EFFECTS OF STAY CABLE ARRANGEMENT ON MECHANICS AND DEFORMATION OF MAIN ARCH CONSTRUCTED BY CANTILEVER CASTING METHOD

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SUMMARY

For cantilever casting method, the star type and fan type arrangements of stay is summarized after compared several typical concrete arch bridges in China and abroad. By taking an 165m span arch bridge as example, the inclination of the longest stay cable are selected 15°, 17°, 20° and 23° respectively, then effects of mechanics and deformation of arch on different cable arrangement are analyzed by ANSYS. The numerical results show that cables near springing could not too large to ensure proper compressive stress. Inclined angles of cables at other positions will reasonably be 17° and 20° in star type and fan type arrangement, respectively. Some of cables should be dismantled during certain construction stages, which ensure tensile stress not to exceed the allowable stress. Moreover, different cable arrangement leads to different sequences of dismantlement.

Keywords: *Concrete arch bridge, Cantilever casting method, Cable arrangement, Inclination of cable, Tensile stress, Deformation.*

1. INTRODUCTION

The construction methods to build concrete arch bridge include bracket casting, cable erection, stiffened scaffolding, rotation construction and cantilever concreting method. Many long-span concrete arch bridges were constructed by using the cantilever concreting method and the combination of cantilever concreting and stiffened scaffolding method around the world. While, in China, cable erection method and stiffened scaffolding method are more popular. In recent years, five concrete arch bridges with main span over 150 m have been built by cantilever casting method in Guizhou and Sichuan province respectively. The longest span among those five bridges is 200 m. In the coming further, another three concrete arch bridges will also be constructed by this method and the span will reaches 240 m. A large arch cross-section results in a heavily dead weight. To improve the mechanics of arch, reduce the stay cable's stress and scale of earth-anchor system as well as cost saving, large incline angles of stay cable is usually employed when using the cantilever casting method. There are two arrangement types of stay cables according to several typical concrete arch bridges around the world, namely, the star and fan style [1-5]. In this paper, the MUPENG arch bridge which was constructed by cantilever casting method was selected as an example. According to the two arrangement types, incline angle of the longest stay cable were set as 15°, 17°, 20° and 23°, respectively. The effects of arrangements on mechanics and deformation of arch were analyzed by ANSYS software.

2. THE GENERAL SITUATION OF MUPENG BRIDGE

MUPENG Bridge is a catenary constant section reinforced concrete arch bridge with clear span of 165m. The clear rise is 30 m and rise-to-span ratio is 1/5.5. Its arch axis coefficient is 1.988. The bridge superstructure comprises of 13×13.2 m pre-stressed concrete hollow slab, which is divided into 3 unions. Steel modular expansion joint devices are set between each unions with 80mm expansion deformation. The approach bridges comprises of pre-stressed concrete T girder with spans of 2×30 m and 4×30 m. The total bridge length is 366.6 m (Fig. 1). The bridge was designed on the basis of Chinese Highway- I class. The pavement width is 24.5 m. The arch is double cell box cross-section with width 7.5 m and depth 2.8 m, the design concrete grade for the arch is C50.

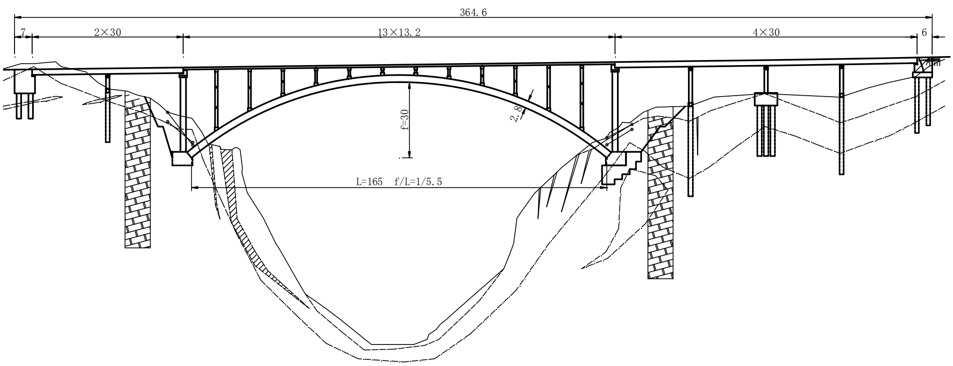

Fig. 1. *Elevation of MUPENG Bridge (unit： m).*

The arch was longitudinally divided into 27 construction segments, including two bracket casting segments at the springing, one 2 m-length closure segment at the crown and 24 normal segments which were constructed by cantilever casting. The cross-sections of the springing and crown are illustrated in Fig. 2. Lengths and weights of each segment are listed in Tab. 1.

