Anti Overturning Performance Evaluation of Medium and Small Span Bridges under Complex Geological Conditions

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Abstract: In recent years, the bridge overturning and collapse events reveal the huge safety risk of medium and small span bridges. When the lateral anti overturning performance of these medium and small span bridges is transformed, affected by the span bridge structure, the bearing capacity of bridge pier, the road layout under the bridge and other objective factors, the commonly used methods are lengthening the beam, adding capping beam, adding pier pile and so on It cannot completely solve the problem of anti overturning performance evaluation of bridges under complex geological conditions. Based on this, the evaluation method of anti overturning performance of medium and small span bridges under complex geological conditions is optimized. Combined with the characteristics of complex geological conditions, the structural characteristics of long-span bridges are analyzed. The calculation of bearing capacity of medium and small span bridges with longitudinal expansion joints is introduced, and the transverse anti overturning performance of adding steel beams at the top box girder of piers between bridges is evaluated So as to ensure the accuracy of anti overturning performance evaluation of medium and small span bridges.

Keywords: Bridge; Single pier; Overturning resistance

1. Introduction

Small and medium span bridges are widely used in ramp bridges, overpasses and urban overpasses because of their light structure, good permeability under bridges, strong adaptability to complex site conditions such as roads and structures under bridges, and cost saving [1]. But in recent years, the accidents of small and medium span bridges overturning and collapsing due to improper construction or overload vehicles in the process of operation occur from time to time [2]. The occurrence of these accidents often has no obvious signs, accidental and destructive, which brings huge loss of life and property, bad social impact, and is a major hidden danger for the safe operation of bridge structure [3]. Based on this, the anti overturning performance of medium and small span bridge design under complex geological conditions is evaluated. Because there are many kinds of single column piers, the lateral anti overturning problem is also more complex. For different structures, the anti overturning checking methods and applicable conditions are not the same [4]. Considering all kinds of critical lateral overturning modes, the bridge structure finite element analysis program is used to analyze the anti overturning performance [5]. The calculation and analysis of overburden stability can provide reference for the design and maintenance of similar bridges.

2. Anti Overturning Performance Evaluation of Medium and small Span Bridge Design

2.1. Anti overturning stability evaluation algorithm for bridge design

The main reason of bridge design anti overturning is that the pier failure and collapse is due to the rotation of the main beam of the span bridge under the action of eccentric load [6]. After the inclination of the beam, the horizontal displacement of the compression pier under the vertical load and the horizontal displacement of the beam away from the pier caused by the rotation of the beam form the horizontal displacement trend of the beam to the supporting pier. When the angle is small, the main beam compresses the pier to form a horizontal force. Within a certain angle range, with the increase of the angle, the horizontal reaction force of the pier increases, resulting in the bending failure of the pier and the overturning and collapse of the main beam [7]. In order to better judge the overturning resistance of the bridge, the overturning failure mechanism and structure of the bridge beam are analyzed, as shown in the following figure 1:

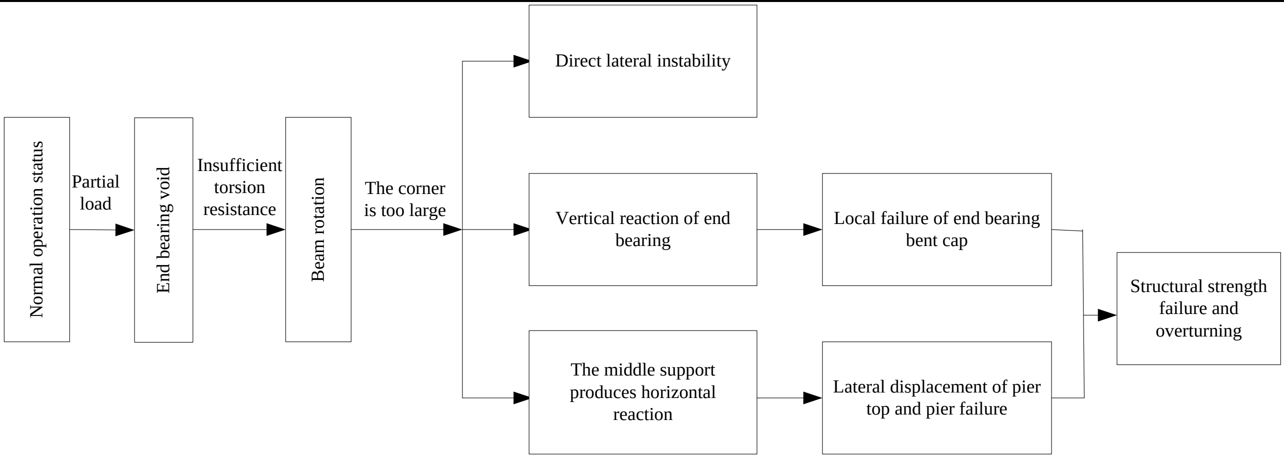

Figure 1. Bridge overturning failure mechanism

It can be seen from the figure above that the overturning failure of the middle and small span structure is caused by the overturning of the supporting structure [8]. It is the stability problem that induces the structural failure, and the strength problem is the main one that finally leads to the structural failure, and the bearing void and beam angle are the main control factors in the process of overturning [9]. The reliability analysis of bridge shape variables is the foundation of the new detection method. Supported by the determination of deformation extreme response surface and the calculation of reliability genetic operator, the deformation extreme response surface can physically combine the dynamic theories such as the principle of flexible multi-body system and the principle of comprehensive mode according to the main characteristics of the bridge structure, and then according to the limit state of the bearing condition of the bridge material State function, in all the data to be detected, a part of quantitative points are selected as the training samples of genetic operators, and then the number of middle-level nodes in the network of reliability genetic operators is determined to achieve the purpose of establishing the framework of bridge shape variable analysis [10]. In the case of bridge structure with shape variables, the initial search space of deformation extremum response surface can fully reflect the individual fitness value of reliability genetic operator, and the calculation process of reliability genetic operator can be reduced to half of the original method by intelligent optimal solution checking. In the process of intelligent optimal solution judgment, the reliability genetic operator meeting the bridge deformation extreme response surface construction conditions can directly obtain the threshold output permission; the reliability genetic operator not meeting the bridge deformation extreme response surface construction conditions needs to return to the initial search stage until it reaches the threshold output standard [11]. The figure below reflects the complete process of determining bridge deformation extreme value response surface.

