# LIGHTWEIGHT CONCRETE FOUR MEN ROWING CANOE

## Problem statement (Student activities):

Four men light weight concrete canoe is constructed for ASCE concrete canoe competition – 2020. Our Canoe MADARASAPATTINAM have won 3rd prize in ASCE concrete canoe competition in ACSE Indian conference. Our canoe got a best racer award too on that day .The challenge of this competition is to build our own concrete canoe for race (two men sprint, two women sprint, Co-ed sprint, two men slalom, two women slalom.).Research significance is to build a performance based analysis to build an economical and light weight canoe to perform better in race especially in slalom race. Our achievement on regional level ASCE was published in CI magazine by ACI, USA in June 2020 in page 17 attached at last page.

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Madras (Chennai), The Detroit of Asia and also the capital of Tamil Nadu, India, being the doorway to South India; Chennai serves as a place for various mixture of culture, tradition, food, etc., Also it carries the legacy of rich cultural heritage imbibed in its fine arts, music, dance forms, people and cuisines. There is a popular saying in Tamil, "Vandharai Vazhavaikkum Chennai" which literally means that "Chennai gives life to all those who seek to live in it". We are profusely elated to live among the people who follow "Yadhum oore yavarum kelir (I am a world citizen; every citizen is my kith and kin)", which was said by a poet named Kaniyan Poongunranar who lived 3000 years ago. In order to tribute its culture, contributions to the global market and harmonious living of the city, we named our canoe as "MADRASAPATTINAM", where 'Pattinam' means 'Coastal port region'.

Averting from the Stereotypical view of a team, where the group is divided into sub teams and the teams work only on the defined and assigned tasks such as hull design, structural analysis,construction, asthetics and rowing. The MADARASAPATTINAM team is very innovative and task centred attitude. Each member of the team does a part of work in all the process right from the start of design and up to the end of Final Completion of the task. The approach is integrated and well connected to encourage and expertise every individual to understand the complete process. brainstorm their views and ideas in their overall project which in turn leads to skill development and Manerigarial abilites.

An immense study was made to make an economical eco-friendly canoe by reducing its size. The key challenges in designing a smaller size canoe with maneuverability and straight-line speed. The length of the canoe was optimized to 4.75m (15.58ft). For optimization on the dimensions three miniature model with a scale ratio of 1:3 were constructed using concrete. ergonomic inputs were to achieve buoyancy, adequate space for rowers, optimum freeboard,

To impart highest accuracy to the mold. It is made with CNC cutting medium density fibre boards(recyclable). The cross sections of the male mould were cut from MDF using CNC cutting and the outer shell was fabricated using light weight lean concrete. The canoe's drag coefficient was found using drag test for all the three miniature canoes. The results of all the miniature canoes helped in designing the bow and stern rocker with reduced drag. Also, the miniature canoes were used to determine the approximate behavior of the practice and final canoe. The practice canoe was designed with a depth of 300mm, but at the time of practice the free board was found to be less. Hence the main canoe is cast with an increased depth of 360mm.

Then the canoe was finally made for the required depth with the special techniques. The thickness of the canoe varies from mid-section to the end section based on the stress requirements. Two layered woven glass fiber mesh with PVA fibers were used. Three special layers were used with main aggregate such as first and last layer is a high dense Glazed Iso Balls (GIB), and the mid layer with poraver. The confined mid layer expected to resist stresses and behaves as a core layer where as the top and inner layer provide durability and impermiability.

To impart sustainability in the whole competetion, Glazed Iso Balls was selected to be used as an aggregate which is a waste glass recycled product. The mould materials such as MDF and Expanded Poly styrene panels can be reused. In light weight concrete production 40% of Ordinary Portland Cement was replaced with Portland Slag Cement considering the sustainability aspects.

**TABLE 1 MADRASAPATTINAM's Specifications**

| | |
|---|---|
| Weight | 93.05 lbs |
| Length | 187 inch |
| Width | 18.11 inch |
| Depth | 14.17 inch |
| Thickness | 0.31 inch to 0.66 inch |
| Concrete Reinforcement | PVA Fibers |
| Hull's Reinforcement | Multi-layer Fiberglass Mesh |
| Non – Structural Concrete Color | Black, White |

**TABLE 2 MADRASAPATTINAM's CONCRETE PROPERTIES**

| | **Hull and Structural Elements Mix** | **Non-Structural Mix** |
|---|---|---|
| Wet unit weight (ASTM C138) | 52.55 lb/ft$^3$ | 58.87 lb/ft$^3$ |
| Oven-dried unit weight (ASTM C138) | 49.87 lb/ft$^3$ | 55.7482 lb/ft$^3$ |
| Concrete compressive strength at 28 days (ASTM C39) | 1725 psi | 1310 psi |
| Concrete tensile strength at 28 days (ASTM C78) | 172 psi | 72.52 psi |
| *Concrete composite flexural strength at 28 days (ASTM C78)* | 427 psi | 365 psi |
| Concrete slumps (ASTM C13) | 4.1" in. | 4.2" in. |
| Concrete air content (ASTM C138) | 2.4% | 4.9 % |

The Hull design of MADARASAPATTINAM was mainly developed from last year's OTTRAI ODAM, which is a single man rower canoe (Figure 1). The weight achieved by OTTRAI ODAM was 9.5kg and it won National Concrete Canoe Challenge in ASCE - NCCC 2019 conducted by SRM institute of Technology, India. OTTRAI ODAM contains a V-shaped hull which provides a smoother ride but reduced initial stability. The bottom of MADRASAPATTINAM was a combined V and Shallow arch, which compromised well between stability and speed. This hull bottom also helped in attaining good maneuverability, steering and good initial stability.

**Figure 1: OTTRAI ODAM**

Based on the performance of OTTRAI ODAM and study of various hull designs, three miniature canoe models of scale ratio 1:3 were designed. Instead of 3D printing, the Miniature canoe was made with concrete to reduce the cost and it also helped in better understanding of the main canoe. The miniature was subjected to drag test (Figure 3A). The outcomes from Figure 3B reveals that miniature 3 shows the better performance than other 2 as it achieved the lesser drag for our required velocity.

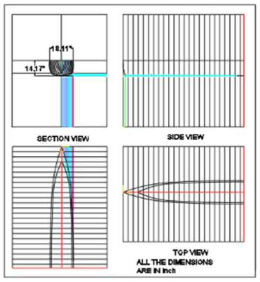



**Figure 2 Hull design using AutoCAD**

Using AutoCAD, the top view and side view was drawn and by fixing these the sectional view was obtained, which was used to calculate the amount of upward buoyant force based on Archimedes principle (Figure 2). On fixing the immersion to 200mm, an optimum shape of the primary canoe was finalized. The hull design team designed the primary canoe with shallow arch bottom at center span with a V bottom at its extremities. Shallow arch bottom will provide partial initial stability and better maneuverability, and V bottom is provided for better cutting and ease of water. Observing the results of the practice canoe by actual rowing, the captains were not satisfied with the results. Hence, two changes were adopted for the final canoe. One being, varying rocker from 2 inch to 4 inches at both bow and stern and the other was to increase the depth from 300mm to 360mm.These changes helped achieve a better free board and a better maneuverability in the final canoe. Though the free board was large it was undesirable. In order to overcome this and achieve optimized depth, canoe was cut and the depth of canoe was reduced. The G-Z curve was obtained using Prolines, from which the lateral stability and resisting moment offered by the hull shape was analyzed and the outcomes were shown in Figure 4.

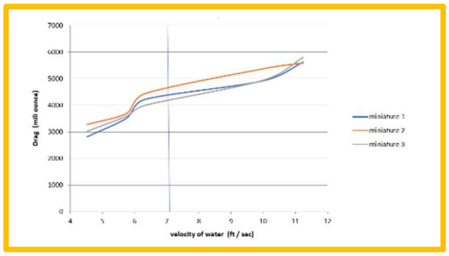



**Figure 3A: Drag Test** **Figure 3B: Drag Test Outcomes**

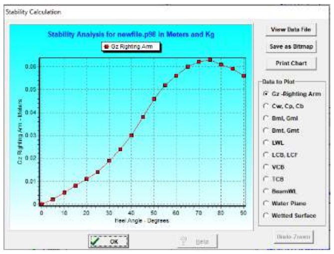


**Figure 4: G-Z Curve**

The GZ curve obtained from, indicated the resisting moment in relation with heel angle which showed that the resisting force offered by MADRASAPATTINAM was high compared to other shapes.

The structural analysis of our canoe was designed using the Working stress method. The working stress method was preferred because loading conditions are linear; there are no further loads in future; to withstand fatigue loads which occur during transportation; there is a variation of pressure due to loading and unloading and the design loads in the canoe remain the same. The main focus was laid up on the material behavior. Hence, the working stress method was performed which is concerned mainly with material behavior.


**Figure 5: Position of paddlers**

The analysis of canoe was done in 5 loading conditions: 1. Two Male paddlers 2. Two female paddlers 3. Co-ed paddlers 4. Transportation 5. Support on the stand. The weight of male paddlers was 112 lbs and 121 lbs. The weight of the female paddlers was 123 lbs and 137 lbs. The weight of the hull was approximately 93.50 lbs. The position of paddlers is fixed as shown in Figure 5. The seating position of the paddlers are 3.84, 7.12, 10.40 and 13.68 feet respectively from the bow (front end) of the ship. For analysis of the paddler load cases, the support conditions were assumed as elastic foundation and the canoe is assumed as a beam for all cases. On account of transportation, the canoe will be transported using a fabric in the form of a hanging cradle holding the canoe. These cradles are helpful in preventing the lateral forces and vibrations caused due to driving and flying, acting on the canoe. The canoe is simply supported at both stands, with the aid of wooden stands for displaying the prototype.

The waterline of the canoe is calculated for each load case. The self-weight of the canoe is evenly distributed over the entire span. Based on the loads and waterline, the buoyant force is calculated. Figure 6 shows the stress distribution analysis done in SOLIDWORKS. The bending moment diagram was obtained from Excel spreadsheet. The section at which maximum bending moment occurred at each case was taken and the case for which maximum tensile and compression stress occurred was used as a reference for further analysis. The paddlers are positioned likely to have a point force. The calculation of stress during turning is necessary because the strength may vary in different transverse angles.

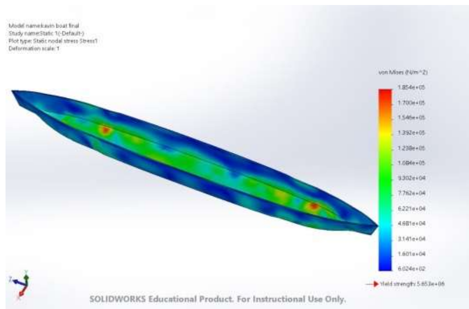



**Figure 6: SOLIDWORKS Stress distribution diagram**

The use of test panels with single layer mesh didn't provide the desired tensile strength. So, double layer mesh was adopted. Though adapting double layer mesh, the stress at the bottom of hull was found to be more as found in Table 3. Hence, overlapping of meshes was done. Thus, based upon the stress results, the thickness of the hull was varied to 0.62 inch in the mid-section and 0.39 inch at the extremities. By reducing the thickness, we reduced the weight of the canoe to 65.80 lbs.

**TABLE 3**: **Maximum Stress and Concrete Strength of Structural elements**

| Stress | Estimated stress (psi) | 28 Days Mechanical properties (psi) |
|---|---|---|
| Max.Tensile | 60.07 | 172 |
| Max. Comp | 43.77 | 1725 |

The main aim of the MADARASAPATTINAM design team was to produce optimized concrete mix having light weight as well as achieving the target strength. To improve the target strength, the team tried the mix design with poraver, by casting poraver cylinders and panels. The strength observed was higher than expected. Our plan was to combine both GIB and poraver in the design. The panel was cast together for checking the strength of GIB and poraver together as a composite and found to be appropriate for our canoe. The baseline materials consisted of Portland Cement as per ASTM C-150, Slag cement as per ASTM C-989, 3M, Polycarboxylate ether as per ASTM C494 Type F & G Poraver as per ASTMC-330, Alccofine, PVA fibre as per ASTM C-1116, glass fibre mesh as per ASTM C1116 and Pigments ASTM C979.

**Core Layer Mix**: The structural mix was designed in such a way that it had good compressive strength with reduced density.

*Ordinary Portland cement* was used mainly due to its cohesive and adhesive property, which makes it capable of combining the different construction materials and form the compacted assembly. The *slag cement* was used for its greenery nature and most importantly for higher long term compressive and flexural strengths, reduced permeability and improved durability. *Alccofine* is a cementitious material. It helps in achieving high strength. Due to its unique chemistry and ultra-fine particle size, ALCCOFINE 1203 is used as a high range water reducer to improve compressive strength or as a super workability aid to improve flow. Pozzolanic materials particles and creates a '*wall effect*' in the transition zone between the paste and the aggregate as shown in Figure 7. The weaker interface zone is strengthened owing to the superior bond developed between these two phases. It also refines the concrete microstructure and enhances the degree of impermeability, thus normally improving the strength and durable characteristics of concrete.

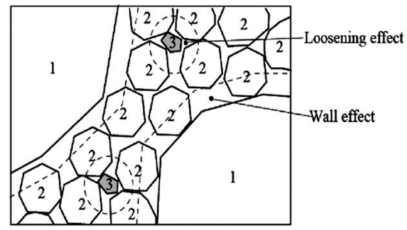



**Figure 7: Wall effect due to Alccofine**

After testing a wide range of aggregates like volcanic aggregate, vermiculite, GIB, perlite and poraver. The performance of poraver was found to be high in density as well as strength. *Poraver*, a white coloured light weight aggregate, consists of recycled glass aggregates. The density of Poraver on an average is 230kg/m$^3$ and the Grain size varies from 0.04 mm to 8 mm. Out of various grades, well graded aggregate of 'S' curve was obtained by grading as shown in table 4. The fineness modulus achieved has a fair packing of voids and high strength.

**TABLE 4 Gradation of Poraver**

| Aggregate Type | SG OD | SG SSD | Abs (%) | Particle Size (mm) | Volume % of Gradation |
|---|---|---|---|---|---|
| Poraver® | 0.260 | 0.30 | 15 | 2-4 | 6.53 |
| Poraver® | 0.450 | 0.375 | 20 | 1-2 | 5.13 |
| Poraver® | 0.470 | 0.391 | 20 | 0.5-1 | 2.13 |
| * OD – Oven Dry * SG – Specific Gravity * SSD – Saturated Surface Dry | | | | | |

*Glass fiber mesh* was used as reinforcement in double layers since it is light, strong as well as weather resistant. It is relatively strong and when embedded, it produces a high specific strength composite.

*PVA fibers* were used in middle layer because of its superior crack-fighting properties, excellent tensile and molecular bond strength, high modulus of elasticity and high resistance to alkali, UV, chemicals, fatigue and abrasion. The PVA fibers having superior crack fighting properties helped in prohibiting micro cracks in concrete. The quantity of PVA fibers required was 1% of cement content.

3M Glass Bubbles, engineered hollow glass microspheres are used as fillers. These low-density particles are used in a wide range of industries to reduce part weight, lower costs and enhance product properties. The unique spherical shape of 3M glass bubbles offers a number of important benefits, including: higher filler loading, lower viscosity/improved flow and reduced shrinkage and warpage.

