68. To optimize the live load that the Styrofoam material platform can withstand with a lightweight concrete cover with dimensions of 2.06 x 2.06 x 0.68 m, the following calculations are performed:

SF = 1.2

Upward Buoyancy (Fa) = 24,328.8 N (Upward)
Stability Control = \( \frac{Fa}{G} > 1.2 \)
= \( \frac{24,328.8}{19,463.04} > 1.2 \)
= 1.25.........................(Ok)

Then the load that can be added to the platform is:

Live load (LL) = 19,463.04 N – 9,073 N
= 10,390.04
= 1,039 kg

| Buoyancy/ Floating (N) | Concrete Cover (N) | Dead load (N) | External Load (N) | Live Load (N) | SF |
|------------------------|-------------------|--------------|------------------|---------------|----|
| Normal Concrete        | 2,328.8           | 12,902.4     | 451.4            | 20            | 6,089.24 | 1.2 | 1.25 |
| Lightweight Concrete   | 24,328.8          | 8,601.6      | 451.4            | 20            | 10,390.04 | 1.2 | 1.25 |

4.4. The lightweight concrete mixture as a cover platform

In testing the compressive strength of lightweight concrete using a cylinder with a diameter of 15 cm and a height of 30 cm, the mix proportions for lightweight concrete with styrofoam shown in Table 2.
Table 2. Material requirements per m³

| No | Material            | Material Need | Denomination |
|----|---------------------|---------------|--------------|
| 1  | Water               | 185           | Liter        |
| 2  | Cement              | 411.11        | Kg           |
| 3  | Fine Aggregate      | 253.40        | Kg           |
| 4  | Coarse Aggregate    | 450.49        | Kg           |
| 5  | Styrofoam           | 0.5           | %            |
| 6  | Viscoscrate         | 0.5           | %            |

4.5. Making Floating Platform Prototypes
In this study, the manufacture of the test object consisted of making a sample for a lightweight concrete cover and making a prototype of a floating building platform.

4.5.1 Objects of Light Concrete Cover Test. The preparation of lightweight concrete samples was carried out using a mixture of styrofoam granules with a diameter of 3-4 mm with 3 sample cylinders with a diameter of 15 cm and a height of 30 cm. The stages of making a lightweight concrete cover test object can be seen in Figure 1 below:

In the process of coating styrofoam with cement mortar, the ratio was calculated so that the dry weight of styrofoam that had been coated was 84 kg. The preparation of the test object for the lightweight concrete cover was carried out from the material weighing stage according to the material requirements after the styrofoam coating was carried out. After weighing, the material was put into the mixing machine. After all the materials were mixed and became a concrete dough, a slump test was carried out and the concrete was ready to be inserted into the formwork. The formwork could be removed after 24 hours of concrete and then immersed for 5 days.

4.5.2 Floating Platform Object. The prototype of the floating platform made from styrofoam was made with a size of 2 x 2 x 0.62 m and the thickness of the concrete cover was 6 cm. The process of making a prototype of a styrofoam material floating platform can be seen in the image below:

The buoyancy force of the styrofoam platform prototype in the field would be compared with the buoyancy in the calculation analysis. The load capacity test in the field would be carried out with gradual loading to the maximum load limit that could be borne by the floating platform.
4.6.1 Lightweight Concrete Testing for Cover

In the lightweight concrete test, the slump test, concrete volume weight, and concrete compressive

**Table 3. Hasil Pengujian Berat Volume Beton**

| No | Codes | Weight (kg) | Volume (m³) | Concrete Volume Weight (kg/m³) | Volume Weight Average (kg/m³) |
|----|-------|-------------|-------------|-------------------------------|-------------------------------|
|    | a     | b           | c           | d                             | e = \frac{c}{d}               |
| 1  | A1    | 7.71        | 0.00529     | 1457.5                        | 1522.8                       |
| 2  | A2    | 9.71        | 0.00529     | 1640.2                        |                               |
| 3  | A3    | 7.78        | 0.00529     | 1470.7                        |                               |

From the table above, it showed that the weight and volume of concrete has met the requirements for lightweight concrete, which is less than 1,900 kg / m³, and concrete with the addition of styrofoam grouting is lighter than normal concrete. The concrete compressive strength test was tested at 7 days of concrete.

**Table 4. The Test Result of Concrete Compressive Strength**

| No | Code | Maximum Load (kN) | 7 Day-Press Power (Mpa) | Kuat Tekan Konversi ke (kg/cm²) | Press Power Average (kg/cm²) |
|----|------|-------------------|------------------------|---------------------------------|------------------------------|
|    | a    | b                | c                      | d                               | e                            |
| 1  | A1   | 125.69           | 7.11                   | 87.32                           | 134.33                       |
| 2  | A2   | 195.9            | 11.08                  | 136.08                          | 209.35                       |
| 3  | A3   | 141.32           | 7.99                   | 98.13                           | 150.96                       |

From the table above, it can be stated that in concrete with the addition of Styrofoam as an added material, the compressive strength in lightweight concrete was relatively small, namely 164.88 kg / cm² or equivalent to K-150.