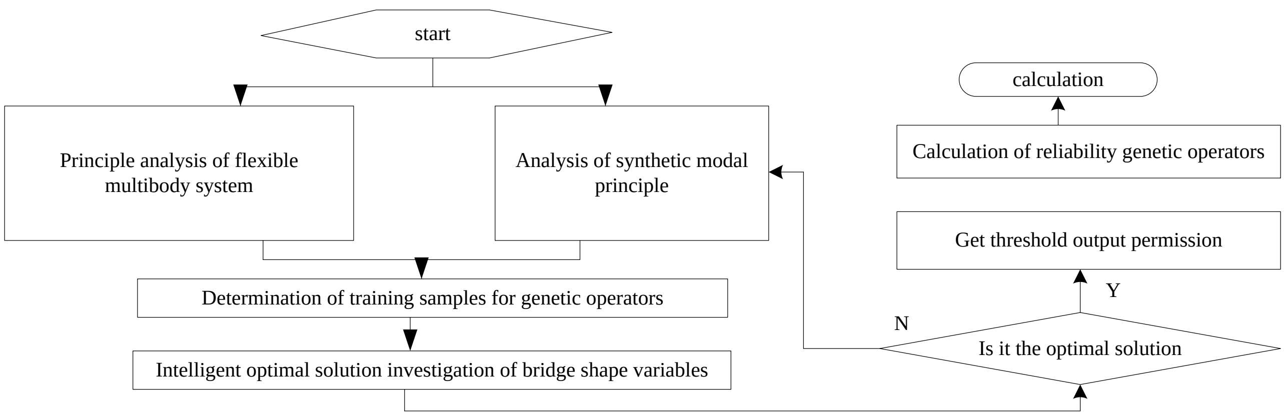

Figure 2. Evaluation steps of bridge deformation extreme value

For medium and small span bridges with integral section, the anti overturning calculation of superstructure shall be carried out, and the anti overturning stability coefficient of superstructure shall meet the requirements of the following formula:

$$r_{af}=\frac{s_{bk}}{s_{sk}}\geq 2.5 \quad (1)$$

Where: raf is the anti overturning stability coefficient, Ssk is the standard value effect of vehicle load (including impact action) to overturn the superstructure, and Sbk is the standard combination of action effect to stabilize the superstructure [12]. Under the combination of action standard value of bridge, any bearing should not appear void phenomenon. For orthogonal bridges and skew bridges with skew angle less than 30 degrees, when the overturning axis is the line connecting the outer abutment supports on the same side of the bridge center line, the calculation formula of anti overturning stability coefficient is as follows:

$$r_{af}'=\frac{\sum R_{Gi}x_i}{(1+\mu)\left(q_k l+P_k\right)e} \quad (2)$$

Where: qk is the uniform load in the lane load, pk is the concentrated load in the lane load, l is the total length of the bridge, e is the vertical distance from the most unfavorable transverse lane position to the overturning axis, u is the impact coefficient, RGi is the bearing reaction of each bearing in the completed bridge state, xi is the vertical distance from each bearing to the overturning axis [13]. When the overturning axis is the connecting line between the abutment outer bearing and the mid span pier bearing, the calculation formula of anti overturning stability coefficient is as follows:

$$\Delta r_{af}=\frac{\sum R_{Gi}x_i}{(1+\mu)\left(q_k\Omega+P_k e\right)} \quad (3)$$

Where: Ω is the area enclosed by the overturning axis and the transverse loading lane, and e is the maximum vertical distance between the transverse loading lane and the overturning axis. The regulation of lateral anti overturning stability is: under the most unfavorable combination of calculated loads, the lateral anti overturning stability coefficient of bridge structure shall not be less than 1.3, and the specific calculation formula is as follows:

$$K=\frac{M_d}{\Delta r_{af}M_q} \quad (4)$$

Where: K is the anti overturning stability coefficient, Md is the stability moment, and Mq is the overturning moment. The general finite element software ANSYS is used to model the ramp bridge with single column pier. The upper concrete slab structure of the bridge is simulated by she1163 element, and the lower steel box structure is simulated by she1143 element. The relevant parameters of the two structures and elements are shown in the table 1.

Table 1. Bridge structure and element parameters

Structure	Unit	Elastic Modulus	Poisson's Ratio	Density	Thickness
Concrete slab structure	Shell63	3.45×1010	0.167	2.5×1035kg/m3	0.2m
Steel box structure	Shell43	2.06×1011	0.300	7.85×1035kg/m3	0.02m

For the selection of the overturning axis of the ramp bridge, because it is a straight bridge, the overturning axis can only be the connecting line of the outer bearing of the abutment. That is to say, the connecting line of No.2 and No.6 supports is the overturning axis. The plane diagram of overturning axis is shown in the figure.

