Application Research on Concrete Slab Renovation Based on Solidworks Finite Element Analysis

She Chen*, Zhengkun Chen, Mingyue Deng, Hong Cheng, Yuanping Geng

Three Gorges Navigation Authority, Yichang 443002, China

*Corresponding author: 284771302@qq.com

Abstract. This paper aims at the problem of difficult inspection of the working conditions of hydraulic pipelines in the large-area oil pipe trench on the lock surface of the Three Gorges ship lock, and proposes a visual transformation of the concrete cover plate of the oil pipe trench. The homogenization method combined with SolidWorks software is used for finite element analysis of the concrete slab. The load-bearing performance of the concrete slabs is verified through construction transformation and actual measurement. The research results show that finite element analysis is instructive for the transformation plan of concrete slabs and can reduce the impact of the transformation of concrete slabs on their load-bearing capacity. It has good feasibility to inspect the working conditions of closed oil pipe trenches by means of the transformation of concrete slabs in combination with industrial endoscope cameras.

Keywords: tubing trench; hydraulic pipeline leakage; concrete slab; finite element analysi

1 Introduction

As the world's largest multi-level ship lock, the Three Gorges ship lock has 24 sets of hydraulic systems. The opening and closing control of each water conveyance valve is realized by laying hydraulic pipelines in the oil pipe trench on the lock surface. According to statistics, the total length of the oil pipe trench reaches 1,100 meters with 62 corners, and concrete slabs are laid on all oil pipe trenches (as shown in Figure 1). This makes it impossible for the ship lock operators to directly inspect the working conditions of the hydraulic pipelines in the oil pipe trench. Even when there is a loss of pressure in the hydraulic system or a drop in the oil level, it is impossible to accurately determine the leakage location, resulting in greater difficulty in inspection and fault handling. At the same time, hydraulic oil leakage not only causes economic losses but also brings potential safety hazards to equipment and environmental pollution. Therefore, transforming the concrete slab to realize the inspection function is the key to strengthening the maintenance of the hydraulic system of the Three Gorges ship lock.

W. Nie et al. (eds.), *Proceedings of the 2024 6th International Conference on Hydraulic, Civil and Construction Engineering (HCCE 2024)*, Atlantis Highlights in Engineering 37,
https://doi.org/10.2991/978-94-6463-726-7_25

Fig. 1. Oil pipe trench and concrete slab on the lock surface of the Three Gorges ship lock.

The existing simulation analyses of reinforced concrete structures mainly adopt the discrete model, the combined model and the integral model[1]. The discrete model treats concrete and steel bars as different elements. The combined model is widely used in three-dimensional finite element analysis[2-3]. First, the contributions of concrete and steel bars to the stiffness matrix of the combined unit are obtained respectively, and then a composite element is formed. The integral model disperses the steel bars throughout the whole unit and equates the unit to a uniformly continuous material[4-6].

Reinforced concrete is composed of two materials, steel bars and concrete, with completely different mechanical properties. Due to the stiffening effect of steel bars, the steel bars bear the tensile force while the concrete bears the compressive stress. Since the transformation of the concrete slabs is bound to damage the internal reinforced bar structure, and the degree of damage cannot be accurately calculated in advance, it will have varying degrees of impact on the load-bearing performance. Therefore, reinforced concrete is equivalent to members made of nonlinear homogeneous materials. The homogenization method is used to calculate the equivalent material properties of reinforced concrete materials[7-8]. Based on the simulation stress analysis in Solidworks, the concrete slab is modified and its load-bearing capacity is verified. Luo[9-10] replaced the original characteristic function with an improved characteristic function to obtain a homogeneous homogenization integral equation, thus explicitly expressing the periodic boundary conditions with exact solutions. Liao[11] applied it to reinforced concrete materials in building structures and fully verified it. The characteristic function is as follows:

Suppose the ratio of macroscopic variable x_i to microscopic variable y_i be the perturbation parameter η.

$$y_i = \frac{x_i}{\eta} \tag{1}$$

The displacement control equation containing global and local coordinates is:

$$u_i(x) = u_i^0(x, y) + \eta u_i^1(x, y) + \eta^2 u_i^2(x, y) + \cdots \tag{2}$$

