EXPERIMENTAL STUDIES ON LOCAL SCOUR AROUND ISOLATED AND TANDEM BRIDGE PIERS

ABSTRACT

Scouring is one of the prominent reasons for the failure of a bridge. It is the erosion of material in the vicinity of a bridge pier. Failure of bridges due to scour results in both human loss and economic loss. Thus, it is important to design bridge piers for scour. Majority of studies in the past have focused on isolated piers. Moreover, most of the studies on isolated as well as pier groups have focused on a single value of equilibrium scour depth at the front of the pier(s) rather than holistic dimensions of the scour hole. It is important to be able to predict all dimensions of the scour hole because these dimensions dictate the extent of the countermeasure required. The present study overcomes the limitations of the previous studies by measuring the detailed dimensions of the scour hole around isolated and tandem bridge piers. Additionally, majority of the studies in the past have been carried out on identical piers in tandem arrangement thus modelling the scour around piers of the same bridge. However, in recent times, due to fast paced urbanization and augmented traffic volume, it is often required to erect new bridges across the rivers in the vicinity of existing bridges (Beg, 2008). Thus, unequal sized piers of different bridges in close proximity often occurs in real life.

In the present study, at first scour study on isolated piers was conducted. Laboratory experiments were conducted in an open channel and consisted of measuring the equilibrium scour geometry around isolated piers of four different diameters viz. 10 mm, 12 mm, 13.5 mm and 15 mm, at three different inflow velocities with $U/U_c =$ 0.4, 0.67 and 0.9. The experiments were run for a duration of 500-600 mins and temporal evolution was observed at the front, side and back of the piers by constructing vertical scales on the piers with waterproof ink. The scour was found to be initiated at $U/U_c = 0.4$ irrespective of the pier size. All dimensions of scour hole were found to increase with the increase in size of the pier and the incoming flow velocity. The scour hole was found to be unsymmetrical about the pier with steeper slopes at the upstream compared to downstream and greater longitudinal spread than transverse spread. Decreasing the flow velocity resulted in steeper deposition profiles with lesser spread and lesser difference between the longitudinal and lateral extents of the scour hole. Finally, a set of five empirical equations were

proposed to predict the equilibrium scour depth, lateral and longitudinal extents of the scour hole, scour surface area and scour hole volume as a function of pier size and the ratio of inflow and critical velocity.

Thereafter, experimental studies were carried out on inline piers by placing an equal or larger diameter pier on the downstream of a smaller pier. The diameter of the smaller pier was fixed as 10 mm and its position was fixed. The diameter of the downstream pier was varied as 10 mm, 12 mm, 13.5 mm and 15 mm and its center-to-center spacing with the upstream pier was varied as 60 mm, 80 mm, 100 mm, 120 mm and 140 mm. This resulted in D_d/D_u values of 1.0, 1.2, 1.35 and 1.5 and L/D_u values of 6, 8, 10, 12 and 14. The results on isolated piers of the same diameters were used as benchmarks or reference to compare the effect of a nearby pier of variable relative diameter and at varied spacings, on the equilibrium scour pattern around the pier in focus. These studies were carried out at $U/U_c = 0.9$. The experiments were run for a duration of 600 mins and temporal evolution was observed at the front, side and back of the piers by constructing vertical scales on the piers with waterproof ink. Equations for normalized maximum scour depth, lateral and longitudinal extents, scour surface area and scour hole volume for inline piers of same and different diameter are presented in the study. The reinforcement effect increases with the increase in scour depth around the rear pier due to which higher scour depths around the upstream pier was observed when downstream diameter is more at the same normalized spacing. The location of the peak of the downstream pier scour curve shifts to higher values of L/D_u with the increase in the diameter of the downstream pier. The longitudinal extent of the scour hole increases with the increase in the spacing between the piers. The peak of the mound formed between the piers moved forwards and upwards with the increase in spacing. The pattern of variation of transverse extent of scour at the pier locations with spacing, closely follows that of the maximum scour depth for the upstream pier but not for the downstream pier where slope in addition to depth affects the dimensions. The downstream pier has a greater effect on scour hole dimensions in most cases.

