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A study on the hydraulic forces on geobag protected revetments

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Abstract

For more than two decades, sand filled geotextile bags (geobags) have been used as a means of long-term riverbank protection. However, despite their deployment in a significant number of locations, design guidelines for such structures are not well established. To date, there is no guidance at all for river bank applications and only one guideline, from Australia, concerning coastal geobag revetments. To influence future design guidelines for geobag riverbank protection work, fundamental knowledge is required on the performance of discrete geobags in a revetment during revetment construction, as well as post construction. This paper outlines the current state of the art in terms of guidelines on geobag launching/placement and geobag revetment performance evaluation. This paper attempts to quantify both pre and post geobag revetment performance using 3D Discrete Element Model (DEM) software. It is envisaged that, using routine field monitoring data, the validated DEM model could provide useful information for design guideline preparation.

Keywords: Geobag; design guideline; riverbank; DEM.

1. Introduction

In this paper the term ‘geobag’ is reserved for sand filled geotextile bags, whereas the term sandbag is used to describe bags manufactured from any materials including geotextiles, nylon, polyester and jute. Geobags are a common geotextile product used for the construction of low cost coastal and river bank protection. Geobags have been used in river protection structures for more than 10 years (JMREM 2006 a, 2006 b). For example, geobag protection has been employed to prevent erosion in the Changjiang River in China (Zhu et al. 2004), the Yangtze River in China (Yang et al. 2009) and in the Jamuna and Meghna Rivers in Bangladesh (JMREM 2006 a). On the other hand, except for a few individual practices there are no standard specifications for the design and implementation of geobag riverbank protection structures. For emergency flood protection, sandbags are the first choice for temporary protection works and thus there are a large number of guidelines available around the world on sandbag design specifications, construction method and placement. However, these emergency sandbag guidelines do not consider any requirement for protection against the significant hydraulic forces arising in riverbank revetments intended for long-term use, and are therefore not considered further in this paper.

The first published paper on sand filled bags for coast protection appeared over more than four decades ago, by Venis (Venis 1968). However, a complete design guideline for long term use in coastal or riverbank protection is still not available. In mid-90's, probably the first suggestion for geobag guidelines for large scale protection was made, in Germany. According to (Saathoff et al. 2007) the German recommendations 'EAG–CON' by the German Geotechnical Society (DGGT) is expected to describe the principles of geobag application, material parameters and system requirements, design, quality assurance, construction and installation possibilities and execution. However, the EAG–CON is still in preparation (personal communication Prof. Oumeraci Hocine 2011).

More detailed guidance is provided by the Australian guidelines on geobag application in coastal protection (NSW 2010) (Table 1).The UK and USA have some guidance on bag design and revetment construction specifications (SNH 2000; USACE 2004; CAMA 2010; NDSU and DOE 2010). In Asia, riverbank experiences from Khando, Bagmati and Lalbakeya Rivers in Nepal (CFM 2004), the Mekong River in Thailand (MRC 2009) and the Jamuna and Meghna Rivers in Bangladesh (Oberhagemann and Hossain 2010) show a lack of proper engineering design of river training works, and the guidelines for geobag construction appeared following the general rules of revetment design. Consideration of the special requirements of discrete Geobags in revetments during construction as well as post construction are therefore absent; thus this potentially cost-effective method might not offer expected performances in adaptive management.

The adaptive approach contains different phases depending on the nature of river erosion, and thus, after the first major construction, the remaining phases are prepared accord to field experience (JMREM 2006 a). As field experiments/tests/experiences are involved, with significant time and money, a numerical model could be engaged to estimate performances of each individual/discrete geobag in a revetment with respect to river dynamics. Thus, to influence future design guidelines for riverbank protection work using discrete Geobags, a 3D Discrete Element Model (DEM) model has been developed.

The discrete element method (DEM) or distinct element method is a numerical technique applied for modelling the movement and interaction of rigid or deformable bodies, particles, or arbitrary shapes which are subjected to external stresses or forces (Crapper et al. 2005; Mustoe and Miyata 2001). To date, DEM usually used in different fields such as rock mechanics, mining, pharmaceutical, chemical, agricultural, advanced materials and food (Bertrand et al. 2005). Despite the widespread use of commercial DEM codes, for example EDEM® in some engineering applications, DEM has not been used previously to model the failure mechanisms in a geobag structure.

