F3. Soil-structure interactions

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Geotechnical structures often combine layers of soil with metal or concrete structures, which are generally much stiffer than soil. The interaction may be limited to a few points where the structure rests on the ground, or it may be continuous over a significant surface, such as the top surface of a tunnel, or retaining wall.

The interaction will be treated more or less precisely depending on the case.

In the case of tunnels, for example, it is very common to consider a perfect bond between the ground and the vault because of the construction method: with traditional (sequential) methods, the retaining wall is made of concrete sprayed directly on the surface of the ground uncovered by the excavation, which in principle ensures good continuity of movement. During tunneling performed by a TBM, efforts are made to ensure good force transmission between the ground and the segments by carrying out backfilling injections into the space between the arch and the ground. However, in older tunnels, the pathologies observed (or the tests carried out in situ) may suggest that contact is locally lost between the vault and the ground. For instance, it can be due to water seepage that may have washed out the ground: the modeling must then describe more precisely the contact conditions between the ground and the vault.

Covered trench tunnels present a different problem, as the ground around the structure is backfilled. The modeling of this operation may require explicit consideration, using specific elements, of the interface between the vault and the ground.

It is also common to introduce explicit modeling of the interface between the soil and the structure for retaining structures, when backfilling behind a wall (the phenomenon of soil sliding at the interface with the structure being similar to that involved in covered trenches), or when excavating in front of a cast wall, for example, the mass of soil supported may slide and present a vertical displacement greater than the height of the wall.

The question of modeling an interface between soils and structures must be considered on a case-by-case basis. One can introduce contact or interface elements specifically intended to represent the mechanical interaction between the two, but these elements introduce new parameters, which can be difficult to identify (such as the normal and tangential stiffnesses of the interface). This modeling approach presents a risk: the interface elements tend to control the behavior of the structure and to blur the role of the soil behavior, giving the impression that the response of the structure hardly depends on the soil anymore.

Reinforced structures

In many cases, the soil is reinforced by inclusions with very high stiffness and strength characteristics. These inclusions are discreetly distributed in the soil and very slender: piles, micro piles, tie rods, wall reinforcement in reinforced soil. This geometrical particularity poses various difficulties. First of all, strictly speaking, a row of piles is not equivalent to a continuous wall, and the use of plane strain assumption is not justified. In practice, one would adopt, for the planar calculations of the wall, mechanical characteristics "equivalent" to those of a row of piles, using assumptions that can be more or less difficult to justify. The same applies to the parameters of the mechanical interface between the soil and the piles/wall. The difficulty is the same if the wall is represented by surface elements or by linear beam-type elements.

To overcome this difficulty, 3D modeling can be used. However, because of the dimensions of the cross-section of the inclusions, whenever there are more than a few units, it becomes impossible to represent in the mesh the real geometry of the inclusions: for a reinforced earth wall, with reinforcements of 5 mm x 45 mm section, at a rate of 4 to 6 reinforcements per 0.75 m x 0.75 m, and for a volume whose dimensions are of the order of ten meters, the number of nodes of a mesh that would respect the real geometry of the inclusions and that would give an acceptable discretization exceeds the current calculation capacities. We can therefore propose to represent the inclusions by 1D elements (with or without considering bending effects). This approach is questionable from a theoretical point of view because the introduction of a linear density of force exerted by the inclusion in a 3D medium is not compatible with the classical representation of internal forces by a stress tensor. It can be used, however, one must be careful in the interpretation of the results, at least with respect to the stresses in the vicinity of the inclusions.

An alternative solution is to adopt homogenization-type approaches to take into account the influence of inclusions on the overall behavior of the structure. More or less complex models have been developed and implemented in some software.

Whatever the choices made (calculation in plane strains or in 3D condition, discretization of inclusions - by linear or non-linear elements - or homogenized approach), it is necessary to represent the mechanical interaction between the pile and the soil that occurs at the contact between the soil and the sidewall of the pile, and also between the soil and the footing of the pile. Modeling the mechanical interaction at the footing of the pile is particularly difficult to master. Modeling a single pile by volume elements, possibly with interface elements with the surrounding soil, gives results that depend on the mesh and the constitutive model used for the soil. It is necessary to use a model that reproduces the soil failure in compression if one is interested in the pile failure. For instance, models such as Mohr-Coulomb or Drucker Prager are not suitable in this context.

In some 2D or 3D models where inclusions are represented by bar or beam elements, a fictitious end (e.g. a horizontal beam element perpendicular to the pile) is associated with the inclusion, in an attempt to better represent the interaction at the footing of the pile: performing studies to determine the sensitivity of the results to the dimension of the added elements seems appropriate to verify the relevance of this approach.

Finally, other modeling techniques are available, which propose to explicitly integrate an interaction model for lateral friction and another one for peak interaction via ad hoc elements.

Without going more into detail, let us highlight the fact that the user is free to choose between numerical simulation techniques and models, which have a direct influence on the obtained results.

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