4.6.2 Testing Buoyancy and Load Capacity. The test of buoyancy and load capacity that could be held by the Styrofoam platform was carried out at the Hydraulics Laboratory of the Sultan Agung Islamic University Semarang. The following are the stages in testing the buoyancy of the floating platform prototype (Figures 3 and 4).

*Figure 3. The Measurement of Platform Buoyancy at No Load*
The test results of the buoyancy and load capacity that could be held by a lightweight concrete cover styrofoam platform can be seen in Table 6 below:

**Table 5. Large volume (V) and weight (W) of floating platform prototype**

| No | Length (m) | Width (m) | Thickness (m) | Volume (m³) | Weight (kg) |
|----|------------|-----------|---------------|-------------|-------------|
| a  | b          | c         | d             | e = b x c x d | f           |
| 1. | 2.06       | 2.06      | 0.68          | 2.885       | 915.916     |

Where: The weight of the test object (W) was obtained from the calculation.

**Table 6. Data of Floating Platform Prototype Test Result**

| No | Load Capacity (kg) | Floating Data (m) | Sinking Data (d₁) (m) | V⁻ (m) | V⁺ (m) | SF |
|----|--------------------|--------------------|------------------------|--------|--------|----|
|    |                    | A  | B  | C  | D  | Average |        |        |        |        |        |
| 1  | 0                   | 0.37 | 0.38 | 0.40 | 0.39 | **0.385** | 0.295 | 1.25  | 1.64  | 2.3   |
| 2  | 248                | 0.33 | 0.32 | 0.35 | 0.33 | **0.33** | 0.348 | 1.47  | 1.41  | 1.95  |
| 3  | 735.4              | 0.24 | 0.25 | 0.19 | 0.29 | **0.2425** | 0.4375 | 1.86  | 1.03  | 1.55  |
| 4  | 1,165.6            | 0.14 | 0.16 | 0.19 | 0.19 | **0.17** | 0.51  | 2.16  | 0.73  | 1.33  |

Where: V⁻ = the volume of the submerged part, b x c x (d₁), b and c
V⁺ = the volume above the water surface,
V⁺ = V – V⁻
V = the volume before the test material got loading.
Figure 5. Comparison Graph Between Analysis and Testing

From the sinking data and volume testing results of the Styrofoam Material Platform Prototype test, it was found that the ability of the Styrofoam platform with a size of 2.06 x 2.06 x 0.68 m was able to withstand a load of 1165.6 kg with an SF value of 1.33.

4.6.3 Floating Platform Stability Testing. Testing the stability of the floating platform was done by calculating its center (m). The results of this stability can be seen in the calculations below:

Metacentric height of the platform without load.

\[
\text{Platform Weight (FG)} = \text{styrofoam weight} + (\text{concrete density} \times \text{cover volume}) \\
= 60 + (1577.2 \times 0.53) \\
= 895.916 \text{ kg} \\
= 0.896 \text{ ton} \\
B_0 = \frac{0.896}{0.896 \times 0.5 \times 0.68} = 0.34 \text{ meter (from the base of the platform)}
\]

The platform sinks to a depth of \( h = 0.295 \) meters, then the volume transferred is

\[
V = 2.06 \times 2.06 \times 0.295 \\
= 1.25 \text{ m}^3
\]

Place of the float center

\[
A_0 = \frac{1}{2} h \\
= 0.148 \text{ m}
\]

So:

\[
A_0B_0 = 0.34 - 0.148 = 0.192 \text{ m}
\]

A submerged moment of floating inertia

\[
I_0 = \frac{1}{12} \times 2.06 \times 2.063 \\
= 1.5 \text{ m}^4
\]

Metacentric Height

\[
m = \frac{I_0}{V - A_0B_0} \\
= \frac{1.5}{1.25 - 0.192} \\
= 1.008 \text{ m}
\]

Because \( m > 0 \), it showed that \( m \) was above \( B_0 \) so that the object is declared stable. The calculations with loads can be seen in the following.
Based on the results of the stability testing that has been carried out, it can be seen in Table 7 that 4 variations of loading the floating platform can be said to be stable because m> B0.

5 Conclusion
The buoyancy force of the floating platform (Fa) was 24,328.8 Newtons (up), the permitted safety figure in this study was 1.2 so that the amount of load that can be borne (G) was the styrofoam platform material of 6,560.64 Newton (down) for normal concrete cover prototype and 10,861.44 Newton (down) for a lightweight concrete cover prototype. With successive loads of 0 kg, 248 kg, 735.4 kg, and 1165.6 kg, the floating platform volume is 1.64 m3, 1.41 m3, 1.03 m3, and 0.73 m3 with an SF number of 2.3, 1.95, 1.55, 1.33. The results of testing the stability of the floating platform with a lightweight concrete cover showed that the height of the center (m) was 1,008 m, 0.716 m, 0.535 m, 0.53 m. The center of the object was at 0.34 m, 0.479 m, 0.493 m, 0.385 m. Based on the three experiments on the stability test, it can be concluded that the floating platform is said to be stable because the result of the 4 loading variations is m> 0.

6 Suggestion
In the experiment of platform buoyancy, it is necessary to test Styrofoam with various densities to obtain the optimal buoyancy of various types of Styrofoam. It is necessary to do further research on the lightweight concrete cover of the floating platform prototype to obtain higher concrete strength.

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