A one-way coupled DEM model showed reasonable performance in replicating laboratory observations (Akter et al. 2011). As DEM can track the motion of each individual particle (geobag), and its interaction with other particles (geobag to geobag) and boundary surfaces (geobag to riverbank material) using Newton's Laws of Motion and contact laws, it is envisaged that DEM could also provide useful information in preparing design guidelines for revetment construction as well as for the adaptive approach.

Table 1
Published geobag guideline obtained for both coastal and riverbank protection works.

Structure zone	Bag design Specification				Construction Specification				Life cycle (Year)	Maintenance and Inspection	Labour Safety	Year	Reference
	Sand d_{50} nm)	Fabric (Thickness)	Fill ratio (%)	Bag size Dry mass Volume	Bond bag-bag	Thickness	Placement (stream wise)	Slope					
Coastal	–	Geotextile	–	3m ×1.5m × 0.5m 3 tonnes	Running bond	2–3bag widths	Parallel	≤1:1.5	5–10	Adaptive management	≤ 50 kg	2000	Scottish Natural Heritage
	–	–	–	2–4.5m × 1–1.5 m	–	–	Parallel	≤1:3.3	2–5	Following standards 15A NCAC 7H Section .0308(a)		2008	[1]CAMA
	.15–.50	Geotextile (5 mm)	67–100	≥ 18 kg 0.75 m^3	Running bond	2 layer	Perpendicular	1:1.5	–	Coastal protection Act 1979 Section 55R(1)(c)		2010	[2]NSW
Riverbank	–	Burlap and plastic	50–67	0.61 m × 0.36m	–	–	–	1:1	–	–	–	2004	US Army Corps of Engineers.
	_	Woven polypropylene	50	0.61 m × 0.36m 16–18 kg	Running bond	–	Parallel	1:2 1:3	–	–	–	2010	NDSU & U.S. Dept. of Agri.
	0.2	Nonwoven geotextile (3 mm)	80	1.03 m × 0.70 m 126 kg	–	1 layer	–	1:2	–	Adaptive approach	–	2006 a, b, c	[3]JMREM

[1]Coastal Area Management Act (CAMA)
[2]This draft document has been prepared to support the Coastal Protection Act 1979once amended by the Coastal Protection and Other Legislation Amendment Bill 2010, which is currently being considered by the NSW Parliament. Department of Environment, Climate Change and Water, NSW.
[3]Jamuna Meghna River Erosion Mitigation (JMREM)

2. Material and method

To achieve their desired design life, it is necessary to enhance the fundamental knowledge of the performance of Geobags in a revetment subject to flowing water, by means of validated numerical model. In this study, a DEM model is proposed to predict geobag performance for revetment construction and post construction phases.

2.1 DEM model

Most DEM models are based on cylindrical or spherical shaped particles, due to the inherent ease in detecting contact between particles in the numerical calculation (Mustoe and Miyata 2001). In this study we used the commercial DEM code EDEM®v2.3 (DEM Solutions 2010). This code allows for the creation of non–spherical particles from overlapping spheres of differing sizes.

Contact model

The default contact model in the EDEM® software is the Hertz Mindlin model (Mindlin 1949), which is regarded as accurate and efficient in force calculation for elastic solids (DEM Solutions 2010).

Mapped fluid velocity field

In this study, a new simple model was used that approximates the hydrodynamic forces and torques acting on a non–spherical particle in a non–uniform flow field. The model discretises the particle into sections with equivalent size by simple geometrical calculations. The Geobags are thus, for hydrodynamic purposes, approximated as a number of inter–connected, simple rectangular flat plates. Drag and lift are calculated for each plate based on semi empirical models, these being the drag model for non–spherical particles from (Hölzer and Sommerfeld 2008) and the lift model from (Yin et al. 2003). The drag and lift coefficients were set manually to replicate the laboratory experiments/field test/field observation. The buoyancy force is included in the calculations. The drag equation is:

$$F_D = \frac{1}{2}\rho_f C_D A_{\mathrm{sect}} V_{rel}\left|V_{rel}\right| \tag{11}$$