The admixture used was Polycarboxylate *ether*. The purpose of Polycarboxylate ether is that it helps in reducing the water cement ratio and delays setting time by Steric Hindrance (Figure 8). The dispersion of cement particles occurs due to steric repulsion. Steric repulsion depends on the length of the main chain, length and number of side chains. However, they are more sensitive to overdosing, and can lead to problems such as retardation and excessive air entrainment. Hence appropriate quantity was calculated and carefully used.

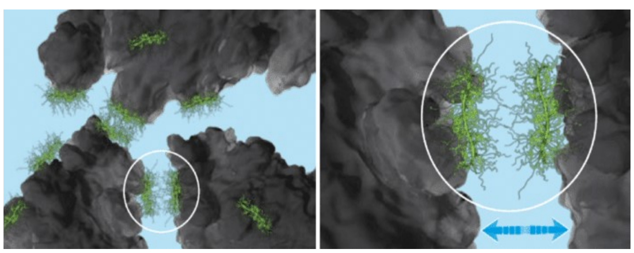


**Figure 8: Steric Hindrance**

The core layer mix as a whole has the constituents shown in table 5.

**TABLE 5: Mix design constituents for core layer**

| Materials | Standards |
|---|---|
| Ordinary Portland Cement | ASTM C-150 |
| Slag Cement | ASTM C-989 |
| Alccofine 1203 | N/A |
| Poraver | ASTM C-330 |
| 3M - K15 | N/A |
| PVA fibers | ASTM C-1116 |
| Glass fiber mesh | ASTM C-1116 |
| Master Glenium SKY 8587 | ASTM C494 Type F & G |

In order to achieve low density concrete, various trail mixes were done. There were 5 trial mixes. The density of the concrete was varied in successive trails by changing the gradation of aggregate and cement aggregate ratio. During the first trial when poraver and 3M was used in the mix, it was found that when the quantity of 3M was increased the setting time was delayed also the water absorption was increased due to poraver. In the second trail, when poraver was added in mix and reducing the 3M followed with well compaction, it led to segregation of concrete mix. Studying this behavior, the water cement ratio was varied in the next trials.

When the PCE was first used, it did not provide the desired result due to settling of PCE in the first layer mainly because of its oily nature. The whole water content was divided equally into two parts. In the first mix, 50% of water was added to the dry mix. In the remaining semi wet mix, PCE was mixed and it was studied.

The mixing was done by two methods: blending and hand mixing. In the blending process, blender is used. Since the crushing value of the poraver is very less, the use of a blender leads to breaking of poraver into powder. So, in order to avoid this problem, hand mixing was done. Finally, the cementitious materials were mixed using a blender and this was mixed with aggregates in hand mixing, which gave expected results in successive trials.

Figure 9 shows the Vacuum dewatering method. By vacuuming, most of the water content present in the concrete was absorbed out. The air pockets in the newspaper helped in absorbing water from the concrete surface excluding the water required for C-S-H gel formation. Following this vacuum dewatering method, the need for a shrinking agent was eliminated.

**Inner and outer layer mix:**

The inner and outer layer was designed in such a way that it was completely devoid of pores and also facilitated aesthetical works. With this in mind, our mix team planned to impart GIB, as this aggregate performed well in our OTTRAI ODAM canoe.

White cement was used in the inner and outer layer of the mix in suitable ratios to the iron pigments in order to ensure required aesthetics. White cement powder has a smoother surface because it is typically finer than gray cement powder. Designated color pigments can add permanent and decorative colors to white cement. Its setting behavior and strength development are essentially the same as that expected in gray cement, and it meets standard specifications such as ASTM C 150 and EN 197.

Higher potential strength also helps to counteract the strength-diminishing effects of pigment addition. Alccofine is also used as additional cementitious material for the wall effect property similar to the core mix.The aggregate used in this mix is GIB replacing Poraver. *GIB* (Glazed Iso Ball) is a light weight material produced by special process and is in the form of glass like bubbles. These are closed cell particles with high mechanical strength, very low water absorption & very high fire resistance characteristic. GIB being chemically inert has excellent heat & acoustic insulation characteristics & once mixed with cement, very high thermal resistance value can be achieved. For innovation we used GIB in mix design to achieve high strength and sustainability. GIB is more sustainable than poraver and therefore it is used in the inner and outer layers.

The mineral filler used is 3M and admixture used is Polycarboxylate ether which along with glass fiber mesh is provided as the reinforcement similar to the core layer mix. *Iron oxide pigment* is added in appropriate proportion to attain the intensity of color desired. Iron oxide pigments produce vibrant, durable colors in concrete and other cementitious materials. Iron oxide pigments are tested and certified by the American Society for the Testing of Materials to be light-fast, insoluble, and alkali resistant.

The final mix for inner and outer layer was obtained with successive trials and also from the experience of the behavior of materials from the core layer mix design. The inner and outer layers mix as a whole has the constituents shown in the table 6.

**TABLE 6 Mix design constituents for Inner and Outer layer**

| MATERIALS | STANDARDS |
|---|---|
| White Cement | ASTM C-150 |
| Alccofine 1203 | N/A |
| White Iron Oxide pigment | ASTM C-979 |
| 3M - K15 | N/A |
| GIB | N/A |
| Glass fiber mesh | ASTM C-1116 |
| Master Glenium SKY 8587 | ASTM C494 Type F & G |
| Master Air Glenium 71 | ASTM C260 |

To check various strength aspects like compression and tension, unit weight corresponding specimens was cast and tested based upon ASTM standards mentioned in table 7.

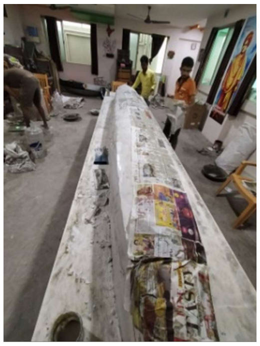


**Figure 9: Vacuum dewatering**

**TABLE 7: Testing Standards**

| ***Tests and Manipulations*** | ***Standard*** |
|---|---|
| Sample Preparation | ASTM C192 / C192M-18 |
| Flexural Strength | ASTM C78 / C78M-18 |
| Compressive Strength | ASTM C39 / C39M-18 |
| Young’s Modulus | ASTM C469 / C469M-14 |
| Unit Weight | ASTM C138 / C138M-17a |
| Air voids | ASTM C457 / C457M - 16 |

The aim of the MADARASAPATTINAM was to produce a robust canoe withstanding all the conditions, with a minimum overall cost and being light in weight without compromising the quality and standard of the canoe. From the culture of MADRAS "Unity in Diversity", the team followed the same by involving all the team members in casting of canoe. Initially the hull design was made using AutoCAD and the 3d model was rendered using SOLIDWORKS©. Following this, the stability was checked using Orca3D and Prolines. Ergonomics of the rowers was taken into account for the effective dimensions and design. Health and safety were prioritized in all areas of construction. A miniature model with 1:3 scale ratio to the main canoe was constructed for drag testing, study of statistical and dynamical behavior of the canoe. The miniature canoe was tested in all aspects for real time experience. The miniature model was constructed using clay mold technique which was tedious for using, as it involved high shrinkage. Keeping this in mind, a primary canoe was constructed which was used for the rowers to practice. The construction of the canoe was carried on a wooden table. The male mold for this primary canoe was prepared using MDF boards (Figure 10). These boards were cut into sections by CNC machines to obtain the shape of the hull. With the aid of Machine cutting, the need for human work was reduced and the safety aspects were ensured. These sections were arranged in order and the gaps between each section were filled with EPS sheets. Then it was covered with cement mortar to obtain the shape of the canoe rather than clay on a performance basis. Machine sanding process was carried out with proper safety equipment to obtain a smooth surface. To avoid voids and undulations cement mortar paste was coated over the mold and dried. Sanding process was iterated to obtain a smooth surface. For the purpose of de-molding easily, enamel coating was applied over the mold. The primary canoe was constructed using one of our trial concrete mix. The baseline materials used were OPC (53 Grade), glass fiber mesh, GIB,3M and additives.

**Figure 10: Mold preparation**

In Main canoe, to withstand the multiple load conditions acting on the canoe, we have used the confined concrete with the double layered glass fiber mesh which increases the flexural strength of the Canoe. The confined layer consists of 5 layers in which the concrete and glass fiber mesh was placed alternatively. A 6-inch overlap of the mesh was provided at all the points where the mesh was cut and also at the keel point of the canoe to have a safe distribution of stresses.

**Figure 11: First layering**

The First layer (Figure 11) was laid with white cement with GIB mix with hand placement and a layer of mesh was fused over the concrete layer by applying lateral load. Following this the second layer of concrete was fused over the primary mesh and a second layer of mesh was fused over the previous concrete layer. In the final layer (Figure 14), color pigments were used in the mix for aesthetic purposes

**Figure 12: Thickness checking**

The process of achieving the required thickness is a tedious process. In order to ensure the accurate thickness of the canoe, sections of the female mold at required thickness (Figure 12) were designed and used accordingly. Figure 13 shows the mesh overlapping and the final layer of canoe was shown in Figure 14.

**Figure 13: Mesh Overlapping**

After the casting of the main canoe, membrane curing was adopted. The removal of canoe from the mold was done by moving the canoe in clockwise and anticlockwise directions at each end respectively, forming a couple reaction. When one end is moved to the right, the other is moved to the left. By doing this process, the mold was detached from the wooden table after a few alternate movements. Once detached partially, the canoe was suspended outside the wooden table such that the MFD boards placed were removed from the underside.

**Figure 14: Final layer**


**Figure 15: Aesthetic stencil work**

After removal of all the MFD boards in this manner, and due to the applying of enamel coating on the concrete mold, it was easy to detach the canoe from the mold by gradual suspension from the wooden table. Emery sheets were used to remove the enamel which is stuck on the canoe. The use of enamel layer made the demolding easier. Finally, the canoe was detached safely from the mold. After demolding. curing process was followed. The curing was done by membranes. After curing, to make the surface smooth emery sheets were used which reduced the friction between water surface and concrete surface. A variety of emery paper was used starting from rough to smoot, to smoothen the surface during which water was sprayed on the surface and cleaned periodically to remove the surface dust. After achieving the satisfied surface, the canoe stencils were used for aesthetics (Figure 15) and was made ready for the NCCC event.

**Approach to Scope, Schedule, and Fee**:

Project management focused on creating organizational framework and attainable project scope and budget. Our ultimate objective was to make a high-quality product in accordance with prescribed standards and under estimated budget. The management team placed the safety of team members as the top priority throughout the project. The project manager administered the team as per timeline and cautiously supervised each and every task. To maximize the efficiency and quality of work, the captains were assigned the responsibility to administer the activities in each sector which includes academics, mix design, construction, aesthetics, management and safety. The project manager notified task deadlines in one-week advance and weekly review meetings were held to ensure team activities and testing process were on track. The meetings also provided a venue to administer updates, discuss new innovative features, make decisions, and resolve minor problems.

The pre-assessment of possible risks helped us to adhere to safe construction and testing procedures. Table 8 shows the schedule variation for our canoe.

**TABLE 8: Schedule variation**

| Milestone | Variance | Reason |
|---|---|---|
| Hull design | 0 | -- |
| Practice Canoe Fabrication | -1 Day | -- |
| Mix Design Finalized | (+) 10 Days | Additional testing for multilayer with varying density. |
| Final Canoe Fabricated | (+) 4 Days | Delay in material arrival |
| Attend PSWC | 0 | -- |

High standards of quality assurance and quality control were implemented into the project to monitor all aspects and improve upon the project's quality. These goals were accomplished through effective communication and exceptional time-management. A team of 10 dedicated members along with 10 supporting team members designed and constructed MADRASAPATTINAM in a total of 5710 man-hours. Table 9 shows the itemized fee summary.

The distribution of man-hours throughout the project duration is illustrated in Figure 16.

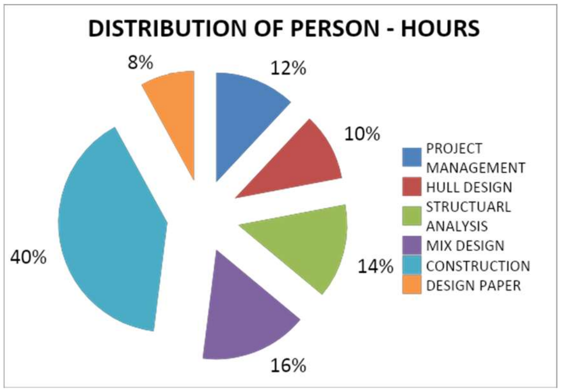



**Figure 16: Distribution chart**

The team determined the critical path by identifying dependent tasks in order to meet the major milestones of the project. It encompasses the finalizing mix and hull design, fabrication of mould, followed by casting of final canoe and ending up with PSWC.

The expected costs were determined to create the final budget. The prime portion of the budget was allocated to mix design and construction area for procurement of materials. The operational budget including travel expense $17400. The team approached local engineering and non-engineering firms for sponsorship and material donations which accounted for $ 8700.

The financial breakdown is shown in Figure 17.

