Exploring Multi-Purpose Floating Structures

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ABSTRACT

Due to land shortage in Singapore, alternative methods have to be explored to combat lack of land space. Sand required for land reclamation is difficult to procure in Singapore as Indonesia and Vietnam, two of Singapore's largest sources of sand, banned sand exports to Singapore in the past decade. Thus, an alternative method to dealing with land shortage is to utilize sea space using floating structures to build industrial, commercial and/or residential buildings upon. This project aims to explore the usage of modules to construct such floating structures. Eight pieces of foam modules were connected and the structure was tested based on its extent of depression under a point load. The investigations show that the structure made from hexagonal modules show the least depression as compared to square modules and triangular modules, thus it is the most suitable module shape for use as a floating structure. The limitation of the research is that the difference in depression between different module shapes may not be as significant in industrial materials such as concrete as compared to foam.

INTRODUCTION

Population growth and urban development has resulted in land scarcity in Singapore and many other countries. Singapore is particularly affected by this problem as Singapore has a relatively small land area as well as a high population density. Land reclamation, a strategy used by many countries such as Singapore and Japan, is widely used to tackle land scarcity. However, land reclamation is only suitable when the water body is shallow with a depth of 20 metres or less. Additionally, the seabed cannot be too soft. Moreover, land reclamation destroys the marine habitat and may even lead to the disturbance of toxic sediments. (Sanatan, 2015) In Singapore's case, sand required for land reclamation is difficult to come by after Indonesia and Vietnam banned sand exports to Singapore in 2007 and 2017 respectively. About 90% of Singapore's sand used for reclamation came from Indonesia before the ban.

Floating platforms can thus be used so that space on vast oceans can be utilised for infrastructure - residential, industrial, or commercial. Hence, the use of modules (smaller, constituent pieces) in building these floating platforms has been proposed. The advantages of utilizing modules to build floating platforms is that should a single module be damaged, it can be easily replaced, allowing for inexpensive repair (Arnold, 1991). The shape and size of a modular floating structure is also more versatile, as individual modules can be added to or removed from the structure to modify it.

The technology of using floating structure is currently being employed in countries with large, unused sea space, with examples being Japan's floating Kansai airport and Mega-float in Tokyo Bay. Floating structures are environmentally friendly as they do not damage the marine ecosystem, silt-up deep harbors or disrupt the ocean currents; they are easy and fast to construct; they can be easily removed or expanded; and they are not affected by seismic shocks since they are inherently base isolated (Wang et al. 2008).

Certain types of module connections leaves gaps between two adjacent platforms and act more like a bridge connection. The connections mostly do not restrict movements in the vertical direction (heave motions). When heave motions are not of great concern for the floating platforms, this type of connection is preferred as the heave motions of one platform will not affect the heave motions of the adjacent platform, so the two platforms can freely move in vertical direction completely independent from each other. This is because the connection does not transfer any vertical forces as the connection is in fact a beam with two hinges at each end. The main failure mechanism of the connection will be because of torsion, which is induced by relative roll and yaw motions. (Ko, 2015)

Currently, different connections have been used by different modular floating structures. For example, the Hann-Ocean connection system is a "drop and lock" rigid pontoon. It is a rigid disconnectable system that connects with two steel "puzzle pieces" per connection. Such connection has the advantage of simple yet strong connections, with the ability to join with self-alignment feature quickly. However, the cavities required in each piece has to be larger due to the size of the connection, which will require thicker edge-beams in concrete floating bodies (Koekoek, 2010).

Thus, by investigating the usage of modular structures to build these floating platforms, this project aims to investigate the most suitable module for use as a floating structure.

SOLUTION DESIGN

In the experiments, the extent of depression of a modular floating structure under a load, as a measure of its suitability for practical use was compared. Ideally, the floating structure should show the lowest extent of depression.

Modules were cut for the floating structure from foam with a thickness of 2.1cm. Different regular shapes of modules were cut, namely triangles, squares and hexagons. These shapes were selected as they can be tessellated, thus making it more convenient to add or remove single modules from a floating structure. The dimensions of the foam are selected such that the total surface area of each module would be similar regardless of shape (Table 1).

