GENERATION AND PROPAGATION OF INSTABILITIES IN MUD FLOWS

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Abstract

Inside the domain of natural disasters and catastrophes, this paper proposes an evaluation of fluid flow down inclined planes (channels, spillways, canals, etc.). Occasionally, these flows develop under sufficient conditions for a specific type of free surface instability to appear: roll waves. This phenomenon is characterized by its periodic configuration and wave fronts moving at high speed on the free surface. When successfully established, it may compromise the integrity of neighboring structures and even enhanced damage arising from such disasters. This work evaluates analytically and numerically the formation of these waves Newtonian and non-Newtonian fluids flow. The analytical model used is broad, covering up from clean water flows to viscoplastic flow (non-Newtonian fluids). This model is the result Cauchy's equation manipulation, inserting the Herschel-Bulkley rheological model in the viscous part of the stress tensor. A linear stability analysis is performed, determining generation criteria for these waves. From the numerical point of view, the finite volume method was employed, using the FLUENT software. A comparative study of methods has been developed, achieving good agreement between them.

1. Introduction

This work include the study of natural phenomenon comprising the muddy flow of materials, commonly non-Newtonian fluids, which succeed the stability of slopes due to land saturation. This type of phenomenon is proved to be increasingly present through events where they were identified as "natural disaster". These mud floods or mudflows, as they are called, are characterized by the strong presence of non-Newtonian matrix on the fluid. From the engineering point of view, these phenomena are represented mathematically by the equations of continuity and momentum. Deepening the study of this system, a specific type of instability of the free surface can be generated and detected depending on flow conditions, favorable to instabilities emergence and propagation. Their presence would significantly change flow configuration, meaning an increase of harmful consequences when acting on civil structures. This type of instability is configured by a permanent state with well defined wave length and amplitude. At this point they are given the name "roll waves" (Coussot, 1994; Balmforth and Mandre, 2004; Maciel et al. 2012). In order to identify the conditions that addressed the occurrence and evolution of these waves, studies have been conducted for both fluid flows, Newtonian non-Newtonian. In this context, the RMVP team - Rheology of Viscous and Viscoplastic Materials - CNPq Research Group - UNESP Ilha Solteira, dedicated to the study of risks and disasters on the environment, comes through this paper, reporting some of its contributions from mathematical and numerical approach, claiming in short term the physical modeling. The acquisition of physical data regarding waves properties are a great need for the physical comprehension of the phenomenon. It is known that for torrential lava and muddy materials the more representative rheological model is the Herschel-Bulkley rheological model (Coussot, 1994; Maciel et al. 2009). For improve understanding of the formation of instabilities in flows on non-Newtonian fluids, a criterion for generating instabilities related to frequency of disturbance is theoretically established. At the same time, a numerical study

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has been performed using CFD techniques, where simulations are carried out through FLUENT software, seeking to verify the validity of the criteria established before for the generation and propagation of these waves.

2. Methodology

The generalized equations of mass and momentum conservation allow the inserting of the suitable rheological model in the stress tensor. As roll waves appear in both Newtonian fluids and non-Newtonian fluid, we initially made up the numerical representation of the system to the simplest case (Newtonian fluid) using experimental results from the work carried out by Fiorot (2012). For the non-Newtonian test case, the rheological model used is the Herschel Bulkley which representation is made through 03 parameters: τ_c, the yield stress (minimum stress required to initiate flow); n, the fluid flow index that represents the non-linearity of the stress with shearing; and K_n, fluid consistency index that indicates the relationship of proportionality with shearing. The system of equations was discretized and properly approached by Fluent software, using finite volume technique and being resolved in transient regimen. As the system represents a free surface flow, it is considered biphasic, with an air phase (ideal gas) and another with target fluid. The method used to detect the interface between the two fluids is VoF (Volume of Fluid) which determines the interface between the two fluids by calculating the fraction volume that evolves from 0 (air) to 1 (liquid), and the isoline of 0.5 is used to identify the free surface.

The simulations were performed with a small perturbation imposed on the inlet mean flow velocity.The first test performed for non-Newtonian fluid was designed for power-law fluids, which can be reached through the model adopted for the system by ignoring the existence of a yield stress and are proved to be able to allow roll waves formation (Ng and Mei, 1994). The properties are given by: non-Newtonian fluid dynamic viscosity, μ_n = 0.00547 Kg $m^{-1}s^{-1}$;solution density ρ = 1120 Kg m^{-3} and fluid flow index, n = 0.4.

Thereafter, some tests were conducted with the insertion of a yield stress τ_c. For both cases, analyzes were conducted with the objective of verifying the criteria of generation and propagation of instabilities.

3. Discussions

In this work, laminar flow simulations were performed to check the formation of instabilities and analyzes were performed to study the generation criterion and properties of these waves, such as period, amplitude and velocity of propagation. In computational modeling is important to set the calculation domain; their dimensions must initially allow the flow to stabilize (constant uniform flow height) so no other hydraulics effects are allowed to interfere on the generation and propagation of these waves. Evidently these goals had to be optimized with the calculation time. For the Newtonian fluid, results indicate good agreement between the numerical model that implements the fundamental equations of the problem through appropriate methods and numerical scheme, and various analytical models in the literature, including the general design team RMVP. For non-Newtonian fluids, it’s possible to observe numerically wave generation and stabilization, including for low yield stress. For high yield stress values, computational problems arise which are still unexplained by the team. These initial results show the validity of the generation criteria established from the linear stability analysis.

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