FLOW AROUND PIER AND ABUTMENT

M. Munsur Rahman, M. Anisul Haque and M. Safikul Islam

IFCDR, BUET, Dhaka 1000, Bangladesh

Abstract The 2-D flow field at several horizontal planes around piers and abutments has been presented from the results of flume experiments in a fixed bank straight rectangular channel with flat bed and mobile bed. The depth averaged flow field is some or similar in different horizontal plane both for pier and abutment. However, there exist significant differences of flow field inside the scour hole. These features are explained on the basis of laboratory data.

Keywords: Pier and abutment, flat bed, mobile bed, flow field

INTRODUCTION

Piers and abutments are the integral part of bridge structures that obstruct the natural river flow resulting from scouring around them. One of the main causes of bridge failure is the excessive local scouring around piers and abutments during floods. Therefore, it is very important to estimate the maximum scour depth precisely around these structures for safe design.

Scour depth estimation around bridge piers have attracted considerable research interest and a number of prediction methods are available at present which are inherently empirical in nature (Laursen, 1963; Breusers et al. 1977; Melville and Sutherland 1988; Melville 1997). On the other hand, the research on abutment scouring received relatively less attention, though the problems of scouring at abutments are quite significant. However, in the recent years, a number of empirical and semi-empirical methods are developed for the prediction of maximum scour depth around abutments (Garde et al., 1961; Gill, 1972; Melville, 1992; Lim, 1997 etc).

A number of researches have already been performed in order to understand the flow structures and scour mechanism around bridge piers (Melville, 1975; Ahmed, 1998) and abutments (Rajaratnum and Nwachukwn, 1983; Kandasamy and Melville, 1994). Melville (1975) had measured the detailed flow patterns (3-D) around a circular pier under clear-water scour conditions at initial flat bed, intermediate scour hole and equilibrium scour hole. It was concluded that there exists a strong down flow in front of the cylinder and a spiraling flow at the base and the circulation is strongest at the line of symmetry. Ahmed and Rajaratnum (1998) also did similar flow measurements, in the smooth, rough and mobile beds and observed strong down flow component near the bed at the line of symmetry. In addition to this observation, from the lateral distribution of flow velocity at the upstream face of pier, significant amount of velocity amplification (typically 1.5 to 1.8 times of average flow velocity) has been occurred at a certain distance away from the pier wall. The point of maximum amplification (or flow concentration) may be close to the outside of the flow separation line as indicated by Richardson and Panchang (1998). It is very interesting to see that the amplification is more pronounced close to the bottom as compared with the surface flow. However, the general trend of the lateral distribution of flow velocity in different vertical plane is quite similar and the 3-D flow structures passing a pier can be approximated as 2-D without having serious error. Rajaratnum and Nwachukwn (1983) measured detailed flow velocity around abutment in flat bed condition and concluded that the shear stresses are amplified near the nose of the structure which indicates significant flow concentration close the abutment structure. Kandasamy and Melville (1994) presented the results of their detailed flow measurements and concluded that a strong flow concentration region exists near the bottom of the scour hole close to the abutment face.