Table 1. Dimensions and surface area of each module shape

Shape	Edge length /cm	Surface area of 1 module (to 2 s.f.) /cm^2	Surface area of 8 modules (to 2 s.f.) /cm^2
Square	7.9	62	500
Triangle	12.0	62	500
Hexagon	4.9	62	500

To connect the modules together, several different types of connectors were tried, such as toothpicks, foam glue and superglue. Using toothpicks and superglue damaged the modules while the foam glue dissolved instantly upon contact with water, hence these connectors were all deemed unsuitable. In the end, glue from a hot glue gun was utilised. A single line of hot glue was applied horizontally through the centre of both adjacent sides to adhere two modules together.

Three floating structures were prepared, with each consisting of 8 pieces of a particular shape arranged in a 4 by 2 formation (Fig 1).

Fig 1. Foam floating structures made from 8 modules each, with different module shapes (from top: hexagonal, square, triangular)

Each floating structure was placed on water and a stack of weights placed at the centre of the structure (Fig 2). The total mass of the weights was varied from 100g to 800g, in 100g intervals. 5 photos of the foam structure were taken for each setup such that the depression can be measured.

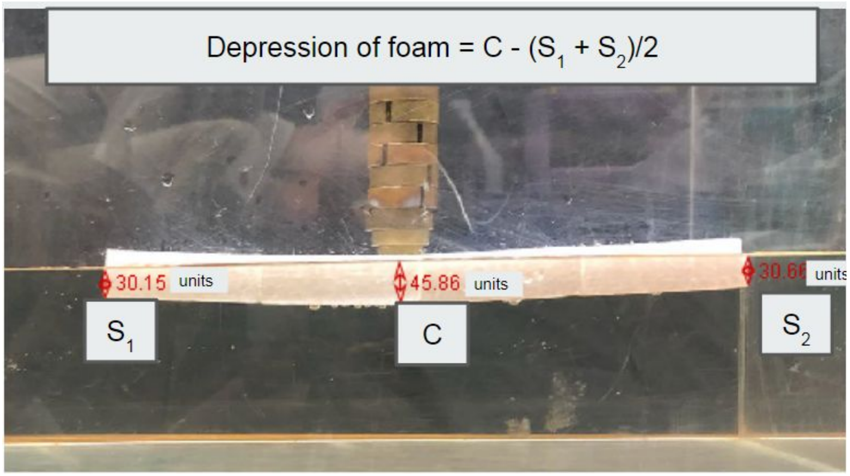

Fig 2. The experimental setup: A stack of weights loaded at the centre of the floating structure. The depth of the centre of the structure is denoted C, and the depth of the two sides denoted S_1 and S_2 respectively. The measurements displayed were measured with the Tracker software

The depression of the foam is measured with the use of the Tracker software, where the equation for the depression of the foam, D, is given in Fig 2.

