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Experimental Study on Vortex-induced Vibration Performance of Torsional Rectangular Arch Rib

*Dang Jiamin[1)] and Li Jiawu[2)]

[1), 2)] *School of Highway, Chang'an University, Xi'an Shaanxi province, China*
[1)] *djm127@chd.edu.cn* [2)] *ljw@gl.chd.edu.cn*

ABSTRACT

Torsional rectangular configuration is a kind of novel atypical arch rib, thus it's significant to study the vibration mechanism of this form of structures. Performance of torsional rectangular sections with different torsional forms and twist angles have been studied by wind tunnel test and CFD simulation. As the typical potential sections for vortex-induced vibration, vault and the quarter span are selected to research the vibration responses. The results indicate that vibration amplitudes of symmetric form are greater than that of antisymmetric form at same twist angles. And the amplitude decreases as the torsion angle increases, but for certain torsional forms, galloping occurs.

1. INTRODUCTION

Arch bridge plays a very important role in the bridge engineering, enjoyed the characteristics of concinnity and strong span ability. The research on the arch bridge has achieved remarkable development in the recent years(Xiang et al. 2007; Xu et al. 2013; Yang and Ge 2013). The hinger, arch ring and girder are prone to wind-induced vibration problems by existing engineering experience and research results. However, the bridge structure as a landmark building, its shape is often ever-changing. And the outline of the structure has a significant impact on the aerodynamic performance, therefore it is very meaningful to study the wind-induced vibration problem of atypical element of arch bridge.

In the tall buildings, there are a kind of novel structural designs in the form of helica that expresses the aesthetics of rhythm, like Spiral skyscraper in Malmö, Sweden, Shanghai Center Building in China, Evolution Tower in Moscow and Mode Gakuen Spiral Towers in Nagoya. Researchers who studied tall buildings wind resistance (Bandi et al. 2013; Kim et al. 2018; Kim et al. 2015; Spence S M J 2008; Y.C. Kim 2014), insisted that this kind of structural shape can significantly reduce the wind loads and decrease the mean and fluctuating displacement responses, compared with

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[1)] Graduate Student
[2)] Professor

square model. This type of structural form also appears in the design of the arch bridge. However, low stiffness and damping are the common properties for the large-span bridges, thus it is necessary to research what changes will be made to the aerodynamic performance of the structure by the application of the torsional structure.

The basic section of research object is rectangular configuration, a typical blunt body, so the probability of appearance of vortex-induced vibration (VIV) is very high. VIV is a kind of self-limiting vibration, impacting the driving safety and fatigue problems. Trans-Tokyo Bay Bridge, Rio-Niteroi Bridge, Great East Belt Bridge and Xihoumen Bridge had obvious VIV phenomena (Battista and Pfeil 2000; Fujino and Yoshida 2002; Hui et al. 2011; Larsen et al. 2000). In this paper, wind tunnel test for a rotatable segmental model is carried out for an atypical arch rib and the full-scale aeroelastic wind tunnel test and numerical simulation are planned to be operated to profoundly study.

2. WIND TUNNEL TEST SETTINGS

2.1 Model design

Wind tunnel tests were conducted in a boundary layer wind tunnel at the Ch-01 wind tunnel, Chang'an University, China. The facility is a closed-circuit wind tunnel, and test section is 15 m long with a cross-section 3 m wide by 2.5 m high. To simulate the twist shape of the arch rib, the design length of the segment model is 1.8m that is consisted of 18 independent parts, and each part is 10 cm and twistable, shown in Fig. 1. The entire section model was attached to a rigid suspending arm at each end and then suspended by springs as shown in Fig. 2.

