STATIC AND SEISMIC CHARACTERISTICS OF MULTI-SPAN CABLE STAYED BRIDGE

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1. INTRODUCTION

Multi-span cable stayed bridge is a new and elegant structure. It is introduced as a modern solution for bridges in need of far-reaching extensive spans. Despite, its structural characteristics are not well understood and, in particular, the seismic behaviors are not clarified. Tower of multi-span cable stayed bridge plays important role in static and seismic behaviors of the structure.

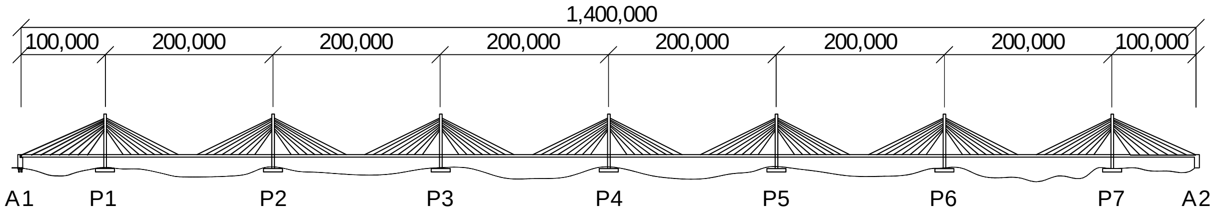

Fig.1 Layout of bridge (mm)

This paper shows how three types of towers in particular; steel/concrete hybrid, RC (Reinforced concrete) and steel towers affect the static and seismic behaviors of multi-span cable stayed bridge. The hybrid tower is basically a sandwich type double steel box section filled with concrete, the RC tower consists of a rectangular hollow section and the steel tower is made of steel box section. For this study Millau bridge in France is taken as an example.

First, static analysis is carried out with critical live load distribution patterns. Bending moment and displacements found and compared. The dimension of towers was determined at this stage.

Second, non-linear elasto-plastic seismic analysis is conducted with three types of towers. The girder is free to move longitudinally. The medium strong and ultra-strong earthquake (L1-EQ, L2-EQ) waves according to Japanese Seismic Code for Highway Bridges were adopted. Three support conditions of the girder at the tower were considered: movable, connection with linear springs and bilinear springs. Dynamic response of the towers with different supports were compared. The restorability of the towers were verified.

2. STATIC ANALYSIS

The side view of the multi-span cable stayed bridge with 8 spans (100+6@200+100) and 7 towers is shown (Fig.1). The tower is H-shape and has 57m height (Fig.2). The girder is an orthotropic girder with a width of 18.8 m and height of 2.2 m (Fig.3). Pre-stressed cables are arranged in two planes. Cross-section of towers under study is shown in Fig.4. Three dimensional FEM model of the bridge consisting of fish-bone beam elements is established (Fig.5). The girder is supported vertically and transversely at the towers but moves longitudinally.

Static analysis is carried out for dead load (D) and the design live loads (L) with three types of towers. The design live loads consist of the uniformly distributed loads p2 of 3.5 kN/m^2 and the equivalent to concentrated loads p1 of 10.0 kN/m^2 with a longitudinal width of 10 m. These design live loads are taken from the Japanese specifications for highway bridges [4]. Three live load cases, LC1, LC2 and LC3 are considered (Fig.6). LC3 which is applied to the alternate spans, produced the maximal effects to the towers compared to LC1 and LC2.

Table 1 shows bending moment at the base and displacement at the top of tower P4 for three types of tower. The displacement and bending moment is kept zero at the dead load stage. But they increase with application of LC1 and reaches maximum with LC3. In all load cases smallest displacement obtained with RC tower followed by hybrid and further increased with steel tower. On the other hand bending moment was largest in RC and smallest with steel tower. Fig. 7 shows the deformed state of bridge due to D+LC3. In P4 RC tower attained 320 mm displacement three time smaller than steel with 880 mm and twice less compared to hybrid tower with 793 mm. Because the bending stiffness of RC tower is much larger and the confined concrete of hybrid tower restricts deformation.

Table 1 Displacement and bending moment of tower P4

Tower type	Longitudinal displacement at the tower top (mm)			Bending moment at the tower base (MN·m)		
	D	D+LC1	D+LC3	D	D+LC1	D+LC3
RC	0	26	128	0	20	101
Hybrid	0	61	375	0	9	57
Steel	0	69	432	0	7	46

Fig.8 shows the longitudinal bending moment distribution throughout towers P2-P4. Although there is significant difference in the behaviors of three types of towers but the tendency is inverse to the displacements: steel and hybrid tower obtained at least twice smaller bending moment compared to RC tower.

