Simulation Analysis of Cantilever Construction of Extradosed Cable-Stayed Bridge

Jingxian Shi[1] and Yingjie Cheng[2]
[1] *Oxbridge College, Kunming University of Science and Technology,KunMing 650106 Yunnan, China；*
[2] *Yunnan Aerospace Engineering Geophysical Detecting Co.Ltd, Kunming 650217, Yunnan, China*
sara_shivip@163.com, 532965722@qq.com

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Abstract: In the construction of long span beam, the bridge is in linear with the requirement of the design alignment is the key to ensure that the bridge is in a reasonable stress state, the safety of the bridge operation and the beautiful appearance of the bridge. An example of a Extradosed cable-stayed bridge is presented in this paper，a three-dimensional finite element solid model is established by the simulation analysis of Midas software, and the deflection and stress of main girder in each construction stage are simulated and analyzed, the bridge construction process is simulated and calculated as well.

1 INTRODUCTION

The simulation analysis of bridge construction includes：set up a detailed model of each bearing member in the whole bridge range; by using the reliable numerical analysis method, such as the finite element method, the above model is analyzed and calculated, and a relatively detailed and reliable analysis result is obtained; with the help of rich and effective graphic display software, a large number of calculated numbers are visualized, and the distribution images of the calculated results of the displacement, stress and strain of all parts of the whole bridge and each stage are seen directly, analyze and judge directly from the image to obtain useful conclusions and guide the construction in time. The bridge structure simulation is built up and improved with the development of finite element technology and computer software and hardware.

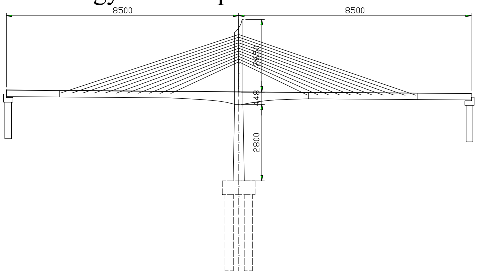

Figure 1: Bridge longitudinal section diagram

In this paper, A 2X175m Extradosed cable-stayed bridge as an example.The main beam is a single box three chamber large cantilever variable cross section PC continuous box girder. the height of the fulcrum beam and middle beam are 4.48m and 2.85m respectively，box beam top width 27m, the length of cantilever flange plate is 4.5m. Reinforced concrete single column solid rectangular cross section in main tower, which the height of tower is 26.5m.The cable-stayed is arranged on the central partition with 11 pairs of 44 rows; tower and beam are consolidated together. design load: Road-Ⅱ, crowd load-3.5kN/m^2;bridge width- 27m.

2 CONSTRUCTION SIMULATION ANALYSIS

The cantilever construction stage of the main bridge box girder is the key and difficult point of the whole bridge construction, the construction of each beam can be decomposed into 6 construction steps: basket moving forward; adjustment the elevation of the mould plate; concrete pouring; tensioning prestress; Preliminary tensioned stayed cable(with cable section)；precise adjustment of stayed cable (with cable section). The division of the main beam segment is shown in Figure 2.

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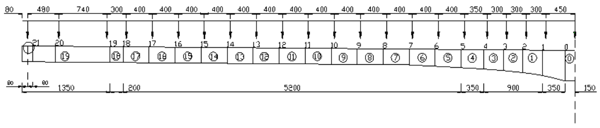


Figure2: The diagram of main beam division

2.1 Parameters obtained by structural analysis

There are 7 types of unit section, in which the variable section is automatically calculated by program, and the type of material is 3. The specific parameters are shown in Table 1 and 2.

2.2 Structural model

The MIDAS Civil analysis program is applied in the construction stage. The structural calculation is carried out according to the spatial truss structure. The structure is composed of piers, main girders, main towers and cables. The discrete model of structural analysis is shown in Figure 3. The whole bridge consists of 146 units and 172 nodes, in which the main beam, the pier and the main tower are the space beam units, and the cable is a space truss unit.

The boundary conditions in the analysis are the lower end of the cable-tower is consolidated; simulation of transition piers and auxiliary piers by movable hinge support; The lower end of the cast-in-place bracket unit is a fixed hinge support.

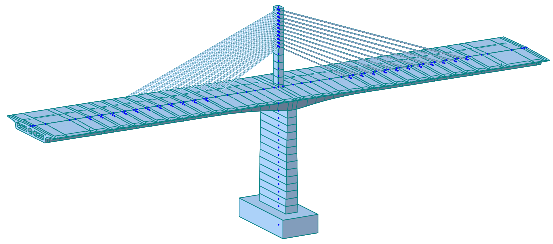


Figure 3: Structural model

2.3 Division of construction stage

The whole bridge construction is divided into 88 calculation stages according to the design drawings and the construction organization design. The total construction period is 284 days. See Table 3 for details.

