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# Aeroelastic instability of steel/composite bridges in the launching phase

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**SUMMARY:**
Steel composite bridges in incremental launching phase may risk aeroelastic galloping instability. These bridges during erection are light-weight and low-damped, have an aerodynamically unfavourable cross-section and will experience a significantly decreased natural frequency. This work presents our recent research on an open cross section typical for composite bridges in the construction phase. Main findings of wind tunnel tests are highlighted, advanced modelling with wake oscillator model in dealing with the VIV-galloping interaction are demonstrated, a potentially efficient and economical way to suppress the galloping instability is proposed.

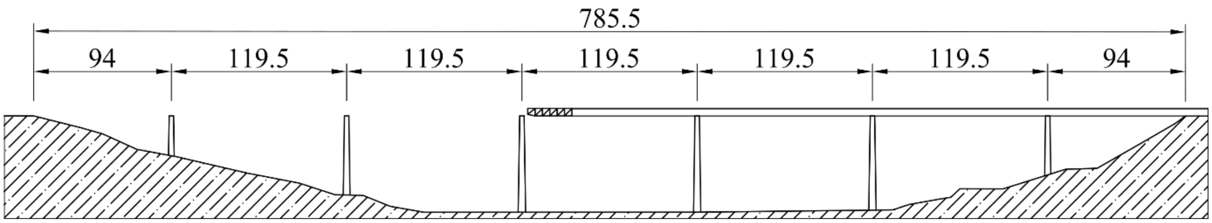
*Keywords: steel/composite bridges, aeroelastic instability, construction phase*

## 1. INTRODUCTION

In Europe, the incremental launching is a popular way to erect bridges, especially in valley areas. For steel/composite bridges, nowadays techniques have allowed a single steel box girder without any auxiliary support to cross spans longer than 120 m, at heights above the ground of more than 100 m. This results, in critical situations, in a cantilever system with a cantilever length equal to the longest span. Furthermore, for weight optimization reason, the concrete deck is not included in the launched girder, resulting in an aerodynamically unfavourable open, mostly trapezoidal, cross section. On top of this, the concerning structures are light-weight, slender and exposed to wind excitation. These unfavourable conditions increase the risk of aeroelastic instabilities. Fig. 1 shows a typical case of launching a composite bridge in Germany.

## 2. OBSERVATIONS IN WIND TUNNEL TESTS

A sectional wind tunnel model of an open cross section (see Fig. 2(a)), typically used for the steel-concrete composite bridges during the construction phase, has been studied in depth in the boundary layer wind tunnel at the Institute of Steel Structures, TU-Braunschweig, Germany. In these tests, attention is mainly put to transverse galloping instability. Wind tunnel tests show the proneness of the studied open cross section to galloping, either in smooth flow or turbulent flow (up to a turbulence intensity $I_u$ at least 15%). This can be learned from the presence of negative slopes in the lift coefficient (Fig. 2(b)) and further confirmed in the aeroelastic tests (Fig. 2(c)-(d)).

