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Interlocking Liquid Containers as Makeshift Shelter for Disaster-affected Communities and Non-load Bearing Walls for Buildings

Arch. Clarissa M. Balante, EnP
University of La Salette, Dubinan East Santiago City, Philippines
architectenpcla@gmail.com

Engr. Charles A. Lejano
University of La Salette, Dubinan East Santiago City, Philippines

Engr. Charmaine Majel A. Panaligan
University of La Salette, Dubinan East Santiago City, Philippines

Abstract

During natural calamities, evacuation centers provide temporary shelters for affected communities. While these facilities provide a haven for the victims, they also engender a host of problems such as lack of privacy, discomfort, the spread of diseases, exposure of women and lactating mothers, and absence of boundaries, among others. These problems can be solved by developing a new geometric design for liquid containers, specifically PET bottles, characterized by an interlocking feature. This feature allows PET bottles to be assembled as makeshift shelters for the victims since each bottle is designed to be a component of modular panels that can function as temporary walls for emergency shelters. The design of the bottle is standard for half a liter, 1.0 liter, and 1.5-liter plastic containers. This design is beneficial to government agencies tasked to respond to natural calamities by improving the physical and social conditions of the victims in evacuation centers. It also reduces the accumulation of non-biodegradable wastes and introduces readily-available but innovative materials to achieve sustainable infrastructure.

Keywords: Interlocking, makeshift, modular, emergency shelter, building material

1. Introduction

1.1 Background of the Problem

The Philippines is an archipelagic country with 7,641 islands. Flanked by the Pacific Ocean and the West Philippine Sea, it is visited by an average of 20 tropical cyclones every year, of which at least 10 are categorized as typhoons, with five having the potential to be destructive (ADRC, n.d.). It is a continuing challenge for urban planners and technical professionals to mitigate and adapt to the effects of these destructive weather disturbances.

Due to the geographic location and condition of the Philippines, natural calamities are inevitably frequent visitors. Typhoon Yolanda is one of the deadliest natural disasters that hit the Philippines. Since the country is located along the typhoon belt, it is vulnerable to typhoons and storm surges. It is also located along the Pacific Ring of Fire, between two tectonic plates (Eurasia and Pacific) which generate earthquake and volcanic activities.

Building capacity and preparedness is the only way to equip Filipinos with the wherewithal to withstand these adversities and be resilient and adaptive. But while Filipinos are not new to natural and man-made calamities, from a typhoon to insurgencies, a systematic approach to managing evacuees and evacuation centers has yet to be attained. It is common to see victims suffer much more when they are not given proper assistance and a decent place to stay.

Evacuation centers are supposed to be the victims' safe refuge but sometimes these turn out to be more dangerous than the actual calamity, most especially to children, women, and the elderly who are the most vulnerable members of society. Most evacuation centers in the Philippines have converted classrooms, gymnasiums, covered courts, open courts, and local government halls, which are usually not equipped to accommodate a large number of victims. These evacuation centers have no designated managers and are usually overcrowded, causing potential risks to the victims. These vulnerable groups, particularly unaccompanied minors, are usually affected by incidents of gender-based violence. This condition also aggravates the rapid spread of diseases among the evacuees, which results in illnesses and sometimes even death.

Given all the potential risks in evacuation centers in the Philippines, the need to provide an individually enclosed space for each family in every evacuation center becomes crucial. These individual private spaces will prevent evacuees from exposing themselves, especially women and lactating mothers. This will also minimize the rapid spreading of diseases, viruses, and bacteria that may develop inside evacuation centers.

One of the most immediate needs of victims and evacuees is potable water. While donations of bottled water help the victims, the plastic containers eventually add to accumulated solid waste that may end up in landfills, or worse, thrown indiscriminately and without regard to potential harm to the environment. Plastic packaging materials in the Philippines account for an average of 38% of the country's total accumulated solid waste based on the National Solid Waste Management Report on Composition of Solid Waste in the Philippines 2008-2014.

Because of this reoccurring problem, the need to address the issue of providing a private space for evacuees and at the same time reducing the accumulated waste of liquid containers is very significant.