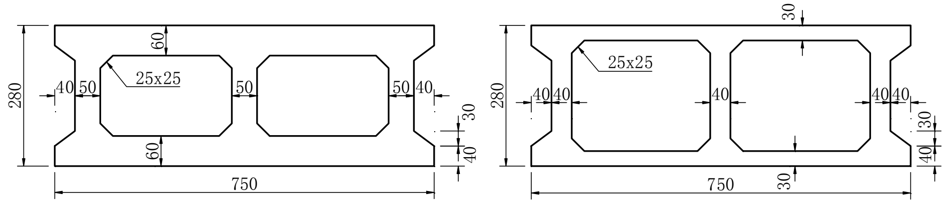

Fig. 2. *Cross-section of arch (unit： cm).*

Table 1. Length and weight of each segment.

No. of segment	Length [m]	C50 [m³]	Weight [t]	No. of segment	Length [m]	C50 [m³]	Weight [t]
1	9.129	90.2	234.6	8	6.776	54	140.4
2	6.6	54.1	140.6	9	6.595	51.7	134.4
3	7.14	55.7	144.8	10	6.595	52.6	136.8
4	7.14	56.7	147.5	11	6.49	50.9	132.3
5	7.064	55.1	143.4	12	6.501	51.9	135
6	7.064	56.2	146	13	4.733	39	101.4
7	6.776	53	137.8	Closure segment	1	15.9	41.3

3. DESIGN OF STAY CABLE AND ANCHOR CABLE SYSTEM

Fig. 3 demonstrate the stay and anchor cable system adopted by MUPENG Bridge, this system consist of pylon, stay, anchor cable and earth-anchor. The 1# to 5# stay cables and anchor cables near the springing were arranged at the top of two juncture piers, the others were set at a pylon of steel tubular truss so as to get a large incline angle of cable . In order to make the horizontal component of cable tensions in both stay cables and anchor-cables approximately the same, tension adjusting ends of the two cables were arranged on the pylon. The longitudinal displacement of the juncture piers and pylons could be controlled by different tensions of stay cables and anchor-cables.

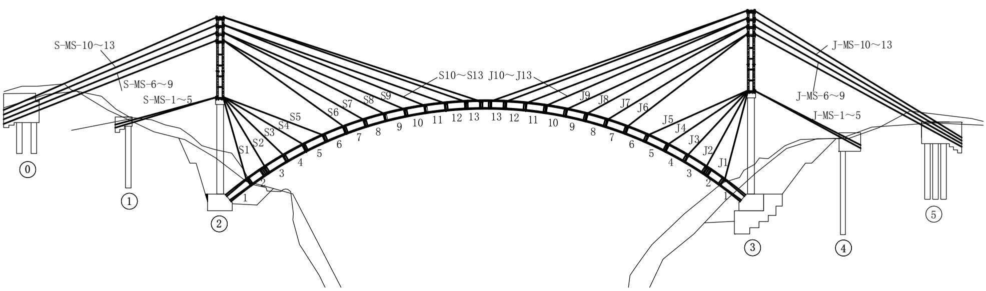

Fig. 3. Stay and anchor cable layout of MUPENG Bridge.

4. EFFECTS OF CABLE ARRANGEMENT TYPE ON ARCH MECHANICS AND DEFORMATION

4.1. Fan type arrangement

For the stay and anchor cable system scheme in Fig. 3, four cases of detail layouts were proposed by prior set the incline angle of longest stay cable (S13 and J13) as 15°, 17°, 20°and 23°, respectively. The height of pylon and incline angle of other stay cables were determined correspondingly. The star type layout were adopted by 1# to 5# stay cables and fan type layout were used by 6# to 13# stay cables. Tab. 2 lists all incline angles of each stay cables in half-bridge.

Table 2. *Incline angles of stay cables in half-bridge.*

No. of stay cable	Angle of Case 1 [°]	Angle of Case 2 [°]	Angle of Case 3 [°]	Angle of Case 4 [°]
S1	73.25	73.25	73.25	73.25
S2	59.15	59.15	59.15	59.15
S3	43.75	43.75	43.75	43.75
S4	30.42	30.42	30.42	30.42
S5	20.64	20.64	20.64	20.64
S6	30.20	33.98	38.08	42.32
S7	24.38	28.03	32.08	36.36
S8	22.17	25.49	29.22	33.22
S9	18.68	21.80	25.34	29.20
S10	17.97	20.80	24.04	27.60
S11	15.87	18.52	21.57	24.95
S12	15.95	18.38	21.19	24.31
S13	15.00	17.00	20.00	23.00