Where,

ρ_f = Fluid density

C_D = Drag coefficient

V_{rel} = Relative velocity

A_{sect} = Cross–sectional area, calculated by the diameter of an equivalent sphere of the volume of the discretised section

The lift equation is adopted from (Yin et al. 2003)

$$F_L = \frac{1}{2}\rho_f C_L A_{\mathrm{sect}} \frac{\vec{z}\bullet V_{rel}}{\left|V_{rel}\right|}\left[\vec{z}\times V_{rel}\right]\times V_{rel} \tag{12}$$

Where,

$\vec{z}$ = the particle major axis direction

The total force is then summed up for all flat plates. The total torque acting on the particle is calculated by summing up the torque generated by the total of the hydrodynamic forces of each of the discretised flat plates with respect to the centre of gravity of the particle as a whole.

The model is implemented in the Application Programmable Interface (API) in EDEM®. The API allows the user to implement custom contact and non–contact type models, such as drag models for DEM modelling.

Riverbank Erosion and Scouring

The mobile bed underneath the geobag revetment needed to be represented in such a way that DEM can simulate the response to bed erosion and scouring. In the model setup, the bed can be represented by geometries such as rectangles and squares. Within EDEM®, all of these geometries are treated individually, and the linear translation feature of the code allows movement of each square either downward or upward at a rate based on observed data.

2.2 Geobag representation

A geobag size of 1.03 m × 0.70 m (dry mass 126 kg) was selected for this study due to its practical basis for riverbank protection. To reduce the computational effort, the geobag was scaled down to 1:10 and a model geobag of 0.103 m × 0.07 m (dry mass 0.126 kg) was prepared in the laboratory to obtain the relevant coordinates (Figure 1a). In DEM, a single geobag was represented by using a total of 110 spheres, 66 spheres of 11 mm diameter, 28 spheres of 20mm and 16 spheres of 28 mm diameter. The spheres were rigidly connected at their point of contact (Figure 1b). Within EDEM®, the 110 spheres were treated as an individual body, with spatial properties such as its location being indexed to the overall centre of mass. For most post processing, a bag template (based on the measured coordinates of the laboratory model Geobags) was placed over the individual sphere grouping (Figure 1 c). This distinguishes between the bags, but it is important to recognize that the template is not the interaction surface of the particles; it is merely applied during post processing to aid in visualizing the individual bags. In fact, the bags can overlap at their edges when the maximum diameter of a sphere protrudes into the 'valley' between adjacent spheres. In DEM, the total contact forces of the Geobags were summed over each sphere within a geobag. All bags were identical. The maximum value for the coefficient of rolling friction, unity, was taken to avoid any unrealistic rolling of the simulated Geobags. A minimum value of coefficient of restitution (0.0001) was selected to reflect the low 'bounce' of the Geobags (Table 2).

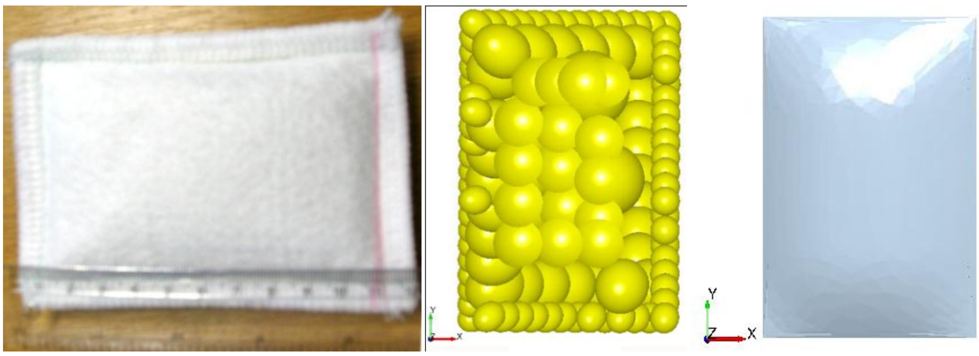


Fig. 1. (a) Geobag (103mmx70mm;0.126kg), (b) 110 spheres and (c) Template; Laboratory model geobag representation in EDEM

3. Application of DEM

3.1 Geobag structure construction

During construction, to achieve the required design of bag layering, bond, placement and slope, there is often a need for mechanical device. Manual bag drop introduces quality control issues and there is therefore uncertainty involved in the final position achieved. Both in mechanized and manual bag placement, the geobag falling/sinking behaviorism a vital issue. Except for a schematic by (Oberhagemann and Hossain 2010), to date there is no information on geobag placement behavior available.

