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In Chinese folklore, the Pixiu is a fierce, auspicious beast and the ninth son of the Dragon. According to legend, the Pixiu, also known as 'brave troops', is an ancient giant panda. The Pixiu is also the symbol of our concrete canoe team. A famous Chinese monarch and yellow emperor once trained a troop of Pixius to defeat his enemy. It is believed that the ferociously devoted brave troops would always guard their Master, even after death. Just as in English, 'brave troops' meant brave troops in ancient times. The term also symbolizes the military discipline and courage of Southwest Jiaotong University's concrete canoe team. In addition to having the qualities described above, the Pixiu represents good luck. One Chinese custom is to perform a Pixiu dance for good luck and smooth sailing.

Table 1:*Pixiu* Specifications	
Name	*Pixiu*
Primary Colors	Red, Orange, Brown,White
Weight	270 lbs
Maximum Length	229.90 in
Maximum Depth	13.70 in
Maximum Width	23.90 in
Average Thickness	0.66 in
Primary Reinforcement	Carbon Fiber Mesh
Secondary Reinforcement	PVA Fibers

Southwest Jiaotong University (SWJTU) was founded as the Imperial Chinese Railway College and is located in Tangshan Hebei province. After changing its location several times because of war, it finally settled in Chengdu and was renamed SWJTU. As the home of China's modern transportation and civil engineering education infrastructure, SWJTU took an active part in the concrete canoe competition, improving gradually over the past two years. SWJTU ranked sixth and fourth in 2018 and 2019, respectively.

Table 2: Material Properties		
Mix	**Structural**	**Aesthetic**
Wet Unit Weight (pcf)	73.62	70.35
Dried Unit Weight (pcf)	71.97	69.09
Compressive Strength (psi)	2503	1985
Tensile Strength (psi)	314	258
Flexural Strength (psi)	804	421
Air Content (%)	0.80	4.10
Slump (in)	2.98	3.02

The hull design was changed to improve user comfort based on feedback from last year's team. In order to verify the design improvements, two preliminary experiments and one formal flume test were carried out on a 1:3 scale.

The materials division was impacted by the new rule, which forbids the use of latex to improve workability. Thus, extensive research was performed to identify new structural and surface layer mixes that meet fluidity and strength development requirements without help from latex. This year, the team introduced silica fume as a supplementary cementitious material intended to improve concrete strength. The closest packing density method was attempted to optimize aggregate gradation in order to improve workability and strength.

Construction was performed smoothly using a combination of male and female molds. The team strove to achieve sustainability by replacing all environmentally harmful materials, such as epoxide adhesive, with more environmentally friendly materials. Inspired by multi-functional trowel and mortar blocks, the team optimized the use of labor, thus speeding the casting process. A remote-controlled, intelligent curing system was used so that the team could supervise the process online during the winter holidays.

The *Pixiu* project management team chose a new collaboration system. Collaboration software named 'nailing' was adopted to allow the weekly schedule to be arranged and clarified by officers and to provide enhanced transparency between divisions.

Condensing the collective innovations and efforts, *Pixiu*, a sustainable and high-quality final product, bears the expectation to achieve breakthrough development in the competition and become valuable experience wealth of SWJTU Concrete Canoe.

ASCE Student Chapter Profile

Established in 2016, the American Society of Civil Engineers (ASCE) International Student Organization Southwest Jiaotong University Branch stands at the forefront of the civil engineering profession. The branch serves ASCE student members and all students. It seeks to build a better quality of life by planning, designing, and operating economic and social engines, while achieving sustainability.

Figure 1: *ASCE Student Chapter Logo*

The members of the Southwest Jiaotong University Branch of the ASCE Student Chapter are a group of students that seek to uphold the ideals and responsibilities of ASCE. The main objective of the Southwest Jiaotong University ASCE Student Chapter is to help students prepare themselves for entry into the civil engineering profession and into society as a whole. This objective is met through learning opportunities and participation in student activities.

