Research and Practice of Mass Concrete Foundation Project Design of Modong No.4 Bridge

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Abstract. Modong No.4 Bridge is an important part of the water environment improvement project in Guangxi Laibin City, Guangxi. Its site conditions are extremely complex. After extensive research and demonstration, considering safety, practicality, economy, beauty and environmental protection, the design proposal was put forward according to local conditions. Abutment foundation uses ultra-high rigidity to expand deep foundation, which makes foundation pit construction extremely difficult. In order to achieve the optimal implementation of the recommended scheme of the bridge, the key technologies and quality control points of mass concrete foundation construction are studied and put forward. The feasibility of the design scheme is improved to the greatest extent, providing an effective reference for similar bridge construction.

1. Introduction
Modong No.4 bridge is an important part of the water environment improvement project in Guizhong water city, Laibin city, Guangxi province, spanning the construction of Modong canal pile no. K0+920. Modong canal is the trunk canal planned by the "Guizhong water city" water network in Lai Bin city. It is a manually dug channel, with a total width of about 25~100m, a channel width of 25~60m, a bottom elevation of 78.25m, a normal water level of 80.000m, and a controlled submerged water level of 80.500m. The canal cross-sectional is inverted trapezoidal, with a bottom width of 32.5~85 m and top 70~165m. In order to achieve Xinqiao road across Modong canal, Modong No.4 bridge is proposed. The present site is on a plain, the bridge is on a road, and the excavation channels are on both sides of the road. After the bridge is completed, both sides of the channel will be connected, forming a watertown landscape.

2. Overall bridge design research
The natural condition, material supply, geological condition, construction plan and using effect of bridge location area are considered comprehensively in bridge design. Combining safety, practical, economic, beautiful, environmental protection, according to local conditions, local materials, choose the best bridge project with feasible technology and reasonable economy.

2.1 Design overview
Modong No.4 bridge is a newly built bridge, spanning the planned Mo Dong canal; The designed characteristic water level is 80.5m of the flood control water level of Mo Dong canal. The riverbed of Modong canal is treated with slurry masonry, without the river bed scour. According to the
topographic cross section of the proposed bridge location, the bridge is located on the straight section and is an orthogonal bridge with a total length of 46m. The transverse width is 40 meters.

2.2 Bridge scheme
The bridge type adopts 1×30m reinforced concrete slab arch bridge. The axis of the main arch arch adopts a circular arc line (controlled by the bottom edge), with the bottom edge of the arch as the origin, and the arc curve equation is: 

\[ x^2 + (y - 16.033)^2 = 22.17^2. \]

2.2.1 Superstructure design.
Net span of main arch L_0=30m, net vector height f_0=6m, vector span ratio 1:5. The arch ring has a uniform section with a height of 0.7m and a width of 2×19.99m. The main arch ring is designed according to the reinforced concrete structure.

On an empty stomach-type arch building is adopted, with three span girders and a net span of 3.3m ~ 3.4m. The thickness of the bridge panel is 0.4m.

The transverse standard width of the bridge deck is: 6m(Sidewalk) +5.5m (Non-motorized lane) +1m (Isolation zone) +7.25m (Car lane) +0.5m (Intermediate partition) +7.25m (Car lane) +1m (Isolation zone) +5.5m (Non-motorized lane) +6m (Sidewalk) =40m.

Main beam transverse slope 1.5%, sidewalk transverse slope 1.5%. The bridge surface is paved with 12cmC50 reinforced concrete.

2.2.2 Lower structure design
The lower structure includes No.0 abutment and No.1 abutment, both of which use U-shaped abutments and expand the foundation.

Gravity abutment is adopted. C30 plain concrete is applied to the side wall and back wall of the abutment within 0.5 meters of the abutment cap, abutment body and abutment top. The packing is made of gravel with good permeability, and the compactness is not less than 95%.

The foundation of the abutment is to expand the foundation, using C25 stone concrete, the stone content is not more than 20%. The foundation is stepped and the base height is 5~12m.

Due to the large depth of foundation pit and limited by the field conditions, slope relief and cantilever pile support are adopted for excavation.