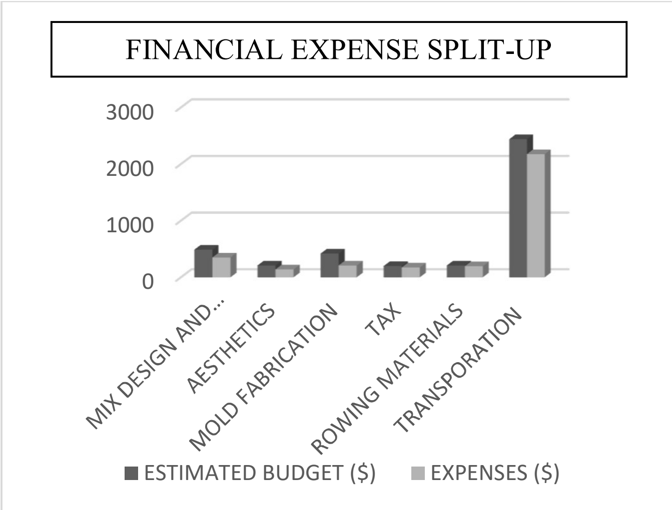



**Figure 17: Financial Expenses**

**Table -9 ITEMIZED FEE SUMMARY**

***Material cost***

| Materials | Unit cost | Quantity Required | Cost ($) |
|---|---|---|---|
| Portland cement | $0.03/lb | 24.15 lb | 0.72 |
| Portland Slag cement | $0.02/lb | 18.58 lb | 0.37 |
| White Portalnd cement | $0.02/lb | 17.62 lb | 0.35 |
| Alccofine | $0.172/lb | 12.64 lb | 2.17 |
| 3M | $6.08/lb | 6.423 lb | 39.05 |
| PVA fiber | $1.05/lb | 0.105 lb | 0.110 |
| GIB | $1.69/gal | 5.268 lb | 8.94 |
| Poraver | $5.09/lb | 42.69 lb | 217.29 |
| Superplasticizer | $3.46/gal | 0.017 gal | 0.058 |
| Air Entrainer | $3.34/gal | 0.045 gal | 0.15 |
| Glass fiber mesh | $0.12/ft$^2$ | 7.72 ft$^2$ | 0.926 |
| Water | $0.03/gal | 7.5 gal | 0.225 |
| Pigment | $5/lb | 0.12 lb | 0.6 |
| Total material cost | | | $270.95 |

***Projected Total Hours***

| Task | Distribution of Person - Hours |
|---|---|
| Project management | 125 |
| Hull design | 84 |
| Structural Analysis | 180 |
| Mix design | 264 |
| Construction | 415` |
| Design paper | 251 |
| Total hours | 1119 |

***Hourly rates***

| Position | Rate | Hours | Cost ($) |
|---|---|---|---|
| Principal Design Manager | $50/hr | 210 | 10500 |
| Design Manager | $45/hr | 53 | 2385 |
| Project Construction Manager | $40/hr | 320 | 12800 |
| Quality Manager | $35/hr | 118 | 4130 |
| Graduate Field Engineer (EIT) | $25/hr | 186 | 4650 |
| Technician/Drafter | $20/hr | 110 | 2200 |
| Laborer/Technician | $25/hr | 122 | 3050 |
| Total Raw Labor | | | $39715 |

***Direct labor***

| Labor cost-Inputs | Cost ($) |
|---|---|
| Raw labor | $39715 |
| Direct Employee | $59572.5 |
| Indirect Employee | $51629.5 |
| Profit Multiplier | $27165.06 |
| Direct labor | $178082.06 |

***Expenses***

| Expenses-Inputs | Costs ($) |
|---|---|
| Material costs | $262.07 |
| Direct expenses | $140 |
| Markup | 0.1 |
| Expenses | $402.07 |

***Estimated shipping Costs***

| Shipping carrier | Fedex |
|---|---|
| Point of origin | Erode, India |
| Destination | Madison, WI |
| Shipping method | Freight |
| Cost | $1400.15 |

***Total project costs***

| Total cost-Inputs | Cost ($) |
|---|---|
| Direct Labor | $178082.06 |
| Expenses | $402.07 |
| Shipping | $1400.15 |
| Total | $179884.28 |

**APPROACH TO HEALTH AND SAFETY:**

The aspects of Health & Safety are given prior consideration and planned for all stages of the process. In our Canoe project team, the engineering characteristics of components used were studied clearly in order to assess how one has to be cautious while dealing with the component. Most of the practical aspects and activities were discussed, pre-empted and then executed with the guidance of professors, lab technicians and senior teams. Use of relevant Personal Protective Equipment (PPE) namely Hand gloves, Safety shoes, Safety goggles & Dust respiratory masks were practiced and due attention was given for the safety of limbs. Also, the life jackets and headgear straps were checked for its functionality and used by everyone. Rowing practice was taught & conducted in a uniform manner after proper stretching exercises to prevent any muscle spasm or strain. A team of trained practitioners for quick support were always kept at bay, lest a contingency arises. Thus, with proper awareness, knowledge, training and by being vigilant the Team's Health & Safety was ensured at all times.

**APPROACH TO QUALITY CONTROL AND QUALITY ASSURANCE:**

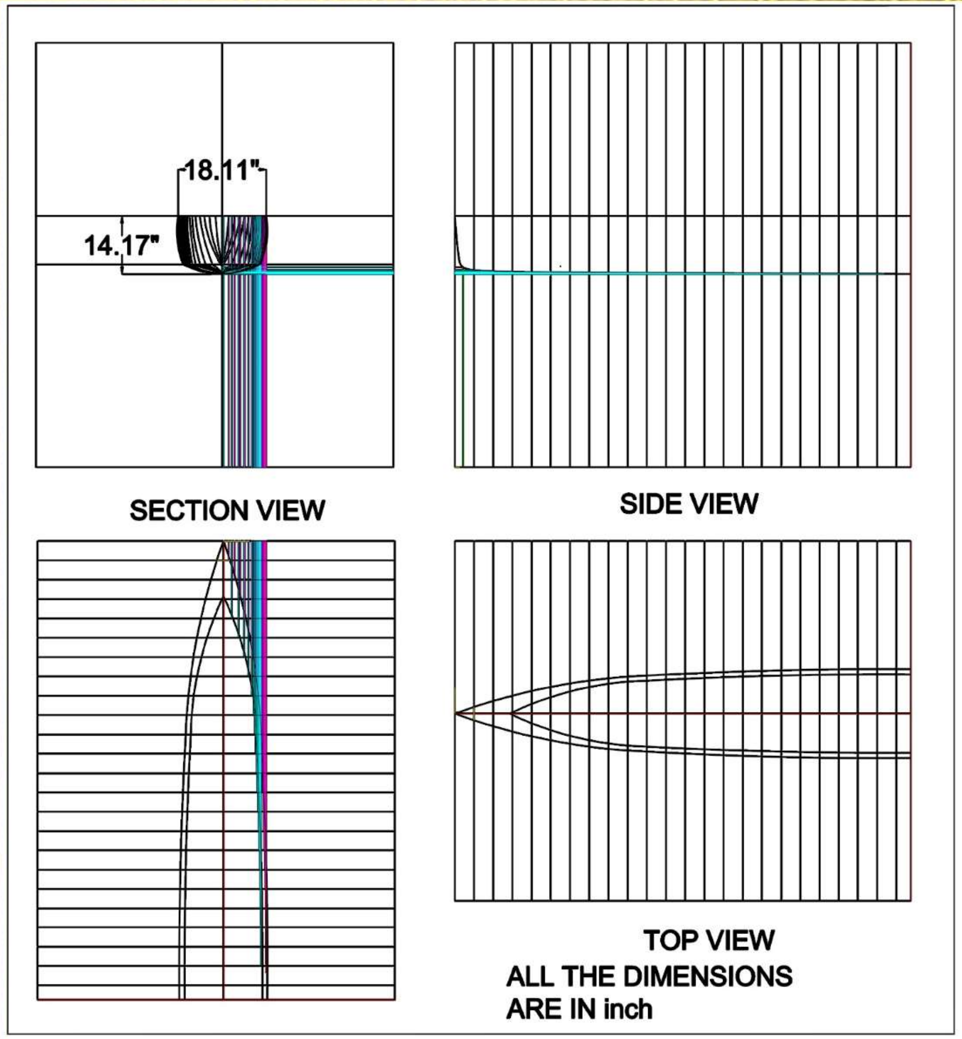
The objectives and goals were explained clearly to the team members, which helped them work more effectively. The team leaders supervised the team right from the start and continued up to the end of the competition. The materials were purchased from an authorized dealer. All the materials were tested and verified with standard codes. The team leaders monitored and maintained documentation of what their respective teams were doing. All the team leaders gathered in weekly meetings to discuss their progress. The method of construction is verified by the project manager as well as the faculty advisor.

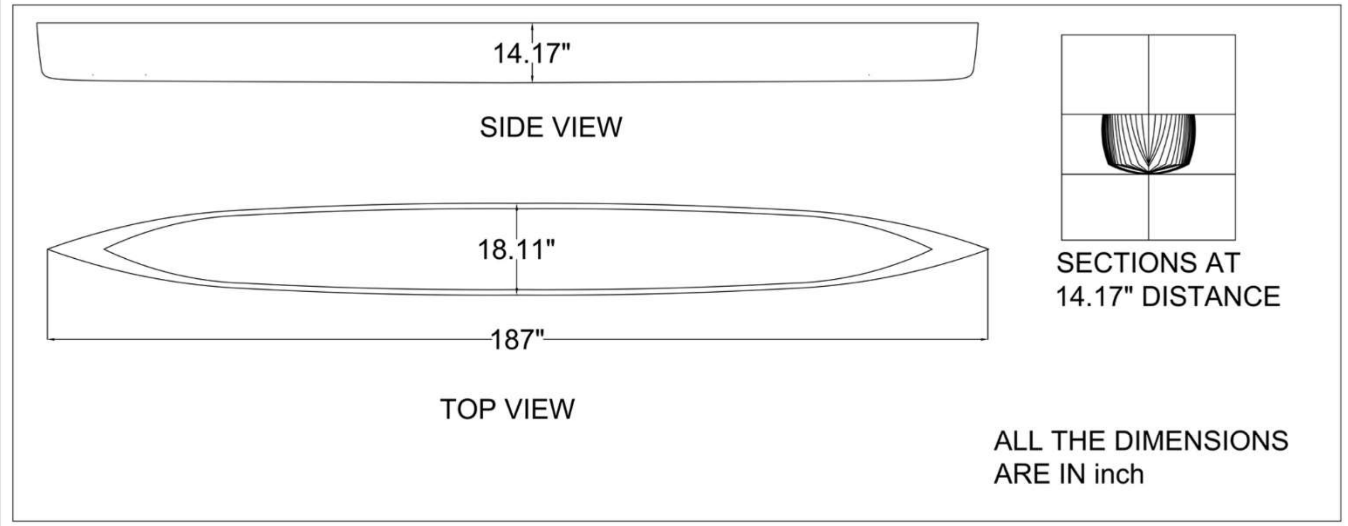
**APPROACH TO SUSTAINABILITY:**

In the construction process, the cement was partially replaced with Ground Granulated Blast Furnace Slag (GGBS). Ground Granulated Blast Furnace Slag is a by-product from the steel industry. It has good structural and durable properties with less environmental effects. In this, the carbon dioxide emission is very low when compared to the ordinary Portland cement and thus being sustainable. In mold preparation the steel sections are used which are reusable for future purposes ensuring economic methodology. The Mold made up of concrete used for primary canoe was reused for Main canoe and this mold can be used for further casting. This type of mold is economical. Poraver, which was used in the mix is made up of recycled glass material. Thus, the canoe is sustainable as well as economical.

**AESTHETICS:**

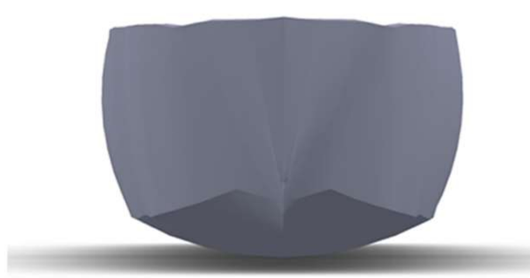
The MADARASAPATTINAM teamhas designed the outer surface of the canoe with various paintings highlighting the culture, tradition and heritage of MADRAS. Based on the Yin Yang symbol showing the balance of life, the canoe is designed with black and white color expressing the balance of canoe in all conditions. For the design on the canoe, coloring pigments were used. The canoe is designed using Adobe Photoshop and then stencils were created by CNC cutting.




SECTIONS DRAWN FROM
TOP VIEW AND SIDE VIEW

# ISOMETRIC VIEW



SECTIONAL VIEW

SOLIDWORKS Educational Product. For Instructional Use Only.

SIDE VIEW

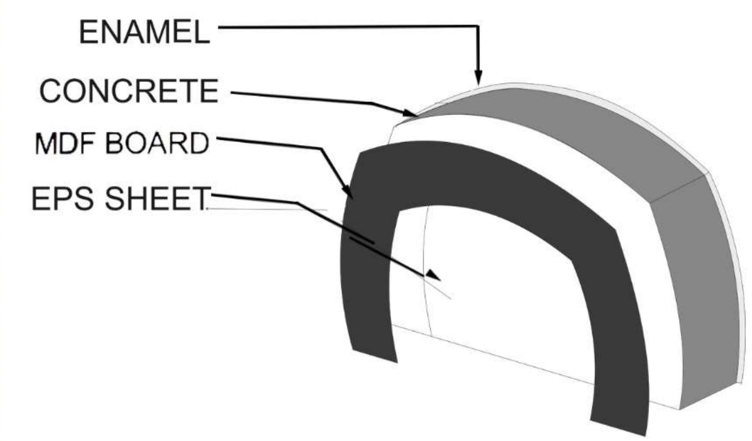
# Construction chart

## PORAVER MIX

| No | DESCRIPTION | QTY | UNIT |
|---|---|---|---|
| 1 | Type1 Ordinary portland cement | 16.6 | lbs |
| 2 | Green cement | 11.069 | lbs |
| 3 | Alccofine | 2.517 | lbs |
| 4 | poraver(2-4)mm | 5.279 | lbs |
| 5 | poraver(1-2)mm | 6.22 | lbs |
| 6 | poraver(0.5-1)mm | 2.82 | lbs |
| 7 | 3M | 1.258 | lbs |
| 8 | Water | 15.244 | lbs |
| 9 | PCE | 0.1173 | lbs |
| 10 | PVA fibers | 0.0629 | lbs |

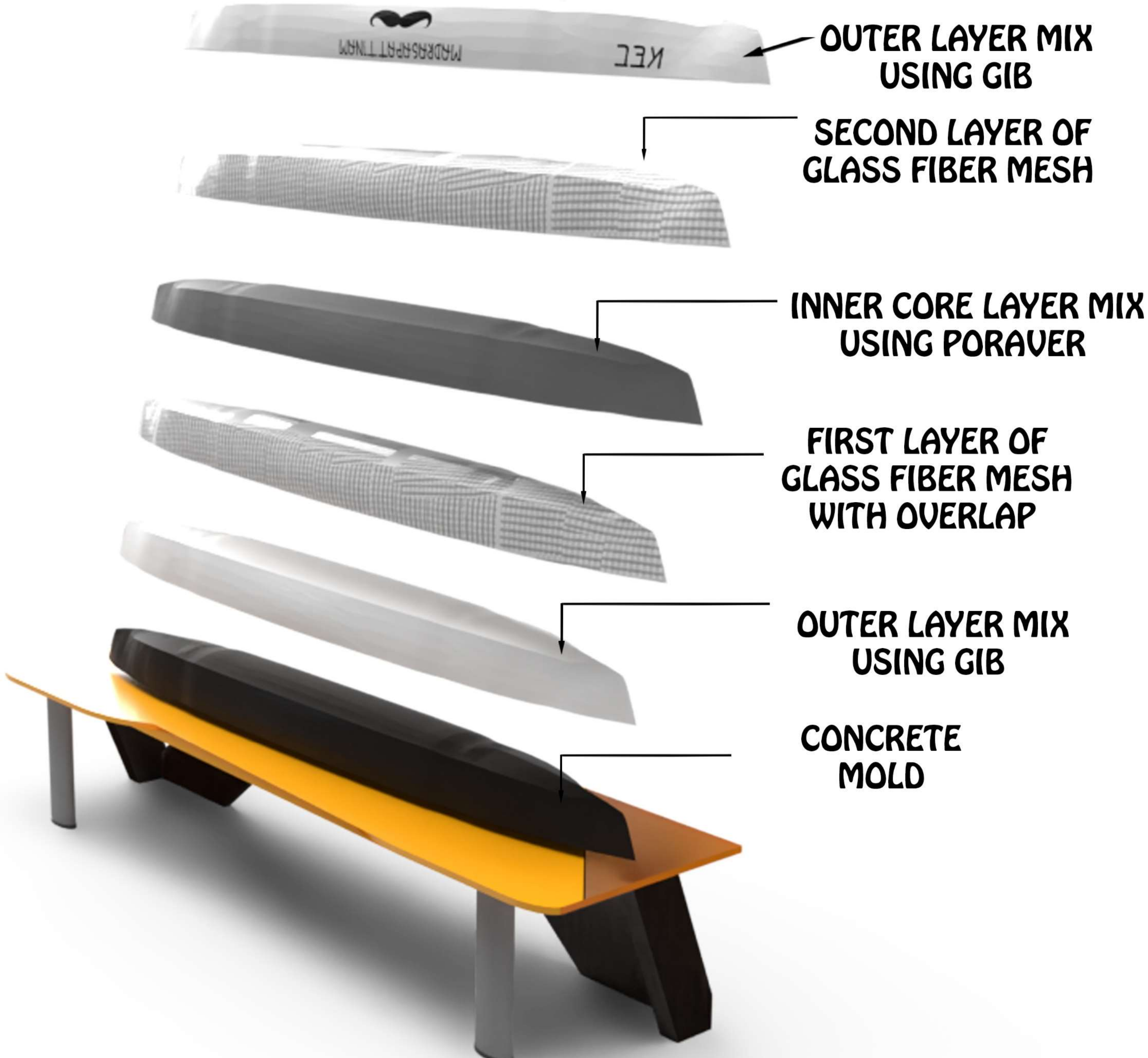
## GIB MIX

| No | DESCRIPTION | QTY | UNIT |
|---|---|---|---|
| 1 | White Cement | 11.544 | lbs |
| 2 | Alccofine | 0.4024 | lbs |
| 3 | GIB | 2.99 | lbs |
| 4 | Master Glesarin 8587 | 0.049 | lbs |
| 5 | Master Air 72c | 0.032 | lbs |
| 6 | Colour pigments | 0.052 | lbs |
| 7 | 3M | 0.524 | lbs |
| 8 | Water | 6.043 | lbs |




