Deployment of Offshore Floating Solar System

2019 GP 11-05

Lin Hongyi(3A215)
Qiu Yiran(3A219)
Li Yalun(3O217)
Zhu Tianyi(3O233)

Hwa Chong Institution(High School)

ABSTRACT

In search of renewable energy such as solar energy, a floating solar testbed was built in Tengeh Reservoir in 2016, consisting of 10 different floating solar systems from both local and foreign enterprises. Housing Development Board(HDB) is also one of the participants in collaboration with the research team from the National University of Singapore(NUS), with an aim to explore possibilities of deploying solar platforms in the open sea. This is named as Floating Solar Farm, in which solar platforms are installed and fixed on platforms and platforms are connected to each other through high-intensity plastic screw bolts. However, when put into actual water test, these platforms are highly unstable and vulnerable to water fluctuation as well as other undesirable water circumstances. There is also a lack of research done on the structural integrity of the solar platform. This group aims to complement the HDB research by assessing the structural integrity of the platform and furthermore, to devise feasible solutions to make the platform more pressure-resistant. Experimental testing demonstrated the feasibility of the proposed mechanisms in which 5052 aluminium alloy bars were utilised as a replacement of previous connectors, with results suggesting a more effective and more economical way of platform connections.

INTRODUCTION

The demand for electricity in society is rising, while traditional methods would generate a tremendous amount of greenhouse gases which accelerate the rate of global warming. Research has shown that in 2018, global electricity demand rose by 4% in 2018 (Global Energy & CO2 Status Report, 2018), nearly twice as fast as overall energy demand, and at its fastest pace since 2010. Renewables and nuclear power met the majority of the growth in demand. However, generation from coal and gas-fired power plants increased considerably, driving up CO2 emissions from the sector by 2.5%. (Global Energy & CO2 Status Report, 2018)

To solve this problem, many countries are in pursuit of clean and renewable energy, one of which is solar energy. For instance, Solar Star in Rosamond in California is one of the most large-scale projects in the U.S. situated on the massive uninhabited deserts. Starting from 2015, this project involved 1.7 million solar platforms installed across 3,200 acres of the westernmost Mojave Desert valley region. Solar Star achieves its output of 579 MW per year (Atwell, C., 2019) by the use of higher-efficiency crystalline silicon solar platforms, which is estimated to be capable to provide sufficient electricity to power 255,000 homes. Another example would be Japan who is the forerunner in floating solar energy. In 2018, Kyocera, a Japanese corporation, has announced that its latest floating solar (FPV) power plant on the Yamakura Dam reservoir in Chiba Prefecture, is operational, making the 13.7MW FPV plant the largest in Japan. The FPV was operated by Kyocera TCL Solar LLC, a joint venture between Kyocera and Tokyo Century, which was established back in 2012 to promote large-scale solar projects in Japan. (Atwell, C., 2019)

In Singapore's context, although more than 95% of the Singapore's grid energy is derived from burning of the natural gas (Tan, A., 2018) which is regarded as the cleanest form of traditional methods, this still produces a large amount of greenhouse gases and contribute to global warming. Therefore, Singapore is also steered towards implementing a photovoltaic system to lessen its dependence on fossil fuels. For example, solar platforms have been installed or are being fitted in more than 2,400 HDB blocks across Singapore, but that is far less than satisfactory. (Tan, A., 2018) One of the struggles encountered when installing the PV system is that the equipment takes up a huge area, as a 1MW photovoltaic power plant occupies an area of 11000 m^2. Given Singapore's small land area, there is a limit to how much solar energy can be harvested from solar platforms on land. It is also not practical to solely install solar platforms in its natural water source to satisfy society's need for energy. Thus, Singapore is placing its focus on the offshore floating solar system.

The experiments conducted by NUS research team have suggested that the weakest point of the platforms is at its connecting sector, where the convex portion of the upper surface of one platform and the protruding portion of the lower surface of the other platform are fixed by nylon screw bolts penetrating throughout this structure. When forces are applied on a row of platforms, the connectors demonstrate the most significant indentation, where the other parts of the platform show slight indentation.

5052 Aluminium is a type of aluminium alloy which possesses a chemical composition of Aluminium(97.2%), Magnesium(2.5%) and Chromium(0.25%) and anodized coatings. Using Magnesium in sufficient quantities and as a major alloying element, 5052 Aluminium has high strength that is far stronger than other types of aluminium alloy, without subjecting it to changes in the surrounding temperature. In addition, its anodized coatings enable it to have excellent resistance to corrosion, especially in salt-water and marine atmospheres. With these properties, 5052 Aluminium appears as the ideal material for the new platform-connecting mechanisms.