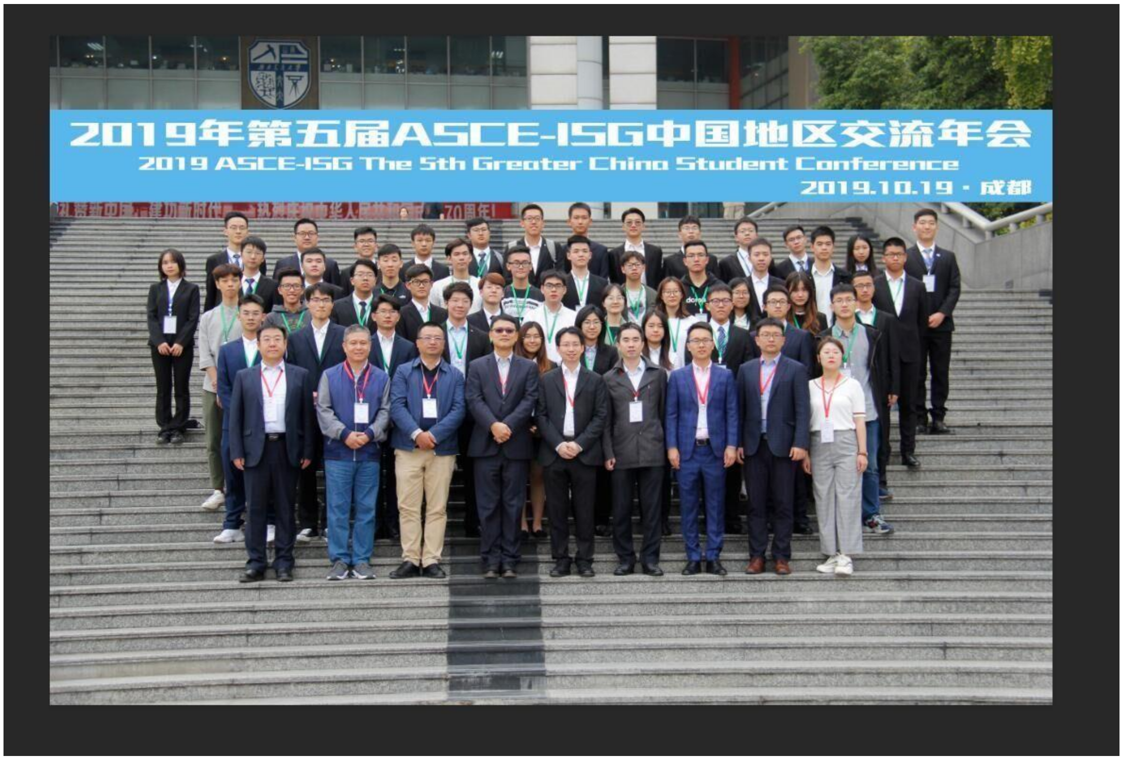

Figure 2: *ASCE Student Chapter*

Student Chapter Activity

- Conduct civil forums: lectures and exchanges for aesthetics and humanistic literacy of civil engineering
- Participate in the annual ASCE Pacific Northwest Student Conference, which is hosted in April at one of the 18 participating schools in the region. Events include:
  i. Concrete canoe design and construction, followed by participation in the concrete canoe competition.
  ii. Steel bridge design and construction, followed by participation in the steel bridge competition.
  iii. Preparation and presentation of technical papers, including those on topics related to engineering ethics.
  iv. Participation in environmental competitions and other conference events.
- Visit local construction sites
- Community service

Since the form of the competition has changed little since the previous year, modifications were made based on feedback from the previous year's paddlers. According to teammates who attended the race last year, the major problems with the *Nezha* (the concrete canoe used during the previous year) were poor stability and comfort. Thus, this years' efforts were focused on improving overall canoe stability and comfort. Two preliminary experiments and one formal physical flume test were performed to compare the stabilities and water resistances of various design models. After these modifications, the overall stability and comfort were improved substantially and the water resistance was reduced to some extent.

The *Pixiu* and other alternative designs were built using the Maxsurf modeler. To increase canoe stability, the block coefficient was increased from 0.477 to 0.526 to produce a flatter bottom this year. The initial stability of the canoe improved upon implementation of this flat bottom. The initial metacentric height was increased from 3.54 in to 3.98 in and the immersion degree increased from 22 degrees (*Nezha*) to 34.4 degrees (*Pixiu*). Therefore, the new canoe is substantially less likely to overturn than the previous one.

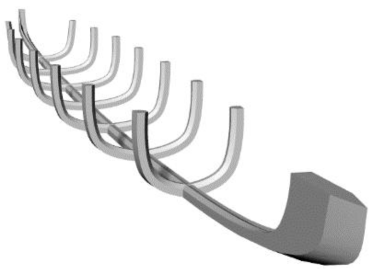

Figure 3： *Keel and Rib design*

Poor comfort is a major shortcoming that was not considered carefully last year. This affected paddler performance. Several structural design changes were made in order to solve this problem. For example, the rib spacing was reduced and a keel was added to lock the paddler position, providing a constraint to aid paddlers in performing well. The addition of a keel and ribs both lowered the center of gravity to enhance stability and strengthened the canoe. One rib-related innovation this year was introduction of a trapezoidal shape. This reduced the pressure on the paddlers and helped the paddlers to remain locked in position. Adding a keel and ribs also increased the canoe weight and thus the displacement. Therefore, extra buoyancy was added above the gunwale. This modification also served to prevent spray in front of the canoe from splashing into the canoe.

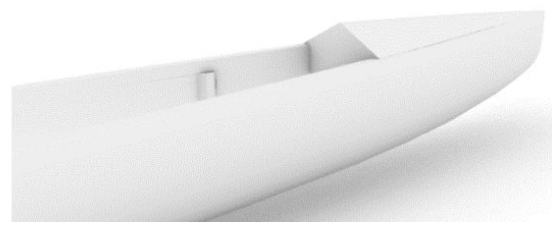

Figure 4: *Buoyancy tank*

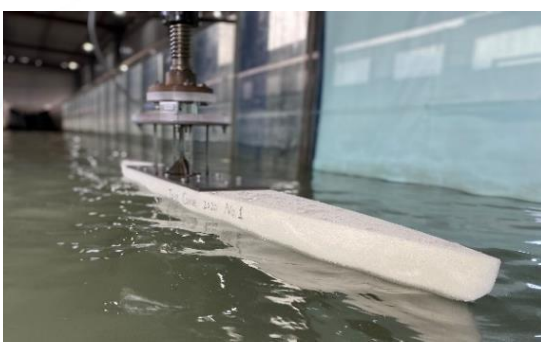

Figure 5: *Hydrodynamic Experiment*

Water resistance is always important to canoe performance. In order to reduce the canoe's drag force, the prismatic coefficient was increased from 0.604 to 0.607. The changes included a larger length-to-width ratio intended to provide better racing performance. In addition, the maximum cross-section was shifted towards the back of the canoe. To verify that increasing the prismatic coefficient reduced the water resistance, two preliminary experiments were performed with seven 3D-printed models using a zoom ratio of 1:20 and various prismatic coefficients. However, the scale effect of the 1:20 model was too large to be neglected. In addition, the drag forces from such small canoes were too small to measure using regular sensors. Hence, a formal flume test was performed with a scale ratio of 1:3. In addition, five-axis sculptured models were tested and a more precise force balance was performed to determine the best design. After comparing the water resistance at 0, 15, 30, and 45 degrees, *Pixiu* is stand out in 3 alternatives and *Nezha* which is the canoe last year.

