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GEOTECHNICS AND ARCHITECTURE. CONSIDERATIONS ON THE CURRENT GEOTECHNICAL PARADIGM AND ITS POSSIBLE FUTURE DEVELOPMENT

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Summary. The understanding of soil behavior is a key element for the development of both architectural works and urban infrastructures, since most of the failures in constructions are related to the relative ignorance of the nature of the soil. Considering the heterogeneous and complex nature of soil, can geotechnical engineering - by today's standards - achieve an understanding of the soil/built dynamics? or is a paradigm shift required, with input from other disciplines, to enable the articulation of more complex and accurate models? The objective of this research is to explore the current paradigm in soil mechanics and to expose possible future scenarios for the discipline, from a quantitative-qualitative methodological design and using data collection techniques; systematization on a Geographic Information System (GIS); with determination of characteristic features -with interpretative and descriptive analysis- of the support structure, we sought to determine the characteristic features of the different types of soils found in the city of Mar del Plata, Republic of Argentina, establishing differentiated geotechnical characterization zones. At present, there are lines of research that seek the development of mathematical models to describe a realistic soil behavior; where, with regard to the lack of data - it is important to note that, although there is currently a large amount of data available from different disciplines, such information is not cross-cutting and interrelated - the incorporation and systematization of such data continues to be the greatest difficulty.

Key words: Urban planning, management instruments, public policies, geotechnics and soil mechanics.

GEOTECNIA Y ARQUITECTURA. CONSIDERACIONES SOBRE EL PARADIGMA ACTUAL EN GEOTECNIA Y SUS POSIBLES DESARROLLOS FUTUROS

Emilio Gastón Polo Friz

Resumen. La comprensión del comportamiento del suelo es un elemento clave para el desarrollo tanto de obras de arquitectura, como de infraestructuras urbanas; ya que la mayor parte de los fallos en las construcciones, están relacionados con el desconocimiento relativo de la naturaleza del suelo. Teniendo en consideración la naturaleza heterogénea y compleja del suelo, ¿puede la geotecnia -según estándares actuales- lograr una comprensión de la dinámica terreno/obra construida? ¿o se requiere un cambio de paradigma con aporte de otras disciplinas, que permitan articular modelos más complejos y precisos? Siendo el objetivo de la presente investigación, el de explorar el paradigma actual en mecánica del suelo y exponer posibles escenarios futuros superadores para la disciplina, desde un diseño metodológico de tipo cuantitativo-cualitativo y utilizando técnicas de recopilación de datos; sistematización sobre un Sistema de Información Geográfica (GIS); con determinación de rasgos característicos -con análisis interpretativo y descriptivo- de la estructura soporte, se buscó determinar los rasgos característicos de los diferentes tipos de suelos encontrados en la ciudad de Mar del Plata, República Argentina, estableciendo zonas de caracterización geotécnica diferenciada. En la actualidad, existen líneas de investigación que buscan el desarrollo de modelos matemáticos que permitan describir un comportamiento realista del suelo; donde, en lo que refiere a la carencia de datos -siendo importante destacar que, si bien en la actualidad existe una gran cantidad de datos disponibles de diverso origen disciplinar, dicha información no se transversaliza e interrelaciona- la incorporación y sistematización de los mismos, sigue siendo la mayor dificultad.

Palabras clave: Planificación Urbana, instrumentos de gestión, políticas públicas, geotecnia y mecánica de suelos.

Introduction

The understanding of soil behavior is a key element for the development of both our architectural works and the civil engineering infrastructures required by a city or region; since, as Brandl (2004) indicates, 80-85 percent of construction failures are related to changes in the dynamics of the supporting structure, its behavior and the emerging stresses that may occur with the constructions that are built on it.

Thus, any uncertainty regarding the nature of the soil, the geotechnical conditions of a city, or the dynamics between the constructed work and the territory on which it is located, are mainly due to the difficulty in obtaining and analyzing data on the subsoil and its interaction with the constructions. This is why, in recent years, the strategic management of the subsoil has come to represent a topic of relevance for the development of cities, constituting a new interdisciplinary field known as "urban geosciences".