1.2 Objectives of the Study

The purposes of the study are 1.) To develop and design an interlocking liquid container as part of a modular panel that can be used as a temporary shelter during natural calamities and man-made disasters, 2.) To use this design as non-load bearing walls for building, and 3.) To improve plastic recycling and solid waste management.

1.3 Hypothesis

The new geometric design of the liquid containers features an interlocking component allowing these to be assembled as temporary shelters and non-load bearing walls for buildings. This can be an alternative material for lightweight walls.

The proposed design of interlocking liquid containers can address issues on plastic waste management and improve evacuation centers in the Philippines.

1.4 Significance of the Study

The study aims to address the issue of plastic waste management, particularly single-use bottled water, and at the same time provide temporary emergency shelter to evacuees during calamities. This will help the authorities in building a more favorable and gender-sensitive evacuation center. It will also help improve the physical, social, and health conditions of the victims, and hopefully support them to recover faster.

2. Review of Related Literature

2.1 Introduction

Plastic has become a ubiquitous part of our daily lives. Lightweight and versatile, it can be easily molded, is corrosion resistive, and is one of the most recyclable and reusable materials. However, it can be a threat to the environment if the volume of used plastic is not properly managed.

One of the most common uses of plastic is as a liquid container, specifically as a single-use water container made of Polyethelene Terephthalate (PET). PET bottles account for the highest consumption of plastic water containers globally.

Evacuation centers in the Philippines and other parts of the world face the common problem of overcrowding. One of the countries where they are able to manage their evacuation centers systematically is Japan. Private cubicles made of cardboard or tents were provided to give private space for each family that minimizes problems that may arise due to exposure of the victims.

2.2 Previous Studies and Projects Related to the Use of Recycled Plastic Bottles as Building Components

2.2.1 Philippine Plastic Bottle Classroom

In a project by Illac Diaz of My Shelter Foundation, the plastic bottle classroom used bottles filled with a mixture of cement and sand. The bottles became part of the masonry wall, thus making the wall stronger and more stable. The project was structurally sound but it resulted in thicker walls of up to 30 centimeters in width since the one-and-a-half-liter plastic bottles were laid horizontally. The use of plastic bottles also did not lessen the construction cost since almost the same amount of concrete was used because the bottles were also filled with concrete.

Figure 1 Inhabitat, Asia's First School Made of Plastic Bottle is 3X Stronger than Concrete, by Yuka Yuneda

Figure 2. Inhabitat, Asia's First School Made of Plastic Bottle is 3 times Stronger than Concrete, by Yuka Yuneda

2.2.2 EcoArk, Taiwan

EcoArk is the world's first PET bottle building, made from one hundred percent recycled plastic, designed and engineered to withstand the forces of nature and even fire. It is a revolutionary building that symbolizes environmental concern and the protection of our future.

EcoArk Taiwan is an innovative design created intentionally to raise awareness of problems caused by unmanaged plastic bottles. Each container used for the building was made of recycled PET bottles, melted and molded specifically for the construction of this monumental structure and not for commercial use.

Figure 3. Inhabitat, EcoARK Pavillion made from 1.5 million Plastic Bottles, by Jill Fehrenbacher, 04/14/2010

Figure 4. Inhabitat, EcoARK Pavillion made from 1.5 million Plastic Bottles, by Jill Fehrenbacher, 04/14/2010

2.2.3 Waste Plastic Bottles Offering Innovative Building Materials with sustainable Application, *Dr. P. Patel et.al. (2016) International Journal of Innovative and Emerging Research in Engineering*

The study presented the use of plastic bottles as building materials. The bottles are filled with soil or sand and form a framework of walls or pillars in which plaster made of clay or cement mixture fills the space between all bottles. It also discussed the energy efficiency of using plastic bottles and how time and cost are saved by using this kind of material.

