

# Research on Evaluation System and Treatment Countermeasures of Concrete Cable Tower

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**Abstract:** In order to study the concrete pylon evaluation system and treatment countermeasures, according to the characteristics of the concrete pylon component level and system level, an evaluation system that comprehensively considers long-term performance indicators and safety performance indicators. The research results can provide references for the long-term performance evaluation of concrete pylons.

## 1. Introduction

Compared with other parts of the cable-stayed bridge, the crack propagation and distribution of the concrete pylon have a more direct impact on its appearance, and the inspection requirements are higher. Its safety and durability are also more concerned. According to incomplete statistics, about 75% of cable-stayed bridge towers across the country have cracks, and as the operation period continues to increase, the cracks are also increasing. As a result, the stiffness, bearing capacity, and durability of the pylon structure will deteriorate, which will directly affect the long-term performance and safe service life of the bridge. Among them, Ah Beng Teebelieves that the weight of the evaluation index is not constant, but changes with the stage of damage, that is, the more serious the damage, the greater the weight[1]. HG Melhem and Senaka Aturaliya established the overall bridge evaluation program, proposed the fuzzy weighted vector method to obtain the fuzzy weighted vector of each evaluation subset, and made the detection and maintenance strategy according to the weights of indicators at all levels and the evaluation results[2]. Xia Jinming, Huo Da et al. divided the bridge evaluation unit into four combination items, and directly rated the reliability at each level [3]. Complete the identification of the risk of the bridge. However, at present, there are not many research results on the evaluation of concrete high towers at home and abroad. In actual work, most of the engineers use the evaluation and disposal plan of the box girder and bridge piers to approximate the tower body, and the evaluation and treatment effects are often scientific[4-6]. Not satisfactory. Therefore, this paper uses the concrete pylons of a super-long-span cable-stayed bridge as the supporting project, combined with the research results of the crack generation mechanism and the analysis of the impact on the performance of the pylons, and attempts to establish a long-term performance evaluation system for the concrete pylons in order to solve the above existing The problem provides a new research idea.

## 2. Pylon Performance Evaluation System

### 2.1 Pylon Performance Evaluation Index

The general meaning of pylon performance evaluation is to try to quantify the integrity level of the structure, its ability to complete the design service function and deadline[7]. Different positions of the pylons and different types of damage have different effects on the overall structural safety of the bridge. Bridge damage assessment is to determine the corresponding evaluation standards for various types of damage at all levels by analyzing various factors that affect the performance of the bridge to determine the impact and weight of each damage on the overall state of the bridge, so as to establish a credible overall bridge damage standard. A reasonable assessment of the existing load-

bearing capacity of the tower is an important part of the bridge condition assessment. For concrete pylons, the most important indicator is the cracks of the pylon. However, due to the many factors that affect the crack width due to coagulation, the crack mechanism is also very complicated. In the past few decades, people have accumulated a lot of experimental data to study cracks, using these own experimental data to analyze various factors affecting the width of cracks, find out the main factors, discard the minor factors, and then use mathematics. The statistical method gives a simple and applicable formula for calculating the crack width with a certain degree of reliability. This method is called a mathematical statistical method. It has researched and put forward the formula of crack width based on mathematical statistics[8].

$$w_{fk} = C_1 C_2 C_3 \frac{\sigma_{ss}}{E_s} \left( \frac{30 + d}{0.28 + 10\rho} \right) \quad (1)$$

$c_1$ - Reinforced surface shape factor,

$c_2$ - The long-term effect coefficient of action (or load),

$c_3$ - The coefficients related to the force properties of the member.,

$d$ - Diameter of longitudinal tension bar (mm).;

$\rho$ - Reinforcement ratio of longitudinal tensile steel bars,

$\sigma_{ss}$ -Stress of cracked section longitudinal tensile steel bars under service load caused by combination of short-term effects of action (or load).

It can be seen from formula (1) that for the tower column of the same section, the crack width  $W_{fk}$  is only related to the size of the external load. According to the “General Code for Design of Highway Bridges and Culverts” for the combination of short-term and long-term loads, it can be seen that  $N_s > N_l$ ,  $c_2 < 1.5$ . Taking into account the safety of the tower column structure crack length, let  $c_2 = 1.5$ , then the tower column structure crack width is only related to the tensile steel stress  $\sigma_{ss}$ . With the increase of external load, the tensile steel stress increases and the crack width expands. Until the crack propagates to a certain value, the structure is destroyed. Whether the selection of the performance evaluation index of the pylon considering cracks is appropriate or not directly affects the evaluation results. In order to objectively, comprehensively and scientifically measure the damage of the arch bridge, the following principles should be followed when researching and determining the evaluation system and methods for the damage of the pylon. 1) Scientific principles. That is, the selection of evaluation indicators, the determination of index weight coefficients, and the selection, calculation and synthesis of data must be established on a scientific basis. 2) Principles of comprehensiveness, typicality and independence. That is to say, the index has a strong comprehensiveness, which can not only simplify the index system, but also reflect the typical disease characteristics of the tower in a comprehensive and concentrated manner. At the same time, the indexes are independent of each other and have little correlation. 3) Principles of feasibility and operability. That is, the data involved in the indicator is easier to obtain and calculate. Through the summary of the relevant performance data of the pylon and the repeated selection and judgment of expert experience, the pylon damage assessment index system is determined. The grade index is the typical evaluation trait parameter.