In this study, the EDEM® model setup was done for a single geobag falling in a 3m × 3m column with1 m deep, still water (Figure 2). The DEM parameters for solid-solid interaction used in the study are shown in Table 2. The required input data for fluid force calculations were: water density (998.2 kg/m^3) and viscosity (1.003 ×10^{-6} m^2/s) at 20°C (Chow 1959),the coefficient of drag (C_D) and lift (C_L) force for the bags, and the 3 D local velocity. As there is no available data on geobag sinking for comparison, the initial values for C_D and C_L were set to 0.05 and 0.05 respectively. For representing still water, the 3D velocity field obviously contains only zero values.

Table 2
Required material and interaction properties for the EDEM® geobag model

Material Properties			Interaction Properties	
Details	Geobag	[4]Flume Bed (Steel)	Details	Value
Modulus of rigidity (G) (pa)	[5]1.9×10^{6}	8.16×10^{10}	Coefficient of static friction	0.55
Poisson's ratio (ν)	[6]0.42	0.293	Coefficient of rolling friction	1
Density (ρ) (kg/m^3)	[7]1596	7852	Coefficient of restitution	0.0001

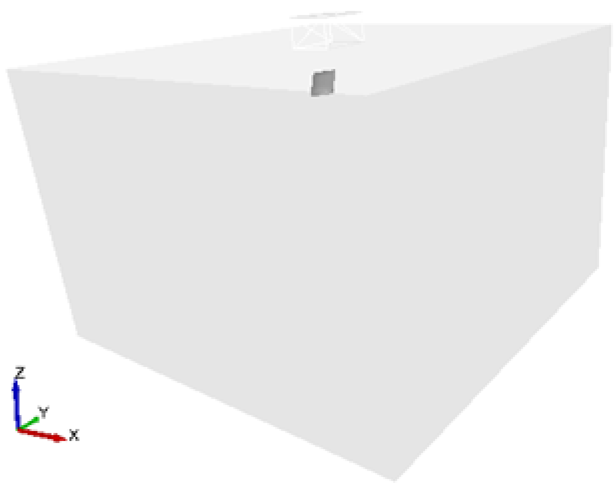


Fig. 2. Model setup for geobag sinking representation in EDEM

The total simulation time was1 s and the bag falling path showed a reasonable match with the schematic described by (Oberhagemann and Hossain 2010). Figure 3 represents bag falling state every 0.1 s; at 0.8 s the bag touched the flume bed .The color bar indicates bag falling velocity in m/s.
If data were available from laboratory and field tests, the DEM model could be validated and used to predict bag placement under water.

[4]Steel properties from Tilley(Tilley 2004).
[5]A shear box experiment was carried out following BS 6906–8:1991(BSI 1991).
[6]Young's modulus was obtained for geotextile only following BS EN 29073–3:1992(BSI 1992).
[7]Considering geobag as coarse aggregate, an experiment was carried out following BS 812: 1995(BSI 1995).

