Production and Construction Technology of the Prefabricated Cascade-Style Special-Shaped Washroom Caisson

Yin Baoquan¹, Wang Xiaoyan¹ and Wu Yong²
¹ Guangzhou City Construction College Guangzhou 510925, China
² China Construction New Building Components (Guang Dong) Co., Ltd., Dongguan, Guangdong, 523550, China

Abstract. Technical research was performed on the production and construction of the fully fabricated cascade-style special-shaped washroom caisson. The BIM technology was used to design the structure of cascade style special-shaped caisson, the arrangement of reinforcing steels, the embedded pipelines and so on. It is a favorable manual to instruct the intelligent production of prefabricated special-shaped washroom caissons. In this thesis, a kind of highly impermeable and cost-saving concrete was developed. It can greatly improve the impermeability of the structural parts. The molding technique of PE film rough surface in conical groove was also developed to improve the molding effect of rough surfaces on the side of structural parts. The researched production and construction technology for prefabricated cascade style special-shaped washroom caisson had been applied in a number of assembly construction projects. It guaranteed the quality and efficiency of prefabricated special-shaped caisson, and thus creating distinct economic and social benefits.

1. Introduction
With the orderly promotion on the building industrialization and commercialization, a host of scholars have dived into research on the whole industry chain of prefabricated integral architecture. The Ministry of Housing and Construction calls for promoting the management of architectural engineering activities and building overall service life cycle on the basis of BIM technology; thus, pushing forward the architectural industrialization level[1]. Zhang Lin et al. acquired the data information of reinforcing steel from the BIM model and exported it into the CNC machine tool so as to proceed automatic sorting, fabricating, cutting and bending of the reinforcing steel. It ultimately realized the optimized[2] consumption of reinforcing steel material. Zhang Yongyi proposed a comprehensive three-dimensional construction technique on caisson-style washroom to reinforce its waterproof performance[3]. Sun Jian put forward the permeable-resistant design and relevant measures on construction for the cast-in-site structure of sink-style washroom[4]. Fu Wei probed into the relevant techniques of drainage on the same floor of washroom[5]. Followed by the “Design Specifications of Concrete Structures” (GB50010-2010) and “Technical Specification for Prefabricated Concrete Structure” (JGJ1-2014), China specified that rough surface ought to be set as the adjoining surfaces of prefabricated parts. It also regulated that “in the midst of fabrication, the rough surface should be processed as per design”; “Chemical treatment, stucco or chipping methods are favorable in fabricating the rough surfaces”[6]. In the national standard “Acceptance Specifications of Construction Quality on Concrete Structure Engineering” (GB50204-2015), it regarded the “quality of rough surfaces in prefabricated structural parts as acceptance content before entrance[7]. Therefore, the domestic manufacturers who supply various fabricated parts also see great
importance on the roughening procedure of these adjoining surfaces. Mostly they use chipping, stucco, printing, water scrubbing and else techniques to complete the roughening process.

In this thesis, it studied the production and construction technology of the cascade style special-shaped caisson in prefabricated washroom; then it used BIM technology to design the caisson and to instruct intelligent manufacturing. Furthermore, it researched a kind of highly permeable-resistant and cost-saving concrete so as to improve the impermeable performance of the structural parts. Additionally, by studying the molding technique of PE film rough surfaces in the conical groove, it helped to promote the molding effect on side rough surfaces of the structural parts. Therefore, the thesis is effective to guarantee the production quality and efficiency for prefabricated special-shaped caisson.

2. Project Overview

The gross floorage of one prefabricated construction project in Gaobu, Dongguan city is 360,000 m². It’s a high-rise building of eleven floors. The height of the building is about 99 meters. It applies the structure of shear walls, specially shaped frame-shear walls and else modalities. In total, this project has 128 cascade-style special-shaped caissons for prefabricated washroom, with the depth dimension of 1950mm×3920mm. In the wake of its complex modeling, complicated procedures and a variety of embedded parts, this is quite a difficult project.