2.3 Engineering material design
(1) Concrete: Retaining pile - underwater C35 concrete; Crown beam - C35 concrete. The bridge is in a class I environment, and all concrete used should meet the requirements of strength and durability. The maximum water-cement ratio should not exceed 0.55, the minimum cement consumption should not be less than 275kg/m³, the concrete strength level should not be less than C30, the maximum chloride ion content should not exceed 0.3%, and the maximum alkali content should not exceed 3kg/m³.

(2) Steel reinforcement: HPB300 grade and HRB400 grade steel reinforcement, the materials are in accordance with the current national standard "Steel for reinforced concrete part 1: hot rolled round steel bar" (GB1499.1-2008) and "Steel for reinforced concrete part 2: hot rolled ribbed steel bar" (GB1499.2-2007×G1-2009), the steel bars shall not be cold processed steel bars.

(3) Section steel and steel plate are made of Q235b steel.

(4) Concrete protective layer of longitudinally stressed steel bars: enclosure pile 70mm; Crown beam 50 mm.

(5) Anchorage and joint of rebar: The anchorage length L_a of HPB300 rebar is 30d, and that of HRB400 rebar is 35d. The stressed steel bars shall be welded or mechanically connected. When welded, the welding length and the performance and quality of the welding rod shall meet the provisions of the current national standards; Using mechanical connection, the fitting level for I, and should comply with the rules of "Technical specification for steel bar mechanical connection" (JGJ107-2010) and other relevant regulations and process requirements, and the field experiments of
qualified rear can use. The distributed rebar and the stressed rebar with a diameter of less than 25mm can be lapped by binding, and the lapped length should not be less than the Ld value calculated by the table.

3. Research on structure design of foundation

The foundation of Modong No.4 bridge is very special, and its design is based on the current national, industrial and local technical standards, design specifications and regulations, and “Detailed geotechnical investigation report of Modong No.1 and No.4 bridge in Laibin city”.

3.1 Foundation design scheme

Bridge abutment foundation is an ultra-high entity expansion foundation, the embedding depth is large. According to the rock trend, it is made into a stepped type, as shown in FIG. 1 and FIG. 2. The foundation height of No.0 abutment is 5m to the south and 8m to the north. The foundation height of No.1 abutment is 9m to the south and 12m to the north. The plane size of the foundation is 41×8.7m, which is self-heavy and requires high requirements for the foundation. The allowable bearing capacity of the foundation is not less than 1000KPa. In order to resist horizontal thrust, the depth of intact rock layer embedded in the back of abutment by expanding foundation is no less than 0.3m, which can be adjusted according to the actual excavation situation to avoid excessive excavation of stone.

![Figure 1. General structure of abutment No. 0](image)

Note:①Graded gravel filter layer, 50cm thick; ②Clay water seal, 30cm thick; ③DSPVC pipe, 30cm high from the ground; ④C40 Concrete abutment.

3.2 Foundation pit site and geological conditions

The foundation pit has a large depth, and there is a hotel in the southeast of the bridge location. The hotel KTV is about 25m away from the edge of No.1 bridge abutment, with a height of about 6 floors and an area of 30m×50m. The main body of the hotel is about 70m away from the edge of No.1 abutment, with a height of about 23 floors, covering an area of 60m×80m, and the foundation is pile foundation. Bridge abutment foundation pit excavation and support requirements are high, the safety level is one. There are also a few temporary single-layer brick structures around the project. According to “Detailed geotechnical investigation report of Modong No.1 and No.4 bridge in Laibin city”, the engineering geological conditions of the site are as follows:
3.2.1 Topographic and Geological structure of the site

The proposed project is located at the intersection of Xinqiao road and Modong canal, Laibin city, Guangxi province. During the exploration period, the original landform is slightly undulating with a ground elevation of about 88m. No fault passes around the site and the geological structure is stable.

3.2.2 Characteristics and distribution of formation geotechnical on the site

Based on drilling exposed case, Within the drilling depth range, the proposed site is covered with clay formed by the residual sediments of the pleistocene (Qel), underlying bedrock for carboniferous (C2d) in thick bedded limestone. The classification of geotechnical layers is based on the field identification, the existing investigation data near the site, the genesis and mechanical properties of geotechnical layers and other factors. The lithologic characteristics of each layer are from top to bottom described as follows:

(1) Concrete

Concrete layer, local distribution.

