Chapter – 1

Introduction

1.1 General

The flow characteristic around bridge pier is important for safe design of pier structure founded on erodible bed of channel. When an obstruction comes in between flow path, flow separates moves around the object and flows downstream. At the point of contact, eddy currents or vortex are formed and creates a local increase in pressure and a local decrease in velocity on one side of the obstruction. Slender structures shed fluid vortices at regular or irregular intervals, producing fluctuating hydrodynamic forces (lift and drag) on the body itself. Under the influence of these unsteady forces, the structures may begin to vibrate.

A body placed in the flow field is of considerable interest as both the flow field and body interact with each other. The flow depends upon the shape of the body. It may be laminar or turbulent depending upon the body shape. It is also called fluid-structure interaction. The interactive phenomena between fluid and body motion represent one of the most difficult problems in the field of fluid dynamics. Despite its difficulty, the study of the interaction between fluid and structure entertains a growing audience, due largely to the increased speed and efficiency of today's numerical techniques. Several problems involving the flow of fluid around submerged objects are encountered in the various engineering fields. Such problems may have either a fluid flowing around a stationary submerged object, or an object moving through a large mass of stationary fluid, or both the object and the fluid are in motion but our main concern when body is at rest and fluid is moving.

All the natural flows are governed by basic laws of physics. These include conservation of mass, momentum and energy. However in case of river dynamics (open channel flows) the major controlling equations are conservation of mass and momentum. The momentum equations for these types of flows are termed as Navior - Stokes equations. These equations are in the form of partial differential equations. These equations are very complicated when expressed for three dimensional flow situations. The analytical solution of these equations exist for 1D flow and sometimes 2D cases only, however no analytical solution has yet been developed for 3D forms of these equations. As a result one has to resort for numerical techniques for their solution in complicated cases. Use of different numerical techniques for simulation of flow fields through a computer is termed as computational fluid dynamics (CFD).

The CFD techniques are being used for enhancing understanding of complex flow situations which are more or less impossible to explore through experimental work or field testing. The experimental work is not only time consuming and costly but also yields results up to certain limits beyond which we have to go for CFD techniques. The CFD methodology is based on computer codes which are being improved for increasing the range of application of such computer models. The application of such codes involves calibration and validation processes before the prediction stage.

FLUENT is widely used for industrial flow application with complex three-dimensional geometry. Ali et al. (2002) used FLUENT may be used to predict the three-dimensional flow field around a circular cylinder for rigid beds. There was satisfactory agreement between the bed shear stresses predicted by FLUENT and those calculated from the experimental velocities near the bed. However, due to the complexities of both the flow field and the scour mechanism, numerical modeling of the scour process around bridge piers remains a difficult research topic. There have been few attempts to numerically model the flow field within a scour hole, much less couple such a hydrodynamic model with a sediment transport model to reproduce the growth of a scour hole. In recent years, with the ever-increasing capabilities of computer hardware and software, computational fluid dynamics (CFD) has been widely used to determine fluid flow behavior in industrial and environmental applications. Some progression of using numerical simulation to study the flow around a pier and scouring process has been made in recent years. Most models for predicting sediment transport are based on a single-phase flow approach. Bakker (1974) developed a numerical model to calculate suspended sediment concentration. Hagatun et al. (1986) presented a turbulence model to simulate the instantaneous sediment concentration and the turbulent boundary layer in the sheet flow regime over a flat bed. Ahilan et al. (1987) investigated the motion of sediment in oscillatory flow over a flatbed both theoretically and experimentally. Nadaoka et al. (1990) developed a mobile bed model considering the mass and momentum transport of a single-phase flow. Olsen et al. (1993) predicted local scour developing processes using a three-dimensional flow and sediment transport model. They solved the Reynolds equations with the k-ε model for turbulence closure. Considering both suspended load and bed load, they solved the bed sediment conservation equation by iterating the procedure until the scour hole at an equilibrium state is obtained. Ribberink et al. (1995) conducted time-dependent measurements of flow velocities and sediment concentrations in a large oscillating water tunnel. The fluid/particle and particle/particle interactions are not accounted for in these models. Thus, the single-phase flow models have their limitation in solving sediment motions with the relatively high sediment concentration that usually happens under sheet flow conditions. Recently, several two-phase flow-modeling techniques have been developed. Richardson et al. (1998) simulated the flow structures around a bridge pier with and without the scour hole. They used FLOW3D with the RNG k-ε model. Comparing the simulated with the experimental results, they found that the 3D hydrodynamic model well simulates the complex flow patterns around the bridge pier. The scour prediction methods developed based on laboratory data did not always produce reasonable results for field conditions (Melville, 1975; Dargahi, 1982; Jones, 1984). The variability and complexity of site conditions make the development of methodology for predicting local scour at bridge piers difficult. Landers et al. (1996) evaluated many relations developed in the laboratory by use of transformed data (to obtain a more normal distribution) and smoothing techniques to assess general trends in the data. They found only minimal agreement between the field data and laboratory-based relations. Laboratory investigations often oversimplify or ignore many of the complexities that are common in the field (Mueller et al., 2002

1.2 Scouring

Scour means removal of sediment around or near structure located in flowing water and the amount of this reduction below an assumed natured level is termed scour depth. Prediction of scour depth is difficult as there are many uncertainties associated with it. Scour depth are determined by various methods, i.e. by use of empirical formula, physical model and theoretical approach. Commonly used equations and models are based on laboratory data and are valid only for non-cohesive channel beds. They do not account for many variables that are typically encountered in a field setting. By adopting different techniques, scour could be reduced up to approximately 60% as per reports available in literature. Though scour depth could be approximately predicted using various available ways, foolproof protection of scour is yet to be achieved. The potential losses accruable from bridge failures and the need to guard against same have prompted for better understanding of the scour process and for better scour prediction methods and equations. Under-prediction of pier scour depth can lead to bridge failure while over-prediction leads to excess expenditure of resources in terms of construction costs.

