Evaluating the behavior of architectural pylons of cable-stayed bridges

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Abstract. The cable-stayed bridge is considered a bridge with beautiful architecture. In recent years, engineers have researched using non-traditional bridge pylon types or adjusting the cable arrangement on the pylon and girder to enhance the architecture, uniqueness, and attractiveness. Constructing a highly aesthetic bridge pylon requires complex structural solutions and higher material costs. The bridge pylon is a significant compression and bending structure. The traditional solution is straight-element pylon branches. However, curved pylon branches are increasingly applied to enhance aesthetics. Meanwhile, the behavior of the curved pylon branches is much more complicated than that of the straight element, and so is the material cost. Therefore, this paper studies the behavior of the curved pylon which is also compared to those with the straight pylon in an actual bridge, i.e., the Song Hieu cable-stayed bridge in Quang Tri province, Vietnam.

Keywords: pylon of cable-stayed bridges, curve pylon, Song Hieu Bridge, H shape pylon.

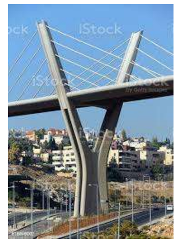
1 Introduction

The cable-stayed bridge is considered a bridge with beautiful architecture. Many cabled-stayed bridges were constructed in the last 20 years and have become famous bridges with unique architecture. The solutions for the beautiful architecture of these bridges mainly focus on the design options such as changing the arrangement of stay cable, the number of pylons, and the shape of pylons as well. Some typical pylon forms were designed as A-shaped pylons, H-shaped pylons, or a hybrid between the A-shaped and H-shaped pylons (see Figure 1) [1].

Several recent cable-stayed projects with unique architecture have proposed designs of pylons with curved shapes as shown in Figure 2. In Vietnam, a bridge with a curved lotus-bud-shaped pylon (i.e., the Song Hieu Bridge in Quang Tri province) has been built and is prepared to be opened.

Euripos Bridge, Evripos Bridge; Greece (H shape pylon)

The Mary Avenue Bicycle Footbridge in California, USA. (A shape pylon)



Wadi Abdoun Bridge or the Kamal Al-Shair Bridge. Amman, Jordan (Y shape pylon)

Rion-Antirion Birdge in Greece (diamond shape pylon)

Fig. 1. Different pylons available for cable-stayed bridge [1]

Samuel Beckett bridge - the newest bridge over the river Liffey in Dublin, Ireland. The shaped pylon is curved in the shape of a harp

Architecture of cable-stayed bridge over Yongding river in beijing city

Song Hieu Bridge in Quang Tri province, Viet Nam with curved lotus-bud-shaped pylon [6]

Fig. 2 Pylon shape of some bridges in the world and in Viet Nam

The pylon is an essential structure that affects not only the bridge's aesthetics but also the behavior of that pylon and other components. Since the bridge pylon is a significant compression and bending structure, the impacts they cause are not minor [3]. Many studies have analyzed the effects of the height of a pylon on the response of a bridge [5] and compared different types of pylons [1, 2, 4].

For the aesthetic bridge pylons, their responses are more complex. According to the revision and independent calculation analysis of the Song Hieu bridge, the present study carries out a more detailed analysis of the behavior of a curved pylon and compares them with that of an H-shaped pylon (columns of the pylon are straight). The results indicate differences in the behavior of curved pylons compared to that of straight pylons. Hence, suggestions can be provided for the alternate design of the pylons of aesthetic cable-stayed bridges.

2 The pylon of Song Hieu Cable-stayed Bridge and problems for analysis

2.1 The pylon of Song Hieu Cable-stayed Bridge

Song Hieu Bridge is a bridge that passes over the Hieu River in Quang Tri province, connecting the Northern Hieu River area with Dong Ha City. This is a cable-stayed bridge with two 100-meter-length spans in which its total length is approximately 210.2m. The bridge is designed with two planes, and the pylon is in the middle of the bridge [6].

Interestingly, a unique feature of this project is that the outermost stay cable is anchored to a lower point than the inner stay cables. Consequently, the innermost stay cable is anchored to the highest point. The Song Hieu Bridge exudes a lotus-bud-like look through the architectural proposal of the bridge pylon which consists of 3 parts with a soft curved shape rising from the foundation to meet at the top of the pylon.