2.2.4 An Overview of the Design of Disaster Relief Shelters, *A. Basharwi et.al. presented in the 4th International Conference on Building Resilience, UK (2014, September)*

The research presented in the paper focused on Disaster Relief (DR) shelters. These shelters are commonly made up of plastic sheets, tents, and pre-fabricated units, and come with the immediate needs of victims such as blankets, sleeping mats, stoves, and easy access to potable water.

The paper discussed the importance of providing emergency shelter to evacuees -- a private and secure space for people who have lost their usual accommodation as a result of a disaster. Disaster relief shelters help victims recover from the trauma as well as provide them a base to start the process of rehabilitation. While the paper stated the importance of emergency shelter, it did not specify what kind of shelter is best used and its materials.

2.3 Key Findings from Previous Studies and Projects

Most of the plastic bottles available are stand-alone, therefore most of the PET bottles used as walls are laid horizontally and are filled with either sand or soil and banded together by cement or clay to create a masonry wall significantly thicker than conventional walls.

No study has been conducted yet on the possibility of redesigning the geometric configuration of the commercial plastic bottle so that these can be used as interlocking walls assembled vertically to form a cubicle that does not occupy too much space. The cubicle will serve as a temporary emergency shelter for evacuees.

3. Method and Materials

3.1 Design

The design of the project is an experimental program that explores the possibility of redesigning the geometric configuration of commercial liquid containers and incorporating an interlocking feature to create a panel or a module that can be used as walls for an easy-to-assemble four-cornered cubicle. During calamities, the cubicles will serve as private spaces for evacuees in evacuation centers.

3.2 Research Sites and Equipment

The test conducted to compare the compressive strength of commercially available PET bottles was at the testing laboratory of the University of La Salette in Santiago City, Isabela using a Universal Testing Machine (UTM).

A similar test was conducted in another testing laboratory to compare the results to validate each test.

3.3 Materials

The most common water container in the market is made of polyethylene terephthalate or more popularly known as PET. PET is a clear, strong, and lightweight plastic that is widely used for packaging food and beverages. PET is approved as safe for contact with food and beverages by Food and Drug Agencies (FDA) and health-safety agencies throughout the world (PETRA, 2015). PET is also an energy-efficient packaging material given its high strength in comparison to its lightweight. It is completely recyclable and is the most recycled plastic in the world.

Commercially available water container bottles will be tested to assess the capacity of the material to carry the load, including its weight by subjecting the material to a compression test (Figures 5, 6, and 7). There are three samples to be tested: the compression capacity of the regular empty PET bottle, the PET bottle filled with water, and another filled with fine aggregates or sand. The sizes of PET bottles tested were 1.5 liters, 1 liter, and 0.5 liter. The same materials will be used for the proposed design of the interlocking liquid container as what is used by commercially available bottled water.

4. Data Gathering Procedure

Compression tests were conducted on several commercially available PET bottles.

4.1 Preparation of Material for Testing

PET bottles were prepared for the test. There were three tests conducted on each 1.5-liter PET bottle: 1) an empty bottle, 2) a bottle filled with water, and 3) a bottle filled with sand.

4.2 Computation

Theoretical computation will be used to compute and analyze from the graphical drawings the distribution of pressure for the proposed design of the PET bottle and compare it to commercially available concrete hollow blocks.

5. Results and Analysis

5.1 Material Testing of PET Bottles

Material testing was done using a regular 1.5 liter PET bottle of water, with a diameter of 75 mm and a height of 233 mm, with approximately 1 mm thickness. Commercially available PET bottles were tested because the same material will be used in the proposed PET bottle design.

Figure 5 shows that the maximum compressive strength of an empty PET bottle is 2.15 megapascal (MPa) when subjected to a Compression test Using the Universal Testing Machine (UTM) at a rate of 0.607 mm/sec.