Table1: Section parameter summary of calculation model

number	1	2	3	4	5	6	7	8	9	10
location	main beam 0#section	main beam 1#section	main beam 7#section	main beam 21#section	Bottom of pier	Top of pier	main tower	cable 31-7	cable 34-7	cable 34-7
Area	42.192	25.493	19.134	30.179	64.824	47.202	5.980	4.34e-3	4.67e-3	5.18e-3
Izz	1511.01	1055.96	910.59	1190.93	1337.31	973.77	4.46			

notes: Izz: The moment of inertia to the Z axis of the unit local coordinate system (m^4)

Table 2: Material parameter summary of calculation model

Material number	Type of components	Material type	Modulus of elasticity (MPa)	Bulk density (kN/m^3)	thermal expansion coefficient ($1/^0C$)
1	Pier, main beam, mian tower	C50	3.45E+04	26	1.00E-05
2	stayed cable and prestress	High strength steel wire	1.95E+05	78.5	1.20E-05

Table 3 Construction stage division of calculation model

construction stage	Name of construction component	Working condition description
1	Pier	Bridge pier construction
2	0#block	Pouring 0# block concrete and tensioning prestress
3	Bridge tower	Bridge tower construction
4-6	1#beam	Install the basket-Concrete pouring-Forming beam section-Tensioning prestress
7-18	2#beam-5#beam	Basket moving forward-Concrete pouring-Forming beam section-Prestressed steel bundles in each section of tensioned beam
19-62	6#beam-16#beam	Basket moving forward-Concrete pouring-Forming beam section-Prestressed steel bundles in each section of tensioned beam-stayed cable on a tensile beam
63-65	17#beam	Basket moving forwardt-Concrete pouring-Forming beam section-Tensioning prestress
66	Side span cast-in-place section	Full framing construction
67-69	Closure section	Cradle at both ends of the closure-Exerting weight at both ends of the closure-Installation of skeleton
70-71		Pouring concrete of closure section-Remove the weight simultaneously-Closure section to form beam section
72-81		Tensioned baseplate continuous steel beam-Tensioned roof continuous steel beam
82-84		Dismantling the cradle of the closing section-Dismantling the basket of 16# beam-Dismantling the side span of the cast-in-place full framing
85	The second phase	Secondary dead load
86	Completion	Working condition of completed bridge
87-88	Operation	Operation stage（10years）,Operation stage（30years）

2.4 Calculation of load parameters

1) The main beam unit has input γ=26kN/m3 in the material characteristics, and has calculated the area in the section characteristics. Therefore, the calculation of dead load weight is automatically counted. Manually add concrete wet weight and diaphragm weight. The beam is exerted in the form of a concentrated force at the forming stage.

2) secondary dead load: bridge deck pavement q_1=66.36 kN/m; Crash barrier of edge q_2=12.43 kN/m; Middle collision guardrail q_3=16.30 kN/m; Sidewalk q_4=25.37 kN/m; Total: q = 120.46kN/m.

3) The specific value of cable force in stayed cables is shown in Table 4

Table 4: Cable force

Cable number	Designed cable force/kN
West1-West3 East1-East3	3150
West4-West6 East4-East6	3400
West7-West11 East7-East11	3650

4) In the checking calculation, the data are input according to the parameters of the design diagram. The pre-stressed reinforcement adopts 9 beams and 12 beams of φ15.24 steel strands, f_{pk}=1860MPa, Anchorage deformation is 6mm, Deviation factors of pipeline is 0.0015. The other related parameters for the calculation of the pre-stressed are shown in Table 5.

Table 5: Physical parameters of pre-stressed reinforcement

The number of physical types of steel beam	1	2
Steel beam model	15—9	15—12
Pipe diameter/m	0.087	0.103
Steel area/m^2	0.00126	0.00238
Tension stress/MPa	1395	1395
coefficient of relaxation	0.3	0.3
coefficient of friction resistance	0.25	0.25

5) The coefficient of shrinkage and creep is calculated by the program according to the current highway bridge design code, and 3000 days after the complete is calculated. The temperature influence is mainly considered as follows: The system has a uniform rise and fall of 20℃； The temperature gradient of the tower section is ±5； The temperature of the cable and tower are ±10℃. Support settlement is calculated by 0.02M.

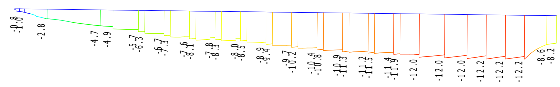
6) The vehicle live load is bi-directional 4 lane, the reduction coefficient is 0.67, and the highway - II grade. The impact coefficient is automatically calculated by program. The load of the crowd is calculated according to the 3.5kN/m^2, and the other loads are calculated according to the standard.

