Application Analysis and Problem Prevention of Cast-in-Situ Beamless Hollow Floor Construction Technique in Large Deep Foundation Pit

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Abstract. Cast-in-place concrete beamless hollow floor is more and more widely used in engineering, especially in basement engineering, due to its characteristics like increase of the structure height, enhancement of heat preservation, heat insulation, noise reduction, rapid construction speed and others. Based on engineering practice, the application of cast-in-situ beamless hollow floor cover in large deep foundation pit is studied. In order to improve the construction quality, the deformation and stress state of long-span hollow plate are analyzed by finite element simulation. By optimizing and improving the process and comparing the results, the process method which is helpful to improve the quality of finished products of beamless floor under this condition is extracted.

1. Introduction
As a mature technology, cast-in-place concrete beamless hollow floor is more and more widely used in modern construction. The hollow floor with this technology has many advantages, such as improving the net height of the structure, enhancing the heat preservation and heat insulation effect, improving the sound insulation and noise reduction function, reducing the amount of concrete, steel bar and formwork, speeding up the construction speed, and increasing the accuracy of the structural section size. However, due to the particularity of the process, there probably are some problems in the quality of the finished cast-in-place concrete hollow floor cover. In addition to the common diseases of concrete, cracks, honeycombs, and pockmarks, there is also the foam floating slurry unique to the hollow floor cover, and the deviation of the floating running mold on the box body, etc. Quality accidents also provide a higher frequency in recent years. In this paper, based on the engineering practice, the deformation and stress state of the plate are analyzed by the finite element method. The construction technology is optimized and improved by combining the engineering practice experience. The construction methods are summarized, which improve the quality of finished products for the large deep foundation pit and long-span beamless hollow floor cover, providing the basis for the research and application of the beamless floor in the future.

2. Project Profile
The general construction contract project in the West part of Nanjing Financial City Phase II is located in Jianye District, Nanjing. The total construction area is about 380,000 square meters. The underground part of this project is an ultra-deep basement with five floors, and the depth of foundation pit is 23.5 m ~ 31.5 m. The basement floor size is 190 m×170 m, and the floor area is about 34,000 m².
The concrete strength is C35. Most of the basement floor plates are hollow floor plates with BDF inorganic flame retardant box as the core mold, which covers a great deal of area, has a large volume, is difficult to construct, and the possibility of quality problems is also strong.

The hollow slabs with a thickness of 330mm are used in both minus three and minus four layers, while in minus two and minus one layer, the 430 mm thick and 480 mm thick hollow slabs are respectively used. In addition, there are three types of inorganic flame retardant boxes, namely 600×600×150, 600×600×250, 600×600×300. The thickness of the upper and lower cast-in-place concrete of the box body is 110 mm and 70 mm individually, and the width of the belly rib is 120 mm and 100 mm. The basement is shown in figure 1.

Figure 1. Aerial view of basement floor and arrangement plan of hollow floor boxes: (a) aerial view (b) arrangement plan.

3. Construction Process

3.1. Formwork Installation
The formwork installation is the same as that of ordinary concrete in-situ. Due to the large span of floor slab in the ultra-deep foundation pit, the formwork shall be arched at a slope of 3%. The position of steel bar, water and electricity pipeline and core box is measured. Ribs, frame beams, ribbed beams and reserved embedded positions are located and marked on the formwork according to the arrangement drawing of inorganic flame retardant box body [1]. It is necessary for the core boxes and the bottom ribs to be fixed and tied with the iron wire against floating. Hand electric drill should be used to drill holes in the formwork equidistant at the gap rib, and small holes should be reserved for interpenetration.

3.2. Rebar Installation and Binding
The bottom bars are layed and tied according to the layout location, whose steps and requirements are the same as ordinary cast-in-place concrete slab. After binding, concrete or plastic cushion blocks are placed at intervals under the reinforcement to ensure the thickness of the concrete cover. The holes, perforated for anti-float fixation of the bottom rib, space 600-700mm. The bottom rib and the bottom formwork are fixed together by tying the 14# iron wire with the outer plastic cover to the formwork, scaffold, or support square through the reserved holes. The wire should be tighten and straighten vertically, which means diagonal pulling is forbidden. As the standard indicates, until the wire can not be moved horizontally, tightening shall not be stopped. During the construction, the trampling may cause the wire to become loose. Therefore, 2–3 mm gap is allowed. Before pouring, special personnel shall be sent for inspection. Figure 2 indicates this measure.
Figure 2. Fixing measures of bottom reinforcement bars.

