DURABILITY OF FERROCEMENT GARBAGE DISPOSAL BARGE

Cheryl Lyne C. Roxas[1], Ronaldo S. Gallardo[1]
Bertrand Teodosio[1], Erika Kassandra Therese Ochosa[1], Svend Ezer Young[1]
[1] De La Salle University – Manila

Abstract: The solid waste disposal problem of Metro Manila has received significant attention over the last decade and waste generation has increased by almost 50%. Dumping, land filling, recycling, and segregation are insufficient disposal methods that compromise the environment and human health, prompting the need for a more effective and sustainable method of permanent garbage disposal. A proposed solution to the given dilemma is the construction of a ferrocement barge that would incorporate non-biodegradable and non-recyclable solid wastes in the structure. In analyzing the durability, a 36-year old ferrocement barge was assessed with respect to the degree of carbonation and the probability of reinforcement corrosion. Results of the transverse load strength test on 6 panels (3 for each type of reinforcement) revealed a 175% advantage of steel over bamboo in terms of load resistance. On the other hand, both types of panels exhibited the same resistance to compressive load when the capacity of the testing apparatus was reached. From the phenolphthalein test results, the ferrocement barge was found to have a service life of 1632 years and is not vulnerable to reinforcement corrosion due to carbonation.

Key Words: durability; ferrocement; garbage disposal

1. INTRODUCTION

In 2010, the population of Metro Manila was estimated to be 11.5 million with an average annual growth rate of 2.11% (NSO, 2010). This increase in population consequently generates a large amount of waste, making solid waste disposal a major problem in the region. Over the last ten years, waste production has increased significantly from 2 million to 2.95 million metric tons (MMDA, 2011).

Conventional waste disposal methods, such as open and controlled dumping, proved to be inadequate in eliminating the amount of waste produced everyday. Furthermore, advanced waste disposal methods in other countries are too expensive for the Philippine government to maintain. Solid waste disposal must be properly addressed in order to reduce its adverse effects to human health and natural resources.

A ferrocement garbage disposal barge is being proposed in this study as alternative solid waste disposal method. Ferrocement is an economic and environment-friendly method of reinforced concrete construction. Marine structures crafted using this technology have lasted a considerable amount of time (Naaman, 2000). However, one of the challenges in working with steel is its high cost and susceptibility to corrosion, thus the need for an alternative resource.

Durability, resulting from high strength, can be achieved by the use of adequately graded aggregates, optimal maximum nominal size, shape and type of coarse aggregate, application of low water/cement ratios, locally-developed plasticizers, preparation of mixes free from clayey particles and organic matter, and the use of progressive curing methods (Arum and Olotuah, 2006). But in order to mitigate a structure's susceptibility to breakdown due to corrosion, the steel reinforcement can be replaced with bamboo. Bamboo has similar mechanical properties as steel. However, its performance with the addition of plastic mesh in creating a hybrid ferrocement panel has yet to be evaluated. Furthermore, its durability when exposed to marine environment lacks further research.

It is important to determine whether bamboo and plastic mesh used as reinforcements are comparable to steel. Also, a ferrocement panel with bamboo and plastic mesh for building a ferrocement barge requires some attention. The competitiveness of the mechanical properties and advantages regarding corrosion resistance of the produced hybrid panels are crucial in determining the service life of a concrete garbage disposal barge.

Ferrocement was first developed by Joseph Lambot in 1847 as an alternative to boat construction. It is a highly versatile type of reinforced concrete composed of cement, sand, water and steel mesh. Today, ferrocement is used in a variety of applications. It is a polytrophic material with distinct properties, making it a worthy competitor in the construction industry (Naaman, 2000). Naaman (2000) illustrates its significance to low-cost housing projects, agriculture, and industry. He provides several applications suitable for emerging countries with developing economies. It can be adapted to a wide range of construction techniques because of its versatility, environment-friendly and readily available raw materials, ease of transportation and material handling, and does not require any particular technique or special skill.