Fig. 3 Song Hieu Bridge in Viet Nam [6]

The width of this bridge, B, is 23.7 m at the normal position and 26.9 m at the expanded position for trees. In which [6]:

- The carriageway consists of 4 lanes, each lane is 3.75 m wide. Hence the total width for vehicles is 15 m (Bxe = 3.75 x 4);
- The width of the median strip and railings on both sides is 2 m (Bat = 1.0 x 2)
- The width of the median strip in the middle is 1.5m (Bpc = 0.5 x 3)
- The width at the areas of extension for cable-stayed layout and pedestrian margin is 6.2 m (Bcap = 3.1 x 2) and 9.4 m (Bcap = 4.7 x 2) corresponding to the normal position and position to plant trees for landscaping.

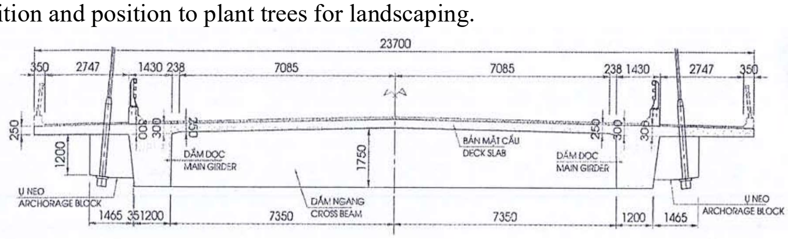


Fig. 4 The cross-section of the girder for Song Hieu Bridge in Viet Nam [6]

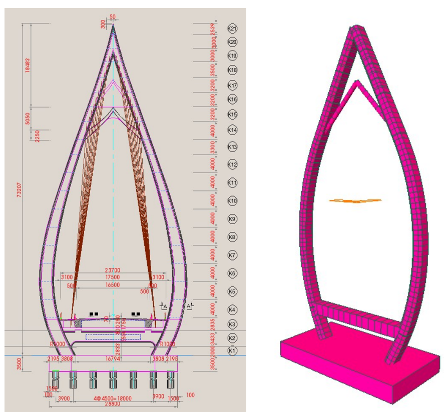
The stay cables are anchored to the pylon by saddle-type anchors at the top of the pylon. All two columns of the pylon body are reinforced by the horizontal beams supporting the span and the horizontal beams at the top of the pylon where the saddle is arranged. The cross beams have was made with a rectangular shape. The horizontal beam supporting the span has a length of more than 20m. The rectangular cross-section at the two ends connects to the curved and hollow pylon body column in the middle of the span. The horizontal beams are arranged with prestressed cables with 8 bundles of 19-strand 15.2 mm cables stretched at both ends.

The corners of the pylon with a solid body cross-section are rounded by a radius of R=500 mm. The pylon has a height of 73,21 and 65 m from the top of the foundation and from the deck to the top of the pylon, respectively.

2.2 The problem for analysis

The lotus bud pylon of Song Hieu Bridge is analyzed based on the global model problem, evaluating both static and dynamic behavior under impact of loads. These results are compared with analyzed data during the stage design and with a similar H-shaped pylon bridge. Thus, two problems for the analysis are as follows:

Problem 1:



The dimension of the pylon's body varies from 2 to 5,075m horizontally, and from 2.9m to 4m along the bridge.

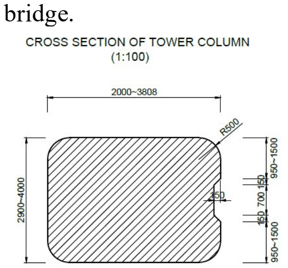


Fig.5 The detail of the pylon of Song Hieu Bridge and its simulation for analysis

Problem 2:

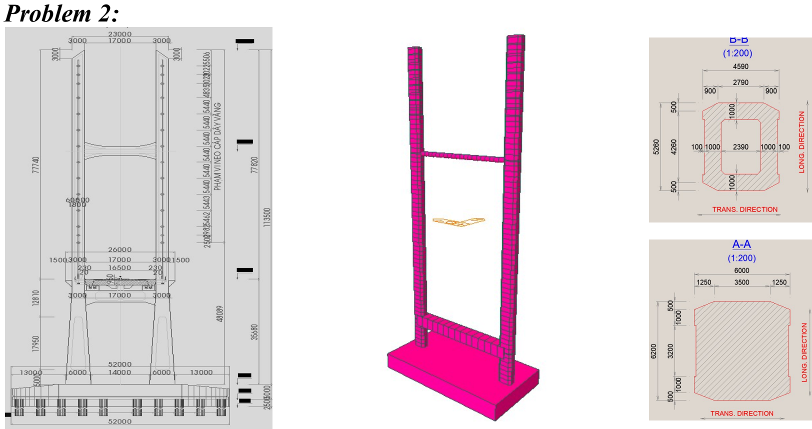


Fig. 6. H-shaped cable-stayed bridge similar to Song Hieu bridge in Viet Nam and its simulation for analysis.