The city of Mar del Plata, Province of Buenos Aires, Argentina, like most of the main capitals in Latin America, has developed its urban planning without taking into consideration basic factors of territorial structuring, such as geology and geotechnics, thus ignoring its vulnerable areas and/or sectors of potential geotechnical risk.

In this sense, the absence of a well-founded and systematized knowledge about the behavior of Mar del Plata's soil makes the correct implementation of instruments for the design and execution of municipal development policies, as well as the adequate implementation of architectural and civil engineering works of medium and high complexity, very difficult.

On the basis of the problems described above, Arq. Emilio Polo -author of the present work- has been developing his doctoral thesis at FAUD-UNMdP, which aims -from the collection of existing data and its systematization on a Geographic Information System (GIS)- to determine the characteristic features of the different types of soils present in the city of Mar del Plata; establishing differentiated geotechnical characterization zones (areas with potential for urban development, geotechnical risk zones, etc.) in order to offer new knowledge in the field of local geotechnics, focused on the dynamics of the Mar del Plata soil, its interaction with the architectural work -built and to be built- and the different foundation alternatives used. As part of this work, and based on the conceptual limitations found on the knowledge of soil behavior -and taking into consideration its heterogeneous and complex nature-, can geotechnical engineering -according to its current standards- achieve a complete understanding of the soil/built dynamics? or is a paradigm shift required that draws from the various disciplines and allows for the articulation of more complex and accurate models?

Method

The research developed, from a quantitative-qualitative methodological design with interpretative and descriptive analysis, has used techniques related to data collection (soil studies, satellite images, geo-referenced information, etc.); systematization of information on a Geographic Information System (GIS); and determination of characteristic features of the city of Mar del Plata; establishing on this, differentiated geotechnical characterization areas (areas with potential for urban development, geotechnical risk areas, etc.).

For this article, a descriptive and interpretative methodology of documentary analysis on secondary sources has been used, where the evolution of geotechnics as a science in the course of time is analyzed, as well as the development of its principles and paradigm changes. As established by Denzin and Lincoln (2017), the integration of methodological instruments, the documented, the observed and the conversed, lead to the recursivity of analysis, synthesis and interpretation processes that enable different perspectives on the same reality.

Results

Soil science seeks to understand its nature, properties, dynamics and functions as part of a multidimensional system that includes physical, chemical and mechanical aspects, but also analyzes -or should analyze- the impact of social, urban development, economic and territorial aspects, in relation to how they influence or affect its behavior as a support structure.

In this context, we cannot ignore the fact that soil dynamics is complex due to its heterogeneous and diverse nature, where its original structural composition coexists with endogenous and exogenous variables that condition its response -affecting its performance, in geotechnical terms-. The interaction of solid particles with the interstitial fluid -which is generally composed of more than one fluid: water, organic and inorganic contaminants, gases, etc.-, the interaction of solid particles with the interstitial fluid, which is generally composed of more than one fluid: water, organic and inorganic contaminants, gases, etc., triggers different behaviors depending on the variation of moisture levels, shape and structure of the granular particles, their heterogeneity, confinement, etc.; where human activities - urbanization processes, transformation of the natural landscape/territory, incorporation or modification of "loads" through the construction of architectural or engineering works - affect the original conditions of the soil, transforming it.

Throughout history, as part of this process of understanding soil mechanics, there has been an ongoing concern to "explain" the fundamentals of soil behavior. From the consideration of failures as "acts of God" (Morley, 1996) to the application of the "law of retaliation" in the Code of Hammurabi - from a legal principle of retributive justice, which have laid the foundations of current codes - to the development of geotechnics as a science in the last part of the 19th century and first half of the 20th century. During the 18th century, we can find the development of the first theoretical numerical models that try to explain the behavior of structures using deterministic concepts.

However, it was not until the second half of the 20th century, with the incorporation of probabilistic concepts, that determinism began to be questioned; where the work built -or to be built- began to be developed taking into account a context where the physical-constructive aspects of the materiality -where the support structure that makes up the territory is located- are dynamic and liable to change.