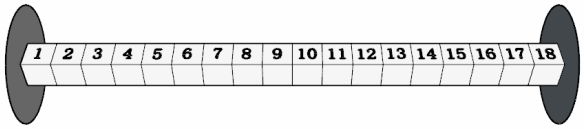


Fig.1 Model division and numbering (ORM)

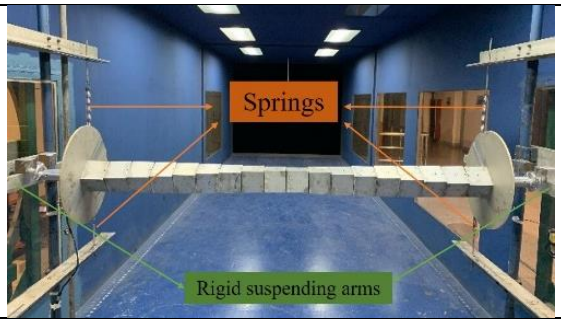
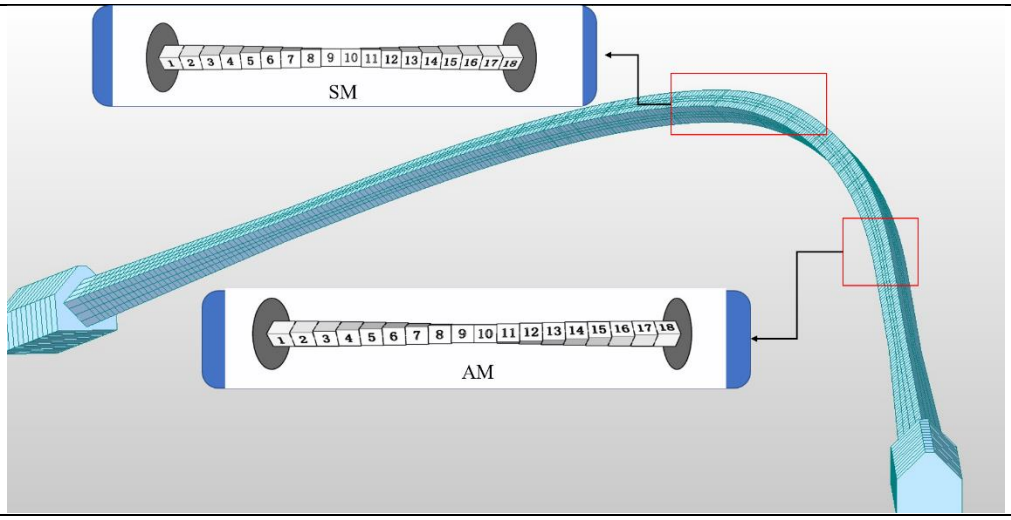


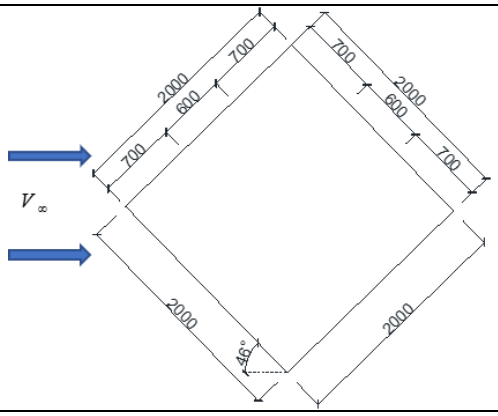
Fig.2 Segment model in ChD-01 wind tunnel

2.2 Case design

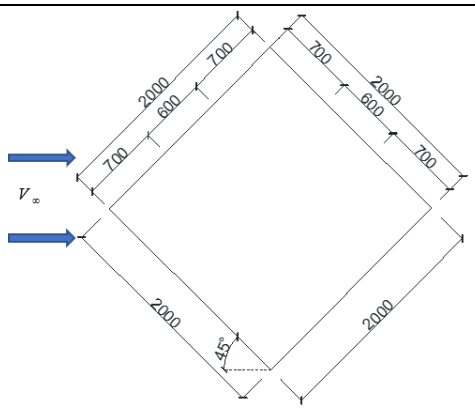
As to research the twisted form of different positions in arch rib, the middle position (9th and 10th blocks) is 0°, and the angle of both ends (1st and 18th blocks) are rotated from 5° to 45, and the rotation ways are symmetry(SM) and anti-symmetry(AM), which has been considered to simulate the structural configuration of arch dome and quarter point, and the related forms are shown in Fig.3. Comparative experiment is the overall rotation model (ORM), which is widely used in overpass bridges, shown in the figure 1. The specific experimental contents are shown in the table 1. The influence of twisted angle can be studied, and comparing three conditions, the most unfavorable configurational form and twisted angle can be summarized.



