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Uniform flow over a permeable plane with downward suction

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In previous research, studies on channel flow were mostly focused on the flow profiles with consideration of the horizontal (or streamwise) velocity component only. Due to the neglect of the vertical velocity component, the governing equations were simplified and then the analytical solutions could be probably derived. However, the vertical velocity as well as the horizontal velocity is actually existent in the real world, especially at the water-porous matrix interface. This study derives an analytical solution to a two-dimensional flow field composed of a uniform flow over a plane homogeneous porous medium with downward suction. The Navier-Stokes equations are employed to describe the water flow, whereas the poroelastic theory is addressed for the pore water flow. Setting the stream function for the velocity components associated with corresponding boundary conditions, we successfully find the solutions to the dimensionless boundary-value problem by taking the six-order power series method (PSM) and differential transform method (DTM), respectively.

After the stream function is solved, the vertical velocity component as well as the horizontal velocity component can be obtained. The present results agree very well with the previous study which was carried out by a numerical method. This validates the presented analytical solutions separately by PSM and DTM. The vertical velocity increases gradually from the top lid to the bottom of the porous medium. The maximum horizontal velocity component is about 1.64 times of the downward suction velocity and occurs at a little below the centerline of the total depth. It is noted that the vertical velocity component should not be neglected in a two-dimensional flow, and the horizontal velocity might be affected by the vertical one. The present study also shows that the flow field of a two-dimensional flow is possible to be solved by analytical approaches. The employed technique and methods will be applied to the future study about the flow over a hillslope.