3. Features and Difficulties of the Project

The project possesses rather complex modeling. Part of it sinks; its upper section is different in either size or height from the bottom section. Meanwhile, three beams are set to hang below the caisson. In addition, the reverse ridges on the upper section of caisson vary in both heights and specifications, and these ridges are processed by one-time molding.

The reinforcing steels of caisson fall into a plenty of varieties. Therefore, the sizes of feeding material vary greatly. For instance, the serial number of reinforcing bars for one caisson is as many as 33.

The embedded parts of a caisson consisted of elevator, wire box, water pipe, elbow pipe, tee joint, wire conduit, galvanized flat iron, embedded screw sleeve, embedded bolt and all kinds of other types. The standpipe caliber of embedded water supply and drainage pipes included two specifications: 50 mm and 110 mm. The sealing joint was preserved in the base board. The tee joint was preserved on the upper outlet of sealing joints. Parallel to the junction of sealing joints was the tee joint. The female elbow was 15mm higher than the concrete wall surface.

The roughness on the side surface of caisson and the beam end is supposed to meet the specifications. Specifically, the roughness for beam-end surface is 6mm, for others is 4 mm.

In the course of caisson production and construction, it came up against following difficulties:

- In the process of caisson production, a great variety of embedded parts and complicated specifications of reinforcing steels are prone to bring about wrong parts, missing parts and other messes. On the other hand, in the midst of installation work, problems caused by wrong parts, missing parts, broken parts, deficient parts and other messes also became unfavorable factors on structural parts construction.
- Being an essential position which requires high waterproof levels, the washroom caisson was originally intended to be coated with concrete; yet its mixture proportion was not effective. Therefore, coiled waterproof materials were mostly used to paste in subsequent waterproof treatment.
- It was going to use water scrubbing method to shape rough surfaces on the side of caisson. Nevertheless, this molding method is harmful for constructors’ health. What is worse, when the sewage is not processed appropriately, it would do harm to the environment and waste the materials.
4. BIM-Based Production Technology for the Prefabricated Special-Shaped Caisson of Washroom

After the design of prefabricated caisson, BIM technology was used to convert the design model into production model. Accordingly, it directed the preparation of materials in caisson production and interfaced the CNC equipment in the process of production to achieve automatic and digital manufacture processing. The model of caisson was shown in Figure 1.

4.1 Establishment and Design of the Caisson Model

In the stage of production, it further developed the information model from the caisson design unit. To be specific, the production procedure, operation period, stock yard position and other essential information in production and transport were added. The production unit worked with the mold factory in developing BIM-based digital mold design. That was, the design of caisson mould was made on the basis of BIM model. The caisson mould drawing was shown in Figure 2. The precision of caisson mould determined the precision of caisson production, and further decided the precision of caisson installation. Additionally, with the help of BIM simulation software, it simulated the assembling and removal orders of caisson mould; as well as interfaced some procedures of the automatic caisson product lines. By this means, it partly realized mould assembly automation.

Figure 1. Prefabricated washroom caisson model. Figure 2. BIM mould drawing of prefabricated caisson.

4.2 Preparation on Caisson Production Materials

Based upon the BIM model, it simulated the demands on manpower, materials and equipment in the stage of caisson production so as to determine the planning of required materials and facilities, and further fix material procurement plan. The collected data from BIM model can be used by the manager to analyze the purchasing of raw materials, storage schedule and data verification thus improving the information level in caisson production.

The caisson production and fabrication involved the platen lineation, the mould assembly equipments, the reinforcing steel fabricating facilities such as mesh machine as well as the industrial fabricating equipments for concrete batching, stirring, in-house transport, material feeding, vibration, curing and so on.

For caisson fabrication, it is favorable to select 10mm thickness of steel plate as the module platen. Automatic cleaning facility should also be equipped to clean up any sundries after module removal. The concrete equipment ought to supply eligible concrete for caisson which possesses relatively higher workability and uniformity along with stable slump constant. The industrialization level of reinforcing steel fabrication determined its productive efficiency of prefabricated caisson. More than that, the processing efficiency of reinforcement steel would improve when BIM technology was interfaced with the automatic bending hoop machine, bending equipment, mesh machine and more CNC machinery.