As stated by Melville (1997) that the flow structure and associated scouring at an abutment are considered to be similar to that at a pier of equivalent shape to the abutment and its mirror image in the channel wall. It has long been recognized that the flow in and around the scour hole at piers and abutments are similar, particularly when abutment is relatively short with respect to approach flow depth. Therefore, the lateral distribution of the flow passing a pier or an abutment is similar and a number of empirical methods have been already developed to estimate the maximum scour depth around piers and abutments in an integrated way (Laursen, 1963; Melville, 1997; Kawn and Melville, 1998). However, as the developed methods are inherently empirical in nature, their general applicability is not out of question and there in a need for the development of a very general theoretical method that can be equally applicable for the prediction of the maximum scour depth at piers
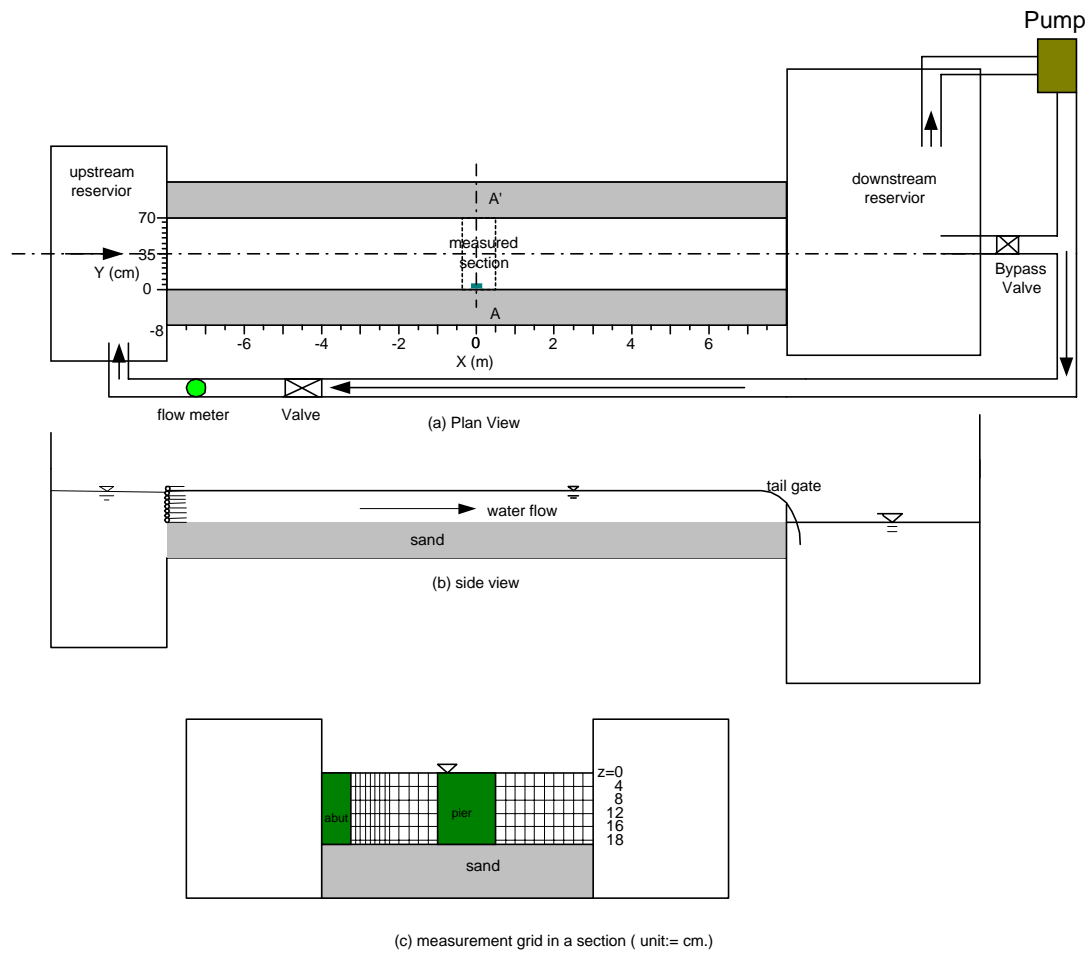
Pump

upstream reservior

70

35

Y (cm)

0

-8

A'

measured section

A

-6 -4 -2 0 2 4 6

X (m)

flow meter   Valve

(a) Plan View

downstream reservior

Bypass Valve

water flow

sand

tail gate

(b) side view

z=0
4
8
12
16
18

abut   pier

sand

(c) measurement grid in a section (unit:= cm.)

Fig. 1 Experimental set up.

