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Development of a Green Floating Breakwater with Re-use of PET Bottles

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Abstract

It is common sense that the ongoing climate changes represent a big challenge to humanity to protect housing, industries, nature and lives. This causes changes in strategies and in the conception of development and growth. Thinking is changing; the planet has to be preserved and protected not only its resources explored. All industries are engaged in this cause and so is construction. This article presents and alternative specifically for sustainable construction in coastal protection. Coastal engineering is constantly developing new projects in turn of shore protection and also to contribute positively to the environment. Despite climate changes, the development of industries and modern lifestyle generate tons of waste every year and, as result, it has to be disposed and treated. One way of reducing the amount of waste that goes into the environment is to reuse disposed items. Another way of reusing plastic bottles, a significant part of Brazil's domestic waste, is presented and in a different application as commonly found: in coastal engineering. The breakwater that is being developed, consumes millions of bottles depending on the extension of the shore protection arrangement. The construction of the green breakwater is environmentally friendly due to the inert materials that will are used. This concept is under development and research but the physical model was built and tested. It consumed 1260 bottles for its construction and pointed to important issues and questions that have to be addressed during the ongoing project.

Keywords: breakwater, environmentally friendly, coast protection, re-use, plastic bottle

1. Introduction

1.1 Environment Considerations

Climate changes naturally occur since the existence of Planet Earth. Despite of many geological eras that the planet has experimented in the last four billion years, the scientific community agrees that inadvertent anthropogenic disturbances are severely interfering in the global climate. It will continue changing, but the concern is the impact of the changes that are becoming more severe. Pollution has caused ecological degradation (Noce, 2011) and Humanity has always feared natural catastrophic events (Singh et al., 2010), which may be caused by floods, winds, storms and sea level increase. Furthermore, approximately 2.5 billion people live within 200 kilometers of a coastline (Folasade, 2010), which aggravates the concern about impacts in coastal regions.

In order to prevent destructive impact of natural disasters, many studies are being developed worldwide in order to understand local parameters and improve shore protection with structure design that is the most applicable. Not only has there been the effort of review existing concepts, but new ones are being developed. Innovative concepts undergo a long process until they are able to be installed, which represents an important aspect of raising questions that have not been made before.

1.2 Breakwater

One way to protect the coastal areas is to reduce the action of waves on the shore line. Breakwaters are structures that act on the dynamic of the water movement as obstacles and absorb or reflect part of the water wave energy, reducing the wave's height after the breakwater. Based on the Shore Protection Manual (USACE, 1984) there are various types of breakwater and they can be classified as shore-connected or offshore breakwater. And the offshore breakwater can be fixed or floating. The structure that is being proposed is an offshore floating breakwater.

Sustainable construction is important when building new infrastructure and also when installing remedy action to existing problems. A green floating breakwater was designed with that approach by choosing alternative materials for its construction when compared to the ordinary. The most usual breakwater is the rubble-mound type (USACE, 1984) using rocks or concrete blocks for its construction and the employ of either material is aggressive to the environment. Rocks are extracted changing the topography and landscape and the fabrication process of concrete is not positive for the environment. A sustainable solution for shore protection together with domestic waste reduction is presented here.

1.3 Waste Reduction

The worry about how to reduce and how to treat the waste is growing due to the fact that waste volume that is produced is increasing along the years. Out of the options of what to do and how to treat industrial and domestic waste, the re-use of disposed items is the best option to reduce waste.

Waste is composed of all possible material, but plastic is a big part of total amount. In the U.S. 12% of the solid waste is plastics, or 30 million tons in 2010 (U.S. Environmental Protection Agency, 2012). The New York Times (2011) states that the annual global production of plastic is 300 million tons and that estimated 7 million tons end up in seas. A considerable part of the Brazilian plastic waste is PET bottles (ABIPET, 2012). Polyethylene terephthalate (PET or PETE) is a material that offers high mechanical and chemical resistance (Guelbert, 2007) which justifies the choice of such elements as floating devices for the breakwater.

