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SIMULATING GEOBAG REVETMENT FAILURE PROCESSES

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ABSTRACT

An experimental and numerical study has been carried out to help develop design guidelines for the construction of low-cost river bank protection using geobags. Building upon previous work, a 1:10 scale model was tested in a laboratory flume, comparing two different construction methods (running bond and stack bond), subjected to three different water depths. It was found that whilst the failure pattern was highly dependent on water depth, the construction method had no noticeable impact, and it was concluded that the dominating factor is the friction between individual geobags, which itself is dependent on bag overlap rather than specific construction method. A simple Discrete Element Method (DEM) model was constructed using the LIGGGHTS open source software with drag and lift models applied to a multi sphere simulation of the laboratory model geobags. It was found that despite its simplicity this DEM model could reproduce the failure pattern of revetments very well, and thus has potential for future use in developing design guidelines aimed at the developing world.

Keywords: Geobag revetment, Failure, DEM, LIGGHTS.

1 INTRODUCTION AND PREVIOUS WORK

Riverbank erosion is a significant problem in rivers which flow through low-lying alluvial plains. Recently, sand filled geotextile bags (geobags) have been applied as a long-term means of riverbank protection in developing countries (JMREM, 2006a, 2006b; Oberhagemann and Hossain, 2010; Akter et al., 2013a, 2013b; NHC, 2006;), and also used as sacrificial protection for bridge piers against local scouring phenomena (Korkut et al., 2007; Akib et al., 2014).

The hydraulic stability of geobag structures is affected by a wide range of factors, which can combine to create a number of different failure modes. To date, the vast majority of previous research has been focused on geobag performance in coastal situations (Bezuijenet et al., 2004; Saathoff et al., 2007; Recio and Oumeraci, 2009a, b; Dassanayake and Oumeraci, 2012a, b). However, the perpendicular wave action found in coastal scenarios is not significant in fluvial applications, where the flow direction is generally parallel to riverbank revetments, so the performance and failure mechanisms of geobag revetments in rivers is considerably different from that of coastal structures. One study that did focus on the use of geobags in the fluvial environment was conducted as part of the wider Jamuna–Meghna River erosion protection scheme in Bangladesh (NHC, 2006). This experimental study concluded that the optimum geobag weight for stability was 126 kg and, when traditionally “launched” from the riverside, geobag revetments tend to form 1V:2H slopes. To date, only one study has considered the hydrodynamic forces associated with varying water depth and toe scouring phenomena affecting a fluvial geobag revetment (Akter et al., 2013a, 2013b). This work successfully simulated initial failure of geobag revetments using the Discrete Element Method (DEM) and predicted the active shear stress necessary to initiate bag movement applying a conveyance estimation system (CES) model, thus yielding a good understanding of conditions leading to failure (Akter et al., 2013b).

Failure mechanisms associated with simple geobag riverbank revetments are now relatively well understood, and numerical modeling has advanced to the stage where incipient failure can be well simulated using DEM. Notwithstanding recent advances, a fuller understanding of geobag fluvial revetment performance is still required to understand geobag revetment in different conditions. As part of a more general study aimed at developing robust design guidelines, this paper focuses both on the effect of construction method on revetment performance and the suitability of a very simple DEM modeling approach as a tool to simulate complete revetment failure. In order to achieve these aims, both experimental and numerical investigations have been.

2 EXPERIMENTS

Whilst the work undertaken focused on the development of efficient numerical simulation techniques, it was necessary to undertake a comprehensive programme of small-scale experimental tests in order to improve our understanding of geobag–water flow interactions and gather the data required to calibrate and validate the numerical model.

2.1 EXPERIMENTAL SETUP

Experiments were conducted in a recirculation flume 23 m long, 0.75 m wide and 0.5 m deep, which contained a 3 m long geobag revetment test section made up of ~600 model geobags on a fixed, non-erodible bed (Figure 1). The full-scale geobags used in the field were scaled down to achieve a laboratory model of geobag size of 103 × 70 mm and a dry mass of 0.126 kg, with approximately an 80% bag filling ratio. Nonwoven geotextiles, identical to that used in the field, and fine sand were used for bag preparation.

