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Scour Experiments on Dike Angle, Porosity, and Hook for a Thin Dike

By

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ABSTRACT

This paper presents preliminary results from laboratory experiments conducted to determine how dike angle, porosity, and hook-length influence local scour at a thin dike (possibly constructed from sheet-pile) for use in deflecting debris and ice away from a water intake for a thermal power station. The experiments involved straight dikes and dikes fitted with an end hook, directed downstream and upstream. The results from the experiments usefully reveal trends between equilibrium scour depth and these aspects of dike design. The relationships may aid in the design of porous dikes. They show how dike angle and porosity may reduce local scour. Additionally, they show that dike hook-length exerts only a minor influence on scour depth. The results also include information on the extent of sediment deposition downstream of a dike.

INTRODUCTION

The present study was prompted by the need to design a flow-guidance dike that would deflect debris and ice away from a water intake located on a riverbank along a mid-size alluvial channel, minimize local scour depth as well as sediment accumulation. Scour was a concern for the foundation depths required for the dike. Sediment deposition was a concern, as it is intended that the dike should not aggravate alluvial-sediment ingestion by the water intake; sediment potentially could accumulate in the flow separation zone behind the dike and thereby move readily into the intake. Two ways to mitigate the two concerns is to make the dike sufficiently porous so as to weaken the stagnation pressure heads associated with the local flow field around the dike, and to enable flushing flow to pass through the dike. To determine how dike porosity and angle influence local scour, series of flume experiments were conducted.

Additional experiments were conducted to determine whether hook length, for a dike perpendicular to the flow, influences scour depth. These experiments also entailed exploring the merits of modifying the flow field at the end of the dike so as to reduce the turbulence generated by flow passing around a dike.

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A considerable number of prior experiments have been conducted to determine dike/wall/abutment angle effects on local scour. Melville and Coleman (2000) usefully summarize the effects. It is noteworthy, though, to mention that the prior studies seem to have been conducted for conditions of clear-water scour, and that the influence of pier or dike width has not been considered in deciphering the data.

Though some prior investigation has been conducted regarding the influence on scour depth of dike porosity, the results of those studies are not widely disseminated, and require further confirmation. Notable studies are those by Subramanya and Gangadharaih (1989) and Juyal (2002), both of whom provide data from laboratory flumes. To date the literature seems to have lacked information concerning the influences on scour of dike angle and dike-spur geometry.

A further novel aspect of the present experiments is the measurement of maximum equilibrium height for the sediment deposited immediately downstream of the dike. Information on deposition height and extent is sometimes needed for assessing the influence that a dike may have on the channel bank downstream of the dike.

As the experiments were underway when this paper was prepared, the results presented are preliminary, and are subject to some conjecture. Further work is underway to confirm the trends revealed by the data obtained to date.

HYDRAULIC MODEL

The layout of the hydraulic model is given in Figure 1. Water flow through the model was circulated by means of a pump, which also re-circulated the sediment forming the model's bed. Similitude was based on a shear-velocity-excess criterion whereby the channel's sand bed was fully mobilized in a dune regime. The hydraulic model discharge was 0.057 cumecs at an average flow depth of 0.15m. Model flow rate was measured using a side-contraction orifice placed in the 0.25m diameter pipe. The median diameter of the prototype bed sediment is in the coarse-sand range, with a medium particle diameter of about 1.5 mm.

Experiments were conducted to determine the maximum scour depth (ds_e) produced by a dike subject to several modifications (Figure 2):

1. Dike porosity (0% to 79%)
2. Dike angled to the flow (15^o to 150^o; with dike pointing upstream when angle exceeds 90^o)
3. Dike hook directed downstream or upstream (hook length = 0 to 3*L*)

Here, *L* is the length that a dike protrudes perpendicularly into the flow.

Except for the first set of experiments in which dike porosity was varied, the subsequent experiments were conducted with solid dikes (porosity = 0). The model did not include simulation of the intake flow. The variables measured were the equilibrium depth of bed scour, ds_e, and the maximum height of sediment deposition, d_D, immediately downstream of the dike. These variables were measured relative to average bed level.

