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Test rig for nonlinear section model tests of cable-supported bridges

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SUMMARY:
Of the different types of wind tunnel tests for bridges, section model tests represent the most common tests utilized in the industry. However, they assume a linear structural behavior of the bridge. This appears reasonable for most cable-supported bridges, but for bridges with very long main spans, this might be inappropriate due to the greater structural contribution of their cable systems, which are geometrically nonlinear. As span lengths are getting longer, it seems appropriate to develop a better understanding of the influence of geometric nonlinearities on the wind response of bridges. Thus, this paper discusses a new wind tunnel approach for cable-supported bridges that allows to study the interaction between nonlinear structural effects and aeroelastic effects. More specifically, the development of a new experimental apparatus for nonlinear section model tests of bridges is presented. At first, it is explained how a nonlinear mechanical system for nonlinear section model tests can be calibrated using a specific numerical procedure. The validity of the mechanical device is demonstrated using four single-span suspension bridges with different span lengths. Then, a discussion on the characteristics needed for a nonlinear section model test rig and the design of such a test rig are presented.

Keywords: cable-supported bridge, geometric nonlinearities, section model tests

1. INTRODUCTION

Section model tests have become the standard approach in the field of bridge engineering due to their affordability, versatility and relative simplicity. Since the modes represented in such tests and their corresponding modal properties originate from linear structural dynamics theory, section model tests therefore assume a linear structural behavior of the bridge. However, cable-supported bridges are nonlinear structures because of their cable systems. It has also been demonstrated for suspension bridges that dynamic vertical forcing can lead to large torsional oscillations as a result of structural nonlinearities, i.e., there is nonlinear vertical-torsional coupling due to the geometric nonlinearities (Arioli and Gazzola, 2017). Consequently, it seems that supplemental investigations are required in order to understand the influence of structural nonlinearities on the aeroelastic stability of cable-supported bridges. For this purpose, a theory for nonlinear section model tests was developed (Maheux et al., 2020, 2022). This paper therefore discusses a mechanical system and an experimental rig for nonlinear section model tests of bridges.

Table 1. Description of cable-supported bridges.

Bridge	Type	Main span (m)	Buffers?	Elevation view
SU4a	Single-span suspension Girder restrained at towers	1200	Yes	
SU4b	Single-span suspension Girder restrained at towers	1800	Yes	
SU4c	Single-span suspension Girder restrained at towers	2400	Yes	
SU4d	Single-span suspension Girder restrained at towers	3000	Yes	

2. SPRINGING SYSTEM FOR NONLINEAR SECTION MODEL TESTS

A nonlinear mechanical device for nonlinear section model tests of bridges must be capable of representing the nonlinear generalized stiffness behavior relative to one vertical mode and one torsional model. This nonlinear behavior is mathematically described by the following equations (Maheux et al., 2022):

$$f^*_{Vm}(y_{Vm}, y_{\theta m}) = L_{mm} \frac{\overline{m}^*_V}{\overline{m}_V} \frac{\lambda_U^2 \lambda_L}{\Gamma_V^h} \cdot \tilde{f}_{Vp} \left(\frac{\beta_V}{\lambda_L} y_{Vm}, \beta_\theta y_{\theta m} \right) \quad (1)$$

