Numerical Modelling of the Assembly of Big Bags to Optimize Landfill Disposal

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Alessandra Insana[1,*], Marco Barla[2], Alberto Minardi[3], Costanza Stimamiglio[4], Giovanni Stevan[4], Mario Manassero[2]

[1] Geosolving srl, corso Orbassano 336, 10137, Torino (Italy)
alessandra.insana@polito.it

[2] Department of Structural, Geotechnical and Building Engineering (DISEG), Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Torino (Italy)

[3] Geotechnical Engineering, Corso Duca degli Abruzzi 42, 10129, Torino (Italy)

[4] Acque del Chiampo S.p.A., Via Ferraretta 20, 36071, Arzignano (Italy)

Abstract The so-called 'big bags' are used in landfills to dispose waste material in a sequential manner. In this study, big bags are constituted by geosynthetics and filled with organic waste similar to granular material. The result is an element having a blocky shape and being highly deformable. The process of deployment of big bags for waste disposal in landfills becomes crucial when considering the stability of these assemblies. This paper is intended to focus on the understanding of the mechanisms governing the stability of these assemblies of blocks by means of Distinct Element numerical modelling. To determine the appropriate properties to be assigned to the model, a calibration process was performed by simulating the behaviour of a single big bag undergoing loading and unloading stages. A real scale experimental setup was implemented at the site to test the behaviour of the block by superimposing a concrete cubic weight to a big-bag and measuring the deformations at different time intervals during loading and unloading. The numerical analyses showed to be appropriate to reproduce the behaviour of the big bag at the single block scale and were adopted to study the stability of the assembly in a variety of geometrical layouts. The work performed allowed the definition of the arrangement that guarantees the stability conditions of the assembly.

Keywords: landfills, DEM, big bags

1 Introduction

Vertical expansion of landfills is often considered to optimize the use of landfill area by increasing the waste volume per unit area (Qian et al. 2001). A special case study is presented in this paper where the landfill waste disposal is performed by using big bags, which are plastic bags, typically made of polypropylene, with a volume equal to about 1-1.5 m^3. Before the disposal in the big bags, the waste material is subjected to a

preliminary drying process. After this treatment, from a granulometric point of view, the waste can be compared to a very fine sand.

The existing landfill has an extension of about 30'000 m², with the current cell (cell 1 in Fig. 1) having a volume of about 360'000 m³. The vertical expansion foresees the construction of a new cell on top of the existing one (cell 2 in Fig.1) with an increase of the storage capacity of about 40%. Among the several aspects considered in the design phase, the definition of the filling methodology of the new cell has required the performance of stability analyses of the big bags assemblies in different sectors of the landfill. The Distinct Element Method (DEM) was considered to carry out such analyses. This approach is often adopted in rock mechanics to study the stability of rock masses as well as fracturing process (e.g. Barla et al., 2001; Insana et al., 2016; Jing & Stephansson 2007; Kalenchuk et al., 2010). Compared to other methods, such as the Finite Element Method, the DEM is capable of reproducing the interaction among the big bags and the overall behavior of the assemblies by overcoming the limitations of a continuum approach. Numerical simulations were performed with the DEM approach, using the software UDEC (Itasca, 2019), considering different geometries of big bags assemblies in different areas of the landfill. Preliminary laboratory and in-situ tests were carried out to calibrate the model parameters required for the numerical simulations. The results of these preliminary tests are illustrated in the following, along with the main outcomes of the numerical simulations that allowed providing the landfill operator with the definition of a safe filling process of the new cell.
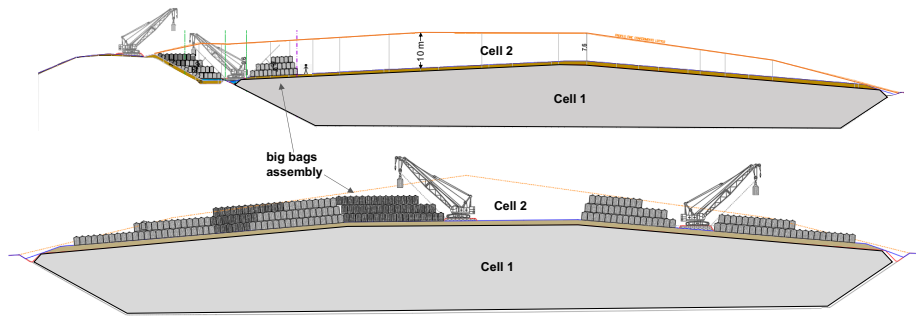

Fig. 1 Main cross sections of the landfill site highlighting the vertical expansion with the new cell and some examples of big bags assemblies.