Keywords: Multi-span cable stayed bridge, RC tower, Hybrid tower, Steel tower, Static analysis, Seismic analysis
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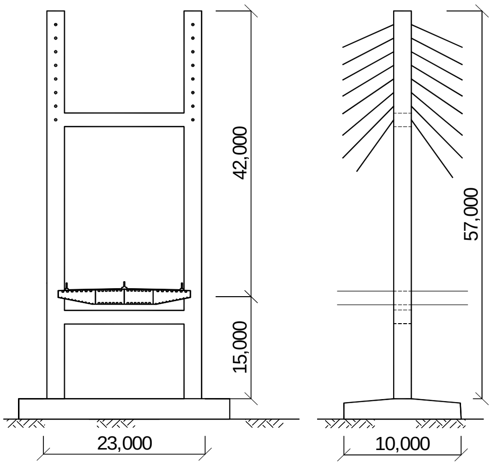


Fig.2 Tower side view and cross-sections (mm)

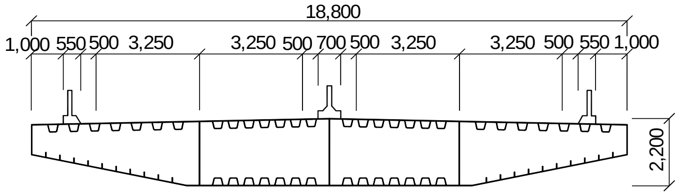


Fig.3 Girder cross-section (mm)

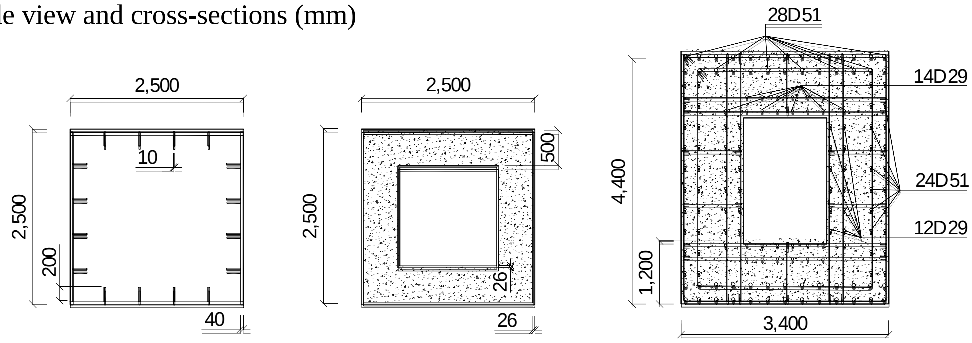


Fig.4 Cross-section of towers (mm)

