

ANALYSIS OF SUPER INSULATED SHELL HOUSE MADE WITH FERRO ALLOY CEMENT

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ABSTRACT:

The development and construction of lightweight pre-fabricated sandwich structural elements in building construction is a growing trend in construction industry all over the world due to its high strength-to-weight ratio, reduced weight, and good thermal insulation characteristics. Sandwich construction element consists of thin face sheets or encasement of high performance material and a thick, lightweight and low strength material as core. Ferro cement is regarded as highly versatile thin material possessing superior properties which cannot be matched by other conventional thin materials. Aerated concrete is a cellular lightweight material which exhibits relatively higher strength than the conventional core materials such as foam. Additionally, sandwich construction deals with the problem of delamination of face sheets leading to their premature failure. This can be avoided by providing encasement over the core. This study was focused on the development of Ferro cement encased aerated concrete sandwich wall elements, where Ferro cement thin box encases a thick core of lightweight aerated concrete. The study was conducted in two phases. First phase involved the development of high workability and high performance slag-cement based mortar mix to cast proposed Ferro cement encasement. The developed mortar was aimed to replace the traditional manual method of plastering the wire mesh by a mechanized casting method. The performance of mortar was investigated in terms of compressive strength, strength development, unit weight, effect of curing regime, and partial replacement of cement by weight with 50% and 60% of slag. The second phase of the study embarked on the development and investigation of the characteristics of Ferro cement encased lightweight aerated concrete sandwich wall elements. To achieve the objective, about 600 specimens including large size wall elements were cast and tested. Ferro cement encasement was maintained at 12mm throughout the study. The parameters studied were compressive strength, flexural strength, failure mode, load-deflection behavior, load-deformation behavior, load-strain behavior, unit weight, water absorption, initial surface absorption uniformity, and role of type and layers of the wire meshes. The results revealed the potential application of Ferro cement encasement of lightweight aerated concrete to produce

lightweight structural elements which leads towards the industrialization of building system. Finally, two mathematical models were developed to predict compressive strength of high workability slag-cement based mortars and the Ultimate load of Ferro cement encased aerated concrete sandwich wall elements. The values predicted from the mathematical models were 95%-100% accurate to the experimental results.

(**Keywords:** Lightweight, pre-fabricated, aerated concrete sandwich Ferro cement)

INTRODUCTION

Among the design hull materials in use for shipbuilding, a specific place is occupied by Ferro-concrete and one of its variants, i.e, and reinforced concrete. The substantial savings in metal (by two-three times) realized the construction of the hulls of floating structures of reinforced concrete, **at a** simultaneous substitution of expensive and scarce sheet and profile rolled iron, with reinforced rod steel, establishes that unvarying interest which is expressed in Ferro-concrete in shipbuilding. Just as much interest in the floating facilities with Ferro-concrete hulls is also manifested by the operating organizations, since in distinction from the structures with steel hulls, the designs with Ferro-concrete hulls do not require layovers in dock for painting the hulls and for the periodic replacement of rusted plates of sheathing and elements of a set, which saves considerable resources. In spite of the circumstances noted above, confirmed by the construction experience and the subsequent operation of the Ferro-concrete floating facilities, as a whole for the Ferro-concrete shipbuilding for the past 50 years, we have typically had both periods of abrupt increases, and periods of equally abrupt declines, including the complete shutdown of this type of floating facilities. Such an instability in the development of the

