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Research Article

Case Study on 4000 m-span Cable-stayed Suspension Bridge

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Abstract: This study describes the case studies for a cable-stayed suspension bridges proposed over the Tsugaru Strait, Japan. Center Bridge is designed as a compound bridge of suspension bridges and cable-stayed bridges with 4000 m super-long-span. Case studies about the effects of cable-stayed bridge length, the design of sub-cable, height and stiffness of main tower, type of foundation and length of side span on displacement were carried out. With appropriate design of above parameters, the compound bridge can reduce horizontal displacement of main tower and vertical deflection in the central portion and enhance resistance to partial loading. The study reports the results based on these case studies.

Keywords: Cable-stayed suspension bridge, case study, compound bridge, Tsugaru Strait Bridge

INTRODUCTION

Among the proposals for Tsugaru Strait Bridge, one is a compound bridge of suspension bridges and cable-stayed bridges with 4000 m super-long-span (Wang *et al.*, 1999). Near to the main towers, cable-stayed bridges and pre-stressed concrete decks are adopted; it can enhance rigidity and endure the great axial compression force (Yukitake *et al.*, 1998). In the center of span, suspension bridges and steel box decks stiffened by trusses are adopted, it can reduce self-weight and the space between girders will contribute to aero-elastic stability. RCFT main tower, RC shell pier and RCFT jacket foundation can enhance rigidity and reduce self-weigh. As a new kind bridge, the influences of compound component parameters are needed to analyze (Satoshi, 1998). Therefore, Case studies about the effects of cable-stayed bridge length, the design of sub-cable, height and stiffness of main tower, type of foundation and length of side span on displacement were carried out.

INFLUENCES OF EFFECTING PARAMETERS ON DISPLACEMENT CHARACTERISTICS

Effect of compound bridge and sub-cables: The difference of displacement characteristics between the proposal and cable-stayed suspension bridge and pure suspension bridge were studied (Yang, 1999), as shown in Fig. 1. The same centre span, steel decks and towers with cable-stayed suspension bridge are set for all the models. Model B is simply combined cable-stayed bridges with suspension bridges. At the joint of two types of bridge, rigid coupling are proposed to keeping the displacement continuity of decks. The length of cable-stayed bridge is the same to tower height (400 m). All the loads on suspension bridge section are carried by three main cables. Model A is based on model B and designed sub-cables between the suspension and cable-stayed bridge sections. All the loadings on section of suspension bridge are carried by three main cables and added sub cables. Model C is a pure suspension bridge with two 4000 m main spans.

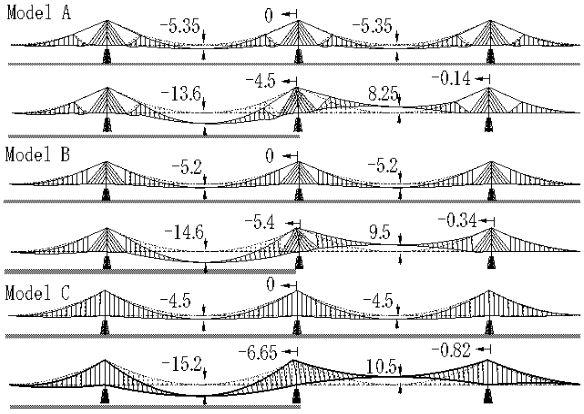

Fig. 1: Effect of compound

According to the results of Static FEM analysis shown in Fig. 1, it was found that under the uniform loading, the model A and B have greater displacement than model C, appearing the displacement characteristics of suspension bridge. Under the partial loading, cable-stayed bridge sections strengthened the

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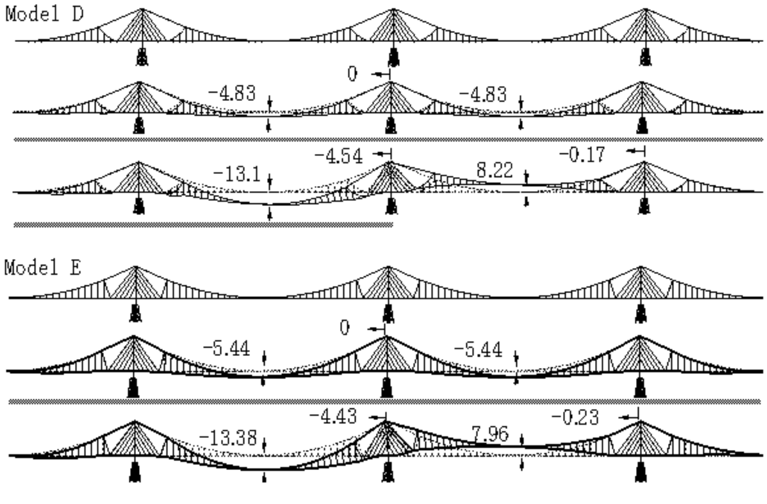
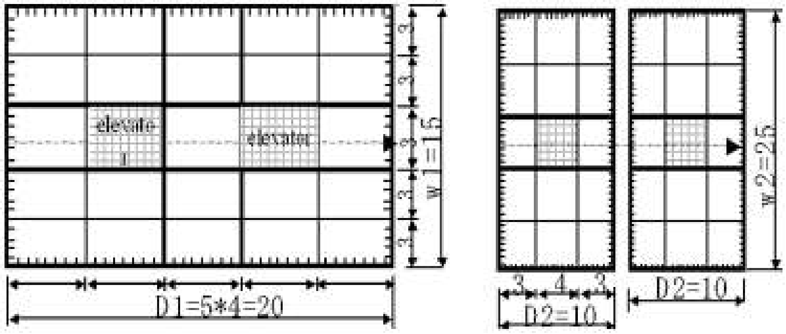


