Force Analysis of Supporting System during Form-Work Construction of Box Culvert without Tie Rod

Guangming Zhai 1, Yuwei Wang1, Liu Liu2 and Pan Guo3*  
1 CCCC-SHB Fourth Engineering Co., Ltd., Luoyang, Henan, 471013  
2 Henan Anluo Expressway Co., Ltd., Zhengzhou, Henan 450061  
3 School of Civil Engineering, Zhengzhou University, Zhengzhou, Henan 450001  
Email: guopan@zzu.edu.cn

Abstract. In the construction process of box culvert form-work without tie rod, the stress state of its supporting system is of great importance. Based on a construction project for the box culvert without tie rod form-work, this paper studied the force characteristics of diagonal braces during the concrete pouring of the box culvert. The force calculation theory of the support system was analyzed and the force was analyzed using the finite element software Midas Civil. The results showed that when the distance between the connection point of the diagonal brace and the foundation was 1 m, the diagonal brace cannot provide effective support for the template, and when the distance between the connection point of the diagonal brace and the template is 2 m, 3 m, and 4 m, the diagonal brace can provide effective support. It was recommended that the diagonal brace connection point is 3 m away from the template as the optimal diagonal brace layout position. It is recommended to strengthen the area of increased local deformation of diagonal braces to a certain extent according to the calculation results of this finite element analysis to improve the safety performance of the entire structure. The research results of this paper can provide reference for follow-up similar construction problems.

1. Introduction
Culvert construction is an important part of highway construction in China [1, 2]. Among many culvert structures, box culvert has become the most commonly used culvert structure in expressway construction in China because of its good overall mechanical performance and strong foundation adaptability [3, 4]. In the past, when the wall body of cast-in-situ slab culvert was constructed, the wall body formwork was often reinforced by pull rod, which would lead to dense pull rod holes on the wall body surface after formwork removal. In the construction process, in order to prevent the water after abutment back backfilling from flowing into the main wall through the tie rod hole and polluting the wall surface, the tie rod hole is generally blocked, but the effect is not ideal, and the tunnel surface needs secondary coating, which not only prolongs the construction period, but also increases the construction measure cost. The construction technology of box culvert without tie rod formwork can solve this problem well.

The concrete will produce certain lateral pressure on the formwork and auxiliary supporting structure during construction [5]. Liu et al [6] studied the lateral pressure of the newly poured concrete on the formwork and the stress characteristics of the support. The results show that the newly poured concrete will produce unbalanced force on the top formwork and bottom formwork of the normal section, and additional force should be applied to support the formwork system. Deng et al [7] studied the economic design of cast-in-situ concrete one-sided formwork and support system, and analyzed the...
economic layout distance of secondary ridge, main ridge and support in the economic design of one-sided formwork and support system, as well as the anchor bolt diameter in the economic layout distance of support, so as to save materials and reduce construction cost. Hu et al [8] analyzed the synergy between the formwork support system and the concrete floor by using the finite element software ANSYS, and proved the necessity of the formwork support system under the middle plate during the construction of the structural roof. During the construction of box culvert without tie rod formwork, due to the lack of the role of tie rod, the stress of its auxiliary diagonal brace is very important, so it is necessary to calculate and study it.

Based on the construction project of a box culvert without tie rod formwork, the mechanical characteristics of diagonal bracing in the process of box culvert concrete pouring are studied in this paper. The stress calculation theory of the support system is analyzed, and its stress is analyzed by using the finite element software MIDAS civil.

2. Project Overview

The schematic diagram of box culvert non tie rod formwork construction is shown in Figure 1. The inner formwork is a steel plate with a height of 6m and a thickness of 1cm. Since there is no internal tie rod, the diagonal brace plays a role in bearing the lateral pressure of concrete. One end of the diagonal brace is connected with the concrete foundation, and the other end is connected with the internal formwork. The diagonal brace is composed of vertical beams placed in parallel at intervals, and the vertical beams are connected through beams. All vertical beams and beams shall be made of steel pipes with an outer diameter of 45 mm and a thickness of 4 mm. Q345 section steel shall be used for formwork and diagonal bracing.