When binding the upper steel bar of the floor slab, a 15 mm protective layer between the upper steel bar and the box body ought to be ensured.

3.3. Electromechanical Installation and Embedment
After completing the binding of floor bottom reinforcement and beam reinforcement, the pipelines shall be laid. The water pipes, wire tubes and reserved boxes must be buried and installed according to positioning strictly.

3.4. Core Die Box Installation
The inorganic flame-retardant boxes ought to be placed one by one according to the box place drawing. In order to ensure the thickness of the lower flange, considering the floating characteristics of the inner mold, horse benches of appropriate height should be adopted according to different plate thickness. For example, the minus 3 floor in this project are 300 mm thick plates, with 60 mm high horse stool, with 10mm floating space and 150 mm core mold thickness. The lower flange space is 70mm and the upper flange space is 80mm. Three horse stools are placed at the lower part of each inorganic flame retardant box, and the 16# iron wire and the lower steel bar are bound together with the box.

Two anti-floating square pipes or Φ10 steel bars shall be used on both sides of the top of the inorganic flame retardant box. Next, the ribs of each inner die shall be fixed vertically with double-ply 16# iron wire. According to the anti-floating calculation, it can ensure that the box meets the anti-floating requirement when concrete is poured.

No box shall be set in the punching range of columns and the post casting belts. Solid concrete areas on both sides of the post-pouring belts shall be adjusted according to the condition of construction site, and the distance from the boxes shall be no less than 100 mm, which is shown in figure 3.

Figure 3. Arrangement principles of the hollow floor plate.

3.5. Pouring of Concrete
Only if the inorganic flame retardant boxes and reinforcement bars are qualified for acceptance, as well as each process is completed, concrete pouring shall be carried out.
4. Finite Element Analysis

4.1. Modelling
The representative floor slabs of the negative three floors in the basement of this project are selected as the prototypes to establish a calculation model. The structure arrangement of floor plate without beam is shown in figure 3. The column network size is 9m×9m, the column section size is 800mm×800mm, and the column height is 3.5 m. As mentioned above, the thickness of the hollow beamless floor cover is 300 mm, the thickness of the bottom plate is 70mm, and the thickness of the top plate is 80 mm. 117 BDF inorganic flame retardant boxes (hollow mold boxes) have been built inside. The size of the boxes is simplified to a hexahedron, 600 mm×600 mm×150 mm, and each box has a perforated circular hole with a diameter of 100mm in the middle. The solid parts around the hollow plate are concealed beams, which have the same thickness of the plate, therefore concealed beams and the plate here can be considered as one body [2]. The preliminary model is shown in figure 4.

Figure 4. Establishment of calculation model.

In order to operate the control experiment, a solid plate model is established for finite element analysis. The model is basically the same, only the floor part adopts the common solid plate.

4.2. Simulation Model
The model of hollow beamless floor is a three-dimensional spatial stress model, which ignores the effect of reinforcement on the overall stiffness. The concealed beams and the plate are considered as one body. The model unit of the hollow plate and the solid plate both adopts the default unit, SOLID186 [3].

Hexahedron is used to divide the grid. Due to the density and complexity of the box parts inside the hollow plate, there are problems in dividing the contact surface by default. Take the grid size as 200mm. Similarly, the grid size of the solid plate is also 200mm.

In order to simulate the situation of use, gravity should be taken into consideration. In addition, distributed load of 4kN/m is applied to the top surface of the plate vertically. As the real situation of stress indicates, the plate is supported on the four columns [4]. These model bodies are imported together at the same time. Column bottom is completely constrained. The adjacent side of the plate imposes symmetric constraints, and only z-direction constraints are released.