The transom stern was also redesigned this year in order to produce a virtual length. The addition of a virtual length increases the total length relative to the actual length, thus reducing the resistance. This theory was verified via the flume test, where No. 1 was in the sharp stern and the other samples were in transom sterns.

As shown on the graph, the transom stern does have a positive effect on resistance reduction. In addition, all experimental data was retained. It can be used in the future to further understand the influences of various parameters.

The objective of the structural analysis was to provide the mixture sub-team with accurate strength requirements critical to concrete mixture design. The critical tensile and compressive stresses were calculated under various loading cases. Different stress states of the canoe were obtained through two-dimensional analysis.

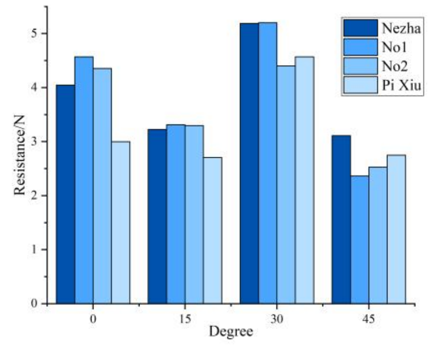

Figure 6: *Experimental results about resistance*

Longitudinally, the canoe was treated as a tapered beam and divided into 20 uniform, U-shaped cross-sections. Some general properties of each section, including their areas, centroid positions, and moments of inertia were obtained using *Inventor* and *MS Excel* (2016). The structural analysis for *Pixiu* included five different loading cases: the co-ed race, men's course, women's course, eight-person transportation, and exhibition cases. The buoyancy and self-weight of the canoe were treated as distributed loads. Paddlers were simplified as point loads, with assumed paddler weights of 140 lbs for women and 170 lbs for men. The self-weight of the canoe was evaluated as 243 lbs. The maximum negative bending moment was determined to be 765.26 lb-ft and was located 9.84 ft from the stern under men's racing conditions. Paddlers were assumed to be 4 ft and 16 ft from the stern. Based on the assumptions above, the plane section hypothesis, and the linear elastic model, a safety factor of 3 was used to calculate maximum tensile and compressive stresses of 532.47 psi and 293.97 psi, respectively. These maxima were located approximately at the centers of the gunwales.

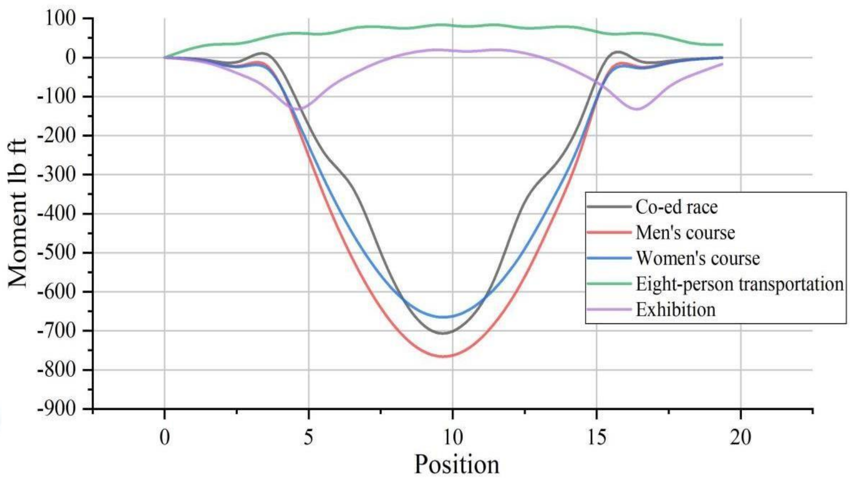

Figure 7: *Moment Envelope Diagram*

Based on the internal force analysis results above, transverse and longitudinal tendons made from high-performance fibers were installed to reduce the maximum tensile stress and enhance crack resistance. A conservative prestress loss of 25% was considered. Longitudinally, each tendon was designed to be jacked to 57.8 lb, for a total of 289 lb. In addition, 20 transverse prestress tendons were set every 11.6 in with 301 lb in total, efficiently reducing longitudinal cracks. Two layers of carbon fiber mesh in the two intersections between the appearance and structural layers also served as reinforcement. Ribs were designed to be trapezoidal to improve canoe stability and comfort. Gunwales were adjusted using replaceable equipment and a buoyancy tank to withstand unexpected collisions.

Two years ago, a considerable crack within the stern of *Lotus* caused canoe failure several meters from the race finish line due to weak material strength. This caused considerable shame for the associated team members. At last year's MidPac competition, *Nezha* made a breakthrough in the materials division, significantly exceeding team expectations for its lighter hull body, gorgeous surface color, and advanced strength and finishing the race without small or large failures. Due to this massive breakthrough despite the team's short history of competition experience, the materials division decided to utilize *Nezha*'s mix design as a baseline this year and add improvements to make the canoe even better than before. The goals of this year's materials division included facilitating material strength and workability to ease construction by testing multiple newly introduced methods and materials and developing improved mixes that were compliant with the new rules.

