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Hydrodynamics of water-worked and screeded gravel-bed flows

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ABSTRACT

Turbulent flow over a gravel bed is one of the important topics of discussion due to its intricate behaviour in the near bed flow zone. Near the bed, the flow is highly influenced by the fluid-gravel interactions and becomes nonhomogeneous. To replicate the flow characteristics of a natural river in the laboratory, it is vital to recapture the bed condition of a natural river to ensure the accurate representation of riverbed. However, in the laboratory, it is very common to create the bed by placing the mixture of gravels randomly in the flume and then screeded manually, called the screeded gravel bed (SGB). Such a bed is quite different from the bed observed in a natural gravel bed river. To overcome this issue, the SGB is required to be water worked before performing the experiments in order to get a bed surface which resembles that of a natural gravel bed river. Such a bed is termed the water-worked gravel bed (WGB).

The bed surface topography of a WGB has been intensively studied (Cooper and Tait 2008; Hardy et al. 2009). However, its actual effects on the near bed flow characteristics in a WGB are required to be explored deeply. Therefore, the aim of this study is to examine the DA streamwise velocity and SA turbulent flow characteristics, e.g. SA Reynolds and dispersive shear stress, SA and dispersive streamwise and vertical TKE fluxes, and SA TKE budget, in a WGB. Besides, to understand the effects of water-work on the turbulence characteristics, an additional experimental run was performed over the SGB keeping the flow conditions identical as in the WGB. The SGB results act as a reference. Analysis of the second-order velocity structure function is performed to identify the presence of the inertial subrange. Moreover, the robustness of Kolmogorov's two-thirds law in the WGB and SGB is verified. To be explicit, this study provides an improved description of the turbulence characteristics in the WGB and SGB, allowing us to have a better understanding of the turbulence mechanism.

Experiments were conducted over both WGB and SGB in the laboratory *Grandi Modelli Idraulici*, Università della Calabria, Italy, by using Particle Image Velocimetry (PIV). For the experiment, coarse gravel having unimodal distribution (4 mm < d < 6 mm) with a median diameter d_{50} = 4.81 mm was used as a bed material. The slope of SGB was found to be 0.7%. Later, the SGB was water-worked by using a flow Froude number Fr ~ 0.88. During the WGB preparation, the sediment transport took place over a period of 28.5 h, when its rate declined exponentially from ~ 0.072 to 0.0003 kg m^{-1} s^{-1}, since there was no sediment feeding. At the end of this phase, the bed slope was measured and found as 0.4%. For both WGB and SGB, all the measurements were taken in the test section, where the flow was quasi-uniform, since during the experiments the flow depth (h ~ 10 cm, where h is measured from the gravel crest level) was controlled by an adjustable tailgate, with a constant Fr ~ 0.52.

A significant change in surface topography is observed due to the water work, resulting in different roughness geometry for WGB and SGB. The roughness height of SGB is found to be higher than that of the WGB. In the near-bed flow, the time-averaged vorticity ϖ changes its sign alternatively throughout the measuring section. It implies that the gravels incite the flow to be heterogeneous. Besides, the fluid parcels have alternate clockwise and anticlockwise motions, which results in flow perturbation. Importantly, the chan-

ge of sense of fluid motions is more frequent in the WGB than in the SGB. It is attributed to the higher WGB roughness than the SGBThe gravels cause the near-bed flow perturbation, resulting in a number of clockwise and anticlockwise motions of fluid streaks (Fig.1). Moreover, the organized roughness structure in the WGB causes the near-bed flow to be more streamlined than in the SGB. As a result, for a given vertical distance, the DA velocity is greater in the WGB than in the SGB. In the near-bed flow, for a given vertical distance, the SA RSS is greater in the WGB than in the SGB owing to the larger temporal velocity fluctuations in the former than in the latter. In addition, the dispersive shear stress is greater in the WGB than in the SGB, because the higher WGB roughness induces larger spatial velocity fluctuations. The SA TKE fluxes infer that in the near-bed flow, the sweeps are the governing events, while in the main flow, the ejections dominate. For small values of separation distance, the second-order velocity structure function follows the 2/3 slope, indicating the presence of inertial subrange in both the beds. The SA TKE budget analysis reveals that at a given vertical distance, all the DA TKE budget parameters are higher in the WGB than in the SGB.

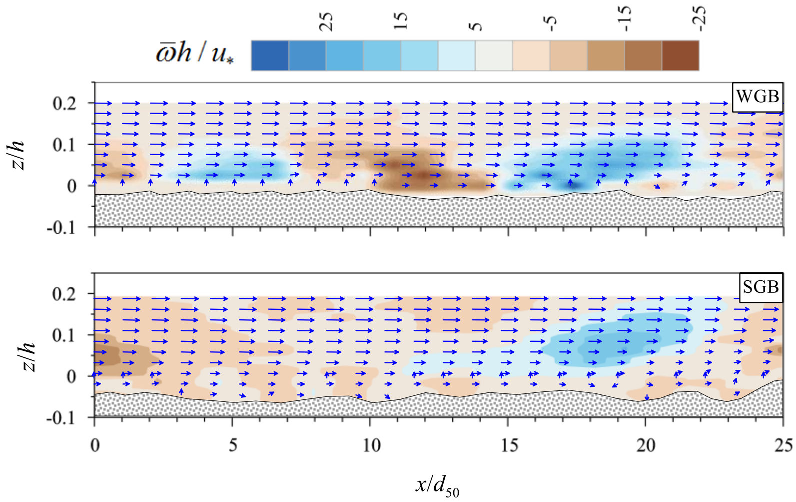

Fig. 1. Dimensionless time-averaged vorticity contours $\bar{\varpi}h/u_*$ and time-averaged velocity vectors on a central vertical plane in the WGB and SGB. The vector (→) refers to a scale $(\bar{u}^2 + \bar{w}^2)^{0.5} = 0.25$ [m s^{-1}]. Here, h is the flow depth, u_* is the shear velocity, $\bar{u}$ and $\bar{w}$ are the time-averaged streamwise and vertical velocities, respectively.

References

J. R. Cooper, and S. J. Tait, “The spatial organisation of time-averaged streamwise velocity and its correlation with the surface topography of water-worked gravel beds,” Acta Geophys. 56, 614–641 (2008).

R. J. Hardy, J. L. Best, S. N. Lane, and P. E. Carbonneau, “Coherent flow structures in a depth-limited flow over a gravel surface: The role of near-bed turbulence and influence of Reynolds number,” J. Geophys. Res. 114, F01003 (2009).