

Calculation of Creep Effect of Extradosed Cable-stayed bridge based on Midas Civil

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Abstract. In order to understand the creep effect of Extradosed bridge, the paper adopted four concrete creep calculation models recommended by Chinese, European, American and Japanese specifications, Taking the first concrete Extradosed cable-stayed bridge under operation in Yunnan Province of China as an example, The effect of creep on the displacement and stress of the main beam, and the Cable Tension were calculated. The results show that as for the impact of creep effect on deflection of the main beam of the Extradosed cable-stayed bridge, the absolute value is smaller than that of the continuous rigid-frame bridge with the same span, but it has a relatively great impact on the stress and cable force. This article is proposed that as reserve of stress at the lower edge of the section in non-stayed cable segment area should be increased appropriately, and the safety coefficient of stay cables at the operating stage can be properly increased, and the value recommended by this article is 1.87

1. Introduction

According to the author's previous research, it was found that the main influencing factor of the creep effect was humidity. The paper adopted four concrete creep calculation models recommended by Chinese, European, American and Japanese specifications, For different humidity, use Midas civil software to calculate comparative analysis of the calculation results.

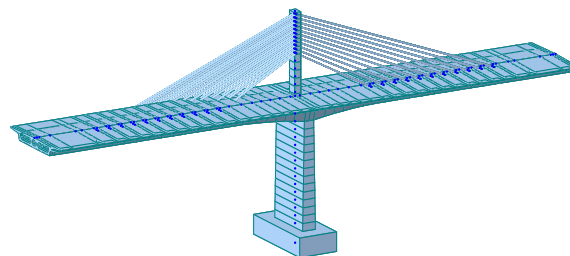


Figure1. Calculation Model

This topic studies the first Extradosed Cable-Stayed bridge which is open to traffic in Yunnan Province of China. The construction period of the entire bridge is divided into 90 calculation stages with the total construction period of 284 days according to the design drawings and construction design for simulation calculation, and it mainly calculates changes in the deflection, stress and cable force at the operating stage.



Parameters selected by the creep model shall be subject to the actual local environment of the project. The main beam, main tower and pier shaft is all made of C50 concrete; low relaxation pressurising steel strand with the nominal diameter (ϕ^s) of 15.2mm are used for pressurising tendon, and its characteristic tensile strength (f_{pk}) is 1,860MPa with the elastic modulus (E_p) of 1.95×10^5 MPa; the OVM250-34 steel strand cable-stayed system is used for stay cables; in addition to the special requirements, all steel is the HRB400 steel, with f_{sk} of 400MPa. The theoretical thickness of members is 498mm and 659mm respectively for different sections; the content of cement is 445kg/m³; the content of fine aggregate is 36%; the slump is 180mm; humidity is an uncontrollable and uncertain factor. Based on local conditions of the project, this article carries out calculation by considering the humidity of 70%, 80% and 90% respectively.

Table 1. The formula of creep effect

specification	Calculation Model of Concrete Creep Effect
European CEB-FIB90 ^[10]	$\phi(t, \tau) = \phi_0 \beta_c(t, \tau) = \phi_{RH} \beta_{fcm} \beta(\tau) \beta_c(t, \tau)$
Japanese specification ^[12]	$\phi(t, t_0) = \phi_{d0} \bullet \beta_d(t - t_0) + \phi_{f0} \bullet [\beta_f(t) - \beta_f(t_0)]$
American ACI209 ^[11]	$\phi(t, \tau) = \frac{(t - \tau)^{0.6}}{10 + (t - \tau)^{0.6}} \phi(u) \quad \phi(u) = 2.35 \beta_1 \beta_2 \beta_3 \beta_4 \beta_5 \beta_6$

Note: Significance of each parameter in the formula and value selection can refer to specifications (literatures) of various countries [9]~[12].

2. Deflection calculation

Deflection caused by creep is an important basis for pre-camber settings at the stage of bridge construction control. The pre-camber shall be reasonably set up, so that the upper structure of the bridge can reach expected elevation line after construction, repeated upward or downward deformation and structural operation in a certain time. This section selects 10 calculation positions to calculate. Five calculation points in the east are shown in Figure 2, and five calculation points in the west are arranged symmetrically.