2. Literature Review

Breakwater are well known and largely chosen when deciding about coastal protection. Floating breakwater exist since 1811 (BRADLEY, 1998) since that the slope type was more explored and developed. The typical rubble-mound type is the most common design (ALFREDINI, 2009). Floating breakwater have smaller application ranges, for shorter wave periods they have demonstrated efficient wave dissipation (US Corps of Engineers, 1984).

Farmer (1999) highlights that there was a lack of publications after the 80's when there was a considerable production on floating tire breakwater articles. As published in the Proceeding of the floating tire breakwater workshop held in Niagara Falls, NY, USA in 1984, Harms figured as an important researcher on this subject. Leading a research for Goodyear about the use of scraped tires in a wave-maze breakwater in 1978 he then built and tested a floating breakwater of scrapped tires in the USA (Harms, 1982). His paper explains the success in wave reduction and also discusses the cost of such structure being much less than conventional, rubble-mound, breakwater. Harms (1982) was able to install such a breakwater prototype in Mamaroneck, NY, USA but no further articles were found regarding the conclusions of the installation and performance of the prototype.

Analyzing the Brazilian context regarding urban waste and its composition, it was found that the equivalent material that causes trouble in similar magnitude is plastic bottles. Those are and will be available in large quantity for a long period of time and being a tropical country with tropical viruses to store tires would be a hazard to health of the involved due to pounded water and the consequent dengue fever risk. No literature was found on any similar concept. This paper brings up an innovative concept of breakwater.

3. Method

3.1 Research

The project began with the analysis of the moduled floating breakwater that Harms (1982) proposed. The structure is a pipe-tire modules (PT modules) assemble. It consists of a combination of scrapped car tires that assure buoyancy and concrete poles that assure stiffness. The tires are tied together with rubber bands and the concrete pole that is fitted through the longitudinal row of tires is fixed with a retainer at the ends, as shown in Figure 1. Harms (1982) observed that sediments can be deposited in the inside of the tires and that it can cause decrease in buoyancy, which is needed to tension the mooring lines and maintain the breakwater in its correct position. Thy buoyancy is also the origin of the resisting force that reacts to the movement caused by incoming waves. In order to avoid the sediment deposit the tires are partly filled with polyurethane foam. During the tests in a wave tank the result was a 40% wave height reduction for incoming waves up to 0.9 meters for the car tire model.

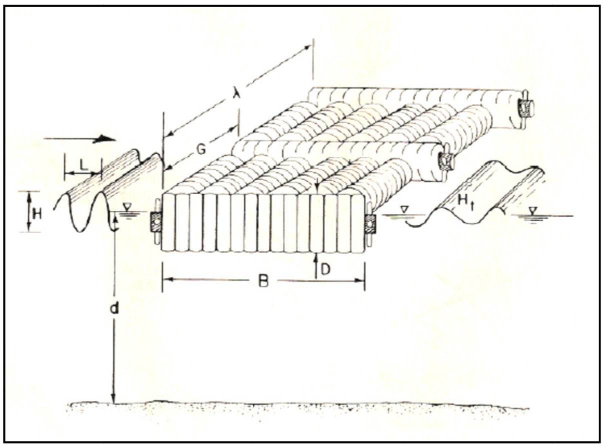

Figure 1. Harms' moduled floating breakwater (Note 1)

Source: Harms, 1982.

As a next step, floating element was searched that suited the conditions that Harms (1982) had highlighted, with high buoyancy, resistant and easy acquisition. It also was interesting to eliminate the foam, being cost and work increasing. The used plastic bottle is a largely available material, which buoyancy is very high and when the bottle is lidded, the air is trapped and sediment deposits will not interfere in the floating devices. Plastic bottles, especially PETE bottles, are very resistant and also easy to purchase.

