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MODELLING THE HYDRODYNAMIC FORCES ON GEOBAG REVETMENTS USING CES

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Sand filled geotextile bag ("geobag") revetments are commonly used for riverbank protection schemes in Bangladesh and other countries around the world. The method is effective however the failure modes are not well understood. To address this, the hydrodynamic forces associated with bag failure need to be better understood. The research reported here addresses this through: (a) Physical modelling using 1:10 scale model geobag revetment, and (b) Conveyance Estimation System (CES) modelling, to estimate hydraulic forces on a geobag revetment. In the physical modelling, the velocities associated with the failure of geobag revetments have been measured. The comparison between the experimental data and the CES data indicates that the CES model can predict model velocities with reasonably accuracy. This validated CES model can then be used to estimate shear stress. In the next stage not reported here, the CES predicted velocities will be used to prepare the mapped velocity field for the Discrete Element Model (DEM) analysis. It is envisaged, that the validated DEM model will provide more details on failure modes, and hence will be used as the basis for the development of a practical design guide for the use of geobags as riverbank protection structures.

INTRODUCTION

Sand filled geotextile bags (geobags) have been used in permanent hydraulic or coastal structures for more than 20 years (Heerten et al, 2000; Saathoff et al, 2007). During the previous decade, geobag revetments became commonly applied to riverbank protection in Bangladesh due to their cost effectiveness. However a hydraulic understanding of the various failures mechanism is still undefined. Typically in the field these failures are the plug, slump, missing top, sliding of geobags and physically damage of the bag (Figure 1; Jackson et al, 2006; Mori et al, 2008).

Zhu et al (2004) described the hydrodynamic forces subjected to bag drops based on experience from both the field and the laboratory. Recio and Oumeraci (2009) studied these forces against wave action using a physical model. Here, an attempt is made to understand riverbank protected geobag failure associated hydrodynamic forces under rigid bed conditions, using the Conveyance Estimation System (CES). The calculation approach used by the CES is based on the depth-integrated Reynolds Averaged Navier Stokes (RANS) equations and the original Shiono-Knight Method (SKM) for conveyance estimation in an open channel (Shiono and Knight, 1989; DEFRA/EA, 2003a). For the drag force determination on geobags resting on the riverbank surface, the section was treated as a trapezoidal section, whereas, in the physical model it was in fact a half trapezoidal section (Figure 2, section bb).

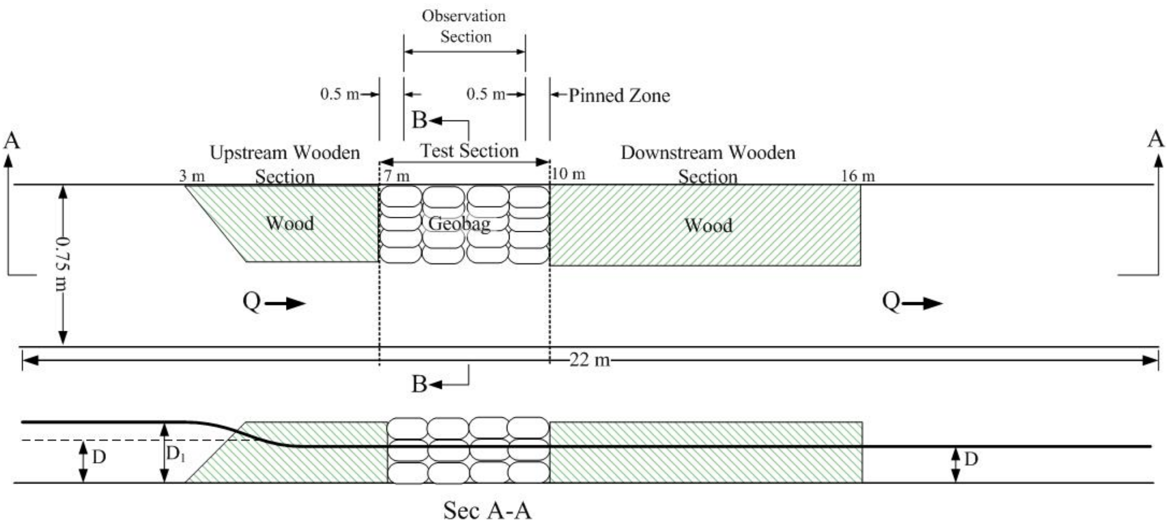
A: Plug, B: Slump, C: Missing top, D: Sliding and E: Physically damaged

