Failure Mechanism in Geobag Structure

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Abstract: - This paper presents observed failure modes for a geobag structure from a series of physical model tests. Six hundred bags were employed to observe the failure in terms of friction force, water depth, flow rate and bag aging. Three different failures are reported. An analysis of the effect of bag aging shows that 52% of saturated bags gain weight in the range 0 to 5% and about 70% of initially dry bags gain weight in the range 10 to 20%. The outcome indicates the importance of bag aging in the 'incipient failure'. These observations will eventually be used to validate an existing numerical model.

Key-Words: - Geobag, failure modes, bag aging, failure mechanisms, Jamuna River.

1 Introduction

The concept of using sediment filled bags (geobags) as permanent hydraulic or coastal structures has been in use for more than 20 years [1, 2]. Examples of successful coastal protection structures using geobags are found in many parts of the world, such as Australia and Germany [3]. Similarly, geobag protection has been utilised as erosion protection measures in the Changjiang River (China) and also in Jamuna and Meghna Rivers in (Bangladesh) [4, 5].

The observed failure zones in the Jamuna riverbank at different depths are the plug, slump, big eroded area and slip [6]. Uneven bag coverage turns the riverbank steep and lumpy in the plug zone (Fig. 1 a). In the slump zone, infill sands become compacted and hard (Fig. 1 b). Slip causes the bag above the water level to become frayed at the exposed surface rather than the underside which shows minor fluffing (Fig. 1 c) [6, 7]. Big eroded areas normally have no bag coverage in the slope against current. Some scatter bags may be found in the bottom of the slope or in a group of bags in anti-current direction [6].

Experience of riverbank protection in the Jamuna River identifies the most critical process in bag revetment failures as: (i) inadequate thickness (crest bag missing), (ii) the loss of hydrostatic counterforce during the rapid drawdown at the end of the flood season (slope bag missing), and (iii) combination of the retarded scour and drawdown (both crest bag and slope bag displaced by slip circle formation) [20].

Similarly, field monitoring of coastal geobag structures indicates that overtopping, sliding, puncturing, pullout/dislodgement and toe scour are the most common failure modes [7, 8]. Laboratory experiments also highlight the importance of pullout, horizontal and/or vertical displacement, uplift and rotation failure mechanisms [9]. The pullout failure mode is often described in terms of friction and the physical properties of bags [8].

Friction is taken as a conservative mode (constant roughness coefficient = 0.6, [10]) or neglected in most of the hydrodynamic behaviour studies of geobags [4, 5, 11]. Different studies suggest the range of friction angle for sand filled geotextiles is 30° to 35° [12, 13, 14, 15] and geobag-geobag sliding friction angle is 50° [16]. A close relationship is observed among friction angle and layer-to-layer (between two different elevation) (Table 1a) or inter-layer (between same elevation) overlapping of the bags (Table 1b). In order to avoid 'interlocking' problems among bags, a fill ratio of approximately 75 to 80% is adopted to optimise stability of the elements [17, 18, 20]. Layer-to-layer overlapping is practiced in different ways: face to face [17, 21], 100% overlapping [21], and 50% overlapping [21, 22, 23]. According to Jacobs and Kobayashi (1985), 50% layer-to-layer overlapping offers the optimum contact area.

Matsuoka and Liu [19] observed that the expansion of the bags and the tensile forces on the bag strengthen the structure and aid it in withstanding the applied external force. Breteler et al [18] worked on the permeability of geotextiles by introducing a geotextile filter behind armour layers of stone revetments. With the geotextile filter placement directly under the cover layer a reduction in permeability of the structure was observed. Recio and Oumeraci [23] reported the internal gaps between bags reduce the stability of the structure; it was also observed that the contact area resistance reduced due to bag deformation.

To achieve a better understanding of the friction force and physical properties of the bags, this study considers the same bag size used in the Jamuna River project (i.e. 126 kg). The flume setup aimed to represent the lower Jamuna River with geobag protection. Hence, a bed slope of 5.5×10^{-5} was selected and the geobag side slope as 1V:2H. Besides the field practice in Jamuna River with 1V:2H geobag slope, Neill et al [16] conducted a laboratory experiment with this slope and the proposed design guideline by Korkut et al [11] noted it as the maximum acceptable slope. The experimental results will be used for the validation of an existing numerical model.

(a) Plug Zone

(b) Slump Zone

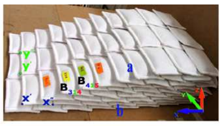
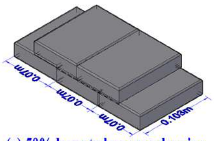
(c) Slip Zone

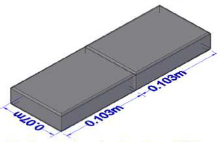
Fig. 1 (a), (b) and (c): Failure zones in geobag protection in the Jamuna riverbank [6]

2 Physical Model Setup

Physical model scale of 1:10 based on the Froude criterion is used considering material distortion. Nonwoven geotextile Secutex® 451 GRK 5 C is