Ferro-concrete shipbuilding, in addition to the purely subjective factors (and in a number of cases, of outright prejudice), has been established mainly by the absence of the necessary objective conditions for the regular construction of Ferro-concrete hull reliable in operation. The seemingly simple organization of construction, the simplicity of the production processes under the possible utilization of specialists with relatively low skills have inevitably involved the appearance of super flours Ly over heavy, over-reinforced hulls with a low quality of concrete, cracking under the effect of atmospheric moisture, -fluctuations in temperature and in sea water. A time was required sufficient In r that the basic conditions, determining the reliable operation of the marine Ferro-concrete hulls, were revealed, understood and strictly regulated. Beginning from 1955, as a result of the accomplishment of a series of scientific-research, planning and testing-design activities, the necessary scientific base was created for developing the plan of Ferro-concrete ships and for the selection of the most effective engineering processes for their building. The systematic studies which were conducted established the necessary extents of reinforcing the main and secondary design elements, the principles of efficient design configuration; standard documents were developed Z:r all types of work in the assembly and concrete reinforcing both of the individual sections, and of the entire hull as a whole; the specific requirements were determined and delineated on monitoring the qualities of the 'Finished products.

As a result of the research activities, it was demonstrated that the conditions of wavering on concrete, reinforced hills, situated in sea water under constantly changing loads (in ueotnt and suIn), the requirnwns of resistance to freezing, complete airtightness end relate resistance to the aggressive effect of see water basically! Distinguish' the floating river and naval faro-concrete facilities from any civil installations, including the hydrates :uncial ones. The book brought to the attention of the readers contained a brief discussion of the basic results of the activities and studies

conducted by the shipbuilding scientific-research organizations, the design bull 'us and the shipyards engaged in reinforced concrete shipbuilding, with the development of design criteria and engineering processes necessary. 'Nine and bulimia,-g the hulls of floating facilities made of reinforced conches.

The technical advantage of using reinforced concrete in the designs of the hulls and superstructures of ships has been confirmed by the experience gained in the construction and operation of various reinforced-concrete ships in our country and abroad. Then the building of the first reinforced-concrete ships, initially there was a definite uncertainty in the new shipbuilding material, especially in respect to the capability of the elements to function during Imp4uct and sign-changing loads.

In spring of 1943, in Italy extensive research and experiments Verse conducted under the supervision of the Naval administration. The purpose of the experiments vas the establishment of the actual value % of the physic-me-maniacal characteristics of reinforced concrete under the effect of permanent and ilia-t (shock) loads. The experimental plates with a dimension of 1.5 X 1.5 a, with a thickness of 30 s, reinforced by thin wires with a total expenditure of metal amounting to 400-500 kg per cubic meter of concrete, were tested by dropping a load on totem weighing 260 kg from a height up to 3 meters. At this time, it vas established that even with the presence of small and partial cracks, in the region of strain, the plates retained their voter tightness. The construction of three motor-driven transport steps for the and a motor-driven transport ship with acar.ocaDoaety of 400 tons was Interrupted' to the war. The construction was renewed in 1940 at the Laztartnl and Mean, -hip yard in Anglo. The motor-driven speed sailboat. weir then e a capacity of 165 tans was built in three months (Fig. 1). The thickness of the hull sheathing on the "Irene" equaled 35 Se. The plating was made of eight layer'- of reinforced screens with a grid size of I cm and a weight of I kg/m 2 . Four layers of the screens were located closer to the external and four layers closer to the inner surfaces

of the plating. Between the layers of screens, three rows of steel *re-* Enforcing rods with a diameter of 6 m were placed, arranged 10 cm from each other. The reinforcement Rids and rods were tightly interconnected by a steel wire; in the preparation of the cement-sandy solution, for the plating, 1000 kg of cement per cubic meter of concrete were used. The placement of the cement- sandy solution on the gr.ds was accomplished manually (by workmen) from the inside of the hull.

SANDWICH STRUCTURAL ELEMENTS/MEMBERS:

A sandwich panel is a three-layer element, comprising two thin, flat facing plates of high-strength material and between which a thick lightweight core of low average strength is attached. Figure 1.1 presents a few types of sandwich panel elements. Such sandwich structures have gained widespread acceptance within the aerospace, naval/marine, automotive and general transportation industries as an excellent way to obtain extremely lightweight components and structures with very high bending stiffness, high strength and high buckling resistance.

