Conclusions

The aim of the present work is to get a better understanding on the time evolution of the scour hole and to provide a further contribution on the analysis of flow field in the scour downstream of the rigid bed of a control structure. For this aim two experimental runs have been performed in a straight rectangular laboratory flume realized at the laboratory of the Department of Hydraulic Engineering and Environmental Applications at the University of Palermo. The mobile-bed run has been carried out in order to analyze the temporal evolution of the bed surface downstream of the rigid bed. The rigid-deformed-bed run has been performed in order to investigate on the velocity field inside the scour hole developed downstream of the rigid bed reach. Both runs have been performed in steady flow condition.

The analysis of the bed evolution has highlighted that, for the examined case, the scour phenomena develops for a total length L_{tot} = 50cm. Inside this channel reach two different zones can be distinguished: for X<X30 where two scour holes develop near the banks; for X30 < X < X50 a sand deposit occurs at the channel axis. The maximum depths are found almost symmetrically with respect to the channel axis. The time evolution of the scouring phenomenon can be divided into 4 evolutive phases. The “equilibrium” scour depth Z_{min} is reached during the fourth phase (for t/T = 0.7). Moreover the analysis of the measured longitudinal profiles has highlighted that the position of the maximum scour depth occurs for $0.3 < X/L_{tot} < 0.4$, in agreement with other experimental studies found in literature (Gaudio and Marion, 2003; Termini, 2007).

The flow velocity field has been investigated by using the longitudinal, transversal and vertical and velocity components measured along the channel reach (50 cm long) interested by the scour phenomena. The analysis of the time-average velocity components has shown that each transversal section can be divided into three region of different velocity pattern: a central region, for 18 cm < Y < 28cm, characterized by low values of velocity and two near bank regions, respectively for Y < 18 cm (right-bank region) and Y > 28 cm (left-bank region). In these regions the longitudinal, transversal and horizontal velocity distributions are characterized by an alternating trend of low/high speed fluid zones, along both the longitudinal and in transversal directions. Such flow velocity pattern is particularly evident where the scour holes develop (X < X30). According with other researchers (Yen, 1972; Parker et al., 1983; Yalin, 1992), the presence of such alternating pattern of high/low flow velocity could be related to the formation of coherent turbulent structures.

Thus, in order to investigate on the turbulent flow characteristics inside the scour hole, the distributions of the Reynolds momentum flux components and of the turbulent kinetic energy have been determined. The analysis of the distributions of the Reynolds momentum flux components has allowed us to verify the existence of three zones of high Reynolds momentum flux near the bed: two zones are in the near bank regions (for Y < 18 cm and Y > 28 cm) where the scour hole develops (X<X30); a third zone is found at the channel axis (for 18 cm < Y < 28 cm), downstream of the deposit of sand (X>X30). Consequently, high values of the momentum flux components have been found where the scour depths increase. Moreover, in the near bank regions, the streaks of high momentum flux, found inside the scour holes, tend to move from the bed towards the free surface, downstream of the sand deposit. Furthermore, the analysis of distributions of all the Reynolds momentum flux components has shown that the turbulent flow activity is more significant along the longitudinal planes, parallels to flow direction.

The maps of the kinetic energy, *K*, and of the turbulent kinetic energy, *K'*, have shown that high values of *K'* occur where *K* assumes low values. The pattern of the kinetic energy, *K*, confirms the flow velocity pattern previously observed: high values of *K* are found near the free surface and low values occur near the bed. With reference to the distributions of the turbulent kinetic energy, *K'*, it has been observed that near the banks (Y < 11 cm and Y > 27 cm) *K'* assumes high values inside the scour hole (X < X30). For X > X30 cm (downstream of the scour hole), high values of the turbulent kinetic energy occur generally at the channel axis. Also streaks of high value have been also found near the free surface, downstream of the scour hole.

The formation of vertical turbulent coherent structures, inside the scour hole, has been verified by applying the conditioned quadrant analysis. The analysis has highlighted that, in the near banks regions, ejection and sweeps events occur; inward and outward interaction events occur essentially in the central region. In particular, ejection events are predominant over sweep events in the deepest part of the scour (bed slope is negative); sweep events occur more frequently in the remaining part of the scour hole (bed slope is positive). Thus, in the near bank regions, ejection and sweep events essentially occur in the whole water depth. In the central region, where erosion is not evident and flow velocity assumes low values, interaction events occur especially near the water surface; ejection and sweep events occur near to the bed, where high values of the Reynolds momentum fluxes have been also observed.

Finally, the estimated values of the longitudinal Reynolds momentum fluxes, have been also used to determine the bed shear stress (τ_b) distribution along the channel reach interested by scouring phenomenon. Such distribution has highlighted that the bed shear stress increases where the scour depths increases and vice-versa. Peak values of τ_b occur where the scour depths assume the highest values.

In conclusion, the analyses presented in this work have highlighted that the detailed knowledge of the flow velocity field and turbulent flow characteristics is essential for the understanding of the scouring mechanisms downstream of a rigid bed. Particularly, turbulent bursting sequences seem to develop inside the scour hole. Ejection and sweeps events, which are responsible for sediment transport, occur inside the scour hole. Sweeps events (fluid streaks directed downward and towards the bed) have been found especially where the bed slope is positive and ejection events especially where the bed slope is negative (i.e. where erosion increases in time).