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*Editorial*

# Special Issue on Numerical Modeling in Civil and Mining Geotechnical Engineering

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Numerical modeling is a widely used method in geotechnical engineering to understand the interactive responses of infrastructures with soils or/and rocks in both civil and mining engineering. Nowadays, computers are more and more powerful and commercialized software has become more and more easy to use because of graphic interfaces to facilitate the input and output parameters of numerical models. Numerical modeling has become much simpler and easier than it was decades ago. For some, numerical modeling can be carried out by anyone, including bachelor students. Ironically, the author's personal surveys indicate that 90% of the people who perform numerical modeling do not believe in their own numerical results. In addition, some believe that numerical modeling can only be used to provide qualitative information, such as a general idea or trend. This is another form of distrust in numerical modeling. How can we explain the crisis of confidence in numerical modeling, a phenomenon particular to geotechnical engineering?

Compared to other fields such as structural and mechanical engineering, one of the particularities of geotechnical engineering is the need to consider the ground. This is also one of the common points between civil geotechnical engineering and mining geotechnical engineering. Normally, the earth should be taken into account in numerical models of geotechnical engineering. However, the full consideration of the earth would result in an immense numerical model, requiring huge computing resource to simulate the earth. For most problems in geotechnical engineering, this is neither feasible nor necessary because the time and cost of calculations would be extremely high, and the uncertainties associated with the internal structures and properties of the earth could render the numerical results highly uncertain and even false. An alternative approach is to consider the studied structures with a semi-infinite space, as if the earth was considered as somehow flat without limit. This is not entirely false because the studied structures in civil engineering and mining engineering are for most cases very small compared to the size of the earth. It is, however, another source of problems in numerical modeling in civil and mining geotechnical engineering.

As most of the commonly used software in geotechnical engineering is based on continuum mechanics, discretization and meshing are necessary to represent the geometries of the ground and studied structures. Considering the whole semi-infinite space is impossible for most geotechnical engineering software developed on the finite element method or finite difference method. Cuts have to be made through the semi-infinite space to generate virtual boundaries, which, along with the ground surface and studied structure surfaces, constitute the domain of the numerical model. Boundary conditions are usually well-known along the ground surface and studied structure surfaces, and unknown along the virtual boundaries. A common method is to apply the initial in situ conditions (i.e., before any constructions or excavations) of the semi-infinite space along the virtual boundaries. The validity or representativeness of this hypothesis depends on the distances between the studied structures and the virtual boundaries. If the distances and the domain of the numerical model are too small, the virtual boundaries may fall within the influenced zones of the construction or excavation of the studied structures. Applying the initial in situ

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conditions of the semi-infinite space along the virtual boundaries is not representative of the field conditions. The constructed numerical model simulates a problem or situation different from the original one. The numerical results could be inaccurate and even false. If the distances between the virtual boundaries and studied structures and the domain of the numerical model are too large, the time of calculations could become uselessly long. Optimization of the domain is necessary to minimize the time of calculations and ensure stable and reliable numerical results. This is only possible through sensitivity analysis of the domain by considering a domain as small as possible to minimize the time of calculations, but large enough to ensure stable and reliable numerical results. The ensuing domain is called the optimal domain of the numerical model.

Another aspect affecting the time of calculations and quality of numerical results is the mesh sizes of the numerical model. Similar to the determination of the optimal domain, sensitivity analysis of mesh sizes is necessary in order to obtain the optimal meshes, which should be as coarse as possible to minimize the time of calculations, but fine enough to ensure stable and reliable numerical results.

Unstable and unreliable numerical results can result from a domain which is not large enough and/or meshes which are not fine enough. A good practice for minimizing the time of calculations and ensuring stable and reliable numerical results is to perform sensitivity analyses of the domain and meshes to obtain an optimal numerical model with an optimal domain and an optimal mesh. An example of this practice can be seen through the article of Zeng et al. [1], who present the validation of a newly implemented numerical model against analytical solutions. The method of obtaining stable and reliable numerical results of stresses in a backfilled stope through sensitivity analyses of the domain and meshes is also illustrated. When time is involved in numerical models, sensitivity analysis of time steps should be performed to obtain the optimal time step, which should be as large as possible to minimize the time of calculations, but small enough to ensure stable and reliable numerical results.

Normally, numerical results tend to become stable as long as the meshes of the numerical model are fine enough. It is, however, not always the case, especially when the default values of the controlling parameters given by commercialized software are used. The numerical results may become unstable, and the trend can even become irregular as the meshes of the numerical model are too fine. This is due to the fact that the default values of the controlling parameters given by commercialized software are valid for most of simple cases. When the number or/and size of the studied structures are large, accumulated errors associated with the approximation of numerical calculations could become large. The problem can be amplified by using meshes which are too fine. It is important to perform sensitivity analyses of all the controlling parameters. Examples can be found in Zhai [2] by increasing the number of iteration steps with FLAC3D [3], or in Jaouhar [4] through a reduction in the error tolerance with SIGMA/W [5].