3 ANALYSIS RESULT

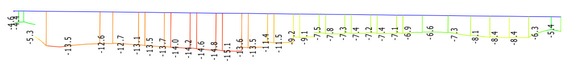
3.1 Stress checking of the main beam

According to the 7.2.8 provision of <code for design of highway reinforced concrete and pre-stressed concrete bridges and culverts>(JTG D62-2004), the limit value of compressive stress of the main beam in construction stage is 0.729.6=20.72MPa and the tensile stress limit value is 1.15X2.51=2.8865MPa. According to the results of simulation analysis, the stress envelope diagram of main beam in all stages of construction is shown in Figure 4, the maximum compressive stress and the maximum tensile stress are 15.1MPa and 0.9MPa respectively, which all meet the specification requirements

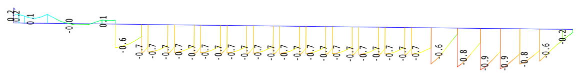
According to the above length calculation, the bridge pier tower is in the safe state. The maximum cantilever phase safety factor of tower bottom section is 2.60; under the special condition of wind, the section safety factors of pier bottom and tower bottom are 5.03 and 2.17 respectively, and all are in a safe state.



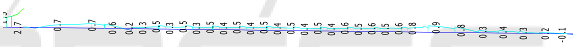
（A）Compression stress envelope of the upper edge of the main beam（half bridge）



（B）Compression stress envelope of the lower edge of the main beam（half bridge）



（C）The tensile stress envelope of the upper edge of the main beam（half bridge）



（D）The tensile stress envelope of the lower edge of the main beam（half bridge）

Figure 4: Calculation result of main beam stress

3.2 Checking calculation of stayed cable force

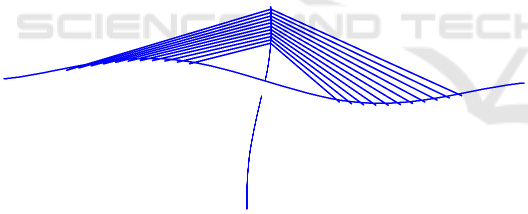
According to the results of the monitoring and calculation, the safety factor of the stayed cable at whole construction process is more than 2. and the minimum safety factor is all up to the specification requirements.

Table 6:Calculation result of stayed cable force in construction stage

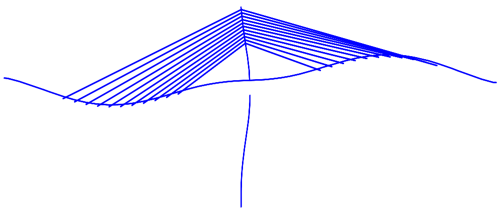
cable number	Number of steel beam	safety factor
West1、East1	31	2.47
West2、East2	31	2.46
West3、East3	31	2.43
West4、East4	34	2.45
West5、East5	34	2.42
West6、East6	34	2.40
West7、East7	37	2.42
West8、East8	37	2.40
West9、East9	37	2.39
West10、East10	37	2.37
West11、East11	37	2.37

3.3 Frequency and mode of vibration

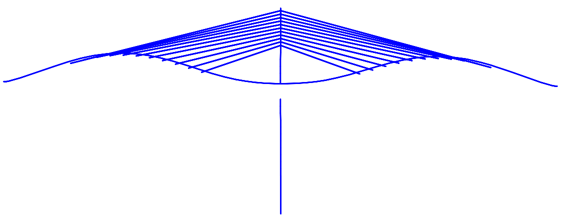
The 20 order modes of vibration is calculated in this paper. The results of the first 4 order frequencies and modes of vibration are shown in Figure 5



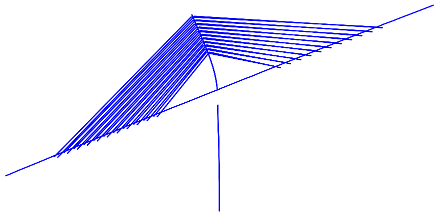
（A）first order mode/f=0.828HZ



（B）second order mode/f=1.600HZ



（C）third order mode/f=1.773HZ



（D）fourth order mode/f=2.969HZ

Figure 5: Modes and frequencies of each order.

4 CONCLUSIONS

Combining with the engineering example of 2X175m Extradosed cable-stayed bridge， the simulation analysis of cantilever construction of the bridge is mainly done. The parameter selection, model establishment, construction stage division and operation result analysis of the construction simulation for the. Extradosed cable-stayed bridge are expounded. The theoretical basis is provided to ensure The linear shape of the bridge. and stress of the bridge, and provide reliable technical guarantee for the safety construction of the bridge.

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