Application of artificial dunes to shoal protection in waterway regulation practice

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ABSTRACT: To preserve or improve the waterway conditions, shoal protection measures are common taken into. One of common ways is to pave concrete blocks on the shoal to keep sands from erosion. The top surface of the traditional concrete block is plane and relatively smooth, which destroys the natural uneven shape and thus reduces the river bed roughness. In order to keep the natural uneven shape and to be more environmental friendly to the river environment and the aquatic organism, a kind of dune-like concrete block is proposed. The present paper experimentally investigated the flow resistance features, flow structures and sand sedimentation dynamics of the proposed shoal protection measures. In addition, two patterns of pavement were proposed to represent the two - and three - dimensional dunes in the field. Compared to two dimensional dunes, the three dimensional dunes were more stable and were with better effect in prompting sediment deposition.

1. INSTRUCTION

Dunes are ubiquitous in river and marine environments. There are lots of works focusing on flow structures (Maddux et al. 2003a, b; Best 2005; Schindler and Robert 2005; Xie et al. 2013), mechanisms of sediment transport over dunes (Qian and Wan 1983; Van Rijn 1984; Best 2005; Wren et al. 2007; Claude et al. 2012), dune initiation (Venditti et al. 2005) and migration celerity (Giri and Shimizu 2006; Paarlberg et al. 2009; Martin and Venditti 2013). Although great progress in knowledge of understanding dunes has been witnessed, there is few works about how to unitize dunes or to mitigate adverse impact of dunes in the riverine and marine environments. In the present work, artificial dune-like concrete blocks are proposed to replace the traditional plain ones as the ballasts in waterway engineering. The top surface of the traditional concrete block is plane and relatively smooth, which destroys natural uneven shape and thus reduces river bed roughness. The dune-like blocks can keep natural uneven shape and are more environmental friendly to the river environment and aquatic organisms. The vertical velocity distribution, turbulent intensity and sediment transport are investigated over the dune-like concrete blocks. Influence of different plain layouts of the dune-like concrete blocks on the dune formation and sediment transport are also studied.

2. EXPERIMENT SETUP

The experiments were carried out in a rectangular glass flume which is 36m long, 3.2m wide and 1.0 m high. The Polymethacrylates particles were adopted as sands with a diameter of 1.2mm, dry density of about 450kg/m^3 and threshold velocity of about 0.16m/s. The experiments were dedicated to investigate the flow resistance, bedload transport and the deposit characteristics over the dune-like concrete blocks.

The flume is divided into three regions, including the sand paved region (SPR), the test region (TR) paved by concrete blocks and the rest region. The SPR is 6m long and is just upstream of the TR (Figure 1). The TR is set to be 12 m to minimize the influence of flow and sediment transport in the transition range between different ranges on the results. Three kinds of concrete blocks with different top surface features or different arc heights are used in the experiments, i.e., Plain, Dune-1, Dune-2 (Table 1). The averaged height of Dune-1 is 10 cm which is the same as that of the Plain.

For the velocity and turbulence distribution, there is no sand paved on the bed upstream of the concrete block domain, while the sand is paved for the sediment transport and deposition experiment.

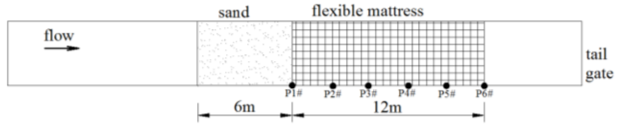

Figure 1. Plane view of the flume and experiment setup.

Table 1. Summary of concrete block sizes (in cm)

Type	Plain	Dune-1	Dune-2
Size	40×40×10	40×40×(8+4)	40×40×(8+7)

3. REULTS

3.1 Flow resistance

Flow resistance is calculated by gradient of water level. The gradients are 0.025%, 0.074% and 0.104% for Plain, Dune-1 and Dune-2 respectively. It is shown that the flow resistance is larger with a larger height. It is implied that the dune-like concrete blocks can increase the roughness of the bed compared with the traditional plain one. Moreover, it will induce more deposition.

3.2 Vertical velocity and turbulence

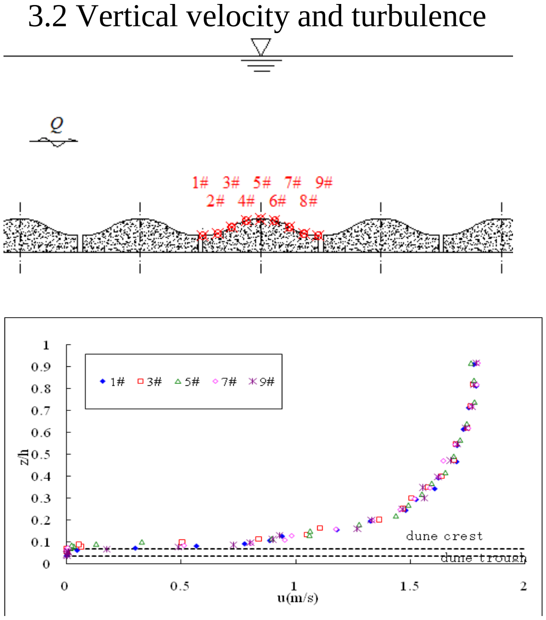

Figure 2. Vertical velocity distribution over Dune-2.

The vertical velocity distribution of Dune-2 is shown in Figure 2. Vertical velocities at nine sites are measured. It is shown that the vertical velocity is generally in line with logarithmic distribution. The difference of velocity among different sites confined to z/h<0.16. For the near bed velocity, the velocity in the dune crest is larger than that in the other sites and that in the trough is with smallest velocity.