## 2.2 Pylon Rating

The reliability index is an intuitive reflection of the overall reliability level of the structure, making it attractive and valuable in bridge health monitoring. At present, the monitoring and evaluation of bridges mostly adopt the methods of sub-item scoring and weighted summation for performance evaluation. When using reliability indicators based on typical failure modes for performance evaluation and monitoring, concise, intuitive and targeted conclusions can also be obtained. When the structural damage is considered, the overall reliability index drops, and different damage types will lead to a decrease in the reliability index under different levels of failure modes. On the whole, the reliability indicators of the structure in the typical failure mode are still at an ideal level even when considering the structural damage under the assumed conditions in the article. For pylons, because the quality evaluation indicators are complex and multi-level, and the determination of weights is vague, and the qualitative indicators are difficult to quantitatively analyze, a series of

problems make it difficult to use other mathematics for quality. Or mechanical method for evaluation. Therefore, the fuzzy comprehensive evaluation method established on the basis of fuzzy theory has strong advantages. On the one hand, the hierarchy of evaluation indicators can be well reflected in the fuzzy comprehensive evaluation method. Fuzziness can also be transformed from qualitative to quantitative based on fuzzy theory, which makes the scope of application of fuzzy comprehensive evaluation method wider and the accuracy of evaluation results improved; on the other hand, based on the original quality evaluation method, Learning from each other's strengths makes the quality assessment results based on fuzzy evaluation more objective and accurate. The weight of the evaluation index is the most important part of the fuzzy comprehensive evaluation method, and the accuracy of the weight directly affects the evaluation result. There are many methods to determine the weight, such as formula calculation method, expert scoring method and so on. However, when evaluating bridge quality, considering that most of the evaluation indicators are qualitative indicators, the number of indicators is usually large, which leads to many difficulties in determining the weight of the evaluation indicators. The degree of influence of different evaluation indicators on the evaluated object is different. In order to make an accurate evaluation, the weight of the dominant evaluation indicator will be higher, and the weight of the secondary evaluation indicator will be lower, but the sum of all indicator weights must meet the normalization condition.

$$\sum_{i=1}^n a_i = 1 \quad (2)$$

$a_i$  is the evaluation index weight;  $n$  is the number of evaluation indicators.

Based on the index system and index weights established above, combined with the fuzzy comprehensive evaluation method, the maintenance construction quality can be effectively evaluated. According to the evaluation results, the performance of the pylon can be divided into five levels according to Table 1. Considering the theoretical analysis and actual bridge research results, the long-term performance indicators of the pylon are determined as shown in Table 1.

Table 1 Long-Term Performance Indicators of Pylon

Serial number	Characterization index	Disease characteristics	Detection Indicator	Weight coefficient
1	Crack characteristics 0.4	The crack width exceeds 0.2mm	Crack width	0.3
2		Whether there are cracks in the anchoring area	Anchorage cracks	0.3
3		The existing cracks are open and closed	Crack behavior after repair	0.2
4		Number and distribution of active fractures	Crack extension phenomenon after repair	0.2
5	Geometry 0.6	The horizontal or vertical displacement exceeds the limit or is abnormal	Longitudinal and vertical alignment of bridge deck structure	0.5
6		Horizontal displacement is out of limit or abnormal	Horizontal displacement of tower top	0.5

In order to comprehensively evaluate the performance of the pylon and the effectiveness of decision-making, the performance of the pylon is graded using the maintenance matrix shown in Table 2.

Table 2 Performance Quality Evaluation Grades of Bridge Pylons

grade	V	IV	III	II	I
Score	0~20	20~40	40~60	60~80	80~100

Through on-site investigation, collect the design drawings of typical disease cases, and consult the existing related literature on the main influencing factors and characterization indexes of the safety performance of the pylon structure, and the safety performance indexes of the pylon structure are preliminarily drawn up in Table 3.

