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Partial Parameter Analysis of the Stability of Small and Medium Span Steel-concrete Composite Bridges

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Abstract **-** Based on a 3 × 35m steel-concrete composite beam bridge of a certain highway project, the finite element software is used to establish a non-linear solid model, and the stability safety factor is used as an evaluation index to perform parameter analysis on the stability and safety of small-span steel-concrete composite continuous beams. The corresponding influence law will be obtained. Except for the width-to-thickness ratio of the compressed flange, the stability and safety of 3 × 35m straight beams are better than those of curved beams in each parameter analysis, and the stability and safety of curved beams is more affected by various structural parameters. For 3 × 35m straight beams, from the perspective of stability, it is recommended to consider the 8.75m beam spacing to save steel. From the comprehensive consideration of structural stability and safety and the amount of steel used, it is recommended that the high-span ratio of medium-small-span steel-concrete composite beams be 1/20. Local buckling will occur in the relatively thin positions of the compressed flange and the web. The value of the width-to-thickness ratio of the compressed flange of a straight beam is suggested.

Keywords**:** Precast composite beam, Stability, Parametric analysis, Small and medium spans.

1. Introduction

With the rapid development of social economy and highway transportation, steel-concrete composite beam bridges with small and medium spans have been increasingly studied and applied. In the design of steel structures and composite structures, stability is an important point that must be considered. In the current code, only the formula for calculating the overall stability coefficient of I-shaped simply-supported beams and the relevant provisions on the limits of the width-to-thickness ratio of the wing and the height-to-thickness ratio of the web are given. Therefore, it is necessary to conduct in-depth analysis and research on the stability of small and medium span steel plate composite bridges.

2. Analysis Method and Content

Numerical analysis method: Elastoplastic stability analysis of ABAQUS finite element program. Evaluation index: Stability was evaluated by stabilizing the structure of the safety factor. The second type of stability evaluation index is adopted, Stability safety factor ξ:

$$\xi = \frac{F_s + \lambda F_c}{F_s + F_c} \tag{1}$$

Among them, F_s is the weight of the steel beam, F_c is the weight of the concrete bridge deck, and λ is the loading coefficient.

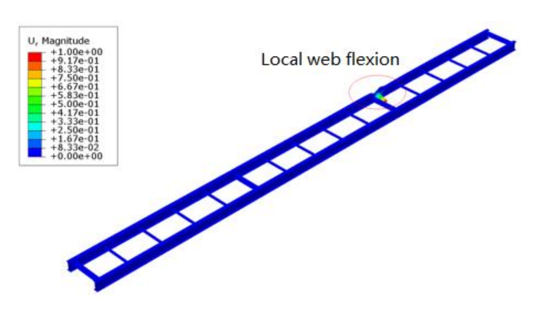

Fig. 1: First-order instability mode map.

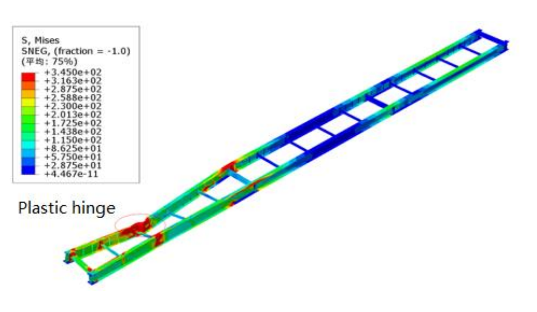

Fig. 2: Limit state stress mode map.