Therefore, this project aims to investigate the effectiveness of the current connecting mechanism when facing downward forces exerted on the connection sector between solar platforms. Furthermore, this group attempted to create a connecting mechanism for the solar platforms on which photovoltaic platforms are installed to significantly increase the stability of the solar platforms and thus avoid possible breakdown under wave conditions. Additionally, the newly introduced mechanism was estimated to be less expensive and easier to assemble than the previous one, which brings in economic benefits incurred from industrial mass production and labour costs. This would add value to the product and make the product more competitive in the market.

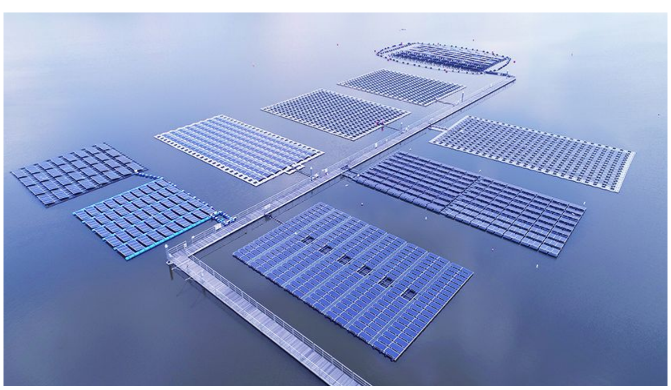


Fig. 1.1 - *Floating solar system test-bed in Tengeh Reservoir, Singapore*

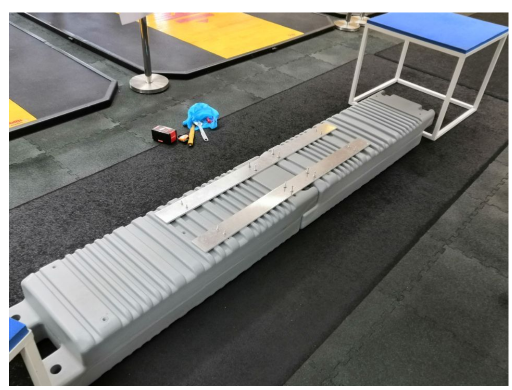


Fig. 1.2 - *Experimental solar platforms*

MATERIALS & METHODOLOGY

1. **Two offshore solar platforms modules**

   The platforms are manufactured by the factories and are used to study the firmness of the connectors which need to be enhanced.

2. **Two screws**

   These screws are used to connect the platforms in the original design.

3. **Two 5052 aluminium alloys(the new connectors)**

   5052 is an aluminium alloy, primarily alloyed with magnesium and chromium. It is an alternative material to be tested in place of the screws.

4. **Some expansion screws**

   In order to fix the alloy on the platforms which originally do not have any holes, the group drilled some holes on the surface of the platforms and use expansion screws to consolidate the connection.

5. **A laser range finder**

   To precisely determine the distance between the surface and ground in order to get more accurate data and determine the effectiveness of the method.

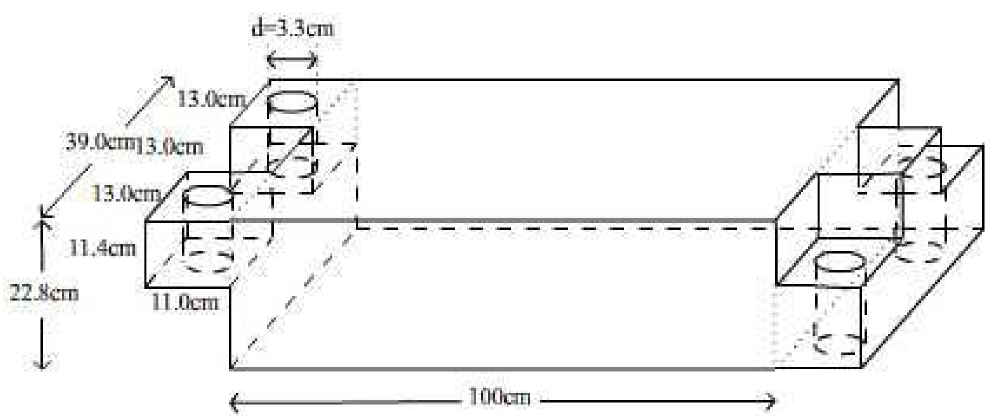


Fig. 2 - *The model of one solar platform*

Methodology:

Mechanical Strength Test

To model the situation of the waves exerting forces on the solar platforms, the group did a mechanical strength test that used two support frames to overhang the modules. Also, putting weight on the modules until it is broken is not practical because the group has only two modules available for study. Thus, the group tested the structural integrity of the platforms by measuring the indentation of the surface of the platforms when standard weights were gradually added on them. As such, it used the method of converting physical quantities that are difficult to measure to a physical quantity capable of measuring or quantifying, under the premise of ensuring the same effects of the experiment and more obvious comparisons.