STATEMENT OF THE PROBLEM:

The development of lightweight, industrialized and sustainable housing system in Malaysia as per modular coordination system is a need of the day. The present modular coordination system usually focus on the use of cement or concrete blocks for the infill or to certain extent as load bearing walls which are heavy in weight. Ferro cement structural elements are widespread as lightweight, high performance composite material which can replace its counterpart conventional materials. However, these could not gain popular acceptance here due to its thin section causing noise and heat transfer and also the perceived corrosion problem particularly in the tropical environment of Malaysia. Moreover, the psychological factor coined with buildings constructed with such thin sections would be perceived as unsafe to live, is also another factor which hinders the application of Ferro cement. Thus, sandwich composite construction system, presents one of the

potential solution, where, Ferro cement is applied as face sheets/encasement and lightweight aerated concrete is adopted as core. The problem of the labor intensive production of Ferro cement may be addressed by developing mechanized system of casting identical to that of the ordinary RC sections. The structural sandwich elements should be as per the standard size leading towards the industrialization of building system, in order to reduce the inside construction which is associated with social and economy problems.

AIM AND OBJECTIVES OF THE STUDY:

The main aim of this research investigation is to manufacture and study the behavior and properties of Ferro cement encased aerated concrete sandwich wall elements. Towards achieving the above mentioned aim, the related objectives associated were identified as follows:

1. To investigate the minimum flow value (flow table) of cement mortar capable to be poured during the casting of thin Ferro cement encasement.
2. To establish the optimum high workability and high performance mortar with slag and super plasticizer.

This pertained to the compressive strength, strength development, unit weight, curing regime, water absorption and ISAT (permeability) as parameters of study

3. To study the behavior of Ferro cement encased aerated concrete sandwich specimens. This part of study was focused on, to optimize the various variables; in compression as principal testing and in flexure as additional

SCOPE AND LIMITATIONS OF THE STUDY:

The study is almost experimental in nature. The study consists of two-phase study scheme. First phase of the present research focuses on development of optimum, high workability and high performance mortar, which should be capable to be poured during the casting of Ferro cement skin boxes over aerated concrete, in single operation. The performance of the mortar was investigated in terms of compressive strength, strength development, water absorption, and unit weight. The specimens

were cured in three curing regimes namely water, air, and natural weather in order to determine the appropriate curing regimes to be adopted for sandwich specimens. The effect of slag as cement replacement in mortar to make it low cost is also included. During the second phase of the experimental programmer, behavior of sandwich specimens; cubes, blocks prism beams and wall elements of relatively large size, were investigated under compression as major parameter and under bending as additional parameter. To achieve the main aim, a stepwise strategy was adopted by addressing a number of variables. Two types of wire mesh namely square welded wire mesh, and chicken wire mesh were incorporated in Ferro cement box by varying the number of layers; 0, 1, 2, 3 and 4. The performance of the sandwich specimens were studied in terms of ultimate compressive strength and flexural strength (modulus of rupture), unit weight load-axial deformation, and load-lateral deformation under compression along with load-deflection and load-strain relationship under bending. The failure mode and composite action of sandwich elements under both the loading conditions were also studied. In addition, efforts were made that it should be low cost, lightweight, and water resistant. To investigate the material uniformity of sandwich wall elements applying UPV test was also included in the scope of this study. Aerated concrete previously developed in UTM and subsequently improvised were used as core during this study. Finally mathematical models were developed which were related to both the phases of this study. The mathematical models developed were applicable to predict compressive strength of high workability slag-cement based mortar and Ferro cement encased lightweight aerated concrete sandwich wall elements.

LITARATURE REVIEW

[1] **Perumal & Sundararajan (2005)** investigated the performance of M110 Grade of high performance concrete trial mixes having different replacement levels of cement with SF. The strength and durability characteristics of these mixes are compared with the mixes without SF. Compressive strength of 110 MPa and 54.65MPa at 28

days is obtained by using 10% and 0% replacement of cement with SF. The results showed that the SF concrete possesses superior durability properties.