3. Parametric Analysis

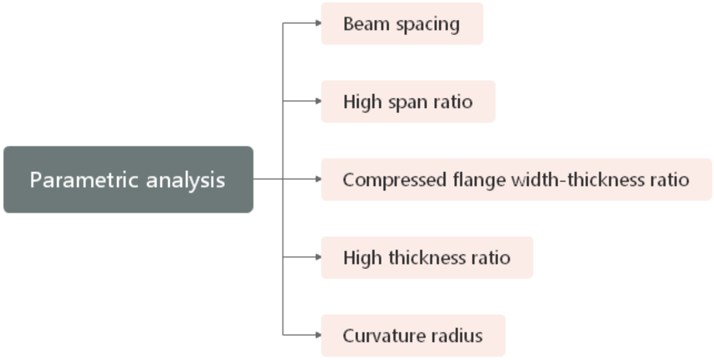

Fig. 3: Parametric analysis type diagram.

3.1. Beam Spacing

According to the principle that under the same load, the stress levels of the upper and lower flanges of the steel beam and the structural bearing capacity are the same. By changing the beam spacing in the model, we got the following data.

Table 1: Caption for table goes at the top.

Beam spacing / m	Load form	Loading factor λ	Stable ultimate bearing capacity KN/m	Stable safety factor	Normal stress at mid-span upper flange /Mpa	Instability mode
35	Uniform load	2.9	107.5	2.47	345	Lateral torsional instability
17.5	Uniform load	6.9	239.8	5.52	345	Lateral torsional instability
11.67	Uniform load	8	275.5	6.34	345	Lateral torsional instability
8.75	Uniform load	8.9	306.9	7.06	345	Web flexion
7	Uniform load	9	309	7.11	345	Web flexion

Table 2. Calculation results of Curved beam.

Radius /m	Beam spacing / m	Load form	Loading factor λ	Stable ultimate bearing capacityKN/m	Stable safety factor	Normal stress at mid-span upper flange /Mpa	Instability mode
460	35	Uniform load	2.4	88.7	2.04	345	Web flexion
460	17.5	Uniform load	5.1	117.9	4.1	345	Web flexion
460	11.67	Uniform load	5.9	205.7	4.74	345	Web flexion
460	8.75	Uniform load	7.5	258	5.94	345	Web flexion
460	7	Uniform load	8.5	290.2	6.68	345	Web flexion

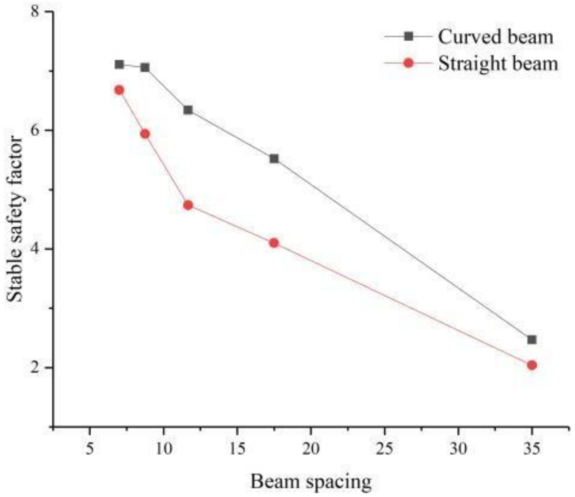

Fig. 4: Relationship between stability factor and beam spacing.

From the above chart, it can be found that as the distance between beams decreases, the stability safety factors of straight beams and curved beams gradually increase;

The stability limit bearing capacity and stability safety factor of beams with a spacing of 8.75m and 7m are almost the same. For 3 × 35m double I-shaped steel straight beams, from the perspective of stability, compared with the beam spacing of ≤7m commonly used in current engineering, the beam spacing of 8.75m can be used to meet the requirements of the specification.

3.2. High Span Ratio

According to the principle that under the same load, the stress levels of the upper and lower flanges of the steel beam and the structural bearing capacity are the same, the size of the upper and lower wing plates is changed as the beam height changes.

Table 3. Calculation results of straight beam.