Figure 1: Failure in geobag revetment (Jamuna river, 2009)

PHYSICAL MODEL

Model setup

The physical model runs were performed in a long open channel hydraulic flume. The flume is 22 m long by 0.75 m wide and 0.50 m deep. The bed slope of the flume was set at 5.5×10^{-3} approximately the bed slope of the Jamuna River. At the upstream end two pumps are engaged for flow generation, each has a maximum pumping rate of 75 l/s. For this study a scale of 1:10 was selected based on Froude criteria by considering the bag material distortion. A geobag revetment was built in the quasi-uniform flow zone within the test flume (Figure 2). To avoid the end effects unduly influencing the geobag revetment both sides of the structure were protected using a wooden frame. All of the four sides of this wood were glued to the flume. The geobag test section was built by 600 geobags following the 50% layer-to-layer overlapping with a slope of 1 V: 2H, i.e., 0.375 m width and 0.18 m depth. The side slope of 1 V: 2 H replicates the previous laboratory work undertaken by Neill et al (2008). Three different revetment construction methods were tested using geobags, namely – (RM1) Jack on jack, (RM2) Running bond, and (RM3) Half basket weave (Table 1).



Quantity	Length, width (L)	Bag volume/ weight (L^3)	Velocity ($L^{1/2}$)	Discharge ($L^{5/2}$)	Shear Stress ($L^{3/2}$)
Scale ratio	1:10	1:1000	1:3.17	1:316	1:31.6

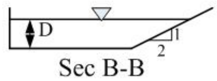


Figure 2: Schematic of flume setup

Each experiment was run for 4.5 hours the same time period as used in the experiments by Neill et al (2008). Initially failure in revetment was observed and then for each section the velocity measurements were performed using a side looking Acoustic Doppler Velocimeter (ADV). Four different scenarios were considered in the full experimental setup to describe the mean velocity features on geobag revetment; these are water level equal to (A) up to 49%, (B) 50 to 64%, (C) 65 to 84%, and (D) 85% to 100% of the geobag revetment height. Velocity observations were made on each model run by positioning the ADV at 0.2, 0.4, 0.6 and 0.8 of the water depth below the surface. Mean velocity in these cases was calculated following the three-point method i.e., average of the values at 0.2, 0.6 and 0.8 of the depth (BS EN ISO 748:2007). During the velocity measurements the bags were pinned in place.

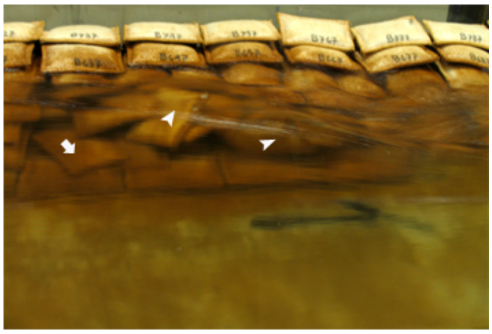
Observation

In the flume a number of model runs show some distinguishable failures with the variation of water level and flow. These failures progress through piping, partial or full uplifting, plugging or pullout, internal sliding (Figure 3). Jackson et al (2006) described pullout as the combined effect of the friction and physical properties of the bag. Recio and Oumeraci (2009) observed the ‘pull-out effect’ as a result of several wave cycles in relatively longer experimental time. Due to wave action Recio and Oumeraci (2009) observed ‘uplifting’ in terms of overturning. The key observations are:

