Frictional hysteresis in geophysical mass flows

J.M.N.T. Gray[1,*]

[1] Department of Mathematics and Manchester Centre for Nonlinear Dynamics, The University of Manchester, Oxford Road, Manchester M13 9PL, UK

[*] Corresponding author. Tel: +44-161-275-5888; E-mail: nico.gray@manchester.ac.uk

Abstract

When a static granular material fails there is often frictional weakening with increasing velocity, before the friction begins to increase again as the flow speeds up further. This can be captured in depth-averaged geophysical mass flow models by making the friction a non-monotonic function of the Froude number as shown in figure 1.

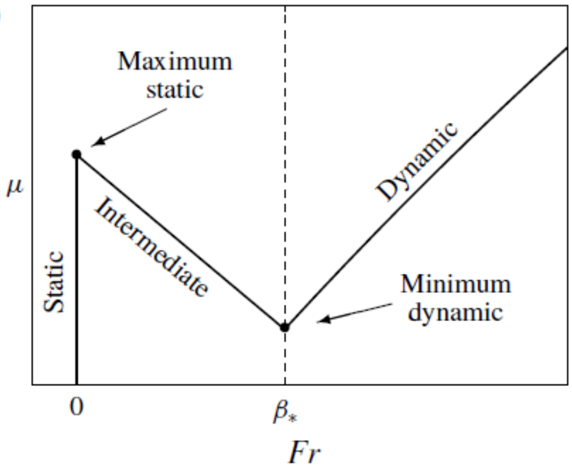

Fig. 1. The friction μ as a function of the Froude number Fr. It consists of a multivalued static friction, a velocity decreasing intermediate friction and a velocity increasing dynamic friction (Edwards *et al.* 2019).

This simple frictional behavior leads to the coexistence of flowing and stationary material, as well as a wide range of striking flow phenomena that are commonly observed in geophysical mass flows. A prime example is the formation of self-channelized flows with static levees (Rocha *et al.* 2019), such as the ones shown in the small scale analogue experiments in figure 2.

Fig. 2 Small scale self-channelized flows of mono-disperse red sand on a rough inclined plane (Rocha *et al.* 2019). Note the formation of static levees.

Frictional hysteresis is also responsible for the spontaneous formation of wave pulses that are separated by regions of static material. These have been termed erosion deposition waves (Edwards & Gray 2015, Edwards *et al.* 2017, Viroulet *et al.* 2019) because each individual pulse erodes static material at their leading edge and deposits material in their tails. The presence of easily erodible material on a slope dramatically changes the apparent mobility of such flows, allowing waves to propagate indefinitely on slopes that would otherwise rapidly bring the grains to rest. Waves may also grow or decay dependent on the slope inclination, the release mass and the amount of easily erodible material, and it is also possible to generate retrogressive failures that propagate upslope (Russell *et al.* 2019).

This talk will describe recent progress in modelling such diverse phenomena with a simple depth-averaged model that differs fundamentally from standard geophysical mass flow models. In particular, it is vital to include depth-averaged viscous terms (Gray & Edwards 2014; Baker *et al.* 2016; Gray 2018) to correctly predict steady-state channel widths (Rocha *et al.* 2019). The model is able to quantitatively capture all of the phenomena observed in small scale experiments. The challenge for the future is to see how these breakthroughs can be applied to improve our understanding of large scale flows in the field.

Acknowledgments

This research was supported by NERC grants NE/E003206/1 and NE/K003011/1 as well as EPSRC grant EP/I019189/1. J.M.N.T.G. is a Royal Society Wolfson Research Merit Award holder (WM150058) and an EPSRC Established Career Fellow.

References

Baker J.L., Barker T., Gray J.M.N.T. (2016) A two-dimensional depth-averaged μ(I) rheology for dense granular avalanches. J. Fluid Mech. 787: 367-395.

Edwards A.N., Gray J.M.N.T. (2015) Erosion–deposition waves in shallow granular free-surface flows. J. Fluid Mech. 762: 35–67.

Edwards A.N., Russell A.S., Johnson C.G., Gray J.M.N.T. (2019) Frictional hysteresis and particle deposition in granular free-surface flows. J. Fluid Mech. (2019), 875: 1058-1095.

Edwards A.N., Viroulet S., Kokelaar B. P. Gray J.M.N.T. (2017) Formation of levees, troughs and elevated channels by avalanches on erodible slopes. J. Fluid Mech. 823: 278–315.

Gray J.M.N.T., Edwards A.N. (2014) A depth-averaged μ(I)-rheology for shallow granular free-surface flows. J. Fluid Mech. 755: 503-544.

Gray J.M.N.T. (2018) Particle segregation in dense granular flows. Annual Review of Fluid Mech. 50: 407-433.

Rocha F.M., Johnson, C.G. Gray J. M. N. T. Gray (2019) Self-channelisation and levee formation in monodisperse granular flows. J. Fluid Mech. 876: 591–641.

Russell A.S., Johnson C.G., Edwards A.N., Viroulet S., Rocha F.M., Gray J.M.N.T. (2019) Retrogressive failure of a static granular layer on an inclined plane. J. Fluid Mech. 869: 313–340.

Viroulet S., Edwards A.N., Johnson Edwards C.G. Johnson, Kokelaar B.P., Gray J.M.N.T. (2019) Shedding dynamics and mass exchange by dry granular waves flowing over erodible beds. Earth and Planetary Science Letters 523:115700.