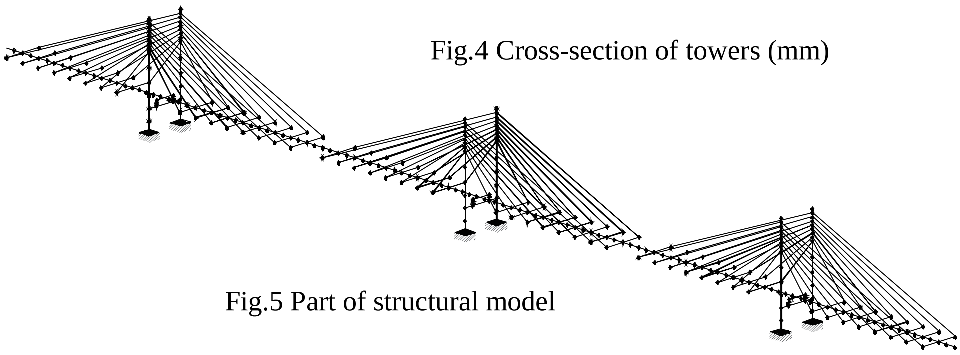


Fig.5 Part of structural model

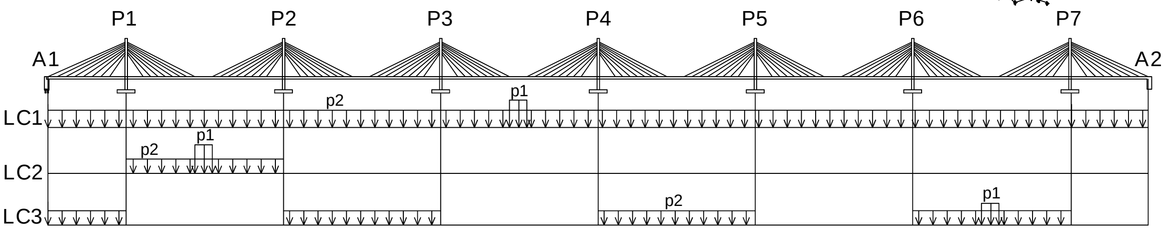


Fig.6 Live load cases

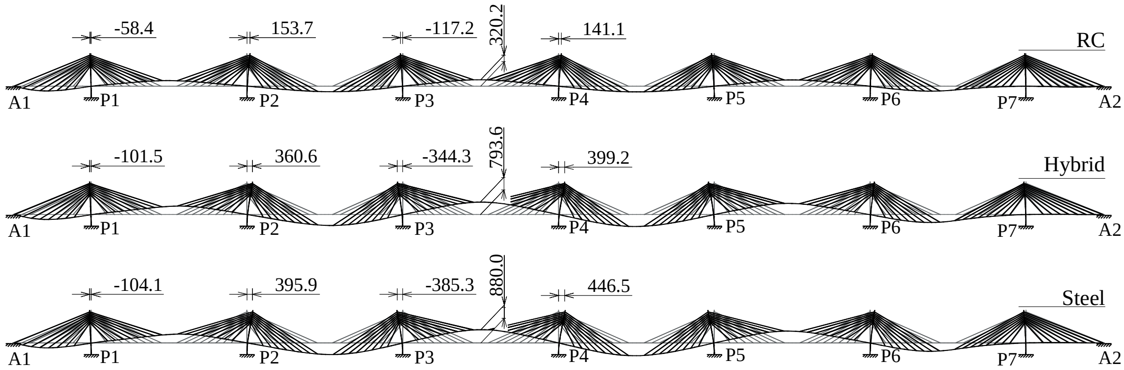


Fig.7 Displacement of bridge elements with RC, hybrid and steel tower due to D+LC3 (mm)

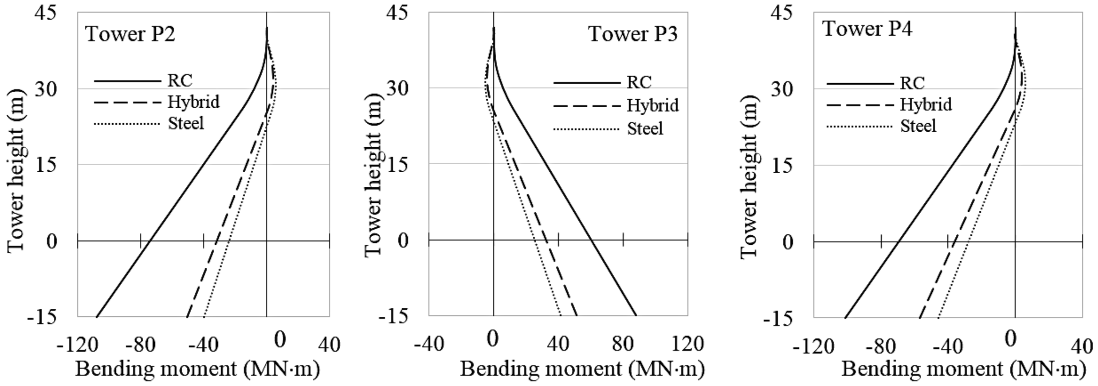


Fig.8 Bending moment of three types of tower due to D+LC3

3. SEISMIC ANALYSIS

Seismic analysis is conducted by accounting the geometrical and material non-linearity. The medium strong and ultra-strong earthquake waves (L1-EQ, L2-EQ) according to Japanese Seismic Code for Highway Bridges were adopted (Fig. 9). For L1-EQ the structural elements should be within their elastic limits and no damage is allowed to the bridge. Plastic behavior is permitted for L2-EQ such that, crossing of emergency vehicles is not interrupted in event of an earthquake. To carry on seismic analysis cross-section of towers is divided into small fiber cells. At each fiber cell is attributed the constitutive law either for concrete, steel reinforcement or steel plate. Hard and good ground condition is assumed. Ground motions are applied to the longitudinal direction of bridge, as it is critical than those of transverse and vertical directions.

Three supports of the girder at the tower is assumed; movable (MOV), connected with linear springs (LS) and connected with bilinear springs (BLS) (Table 2). These springs only controls the longitudinal displacement of girder and are fixed in other directions. The LS follows only elastic modulus K1. BLS follow elastic modulus K1, reaches yield displacement δy then follows second modulus K2. This bilinear hysteretic property produces energy absorbing effect.