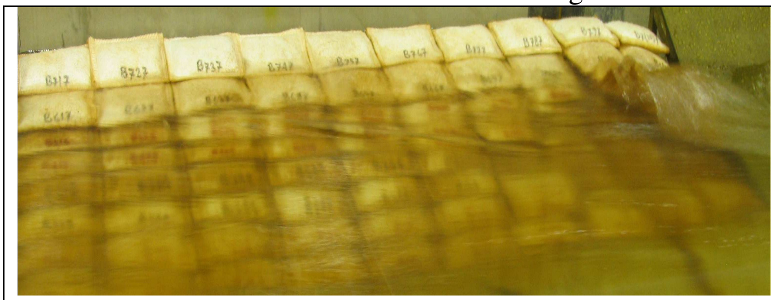
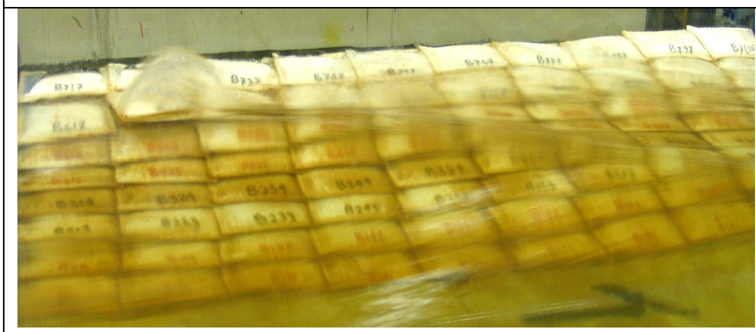
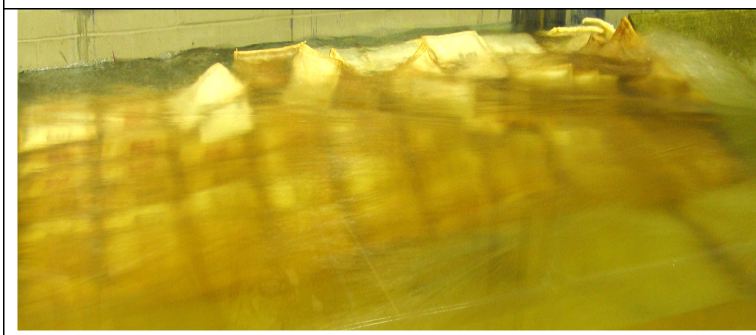
Table 1: Failure mode observes in “dry” test rig

<table>
<tr><th>Initial Set up</th><th>Failure Mode
(at 10 cm scour depth)</th><th>Observation</th></tr>
<tr><td rowspan="2">


(a) 50% layer to layer overlapping


(b) Face to face (or less than 10%) interlayer overlapping
Total bags : 153 nos</td><td>
(i) Dry bags</td><td>• Sliding starts at 6 cm scour depth;
• Failure line observed at 7 cm scour depth; and
• At 9.82 cm scour depth the bottom series bags of the 4th row stand perpendicular to the mobile bed. Two bags, from the middle and at the far end have dropped.</td></tr>
<tr><td>
(ii) Soaked bags</td><td>• Failure line observed at 8 cm scour depth; and
• The structure height decreases by 2.43% (i.e., 0.5 cm) from dry condition.</td></tr>
</table>

Table 2: Geobag failure observation in flume

<table>
<tr><td>
</td><td>Case I: Piping
• Secondary flow gradually creates piping in between 4th and 5th layer; and
• Failure starts by uplifting.</td></tr>
<tr><td></td><td>Case II: Local Vortices
• Local vortices start just below the water surface; and
• Anticlockwise rotation of the bag progresses failure.</td></tr>
<tr><td></td><td>Case III: Overtopping
• Overtopping cases quick removal of the three top layer of bags from upstream; and
• Two major zone of displacement observed.</td></tr>
</table>

used for bag preparation, with a bag size of 10.3 cm by 7 cm. Each bag was created by two stitches of 301 Type (ordinary lock stitch) as an initial stitch and then completed by 514 Type (4 thread over edge). This is significantly different from field practice [6] as four sides have the same stitches to ensure the uniform seam strength. Sand with a Fineness Modulus of 1.72 and a relative density of 1.83 was used for bag filling. An 80% filling ratio of bag was used to achieve the 0.126 kg. Neill et al. have worked with a scale of 1:20 for the target dry bag weight 126 kg [16].

To observe the failure modes in the physical model tests experiments have been conducted using a "dry" test rig and a hydraulic flume. The "dry" test rig was constructed to represent the features of Geobag movement due to river bed scour and bag self weight. Medium Density Fiberboard (MDF) was used to construct the test rig which was 100 cm long, 96 cm wide and 50 cm deep test rig. The width of the rigid bed (37.5 cm) was half the width of the flume. The mobile portion was fixed on two lab jacks (individual size 17 cm × 17 cm × 17 cm) and clockwise rotations of the lab jacks allowed downward movement of the mobile bed by up to 10 cm; this movement represents the scour of the river bed during a flood event.