4.3. Calculation Results and Analysis
Via operating finite element calculation and analysis, the deflection and stress cloud pictures of the beamless hollow floor and the solid floor can be obtained. The deflection cloud diagrams are shown in figure 5.
The deformation of hollow beamless floor and solid beamless floor is basically the same, and the displacement isolines are distributed approximately in concentric circles with the middle point of the plate and four column points as the center. The deformation at the top of the four columns is the smallest, while the closer to the center of the plate, the greater the deformation. The deformation at the center of the plate is the greatest. As the gravity is considered, the deflection of the solid plate is larger than that of the hollow plate. The maximum displacement of the hollow plate is 1.58 mm, while that of solid plate is 2.11 mm.

The x-direction and Y-direction positive stress cloud diagrams of the hollow plate bottom are shown in figure 6. The x-direction and Y-direction positive stress cloud diagrams of the solid plate bottom are shown in figure 7.

**Figure 5.** Cloud pictures of the deflections. (a) hollow slab (b) solid slab.

![Figure 5](image)

**Figure 6.** Cloud pictures of the stresses at the bottom of the hollow slab. (a) $\sigma_x$ (b) $\sigma_y$.

![Figure 6](image)

**Figure 7.** Cloud pictures of the stresses at the bottom of the solid slab. (a) $\sigma_x$ (b) $\sigma_y$.

![Figure 7](image)
The positive stress distribution of hollow plate and solid plate is approximately the same. The stress in X direction and Y direction is of the same distribution shape. The middle part of the plate bottom is under tension, and gradually becoming under pressure on both sides, which indicates a relative flat change. However, for the solid plate, the distribution of tensile stress in the middle and compression stress on both sides is more concentrated than that of the hollow plate with more obvious boundary. On the whole, the bottom stress of the solid plate is larger than that of the hollow plate, and the stress distribution and transformation boundary are more obvious.

The cloud diagram of the maximum tensile stress on the plate bottom is shown in figure 8.

![Cloud diagram of maximum tensile stress on the plate bottom](image)

Figure 8. Cloud pictures of maximum tension stresses at the bottom of the slab. (a) hollow slab 61 (b) solid slab 61’.

The maximum tensile stress distribution of hollow plate and solid plate bottom is similar, which reach its maximum at the middle point or on the four sides.

Based on the above finite element analysis results, it can be seen that under such simulated conditions, the stress deformation of the hollow plate is roughly the same as that of the solid plate. The deformation of the bottom of the hollow slab is distributed in a concentric circle with the center of the slab and the four column points. The deformation of the plate is the greatest, while the deformation of the column is the least. The stress distribution at the bottom of the plate is more uniform than that of the solid plate. Based on the above analysis results and practical engineering experience, corresponding quality assurance measures can be taken [5].

5. Prevention and Control of Problems

5.1. Prevention Beforehand

5.1.1. Preliminary Inspection of Materials. The box size should be qualified. There shall be no damage on the surface. More importantly, the performance parameters of the factory certificate must meet the requirements. The yield strength of the metal strips meets the requirements without breaking or deformation. There shall be no missing or damage to the horse stool, whose height must meet the requirement that ensure the thickness of the plate bottom. In this case, 10mm of floating space shall be deducted. The plastic cover matches the size of the anti-float wire, which meets the requirements.

5.1.2. Horizontal Arrangement of the Boxes. Lofting, marking and placing the boxes should be done strictly according to the construction drawing of the box arrangement. The spacing of the box body shall be no less than 120mm in rib width. The stress is large at edges of the plate, and the distance between the boxes and the inner sides of the columns should be no less than 300mm to make sure the strength enough at edges of the plate [6]. Damages taking place at column side provides a higher frequency in quality accidents, so no box could be arranged within the punching shear scope of the column. Taking the plate used in the model in this paper as an example, there is an empty box position
near the column end of the plate. Taking the plate used in the model in this paper as an example, the space of an empty box is left near column ends on the plate. Solid areas on both sides of the post-pouring belt shall be adjusted according to the construction site, and the distance from the boxes shall be no less than 100 mm.

5.1.3. Vertical Thickness Control. Verification of anti-floating measures is necessary. There ought to be at least 2 metal layering strips on the top of each row of boxes, arranged in one direction. The layering strips and rebar are both secured through binding of steel wire, which is protected by plastic cover. As shown in figure 9.