Table 3: Constituents Used

Material Name	Intended Use	Applicable ASTM Standard
AALBORG WHITE® Portland Cement	Cement	ASTM C150
RIZHAO YIXINLI CGEMICALS CO., LTD. Fly Ash	Supplementary Cementitious Material	ASTM C618
SUPER® Metakaolin	Supplementary Cementitious Material	ASTM C618
ALSHAM ALMASIEA® Densified Micro Silica Fume	Supplementary Cementitious Material	ASTM C1240, ASTMC114, ASTM C430
HUIYANG CHEMICAL INDUSTRY QUANZHOU CO., LTD. Zeolite Powder	Supplementary Cementitious Material	ASTM C618
YICHANG BAOZHU CO., LTD. Haydite	Aggregate	ASTM C127
PORAVER® Expanded Glass	Aggregate	ASTM C128, ASTM C330
3M® VS5500	Aggregate/Mineral Filler	ASTM C128, ASTM C330
NYCON®PVA RES100	Fibers	ASTM C1116
BASF Masterglenium® Sky 8860	Superplasticizer	ASTM C494
VENATOR® Concrete Pigment	Pigment	ASTM C979
BASF Mastermatrix® VMA450	Viscosity-Modifying Admixture	ASTM C1438

All of the tests implemented to test concrete mix performance referred to related ASTM standards, thus ensuring that the derived data complied with the RFP. Tension (ASTM C496, 2011) and compression (ASTM C39, 2016) tests were used to determine the strength of each mix after 7 and 28 days. The concrete mixes reached approximately 25% and 80% of their final strengths at these respective points. The slump test (ASTM C143, 2014) allowed an assessment of mix cohesiveness and workability, which further helped to determine mix performance.

Due to the rule change that prohibited use of latex and thus triggered poor construction workability, material division members decided to make a workability improvement adjustment based on the mix used in the previous year. The mix from the previous year was used as a basis because it exhibited excellent performance. In this year's structural layer mixture, the water-to-binder ratio in the baseline mix was changed from 0.29 to 0.55. Additional water was added to improve mixture fluidity in the absence of latex. In addition, the total mass of supplementary cementitious materials (SCMs) in Mix I was increased from last year's 640 to 680 lb/yd^3.

Table 4: Development Process of Structural Mix		
Material	**Baseline**	**Mix I**
Mass of cm(lb/yd^3)	640	680
w/cm	0.55	0.4
Dosage superplasticizer(fl oz/cwt)	34.76	99.99
Tensile strength（psi）	278	299

The superplasticizer concentration was increased to 99.99 fl oz/cwt, ensuring appropriate workability at a low water-to-binder ratio of 0.4 and contributing to strength improvements. The same Portland white cement. (ASTM C150, 2015) was used for its ease of coloring and high purity. These characteristics stem from a production process that is more complex than that of ordinary Portland cement. Metakaolin (ASTM C618, 2015) was considered this year because of its brilliant color compatibility, but was eventually abandoned. The zeolite powder used last year was abandoned because of its high price but replaced with a new SCM, silica fume, for the structural layer mix. The average silica fume particle size of less than 5 microns reduced concrete porosity, thus improving tensile strength. However, heat evolution surged during blending due to its rapid reaction rate, causing additional surface voids on specimens. The problem was finally fixed by making a silica fume slurry ahead of material blending in order to release the heat in advance and evade void formation.

Figure 8: *Hand-made slurry of silica fume*

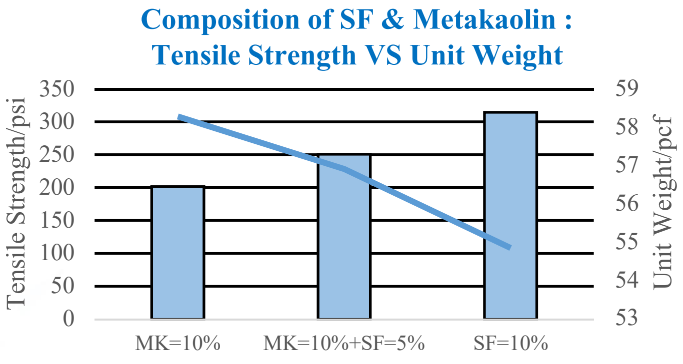

Figure 9: *Tensile strength vs Unit weight*

As in the previous year, this year's structural layer mix design included metakaolin. The amount of metakaolin was increased by 10% in each mix with whose tensile strength developed. Next, silica fume (5%) was introduced by replacing an equal quantity of cement in a further attempt to derive higher strength. However, considerable fluidity was lost because of the high water absorption of metakaolin and heat evolution from silica fume when both were present in the mix. It was immediately discovered that a significantly higher average strength was achieved when silica fume was added without any metakaolin. The resulting concrete strength could reach up to 330 psi. Therefore, metakaolin was abandoned and an optimized quantity of silica fume (10%) was used to replace the same quantity of cement. Since Mix I-1 achieved relatively poor strength under gradation of G1, the aggregate gradation used in Mix I-2 (G2) was slightly adjusted via Fuller's method. This mixture achieved a higher strength and was thus used for subsequent mixes.