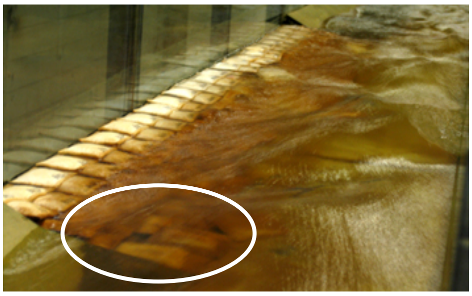
- Initial failure due to piping was normally observed at a range of water depths of around 50% of the revetment height and failure at higher water depths was normally precipitated by local flow vortices previously initial failure;
- Higher water level, normally around 75% of the geobag structure height, caused failure due to entrapped air surrounding the neighbouring bags. However, the maximum range for water level associated with this type of failure is arbitrary as there is a strong chance of overtopped based on the dryness of the bag (Table 1); and
- About 90% of the bag top surface was effectively exposed to flow.

Initiation of bag movement started at 1.1 to 1.3 m/s model velocity (Table 1). According to Breteler et al. (1998) geobags become unstable above a flow velocity of 1.5 m/s. Neill et al (2008) found prototype incipient velocity of 2.9 m/s and 2.6 m/s for the side slopes of the structure of 1V: 2 H and 1V:1.5H respectively. These velocities were the depth – averaged values at 0.6 of the depth from toe of the bank.

(a) Piping



(b) Piping and uplifting



(c) Plugging and sliding

(d) Rotation and uplifting

Figure 3: Different failure modes observed in the physical model (a to d)

Table 1: Physical model outcomes with different revetment construction method

Model Setup	Scenario[a]/	Number	Mean water level (m)	Mean near bank velocity (m/s)	Flow rate (cumec)	Froude Number	Initial Failure type	Associated failure process[b]
(RM1) Jack on jack								
	A	1	0.051	1.09	0.024	1.54	Piping	Internal sliding
	B	2	0.065	1.13	0.033	1.42	Piping	
	C	3	0.095	1.27	0.055	1.32	Uplift [c]	Local vortices and/or plug
	D	4	0.110	1.30	0.070	1.25	Uplift	
(RM2) Running bond								
	A	5	0.054	1.13	0.027	1.55	Piping	Internal sliding
	B	6	0.072	1.18	0.039	1.40	Piping	
	C	7	0.098	1.28	0.058	1.31	Uplift	Local vortices and/or plug
	D	8	0.112	1.30	0.071	1.24	Uplift	
(RM3) Half basket weave								
	B	9	0.079	1.21	0.043	1.38	Piping	Plugging
	D	10	0.115	1.36	0.071	1.28	Uplift	Local vortices and/or plug

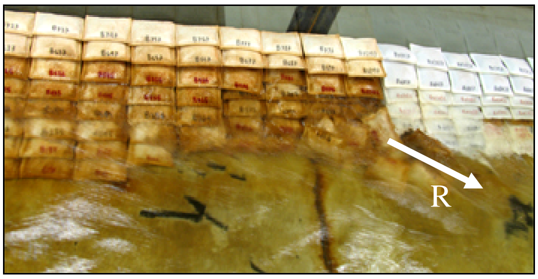
[a]The scenario had classified for 0.13 m revetment height.
[b] Associated with the initial failure leads to bag movement from the test section.
[c] Partial or full uplifting .

Froude Number, $F = \frac{V}{\sqrt{gL}}$, L= Characteristic length , i.e., hydraulic depth, h (for open channel)

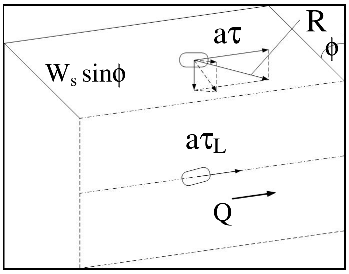
HYDRODYNAMIC FORCES

When water flows over the test section in the flume the active forces can be explained following the force analysis carried by Chow (1959) on a sediment particle resting on the sloping side of the channel (Figure 4). In this case two forces are active, the shear force or drag force, $a\tau$, and the gravity force component, $W_s \sin\phi$. Where, a = Effective area of the geobag, τ = Shear stress on the side of the channel i.e., on the slope bags, τ_L = Shear stress on the level surface, W_s = submerged weight of the geobag = 0.126 kg, and ϕ = angle of the side slope = 26°.

