Numerical Prediction Of The Eigenfrequencies Of An Idealized Bridge Pier Under Local Scour

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Abstract

Foundation scour is a major cause of bridge collapse worldwide (e.g., Kirby et al., 2015). Indeed, several studies have demonstrated its detrimental effects on the soil-structure system, both in terms of the foundation capacity and stiffness (e.g., Foti et al., 2023). Furthermore, the difficulty in detection of foundation scour and the budgetary delays in retrofitting increase the likelihood that scour-prone piers will be exposed to events as earthquakes. For this reason, it is essential to investigate the dynamic response of bridge piers before and after foundation scour. This study addresses the dynamic behavior of an idealized reinforced concrete bridge pier supported on a cylindrical caisson foundation embedded in sand, and it estimates the system eigenfrequencies under various scour scenarios.
The numerical model was implemented using the Structural Mechanics module of the COMSOL Multiphysics® software. The Beam interface was used to model the bridge pier and the deck mass, assigning section and material parameters to reproduce the real mass and stiffness distribution of the superstructure. Instead, the caisson foundation and the sand deposit were introduced through the Solid Mechanics interface. The connection between the superstructure and the foundation was provided by a Solid-Beam Connection node. Simulations were performed with the foundation fully embedded (label "S0") and with foundation scour to a maximum depth equal to 38% and 75% of the caisson height (labels "S1" and "S2", respectively). Foundation scour was introduced by removing a portion of the soil from the sides of the caisson to create an excavation consistent with the typical shape observed in hydraulic engineering (e.g., Kirby et al., 2015; Figure 1a). For simplicity, the materials were modeled as isotropic linear elastic, with a pressure-dependent stiffness for the sand to account for the effect of confinement on its behavior. The pressure-dependent behavior required the inclusion of a Weak Contribution node to update this parameter as a function of the soil stress state. The implemented numerical model has successfully predicted the eigenfrequency of the first shear mode of the sand deposit and that of the first rocking mode of the caisson-pier system in the "S0" scenario, based on the consistent comparison with the results of Deepsoil (Hashash et al., 2017) and SAP2000 software (CSI, 2023), respectively. For the first rocking mode (Figure 1b), the presence of a deeper scour hole results in a reduced eigenfrequency and a large increase in the caisson rotation, up to 50% (Figure 2). This is partially compensated by a smaller curvature in the pier (Figure 2b). Figure 2 also includes a comparison with "general scour" scenarios, corresponding to a uniform lowering of the ground surface down to the considered scour depth, in contrast to the simulated "local scour" schemes. This simplifying scheme is often adopted in the practice, but it results in much larger variations in both eigenfrequencies and mode shape parameters. Such a discrepancy highlights the importance of properly modeling the hydraulic scenario when dealing with the dynamic response of bridge piers under scour.

Reference

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Hashash, Musgrove, Harmon, Okan, Groholski, Phillips, and Park. 2017. DEEPSOIL 7.0, user manual. In.: University of Illinois at Urbana-Champaign.
Kirby, Roca, Kitchen, Escarameia, and Chesterton. 2015. Manual on scour at bridges and other hydraulic structures (Ciria).