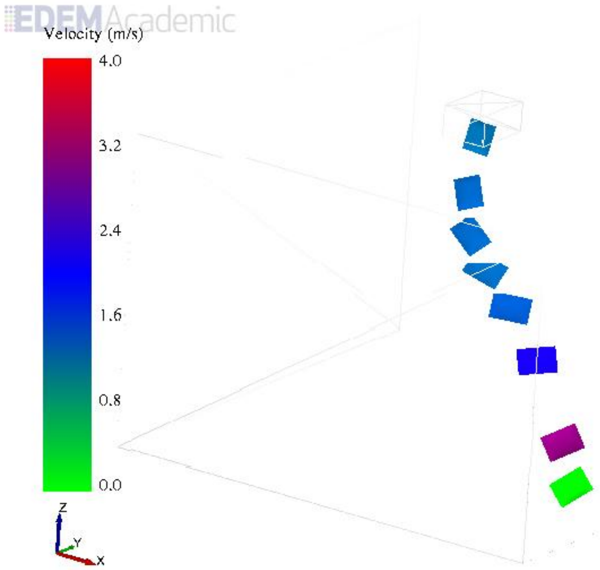


Fig. 3. Geobag sinking (bag position at 0.1 s intervals) in EDEM

3.2 Post construction geobag performance

The stability of geobag revetment depends on both geotechnical and hydraulic stability of Geobags in a real river environment Figure 4. This can be represented by a further DEM model.

3.2.1 Laboratory scale

The details of DEM model application for replicating laboratory experiments were described in (Akter et al. 2011). The unique finding in that study was the identification of geobag displacement under drag and toe scouring in different water depths and changes in the sand bed underneath the geobag revetment (Akter et al. 2011).

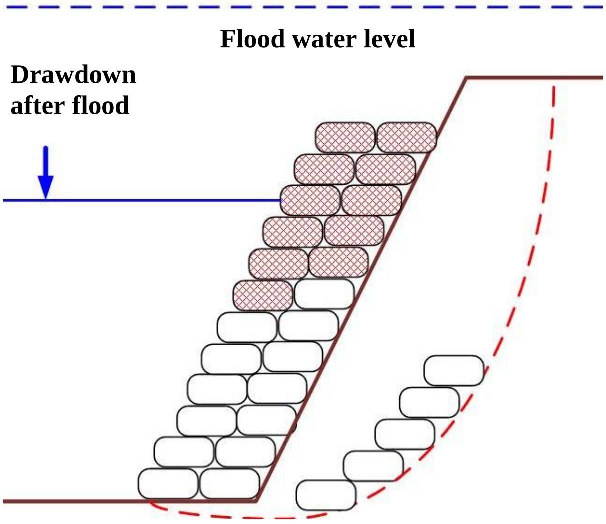
3.2.2 Field level

The selected river cross section was from the Jamuna Meghna River Erosion Mitigation (JMREM) project (JMREM 2006 a). Two distinct soil layers,fine grained (cohesive) soil in upper layer and medium grained sandin the lower layer were normally observed in the geobag protected revetments (JMREM 2006 b, 2006 c). To represent a geobag protected revetment of prototype length 8 m (stream wise/parallel to main river flow) and 40 m prototype deep in the DEM model, a total 326 Geobags were used (Figure 5). A total of 144 rectangular geometry sections of prototype size 1 m × 8 m and differing heights were used to represent the underlying soil layers. Details of flow data and riverbank change data are needed for validation of this model setup; however, once validated, it is expected to represent the post construction features in geobag revetments.

4. DEM model in future design guideline

To prepare a design guideline aimed at ensuring geobag revetment stability, the DEM model prediction can play a vital role. The importance of a 3D representation of geobag revetment is well understood in terms of performance evaluation. The unique significance of this study is to replicate the laboratory observation using a 3D DEM model. The commercial EDEM® model is the tool to serve this purpose. Manual or mechanical bag placement can be support with the details knowledge on geobag falling velocity using DEM model.

(a) Sandbag displacement



(b) Schematic of the combined effect of retarded scour and drawdown

Fig. 4. Geobag displacement in Jamuna River , Bangladesh (Field study, 2009)

