

Characterization and modelling of pervious concrete.

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Barcelona, March 2016

Universitat Politècnica de Catalunya

Departament d'Enginyeria de la Construcció

DOCTORAL THESIS



Acta de calificación de tesis doctoral

Curso académico:

Nombre y apellidos: Ricardo Pieralisi

Programa de doctorado: Ingeniería de la Construcción

Unidad estructural responsable del programa: Departamento de Ingeniería de la Construcción

Resolución del Tribunal

Reunido el Tribunal designado a tal efecto, el doctorando / la doctoranda expone el tema de la su tesis doctoral titulada Characterization and modelling of pervious concrete

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“You see, I went on with this research just the way it led me. That is the only way I ever heard of true research going. I asked a question, devised some method of obtaining an answer, and got a fresh question. Was this possible or that possible? You cannot imagine what this means to an investigator, what an intellectual passion grows upon him! You cannot imagine the strange, colourless delight of these intellectual desires!”

Doctor Moreau (from the book “The Island of Doctor Moreau” H.G. Wells)

ACKNOWLEDGEMENTS

Once Isaac Newton states, “*If I have seen further it is by standing on the shoulders of Giants*”. I would like to thank the giants that help me expand the limits of my horizon Sergio and Antonio. For both of them I would like to thank the opportunity of working with an excellent team, and for believe that I was strong enough to success and grow on the doctoral journey. Sergio, thank you for the very productive talks that we had during these years. Be sure that each one of the thought exchanges was special and I will carry them with me. Antonio, thank you for guiding me and instigating me to always do my best in each task.

The development of this thesis would not have been possible without the financial support of the Educational Ministry of Spain for the FPU Scholarship (AP2012-4188). I would like to thank the companies CPV and BASF for the dedication to several research projects (especially HoPo) throughout the years.

I thank Montse Santos, Mercè, Carme and Carmeta who have always been very attentive. Also, I thank the technicians of the laboratory, especially to Camilo and Robert for the attention and the help during the experimental programs.

I would like to thank the friends that I met during these years in Barcelona: Ahmed, Albert, Amin, Ana, André, Addressa, Carlos, Cécile, Cristián, Cristina, Daniela, Diego, Eduardo, Francesc, Gustavo, Helen, Jenny, Jordi, Jorge, Julia, Juliana, Karmele, Liao, Liliana, Martha, Mylene, Nacho, Natalia, Pau, Razmik, Ricard, Ruben, Sandra, Talita, Tai and Yohei. In special, I would like to thank Fran, Isaac, Luis Segura (Nico Perez, the zookeeper), Luis and Renan.

I would like to express my deepest gratitude and love to Lu for her patience and understand for the years that we shared during my PhD, special the moments that I was on the verge of madness (with my thesis) and you rescued me. You helped me grow and mature. Also, we had countless amazing experiences during the last two years!

I would like to thank my family (Wilson, Luzia, Osvaldo, Cida, Nelci, Sergio, Nelí, Dilene, Marcos, Sergio Henrique, Maria Fernanda, Ana Elisa, Guilherme, Luis Gustavo, Luisa, Keila, Claudia and Frida) for the love and support that you all gave me during my life.

Finally, I want to express all the love that I have to the four most important people in my life. Nelson and Denise (my parents), thank you for all the love and affection that you have brought me up. If today I am who I am, you can be sure that you are the major responsible. Júnior and Rodrigo (my brothers), thank you for grown up with me and taught me many things about life, you were and always will be my first and most important friends.

SUMMARY

Pervious concrete is a special material with high permeability usually obtained by reducing the amount of fine aggregates in the composition of concrete. The increase in permeability generally implies a reduction in the mechanical performance. The properties of pervious concrete not only depend on its composition but also on the construction methods. The compaction process has a direct influence on the values of permeability and mechanical properties achieved. In fact, depending on the level of compaction applied, the same composition might give a highly pervious or even an almost impervious concrete. The interest of the scientific and technical community about pervious concrete has increased significantly since the 90's. Nowadays the most common applications are found in the field of pavements, in which the material contributes to mitigate problems such as flooding and runoff water that affect densely populated areas. For that reason and due to the smaller consumption of materials and resources, pervious concrete is perceived as an environmental friendly alternative.

Despite the technological advances on this field, the definition of the most adequate composition and compaction process to comply with the requirements of each application is normally based on trial and error or previous experiences. The lack of composition design methods in the literature may be attributed to the high complexity of the factors that intervene in the final performance of pervious concrete, which may hardly be generalized for all practical situations. In this context, the objective of this PhD thesis is to achieve a deeper understanding about pervious concrete and promote a new composition design philosophy based on advanced numerical simulations to minimize the need of experimental tests.

This work covers the main aspects of production and performance of pervious concrete, from the fresh to the hardened state. The first subject refers to the compaction process in the fresh state. An Evolutionary Lattice Model (ELM) is developed for simplified 2D simulations. As a more realistic alternative, new constitutive laws are developed and implemented in Discrete Element Models (DEM) for 3D simulations. To validate these models, experimental programs that emulate a controlled compaction were performed. The results confirm the representativeness of the models developed.