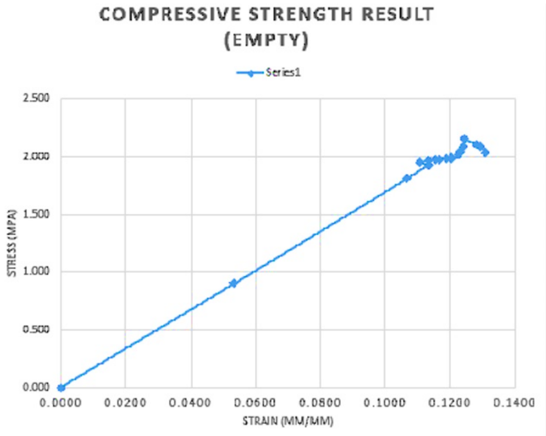

Figure 5. Stress-Strain of an empty bottle

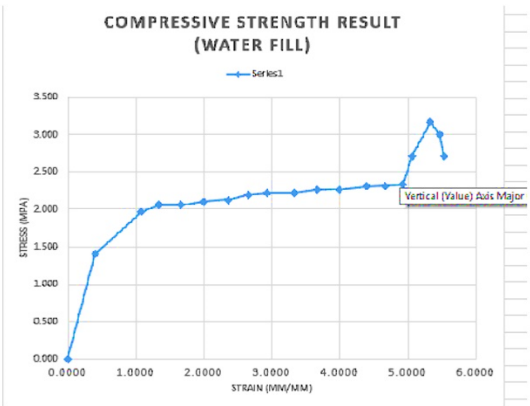

Figure 6. Stress-Strain of a PET bottle filled with water

The test found that the maximum compressive strength of a PET bottle filled with water is 3.169 MPa when subjected to a Compression test Using the Universal Testing Machine (UTM) at a rate of 0.562 mm/sec (Figure 6).

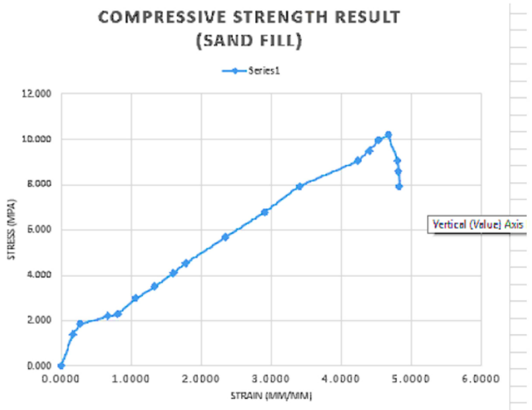

Figure 7. Stress-Strain Results of a PET bottle filled with sand

The test found that the maximum compressive strength of a PET bottle filled with sand is 10.186 MPa when subjected to a Compression test using the Universal Testing Machine (UTM) at a rate of 0.599 mm/sec (Figure 7).

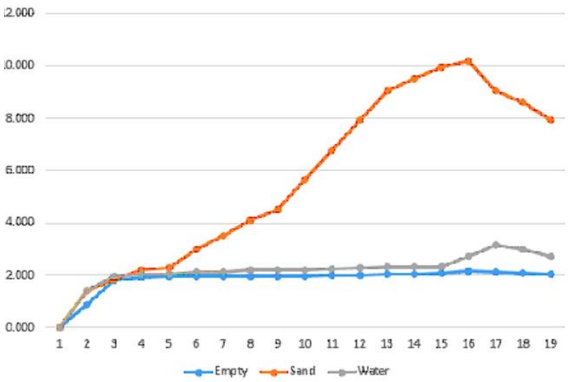

Figure 8. Comparative Results of the Compressive Strengths of PET bottles: 1) filled with sand, 2) filled with water, and 3) empty bottle

Non-load-bearing concrete hollow block (CHB) has a compressive strength of 3.4 MPa. Comparing all three tests, the PET bottle filled with sand has a higher compressive strength than CHB, while the other two (the empty bottle and the bottle filled with water) have lower compressive strength than commercially available CHB (Figure 8 and Table 1).

Table 1. Compressive Strength of CHB and PET Bottle

Material	Compressive Strength in MPa
CHB	3.400
Empty PET Bottle	2.150
PET Bottle with Water	3.169
PET Bottle with Sand	10.186

5.2 Design of Liquid Container

The proposed design of a liquid container shall be for half-liter and 1-liter containers, but this can be modified or re-scaled to another capacity unit such as a 1.5-liter container.

