ABSTRACT

1. Introduction

Bridges are structures constructed over a body of water like a river, stream, valley, or a road for the purpose of providing passage over the obstacle. Bridges are essential for the transfer of people and goods from one place to the other. Construction of bridges across a river partially obstructs the flow path and modifies the geometry and velocity of flow. In the field of hydraulic engineering and its associated fields, sediment transport, degradation and deformation of the riverbed, scouring and flooding are considered significant issues. Out of these issues, scouring around bridge piers is a crucial area of interest to hydraulic engineers and designers. Past studies indicate that scouring around bridge elements is a major factor in the failures of bridges.

2. Literature

According to Melville (1975), three factors are mainly responsible for the change in bed elevation around the bridge piers. One, due to progressive aggradation and degradation of sediment particles, two, due to temporary scour due to change in bed level of the river and three, due to an obstruction, such as a bridge pier, which obstructs the flow. Scour around an obstruction like a bridge pier is a local phenomenon arising out of the three-dimensional separation of flow upstream of the obstruction giving rise to a horseshoe vortex system. The process commences with a three-dimensional separation of flow on the upstream front of the pier owing to an adverse pressure gradient. This separation results in the formation of a vortex in a vertical plane which wraps around the pier at the sediment-pier interaction junction and looks like a horseshoe in plan. This horseshoe vortex system is responsible for scraping the material from upstream of the pier and releasing it in suspension at the rear of the pier, thus causing scouring around the pier, Setia (1997).

In the past about half a century, numerous investigations have been recorded on the bridge failures to understand the process of scouring around the single bridge pier. Breusers et al. (1977), Chiew (1984), Breusers and Raudkivi (1991), Garde and Rangaraju (1992a), Gangadharaiah et al. (2012), and others. These researchers have studied and explained the phenomenon of scouring around a single bridge pier. Further, studies have also been conducted on the estimation of scour depth around a pier and its

prevention. But due to rapid urbanization more and more bridges are being constructed in close proximity of each other which have an interference effect on each other. Not much work has been done on the possible when the interference of such bridges which are present at very close proximity. Few researchers, mainly Hannah (1978), Parsad (1993), Beg (2002), Movahedi et al. (2013) Khaple et al. (2014) and Ali et al. (2017) have initiated work around different arrangements and groups of piers. Further, there is a large variation in the use of different parameters adopted for experimentation. That makes it difficult to generalize the results obtained through such experiments. Thus, the interference study around bridge piers is in underdeveloped stage and works in the laboratory as well as in the field are required to be directed and planned towards such studies. The present study is one such study in this direction. The main objectives of this experimental research were to analyse the mechanism of flow in the presence of some interfering geometries and to determine the effect of varying parameters on the scour depth around such groups of piers and units.

3. Scheme of experimentation

A laboratory study had been planned and conducted to investigate the interference effects of various piers in different geometries, and interference of pipelines and groynes with a pier. The experimental study was carried out on a mobile as well as rigid bed in the Hydraulic Laboratory of Civil Engineering Department at the National Institute of Technology Kurukshetra, India. Three different types of flumes were used for the experimental study. In this thesis, the flumes were denoted by Flume A, Flume B and Flume C. Flume A is 12m long, 0.60m wide and 0.70m high. The working section of the flume, which is 2m long, 0.6m wide and 0.24m deep, was located at 5m downstream from the inlet section. The working section was filled with fine sand having a mean size, d_{50} = 0.23mm. Flume B had nominal dimensions of 15m length, 0.40m width and 0.60m height. The side walls of the flume are made of Perspex to easily visualize the flow around the bridge piers. An outlet tank has been provided at the end of the flume for collecting the water. Flume C is a standard recirculating tilting bed water flume with nominal dimensions 5 m long, 0.25 m wide and 0.305 m deep. Flume C has been used to study the behavior of flowing water on the surface with the help of ‘Aluminium paint technique’ and ‘Wet paint technique’.

Three types of the sediments, with mean size d_{50} 0.23mm, 0.30mm and 0.50mm were used to perform the experimental work. However, majority of the work had been conducted on the sediment size 0.23mm.For this sediment geometric standard deviation, the coefficient of uniformity and the coefficient of curvature was 1.5, 1.3 and 0.88, respectively.

Two sizes of circular piers having diameters 62mm, 42mm besides an oblong pier of frontal size 62mm and length 22cm were used. A group of piles of diameter 25mm each, a pipeline of 62mm diameter and a thin groyne of 11cm were the other models used during the study. The velocity of flow for those experiments involving uniform flow was maintained such that it was close to the incipient conditions. Guided by literature, the depth of flow was maintained such that its effect was negligible. Duration of each run for the uniform flow experiment was 300 minutes. The maximum scour depth observed during this time was recorded for reporting and comparison.

Flow parameter comprising of type of flow, velocity and depth of flow and duration of test run was maintained similar throughout the study for the case of experiments under clear water scour condition. Some experiments were conducted under unsteady flow conditions, combining clear water and live bed scour in the form of a single-peaked hydrograph. In these cases, the discharge was increased in four steps of small-time durations and then decreased in the next three steps.

