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Design and Construction Technology of Prefabricated Reinforced Concrete Slab Culverts

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Abstract: Compared with traditional cast-in-situ concrete slab culverts, prefabricated reinforced concrete slab culverts can be produced more quickly and has strong quality controllability, strong earthquake resistance, and repeatability. They will be the primary production method of slab culverts in the future. This article offers a comprehensive review of the design and construction technology associated with prefabricated reinforced concrete slab culverts. The objective is to provide a valuable reference for related enterprises, enhance the quality of design and construction in precast pile configuration, and, in turn, contribute to the advancement of construction projects within our country.

Keywords: Slab culvert; Prefabricated reinforced concrete; Design points; Construction technology

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1. Introduction

The staff involved in designing and producing the slab culverts should be skillful and experienced to ensure that the design and manufacturing of slab culverts comply with national and local standards and specifications and ensure the quality and safety of the project. To avoid problems in terms of the quality and design of the slab culverts, research on the design and construction technology of prefabricated reinforced concrete slab culverts essential, so as to improve the overall quality of projects in China.

2. Overview of prefabricated reinforced concrete slab culverts

Prefabricated reinforced concrete slab culvert is used to build the upper covering structure of a tunnel. It usually comprises precast concrete panels, steel bars, bolts, and splices. Many factors need to be considered in the design and manufacture of tunnel covers, such as support, load, and stability. In terms of function, in transportation projects such as railways, roads, and subways, slab culverts serve the purpose of spanning over roads or railway tracks when they intersect with mountainous terrain or water systems[1].

3. Key points in the design of prefabricated reinforced concrete slab culverts

3.1. Material selection

Prefabricated reinforced concrete slab culvert is a novel structure in road and railway traffic engineering. It is important to select suitable materials when designing and manufacturing concrete slab culverts to ensure its firmness, durability, and safety. Prefabricated reinforced concrete slab culverts are mainly made of concrete, steel bars, bolts and expansion anchors, steel plates, and pieces.

Factors to consider during material selection include strength grade, impermeability, and performance. Among them, the strength of the materials should be determined based on the load-bearing requirements of the slab culvert. The choice of impermeability level should align with the project's need to resist water seepage. Construction performance primarily revolves around factors like concrete slump and setting time, ensuring a smooth pouring process.

As for the steel bars, the diameter and cross-sectional area of the steel bars should be selected based on the design requirements and structural stress characteristics of the slab culvert to ensure sufficient load-bearing capacity. Characteristics like tensile strength and durability should be considered.

The primary consideration for bolts and expansion anchors is their strength and durability, so as to ensure they can bear the load of structural connections [2].

3.2. Key points of component design

The components of prefabricated reinforced concrete slab culvert mainly include side wall T-shaped components, cover components, and corbel components.

3.2.1. Side wall T-shaped component design

When designing side wall T-shaped component, it is necessary to ensure appropriate strength and stability while also ensuring the convenience of the whole construction process. Besides, it is necessary to consider its relationship with the cover plate, corbels, and other components. The T-shaped components should be easily installed and connected. The criteria for the T-shaped components are listed below.

(i) The specific dimensions of the components should be designed according to the needs of the project. They are generally poured with reinforced concrete, and their appearance should be consistent with the culvert wall material used on the other side of the wall.

(ii) Q235B steel bars are commonly used; the diameter of the steel bars is 28 mm, and the steel bars are reinforced with 6\Φ 28 steel bars.

(iii) C50 grade concrete should be used, and the concrete thickness should be 25cm.

3.2.2. Cover plate design

As one of the load-bearing parts of the culvert, the cover plate needs to be strong and stable while using the least amount of raw materials to reduce costs. Specific relevant design parameters can be found below.

(i) The specific dimensions of the cover plate should be designed according to the needs of the project and are generally poured with reinforced concrete.

(ii) It is generally recommended to use Q235B steel bars with a steel bar diameter of 10 mm and 6\Φ10 steel bars for reinforcement.

(iii) C50 grade concrete should be used; the thickness of the concrete should be 20–25 cm. The length and width of the cover plate depend on the specific situation and are generally 5 m × 2 m.

3.2.3. Corbel design

When determining the size of the corbels for prefabricated reinforced concrete slab culverts, the primary consideration is its load-bearing capacity. As one of the load-bearing parts of the culvert, the corbels need sufficient strength and stability. At the same time, it is also important to ensure the convenience of processing and construction. Q235B steel bars with a steel bar diameter of 14 mm and 6\Φ14 bars for steel bar reinforcement are usually recommended. Besides, it is recommended to use C50 grade concrete. The thickness of the concrete should be designed between 20 and 25 cm. The length and width of the corbels depend on the specific situation, but they are generally 5 m × 1 m [3].