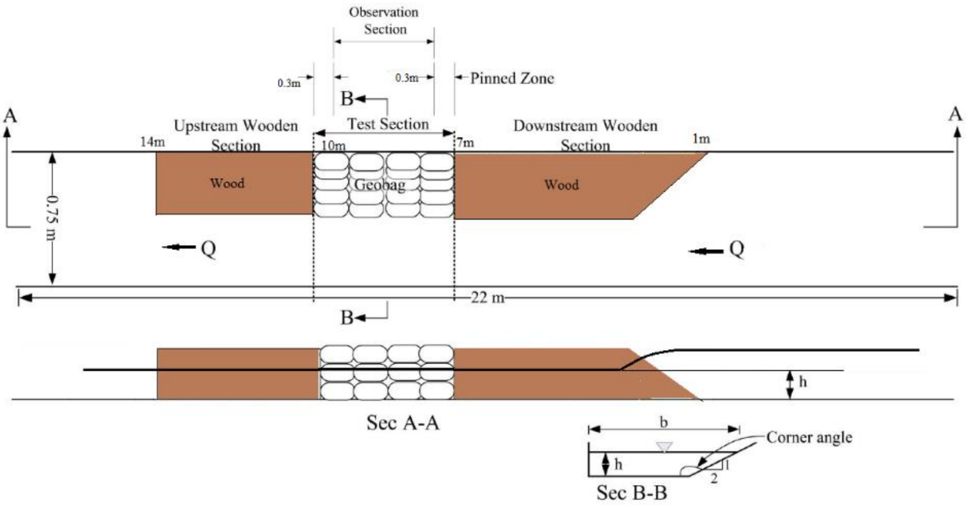

Figure 1: Experimental apparatus

Following previous laboratory work (NHC, 2006; Akter et al., 2013a), a side slope of 1V:2H was selected, resulting in revetment dimensions of 0.375 m width and 0.18 m height. To overcome the influence of the sudden flow contraction and expansion at the upstream and downstream ends of the test section, tapered wooden sections were installed to smooth the transitions. Furthermore, to avoid adverse effects from the interface between the wooden tapers and the geobag structure, the geobags were pinned down a distance 0.3m of the test section at either end.

In order to determine the likely effects of construction method on revetment failure, two different bonds were tested; a running bond, with 50% longitudinal overlap, and a stack bond, with no longitudinal overlap (Figure 2). For both construction bonds, geobags were placed with their longer axis parallel to the flow direction, and with a transverse overlap of 50%.

Figure 2: Revetment construction - stack bond (left), running bond (right)

Experiments ran for approximately seven hours, which was sufficient for the failure processes to stabilise, i.e. there was no significant further change in revetment structure. From previous studies (Akter et al., 2013a), it was observed that specific failure modes tend to occur in different ranges of water-depth.Thus, experiments were run with 3 different water depths, as detailed in Table 1.

Table 1: Flow conditions at different water depths

Condition	Water depth % revetment height	Mean water level (m)	Mean velocity (m/s)	Flow rate (m^3/s)	Froude number	Reynolds number
Low	0-49%	0.07	1.12	0.035	1.52	58623
Medium	50-60%	0.095	1.23	0.055	1.47	82458
High	60-80%	0.115	1.30	0.072	1.44	101605

2.2 Experimental Results and Discussion

Figures 3 and 4 show images taken during and after experiments undertaken with both construction bonds. Experimental observations highlighted a number of different failure modes in the submerged layers of geobags, including pull-out, dislodgement and uplifting. Vertical sliding failure, initiated with the failure of the submerged supporting bags, was also observed in the layers above the water surface.