LAYERS OF MOLD

MADRASAPATTINAM

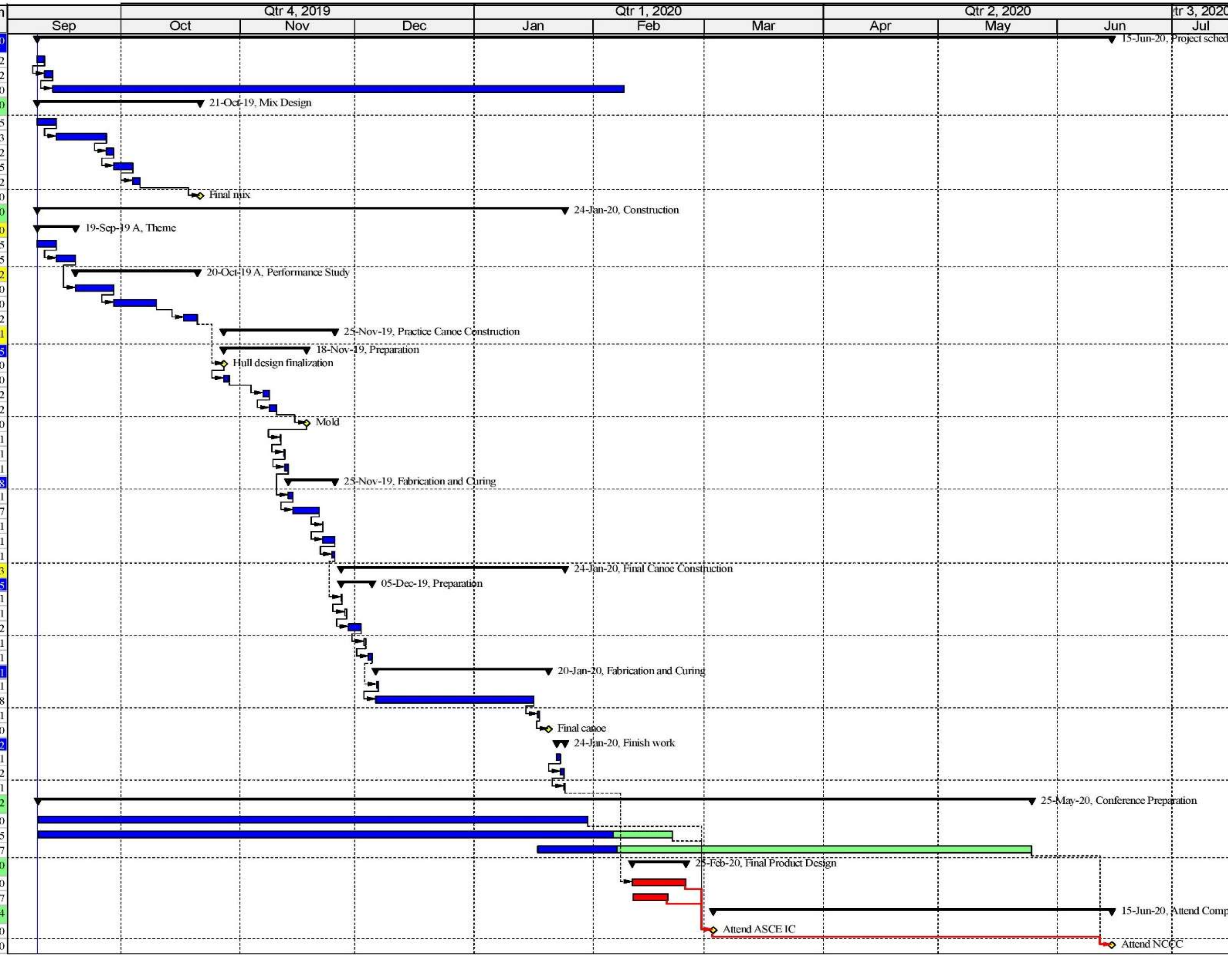

OUTER LAYER MIX
USING GIB
SECOND LAYER OF
GLASS FIBER MESH
INNER CORE LAYER MIX
USING PORAVER
FIRST LAYER OF
GLASS FIBER MESH
WITH OVERLAP
OUTER LAYER MIX
USING GIB
CONCRETE
MOLD

TOP VIEW

# PROJECT SCHEDULE

MADRASAPATTINAM

| # | Task Name | Start | Finish | Duration |
|---|---|---|---|---|
| 1 | **Project schedule** | 09-Sep-19 A | 15-Jun-20 | 200 |
| 2 | Inaugural meeting | 09-Sep-19 A | 11-Sep-19 A | 2 |
| 3 | Recruitment | 11-Sep-19 A | 13-Sep-19 A | 2 |
| 4 | Fundraising | 13-Sep-19 A | 09-Feb-20 | 100 |
| 5 | **Mix Design** | 09-Sep-19 A | 21-Oct-19 | 30 |
| 6 | Selection of material | 09-Sep-19 A | 14-Sep-19 A | 5 |
| 7 | Purchasing of material | 14-Sep-19 A | 27-Sep-19 A | 13 |
| 8 | Testing of material | 27-Sep-19 A | 29-Sep-19 A | 2 |
| 9 | Trial mixes | 29-Sep-19 A | 04-Oct-19 A | 5 |
| 10 | Finalization of mix design | 04-Oct-19 A | 06-Oct-19 A | 2 |
| 11 | Final mix | | 21-Oct-19* | 0 |
| 12 | **Construction** | 09-Sep-19 A | 24-Jan-20 | 100 |
| 13 | **Theme** | 09-Sep-19 A | 19-Sep-19 A | 10 |
| 14 | Decide theme | 09-Sep-19 A | 14-Sep-19 A | 5 |
| 15 | Develop aesthetic design | 14-Sep-19 A | 19-Sep-19 A | 5 |
| 16 | **Performance Study** | 19-Sep-19 A | 20-Oct-19 A | 32 |
| 17 | Hull design | 19-Sep-19 A | 29-Sep-19 A | 10 |
| 18 | Construction of canoe miniature | 29-Sep-19 A | 10-Oct-19 A | 10 |
| 19 | Testing of miniature | 17-Oct-19 A | 20-Oct-19 A | 2 |
| 20 | **Practice Canoe Construction** | 27-Oct-19 A | 25-Nov-19 | 21 |
| 21 | **Preparation** | 27-Oct-19 A | 18-Nov-19 | 15 |
| 22 | Hull design finalization | | 27-Oct-19 A | 0 |
| 23 | Prepare mold material | 27-Oct-19 A | 29-Oct-19 | 10 |
| 24 | CNC cutting of section | 06-Nov-19 A | 08-Nov-19 A | 2 |
| 25 | Laser cutting of base | 08-Nov-19 A | 10-Nov-19 A | 2 |
| 26 | Mold | | 18-Nov-19* | 0 |
| 27 | Filling of mold | 11-Nov-19 A | 11-Nov-19 A | 1 |
| 28 | Finishing of mold | 12-Nov-19 | 12-Nov-19* | 1 |
| 29 | Prepare reinforcement layers | 12-Nov-19 A | 13-Nov-19 A | 1 |
| 30 | **Fabrication and Curing** | 13-Nov-19 A | 25-Nov-19 | 8 |
| 31 | Fabricate practice canoe | 13-Nov-19 A | 14-Nov-19 A | 1 |
| 32 | Cure practice canoe | 14-Nov-19 A | 21-Nov-19 A | 7 |
| 33 | Demold practice canoe | 22-Nov-19* | 22-Nov-19 | 1 |
| 34 | Sanding practice canoe | 22-Nov-19 A | 25-Nov-19 A | 1 |
| 35 | Refine fabrication methods | 25-Nov-19 A | 25-Nov-19 A | 1 |
| 36 | **Final Canoe Construction** | 27-Nov-19 A | 24-Jan-20 | 43 |
| 37 | **Preparation** | 27-Nov-19 A | 05-Dec-19 | 5 |
| 38 | Cleaning canoe mold | 27-Nov-19* | 27-Nov-19 | 1 |
| 39 | Level construction table | 28-Nov-19* | 28-Nov-19 | 1 |
| 40 | Dry batch mix material | 29-Nov-19 A | 02-Dec-19 A | 2 |
| 41 | Prepare reinforcement layer | 03-Dec-19* | 03-Dec-19 | 1 |
| 42 | Apply release agent to canoe mold | 04-Dec-19 A | 05-Dec-19 A | 1 |
| 43 | **Fabrication and Curing** | 06-Dec-19 A | 20-Jan-20 | 31 |
| 44 | Fabricate final canoe | 06-Dec-19 A | 07-Dec-19 A | 1 |
| 45 | Cure final canoe | 06-Dec-19 A | 16-Jan-20 A | 28 |
| 46 | Demold final canoe | 17-Jan-20 A | 18-Jan-20 A | 1 |
| 47 | Final canoe | | 20-Jan-20* | 0 |
| 48 | **Finish work** | 22-Jan-20 A | 24-Jan-20 | 2 |
| 49 | Place 3D Elements | 22-Jan-20 A | 23-Jan-20 A | 1 |
| 50 | Apply colour concrete Layer | 23-Jan-20 A | 24-Jan-20 A | 2 |
| 51 | Apply lettering | 24-Jan-20* | 24-Jan-20 | 1 |
| 52 | **Conference Preparation** | 09-Sep-19 A | 25-May-20 | 182 |
| 53 | Technical proposal and MTDS | 09-Sep-19 A | 30-Jan-20 | 100 |
| 54 | Technical presentation | 09-Sep-19 A | 21-Feb-20 | 125 |
| 55 | Paddling practice | 17-Jan-20 A | 25-May-20 | 87 |
| 56 | **Final Product Design** | 11-Feb-20 | 25-Feb-20 | 10 |
| 57 | Design and build canoe stands | 11-Feb-20* | 25-Feb-20 | 10 |
| 58 | Design and build poster | 11-Feb-20* | 20-Feb-20 | 7 |
| 59 | **Attend Competetions** | 03-Mar-20 | 15-Jun-20 | 74 |
| 60 | Attend ASCE IC | 03-Mar-20* | | 0 |
| 61 | Attend NCCC | 15-Jun-20* | | 0 |




Actual task | Critical task | Summary
Planed task | Milestone

Madrasapattinam Project Schedule

### TABLE 10: MIX PROPORTIONS: CORE LAYER

***CEMENTITIOUS MATERIALS***

| *Component* | *Specific Gravity* | *Volume(ft³)* | *Amount of CM (lb/yd³)* | |
|---|---|---|---|---|
| *Portland cement, $cm_1$* | 3.15 | 1.96 | 384.702 | *Total cm (includes c)*<br>**699.492***lb/yd³*<br>*c/cm ratio, by mass*<br>**0.55** |
| *Portland Slag Cement , $cm_2$* | 2.90 | 1.417 | 256.468 | |
| *Alccofine, $cm_3$* | 2.86 | 0.293 | 58.32 | |

**FIBERS**

| *Component* | *Specific Gravity* | *Volume(ft³)* | *Amount of Fibers(lb/yd³)* | |
|---|---|---|---|---|
| *PVA microfibres* | 1.19 | *0.0292* | *1.458* | *Total Amount of Fibers*<br>**1.458***lb/yd³* |

**AGGREGATES (EXCLUDING MINERAL FILLERS PASSING NO. 200 SIEVE)**

| *Aggregates* | *Expanded Glass (EG)* | *Abs (%)* | *$SG_{OD}$* | *$SG_{SSD}$* | *Base Quantity, W(lb/yd³)* | | *Volume, $V_{agg, SSD}$(ft³)* |
|---|---|---|---|---|---|---|---|
| | | | | | *$W_{OD}$* | *$W_{SSD}$* | |
| *Poraver® 2.0-4.0mm* | Yes | 15 | 0.260 | 0.300 | 106.37 | 122.32 | 6.53 |
| *Poraver® 1.0-2.0mm* | Yes | 20 | 0.450 | 0.375 | 120.779 | 144.142 | 5.13 |
| *Poraver® 0.5-1.0mm* | Yes | 20 | 0.470 | 0.391 | 54.45 | 65.34 | 2.13 |

**LIQUID ADMIXTURES**

| *Admixture* | *lb/ US gal* | *Dosage (fl.oz/cwt)* | *% Solids* | *Amount of Water in Admixture(lb/yd³)* |
|---|---|---|---|---|
| ***Master Glenium Sky 8587*** | 8.90 | 8.5 | 34% | 2.72 |

**SOLIDS (DYES, POWDERED ADMIXTURES, AND MINERAL FILLERS)**

| *Component* | *Specific Gravity* | *Volume(ft³)* | *Amount (lb/yd³)* | |
|---|---|---|---|---|
| ***Solid Component of Liquid Dye, $S_{ld}$*** | NA | NA | NA | *Total Solids. $S_{total}$*<br>29.17 lb/yd³ |
| ***Powdered Admixture, $S_{p\ admix}$*** | NA | NA | NA | |
| ***3M K-15 Glass Microspheres*** | 0.15 | 3.12 | 29.17 | |

**WATER**

| | | *Amount(lb/yd³)* | *Volume(ft³)* |
|---|---|---|---|
| ***Water, $w$,[=∑ ($w_{free}$ + $w_{admx}$ + $w_{batch}$) ]*** | *w/c ratio, by mass*<br>**0.91**<br>*w/cm ratio, by mass*<br>**0.5** | 353.208 | 5.660 |
| ***Total Free Water from All Aggregates, ∑$w_{free}$*** | | -51.61 | |
| ***Total Water from All Admixtures, ∑$w_{admx}$*** | | 2.70 | |
| ***Batch Water, $w_{batch}$*** | | 402.118 | |