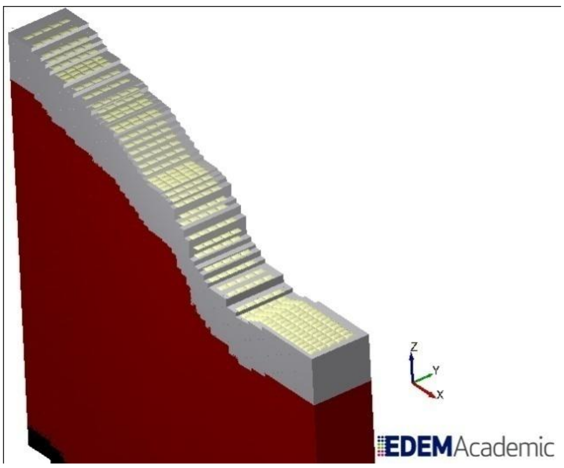


Fig. 5. DEM Model representation of a prototype geobag revetment

The present practice of JMREM is to place a batch of Geobags near the top of the bank literally just below low surface water level and the launching on slope of the river followed by the same manner of the quarry rocks (JMREM 2006 a). The assumption behind this practice was that the Geobags would slide from the dumped batch in an orderly manner in layers while toe scour progresses and thus a protected slope of 1V:2H could be achieved (JMREM 2006 a). Here an important factor was unknown i.e. the portion of batch revetment height, contributing to slope formation. Possibly an idea can be drawn while the post construction features is established using DEM.

The presently setup DEM model needs the following field information to be useable in field geobag revetment performance evaluations:

– Water depth and systematic evaluation of relevant 3D water flow velocity
– Their relationship with riverbank erosion and scour rates, so a 3D bed profile should be included and
– All of the above mentioned parameters should be considered along with the specific failure mode identification in geobag revetment and thus contribute to the adaptive approach.

4.1 *Bag design specification*

Based on availability of materials and resources this needs to be selected.

4.2 *Construction specification*

Steps in applying the DEM to evaluate the performance of geobag during construction follow:

Step 1. Measure a real size geobag coordinates for representing the bag size using different size spheres;

Step 2. Measure or estimate material properties of geobag and riverbank, these are Shear modulus(G), Poisson's ratio (ν) and density(ρ); and then three interaction properties for geobag and riverbank i.e. the coefficient of restitution (e), Coulomb or static friction coefficient (μ_s) and the coefficient of rolling friction (μ_r);

Step 3. Enter values for water density (998.2 kg/m^3) and viscosity (1.003 ×10^{-6} m^2/s) (at 20°C, Chow, 1959). Prepare a mapped fluid velocity based on 3D measured water velocity and the model setup would be similar to Figure 2;

Step 4. Calibrate the coefficient of drag (C_D) and lift (C_L) to get a geobag falling path to replicate the field/experimental observation.

Note the theoretical calculation time step in DEM simulation (DEM Solutions 2010) is carried out as:

$$T_R = \frac{\pi R\sqrt{\frac{\rho}{G}}}{(0.1631\nu + 0.8766)} \tag{13}$$

So the computational time will depends on geobag size, to reduce the computation effort there is an urgent need to acquire a relationships between prototype and scale down size.

4.3 *Maintenance and inspection*

When designing a discrete geobag revetment/structure the following steps can be followed to estimate the geobag performance for strengthen the adaptive approach:

Step 1. Measure a real size/model geobag coordinates for representing the bag size using different size spheres. Specify how many bags are simulating in DEM and based on their position prepare an external factory for importing in EDEM®;

Step 2 & 3. Similar to sub-section 4.2;

Step 4. Manually place geometry (rectangular / square) to represent the riverbank based on different soil layers and updates their properties as per measured or estimated river morphological data. Up to this the model setup would be similar to Figure 5;

Step 5. Calibrate the coefficient of drag (C_D) and lift (C_L) to get estimation of geobag performances to replicate the field/experimental observation.

5. Conclusion

The study attempted to describe the applicability of DEM in future geobag guideline preparation. In this proposed DEM model geobag physical state i.e. wetness of the geobag or aging is ignored and the basic geotechnical features are absent. An immediate potential research issue concerns the implementation of geotechnical stability models of the geobag revetment. This will allow simulation of features of permeability and durability of Geobags in terms of river bank environment. This needs to be more on basic geotechnical knowledge based. So that this can work in coupled with DEM model or might work based on sharing information and thus can provide more realistic prediction. A further development of the numerical simulation would be the representation of fluid forces using a Monte Carlo simulation.

In further research, DEM can be applied in evaluating the performance of other discrete riverbank protective materials, for example concrete blocks or riprap.

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