For this study shear stress was evaluated using two methods, Membrane Analogy (Chow, 1959) and Conveyance Estimation System (CES).



(a) Force caused washed geobag



$$R = \sqrt{W_s^2 \sin^2\varphi + a^2\tau^2}$$

(b) Sediment particle resting on channel (Chow, 1959)

Figure 4: Active forces on (a) Washed away geobag (b) Sediment particle on channel surface

Membrane Analogy Method (MAM)

It was assumed that the geobag slope on a rectangular channel followed the drag force distribution similar to the slope of the trapezoidal channel. Several researchers have attempted to determine this distribution using membrane analogy and analytical and finite difference methods for different shapes of channel (Leighly, 1932; Olsen and Florey, 1952). Based on membrane –analogy study, Chow (1959) provided a typical distribution of the drag forces against the width to depth ratio in a trapezoidal channel.

Conveyance Estimation System (CES)

For the CES predicted velocity, the first step was to use the measured flow and depth to calibrate a roughness value for the flume and geobag revetment. In this study an attempt was made to calibrate to a common roughness value for a different experimental setup. Karamisheva et al (2005) described the performance of the CES model mean channel velocity prediction over the Lambert and Myers method and their proposed method. They conclude that the right choice of the unit roughness value can provide a good agreement between the observed data and the CES predicted data (Karamisheva et al, 2005). In the CES, the unit roughness is provided for a 1 m flow depth, and the depth variation of roughness is estimated using the Colebrook-White law (Defra/EA, 2003 b; Mc Gahey and Samuels, 2004; Mc Gahey et al, 2008). So, the unit roughness was calibrated using data from scenario A and validated using in other three scenario data (Table 2).

Table 2: Summary of the CES predicted velocity for the four scenarios

Scenario	Calibrated unit roughness			Statistical Parameters	
	Flume bed	Geobag	Flume Wall	Mean Λ (%)	Std Dev,σ
A	0.009	0.009	0.01	1.84	4.70
B				1.05	3.94
C				8.98	6.77
D				8.12	6.72

COMPARISON BETWEEN MAM AND CES ESTIMATED DRAG FORCE

Two conditions were tested with both of these methods, stable and washed away geobags in revetment.

Stable geobags

The MAM used the measured water depth for shear stress calculations using values from Chow (1959) chart (Table 3). In the CES, the shear stress was evaluated from the local friction, local depth and the dimensionless eddy viscosity (DEFRA/EA, 2003 b). Comparison between these two methods shows good agreement in the observation section up to a water depth equal to 40% of the revetment height (Table 3). Zarrati et al (2008) derived semi-analytical equations for compound open channel based on Chow (1959) chart and compared this with the analytical data by Shiono and Knight

(1991) and experimental data by Tominaga et al (1989). With three different corner angles (i.e., 120°, 136° and 148°) Zarrati et al (2008) observed their prediction of shear stress distribution on wall of the trapezoidal channel underestimates those two dataset as the increment of the interior angle the intensity of the secondary flow increases near the free surface and decreases near the corners (Tominaga et al, 1989). In our study the corner angle was 154° (= 180° - 26°) and the change in roughness due to discrete geobags with varying water depth had underestimated in the CES prediction. On the other hand the MAM method underestimated the discontinuity of the geobags in revetment.