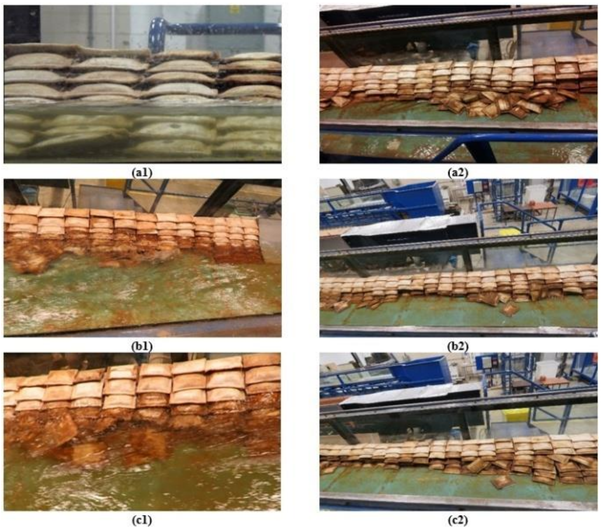

Figure 3: Failure processes for stack bond construction for low (a1, a2); medium (b1, b2); and high water depths (c1, c2)

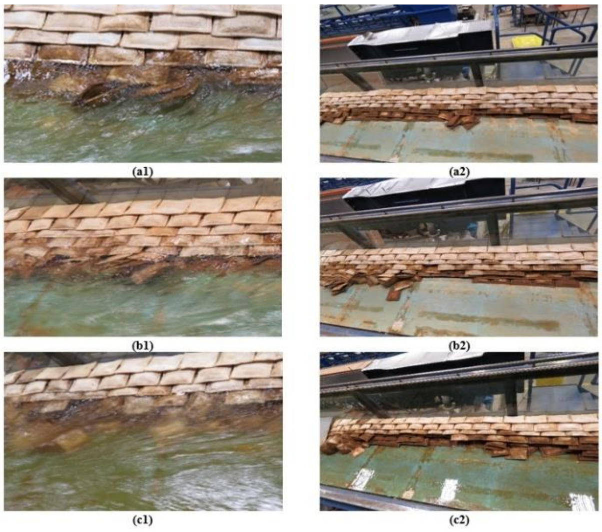

Figure 4: Failure processes for running bond construction for low (a1, a2); medium (b1, b2); and high water depths (c1, c2)

For the low to medium water depths (40-60% of revetment height), and for both different bonds, the failure process created a clump of collapsed bags, which then led to a localised increase in upstream water depth. Whilst this phenomenon exposed the upper layers of geobags to the flow, it also decreased local flow velocities, which seemed to help prevent more upstream bags from being washed away.

Figure 5 illustrates the number of geobags dislodged and washed away at the end of each test, for different bonds and water depths. As can be seen, whilst the extent of failure depends severely on water depth, it is generally independent of the construction method. Laboratory observations showed that once the first bags started moving and pulling out from the revetment, the failure process occurred quickly. Since there are no mortar-like bonds between individual geobags, it is likely that the integrity of a revetment is dependent on the contact area between individual geobags, which can be considered a proxy for frictional resistance, rather than specific construction method. This finding has potentially important implications for revetment construction methods which often depend on the dropping of bags by unskilled manual labourers. However, further tests with different levels of bag overlap in the transverse direction will be required to fully investigate this.