Pier scour

Photo 1 Pier scouring

Depth averaged (fixed)

depth avg (pier, sand bed)
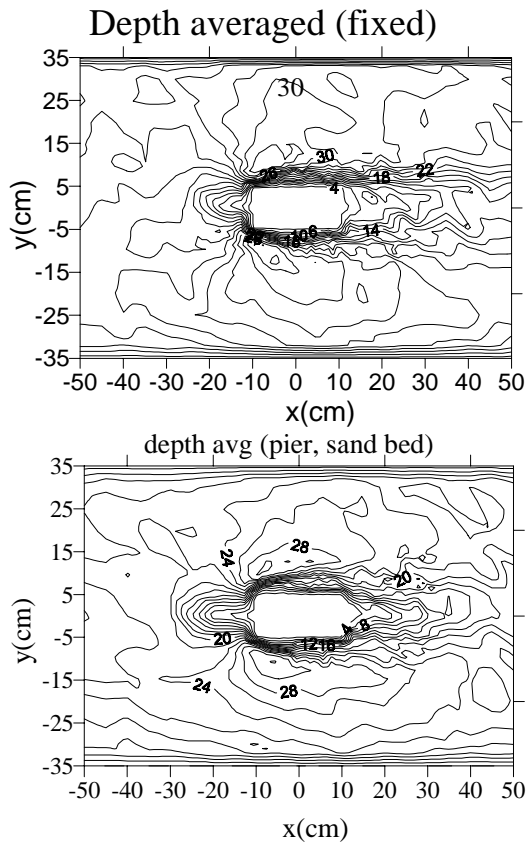
Fig. Velocity contours around pier.

and abutments. To this extent, Rahman and Muramoto developed an analytical model to predict the maximum scour depth around abutment considering flow concentration into the restricted region of the scour hole. However, they used a constant flow concentration parameter (= 0.2) from many experimental data and was not able to correlate the flow concentration parameter with the flow parameters related to the vortices close to the abutment. Moreover, their model is only applicable to the abutment scour.

In the present study, detailed flow structures around piers and abutments are presented from the measured data in the flume experiments under fixed bed and mobile bed condition. The similar flow concentration close to both types of structures is identified only if average flow is considered.

EXPERIMENTS

Experiments were performed using a straight concrete re-circulating flume that is 16.8 m long, 1.5 m wide, and 50 cm deep with rectangular cross section. To establish the uniformly distributed flow in the experimental reach, a distributor was placed in front of the delivery pipe in the upstream reservoir. Moreover, 2.5 cm hollow plastic pipes are placed at the upstream entrance. The control section was selected at 5 m downstream from the channel inlet in order allow sufficient length of for boundary layer development. The downstream outlet was controlled by a tail-gate to maintain an uniform flow depth throughout the flume. Experiments were carried out both in the fixed bed and the mobile bed. For the fixed bed experiments, smooth concrete boundary was used. On the other hand, the channel bed was made of uniform sand having d_{50} is equal to 0.70 mm for the mobile bed experiments. The experimental flume, the water circulation system, the upstream and downstream control structures and sample grid points for velocity measurement in a cross section is shown in Fig. 1. Grid points were varied depending on the location. Denser grids were used close to the abutment. When the scour was allowed in a mobile bed condition, additional grid points were set at 1 cm vertical distance inside the scour hole.

In the control section, pier with rectangular shape having 20cm length, 10cm width and 50cm height and abutment with 20cm length, 5cm width and 50cm height was placed. Pier was set in the middle of the channel and abutment was set at right channel wall. However, the experiments with piers and abutments were done separately. Detailed flow velocity was measured covering 50 cm upstream and downstream of the structure. The measuring grid spacing varies from 1-5cm along the lateral and longitudinal direction and 1-4cm in the vertical direction. Velocity vectors were measured using a 2-D programmable electro-magnetic liquid velocity meter (P-EMS-E40) interfaced with a Laptop computer. For each point, the average values of 10 seconds were selected as the representative velocity after a number of trial and error. For each of the horizontal planes, velocities were measured at more than 300 points that consumed 6-8 hours.