Besides the mobile bed, experiments were also carried out on a rigid bed to understand the mechanism and behaviour of flow in the presence of different arrangements of piers.

- **Rigid bed**

Three different techniques namely

(i) Dry silver paint technique

(ii) Wet paint technique

(iii) ANSYS 17.2 and 18.0 (Swanson Analysis System)

were used to study the physics of flow and its modification.

- **Mobile bed**

Experiments on mobile beds were carried out under four categories of piers and other appurtenances:

a) Tandem arrangement, two or more equal or unequal diameter of piers in a line along the direction of flow.
b) Two piers in 'Side by Side' arrangement, 90° to the direction of flow

c) Three piers in a ‘Staggered’ arrangement

d) Other arrangements.

(i) A group of piles in different arrangements, with and without pier

(ii) A pipeline and a pier

(iii) A groynes and a pier

Modelling Analysis

Two methods, namely Artificial Neural Network (ANN) and Regression Forest Tree (RF) were used for the analysis of the experimental results.

- ANN is a data handling framework that is analogous to the neural networks in living organisms both structurally and functionally. It aims at yielding relevant outputs for some given inputs processing the input as a black-box. Neural systems are prepared for different parameters to involve in the phenomena and relate to the weights provided to them. The neural network comprises of neurons which connected mutually through weight components that are ultimately used for the comparison of certain predictions and the actual parameters based on the adjustment of these weights.
- Random Forest Tree is a suite of learning methods used for classification, regression and other tasks. The suite operates by constructing an array of decision trees at the time of training and resulting into outputs in the form of classes (classification) or mean prediction (regression) of the trees at an individual level. Random forests are used to naturally prioritize variables in a regression or classification problems as well.

4. Results, Analysis and Discussion

The results, their analysis and discussion has been dealt with in five chapters covering both, the studies on a rigid bed and the mobile beds.

4.1 Mechanism of interference studies (Rigid Bed)

In order to study the mechanisms involved in the case of groups of piles or piers, a series of experiments was performed with the help of two transparent cylindrical glass piers of diameter 62mm each. The cylindrical pier models were placed in different orientations and the flow modification was observed with the help of the techniques described earlier.

a) Tandem arrangement

In the tandem arrangement it was observed that the flow approaching the front pier gets divided and move on from the sides of the pier. It creats its wake zone on the downstream of the front pier and as it tends to converge, it encounters the sides of the rear pier and once again diverges. The formation of eddies and swirls is more easily visible. Thus, the zone falling in between the two piers when they are very close to each other is protected from the direct attack of flow.In other words, the downstream pier is completely protected or shielded in this position. However, when the spacing between the two piers increases, the downstream pier also faces the flow which enters the wake zone of the front pier. The arrangement exhibited the mechanisms of 'Shielding'as also explained by Hannah (1978).

b) Side by Side arrangement

Inthe side by side arrangement whenthe spacing between the two piers was zero, the two piers were touching each other shoulder to shoulder. By defination, there was no flow taking place between them and it was as if it was a single pier with size 2D. As expected, the dry paint which was sprinkled on the upstream of the unit was moving past the piers and was creating a large wake zone on its downstream.This unit of two piers had a single but larger horse shoe vortex wrapping around the combined unit. When the spacing between the piers kept was 1.5 times the diameter of the pier. It showed two horseshoe vortices wrapping around each of the two piers. These two individual horse-shoe vortices were smaller in size in comparison to the previous discussed case and theirarms were getting compressed as they competed to enter the space between the two piers. The 'compression of the horse-shoe vortices' was very conspicous at smaller inter pier spacing. At the same time the outer arms of the horseshoe vortex exhibited shedding of the vortices.

c) Staggered arrangement

In order to study the mechanism involved in this type of geometry of three piers, two staggered arrangements of spacing, S equal to zero and 2.5 times the diameter of the pier had been tried. When the three piers are touching each other, their centers when joined together, make an equilateral triangle of sides 1D. Now size of the obstruction facing the flow is equal to twice the diameter of the pier. For the front portion of this arrangement it is the same as the side-by-side arrangement with zero spacing. The flow can be observed to be traversing from the outside of the two front piers and forming a large single horseshoe vortex. The wake zone created at the downstream of the arrangement is also larger in comparison to the wake zone of a single pier. The converging of the wake zone is not occurring immediately after passing the two piers as there is another pier forming an extension of this obstruction. This arrangement of three piers in a staggered pattern showed the mechanics of compression of the horseshoe vortices, shedding of vortices. While the effect of 'reinforcing' could not be established with these techniques, the effect of 'shielding' was certainly absent.

The pictorial views obtained with the aid of ANSYS 17.2 and 18.0, gave information of velocity vectors, streamlines and velocity contours. This was used to have an insight into the mechanism. The results indicated that the mechanism of flow around groups of piers is much different as compare to the mechanism of flow around an isolated pier.

