Galloping performance of various shape of bridge hanger

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Abstract. Long span bridge and slender element of the bridge is sensible to dynamic wind action such as flutter buffeting, vortex induced vibration and galloping. For arch bridge, vibration of hanger due to dynamic action of the bridge has been experienced including hanger vibration of Tayan Bridge. The possible phenomena of the vibration are flutter, galloping and vortex induced vibration. This paper presenting the study of galloping phenomenal on the hanger of the Tayan Bridge. Several shape of the bridge hanger has been considered in this study. Computation Fluid Dynamic has been used to determine the static wind coefficient of the hanger. Glauert-Hartog Criteria has been applied to examine the performance of the bridge hanger to galloping. The result showed that that only circle shape that is not experiencing galloping

Keywords: Galloping, Static Wind Coefficient, Bridge, Hanger, Vibration

1. Introduction

The Tayan Bridge is steel arch bridge located 112 km from the city of Pontianak, West Kalimantan Province, Indonesia. The Tayan Bridge consist of The approach bridge which is a simple composite steel girder bridges with span of 40 m and The main bridge which is a steel arch bridge with main span of 200 m provides vertical clearance of 13 m for river traffic. The total length of the bridge is 1,420 m with 11 m width. The construction of the main steel arch bridge is full shoring method. The Steel Arch bridge has 35 hangers at one side with the length varies from 0.90 m to 26.80 m as shown in figure 1. Web Flange (WF) is used with the dimension of 450x150x12x15.

Figure 1. Tayan steel arch bridge

An excessive vibration has been sought several time at bridge hangers. The vibration starting to happened after the temporary shoring removed, during final preparation for opening. To investigate
the vibration, anemometer then installed at bridge to record the wind speed and direction from November 28, 2015 to December 8, 2015 [1].

On December 2, 2015, significant wind speed is recorded from 17:13 PM to 18:28 PM with wind speed of 6.3 m/s and 11.2 m/s and direction between W-SW. Small vibration has been sought at hanger H-6 to H-10 and hanger H-26 to H-30, and excessive vibration has been sought at hanger H-11 to H-25 in first asymmetric torsional mode.

On December 6, 2015, significant wind speed is recorded from 14:15 PM to 15:11 PM with wind speed of 6.3 m/s and 12.1 m/s and direction between W-SW. Another significant wind speed is recorded from 17:24 PM to 17:35 PM with wind speed of 6.7 m/s and 7.2 m/s and direction between W-SW. Small vibrations has been sought at hanger H-6 to H-10 and hanger H-26 to H-30, and excessive vibration has been sought at hanger H-11 to H-25 in first asymmetric torsional mode.

![Figure 2. Direction of wind to the hanger](image)

There are 3 possible reasons of the hanger vibration including Vortex Induced Vibration (VIV), Galloping and Flutter. To overcome the vibration several alternative has been considered including modifying the hanger cross section and increasing the hanger stiffness. [1] [2] [3] [4].

2. Objectives

The objectives of the research is to investigate if the Galloping is the reason that cause the hanger of Tayan Bridge vibrates under low wind speed. Several shape of hanger cross sections are considered in this study, including H shape, square shape, rectangular shape, circle shape and hexagonal shape. The Computational fluid Dynamic (CFD) software is used to determine the static wind coefficient of each sections. The analysis has been done under 10 m / s laminar wind speed with Re 105. The Glauert - Hartog Criterion the applied to examined if the each section prone to the galloping

3. Theory

3.1 Static Wind Coefficient

Static wind load has a coefficient of static wind which consists of a resistant force coefficient ($C_D$), lift coefficient ($C_L$), and the moment coefficient ($C_M$). Calculation of the coefficient of static wind experimentally carried by wind tunnel tests and can also be done computationally using Computational Fluid Dynamic (CFD) software.

In this study, the computational fluid dynamic analysis were performed using the FLUENT’s program to determine the coefficient of static wind which will be used to check whether the hanger is experiencing galloping.

3.2 Galloping

The term galloping is used to explain the large amplitude of vibrations that occur in the normal direction from the direction of the average wind velocity at lower frequencies than vibrations due to vortex shedding. Vibration due to galloping commonly found in a long and slender elements.
One of the method to investigate if the structure or element of the structure experienced vibration due to Galloping is The Glauert-Hartog Criterion as in Equation 1 Galloping instability will occur if the following equation is fulfilled [1][2][3][4][5]:

\[
\frac{dC_a}{da} + C_d = 0
\]

(1)

3.3 Vortex Induced Vibrations (VIV)

Vortex Induced Vibrations (VIV) is vibration of structure which occur at low wind speed and will disappear as the wind speed increase. Vortex Induced Vibrations (VIV) occur when the frequency of the wind turbulence equal to the frequency of the structure. When wind moves through an object, then the flow pattern will be disrupted look for new equilibrium condition. Separation of vortex flow through an object is called vortex shedding. At low flow velocities, flow separation occurs smoothly without local vortices (vortex), while at high flow speeds, the flow field that occurs causes the formation of vortex formation to form a mess with certain patterns[1][2][4].