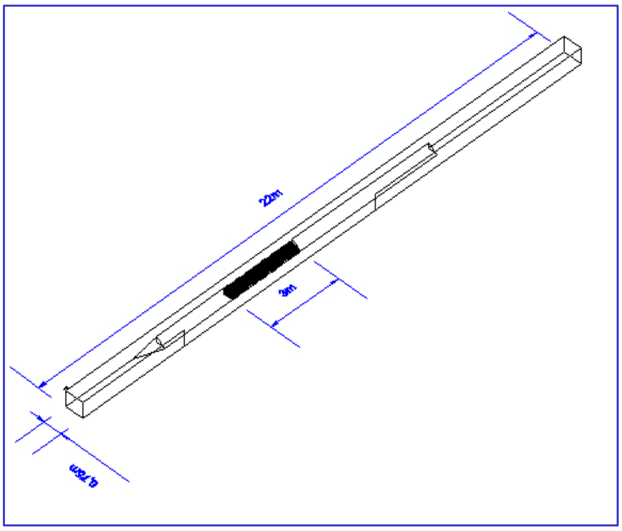


Fig. 2: Schematic view of Geobag setup in flume

2.1 Test Rig

A total of 10 model runs using dry and soaked bags have been undertaken using two different set-ups (Table 1): (i) layer-to-layer overlapping and (ii) inter-layer overlapping. The length (y = 33.3 cm) and width (x = 57 cm) remained the same for all cases; note that the width is the sum of the rigid and mobile portions.

2.2 Flume

The open channel hydraulic flume is 22 meter long by 0.75 meter wide and 0.50 meter deep (Fig. 2).Initially, 200 bags were positioned in one meter long, 0.375 meter wide and 0.18 meter high geobag structure. The initial failures were observed on 1 meter (7 meter to 8 meter flume length) and then 3 meter (7 meter to 10 meter flume length) long geobag structure with different water level.

3 Results and Discussion

The difference between dry and soaked bags shows the effect of friction coefficient on rigid beds giving about 10% (i.e. 1 cm) of scour difference. Comparisons of horizontal and vertical displacements show soaked bags are more stable (Table 1). The structure height decreases by approximately 2.5% of the dry condition in model; Krahn et al (2004) observed a 5% difference in the height of a sand bag dike due to densification by wetting in large scale experiment [25].

In the flume a number of model runs show three distinguishable failures with the variation of water level and flow (Table 2). At different flow rates and water level, three types failure mode observed (Table 2).

- At low water flow rates, failure occurs due to secondary flow and follows similar mechanisms of piping failure in dam,
- At higher water depths, failure occurs due to local vortices and the failure progresses neighbouring bags as well, and
- Overtopping water level causes the rapid failure.

The failure was normally observed to start in the layer just below the surface water level; similar findings are also noted by Recio & Oumeraci [23]. In most cases two common processes were involved in failure progression, i.e., uplifting and rotation (normally anti clockwise).

Each model run in flume records the time of first failure, the settling distance and weight of the individual bags washed away and settling distance observed in terms of Froude number (Fig.3). Bag aging has justified on the weight gained by washed away bags. Structure built with saturated bags results 52% of the total washed away bags gain weight in the range of 0 to 5%. On the other hand 7 day dry bags results about 70% of the total washed away bags gain weight in the range of 10 to 20%.

nhc [24] found an incipient velocity of 2.9 m/s and 2.6 m/s for the side slopes of 1V: 2 H and 1V:1.5H respectively. The definition of incipient motion is the flipping over of 10 bags from the slope surface of about 20m prototype length [16]. At the end of the experiment (4.5 hours) 22 bags had been displaced from the test section, and the maximum recorded settling distance was 6 meter [24].

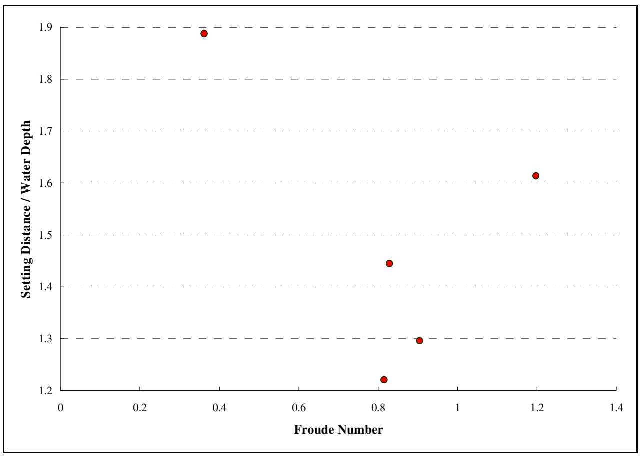


Fig. 3: Relationship between relative settling distances and flow type

4 Concluding Remarks

Based on the test rig and flume experiments, a better understanding of the geobag structure failure processes has been achieved. The failure observation will also be carried out with different side slopes of geobag structure in flume.The data collected will be used in numerical model verification. The successful numerical model assumes to provide the failure mechanism in terms of incipient motion, settling distance, number of bags displacement, bag aging consideration and further related effects.

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