Polyethylene terephthalate or PET shall be used for this design since PET has already been proven to be safe. It is also lightweight and therefore will be easier to handle.

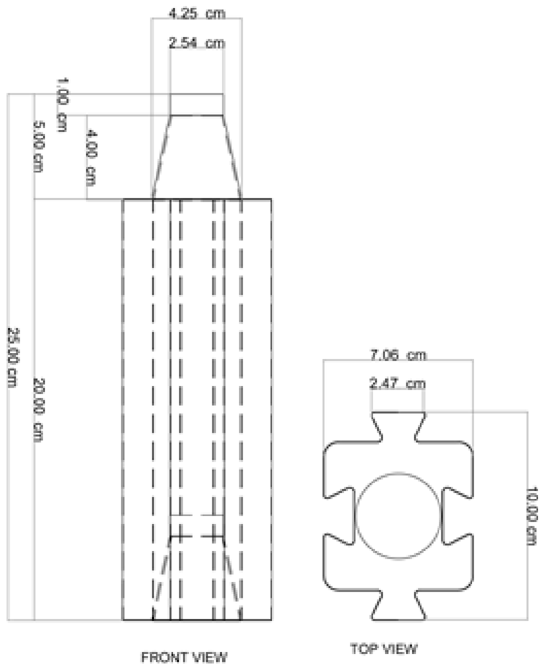

Figure 9. Details of the design of the liquid container (PET bottle)

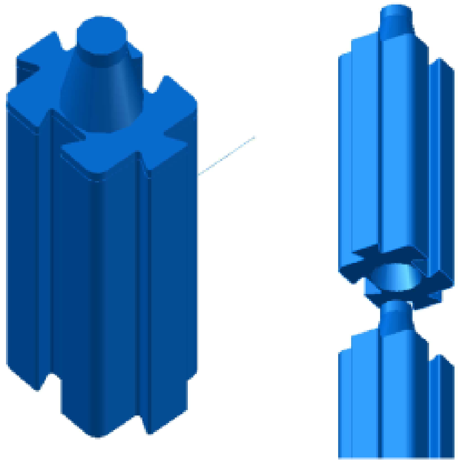

Figure 10. Three-dimensional drawing of the liquid container (PET bottle)

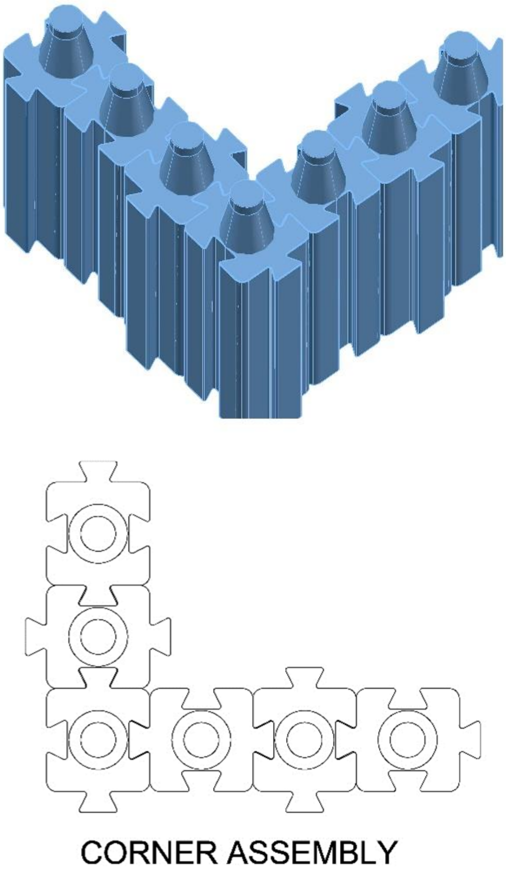

Figure 11. The Interlocking Assembly

Liquid Capacity	Height of Body t = 0.3 mm
1.5 liter	31 cm
1.0 liter	20 cm
0.5 liter	10 cm

5.3 CHB and Proposed PET Bottle Design Analysis

Table 2. Distribution of Stress in Non-load Bearing Concrete Hollow Blocks (CHB)