By using the chain rule of differentiation, the homogenized elastic constant D_{ijkl}^H represented by the eigenfunction can be obtained:

$$D_{ijkl}^{H}(x) = \frac{1}{|Y|}\int_{Y} E_{ijpq}\frac{\partial \chi_{p}^{kl}}{\partial y_{q}}\, dY \tag{3}$$

Among them, the elastic modulus E_{ijkl} encompasses the material properties of steel bars and concrete in the characteristic volume element. The eigenfunction tensor χ_{k}^{pq} is an unknown third -order y periodic function and satisfies the homogeneous integral equation:

$$\int_{Y} E_{ijkl}\frac{\partial \chi_{k}^{pq}(x,y)}{\partial y_{l}}\frac{\partial v_{i}(y)}{\partial y_{j}}\, dY = 0 \tag{4}$$

2 Structural Analysis

Through statistical analysis of hydraulic oil leakage faults in the oil pipe trench in the past five years, it is found that the main reasons for hydraulic pipeline leakage lie in loose connections, aging of sealing rings and weld cracking. Among them, 70% of faults occur at the connection of right-angle elbows. The structure of the corner concrete slab of the oil pipe trench is shown in Figure 2. The design size is 980×980×180mm. The upper layer of the internal steel mesh is 7Φ8@16 longitudinally and transversely, and the lower layer is 9Φ16@11.8 longitudinally and transversely. The volume ratio of steel bars is 2.3%.

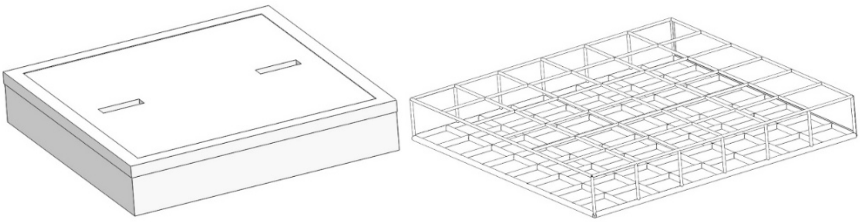

Fig. 2. Schematic diagram of the structure of the concrete slab in the oil pipe trench.

The concrete grade used for the cover plate of the oil pipe trench on the lock surface of the Three Gorges ship lock is C30. The mechanical parameters of the main materials are taken according to the standard values in the "Code for Design of Concrete Structures" (GB50010-2010). The relevant parameters are shown in Table 1 below.

Table 1. Performance parameters of C30 concrete and HRB335 steel bar.

Category	Elastic modulus (GPa)	Poisson's ratio	compressive strength (MPa)	tensile strength (MPa)	Yield strength (MPa)
C30 concrete	30	0.2	30	2.0	
HRB335 rebar	200	0.3			335

The installation situation of the concrete slab at the corner of the oil pipe trench is shown in Figure 3. Field measurements indicate that the installation boundary conditions are 1000×1000×180 mm. As shown in Figure 4, the oil pipe trench is 620 mm wide, and the width of the load-bearing area is 190 mm. The load-bearing area at corner A is relatively small, and the load-bearing surface is unevenly distributed.

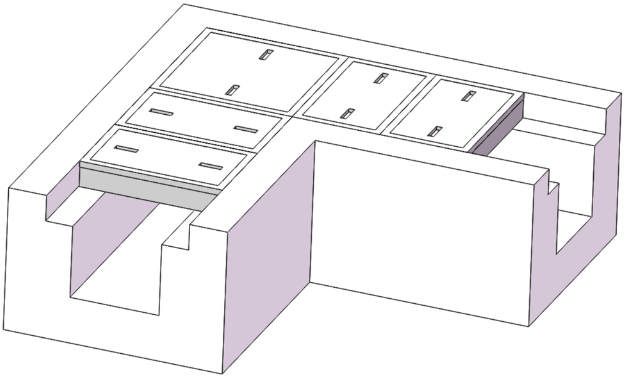

Fig. 3. Installation schematic diagram of the concrete slab at the corner of the oil pipe trench.