The main objective of this study is to determine whether the use of bamboo and plastic mesh as reinforcements for ferrocement panels can be an effective alternative for steel. This paper focuses on the durability of the ferrocement garbage disposal barge by investigating the service life of an existing and operational ferrocement barge through non-destructive field tests.

In this study, a ferrocement garbage disposal barge is being proposed to address the economic and environmental issues on solid waste disposal in Metro Manila. The structure utilizes bamboo and plastic mesh as an alternative to steel reinforcing bars and steel mesh, which can help reduce costs. Furthermore, the vulnerability of steel reinforcement to corrosion compels the need of finding a suitable replacement to ensure a longer service life and keeping it afloat Manila bay. Panels made of conventional materials and the proposed alternatives were fabricated. Both types of panels produced were subjected to two strength tests, namely, the axial compression load test and transverse toad test – with specimen in a horizontal position. The current degree of carbonation of a ferrocement barge was also examined through the phenolphthalein test.

2. METHODOLOGY

The panels were designed based on a blueprint of the proposed barge model. According to ASTM E 72-05, a panel’s height should conform to the height of the structure where it will be applied. In this case, the height was designated at 2.4 meters, which was also the maximum height that the apparatus could accommodate. The said width was limited to 1.2 meters and the thickness was at .05 meters. Figure 2.1 shows the skeletal reinforcements of the cross-section of the panels. Table 2.1 gives the summary of the panel design specifications.

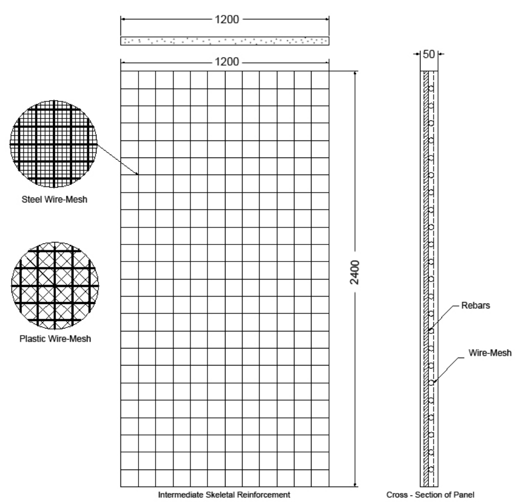

Figure 2.1 Skeletal reinforcement and cross-section of panels

Table 2.1 Summary of panel design specifications

Criteria	Regular Panel	Hybrid Panel
Intermediate Skeletal Reinforcements	10mm RSB	¾" Bamboo
Spacing	100mm	100mm
Wire-Mesh Reinforcements	1"x1" Welded Wire Mesh	1"x1" Hexagonal Plastic Mesh
Cement	Type I, Portland Cement	Type I, Portland Cement
Sand	Crushed Sand	Crushed Sand
Water	Potable Water	Potable Water
Mix Design	1C: 2S: 0.5W	1C: 2S: 0.5W
Thickness	50mm	50mm

This study consists of two phases: the structural and durability investigation of ferrocement garbage disposal barge. This paper covers the second phase, durability investigation, which involves the field examination of an operational concrete barge, specifically the carbonation test, service life computation, environmental influence on carbonation rate, buoyancy of the proposed barge and investigation of the panels' capacity against tidal forces.

3. RESULTS AND DISCUSSION

3.1 Carbonation Test

The barge was built in 1976 and is situated at Del Pan, Tondo, Manila. It is owned by the L.C. Bautista Company, who utilized the barge for transporting soya and wheat. The barge is 36.28m-length x 12.80m-width x 3.05m-height. Data for analysis were obtained only on three sides of the barge, leaving one side in the longitudinal section that was inaccessible. Only the top portion of the barge was tested.

On both sides of the barge with the shorter span (width), three areas were drilled. Ten areas were drilled on the remaining side of the barge (length). A total of 16 points were obtained for the test. Figure 3.2 shows a sample of an area tested.