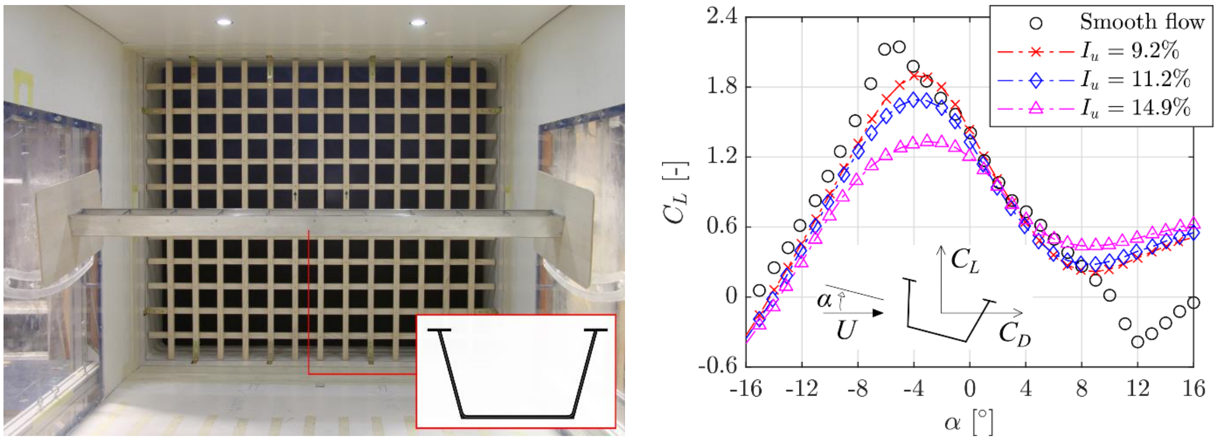


(a) span arrangement, dimension in m

(b) bridge deck in service

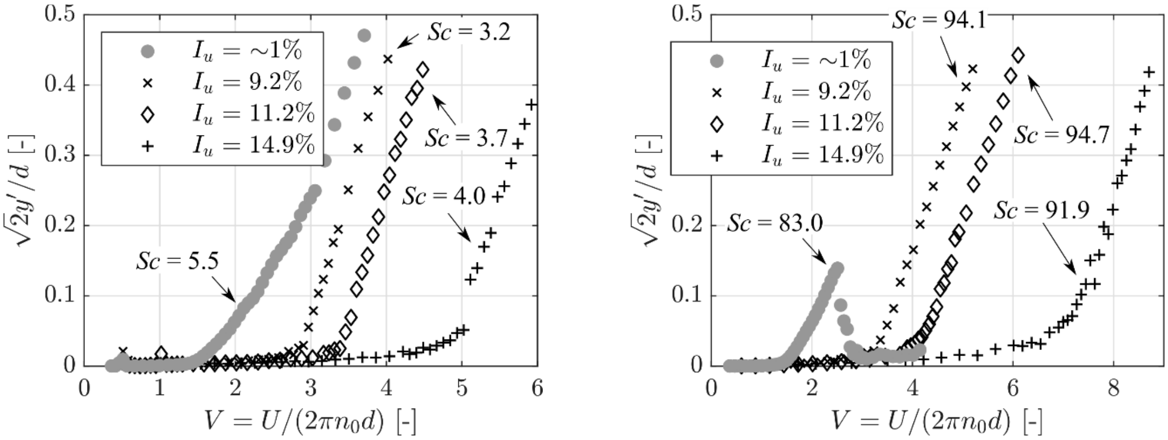
(c) bridge deck in launching phase

**Figure 1.** Incremental launching of the Aftetal Bridge, Germany (redrawn from Hanswille (2014)).



(a) wind tunnel model and cross section

(b) lift coefficient vs. angle of attack



(c) aeroelastic response at α = 4°, *Sc* = 3.2-5.5

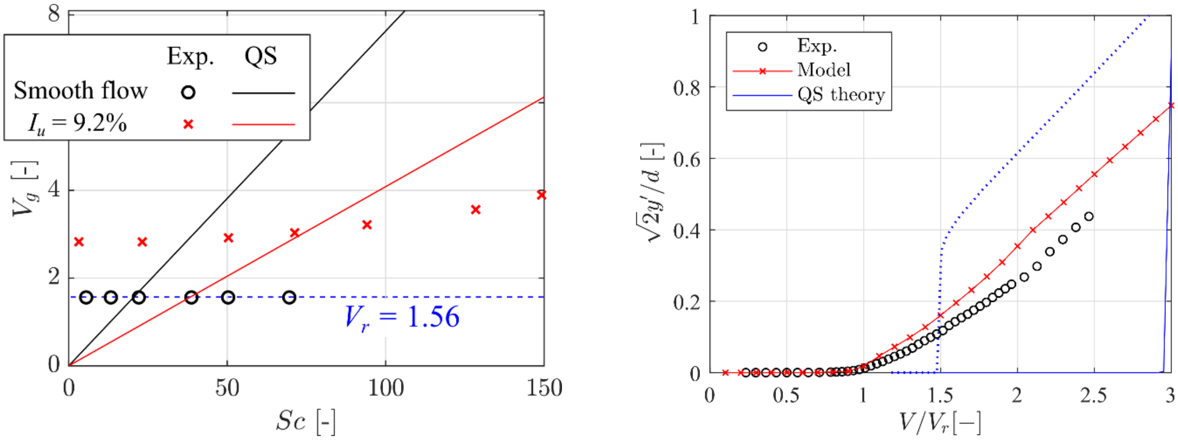
(d) aeroelastic response at α = 4°, *Sc* = 83-95

**Figure 2.** Wind tunnel test results for the galloping instability of the studied open cross section. $C_L = L/(0.5\rho U^2 d l_e)$, where $L$ is the mean lift measured by force balance, $\rho$ the air density, $U$ the mean wind speed, $d$ the cross section height, $l_e$ the model length between end plates. $Sc = 4\pi M\xi_0/(\rho d^2 l_e)$, where $M$ is the model weight, $\xi_0$ the mechanical damping ratio. $n_0$ is the natural frequency of wind tunnel model, $y'$ the standard deviation of the displacement response.

Particular attention should be paid to the 4° wind angle of attack. In smooth flow, strong interaction between vortex induced vibration (VIV) and galloping has been observed up to a very high Scruton number ($Sc$, about 70). Moreover, the incident turbulence is observed to enhance the galloping instability. For the same level of Scruton number, galloping can arise at lower reduced wind speed ($V$) in turbulent flow than that in smooth flow, see Fig. 2 (d). For low $Sc$ (Fig. 2 (c)), the condition is reversed. Complete experimental dataset can be found in Chen et al. (2020) as well as Chen and Thiele (2023). Finally, the open cross section, if not well supported, can be also prone to the torsional galloping instability as reported in Höffer et al. (2022).