H (mm)	Z (mm)	Area (mm^2)	Weight (N)	Load (N)	Stress (N/m^2)
0.00	0.00	10000	0.00	34000.00	3.40
19.85	19.85	10000	4.17	34004.17	3.40
19.85	39.70	10000	4.17	34008.34	3.40
150.00	189.70	10000	31.50	34039.84	3.41
10.00	199.70	10000	2.10	34041.94	3.40

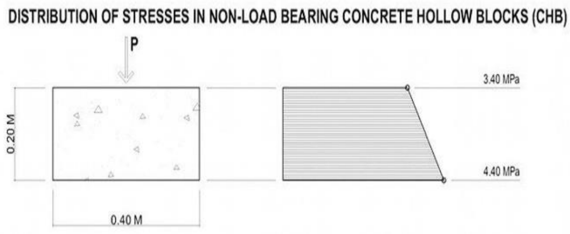

Figure 12. Distribution of Stress in Non-load Bearing Concrete Hollow Blocks (CHB)

Table 3. Distribution of Stress in Sand-filled PET bottles

H (mm)	Z (mm)	Area (mm2)	Weight (N)	Load (N)	Stress (N/mm2)
0.00	0.00	444.88	0.0000	8500.00	19.11
19.85	19.85	824.48	0.2109	8500.21	10.31
19.85	39.70	1320.25	0.3586	8500.57	6.44
150.00	189.70	4782.00	12.1941	8512.76	1.78
10.00	199.70	4782.00	0.8129	8513.58	1.78
19.85	219.55	3956.00	1.4721	8515.05	2.15
19.85	239.40	3462.00	1.2507	8516.30	2.46

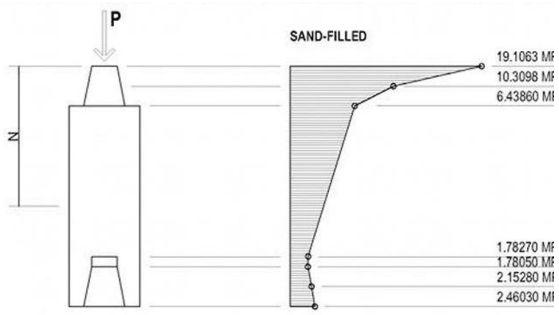

Figure 13. Distribution of Stress in the Proposed Design of PET Bottle (Sand-Filled) - 1 Liter

Table 4. Distribution of Stress in the Proposed Design of PET Bottle (Water-Filled) – 1 Liter

H (mm)	Z (mm)	Area (mm2)	Weight (N)	Load (N)	Stress (N/mm2)
0.00	0.00	444.88	0.000	8500.00	19.11
19.85	19.85	824.48	0.1217	8500.12	10.31
19.85	39.70	1320.25	0.2069	8500.33	6.44
150.00	189.70	4782.00	7.0367	8507.37	1.78
10.00	199.70	4782.00	0.4691	8507.83	1.78
19.85	219.55	3956.00	0.8495	8508.68	2.15
19.85	239.40	3462.00	0.7217	8509.41	2.46

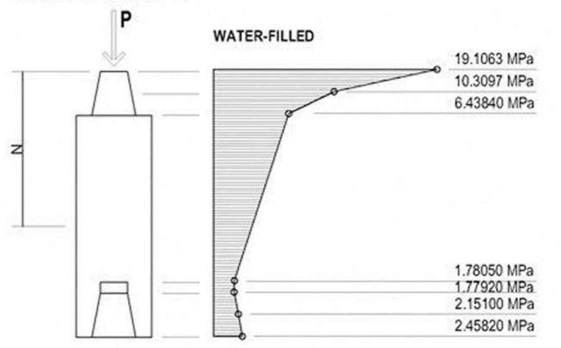

Figure 14. Distribution of Stress in the Proposed Design of PET Bottle (water-filled) - 1 Liter