(2) Red clay (Q3el) –1: mainly maroon, yellow, brown yellow, hard plastic, medium compression, soil is relatively uniform, local contains a few gravel particles, the section is slightly smooth, no shaking response, high toughness, high dry strength. This drill debunking this layer. The layer thickness is 3.0m ~ 8.0m, with an average thickness of 4.5m and uneven thickness. Standard penetration test was carried out in this layer for 6 times, with the maximum value of 13.8, the minimum value of 10.5, the average value of 12.2 and the standard value of 11.

(3) Red clay (Q3el) –2: mainly brown yellow, plastic, other with –1. The layer thickness is 3.5m~12.0m, with an average thickness of 7.1m and uneven thickness. Standard penetration test was carried out in this layer for 6 times, and the revised, the maximum value was 7.8, the minimum value was 5.5, the average value was 6.6, and the standard value was 6.

(4) Broken limestone (C2d) layer –1: gray ~ dark gray, the main diagenetic mineral of the rock is calcite. Dense massive, network fracture development, secondary calcite cement, a small number of closed, so in the process of drilling easily ground. Most of the cores are fragmentary, massive, clubbed, and locally short columnar, with well-developed fractures and obvious corrosion traces. There are multiple corrosion surfaces in the local rocks. The core recovery rate is about 68%, and the exposed thickness ranges from 0.5 to 5.7m, with an average thickness of 1.6m.

The compressive strength of rock samples was tested for 6 periods, with a range of 28.3~32.8MPa and an average value of 30.7MPa. Rock belongs to a hard rock, rock mass basic quality of classification for IV class exposes thickness.
(5) Intact limestone (C2d) ③-2 layers: gray~dark gray, the main diagenetic mineral of the rocks is calcite. Dense massive structure with medium to thick layer-like structure. The rock mass is developed with a few cracks, which are mostly cemented and filled by calcite veins and present a closed form. The core recovery rate is about 80~85%, and the RQD value is about 77%. Most of them are long columns~short columns, with complete rock mass and hard and brittle rock.

The compressive strength of rock samples was tested in 6 stages, and its compressive strength ranged from 30.7 MPa to 45.7MPa, with an average value of 37.8MPa. Rock belongs to a hard rock, rock mass basic quality of classification for II class exposes thickness.

| Table 1 | Recommended values of physical and mechanical parameters of main rock and soil layers |
|---------|-----------------------------------------------------------------------------------|
| Soil    | Indicators | Natural gravity \( \gamma \) \((\text{kN/m}^3)\) | Angle of internal friction \( \varphi \) \((\text{Deg})\) | Cohesion \( C \) \((\text{kPa})\) | Compression modulus \( E_s \) \((\text{MPa})\) | Carrying force characteristic value \( f_{ak} \) \((\text{kPa})\) |
| Red clay②-1 | 18.03 | 16.18 | 48.88 | 6.62 | 250 |
| Red clay②-2 | 17.35 | 11.30 | 35.99 | 4.66 | 170 |
| Broken limestone③-1 | 22* | ----- | ----- | ----- | 1000 |
| Intact limestone③-2 | 22* | ----- | ----- | ----- | 9000 |

Note: Those with * are experience value; The parameters in the table are used under natural conditions and should not be exposed or soaked for a long time.

3.2.3 Features and distribution of buried objects unfavorable to the project
No buried river, creek, air-raid shelter, isolated stone and other buried objects unfavorable to the project have been found in the survey site and adjacent sections. No active faults or structural fracture zones were found, nor were there any signs of new structural activity. The proposed site has good regional stability.

3.2.4 Surface water and groundwater
(1) Surface water and groundwater characteristics of the site
The maximum drilling depth is 24.5m, and no underground water is revealed during the drilling process. No groundwater was found on the site during the investigation stage, and the surface water had little impact on the construction. There is no pollution source of surface water and groundwater in the proposed site and surrounding area.