Table 3 Safety Performance Index of Pylon Structure

Grade	Rating standard
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	specifications			Set standards
I	/	Intact, no cracks	Intact, no corrosion	Intact, no cracks
II	Cumulative area $\leq$ 20% of component area, single area $<1\text{m}^2$	Reticulated cracks: partial reticulated cracks	Corrosion, cracks along the steel bars on the surface of the concrete or rust marks on the surface of the concrete	Reticulated cracks: partial reticulated cracks
	Seam length $\leq$ 1/3 of section size	Other cracks: there are a few cracks, the width of the crack is $<0.3\text{mm}$	/	Other cracks: there are a few cracks, the width of the crack is $<0.3\text{mm}$
III	Cumulative area $>20\%$ of component area, single area $>1\text{m}^2$	Reticulated cracks: partial reticulated cracks	There is corrosion phenomenon, the main reinforcement is corroded or the concrete surface is peeling off	Reticulated cracks: partial reticulated cracks
	Seam length $>1/3$ of section size and $\leq 2/3$ of section size, spacing $\geq 20\text{cm}$	Other cracks: there are a lot of cracks, the cracks are wide $<0.3\text{mm}$	/	Structural cracks Seam length $>1/3$ of section size and $\leq 2/3$ of section size, spacing $\geq 20\text{cm}$
IV	Seam width $>0.3\text{mm}$ , seam length $>2/3$ of section size, spacing $<20\text{cm}$	There are a lot of cracks, the cracks are wide $\geq 0.3\text{mm}$	The steel bars are severely corroded, and the concrete surface is severely cracked	There are a lot of Structural cracks Seam width $>0.3\text{mm}$ , seam length $>2/3$ of section size, spacing $<20\text{cm}$

In order to comprehensively evaluate the performance of the pylon and the effectiveness of decision-making, the performance of the pylon is graded using the maintenance matrix shown in Table 4.

Table 4 Classification of Post-Assessment Grades of Pylon Performance

Decision effectiveness Pylon performance	I	II	III	IV	V
I	I	I	II	II	III
II	I	II	II	III	III
III	II	II	III	III	IV
IV	II	III	III	IV	IV
V	III	III	IV	IV	IV

### 3. Countermeasures for Cracks in Pylons

#### 3.1 Pylon Crack Repair Plan

Research on countermeasures for crack treatment of pylons is essentially based on the force characteristics of the pylon itself. The main goal of its treatment is the durability of the pylon, rather than improving the bearing capacity of the structure through crack repair and reinforcement. In short, it is the purpose of filling the inside of the crack gap with a material with good elasticity and plasticity to isolate the internal concrete, steel bar and the external environment, and to avoid the effects of corrosive media, moisture, etc. Therefore, reasonable post-cylinder treatment countermeasures should be differentiated according to the causes and types of cracks. The treatment methods and timings of stable cracks and unstable cracks are also different and cannot be generalized simply. Especially for unstable cracks, the choice of treatment time and method is also the focus of research. The basic ideas for the maintenance and repair design of the pylon are: (1) Concrete damaged and exposed bar repair; (2) Crack treatment (sealing and grouting); (3) DPS crack sealing waterproof material treatment;

Through on-site investigations, the collection of typical examples is to improve the assessment of pylons to ensure the safe and durable use of the bridge, determine maintenance countermeasures, and reasonably spend maintenance costs. For this reason, the bridge management department should pay attention to the following issues when formulating maintenance management strategies: ①The

inspection time of the bridge must be reasonable, and the inspection interval must be determined according to the bridge safety assessment theory based on the damage mechanism; ② The comprehensive damage recognition technology should be used to determine the structural weaknesses. To reduce blindness in detection and improve detection efficiency; ③ The methods and methods used in detection should be optimized according to the specific conditions of the structure; ⑤ Regular maintenance of bridges and timely repair of structural damage; ⑥ Corrosion detection and anti-rust treatment should be strengthened for steel bars, steel components, stay cables, main cables, booms, etc.

#### 4. Conclusion

(1) The damage assessment of the pylon needs to determine the influence and weight of each damage on the overall state of the bridge through analysis of the impact on the performance of the bridge, so as to establish a credible overall damage standard of the bridge. The existing standard assessment system is not sufficiently targeted for the pylon;

(2) The evaluation system that comprehensively considers long-term performance indicators and safety performance indicators has a certain reference value for the scientific evaluation of pylons at this stage;

(3) The maintenance and disposal decision of the pylon should comprehensively consider the safety, durability, maintenance cost and inspection frequency of the pylon, and finally determine a reasonable maintenance and disposal plan.

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#### References

- [1] Ah, T.B., The Application of Fuzzy Mathematics to Bridge Condition Assessment. 1988, the Faculty of Purdur University..
- [2] Hani, G., Melhem, and S. Aturaliya, Bridge Condition Rating Using an Eigenvector of Priority Settings Microcomputers in Civil Engineering, 1996(11).
- [3] Xia Mingjin, Huo Da, Fujihaven, Reliability Analysis of Existing Bridges. Journal of Beijing University of Technology, 2004. 30(1).
- [4] ACI, SP-88: Strength Evaluation of Existing Concrete Bridges. 1985: Amer Concrete Inst.
- [5] Moses F, V.D., Load capacity evaluation of existing bridges, V. D, Editor. 1987, Transportation Research Board.
- [6] Pan Liming, Shi Jiajun, Comprehensive Evaluation of Bridge Safety and Durability. Shanghai Highway, 1997(11): p. 27~32.
- [7] Chen Shaowen, Yuan Haijin, Xu Junliang, Research on the System of Damage Grade Evaluation and Treatment Measures for Highway Bridges. Central South Highway Engineering, 1997(04).
- [8] Hu Xiong, etc., Expert System Design for Safety and Durability Evaluation of Cable-stayed Bridges. Chinese Journal of Applied Mechanics, 1998(04).