The flow discharge was set at 33 l/s using a flow meter and flow depth was 20 cm for experiments. The average flow velocity thus obtained was equal to 23.6 cm/s. The underlying reason of setting such a hydraulic condition was to achieve clear-water scouring condition during the mobile bed experiments as well as to ensure minimum depth required for velocity measurement. The critical shear velocity u_{*c}, for sediment used in the mobile bed experiments is equal to 1.96 cm/s. Whereas, the average shear velocity exerted on the bed by the flow discharge is equal to 1.66 cm/s. The velocity meter was set into the desired depth and the velocity measurement was continued at each of the pre-determined grid points. A mounted platform that could move through a rail was used to move to a desired grid point. The measured velocity data was then processed and graphical presentation was made according to the requirement. For the geometry of the scour hole, bed levels were measured after the equilibrium condition of the mobile bed experiment using a point gauge.
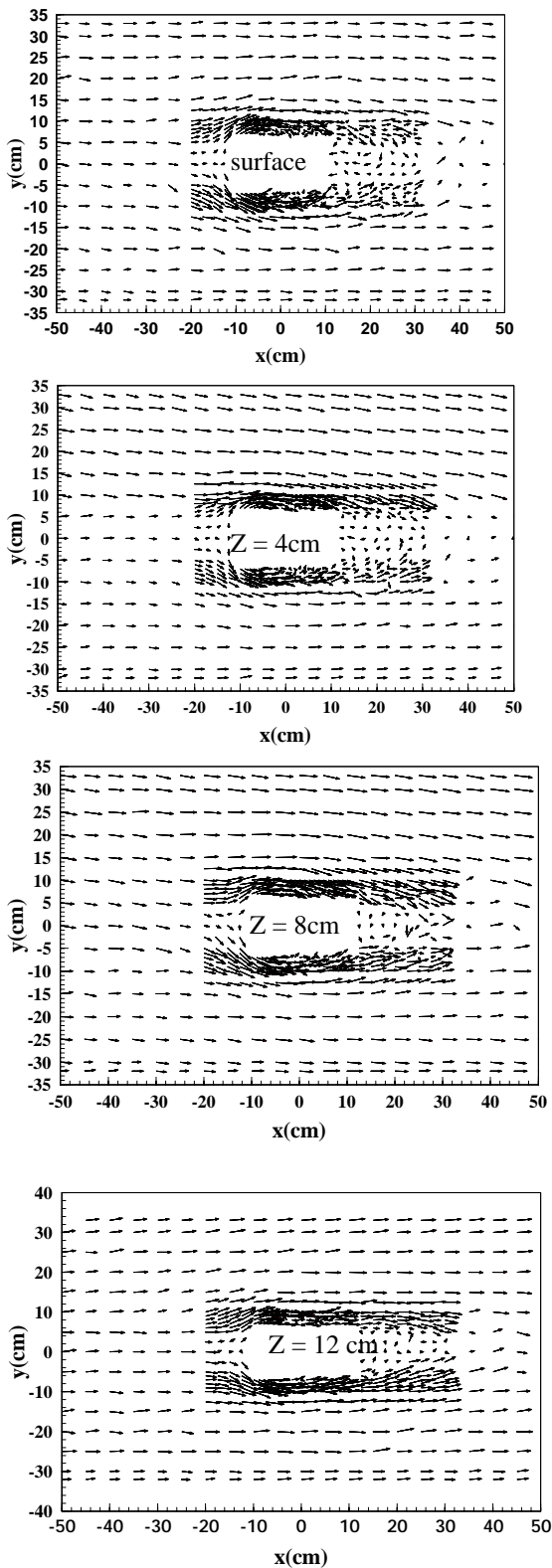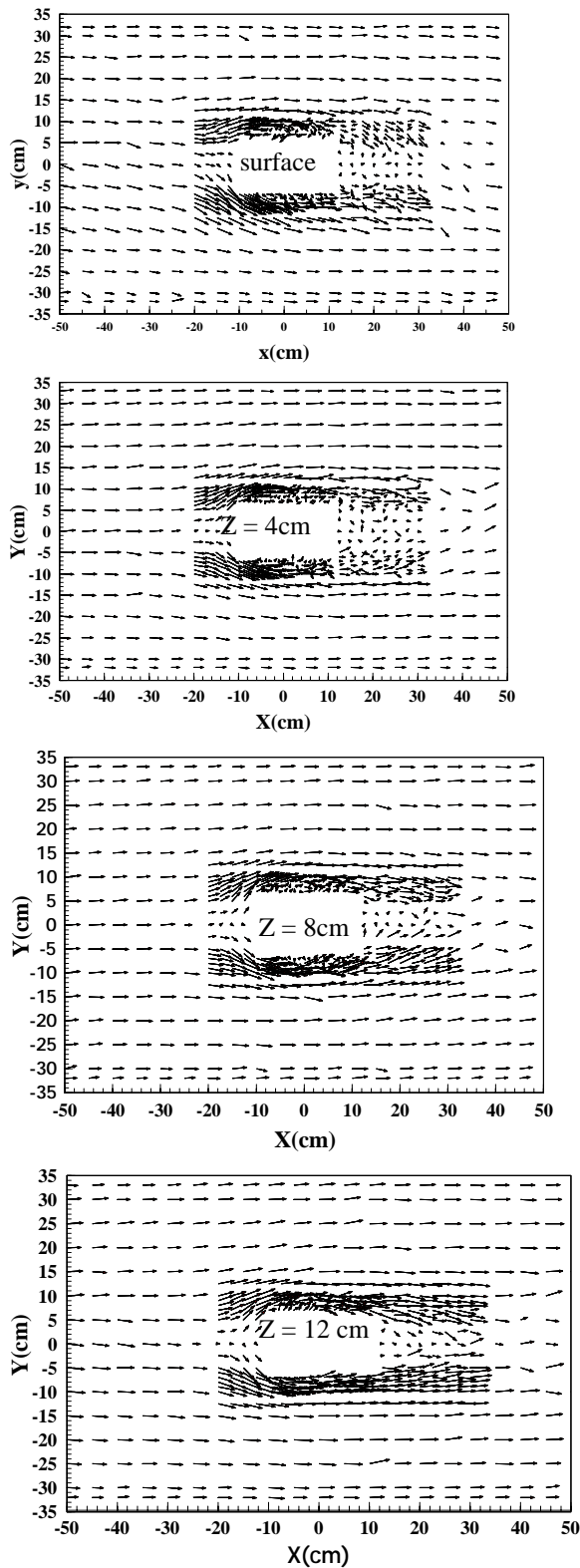
Fig. 3 Velocity vectors around piers (fixed bed).