Thereafter, another set of experimental studies were carried out on inline piers by placing an equal or smaller diameter pier on the downstream of a larger pier. The diameter of the larger pier was fixed as 15 mm and its position was fixed. The diameter of the downstream pier was varied as 10 mm, 12 mm, 13.5 mm and 15 mm and its center-to-center spacing with the upstream pier was varied as 60 mm, 80 mm, 100 mm, 120 mm and 140 mm. This resulted in D_d/D_u values of 1.0, 0.9, 0.8 and 0.67 and L/D_u values of 4, 5.33, 6.67, 8 and 9.33. The results on isolated piers of the same diameters were used as benchmarks or reference to compare the effect of a nearby pier of variable relative diameter and at varied spacings, on the equilibrium scour pattern around the pier in focus. These studies were carried out at $U/U_c = 0.67$ since the combined scour hole of 15 mm identical piers in tandem arrangement at velocities close to critical values exceeded the width of the flume during trial runs. The experiments were run for a duration of 600 mins and temporal evolution was observed at the front, side and back of the piers by constructing vertical scales on the piers with waterproof ink. Equations for normalized maximum scour depth, lateral and longitudinal extents, scour surface area and scour hole volume for circular piers in tandem arrangement with the higher diameter pier placed upstream of the lower diameter pier at varied spacings are presented in the study for four different ratios of upstream and downstream piers. As for the upstream pier, the reinforcement effect increases the scour around the upstream pier which is reflected in greater than unity normalized scour depths. This reinforcement effect reduces with spacing causing the scour depths to decline in the range of normalized spacings considered in the study. At the downstream pier, as the sheltering effect decreases and sediment deposition becomes insignificant, the normalized scour depth again starts to increase in the range of spacings taken. This minimum which generally occurs in the range $11 \leq L/D_u \leq 40$ as reported in literature, occurs at a much lower L/D_u around $L/D_u = 7$, when the incoming velocity is reduced to $U/U_c = 0.67$. The longitudinal extent of the scour hole is found to increase with the increase in spacing between the piers. The location of the peak between the piers is found to shift downstream and upwards with the increase in the normalized spacing between the piers. Mostly, in line with the observations of the maximum scour depth at the upstream and downstream pier, the transverse extent at the upstream pier for $D_d/D_u = 1$ decreases and then remains almost constant, while the transverse extent at the downstream pier sees a sharp rise at higher spacings. The pattern is not perfectly the same as that of maximum scour depth since side slope of the scour hole also plays a vital role in determining the transverse extent of the scour hole at the piers, the variation of which is not always unpredictable. As the spacing between the piers increases, separate scour holes are observed with prominent deposition mounds between the piers. It is seen that the contribution of the upstream pier to the combined area of hole is significantly higher than the downstream pier in terms of combined area and volume of the scour hole around the piers.

Knowledge of temporal variation of scour depth at pier is essential to enable the hydraulic engineer to design the pier for scour for short duration flows. While numerous studies have been conducted on the temporal variation of scour depth around isolated piers, temporal studies on pier groups are scanty. This study investigates the temporal variation of scour depth around isolated piers against two variables i.e. diameter of the pier and inflow velocity. Moreover, it also investigates the temporal variation of scour depth at the upstream and downstream pier for two piers in tandem arrangement against two variables i.e. spacing between the piers and relative diameter of the two piers. Larger sized piers require a greater proportion of the equilibrium time to attain a certain value of non-equilibrium scour depth. The inflow velocity affects the intercept of the d_s/D vs t/D^3 curve but not its slope. For piers in tandem arrangement, the nature of the temporal variation of scour depth at the upstream pier is essentially independent of the spacing and relative diameters of the pier and follows that of the isolated pier curve. However, at the downstream pier, the nature of temporal variation depends both on the ratio of downstream pier and upstream pier diameters as well as the spacing between the piers. Generally, two types of curves apart from the isolated pier curve viz. Type I and Type II are observed depending on spacing and D_d/D_u ratio which are explained in the study. At the end, dimensionless curves for each case are presented in the study, which can be used to assess the scour depth as a function of the time stage of scour.