(2) Permeability of bedrock soil layers throughout the site
The permeability coefficient \( (K) \) values of each subsoil layer of the site are determined as follows according to the drilling data and the empirical values under similar geological conditions:
- Red clay ②-1: \( K = 0.005\text{m/d} \)
- Red clay ②-2: \( K = 0.005\text{m/d} \)
- Broken limestone ③-1: \( K = 0.01\text{m/d} \)
- Intact limestone③-2: \( K = 0.001\text{m/d} \)

3.3 Design of foundation pit support scheme
The design service life of foundation pit is 1 year. Considering the feasibility and cost of support, the support scheme is as follows:

(1) In the foundation pit construction of south abutment, Slope release and concrete pile row are adopted for support. Slope release rate :1 :1.5. A platform is set every 6m high. The platform is 1.5m wide and the bottom line of the slope is 1m away from the base edge. Pile row diameter 1.2m, spacing 1.5m, pile length 16m, no. 0 abutment laid 14, no. 1 abutment laid 18.

(2) Make full use of the excavation space of the canal on the north side of the bridge, increase the excavation surface of the foundation pit, and reduce the difficulty of supporting.

(3) Resume the river course after the completion of the project construction.
4. Foundation construction technology research
The foundation height is 5~12m, and the construction is greatly affected by the surrounding buildings. The north foundation pit can be excavated by slope excavation, while the south foundation pit should be excavated by sheet pile support. There are many disturbances and difficulties in foundation construction. In order to ensure the safety and progress of foundation construction, the construction form should be completely closed.

4.1 Foundation pit construction technology

4.1.1 Foundation pit construction steps
(1) Complete closure of Xinqiao section between Sihua road and Xingcheng road.
(2) Excavate the river and roads on the north side of the bridge position according to the slope of 1:1.5 to expand the bottom elevation of the foundation. Then pour the shallow-buried concrete foundation of the north side of the bridge abutment.
(3) Drill hole to 8m below the bottom elevation of foundation pit in plane position of row pile, and then construct row pile to 8m above the bottom elevation of foundation pit. The diameter of pile row is 1.2m, the spacing is 1.5m, and the pile length is 16m. The south side of the foundation pit is excavated to the elevation of the top of the cast-in-place pile and crown beam is constructed. The longitudinal bridge is excavated to the elevation of the bottom of the foundation pit.
(4) Pour the abutment foundation on the north side to the designed elevation, and then construct the arch seat and superstructure.
(5) After the foundation pit construction is completed, the river and vegetation on both sides shall be restored. Pile row structure is retained as a part of abutment foundation.

4.1.2 Technical points of foundation pit construction
(1) Make an on-site check of the structures around the foundation pit before construction. If there is any discrepancy with the design document, the construction unit shall contact the design unit to deal with it in time.
(2) Circular drilling is adopted for pile row, and the distance is relatively close, so pile jumping construction should be adopted. Mud wall protection should be applied during drilling.
(3) The load of construction materials, facilities or vehicles around the foundation pit shall not exceed the ground load limit required by the design. The load limit of road slope excavation section is 20kPa, and the load limit of excavation + row pile support section is 10kPa.
(4) The foundation pit excavation shall be monitored according to the design requirements, and the dynamic design and information construction shall be implemented.
(5) Blasting construction may be required for foundation pit stone excavation. Before excavation, the construction unit shall work out a special plan for stone excavation and obtain the approval of experts and relevant departments. Excessive blasting vibration may cause different degrees of damage to surrounding buildings. Construction units should adopt appropriate methods to control the blasting vibration velocity and strengthen the monitoring work before and after blasting.

4.1.3 Foundation pit drainage
The measure of foundation pit drainage is to reserve the drainage hole on the shotcrete anchor surface and the drainage hole on the shotcrete anchor between piles. Drainage hole layout should meet the requirements of design drawings.
During the construction period, attention should be paid to the drainage of the ground and the foundation pit. During the rainy season, a certain amount of pumping equipment should be prepared to drain the water in time to ensure the safety of the project and the normal operation of the equipment, so that the work can be resumed immediately after heavy rain. In addition, cut ditches are set on the ground around the foundation pit. Temporary drainage ditches and collecting Wells can be set up in...
the foundation pit according to the actual situation, and the set quantity shall meet the drainage requirements.

