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Slope-Stabilizing Works as Potential Scour Countermeasures for Bridge Foundations: Evidence from Physical and Numerical Modelling

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ABSTRACT: Bridge foundations are highly susceptible to scour, which is the leading cause of bridge failures worldwide. When retaining structures are placed near bridge foundations, they may also influence the hydraulic processes and help mitigate scour effects, even if primarily designed for slope stabilization. However, evidence supporting this potential beneficial interaction is limited. This study investigates a bridge foundation system through a physical modelling campaign conducted at ETH Zurich, using the Miniaturized Tsunami Generator. Reduced-scale (1:200) models were tested under flood-induced loading, focusing on retaining wall configurations located near the foundation. The experimental results reveal that the retaining structure delays scour initiation and reduces its extent. The experimentally observed scour patterns were incorporated within 3D finite element (FE) analyses, revealing a reduction in lateral bearing capacity and establishing a direct link between scour development and foundation response. The study highlights the relevance of cross-hazard interactions and the value of integrated modelling strategies for bridges exposed to scour.

1 INTRODUCTION

Scour is widely recognised as one of the primary causes of bridge failure worldwide (Xiong et al., 2023). Although scour mitigation is commonly addressed from a hydraulic perspective, the potential influence of slope-stabilizing works on local scour processes remains inadequately understood. This contribution investigates the interaction between scour evolution and foundation response through a representative case study, adopting a combined physical–numerical modelling framework (Jones & Anastasopoulos, 2023). Several configurations were modelled experimentally and analyzed numerically; a representative case is presented herein.

2 PROTOTYPE PROBLEM AND PHYSICAL MODELLING

A reduced-scale physical modelling campaign was carried out to investigate scour development around a bridge foundation, in the presence of nearby slope-stabilizing countermeasures. The study focuses on a representative bridge foundation system protected by a retaining wall equipped with buttresses; details of the prototype bridge and foundation system are reported in previous studies (Pecce et al., 2019; Ambrosino et al., 2023).

Physical modelling tests were conducted at ETH Zurich using the Miniaturized Tsunami Generator (MTG) (Jones & Anastasopoulos, 2021). Reduced-scale (1:200) models were subjected to controlled flood-induced unsteady flow conditions, allowing progressive scour development around the foundation and the adjacent retaining structure. An overview of the adopted hybrid physical–numerical workflow is shown in Fig. 1.

While several retaining wall configurations were analysed, our focus lies in the configuration that incorporates buttresses. Experimental observations indicate that the buttresses are the first structural elements affected by the incoming flow, inducing preferential erosion upstream of the retaining structure, while limiting scour development around the foundation. Scour evolution was monitored through visual observations and high-resolution 3D surface acquisition. Observed at a characteristic model-scale time instant (t = 600 s), the scour geometry shown in Fig. 2a is considered representative of an advanced stage of erosion. The observed scour patterns indicate that the presence of buttresses modifies the local flow field, promoting erosion upstream of the retaining structure, while limiting direct exposure of the foundation to the incoming current.

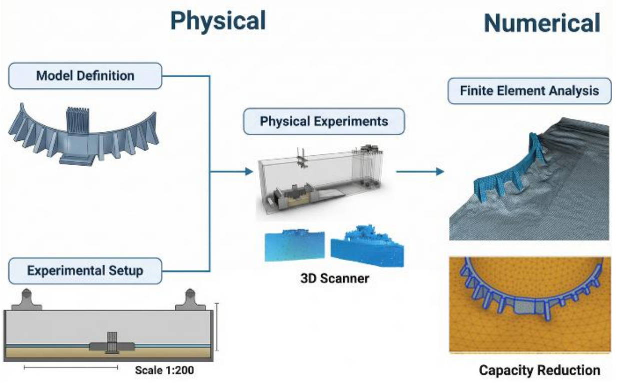

Figure 1. Overview of the hybrid physical–numerical modelling framework adopted in this study.

3 NUMERICAL MODELLING

To investigate the structural implications of the experimentally observed scour patterns, 3D FE numerical analyses were performed. Two numerical models were developed: (a) an unscoured reference model; and (b) a scoured model incorporating the erosion geometry, directly derived through 3D-scanning from the physical model tests. The site-specific soil stratigraphy was explicitly implemented in both models, and soil behaviour was simulated using the HSsmall constitutive model.

Lateral monotonic loading was applied in the transverse direction (Y), selected as representative of the interaction between the asymmetric scour morphology and the foundation–soil system. The numerical results show that the presence of scour leads to measurable reduction of the lateral bearing capacity and stiffness of the foundation, with marked differences in terms of its moment–rotation response (Fig. 2b). The response is governed by the spatial distribution of scour, confirming the controlling role of scour geometry in the mobilisation of soil resistance under lateral loading.

4 CONCLUSIONS

Physical modelling results demonstrate that retaining walls with buttresses can influence local scour development by shielding the foundation from direct flow action and reducing the extent of erosion. Numerical analyses confirm that the experimentally observed scour geometry governs the mobilisation of soil resistance, resulting to a reduction of the foundation lateral bearing capacity. The study highlights the relevance of integrated physical and numerical modelling for the assessment of bridge foundations exposed to scour.

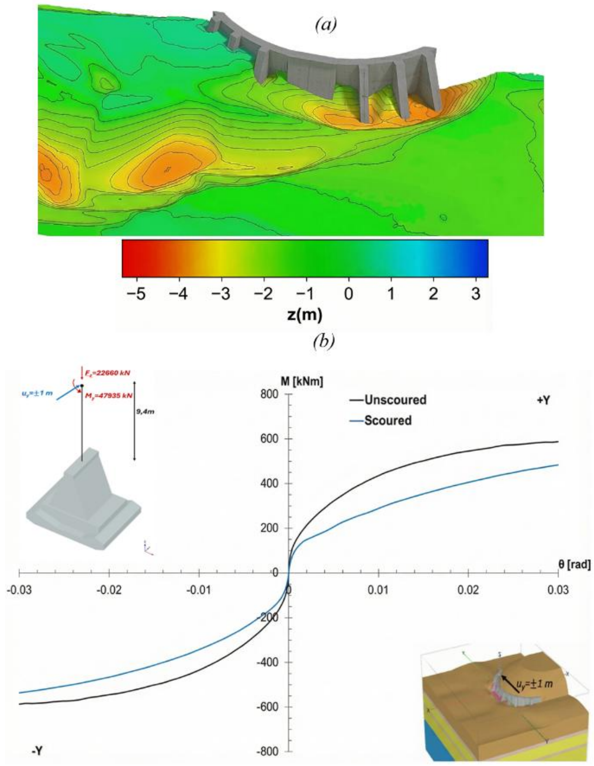

Figure 2. (a) experimentally derived scour depth distribution at prototype scale; and (b) M–ϑ response in the Y direction for scoured and unscoured conditions.

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