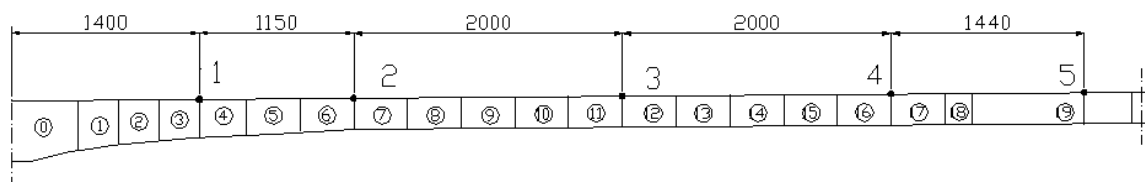


Figure 2. East of the calculation point

From the sensitivity analysis of parameters from the previous section, it can be seen that humidity is the main factor affecting the creep effect. According to the actual local conditions, the average humidity in the area is 80%, and the humidity will alternate from the fourth level from 79% to 90%. Therefore, calculation in this section is conducted respectively based on 70%, 80% and 90%. After the 30-year operation of completed bridge, deflection calculation results caused by creep are shown in Table 2.

Table 2. Deflection Caused by Creep (Unit: mm)

location	Chinese 04 standard model			CEB-FIP 90 model		
	70%	80%	90%	70%	80%	90%
E5	-1.5	-0.3	1	-1	0	1
E4	-10.2	-6.1	-1.5	-7.6	-4.3	-0.6
E3	-19.3	-14.3	-8.5	-15.3	-11.2	-6.5
E2	-14.8	-11.6	-7.7	-12.1	-9.5	-6.2

E1	-8.8	-4.9	-4.6	-7.4	-4.1	-3.8
location	American ACI209 model			Japanese specification		
	70%	80%	90%	70%	80%	90%
W1	-1.8	-0.7	-1.4	-12.2	-6.2	-6.3
W2	-3.7	-3.3	-2.8	-20.9	-15.6	-10.7
W3	-2.5	-1.9	-1.3	-22.1	-15	-8.5
W4	1.7	1.8	2.1	-7.2	-3	0.7
W5	1.7	1.7	1.7	1.2	2	2.6

Note: E in the table means east side, W means west side.

After the 30-year operation of completed bridge, deflection calculation results caused by creep in each model are quite different. The deflection of the main beam calculated by Japan specifications is the largest, followed by China and Europe specifications, and deflection of the main beam calculated by the United States specifications is the smallest. It can be found that as if the pre-camber in the design is set up according to calculation results of Japanese specifications, difference value from the pre-camber is set up according to calculation results of the United States specifications can reach up to 20mm.

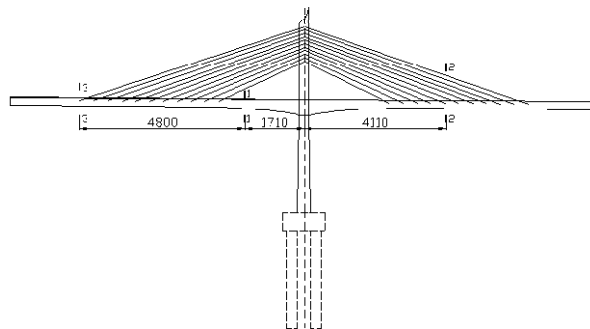


Figure 3. Schematic Diagram of Stress Calculation Section Elevation

When the humidity is 80%, the deflection of the main beam is smaller than that when the humidity is 70%, and when the humidity is 90%, the deflection caused by the creep effect in the later period is 50% smaller than that when the humidity is 80%. In a relatively dry environment, the creep effect is relatively large, and deflection caused the pre-camber of bridge settings are also relatively large.