3.2 Design Phase

A small case physical model was designed according to the dimensions of the available wave flume at the Hydraulics Research Centre at the University of São Paulo (FCTH) and inspired by Harms' (1982) successful experience with the tire floating breakwater. The available installation for future testing was a 50m long, 1m wide and 1.40 m high wave channel. The wave generator is a horizontally moving plate that has a controller attached to the rod. A program developed by Gireli (2008) translates the input generating the waves according to the testing program. Capacitive sensors measure the height of the incident and resultant wave in the channel shortly before and after the breakwater, respectively, while the control program organizes and records the data.

For dimensioning the wave flume dimensions and the average measurements of the plastic bottles used for this small case model are the starting point. The bottles that were used have approximately 500 ml volume, 0.06 m diameter and 0.2 m high. The width was calculated by finding a multiple of the bottle diameter that fits in the channel with clearance on the sides in order to avoid rubbing on the walls.

The height of the model was determined to be 0.24 m which are 4 rows of bottles. This configuration results in a more than 3 rows of empty spaces and a reasonable height regarding the water depth of 1.00 m in the channel.

The length of the breakwater is the relevant dimension to be considered when predicting wave height reduction. The structure must be longer than a wave length in order to reduce the wave height significantly. The longest wave to be tested in the flume is a wave, which period is 1.7 s. By means of the linear wave theory that results in a length of 4.50 m. Figure 2 shows the model floating in the wave flume.

Figure 2. Small case physical model (front – top view)

3.3 Construction

The small case physical model was built with 1260 plastic bottles of approximately 500 ml each. For assembling the bottles in the steel cage simple materials were used: duct tape, construction steel, recycled PETE ropes, manual winches and a metal mooring support system. The bottles were firmly closed and tied together in groups. Stirrups were positioned on the blocks and six long ribbed steel bars were used in the four corners and two stiffen the upper side of the model.

The eight mooring lines were fixed on the ends and in the middle of each side of the model a manual winches were used to tension the ropes ones the module was floating in the correct position. Because of the length of the channel, the metal mooring support was fixed to the wall of the channel in order to guide the ropes down from the breakwater and decrease the angle of the mooring lines to the manual winches, for less resultant force on the ropes (Figures 3 and 4).

Figure 5 shows details of the metal support that was designed, built and installed in order to reduce the resultant force from the buoyancy on the mooring lines, when the breakwater was not submerged.

Figure 3. Plan view of the anchorage points

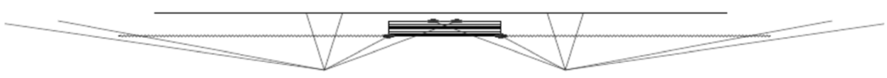

Figure 4. Side view of the anchorage points

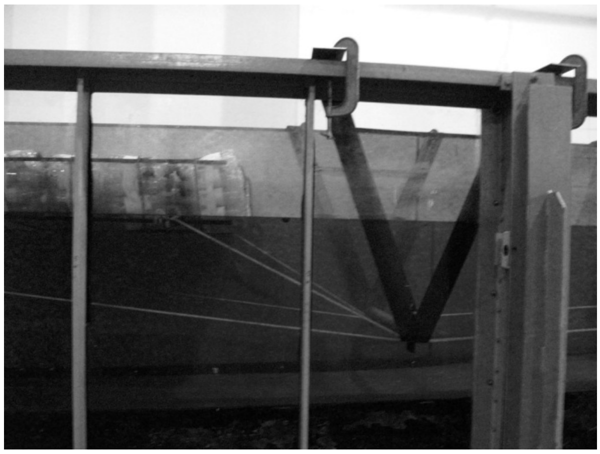

Figure 5. Detail of mooring lines and metal support

4. Results and Discussion

After having established the questions about the size of the bottles and the length of the design wave, calculations for the small case physical model were uncomplicated to conclude. Floating breakwaters are known costal protection structures and the calculations are simple. The challenging part is to find a scale that is applicable in this wave flume and also compatible with the available plastic bottles.

There is an unknown scale factor in this modeling, because the module is scaled 1:25, but the bottles are not. They are scaled 1:4 in volume and about irregularly scaled in dimensions. The construction of the model and future wave testing will produce data and information, but certainly many answers will lead to new and more questions.