Table 5: Development Process of Cementitious Materials				
Material	**Mix I-1**	**Mix I-2**	**Mix I-3**	**Final Mix**
Cement	0.73	0.73	0.5	0.5
Metakaolin	0.09	0.09	0.1	0
Fly ash	0.11	0.11	0.4	0.4
Zeolite powder	0.07	0.07	0	0
Silica fume	0	0	0.05	0.1
Aggregate gradation	G1	G2	G2	G2
Tensile strength（psi）	188	201	250	314

No reinforcement material was incorporated in the surface layer mix last year. This caused poor strength. In concurrence with this year's requirements to add both inner and outer surface layers during construction and to improve the materials' chromogenic qualities, reinforcement was added alongside adjustments in cementitious materials intended to produce better color performance. Thus, we introduced NYCON® RECS100 fiber (ASTM C1116, 2015) to the surface layer mix. This was also used to develop ductility and strength in the structural layer. To address chromogenic quality, fly ash was not used this year because its low purity could be seen via its relative dim color. GGBS (ASTM C618, 2015) was introduced for its brilliant white color and better purity, but revealed poor workability in later tests; thus, the optimal mix was obtained by removing metakaolin and aggregate gradation was performed by combining information from previous mixes with introduction of fiber reinforcement.

Significantly, a new grille-shaped carbon fiber mesh was used as a reinforcement material intended to be attached between various layers this year. The improvement embodied in this year's mesh used a two-way precast fiber mesh to replace one-way stationary carbon strips. This facilitated working efficiency when spreading the mesh during construction and further improved hull body safety relative to the previous simple stationary fiber strips. Further developments were made according to the theory of mechanical anchorage. This was implemented by using pre-made mortar specimens to increase the fiction and bite force between the mesh and concrete, thus taking maximum advantage of the tensile strength of the fiber.

This year, the same types of aggregates were used as in the previous year. They previously provided good weight control and strength gain performance. VS5500™ is a high-strength polymer additive made from a water-resistant, chemically stable soda-lime-borosilicate glass with a particle size of less than 0.1 microns. Poraver® expanded glass bubbles were used again, as well. Their particle sizes ranged from 0.1 microns to 2 microns. Since the same aggregates were used as in the previous year, material division members arranged to optimize the aggregate gradation to develop strength using the closest packing density method (Li Yulong, 2015). This method is typically used for aggregate gradation in ultra-high performance concrete (UHPC). Although an ultra-high peak tensile strength (approximately 400 psi) was achieved once, most of the strength data revealed severe instability. Thus, the final aggregate gradation determination was performed based on Fuller's method once again. The closest packing density method was tested this year without being adopted. However, it may be further developed next year in order to produce a system in which aggregate optimization generates strength distribution stabilization. Because it releases trapped water in flocs around cement particles to develop fluidity without increasing the w/cm ratio and thus damaging mix strength and durability, MasterGlenium® Sky 8860 superplasticizer was used again this year to develop workability. One of its best ratios was appropriate for the desired mixture performance well and was thus applied. The MasterMatrix® VMA450 stabilizer that was used in the previous year was applied again to provide mixture proportioning flexibility.

Table 6: Physical Properties of used Aggregates

Aggregate Type	Specific Gravity	Absorption(%)
0.1-0.3mm Poraver® Expanded Glass	0.85	35
0.25-0.5mm Poraver® Expanded Glass	0.68	28
0.5-1mmPoraver® Expanded Glass	0.45	20
1-2mmPoraver® Expanded Glass	0.41	20
3M® VS5500	0.38	0

This year, the materials division started with materials that were almost the same as those used in the *Nezha*. They then introduced new SCMs in the structural layer, fibers in the surface layer, and fiber mesh improvements, as well as attempting to optimize aggregate gradation using the UHPC method. The team then successfully developed new mixes that satisfied strength and workability improvement predictions.

The *Pixiu* construction division combined experimentation-based inspiration with instruction from previous team members, providing the SWJTU canoe team with extensive support. Various innovations were developed via extensive experimentation based on a desire to contribute to practical construction methods. This year's team was determined to implement these innovative construction methods with the help of homemade tools.

To improve team construction skills, construction training was arranged and divided into two parts, model canoes rebuilding and weekly casting training. Two types of practice molds were designed with the intent of further improving them: the jigsaw molds and multi-functional cross-section molds. The multi-functional cross-section mold included male and female molds, and thus provided opportunities to practice both types. Made from Expanded Polystyrene (EPS) foam, it was measured and cut using a full-scale aluminum board that was first cut via Computerised Numerical Control Machine (CNC). Besides, a full-scale trial canoe was finished a month ahead of real construction. By building a trial canoe, the team could test how their experimental ideas worked on the final canoe and thus avoid predictable obstacles.

Figure 10 : *The combination of male and female molds with infrared positioning*

From the beginning, we understood the importance of female mold development. After combining initial exploration with our strengths and weaknesses as discovered during the construction training, we finally selected male mold as this was appropriate to our construction-related abilities. Foam glass is an ideal mold material because of its good resistance to pressure and corrosion. Its stiffness requires high construction accuracy. Because of this, it was eventually abandoned. Consequently, the team chose to work with a male mold made from EPS foam. This year's mold consisted of two main portions: the hull and base. The base was designed to have a pontoon and gunwale, as well as to aid in hull mold positioning.

Silica gel was used innovatively this year to treat the mold. It provided better demolding and protection performance than the plastic membrane that was used last year. Experience has indicated that silicone molds can produce smooth concrete surfaces. More importantly, silica has good biocompatibility, is non-irritating, non-toxic, and non-allergic to human tissue, and is degradable. Since the foam was received in pieces, team members initially applied a mix of silica gel and hardener to the mold surface in constant 100:0.7 proportions. After hand-smoothing, the mold was allowed to harden for 24 h at 77 °F. The mold pieces were then assembled using mortise and tenon joints. Here it served as adhesive to replace epoxy glue to achieve sustainability.