BIM 4D technology was developed to simulate the technological process and work flow. It consequently showed the latent technical defects on caisson product lines. In this project, the semi-automatic assembly line with fixed pedestal was applied in production. During the whole
process of structural part production, the module platen was stationary; the workers and equipment operated around the module platen. Some procedures were completed by automatic equipments. This technology possesses outstanding adaptability, strong flexibility and low cost on equipments. Moreover, some standardized procedures have advanced grade of mechanization and operation efficiency, therefore, it was applicable for fabricating special-shaped structural parts.

4.3 Production Simulation, Worksite Utilization
Accessible design and arrangement on the worksite arrangement and product line layout would improve the productive efficiency of structural parts, and further decrease re-handling. Before caisson production and fabrication, this project used BIM software to undertake simulation check on the well planned and designed caisson production workshop and work flow. By rectifying and optimizing the improper items, it helped to reduce the incidence of equipment breakdown and structural part damage.

It virtualized the caisson production process via BIM technology; optimized the configurations of production means; tweaked the size and position of module platen; simulated the track route of concrete supply equipment to guarantee the continuous supply of materials. The simulation drawing was shown in Figure 3. It estimated the invested resources and labor scheduling in advance, meanwhile planned the automatic production flow for part of technical flow.

![Figure 3. Simulation on caisson production flow and workshop tour.](image)

BIM technology was applied to spot and solve the site issues in the course of caisson production, and thus ensuring orderly manufacturing, stacking, transport and dispatching.

4.4 Caisson Fabrication and Production Management Based upon BIM
It interfaced the BIM processing model of prefabricated caisson with the factory productive information management system so as to achieve digital and automatic production and fabrication of structural parts. In addition, after the optimization of caisson and its module design on BIM platform, it exported detailed design drawings and BOM list of prefabricated caissons for technicians’ check.

In the stage of caisson production, Revit, PKPM-PC or Tekla Structures software was used to build 3D model. After that, it interfaced the model with production system and then input the BIM information into CNC processing equipment for information recognition. Accordingly, the CNC machine tool for reinforcement steel fabrication can do a lot of work automatically such as classifying, processing, cutting and bending. It also realized the optimal feeding for reinforcing steel materials. Besides, BIM data can assist in marking, positioning, module layout, reinforcing steel arrangement, concrete auto-vibration and more automatic work flows. The data information transmitted in a more effective way as well.

It exported the data of caisson model to generate various detailed fabrication drawing automatically. It was shown in Figure 4. The BIM platform helped to realize interactive update of the model and the drawing, thus securing their uniformity. What’s more, the BIM supports direct release of DWG drawing to reduce mistakes and improve the collaborative efficiency between the involved parties.
IOT technology was applied in BIM platform. By implanting RFID chip in the caisson as the identification code, it continuously collected the caisson information and uploaded it onto the BIM cloud platform, thus recording all the real-time information of structural parts in various phases including design, production, stacking, transport, construction and else stages. In the meanwhile, the BIM cloud platform supported printing caisson QR code. The code was pasted on the structural parts. By scanning the QR code, the real-time information about the caisson was accessible for whole process follow-up and management. This technology helped factory managers to completely control on the plant, so it prevented insufficient space issue caused by over storage of structural parts, as well as handled the supply chain disruption issue caused by insufficient output.

5. Optimal Design of Concrete Proportioning and Pouring Construction Technology

5.1 Preparation on optimal design of proportioning

Referring to the design parameters of waterproof concrete proportioning which was proposed by the project design documents, it drafted the proportioning scheme. Next the test engineer trialed mixing and adjusted the proportioning. Then the chief engineer of the project organized personnel from relevant departments to compare, select and determine the proportioning scheme. After that, the optimal proportioning was submitted to superior unit for approval and implementation. Before implementation, the laboratory director was supposed to elaborate on the proportioning and supervise the mixing work.