In this sense, as proposed by Antonio Gens Solé (2005) in his speech to the Royal European Academy of Doctors, contributions such as those made by Coulomb (1736-1806) with the calculation of earth thrust on walls and the analysis of friction phenomena; the contributions of Rankine (1820-1872) with the development of his investigations on limit equilibrium states in a semi-infinite earth mass; and the contribution of Boussinesq (1842-1929) with the solution of the elastic problem of a point load placed on a semi-infinite isotropic elastic half-space; as well as other researchers such as: J.R. Perronet (1769) who provides the first study on slope stability; G.C. Prony (1802), J.F. Français (1820), C.V. Poncelet (1840) and C. W. Hope (1845) who work on earth and wall overpours; A. Collin (1846) who discovers the undrained shear strength of clays; H.P.J. Darcy (1856) who proposed the law of flow in a porous medium that has withstood all the ravages of time; O. Reynolds (1887) who discovered the dilatancy of sands; allowed to lay the foundations of Geotechnics as a science at the dawn of the twentieth century.

The understanding -and formulation of the principle- of effective stresses for saturated soils proposed by Terzaghi in the 1920s, was one of the great contributions to the discipline, where the consideration of soil as a porous material (unlike Coulomb and Rankine who considered it as a solid) allowed him to advance where they could not. Terzaghi himself, from his numerous publications -produced between 1936 and 1961- that address the disconnection between the codes and standards of the time with the technical foundations (what Terzaghi calls "the old code" in reference to the ideas of the early twentieth century), is the one who proposes a first paradigm shift that brings him closer to the discipline as a science.

The principle of effective stresses implied - for the time - a great unification of the hydraulic and mechanical aspects of soil behavior, but the rupture was still considered separately (developments from the works of Coulomb and Rankine), which did not allow the integration of the soil behavior as a coherent whole. In pursuit of this objective, the

Cambridge University Geotechnical group (Roscoe, Schofield and Wroth in the 1960s) set out to achieve a unified model that would allow linking aspects of ground behavior that - at that time - were separate entities, incorporating the concept of critical state and later, the concept of mixed fluid phase and unsaturated soils (Bishop, Aitchinson, Fredlund and Morgenstern in the second half of the 1960s).

Around the same time -1968-, Roscoe and Burland proposed the Modified Cam-clay model, which corrected some important defects of the original Cam-clay, giving rise to the critical state models. These models allowed considering a large number of soil behavior characteristics in a unified way, concepts such as breakage, deformation, volume changes, soil memory, consolidation, critical state could be integrated in a model that allowed a more global understanding of soil behavior.

While it is true that the paradigm represented by the critical state models has been able to satisfactorily characterize some of the most common behaviors of soils, when looking at the actual behavior of many natural soils, we find that the Cam-clay model is often oversimplified, requiring amplification for its effective use.

In this sense, the different soil classifications currently existing are intended to describe and integrate the main characteristics and behaviors of the soil according to the needs of different activities or disciplines -road and pavement construction, agriculture, mining, geomechanics, geology, etc.-, but so far no unified general classification has been achieved.

Some of the classifications that can be referenced are:

1) The Unified Soil Classification System -SUCS-.
2) The American Association of State Highway & Transportation Officials (AASHTO) System.
3) The method proposed by the Federal Aviation Administration -FAA-.
4) The US Department of Agriculture (USDA) system.
5) and the Eurocode taxonomy, among others.

At present, there are several lines of research that seek the development of mathematical models that allow describing a realistic behavior of the soil, facing to a great extent -these systems-, the unpredictability resulting from the uncertainty due to the variability of action of the material, according to the change of the conditions in which it is immersed -changes in humidity levels, higher loads, etc.-.