![Figure 1. Diagram of construction of culvert without tie rod formwork.](image)

3. Calculation Theory and Model Establishment

3.1. Calculation Theory

During the concrete pouring of box culvert, the concrete will produce lateral pressure on the inner form-work, and then transfer the force to the diagonal brace. According to relevant theoretical research [9], The lateral pressure can be calculated according to the following two formulas, and the minimum value is taken as the lateral pressure value of the form-work:

\[ F = 0.22 \gamma_c t_o \beta_1 \beta_2 V^{1/2} \]  
\[ F = \gamma_c H \]
Where, $\gamma_c$ is the unit weight of concrete, $\gamma_c = 25 \text{ kN/m}^3$; $t_0$ is the initial setting time of newly poured concrete, $t_0 = 6h$; $V$ is the initial setting time of newly poured concrete and the pouring speed of concrete, $V = 2 \text{ m/h}$; $\beta_1$ is the influence correction coefficient of admixture, $\beta_1 = 1.0$; $\beta_2$ is the influence correction coefficient of concrete slump, $\beta_2 = 1.15$; $H$ is the formwork height, $H = 6 \text{ m}$.

The lateral pressure of formwork is calculated according to the above two formulas, and the results are 53.67 kn/m$^2$ and 150 kn/m$^2$ respectively. Therefore, in this calculation, the lateral pressure of newly poured concrete on the formwork is taken as 53.67 kn/m$^2$.

3.2. Finite Element Model and Calculation Conditions

As shown in figure 2, the finite element analysis model established in Midas civil software. Plate element is selected for internal steel formwork and truss element is selected for diagonal bracing. The dimensions and materials of all elements are consistent with the actual project. In the actual construction process, the placement angle of the diagonal brace will have a great impact on the stress of the diagonal brace. Therefore, in this calculation, the analysis and calculation are carried out according to the four working conditions that the distance between the diagonal brace and the foundation connection point is 1 m, 2 m, 3 m and 4 m respectively.

![](image1)

(a) The connection point of diagonal bracing is 1m from the formwork (b) The connection point of diagonal bracing is 2m away from the formwork

![](image2)

(c) The connection point of diagonal bracing is 3m from the formwork (d) The connection point of diagonal bracing is 4m away from the formwork

**Figure 2.** Finite element analysis model for different calculation conditions.

4. Results and Analysis

4.1. Stress Analysis of Diagonal Bracing

The cloud diagram of diagonal brace stress under different calculation conditions is shown in figure 3. The farther the diagonal brace connection point is from the formwork, the smaller the stress of the
diagonal brace. Under the working conditions of 1 m, 2 m, 3 m and 4 m, the maximum stress of the diagonal brace is 452 MPa, 270 MPa, 214 MPa and 189 MPa respectively. Considering that the diagonal brace is made of Q345 steel and its yield strength is 345 MPa, when the diagonal brace connection point is 1m away from the formwork, the diagonal brace stress has exceeded the yield strength of the material. Therefore, it can be considered that the diagonal brace cannot provide effective support for the concrete formwork under this working condition. When the distance between the connection point of the diagonal brace and the formwork is 2 m, 3 m and 4 m respectively, the stress of the diagonal brace does not exceed the limit.

(a) The connection point of diagonal bracing is 1m from the formwork
(b) The connection point of diagonal bracing is 2m from the formwork
(c) The connection point of diagonal bracing is 3m from the formwork
(d) The connection point of diagonal bracing is 4m from the formwork

Figure 3. Stress cloud diagram of diagonal braces under different calculation conditions.

4.2. Deformation Analysis of Diagonal Bracing

The displacement nephogram of diagonal bracing under different calculation conditions is shown in figure 4. The displacement of diagonal bracing is small in other areas except that it shows large deformation in individual areas on the whole. Under the working conditions of 1 m, 2 m, 3 m and 4 m, the maximum deformation of diagonal bracing is 914 mm, 18.1 mm, 16.7 mM and 31.6 mm respectively. When the connection point between the diagonal brace and the foundation is 1m away from the formwork, serious large deformation occurs in the diagonal brace, indicating that the diagonal brace cannot provide effective support under this working condition, which is consistent with the results of stress analysis. Under the condition that the distance between the connection point of diagonal bracing and the formwork is 2 m, 3 m and 4 m respectively, the maximum deformation of diagonal bracing is small.