Table 5. Stress Distribution Summary

Z (mm)	CHB	Water-Filled	Sand-filled
0.00	3.40	19.11	19.11
19.85	3.40	10.31	10.31
39.70	3.40	6.44	6.44
189.70	3.41	1.78	1.78
199.70	3.40	1.78	1.78
219.55		2.15	2.15
239.40		2.46	2.46

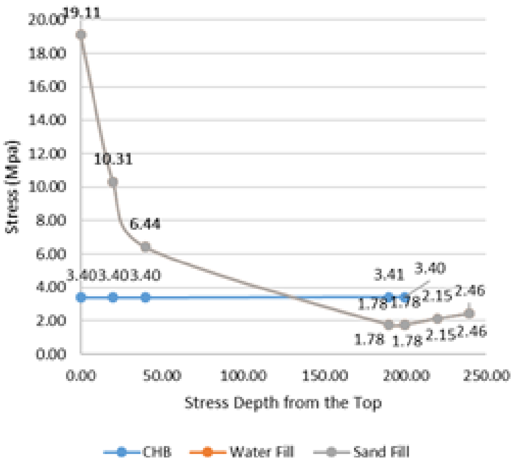

Figure 15. Stress Distribution Summary

It could be analyzed from Figure 15 that the distribution of pressure for the proposed design of a PET bottle when filled with water or sand has the same stress diagram. It could also be seen that the maximum pressure in the said design occurs at the cup and neck part of the bottle due to the small amount of cross-sectional area in resisting compression loads compared to its body. The irregularity in the shape of the proposed design of the PET bottle creates staggered stress in the bottle while the CHB illustrates linearity of pressure due to its constant dimension and property.

5.4 Temporary Shelter and Non-Load Bearing Wall and Interlocking Wall for Buildings

The primary objective of the study is to provide easy-to-assemble temporary shelter and private space for victims of calamities in evacuation centers with the aim of giving families some sense of privacy inside evacuation centers.

5.4.1 Interlocking Liquid Container as Modular Wall Panel

Each bottle shall act like a piece of LEGO block that will interlock with each other (Figures 9, 10, and 11), and it can be easily assembled to form a modular wall panel (Fig.16 and Fig.17).

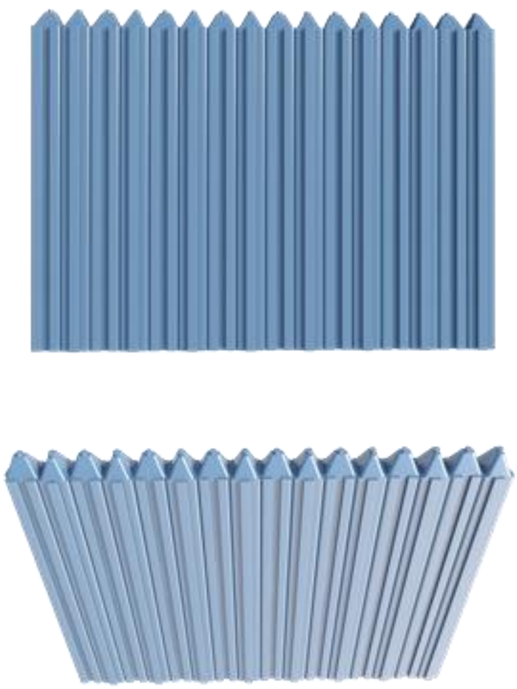

Figure 16. The modular wall panel assembly of the liquid container

The interlocking assembly of each piece of PET bottle is assembled vertically to produce a thinner wall, therefore saving space compared to laying it horizontally as in the EcoArk of Taiwan and in other buildings that used PET bottles as a building material.

The proposed design of the PET bottle also provides an alternative non-load-bearing wall and light interior partition for buildings. These can be used as non-permanent or permanent walls. For non-permanent walls, empty bottles without any concrete coating can be used. For permanent wall assemblies, these should be coated with concrete reinforced by welded wire or wire mesh, and an additional steel frame shall be used to strengthen the wall.

