

# Arch-Axis Coefficient Optimization of Long-Span Deck-Type Concrete-Filled Steel Tubular Arch Bridge

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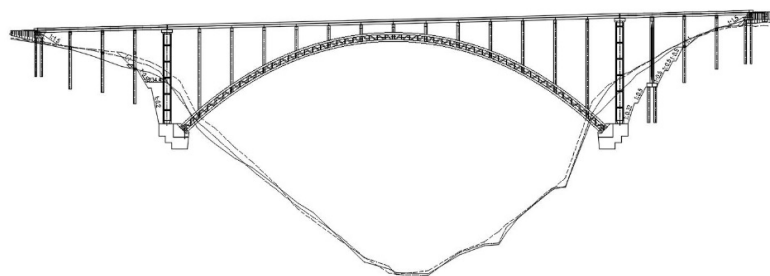
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**Abstract.** This paper is based on Nanpuxi super major bridge which is under construction and starts from Wencheng Zhejiang province to Taishun highway. A finite element model of the whole bridge is constructed using Midas Civil finite element software. The most adverse load combination in the specification is taken into consideration to determine the method of calculating the arch-axis coefficient of long-span deck-type concrete-filled steel tubular arch bridge. By doing this, this paper aims at providing references for similar engineering projects.

## 1. Project overview

Nanpuxi super major bridge is located in Taishun county, Zhejiang province. It spans the cliffs of the two sides of the canyon, and the elevation of the mountaintop is 271m, the elevation of the ditch is 115m, and the relative elevation is 156m. The main bridge is a deck-type concrete-filled steel tubular arch bridge with a net span of 258m, and the net rise-span ratio is 1/4.6. The axis of the arch is catenary. Based on previous engineering experience, the paper uses six arch axis coefficients-1.5, 1.6, 1.7, 1.756, 1.8, 1.9 to carry out the research.

The cross section type of the bridge is integral, and the width of the bridge is 25m. The whole bridge consists of two pieces of arch rib, rib spacing is 17m, and each arch rib consists of four steel pipes with 1200 mm diameter, and is 3m wide, 5.5m high. The steel pipe has a thickness of 22mm, and is filled with C50 expansion concrete. The column above the arch adopts stiffener steel box section. And the bent cap above the column adopts steel box structure. The bridge deck is composed of continuous 20m steel-concrete composite beams. The composite beams are composed of 85cm high I-shape beam and 23cm thick precast and cast-in-place concrete plates, and the nominal beam height of the composite beams is 1.2m. The bridge deck consists of 10cm-thick asphalt concrete and 10cm-thick cast-in place concrete. The layout of Nanpuxi super major bridge is shown in figure 1. The design load is: vehicle highway-class I.

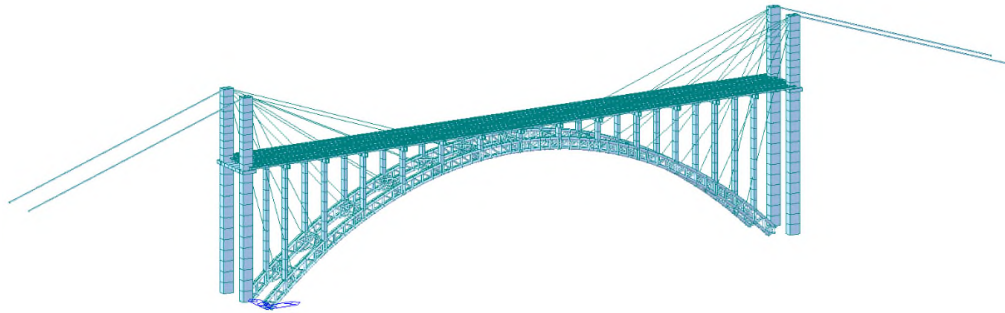


**Figure 1.** The layout of Nanpuxi super major bridge.



## 2. Overall calculation

The bridge integral calculation is carried out by using finite element software Midas civil 8.3.2 to construct a whole bridge finite element model. Space truss elements are used in the model to get stress calculation results. The model is constructed according to the actual construction process of construction stage. The first period dead load and second period dead load and basic variable load such as vehicle load, and temperature load, deformation and additional load are combined in different ways to get the stress results in arch bridge under the most unfavorable load combination. The finite element model of arch bridge is shown in figure 2.



**Figure 2.** The finite element model of the concrete-filled steel tubular arch bridge.

### 2.1. Load condition and load combination

**2.1.1. Main load conditions.** (1) Dead load: the structural self-weight and phase ii dead load including the guardrail and the paving of the bridge deck.