3.3. Foundation design

The type of foundation used for prefabricated reinforced concrete slab culverts is selected based on the following factors: geological conditions and load-bearing requirements. Architects can choose between simple foundations (such as plate and strip foundations) or complex foundations (such as pile and capped foundations). The steps in designing prefabricated reinforced concrete slab culvert foundation are described below.

Step 1: The foundation bearing capacity and internal force calculation are calculated. Bearing capacity refers to the load the foundation can withstand within a certain depth. The main calculation methods include standard static pressure plate load test, drilling coring test, depth standard penetration test, etc. Through these calculations, the suitable type of foundation can then be selected and the dimensions of the foundation can be determined. The calculation of foundation internal forces involves the design unit determining the foundation's internal forces, including bending moment, shear force, axial force, and so on. These calculations are based on the load conditions, foundation type, and design dimensions of the prefabricated reinforced concrete slab culvert.

Step 2: The foundation size is determined by calculating the internal forces of the foundation. The length, width, and depth of the foundation are then determined to satisfy the load-bearing requirements of the prefabricated reinforced concrete slab culvert.

Step 3: Material calculation is performed to determine the quantity of materials needed for the foundation. This process involves estimating the total amount of reinforcement, concrete, and other materials based on the foundation's size [4].

The specifications of designing prefabricated reinforced concrete slab culvert foundation is described below.

Table 1. Design of prefabricated reinforced concrete slab culvert foundation (with steel bars)

No.	Elements	Description
1	Geological conditions	The foundation is yellow soil, and the foundation bearing capacity coefficient is k = 60kPa/m²
2	Load condition	The load on the prefabricated reinforced concrete slab culvert is a static load of 20kN/m² and a dynamic load of 25kN/m²
3	Size of foundation	Taking a 3 m × 3 m foundation as an example, its depth should be 1.2 m, C50 concrete should be used, and the HRB400 threaded steel bars should be used as reinforcement, which are reinforced according to the design load ratio.
4	Area	9 m^2
5	Nett height	1.2 m
6	Concrete	Concrete C35: 2.16 m^3
7	Steel bars	HRB400 spiral steel bar: 8t, steel bar diameter (16 mm)
8	Base depth	1.2 m

3.4. Calculation of soil pressure at culvert top under different embedding methods

3.4.1. Soil pile method

The soil pile method is commonly used to calculate soil pressure at the top of a culvert. This method is based on the following assumption: The bearing effect of the soil on the top of the channel on the channel is mainly transmitted through the soil piles. According to this assumption, the soil pressure on the soil piles at the bottom of the trench is the pressure evenly distributed on the top. The calculation formula of earth pressure at the culvert top is as follows:

$$P = \gamma \times H \times L \times K \qquad (1)$$

In Formula (1), P is the soil pressure at the top of the culvert, γ is the unit weight of the soil, H is the distance from the top of the culvert to the bottom of the soil pile, L is the width of the culvert, and K is the influence coefficient of the soil pile.

3.4.2. Soil pile force concentration coefficient method

The soil pile stress concentration factor method is simplified for calculating soil pressure on the culvert top. This method assumes that the soil-bearing effect at the top of the culvert is concentratedly borne by one or more soil piles located at the bottom of the culvert in a smaller size. In this case, the soil pressure on the culvert top is seen as a concentrated effect on the soil piles rather than evenly distributed on the entire culvert top. The formula for calculating earth pressure at the culvert top is as follows:

$$P = \gamma \times H \times K \qquad (2)$$

In Formula (2), P is the soil pressure at the top of the culvert, γ is the unit weight of the soil, H is the distance from the top of the culvert to the bottom of the soil pile, and K is the force concentration coefficient of the soil pile.

3.4.3. Limit equilibrium method

The limit equilibrium method relies on an internal mechanical analysis of the soil to compute the soil pressure on the culvert top. This method makes an assumption regarding a specific friction angle within the soil, implying that the shear strength within the soil can counteract the shear force exerted on the ground. The soil pressure at the top of the culvert can be calculated by applying the equilibrium principle in soil mechanics. In this method, the friction angle of the soil at the bottom of the culvert and the friction angle of the external earth are the key parameters that need to be considered [5].

4. Research on construction technology of prefabricated reinforced concrete slab culverts

4.1. Production of prefabricated components

Prefabricated component production is the first link in the construction stage of prefabricated reinforced concrete slab culverts. The key points of this link include formwork production, steel bar processing, concrete pouring, and quality inspection. **Figure 1** are photos of the production site of prefabricated reinforced concrete cover components.