1.3 Effects of collar on scouring

Local scour at a bridge pier principally results from the down flow along the upstream face of the pier and the resulting horseshoe vortex which forms at the base of the pier aids the phenomenon. One way of reducing pier scour is to combat the erosive action of the horseshoe vortex by armouring the riverbed using hard engineering materials such as stone riprap. Another approach is to weaken and possibly inhibit the formation of the down flow and thus the formation of the horseshoe vortex using a flow-altering device. Flow-altering devices that have been used to protect piers against local scour include sacrificial piles placed upstream of the pier, Iowa vanes, a slot through the pier, and a flow deflector attached to the pier, such as a collar. The use of collars has been studied by several researchers. In general, the results from collar studies have shown that they can be very effective in reducing the scour depth at a bridge pier. Since a collar acts to reduce the scour depth at a bridge pier, the parameter of interest, therefore, is the scour depth. However, just as the scour depth is important in scour studies, the time taken to reach a particular scour depth is also very significant as scour holes take some time to form. For this reason, it becomes necessary to understand the development of the local scour hole with time. Also, in clear-water scour conditions, the depth of a scour hole approaches an equilibrium condition asymptotically with time. Consequently, time is an important factor in undertaking scour studies.

When a collar is installed on a pier, the direct impact of the down flow to the riverbed is prevented, which serves to reduce the depth of scour that can take place. In addition to reducing the depth of maximum scour, the rate of scouring is also reduced considerably. In this regard, reducing the rate of scouring limits the risk of pier failure when short duration floods occur. On the matter of time development of maximum scour depth, the time to reach an equilibrium condition depends on whether the pier is protected with a collar or not. This difference in the time development of local scour has significant implications for those researchers choosing to stop their tests after a fixed length of time. While the ultimate or equilibrium scour for two situations may be the same, the temporal development of the scour hole may vary.

1.4 Morphology of channel

The structures built on open channel or flow path reduces the flow area and alter the flow patterns which increases the local velocities and turbulence and result in significant changes in the morphology. The morphology of a river can be viewed conveniently by considering its long profile and cross profile. The degrees of freedom of a river consist of the width, depth, channel slope, bank slope and geo-morphological condition in the zone where the river flows. As water flows along the channel of a river, its long profile will be determined by several factors, which include geological condition, different hydraulic structure made in the channel, discharge and velocity. Alluvial rivers are self-regulatory in that they adjust their characteristics in response to any change in the environment. An alluvial river is unconstrained, in the long term, in developing its stable width to which the depth, slope, velocity, and flow resistance are closely related.

Meandering channels is a vast research field, spanning a broad variety of time and space scales, environmental domains, and conceptual and methodological approaches. A regime river is a system in dynamic equilibrium, or, to be more precise, a system in quasi-equilibrium, for which the sediment transport is balanced by the sediment supply. The three main types of river patterns are braided, meandering and straight, although there are rare straight rivers. As the river precedes downstream the volume increases and erosion gains momentum. The planform of a river depends on both the size of the river and the part of the fluvial system. The type of planform or pattern is key interested for geo-morphologist and geologist. The meandering of river depends on the hydraulics of flow, the sediment transport and the potential for bank erosion that closely related to distribution of sediment within the bend and bed form with the channel. The distinct morphological characteristic of any river shows that relationships for river morphology are not continuous and that there exist several apparent discontinuities between pattern states. The conditions under which different river patterns and types occur have been received interest by many scientists and engineers.

Meandering rivers have drawn considerable attention from a large group of researchers in various fields, ranging from fluvial geomorphology (e.g., Leopold and Wolman, 1960) to fluid mechanics and morphodynamics (e.g., Ikeda et al., 1981). The scope of research also encompasses a broad range of spatial scales, from the detailed studies off low properties at the scale of turbulent eddies (e.g., Blanckaert and de Vriend, 2003) to investigations of the evolution of meander trains (i.e., series of meander bends) over the entire length of an alluvial floodplain (e.g., Gautier et al., 2007). Similarly, studies on river meandering vary in temporal scale, ranging from the response to a single channel-forming event (Hooke, 2004) to the evolution of floodplains over millennia (e.g., Howard, 1992).

The main objective of present investigation is study on flow field around slender structure and its influence on the course of rigid and erodible channel section.

In the present study, experimental study has been carried out in laboratory flume and numerical modeling of the same is done by HEC-RAS and ANSYS software for better understanding the fluid flow characteristics in laboratory model. The maximum scour depth around piers is measured when the rate of scouring is very small in the laboratory. The effect of collar as a counter measure of scouring is studied.

An analytical approach is proposed for most efficient channel section with multiple barriers. The influence of slender structure in shape of piers in rectangular and trapezoidal section is proposed and comparison is carried out for flow condition without any barrier in flow path.

In the present study, the course of River Ganga at Varanasi is studied for last 10 years satellite image available in Google Earth. The picture reveals that the morphology of the Ganga River has been changed in last few years in terms of sinuosity and silt deposition.

1.5 Organization of thesis

The present thesis is divided into six chapters. The general introduction of fluid flow around slender structure, scouring and channel morphology is discussed in Chapter 1. The Chapter 2 gives the literature survey of previous experimental and numerical work related to present study. In chapter 3, experimental investigation on clear water scouring around pier model and collar fitted with pier is presented. The flow behavior around slender structure in rigid and erodible channel section is presented by numerical modeling in Chapter 4. In chapter 5, the morphology of River Ganga at Varanasi is presented. The conclusions drawn out of the present work and the future scope of work s are summarized in Chapter 6.