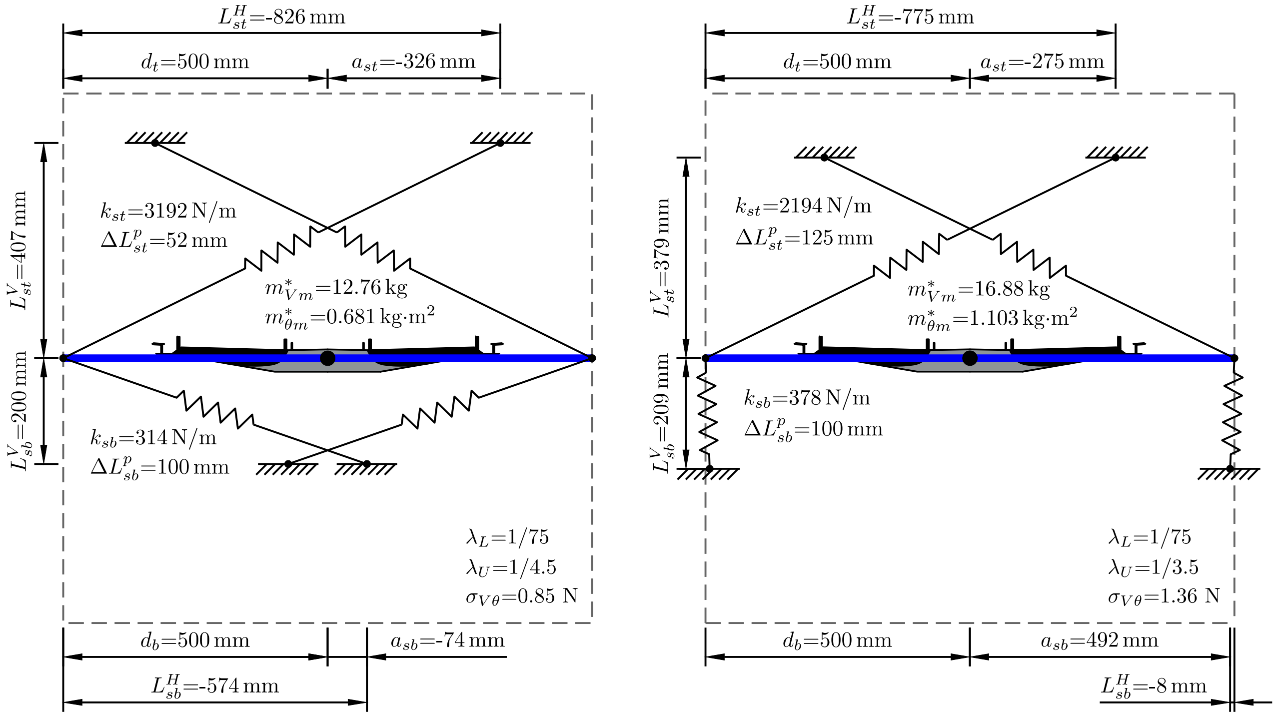
$$f^*_{\theta m}(y_{Vm}, y_{\theta m}) = L_{mm} \frac{\overline{m}^*_\theta}{\overline{m}_\theta} \frac{\lambda_U^2 \lambda_L^2}{\Gamma_\theta^\alpha} \cdot \tilde{f}_{\theta p} \left(\frac{\beta_V}{\lambda_L} y_{Vm}, \beta_\theta y_{\theta m} \right) \quad (2)$$

where $f^*_{Vm}(y_{Vm}, y_{\theta m})$ and $f^*_{\theta m}(y_{Vm}, y_{\theta m})$ are the scaled mass-corrected restoring vertical force and moment; y_{Vm} and $y_{\theta m}$ are the vertical displacement and rotation of the section model; $\tilde{f}_{Vm}(z_V, z_\theta)$ and $\tilde{f}_\theta(z_V, z_\theta)$ are the generalized restoring forces which represent the nonlinear structural behavior of a cable-supported bridge; $\overline{m}_{Vm}$ and $\overline{m}_{\theta m}$ are the mass and mass moment of inertia per unit length of the scaled section model; $\overline{m}^*_{Vm}$ and $\overline{m}^*_{\theta m}$ are the corrected mass and mass moment of inertia per unit length; L_{mm} is the length of the section model; λ_L is the geometric scale; λ_U is the velocity scale; Γ_V^h, Γ_θ^α, β_V and β_θ are mode correction factors.

Using the bridges described in Table 1 as test cases, it was found that the nonlinear behavior described by Eqs. (1) and (2) can be mechanically represented by suspending a section model to inclined springs. Two examples of inclined spring configurations are presented for bridges SU4b and SU4d in Fig. 1. As shown in Fig. 2 for bridge SU4d, there is a good agreement between the target nonlinear behavior and the spring-simulated one.

