THE HORSESHOE VORTEX SYSTEM AROUND A CIRCULAR BRIDGE PIER ON A FLAT BED

GOKHAN KIRKIL[1], GEORGE CONSTANTINESCU[2] and ROBERT ETTEMA[3]

[1]Graduate Research Assistant, Civil & Environmental Engineering,
IIHR-Hydroscience and Engineering, The University of Iowa,
Stanley Hydraulics Laboratory, Iowa City, IA 52242
(Tel: +319-384-0642, Fax: +319-335-5238, e-mail: gokhan-kirkil@uiowa.edu)
[2]Assistant Professor, Civil & Environmental Engineering, IIHR-Hydroscience and
Engineering, The University of Iowa, Stanley Hydraulics Laboratory, Iowa City, IA 52242
(Tel: +319-384-0630, Fax: +319-335-5238, e-mail: sconstan@engineering.uiowa.edu)
[3]Professor, Civil & Environmental Engineering, IIHR-Hydroscience and Engineering, The
University of Iowa, Stanley Hydraulics Laboratory, Iowa City, IA 52242
(Tel: +319-384-0596, Fax: +319-335-5238, e-mail: robert-ettema@uiowa.edu)

Large eddy simulation (LES) is used to study the horseshoe vortex (HV) system (e.g., see Fig. 1 where the instantaneous structure of the HV system is visualized using 3D streamlines) around a cylindrical bridge pier of circular section in a shallow channel with a flat bed and to investigate the mechanism responsible for the scour initiation. The simulation is performed with fully turbulent inflow boundary conditions at a Reynolds number of Re_D=18,000. The mesh is fine enough (over 4 million grid points) to resolve the main coherent structures of interest. The spatial (e.g., see Fig. 2 where the instantaneous structure of the HV system is visualized at several polar angles around the pier and Fig. 3 where the spatial extent of the necklace like structures is visualized using in-plane vorticity magnitude contours in a plane cutting approximately through the core of these vortices) and time variations of the HV system structure are analyzed and its spectral content is investigated. It is observed that the HV system is not formed of structures that wrap more or less uniformly around the cylinder (see Fig. 3) as is the case when the HV system is laminar. Rather, the structure of the HV system varies considerably in time, though typically a larger relatively stable necklace like vortical structure is present around the upstream part of the cylinder and oscillates randomly. However, from time to time this structure is destroyed and the HV system undergoes a transient phase in which no dominant coherent structure is present. Such a new structure can eventually form due to shedding of smaller vortices from the upstream separation region through merging of these small eddies into a more stable coherent structure or due to ejection of patches of vorticity from the boundary layer on top of the cylinder surface. These patches are convected down toward the bed. As they approach the bed they start moving away from the cylinder and interact with the other smaller vortices in the HV region to eventually create a larger vortex. As expected, the regions characterized by large values of the bed shear stress are situated beneath the eddies associated with the HV system and the detached shear layers where very energetic vortex tubes structures are shed at a high frequency. The largest bed shear stress values are recorded for polar angles larger than 30^0 very close to the junction which explain why the scour is initiated on the sides of the cylinder in the case of a loose flat bed. The instantaneous bed shear stress in these regions is characterized by large variations around the mean. The simulation confirms that the mean the HV system region

is characterized by high pressure fluctuations and turbulent kinetic energy levels. In the case of movable beds the effect is the scouring of bed material away from the HV region.

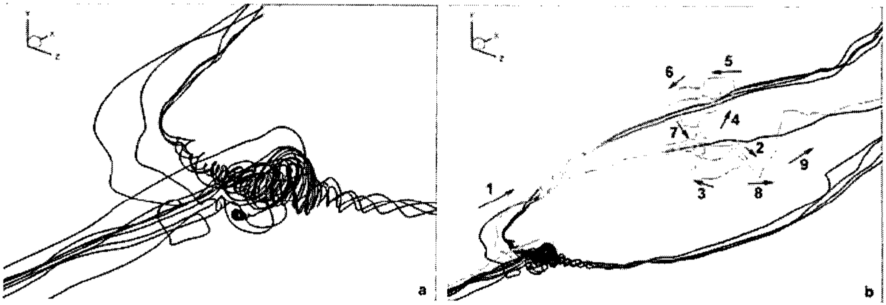

Fig. 1 3-D instantaneous streamlines launched in the HV region; a) close view; b) far view.

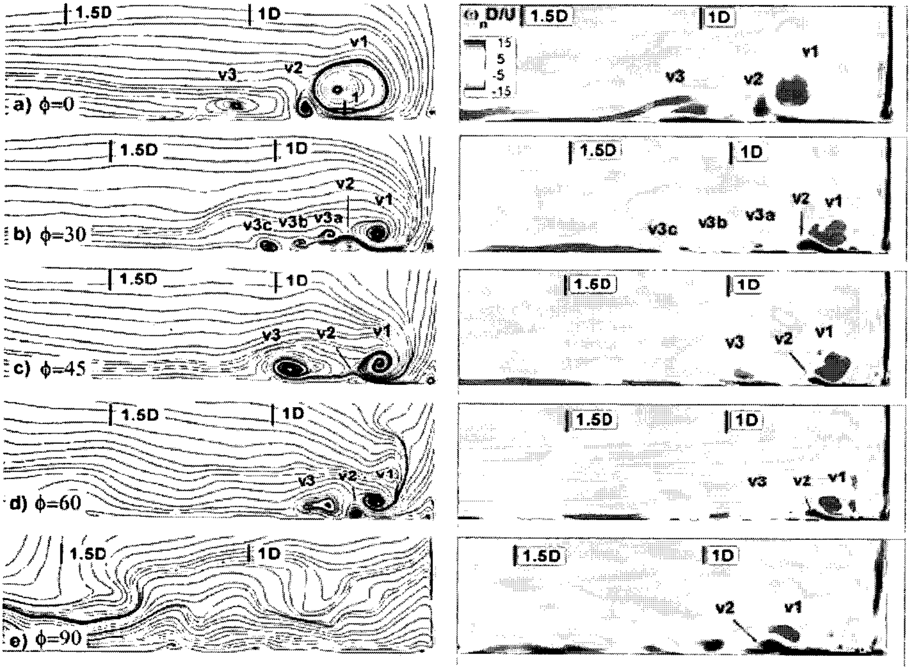

Fig. 2 Instantaneous streamlines and out-of-plane vorticity contours. a) ϕ=0° plane; b) ϕ=30° plane; c) ϕ=45° plane; d) ϕ=60° plane; e) ϕ=90° plane.

Fig. 3 In-plane instantaneous vorticity contours in y/D=0.04 plane a) t=0; b) t=3.5 D/U; c) t=7.0 D/U; d) t=8.5 D/U.