Fig. 2: Effect of sub-cable



Up section Down section

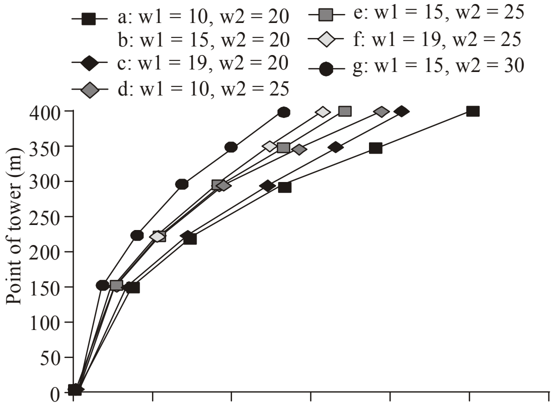


Fig. 3: Effect of rigidity displacement increases in sharp curve

rigidity of main tower and decreased horizontal displacement of main tower and vertical deflection of span centre; compound bridges have better displacement characteristics than pure suspension bridge.

Figure 2 shows the effect of sub-cables (Niels, 1998). The added sub-cables in model A almost have no effect on decreasing downward deflection, but it seems that it could decrease horizontal displacement of main tower and upward deflection of the central portion in partial load. If sub-cables joints were dropped 20 m down to forming curved sub-cables, all members of hanger would be in a state of tension in any live loading case. The curved sub-cables can decrease the deflection under uniform load and the deflection under partial loading. When the sub-cables are set in vertical

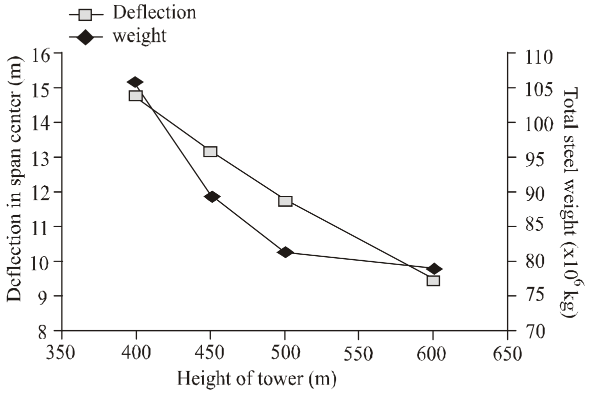


Fig. 4: Effect of tower height

direction of main cables as model E, it can decrease the horizontal displacement of main tower and deflection of the central portion in partial load. With appropriate design of sub-cable, the model would carry partial loading more uniformly than linear sub cables.

Effect of tower stiffness and height: The towers use CFT structures as shown in Fig. 3. Concrete is filled to strengthen the tower stiffness. Light concrete is used in the upper portion to reduce self-weight and general concrete is used in the lower portion to endure the powerful reaction. The sizes D1 and D2 are decided by structural requirement, therefore, main tower stiffness determined by the size of w1 and w2. With the cross section increase of upper portion, horizontal displacement of main tower is decreasing at the same Ratio with upward deflection of center, but the decrease ratio of downward deflection is smaller. Decrease ratio of horizontal displacement for main tower at the size from 10 to 15 m is bigger than that from 15 to 19 m, respectively. For the design of upper portion a (w1 = 10 m, w2 = 20 m), horizontal.

This means the stiffness of upper portion is not enough. Increasing the cross size of upper portion, horizontal displacements of lower portion almost do not change, but that of upper portion decrease greatly. At the size of w1 = 15 m, horizontal displacement of upper portion becomes nearly linear and becomes linear at w1 = 19 m. Considering structure cost, size of upper portion w1 = 15 m is suitable.

Increasing the size w2 of lower portion can reduce horizontal displacements of tower more effectively. For example, design b (w1 = 15 m, w2 = 20 m) and d (w1 = 10 m, w2 = 25 m) with the same volume of materials, but design d reduces the horizontal displacements of tower top 14% than b. For design e (w1 = 15 m, w2 = 25 m), the horizontal displacement of tower top is 1/117 of tower height and vertical deflection of centre is 1/350 of span, arriving to the allowable limitation of displacement.