(a) The connection point of diagonal bracing is 1m from the formwork
(b) The connection point of diagonal bracing is 2m from the formwork
(c) The connection point of diagonal bracing is 3m from the formwork  
(d) The connection point of diagonal bracing is 4m from the formwork

**Figure 4.** Deformation cloud diagram of diagonal braces under different calculation conditions.

### 4.3. Optimal Diagonal Brace Layout Position

According to the comprehensive analysis of the force and deformation of the diagonal brace, when the connecting point between the diagonal brace and the foundation is 1m away from the formwork, the force and local deformation of the diagonal brace exceed the limit, indicating that the diagonal brace cannot provide effective support under this working condition. When the distance between the connection point of the diagonal brace and the formwork is 2 m, 3 m and 4 m respectively, the stress and local deformation of the diagonal brace are maintained at a low level, indicating that the diagonal brace can provide effective support for the concrete formwork. Considering the maximum stress and local maximum deformation of diagonal bracing under these three working conditions, 3M from the connection point between diagonal bracing and foundation to the formwork can be selected as the optimal layout position of diagonal bracing.

In addition, according to the finite element analysis and calculation results, the area with increased local deformation of diagonal bracing can be strengthened to a certain extent, so as to improve the safety performance of the whole structure.

### 5. Conclusions

In this paper, MIDAS / civil finite element analysis software is used to analyze the stress of the support system during the construction of culvert tie free formwork, and calculate the stress and deformation of the diagonal brace under the working conditions of different diagonal brace layout positions. The main conclusions and relevant suggestions are as follows:

1) When the connection point between the diagonal brace and the foundation is 1m away from the formwork, the stress and local deformation of the diagonal brace exceed the limit, indicating that the diagonal brace cannot provide effective support for the concrete formwork under this working condition, while the diagonal brace can provide effective support under the other three working conditions.

2) Considering the maximum stress and local maximum deformation of the diagonal brace under the three working conditions of 2m, 3M and 4m from the connecting point between the diagonal brace and the foundation to the formwork, it is recommended to select 3M from the connecting point between the diagonal brace and the foundation to the formwork as the optimal layout position of the diagonal brace.

3) It is suggested to strengthen the area with increased local deformation of diagonal bracing to a certain extent according to the finite element analysis and calculation results, so as to improve the safety performance of the whole structure.

### Acknowledgments

Authors wishing to acknowledge assistance or encouragement from colleagues.
References

[1] Ding L T, Wang X C, Fu L J, et al. 2021 Differential settlement technology of culvert subgrade treated by geogrid based on driving comfort Material guide 35 (4) 79-87.

[2] Zhao Y H, Mi W J, Sun R D, et al. 2017 Study on the effect of highway culvert foundation treatment measures in collapsible loess area [J] Journal of railway engineering 34 (1) 6-10 74.

[3] Zhou G Y, Li C, Hu Y, et al. 2020 Numerical simulation analysis of pavement settlement during box culvert jacking construction Highway engineering 45 (3) 29-37.

[4] Wang S H, Alepujiang J, Wang P Y, et al. 2018 Mechanical performance simulation and potential failure mode of prefabricated rectangular box culvert. Journal of Northeast University (Natural Science Edition) 39 (2) 260-265.

[5] He X P, Zhang Y S, Cheng Q, et al. 2014 Study on force transfer law of interlayer formwork support frame of cast-in-situ concrete structure Industrial architecture (1) 107-111.

[6] Liu Y T, Huang J, Jiang J S, et al. 2012 Analysis of lateral pressure of newly poured concrete on inclined formwork and stress of support Construction technology 41 (11) 85-87.

[7] Deng T J, Zhu M. 2015 Study on economic design of cast-in-situ concrete unilateral formwork and support system [J] Journal of Hunan University (Natural Science Edition) 42 (11) 133-138.

[8] Hu C M, Zhao Y B, Wang J, et al. 2014 Finite element analysis of the synergy between formwork support system and concrete floor [J] Industrial architecture (5) 106-110.

[9] Cao Y G, Tan X D, Lv S, et al. 2020 Structure and stress analysis of mass concrete construction formwork [J] Ceramics (8) 101-103.