High span ratio	Load form	Loading factor λ	Stable ultimate bearing capacity KN/m	Stable safety factor	Normal stress at mid-span upper flange /Mpa	Instability mode
1/18	Uniform load	9.1	310.7	7.15	345	Web flexion
1/19.44	Uniform load	9	309	7.11	345	Web flexion
1/21	Uniform load	8.3	285	6.59	345	Web flexion
1/24	Uniform load	7.8	269.3	6.19	345	Web flexion
1/27	Uniform load	7.5	259	5.91	345	Web flexion

Table 4. Calculation results of curved beam.

radius /m	High span ratio	Load form	Loading factor λ	Stable ultimate bearing capacity KN/m	Stable safety factor	Normal stress at mid-span upper flange /Mpa	Instability mode
460	1/18	Uniform load	9.4	318.2	7.32	345	Web flexion
460	1/19.44	Uniform load	8.5	290.2	6.68	345	Web flexion
460	1/21	Uniform load	8	271.5	6.3	345	Web flexion
460	1/24	Uniform load	7.1	243.5	5.6	345	Web flexion
460	1/27	Uniform load	5.6	193.5	4.39	345	Web flexion

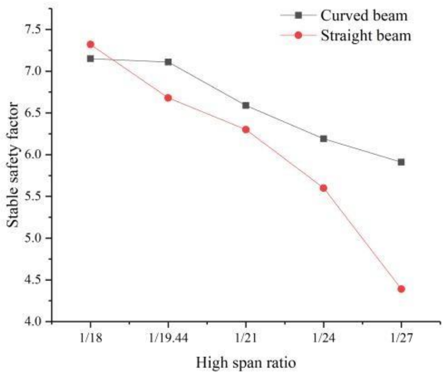

Fig. 5: Relationship between stability factor and high span ratio.

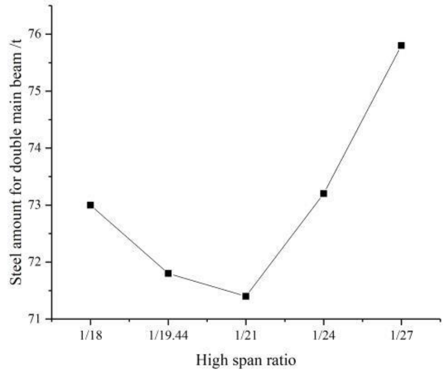

Fig. 6: Comparison of the amount of steel used in different high span ratio models.

It can be seen from the Figure 5 and 6, as the high-span ratio decreases, the stability and safety factor of the structure gradually decreases, and the two are basically in a linear relationship; the stability safety factor of curved beams is more affected by the high-span ratio; Comprehensive stability and safety and economic performance factors, for small and medium-span double-steel composite continuous beam bridge, it is recommended to adopt a high-span ratio of about 1/20.

3.3. Width-Thickness Ratio

By changing the width-thickness ratio in the model, we got the following data.

Table 5. Calculation results of straight beam.

Width-thickness ratio	Load form	Loading factor λ	Stable ultimate bearing capacity KN/m	Stable safety factor	Normal stress at mid-span upper flange /Mpa	Instability mode
8	Uniform load	9.3	317.6	7.33	345	Web flexion
10.7	Uniform load	9	309	7.11	345	Web flexion
13	Uniform load	8.8	299.5	6.91	345	Web flexion
14	Uniform load	7.4	255.5	5.89	345	Flap buckling
15	Uniform load	7.5	256.7	5.93	345	Flap buckling
17	Uniform load	7.4	254.7	5.87	345	Flap buckling

Table 6. Calculation results of curved beam.

radius /m	width-thickness ratio	Load form	Loading factor λ	Stable ultimate bearing capacity KN/m	Stable safety factor	Normal stress at mid-span upper flange /Mpa	Instability mode
460	8	Uniform load	8	274.4	6.33	345	Web flexion
460	10.7	Uniform load	8.5	290.2	6.68	345	Web flexion
460	13	Uniform load	8.8	300.3	6.92	345	Web flexion
460	14	Uniform load	8.7	296.6	6.85	345	Web flexion
460	15	Uniform load	8.6	292.5	6.76	345	Web flexion
460	17	Uniform load	8.4	285.3	6.58	345	Web flexion