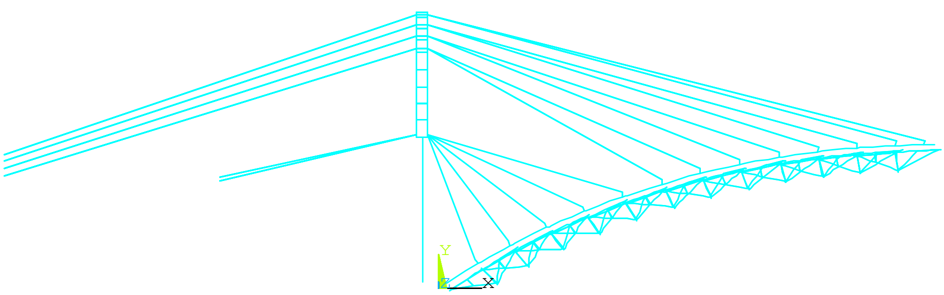

Fig. 4. *The calculation model of MUPENG bridge.*

The entire construction phase was divided into 28 computation conditions. The technology of element birth and death in ANSYS was employed to simulate concrete cast. The BEAM44 element was used to simulate the arch, juncture piers，pylon and travelling formwork carriages, while LINK10 element was used to simulate the stay cables and anchor cables. Diaphragms of arch was applied as load on nodes in FE model. Only half of the bridge was established into ANSYS to simplify the calculation. The FE model is shown in Fig. 4.

For the four arrangement types of stay cables, cable forces and arch stresses which could satisfy the allowable value were calculated on the premise that any tensile stress of arch could not exceed 2.0 MPa. The tension stress usually appears on arch top edge in process of cantilever casting, the stress calculation on the top of arch sections should be performed. Fig. 5 shows the variation of cross-section stresses on the upper edge of springing during each construction stages. The results indicate that stresses at the upper edge could be controlled less than 2.0 MPa for those four arrangement types. However, different arrangement types shown different stress variations. The minimum variation appears when the incline angle of stay cable is 20°, which is beneficial for construction control. Also, when the incline angle is 20°, arch deformation after removing the stay cables agrees well with the result produced by bare arch self-weigh.

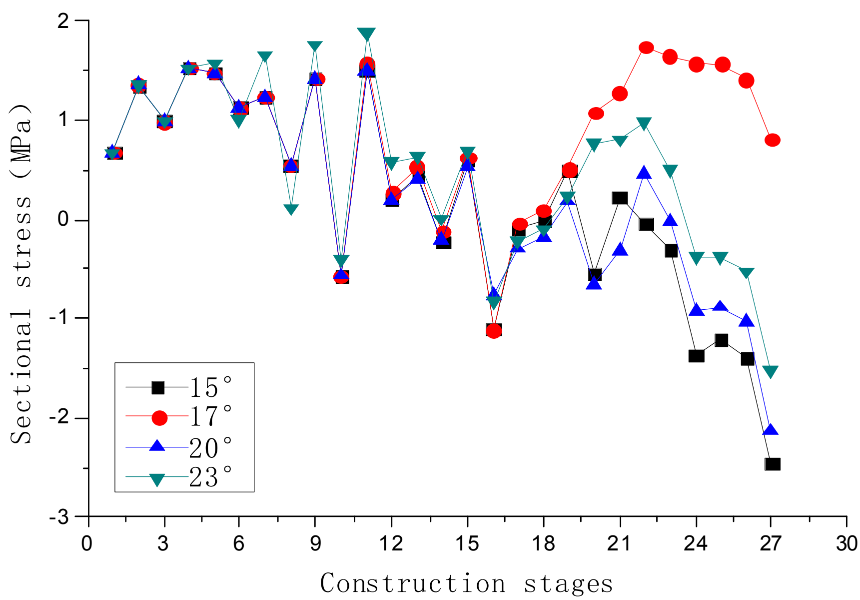

Fig. 5. *Stress variation of upper edge at springing.*

4.2. Star type arrangement

The former fan type of stay cables 6#~13# in Fig. 3 were changed to star type(Fig. 6), consequently, four layouts of stay cable and anchor cable were determined as the incline angle of the longest stay cable (S13,J13) was set to 15°, 17°, 20° and 23°, respectively. The inclination of each cable is shown in Tab. 3.