**DENSITIES, AIR CONTENT, RATIOS, AND SLUMP**

| | *Cm* | *Fibers* | *Aggregate (SSD)* | *Solids, $S_{total}$* | *Water, w* | *Total* |
|---|---|---|---|---|---|---|
| ***Mass, M (lb)*** | 699.49 | 1.458 | 331.802 | 29.17 | 353.208 | *∑M:1415.128* |
| ***Absolute Volume, V( ft³)*** | 3.67 | 0.0196 | 13.812 | 3.12 | 5.660 | *∑V:26.28* |

| | | | |
|---|---|---|---|
| ***Theoretical Density, T, (=∑M / ∑V)*** | *53.85 lb/ft³* | ***Air Content, Air,**[= (T – D)/T x 100%]* | *2.4 %* |
| ***Measured Density, D*** | *52.55 lb/ft³* | ***Air Content, Air,** [= (27 – ∑V))/27 x 100%]* | *2.6 %* |
| ***Total Aggregate Ratio²**(= $V_{agg, SSD}$/ 27)* | 0.516 | ***Slump, Slump flow, Spread** (as applicable)* | *4.3" in.* |
| ***EG+C Ratio³**(=$V_{EG+C}$ / $V_{agg,SSD}$)* | *NA* | | |

# TABLE 11: MIX PROPORTIONS: OUTER LAYER AND INNER LAYER

| ***CEMENTITIOUS MATERIALS*** | | | | |
|---|---|---|---|---|
| ***Component*** | ***Specific Gravity*** | ***Volume(ft³)*** | ***Amount of CM (lb/yd³)*** | |
| *White Cement $cm_2$* | *2.90* | *4.4364* | *802.829* | *Total cm (includes c)* ***802.829*** *lb/yd³ & c/cm ratio, by mass* ***0.91*** |
| *Alccofine, $cm_1$* | 2.86 | 0.4089 | *72.9845* | |
| **FIBERS** | | | | |
| ***Component*** | ***Specific Gravity*** | ***Volume(ft³)*** | ***Amount of Fibers(lb/yd³)*** | |
| *Microfibres* | **NA** | **NA** | **NA** | **NA** |

| **AGGREGATES (EXCLUDING MINERAL FILLERS PASSING NO. 200 SIEVE)** | | | | | | | |
|---|---|---|---|---|---|---|---|
| ***Aggregates*** | ***Expanded Glass (EG)*** | ***Abs (%)*** | ***$SG_{OD}$*** | ***$SG_{SSD}$*** | ***Base Quantity, W(lb/yd³)*** | | ***Volume, $V_{agg, SSD}$(ft³)*** |
| | | | | | ***$W_{OD}$*** | ***$W_{SSD}$*** | |
| *Glazed Iso Ball* | No | *11* | 0.32 | 0.288 | *187.34* | *207.94* | *10.424* |

| **LIQUID ADMIXTURES** | | | | |
|---|---|---|---|---|
| ***Admixture*** | ***lb/ US gal*** | ***Dosage (fl.oz/cwt)*** | ***% Solids*** | ***Amount of Water in Admixture(lb/yd³)*** |
| *Master Glenium Sky 8587* | *8.90* | *8.5* | *34%* | *3.41* |
| *Master Air 721* | *9.10* | *4.25* | *15%* | *2.24* |

| **SOLIDS (DYES, POWDERED ADMIXTURES, AND MINERAL FILLERS)** | | | | |
|---|---|---|---|---|
| ***Component*** | ***Specific Gravity*** | ***Volume(ft³)*** | ***Amount (lb/yd³)*** | |
| ***Solid Component of Liquid Dye, $S_{ld}$*** | NA | NA | NA | *Total Solids. $S_{total}$* ***40.141***lb/yd³ |
| ***Iron Oxide Colour pigments*** | 4.3 | 0.0135 | 3.649 | |
| ***K-15 Glass Microspheres*** | 0.15 | *3.898* | *36.4923* | |

| **WATER** | | | |
|---|---|---|---|
| | ***Amount(lb/yd³)*** | | ***Volume(ft³)*** |
| ***Water,*** *w,[=∑ ($w_{free}$ + $w_{admx}$ + $w_{batch}$) ]* | *w/c ratio, by mass* ***0.902*** *w/cm ratio, by mass* ***0.5*** | *419.653* | *6.725* |
| ***Total Free Water from All Aggregates,*** *$\sum w_{free}$* | | *-19.768* | |
| ***Total Water from All Admixtures,*** *$\sum w_{admx}$* | | *5.65* | |
| ***Batch Water,*** *$w_{batch}$* | | *433.77* | |

| **DENSITIES, AIR CONTENT, RATIOS, AND SLUMP** | | | | | | |
|---|---|---|---|---|---|---|
| | ***Cm*** | ***Fibers*** | ***Aggregate (SSD)*** | ***Solids, $S_{total}$*** | ***Water, w*** | ***Total*** |
| ***Mass, M (lb)*** | 875.813 | NA | 207.94 | 40.14 | 419.653 | ***∑M: 1547.44*** |
| ***Absolute Volume,*** *V(* ***ft³*** *)* | 4.436 | NA | 10.41 | 3.915 | 6.725 | ***∑V: 25.486*** |
| ***Theoretical Density,*** *T, (=∑M / ∑V)* | *61.77* | | ***Air Content, Air,***[= (T – D)/T x 100%] | | | *4.9 %* |
| ***Measured Density,*** *D* | *58.87* | | ***Air Content, Air,*** *[= (27 – ∑V))/27 x 100%]* | | | *5.6%* |
| ***Total Aggregate Ratio²*** *(= $V_{agg, SSD}$/ 27)* | 0.38 | | ***Slump, Slump flow, Spread*** *(as applicable)* | | | *4.1" in.* |
| ***EG+C Ratio³*** *(=$V_{EG+C}$ / $V_{agg,SSD}$)* | *NA* | | | | | |

## TERMS AND FORMULAS

***Abs*** = absorption of an aggregate, whether taken as a whole, the coarse, or the fine aggregate, *%*.
***admx*** = admixtures
***air*** = gravimetric air content, per ASTM C138, *%*.
***agg*** = aggregate
***c*** = cement
***cm*** = cementitious materials (including cement)
***c/cm*** = ratio of cement to cementitious materials, by mass, *dimensionless*
***cwt*** = hundred weight of cementitious material (example 750lb/yd$^3$ of cm is 7.5cwt)
***f*** = fibers
***ld*** = liquid dyes
***M*** = mass, *lb*.
$MC_{total}$ = total moisture content referenced to the oven-dried condition of the aggregate, *%*.
$MC_{free}$ = free moisture content, referenced to the saturated, surface-dry condition (SSD), of the aggregate, *%*.
***mf*** = mineral fillers (i.e., aggregate-like materials passing the No. 200 sieve (75□m)
***D*** = measured density (wet, plastic) of concrete test cylinders, per ASTM C138, *lb/ft*$^3$.
***T*** = theoretical density of concrete (zero air voids), per ASTM C138, *lb/ft*$^3$.
$S_{ld}$ = solids in liquid dyes
$S_{padmx}$ = solids of powdered admixtures
$S_{total}$ = total solids of liquid dyes, powdered admixtures, and mineral fillers, *lb/yd*$^3$.
$SG_{SSD}$ = specific gravity, in the saturated, surface-dry condition, of aggregate, *dimensionless*.
$SG_{OD}$ = specific gravity, in the oven-dried condition, of aggregate, *dimensionless*.
***V*** = volume, *ft*$^3$.
$V_{agg,SSD}$ = volume, in the saturated, surface-dry condition, of aggregate,*ft*$^3$.
***EG*** = expanded glass
**C** = cenospheres
$V_{EG+C}$ = volume, in the saturated, surface-dry condition, of aggregate classified as expanded glass or as cenospheres, *ft*$^3$.
$W_{SSD}$ = mass, in the saturated, surface-dry condition, of aggregate per unit volume of concrete, *lb/yd*$^3$.
$W_{OD}$ = mass, in the oven-dried condition, of aggregate per unit volume of concrete, *lb/yd*$^3$.
$W_{stk}$ = mass, in the stock moisture condition, of the aggregate per unit volume of concrete, *lb/yd*$^3$.
$w_{admx}$ = the mass of water in the admixtures, per unit volume of concrete, *lb/yd*$^3$.
$w_{batch}$ = the mass of water to be batched per unit volume of concrete when the aggregates are in a stock moisture condition, *lb/yd*$^3$.
$w_{free}$ = free water carried into the batch by a wet per unit volume of concrete, *lb/yd*$^3$.
***w/c*** = water to cement ratio, by mass, *dimensionless*.
***w/cm*** = water to cementitious material ratio, by mass, *dimensionless*

## MIX CONSTITUENTS

| Materials | Quantity | Properties |
|---|---|---|
| Portland Cement Type IL | $384.702 lb$ | $SG = 3.15$ |
| Green Cement | $256.468\ lb$ | $SG = 2.90$ |
| $PVA\ Micro - Fibers$ | $1.458\ lb$ | $SG = 0.91$ |
| $Alccofine$ <br> $*\ Dosedat\ 8\%\ of Cementious Material amount$ | $58.32 lb$ | $SG = 2.86$ |
| $3M\ K\ 15\ Microspheres$ | $29.17\ lb$ | $SG = 0.15$ |
| $\frac{W}{CM} Ratio$ | 0.50 | - |
| $Dosage Admixtures$: <br> $(32\%\ solids\ by\ weight, 8.9\ \frac{lb}{gal})$ | $8.5\ \frac{fl oz}{cwt}\ Mastergleniu mSky\ 8587$ | $SG = 1.08$ |

### ***Mass of Cementitious Material, Fibers, Solids, & Water***

$$Mass_{Portland\ Cement} = 384.702\ \frac{lb}{yd^3}$$

$$Mass_{\ Portland\ Slag\ Cement} = 256.468\ \frac{lb}{yd^3}$$

$$Mass_{\ alccofine} = 58.32\ \frac{lb}{yd^3}$$

$$\boldsymbol{Mass_{Cementitious\ Materials} = Mass_{Portland\ \ Cement} + Mass_{Portland\ Slag\ Cement} + Mass_{\ alcofine}}$$

$$= 384.702\ \frac{lb}{yd^3} + 256.468\ \frac{lb}{yd^3} + 58.32\ \frac{lb}{yd^3}$$

$$= 699.49\ \frac{lb}{yd^3}$$

$$\boldsymbol{Mass_{Water} = \frac{Water}{CM}\ Ratio * Mass_{Cementitious\ Materials}}$$

$$= 0.50 * 699.49\ \frac{lb}{yd^3} \quad = 349.75\ \frac{lb}{yd^3}$$

$$Mass_{fibers} = 1.458\ \frac{lb}{yd^3}$$

$$Mass_{\ 3m}(mineral\ fillers) = 29.17\ \frac{lb}{yd^3}$$

### ***Volume of Cementitious Materials, Fibers, 3M, & Water***

$$Volume_{Portland\ Cement} = \frac{Mass_{Portland\ Cement}}{SG_{Portland\ Cement} * 62.4\ \frac{lb}{ft^3}} = \frac{384.702\ \frac{lb}{yd^3}}{3.15 * 62.4\ \frac{lb}{ft^3}} = 1.96\ \frac{ft^3}{yd^3}$$

$$Volume_{Portland\ Slag\ Cement} = \frac{Mass_{\ Portland\ Slag\ Cement}}{SG_{Portland\ Slag\ Cement} * 62.4\frac{lb}{ft^3}} = \frac{256.468\ \frac{lb}{yd^3}}{2.90 * \ 62.4\ \frac{lb}{ft^3}} = 1.417\ \frac{ft^3}{yd^3}$$

$$Volume_{alccofine} = \frac{Mass_{\ alccofine}}{SG_{alccofine} * 62.4\frac{lb}{ft^3}} = \frac{58.32\ \frac{lb}{yd^3}}{2.86 * \ 62.4\ \frac{lb}{ft^3}} = 0.326\frac{ft^3}{yd^3}$$

$$Volume_{Cementitious\ Materials} = Volume_{Portland\ \ Cement} + Volume_{\ green\ \ Cement} + Volume_{alcofine}$$
$$= 1.96\ \frac{ft^3}{yd^3} + 1.417\ \frac{ft^3}{yd^3} + \ 0.3\frac{ft^3}{yd^3}$$
$$= 3.68\ \frac{ft^3}{yd^3}$$

$$Volume_{Fibers} = \frac{Mass_{Fibers}}{SG_{Fibers} \ * \ 62.4\ \frac{lb}{ft^3}} = \frac{1.458\frac{lb}{yd^3}}{1.19 * 62.4\ \frac{lb}{ft^3}} = \ 0.0196\ \ \frac{ft^3}{yd^3}$$

$$Volume_{3m} = \frac{Mass_{3m}}{SG_{3\ m} * \ 62.4\ \frac{lb}{ft^3}} = \frac{29.17\frac{lb}{yd^3}}{0.15 * 62.4\ \frac{lb}{ft^3}} = \ 3.12\ \ \frac{ft^3}{yd^3}$$

$$Volume_{Water} = \frac{Mass_{Water}}{62.4\ \frac{lb}{ft^3}} = \frac{353.208\ \frac{lb}{yd^3}}{62.4\ \frac{lb}{ft^3}} = \ 5.660\ \ \ \frac{ft^3}{yd^3}$$

***Water from Admixtures***

$$\boldsymbol{Water_{Admx} = Dosage\ oz * Cwt_{Cementitious\ Materials} * Water\ Content * \frac{1\ gal}{128\ fl\ oz} * \frac{lb}{gal\ of\ admixture}}$$

$$Water_{MastergleniumSky\ 8587} = 8.5\frac{fl\ oz}{cwt} * \frac{699.49\ \frac{lb}{yd^3}}{100} * (1-0.34) * \frac{1\ gal}{128\ fl\ oz} * 8.9\frac{lb}{gal} = 2.72\ \frac{lb}{yd^3}$$

***Volume of Aggregates***

$$Volume_{Aggregate} = 27\ \frac{ft^3}{yd^3} - Volume_{Cementious\ Materials} - Volume_{Fibers} - Volume\ _{3m} - Volume_{Water} - Volume_{Air}$$

| ***Aggregate Distribution*** | |
|---|---|
| *Poraver ®2- 4 mm* | *47%* |
| *Poraver ® 1-2 mm* | *37%* |
| *Poraver ® 0.5-1 mm* | *16%* |