Table 3: Comparative shear stress estimation by MAM and CES (Stable Geobag)

Scenario/ Number		Membrane Analogy Method (using measured water level)			CES Predicted Shear Stress	Std Dev	R^2
		Width to depth ratio	Used Formula	Shear Stress (N/m^2)			
A	1	34.98 i.e. > 10	$0.785\gamma DS$	0.86	0.86	0.02	0.72
	2	21.58 i.e. > 10	$0.785\gamma DS$	1.42	1.59	0.09	0.52
	3	14.25 i.e. > 10	$0.785\gamma DS$	2.17	2.34	0.10	0.47
B	4	10.61 i.e. > 10	$0.785\gamma DS$	2.94	2.98	0.08	0.68
C	5	8.51	$0.78\gamma DS$	3.65	3.49	0.11	0.75
	6	7.30	$0.78\gamma DS$	4.28	3.89	0.19	0.71
D	7	6.04	$0.77\gamma DS$	5.08	4.28	0.40	0.75

Washed away geobags

For each model run the settling distance of the displaced bags from the test section in the streamwise direction was recorded. The relationship between the shear stress and settling distance showed that with the shear stress limited to 2 to 5 N/m^2, about 63% of the washed away bags settled at the end of the flume. In the context of settling distance, it was observed the physical state of the bags play an important role compared with water depth, flow condition and bag position in the structure. In the extreme case (i.e., overtopping case) 89 bags (i.e., 14.83%) out of a total of 600 (saturated) bags were displaced from the test section. At the end of the experiment (4.5 hours), nhc (2006) found 22 bags had been displaced from the test section, and the maximum recorded settling distance was 6 m with 1:20 scale. The MAM and CES estimation for the active drag force on the washed away bag (350 bags) showed similar responses in most of the cases (Figure 5). So, the typical total force, R, on a washed away bag would be 0.544 Newton (MAM) and 0.542 Newton (CES).

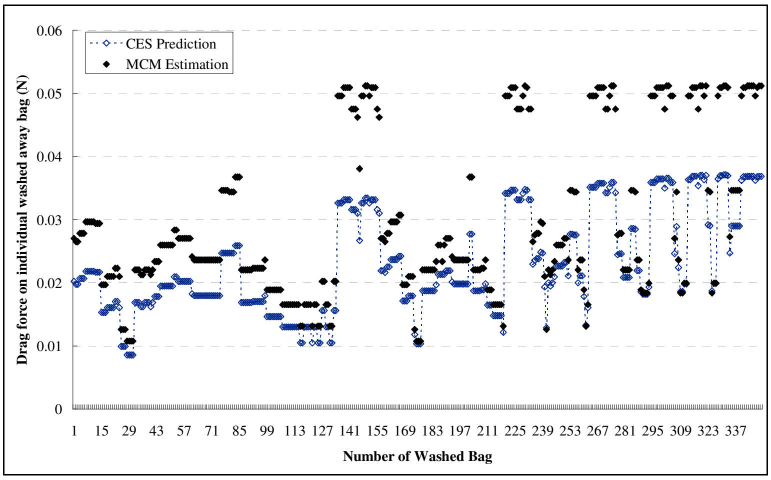


Figure 5: Estimation of the drag force on the washed away bag using MAM and CES

CONCLUSION

The following conclusions can be drawn:

- The maximum velocity in a single case observed at 0.6 of the water depth and the initiation of bag failure was between 1.1 to 1.3 m/s i.e., the prototype velocity of 3.5 to 4 m/s. CES showed good agreement with this measurement;
- The first washed away bag was usually subjected to the shear stress of 2 to 5 N/m^2, i.e., the prototype shear stress of 63.2 N/m^2 to 158 N/m^2;
- Displaced bags with their settling distance had shown their stability against higher active force; and MAM and CES provided reasonable estimation in this regards.

The CES results will be used to prepare the flow field for a Discrete Element Model (DEM). Using Sommerfeld's drag model and Rosendahl's lift model, a one-way coupling will be employed to link the mapped velocity field to the DEM calculation. Once validated, it is envisaged that the DEM model will provide more details on failure modes due to the influence of flow and the effects of bag ageing, and thus will be useable as a basis for the development of a practical design guide for the use of geobag revetment as riverbank protection.

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