As for the Extradosed cable-stayed bridge, the influence of shrinkage and creep effect on deflection of the main beam is much smaller than that of the continuous rigid-frame bridge. In terms of the research object of this article, the displacement caused by the effect of shrinkage and creep in the later period is only about 2cm. In the early design, the part of creep in the pre-camber was considered as about 2cm. After the bridge was closed, the team tested it and found out that pre-camber of this concrete Extradosed cable-stayed bridge was too small.

3. Stress calculation

The Extradosed cable-stayed bridge belongs to the high-order statically indeterminate structure. In addition to affecting the settings of pre-camber of the bridge, the shrinkage and creep effect also has great influence on the internal force of the structure. This section selects three stress calculation sections shown in Figure 3 to calculate and analyze changes in the stress of the bridge at the stage of operation. The section of the main beam is the big single-box and three-room box girder shown in Figure 4.

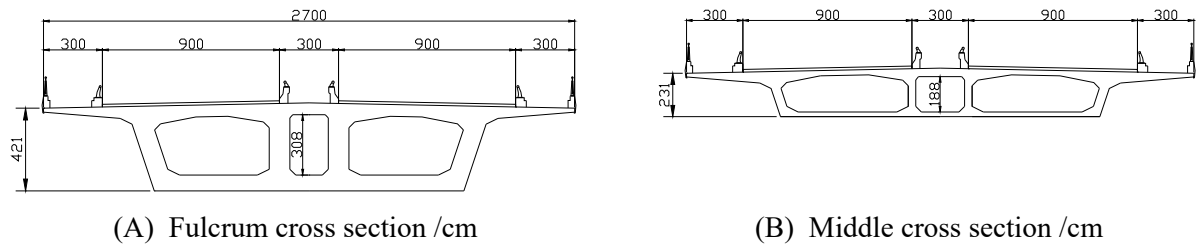


Figure 4. Main Bridge PC Continuous Box Girder Layout

The I-I section belongs to the edge of No.0 block in the non-stayed cable segment, II-II section is in the middle of the stay cable segment, and III-III section is the beam section at the end of the stay cable segment. Stress calculation of three sections is shown in Table 3-5. It can be seen that as 1) With the increase of the operation time of the completed bridge, the stress gradually decreases, located at the upper edge of the section in the non-stayed cable segment near No.0 beam section, while the stress at the lower edge gradually increases. The compressive stresses at the upper and lower edge of the section in the stay cable segment decrease; the compressive stress at the upper of the section near the side span outside the stay cable segment gradually increases while the compressive stress at the lower edge gradually decreases. 2) Changes in the stress of each section decreases with the increase of humidity. 3) There is a big difference in the calculation results of each standard model of the section in the non-stayed cable segment, but small difference in the stay cable segment. 4) The difference in the calculation results of each model decreases with the increase of humidity.

Table 3. Changes in the Stress of the I-I Section (Unit:MPa)

Specification	Position	Humidity is 70%			Humidity is 80%			Humidity is 90%		
		Completed bridge	After 30 years	Δ	Completed bridge	After 30 years	Δ	Completed bridge	After 30 years	Δ
Chinese 04 model	Upper	-10.8	-9.24	1.56	-11.79	-10.28	1.51	-11.1	-9.83	1.27
	Lower	-4.02	-5.48	-1.46	-4.97	-6.51	-1.54	-3.67	-5.1	-1.43
CEB-FIP 90 model	Upper	-11	-9.58	1.42	-11.95	-10.61	1.34	-11.2	-10.1	1.1
	Lower	-3.79	-5.16	-1.37	-4.77	-6.18	-1.41	-3.48	-4.79	-1.31
ACI209 model	Upper	-10.8	-10.2	0.6	-11.69	-11.06	0.63	-11	-10.4	0.6
	Lower	-4.05	-4.82	-0.77	-5.1	-5.84	-0.74	-3.83	-4.56	-0.73
Japanese specification	Upper	-10.8	-8.55	2.25	-11.9	-9.73	2.17	-11.2	-9.44	1.76
	Lower	-4.02	-6.36	-2.34	-4.87	-7.18	-2.31	-3.61	-5.6	-1.99

Note of table3-5: Upper -Upper edge; Lower-lower edge ;the Δ value (positive number) in the table indicates that the stress is increasing, and the negative number for decreasing.