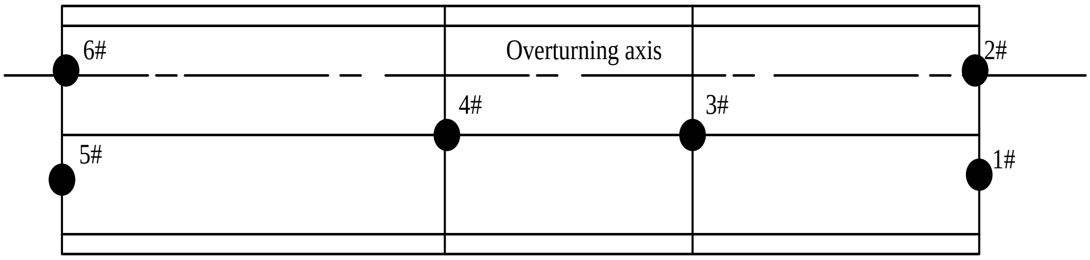

Figure 3. Schematic plan of bridge overturning axis

Table 2. Reaction value of each support under gravity (KN)

Bearing No.	1	2	3	4	5	6
Support reaction	110.873	110.873	584.480	584.480	110.873	110.873

According to the anti overturning stability calculation of the bridge by ANSYS, the reaction value of each support under the action of gravity is shown in the table 2.

The fundamental frequency f of the bridge is 1.9371 by ANSYS, and the impact coefficient u of the bridge is 0.101 by u = 0.1767ln (f) - 0.0157. Since the overturning axis of the straight bridge is the connection line of the outer bearing of the abutment, the formula should be applied to calculate the anti overturning stability coefficient according to the code. The vertical distance E from the most unfavorable transverse lane position to the overturning axis is calculated below. The most unfavorable overturning loading lane position of the ramp bridge has been determined above. Therefore, e is 0.6m through calculation. As the span of the ramp bridge is 20 meters long, the concentrated load is 240 kN by linear interpolation. The data required for calculating the anti overturning stability factor are shown in the table 3 and table 4:

Table 3. Distance between supports and overturning axis (m)

Bearing No.	1	3	4	5
Distance	3	1.5	1.5	3

Table 4. Bridge load parameters

u	qk	l	Pk	e
0.101	10.5kN/m	60m	240Kn	0.6m

According to the formula, the anti overturning stability coefficient of the ramp bridge under the first level Lane load is calculated:

$$r_{af}=\frac{\sum R_{Gi}x_i}{(1+\mu)(q_k l+P_k)e}=4.208 \qquad (5)$$

According to the formula, the anti overturning stability coefficient of the single column pier ramp bridge under the secondary vehicle load is obtained as follows:

$$r_{af}'=\frac{\sum R_{Gi}x_i}{(1+\mu)\left(\sum Z_i Li\right)}=\frac{2418.678}{1.101\times 660}=3.329 \qquad (6)$$

Under the above algorithm, we can meet the research requirements of bridge anti overturning stability design, but in fact, this method cannot simulate exactly the same load effect value, and the effect value is only an approximate value. There are two reasons for this phenomenon: one is that any grid in the beam grid will directly produce bending moment after the force is applied, but in reality, the bridge is not stable The steel bars of beam construction are arranged crosswise and crosswise, and the Poisson ratio of the concrete wrapped around the steel bars is small, which leads to the force exerted by the vehicle will be decomposed, and the resulting bending moment is generally less than the bending moment of the simulation mapping. Second, because the shear force is easily affected by the bridge building materials, there is a certain gap between the simulated shear force and the real result, but the gap is not too big, generally not more than 0.3kn, so it is necessary to optimize the evaluation algorithm in one step to ensure the bridge structure and quality.

2.2. Optimization of anti overturning evaluation algorithm for small span bridge

A large number of uncertain parameters need to be considered in the design and analysis of bridge structures. The traditional design method simplifies the uncertain parameters by considering them as certainty, and explains the uncertainty by using the safety factor. Although the calculation result of this design method is intuitive, the value of the safety factor usually depends on the experience of the engineer, which cannot absolutely guarantee the required reliability, and cannot give the influence degree of each parameter on the safety factor. The reliability analysis method can consider the uncertain parameters in the single degree of bridge structure, and reflect the anti overturning performance of medium and small span bridges objectively and truly. The reliability analysis method evaluates the anti overturning performance of medium and small span bridges by failure probability or reliability index, which is not convenient for engineering application. Therefore, it is necessary to find an analysis method to connect the reliability index or failure probability with safety factor, so that the analysis results are simple and direct, and the uncertain parameters existing in the actual bridge structure can be considered, so as to enrich the medium and small span bridges Evaluation index of bridge anti overturning performance. Suppose that there are functional functions in independent standard normal space:

$$G(u)=g(x,\theta) \qquad (7)$$

$$x_i=F_{x_i}^{-1}\left(\Phi\left(u_{x_i}\right)\right) \quad i=1,2\ldots,n \qquad (8)$$

$$\theta=F_{\theta}^{-1}\left(\Phi\left(u_{\theta}\right)\right) \qquad (9)$$

Where, Φ standard normal distribution function, Fxi and F_θ are cumulative distribution function of xi and θ.According to the number of unknown parameters, the inverse reliability problem is divided into single unknown parameter inverse reliability problem and multiple unknown parameter inverse reliability problem. The inverse reliability problem of single unknown parameter can be determined by one limit state equation, and the inverse reliability problem of multiple unknown parameters needs to be solved by multiple limit state equations. The trial and error method was first proposed to solve the inverse reliability problem. By continuously modifying the unknown parameters, the limit state equation was solved repeatedly to achieve the allowable error. Obviously, the calculation efficiency of this method is low and the calculation workload is large. In order to improve the anti overturning performance of bridge, this paper further studies the inverse reliability of bridge, and puts forward some analysis methods with high computational efficiency. At present, the more commonly used analysis methods are the primary inverse reliability analysis method and the inverse reliability analysis method based on hlrf. There are some differences in the solving process of the two analysis methods. The following is the solution of the two analysis methods Analysis. The first-order inverse reliability analysis method is derived from the first-order second moment method. By iterating the limit state equation repeatedly, the unknown parameters satisfying the given target reliability index can be determined. The first-order inverse reliability analysis method is a common analysis method for solving the inverse reliability problem at present. According to the basic principle of the first order second moment method, the standard normal random variable U satisfies the equation at the checking point:

$$u = \left(\frac{\nabla_u G^T u}{\nabla_u G^T \nabla_u G} \right) \nabla_u G \qquad (10)$$

Where, $\nabla_u G$ is the gradient vector of the bridge load function g to the standard normal random variable u. The target reliability index is calculated by the formula:

$$\beta_t = \frac{-\nabla_u G^T u}{\left(\nabla_u G^T \nabla_u G\right)^{1/2}} \qquad (12)$$

In this way, we can get the following results:

$$u = \frac{-\beta_t \nabla_u G}{\left(\nabla_u G^T \nabla_u G\right)^{1/2}} \qquad (13)$$

In order to improve the efficiency of solving the inverse reliability problem, the modified HLRF iterative algorithm is introduced into the analysis of the inverse reliability problem. The initial value of each iteration is determined by linear search, and the iterative efficiency is improved, thus forming the inverse reliability analysis method based on hlrf. The inverse reliability problem is expressed as:

$$\| u \| - \beta_t = 0 \qquad (14)$$

$$u + \frac{\| u \|}{\left\| \nabla_u G(u,\theta) \right\|} \nabla_u G(u,\theta) = 0 \qquad (15)$$

$$G(u,\theta) = 0 \qquad (16)$$

A sequence is further constructed:

$$\begin{pmatrix} u_{k+1} \\ \theta_{k+1} \end{pmatrix} = \begin{pmatrix} u_k \\ \theta_k \end{pmatrix} + \lambda_k d_k \qquad (17)$$

