F1. Geometric aspects

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One of the advantages of the FE method is the possibility of describing the exact geometry of the structures even during the various construction phases. CAD-like pre-processing tools make it easy to generate very complex geometries. One of the features of geotechnical structures is that, generally, the earth mass that constitutes or surrounds the structure must be considered within the mesh.

1. **Boundaries of the studied domain**

The first challenge is to identify the boundaries of the domain considered for the analysis. For a geotechnical structure, the horizontal and the lower boundaries of the studied domain are rarely determined with precision: the extent of the domain is then bounded by vertical planes whose position is generally fixed by using empirical rules.

Using the plane strain assumption, for example, the position at which the lower limit of the mesh is set has a direct impact on the calculated settlement for a strip footing or above a tunnel. This relation is clear in the case of a homogeneous linear elastic soil mass. It can be reduced by taking into account elastic moduli, which increases with depth. Nevertheless, it is likely to induce a significant error in the calculated displacements. The ideal case is when a rigid bedrock has been found at a given depth, which assumes that the research has been carried out to a sufficient depth. To model a tunnel, for instance, it is advised to collect soil sampling way beyond the depth of the shaft, which is generally not the case in real projects.

In the lateral directions, considering a domain that is too small can also significantly modify the response of the numerical model. Fixed displacements lead to an overestimation of the stiffness of the solid, and "smooth contact" type conditions lead to an overestimation of the displacements. The choice of the mesh dimensions adapted to a structure remains a largely open problem even if some authors have suggested practical rules. However, those rules should not be taken as absolute prescriptions (see Mestat and Prat, 1999).

Consequently, choosing the size of the domain considered for the mesh is an important step in the modeling of geotechnical structures, even for relatively simple static analyses. In the case of dynamic calculations, the question of the size of the meshing domain raises specific issues and is a crucial part of the modeling strategy. This will be detailed in section 8.

2. **Soil heterogeneities**

In some regions, such as London or Frankfurt, geology allows the soil in the vicinity of the structure to be considered homogeneous (in the sense that its mechanical and hydraulic behaviors can be represented by a single model). However, in other contexts, particularly in the Paris region, it is common for the studied area to include several layers of soil of very different natures and characteristics (particularly mechanical). Therefore, the elaboration of a computational model begins, as for traditional methods, with a detailed study of the soil layers in the area of interest. The goal is not to reproduce the exact geometry of the geological layers (which may be locally thin), but to define geotechnically homogeneous sets.

3. **Discontinuities**

An important particularity of geotechnical calculations is the presence, within the solid, of failure planes that existed before the construction of the structure or the implementation of the studied load. They produce a discontinuity of displacement between the blocks located on either side of the failure plane. The FE method is well adapted to search for continuous displacement fields, and the consideration of this type of discontinuities requires the implementation of special techniques (specific elements are generally used) or even the use of another calculation method such as the discrete element method.

Behaviors such as landslides are extremely complicated to predict. Nowadays, it is extremely difficult to predict the occurrence and development of failure planes. Usually, the engineer is forced to consider an existing plane whose position has been identified with more or less precision using the adapted equipment (for example, inclinometers that follow the deformation of a slope).

Solid rocks often contain a large number of fractures with directions that are seemingly parallel to one or two main directions (local diaclases). The fracture distribution is diffuse, and random, or at least impossible to characterize completely at the scale of the solid. If the global behavior of the solid is of interest, it can be modeled as a continuous medium employing a constitutive model, which incorporates, at the calculation scale, the effects of the discontinuities: homogenization methods are generally used.

One may also have to consider large discontinuities in a solid bedrock (fractures), which can be treated as the failure planes of landslides.

4. **An "open" material system and construction techniques to be modeled**

As stated in the introductory chapter, a peculiarity of civil engineering calculations is the need to consider construction phases such as clearing or backfilling, implementing a concrete mass, tensioning cables, etc. Taking these construction phases into account within the framework of the FE method can be a lengthy and complicated process: the method consists of reducing the problem to the calculation of a stiffness matrix, a vector of nodal forces, then solving the system obtained by considering the boundary conditions. To model the construction phases, one must perform a series of calculations taking into account the change in stiffness of some elements, disappearance or modification of some supports, changes in the point of application of the loads, etc.

Therefore, the issue is to propose simulation techniques that can take into account a large number of constructive arrangements within the relatively narrow framework of the FE method. It is up to the user to decide whether the modeling tools proposed by the software correctly reflect the phenomena involved.

In the case of tunnels dug by TBM, the stresses applied onto the ground during the various digging phases are complex as the soil is closing in on the ring formed by the segments as the TBM advances. Pile driving is another example, which is difficult to simplify to the FE method framework.

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