## 3. PREDICTIONS

Predictions of galloping instability usually relies on the quasi-steady theory (QS), which is valid only for the high reduced wind speeds. However, for the steel/composite bridges in the launching phase, the Scruton number after a statistical survey was found usually not high enough (say, < 30) to ensure a high reduced wind speed. In Fig. 3(a), the failure of the QS predictions on the reduced critical velocity ($V_g$) is apparent (up to very high $Sc$), either in smooth or turbulent flow. In particular, the occurrence of the combined VIV-galloping instability in smooth flow actually fixes the experimental $V_g$ at the reduced critical velocity for VIV ($V_r$). For this case, the use of more advanced mathematical models such as the wake oscillator model of Tamura’s form can provide better predictions as exemplified in Fig. 3(b). Moreover, the recent application of wake oscillator model for a 3:2 rectangular cylinder in turbulent flow also shows certain success (Mannini, 2020).



(a) QS predictions of $V_g$ vs. Exp. observations

(b) wake oscillator model predictions, $Sc$ = 50

**Figure 3.** Suppression of the galloping instability of bridge deck in the launching phase using passive measures.

## 4. PASSIVE MEASURES FOR SUPPRESSIONS OF GALLOPING

To suppress the risk of galloping instability, temporary wind clapping may be considered to modify the aerodynamics of the cross section. Such a passive measure has been adopted for the Aftetal bridge in the launching phase (Fig. 4 bottom right). Particularly suitable for the incremental launching, applying the aerodynamic modification to the launching nose could be a more efficient and economical way. The concerning observation is that the launching nose locates at the tip of the cantilever part thus it can make a significant contribution in determination of the aerodynamic instability of the structural system (in the mode space). Therefore, if the launching nose is well optimized, it may generate sufficient positive aerodynamic damping to balance the negative damping arising from the main girder. Such an idea was checked for a lattice launching nose by simply sealing its top and bottom sides (Fig. 4 bottom left). Wind tunnel static tests first show that this modification leads to the emergence of a strong lift variation with the wind angle of attack, which is positive sloped over a large range of angles of attack. Although it remains to examine its performance more reliably on an elastically-supported cantilever wind tunnel model, the predictions according to the quasi-steady theory and the wake oscillator modelling both suggest a very good suppression effect. More detailed reports can be found in Chen et al. (2021).

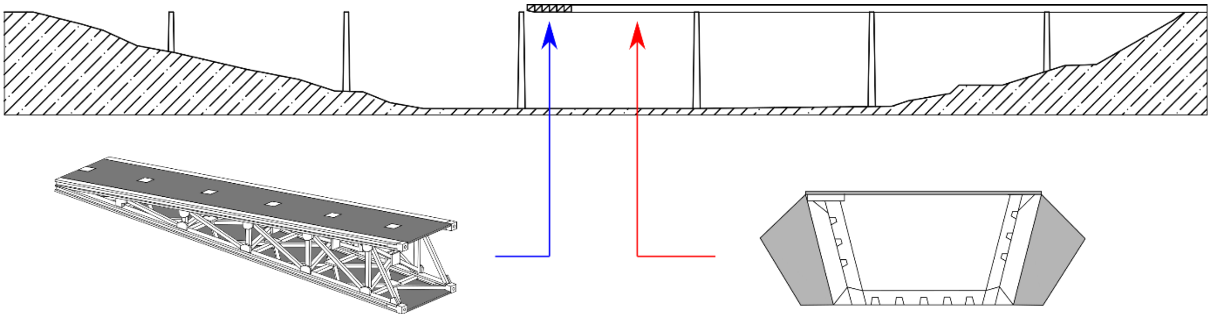


**Figure 4.** Suppression of the galloping instability of bridge deck in the launching phase using passive measures.

## 5. CONCLUSION AND FUTURE WORK

This work collects the main findings of our recent research on the galloping problem of the steel/composite bridge decks in the launching phase. Several points concerning the studied open cross section deserve attentions of engineers. As it is quite light-weight, it may encounter the risk of the interaction between VIV and galloping, which can lead to a divergent oscillation starting at the critical wind speed of VIV. Moreover, the incident turbulence plays a complex role and in this study it leads to a higher galloping factor (thus lower critical wind speed). Future works ongoing and planned include: further development of the wake oscillator model to consider the spanwise loss of correlation, and wind tests on an elastically supported cantilever model to evaluate the more realistic condition and to examine the performance of the modified launching nose.

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