[2] **Parichatprecha et al (2006)** conducted a experimental investigation on the influence of using different pozzolanic materials, cement content, and water to binder ratios on the durability of concrete by measuring the charge passed of concrete in accordance with ASTM C 1202-97. Two types of pozzolanic material were used namely pulverized fly ash and condensed silica fume. The cementations materials were varied from 400-550 kg/m³ with w/b ratio ranging from 0.3 to 0.4. It was found that the increase in cement content of concrete resulted in higher charge passed. The optimum cement content for producing high strength and durable concrete was found to be 450 kg/m³. It was noticed that the lower the w/b, the lower the charge passed of the corresponding concrete, which agrees with the general concepts of concrete.

[3] **Selcuk tu rkel & yigit altuntas (2009)** compared the effect of limestone powder (LP) on the properties of Supplementary Cementations Replacing Materials (SCRM) with other mineral additives such as silica fume (SF) and fly ash (FA) and their combination effects. Fresh properties, flexural and compressive strengths and water absorption properties of mortars were determined. The use of SF in mortars significantly increased the dosage of super plasticizer (SP). At the same constant SP dosage (0.8%) and mineral additives content (30%), LP can better improve the workability than that of control and FA mixtures by 19% and 27%. However, the results of this study suggested that certain FA, SF and LP combinations can improve the workability of SCRMs, more than FA, SF and LP alone. LP can have a positive influence on the mechanical performance at early strength development while SF improved aggregate-matrix bond resulting from the formation of a less porous transition zone in mortar. SF can better reduce the effect on total water absorption while FA and LP would not have the same effect, at 28 days.

[4] **Rathish kumar (2010)** conducted an experimental program to study the functional efficacy of an Sulphonated Naphthalene Formaldehyde condensate (SNF) condensate used as a water reducing super plasticizer. The compressive strength and flow characteristics of the mortars were determined to decide their suitability for Ferro cement works. The parameters included the mix proportions, the grade of cement, age of curing and the dosage of super plasticizer. It was concluded from the study that the addition of an optimum dosage of super plasticizer improved the workability and strength characteristics of silica fume mortars.

[5] **Yilmaz kocak (2010)** determined the mutual influence of fly ash and silica fume with Portland cement. For this purpose physical, chemical, X-ray Diffraction Analysis (XRD) and particle size analysis were applied to these raw materials. The results indicated that fly ash and silica fume had shown different surface features compared to Portland cement. The variations in surface features affected on compressive strength of mortar samples. The ternary use of fly ash and silica fume provided the optimum results, when the compressive strength properties of the cement mortars were taken into account.

[6] **Ali Reza Bagheri et al (2011)** studied the rate of strength gain and durability of ternary cement concretes containing both fly ash and silica fume compared with binary cement based mixes. The w/b ratio and total cementations materials were kept constant for all mixes at 0.38 and 420 Kg/m³. Durability tests including water permeability, chloride diffusion and electrical resistance were conducted. The results showed that simultaneous use of fly ash and silica fume overcomes the deficiency of slow rate of strength gain of binary mixes containing fly ash and also enhances their durability considerably. Ternary mixes have the advantages of reduced water demand and reduced costs over binary mixes containing silica fume.

METHODOLOGY

This chapter presents the methodology and implementation of structural shell modeling. The three house case studies are built using

this system and also presented. The goal of the system is to make the design and structural analysis as quick and easy as possible. To this extend, various software solutions are explored. It's unavoidable that some complexity exists, for example in scripting, but the overhead of learning and using the tools should be as small as possible. The designer should be able to convert hand sketches, rough dimensions and ideas into a functional model with a few hours' worth of work.

EXPERIMENTAL PROGRAMME OF STUDY

the main aim of the study was to investigate the characteristics of Ferro cement encased aerated concrete sandwich wall element. in order to achieve the aim and the related objectives mentioned in chapter one, a two-phase experimental study; each comprised of stepwise strategy was adopted. Following are the details of the two phases, stepwise research methodology adopted.