The technical parameters such as the geometric characteristics of the two pylons are similar in models for analysis as below:

The pylon is made of concrete with a class of C50 (f'c = 50Mpa)

The elastic modulus of concrete is 36.397 Mpa

Both two pylons are modeled with 2 fixed connection points; one is at the transverse beam to support the girder and one is on the top of the pylon at the edge stayed cable connection to the pylon.

3 Results and discussions

The comparison of the response of the pylon of Song Hieu Cable-stayed Bridge with the same height H sharp pylon will be presented in detail in Sections below.

3.1 Comparison in terms of static action

The Axial force of the curved pylon is similar and not much larger than that of the H-shaped pylon at most cross-sections of the pylon. Especially, the axial force along the height of the H-shaped pylon and the axial force of the curve pylon at the footing cross-section are not significantly different. Particularly, this value in the case of the curve pylon is 1.25 times compared with that of H-shaped pylon.

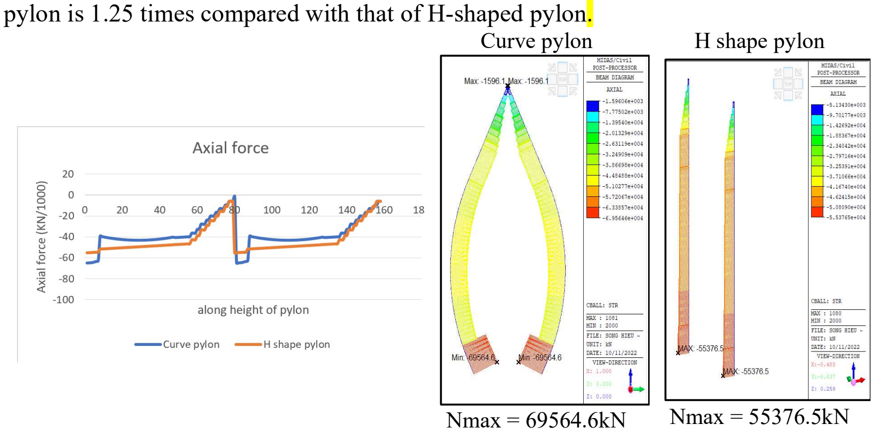
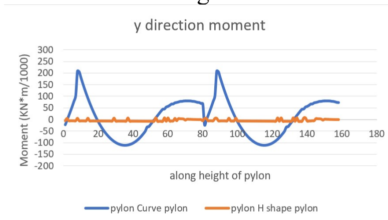


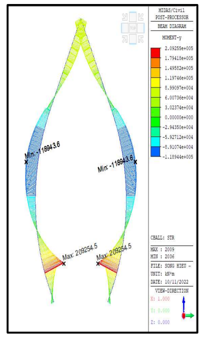
Fig. 7. Comparison of the axial force

The horizontal moment of the curved pylon is much larger than that of the H-shaped pylon at most cross-sections of the pylon. These maximum values for the curved pylon is larger than 5.7 times for H-shaped pylon.

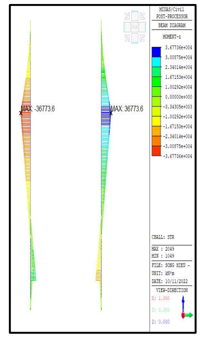
curve pylon H shape pylon

Similar to the axial force, the horizontal moment of the curve pylon is larger than that of the H-shaped pylon at the footing cross-section.





Mmax=209254.5(kN.m)

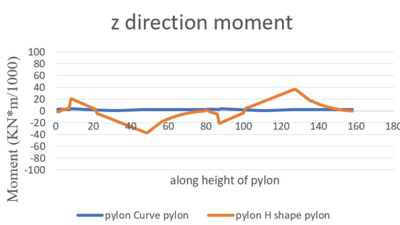


Mmax = 36773.6 (kN.m)

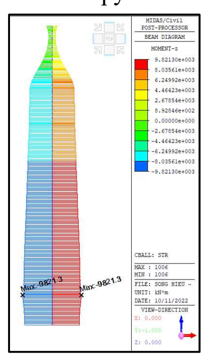
Fig. 8. Comparison of the horizontal moment

The longitudinal moment of the curve pylon is much larger than that of the H shape pylon at most cross-sections of the pylon.