The optimized design flow of caisson proportioning is as follows. (1). The research group proposed relevant parameters on the basis of actual conditions. (2). Together with the laboratory engineer, the head of research group drafted the “preliminary proportioning scheme”. (3). Sent the sampling specimen to laboratory for testing. The specimen ought to be representative. (4). Based upon the design requirement, raw material quality and more elements, the laboratory engineers designed preliminary proportioning. (5). Proceeded trial proportioning. (6). Released the proportioning design
Compared the proportioning schemes and calculated the proportioning cost then chose the perfect one. Submitted the selected concrete proportioning for this project to the central laboratory for approval. The laboratory engineers elaborated on the proportioning to relevant personnel in the mixing station, then they set the parameters of mixing equipment, organized and supervised the mixing station operators to follow the proportioning strictly, finally formulating “Letter of Proportioning Disclosure” in written form.

5.2 Optimal Design of Proportioning

Through examination, the selected raw materials were shown in Table 1.

| Table 1. Raw Material in Concrete Proportioning |
|-----------------------------------------------|
| cement (Yingde CONCH brand)                   |
| variety                                       |
| intensity level                               |
| 3d flexural strength (MPa)                    |
| 28d flexural strength (MPa)                   |
| 3d compressive strength (MPa)                 |
| 28d compressive strength (MPa)                |
| place of origin                               |
| fineness modulus                              |
| apparent density (kg/m³)                      |
| stacking density (kg/m³)                      |
| mud content (%)                               |
| chloride content (%)                          |
| Huizhou                                        |
| grading specifications (mm)                   |
| stacking density (kg/m³)                      |
| content of elongated and flaky particles (%)  |
| mud content (%)                               |
| crush value (%)                               |
| granite                                       |
| 5~10                                          |
| 1550                                          |
| 4.0                                           |
| 0.8                                           |
| 13                                            |
| granite                                       |
| 5~25                                          |
| 1600                                          |
| 8                                             |
| 0.6                                           |
| 13                                            |
| name and variety                              |
| grade                                         |
| proportion (%)                                |
| admixture name and variety proportion (%)     |
| proportion (%)                                |
| source                                        |
| mineral admixture                             |
| 1 fly ash                                     |
| grinding II                                   |
| fly ash                                       |
| 1 poly-hydroxyl acid high performance water reducing agent |
| sodium abietate high performance air-entraining agent |
| 2 drinking water                              |
| granulated blast furnace slag                 |
| S95 grade                                     |
| 2 ——                                          |
| ——                                           |

The trial mixing aims at selecting out an optimal proportioning which possesses excellent impermeability, powerful workability, appearance quality and outstanding economical efficiency.

In the first phase, irrespective of admixture, totally eight concrete proportional specimen blocks were tested by impermeability and compressive strength. The selected proportioning was shown in Table 2.

| Table 2. Concrete Proportioning |
|--------------------------------|
| Group | cement | gel material | sand | pebble | water |
| 1-1   | 405    | 0            | 798  | 1000   | 124   |
| 1-2   | 320    | 85           | 798  | 1000   | 124   |
| 2-1   | 359    | 0            | 721  | 1081   | 158   |
| 2-2   | 273    | 86           | 721  | 1081   | 158   |
| 3-1   | 355    | 0            | 760  | 1050   | 165   |
| 3-2   | 270    | 85           | 760  | 1050   | 165   |
| 4-1   | 352    | 0            | 768  | 1106   | 169   |
| 4-2   | 267    | 85           | 768  | 1106   | 169   |

Impermeability test (six specimen blocks in each proportioning group) and compressive strength test (three standard specimen blocks in each proportioning) were developed as per above table. The compressive strength test was shown in Figure 5, and the impermeability test was completed by professional material inspection constitute.
After comparison and analysis on the experimental results, it proposed that the strength grade in all groups accord with the design requirement. Among these statistics, Group 4-1 ranked first in terms of concrete impermeability. Accordingly, this project selected the basic material proportioning as 352:768:1106:169 (i.e. 1:2.18:3.14:0.48) for construction.