Four layers of concrete were required: the inner apparent layer, two structural layers, and a surface layer. Two types of concrete were produced to match the layer casting sequence. Fiber meshes were placed between the two structural layers and in the gap with the outer apparent layer. Depth control lines were previously prepared on the base mold. Silicone slices of the same thickness were pinned to the hull mold. Silicone was selected as the apparent layer color block. Prior to this decision, pearl wool and Thermoplastic Elastomer (TPE) were considered, but silicone performed more competitively with regard to compactness and biocompatibility.

Fiber mesh was bonded between two structural layers using mortar blocks at joints. This was intended for pre-stress implementation and depth control. The fiber mesh was first to cut isometrically relative to the canoe and then fixed to a full-scale board. Tiny 1.18 in×1.18 in×0.24 in Polyvinyl Chloride (PVC) boxes were adhered the joints on the board. The mortar was poured into boxes when the adhesive dried out. This design combined solutions to various problems, expediting the casting process and avoiding potential complications. In addition, an infrared positioning device was implemented during casting to confirm construction accuracy.

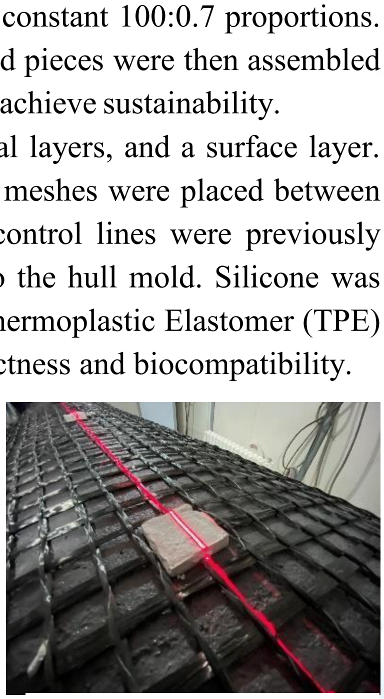

Figure 11: *The fiber meshes under infrared positioning*

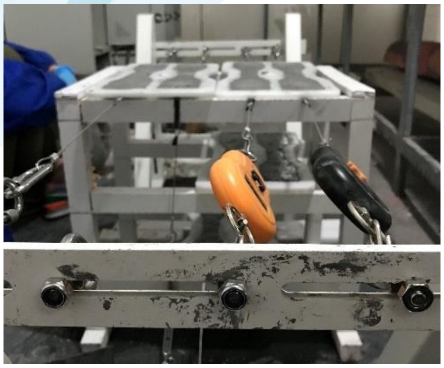

Figure 12: *The pre-stress device*

For pre-stress application, the team studied research by Tongyan Lin, an alumnus. The research shows that pre-tensioning is used universally in engineering, but was not appropriate for the curved part of the canoe. Because tension damages the hull to some extent and the hull is quite thin, pre-stressed tendons were not a satisfactory choice for us. To maximize resistance to pressure and tensile stress, this year's pre-stress device focused on fixing fiber mesh nodes to strengthen the desired properties. After various tests, the tensile strength reached a maximum of 314 psi， which increased 6% of the level achieved last year.

Figure 13: *The multi-functional trowel*

A new tool was designed this year and used during casting. It is a multi-functional trowel that is capable of adjusting to various angles, widths, and lengths. The multi-functional trowel drastically reduced the scratches caused by a normal trowel on the concrete surface. As a Chinese saying goes, "homemade may not be the best, but the best must be homemade". The expression comes from the field of pottery and notes that all pottery masters own a set of homemade tools. Our experience during female mold construction indicated strong demand for a curved trowel. Therefore, the team made efforts to create a tool that could be used for the planar and curved parts simultaneously.

Degradable packing bags were applied to the concrete distribution. Concrete inevitably dries during long casting times, resulting in additional construction challenges. It has been observed that concrete stored in a relatively closed space can maintain its moisture. Hence, packing bags were used to ensure concrete quality and construction speed. In addition, the packing bags allowed team members to accurately control of the amount of concrete applied. This unique method allowed the team to control the canoe thickness. Instead of plastic bags, biodegradable packing bags made from corn were chosen for sustainability. Besides, unused concrete was carefully recycled into packing bags and made into concrete crafts which eventually were donated to local community.

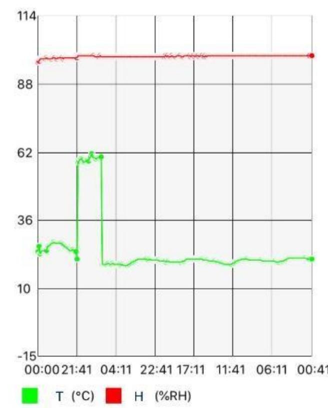

Figure 14: *Supervision display*

In order to ensure the quality of maintenance for this year's concrete canoe, the team independently manufactured a maintenance (curing) box. During the first two years, a wet quilt kept below 50 °F was used for curing and large cracks appeared. This year, suitable independent design and production were performed to generate a '5G' intelligent curing box for large components. The box provided intelligent constant temperature, constant humidity curing and managed electricity use. It was a solar-powered intelligent network monitoring control system with an automatic water supply device that could provide unmanned maintenance for long periods. In addition, the water used was obtained via filtration and purification of rainwater and wastewater using homemade devices. To increase the hull stiffness, short-term steam curing was used. Long-term curing was performed in the curing room for 28 days at 77 °F and a relative humidity of 99%RH. Once curing was completed, the team members began sanding wearing professional dust-proof suits then finished dismantling the molds from inside to outside using high-pressure water.

