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Based on the Theory of Reliability High Piers Short Towers Cable-Stayed Bridge Characteristic Parameter Analysis

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Abstract

In view of high pier extradosed cable-stayed bridge structure characteristics, Yunnan Nanpangjiang River Bridge is taken as an example. This paper studies the influence of parameter change on the structure of the main girder by adjusting the girder height, cable tower height, bending stiffness and the cable tower pier stiffness. It can help us understand mechanical properties of the structure so as to estimate safety evaluation when the structure parameters are changed. Furthermore, it can provide the reference for economic and reasonable structure form design in the bridge of safety evaluation. It also can evaluate the safety of girder and tower through reliability theory. The result shows that the application of reliability theory is reliable and practical to evaluate the high pier extradosed cable-stayed bridge safety performance.

Keywords: low-pylon cable-stayed bridge, reliability, over-height pier, characteristic parameters

1. Introduction

Low-pylon cable-stayed bridge named Extradose bridge is put forward by the French engineers Jacques Mathivat in 1988 (Song, Wang, & Shang, 2011; Lin, Sun, & Liu, 2005; Ouyang, 2006; Zheng, Huang, & Zhang, 2003; Zhou, 2005; Yan, 1996). And then it rose and developed in Japan. Though domestic relative research started later but the development is rapid, such as has more than 30 seats short towers cable-stayed bridge which has been built and constructed. The characteristics of short towers cable-stayed bridge is short tower, the focus cable on structures and for high time for the static structure (Housner et al., 1997; Myroll & Dibiagio, 1994; Andersen, 1994; Curran & Tilly, 1999). The mechanical behavior depends on the girders, the main tower, main piers and the stiffness of the lasso. But ultra short towers cable-stayed bridge pier stress is more complex, it is necessary to analysis characteristic parameters (Chueng et al., 1997; Lau et al., 1999) and assess safety by the reliability theory.

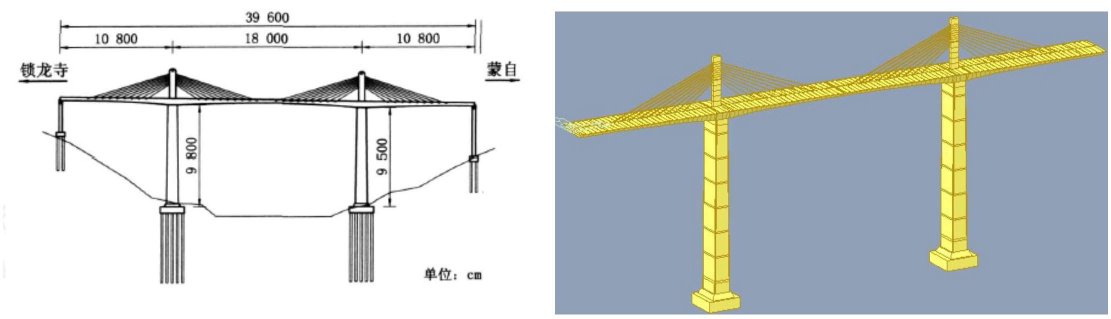


Figure 1. The overall layout and finite element model

Yunnan nanpanjiang bridge is a main 108 + 180 + 108 short towers cable-stayed bridge, for single box girder three room oblique webs cross-section of box girder, beam high by two parabolic change, root beam high 5.8 m, such as high beam at the end of the 3 m. The main tower adopts rectangle solid section plane size 5.5 m multiply 2.6 m, bridge deck above 29 m high tower. The whole bridge 4 multiply 9 to lasso with single cable plane double row layout in the central space. Stay-cables tower on anchoring way in the steel strand stay-cables on the tower through the cluster steel tube breakthrough (cable saddle) anchoring way, the main structure is welding cluster points wire steel tube. The main pier cross-section of reinforced concrete hollow pier, due to the characteristics of high piers as high as 98 m, in the country has built more than 30 a short towers cable-stayed bridge belongs to the highest pier which it is shown in Table 1. The whole bridge tower pier beam for consolidation system, the bridge is scheduled for completion by the end of 2012.

Table 1. China has built the extradosed cable-stayed bridge high statistics

The Bridges	Span (m)	Pier high (m)
Yunnan nanpanjiang bridge	108+180+108	98
Chongqing jia yue bridge	145+250+145	88.8
Wuhu changjiang river bridge	180+312+180	72.2
Lotus hemp creek bridge	125+230+125	30.492
Liuzhou three river bridge	100+160+100	24.3
Zhoushan three reef port bridge	120+210+210+115	20.1
LiShi viaduct	85+135+85	20
Zhangzhou combat readiness bridge	80.8+132+80.8	16.5
Small west lake bridge	81.2+136+81.2	15
Kaifeng Yellow River bridge	85+6*140+85	12

2. Methodology

2.1 Calculation Mode

In order to analyze the effect of the live following five calculation model to calculate structural contrast: a, according to three span continuous beam calculation, not considering the role of lasso. b, the only change main piers stiffness. c, only change inertia. d, girder only change tower (i.e. H stay-cables θ dip Angle and length L). e, only change lasso sectional area.