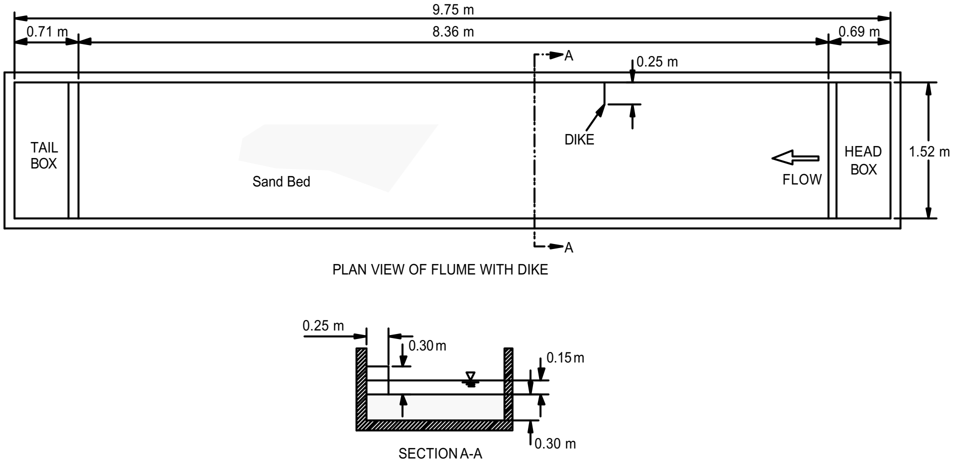

Figure 1. Layout of flume and model dike.

The model dike projected a length into the flow, for all dike angles, equal to 0.254m. Each test was run for a 24-hour period, which proved sufficient to attain equilibrium conditions of sediment accumulation and scour. The same water discharge (0.057 m^3/s) was used for all tests. The geometric features of dike investigated are illustrated in Figure 2.

RESULTS

Figures 3a-e provides views of the scour holes observed during the experiments. The scour data presented in this paper are for the deepest scour, which invariably occurred at the end of each dike.

The data resulting from the experiments provide trends indicating how scour depth decreases with increasing dike porosity and with diminishing dike angle to the flow. The experiments also show that dike width did not exert a significant influence on scour depth. Additionally, they show that an upstream spur does not significantly reduce scour depth. Figures 4 and 5 show the trends for scour depth versus dike angle and porosity. The data for ds_e and d_D are presented below in normalized format, whereby the values of ds_e and d_D resulting with the modified dike are normalized using their values as obtained for the baseline case for which the non-porous dike was at 90° to the bank (ds_{e-o} or d_{D-0}).