PROCEDURE

The equipment used in the experiment is two thick aluminium bars, screws, a few expansion screws and two stable chairs. In this group's experiment, the structural integrity of the modules under the solar platforms is tested under three different types of conditions, which are:

1. Use aluminium bars only (***Fig. 3.1***);
2. Use Nylon screw bolts only (***Fig. 3.2***);
3. Combine the former two methods (***Fig. 3.3***).

The following diagram demonstrates how it works.

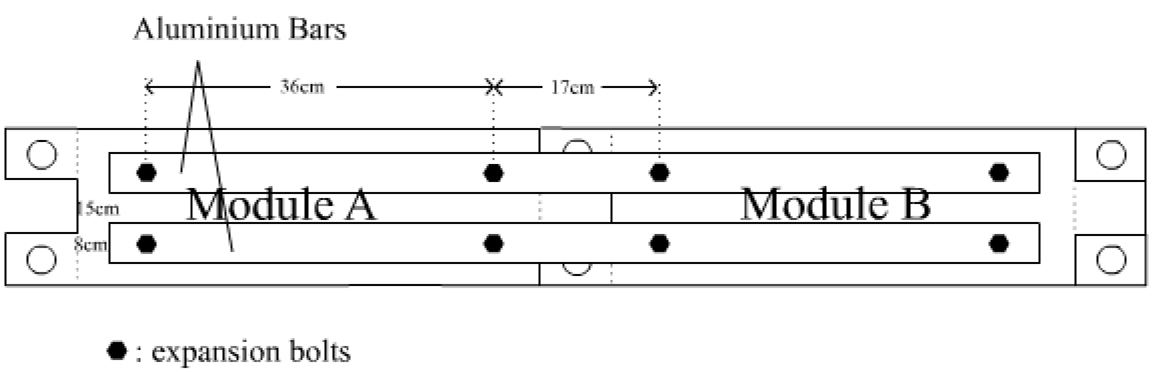


Fig. 3.1 *- Method 1*

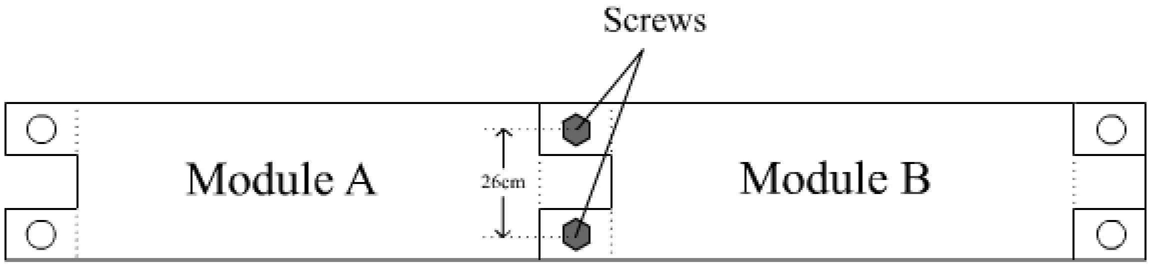


Fig. 3.2 *- Method 2*

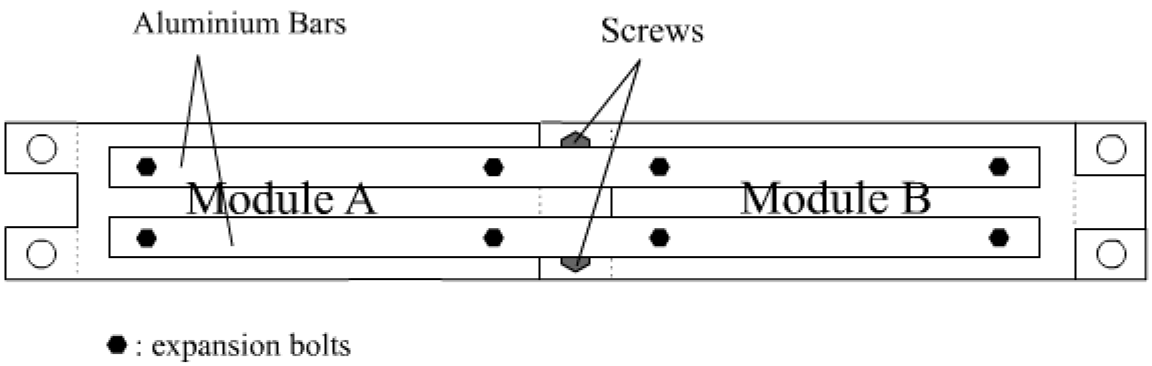


Fig. 3.3 *- Method 3*

For each experiment under different conditions, the steps involved are:

1. Place loads of increasing weights on the connection part of two solar platforms, which were placed on two chairs at a fixed distance of 195 centimetres. Standard weights of 5-kg were added piece by piece.