![Figure 9. Anti-floating fixation measures: (a) cutaway view (b) top view.](image)

The number of horse stools placed at the bottom of each inorganic flame retardant box shall be no less than 4. In this way, the number of fulcrum points could be ensured in each box, so as to prevent the box body from tilting due to the lack of horse stools during the pouring process, which may cause the thickness of the plate uneven up and down. It is shown in figure 10.

![Figure 10. Set and inspection of the horse stools.](image)
The deformation reaches the maximum at the mid of the plate, especially the large-span plates in this project. The formwork arch towards the center according to the gradient of 2/1000 ~ 3/1000, while plate bottom and plate top thickness should also be ensured during arching.

5.2. In-process Control

5.2.1. Reinspection of Materials. During the construction process, each procedure shall be supervised with full-time management personnel standing by. The number and damage of horse stools shall be checked before and after the box is arranged. Materials must be replaced in time, if there is any damage or lack. Stepping on the boxes or metal layering strips is strictly prohibited, which must be replaced immediately if any damage inspected [7]. In order to fix this problem, temporary pavement boards can be made from leftover formwork, which can be set up at the sides of the columns and from concealed beam to concealed beam for people to walk.

5.2.2. Concrete Control. Leakage problem is frequent in basement projects, the parameters of concrete should be controlled strictly, like the concrete mix proportion, the strength grade etc. when necessary the impermeability grade should also be taken into consideration. There is relatively little space at these positions, like the rib beam between the boxes, the hole in the center of the box body, the bottom flange and the top flange of the plate, where it is difficult for concrete to compact the gravity flow, so the slump shall not be less than 160 mm.

5.2.3. Casting Process Control. When pouring, one slab should be poured at a time. When construction joints are necessary to be left, they shall be set between the ribs and shall not cross the boxes. Before repouring, the construction joints should be roughened.

During pouring, 35 mm vibrating rods shall be used to vibrate. The vibrating rod shall not be tamped on the surface of the boxes in direct contact. The vibrating rod shall be inserted until it reaches about 20 mm above the upper opening of the bottom formwork, in order to reduce the vibration spacing, to ensure the flow of the bottom concrete and compactness. Vibrating between the ribs until the concrete in the middle hole is spilled. Then we vibrate the concrete in the middle hole of the box. As shown in figure 11.

![Figure 11. Full vibration during the pouring process.](image)

Always pay attention to whether the box body floats, especially the box near the beam. Once the boxes float, the pouring must be stopped immediately, and appropriate remedial measures should be taken [8]. The elevation is controlled by the steel bar with coating line. The surface should be coated twice, to ensure it flat. The bottom formwork could be removed, only if the strength of the specimen cured in atmosphere condition raised to 100%.

5.3. Post-treatment

Filling plaster is used to small cracks, which is less than 0.2 mm. In case of large cracks, honeycomb surface and exposed tendons, the damaged parts should be removed. They need to be reinforced by implanting rebars, and the contact surface should be gouged out. At last, set up the formwork and cast.
6. Effect Test

The surface quality of the roof and bottom was checked by comparing the process improvement and construction control of negative four and negative three layers, as the figure 12 indicates.

![Figure 12](image1.png)

**Figure 12.** Comparison of hollow slab bottom before and after quality measure control: (a) before (b) after.

The vertical thickness distribution of the hollow plate is measured by random coring, which is shown in figure 13.

![Figure 13](image2.png)

**Figure 13.** Core testing of hollow plate at random points.

Check and compare whether the vertical layer thickness of the plates before and after quality control measures is qualified, and record results. The results are shown in table 1.

| Number | Lower flange height (mm) | Box height (mm) | Upper flange height (mm) | Testing result | Qualification rate |
|--------|------------------------|-----------------|------------------------|----------------|-------------------|
| 1      | 7                      | 15              | 11                     | qualified      |                   |
| 2      | 6                      | 15              | 12                     | qualified      |                   |
| 3      | 5                      | 15              | 13                     | unqualified    |                   |
| 4      | 8                      | 15              | 10                     | unqualified    |                   |
| 5      | 6                      | 15              | 12                     | qualified      |                   |
| 6      | 7                      | 15              | 11                     | qualified      |                   |
| 7      | 7                      | 15              | 11                     | qualified      |                   |
| 8      | 7                      | 15              | 11                     | qualified      | 100%              |
| 9      | 6                      | 15              | 12                     | qualified      |                   |
| 10     | 7                      | 15              | 11                     | qualified      |                   |