(2) Live load: highway I class load, its fabric can be divided into two different modes according to the specification: symmetrical loading and partial loading.

(3) Bearing settlement:

1) Each bearing moves 1cm backward

2) One bearing sinks 1cm downward

(4) Temperature effect

1) Uniform heating and cooling, the overall rise and drop of the temperature is 25°C.

2) Gradient heating and cooling

The gradient heating and cooling of bridge panel is implemented according to article 4.3.12 in the highway bridge design general specification (JTG d60-2015).

The gradient heating of arch ribs is implemented according to article 4.2.5 in the highway concrete-filled steel tubular arch bridge design specification (JTG/T D65-06-2015) and the rise of the temperature is 5°C.

(5) Wind load

The calculation results are mainly used to determine the arch axis coefficient of the arch rib, and vertical load is mainly considered in this case, so the wind load is not considered.

(6) Shrinkage creep

The shrinkage creep is determined according to article 4.2.4 of the highway bridge design general specification (JTG d60-2015) and the relevant provisions in appendix F in Code for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts (JTG D62-2004).

The shrinkage and creep of the concrete used in the composite beam as well as the bridge panel and the steel tube of the arch rings are considered in the model. The relative humidity is 90%.

**2.1.2. Load combination.** The load combination is considered according to article 4.1.5 and 4.1.6 of the general specification of highway bridge design (JTG d60-2015).

### 2.2. Construction stage division

The construction stage is divided as the table 1 shows.

**Table 1.** Construction stage division.

Construction stage	Construction content
1	constructing arch abutment, constructing transition pier, installing cable tower
2	hoisting the first segment of the arch ribs, installing buckle cable, back stay and k-shape support
3	hoisting the second segment of the arch ribs, installing buckle cable, back stay and k-shape support
4	hoisting the third segment of the arch ribs, installing buckle cable, back stay and k-shape support
5	hoisting the fourth segment of the arch ribs, installing buckle cable, back stay and k-shape support
6	hoisting the fifth segment of the arch ribs, installing buckle cable, back stay and k-shape support
7	hoisting the sixth segment of the arch ribs, installing buckle cable, back stay and k-shape support
8	hoisting the seventh segment of the arch ribs(closure segment), installing H-shape support
9	demolishing buckle cable and placing concrete in skewback to seal the hinges after the closure
10	placing concrete in the first steel tube of the bottom chord
11	placing concrete in the first steel tube of the top chord after concrete in the former phase reaches requirements
12	placing concrete in the second steel tube of the bottom chord after concrete in the former phase reaches requirements
13	placing concrete in the second steel tube of the top chord after concrete in the former phase reaches requirements
14	the concrete in the second steel tube of the top chord reaches enough strength and starts to get into function
15	placing concrete in batten plate
16	installing columns in 3# and 4# and 10# and 11# after the batten plate concrete reaches the required strength
17	installing columns in 5#~9#
18	installing columns in 1# and 2# and 12# and 13#
19	installing copings on columns in 3# and 4# and 10# and 11#
20	installing copings on columns in 5#~9#
21	installing copings on columns in 1# and 2# and 12# and 13#
22	installing bridge deck on columns in 2#~4# and 10#~12#
23	installing bridge deck on columns in 4#~10#
24	installing bridge deck on columns in 0#(transition pier)~2# and 12#~14#(transition pier)
25	secondary dead load (guardrail load and bridge deck pavement load)
26	shrinkage creep in 3 years after the completion and support displacement

### 3. Optimization of arch-axis coefficient(m)

The arch-axis line adopts the catenary line, combined with the previous engineering experience, this paper intends to take six values of arch-axis coefficient to make comparisons:  $m = 1.5$ ,  $m = 1.6$ ,  $m = 1.7$ ,  $m = 1.756$ ,  $m = 1.8$ ,  $m = 1.9$ , the static analysis is carried out with the help of Midas civil 8.3.2 program. The whole ridge finite element model is constructed for calculation comparison.

#### 3.1. Comparison of dead load stress under long-term effect after the completion

From the comparison results of the different arch-axis coefficient, the conclusion that difference between axial stress under dead load with different coefficient is minimal. Under dead load situation, there are great changes in the stress of the arch ribs. With the increase of the  $m$  coefficient, the absolute value of the negative moment in skewback has gradually reduced, the positive moment in skewback has gradually increased, and the compressive stress of the bottom chord bar has reduced.

**Table 2.** Comparison of stress in arch rib steel tubes with different arch-axis coefficient under dead load (N/mm<sup>2</sup>)<sup>a</sup>.