2 Definition of the mechanical properties of the blocks

The mechanical properties of the blocks used to simulate the big bags in the numerical models were evaluated by reproducing and back-analyzing the outcomes of an in situ, real-scale loading test on a big bag. The test was performed by locating a big bag within a steel cage and by superimposing a 2560 kg concrete block provided with a 120 cm x 120 cm metal plate to regularize the big bag-block contact (Fig. 2a). Next, the concrete

block was removed. 2D and 3D geometric survey of the big bag was performed after the application of the load at different timeframes and at the end of the test, after the block removal (Fig. 2b).
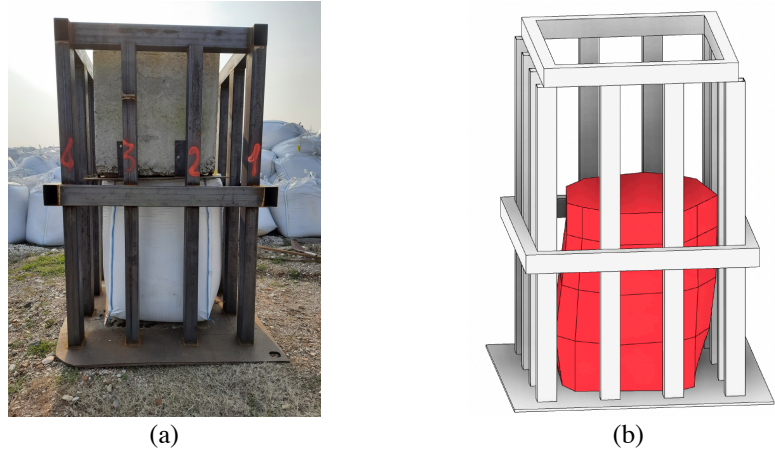

(a) (b)

Fig. 2 (a) In situ loading test and (b) 3D geometric survey of the deformed big bag after removing the concrete block

A numerical model was built in UDEC to reproduce the geometry of the test and the test conditions (Fig. 3). A single big bag was simulated as a deformable distinct element. Parametric analyses allowed to study different combinations of the mechanical parameters of the material constituting the blocks.
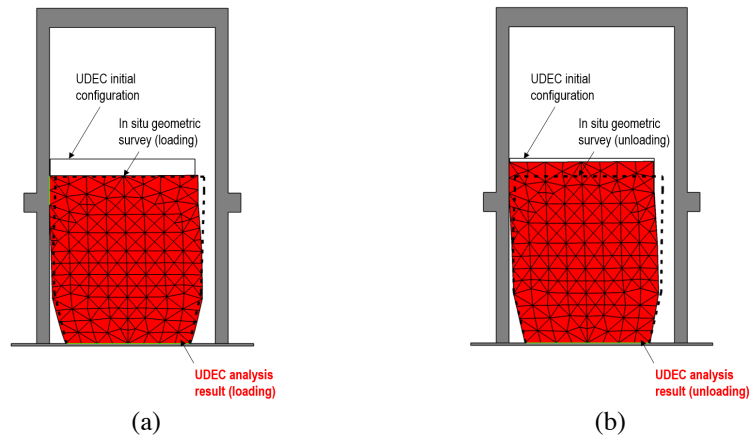

(a) (b)

Fig. 3 Numerical modelling results at the end of (a) the loading and (b) the unloading stages

An elastic perfectly plastic constitutive law with Mohr-Coulomb failure criterion was assumed. In particular, the role of Young's modulus, Poisson's ratio, cohesion and

friction angle were investigated. The parameters of the big bag-cage contact were a normal stiffness of 10^{12} Pa/m, a shear stiffness of 10^{11} Pa/m, a null cohesion and a friction angle of 10°. The final set of parameters, which according to the Authors is reputed to represent a satisfying compromise for the aim of the study, comprises a density of 763.85 kg/m³, a Young's modulus of 270 kPa, a Poisson's ratio of 0.29, a cohesion of 50 kPa and a friction angle of 20°. Fig. 3 shows the outcome of the simulation and depicts the big bag at the end of the loading and unloading stages. As it can be seen, the experimental and the numerical deformed boundaries compare pretty well, especially in the loading phase, which is of primary interest.