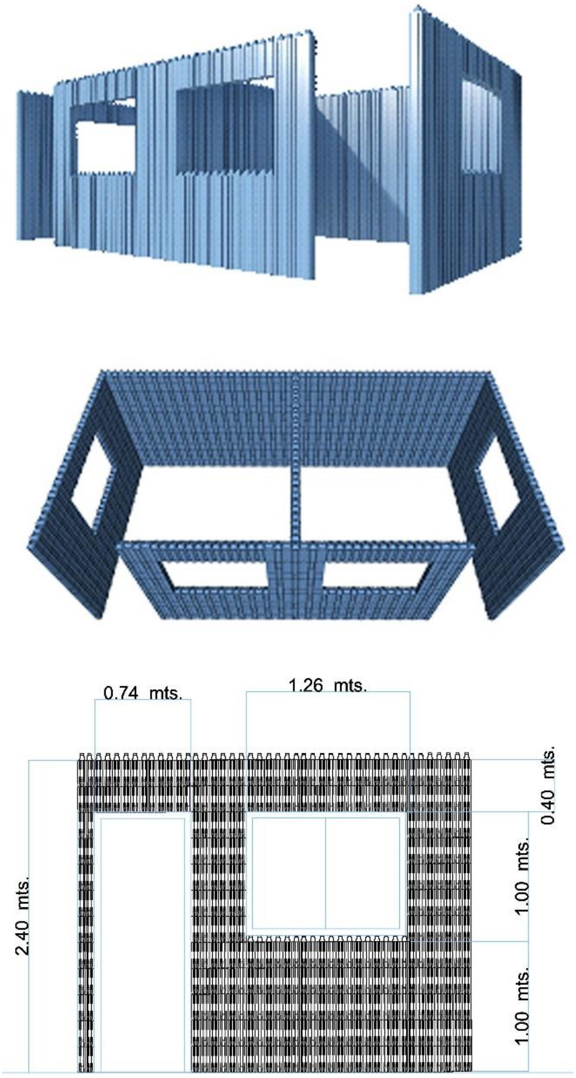

Figure 17. Makeshift Emergency Shelter Assembly

6. Observations

6.1 The Conditions of Evacuees and Evacuation Centers

The Philippines has experienced several calamities during the past years, from natural to man-made disasters. It has been a constant problem for the Philippine government to provide a decent evacuation center for the victims. During the Marawi Seige in 2017, residents of Marawi City had to be evacuated. Aside from the vast volume of evacuees, it is not yet certain when they will ever return to their homes. Some evacuees have already died in evacuation centers, with the women being exposed and children constantly under the threat of contracting various diseases (Unson, 2017). Providing a private space or an emergency shelter for each family is very important to avoid these adversities.

6.2 PET Bottles as Temporary Shelter and Non-Load Bearing Wall

The PET bottle is the most widely used portable bottled water container because of its properties and convenience in handling. Reusing this type of plastic in other forms such as temporary shelter and building walls can help reduce the accumulation of plastic wastes that may end up in landfills, and bodies of water, among others. Plastic bottles may be the most recycled solid waste but through innovative designs and ideas, this can be transformed to become sustainable and relevant, thereby addressing several issues with just one approach.

7. Recommendations

The main purpose of this study is to use the proposed design of the PET bottle as interlocking pieces for a temporary shelter for disaster-affected communities. The PET bottle is not designed to withstand the extreme forces of nature. Based on the material test conducted, the empty PET bottles and the ones filled with water can be used for the said purpose. But it is advisable to fill the first two to three layers of the temporary shelter with sand or water to stabilize the base of the wall while the remaining upper layer shall be filled with empty bottles to avoid piling up the additional weight that may stress the lower layers.

Emergency shelters during calamities will help evacuees improve their physical and social conditions which may help them recover faster. It will shield them from exposure to diseases and viruses and the possible adverse effects of overcrowding.

This interlocking makeshift shelter will not only help victims and evacuees of calamities have an acceptable private space for their families but will also contribute to the plastic waste management program of the government and non-government agencies. It reduces the accumulation of non-biodegradable wastes and introduces readily available but innovative materials to help achieve sustainable infrastructure.

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