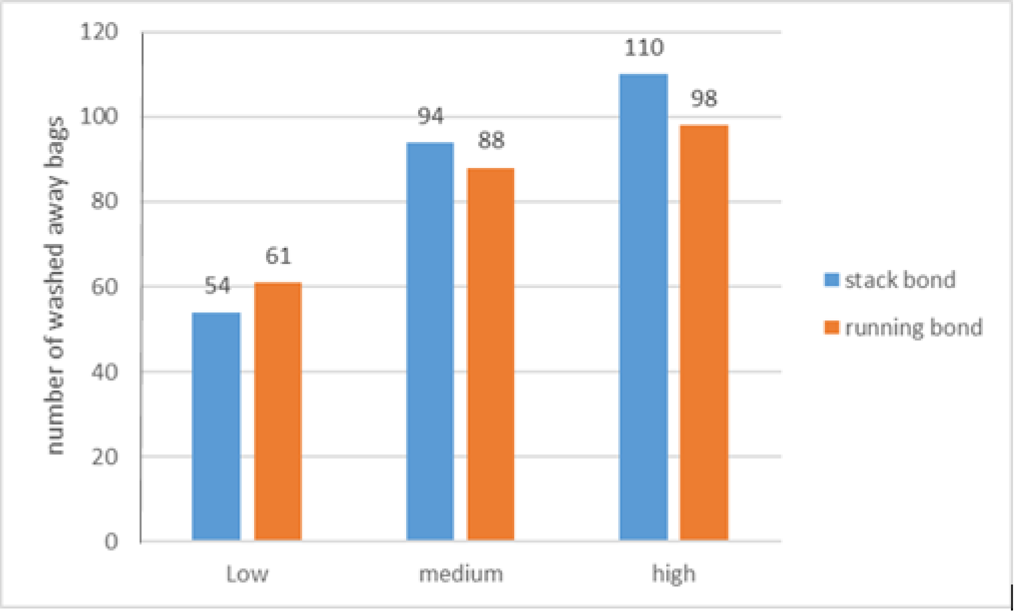

Figure 5: Number of bags which were washed away from revetment at the end of each test for two different bonds.

3 NUMERICAL MODELLING

In order to work towards the primary aim of developing design guidelines for geobag revetments in rivers, numerical simulations were attempted using the Discrete Element Method (DEM) (Akter et al., 2013b). DEM simulates the movement of each element, in this case each geobag, according to Newton’s Laws of Motion, accounting for collisional and frictional forces between elements and between elements and boundaries, and for hydraulic forces, in particular drag, lift and buoyancy.

Hydraulic forces in DEM depend on a formulation to describe them in terms of the surrounding fluid. This can come directly from experimental measurements, from a modeling approach such as CES (Akter et al, 2013b) or from CFD simulations. In the latter case, the link between the DEM and the CFD can be one-way, in which the discrete elements (geobags) have no impact on the flow field, or fully-coupled, in which the momentum and volume of the geobags are source terms in the CFD simulation and are updated at every computational time step. The latter is theoretically more accurate, but requires vastly more computational resource to transfer data between the DEM and CFD aspects of the simulation.

The approach followed herein was to use a one-way coupled approach for initial model runs, with additional comparisons to a full-coupled approach to determine whether the additional computational expense was warranted.

3.1 REPRESENTING GEOBAGS AS DISCRETE ELEMENTS

In order to represent the characteristic shape of geobags in a DEM framework, a multi sphere approach was adopted, in which a rigid body representing a geobag is built by combining spheres of different sizes. This method is extensively used for approximating complex particle shapes in DEM simulations (see for example Ferellec and McDowell, 2010). For this work, a model of 178 spheres, using four different sizes, was employed (Figure 6).

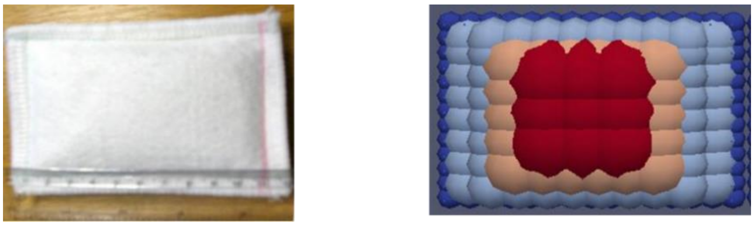

Figure 6: Laboratory (left) and DEM representation (right) of a geobag

3.2 Simulation Setup

A 3D DEM model of the laboratory experiment was created using the LIGGGHTS open source, C++, MPI parallel DEM code (Kloss, 2016). In addition to hydraulic forces, the LIGGGHTS model accounted for geobag self-weight under gravity, sliding friction and tangential and normal forces in collisions using a Hertz-Mindlin soft-sphere collision model (Kloss, 2016). Figure 7 shows the two different construction bonds as in the numerical model (refer to Figure 2 for the experimental equivalent).

