# Numerical and Experimental Investigation of the Jack-Up Technology based on Anti-Overturning of the Single-Column Pier Bridge

Hao Xu[1a], Yidian Dong[2*], Xun Song[3b], Xiaogong Zheng[3c], Xingshi Fang[3d], Jinlong Zhao[3e], Wenkui Liu[1f]

[1]Heilongjiang Transportation Investment Engineering Construction Co., Ltd., Harbin, China
[2]School of Transportation Science and Engineering, Harbin Institute of Technology, Harbin, China
[3]Heilongjiang Dingjie Road and Bridge Engineering Co., LTD, Harbin, China

[a]23326326@qq.com, [*]23S032005@stu.hit.edu.cn, [b]171537215@qq.com
[c]912151095@qq.com, [d]948739204@qq.com, [e]2705253984@qq.com
[f]191003136@qq.com

**ABSTRACT.** Under the eccentric load of heavy-duty vehicles, single-column pier bridges are prone to accidents such as pier deviation, bearing extrusion, and main beam overturning, which seriously affect safety hazards. Therefore, it is necessary to reinforce the anti-overturning stability of the existing single-column pier bridge. In this paper, based on anti-overturning theory, a jacking reinforcement technology of single-column pier bridge is proposed. Then, the finite element model of single-column pier bridge is established and parameter analysis is conducted to obtain the influence of essential parameters on the anti-overturning stability of single-column pier bridge. Finally, field tests are carried out to verify the validity of the proposed method. The results show that it is reasonable and feasible to use jack synchronous jacking reinforcement technology for single-column pier bridges, and the effect is remarkable. It can provide technical reference for the reinforcement and bearing replacement of single-column pier bridges in similar projects.

**Keywords:** single-column pier bridges; jack-up technology; numerical simulation; field test; anti-overturning

## 1 INSTRUCTION

Single column pier bridges are widely used in the construction of highway bridges due to their advantages of light structure, small occupied space under the bridge, material saving and wide view under the bridge [7,9] (TB 10002-2017 2017, Xiong 2017). However, under the eccentric load of heavy vehicles, single-column pier bridges are prone to accidents such as pier bias, bearing extrusion, and girder overturning, which seriously affect safety hazards [2-3] (Peng 2015, Peng 2016).


Z. Ahmad et al. (eds.), *Proceedings of the 2023 5th International Conference on Structural Seismic and Civil Engineering Research (ICSSCER 2023)*, Atlantis Highlights in Engineering 24,
https://doi.org/10.2991/978-94-6463-312-2_36

Hambly studied the overturning safety factors regarding structural weight, height and overturning arm [1] (Hambly 1990). Sasaki analyzed the impact of vehicle loads on concrete box girder bridges [6] (Sasaki 2010). The study showed that vehicle overweight and lateral overturning moments generated by vehicle loads would have adverse effects on bridges, and put forward corresponding preventive measures. Pennington collected relevant data on the overturning accident of the Bussey railroad bridge, studied the causes of the overturning instability of the bridge, and proposed measures to improve the overturning performance of the bridge [4] (Pennington 2009). Zhuang pointed out that the study of single-column pier-beam bridges need to focus on the mechanical performance of the supports and the relationship between the support box beams [11] (Zhuang 2014)."Technical requirements for spherical bearings" [8] (GB/T17955-2000 2000) stipulates that within the normal working range of the bearings, the rotation angle limits of the middle bearings are 0.02, 0.04, and 0.06rad respectively. "Pot bearing for highway bridge" [5] (JT/T 391-2019 2019) stipulates that within the normal working range of the support, its rotation angle shall not be greater than 0.02rad.In 2018, Ministry of Transport of the People's Republic of China promulgated "Specifications for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts" [10] (JTG 3362-2018 2018), through the concept of lateral anti-overturning stability coefficient, the anti-overturning stability check calculation becomes simple and effective.

According to the code, there are a large number of bridges that do not meet the anti-overturning requirements. In addition, after a long period of use, it is necessary to carry out synchronous jacking and replacement of damaged bearings, so that the bridge structure is still in a stable state and avoid overturning and other phenomena. Therefore, it is necessary to carry out anti-overturning reinforcement construction work for such bridges. However, most of the existing research focuses on the failure mode and anti-overturning calculation method of single-column pier bridges, and there are few studies on how to strengthen the safety and stability of single-column pier bridges.

In this paper, based on anti-overturning theory, a jacking reinforcement technology of single-column pier bridge is proposed. Then, the finite element model of single-column pier bridge is established and the parameter analysis is conducted to obtain the influence of essential parameters on the anti-overturning stability of single-column pier bridge. Finally, field tests are carried out to verify the validity of the proposed method.