In the second phase, the admixture was taken into account for affecting the concrete impermeability and compressive strength. On the basis of experimental results in the first phase, various percentages of water reducing agent and air-entraining agent were added to make a number of specimen blocks. The percentage of admixture was respectively 1%, 1.25%, 1.5%, 1.75% and 2%. The individual influence from both admixtures on concrete intensity and impermeability was analyzed as below:

1) Based upon of the basic material mix proportion that cement: sand: pebble: water as 1:2.18:3.14:0.48, the high-performance poly-hydroxyl acid water reducing agent was added as per proportion of 1%, 1.25%, 1.5%, 1.75% and 2% respectively to develop the impermeability test. The curve of intensity corresponding to their proportion changes as well as the intensity changes was shown in Figure 6. The curve of corresponding impermeable effects and their changes was shown in Figure 7.

2) Based upon the basic material proportion that cement: sand: pebble: water as 1:2.18:3.14:0.48, the high-performance sodium abietate air-entraining agent was added as per proportion of 1%, 1.25%, 1.5%, 1.75% and 2% respectively to develop the impermeability test. The curve of intensity corresponding to their proportion changes as well as the intensity changes was shown in Figure 8. The curve of corresponding impermeable effects and their changes was shown in Figure 9.
Result analysis: 1) As the water reducing agent was added, the impermeable performance of structural part showed a parabolic rise tendency to some extent. Shown in other experiments, its slump constant increased. It indicated that the fluidity of concrete increased and this was beneficial for construction. However, the intensity level increased to a certain extent and then decreased, so the admixture contents at the knee point was selected for this project.

2) The application of air-entraining agent can partly prevent penetrating bubbles in the concrete, thus improving its impermeability. Nevertheless, as the contents increased, it also had the inflection point. Furthermore, the intensity of structural parts fell sharply when air-entraining agent was added. Taking all aspects into account, the optimized proportioning of basic materials in this topic was cement: sand: pebble: water as 1:2.18:3.14:0.48. Additionally, 1.5% water reducing agent and 0% air-entraining agent were added. This proportioning had improved the impermeability of structural parts without cost growth or concrete intensity reduction.

6. Construction Technology on the Rough Surfaces of Special-Shaped Caisson
The special-shaped caisson constructed in this project has three rough side surfaces. As planned, the roughening work on surfaces was finished by airbrushing retarder agent first, then scrubbing by water cannon after mould removal. In real operation, after structural part formwork, the retarder agent was airbrushed on the rough surfaces of mould; when removed from the mould the following day, the structural part was hoisted to the washing area. Using the principle of retarding time difference, it then was scrubbed by water cannon until aggregate exposed to ensure the roughness.

6.1 Defects in Water Scrubbing Rough Surfaces
As specified in JGJ1-2014 “Technical Specification for Prefabricated Concrete Structure”, rough surface should be processed on the conjunction between the prefabricated structural parts and the lamination layer of subsequently poured concrete. Moreover, the area of rough surface is supposed to fill up 80% and more of the conjunction area. The concave-convex depth should be 4mm and more; the concave-convex depth on rough surfaces for prefabricated beam end, column end and wall end should be 6mm and more. All rough surfaces of the structural parts must be inspected by relevant unit before entering the work site. By this means, the rough surfaces would meet the design requirements. In case insufficient amount of retarding agent was brushed on the side surface, or the retarding agent lost in the procedures of reinforcement assembly, pipe fitting embedment and other flows, the washing effect would be greatly reduced. As a result, the washed rough surfaces would not accord with specifications. Therefore, chipping and else methods were indispensable to complete the roughening process. In addition, washing is manual work, so it is harmful to human body by prolonged exposure to the cement paste with retarding agent. On the other hand, the produced sewage is now allowed to be discharged unless being treated; it was also a waste when part of materials was washed away [8]. Therefore, washing method also has some disadvantages.
6.2 Research on Rough Surface Shaping Mould