*Note: Percentages based on gradation distribution*

$$Volume_{Aggregate} = 27\ \frac{ft^3}{yd^3} - 3.68\frac{ft^3}{yd^3} - 0.0196\ \frac{ft^3}{yd^3} - 3.12\ \frac{ft^3}{yd^3} - 5.66\ \frac{ft^3}{yd^3} - 0.54\ \frac{ft^3}{yd^3} = 13.98\ \frac{ft^3}{yd^3}$$

$$Volume_{Poraver\ 2-4} = Volume_{Aggregate} * \ Poraver\ 2-4Ratio = 14.52\frac{ft^3}{yd^3} * 0.47 = 6.824\ \frac{ft^3}{yd^3}$$

$$Volume_{Poraver\ 1-2} = Volume_{Aggregate} * \ Poraver\ 1-2\ Ratio = 14.52\frac{ft^3}{yd^3} * 0.37 = 5.372\ \frac{ft^3}{yd^3}$$

$$Volume\ _{Poraver\ 0.5-1} = Volume_{Aggregate} * \ Poraver\ 0.5-1\ Ratio = 14.52\frac{ft^3}{yd^3} * 0.16 = 2.323\ \frac{ft^3}{yd^3}$$

***Volumetric Check***

$$Aggregate\ Ratio = \frac{Volume_{Aggregate}}{27\ \frac{ft^3}{yd^3}} * 100 = \frac{13.955\ \frac{ft^3}{yd^3}}{27\ \frac{ft^3}{yd^3}} * 100 = 51.6\ \%$$

$$Aggregate\ Ratio > 25 = \boldsymbol{Acceptable}$$

**Mass of Aggregates**

| | | | |
|---|---|---|---|
| $\mathbf{SG_{SSD\ (Poraver\ 2-4)}}$ | $= \mathbf{0.300}$ | $\mathbf{Abs_{Poraver\ 1-2}}$ | $= \mathbf{15.0}\ \%$ |
| $\mathbf{SG_{SSD\ (Poraver\ 1-2)}}$ | $= \mathbf{0.450}$ | $\mathbf{Abs_{Poraver\ 1-2}}$ | $= \mathbf{20.0}\ \%$ |
| $\mathbf{SG\ _{SSD\ (Poraver\ 0.5-1)}}$ | $= \mathbf{0.470}$ | $\mathbf{Abs\ _{Poraver\ 0.5-1}}$ | $= \mathbf{20.0}\ \%$ |

**Oven Dry Specific Gravity**

$$SG_{OD(Aggregate)} = \frac{SG_{SSD(Aggregate)}}{1 + \ Abs_{Aggregate}}$$

$$SG_{OD(Poraver\ 2-4)} = \frac{0.30}{1+0.15} = 0.260$$

$$SG_{OD(Poraver\ 1-2)} = \frac{0.450}{1+0.20} = 0.375$$

$$SG_{OD(Poraver\ 0.5-1)} = \frac{0.470}{1+0.20} = 0.391$$

**Base Quantities of Aggregates**

$$W_{OD(Aggregate)} = Volume_{Aggregate} * SG_{OD(Aggregate)} * 62.4 \frac{lb}{ft^3}$$

$$W_{SSD(Aggregate)} = W_{OD(Aggregate)} * \left(1 + Abs_{Aggregate}\right)$$

$$W_{OD(Poraver\ 2-4)} = 6.556 \frac{ft^3}{yd^3} * 0.260 * 62.4 \frac{lb}{ft^3}$$

$$= 106.37 \frac{lb}{yd^3}$$

$$W_{SSD(Poraver\ 2-4)} = 106.37 \frac{lb}{yd^3} * (1 + 0.15)$$

$$= 122.32 \frac{lb}{yd^3}$$

$$W_{OD(Poraver\ 1-2)} = 5.1615 \frac{ft^3}{yd^3} * 0.375 * 62.4 \frac{lb}{ft^3}$$

$$= 120.779 \frac{lb}{yd^3}$$

$$W_{SSD(Poraver\ 1-2)} = 120.779 \frac{lb}{yd^3} * (1 + 0.20)$$

$$= 144.142 \frac{lb}{yd^3}$$

$$W_{OD(Poraver\ 0.5-1)} = 2.232 \frac{ft^3}{yd^3} * 0.391 * 62.4 \frac{lb}{ft^3}$$

$$= 54.45 \frac{lb}{yd^3}$$

$$W_{SSD(Poraver\ 0.5-1)} = 54.45 \frac{lb}{yd^3} * (1 + 0.20)$$

$$= 65.34 \frac{lb}{yd^3}$$

## *Aggregate Volume Check*

$$Volume_{Aggregate} = \frac{W_{SSD(Aggregate)}}{SG_{SSD(Aggregate)} * 62.4\ \frac{lb}{ft^3}}$$

$$Volume_{Aggregate} = \frac{W_{OD(Aggregate)}}{SG_{OD(Aggregate)} * 62.4\ \frac{lb}{ft^3}}$$

$$Volume_{Poraver\ 2-4} = \frac{122.32\ \frac{lb}{yd^3}}{0.30 * 62.4\frac{lb}{ft^3}} = 6.53\ \frac{ft^3}{yd^3}\ Volume_{Poraver2-4}$$

$$= \frac{106.37\frac{lb}{yd^3}}{0.260 * 62.4\ \frac{lb}{ft^3}} = 6.55\frac{ft^3}{yd^3}$$

$$Volume_{Poraver\ 1-2} = \frac{144.142\ \frac{lb}{yd^3}}{0.45 * 62.4\frac{lb}{ft^3}} = 5.13\frac{ft^3}{yd^3}\ Volume_{Poraver\ 1-2}$$

$$= \frac{120.779\frac{lb}{yd^3}}{0.375 * 62.4\ \frac{lb}{ft^3}} = 5.16\ \frac{ft^3}{yd^3}$$

$$Volume\ _{Poraver\ 0.5-1} = \frac{65.34\ \frac{lb}{yd^3}}{0.470 * 62.4\frac{lb}{ft^3}} = 2.13\frac{ft^3}{yd^3} Volume\ _{Poraver\ 0.5-1}$$

$$= \frac{56.68\frac{lb}{yd^3}}{0.391 * 62.4\ \frac{lb}{ft^3}} = 2.32\ \frac{ft^3}{yd^3}$$

## *Mass of Aggregates*

$$Mass_{Aggregate} = \sum W_{SSD(Aggregate)}$$

$$Mass_{Aggregate} = 127.319\frac{lb}{yd^3} + 150.865\frac{lb}{yd^3} + 68.016\frac{lb}{yd^3} = 331.802\frac{lb}{yd^3}$$

## *Total Concrete Mass*

$$Mass = Mass_{Cementious\ Material} + Mass_{Fibers} + Mass_{Aggregates} + Mass\ _{3m} + Mass_{Water}$$

$$Mass = 699.49 \frac{lb}{yd^3} + 1.458 \frac{lb}{yd^3} + 331.802 \frac{lb}{yd^3} + 29.17 \frac{lb}{yd^3} + 353.208 \frac{lb}{yd^3} = 1415.128 \frac{lb}{yd^3}$$

***Absolute Concrete Volume***

$$Volume = Volume_{Cementious\ Materials} + Volume_{Fibers} + Volume_{Aggregates} + Volume_{3m} + Volume_{Water}$$

$$Volume = 3.67 \frac{ft^3}{yd^3} + 0.019 \frac{ft^3}{yd^3} + 13.812 \frac{ft^3}{yd^3} + 3.12 \frac{ft^3}{yd^3} + 5.66 \frac{ft^3}{yd^3} = 26.281 \frac{ft^3}{yd^3}$$

***Theoretical Density***

$$T = \frac{Mass}{Volume} = \frac{1415.128 \frac{lb}{yd^3}}{26.281 \frac{ft^3}{yd^3}} = 53.85 \frac{lb}{ft^3}$$

***Measured Density***

$$M = 52.55 \frac{lb}{ft^3}$$

***Air Content***

$$Air\ Content = \frac{(T - M)}{T} * 100 = \frac{53.85 - 52.55}{53.85} * 100 = 2.4\%$$

***Air Content Check***

$$Air\ Content\ Check = \frac{\left(27 \frac{ft^3}{yd^3} - Volume\right)}{27 \frac{ft^3}{yd^3}} * 100 = \frac{\left(27 \frac{ft^3}{yd^3} - 26.281 \frac{ft^3}{yd^3}\right)}{27 \frac{ft^3}{yd^3}} * 100 = 2.6\ \%$$

**Free Water from Aggregates**

| Stock Moisture Content |
| --- |
| *Poraver®2.0-4.0 mm, Poraver®1.0-2.0 mm, Poraver®0.5-1.0 mm,* |
| *assumed Moisture Content Stock = 0.5%* |

***Mass in Stock Moisture Content***

$$MC_{stk(Aggregate)} = W_{OD(Aggregate)} * \left(1 + \frac{MC_{stk}}{100}\right)$$

$$MC_{stk\ (Poraver\ 2-4)} = 110.712 \frac{lb}{yd^3} * \left(1 + \frac{0.5}{100}\right)$$

$$= 111.26 \ \frac{lb}{yd^3}$$

$$MC_{stk\ (Poraver\ 1-2)} = 125.721 \frac{lb}{yd^3} * \left(1 + \frac{0.5}{100}\right)$$

$$= 126.349 \ \frac{lb}{yd^3}$$

$$MC_{stk\ (Poraver\ 0.5-1)} = 56.68 \frac{lb}{yd^3} * \left(1 + \frac{0.5}{100}\right)$$

$$= 56.96 \ \frac{lb}{yd^3}$$

***Total Moisture Content***

$$MC_{Total\ (Aggregate)} = \frac{\left(MC_{stk(Aggregate)} - W_{OD(Aggregate)}\right)}{W_{OD(Aggregate)}}$$

$$MC_{Total\ (Poraver\ 2-4)} = \frac{\left(111.26 \frac{lb}{yd^3} - 110.712 \frac{lb}{yd^3}\right)}{110.712 \frac{lb}{yd^3}} = 0.005$$

$$MC_{Total\ (Poraver\ 1-2)} = \frac{\left(126.349 \frac{lb}{yd^3} - 125.721 \frac{lb}{yd^3}\right)}{125.721 \frac{lb}{yd^3}} = 0.005$$

$$MC_{Total(Poraver\ 0.5-1)} = \frac{\left(56.96 \frac{lb}{yd^3} - 56.68 \frac{lb}{yd^3}\right)}{56.68 \frac{lb}{yd^3}} = 0.005$$

$$MC_{Total\ (Poraver\ 0.25-0.5)} = \frac{\left(47.044 \frac{lb}{yd^3} - 46.81 \frac{lb}{yd^3}\right)}{46.81 \frac{lb}{yd^3}} = 0.005$$

$$MC_{Total\ (Poraver\ 0.1-0.3)} = \frac{\left(22.59 \frac{lb}{yd^3} - 22.47 \frac{lb}{yd^3}\right)}{22.47 \frac{lb}{yd^3}} = 0.005$$

**_Free Moisture Content_**

$$MC_{Free\ (Aggregate)} = MC_{Total\ (Aggregate)} - Abs_{Aggregate}$$

$$MC_{Total\ (Poraver\ 2-4)} = 0.005 - 0.15 = -0.145$$

$$MC_{Total\ (Poraver\ 1-2)} = 0.005 - 0.20 = -0.195$$

$$MC_{Total\ (Poraver\ 0.5-1)} = 0.005 - 0.20 = -0.195$$

**_Mass in Stock Moisture Content Condition_**

$$W_{Stk\ (Aggregate)} = W_{OD(Aggregate)} * MC\ _{Free\ (Aggregate)}$$

$$W_{Stk(Poraver\ 2-4)} = 110.712\frac{lb}{yd^3} * -0.15 = -16.05\ \frac{lb}{yd^3}$$

$$W_{Stk(Poraver\ 1-2)} = 125.721\frac{lb}{yd^3} * -0.20 = -24.51\ \frac{lb}{yd^3}$$

$$W_{Stk(Poraver\ 0.5-1)} = 56.68\ \frac{lb}{yd^3} * -0.20 = -11.05\ \frac{lb}{yd^3}$$

**_Batch Water Calculations_**

$$W_{Free} = \sum W_{Stk(Aggregates)}$$

$$W_{Free} = -16.05\frac{lb}{yd^3} + -24.51\ \frac{lb}{yd^3} + -11.05\ \frac{lb}{yd^3} = -62.692\frac{lb}{yd^3}$$

$$W_{Batch} = Mass_{Water} - W_{Admx} - W_{Free}$$

$$W_{Batc} = 353.208\frac{lb}{yd^3} - 2.70\frac{lb}{yd^3} - (-51.61)\frac{lb}{yd^3} = 402.2118\frac{lb}{yd^3}$$

**_Cement – Cementitious Materials Ratio_**

$$\frac{C}{CM} = \frac{384.702\ lb}{699.49\ lb} = 0.55$$

**_Water- Cementitious Materials Ratio_**

$$\frac{W}{CM} = \frac{346.375}{699.49} = 0.50$$

**_Water- Cement Ratio_**

$$\frac{W}{C} = \frac{353.208}{384.702} = 0.91$$

## MIX PROPOTIONS: OUTER AND INNER LAYER MIX

| Materials | Quantity | Properties |
|---|---|---|
| White Cement | 802.829 lbs | $SG = 3.15$ |
| $Alccofine$ $* Dosedat\ 8\%\ of CementiousMaterialamount$ | 72.9845 lbs | $SG = 2.86$ |
| $K\ 15\ Microspheres$ | 36.4923 lbs | $SG = 0.15$ |
| $\frac{W}{CM} Ratio$ | 0.50 | |
| $DosageAdmixtures$: $34\%\ solidsbyweight, 8.9\ \frac{lb}{gal})$ $(15\%\ solidsbyweight, 9.10\ \frac{lb}{gal})$ | $8.5\ \frac{floz}{cwt} MastergleniumSky\ 8587$ $4.25\ \frac{floz}{cwt} Masterair\ 721$ | $SG = 1.08$ $SG = 1.01$ |

### *Mass of Cementitious Material, Fibers, Solids, & Water*

$$Mass_{White\ Cement} = 802.829 \frac{lb}{yd^3}$$

$$Mass_{\ alcofine} = 72.984 \frac{lb}{yd^3}$$

$$\boldsymbol{Mass_{Cementitious\ Materials} = Mass_{White\ Cement} + Mass_{\ alcofine}}$$

$$= 802.829 \frac{lb}{yd^3} + 72.984 \frac{lb}{yd^3}$$

$$= 875.813 \frac{lb}{yd^3}$$

$$\boldsymbol{Mass_{Water} = \frac{Water}{CM} Ratio * Mass_{Cementitious\ Materials}}$$

$$= 0.50 * 875.813 \frac{lb}{yd^3} = 437.90 \frac{lb}{yd^3}$$

$$Mass_{\ 3m}(mineral\ fillers) = 36.492 \frac{lb}{yd^3}$$

### *Volume of Cementitious Materials, Fibers, Sm, & Water*

$$Volume_{White\ Cement} = \frac{Mass_{White\ Cement}}{SG_{White\ Cement} * 62.4 \frac{lb}{ft^3}} = \frac{802.829 \frac{lb}{yd^3}}{2.90 * 62.4 \frac{lb}{ft^3}} = 4.436 \frac{ft^3}{yd^3}$$

$$Volume_{alcofine} = \frac{Mass_{\ alcofine}}{SG_{alcofine} * 62.4 \frac{lb}{ft^3}} = \frac{72.984 \frac{lb}{yd^3}}{2.86 * 62.4 \frac{lb}{ft^3}} = 0.408 \frac{ft^3}{yd^3}$$

$$Volume_{Cementitious\ Materials} = Volume_{White\ Cement} + Volume_{alcofine} = 4.436 \frac{ft^3}{yd^3} + 0.408 \frac{ft^3}{yd^3}$$

$$= 4.844 \frac{ft^3}{yd^3}$$

$$Volume_{3m} = \frac{Mass_{3m}}{SG_{3m} * 62.4 \frac{lb}{ft^3}} = \frac{36.492 \frac{lb}{yd^3}}{0.15 * 62.4 \frac{lb}{ft^3}} = 3.898 \frac{ft^3}{yd^3}$$

$$Volume_{Water} = \frac{Mass_{Water}}{62.4 \frac{lb}{ft^3}} = \frac{419.653 \frac{lb}{yd^3}}{62.4 \frac{lb}{ft^3}} = 6.725 \frac{ft^3}{yd^3}$$