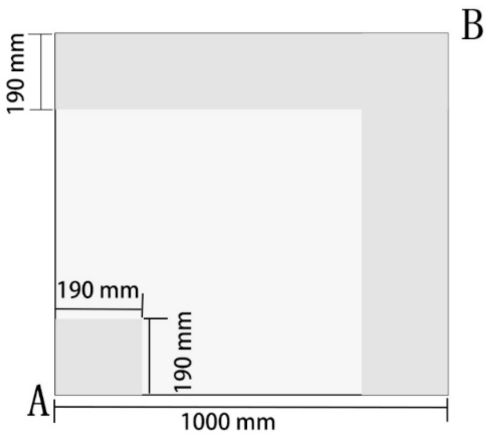

Fig. 4. Load-bearing boundary conditions of the concrete slab.

3 Finite Element Analysis

According to the calculation of the eigenfunction, the elastic modulus of the concrete slab is 2.78×10^{10} N/m², and the Poisson's ratio is 0.21. Finite element analysis is carried out using Solidworks. A static load pressure of 10^5 N is applied to the concrete slab, and the stress simulation results are shown in Figure 5. The stress of each element is less than the tensile strength of concrete, which is 2.0×10^6 N/m². This indicates that the bearing capacity of the original concrete slab is much higher than the static pressure brought by a 10-ton vehicle. The simulation results of the vertical displacement are shown in Figure 6. Under the action of the 10^5 N static pressure, the maximum displacement is 0.01243 mm. The deformation is symmetrically distributed about the diagonal of the concrete slab and tends to be on the side of corner A.

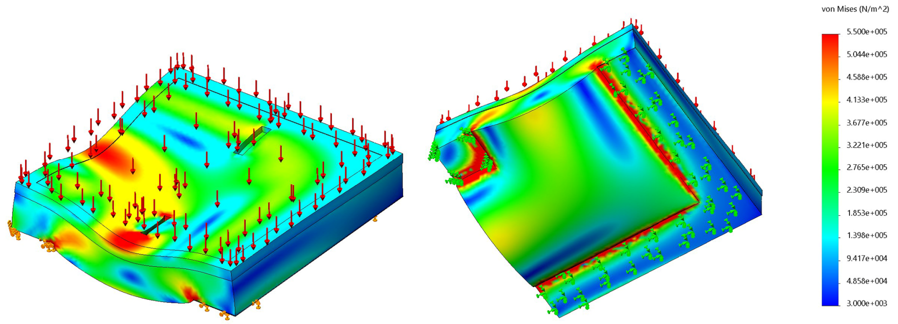

Fig. 5. Simulation stress analysis based on Solidworks software.

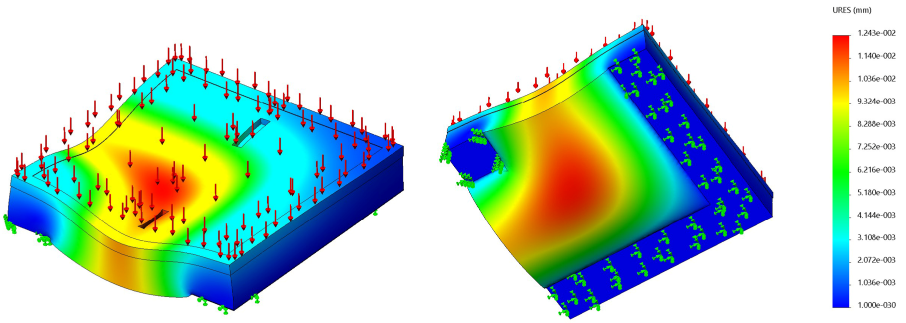

Fig. 6. Simulation vertical displacement analysis based on Solidworks software.

In view of the above simulation results, the displacement of the stress on the concrete slab at corner B is the smallest. Performing transformation here will have the least impact on the load-bearing capacity of the concrete slab. Since the concrete slab is square and the steel mesh is evenly distributed in the front, back, left, and right directions, as shown in Figure 7, select any corner of the C-type concrete cover plate for transformation. Use a hole opener to open a through hole at a position 250 mm away from the two edges. Since the minimum interval between the internal steel bars of the C-type concrete cover plate is 118mm, in order to minimize the damage to the internal reinforcing bars to the greatest extent, the diameter of the through hole is 100 mm.