In contrast to a belief that numerical modeling can be performed by anyone, the author believes that numerical modeling can only be performed by a qualified person. A minimum of training is necessary. The validation or verification of the used numerical code against closed-form (analytical) solutions should be the first step in the training. This is necessary for any new user, firstly to verify if the numerical code contains any errors or limitations, and secondly to verify if the new user can correctly use the numerical code to produce meaningful numerical results. It is very important for the trainee to understand that the most important aspects of the validation or verification step are the procedure of diverse sensitivity analyses, through which stable and reliable numerical results can be obtained. It is also very important for the trainee to apply the procedure of sensitivity analyses in all the numerical modeling with any specific projects.

A quite common and poor practice is to use an extremely large domain and very fine meshes through the whole domain during the step of validation or verification against a closed-form (analytical) solution. As the structure of closed-form solutions is usually simple and small, the time of calculation is not a problem. The trainee could quickly complete the validation step, but gains little knowledge on the limitation of the numerical models and on how to obtain stable and reliable numerical results. During the step of numerical modeling with a specific project, the number and size of studied structures become large. The power and availability of computing resources along with the time of calculations then become prevailing concerns, neglecting to examine whether the domain is large enough and whether the meshes are fine enough. The numerical model can be too small in domain and/or too coarse in meshes, resulting in unstable and unreliable numerical results. This is an importance source feeding people's distrust in numerical modeling in civil and mining geotechnical engineering.

Despite the importance of the step of validation or verification against closed-form (analytical) solutions, some people believe that this step is unnecessary, arguing that the numerical code employed is very popular and widely used. If one recognizes the fact that a good car tested by many people is not equivalent to a good driving by anyone, one would understand that a widely used numerical code does not automatically result in good numerical modeling by any new users. Subsequently, any new users must pass the step of validation, through which the new users can learn how to use the software, verify if the numerical code contains any errors and limitations, and learn how to obtain stable and reliable numerical results through the diverse sensitivity analyses.

Over the years, numerical codes based on the distinct element method or mesh-free methods are becoming more and more popular in geotechnical engineering to simulate the behavior of granular or fluid materials. While the domain and meshes are critical concerns of numerical modeling with numerical codes based on continuum mechanics, they are not applicable to numerical modeling with numerical codes based on distinct element method or mesh-free methods. However, the representativeness of the particles in numerical models based on the distinct element method and the density of nodes in numerical models based on the mesh-free methods become critical. How to obtain stable and reliable numerical results is still a critical concern. Again, their sensitivity analyses along with the sensitivity analyses of controlling parameters are necessary to obtain an optimal numerical model and ensure stable and reliable numerical results.

Another point of view quite common in geotechnical engineering is the need for validation of numerical models by experimental results. The numerical results are even considered unreliable and useless if there is no validation by experimental results. This point of view neglects the fact that experimental results can also involve numerous uncertainties and even errors due to human errors, instrumentation inaccuracy and flaws in testing norms [6,7]. A long discussion on the stability and reliability of experimental results is beyond the scope of this Special Issue (SI), but it is not uncommon to see geotechnical tests realized without calibrating all the testing instrumentation before and/or after the tests. This is particularly true in field measurements. The obtained experimental results can contain high uncertainties or even errors. In many cases, people make use of their own experimental results or published data to calibrate their numerical model by adjusting some model parameters to obtain good agreements between the numerical and experimental results. The ensued good agreement is usually called a "validation" of the numerical model or "prediction" of the experimental results. In the author's point of view, this process of calibration is neither a validation of the numerical model nor a prediction of the experimental results. If the experimental results are erroneous, it would be odd to conclude that the numerical model is validated by erroneous data and the numerical model successfully predicts wrong experimental results. If the experimental results are reliable, the process of calibration can then be considered as a test of the power or applicability of the numerical model. The numerical model along with the measured and calibrated model parameters can then be called "calibrated numerical model" [8–10]. The predictability of the calibrated numerical model needs to be verified against additional experimental data that are not used in the process of calibration.

The above-mentioned aspects are not the only sources feeding people's distrust in numerical modeling in geotechnical engineering. There exist other sources, such as the heterogeneity of material in space and poor investigation of sites. The reliability of numerical modeling diminishes as the reliability and representativeness of measured parameters decrease. This is, however, a problem of site investigation and parameter measurements, not a problem of numerical modeling. Here we understand that the reliability of a system needs the reliability of every element which constitutes the system.

Aiming to increase people's confidence in numerical modeling in civil and mining geotechnical engineering, the author accepted the journal invitation to host this SI. The collected articles not only present original and novel contributions to civil and mining geotechnical engineering, but also include sufficient details in order for readers to be able to reproduce the published results of the physical and numerical models. Comparisons between numerical and experimental results were encouraged, but not considered as mandatory. Emphasis was placed on the validation or verification of the used numerical model, including domain and mesh sensitivity analyses of numerical models as long as they are applicable.

Upon our invitations, more than 27 articles were submitted in this SI. A few had been rejected without being sent to the process of review as their contents were beyond the scope of this SI. Thirteen articles were rejected after evaluation by either academic editors or reviewers, while fourteen articles were published based on the positive recommendations of at least two reviewers for each article and the positive recommendations of academic editors. The SI contains seven articles in civil engineering [11–17] and seven articles in mining engineering [1,8,18–22]. Each of the published papers has its own merits and limitations (very normal in research). As the guest editor of this SI, the author hopes the readers enjoy the reading of all the 14 published articles. Any comments, suggestions and criticisms are welcome either in form of discussion articles or in form of personal communications.

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