***Water from Admixtures***

$$Water_{Admx} = Dosage\ oz * Cwt_{Cementitious\ Materials} * Water\ Content * \frac{1\ gal}{128\ fl\ oz} * \frac{lb}{gal\ of\ admixture}$$

$$Water_{Masterglenium Sky\ 8587} = 8.5 \frac{fl\ oz}{cwt} * \frac{875.813 \frac{lb}{yd^3}}{100} * (1 - 0.34) * \frac{1\ gal}{128\ fl\ oz} * 8.9 \frac{lb}{gal}$$
$$= 3.41 \frac{lb}{yd^3}$$

$$Water_{Master\ Air\ 721} = 4.25 \frac{fl\ oz}{cwt} * \frac{875.813 \frac{lb}{yd^3}}{100} * (1 - 0.15) * \frac{1\ gal}{128\ fl\ oz} * 9.10 \frac{lb}{gal} = 2.24 \frac{lb}{yd^3}$$

***Volume of Aggregates***

$$Volume_{Aggregate} = 27 \frac{ft^3}{yd^3} - Volume_{Cementious\ Materials} - Volume_{\ Solids} - Volume_{Water} - Volume_{Air}$$

$$Volume_{Aggregate} = 27 \frac{ft^3}{yd^3} - 4.842 \frac{ft^3}{yd^3} - 3.915 \frac{ft^3}{yd^3} - 6.7252 \frac{ft^3}{yd^3} - 1.09 \frac{ft^3}{yd^3} = 10.424 \frac{ft^3}{yd^3}$$

***Volumetric Check***

$$Aggregate\ Ratio = \frac{Volume_{Aggregate}}{27 \frac{ft^3}{yd^3}} * 100 = \frac{10.424 \frac{ft^3}{yd^3}}{27 \frac{ft^3}{yd^3}} * 100 = 38.60\ \%$$

$$Aggregate\ Ratio > 25 = \boldsymbol{Acceptable}$$

**Mass of Aggregates**

$SG_{SSD\ (GIB)} = 0.32$  $Abs_{GIB} = 11.0\ \%$

**Oven Dry Specific Gravity**

$$SG_{OD(Aggregate)} = \frac{SG_{SSD(Aggregate)}}{1 + Abs_{Aggregate}}$$

$$SG_{OD(GIB)} = \frac{0.32}{1 + 0.11} = 0.288$$

**Base Quantities of Aggregates**

$$W_{OD(Aggregate)} = Volume_{Aggregate} * SG_{OD(Aggregate)} * 62.4\ \frac{lb}{ft^3}$$

$$W_{SSD(Aggregate)} = W_{OD(Aggregate)} * \left(1 + Abs_{Aggregate}\right)$$

$$W_{OD(GIB)} = 10.424\ \frac{ft^3}{yd^3} * 0.288 * 62.4\ \frac{lb}{ft^3}$$

$$= 187.34\ \frac{lb}{yd^3}$$

$$W_{SSD(GIB)} = 187.34\ \frac{lb}{yd^3} * (1 + 0.11)$$

$$= 207.94\ \frac{lb}{yd^3}$$

***Aggregate Volume Check***

$$Volume_{Aggregate} = \frac{W_{SSD(Aggregate)}}{SG_{SSD(Aggregate)} * 62.4\ \frac{lb}{ft^3}}$$

$$Volume_{Aggregate} = \frac{W_{OD(Aggregate)}}{SG_{OD(Aggregate)} * 62.4\ \frac{lb}{ft^3}}$$

$$Volume_{GIB} = \frac{207.94\ \frac{lb}{yd^3}}{0.32 * 62.4\ \frac{lb}{ft^3}} = 10.42\ \frac{ft^3}{yd^3} \qquad Volume_{GIB} = \frac{187.34\ \frac{lb}{yd^3}}{0.288 * 62.4\ \frac{lb}{ft^3}} = 10.424\ \frac{ft^3}{yd^3}$$

***Mass of Aggregates***

$$Mass_{Aggregate} = \sum W_{SSD(Aggregate)} \qquad Mass_{Aggregate} = 207.94\ \frac{lb}{yd^3}$$

***Total Concrete Mass***

$$Mass = Mass_{Cementious\ Material} + Mass_{Aggregates} + Mass_{Soilds} + Mass_{Water}$$

$$Mass = 875.813\ \frac{lb}{yd^3} + 207.94\ \frac{lb}{yd^3} + 40.14\ \frac{lb}{yd^3} + 419.653\ \frac{lb}{yd^3}$$

$$= 1547.44\frac{lb}{yd^3}$$

***Absolute Concrete Volume***

$$Volume = Volume_{Cementious\ Materials} + Volume_{Aggregates} + Volume_{Solds} + Volume_{Water}$$

$$Volume = 4.436\ \frac{ft^3}{yd^3} + 10.41\frac{ft^3}{yd^3} + 3.915\ \frac{ft^3}{yd^3} + 6.725\frac{ft^3}{yd^3}$$

$$= 25.486\frac{ft^3}{yd^3}$$

***Theoretical Density***

$$T = \frac{Mass}{Volume} = \frac{1547.44\ \frac{lb}{yd^3}}{25.486\ \frac{ft^3}{yd^3}} = 61.77\ \frac{lb}{ft^3}$$

***Measured Density***

$$M = 58.87\ \frac{lb}{ft^3}$$

***Air Content***

$$Air\ Content = \frac{(T-M)}{T} * 100 = \frac{61.77 - 58.87}{58.87} * 100 = 4.9\%$$

***Air Content Check***

$$Air\ Content\ Check = \frac{\left(27\ \frac{ft^3}{yd^3} - Volume\right)}{27\ \frac{ft^3}{yd^3}} * 100 = \frac{\left(27\ \frac{ft^3}{yd^3} - 25.486\frac{ft^3}{yd^3}\right)}{27\ \frac{ft^3}{yd^3}} * 100 = 5.6\ \%$$

**Free Water from Aggregates**

| Stock Moisture Content<br>*Glazed Iso Ball (GIB) 0-2mm* |
| --- |
| *assumed Moisture Content Stock = 0.5%* |

***Mass in Stock Moisture Content***

$$MC_{stk(Aggregate)} = W_{OD(Aggregate)} * \left(1 + \frac{MC_{stk}}{100}\right)$$

$$MC_{stk\ (GIB)} = 187.34\frac{lb}{yd^3} * \left(1 + \frac{0.5}{100}\right) = 188.276\ \frac{lb}{yd^3}$$

***Total Moisture Content***

$$MC_{Total\ (Aggregate)} = \frac{\left(MC_{stk(Aggregate)} - W_{OD(Aggregate)}\right)}{W_{OD(Aggregate)}}$$

$$MC_{Total\ (GIB)} = \frac{\left(188.276\frac{lb}{yd^3} - 187.34\frac{lb}{yd^3}\right)}{188.276\ \frac{lb}{yd^3}} = 0.005$$

***Free Moisture Content***

$$MC_{Free\ (Aggregate)} = MC_{Total\ (Aggregate)} - Abs_{Aggregate}$$

$$MC_{Total\ (GIB)} = 0.005 - 0.11 = -0.105$$

***Mass in Stock Moisture Content Condition***

$$W_{Stk\ (Aggregate)} = W_{OD(Aggregate)} * MC\ _{Free\ (Aggregate)}$$

$$W_{Stk(GIB\ )} = 187.34\frac{lb}{yd^3} * -0.105 = -19.768\ \frac{lb}{yd^3}$$

***Batch Water Calculations***

$$W_{Free} = \sum W_{Stk(Aggregates)}$$

$$W_{Free} = -19.768\frac{lb}{yd^3}$$

$$W_{Batch} = Mass_{Water} - W_{Admx} - W_{Free}$$

$$W_{Batch} = 419.653\frac{lb}{yd^3} - 5.65\frac{lb}{yd^3} - (-19.768)\frac{lb}{yd^3} = 433.77\frac{lb}{yd^3}$$

***Cement – Cementitious Materials Ratio***

$$\frac{C}{CM} = \frac{802.829\ lb}{875.813\ lb} = 0.916$$

***Water- Cementitious Materials Ratio***

$$\frac{W}{CM} = \frac{419.653}{875.813} = 0.50$$

***Water- Cement Ratio***

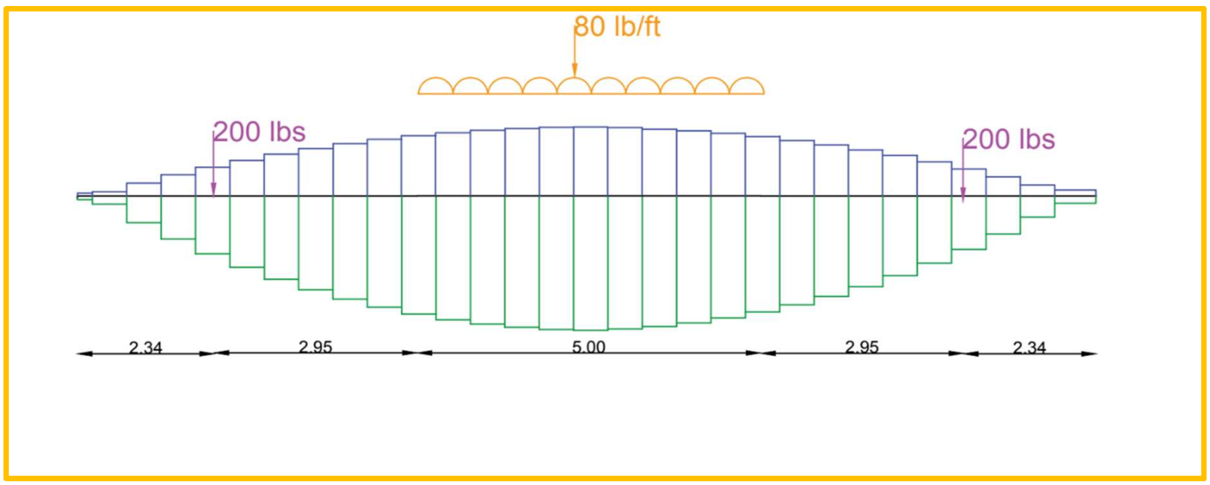
$$\frac{W}{C} = \frac{419.653}{802.829} = 0.52$$

## Appendix B - Structural Calculation

**Assumptions:(Given in competition rule)**

- Canoe was analyzed as a beam and free body diagram shows the longitudinal centerline of the canoe.
- The material is elastic and homogenous.
- The Canoe weight and buoyant force are distributed load calculated at an interval of ½ foot.
- Deflection is small relative to length.
- Two 200 lb. paddler is considered as a point load positioned at 15% and 85% of entire length and a load of cargo that is equivalent to an 80 lb./ft. distributed load applied to 5 ft. length of canoe.
- Neglect the contribution of Reinforcement for this Structural analysis.

**Free body diagram:**




**Necessary data:**

$L_{canoe}$ = 15.58 ft. (Length of canoe)

$Weight_{paddler}$ =200 lb. at 15% and 85 % of the total canoe length

$d_1 = 0.15 \times L_{canoe} = 0.15 \times 15.58 = 2.34$ ft. (Distance from bow to first paddler)

$d_2 = 0.85 \times L_{canoe} = 0.85 \times 15.58 = 13.24$ ft. (Distance from bow to second paddler)

$Weight_{cargo}$ = 80 lb. /ft. over 5 ft. span (shown in figure)

$Weight_{canoe}$ = 93 lb. (Approximate).

Total buoyant force = $weight_{paddler} + weight_{paddler} + (weight_{cargo} \times span) + weight_{canoe}$

= 200 + 200 + (80 x 5) + 93

= 893 lb.

**Shear Force Calculation:**

$V_1(x) = \sum_0^x fb - w_{canoe}$ **$0 \le X \le 2.34$**

$V_2(x) = (\sum_0^x fb - w_{canoe})-200$ **$2.34 \le X \le 5.29$**

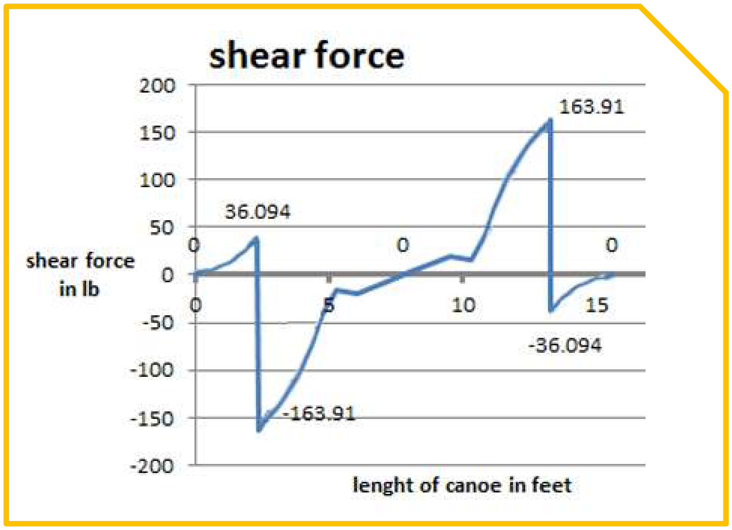
$V_3(x) = (\sum_0^x fb - w_{canoe}) - 80x + 223.2$ **$5.29 \le X \le 10.29$**