$$\delta f = \frac{\left(f_{continuous\ beam} - f_{cable\ stable\ bridge}\right)}{f_{continuous\ beam}}, \quad \delta M^t = \frac{\left(M^t{}_{continuous\ beam} - M^t{}_{cable\ stable\ bridge}\right)}{M^t{}_{continuous\ beam}},$$

$$\delta M^b = \frac{\left(M^b{}_{continuous\ beam} - M^b{}_{cable\ stable\ bridge}\right)}{M^b{}_{continuous\ beam}},$$

$$\delta T = \frac{T_{cable\ stable\ bridge}}{Pl}, \text{ (} Pl \text{ is Live load weight)}$$

$$\delta f 、\delta M^t 、\delta M^b 、\delta T$$

For the main girder respectively across deflection, the tower in the root bending moment, cross bending moment and the effect of cable force.

$$f_{cable\ \ stayed\ \ bridge}, M^t_{cable\ \ stayed\ \ bridge}, M^b_{cable\ \ stayed\ \ bridge}, T_{cable\ \ stayed\ \ bridge}$$

Where short stay in the tower bridge cross deflection, the tower across the bending moment, the bending moment and the vertical component of total cable force.

$$f_{continuous\ \ beam}, M^t{}_{continuous beam}, M^b{}_{continuous\ \ beam}$$

For continuous girder overhead traveling crane respectively the midspan deflection, the pillar top bending moment, the midspan bending moment.

2.2 Parameter Analysis Results

Table 2. The main pier of flexural rigidity

The rigidity of pier β1	0.5	1	1.5	2	2.5	3	5	10
δf (%)	29.85	29.97	30.13	31.26	31.37	32.56	33.70	35.77
δM^b (%)	40.60	40.12	38.69	37.30	35.42	34.77	33.61	30.27
δM^t (%)	22.99	23.21	23.39	23.40	23.45	23.57	23.98	25.20

Notes: β1 is the main pier stiffness and real bridge main pier stiffness ratio in the "b" pattern.

Table 3. Main beam flexural stiffness

Beam rigidity β2	0.5	1	1.5	2	2.5	3	5	10
δf (%)	25.65	19.72	15.56	9.41	7.88	6.71	4.33	2.01
δM^b (%)	28.69	20.53	17.74	13.26	9.41	7.69	5.42	1.98
δM^t (%)	44.90	37.45	29.88	22.80	18.78	12.59	8.37	3.77
δT (%)	30.46	23.74	17.66	14.95	12.38	10.55	7.93	3.01

Notes: β2 is beam rigidity and real bridge girder stiffness ratio of c model.

Table 4. Pylon height variation

Tower H/m	0	5	10	15	20	25	30	40
δf (%)	0.24	2.01	4.74	12.33	17.89	23.67	28.01	32.11
δM^b (%)	0.15	1.95	7.44	13.57	20.23	23.55	28.34	33.67
δM^t (%)	0.27	2.33	9.56	23.43	33.09	45.88	53.29	55.81
δT (%)	0	1.23	5.66	15.34	23.73	30.98	34.21	39.44

Notes: H is the tower height, when tower height is zero, Cable is equivalent in vitro prestressed beam.

Table 5. Cable area change

Cable area β	0	0.1	0.2	0.4	0.5	0.75	1	2
δf (%)	0	4.62	6.73	10.25	15.33	24.95	32.17	45.95
δM^b (%)	0	7.54	9.35	11.23	13.84	16.13	18.56	21.33
δM^t (%)	0	9.95	11.98	15.62	17.33	20.48	24.76	35.83
δT (%)	0	2.38	4.47	7.22	11.58	15.49	17.88	25.41

Notes: β is sectional area of cable and cable section area ratio the "e" model.

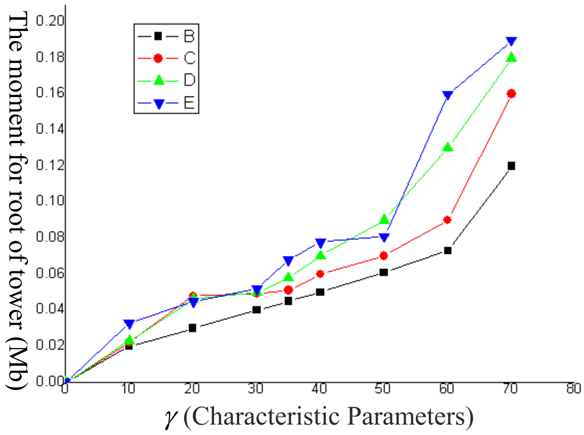
2.3 Analysis of Characteristic Parameters

$$\gamma = \frac{\sum_{i=1}^{n}(E_i A_i \sin^2\theta_i / L_i)}{(E_g I_g E_d I_d / L_0^6)}$$

E_i, A_i, θ_i, L_i Respectively of stay-cables elastic modulus, area, dip Angle, length; E_g, I_g, E_d, I_d Were short towers cable-stayed bridge girder of the elastic modulus, main piers of inertia and the elastic modulus, inertia; N, L_0 respectively in the main span cable tower of the number of its Suo Gen cables to the influence of the main girder range, $L_0=\lambda L$, including L main span span, and the λ main span for edge than. For this bridge λ = 108/180 = 0.6.