a) Diagram of torsional arch rib



b) Cross-section in dome (Unit: mm)



c)Cross-section in quarter point (Unit: mm)

Fig.3 Test model patterns [Anti-symmetric model (AM), Symmetric model (SM)]

Tab.1 Parameters of example toroidal drive system

	Twisting Angle
Symmetrical Twist	5° ~0° ~5° 、8° ~0° ~8° 、10° ~0° ~10° 、15° ~0° ~15° 、20° ~0° ~20° 、30° ~0° ~30° 、45° ~0° ~45°
Anti-symmetrical Twist	5° ~0° ~ -5° 、8° ~0° ~ -8° 、10° ~0° ~ -10° 、15° ~0° ~ -15° 、20° ~0° ~ -20° 、30° ~0° ~ -30° 、45° ~0° ~ -45°
Overall Rotation	0° ~0° ~0° 、5° ~5° ~5° 、10° ~10° ~10° 、15° ~15° ~15° 、20° ~20° ~20° 、30° ~30° ~30° 、45° ~45° ~45°

3. AERODYNAMIC OSCILLATION

From the nondimensional vertical bending amplitude, the results of the three test conditions are compared from Fig.4-5. The VIV responses of SM are larger than that of AM at any twist angles, both of which are larger than the VIV amplitude of ORM when the rotation angles are less than 15°. Fig.4 shows that, at the rotation angle of 13° and 45°, VIV responses have been eliminated for ORM. While for the torsional models, the variation of nondimensional amplitude decreases with the twist angle 0°-45°, and at the angle of 45°, VIV is eliminated. It should be noted that, in the specific twist angles, galloping occurs in SM (5° and 8° twist angle), AM (8° twist angle) and ORM (0° rotation angle) at high wind velocity.