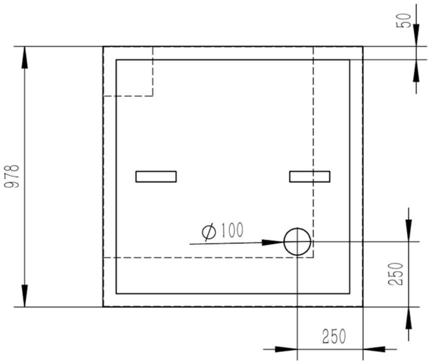

Fig. 7. Schematic diagram of concrete slab renovation.

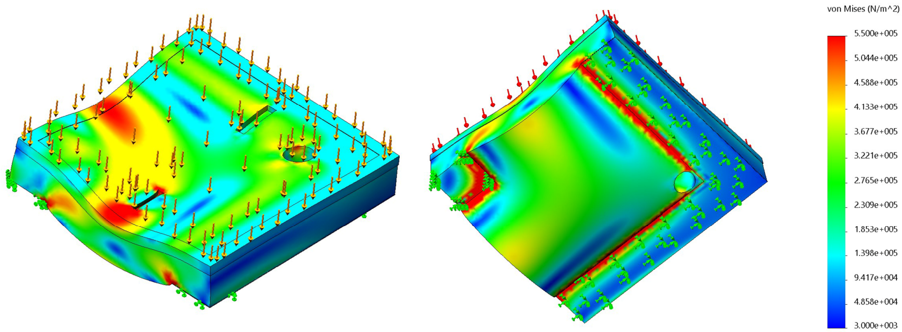

Fig. 8. Simulation stress analysis based on Solidworks software after renovation.

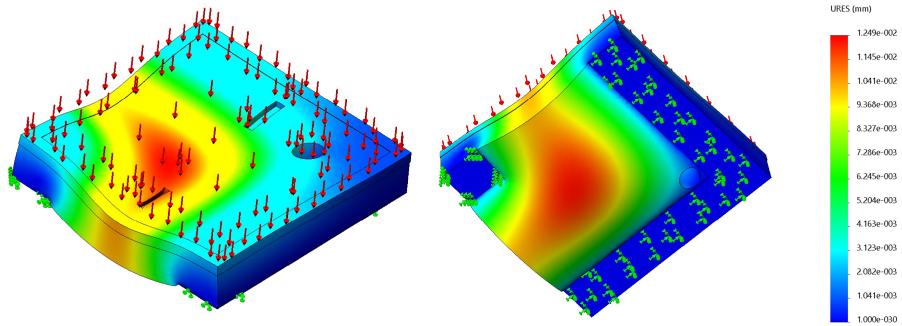

Fig. 9. Simulation vertical displacement analysis based on Solidworks software after renovation.

The parameter settings of the Solidworks software are the same as before the transformation. The stress and displacement simulation results are shown in Figures 8 and

9. Compared with the stress distribution diagram before the transformation, it can be seen that local stress is generated at the openings of the concrete slab, but it is still less than the tensile strength of concrete, which is 2.0×10^6 N/m^2. After the transformation, the vertical displacement is 0.01249 mm, which is slightly increased compared to before, but the displacement is still very small. This shows that the transformed concrete slab can fully meet the load-bearing requirements.

4 Testing and Application

According to the above simulation results, the concrete slab is renovated and constructed. A 100mm through hole is opened at a distance of 250mm from the edges on both sides. As shown in Figure 10, C-shaped steel is used to simulate the installation conditions of the corner of the oil pipe ditch. The spacing is 620mm. The concrete slab is placed on the test plane composed of C-shaped steel.

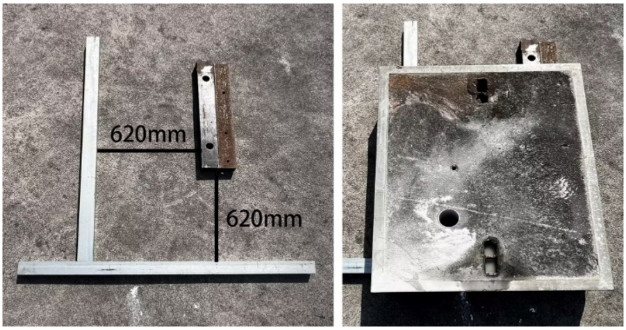

Fig. 10. Layout diagram of field test of concrete cover plate after renovation.