With high piers short towers cable-stayed bridge response characteristic parameters main piers stiffness, tower, lasso section area, girders of bending stiffness changes.

The four models of ultra high piers short towers cable-stayed bridge tower the influence of the root bending moment $M^t{}_{cable-stayed\ bridge}$ trend.



B-The main pier stiffness, C-Tower height changes, D-Cable cross-sectional area changes, E-Main beam flexural stiffness

Figure 2. Relationship between bending moment and characteristic parameters

From the Figure 2 see $M^t{}_{cable-stayed\ bridge}$ value along with the increase of increases, when the $\gamma < 40$ when C, D, E mode $M^t{}_{cable-stayed\ bridge}$ and γ the relevance of the consistent, B mode influence after three of the contrast little influence. Ultra short towers cable-stayed bridge pier characteristic parameters can reflect the pier stiffness, tower, lasso section area, girders of bending stiffness changes on the structure performance impact.

3. Reuslts

3.1 Girders Failure Mode

Key section caused by excessive moment strength failure (static bending failure)

Function:

$$Z_1 = M_b - \left[\pi P_w (l')^2/16 + QL^2/800 + 3EI_x d/L_0^2\right]$$

M_b-Girders resistance moment

P_w-Automobile loading

L'-The elastic supporting beams of the convert length

Q-unbalance loading

L-Bridge span

E-Elastic modulus

I_x-Section of the girder of inertia

d-Temperature caused by the lasso displacement

L_0-Recent stay-cables feet distance to tower

M_b, P_w, L', Q, E, I_x, d-Random variables

Table 6. Main basic variables

variables	Mb	Pw	L'	Q	E	I	d
Distribution type	Normal	Normal	Normal	Normal	Logarithmic normal distribution	Normal	Normal
Average value	2.5x105 (kN.m)	47 kN	56 m	301 kN	$3x10^4$ (Mpa)	18 m^4	0.02 m
Coefficient of variation	0.15	0.1	0.1	0.1	0.1	0.1	0.1

Table 7. Main reliability results

Failure mode	Genetic algorithm		JC method	
Static bending failure	β	P_f	β	P_f
	3.8345	$1.32x10^4$	3.9021	$1.39\ x10^4$

3.2 The Main Tower Failure Mode

1) Transverse Buckling

Considering the extradosed cable-stayed bridge, the tower as consolidation and pier top single cantilever column, its critical pressure can use the following formula:

$$Z_2=\pi^2 EI/l^2 - P$$

On the function of I is considered effect of conversion of variable cross section moment of inertia; E is calculation of elastic modulus; L is cable force of the distance from the point to the tap root; PVertical pressure. The type of I, E, P are considered as random variables.

2) Along the Bridge to the Strength Failure

Vehicle live load, cable heating, unilateral sunshine will cause the tower lateral displacement, at the same time in the tower root section generates additional bending moment. The additional bending moment in the calculation of equivalent horizontal force is replaced available. Function is the following:

$$Z_3 = M - PQ'l^3 / \left[3EI\left(1-\frac{2}{5}\frac{Pl^2}{EI}\right)\right] - WQ'lh / \left[3EI\left(1-\frac{2}{5}\frac{Pl^2}{EI}\right)\right] - Q'l$$

Where h is tower to tower root distance of center of gravity; P is Vertical component; W is Weight; M is the tower root section resistance moment, Q' is Total equivalent horizontal force, I, E, P, Q'and M is random variables.

Table 8. The main tower of basic variables

Variable	I(m^4)	E(10^3kN/m^2)	P(kN)	Q(kN)	M(kN.m)
Distribution type	Normal distribution	Logarithmic normal distribution	Normal distribution	Normal distribution	Normal distribution
Average value	15.2	$3.5x10^4$	$8.7x10^4$	$2.0x10^4$	$2.5x10^4$
Coefficient of variation	0.1	0.08	0.1	0.15	0.15

Table 9. Reliability calculation of main tower

Failure mode	Genetic algorithm		JC method	
	β	P_f	β	P_f
Transverse buckling failure	9.605	$4.332\text{x}10^{-15}$	9.593	$4.41\text{x}10^{-15}$
Along the bridge to the strength failure	3.343	$2.551\text{x}10^{-15}$	3.405	$2.605\text{x}10^{-15}$

4. Conclusion

1) High piers short towers cable-stayed bridge structure stress is more reasonable by the characteristic parameters.
2) With high reliability theory to evaluate the main pylon cable-stayed bridge pier short failure mode, the main tower failure mode that the structural behavior failure probability can provide the basis for the safety assessment.
3) Super high pier extradosed cable-stayed bridge stiffness is composed of the rigidity of main beam, the rigidity of pier, tower stiffness and cable stiffness. The biggest influence on structure is girder stiffness, followed by cable and tower, the minimum impact is main pier stiffness.

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