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BED FORM DEFORMATION DUE TO UPSTREAM GROUP PILES

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Abstract

Deformation of bed forms by passing through a group of vertical piles installed upstream in an open channel was examined experimentally. With Froude number the heights and lengths of dunes are increased and the steepness of dunes decreases. The heights of piles were found to have negligible impact on the variation of bed forms. The pile diameter is a significant factor that causes the reduction in the dimensions of dunes. Increase in number of piles per unit area defined as a pile density brings about the decrease in the size of dune as much as 60%. However, there exists an upper limit of the pile density beyond which the deformation of dune becomes independent of the density. The steepness of dunes becomes steeper with increase of the density. The deformed bed forms resume their original states at a distance downstream X/L ≈ 6 from the end of pile zone.

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Introduction

Depending on the flow parameters and sediment properties, an alluvial stream may undergo different bed forms. For the lower regime of a subcritical flow, the stream bed can exhibit ripples and dunes with the water surface being approximately flat. Kennedy(1969) argued that the occurrence of bed forms is due to (1) the result of an orderly pattern of scour and deposition, (2) the instability phenomenon and (3) the flow parameters and sediment properties. Yalin(1977) pointed out that the dunes are caused by a discontinuity(ridge) of a plane initial bed, which induces an alternation in velocity profile through disturbance of turbulence structure and in consequence the velocity alternation is resulted in the decrease of sediment transport, the growth of accretion must take place, and the variation of bed level by the Exner equation must be accompanied.

Based on the aforementioned reasonings, any physical addition to a flow, which causes an alternation in the flow structure and in the alluvial stream bed features, will bring about change in sediment transport. Such change will lead to either increase or decrease the magnitudes of bed form geometries such as the dimensions of dunes. Placing piles on the stream bed may be one of the additions resulting in the alteration, possibly reduction, of the dimensions of dunes. In alluvial streams, when the troughs of dunes pass hydraulic structures, substantial part of their foundation may be exposed to flow and it may endanger the safety of structures. Therefore, for proper management, maintenance and safe design of hydraulic structures, it is very important to develop measures to reduce the magnitudes of dunes or antidunes passing hydraulic structures or eliminate them entirely if possible.

The objective of this paper is to examine how the dimensions of dunes are affected by passing through a group of piles with different combination of pile installation on the bed in an open channel.

Experiments

Experiments were conducted in a recirculating tilting flume that is 20m long, 0.9m wide and 0.4m deep. Uniform bed sediments with a median particle diameter of 0.45mm were placed with the depth of 10cm in the flume bed. The piles were positioned at the central region of the flume with different combination of pile diameter, distance among piles and pile density. Fig.1 shows the definition sketch of experimental setup.

The development duration of sand waves varies from 20min to 20hr depending on the value of τ_o / τ_{oc} (Yalin 1979). However, each experiment was run for a duration of 4 hour since the experiments were aimed to find how the alternation of dunes take places.

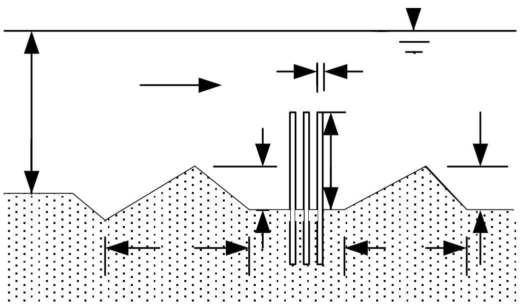

Fig. 1 Definition sketch of experimental setup

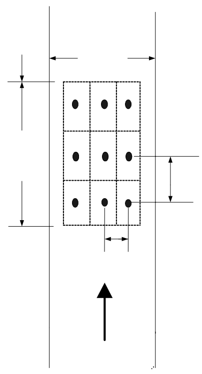

Fig. 2 Layout of pile installation

The heights and lengths of dunes were measured by a point gage and a ruler. At each run more than ten measurements were made and their dimensions were averaged. Most of experiments were performed under conditions of flow depth of y_o = 13cm and flow velocity of u = 0.6m/s.