## 2 ANTI-OVERTURNING CHECKING THEORY

According to the "Specifications for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts" (JTG 3362-2018), the anti-overturning calculation should meet the following requirements. When combined according to the standard value, the effect of the integral cross-section simply supported beam and continuous beam should meet the requirements of formula (1).

$$\frac{\sum S_{bk,i}}{\sum S_{sk,i}} \geqslant k_{qf} \tag{1}$$

where, $k_{qf}$ is the anti-overturning stability coefficient of the transverse bridge; $\Sigma s_{bk,i}$ is the effect design value to make the superstructure stable ; $\Sigma s_{sk,i}$ is the effect design value to make the upper structure unstable.

When checking according to the above formula, it should be calculated according to formulas (2)-(3).

$$\sum S_{bk,i} = \sum R_{Gki} l_i \tag{2}$$

$$\sum S_{sk,i} = \sum R_{Qki} l_i \tag{3}$$

Where, $l_i$ is the bearing center distance between the failure bearing and the effective bearing at the i-th pier; $R_{Gki}$ is the bearing reaction force of the failure bearing at the i-th pier under the permanent action, which is determined by the calculation of the effective bearing system of all the bearings and the combination of the standard values; $R_{Qki}$ is the bearing reaction force of the failure bearing at the i-th pier under the variable action, which is determined by the calculation of the effective bearing system of all bearings, and the value is determined by the combination of standard values. The vehicle load effect (considering the impact) is determined by the most unfavorable layout form corresponding to each failure bearing.

## 3 Numerical analysis and experimental verification

### 3.1 Finite element model

As shown in figure1-3, the span combination of the bridge is 24m+35m+24m. The upper structure is a continuous box girder of variable cross-section single-box double-chamber prestressed concrete structure. The bottom curve of the beam adopts a straight section. The height of the main beam of the middle fulcrum is 1.9m, and the height of the beam of the mid-span and the side fulcrum is 1.3m. The plate bearing is adopted. As shown in figure 4, one bearing is arranged in the middle pier and two bearings are arranged in the side pier.

According to the design drawings and construction scheme, the finite element model of the original bridge and the finite element model of the jacking state of the separation overpass are established respectively, as shown in figure 5. The model only considers the dead weight of the main beam, bridge deck pavement and vehicle load.

**Fig. 1.** The real picture of the single-column pier bridge

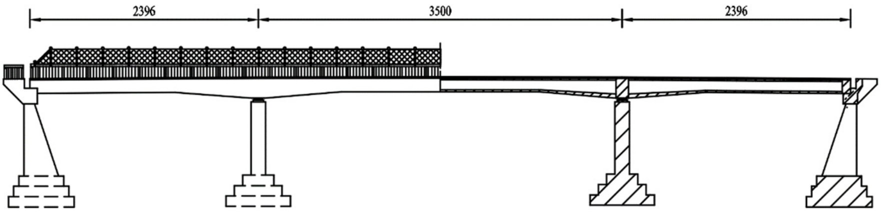
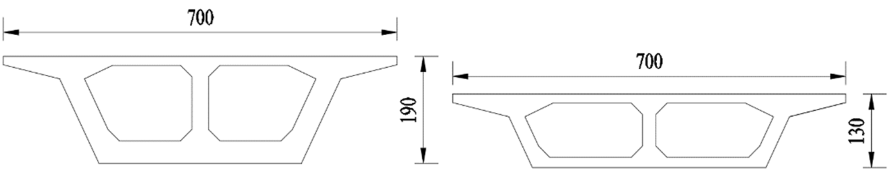



**Fig. 2.** Bridge elevation diagram (cm)




(a) Position on the top of the main pier (b) Position on the top of the abutment pier

**Fig. 3.** Cross-section diagram of the girder (cm)

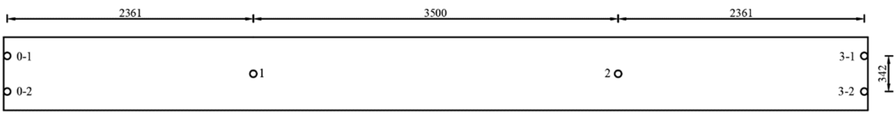



**Fig. 4.** The bearing arrangement diagram (cm)

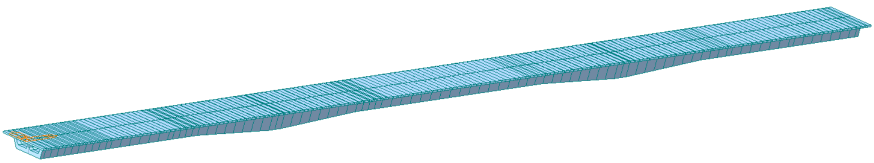


**Fig. 5.** Bridge finite element model

### 3.2 Result analysis

Through the theoretical analysis of the finite element model, the factors affecting the stability of the single-column pier bridge under the jacking condition are further discussed. In this section, three parameters affecting the anti-overturning stability are selected, namely, the spacing of the jacks, the load level, and the lateral position of the vehicle.