Fig. 4 (a) Velocity vectors around piers (mobile).
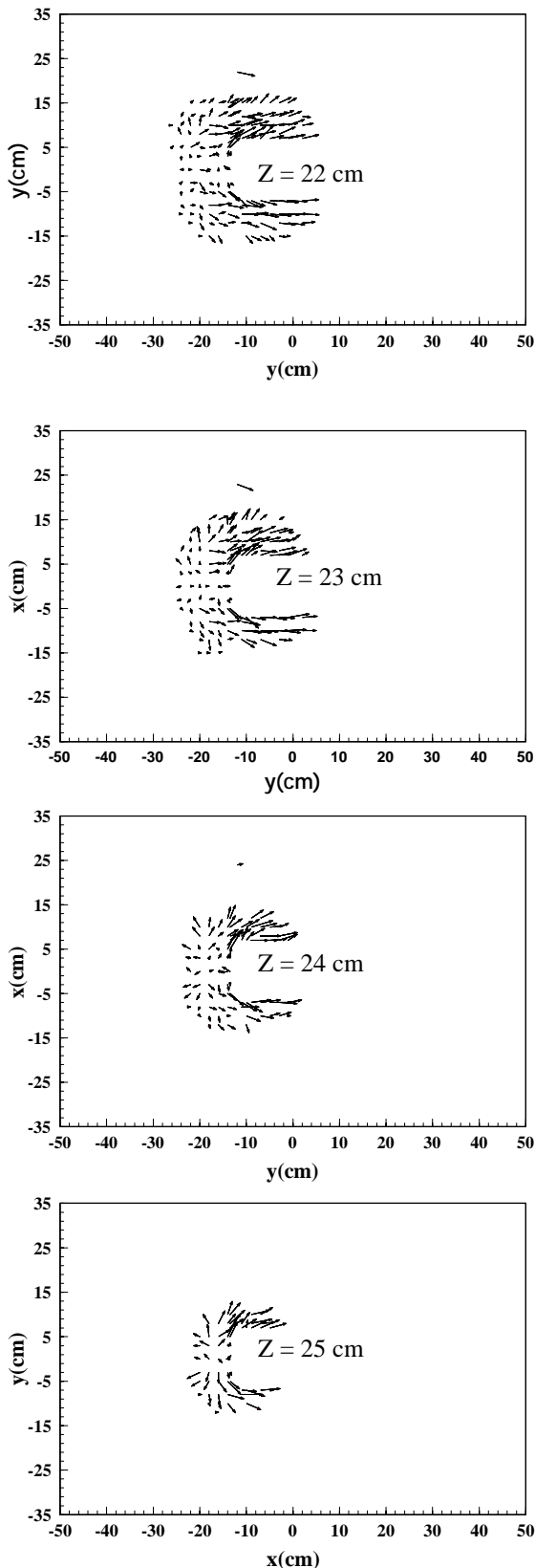
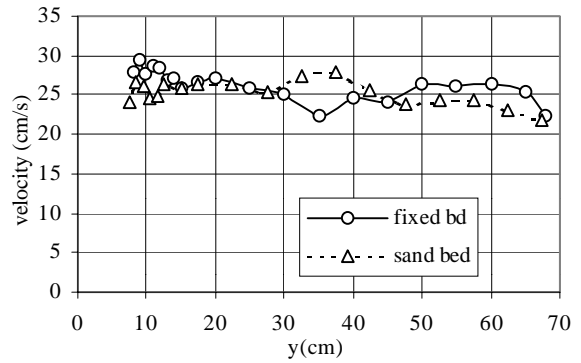Fig. 4(b) Velocity vectors inside the scour hole around the pier.