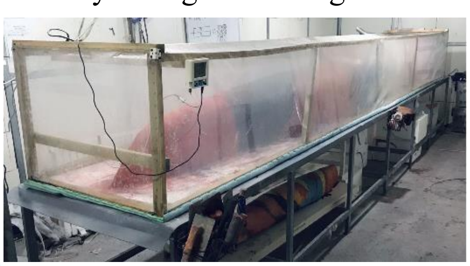

Figure 15: *The maintenance box*

Due to the smooth surface created by the silica membrane, the interior of the canoe required little sanding. In addition, our improved construction skills reduced the effort required to perform sanding. After sanding, buffing was performed and a layer of waterproof sealant was applied to preserve the vivid design of the *Pixiu*.

Project Management

Project management included *Pixiu*'s design, various innovations, and efforts towards sustainability, which ultimately determined its performance. The key strategies for this year included a weekly work plan, meeting routine, and collaborative efficiency software named '*Nailing*'.

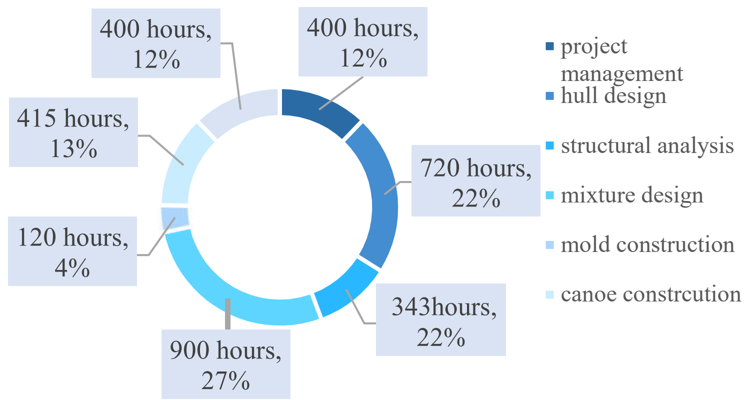

Figure 16: *Project total hours*

The initial schedule was set based and each group leader kept adjusting while progressing. An extra 15 days was left in the schedule to account for uncertainty. In addition, a free float period was provided for each task to compensate for potential delays.

As to hull design and analysis, more conditions and models were considered and more precise experiments were performed this year than last. The mold was customized at the factory to ensure its punctual completion. Previous preparations accelerated the construction process. Although scheduled to take 600 h, casting was completed in 476 h to save time for curing. The material division adjusted the mixture by implementing silica fume to improve strength, incorporating using the closest packing density method and considered the use of fibers in the surface layer, which minimized the delay for 15 days.

This year, financial support was relatively abundant because our early achievements were appreciated by the university. As the figure shows, the largest part of the total expenditure was equipment. Before our final canoe was finished, we had conducted extensive training, including the section parts and a full-scale canoe. The construction environment was substantially improved after our renovations. As for materials, the team purchased a batch of new plastic tensile specimen molds in order to make smoother specimens. The cost of training was nearly three times that from last year. This was driven primarily from our professional coach, a famous Olympic canoeing champion. The main cost of structural analysis was for our experimental wave flume components and team construction activities accounted for the largest proportion of other expenditures, which included the visit to the museum and the pottery experience. We made full use of our financial support and created a warm, efficient team atmosphere.

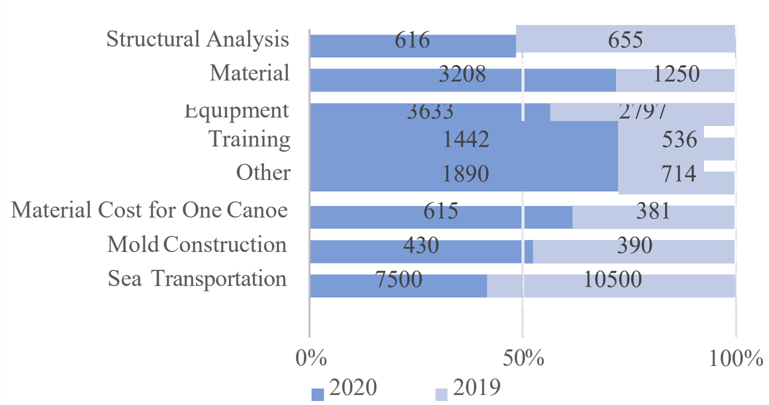

Figure 17: *Fee summary chart*

Health & Safety

Health and safety are of vital importance when performing material testing and construction, thus are always significant considerations for us. Potential hazards include electric shock, fire, dust hazards, theft, etc. In order to manage these risks, laboratory health and safety rules were used throughout the whole project. The rules were as follows:

- All the teammates must wear uniforms and dust masks when entering the lab area. No vests, slippers, or high-heeled shoes are allowed.

- The lab area must be cleaned after every construction project or material test. Tools such as agitator kettles and mason's knives must be cleaned and put in their proper places.
- Keep the laboratory quiet. Smoking, spitting, and littering are strictly prohibited in the lab.
- The electricity must be disabled when working on electrical devices and after using the devices. Make sure to turn the power off when leaving the laboratory.
- Do not panic when accidents such as fires or electric shocks occur. Contact advisors immediately.
- Remember to close the door before leaving. Persons who are not involved in the project are not allowed to enter the laboratory.