As stated by Baecher & Christian (2003), sources of uncertainty, in general, can come in three main categories:

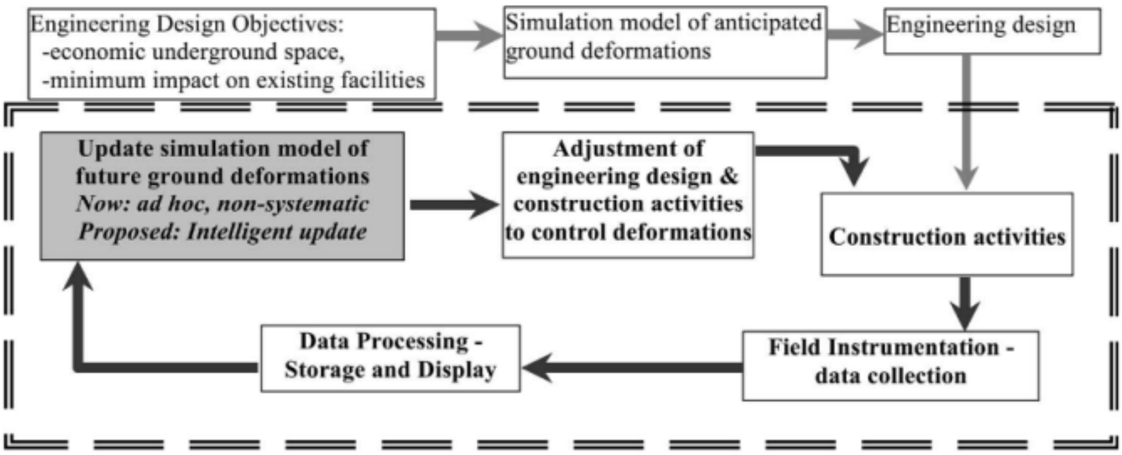
- Those related to natural variability.
- Those related to epistemic uncertainty.
- Those related to decision models.

The first category is related to the variability of soil material behavior due to its heterogeneity and dynamics of change.

Epistemic uncertainty refers to the lack of data or lack of understanding of the emerging physical processes; where the uncertainty in the decision models is determined by the methodology of data interpretation and the achievement of instruments that produce models that produce realistic behaviors.

Figure 1

Systematic procedure of the observational method



Note. Source: Hashash, Marulanda, Ghaboussi, & Jung (2006).

In this sense, any uncertainty related to geological and geotechnical conditions is mainly due to the difficulties in obtaining, selecting and systematizing subsurface data, its heterogeneity and its mechanical dynamics. Therefore, a multidisciplinary approach to data analysis becomes essential.

In line with this framework for action, in recent years, the strategic management of the subsoil of cities has come to represent a topic of relevance for the development of cities, constituting a new interdisciplinary field known as "urban geosciences". This new discipline studies the geological environments of cities in order to provide a scientific basis for rational use in city planning and development.

Where, the advancement of geotechnical science, in addition to the need to propose a global soil classification system, faces the enormous challenge of developing new realistic predictive models that can accurately mimic the behavior of natural and/or modified soils, in each of their conditions -saturated, unsaturated- taking into consideration the influences of the environment, external and internal agents, etc., as well as their interaction with the built object -architectural/civil engineering work-.

Discussion and conclusions

The complexity of the nature of the soil -and the dynamics of its emergent behavior, product of extrinsic and intrinsic factors- has meant that progress in understanding it -in global terms- has been limited, despite the new tools available in terms of exploratory methods.

Currently, most of the surveys are based on vertical unidimensional profiles, where the information obtained is partial and of local use -and/or regional at best-, where the integration of the information through its systematization, in an intelligent database, is far from being extended.

The integration of quantitative information, observational information, and mathematical models -descriptive and predictive-, is a line of research that has been approached in a limited way and that could contribute great advances to the understanding and development of predictive instruments for the realistic behavior of soil dynamics. At present - and thanks to the massiveness of digital media in all its forms - there is a large amount of data available from different disciplinary origins, which describe or provide information on the soil in multidimensional perspectives - physical, chemical, mechanical -; this information is often not taken into account because it is not systematized, cross-cutting and interrelated in unified systems of global use.

