The Purpose of Numerical Modeling


Numerical modeling or numerical analysis is an integral part of geotechnical engineering, as was so validly illustrated by Professor John Burland from Imperial College, London in his 1987 Nash Lecture, *The Teaching of Soil Mechanics—a Personal View* (Burland 1987, 1996). Burland envisaged geotechnical practice as involving a clear understanding of the ground profile established from a site investigation, the definition of soil behavior provided from field and laboratory measurements, and then the application of this understanding through the use of modeling (Figure 1).

Numerical modeling is increasingly taking its rightful role in geotechnical practice due largely to the software tools and computing power that are now so readily available. However, proper use of these powerful numerical tools remains somewhat immature. Too often the expectation of what is to be achieved is unrealistic, and the purpose of the numerical modeling is unclear.

This article briefly reviews the purposes and benefits of numerical modeling, and introduces several key concepts to help you properly think about this subject.

**What Is Numerical Modeling?**

Numerical modeling is fundamentally an attempt to replicate some real-world object or system using mathematics. The key word here is "replicate." Stated another way, "modeling" is the process by which we extract from a complex physical reality an appropriate mathematical model on which we can base a design. The role of the numerical model is simply to assist us in developing an appropriate understanding of the real-world object or system.

**Why Model?**

One of the main reasons for using numerical models is to solve a simultaneous set of highly non-linear equations for which it is impossible to obtain a hand-calculated solution. In fact, some building codes now require the use of computer analysis due to the complexity of certain required structural calculations.

If a group of engineers was asked to state the main purpose of numerical modeling, the majority would likely respond that it is to make a quantifiable prediction about future behavior. This might be to predict the settlement of a footing, the first arrival of a contaminant, or to quantify seepage. However, making effective predictions is not so much a function of the numerical model as it is our ability to accurately quantify the material properties. Since quantifying the material properties is often an estimate of the actual field conditions, numerical modeling is sometimes dismissed as useless.

This misconception blinds us to the greatest benefit of numerical modeling, which is to help train our thinking and to enlighten our understanding of real-world physical processes. The key advantage of modeling is to enhance our judgment and understanding—not simply to enhance our predictive capabilities. M.P. Anderson and W.W. Woessner (1992) similarly state: "the attraction of … modelling is that it combines the subtlety of human judgment with the power of the digital computer."

The most satisfying moments during a modeling exercise
often occur when the mental “light bulb” comes on and the analyst is able to exclaim, “Yes! The solution makes perfect sense and is completely logical.”

**Complexity**

There is no doubt that we, as geotechnical engineers, deal with highly complex natural geological and hydrological settings and highly complex material properties. The tendency therefore is to include as much complexity in a numerical model as possible, particularly by novice modelers. Thinking that adding complexity will give the most “accurate” solution is simply erroneous. Overly complex models will often lead to un-interpretable solutions. At best, the numerical model should be a simplified abstraction of the actual field complexity.

Muir Wood (2004) points out that modeling should be adequately complex. He goes on to state, “... that the more complex the model, the more the modelling itself will obscure the underpinning mechanics of soil behavior and geotechnical system behavior which we are trying to probe and understand. The art of successful modelling is to include just enough detail for the implied simplifications to be reasonable for the particular application.”

The issue of complexity is not unique to geotechnical engineering. Baran and Sweezy (1968), while discussing social and financial issues, state that, “Scientific understanding proceeds by way of construction and analyzing models of the segments or aspects of reality under study. The purpose of these models is not to give a mirror image of reality, not to include all segments in their exact sizes and proportions, but rather to single out and make available for intensive investigation those elements which are decisive. We abstract from non-essentials, we blot out unimportant to get an unobstructed view of the important; we magnify in order to improve the range and accuracy of our observation. A model is, and must be, unrealistic in the sense in which the word is commonly used. Nevertheless, and in a sense, paradoxically, if it is a good model, it provides the key to understanding reality.” This is equally applicable to geotechnical modeling as well.

We, as engineers, often tend to concentrate our efforts on the aspects of a project that we find most comfortable and familiar. In the case of numerical modeling, it is the geometry, and consequently, the analyst tends to set up a very complex geometric and stratigraphic cross-section including the smallest details. Yet, the geometric complexity offers no added value to the model if the material properties and boundary conditions are not well understood. Care is required to ensure that all aspects of abstraction are on the same level.

The best approach for all modelers, whether novice or well-seasoned, is to start simple and gradually move toward the complex in stages.

**Conceptualization**

The first step to effective numerical modeling is to form a mental image of what we expect the solution to look like. This thought has been echoed by many prominent engineers. For example, Muir Wood (2004) noted that, “…before we embark on the analysis, we should have some idea of what to expect to happen.”

This is most difficult for a recent graduate, but since the newest generation of engineers is highly adept at using computers, computer modeling within an engineering firm is invariably mandated to this group. Consequently, we have a modeler with savvy computer skills who may not be able to conceptualize the possible end result. A team approach to modeling, including both experienced and novice engineers, is therefore highly advisable.

So, what should the response be if the computed solution does not match your mental image of the anticipated behavior? The obvious verification of input data, boundary conditions and discretization level needs to be made. However, if these are correct and the solution still does not meet your expectations, then it is perhaps necessary to re-evaluate your understanding of the anticipated behavior. Perhaps there is something new to be learned or discovered. A systematic modeling methodology is required for this type of situation. Space limitations preclude providing a detailed discussion here, but interested readers are encouraged to read Barbour and Krahn (2004), where a suggested methodology is described.
Summary

There are a number of features of numerical models that must be appreciated to make effective use of these analytic tools in the modeling process. These features include the fact that all models are only simplified abstractions of a complex reality. It is important to keep in mind that the purpose of modeling, particularly in the use of numerical models, is not to try to replicate all of nature’s complexity. The genius in modeling is the ability to only develop as complicated a representation of the physical reality as necessary to sufficiently understand the underlying behavior of a particular design.

Ironically, the primary reason we use complicated numerical models is so that we can sort through the complexity of the physical system until we isolate one or two simple issues on which we can base our design. Inevitably, as you begin to reach the end of a long and lengthy modeling project, you will find that your understanding of what appeared to be a complex enigma will suddenly boil down to one or two central, simple ideas. In many cases, there is almost a sense of personal embarrassment that you weren’t able to grasp these simple principles from the beginning.

This is a critical lesson in modeling and the use of numerical models in particular. The key advantage to modeling and using computer modeling tools is the capability it has to enhance engineering judgment. It is not only about enhancing our predictive capabilities. While it is true that sophisticated computer tools greatly elevate our predictive capabilities relative to hand calculations, graphical techniques, and closed-form analytical solutions, prediction is not the most important advantage these modern tools provide.

In the end, the modeling process is indeed a journey of discovery—a way of learning something new about the complex behavior of our physical world. Furthermore, it is a process that can help us more fully understand highly complex real physical processes, and that, in turn, can help us exercise our engineering judgment with increased confidence to make predictions.

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