In addition to the laboratory health and safety rules, various other innovations were put forth to reduce health and safety risks. Throughout the project, acrylic plates were commonly used because they are more difficult to break than their glass counterparts. Even when they break, it is unlikely for them to form sharp fragments that can scratch skin. In addition, acrylic plates have excellent weather and corrosion resistances that make them perfect laboratory materials. Some teammates complained about the use of foam glue since it emits a toxic smell and is caustic. Therefore, foam glue was replaced with silica gel, which is non-toxic and has high thermal stability. In addition, an online monitoring system that included cameras, humidity sensors, and temperature sensors was placed in the laboratory to ensure safety within it.

In order to improve the physical attributes of our team members, the team established a system to ensure the participation of each member in sport, such as group night runs, volleyball competitions and so on.

QA & QC

This year's Quality assurance & Quality control (QA/QC) team attached vital importance to ensuring that canoe construction was complete before the winter holiday in order to avoid unnecessary complications when going through customs. From the beginning, various measures were taken to ensure the final canoe quality as well as the schedule. These measures mainly cover risk management, communication, and construction training.

Risk management is the decision-making process that social organizations or individuals use to reduce the negative results of risk. Based on lessons from last year, it is important to have a full understanding of potential risks. For instance, personnel risk can prevent assigned tasks from being completed punctually, environmental risks are present, unexpected power outages in the studio can lead maintenance equipment to stop, etc. Several potential risks are listed alongside the corresponding regulations:

- Cementitious and aggregate materials may be affected by moisture during storage. Moisture-proof bags were purchased to store the materials on numbered on shelves.
- To manage personnel risks, regular weekly online or offline meetings were held to confirm the completion of each team's tasks.
- Concerning mold customization, the prices and sample quality levels from CNC processing manufacturers should be compared searching for the most suitable one to avoid delays resulted in poor quality molds.

After risk identification, it was agreed that the best construction results could be achieved via a combination of three types of specimen testing: a scaled-down canoe, a tensile test specimen, and a casting test specimen. During specimen production, experienced members carefully explained the concrete mixing procedure and precautions. In construction practice, new members improved their skills. Hull depth control and apparent color block construction skills were strengthened during construction of small canoes and first full-scale trial canoe. Consequently, the canoe casting quality was guaranteed.

The couple-management system was adopted for fitness management. The team performed sports activities such as group running and swimming every week, incorporating ball games, regularly. Especially, paddling members seized the precious chance to learn from our canoeing world champion. This provided an excellent opportunity of obtaining precious race experience simultaneously having their bodies built up with professional guidance.

Sustainability

Sustainability is a process of maintaining resource balance in the fragile environment, in terms of which the most significant fields so far are energy and transportation. This year, the canoe team applied many sustainable concepts into every aspect of canoe construction.

In order to ensure the maintenance quality of this year's concrete canoe, the team independently made maintenance(curing) box this year, realizing full intelligent maintenance. Thanks for 5G technology, we have achieved the goals of intelligent network control and unmanned constant temperature and humidity automatic control system. In the material selection of the curing box, we use environmental protection materials and consider the durability of the material, the curing box USES PVC material with industrial grade heating and humidification equipment. Transparent PVC material can also facilitate real-time monitoring of maintenance status and aspect of aesthetics.

Figure 18: *The water treatment device*

The main function of the water treatment device is to filter coarse particles, efficiently cultivate bacteria, quickly purify water, and provide a water source for the flow velocity measurement device, which plays a two-in-one effect and saves water. There are three levels. In terms of materials, the first layer USES filter cotton for physical filtration, filtering out the coarse particles. The second layer USES biochemical spheres and other filter materials for biochemical filtration, and pads to filter cotton. The third layer USES biosphere for biochemical filtration. In terms of the structure, laser cutting was used in the first layer to remove the holes evenly distributed to make the sewage even infiltration. The second and third layers adopt zigzag seepage to obtain the maximum discharge.

This year, the team has achieved intelligent solar control, rainwater collection, sewage purification and treatment, and 5G intelligent maintenance of large components. However, due to the limited space, it was decided to integrate the four into one. Simultaneously, the experiment platform for students' independent innovation was also taken into consideration, which could also be used as a boat shed. In order to regulate the experiment, the control/storage area (water, electricity and equipment) was separated from the experiment to ensure the safety of the experiment. At present, the team has completed the modeling work through the BIM cloud platform. For the design of the energy experimental station based on 5G intelligent, the solar power system and rainwater collection/treatment system are combined with it. It is also an experimental platform for students' independent innovation, which may help the canoe team achieve some sustainable ideas and concepts.

Apart from the recycle of containing concrete, in daily construction training, the team used silica gel instead of a plastic sheet to wrap the mold to achieve the same function of protecting the mold as plastic film. At the same time, silica gel is also used as an adhesion foam ship model, replacing the toxic foam glue. In addition, all the materials used in the construction are green and biodegradable, including acrylic sheets, glass foam, pearl cotton and bamboo. As to the ship model used for construction training, the team is recycling, in the effective protection measures under the ship mold can be repeatedly used for section construction practice. The demolding process is also very rigorous. With the help of silicone and other protective measures, compared with the previous disposable ship model, this year's team has achieved the sustainable use of the ship model comprehensively.