Fig. 11. Field load-bearing capacity test of concrete slab after renovation.

According to the load-bearing requirements of the laying surface of the oil pipe trench on the gate surface, it needs to meet the passing capacity of 10-ton vehicles. In the on-site test, a 16-ton engineering vehicle is used for testing. As shown in Figure 11, the vehicle is stationary and completely passes through the concrete slab, and the concrete slab structure is intact.

As shown in Figure 12, with the help of equipment such as an industrial endoscope camera, the leakage situation of hydraulic pipelines in the oil pipe trench can be clearly observed, which can meet the inspection requirements of the enclosed oil pipe trench.

Fig. 12. Field application of industrial endoscope camera.

5 Conclusion

Through the research in this paper, the finite element analysis based on Solidworks can be applied to the stress analysis of reinforced concrete slabs. The results of finite element analysis can guide the transformation plan and reduce the influence of concrete slab transformation on its load-bearing capacity. It has relatively good feasibility to inspect the working conditions of the closed oil pipe trenches by means of the visual transformation of the concrete slabs in combination with the industrial endoscope camera.

References

1. Ngo D., Scordelis A C. Finite element analysis of reinforced concrete beams[J]. ACI Journal, 1997, 64(2):152- 163. https://www.concrete.org/publications/internationalconcreteabstractsportal/m/details/id/7551.
2. Ziyu Wang, Ming Yang, Tao Ma, et al. A finite element modeling and analysis method for ultra-high performance concrete[J]. Construction and Building Materials, 2024. https://doi.org/10.1016/j.conbuildmat.2024,456:0950-0618. https://doi.org/10.1016/j.conbuildmat.2024.139258.
3. Dhert W J A , Verheyen C C P M , Braak L H ,et al.A finite element analysis of the push-out test: influence of test conditions.[J].J Biomed Mater Res, 2010, 26(1). DOI:10.1002/jbm.820260111.

4. Yoo,Doo-Yeol,Kang,et al.Nonlinear finite element analysis of ultra-high-performance fiber-reinforced concrete beams.[J].International Journal of Damage Mechanics, 2017.DOI:10.1177/1056789515612559.
5. Luu X B , Kim S K .Finite Element Modeling of Interface Behavior between Normal Concrete and Ultra-High Performance Fiber-Reinforced Concrete[J].Buildings (2075-5309), 2023, 13(4).DOI:10.3390/buildings13040950.
6. Long L , Songqiang W .Flexural strength of ultra-high performance concrete beams with stainless steel wire mesh: experimental and finite element analysis[J].Journal of Sustainable Cement-Based Materials, 2024(1/4):13.
7. T.L.Teng, Y.A.Chu, F.A.Chang, et al. Calculating the elas- tic moduli of stee-l fiber reinforced concrete using a dedicated empirical formula[J].Computational Materials Science,2004(31):337-346. https://doi.org/10.1016/j.commatsci.2004.04.003.
8. H.A.Ahmad, C.L.Lagoudas. Effective elastic properties of fiber-reinforced concrete with random fibers[J].Journal of En- gineering Mechanics,1991,117(12):2931-2938. https://doi.org/10.1061/(ASCE)0733-9399(1991)117:12(2931).
9. Luo Dongmei, Wang Wenxue, Kaohsiung Shanyu, et al. A new solution method for determining the precise periodic boundary conditions in the homogenization method and its application in the stiffness prediction of composite materials[J]. Mechanical Strength, 2006, (04):517-523. DOI:10.16579/j.issn.1001.9669.2006.04.010.
10. Luo Dongmei, Wang Wenxue, Kaohsiung Shanyu. Application of homogenization method in the analysis of microscopic stress distribution of discontinuous carbon nanotube reinforced composites[J]. Journal of Composite Materials, 2007, (03):186-192. DOI:10.13801/j.cnki.fhclxb.2007.03.033.
11. Liao Qian, Fu Wensheng, Luo Dongmei. Finite element simulation and analysis of mechanical properties of reinforced concrete beams[J].Shanxi Architecture, 2009, 35(34):52-53. DOI:10.13719/j.cnki.cn14-1279/tu.2009.34.119.