$V_4(x) = (\sum_0^x fb - w_{canoe})-600$ **$10.29 \le X \le 13.24$**

$V_5(x) = (\sum_0^x fb - w_{canoe})-800$ **$13.24 \le X \le 15.58$**

*X – longitudinal length of canoe*

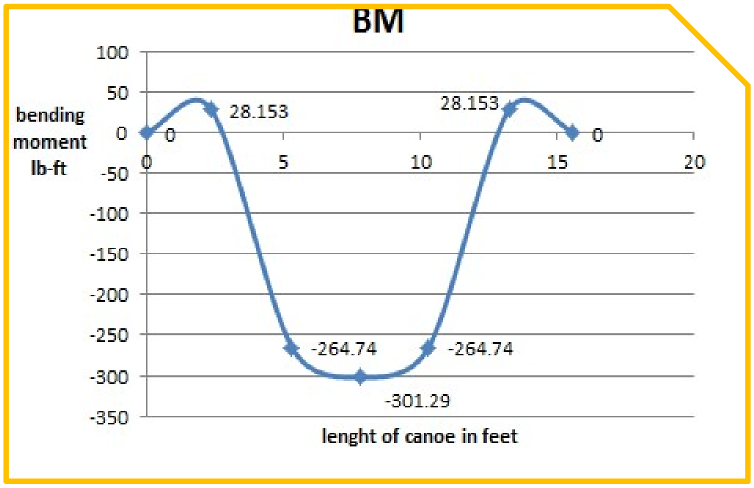
**Shear Force Diagram:**




**Bending Moment Calculation:**

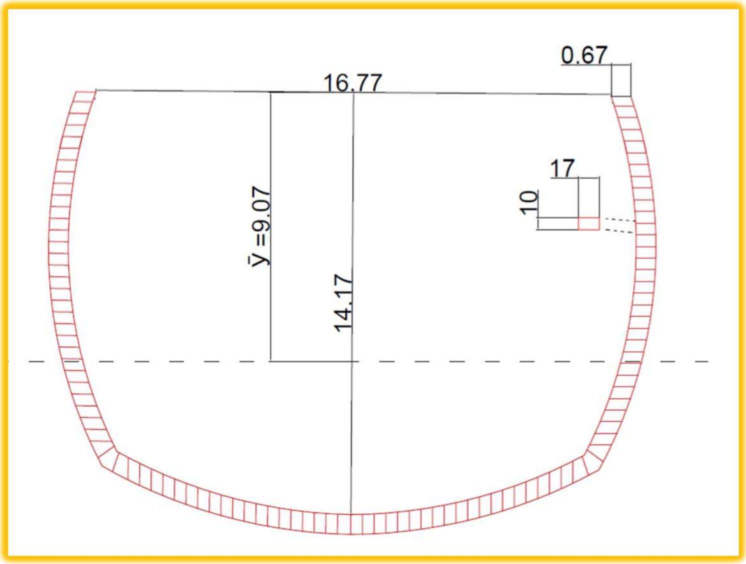
$M(x) = \int v(x)$ **$0 \le X \le 15.58$**

**Bending moment Diagram:**



**Moment of inertia**

The analysis of the longitudinal bending moment shows that the section at 7.79 feet from bow has maximum bending moment of 301.05 lb.-ft. The hull has the uniform thickness of 0.67 inch. The shape of cross section of canoe is assumed as 104 rectangles of size 0.39 x 0.66.




**Sectional view of Canoe at 7.79 feet**

Neutral axis = ∑AY/ ∑A (summation for 104 section are done in spread sheet)
Neutral axis = 9.07 inch (distance from the bottom of cross section)
$\bar{y}$ = | Neutral axis - Y |
$\bar{I} = bh^3/12$ (Rectangular cross section)
$I = \sum \bar{I} + \sum A \bar{y}^2 = 544.88 + 0.585 = 545.46\ in^4$

**Tensile stress**

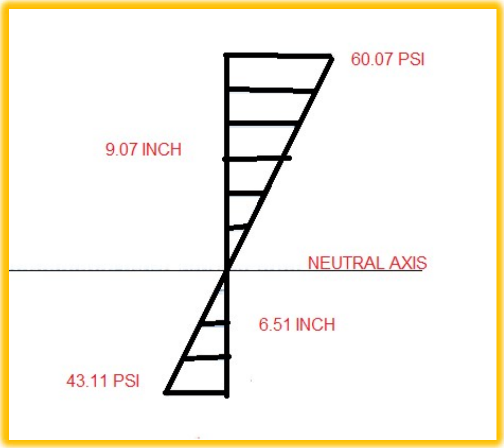
$\sigma = MY_T / I = 301.05 \times 12 \times 9.07 / 545.46$

**σ = 60.07 psi. (tension)**

**Compressive stress**

$\sigma = MY_B / I = 301.05 \times 12 \times - 6.51 / 545.46 = - 28.58$ psi.

**σ = - 43.11 psi. (compression)**



**Cracking moment**

**(The bending moment at which cracking of the concrete begins to occur.)**

Bending stress for concrete at the distance y from neutral axis can be calculated using Elastic beam theory. The cracking moment is the moment corresponding tensile stress at which concrete start to crack. Maximum tensile stress occurs at gunwale, 9.07 inch above the neutral axis. Compression strength result at 1740 psi (28 days result)

$f_C$= 1725 psi (28 days result)

$f_R = 7.5\ \lambda\ \sqrt{fc'}$ (ACI 318 - 14, Eqn.19.2.3.1)

$\lambda = 0.75$ (modification factor for light weight concrete table 19.2.4.2 of ACI 318-14)

$f_R = 7.5 \times 0.75 \times \sqrt{1725} = 233.62$ psi (modulus of rupture)

$M_{CR} = f_R \times I / y_R$ (ACI 318 - 14, Eqn.24.2.3.5 (b))

$= (233.62 \times 545.46) / (9.07 \times 12)$

$M_{CR} = 1170.82$ lb. – feet

**Ultimate bending moment:**

**(The ultimate bending moment, with the effect of reinforcement)**

Assume that the concrete has no tensile strength; reinforcement is the only source of tensile strength and bond between concrete and reinforcement is perfect. Assume that concrete is singly reinforced and flexural strength result = 427 psi

$\sigma_{ultimate} = M_{ultimate} \times Y / I$

$M_{ultimate} = \sigma_{ultimate} \times I / Y = (427 \times 545.46) / (9.07 \times 12)$

$M_{ultimate} = 2139.94.$ lb. - feet

From these calculations, we can assess that the canoe can easily withstand the tensile and compressive stress of 60 and 43psi respectively, because they do not exceed our test mix results of 320 psi and 1740 psi of tensile and compressive respectively. As per the result obtained from SOLIDWORKS, stress is high at keel bottom when compared to other places. In this condition, the concrete will fail at bottom of keel, hence the installation of extra reinforcing mesh is recommended at keel for extra safety. As we go for double layer mesh, the overlapping of mesh at keel bottom is done.

***Reinforcement Thickness Calculations:***

*(For checking the usage of mesh is limit to the competition rules)*

| Reinforcement Material | Material Thickness (in.) |
|---|---|
| Glass Fiber Mesh | 0.02 |

**Standard Canoe Wall**

Minimum Concrete Wall Thickness: 0.314 in and maximum layer of mesh is two.

$$\frac{T_{REINFORCEMENT}}{T_{concrete}} = \frac{2 \times t_{glass\ fiber}}{T_{concrete}} = \frac{2 \times 0.02\ in}{0.314} = 0.127 * 100\% = 12.7\% \leq 50\%$$ (O.K)

**Rib Location**

Minimum Concrete Wall Thickness: 0.314 in.

Maximum layer of Mesh in rib is four due to overlapping of mesh at keel.

$$\frac{T_{REINFORCEMENT}}{T_{concrete}} = \frac{4 \times t_{glass\ fiber}}{T_{concrete}} = \frac{4 \times 0.02\ in}{0.314} = 0.254 * 100\% = 25.4\ \% \leq 50\%$$ (O.K)

**Gunwale**

$$\frac{T_{REINFORCEMENT}}{T_{concrete}} = \frac{2 \times t_{glass\ fiber}}{T_{concrete}} = \frac{2 \times 0.02\ in}{0.314} = 0.127 * 100\% = 12.7\ \% \leq 50\%$$ (O.K)

**Thwarts**

There is no Thwart in our design.

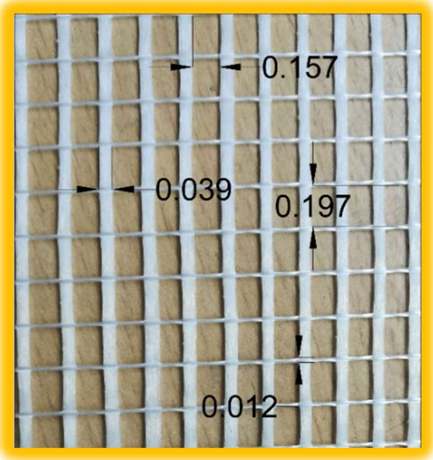
**Bulk head**

There is no bulk head in our design

| | |
|---|---|
| **N1 - Number of apertures along sample length** | 6 |
| **N2 - Number of apertures along sample width** | 6 |
| **Aperture 1 - Center to center spacing of reinforcement** | 0.19685 in. |
| **Aperture 2 - Center to center spacing of reinforcement** | 0.15748 in. |
| **T1 - Thickness of reinforcement along sample length** | 0.03937 in. |
| **T2 - Thickness of reinforcement along sample length** | 0.01181 in. |

**FIBER MESH DETAILS**

The aperture size of glass fiber mesh was measured by magnifying the photo in AutoCAD in correct scale size and then the values of aperture 1 and 2 were measured




**Glass fiber mesh**

**Glass Fiber Grid Reinforcement**

Total length $T_L = N_1 \times (t_1 + L_1) = 6*(0.03937 + 0.19685) = 1.41732$ in.

Total Width $T_W = N_2 \times (t_2 + L_2) = 6*(0.01181 + 0.15748) = 1.01574$ in.

Total Area $A_T = T_L \times T_W = 1.41732 \times 1.01574 = 1.43962$ in$^2$

Open Area Ao: N1 x L1 x N2 x L2 = 6 x 0.19685 x 6 x 0.15748 = 1.1160 in$^2$

**Percent Open Area**

$$\text{Percent Open Area} = \frac{\text{Open area}}{\text{Total Area}} \times 100\% = 1.1160 / 1.43962 \times 100$$

= 77.52 % > 40% (O.K)

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21)Prolines 98 to identify (G-Z) Curve.

22)Solid works (2018). Computer Software for Design and Analysis.

23) Adobe Photoshop Cs6 and Adobe Dimensions (2019) for Aesthetics.

24) Primavera P6 for Project schedule.

## Acknowledgement

Authors grateful to our Mentor Er.L.Suresh kumar and Team members S.K Jeeva , V.Gowtham , N.Balaji, J.Karpagavarsini ,A.S. Madhan, T.Shimar Ahamed, J.Om praksh , K.Rakesh, S.Prasath, J.Rahul, V.Ranjani, G.Varrsini, S.Arshiya, G.Gowthaman, P.Kavin, L.Kaven Krishna , R.Aparna, T.Deepika and Y.Rethanya.


**TEAM MADARASAPATTINAM**


**DISPLAY TABLE**

**RACE DAY**

**FLOATATION TEST**

20 teams participate in canoe competition

STAFF REPORTER
ERODE

Twenty teams from various institutes from across the country participated in the concrete canoe competition held at a pond located near Bannari Amman Institute of Technology at Sathyamangalam here.

The institute in association with the American Society for Civil Engineers, organised the ASCE Indian Region Student Conference 2020 from March 3 to 6 during which the competition was held. The competition for civil engineering students was an opportunity to gain hands-on experience and leadership skills by working with concrete mix designs and project management as the event challenged the student's knowledge, creativity and stamina. The canoes, made up of concrete that were very strong, sustainable and never affected by pressure and wind, and based on factors like dynamic, pressure, dropping capacity, travelling capacity and weight the students' canoe were ranked.

Organisers said that the competition had four categories and the concrete canoe were tested during a race.

Skilled teams would be chosen for the International Concrete Canoe Competition to be organised by the ASCE in the United States.

Students taking part in the concrete canoe competition held at a pond near Bannari Amman Institute of Technology at Sathyamangalam.

THE HINDU COIMBATORE
SUNDAY, MARCH 8, 2020 2

**NEWSPAPER CLIPINGS**

**WON THIRD PRIZE IN ASCE CANOE COMPETITION (INDIAN CONFERENCE) IN MARCH 8, 2020.**

- Industrial—Delta Jet Engine Test Facility, Delta Air Lines, Inc.

—*submitted by Wayne Wilson, Executive Director, Georgia Chapter – ACI*

## ACI Concrete Field Testing Technician – Grade I Certification Exam in Jakarta

The Singapore Chapter – ACI (SC-ACI) successfully conducted its first ACI Concrete Field Testing Technician – Grade I certification examination in Jakarta, Indonesia, on June 8, 2019. The exam was conducted for the technical staff of PT Pionirbeton Industri (PBI), one of the leading ready mixed concrete suppliers in Indonesia. PBI is a subsidiary of Indocement Tunggal Prakarsa (ITP), and ITP's parent company is HeidelbergCement, Germany, the second largest producer of cement in the world.

Ten examinees took the certification examination in the central laboratory of PBI at Pulogadung, Jakarta. Lu Jin Ping, SC-ACI President, and Joseph Lim, SC-ACI Director, were in Jakarta to conduct the exam. The event was coordinated by Arvind Suryavanshi, General Manager, Technical, of PBI, who is also a past Director and Head of the SC-ACI Education Committee.

**SC-ACI examiners Joseph Lim and Lu Jin Ping (eighth and ninth from left), with Arvind Suryavanshi (seventh from left) and Kuky Permana (10th from left) of PBI, and the certification examinees and support staff**

## Kongu Engineering College Participates in ASCE Canoe Competition

The Kongu Engineering College team finished in third place in the 2020 American Society of Civil Engineers (ASCE) Indian Region Concrete Canoe Competition. Team MADRASAPATTINAM was guided by L. Suresh Kumar, Assistant Engineer, Central Public Works Department, Chennai, and G.S. Rampradheep, Associate Professor, Kongu Engineering College. Team members included S.K. Jeeva,

**Team MADRASAPATTINAM of Kongu Engineering College**

V. Gowtham, N. Balaji, J. Karpagavarsini, A.S. Madhan, T. Shimar Ahamed, K. Vignesh Kumar, C.N. Vinish Nandan, J. Omprakash, K. Rakesh, S. Prasath, J. Rahul, V. Ranjani, G. Varrsini, S. Arshiya, G. Gowthaman, P. Kavin, L. Kaven Krishna, R. Aparna, T. Deepika, and Y. Rethanya.

The team approached the project with an integrated plan to rely on the expertise of every individual and encourage them to understand the complete process. The objectives and goals were explained clearly to the team members, which helped them work more effectively.

Research was undertaken to fabricate an economical, eco-friendly canoe by reducing its size. Initially, the hull design was done using AutoCAD and the three-dimensional model was rendered using SOLIDWORKS*. The length of the canoe was optimized to 4.75 m (15 ft 7 in.). A model with a 1:3 scale ratio was constructed for testing drag and studying the dynamic behavior of the canoe. From the knowledge gained regarding the model canoe behavior and material study, a practice canoe was constructed.

The positive mold for the canoe was prepared using medium-density fiber boards, cut into sections with CNC machines to obtain the shape of the hull. These sections were covered with cement mortar to obtain the shape of the canoe. After sanding, cement mortar paste was coated over the mold. After the paste cured, the sanding process was repeated to obtain a smooth surface. For the purpose of easy demolding, an enamel coating was applied over the mold. To impart sustainability to the project, glazed iso balls (GIB), a recycled waste glass product, were used as an aggregate. The baseline materials used for canoe construction were ordinary portland cement 53 Grade (53 MPa [7690 psi]), glass fiber mesh, GIB, and admixtures.

The completed concrete canoe weighed about 114 lb (52 kg).



**Our achievement is published in CI magazine ACI,USA in June 2020 .**

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