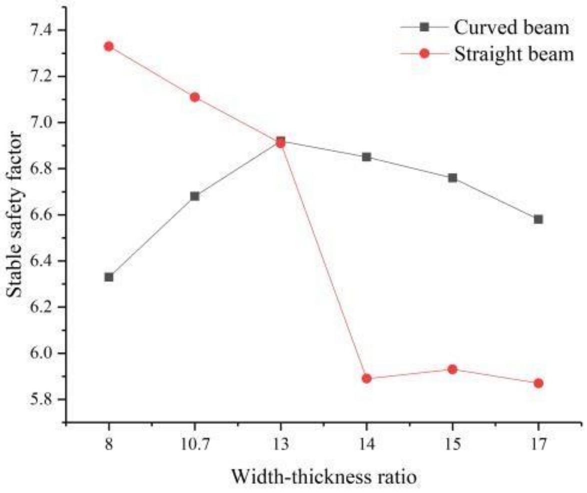

Fig. 7: Relationship between stability coefficient and aspect ratio.

From the Figure 7, it can be seen that with the increase of the width-to-thickness ratio of the compressed flange, the stability safety factor of the straight beam gradually decreases, and the stability safety factor of the curved beam is basically unchanged.

For straight beams, local buckling of steel beams will occur in relatively weak areas of both the compressed flange and the web. Studies have shown:

When the height-to-thickness ratio of the web is 50 to 80, the width-to-thickness ratio of the compressed flange can be calculated according to Equation:

$$\frac{b}{t} = 0.02119\left(\frac{h_0}{t_f} - 34.685\right)^2 + 19.177 \tag{2}$$

When the height-to-thickness ratio of the web is less than 50, the width-to-thickness ratio of the compressed flange is taken as 12 according to specifications;

When the height-to-thickness ratio of the web is greater than 80, the width-to-thickness ratio of the compressed flange may be the minimum value that meets the requirements of the stress, the construction, and the arrangement of the shear pins.

3.4. High thickness ratio

By changing the high thickness ratio in the model, we got the following data.

Table 7. Calculation results of straight beam.

High thickness ratio	Load form	Loading factor λ	Stable ultimate bearing capacity KN/m	Stable safety factor	Normal stress at mid-span upper flange /Mpa	Instability mode
64	Uniform load	9	309	7.11	345	Web flexion
80	Uniform load	8.4	287.9	6.64	345	Web flexion
100	Uniform load	7.7	265.6	6.13	345	Web flexion
120	Uniform load	7.2	248.8	5.74	345	Web flexion
140	Uniform load	6.7	230.6	5.32	345	Web flexion
160	Uniform load	5.9	206.2	4.76	345	Web flexion

Table 8. Calculation results of curved beam.

radius /m	High thickness ratio	Load form	Loading factor λ	Stable ultimate bearing capacity KN/m	Stable safety factor	Normal stress at mid-span upper flange /Mpa	Instability mode
460	64	Uniform load	8.5	290.2	6.68	345	Web flexion
460	80	Uniform load	7.4	256.2	5.9	345	Web flexion
460	100	Uniform load	6.2	214.8	4.94	345	Web flexion
460	120	Uniform load	4.8	166.6	3.83	345	Web flexion
460	140	Uniform load	3.7	132.4	3.05	345	Web flexion
460	160	Uniform load	2.9	106	2.44	345	Web flexion

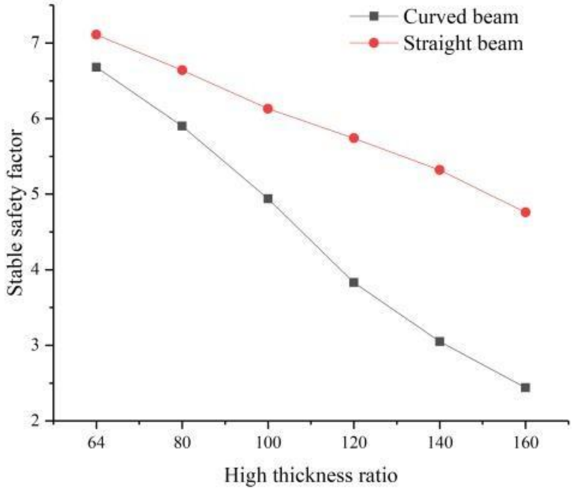

Fig. 8: Relationship between stability factor and high thickness ratio.