Arch-axis coefficient	Stress of top chord in skewback (N/mm <sup>2</sup> )	Stress of bottom chord in skewback (N/mm <sup>2</sup> )	Stress of bottom chord in 1/4 midspan (N/mm <sup>2</sup> )	Stress of top chord in vault (N/mm <sup>2</sup> )	Stress of bottom chord in vault (N/mm <sup>2</sup> )
m=1.9	-1.33e+002	-9.98e+001	-9.45e+001	-1.37e+002	-8.18e+001
m=1.8	-1.23e+002	-9.88e+001	-9.28e+001	-1.34e+002	-8.32e+001
m=1.756	-1.19e+002	-1.03e+002	-9.20e+001	-1.32e+002	-8.39e+001
m=1.7	-1.13e+002	-1.08e+002	-9.10e+001	-1.30e+002	-8.46e+001
m=1.6	-1.03e+002	-1.18e+002	-8.90e+001	-1.25e+002	-8.61e+001
m=1.5	-9.22e+001	-1.29e+002	-8.66e+001	-1.23e+002	-8.77e+001

<sup>a</sup> The negative values in the table above represent compressive stress, and positive values represent tensile stress.

**Table 3.** Comparison of stress in arch rib concrete with different arch-axis coefficient under dead load (N/mm<sup>2</sup>)<sup>a</sup>.

Arch-axis coefficient	Stress of top chord in skewback (N/mm <sup>2</sup> )	Stress of bottom chord in skewback (N/mm <sup>2</sup> )	Stress of bottom chord in 1/4 midspan (N/mm <sup>2</sup> )	Stress of top chord in vault (N/mm <sup>2</sup> )	Stress of bottom chord in vault (N/mm <sup>2</sup> )
m=1.9	-1.15e+001	-1.14e+001	-9.80e+000	-1.14e+001	-6.61e+000
m=1.8	-1.05e+001	-1.10e+001	-9.62e+000	-1.12e+001	-6.72e+000
m=1.756	-1.02e+001	-1.09e+001	-9.54e+000	-1.11e+001	-6.77e+000
m=1.7	-9.60e+000	-1.12e+001	-9.44e+000	-1.10e+001	-6.83e+000
m=1.6	-8.65e+000	-1.23e+001	-9.23e+000	-1.05e+001	-6.95e+000
m=1.5	-7.69e+000	-1.36e+001	-9.03e+000	-1.06e+001	-7.08e+000

<sup>a</sup> The negative values in the table above represent compressive stress, and positive values represent tensile stress.

### 3.2. The comparison of stress under the most unfavorable fundamental combination effects of persistence condition

The table below shows the comparison of stress under the most unfavourable fundamental combination effects of persistence condition with different arch-axis coefficient.

**Table 4.** Comparison of stress in arch rib steel tubes with different arch-axis coefficient under the most unfavourable fundamental combination effects of persistence condition (N/mm<sup>2</sup>)<sup>a</sup>.

Arch-axis coefficient	Stress of top chord in skewback (N/mm <sup>2</sup> )	Stress of bottom chord in skewback (N/mm <sup>2</sup> )	Stress of bottom chord in 1/4 mid span (N/mm <sup>2</sup> )	Stress of top chord in vault (N/mm <sup>2</sup> )	Stress of bottom chord in vault (N/mm <sup>2</sup> )
m=1.9	-2.71e+002	-2.00e+002	-1.60e+002	-2.48e+002	-1.39e+002
m=1.8	-2.48e+002	-1.99e+002	-1.57e+002	-2.38e+002	-1.41e+002
m=1.756	-2.43e+002	-2.05e+002	-1.56e+002	-2.36e+002	-1.42e+002
m=1.7	-2.43e+002	-2.13e+002	-1.54e+002	-2.38e+002	-1.44e+002
m=1.6	-2.28e+002	-2.27e+002	-1.51e+002	-2.33e+002	-1.46e+002
m=1.5	-2.04e+002	-2.43e+002	-1.48e+002	-2.23e+002	-1.48e+002

<sup>a</sup> The negative values in the table above represent compressive stress, and positive values represent tensile stress.

**Table 5.** Comparison of stress in arch rib concrete with different arch-axis coefficient under the most unfavourable fundamental combination effects of persistence condition (N/mm<sup>2</sup>)<sup>a</sup>.