The turbulence intensity distribution has illustrated that the maximum value occurs in the near-bed boundary for the Plain and it decreases with the z/h increased (Figure 3). In contrast, the maximum turbulence intensity occurs at the crest of the dune block and it declines in the trough.

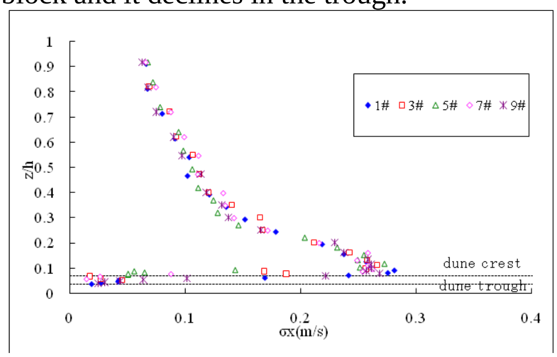

Figure 3. Turbulence intensity distribution over Dune-2.

3.3 Sediment transport and deposition

To investigate the sediment transport and deposition characteristic of different kinds of concrete blocks, experiments over mobile bed are carried out. In a 6m range domain of the flume sands are paved on to provide sands in the concrete block domain. Two types of dune plain layout are proposed representing two- and three- dimensional dune distributions in the field. ie., symmetric and staggered distribution respectively(Figure 4).

The influence of dune height and plain layout of dune are also studied.

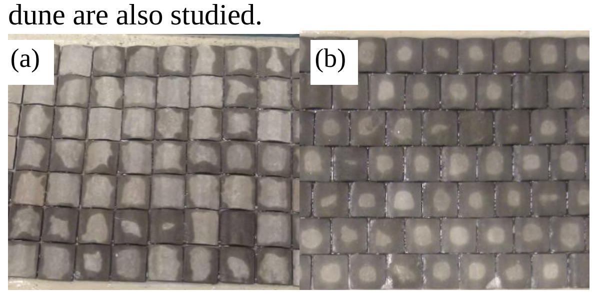

Figure 4. Symmetric (a) and staggered distribution dunes (b), the water flows from left to right.

The results demonstrate that sands in the SPR are moved and transported downstream to the TR (Figure 5). The dunes are formed downstream in the TR. Over all, the characteristics of the dune are different for different bed surface. If there is no concrete blocks paved on the bed in the TR, the length of dune in the equilibrium state is about 5~7cm, the height is about 2~3 cm, the slope for the stoss side and lee side are 1:3~4 and 1:1~2 respectively.

Figure 5. Dunes over glass bed in the test region.

If the Plain blocks are paved in the TR, characteristics of dune is similar to those over glass bed, with dune length of about 10cm, height of 2~3cm stoss and lee side slopes of 1:3~4 and 1:1~2 respectively (Figure 6).

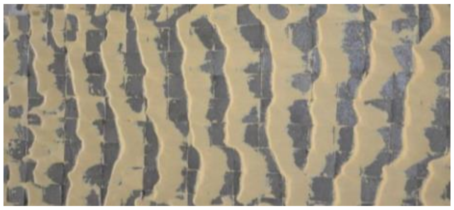

Figure 6. Dunes over Plain blocks in the test region.

If the Dune-2 is paved on in the TR, the dunes are different from those on glass bed and Plain blocks. Due to the uneven shape of the dune-like blocks, there is circulation current in the trough region. The dunes will form until the trough is filled by sands. It should be note that the sands deposited in the trough remains unmoved as the dunes move downstream. Moreover, the dunes are not moved in continuous form (Figure 7). Sands covering the crest of dune block may be moved away, which lead the crest to be exposed. The crest can also be covered by the sands from upstream. The height of dunes over the crest is up to 5~6cm for Dune-1, which is much higher than those over glass bed and over Plain blocks. What's more, the height of dunes over Dune-2 is larger than that of Dune-1. It means higher dune blocks will lead to higher dunes.

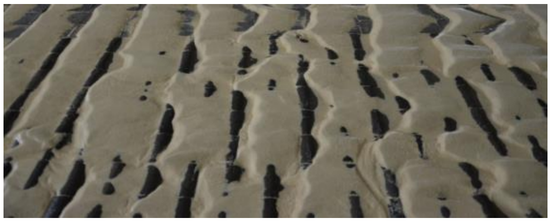

Figure 7. Dunes over Dune-1 in symmetric layout.

Both the symmetric and staggered layout of dune blocks can induce sand depostion in the trough region. However, the depostion form is different. The dunes are in parallel and the space between dunes are similar for the symmtric layout. The dunes are likely the point bar and forms a continous sediment transport passage at the interface of two group of dunes (Figure 8).
It is also shown that the height of two dimensional dunes are smaller than that of the three dimesional dunes.

Figure 8. Dunes over Dune-1 in staggered layout.

4. CONCLUSIONS

The paper presents flow and sediment transport over dune-like blocks. Vertical velocity distribution implys the influence of the dunes geometry confined in a small region. The results show that the dunes over dune-like blocks are much higher than thosed over glass bed and plain blocks. The height of formed dunes will increase with a larger height of dune blocks. Different layouts of dune-blocks also result in different dune forms and dune heights, two dimesional dune-block induces higher dunes than those of three dimensional dune-blocks.

5. ACKNOWLEDGMENT

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