Now that various defects were brought about when washing method was used to produce rough surfaces, to cope with the problems, it used customized template in the course of rough surfaces construction on special-shaped caisson. Various scores were set on the templates in hope that the scores would leave on the conjunction surface of prefabricated structural parts after mould removal. Through multiple tests, it found that when marks were directly scored on the steel template, the roughness grade cannot meet the specifications if the scores were excessively shallow; otherwise, it is difficult for structural parts to remove from template if the scores were too deep. In the purpose of getting an adequate material for molding template, after repeated tests, the research team finally found PE film a perfect material for making rough surface molding template. PE film has excellent molding effect and low cost, also it is convenient in construction. After recycling, PE film can be made into other modules so it does no harm to the environment.

The author designed various surface-roughening moulds. The representatives were shown in Figure 10.

Pattern 1  Pattern 2  Pattern 3

Figure 10. Typical patterns one to three of the PE film rough surface.

After a number of repeated experiments, in consideration of the construction convenience and the visual comfort in the course of mould removal, Pattern 1 was chosen as the prototype module in bulk production.

6.3 Comparison Experiment on the Roughness Molding of Prototype Module

The prefabricated structural parts that were produced in plant vary in shapes. Furthermore, most parts were special-shaped and it was difficult to scale their roughness. Normally, visual estimation method is directly used to do qualitative inspection. To verify the quality of roughness on the surface of structural parts which was molded via this construction technology, the research team made six concrete specimen blocks in two groups to simulate the roughening treatment on the joint surface of structural parts. Two molding styles were respectively used on the upper rough surfaces of both specimen block groups, that is, roughening by shaping mould and roughening by airbrushing water retarder agent then scrubbing with water. After that, both were cured well. By comparative experiment, both groups of specimen parts met the design requirements and specifications on surface roughness.

6.4 Extensive Application of Rough Surface Molding PE Film

This thesis took theoretical research on the construction technology which was used when the PE film molded on the rough surfaces of caisson. It compared and selected the optimal solution then undertook specimen trial production. In comparison with the molding effect made by traditional technique, it developed laboratory demonstration on latent quality issues. What’s more, the proprietors, the designing party and the specialists in this industry were invited to attend the special conference again. Through demonstration from various parties, it approved the feasibility and advancement of this technology. In this project and subsequent projects, the roughening of caisson surface was constructed with this technology. Furthermore, all constructions accorded with the design requirement and national standards. The molding effect of actual products in project is shown in Figure 11.
7. Construction Technology of Cascade Style Special-Shaped Caisson for Prefabricated Washroom

7.1 Work Flow of Cascade Style Special-Shaped Caisson for Prefabricated Washroom

The constructive work flow was shown in Figure 12.

![Figure 12. Work Flow of Cascade Style Special-Shaped Caisson for Prefabricated Washroom.](image)

7.2 Operational Essentials

7.2.1 Cleaning the Mould Platen. Before construction starts, following work should be done first: installing and commissioning of various production machinery and facilities, checking operation conditions and safety. Every index ought to comply with requirements. Use sweeper to clean the mould platen intensively, if necessary, clean it manually together with sweeper until the platen and joints meet the requirements. Then use air compressor to clean the inside of the mould. Adequate maintenance on the mould is needed to protect the module from deformation or unevenness. The tooling of mould should be clean and free from residual concrete. Clean the mould and maintain it with fabricant. Make sure that no deviation in size occurs in mould assembly. Clean the edges of mould so that the plastering surface is favorable to guarantee the sizes of structural parts. The molding PE film can be directly paved onto the rough surfaces of mould without being cleaned.

7.2.2 Brushing Mold Release Agent. Spray the mold release agent by manual application. Spray the mold release agent to ensure the evenness of coating. It is prohibited to splash agent onto a large area then to wipe it evenly with mops or rags. Ensure the caisson to remove from the mould successfully. After the mold release agent is sprayed, the surface of module should be clean from apparent dents.
7.2.3 Mould Assembly. Before mould assembly, draw lines by hand at any complex positions of the caisson. Select the correct model of side boards to assemble the mould. Ahead of assembly work, check the moulds first; in case they are not well cleaned, mould assembly cannot be continued. Fasten every bolt and magnetic box to ensure solid connection between the mould and the base mould. Check the position of mould and control lines; tweak the positions which exceed the controlling standard on mould assembly dimensions. In the midst of mould assembly, check everything carefully to guarantee the templates in complete and intact conditions. Fasten the screw at all parts. Eliminate any possible interstice between moulds; confine the deviation of all mould dimensions within the error range.