Table 4. Changes in the Stress of the II - II Section (Unit:MPa)

Specification	Position	Humidity is 70%			Humidity is 80%			Humidity is 90%		
		Completed bridge	After 30 years	Δ	Completed bridge	After 30 years	Δ	Completed bridge	After 30 years	Δ
Chinese 04 model	Upper	-9.21	-8.96	0.25	-9.3	-9.06	0.24	-9.29	-8.99	0.3
	Lower	-8.26	-7.01	1.25	-8.32	-7.46	0.86	-8.29	-7.73	0.56
CEB-FIP 90 model	Upper	-9.26	-9.03	0.23	-9.34	-9.11	0.23	-9.32	-9.05	0.27
	Lower	-8.27	-7.22	1.05	-8.33	-7.62	0.71	-8.29	-7.85	0.44
ACI209 model	Upper	-9.23	-9.03	0.2	-9.3	-9.13	0.17	-9.27	-9.09	0.18
	Lower	-8.24	-8.05	0.19	-8.3	-8.17	0.13	-8.26	-8.13	0.13
Japanese specification	Upper	-9.2	-8.79	0.41	-9.32	-8.96	0.36	-9.3	-8.91	0.39
	Lower	-8.36	-6.85	1.51	-8.39	-7.39	1	-8.33	-7.6	0.73

Table 5. Changes in the Stress of the III-III Section (Unit:MPa)

Specification	Position	Humidity is 70%			Humidity is 80%			Humidity is 90%		
		Completed bridge	After 30 years	Δ	Completed bridge	After 30 years	Δ	Completed bridge	After 30 years	Δ

Chinese 04 model	Upper	-5.11	-5.44	-0.33	-5.1	-5.37	-0.27	-5.09	-5.27	-0.18
	Lower	-8.69	-6.93	1.76	-9.02	-7.51	1.51	-8.84	-7.79	1.05
CEB-FIP 90 model	Upper	-5.09	-5.38	-0.29	-5.08	-5.31	-0.23	-5.08	-5.23	-0.15
	Lower	-8.78	-7.27	1.51	-9.1	-7.81	1.29	-8.91	-8.02	0.89
ACI209 model	Upper	-5.12	-5.2	-0.08	-5.11	-5.18	-0.07	-5.1	-5.16	-0.06
	Lower	-8.67	-8.15	0.52	-8.96	-8.47	0.49	-8.77	-8.33	0.44
Japanese specification	Upper	-5.08	-5.55	-0.47	-5.08	-5.45	-0.37	-5.08	-5.34	-0.26
	lower	-8.84	-6.57	2.27	-9.15	-7.25	1.9	-8.92	-7.56	1.36

4. Cable force Calculation

As for the Extradosed cable-stayed bridge, creep affects the amount of cable elongation by changing the vertical displacement of the main beam, thereby changing the internal force of the cable, so that the impact of the creep effect on cable force cannot be ignored. This section uses various kinds of creep models to analyze the cable force of 22-pair stay cables of the bridge.

Cable force of each cable is lost to different degrees after the bridge is completed. When the humidity is 70%, values of cable force loss calculated by each model are different. Figure 5 shows cable force at the time when the bridge was completed and when the bridge has been under operation for 5, 10, 20 and 30 years, and Table 6 lists specific values of its changes in detail.