**Table 1.** Comparative record sheet before and after quality control measures.
7. Conclusion
Cast-in-place concrete beamless hollow floor has the characteristics of large net height of structure, good heat preservation, heat insulation and sound insulation performance, saving concrete consumption, fast construction speed and cost saving, etc. It is widely used in engineering, especially in basement engineering.

When cast-in-place concrete beam-less hollow floor slab is applied to the basement slab of large deep foundation pit, due to its large area, large span and the quality problems of the finished products of cast-in-place beam-less hollow floor slab, it is necessary to take targeted measures to control it, so as to ensure the structure safety and the quality of finished products.

According to the engineering practice, the application of cast-in-situ beamless hollow floor cover in large deep foundation pit is studied. ANSYS software is used, through the finite element analysis of simulating the actual situation of single hollow floor plate. It is found that the deformation of the plate at the four column ends is the smallest, the more close to the center of the plate, the larger the downward deformation of the plate. The stress at the bottom of the plate is positive. Tension is in the middle, while compression on sides. Maximum tensile stress at the bottom of the slab peaks in the middle and the sides of the plate. In addition, by comparing the finite element analysis results of solid plate under the same conditions, it can be seen that the displacement and stress distribution of hollow plate are approximately the same as that of solid plate. The bottom displacement of hollow plate is smaller than that of solid plate. The bottom stress is smaller than that of solid plate, and the stress distribution is more uniform.

According to the analysis results, the construction technology of cast-in-place concrete beamless hollow slab is optimized and adjusted. In engineering practice, the quality of finished products is tested before and after taking optimization measures. Comparing the test results, it was confirmed that the optimized organizational measures had been taken to improve the quality of finished products significantly.

The key factors to improve the quality of finished products are summarized, qualified material, little damage found on materials through whole process, appropriate horizontal pre-arrangement for the boxes, fine control of vertical thickness, concrete performance, optimized pouring process, protection of the finished products. The key measures to ensure the quality of hollow beamless floor are also extracted, with qualified materials, commissioner supervision and protection of the whole process. No box could be arranged in the punching shear scope of columns. The distance between boxes and the distance between boxes and beam sides must be controlled. Four horse stools provide enough fulcrums, which make sure the boxes uniform.

References
[1] Lu B, Lu J and Zhu D M 2016 BDF inorganic flame retardant thin-wall core box construction method of cast-in-place hollow floor Jiangsu Construction 3 54-57.
[2] Shi C J, Wu E J, Chen X T and Zhang W 2018 Numerical simulation analysis of mechanical behavior of large-span hollow floor Construction Technology 47 164-167.
[3] Wu C P and Bai D L 2010 Finite element analysis of mechanic performance of cast-in-situ concrete hollow flat slab Journal of Hefei University of Technology 33(5) 726-730.
[4] Qu C P, Yang R F, Huang C C and Yang S C 2013 Structure performance analysis of cast-in-place flat hollow slab Construction Technology 42(18) 81-82,117.
[5] Cheng Y B, Cheng W R and Dang J 2009 Numerical solution for the deformation of cellular voided slabs fixed supported by four edges Journal of Henan University (Natural Science) 39(5) 534-538.
[6] Yan H W 2009 BDF high strength thin-wall box or tube filler cast-in-situ hollow concrete floor system Industrial Construction S1 288,304-306.
[7] Huang H H, Li S L, Zheng X Y, Ao Z N, Guo D W and Zhang M 2015 Application of the Hollow Ribbed Slab Floor Structure Form in Large Span Structures Building Structure 45 497-500.
[8] Cheng Z J and Wang X F 2004 Technical Specification for Cast-in-situ Concrete Hollow System *Building Structure* (CECS175).