FUNCTIONALITY:

The scope of features desired in the modeling system is: 3D geometry The entire house shell must be modeled as a solid, with discrete reinforcing bars. Other reinforcement, such as welded wire and meshes are best modeled as shells onset from the rebar's. Ease of use of the CAD software is important, as is adorability to the designer/builder.

Change management Changes in 3D geometry need to be easy to incorporate without manually changing surface points. This includes enlarging spaces, recon_guring rooms, recon_goring penetrations, changing shell shape and others. This is critical to successful exploration in the design phase and optimizing the structure for loads.

2D drawings The 3D model must be able to export 2D drawings of any desired parts of the geometry. This includes cross sections with dimensions. Every rebar's dimensions and shape can be exported separately to aid in shop bending. FEA link The relevant geometry must be cleanly exported to the FEA software such that additional tweaking isn't necessary. This includes assemblies and material types. Relevant geometry is the structural framework and doesn't need to

include non-structural details. Scripting and automation The entire design and analysis process must ultimately be represented in macros and scripts. This is critical for automating routine tasks in creating geometry and performing the structural analysis.

There needs to be a template for any project, where the user concentrates only on the structure's features and has the remaining worked automated. Common textiles should include all inputs such as material properties and loads. Text _les should also be used where possible for transferring information between different software packages and debugging. The scripting language should be easy for the user to learn.

SHELL RETROFIT:

The purpose of a retrofit is to build a protective shell on an existing wooden house, especially in high-wind regions of the country. The advantage of this approach is that it's relatively easy to implement with minimal disturbance to the occupants. A typical one story, three bedroom house is assumed, with the wall shell having dimensions of 8 x 15.5 x 2.5 m, a roof angle of 30 degrees and an overhang of 0.3 m. Standard window and door sizes are assumed. The

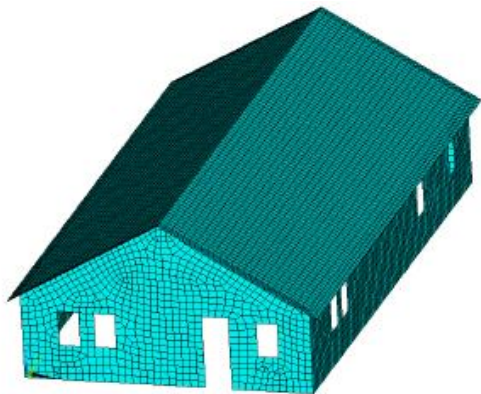


Figure Case Study 1 Geometry

FLOW VERSUS MIX PROPORTIONS:

On the basis of the results of previous two steps a comprehensive test programmer was conducted to establish the criteria between mix proportions, water binder ratio, dosage of super plasticizer and partial replacement of cement with GGBFS at constant mortar flow determined previously. The details of the mix proportion, level of partial replacement of cement with GGBFS to achieve the economy and the dosage of the

super plasticizer applied to reduce the water-binder ratio at specific flow, are as follows:

(a) Mix proportion: binder : sand 1: 2, 1: 2.5, 1: 3

(b) GGBFS : 0%, 50% and 60% by weight of the total binder as partial replacement of cement

(c) Super plasticizer : Used from 0.1%; of total binder by weight up to maximum dosage determined during previous step.

It was applied in an increment of 0.1% each time All in all 54 mixes were developed, tested and analyzed during this step.

Characteristics of High Workability Slag Cement Based Mortar

Initially cube specimens of size 70.6mm x 70.6mm x 70.6mm for all the 54 mixes developed from previous step were cast and tested with following variables

(a) Curing regime: Water

(b) Age of Mortar: 28 days.

(c) Tests: Cube crushing strength and Density of mortar

As a step further, based on the strength and density results obtained, seven high strength (compressive strength > 45MPa) and economical mixes (with GGBFS) including one control mix were selected and were tested with following variables.