The positioning of piles was rather arbitrary, i.e. the longitudinal distance and transverse spacing between piles were set as 52cm and 20cm, respectively as shown in Fig. 2. The longitudinal distance of 52cm is the average length of dunes at y_o = 13cm and u = 0.6m/s. Throughout the experiments the pile zone was a rectangular of 156cm in the direction of flow and 60cm in the transverse direction.

Flow

D

H

Piles

Table 1. Flow conditions and average dimensions of dunes

Flow depth (cm)	Velocity (m/s)	Fr	Av height (cm)	Av length (cm)
13	0.2	0.18	1.10	12.12
	0.3	0..27	1.49	17.23
	0.4	0..35	2.05	23.25
	0.5	0.44	2.88	33.88
	0.6	0..53	4.27	52.74
	0.7	0.62	5.91	74.47

Table 2. Properties of piles

Diameter (mm)	2.0	4.0	6.0	8.0
	10.0	12.0	14.0	
Height (h_p/y_0)	0.0	0.15	0.30	
	0.45	0.60		
Density	0.97	1.47	1.97	2.47
(cm^2/cm^2) x10^3	2.96	3.45	4.93	

Dunes

A dune is one of typical bed forms with shape that has an upstream face with a gentle, gradually varying slop and an abrupt downstream face with a constant slope, which is approximately equal to the tangent of the repose angle of bed material. Dunes found in a subcritical flow region of F_r=0.2 - 0.6(Mercer 1971) are not stationary but they move in the direction of flow. The dimensions of the bed forms are dependent on the properties of the flow, fluid and bed material. Yalin(1964) showed a linear relation of L = 5 y_o and Hino(1969) reported a similar relation of L = 7 y_o .

Allen(1963) presented the following relationship from the observed data.

$$\log y_o = 0.8271 \log H + 0.8901 \quad (1)$$

$$\log H = 0.7385 \log L - 1.0746 \quad (2)$$

in which L is the length of a sand wave or dune and H is the height of a dune. Froude numbers of the flow that induced the dunes in this study fall in the range of 0.18 and 0.62(Table 1), which agrees with the findings by Goswami(1967). As can be seen in Fig. 3 the heights and lengths of dunes are noted to be dependent on Froude number for a given flow depth.

$$H/y_o = 0.0407e^{3.885Fr}, \quad L/y_o = 0.0949e^{4.174Fr} \quad (3a,b)$$

where Fr is the Froude number $(u/\sqrt{gy_o})$.

The plotted data of the heights versus lengths shown in Fig.4 might be said to agree to Allen's relationship of Eq.2 if it stands for large ripples, and the steepness of dunes

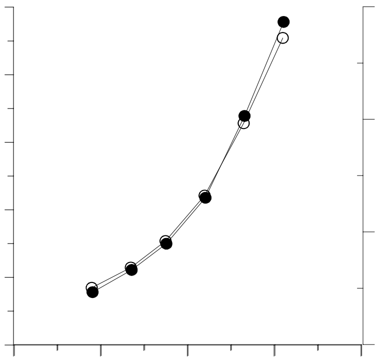

Fig. 3 Increase of dune dimensions with Froude number

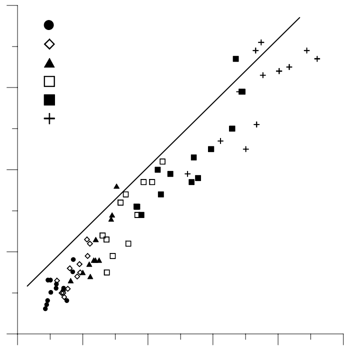

Fig.4 Plot of heights versus lengths of dunes for different velocities

has the value of 1/14, whereas Yalin(1964, 1977) showed H/L=1/30 – 1/5. The steepness was found to be a function of Froude number for a given flow depth. In this particular case it can be defined in terms of Froude number Fr as

$$H/L = 0.0949e^{-0.289Fr} \tag{4}$$

Effects of Piles on Dimensions of Dunes

Effect of pile height **:** As shown in Fig. 5, the effect of pile height at the density of piles of 1.47/1000 is negligible on both heights and lengths of dunes regardless of the diameter of pile. Meanwhile, the flow in an open channel are influenced significantly by the height of vegetation zone placed upstream(Yoon et al. 2004). The effect of vegetation height on the velocity profile leads to the reduction in the scouring depth around a pier with different vegetation height. The above facts call for further research for the effect of pile height on the bed forms with higher density of piles. From Fig. 5 it is noted that the variation of heights and lengths of dunes with different pile height is negligible.

