Turbulence and flow resistance in gravel-bed rivers

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Introduction:

This experimental project aims to develop new understanding of the role of bed topography in the generation of turbulence and flow resistance in gravel-bed rivers. This new understanding will be gained by addressing the following question: What is the effect of grain arrangement on the size and dynamics of coherent motions, and on their role in the generation of flow resistance? Without this fundamental answer it will remain impossible to predict accurately flow resistance, nor understand the role that turbulence has on other processes such as morphological evolution and the transport and dispersion of sediment and pollutants. This information is crucial if we wish to understand how the increased threat of climate change will impact upon flood risk.

The accurate estimation of flow resistance in rivers is of fundamental importance for river hydraulics and fluvial geomorphology because it measures how much energy is extracted from the flow by the channel. Thus, flow resistance governs flow properties such as mean flow velocity, water depth and turbulence, and dictates the energy available for the flow to entrain, transport and deposit sediment. A key problem has been the adequate evaluation of the resistance imposed by different bed morphologies on the flow.

Generally, in rivers, a representative surface grain or roughness size is used to account for the effects of grain roughness on turbulence and flow resistance (e.g. Bathurst, 1985; Aberle and Smart, 2003). However, gravel river bed surfaces display a spatially complex, three-dimensional structure that has systematic patterns of grain arrangement according to flow and transport conditions (Cooper and Tait, 2009; Mao *et al.*, 2011). Our hypothesis is that a representative surface grain or roughness size therefore does not contain sufficient information to determine fully the influence of bed topography arrangement on flow resistance. If this hypothesis is true, then gaining new understanding of the link between grain arrangement and the generation of turbulence and flow resistance could be key to developing new river flood models.

Project Summary:

Objectives

Using detailed measurements of hydrodynamics over gravel beds in a laboratory flume, the project will achieve the following objectives:

- Characterizing the evolution, geometry and stability of coherent flow structures
- Understanding the effects of grain arrangement on these flow properties, and thus on the exchange of fluid momentum between the bed surface and the overlying flow
- Linking the geometrical and dynamic properties of the flow to grain arrangement so that more suitable parameterisations of flow resistance can be developed

The new dataset collected from the experiments will be invaluable for the advancement of state-of-the-art 3D modelling approaches, as it will provide essential high-resolution measurements in the boundary layer. Thus providing a unique source for model calibrations, helping to inform the direction of future model formulation.

Methods

The project will involve an extensive set of controlled laboratory experiments in the Liverpool River Flow Channel. The channel generates open channel flows with different discharges, slopes and flow depths and therefore enables flow-generated processes to be studied under controlled conditions. The student will use Liverpool's new state-of-the-art Particle Image (PIV) system to measure the flow field in great detail. The system involves using a laser and high-speed cameras to image the movement of buoyant particles within the flow in 3D. The PIV system will allow the student to identify turbulent events and the role these events have on the exchange of momentum between the bed and the overlying flow, and thus on flow resistance. Co-located measurements of bed geometry will also be taken using compact cameras and structure-from-motion photogrammetric algorithms developed at Liverpool to provide sub-mm resolution DEMs.

Work plan

- Formulation of key research questions based on critical review of literature, state-of-the-art knowledge, and existing datasets
- Research training: in particular, familiarisation with laboratory flume experimentation, PIV, structure-from-motion photogrammetry, and data analysis techniques (time series analysis, spatial correlation analysis, double-averaging)
- Laboratory work: running a series of flume experiments to explore the effects of grain arrangement on flow dynamics, and on the exchange of fluid momentum between the bed surface and the overlying flow
- Data analysis: analysis of PIV and topography data, development of parameterisations that link the properties of the flow to grain arrangement
- Outputs and dissemination: presentations at national and international conferences, writing reports and papers, PhD thesis

Image 1: Multi-scale roughness and preferential grain arrangement have a critical affect on turbulent flows

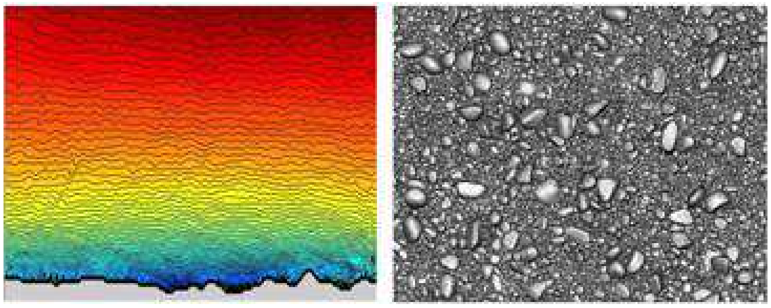

Image 2: Linking PIV measurements of turbulence with a DEM is key to understanding flow resistance

References

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