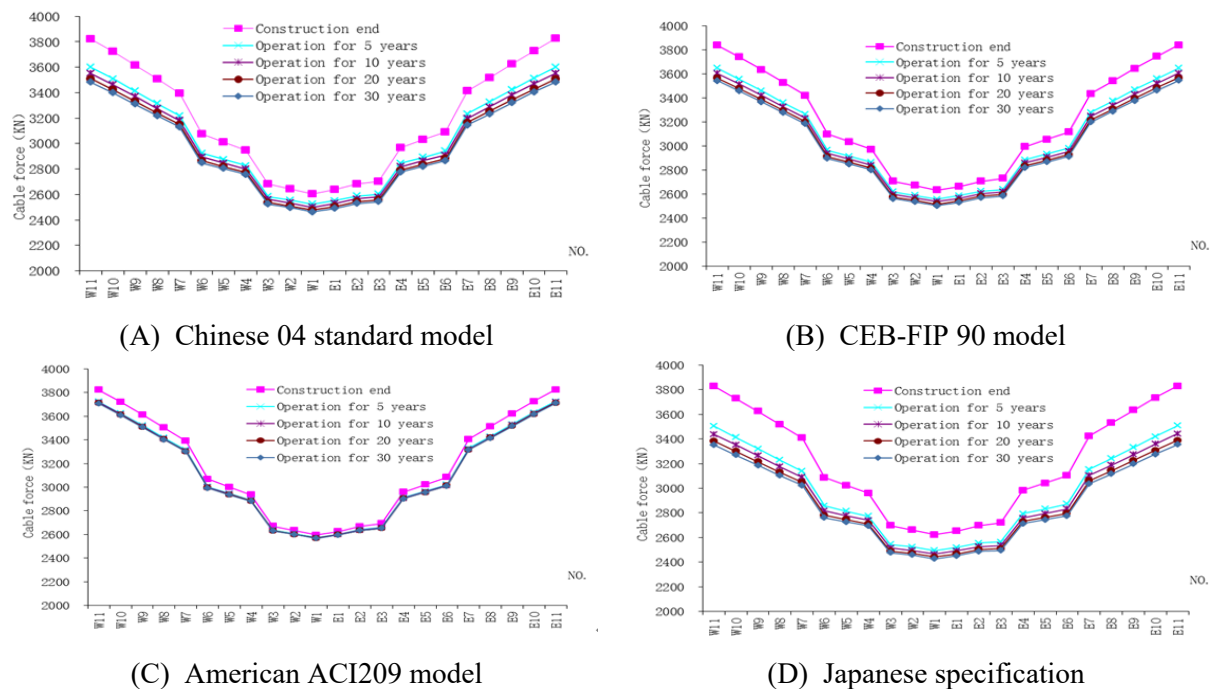


Figure 5. Changes in the Cable Force

The cable force of 22-pair stay cables of the bridge decreases after the bridge is under operation. The cable force of the stay cable near the No. 0 beam segment decreases less, while that near the side span decreases significantly. It can be seen from Table 10 that: 04 specifications of China calculate changes in the cable force, the cable force of the 11th stay cable on east and west sides 30 years after the bridge was completed has been reduced by 34 tons, and the stay cable with the minimum amount decreased is the first in the west with the amount decreased of 14.3 tons.

The difference in the cable force calculated by each model at the stage of bridge completion is small, and cable force gradually begins to vary at the operating stage. The difference in the calculated results of each model after 30 years of operation is the largest. When the humidity is 70%, the largest difference of the first stay cable in the east and west calculated by each model is 63kN, and as for the smallest difference of 34kN, it's the 11th stay cable in the east and west.

The impact of humidity on shrinkage and creep effect is relatively great, thereby having a relatively great impact on the loss of cable force. A quantitative analysis of the impact of humidity on the cable force is conducted in the following Table 10. The total loss of the cable force after 30 years of operation of different models at different humidity is calculated in the table below.

Table 6. Cable Force Loss Calculation Results

No.	Japanese specification			Chinese 04 standard model			CEB-FIP 90 model			American ACI209 model		
	90%	80%	Δ	90%	80%	Δ	90%	80%	Δ	90%	80%	Δ
W11	313	404	53%	229	296	48%	255	197	33%	108	99	14%
W10	306	392	50%	222	283	45%	246	191	32%	104	96	14%
W9	296	377	48%	213	269	43%	235	184	31%	100	92	13%
W8	283	359	46%	203	254	41%	223	176	30%	94	87	12%
W7	268	337	44%	190	238	40%	209	166	30%	87	81	12%
W6	228	287	43%	162	202	39%	179	142	29%	71	67	11%
W5	209	262	42%	148	185	39%	165	131	29%	62	59	10%
W4	189	237	41%	135	169	39%	152	119	30%	52	50	9%
W3	155	196	42%	112	142	41%	127	99	31%	40	38	7%
W2	142	181	44%	102	132	46%	119	92	32%	33	32	6%
W1	133	171	47%	96	126	49%	113	86	34%	28	27	5%

Note: the increment in the table refers to the increased percentage of the loss when the humidity is reduced from 90% to 70%; W1 refers to the first stay cable in the west and Unit is kN.