(a) Curing regime: Water (at 27⁰C room temperature in water tank)

(b) Strength development: 3, 7, 28, 90, and 180 days

(c) Water absorption: at 28 days

(d) ISAT (permeability): at 28 days

As the concluding step, two mixes were selected based on the results from previous testing, and were tested for effect of curing regime by curing with following variables

(a) Curing regime: Water (in water tank at 27 0C room temperature .Air (inside room at 27 0C room temperature) Natural whether (ambient environment; outside the laboratory under open sky at temperature from 25 0C to 35 0C)

(b) Tests: Compressive strength

(c) Specimens Age: 3, 7, 28, 90, and 180 days.

Finally on the bases of the entire results and the discussions made, an optimum high workability and high performance mortar was selected to cast Ferro cement encasing

box to produce Ferro cement-aerated sandwich.

TO INVESTIGATE CHARACTERISTICS OF FERRO CEMENT ENCASED AERATED CONCRETE SANDWICH WALL ELEMENTS

This phase of the experimental study was accomplished in two parts. As the wall elements considered in the final step of this study were of relatively large size, hence it was deemed necessary to carry an intensive experimental programmer with large number of variables but with small size specimens as per the specifications of various standards. Throughout the study it was decided to adopt 12mm thick Ferro cement encasement to produce sandwich. The encasement was achieved by producing Ferro cement box around four sides of the entire specimens. The details of the study are as follows:

SANDWICH CUBES, BLOCKS AND PRISM BEAMS:

SHAPE AND SIZE OF SPECIMENS

Cubes A: 70.6mm x 70.6mm x 70.6mm (Figure 3.5)

Cubes B: 100mm x 100mm x 100mm (Figure 3.6)

Blocks: 400mm x 200mm x 100mm (Figure 3.7)

Prism beams : 500mm x 100mm x 100mm (Figure 3.8)

• VARIABLES:

Type of mesh: Chicken and square weld wire meshes

Number of mesh layers: 1 to 4 layers in chicken wire mesh and 1 to 3 layers in square weld wire mesh (Since square weld mesh was of greater diameter thus the maximum number was limited to in this case)

Curing regime : Water

Age of specimen: 28 days,

Core Volume : Varying with size of specimens

Encasement effectiveness Method of testing the specimen for compression comprised of
(i) Holding encasement parallel to loading direction

(ii) Holding encasement perpendicular to loading direction

SANDWICH WALL ELEMENTS :

Finally ferrocement encased aerated concrete sandwich wall elements of relatively large size were tested. The details are as follows:

(a) Dimensions of wall elements

Wall elements 700 x 300 x 100 mm (Figure 3.10)

Wall elements 700 x 400 x 100 mm (Figure 3.11)

Wall elements 1400 x 400 x 100 mm (Figure 3.12)

(b) Variables

Mesh layers: Optimum number of wire mesh obtained from previous step

Curing regime: Water moist Age of Wall element: 28 days.

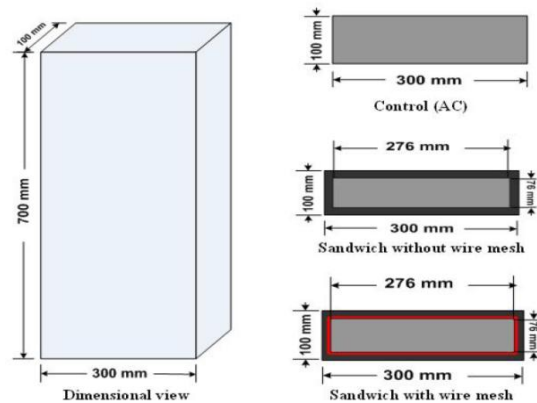
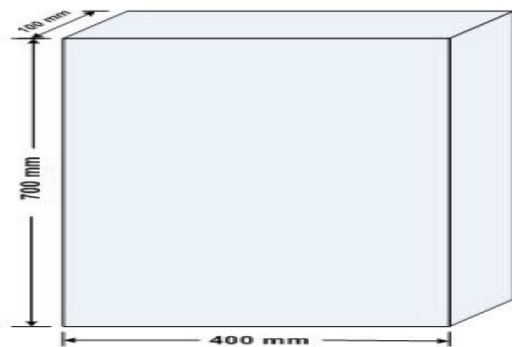