7.2.4 Installation of Reinforcing Cage, Embedded Parts, Water Supply and Drainage Pipes. Install the well-bound reinforcing cage into the mould; inspect its fabrication quality including the model of reinforcing steel, the dimension deviation and else items. In the light of drawing, install the embedded parts; check the installation quality of electrical box and other embedded parts in terms of their quantity, position, model number, dimension deviation and so forth. In the light of drawing, install the drainage water pipe; Use simple tooling to precisely fix the position of water supply and drainage pipes. Inspect the installation quality of drainage pipelines in terms of their model number, dimension, quantity, location and so on.

7.2.5 Installation of Side Molding PE Film. Paste the PE film shaping mould onto the steel mould of rough surfaces. The film is requested to be pasted compactly; any missing or unstable pastes should be prevented. In addition, inspect the pasting size, position, quality and other aspects of PE film. The position where PE film is pasted should be free from retarder spray.

7.2.6 Concrete Pouring and Vibrating. Check the slump constant and else properties of concrete before pouring work to make sure it complies with the requirement. In the process of pouring, keep the concrete away from the embedded positions to protect the parts from displacement. Use automatic feeding machine to convey the concrete to pouring workshop. After pouring work is finished, use the self-vibrated platen to vibrate the concrete for around 10s until it becomes leveling inside the mould. In exceptional cases (for instance, the slump constant is far below standard, the concrete is partially piled up excessively high, etc.), it needs manual intervention in vibration assisting by vibrator. Clean the tools after use and clear the work site after construction.

7.2.7 Top Layer Smoothing and Calendaring. Smooth the concrete surface with scraping bar to keep its thickness within the upper edge of mould. Plaster roughly with plastic spatula until the surface is basically even. On the surface, there should be no pebbles or concave-convex flaws. Besides, the upper edge of surrounding side boards must be clean from any extra thickness or burrs. Leveling the surface with iron spatula. Pay particular attention to the evenness of the embedded parts, wire boxes and surrounding exposed conduits. Confine the surface evenness within 3mm and cure it for two hours. Calendar the upper surface of concrete with iron spatula to ensure the surface free from crack, bubble or impurity. Meanwhile, the surface should be even and smooth with no concave-convex flaws.

7.2.8 Caisson Curing. Normally the structural parts are cured in nature. In winter, they are cured in the curing chamber to enhance the concrete strength in early stage. In case the parts are cured by steam, static curing is a crucial procedure after the plaster work and ahead of steam operation. The duration of static curing is determined when pressing by hands, no dents are left on the surfaces. The maximum curing temperature ought to stay below 60℃; and the whole curing process is separated into three phases: heating, constant temperature and cooling. The heating rate is supposed to be 10℃/h or lower, and the cooling rate to be 15℃/h or lower, the total curing period to be 8 hours and
more. The temperature in curing chamber should be monitored in real time. Furthermore, the steamed parts of the same batch are supposed to be measured hourly.

7.2.9 Caisson Mould Removal. Use stacker machine to take out the well cured parts and their base mold from the curing chamber, and then send them to the mould releasing station. All removed tooling, screws, all kinds of components and else parts are supposed to be placed in specified positions. It’s crucial to keep the concrete prefabricated parts intact on both surfaces and edges in the midst of mould removal. Remove the template in accordance with the procedure of mould design and construction plans; after template removal, clean the platen surface promptly and coat it with mould releasing agent; Repair the deformed position in time.

7.2.10 PE Film Removal from the Sides of Caisson. After the steel mould is removed from the rough sides of caisson, release the PE film mould by hand. Be aware of protecting the edges of caisson in the process of mould removal.