The properties assigned to interfaces between different big bags were assessed based on the results of direct shear tests (Fig. 4). To such interface, a null cohesion and a friction angle of 10° were assigned in all the interaction analyses.
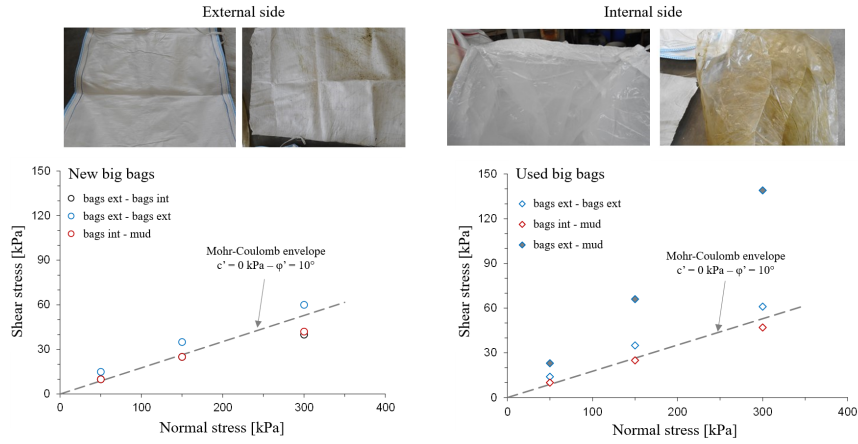

Fig. 4 Direct shear tests results for the evaluation of interface strength on new and on used big bags

3 Simulations of the assembly of big bags in different conditions

In this chapter, the results of the numerical analyses performed to study the behavior of big bags assemblies in different geometrical conditions is presented. The analyses considered the parameters illustrated in Chapter 2. Disposal geometries on a horizontal plane, on an inclined surface and on a side bank were taken into account and are described in the following sections.

3.1 Equilibrium of the assembly of big bags on a horizontal plane

The first set of analyses was aimed at studying the stability conditions of three geometrical configurations, characterized by a pyramid-shaped geometry with different slope

of the side, that differ in the way big bags are placed row after row, that is by leaving one and a half big bag spacing on the sides, one big bag and half big bag (Fig. 5).
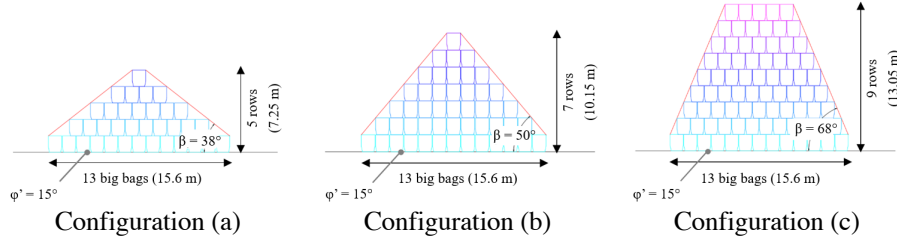

Fig. 5 Geometrical configurations of big bags assemblies on a horizontal plane

The numerical models were built by generating big bags row by row, until completing the defined configuration. At the beginning of the analyses, gravity was turned on and then the models were run until equilibrium, whenever possible. The friction angle of the interface between the ground surface and the big bags is 15°. The results showed that while configurations (a) and (c) reach a full equilibrium, in configuration (b) the assembly does not reach a stable condition, highlighting the importance of the interlocking among the blocks. Hence, configuration (b) which foresees the big bags being stacked vertically cannot be considered stable and should be avoided. Additionally, the factor of safety was calculated for (a) and (c) by using the Shear Strength Reduction method (SSR) that progressively reduces the strength parameters of the materials (Duncan, 1996). The obtained results show that in configuration (a) the safety factor is higher than 3, while in configuration (c) it is slightly lower than 1.5.