During constructions many inconvenient facts occurred, as usual in physical modeling. The absolute first one was collecting the bottles. Since one of the design boundaries was the size of the bottles and they should be uniform and contain volume of about 500 ml it took the team longer than expected to gather the needed amount. 1260 bottles and caps, apart from some spares, were collected prior to commencing of the construction itself.

The green floating breakwater made of scraped plastic bottles is designed to have the bottles as the only floating device, if used plastic bottles are not available, this idea is not applicable. Similar floating breakwater are being developed with different floating elements, but the proposal of this concept is to combine waste reduction with coastal protection.

Clustering the bottles into blocks of 60 bottles (4 rows of 15 bottles) was not a challenge, but the difficulty showed when the model was assembled and it was picked up to be moved. Rigidity was to low. Due to logistic issues the long steel bares had to be cut into 1.50 m segments for transportation and that where the identified week points. Wire reinforcements were attached to the end at the overlapping length of the bars and the steel cage was strengthened.

The anchor points were defined according to estimated bend of the model due to buoyancy force. The calculated resultant buoyancy force that the entire model produced is approximately 520 kgf. This means that each one of the 8 mooring lines should be stressed with less than 100 kgf. During the first attempts of submerging the model the anchor lines became to stiff and thin that the operation was aborted and new calculations with *in situ* measurements of the angle of the lines were made. These resulted in an unexpected big angle that consequently increased the resultant force on the anchor lines. The support structures as mentioned and shown in Figure 5 was developed and installed in order to guide the lines and decrease the angle. This was indispensable to the configuration of the experiment and showed that the anchor system is a critical point of the concept.

During the submergence test the structure was submerged by operating the manual winches, which tensioned the mooring lines. As expected, deformation increased as the model was submerged more. Curves were observed in the longitudinal direction and also in the transversal direction, which shows that this configuration of the steel cage is not appropriate for the prototype. Despite the deformation being worse than expected the model was able to be validated as such for the future wave tests, specially when found that Harms (1982) also used overweight to stabilize his conception while anchoring. This model also received overweight and rigidity increased significantly. This observation was a very good hint in the direction of what has to be resized and considered for the prototype.

The initial wave test was performed and noteworthy wave height reduction was noticed without measuring equipment. An incoming wave calibrated to 0.08 m produced the picture as shown in Figure 6, where hardly any wave can be recognized leeward.

Figure 6a. incoming wave

Figure 6b. remaining wave

The movement of the breakwater when submitted to wave action is above the desired. The current model is approved and validated for modeling proposes and initial tests. The future of this project will be to build more other small case models, with different cage configurations and improved rigidity as well as tests with bigger bottles or even a mixed bottle size configuration. From the observations that were made so far, the use of gabions is under evaluation.

Material usage and costs were low for the construction and testing of the small case model. Wave reduction was above expected, once 98% of reduction means a practically inexistent resultant wave. This breakwater concept and design is an efficient and environmentally friendly way to protect coastal regions from undesired wave occurrence.

Research is ongoing in order to construct a prototype and also to verify the cost of this breakwater that is expected to be low when compared to rubble-mound breakwater. The mooring and anchorage system is also an outstanding discussion, which will be covered by further steps of the project, as well as more small case physical models and material testing.

5. Conclusion

At this early state of the project its possible to realize how much has to be done in this research area. There was interest in similar research and conceptions in the 80's but that period is followed by a lack of publications and research. Sustainable concepts for coastal protection are of big importance and the métier must be expanded. Re-using disposed items reduces the volume of waste on the planet, which means that at least two things are being done for the environment a green structure is being developed and a new proposal for re-use of plastic bottles has been made.

The model showed that alternative construction materials for the cage have to be identified, which must be commercially available, easy and of inexpensive acquisition and inert in water. The development of such a breakwater represents one more step towards sustainable construction.

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Notes

Note 1. In Figure 1: H is incoming wave height; L incoming wave length, d water depth, G center-to-center distance between pipes, λ length of breakwater, B width of breakwater (parallel to wave direction), D tire diameter and H_t transmitted wave height.