Where k is the number of iterations and dk is the search direction vector

$$\| u \| - \beta_t = 0 \qquad (18)$$

$$u + \frac{\| u \|}{\left\| \nabla_{uu_{u_k},\theta_k} (u,\theta) \right\|} \nabla_{uu_{u_k},\theta_k} (u,\theta) = 0 \qquad (19)$$

$$l_{u_k,\theta_k}(u,\theta) = 0 \qquad (20)$$

Bridge overturned surface load effect refers to the internal force (such as shear, bending moment, etc.) deformation and cracks in the structure or structural components caused by the load, so the calculation of bridge load effect is to calculate the bending moment and shear force of the bridge, which is mainly calculated by the grillage method. The basic idea of grillage method is to simulate the bridge structure with an equivalent plane grillage or spatial frame, and then map the vehicle force on the bridge to the nearest grillage, and finally simulate the bridge load effect through the grid change. When using grillage method to complete the load effect calculation, the following equivalent principle must be met: the force applied to grillage is the same as that applied to bridge by vehicles, so as to ensure that the shear force and bending moment in grillage are consistent with the actual situation.

3. Analysis of Experimental Results

In order to verify whether the evaluation method of anti overturning performance of medium and small span bridges under complex geological conditions is reasonable, the following experiments are designed. In order to better detect the anti overturning performance of the bridge, the following parameters are set firstly, shown in the table 5.

Table 5. Shear parameters of bridge structure

Bridge correlation coefficient	Set parameter size
Effect coefficient of structural permanence	1.1
Structural importance coefficient	1.0
Coefficient of variable frequency even value	1
Car load	0.8
Human load	0.9
Variable effect coefficient of structure	1.3

In the process of long-span bridge structure analysis, it is necessary to combine the area of bridge interface, nonlinear material, linear aggregate material and other factors to evaluate the influence degree. The gravity acting on the bridge structure can be regarded as the input value, and the displacement, stress and vibration of the bridge structure caused by the external action can be regarded as the output of the system. According to the specific requirements for the construction of the bridge, the stress and displacement constraints are put forward as follows:

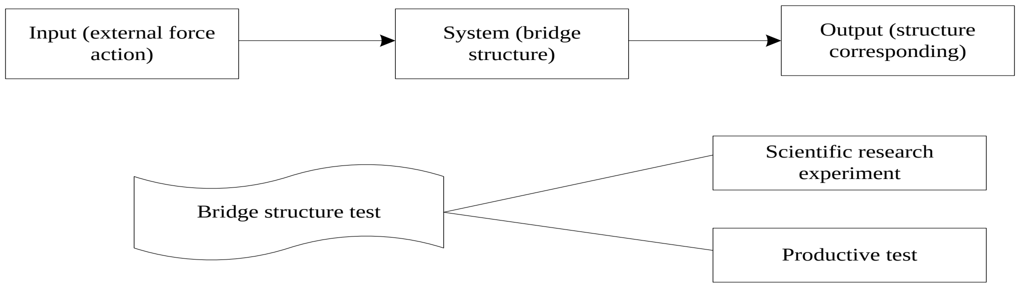

Figure 4. Experimental steps of anti-overturning load of bridge

The task of bridge capsizing test is to obtain the output (test data result) of a given system by applying external force (section load) to it. After the output is obtained, the following analysis can be carried out: directly compare the test value with the analysis value to verify the rationality and correctness of the rating method; in the case of unknown bridge structure characteristics, invert the characteristics of the system according to the input and output of the system, and then determine whether the actual characteristics of the system meet the design requirements. In the case that the input characteristics are unknown, the dynamic identification system characteristics of the bridge structure are obtained according to the output. Static test of bridge against overturning is an important means to understand the structure characteristics. Static test can not only solve the static problem of the structure, but also be carried out in the dynamic test of the structure to determine the characteristic parameters related to the structure.