4.1.4 Foundation pit construction monitoring

Obtain quantitative data mainly by special instrument measurement or special test component monitoring, supplemented by on-site visual inspection. The arrangement of observation points should meet the monitoring requirements, and the scope of influence of foundation pit excavation increases with the increase of excavation depth. Generally, buildings (structures) and underground pipelines in the range of 1-3 times of excavation depth from the edge of foundation pit are taken as monitoring objects. The specific monitoring program and monitoring requirements are as follows.

1) According to the technical regulations for supporting foundation pit, the safety grade of foundation pit is grade 1. Foundation pit construction must be carried out in accordance with relevant requirements.

2) In the construction of enclosure structure and excavation of foundation pit, the settlement, displacement, inclination and crack of adjacent buildings must be monitored comprehensively. Once appear unusual circumstance, should stop work immediately, deal with effectively.

3) In the process of construction and the foundation pit excavation retaining structure, should be strictly in accordance with the requirements of pipeline management of underground pipeline monitoring stations arrangement and monitoring control values on the surrounding pipeline monitoring, and meet the requirements of various pipeline ownership unit value, such as found that more than permitted, should immediately stop the construction, and inform the relevant units, to take effective measures.

4) Because there are high-rise buildings nearby, the whole process of pile row support construction on the south side is required to monitor the displacement of surrounding soil in real time. When the soil displacement exceeds the standard requirements or the structure displacement occurs, the foundation pit construction should be stopped immediately. The foundation pit construction can be continued after the peripheral soil is treated with reinforcement or internal support is added.

5) In the whole construction process, settlement monitoring should be carried out on adjacent roads and surrounding buildings, and all-round monitoring should be carried out on the horizontal displacement of the top surface of the envelope structure and the deformation of the envelope pile. If any abnormality is found, the next process construction should be stopped immediately, continuous monitoring should be carried out and corresponding measures should be taken to deal with it in time to ensure construction safety.

6) The change of groundwater level should be measured during the whole construction process.

7) Before the impact of foundation pit construction on each monitoring project, the average value of stability value of 3 consecutive times shall be observed as the initial value of the monitoring project. When deformation exceeds relevant standards or site conditions change greatly, it should be observed intensively. When the heavy rain, rainstorm or the side load condition of foundation pit changes, it should be timely monitored; When there are signs of dangerous accidents, continuous tracking should be observed.

8) The principle to determine the measurement frequency: during the steep unloading phase of excavation, the measurement interval shall not be more than 2 days; The main structure and pipe jacking are measured every 0.5~7 days during construction. When deformation exceeds relevant standards or site conditions change greatly, it should be observed intensively. When the heavy rain, rainstorm or the side load condition of foundation pit changes, it should be timely monitored; When there are signs of dangerous accidents, they should follow up and observe; Rescue process to encrypt the monitoring frequency. After the completion of each monitoring work, the monitoring report and handling opinions shall be submitted in time.

9) The plane position of the monitoring points can be appropriately adjusted according to the specific construction conditions near the site plan, and the buried settlement measuring points should be determined according to the site conditions.
(10) On-site monitoring and measurement should run through the whole construction process. When the situation changes suddenly, it should be observed and reported in time. Monitoring results should be recorded and processed in detail.

(11) Monitoring management should be strengthened to ensure accurate and timely information feedback.

(12) Before the construction of foundation pit supporting structure, it is required to conduct the inspection and technical appraisal of third-party houses and existing structures, so as to provide necessary basis for monitoring, emergency rescue and possible disputes in the construction process.