**(1) Spacing of the jacks.**

Considering that the spacing of jacks is flexible under the jacking condition of single-column pier bridge, this paper studies the variation law of anti-overturning stability of single-column pier bridge when the spacing of jacks is 0.4m, 0.8m, 1.2m and 1.6m respectively.

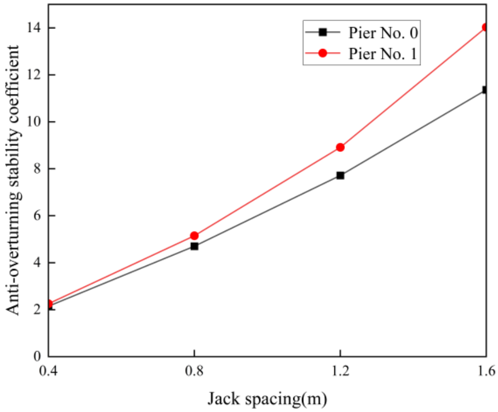



**Fig. 6.** The influence of jack spacing on the anti-overturning stability coefficient

According to figure 6, with the increase of the spacing of the jacks, the anti-overturning stability coefficient of the bridge shows a gradually increasing trend. Therefore, for the jacking condition of single-column pier bridge, the balance between the spacing of jacks and the size of steel hoops should be sought to improve the anti-overturning stability of the bridge.

**(2) Load level.**

Considering the complex changes of vehicle driving conditions during the jacking process of single-column pier bridges, this paper studies the anti-overturning stability of single-column pier bridges when the vehicle weights are 25t, 35t, 45t, and 55t, respectively, and driving 1,2, and 3 vehicles.

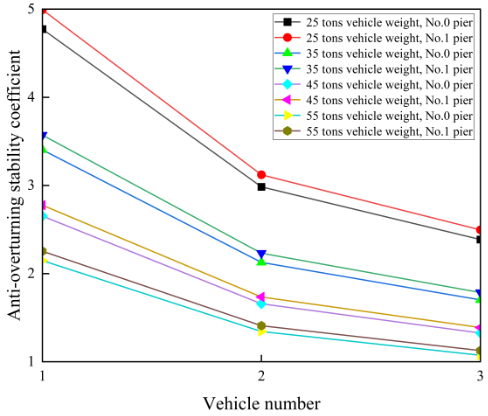



**Fig. 7.** The influence of load level on the anti-overturning stability coefficient

According to figure 7, when the load level increases, the anti-overturning stability coefficient of the bridge gradually decreases. Therefore, under the jacking condition of single-column pier bridge, the load should be strictly limited.

**(3) Lateral position of the vehicle.**

Considering the influence of vehicle partial load on the anti-overturning stability of the bridge during the jacking process of the single-column pier bridge, this paper studies the variation law of the anti-overturning stability of the single-column pier bridge when the distance from the centerline of vehicle to bridge is 0.4m, 0.8m, 1.2m and 1.6m respectively.

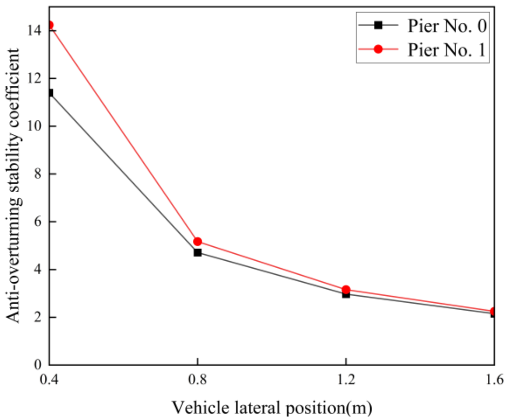



**Fig. 8.** The influence of vehicle lateral position on the anti-overturning stability coefficient

According to figure 8, with the increase of the lateral position of the vehicle, the anti-overturning stability coefficient of the bridge shows a gradually decreasing trend. Therefore, it is recommended to place the barrier walls for diversion during the jacking process to make the vehicle bridge center-line travel.

### 3.3 Field test

In order to further verify the effectiveness of the finite element analysis, we carried out field tests. In order to ensure the safety of the experimental process, 25t, 35t and 45t heavy vehicles are used in the field. The lateral position of the vehicle is 1.2m, and the distance between the jacks is 1.4m. At the same time, the finite element analysis method is used for verification, and the comparison results are shown in figure 9.