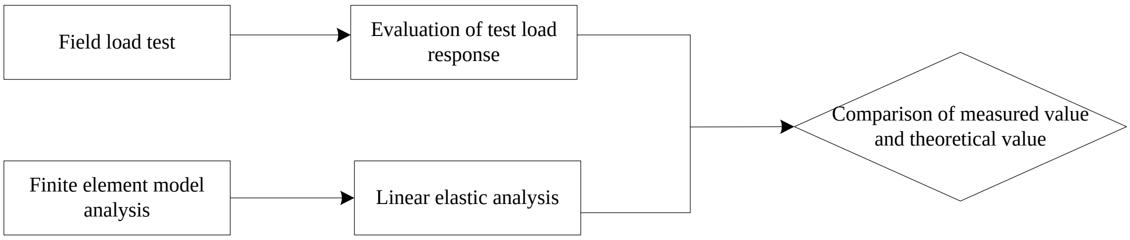

Figure 5. Static experiment steps of bridge structure

The anti-overturning load and the torsion Angle of bridge support are two important indexes for the anti-overturning performance evaluation of small and medium-sized span Bridges. Because there are a large number of curved beam Bridges in medium and small span Bridges, the beam ends are generally arranged with torsion resistance supports. If the beam ends are empty, the bridge's torsion resistance ability will be insufficient, the torsion stiffness will be reduced, whether the support is empty and the bearing's stress working state are important factors affecting the anti-capsizing performance of medium and small span Bridges. Because whether the support is empty or not is one of the important evaluation indexes to evaluate the anti-overturning performance of small and medium-sized span Bridges, it is an important step to judge whether the support is empty or not. According to the current condition of the bridge in operation, the method of special load test is adopted to evaluate the anti-capsizing performance of small and medium-sized span Bridges. From the point of view of testing whether the support of the bridge has been vacated and the torsion Angle of the bridge, the contents of the test evaluation method for the anti-capsizing performance of the bridge are composed of the following methods: linear measurement, support compression test and beam torsion test respectively.

