Effect of modal coupling on the assessment of footbridge vibrations

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Abstract

The evolution of pedestrian bridge design is tending towards increasingly flexible and slender structures which are more sensitive to vibrations caused by pedestrians. The accelerations induced by the dynamic response are checked to fulfil the comfort criteria. Traditionally, the calculation is done in the modal basis without modal coupling. This paper shows the limitation of this method and show the benefits of considering it.

Keywords: Modal basis, modal interaction, frequency analysis

1 Introduction

In the design of footbridges, comfort criteria must be fulfilled. Due to the increasing slenderness of footbridges, the vibrations and accelerations felt during the crossing of pedestrians can be unpleasant. Pedestrian's loading can be considered as a sum of harmonic loads that set the footbridge in motion and can resonate with the footbridge's vibration eigen modes. The acceleration must be bounded to ensure the comfort of pedestrians. To carry out these comfort checks, engineers can rely on the SETRA and HIVOSS guidelines[1],[2].

2 Application to a practical example: L'ENJAMBEE

Figure 1. Footbridge " L'Enjambée"

Namur footbridge "L'Enjambée" [3] was opened in 2020. It is composed of a 2 m wide metal box section with a variable height from 0.4 to 1 m. The structure is a rigid frame bridge with inclined legs that serve as stairs and with two access spans at deck level. It has a main span of 100 m over the Meuse river and is 184 m long.

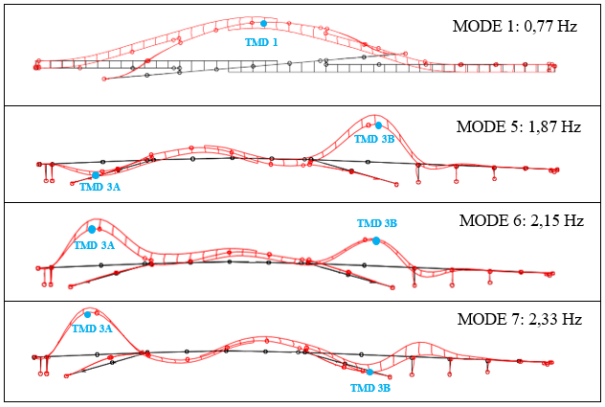

Figure 2. Modes and TMD position

The vibration modes and the TMDs (in blue) placed on the footbridge are given in Figure 2. The mode 1 is transversal and the three others are vertical.

2.1 Bridge accelerations without any TMD

Table 1. Footbridge acceleration without TMD

	Mode 1	Mode 5	Mode 6	Mode 7
A [m/s²]	0,8	6,1	4,8	2,9

Without any TMDs, the accelerations calculated with Setra recommendations [1] are above the

comfort limits (vertical: 1 m/s² & transversal 0.1 m/s²)

2.2 Footbridge acceleration with TMDs

As the comfort criteria are not respected, TMDs are added to the structure to reduce the accelerations. If no modal interaction is considered, the acceleration can be obtained by resolving the classical 2 degrees of freedom model.

When modal coupling is considered [4], the TMDs are added to the model. A frequency analysis is done in the modal basis (as in equation 1). The modal matrices ($\boldsymbol{M}^*$, $\boldsymbol{C}^*$, $\boldsymbol{K}^*$) consider TMD and Structural properties.

$$\ddot{\boldsymbol{q}}(\omega) = (-\boldsymbol{M}^*\omega^2 + \mathrm{i}\boldsymbol{C}^*\omega + \boldsymbol{K}^*)^{-1}\boldsymbol{P}^*(\omega).\omega^2 = \boldsymbol{H}(\omega).\boldsymbol{P}^*(\omega).\omega^2 \quad (1)$$

2.2.1 Verification of the transversal mode

On the footbridge "L'Enjambée" only one transversal mode creates large accelerations. No other transversal modes have a close frequency.

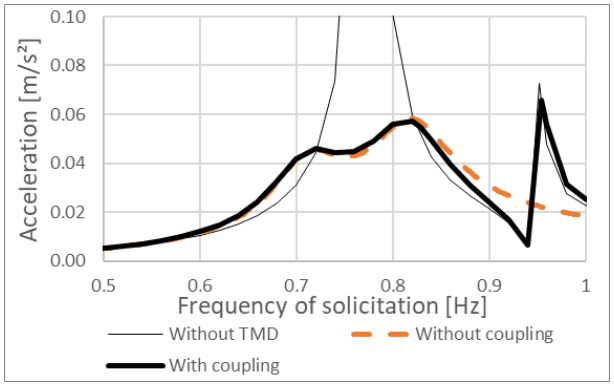

Figure 3. Acceleration observed at TMD 1 position

As shown in Figure 3 , both types of resolution give the same type of accelerations. Modal interactions with other modes are negligible. The comfort criterion is fulfilled, with a maximal acceleration of 0.06m/s².

2.2.2 Verification of the vertical modes

For the vertical modes, the focus is made on the mode 5 ,6 and 7 having close natural frequencies. The 3 mode shapes are close together and can be excited by the same pedestrian loads. In Figure 4, only the TMD 3A is placed and accelerations are observed at TMD 3B position.

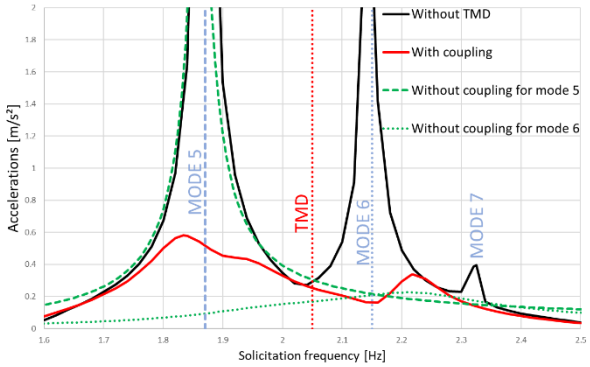

Figure 4. Accelerations at TMD 3B position

In Figure 4, the methods with (red curve) and without (green curves) modal interaction gives not the same accelerations. The introduction of TMD 3A impacts the 3 modes, so neglecting the interaction between them and the TMD gives wrong results. In this case, the acceleration at the frequency of mode 5 is overestimated without modal coupling. At the mode 6 frequency, the accelerations are underestimated without modal coupling.

3 Conclusions

The modal coupling has to be considered if two conditions are met: TMDs are used and impact several modes, the footbridge has modes with close frequencies and mode shapes.

Otherwise, neglecting the modal coupling is sufficient for the assessment of footbridge vibration.

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References

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