Figure Dimensions and cross sections of wall elements (700 mm x 300 mm x 100 mm)



Dimensions of wall elements (700 mm x 400 mm x 100 mm)



Dimensions of wall element (1400 mm x 400 mm x 100 mm)

RESULTS

Representative displacement plots for two load cases are shown in Fig. 4.1, showing a roof sag

in the 1:4D load combination and a wall bulge in the 1:2D+Enorth combination. Specie notes

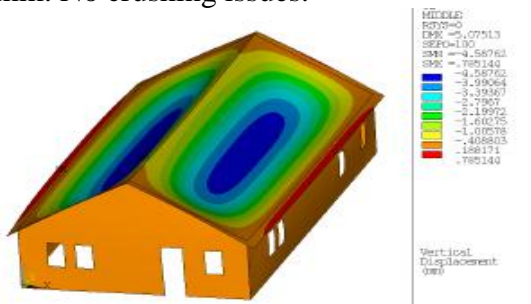
for each load combination are discussed here:

1.4D Roof sags by 5 mm. Tension due to bending is highest on the roof's inside surface and requires another layer of mesh reinforcement.

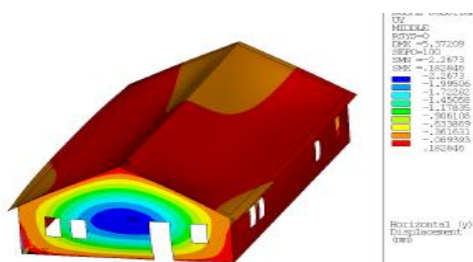
Seismic the walls bulge out a little due to horizontal acceleration. The maximum of 2 mm occurs on the southern wall during the 1:2D + E_{north} load combination. Generally the 1:2D combinations yield higher displacements and stresses than the 0:9D combinations.

Roof sag increases to 6 mm for E_{west} and E_{east}. The largest tension occurs on the roof ridge, in the middle of each roof section and in the corners of window and door openings. No crushing issues.

Wind loads stress the structure less than seismic. Maximum wall bulge is 4 mm on the north and south walls. The north and south walls exhibit more bulging than the east and west walls, even in cross winds. Roof uplift is maximum for 0:9D + W_{east}=E_{west} combinations, but is under 2 mm. No crushing issues.



(A) Vertical Displacement For 1:4d



(B) Horizontal Y Displacement For 1:2d + Enorth

ANALYSIS SETUP:

The initial design of the shell was for a 25 mm concrete composite. It was found that the displacements were unacceptable at over 25 mm under dead load and bending caused excessive stresses. Ribs were added in-between shell bulges that spanned the wall. These still proved insu_cient at resisting bending, so they now run continuously from the walls, to the roof and only get smaller down the center column. The \face" windows also needed to be redesigned so that the center rib would be uninterrupted. The shell thickness also needed to be increased to 40 mm. The volume ratio of reinforcement, V_r, of the composite described below is 3%. It's assumed that a third of the reinforcement resists surface tension, so that is 1/3

CONSTRUCTION NOTES:

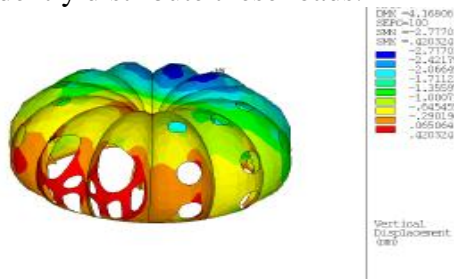
The proposed construction technique is similar to classic Ferro cement. A rebar armature of the

Whole structure is erected. Expanded metal lath is attached on the interior of the shell. Two layers of 150 x 150 x 5 mm mesh are stacked on the exterior. Concreting begins by plastering the lath, which becomes formwork for shot Crete on the other side. The composite is 40 mm. Thick after including 5 mm cover. There is no LINER mesh on the shot Crete side as is commonly Found in classic Ferro cement to speed up construction.