3.2 Equilibrium of the assembly of big bags on an inclined surface

The second set of analyses (Fig. 6) was devoted to the evaluation of stability conditions of the big bags assembly on a surface with an 8.5% inclination (about 5°). In configuration (d) the big bags are assembled in rows leaving a gap at the edges equal to half a big bag, whereas in configuration (e) the assembling requires the rows to leave a gap of one and a half big bags at the edges. In both configurations, the angle of friction considered at the contact between the base plane and the bags is 10°. The arrangement of the assembly was simulated in a similar way to what was done previously, i.e. by generating the big bags per row, assigning the gravity and iterating to equilibrium.

None of the configurations proved to be stable. In the case of configuration (d) the instability is evident and occurs on the assembly downstream side, unlike configuration (e) where the instability is less evident and occurs within the stack itself (Fig. 6). The phenomena are well documented by analyzing displacements and velocities during the analyses which show how some portions of the assembly do not reach an equilibrium.
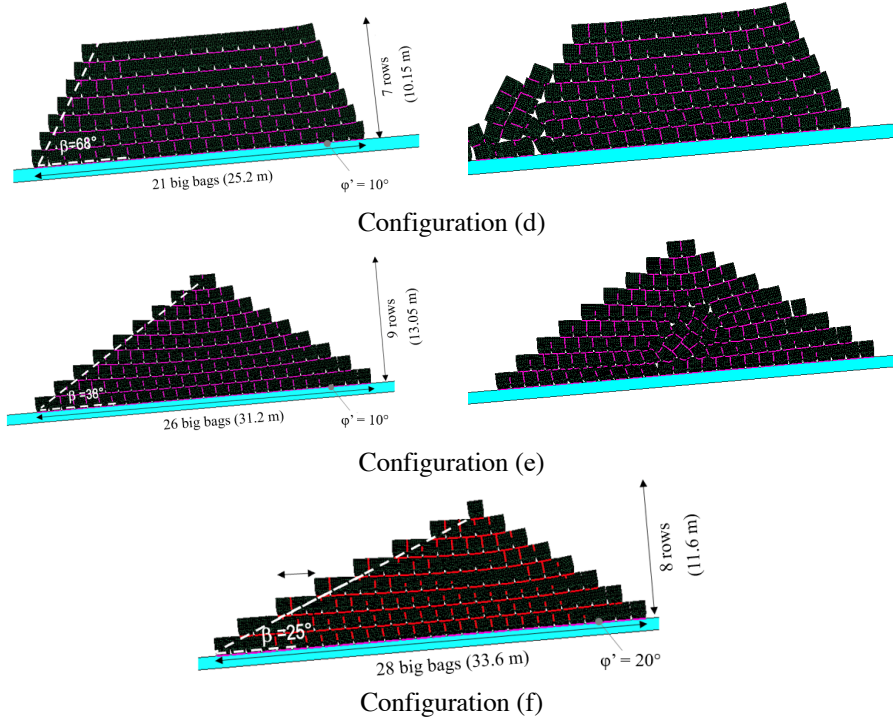
Configuration (d)

Configuration (e)

Configuration (f)

Fig. 6 Initial and final layouts for configurations (d), (e) and (f) on an inclined surface

Looking for a configuration that could guarantee stability, a further analysis was carried out, similar to configuration (e) but with a friction angle at the base equal to 20°. The analysis did not allow to clearly highlight the achievement of equilibrium. It was therefore decided to investigate a third configuration (f) in which the assembly is made in such a way as to leave a gap between the rows equal to two and a half big bags on the downstream side with the exception of the second row (Fig. 6). In this case, the analysis shows that the assembly is stable with a safety factor between 1.3 and 1.5.