As can be seen from the Figure 8, as the height-to-thickness ratio of the web increases, the stability and safety factor of the structure gradually decreases, and the two are basically in a linear relationship;

The stability safety factor of curved beams is more affected by the web height-thickness ratio

3.5. Curvature Radius

By changing the curvature radius in the model, we got the following data.

Table 9. Calculation results of curved beam.

radius /m	Center angle / °	Load form	Loading factor λ	Stable ultimate bearing capacity KN/m	Stable safety factor	Normal stress at mid-span upper flange /Mpa	Instability mode
1000	6	Uniform load	9	309	7.11	345	Web flexion
800	7.5	Uniform load	8.9	305.4	7.03	345	Web flexion
600	10	Uniform load	8.8	299.7	6.9	345	Web flexion
500	12	Uniform load	8.7	296.3	6.82	345	Web flexion
460	13.1	Uniform load	8.5	290.2	6.68	345	Web flexion
200	30.1	Uniform load	6.7	231.9	5.34	345	Web flexion
100	60.2	Uniform load	4.7	165.3	3.81	345	Flap buckling

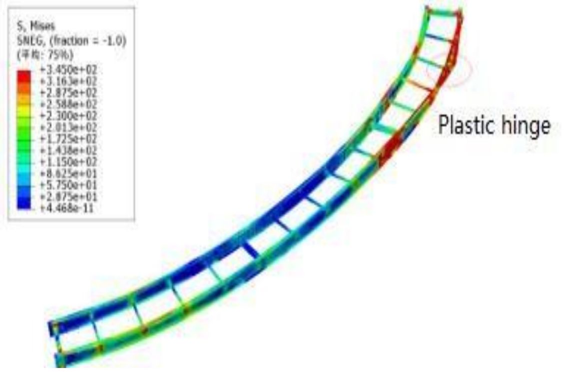

Fig. 9: Curved beam stress cloud map.

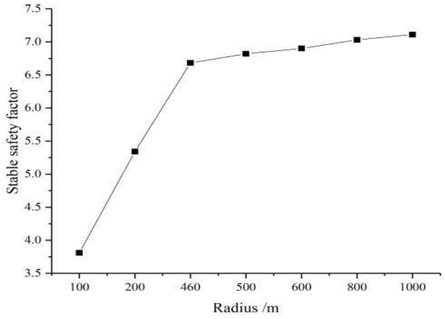

Fig. 10: Relationship between stable safety factor and radius of curvature.

From the Figure 9 and 10, it can be seen that with the increase of the radius of curvature, the stability and safety factor of the structure gradually increases. The factor grows faster when radius = 100~500m, and the growth is more stable when radius = 600~1000m. All of outer main beam are unstable first.

4. Conclusion

Except for the width-to-thickness ratio of the compressed flange, the stability and safety of 3 × 35m straight beams are better than curved beams in the analysis of various parameters, and the stability and safety of curved beams are more affected by various structural parameters.

For 3 × 35m straight beams, from the perspective of stability, it is recommended to consider the 8.75m beam spacing to save steel.

From the comprehensive consideration of structural stability, safety and steel consumption, it is recommended that the high-span ratio of medium-small-span steel-concrete composite beams be 1/20.

Local buckling will occur in the relatively thin positions of the compressed flange and the web. The value of the width-to-thickness ratio of the compressed flange of the straight beam is suggested.

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