Especially, there is a reversal of the maximum value position. For the H-shaped pylon, the maximum value position is the position of the edge stayed cable connect to the pylon, while the maximum value position of the curve pylon is the footing of the pylon.

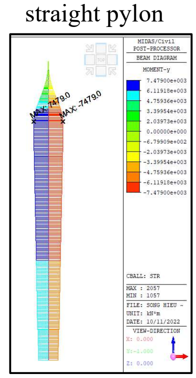


curve pylon



Mmax=9821.3(kN.m)

straight pylon

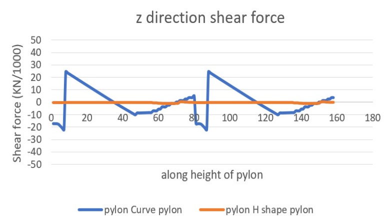


Mmax=7479(kN.m)

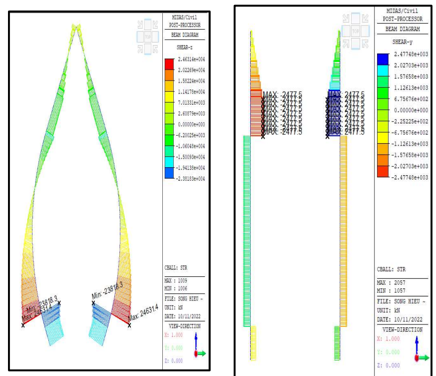
Fig. 9. Comparison of the longitudinal moment

The horizontal shear force of the curved pylon is much larger than that of the H shape pylon at most cross-sections of the pylon.

Especially, there is a reversal of the maximum value position. For the H-shaped pylon, the maximum value position is the position of the edge stayed cable connect to the pylon, while the maximum value position of the curve pylon is the footing of the pylon. That is similar to the longitudinal moment.



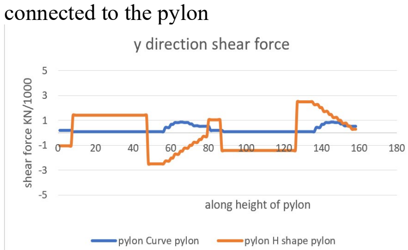
curve pylon straight pylon



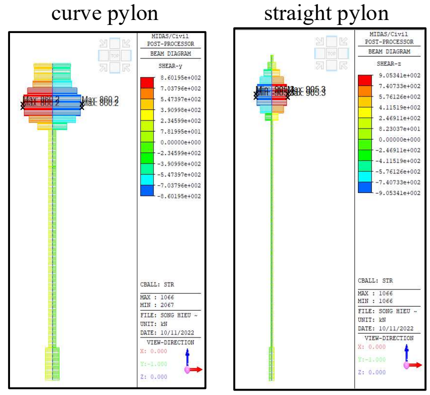
Fmax = 24631.4 (kN) Fmax = 2477.5 (kN)

Fig. 10. Comparison of the horizontal Shear force

The longitudinal shear force of the curve pylon is much larger than that of the H-shaped pylon at most cross-sections of the pylon. This is focusing the anchored of stayed cable connected to the pylon



curve pylon straight pylon



Fmax = 860.2 (kN) Fmax = 905.3 (kN)

Fig. 11. Comparison of the longitudinal Shear force

3.2 Comparison in terms of dynamic action

The dynamics of any structure are governed by a simple equation of motion mentioned in Eq. 2, assuming the damping coefficient to be zero [2].