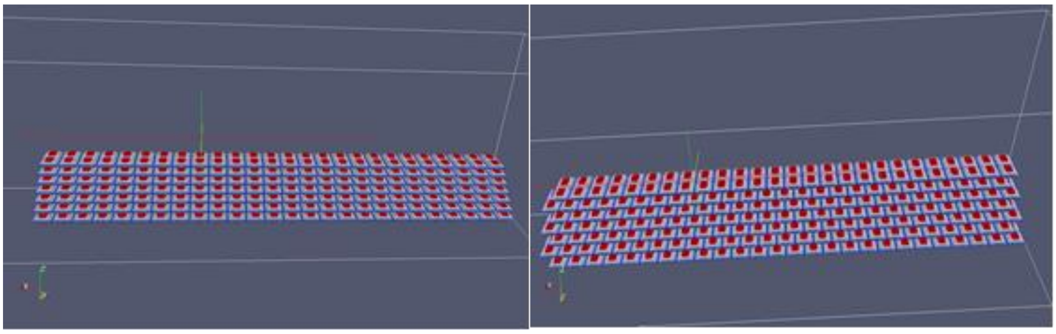

Figure 7: Simulated revetment with stack bond (left) and running bond (right)

3.3 Hydrodynamic forces on geobags: one-way coupling

One-way coupling is in essence a very simple method of simulation. Constant drag and lift forces were applied using traditional simple formulations as in equations 1 and 2:

$$F_D = 0.5C_D\rho_w A_S u^2 \qquad [1]$$

$$F_L = 0.5C_L\rho_w A_T u^2 \qquad [2]$$

Here, ρ_w is the density of the water, C_D and C_L are drag and lift coefficients, u is the velocity of the geobag relative to the water, A_S is the cross-section area normal to the flow and A_T the cross-sectional area tangential to the flow.

The buoyancy force was also included in the calculations, and forces were calculated and applied individually for each sphere in the multi sphere geobag model. A constant drag coefficient of 0.47, appropriate to spheres (Bird et. al, 2002; White, 2006) was used and a constant lift coefficient of 0.88 was calibrated using data from low water depth conditions and validated using the other water depth condition data sets.

3.3 Simulation results and discussion

Visual comparison is the most common, and often the only available technique for validating DEM models (Yang et al., 2006), and in this study the laboratory results have been visually compared with the LIGGGHTS simulations.

Comparing the simulation results with experimental observations (Figures 8 and 9) show that the basic modeling approach replicates failures very well, especially some important failure modes such as uplifting, vertical sliding and dislodgement. Comparisons also show that the model is capable of predicting the position of failure in the revetment in different water depths.

4 CONCLUSIONS AND RECOMMENDATION

An experimental and numerical study has been conducted with a view to ultimately producing design guidelines for low-cost river bank protection using geobags. Two construction bonds were tested. Experimental results indicate that although failure mechanisms strongly depend on water depth and flow conditions, construction method does not noticeably impact the progress of failure.

The numerical results show that a simple, one-way coupled CFD-DEM simulation with basic drag and lift formulations is capable of reproducing the experimental results very well, including the location and pattern of failure.

Further work will extend the study to a variety of different construction methods and revetment geometries, resulting in useable design guidelines for construction.

