Towards a simple calibration of a scour-depth sensor

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Summary. This extended abstract presents an innovative method for scour monitoring, based on the dynamic response of a bridge pile embedded in the riverbed. Apart from the mechanical and physical characteristics of the pile itself, soil-structure interaction (SSI) affects the dynamical behaviour of the system. This may result in a sensibility of the eigenfrequencies of the pile to soil conditions. As a consequence, analytical and numerical developments are carried out for an Euler-Bernoulli beam model (representing the pile), which is embedded in a Pasternak soil (springs with a shear layer) for SSI. Using Hamilton's Principle and endowing the non-linear boundary conditions, system frequencies are derived by seeking for non-trivial roots of the characteristic equation of the system.

Introduction

A majority of bridge collapses are due to hydraulic risks [1], among which scour. Today, several scour monitoring techniques exist [2], as for example:

- Water depth-measuring devices,
- Analyzing changes in dynamic behavior of structural elements (bridge pier or instrumented rod).

In this study, we will consider both technologies in order to characterize scour.

Evaluation of natural frequencies of the system

Let us consider an Euler-Bernoulli Beam partially embedded in a Pasternak-modelled Soil [3] (see Fig. 1): Hamilton's principle with specific boundary conditions leads us to a non-linear formulation. In fact, because of the external environment change, the formulation makes us deal with non-linear boundary conditions, in particular at the end of the pile in the soil.
In our investigation, we treat the general nonlinear problem in two sets of linear problems with two constitutive dynamical equations:

- An equation for the free part of the beam $x < 0$:

$$EI\frac{\partial v^4}{\partial^4 x}(x,t) + \rho A\frac{\partial v^2}{\partial^2 t}(x,t) = 0,$$

- and an equation for the embedded part of the beam $x > 0$:

$$EI\frac{\partial v^4}{\partial^4 x}(x,t) - g\frac{\partial v^2}{\partial^2 x}(x,t) + kv(x,t) + \rho A\frac{\partial v^2}{\partial^2 t}(x,t) = 0.$$

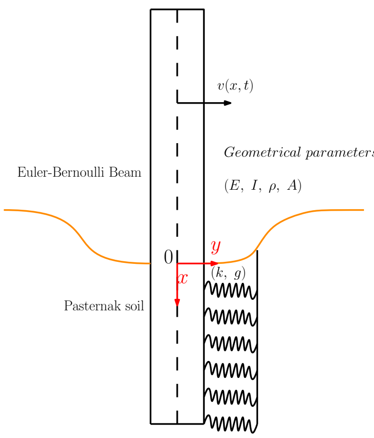

Figure 1: Mathematical model of the considered sysetm.

In our study, we focus on the modal analysis of the structure. Then, using modal projection and by solving equation of eigenfrequencies numerically (Newton method), the response of frequency as a function of scour depth is plotted. This response is also compared with finite difference method. The first step of our investigation permits us to see that reaching to correct numerical results can be elaborating for being sure that the system is not attracted by another root. Even if it converges, this method may be long.

Equivalent cantilevered beam of the system

The straightforward method of the previous section is costly. When we plot the natural frequency as a function of scour-depth (Fig. 2), variations are similar to a behaviour of cantilevered beam of a given length. This observation results in the development of the concept of added free length "ϵ" in the cantilevered beam (see Fig. 3): an equivalent length can be defined.

This means that we can include a modification of the length, adding "ϵ", to have the same frequency.

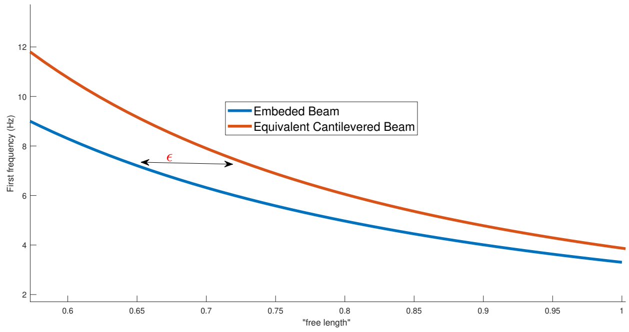

Figure 2: Variation of the first frequency with the normalized free length

The next step in our investigation is to introduce analytically this equivalent length to fix the same eigenfrequencies for the scour-depth sensor of a given length: this equivalent length can be obtained as a result of an asymptotic approach of the non-trivial function of which natural frequencies are solutions. The precision of this method depends on the depth of foundation and a coefficient which is linked to the SSI.

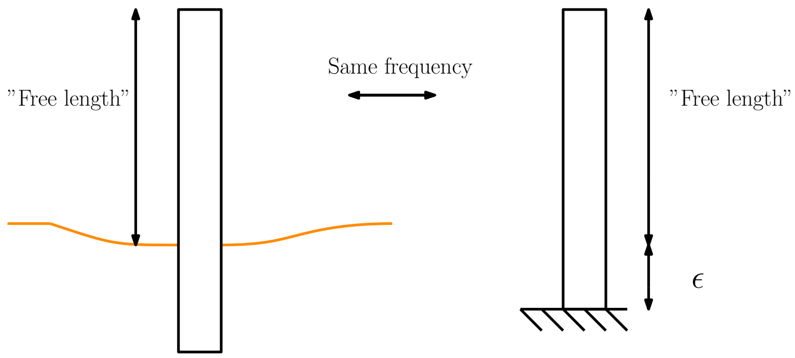

Figure 3: Equivalent cantilevered beam

Conclusions

Comparison between our analytical and numerical model and experimental results [4] are carried out to obtain the validation of the equivalent length as parameters of an inverse problem. It is shown that for deep foundations where the flexural rigidity of the beam is higher than the soil rigidity, the analytical model matches with the experimental results: depth sensor measures accurately the progression of scour depth. In the other case, non-linearities can no longer be treated with this method: the soil reaction itself has a nonlinear behavior.

References

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