Effect of pile diameter**:** Fig. 6 shows the variation of the heights and lengths of dunes in the downstream region of the pile zone of X≅0 - 1.0m or X/L≅0 - 2.0, where X starts at the downstream end of the pile zone. It is noted that the heights and lengths of dunes decrease with increase of pile diameter and the reductions amount to 24% and 40% of the original sizes at D/y_o=1.0. Based on the limited data in Fig.6, the dimensions of dunes downstream region of the pile zone can be predicted as

$$\frac{H_d}{H_u} = 1 - 26.3\left(\frac{D}{y_o}\right)^2, \qquad \frac{L_d}{L_u} = 1 - 43.2\left(\frac{D}{y_o}\right)^2 \tag{5a,b}$$

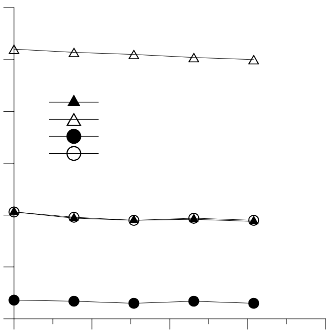

Fig. 5 Effect of pile height on height and length of dunes

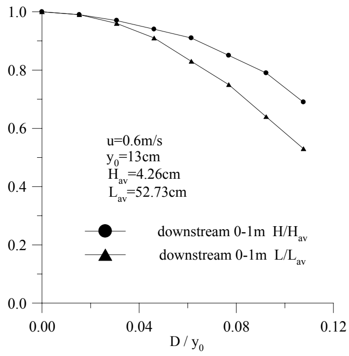

Fig. 6 Effect of pile diameter on dimensions of dunes

Effect of pile density: The density of piles is defined as the ratio of areas of pile group and pile zone. For the positions of piles within the pile zone, three row of piles are placed in the transverse direction and in the longitudinal direction the number piles were varied in the range of two to ten piles resulting in densities ranging from δ_p = 0.97/1000 to 4.93/1000.