RESULTS AND DISCUSSION

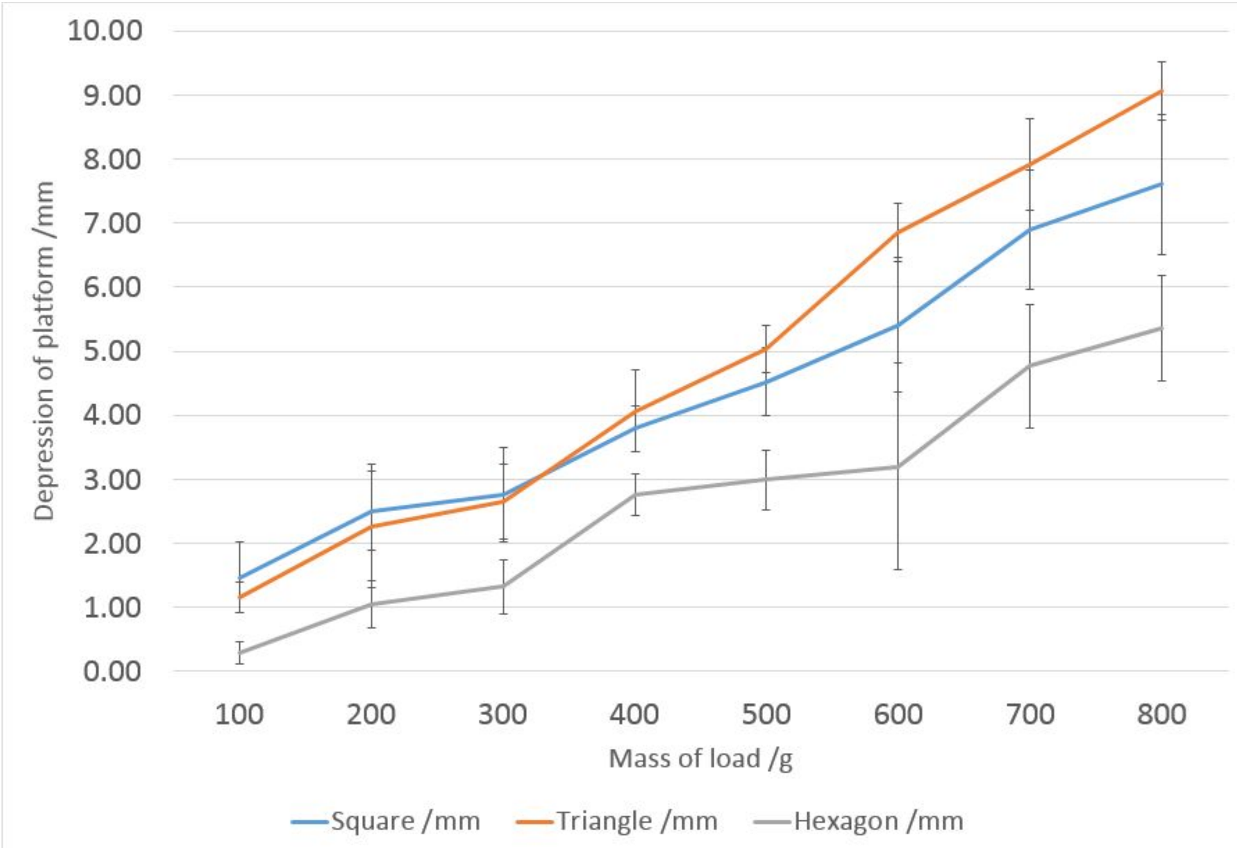

Fig 3. Graph of depression of floating platform /mm against mass of load /g.

The average depression for each setup was graphed in Fig 3. By observation, the floating structure created from hexagonal modules showed consistently lower depression than the other floating structures.

Table 2. p-values obtained from Mann-Whitney U Test conducted on selected data values

Mass of load /g	p-value of hypothesis that depression of structure made from hexagonal modules is less than that from square modules	p-value of hypothesis that depression of structure made from hexagonal modules is less than that from triangle modules
100	0.0058	0.0058
400	0.0061	0.0108
800	0.0061	0.0061

The Mann Whitney U-Test was used to analyse the data and see if the sets of data are different to a statistically significant extent, using data from the two extreme ends of the mass of load used (100g and 800g) as well as the centre reading (at 400g). The p-value for each statistical test was obtained and displayed in Table 2. All 6 comparisons conclusively show that the hexagon platform has the lowest depression under a load as the p-value is lower than 0.05, implying a confidence of at least 95%.

From the results, it can be seen that the hexagonal platform has the least depression under the point load. This could be due to the alignment of the axis in the different platforms.

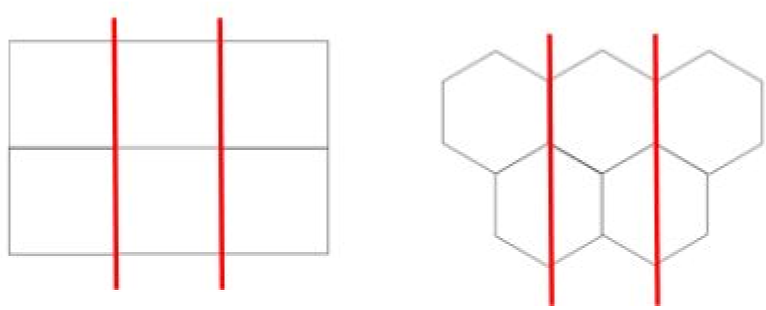

Fig 4. Illustration of a few axes (marked out in red) which can bend under stress on a floating structure made out of square modules (left) as compared to hexagonal modules (right)

With reference to Fig 4, when the platform made from hexagonal modules bends along one edge connection, adjacent edge connections are not aligned along the same axis. On the other hand, when a floating structure made from square or triangular modules bends along one edge connection, it also bends along other connections adjacent to it along the same axis. This makes the platforms made from square or triangular modules more prone to bending as compared to the hexagonal platform.