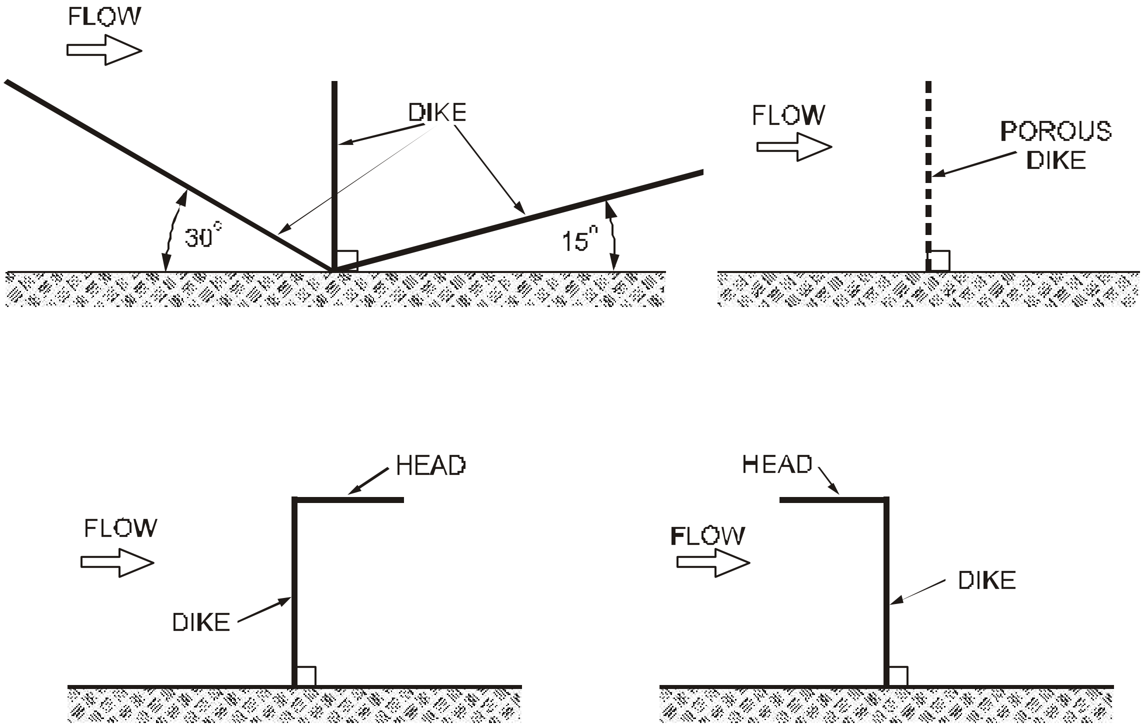

Figure 2. Variations of dike layout investigated. Dike orientation was varied from 15^{o} to 150^{o}; dike porosity was varied from 0 to 79%; the dike hook was varied in length and direction.

Dike Angle

Figure 4 shows how depth of local scour varied as dike angle changed from $+15^{o}$ to 90^{o} (dike normal to the flow), and from 90^{o} to 150^{o}. As the dike swung from pointing upstream to pointing downstream, ds_e increased, attaining a maximum at 90^{o}, then decreased. It is interesting to note that the variation of ds_e with angle is appears to be almost symmetrical for the dike oriented upstream or downstream. As mentioned above, for all angles, the deepest scour occurred at the end of the dike. The trend shown in Figure 4, however, differs from that indicated by Melville and Coleman (2000). They provide an upper-bound curve enveloping data from several studies. Their upper bound curve shows ds_e to increase with angle beyond 90^{o}, and to decrease less steeply as angle diminishes below 90^{o}. However, data obtained by T.F Kwan (1984) showed a trend similar of scour variations to figure 4. As of the time this paper was written, the writers are planning further diagnostic experiments to determine why their data show different trends to the data from prior studies. Factors being considered are that the present study was conducted with a very thin dike placed in a mobile bed.

(a) Wall 90^0 with 0% porosity *(b) Wall 90^0.L_{headt}/L=1,downstream*

(c) Wall 30^0 with 0% porosity *(d) Wall 30^0 with 79% porosity*

(e) Wall 30^0 with 50% porosity

Figure 3. View of the experiments

Observations from the present experiment indicate that the downflow and horseshoe vortex decreased in strength as the thin dike pointed upstream, as they did when the dike pointed downstream. Additionally, the presence of dunes affected local orientation of flow toward the dike.

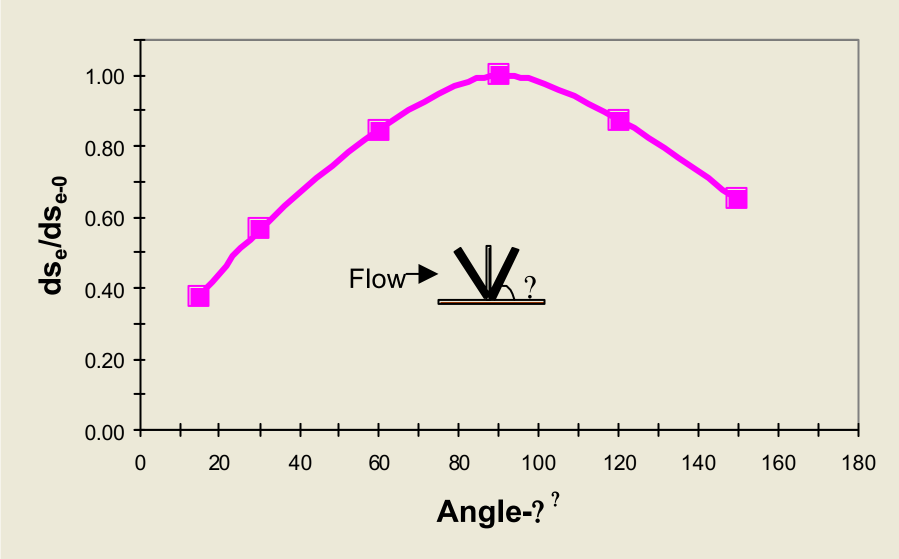

Figure 4. Variation of ds_e/ds_{e-0} with dike angle.

Porosity

Dike porosity significantly affects scour depth. Figure 5 shows the ratio (ds_e/ds_{e0}) versus dike porosity. The figure shows that the scour depth decreases with the porosity; a porosity in excess of about 44% reduced scour depth by more than 50%. A practical difficulty, however, is that the dike porosity may diminish owing to blockage by debris and possibly ice. This consideration is being considered further.