It can be seen from the calculation results of specifications of countries that humidity is an important factor that causes the loss of the cable force due to the creep effect. Humidity is reduced from 90% to 80%, and the loss of cable force is increased by more than 25%; humidity is reduced to 70%, and the loss of cable force is increased by more than 40%.

In the four specifications calculations models selected by this article, the loss of cable force calculated by Japanese specifications is the worst with the maximum loss of 478kN. When ambient humidity is reduced by 20% from 90%, the loss of cable force is increased by more than 40%, and the most serious is 53%. As for the same stay cable, the maximum loss of cable force calculated by the model in 04 specifications of China is 340kN, which can be seen that in the model of the calculation of the creep effect of the Extradosed cable-stayed bridge, 04 specifications of China are not the most conservative model. Therefore, under the premise that the shrinkage and creep effect has not been fully solved, it's recommended to choose a more conservative safety coefficient in terms of design.

According to the analysis, there is a gap between the calculated result of 04 specifications of China and the most adverse specifications, that is, Japanese specifications. The average difference in 44 stay cables is about 12% based on the comprehensive analysis. Therefore, the safety coefficient of cable force at the operating stage can be increased to 1.87 properly from 1.67 as required by specification requirements based in the coefficient of 1.12.

5. Conclusion

In this article, four commonly used calculation models of the creep effect are selected. Taking the first concrete Extradosed cable-stayed bridge under operation in Yunnan Province of China as an example, the overall impact on the creep effect is analyzed, and conclusions are as follows:

1) The deflection caused by creep increases with the decrease of humidity; the loss of cable force is aggravating with the decrease of humidity, and the calculation gap of each model also increases; when the humidity reaches up to 90%, the difference in the calculated results of each model is very small, and the changes in the stress, deflection and cable force during operating stage are also small.

Therefore, as for dry areas, it is particularly important to choose the proper model for creep calculation and humidity calculation in terms of design.

According to the design specifications in China, the design calculation is based on the average value of the local ambient humidity, and the pre-camber usually obtained is small. Therefore, the creep effect of concrete can be calculated according to the minimum value of the scope of local ambient humidity. For example, local average humidity of the bridge studied in this article is 80% and the scope of humidity is from 70% to 90%; it can be considered as 70% in terms of the design calculation, which is more aligned with the pre-camber settings of the Extradosed cable-stayed bridge.

2) As for the impact of creep effect on deflection of the main beam of the Extradosed cable-stayed bridge, the absolute value is smaller than that of the continuous rigid-frame bridge with the same span, but it has a relatively great impact on the stress and cable force. The impact of the creep effect on the stress at the lower edge of the section near the No. 0 beam section in the non-stayed cable segment is relatively great. After 30 years of operation of the completed bridge, the stress at the lower edge increases by about 2MPa. Therefore, reserve of stress at the lower edge of the section in this area should be increased appropriately.

3) After the 30-year operation of completed Extradosed cable-stayed bridge, the loss of cable force of the bridge is relatively large, and the difference value calculated by models in different specifications is also large, the difference in models with maximum and minimum calculation values is up to 30 tons, and 10 cables reach up to 300 tons, equivalent to the load of a trailer, which can be seen that the selection of the creep model has a relatively great impact on cable force. However, model calculation results, currently used in China, are not the most unfavourable in all specifications mentioned in this article. Therefore, the safety coefficient of stay cables at the operating stage can be properly increased, and the value recommended by this article is 1.87.

Acknowledgment

Project Source: Yunnan Provincial Department of Education(2017ZZX319)

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