   The main contents of foundation pit monitoring include but not limited to: hotel KTV buildings, river piles, peripheral pipelines, etc. See table 2 for details:

| Serial number | Monitoring project                                                                 |
|---------------|------------------------------------------------------------------------------------|
| 1             | Internal force of support pile, Settlement of support pile, Horizontal displacement of pile top, Settlement of pile top, Displacement of pile body |
| 2             | Slope top settlement, Slope body horizontal displacement, Pit side ground settlement |
| 3             | Foundation pit peripheral construction (structure) building, Underground pipeline, Road deformation and crack |

Table 2: Foundation pit monitoring items table

According to the relevant regulations, the safety level is the first-level supporting structure. During the excavation process of the foundation pit and the use period of the supporting structure, the horizontal displacement monitoring of the supporting structure must be carried out. Monitoring the settlement of buildings and ground in the influence area of foundation pit excavation. In case of any of the following situations, the monitoring shall be strengthened, the monitoring frequency shall be increased, and the monitoring results shall be reported to the entrusting party and relevant units in a timely manner:

(1) Monitoring data reach alarm value;
(2) The monitoring data change greatly or speed up;
(3) No unfavorable geological conditions were found during the survey;(4) Ultra-deep and ultra-long excavation or construction not in accordance with the design;
(5) A large amount of water accumulated in the foundation pit and surrounding areas, continuous precipitation for a long time, leakage of municipal pipelines, etc.;
(6) The ground load near the foundation pit suddenly increases or exceeds the design limit;
(7) Support structure cracking;
(8) Sudden large settlement or severe cracking of surrounding ground;
(9) Sudden large settlement, uneven settlement or severe cracking of adjacent buildings (structures);
(10) Piping, leakage or sand flow occurs at the bottom of the foundation pit, slope body or supporting structure;
(11) Reorganize the construction after the foundation pit accident;
(12) Other abnormal conditions affecting the safety of foundation pit and surrounding environment occur.

4.1.5 Foundation pit quality inspection

Quality inspection shall be conducted after foundation pit excavation, including basal plane position, plane size, elevation, geology, soil quality, drainage, bearing capacity, etc. The testing method, operation procedure and data analysis of each index should be standardized. Only when the test results of each index meet the requirements of quality standards can the construction of foundation engineering be carried out.

4.2 Foundation construction technology

The plane size of the foundation is 41×8.7m, and the height of the foundation is 5m~12m. As a large-volume concrete structure, the integrity requirements are high, usually not allowed to remain the construction joints, the temperature difference between the inside and outside concrete caused by hydration heat during construction should not be too large, etc., in order to ensure the quality of
construction, the key construction technical points of large-volume concrete construction pouring are as follows:

1. Cold joints should not be left in concrete pouring to ensure continuous supply of concrete, and pouring control should be completed before initial setting.

2. Concrete vibration should be timely, and vibration time, moving distance and insertion depth should be strictly controlled to ensure vibration compaction, strictly prevent vibration leakage and overvibration, and avoid segregation.

3. Timely test the temperature difference between inside and outside concrete. Adjust the flow rate of cooling pipe in time according to the regulation of temperature difference to ensure the hydration heat during construction. The difference between the temperature inside the concrete and the outside temperature is controlled below 25℃ to avoid temperature cracks.

4. The construction measures of large volume concrete to prevent temperature crack include the selection of cement with low hydration heat, the inclusion of appropriate additives, the use of coarse sand and large particle size graded well gravel; Determine the appropriate mix ratio, Minimize temperature cracks; Install cement slurry, Adopt heat preservation and cooling measures, expand the heat dissipation area and slow down the pouring speed; Suitable pouring scheme can be selected.

5. Choice of pouring scheme: overall layering, suitable for the case of plane size is not too large; Segmented layering, suitable for large plane size, but the thickness is not big of the case.

5. Conclusion
The site conditions of Modong No.4 bridge are complex, ultra-high rigidity is adopted to expand the deep foundation, and the foundation pit engineering is very difficult. According to the detailed investigation data, the engineering application requirements and the related regulations of the specification, after extensive research and demonstration, the reasonable recommendation scheme is put forward according to the local conditions. In order to achieve optimal implementation of the recommended scheme of the bridge, the construction technology and quality control of its mass concrete foundation are studied in depth, and the key technology and quality control points of foundation construction are put forward. It maximizes the feasibility of the design scheme, not only guarantees the quality of bridge engineering construction, but also provides effective reference for similar bridge construction.

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