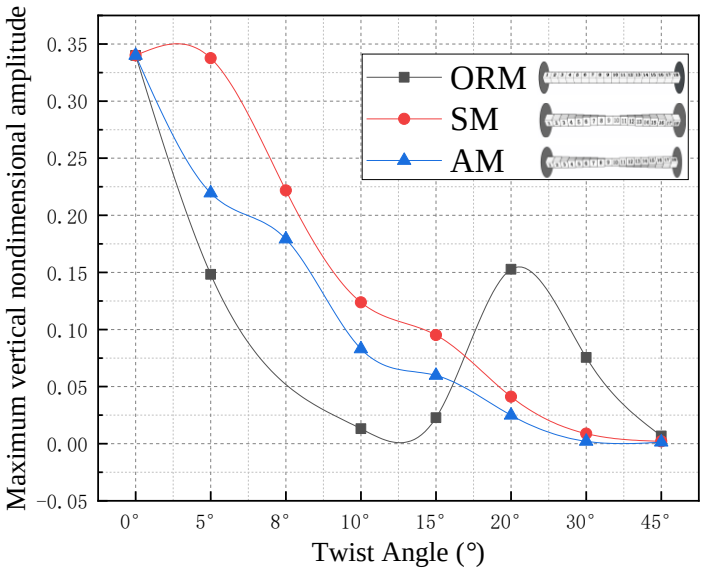


Fig.4 Variation of maximum nondimensional vertical amplitude

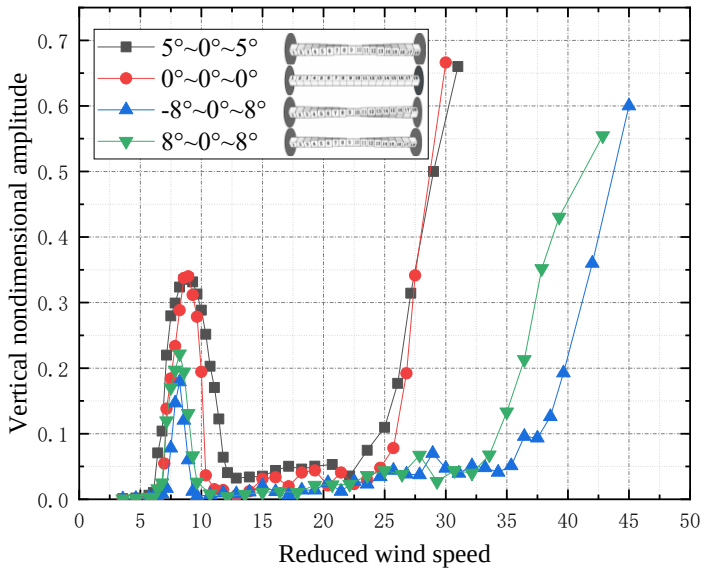
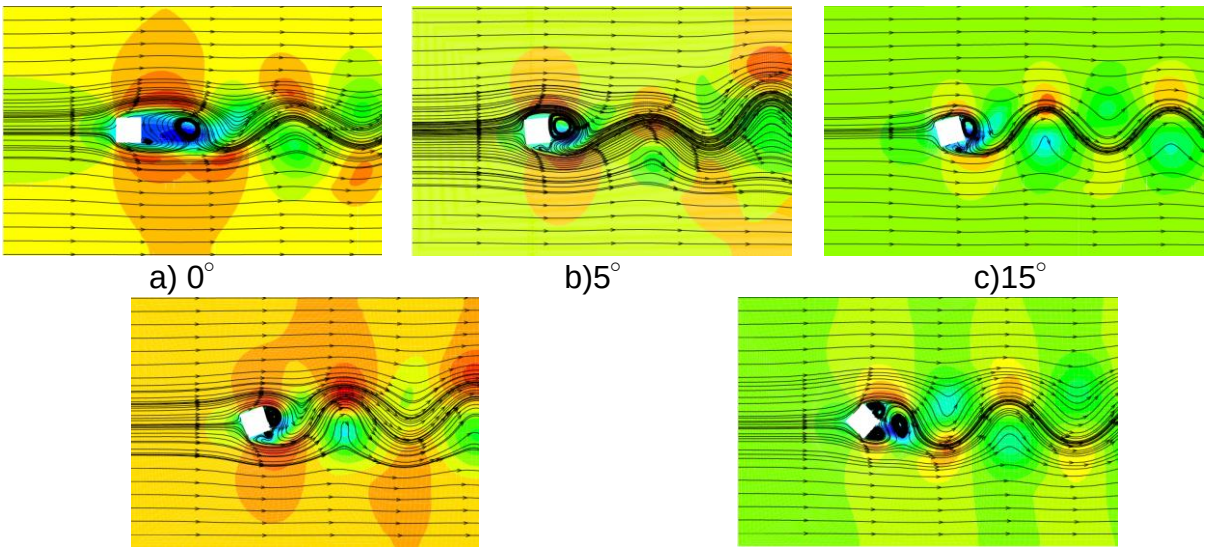


Fig.5 Galloping in certain conditions

4. FLOW FIELD ANALYSIS

Based on the numerical simulation method, the flow field properties of the twisted rib can be modeled to analyze the oscillation mechanism. In this paper, the influence of the twist angle can be simulated by the two-dimension CFD.