2. Record the degree of deformation by measuring the decrease in height (in cm) at the connection point of modules, both for the upper surface and the lower surface.
   - The lower surface: the laser range finder was placed right beneath the module and the distance was measured and any change was detected when any deformation happens.
   - The upper surface: the "reflection of light" series was used to more conveniently measure the height of the upper surface. Accurate data were taken by laying a ruler on top of the modules to reflect the laser to the laser receiver, so as to measure the deformation of the upper surface.
3. Compare the statistics and find the relationship between pressure applied and the extent of deformation.

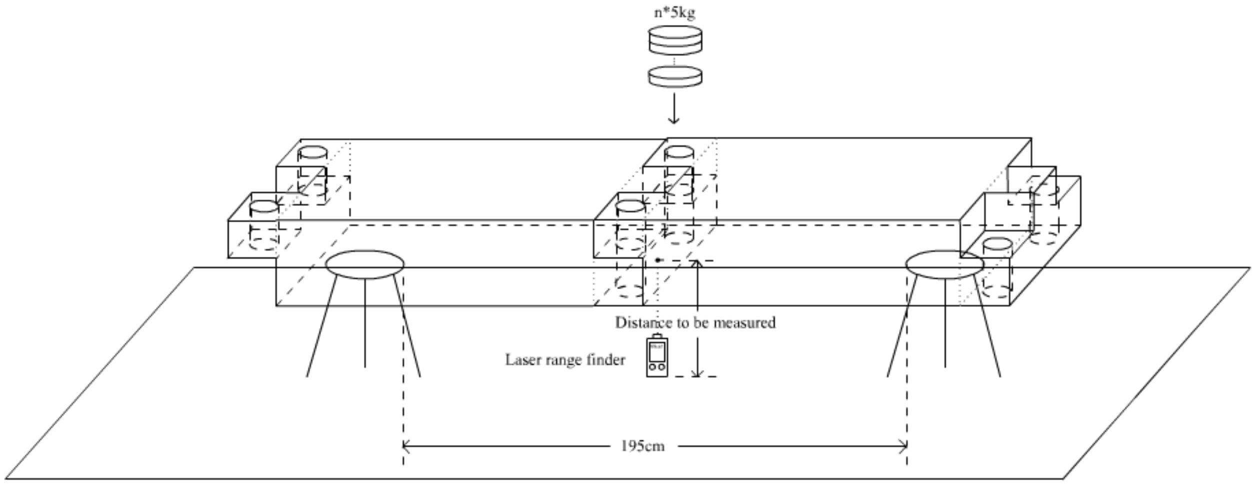


Fig. 4 *- Measurement installation*

RESULTS & DISCUSSION

Through repeated tests, sufficient data of the three different methods were obtained, which are illustrated as follows:

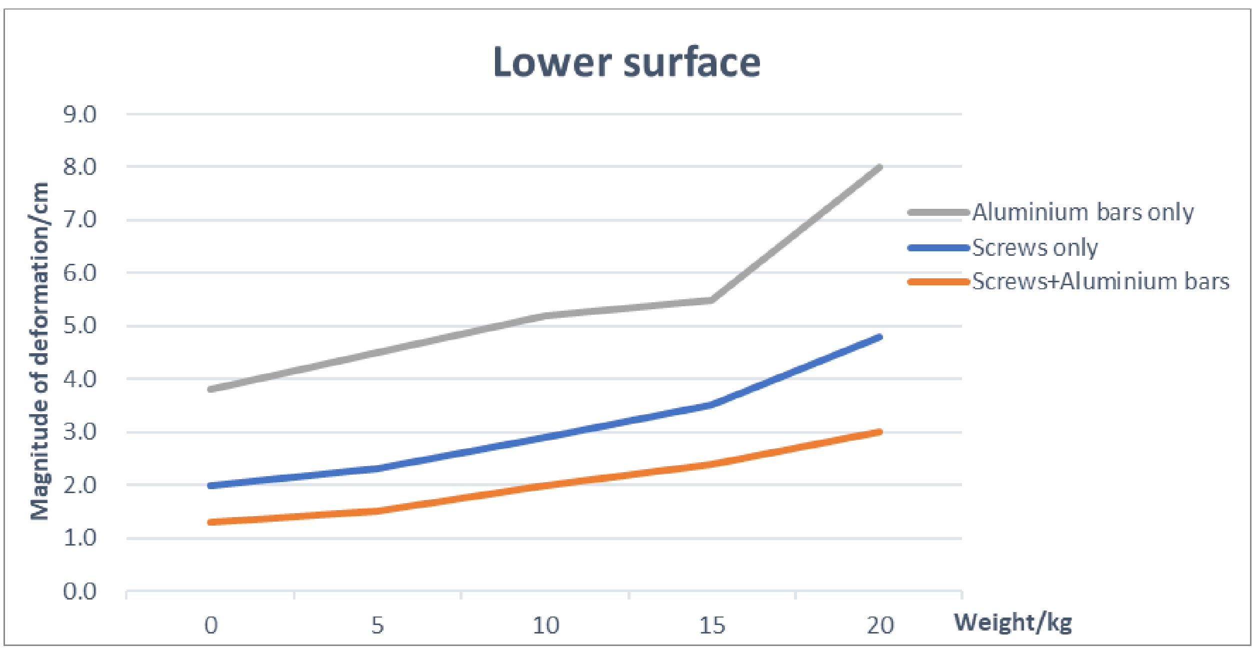


Fig. 5.1 *- Degree of lower surface's deformation against weight applied*

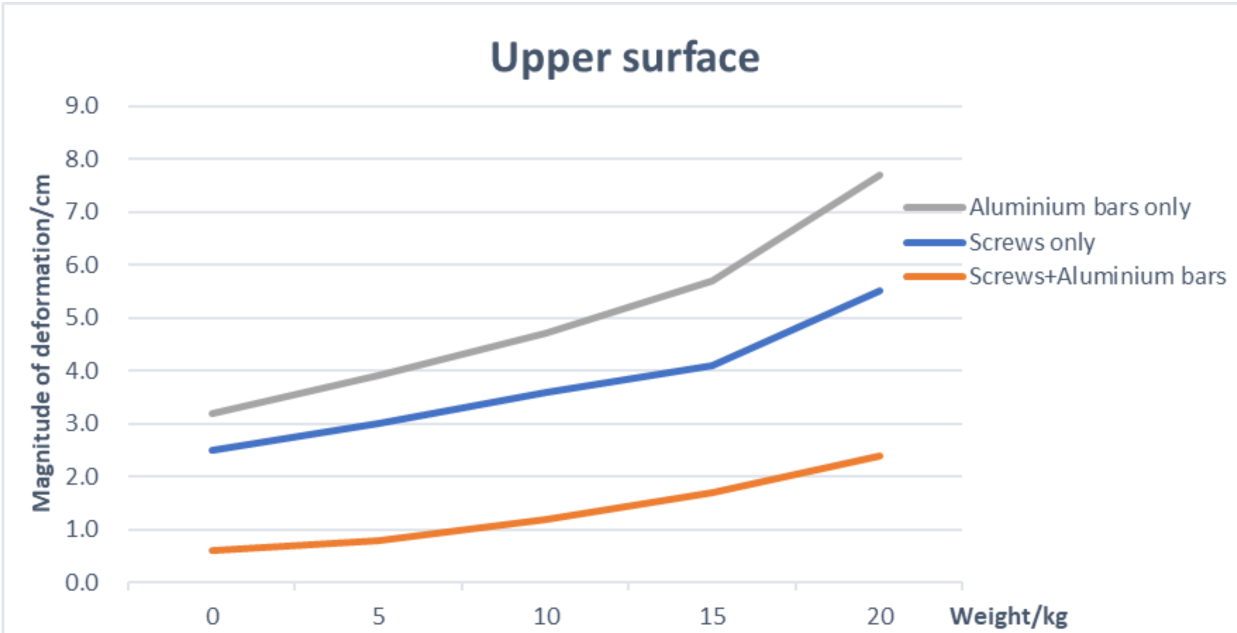


Fig. 5.2 *- Degree of upper surface's deformation against weight applied*

Figure 5.1 and Figure 5.2 record the magnitude of the dip in the middle part of the connection as the standard weights are added. Due to the weight of the modules themselves, the starting points are above the origin.