Figure 1. Photos of the production site of prefabricated reinforced concrete cover components

The manufacturing of molds requires high precision, exquisite shape, and accurate parameters. During the manufacturing process, it is essential to prioritize factors such as stability, resistance to rust, and ease of maintenance for the mold. This ensures that the mold can be utilized effectively over an extended period, maintaining its accuracy and quality. Secondly, in the process of working with steel bars for prefabricated components, crucial technical aspects include the control of steel bar dimensions and spacing, bending, cutting, and more. Employing suitable steel bar processing techniques can enhance production efficiency, guarantee construction quality, and minimize wastage. Thirdly, while pouring concrete, attention should be paid to the uniformity and quality of the concrete to avoid problems such as gaps, waves, cracks, etc. When pouring concrete, the water-cement ratio must be controlled to ensure the strength and durability of the concrete. Finally, after prefabricated components are produced, they must undergo inspection and quality control. Strict inspection and quality control can ensure product reliability and reduce construction risks, thereby meeting the usage requirements of highways and bridges [6].

4.2. On-site foundation construction

Key points of on-site foundation construction include foundation treatment and construction.

On one hand, on-site foundation treatment is the first step in on-site foundation construction. Before carrying out the culvert foundation treatment, it is necessary to clean up the debris and sediment on surface of the foundation to ensure that it is completely flat. In instances with more complex geological conditions, surveys and preparatory work are necessary to establish the foundation's bearing capacity and stability. On the other hand, foundation construction encompasses activities such as measuring foundation elevation, cleaning the foundation base, creating foundation formwork, processing foundation steel bars, and more. In cases involving deeply buried culverts, additional measures like wellhead piping or pipe gallery connections are required. Throughout the construction process, strict control over the entry and exit of personnel and machinery is crucial to prevent any impact or damage to the foundation surface. Besides, ensuring the personal safety of on-site workers is also paramount [7].

4.3. Transportation and assembly of prefabricated components

During the transportation stage of prefabricated components, the construction unit must reasonably arrange the loading and unloading sequence, use appropriate lifting equipment and tools to ensure the safe transfer of prefabricated components, and take appropriate protective measures, such as reinforcing packaging or using anti-shock linings, etc, so that the components would not be damaged during transportation. Second, the components should be delivered using proper vehicles to ensure that the prefabricated components can be transported safely and provide necessary support and fixation as required [8].

It is necessary to ensure that the flatness and levelness of the foundation during the preparatory phase to facilitate the assembly of components. Secondly, the prefabricated components should be transported to the installation location based on a predetermined sequence. It is also important to ensure correct alignment and connection of the components to ensure the stability of the overall structure, as shown in **Figure 2**.

Figure 2. Photos of transportation and assembly of prefabricated components

During joint treatment, it is crucial to use suitable treatment materials and methods to ensure that the prefabricated components are tightly connected and have sufficient strength and waterproof performance. Lastly, during the assembly process, the construction unit must maintain continuous monitoring and make necessary adjustments to the components' position and orientation, ensuring that the assembly quality aligns with the design specifications [9].

4.4. Finishing of the prefabricated slab culvert

After the prefabricated slab culvert is completed, the surface of the cover plate should be cleaned. This includes removing stains, grout, and particles that may be present. A high-pressure water gun can be used to clean the surface and grinding and plastering can be performed to smoothen out the surface. Secondly, the gaps between the prefabricated cover plate and other components or openings should be filled to ensure the tightness of the overall structure. To achieve sealing and waterproofing, durable materials like sealants can be used for filling, or substances such as mortar can be used to establish a strong bond between the filling material and the cover plate. The overall aesthetic of the culvert is also important. The concrete sections should undergo treatments such as polishing or spraying, and exposed steel bars should be protected with galvanization or anti-rust paint for corrosion prevention. Thirdly, it is crucial to timely enhance the drainage system to prevent water accumulation within the structure. This involves setting up drainage holes or pipes, which should be made from materials like ceramics, winding, or PVC with good corrosion resistance and proper sealing. Finally, after constructing the prefabricated slab culvert, adjustments should be made to suit the specific circumstances. For instance, during winter or in cold areas, immediate insulation of the concrete components is necessary to improve their strength and anti-freeze performance [10].

5. Conclusion

This article presents a review on the design and construction technology of prefabricated reinforced concrete slab culverts. It delves into the critical design aspects of prefabricated reinforced concrete slab culverts, considering four dimensions: material selection, component design, foundation form design, and culvert top soil pressure calculation. Simultaneously, the article examines key construction techniques for prefabricated reinforced concrete slab culverts across four stages: production, foundation construction, component transportation and assembly, and refinement. This comprehensive exploration provides us with a thorough understanding of prefabricated reinforced concrete slab culverts, offering a strong foundation for enhancing the design and construction standards of future engineering projects.

Disclosure statement

The author declares no conflict of interest.

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