The combination of dike angle and dike porosity substantially reduces sediment accumulation behind a dike, as well as reducing scour depth. Figure 6 shows the variation of sediment accumulation height when a thin porous dike is set at 90^o and 30^o. In the case of 90^0 dike setting, ds_e is 20% larger than 30^0 case, and porosities are effective up to the 75% porosity dike. Above this porosity it is tedious to make a difference between the natural riverbed oscillations and the induced scouring and accumulation due to the dike implementation. The average height of the bedforms is presented in both plots by a horizontal straight line. In the case of accumulation, the 90^0 dike appears to be ineffective beyond 50% porosity.

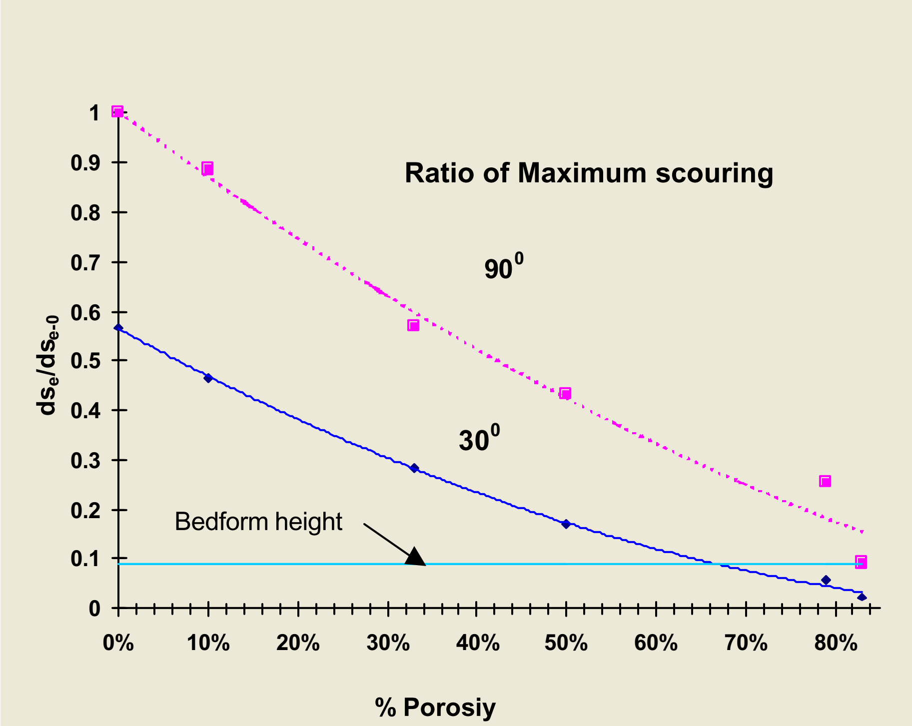

Figure 5. Variation of ds_e/ds_{e-0} with dike porosity; de_{s-0} was 0.22m.