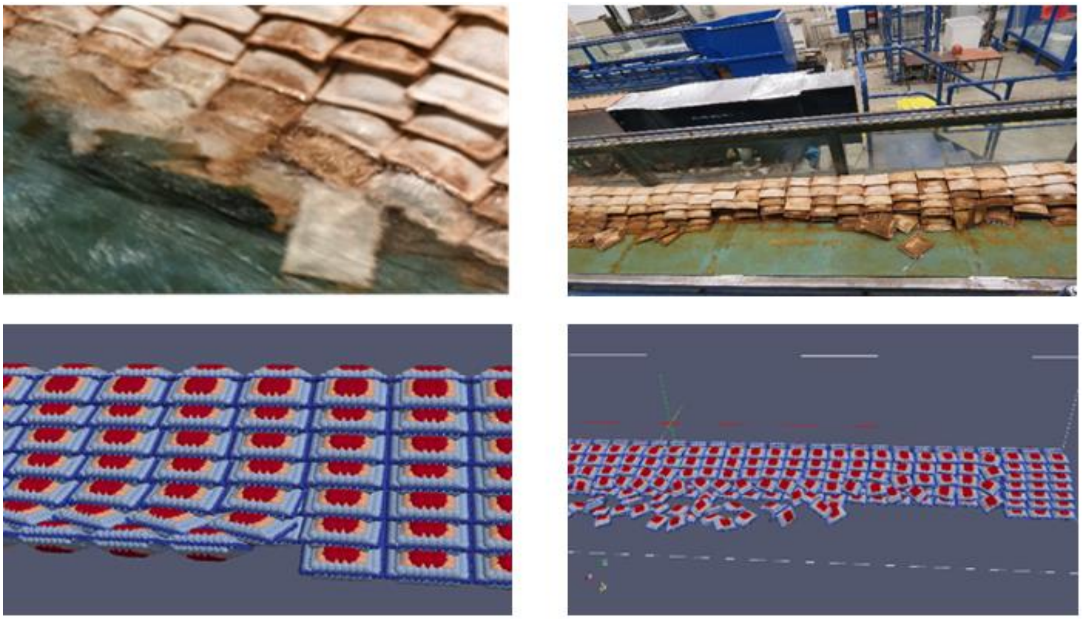

Figure 8: Experimental and numerical results for revetment failure processes (stack bond construction, low depth)

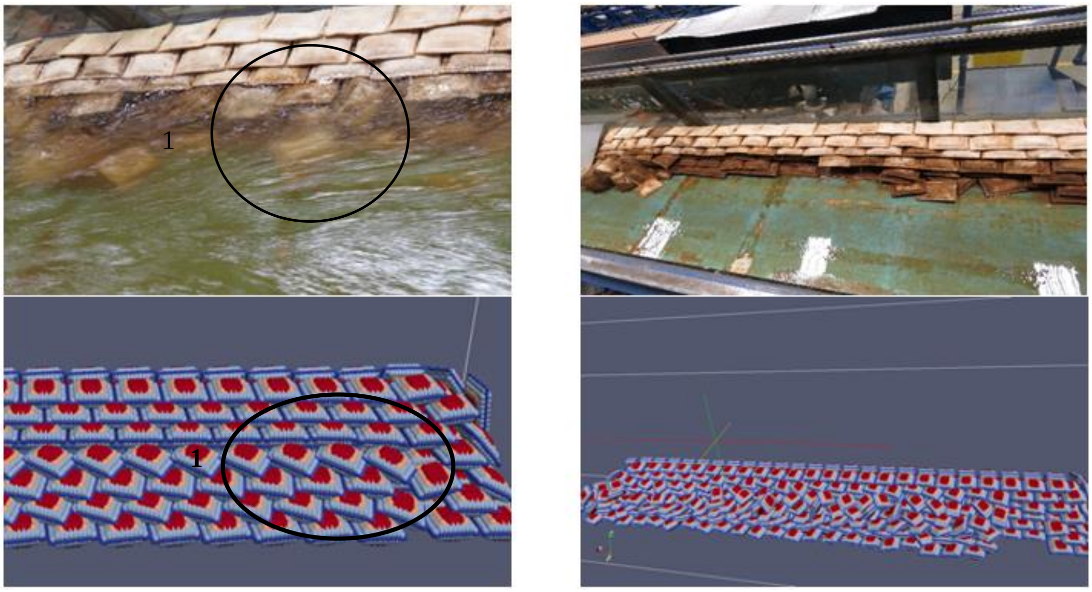

Figure 9: Experimental and numerical results for revetment failure processes (running bond construction, high depth)

ACKNOWLEDGMENTS

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