Even though the only material tested on was foam, the results are likely able to be extrapolated to other materials such as concrete. A force diagram analysis was used to show that using any material will result in the bending effect observed as the bending phenomenon is irrespective of the density, hardness nor strength of the material.

On a floating structure, a buoyant force is present across all points on the bottom surface while a point load is focused on the centre point (Fig 5). When the floating structure remains afloat, the downwards force of the load is cancelled out by the upwards buoyant force.

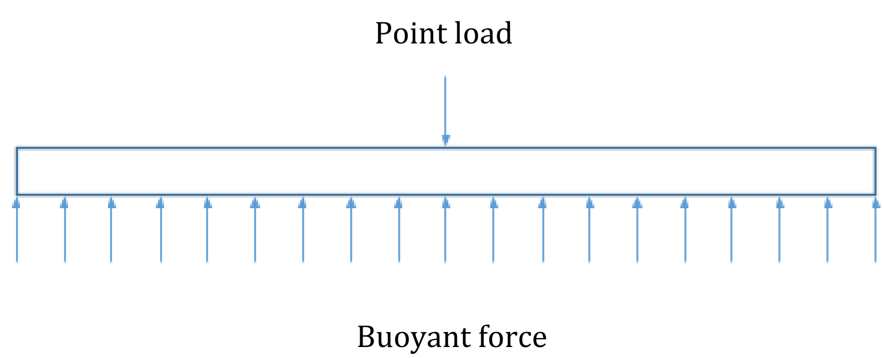

Fig 5. Force diagram schematic of the forces acting on a floating structure

Assumptions made are that the buoyant force by water is uniformly distributed, the platform acts as one continuous rigid body and both ends of the platform are free ends as they are not attached to any objects.

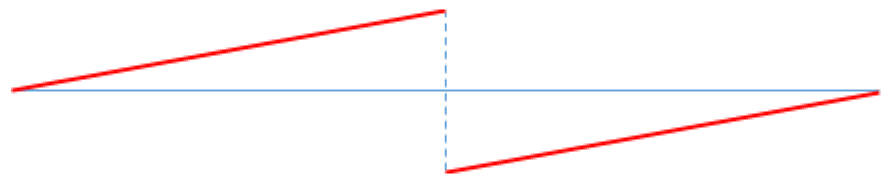

Fig 6. Shear diagram for a floating structure

From the force diagram, the shear force acting on the floating structure can be graphed in a shear diagram in Fig 6, which shows the force acting on each point on the platform.

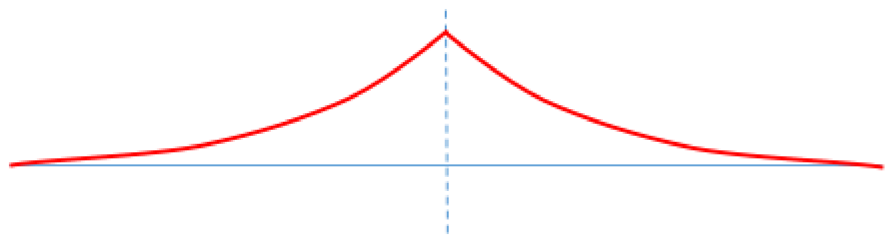

Fig 7. Bending moment diagram of the floating platform

By plotting a graph of shear force against x, a bending moment diagram which depicts the induced bending moment of the structure is created (Fig 7).

Hence, regardless of material, all modular platforms will experience this bending effect. Instead, what may differ between various materials is the extent of the depression under the same load.

CONCLUSION

Based on the findings, the platform made of hexagonal modules has the least depression under a point load. This shows that the hexagonal modules are the most suitable for a modular floating structure.

As this project used foam instead of concrete to build the prototype modules, whether the difference in extent of depression between various shapes of concrete modules is significant remains uncertain. Further studies may be conducted using concrete modules to verify this result.

In an industrial setting, there would also be many other factors that would affect a platform, such as the draught and sea waves which will affect the stability of a floating platform. These factors may also be tested in further studies.

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