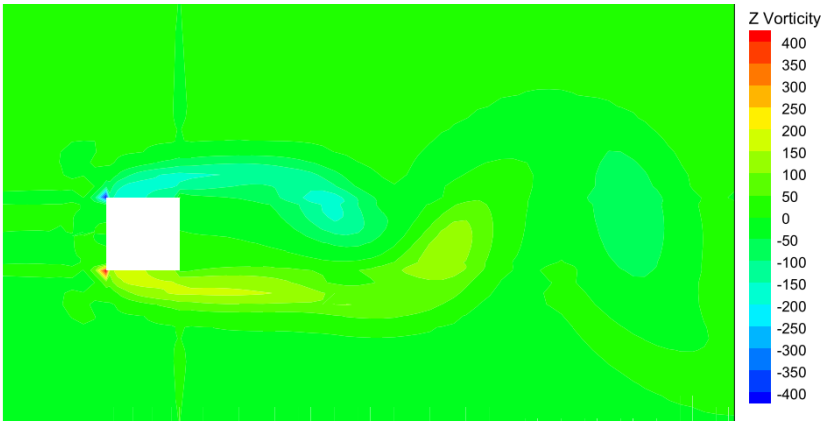
a) 0° b)5° c)15°

d)20° e)45°

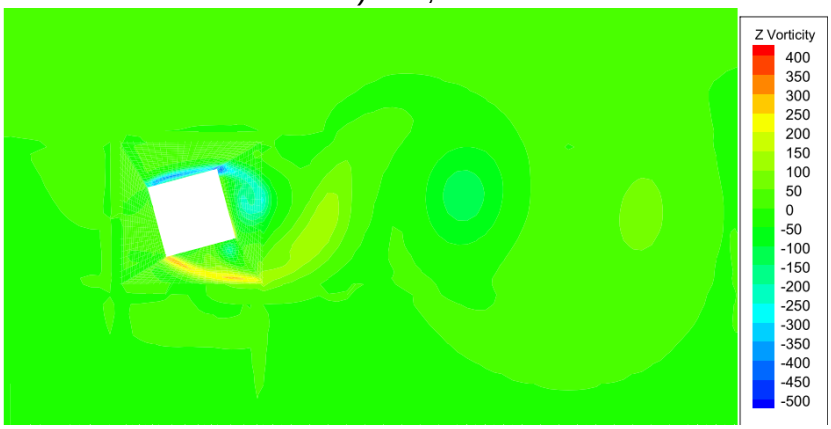
Fig.6 Streamline diagram for each twist angle

From the Fig.6, it can be indicated that, when the upper edge vortex is formed, a small vortex is formed on the lower edge simultaneously. And as the twist angle bigger, the size of the lower vortex become larger. So, it is can be explained from this perspective that, in the Fig.4 for the ORM, the maximum amplitude decreases with the increase of twist angle, because the lower vortex offsets part of the effects of the upper vortex, so the vibration is eliminated at the twist angle of 45.

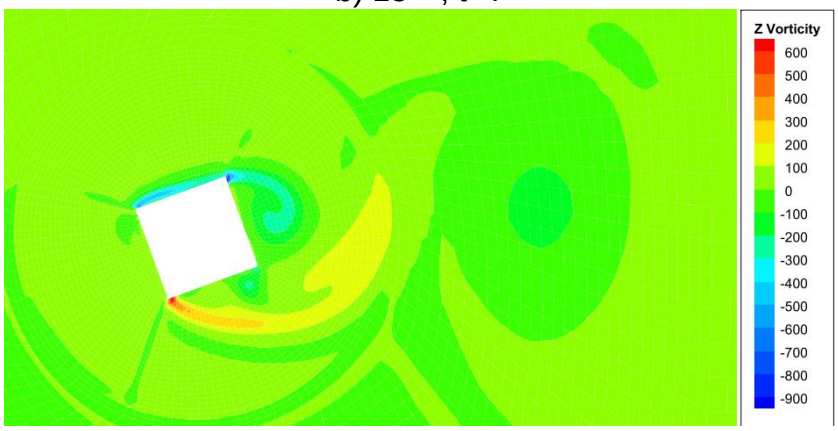
The vortex-induced vibration is significant induced by the vortex shedding, therefore, the vortex properties are also necessary to be simulated. Based on the Fig.6, streamline diagrams of 0°, 15°, 20° can clearly show the flow field changes, so vortex can be analyzed in the three conditions. Fig.7 shows that as the twist angle increases, the position of shedding vortex is closer to the downstream of the rectangle.From the view of vortex, the effect of the vortex on the structure is related to the vorticity and the position of the vortex. Combined with wind tunnel test results, it can be suggested the vorticity may be more important for the VIV.