The three lines each graph, representing the three different methods, obviously show the rank of the usefulness of the three graphs:

- Method 1 (Aluminium bars only): This method ranks the lowest as the largest deformation was observed, as seen from its graphs which are on the top among the rest for both upper surface and lower surface cases.
- Method 2 (Screws only): Screws did better than aluminium bars, but their ability to reduce deformation is still not good enough.
- Method 3 (Combination): This method did the best in reducing the deformation of the connection part since the connection is strengthened by two tools simultaneously.

Hence, Method 3 is the optimum way to use rather than the other two.

For graphs representing Method 1 and 2, relatively sharp turn upwards at the point of 15 kg are observed. As such, it is concluded that if Method 1 or 2 is used, the modules' load capability is capped at 15 kg, while the connection may be permanently damaged if weights of more than 15 kg are added. However, if Method 3 is used, there is no risk of adding 20 kg or even more weights.

Although unlikely to be deployed in waters, it would be interesting to investigate the extent of dip when the aluminium support or the supporting screws were placed on the underside of the module, essentially testing the module upside down. The results are presented in Fig. 5.3.

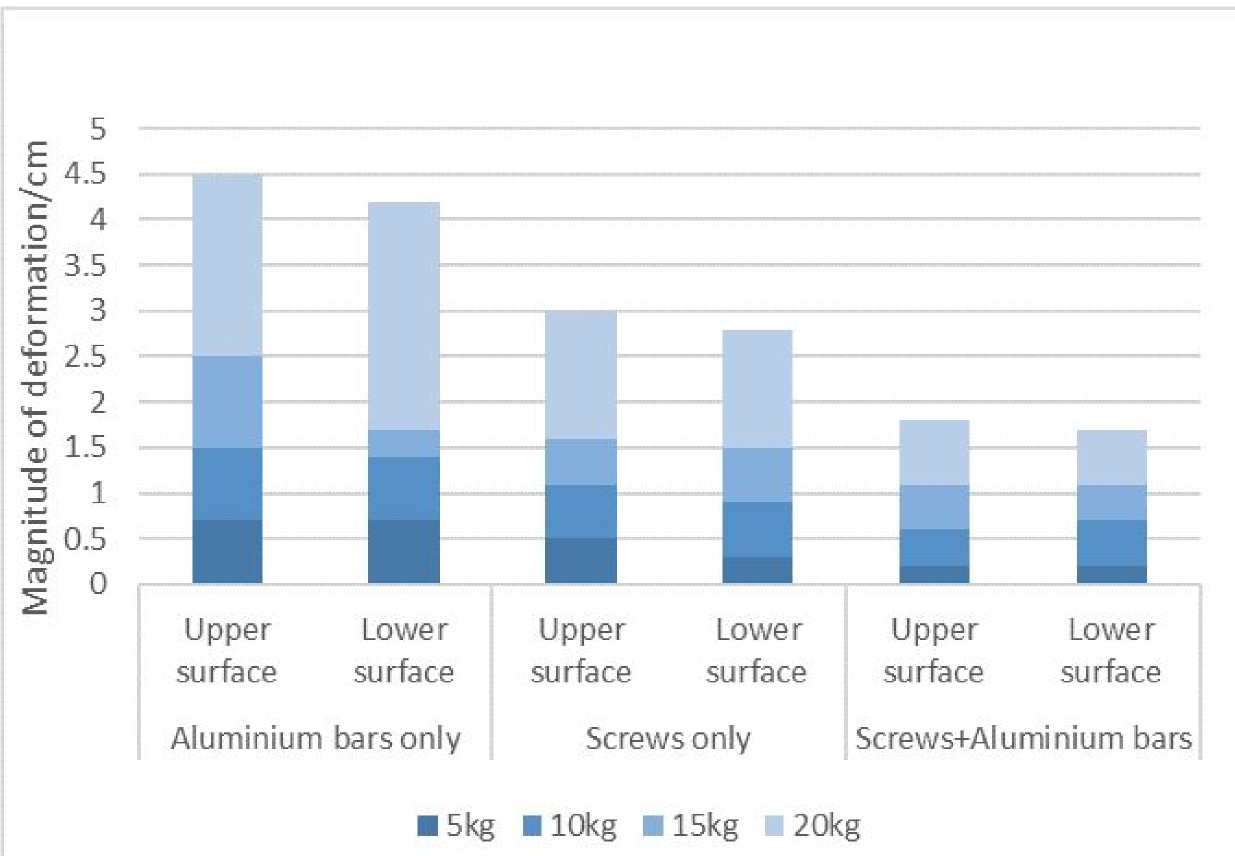
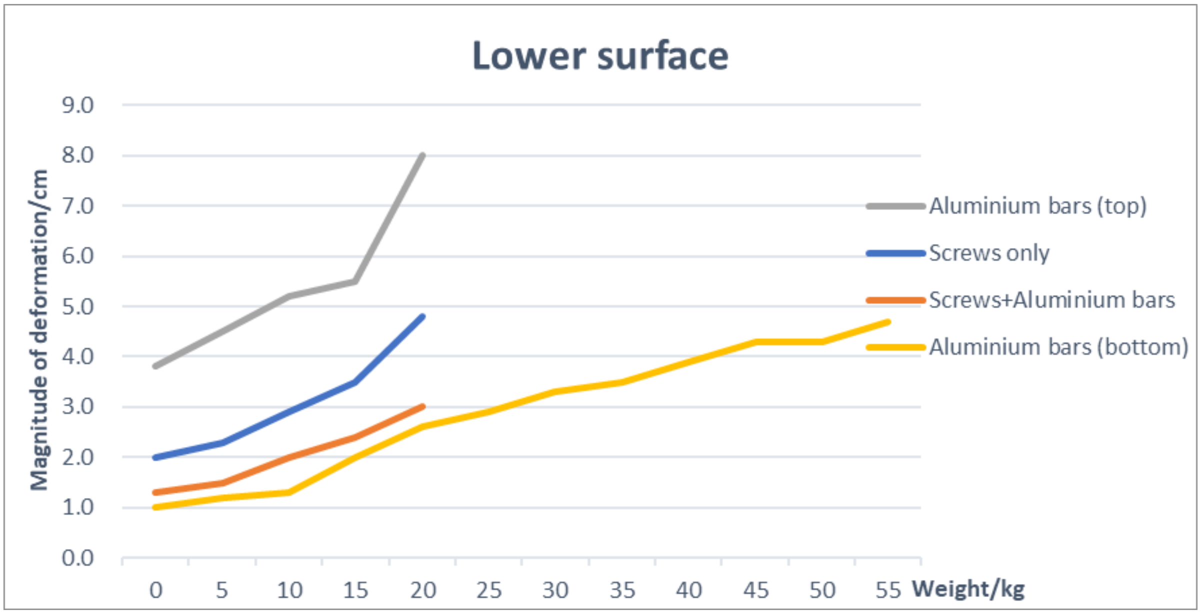