4.2 Mobile bed studies

The phenomena were collaborated with a series of experiments conducted on a mobile bed of different grades of sediment.

a) Tandem arrangement

In the tandem arrangement, it was observed that for all values of T/D = 16 that were experimented upon; the scour depth at the upstream pier was more than that of the downstream pier. When the two piers are attached to each other or the spacing between the piers is zero, it is analogous to the case of a single pier and the scour depth is also same. As the spacing shifts to one time the diameter of the pier, the downstream pier also registers its own scour depth. Individually, the scour at upstream pier shows a rising trend up to a T/D of 4, beyond which it shows a gradually decreasing trend. Interestingly, the scour depth at T/D = 0 and T/D = 16 are the same at the upstream pier. With increasing (T/D), initially, the downstream pier shows more scour depth. But when (T/D > 4) times, it shows a decrease in scour depth. In the initial stage, when the spacing (T/D) between the piers increases from 0 to 8 times the diameter of the pier, then the scour depth is very high and reaches up-to maximum and after that when T/D> 10, it decreases. At T/D >10 the scour depth becomes constant.

The shed vertices from the shielding pier tend to deposit the sediment on the downstream of it (front pier). In this case, the deposition is taking place on the upstream of the downstream pier. Thus, with the downstream pier also causing scour of its own, does not allow the sediment to deposit in front of it and thus act as a conveyor belt and the upstream pier has to experience more scour.

This arrangement verifies the two mechanisms of 'shielding' and 'reinforcing'. The increase in scour depth of u/s pier in the presence of a d/s pier exhibits the conveyor belt phenomenon.

b) Side by side arrangement

In the side by side arrangement, at zero spacing, the two individual piers join together to form a single united obstruction and yield a high value of scour equal to 2D. In terms of the scour depth of an individual pier of size D, the scour depth at this stage is 1.66 times. Infect, the combined unit shows a common scour hole. When the spacing between the piers was one time the diameter, the scour depth dropped to 0.9 and 0.85 times the scour depth of the zero spacing position, for the left and right piers, respectively.

For the present experimentation, the maximum spacing tried was 4D at which the scour depths for the left and right piers were 1.08 times and 1.10 times that of the scour of an individual pier. Taking the zero spacing as the reference, it was equal to 0.65 to 0.66 times. Furthermore, a semi empirical equation in the form of D_{eq} is developed to predict the maximum scour depth as a function of the spacing between two bridge Piers. This arrangement also verified the mechanism of compression of the inner arms of developed around the two piers in close proximity of the 'side by side' arrangement. This compression generates higher velocity thus resulting in higher scour depth.

c) Staggered arrangement

Experiments in the staggered arrangement were conducted for two orientations, ie. A triangular geometry of three piers, once it was the single pier facing the flow first and then it was the two piers facing the flow first. In the latter geometry of staggered arrangement, it was observed that the arrangement experienced the maximum scour depth when spacing between the piers is zero. It is easy to perceive that in this geometry the size of the unit has enlarged and now the effective size facing the flow is 2D. There is only a single horseshoe vortex system formed at this stage. Thereafter, as the spacing S increases, the scour depth decreases. The decrease in scour depth is because the flow is now not fully blocked and its pressure difference becomes favorable between the piers in the spacing region. In the former arrangement shedding of vortices of the front pier combines with the activity of the rear piers and the sediment from the front pier is likely to be conveyed to its rear and to the rear of the rear piers. In that arrangement, all the three piers are generally having a decreasing trend of scour depth. The slope of the decreasing trend of scour of the front pier was high. At a spacing close to 4 and above, the front pier starts showing the scour associated with a single pier. Furthermore, a semi empirical equation in the form of D_{eq} is developed to predict the maximum scour depth as a function of the spacing between the three bridge piers. The staggered arrangements exhibit the mechanisms of compression of the horseshoe vortices and shedding of vortices besides showing partial existence of the reinforcing effect. In all the three arrangements, the phenomena were corroborated with the help of ANSYS 17.2 and 18.0.

d) Miscellaneous arrangements

Under this category group of five arrangements namely, a row with three piles equilateral triangle with three piles, equilateral triangle with five piles, an arc with five piles and staggered arrangement with nine piles in two rows (4+5) were used on the upstream of a pier. Out of the five arrangements, an arc of five piles was least effective and shows the maximum scour depth (1.04D) at the pier and the staggered arrangements with nine piles in two rows was most effective and show the minimum scour depth (0.65D).Other experiments in this chapter pipeline that has been placed on the upstream side of the bridge pier. From the observation it can be concluded that, if the distance between the pipeline and bridge pier is small the scour depth was found to be more. After that, when the spacing between the piers and pipeline greater than 3 times the diameter of the pier, both the pier and pipeline does not affect each other.

The interaction of a pipeline of diameter 62mm with a pier was also experimented upon under uniform and non-uniform flow conditions.

A groyne with different angular orientations varying from $30^{\circ}$to 150°w.r.t the side walls of the flume were tried and the effective change in scour at the bridge pier was noted.

5. Outcomes of the study

The study, besides filling up the gaps in information has been useful in generating laboratory data. It could be helpful to the planners in deciding the suitable sites for the bridges and other structures which could otherwise interference and be dangerous to the stability of piers. The visualization techniques have been useful in having an insight into the modification of flow.