Seismic analysis executed with three types of towers. The displacement and bending moment are found for all type of towers. The maximum responses presented in this chapter. Fig.10 illustrates the displacement at the top of tower P4 due to L2 for three types of tower with MOV springs. Displacement of RC tower is smaller than those of hybrid and steel towers. Response of hybrid tower with different springs are shown in Fig.11. The displacement is smallest with BLS, followed by LS and further increased with MOV.

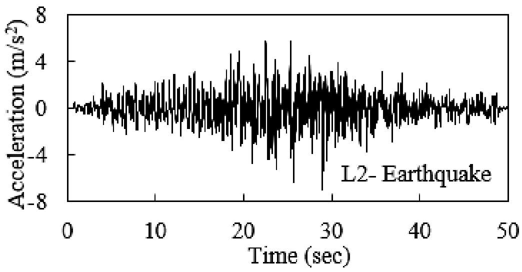
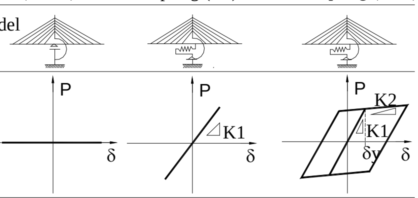


Fig. 9 Seismic waves for L2 earthquake

Table 2 Girder and tower connection models

	Movable (MOV)	Linear Spring (LS)	Bilinear Spring (BLS)
Spring model			
P-□			
K1	-	11,000 kN/m	33,000 kN/m
K2	-	-	4,950 kN/m



The bending moment-curvature hysteresis of RC tower in combination with different springs is shown in fig.12. Plastic hinge developed at the base of tower P4 with MOV however the response is elastic with BLS. The LS is good in reducing displacements but not the intensity of bending moment. Fig.13 shows bending moment-curvature hysteresis at the base of towers. Hybrid tower showed exceptional energy dissipating property whilst keeping elastic behavior.

Fig.14 presents maximum responses of three types of tower due to L1 and L2 earthquakes. The steel tower attained the least bending moment and the largest displacement. Dynamic displacement and bending moment with MOV spring was maximum compared to BLS. Responses with BLS was minimum and the behavior of LS was in between. This is because the hysteretic property of BLS absorbs energy. BLS was very effective in controlling the dynamic responses of towers, especially with steel tower.

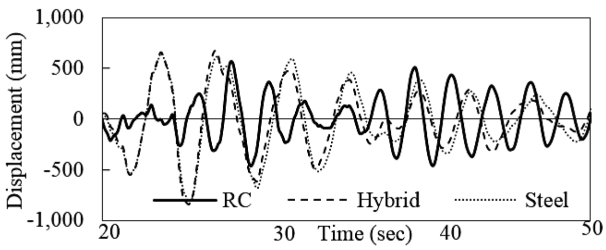


Fig.10 Displacement at the top of tower P4 due to L2 (MOV)