Fig. 5.3 *- Accumulated deformation with respect to three methods*

Fig. 5.3 shows that in general, the module tends to deform more when the supporting aluminium bars or the supporting screws were placed on the top side. This is because when the aluminium supports are on the topside, it is the sections near the expansion screws which are resisting the deformation. In contrast, when the aluminium bars were on the underside, almost every part of the bar is in contact with the deforming module which will be more effective in countering the stress which acts on the module. Unsurprisingly, the combination of supporting screws and aluminium bars will provide the greatest mechanical strength.

OPTIMISATION

In the original design, when the aluminium bars were deployed between the solar platforms on the top side of the module, the strength of the connection was much lower than expectations. The reason was that when weights were added on the aluminium bars, the solar platforms exerted a downward force on the expansion screws. A gap might appear at where the screws were not tightly installed, hence not all the forces were passed to the bars, causing the modules to deform more than the bars. In comparison, installing the aluminium bars at the bottom completely avoided the problem. The forces were directly transferred to the aluminium bars, which supported the modules from below. In addition, more expansion screws were installed to press the aluminium bar tightly against the surface, with gaskets between the screws and the surface to increase the friction between them so as to stabilise the expansion screws. Hence, we decided to include the results of Fig. 4.3 as part of a more comprehensive comparative study (Method 4).