7.2.11 Quality Inspection and Repair on Caisson. When the caisson mould releases, examine the cross section of structural parts, then inspect the appearance quality, model number and quantity of caisson alongside the position and quality of embedded parts. Simultaneously, surface cleaning work ought to be done well. Use grinding machine to sand the protruded concrete near the iron mould seams of prefabricated caisson; fill up the concave position until the surface is flat. Chisel off the floating materials at honeycomb position then wash it well. Mix the approved mending materials with water and stir it evenly until the mending cement paste stops shrinking any more.

7.2.12 Caisson Identification. When the caisson is accepted in quality inspection, identification must be sprayed immediately at prominent position of its surface as per the production drawing number. The identification is supposed to consisting following contents: serial number, weight, using position, manufacturer and date of production (batch). In accordance with the type of caisson, relevant installation and operation instructions along with technical specifications should be provided to instruct the whole process in transport, storage and hoisting.

7.2.13 Hoisting in Plant. Level operation is required in caisson hoisting. Pay attention to the operational environment and hoist at low, even speed. Lower the caisson slowly to protect it from edge damages or surfaces scratches caused by sway or crash. In the midst of hoisting, personnel staying or moving under the crane arm is prohibited. When the parts are hoisted, personnel are not allowed to stand or operate on the parts. “Ten prohibitions on hoist operation” must be implemented strictly.

7.2.14 Caisson Storage. The prefabricated caissons are supposed to be stacked and numbered respectively in the light of category, specifications and loading order. For convenient and safe purposes, it’s better to set the stored stacks within the range of hoist operation and away from the pedestrian path. In the process of prefabricated caisson storage, the position of embedded parts is favorably set away from shielding for easy hoisting.

8. Conclusion
The production and construction technology of the cascade style special-shaped caisson for prefabricated washroom had ensured its quality and efficiency in production. The key innovations were reflected in three following aspects.

BIM technology was used to design the structure of cascade style special-shaped caisson, the arrangement of reinforcing steels and the pipeline embedment as well as to instruct intelligent assembled production. By means of BIM technology, the thesis subdivided the caisson patterns. It
then developed visual simulation and economic comparison on the design scheme; after that the structural model of special-shaped cascade caisson was built to support the implementation of reinforcing steel arrangement, pipeline embedment and a series of other procedures. Consequently, the established model helped design the special-shaped caisson and realize the standardization in production. The application of BIM technology on product line simulation achieved rational development and use of fabrication site. It regulated to ensure effective operation on facilities and precise supply of materials. Furthermore, it is partly connected to the steel mesh machine, automatic stirrup feeding machine and other CNC fabricated equipment, thus realizing automatic and digitized fabrication.

It researched on the mix proportion of the highly-impermeable and cost-saving concrete, and thus improving its impermeable performance. Under multiple groups of experiments, the thesis studied the proportioning scheme of highly permeable-resistant and cost saving concrete. The mix proportion of concrete was designed as cement: sand: pebble: water equaled 1:2.18:3.14:0.48; additionally, 1.5% water reducer was added. Through multiple project applications, it indicated that, the scheme had improved the permeable-resistant performance without intensity reduction or cost growth.

It researched on the construction technique of PE film rough surfaces in the conical groove to improve the molding effect of rough surfaces at the sides of caisson. Under a number of experiments, this thesis determined the perfect material and molding method for shaping mould. It also studied the PE film as rough surface shaping mould. The PE film was pressed into 6.5mm of deep conical groove to ensure 6mm depth requirement on roughness. This mould possesses excellent performance in mould shaping and releasing; meanwhile it is cost-saving and convenient to use in construction. Moreover, recycled PE film can be fabricated into other moulds which are environmentally friendly.

The production and construction technology of cascade style special-shaped caisson for prefabricated washroom was applied on many fabricated projects under construction in Gaobu, Dongguan City. By inspection and acceptance, all projects had met the design requirements and national standards. It guaranteed the quality and efficiency in production and created apparent economic and social benefits.

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