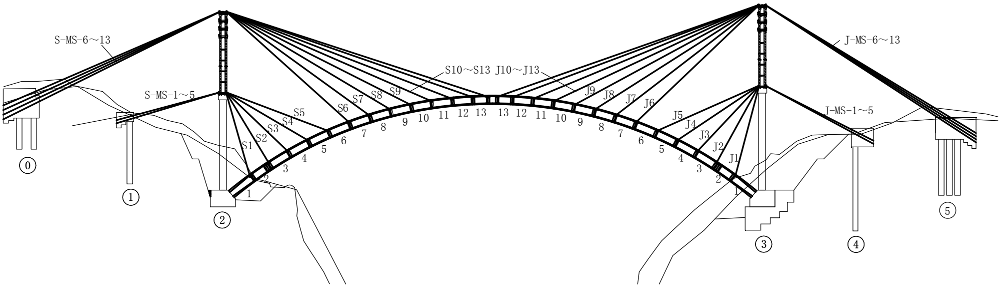

Fig. 6. Stay cable arrangement in fan type.

For the four arrangement types, stress variation on the upper edge of arch springing are shown in Fig. 7 at different construction stages. As we can see in Fig. 7, the stress variation is minimum when the incline angle is 17°. Besides, arch deformation after releasing the cables has a good agreement with the result caused by arch self-weigh. The result shows that the stay inclination near springing should not be large, otherwise the compressive stress couldn't counteract tension stress produced in process of concreting for the two kinds of stay cable arrangement.

Table 3. The angles of stay cable in star type of half span arch.

No. of stay cable	Angle of Case 1 [°]	Angle of Case 2 [°]	Angle of Case 3 [°]	Angle of Case 4 [°]
S1	73.25	73.25	73.25	73.25
S2	59.15	59.15	59.15	59.15
S3	43.75	43.75	43.75	43.75
S4	30.42	30.42	30.42	30.42
S5	20.64	20.64	20.64	20.64
S6	37.54	40.29	44.13	47.65
S7	31.54	34.29	38.21	41.88
S8	26.61	29.28	33.14	36.82
S9	22.86	25.40	29.12	32.71
S10	19.89	22.28	25.81	29.28
S11	17.67	19.91	23.24	26.54
S12	15.95	18.05	21.19	24.31
S13	15.00	17.34	20.00	23.00

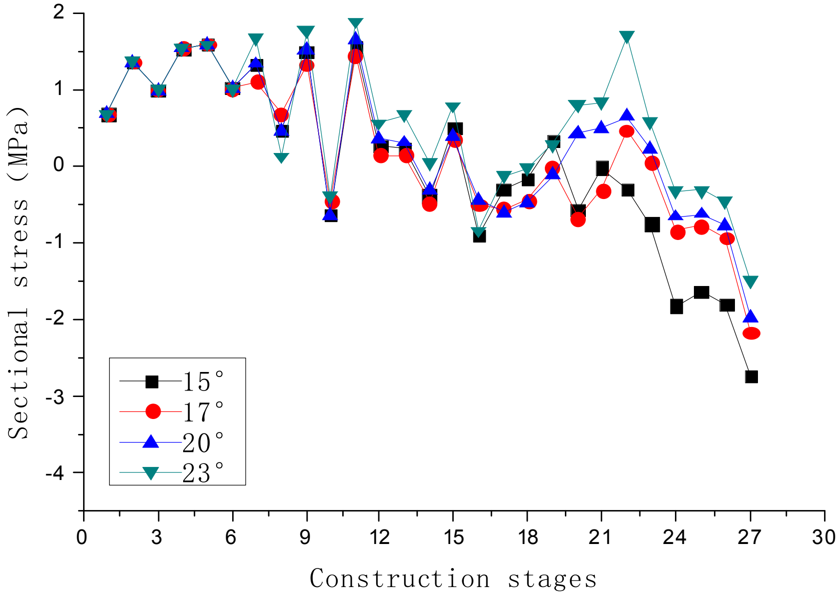

***Fig.** 7. Stress variation of upper edge at springing.*

It should be noted that the above results are based on one-time concreting and cable tensing, however, the arch in cantilever states is constrained by multi-elastic supports of stay cable, and stress in some cross-sections will exceed 2.0MPa. Some stay cables must be removed or released during cantilever construction to ensure allowance stress. The calculation results indicated that the less inclination the earlier stay cable should be removed in the fan type and star type. For example, the inclination of the longest stay cable is both 17° in the two cable arrangement type, when casting segment 8th and tensioning the stay cable S8, the angle of S8 in fan type is smaller than in star type, so it needs to remove the stay 4# in fan type and remove stay 5# in the star type.

5. CONCLUSIONS

This paper discusses the effects on mechanics and deformation of arch about fan type and star type stay cable layout by the way of cantilever casting method. It is reasonable that inclination of the longest stay cable is between 17° to 20° in fan type and star type. The MUPENG Bridge adopts stay layout of fan type, the reasonable inclination of S13 and J13 should be around 20°. Meanwhile, if the star type was applied to the bridge, the reasonable inclination of S13 and J13 should be 17°.

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