Figures used in the abstract

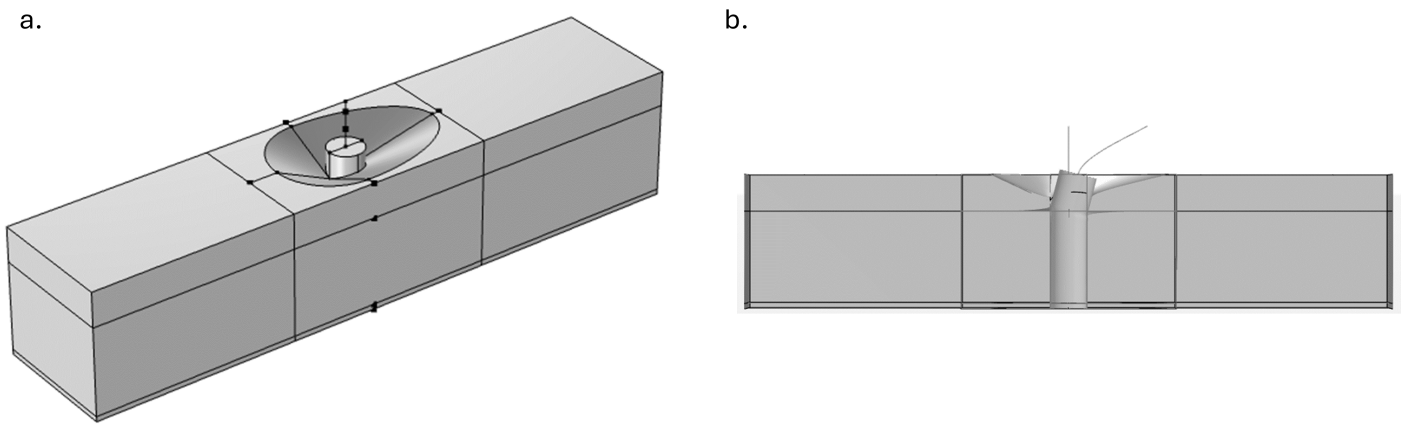

Figure 1 : a) Overview of the geometry of the numerical model; b) Cut plane view of the deformed model in the first rocking mode of the pier. Both models refer to the scour depth scenario “S2”.

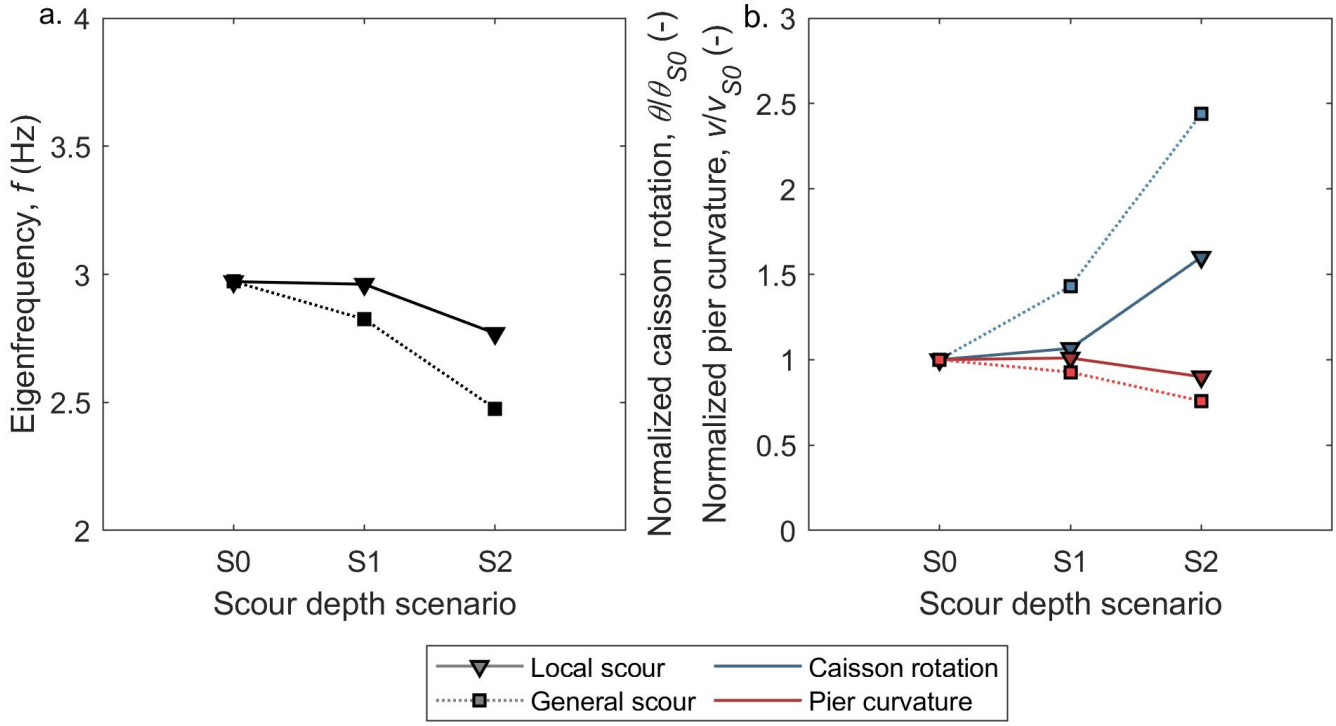

Figure 2 : Influence of the scour depth on the modal parameters of the first rocking mode of the caisson-pier system: a) Eigenfrequency; b) Caisson rotation and pier curvature. The “Local scour” label refers to scenarios characterized by the creation of an excavatio