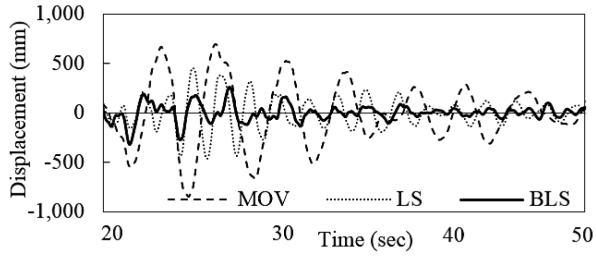


Fig.11 Displacement at the top of hybrid tower P4 due to L2

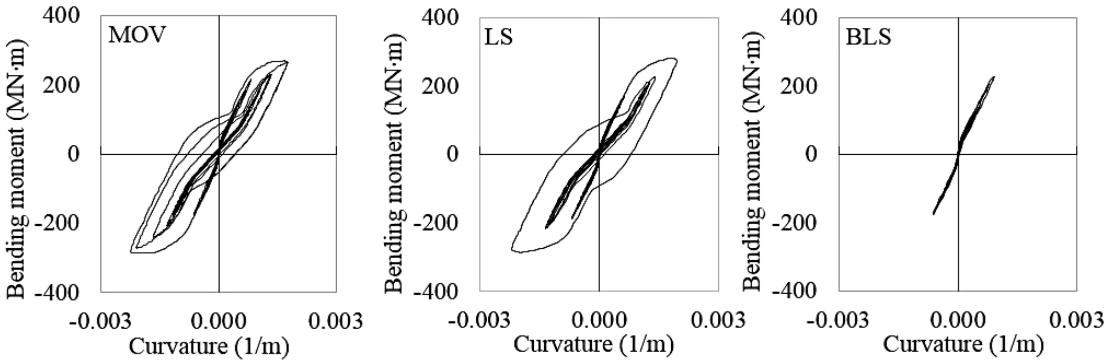


Fig.12 Bending moment-curvature hysteresis at the base of RC tower P4 due to L2

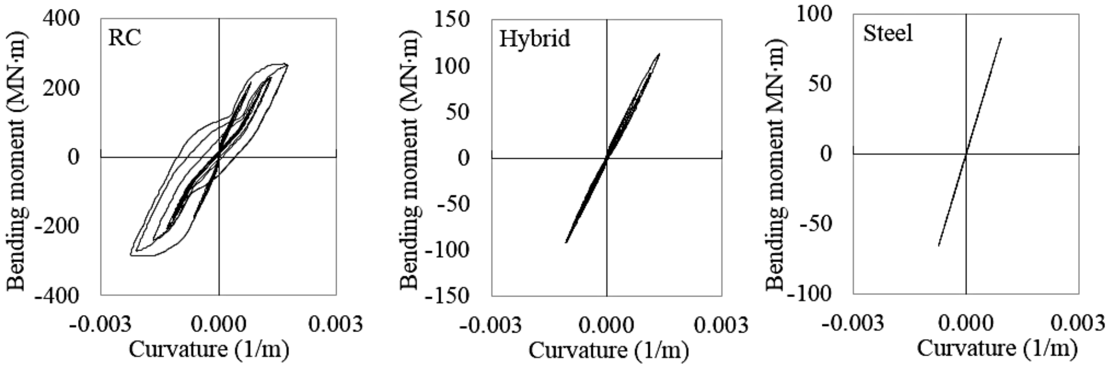


Fig.13 Bending moment-curvature hysteresis at the base of tower P4 due to L2 (MOV)

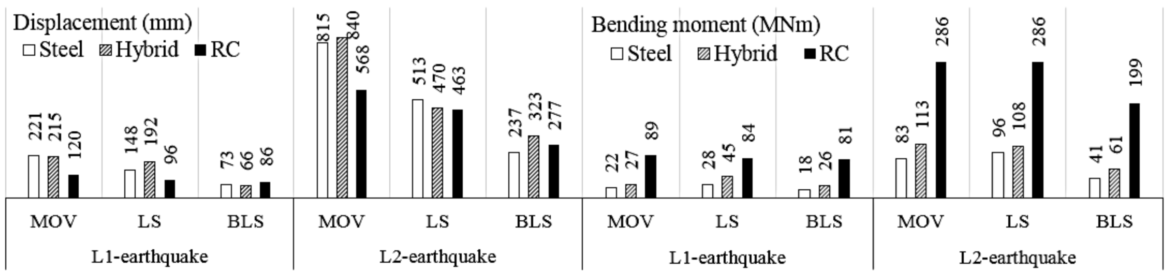


Fig.14 Peak dynamic displacement and bending moment of tower P4 due to L1, L2

4. Conclusion

A study is conducted to clarify static and seismic behavior as well advantage of three types of towers for a multi-span cable stayed bridge. Steel/concrete hybrid tower, RC tower and steel tower. It is explained that all three types of towers are feasible from static and seismic aspects. RC tower showed triple less displacement and several times larger bending moment in contrast to other towers. Steel tower had the largest displacement but the least bending moment. In addition, the seismic properties are described for three kind of springs at girder and tower connection. The bilinear spring is very effective in reducing the dynamic response of all the towers. The minimal dynamic response of bridge is achieved at steel tower with BLS assemblage.

In conclusion, RC and hybrid tower showed very good static features plus energy dissipating behavior during earthquake. BLS used with steel tower was very effective in reducing the dynamic displacement and bending moment.

References

[1] Nakamura, S.: New Structural Forms of Steel Concrete Composite Bridges, Structural Engineering International, Journal of IABSE, Vol.10, No.1, 2000, pp. 45-50.

[2] Okamoto, Y.: Static and seismic studies on steel/concrete hybrid towers for multi-span cable-stayed bridges, Elsevier, Journal of Constructional Steel Research, 67, 2011, pp. 203-210

[3] Virlogeux, M.: Bridges with multi-span cable-stayed spans, Structural Engineering International, Journal of IABSE, Vol.11, No.1, 2001, pp. 61-81.

[4] Japan Road Association: Specifications for highway bridges, I. General, IV. Seismic Design, 2002.

[5] Japanese Association of Civil Engineers: Guidelines for performance verification of steel–concrete hybrid structures. 2006