The second subject focuses on the permeability of concrete in the hardened state. The meso-structure derived from 3D simulations of the compaction process in the previous subject are evaluated in terms of their permeability. Computational Fluid Dynamics (CFD) models are used to simulate the water flow through the material. An experimental program is conducted with a constant head permeameter and different types of pervious concrete. The results obtained are used to validate the numerical models, confirming that it is possible to reproduce the real permeability results based on combined

numerical simulations of the compaction process and of the water flow within the material.

The third subject is centred on the mechanical properties of pervious concrete in the hardened state. A new constitutive law is developed and implemented in DEM to simulate the interaction between the connected particles that form the material. The meso-structure obtained as a result of the compaction simulations are used to assess numerically the expected mechanical properties of the pervious concrete. An experimental program is conducted to evaluate the compressive and indirect tensile strength of pervious concrete with different compositions and subjected to several degrees of compaction. The numerical results estimated with this constitutive law together with the meso-structure show good agreement with the experimental results.

The studies conducted in this work confirm that it is also possible to predict the performance expected in reality. Consequently, the numerical tools might be used to accelerate the process of defining the concrete composition and the production process for each application.

RESUMEN

El hormigón poroso es un material especial de alta permeabilidad que se obtiene generalmente mediante la reducción de la cantidad de áridos finos en la composición del hormigón. El aumento de la permeabilidad suele implicar una reducción del comportamiento mecánico. Las propiedades del hormigón poroso no sólo dependen de su composición, sino también de los métodos de construcción. El proceso de compactación tiene una influencia directa en los valores de la permeabilidad y propiedades mecánicas obtenidos. De hecho, dependiendo del nivel de compactación aplicada, la misma composición podría resultar en un hormigón altamente permeable o incluso casi impermeable. El interés de la comunidad científica y técnica sobre el hormigón poroso ha aumentado significativamente desde la década de los 90. En la actualidad las aplicaciones más comunes se encuentran en el campo de los pavimentos, en el que el material contribuye a reducir problemas tales como las inundaciones que afecta a las zonas densamente pobladas. Por esta razón y debido al menor consumo de materiales y recursos, el hormigón poroso es percibido como una alternativa ecológica.

A pesar de los avances tecnológicos en esta temática, la definición de la composición y del proceso constructivo y de compactación más adecuados para cumplir con los requerimientos de cada aplicación se basa normalmente en prueba y error o experiencias previas. La falta de métodos de diseño en la literatura se puede atribuir a la alta complejidad de los factores que intervienen en el comportamiento final del hormigón poroso, que difícilmente pueden generalizarse para todas las situaciones prácticas. En tal contexto, el objetivo de esta tesis doctoral es lograr una comprensión más clara sobre el hormigón poroso y promover una nueva filosofía de dosificación basada en simulaciones numéricas avanzadas para reducir la necesidad de pruebas experimentales.

Este trabajo abarca los principales aspectos de la producción y del comportamiento del hormigón poroso, desde el estado fresco hasta el estado endurecido. El primer tema se refiere al proceso de compactación en el estado fresco. El Evolutionary Lattice Model (ELM) ha sido desarrollado para simulaciones 2D simplificadas. Como una alternativa más realista, nuevas leyes constitutivas han sido desarrollados e implementados en Discrete Element Method (DEM) para las simulaciones 3D. Con el fin de validar estos modelos, se llevaron a cabo campañas experimentales que emulan una compactación controlada. Los resultados confirman la representatividad de los modelos desarrollados.

El segundo tema se centra en la permeabilidad del hormigón en el estado endurecido. Las meso-estructuras derivadas de las simulaciones 3D del proceso de compactación en el tema anterior han sido utilizadas para evaluar numéricamente la permeabilidad. Modelos de Computational Fluid Dynamics (CFD) han sido empleados para simular el flujo de agua a través del material. Asimismo se llevó a cabo una campaña

experimental con un permeámetro de carga constante y diferentes tipos de hormigones porosos. Los resultados obtenidos en dicha campaña han servido para validar los modelos numéricos, confirmando que es factible reproducir los resultados reales de permeabilidad basado en simulaciones numéricas combinando el proceso de compactación y el flujo de agua dentro del material.

El tercer tema se centra en las propiedades mecánicas del hormigón poroso en el estado endurecido. Una nueva ley constitutiva ha sido desarrollada e implementada en DEM para simular la interacción entre las partículas que forman el material. Las meso-estructuras derivadas de las simulaciones 3D del proceso de compactación en el tema anterior han sido usadas para evaluar numéricamente las propiedades mecánicas esperadas del hormigón poroso. Además, se llevó a cabo una campaña experimental para evaluar la resistencia a compresión y a tracción indirecta de hormigones porosos con diferentes composiciones y sometido a varios grados de compactación. Los resultados numéricos estimados con esta ley constitutiva en la meso-estructura muestran una buena concordancia con los resultados experimentales.

Los estudios realizados en este trabajo confirman que es posible predecir el desempeño esperado de los hormigones porosos en la realidad. Consecuentemente, las herramientas numéricas pueden ser utilizadas para acelerar el proceso de definición de la composición del hormigón y el proceso de producción adecuado para cada aplicación.

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