Arch-axis coefficient	Stress of top chord in skewback (N/mm <sup>2</sup> )	Stress of bottom chord in skewback (N/mm <sup>2</sup> )	Stress of bottom chord in 1/4 mid span (N/mm <sup>2</sup> )	Stress of top chord in vault (N/mm <sup>2</sup> )	Stress of bottom chord in vault (N/mm <sup>2</sup> )
m=1.9	-2.24e+001	-1.78e+001	-1.12e+001	-1.76e+001	-8.27e+000
m=1.8	-2.00e+001	-1.75e+001	-1.10e+001	-1.65e+001	-8.39e+000
m=1.756	-1.97e+001	-1.74e+001	-1.09e+001	-1.64e+001	-8.45e+000
m=1.7	-2.06e+001	-1.73e+001	-1.08e+001	-1.71e+001	-8.51e+000
m=1.6	-1.97e+001	-1.80e+001	-1.06e+001	-1.69e+001	-8.64e+000
m=1.5	-1.73e+001	-1.91e+001	-1.04e+001	-1.59e+001	-8.79e+000

<sup>a</sup> The negative values in the table above represent compressive stress, and positive values represent tensile stress.

### 3.3. Comparison of stress under the most unfavorable standard combination effects of persistence condition

The table below shows the comparison of stress under the most unfavourable standard combination effects of persistence condition with different arch-axis coefficient.

**Table 6.** Comparison of stress in arch rib steel tubes with different arch-axis coefficient under the most unfavourable standard combination effects of persistence condition (N/mm<sup>2</sup>)<sup>a</sup>.

Arch-axis coefficient	Stress of top chord in skewback (N/mm <sup>2</sup> )	Stress of bottom chord in skewback (N/mm <sup>2</sup> )	Stress of bottom chord in 1/4 midspan (N/mm <sup>2</sup> )	Stress of top chord in vault (N/mm <sup>2</sup> )	Stress of bottom chord in vault (N/mm <sup>2</sup> )
m=1.9	-2.28e+002	-1.72e+002	-1.36e+002	-2.11e+002	-1.19e+002
m=1.8	-2.08e+002	-1.70e+002	-1.33e+002	-2.03e+002	-1.21e+002
m=1.756	-2.04e+002	-1.74e+002	-1.32e+002	-2.01e+002	-1.22e+002
m=1.7	-2.04e+002	-1.81e+002	-1.31e+002	-2.03e+002	-1.23e+002
m=1.6	-1.92e+002	-1.94e+002	-1.29e+002	-1.99e+002	-1.25e+002
m=1.5	-1.71e+002	-2.07e+002	-1.26e+002	-1.90e+002	-1.27e+002

<sup>a</sup> The negative values in the table above represent compressive stress, and positive values represent tensile stress.

**Table 7.** Comparison of stress in arch rib concrete with different arch-axis coefficient under the most unfavourable standard combination effects of persistence condition (N/mm<sup>2</sup>)<sup>a</sup>.

Arch-axis coefficient	Stress of top chord in skewback (N/mm <sup>2</sup> )	Stress of bottom chord in skewback (N/mm <sup>2</sup> )	Stress of bottom chord in 1/4 midspan (N/mm <sup>2</sup> )	Stress of top chord in vault (N/mm <sup>2</sup> )	Stress of bottom chord in vault (N/mm <sup>2</sup> )
m=1.9	-1.74e+001	-1.42e+001	-8.36e+000	-1.38e+001	-6.32e+000
m=1.8	-1.54e+001	-1.40e+001	-8.23e+000	-1.29e+001	-6.41e+000
m=1.756	-1.52e+001	-1.40e+001	-8.17e+000	-1.28e+001	-6.46e+000
m=1.7	-1.60e+001	-1.38e+001	-8.10e+000	-1.34e+001	-6.51e+000
m=1.6	-1.54e+001	-1.39e+001	-7.95e+000	-1.33e+001	-6.62e+000
m=1.5	-1.34e+001	-1.47e+001	-7.79e+000	-1.24e+001	-6.73e+000

<sup>a</sup> The negative values in the table above represent compressive stress, and positive values represent tensile stress.

From the results of the stress comparison results above, the conclusion that the absolute value of the cross-section stress in skewback and vault is the smallest when the arch-axis coefficient is 1.5 ~

1.7 under the effect of the most unfavorable fundamental combination effect and the most unfavorable standard combination effect. So the optimal arch-axis coefficient is 1.6.

#### 4. Conclusion

Generally, dead weight of the arch and dead load on the arch are taken into consideration to determine the optimal arch-axis coefficient, and the variable load such as shrinkage and creep of the arch rib concrete and the vehicle load hasn't been taken into account. However, for long-span deck-type concrete-filled steel tubular arch bridge, variable load accounts for a large proportion of the total load, and the shrinkage and creep of the arch rib concrete is unneglectable and exist permanently, so these loads should be taken into account in arch-axis coefficient optimization. By comparing the stress in skewback and vault, the optimal arch-axis coefficient that makes the least differences in these two parts can be obtained.

#### 5. References

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