Figure 3.1 Topmost portion of the ferrocement barge specimen

The purple color indicates the onset of the non-carbonated portion of the concrete cover. The depth at which the purple color was emitted by the concrete while drilling was very shallow, which is clearly noticeable on most areas. The average concrete cover of all the areas tested was found to be 37.81 mm, with a standard deviation of 6.81 mm. Table 3.1 summarizes the tests results and shows that points drilled along the same areas have similar carbonation depth values. Carbonation depths obtained had an average value of 5.61 mm with a standard deviation of 4.57 mm.

The percentage of carbonation depth with respect to the total concrete cover was calculated to determine the extent of carbonation. For each point, the percent carbonated depth was calculated by dividing the carbonation depth to the concrete cover. The highest percent carbonated area is located somewhere in the middle of the longitudinal side of the barge. The largest of which was Point 10 with a value of 13.89mm, which is 41.71% of its total concrete cover. The average percent carbonated area of all the holes is 15.03%.

Table 3.1 Summary of Carbonation Test

Pt.	**Area on Barge**	**Concrete Cover (mm)**	**Carbonation Depth (mm)**	**% Carbonated**
1	WIDTH - side	40.00	7.45	18.62
2	WIDTH - middle	36.70	3.84	10.47
3	WIDTH - side	30.00	2.46	8.19
4	LENGTH - side	40.00	2.21	5.53
5	LENGTH - side	33.30	1.40	4.19
6	LENGTH - side	46.70	1.92	4.10
7	LENGTH - middle	43.30	9.92	22.91
8	LENGTH - middle	40.00	15.37	38.42
9	LENGTH - middle	40.00	11.41	28.52
10	LENGTH - middle	33.30	13.89	41.71
11	LENGTH - side	40.00	2.32	5.79
12	LENGTH - side	40.00	2.46	6.14

13	LENGTH - side	40.00	5.66	14.15
14	WIDTH - side	23.30	3.50	15.01
15	WIDTH - middle	28.30	2.97	10.48
16	WIDTH - side	50.00	3.09	6.17

3.2 Computation of Service life

The service life of a concrete structure can be determined when the values of carbonation depth and concrete cover are known. Using the averaged values of the concrete cover and the carbonated depth at t=36 years, the service life is found to be 1632 years. At the given service life, the rate of carbonation is calculated and is found to be 0.9351 mm/year$^{0.5}$.

3.3 Environmental Influence on Carbonation Rate

If only the carbonation of the specimen is taken into consideration, these values would be reasonable for although it is exposed to marine environment, the area tested was not in close contact with seawater. Seawater would only be a factor for consideration in chloride attack.

Furthermore, studies present that a structure with a relative humidity beyond 70% and a temperature close to 20% is not vulnerable to carbonation. Thus, for the current barge in study, the relative humidity and the temperature of the specimen were estimated to be 76.92% and 26.68°C, respectively.

3.4 Investigation of the Panels' Capacity Against Tidal Forces

According to AASHTO Guide Specifications for Bridges Vulnerable to Coastal Storms (2007), typical wave loading during storms ranges from 15 kPa and above. In the context of the strength acquired in the transverse and axial load tests, it can be said that bamboo-reinforced ferrocement panels cannot withstand the loads during storms. Because of this, enhancements to the bamboo-reinforced panels must be done in order to make it feasible against tidal forces. Nevertheless, test results show that steel-reinforced panels have the capacity to withstand waves during storms and further make it a better option as compared to bamboo.

4. CONCLUSION

Given that the problem on solid waste disposal is aggravating, the conditions of the existing garbage disposal procedures were examined. The analysis of the deficiencies of the current disposal procedures stimulated the conception of the ferrocement garbage disposal barge. The proposed disposal method was tested for feasibility by evaluating its durability and structural stability when concrete was reinforced with bamboo and plastic mesh rather than steel.

An existing ferrocement barge was tested for carbonation and found to last for a considerable period of time and is not vulnerable to corrosion due to carbonation. The relative humidity did not have much affect the carbonation results. In terms of the capacity against tidal forces, the steel-reinforced panel is still a better option.

5. ACKNOWLEDGMENTS

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