$$MU + KU = F(t) = 0 \ [2]$$

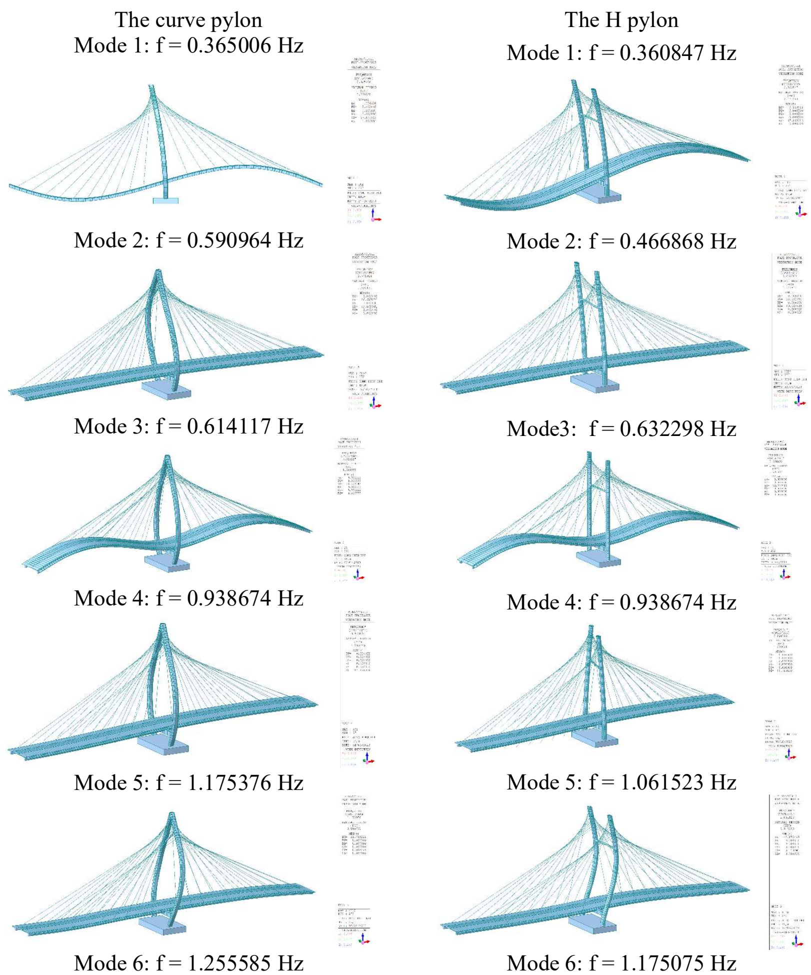
The modal analysis is carried out for two scenarios with 2 cases of the pylon of cable-stayed bridge: curve pylon and H shape pylon. The dynamical analysis results are as follows:

Table 1: Dynamical analysis results

No	Contents	Song Hieu pylon		Equivalent H-shaped pylon	
1		Frequency of pylon (Hz)	Time period (s)	Frequency of pylon (Hz)	Time period (s)
	Mode 1	0.365006	2.739678	0.360847	2.77126
	Mode 2	0.590964	1.692151	0.466868	2.141934
	Mode 3	0.614117	1.628355	0.632298	1.581533

No	Contents	Song Hieu pylon		Equivalent H-shaped pylon	
1		Frequency of pylon (Hz)	Time period (s)	Frequency of py-lon (Hz)	Time period (s)
	Mode 4	0.938674	1.065333	0.926766	1.079021
	Mode 5	1.175376	0.850791	1.061523	0.942043
	Mode 6	1.255585	0.796442	1.175075	0.85101

The first 6 vibration modes of both analysis cases show that the natural frequency of the bridge pylon in the two analysis cases is not too different from one another. Hence, they can be considered similar. However, the curve pylon obtains a higher stiffness than the H-shaped pylon due to the 2 parts of the body pylon connecting at the top of the pylon. Thus, the displacement of H shape pylon is more sensitive than the curve pylon.



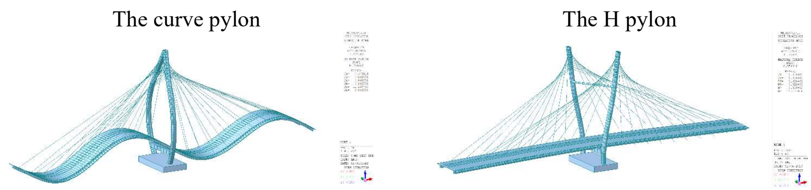


Fig. 11. Comparison of the frequency of the first 6 modes in dynamical analysis

There is a problem with the girder when this pylon is harder, at the mode 6^{th}. The pylon is torsion in different directions and the deflection of the girder with a curve pylon is larger than that of H shape pylon.

4 Conclusions

Based on the analysis conducted in the current study, the conclusions can be given as follows:

1. The curve pylon with two fixed connection points at the transverse beam to support the girder and at the top of the pylon at the edge stayed cable connection to the pylon made the curve pylon works as an arch structure; thus, the internal force at the footing of curve pylon is quite large compared to other cross-section and the similar bridge with the H-shaped pylon.
2. The curve pylon obtains a higher stiffness than the H-shaped pylon due to the two parts of the body pylon connecting at the top of the pylon.
3. The axial force of a curve pylon along the height is the same value as an H-shaped pylon except for the footing position of the pylon.
4. The moment and shear force of the curve pylon are different from the H shape pylon, and the trend is focused on the footing cross-section with the large value. Especially, there is a reversal in the position to reach the maximum value for the longitudinal moment.

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