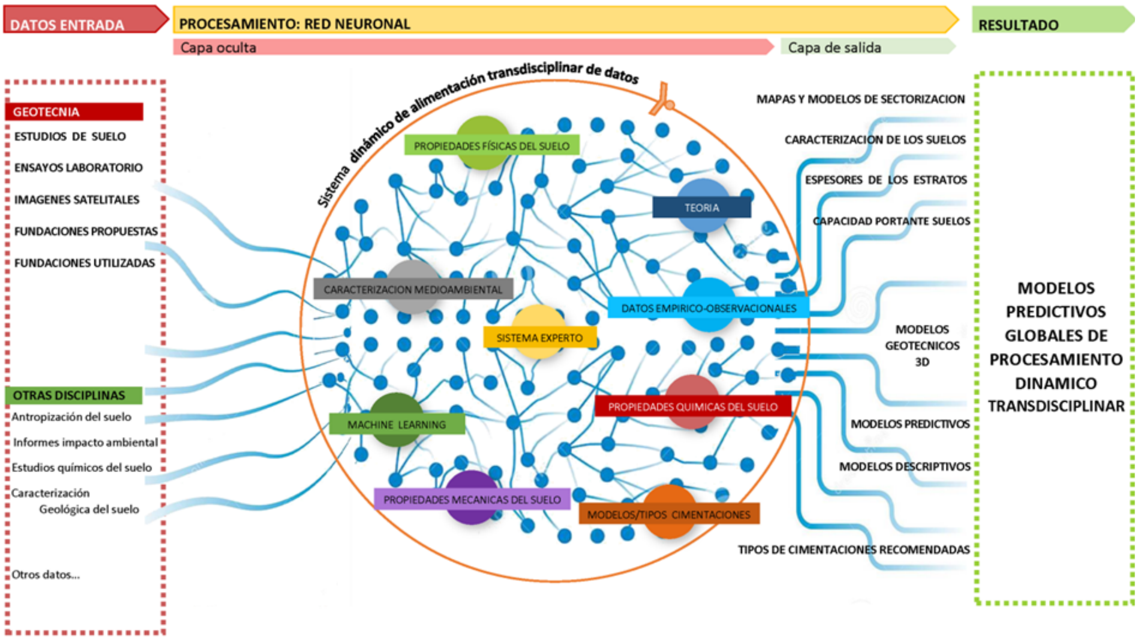
In the era of information technologies, the use of Artificial Intelligence - from its contribution in terms of machine learning, pattern recognition and deep learning - emerges as an indispensable tool to link ground behaviors in macroscopic terms, with the microscopic and nano; the local with the regional and global; scientific theory with the empirical-observational; proposing -or requiring- new measurement systems, where the information obtained is systematized in three-dimensional dynamic models of global scope.

In this sense, A.I. algorithms have already been used with great success in various fields. have already been used with great success in various fields of the discipline, as established by Levasseur, Malécot, Boulon, & Flavigny (2008) for the characterization of soils from dilatometer tests; in the analysis of rock mass strength parameters, according to Ling, Zhang, Zhu, & Tang (2008); for the analysis of earth dams, as reported by Yuzhen, Bingyin, & Huina (2007); or as reported by LI & others (2006) for tunnel analysis; among many other possible applications.

These Artificial Intelligence systems allow to interrelate in a single instrument, components as dissimilar as the empirical -emerging from the practice and observation of the natural environment and its behavior-; the theoretical -as a scientific basis-; the descriptive models of the possible types of soils and their characterization; the mathematical and predictive models; the emerging dynamics between the physical, mechanical and chemical characteristics; where such instrument, can and should -preferably, in order to obtain more complete, complex and closer to reality- obtain more complete, complex and closer to reality models; the mathematical and predictive models; the emerging dynamics between physical, mechanical and chemical characteristics; where this instrument can and should -preferably, in order to obtain more complete, complex and closer to reality models- be fed with dynamic data from the various disciplines whose object of study is the soil, or its interaction with it.

Figure 2

Artificial Intelligence structuring scheme specific to geotechnical development, of neural type with incorporation of transdisciplinary information



Note. Own elaboration.

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