The frequency of vortex shedding known as the symbol \(N_s\), the speed of the wind (U) dimensions of the structure perpendicular to the wind flow (Lb). S is the Strouhal Number.

As the wind speed increase, then the value of vortex shedding frequency will increase up to certain conditions, the \(N_s\) frequency of vortex shedding will approach the natural frequency of the structure so that resonance vibrations occur.

3.4 Flutter

Flutter is a divergent vibration condition that is self-feeding (enlarged by itself) and the result of this aerodynamic vibration that works together with the movement of the structure itself has the potential to damage the structure. If the energy received by the structure due to gusts of wind is greater than the damping capacity of the structure, the amplitude of the vibration of the structure will continue to increase. The vibrations will further enlarge the aerodynamic force which will cause self-exciting forces and self-exciting oscillation [2][6].

The phenomenon of flutter occurs at high speeds speed, the greater the wind speed, the vibration that occurs also will increase.

![Vortex induced vibrations (VIV) and Flutter instability](image)

(a)Vortex induced vibrations (VIV)  (b) Flutter instability

Figure 3. Vortex induced vibration and flutter instability

4. Results and Discussion

4.1 Square Cross Section

A 1x1 m square cross-section is considered in this study to determine the static wind coefficient and investigate the galloping phenomena.
The contour speed for 1x1 m square cross-section from simulation using FLUENT software is presented in Figure 5.

![Contour speed of square section](image)

**Figure 5.** Contour speed of square section

The static wind coefficients $C_D$ and $C_L$ for angle of attack $-45^\circ$ to $+45^\circ$ are presented in Figure 6.

![Static wind coefficient static wind $C_D$ and $C_L$ of square cross section](image)

**Figure 6.** Static wind coefficient static wind $C_D$ and $C_L$ of square cross section

Potential to galloping phenomena is checked using the Glauert - Hartog Criterion and the result of analysis is plotted into graph as presented in Figure 7. It can be seen that 1x1 square cross section will experiencing galloping at angle of attack of $-42^\circ$, $-30^\circ$, $-6^\circ$ to $6^\circ$, and $30^\circ$.

![Potential to galloping phenomena](image)

**Figure 7.** $(\frac{dC_L}{d\alpha} + C_D)$ value for square cross section
4.2 Rectangular Cross Section in y-direction

A 1x2 m rectangular cross-section in y-direction is considered in this study to determine the static wind coefficient and investigate the galloping phenomena.

![Figure 8](image)

Figure 8. Rectangular cross section in y-direction

The contour speed for 1x2 m rectangular cross-section in y-direction from simulation using FLUENT software is presented in Figure 9.

![Figure 9](image)

Figure 9. Contour speed of rectangular cross section in y-direction

The static wind coefficients $C_D$ and $C_L$ for angle of attack $-45^\circ$ to $+45^\circ$ are presented in Figure 10.

![Figure 10](image)

Figure 10. Static wind coefficient $C_D$ and $C_L$ of rectangular cross section in y-direction

Potential to galloping phenomena is checked using The Glauert - Hartog Criterion and the result of analysis is plotted into graph as presented in Figure 11. It can be seen that Rectangular Cross Section in y-direction will experiencing galloping at angle of attack of $-8^\circ$ to $-4^\circ$ and $4^\circ$ to $8^\circ$.
4.3 Rectangular Cross Section in x-direction

A 1x2 m rectangular cross-section in x-direction is considered in this study to determine the static wind coefficient and investigate the galloping phenomena.

Figure 11. \( \frac{\partial C_D}{\partial \alpha} + C_D \) value for rectangular cross section in y-direction

Figure 12. Rectangular cross section in x-direction

The contour speed for 1x2 m rectangular cross-section in x-direction from simulation using FLUENT software is presented in Figure 13.

Figure 13. Contour speed of rectangular cross section in x-direction

The static wind coefficient \( C_D \) and \( C_L \) for angle of attack -45° to +45° are presented in Figure 14.

Figure 14. Static wind coefficient \( C_D \) and \( C_L \) of rectangular cross section in x-direction

Potential to galloping phenomena is checked using The Glauert - Hartog Criterion and the result of analysis is plotted into graph as presented in Figure 15. It can be seen that Rectangular Cross Section in x-direction will experiencing galloping at attack angle -45° to -32° and 32° to 45°.
4.4 Circular Cross Section

A 1 m diameter of cross-section is considered in this study to determine the static wind coefficient and investigate the galloping phenomena.

![Circular cross section](image)

The contour speed of 1 m diameter of cross-section from simulation using FLUENT software is presented in Figure 17.