a) 0° , t=T



b) 15° , t=T



c) 20° , t=T

Fig.7 Vortex diagram for each twist angle

5. CONCLUSION

For the atypical arch rib, the special aerodynamic shape can cause different structural responses, comparing with conventional rib. Experimental analysis indicates that the twisted configuration will decrease the VIV amplitude, improve the VIV performance of the rectangular rib. However, in some certain conditions, galloping

phenomenon appears at high wind velocity with atypical shapes. Numerical analysis can give the visual flow field that as the twist angle is bigger, the lower vortex offsets more part of the effects of the upper vortex and the vorticity may be more important factor than position of vortex in analyzing VIV.

REFERENCES

Bandi, E. K., Tamura, Y., Yoshida, A., Chul Kim, Y., and Yang, Q. (2013). "Experimental investigation on aerodynamic characteristics of various triangular-section high-rise buildings." Journal of Wind Engineering Industrial Aerodynamics 122, 60-68.

Battista, R. C., and Pfeil, M. S. (2000). "Reduction of vortex-induced oscillations of Rio–Niterói bridge by dynamic control devices." Journal of Wind Engineering and Industrial Aerodynamics, 84(3), 273-288.

Fujino, Y., and Yoshida, Y. (2002). "Wind-Induced Vibration and Control of Trans-Tokyo Bay Crossing Bridge." Journal of Structural Engineering.

Hui, L., Laima, S., Ou, J., Zhao, X., Zhou, W., Yu, Y., Li, N., and Liu, Z. (2011). "Investigation of vortex-induced vibration of a suspension bridge with two separated steel box girders based on field measurements." Engineering Structures, 33(6), 1894-1907.

Kim, W., Yoshida, A., Tamura, Y., and Yi, J. H. (2018). "Experimental study of aerodynamic damping of a twisted supertall building." Journal of Wind Engineering & Industrial Aerodynamics, 176, 1-12.

Kim, Y. C., Bandi, E. K., Yoshida, A., and Tamura, Y. (2015). "Response characteristics of super-tall buildings – Effects of number of sides and helical angle." Journal of Wind Engineering Industrial Aerodynamics
145, 252-262.

Larsen, A., Esdahl, S., Andersen, J. E., and Vejrum, T. (2000). "Storebælt suspension bridge – vortex shedding excitation and mitigation by guide vanes." Journal of Wind Engineering Industrial Aerodynamics, 88(2), 283-296.

Spence S M J , G. M. (2008). "Influence of Higher Modes on the Response of Irregular Tall Buildings." IABSE Congress Report, 17(2), 582-583.

Xiang, H. F., Pang, J. B., Yang, Y. X., and Ge, Y. J. (2007). "Wind-Induced Damages to a Three-Span, Continuous, Concrete Arch Bridge under Construction." Structural Engineering International, 17(2), 141-150.

Xu, F. Y., Wang, H. L., Zhang, Z., and Huang, C. L. (2013). "Study on one Special-Shaped Long-Span Arch Bridge Using Wind Tunnel Test." Applied Mechanics Materials, 29-32, 370-376.

Y.C. Kim, Y. T., H. Tanaka, K. Ohtake, E.K. Bandi, A. Yoshida,. (2014). "Wind-induced responses of super-tall buildings with various atypical building shapes %J Journal of Wind Engineering and Industrial Aerodynamics." Journal of Wind Engineering and Industrial Aerodynamics, 133, 191-199.

Yang, Y. X., and Ge, Y. (2013). "Equivalent Wind Loading of Long-span Arch Bridges." IABSE Symposium Report, 101(4), 1-8.