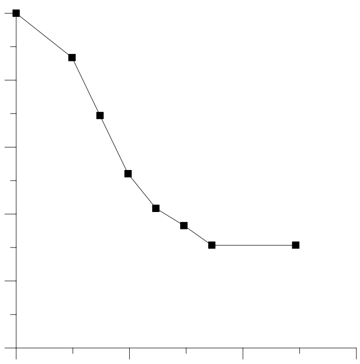

Fig. 7 Effect of pile density on height of dunes

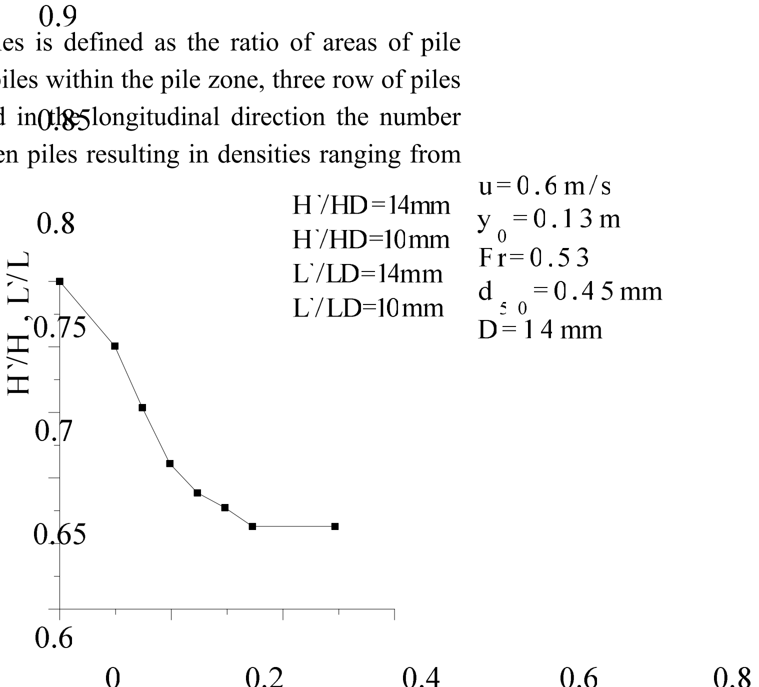

Fig. 8 Effect of pile density on length of dunes

The facts noted in Figs. 7 and 8 are that the effect of pile density is significant in the reduction of the dimensions of dunes and there exists a limiting density of piles of ρ_p=3.45/1000 beyond which the dimensions of dunes are ceased to decrease. The steepness of dune was found to increase with the increase of pile density and the dimensions of dunes are reduced with the density of piles.

***Alternation of dunes in downstream region of pile zone*:** Figs.9 and 10 show the variations of the heights and lengths of dunes in the downstream region of the pile zone and they indicate that the reduced heights and lengths of dunes due to passing through

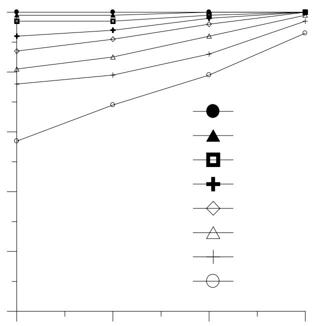

Fig. 9 Heights of dunes with distance downstream from pile zone for different pile diameters

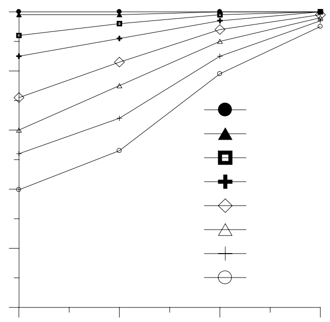

Fig. 10 Lengths of dunes with distance downstream from pile zone for different diameters

the pile zone increase with distance in downstream direction from the pile zone, i.e. the reduced heights and lengths of dunes are recovering gradually to their original dimensions before entering the pile zone. At the distance of X=3m or X/L≅6 downstream from the pile zone the reduced heights and lengths of dunes resume approximately 90% of their original dimensions

***Estimation of alternation of dunes due to passing through pile zone*:** Under the limited conditions of bed sediment d_{50} = 0.45mm, 0.015 ≤ D/ y_o ≤ 108, and 0.97/1000 $\rho_p \leq$ 4.93/1000, the altered heights and lengths of dunes after passing through the group of pile placed upstream may be estimated in terms of flow depth y_o, pile diameter D, pile density ρ_p and Froude number Fr as

$$H_d = \{0.04 - 0.55(\frac{D}{y_0}) - 6.19\rho_p\} e^{3.89Fr} y_0 \tag{6}$$

$$L_d = \{0.2 - 2.05(\frac{D}{y_0}) - 14.39\rho_p\}e^{4.17Fr}y_0 \quad (7)$$

where H_d and L_d are the height and length of dunes in the downstream region after passing the pile zone .

Conclusions

The deformation of dunes by passing a group of piles in an open channel was investigated experimentally and the findings are summarized. The dimensions of dunes are an increasing function of Froude number in a subcritical flow region, and over a wide range of the length of dunes a constant steepness prevails and the steepness can be estimated in terms of Froude number. At a lower density of piles such as ρ_p=1.47/1000, the effect of pile height is negligible and it needs further study at higher density of piles if the significant effect of vegetation is considered. With increase of pile diameter, reduction in the heights and lengths of dunes amounts to 24% and 40%, respectively at $D/y_o = 1.0$. The dimensions of dunes are reduced significantly with the density of piles but there exists an upper limit of ρ_p=3.45/1000 above which the dunes cease to decrease further. The reduced dunes in their size in the downstream region of the pile zone resume their original magnitude gradually as they move downstream and at X/L$\cong$ 0.6 they reach 90% of the original size. Equations were derived to be able to predict the heights and lengths of dunes in terms of parameters of flow and piles at a given properties of bed material.

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