Creating the armature and concreting the lower half of the shell _rst, including the second story oor, would reduce scolding for completing the upper half. Insulation is attached to the outside of the shell. Spray foam is the most convenient solution, but also expensive. It would be more economical to use foam as only a glue that holds EPS blocks together and seals gaps. The exterior of the insulation may be smoothed and painted as is done with Mesolithic's domes. Otherwise, a thin concrete shell can be built with either the laminated technique. The mass of the shell consists of 51.8 tons of concrete and 4.5 tons of steel.

Displacement under dead load is less than 2 mm for the structure. For seismic load cases, the horizontal acceleration causes one side

to lift slightly and the other to slump, The maximum uplift for the 0:9D + E cases is 3 mm. The highest stresses occur in the ribs, as they resist the shell's tendency is to further push out the walls. There are still surface stresses in the shell, especially at the top near the column as shown in Fig. Thickening the ribs would reduce this tension. Window areas, especially at the "face", would also benefit from additional minor reinforcement. These openings are generally not problematic because of the ribs. Seismic load combinations govern in general. Wind loads only affect the large windows, where the net force from pressure is resisted by the shell. Most of the windows are centered on bulge sections to most evidently distribute these loads.



(a) Vertical displacement for 1:2D + E east



b) Surface_3 for 1:4D

In general, a structure like this which is designed with aesthetics as the priority is relatively expensive. There is considerable effort devoted to studying weak areas, designing reinforcement and ultimately more material is needed as opposed to designing with loads as the priority. This is in stark contrast to the Bellona case study, which has a shape optimized for resisting loads and performs accordingly.

CONCLUSIONS

Ferro cement construction is an exciting alternative to conventional wooden and masonry methods. In the context of

sustainable housing, aspects such as strength, durability, architectural freedom, occupant comfort, adorability and energy efficiency align well with Ferro cement's qualities. This project explores its rich history and structure types, including water tanks, houses, boats and large public areas. Various options are explored to reduce construction labor costs, which is the biggest reason for its low adoption in today's buildings. There are many modern improvements possible, including new materials, innovative fabric forming methods, computer modeling and analysis, among others. Traditional Ferro cement's large labor requirements can be reduced. Computer-generated, projected layouts allow for shop fabrication of rebar armature, which is only assembled on-site. Innate fabric, spray foam insulation and the laminated Ferro cement technique can drastically reduce armature work. The use of flexible, non-metallic materials such as basalt increases durability and makes the mesh easier to handle and shape. Mortar composition can be improved with y ash for quicker shot create application. Modern CAD tools allow for quick exploration of ideas and sophisticated form finding. The combination of Rhino3D with the Kangaroo physics plugin is one of a few powerful options available to a designer today. These tools allow an amateur to create shapes that in the past required complex physical models.

The prefabricated houses made of ferro cement

have a good seismic behavior.

- Houses in Ferro cement can easily sustain in earthquake up to scale 7.5-8.
- Technique can be used for watertight structures and retrofitting of water structures
- The Ferro cement layers will substitute as shear reinforcement in the joint region. Hence the use of Ferro cement layers in strengthening joints without shear reinforcement will enhance the
- behavior of these joints and will reduce the vulnerability of these joints to be excessively

- damaged when subjected to seismic loading.
- Ferro cement construction is an exciting alternative to conventional wooden and masonry methods.
- Ferro cement is an innovative material and the ready availability of materials and ease of construction make it suitable in developing countries for housing, and water and food storage structures.

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