For long span suspension bridge over 1000 m, the averaged sag span ratio is about 9.3 to 10.5; for the proposal in this study, optimum sag span ratio is 8.9 to 10. Namely, the reasonable height of tower is 400 m to 450 m. To consider the optimum sag span ratio, four models with different tower height 400, 450, 500 and 600 m, respectively were analyzed under the condition of 0.9 Ta≦T≦Ta, where T and Ta are the maximum tensile and the allowable tensile of main cables respectively; The galvanized stranded tensile strength is assumed to be 1960 N/mm^2. Figure 4 shows the effect of tower height on deflection in span center and the total steel weight. The maximum deflection in span center almost decreases linearly with the increase of tower height. However, the total steel weight decreases sharply with the increasing of tower height from 400 to 500 m and decreases only a little from 500 to 600 m, respectively.

Effect of length of cable-stayed bridge and side span: To describe the effect of cable-stayed bridge length, three types of cable-stayed suspension bridge with different ratios of stayed length to suspension length were analyzed. Length of cable-stayed bridges is 1, 1.5 and 2.0 times the length of main tower, namely 400, 600 and 800 m long, respectively. The 600 m

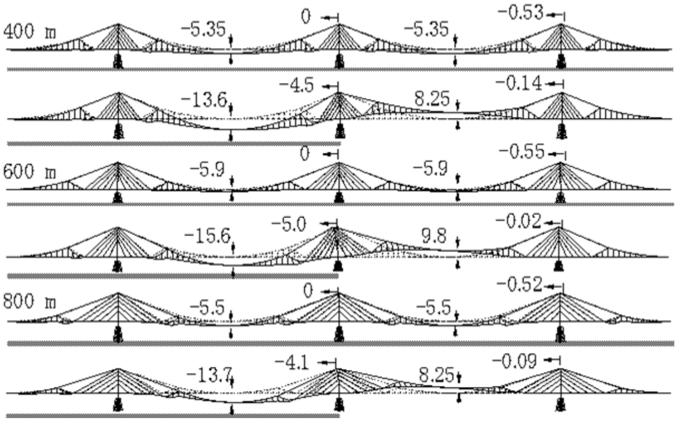


Fig. 5: Effect of cable-stayed bridge

Table 1: Effect of side span on displacement

Span		Maximum disp. of tower (m)		Deflection in half load (m)		Deflection in partial load (m)	
s1-side span; s2-center span	s2/s1	Half load	Partial load	Downward	Upward	Downward	Upward
A:s1 = 2000, s2 = 4000	2.00	4.54	4.34	13.69	8.36	16.41	8.01
B:s1 = 1800, s2 = 4000	2.22	4.89	4.67	14.90	9.01	17.20	8.60
C:s1 = 1600, s2 = 4000	2.50	4.57	4.33	14.79	8.51	16.57	8.09
D:s1 = 1500, s2 = 4000	2.67	4.53	4.36	15.01	8.36	16.60	8.05

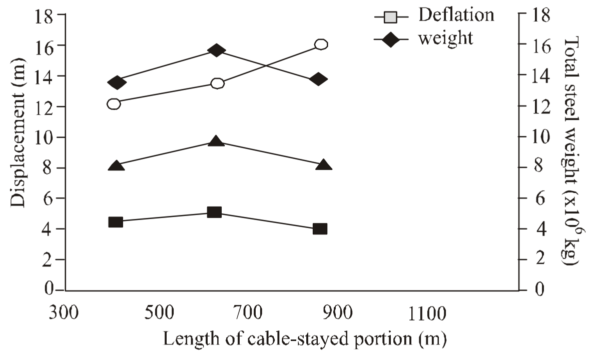


Fig. 6: Displacement and steel weight

model always produces the biggest horizontal displacement at tower top and deflection at span center under any load case and 400 m model has the same displacements with 800 m model (Fig. 5). On the other hand, the total steel weight of 400 m model is the least among three models, as shown in Fig. 6. On this standpoint, it could be said that reasonable length of cable-stayed bridge maybe is the length of main tower. The length of side span is also another important parameter influencing the displacement characteristics of compound bridge.

Table 1 shows four types of side span length, the ratio of center span to side span is 2.00 to 2.67. At the ratio of 2.22, the model appears the worst, producing the biggest displacement both in tower and span. At the ratio of 2.00, the model is the best. At the ratio of 2.67, produced displacements are almost the same to model A, only that the displacements in half live load are bigger a little.

CONCLUSION

Above analyses show us some new conclusions as follows:

As a compound bridge, the proposal has better displacement characteristics than suspension bridge. Especially, compound bridge can decrease horizontal displacement of main tower and upward deflection at the midpoint of span in partial load effectively. The added sub-cables in compound bridge can decrease horizontal displacement of main tower and upward deflection at the midpoint of span in partial loading effectively. It can enhance the resistance to partial loadings.

The suitable height of main tower is at the range of 400 to 450 m. The suitable length of cable-stayed bridge is one times the height of main tower and the length of side span is half of the length of center span.

Above conclusions is useful for next step study of optimum design of structures-program.

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