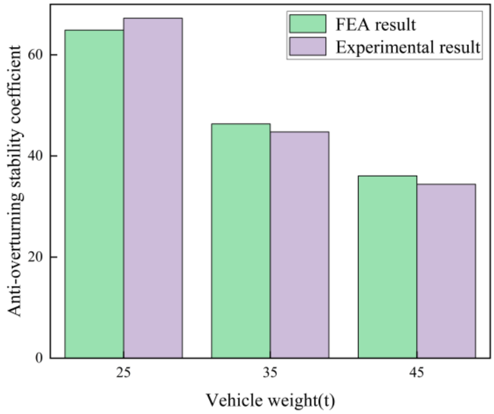



**Fig. 9.** Comparison diagram of the FEA result and the experimental result

According to the figure above, the safety margin of the theoretical calculation results of the jacking condition is large. Because the uncertainty of the jack is large, and the absolute safety of the construction cannot be guaranteed.

It is found that the analysis results of the anti-overturning field test are consistent with the analysis results of the finite element analysis. With the increase of vehicle weight, the anti-overturning stability coefficient decreases, but they all meet the anti-overturning stability requirements, ensuring the safety of single-column pier bridges during reinforcement, which verifies the effectiveness of the method proposed in this paper.

## 4 Conclusion

In this paper, based on anti-overturning theory, a jacking reinforcement technology of single-column pier bridge is proposed. Then, the finite element model of the continuous single-column pier box girder of variable cross-section single-box double-chamber pre-stressed concrete structure is established and parameter analysis is conducted to obtain the influence of the spacing of the jacks, load level and lateral position of the vehicle on the anti-overturning stability of single-column pier bridge. Finally, field tests are carried out to verify the validity of the proposed method. The conclusions are as follows:

(1) With the increase of the spacing of the jacks, the anti-overturning stability coefficient of the bridge shows a gradual upward trend. When the load level and the lateral

position of the vehicle increase, the anti-overturning stability coefficient of the bridge decreases gradually.

(2) It is suggested that the position of the jack should be reasonably arranged, and the water horse should be placed for diversion, so that the center line of the axle can move forward. At the same time, it is recommended to limit the load by referring to the critical load of the original bridge state.

(3) The field experimental results are consistent with the finite element simulation results, which proves that the proposed method of bridge jacking reinforcement based on single column pier has certain accuracy, and has certain reference significance for similar single-column pier bridge jacking projects.

## REFERENCES

1. Hambly, E. C. (1990). Overturning instability. Journal of geotechnical engineering, 116: 704-709. https://doi.org/10.1061/(ASCE)0733-9410(1990)116:4(704)
2. Peng, W. B., Pan, R. D., Ma, J., Jiao, B. (2016) Study of Overturning Failure Modes and Anti-Overturning Calculation Methods for Single-Column Pier Beam Bridges. Bridge Construction, 46: 25-30. DOI: 10.19721/j.cnki.1001-7372.2015.03.009
3. Peng, W. B., Xu, W. T., Chen, G. J, Lu, F. Y. (2015) Calculation Method for Anti-overturning Capacity of Single Column Pier Girder Bridge. China Journal of Highway and Transport, 28: 66-72.
4. Pennington, S. M. (2009). The Bussey railroad bridge collapse. In Forensic Engineering 2009: Pathology of the Built Environment, 105-114. https://doi.org/10.1061/41082(362)11
5. JT/T 391-2019. (2019). Pot bearing for highway bridge, Ministry of Transport of the People's Republic of China, Beijing, https://www.mot.gov.cn
6. Sasaki, K. K., Paret, T., Araiza, J. C., Hals, P. (2010) Failure of concrete T-beam and box-girder highway bridges subjected to cyclic loading from traffic. Engineering Structures, 32: 1838-1845. https://doi.org/10.1016/j.engstruct.2010.01.006
7. TB 10002-2017. (2017). Fundamental code for design on railway bridgeand culvert, China Railway Publishing House, Beijing, https://www.tdpress.com
8. GB/T17955-2000. (2000). Technical requirements for spherical bearings", State Administration for Market Regulation, Beijing, https://www.samr.gov.cn
9. Xiong, W., Cai, C. S., Kong, B., Ye, J. S. (2017) Overturning-collapse modeling and safety assessment for bridges supported by single-column piers. Journal of Bridge Engineering, 22: 04017084. https://doi.org/10.1061/(ASCE)BE.1943-5592.0001133
10. JTG/T 3362-2018. (2018). Specifications for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts. China Communications Press Co., Ltd., Beijing, http://www.ccpress. com.cn
11. Zhuang, D. L. (2014). Study of Overturning Stability lssues of Box Girder Bridges Under Action of Eccentric Load. Bridge Construction, 44: 27-31.