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Flow of fresh concrete through steel bars: A porous medium analogy

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ABSTRACT

Although being a very promising area of concrete technology, computational modeling of fresh concrete flow is a comprehensive and time consuming task. The complexity and required computation time are additionally increased when simulating casting of heavily reinforced sections, where each single reinforcement bar has to be modeled. In order to improve the computation speed and to get closer to a practical tool for simulation of casting processes, an innovative approach to model reinforced sections is proposed here. The basic idea of this approach is to treat the reinforcement zone as a porous medium in which a concrete is propagating. In the present paper, the numerical implementation of this concept is described. A methodology allowing for the computation of the equivalent permeability of the steel bars network is suggested. Finally, this numerical technique efficiency is evaluated by a comparison with experimental results of model fluids casting in model formworks.

1. Introduction

During the last decade, numerical modeling of fresh concrete flow has become an important tool for the prediction and optimization of casting processes [1–7]. The modeling of the complex rheological behavior of concrete in the fresh state is not a trivial task and the research community still works on development of appropriate rheological and numerical approaches to simulate fresh concrete flow [1,8–16]. In addition to this complex rheological behavior, the influence of reinforcement on the flow has to be taken into account as well. Modeling of each steel bar significantly increases not only computing but also pre-processing time (time for geometry generation and meshing). In order to simplify pre-processing and to reduce computational time, the idea of treating reinforcement as a porous medium was proposed [17–19]. In this approach, the network of steel bars is considered as a homogeneous porous zone (Cf. Fig. 1).

The duration of numerical casting process prediction can be divided in two parts: the pre-processing time during which the geometry and the mesh are generated and computation time during which the fluid mechanics equations are numerically solved at each point of the mesh. It can be seen in the example shown in Fig. 1 that the geometry to be modeled is obviously far simpler in the case of the porous medium analogy. As a consequence, the time needed to generate it will be strongly reduced. It can be moreover expected that, as the number of mesh points decreases, the computation time will also be reduced.

As a first approximation, it is possible to estimate the reduction in pre-processing time and calculation time by considering the following orders of magnitude in ideal computation conditions. In most concrete casting situations, the characteristic size of the flow is of the order of a few tens of cm. This is for example the typical thickness of a wall or a slab. This shall also be the characteristic dimension of the porous medium. When considering steel bars, the characteristic size of the flow is reduced to a few centimeters (*i.e.* 10 times lower). The number of cells to be implemented within the considered characteristic distance is imposed by the numerical convergence criteria. As steel bars are mainly cylindrical obstacles (*i.e.* 2D obstacles), this means that the number of cells will decrease by a factor 100 between the cases with and without steel bars. It can therefore be roughly estimated that the computation time will also decrease by a factor 100. It is more delicate to estimate how the time needed for geometry and mesh generation shall be affected. However, as we are considering here some periodic systems, it is possible to assume that the preprocessing time shall decrease by a factor 10 between the cases with and without steel bars (*i.e.* 10 being the number of obstacles in one direction, the use of copy–paste functions will allow for a fast meshing of the rest of the domain).

Consequently, we suggest here to model the flow of concrete through a reinforced zone as the free surface flow of a yield stress fluid through a continuous porous medium. In the present paper, numerical implementation of this concept is described. A methodology allowing for the computation of the equivalent permeability of the steel bars network is suggested. Finally, this numerical technique efficiency is evaluated through a comparison of numerical predictions with experimental results of model fluids castings in model formworks.

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