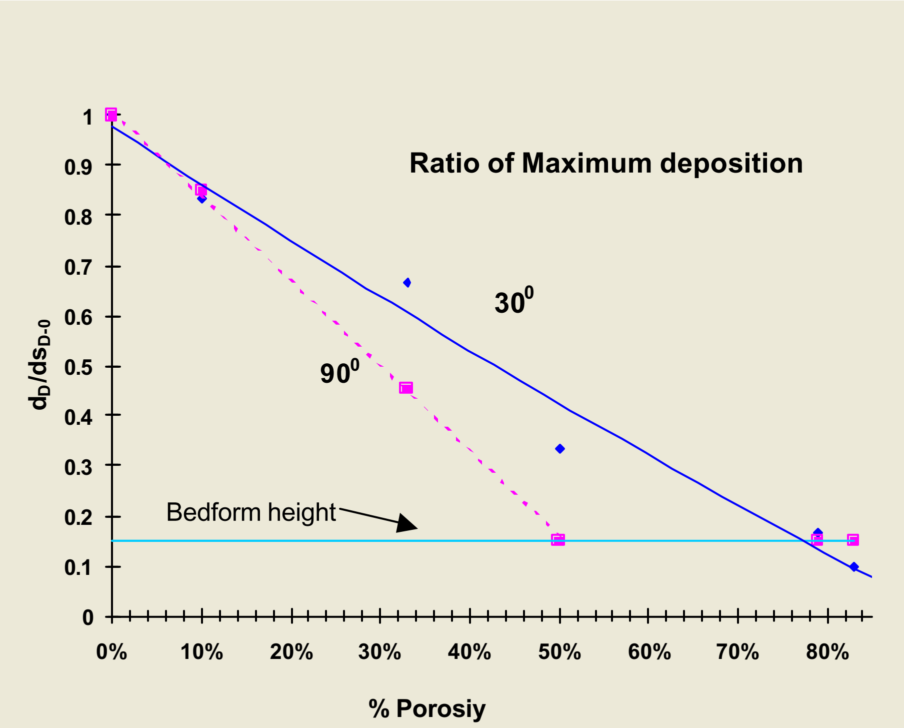

Figure 6. Variation of d_D/ds_{D-0} with dike porosity.

Dike Hook

The downstream-directed dike in effect acted to increase dike width. The experiments show that dike thickness (for a dike at 90^{o}) had a minor influence on scour depth. Figure 7 shows that a hook pointing downstream slightly increased scour depth ($ds_e/ds_{e-0} = 1.1$).

Widening the dike appeared to strengthen the horseshoe vortex around the dike's upstream face and side. Also, it seemed to strengthen the down flow into the scour hole at the end of the dike. It also moved the wake vortex downstream from the face of the dike. The net effect on scour was a mild (10%) increase in scour depth, as shown in Figure 7.

A hook pointing upstream of the dike decreased scour slightly, as shown in Figure 7. An upstream pointing hook appeared to weaken the horseshoe vortex and the down flow into the scour hole. Additionally, turbulence generated by the wake vortex was shifted downstream away from the front of the scour hole. The net effect was a mild (10%) decrease in scour depth.

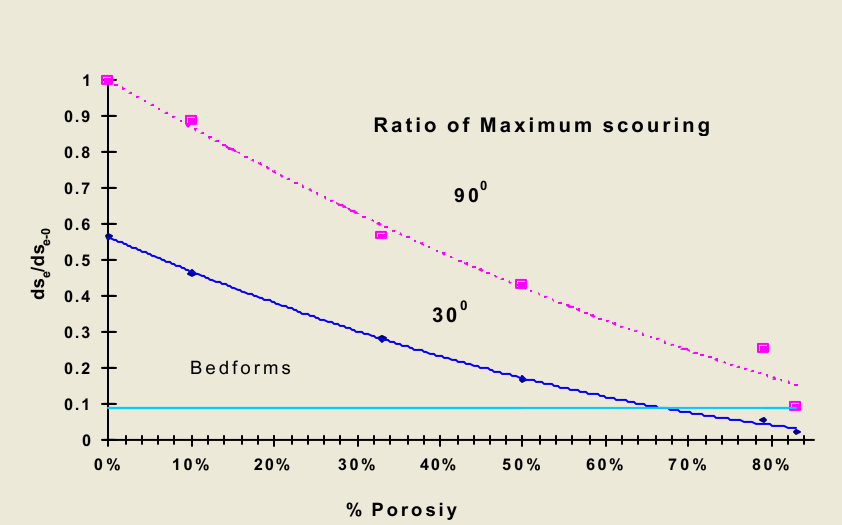

Figure 7. Variation of ds_e/ds_{e-0} vs. Dike Thickness and Upstream Hook

CONCLUSIONS

The data in hand enable some preliminary conclusions to be drawn. Further experiments are underway to confirm and explain some of the results obtained.

Dike angle and porosity significantly influence scour depth. Widening the dike, or the addition of an upstream-pointing hook, did little to reduce scour depth. The relative insensitivity of scour depth to dike width and hook presence is attributable to the consideration that the flow still was forced to pass around the dike, which extended a constant distance into the flow. Once a scour hole formed, the major factor influencing scour development appears to be the overall distance that the dike extends into the channel.

The mild decrease in scour depth observed for the upstream-pointing hook agrees qualitatively with the decrease in scour depth observed when the dike was angled upstream. In both cases, the flow, though still contracting around the dike, essentially impinged against a narrower body (dike).

The experiments showed that porosities of about 50% reduced scour and sediment accumulation downstream of a dike. Moreover, porosity higher than 75% does not modify channel bathymetry.

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