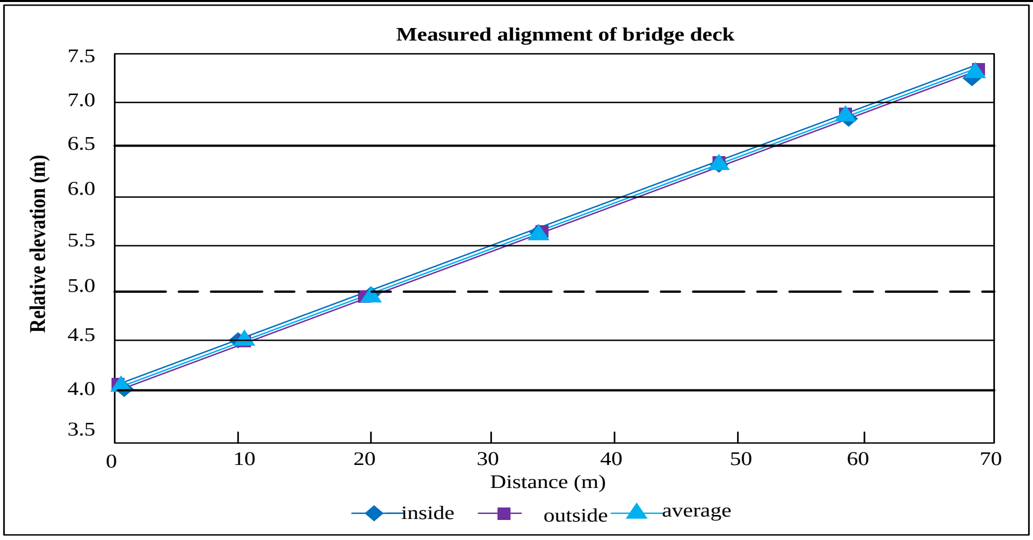

Figure 6. Load line diagram of measured bridge section

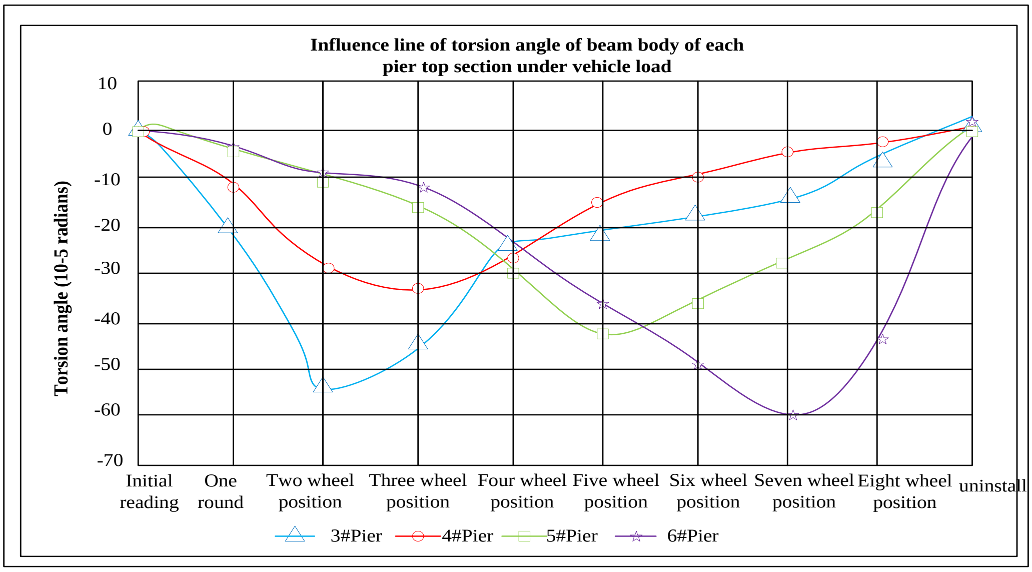

Figure 7. Load torsion Angle of bridge section

Furthermore, Leica DNA03 precision electronic level was used to arrange linear measuring points on the fulcrum of the beam and the inside and outside of the mid-span section to measure the transverse slope of the curved bridge. Meanwhile, the measurement results of each test stage were compared at the same time to grasp the changes of the transverse slope of the bridge deck during the test, so as to help analyze the working conditions of the supports in the test. The distribution of the internal force of the bridge and the displacement of the structure are asymmetrical in theory, and the internal force is larger than the vertical displacement of the main bridge. Thus, the comparison structure of the accuracy of anti-capsizing performance evaluation can be obtained, shown in the table 6.

Table 6. Comparison of accuracy of anti-capsizing performance evaluation

Position	Object	Traditional technology	Method of this paper
The lower edge of the bridge	Maximum tensile force / MPa	36.1	40.1
	Maximum pressure / MPa	145	180

	Maximum / M	0.134	1.562
Plate of bridge deck	Maximum pressure / MPa	12.2	20.2
Pier	Maximum pressure / MPa	15.4	16.7
Diagonal tension	Maximum pressure / MPa	723	895

Which can be concluded that the bridge overturning resistance performance is associated with the bridge of long-span Bridges, also related to such factors as the environment, site condition, and in the actual work, according to the specific situation into account various factors, follow the small earthquakes are not bad, not repairable, strong earthquakes in the thoughts, the application of this technology fully combines these advantages, its detection technology can in the construction of practical bridge project to solve the design of the overturning resistance.

4. Conclusion

Nowadays, bridge workers gradually understand and pay more attention to the transverse stability of bridge, the new bridge has avoided setting single pillar pier as much as possible. However, a large number of small and medium-sized span Bridges built in the past decades are still in service. When carrying out transverse anti-overturning transformation of these small and medium-sized span Bridges, they are often restricted by the original bridge structure and site conditions, so the conventional scheme cannot be adopted. For medium and small span Bridges with width on both sides, the scheme of adding steel beams between the original bridge and the extended bridge body is reasonable in stress, simple in construction and effective in effect, which can be used for reference for similar projects.

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