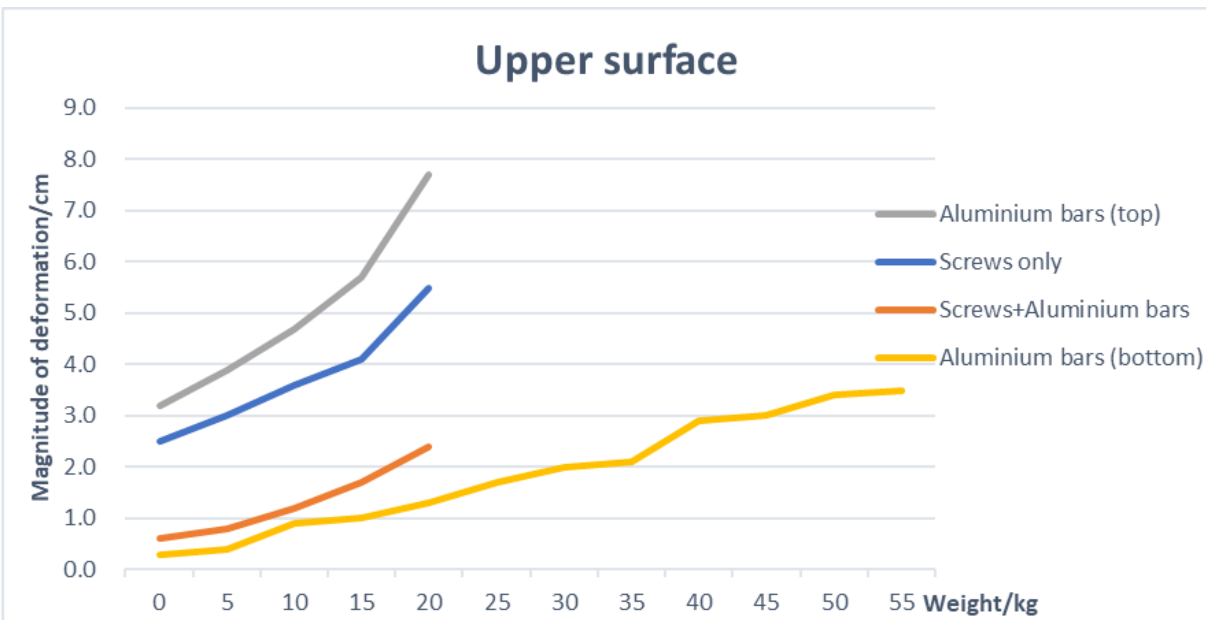


Fig. 6.1 & 6.2 - *Optimised solution (yellow line) compared to original 3 methods*

The data justifies the effectiveness of Method 4. Both surfaces experienced the smallest deformation ever, even when the weight had been increased to 55 kilograms. Hence Method 4 is the most feasible way in consideration of both cost and effect.

In effect, when the modules are deployed at sea, the waves apply upward forces instead of downward when tested, hence the aluminium bars will be installed on the top in future real-life application. This is easier for regular maintenance work to be carried out, as working underwater is difficult. Moreover, erosion is avoided as well.

CONCLUSION

The project had successfully tested the structural integrity of the original connections and designed practical mechanisms in making the platform more pressure-resistant. This is demonstrated by stark comparison in statistics collated during structural integrity testing between the previous connectors and the group's product.

The product has been improved in various aspects. The optimisation of the results was achieved by sourcing for the fittest materials for connecting mechanisms, which turned out to be a 5052 aluminium bar with a greater thickness of 8mm. Besides, expansion screws were also utilised to further tighten the connectors to the platforms and maximise its capability as shock absorbers. These allowed the device to be more cost-effective, conducting an almost doubled structural integrity performance.

Possible future work includes the application of the platforms in actual water conditions to further improve on its stability when encountering waves from various directions and other possible water circumstances. It is also in demand to develop a sealing system to prevent platforms from water seepage at the location where expansion screws are fixed so as to maximize its functionality as an aid mechanism. In addition, from an economic perspective, the group's product costs less than the original mechanism and easy to assemble and maintain regularly, thus making it an economically viable option for massive production.

ACKNOWLEDGEMENT

We would like to acknowledge and extend our deepest gratitude to the following individuals, without whose help the project would never have been a success.

Our external mentor, Professor Vincent Lim from HDB Building & Research Institute, Doctor Zhang and the NUS Engineering Department for providing us with the necessary expertise and sufficient references as well as patiently teaching us during the whole process. Their precious help is indispensable to the success of the project. We truly appreciate NUS for their many teachings, and for investing all the time and effort in helping us.

Our school mentor, Mr Sim, for providing us with guidance along this whole journey. Be it in checking our work, answering any queries we may have or contacting staff in HCI to arrange for our experiments, Mr Sim has been very supportive and was always there to help us when we were in need.

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