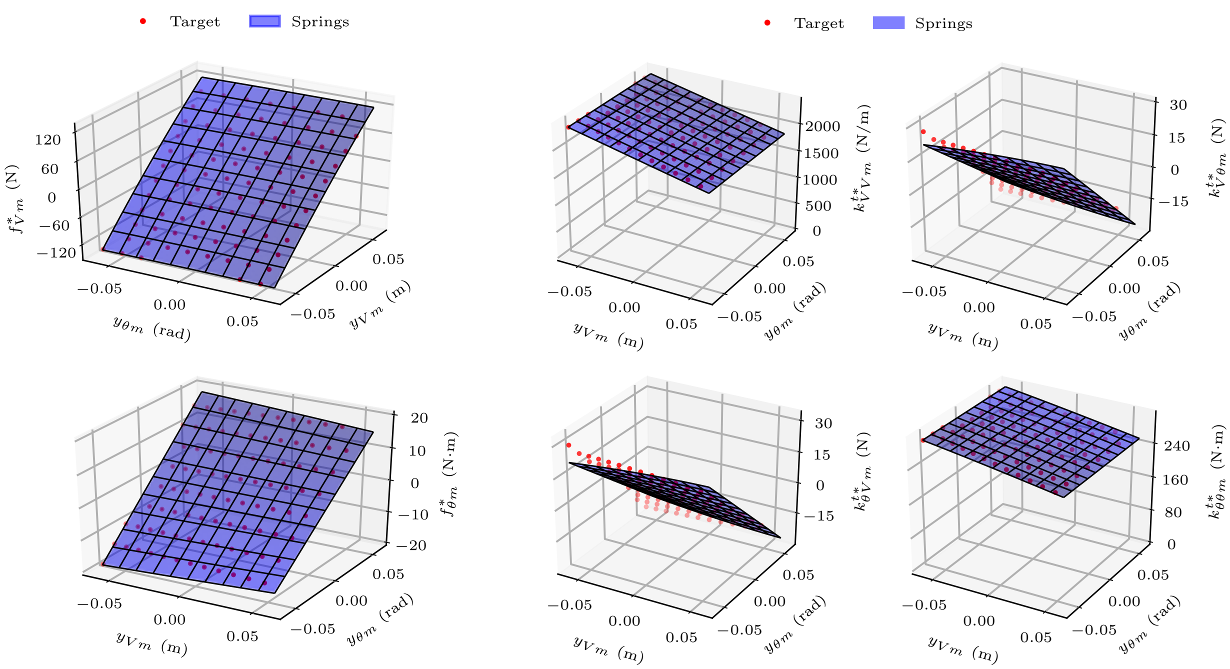
3. DESIGN OF NEW SECTION MODEL TEST RIG

In order to achieve nonlinear spring configurations like those of Fig. 1, a new dynamic test rig for section model tests is required. Such test rig needs to be simple to adjust so that it is easy to change the vertical and horizontal positions of the attachment points for the inclined springs. It needs to be able to represent the structural coupling between the vertical and torsional behaviors. Also, it should be possible to conduct linear section model tests using a nonlinear test rig. Based on these requirements, the design presented in Fig. 3 was developed.



(a) (b)

Figure 1. Nonlinear spring configurations for the single-span suspension bridges: (a) bridge SU4b; (b) bridge SU4d.



(a) (b)

Figure 2. Comparison between target and spring-modeled scaled nonlinear generalized behavior for bridge SU4d: (a) generalized restoring forces; (b) generalized stiffnesses.

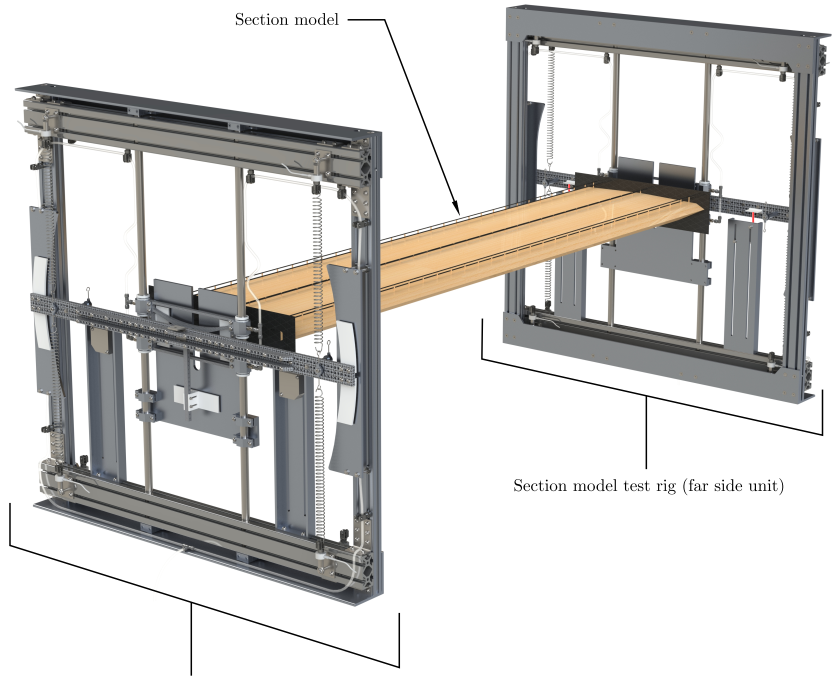


Figure 3. Three-dimensional model of new section model test rig.

4. CONCLUSIONS

In order to experimentally assess the effect of structural nonlinearities, the idea of suspending a bridge section model to inclined springs was developed. This led to the development of an experimental rig for nonlinear section model tests of cable-supported bridges. It is expected that this research will lead to a better understanding of the interaction between structural nonlinearities and aeroelastic effects in the case of very long cable-supported bridges.

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