![Contour speed of circular cross section](image)

The static wind coefficient $C_L$ and $C_D$ form circular cross section is constant at each angle of attack.

Potential to galloping phenomena is checked using The Glauert - Hartog Criterion and the result of analysis is plotted into graph as presented in Figure 18. It can be seen that for circular cross section no potential to galloping has been found.

![Graph of (dC_L/du + C_D) value for circular cross section](image)

4.5 I-Shaped Cross Section

I-Shaped cross-section as presented in Figure 19 is considered in this study to determine the static wind coefficient and investigate the galloping phenomena.
The contour speed of I-shaped cross-section from simulation using FLUENT software is presented in Figure 20.

The static wind coefficient $C_D$ and $C_L$ for angle of attack $-45^\circ$ to $+45^\circ$ are presented in Figure 21.

Potential to galloping phenomena is checked using The Glauert - Hartog Criterion and the result of analysis is plotted into graph as presented in Figure 15. It can be seen that I-Shaped Cross Section will experiencing galloping at angle of attack of $-42^\circ$ to $-38^\circ$, $42^\circ$ to $-38^\circ$ and $40^\circ$ to $44^\circ$.

Hexagon cross-section as presented in Figure 23 is considered in this study to determine the static wind coefficient and investigate the galloping phenomena.
Figure 23. Hexagonal cross section

The contour speed of hexagonal cross-section from simulation using FLUENT software is presented in Figure 24.

Figure 24. Contour speed of hexagon cross section

The static wind coefficient $C_D$ and $C_L$ for angle of attack -45° to +45° are presented in Figure 25.

Figure 25. Static wind coefficient $C_D$ and $C_L$ of hexagonal cross section

Potential to galloping phenomena is checked using the Glauert - Hartog Criterion and the result of analysis is plotted into graph as presented in Figure 15. It can be seen that Hexagonal Cross Section will experiencing galloping at angle of attack of -42°, -40°, 2°, 16° and 42°.

Figure 26. $(\frac{dC_L}{d\alpha} + C_D)$ value for hexagon cross section

5 Discussion

In this study several shape of bridge hanger cross section has been considered and checked for galloping potential including Square, Rectangular in y-direction, Rectangular in x-directions, Circular, I-shaped and Hexagonal cross section. The static wind coefficient of each hanger cross section are
determined using CFD analysis. The static wind coefficient from the CFD analysis compared with the previous data and study. The results obtained using FLUENT software agree well with the previous study and data.

Based on the analysis performed using The Glauert - Hartog Criterion, the galloping potential of each hanger cross section. It can be identified that square, rectangular directions x, rectangular direction y, profile I, and hexagon cross section has galloping potential at some angle of attack. Circular hanger cross section has no potential of galloping vibration

6 Conclusion
From this study, the following conclusion can be concluded:

a. Computational Fluid Dynamic (CFD) Software gives an accurate value of static wind coefficient
b. For square section, potential galloping has been found at angle of attack -42 °, -30 °, -6 ° to 6 °, and 30 °.
c. For Rectangular Section in y-direction potential galloping has been found at angle of attack of -8 ° to -4 ° and 4 ° to 8 °.
d. For Rectangular Section in x-direction potential galloping has been found at angle of attack of -45 ° to -32 ° and 32 ° to 45 °.
e. For circular section no potential to galloping has been found
f. For I-Shaped Section potential galloping has been found at angle of attack of -42 ° to -38 °, 42 ° to -38 ° and 40 ° to 44 °.
g. For Hexagonal Section potential galloping has been found at angle of attack of -42 °, -40 °, 2 °, 16 ° and 42 °.

References
[1] Made Suangga and Prasetyo Eko Junianto. Vibration of Tayan Bridge’s Hanger in West Kalimantan, Indonesia (2019) International Journal of Engineering and Advanced Technology (IJEAT), Volume-8 Issue-4, April 2019
[2] Y. L. Xu, Wind Effects on Cable Supported Bridges. 2013. Wiley. pp. 83 - 103.
[3] M Keerthana and P Harikrishna. (2013). Application of CFD for assessment of galloping of rectangular and H-sections. Journal of Scientific and Industrial Research (JSIR) JSIR Vol.72 [2013] pp.419-427
[4] M. G. Liu, T. M. Mou, X. G. Hua and Z. Q. Chen. Flutter, galloping, and vortex induced vibrations of h-section hangers. (2012) ASCE Journal of Bridge Engineering, 2012, pp. 1 - 9.
[5] Fernando Gandia, Jose Meseguer, Angel Sanz. (2014). Influence of aerodynamic characteristics of “H” beams on galloping stability. IABSE Madrid Symposium Report, Vol. 102, p. 277 - 284
[6] Emil Simiu & Robert H. Scanlan. (1985). Wind Effects on Structures. Second Edition. New Jersey John Wiley & Sons, 1986, pp 198 – 247.