Fig. 5 Lateral distributions of the depth averaged velocity in the fixed bed and mobile bed condition around abutment.

RESULTS

The results of the depth averaged velocity contours around piers at flat bed and mobile bed condition is shown in Fig. 2. It is seen that the depth averaged velocities are more or less similar in both cases. However, the magnitude of the resultant velocity close to the pier is reduced as compared with the fixed bed experiment. This is due to the scour development around the structure. Similar phenomenon was also observed in the case of abutment experiments. The typical scour formation around pier is shown in Photo 1. The scouring around one side of pier is quite similar to the abutment scouring.

The velocity vectors around the rectangular pier in the flat bed condition are similar in the different horizontal plane as shown in Fig. 3. On the other hand the velocity vectors around the same structure in the mobile bed is quite different, specially, inside the scour hole as shown in Fig.4. The flow obstructed by the pier goes downward towards the scour hole bed and part of the flow is diverting towards the side of the pier and some fraction is deflecting towards upstream direction. This phenomenon gives an indication that the flow inside the scour hole is very complex. In the fixed bed condition, 2-D flow field can be assumed even close the pier, in mobile bed condition, the situation is different and the assumption of 2-D flow field may lead to significant error. The similar phenomenon is also true pier abutment experiment.

The lateral distribution of the depth averaged flow velocities at the upstream corner of abutment in the fixed bed and mobile bed condition is presented in Fi.g.5. It can be seen that the magnitude of the resultant depth average velocity is decreased in the mobile bed as compared with the fixed bed as system tends towards equilibrium.

CONCLUSIONS

(1) In the flat bed condition, the 2-D flow field around piers and abutments can be assumed with reasonable accuracy.

(2) Inside the scour hole in the mobile bed condition, the flow field is strongly 3-D.

(3) The average flow velocity inside the scour hole reduced as compared with the results of the fixed bed experiment in the same region.

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