3.3 Equilibrium of the assembly of big bags on a side bank

The third set of analyses was aimed at studying the stability conditions of the big bags assemblies in the case of a horizontal base plane coupled with a side bank inclined of about 28°. After some preliminary numerical considerations on the big bags layout and with sole reference to the configuration stable both on a horizontal and on an inclined plane (1.5-2.5 big bags) , the configurations (g) and (h) in Fig. 7 were set-up. Configuration (g) is characterized by the fact that the big bags are arranged in four rows and are stacked in such a way as to leave one and a half big bags free at the edges. Configuration (h), on the other hand, provides for the same gap between the big bags adopted for

configuration (g), but the height reached is higher (seven rows). In configuration (i) a part of the upstream big bags present in configuration (h) was removed in an attempt to relieve the downstream big bags, assuming that their installation may take place in a final stage of the overall landfill disposal. In all configurations, the angle of friction considered at the contact between the inclined side and the bags is equal to 10°. Only in configuration (g) the friction angle between the base plane and the bags corresponds to 15°, while in configurations (h) and (i) it was increased to 20° to improve the stability.
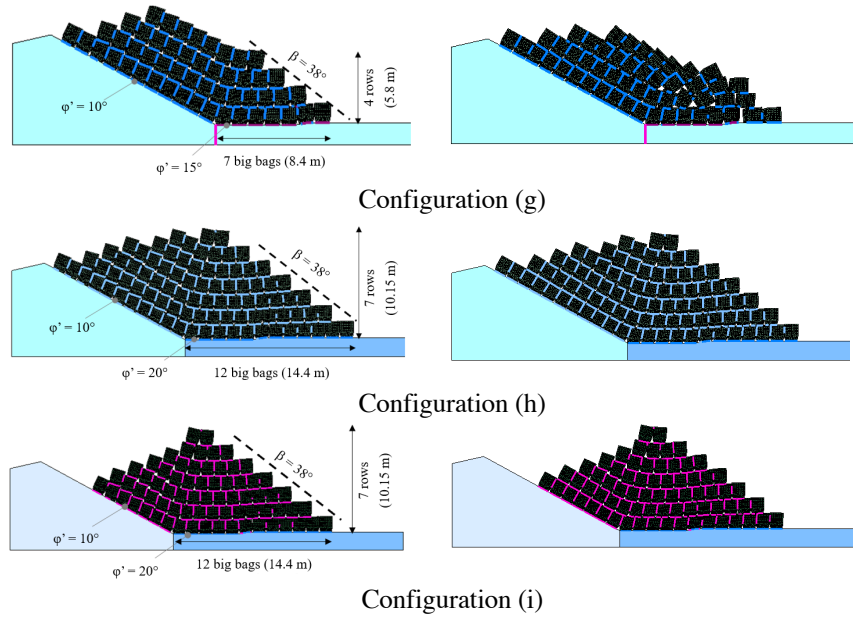

Fig. 7 Initial and final layouts for configurations (g), (h) and (i) on a side bank

The analyses showed that configuration (g) is not stable due to a downstream tilting collapse kinematics and that configuration (h) does not reach an evident equilibrium in the calculation window considered for the analysis. The configuration (i), although it does not reach a clear equilibrium denoted by an evident horizontal plateau of displacements, provides the elements to deduce a condition of substantial stability. This conclusion seems to be confirmed by the further SSR analyses carried out for the configuration (i) with safety factors 1.3 and 1.5, which indicate a limited increase in displacements followed by an equilibrium phase. It is therefore possible to state that the safety factor related to the configuration (i) is higher than 1.5.

4 Conclusions

The numerical modeling carried out by making use of the Distinct Element Method allowed to study the procedures of arranging big bags containing waste material for the

vertical expansion of a landfill. First, the mechanical properties were determined by simulating the mechanical behavior of a single big bag and reproducing a loading-unloading test performed on site. Then, the numerical modeling dealt with the verification of the behavior of different assemblies of big bags to evaluate their stability. The following conclusions can be drawn: i) the pyramid-shaped geometry which foresees big bags rows aligned on a horizontal plane is not stable and should be avoided; ii) arrangement geometries on a horizontal plane with half big bag gap and one and a half big bag gap are stable and have a safety factor between 1 and 1.5 and greater than 3 respectively; iii) in the case of a 5° inclined plane, the most stable configuration is the asymmetrical one (side slope equal to 25° and 38° on the downstream and upstream) with a safety factor between 1.3 and 1.5; iv) the analyses carried out with different configurations on the side bank do not lead to stable conditions unless some of the big bags in the upper location are placed in the final phase of the filling process. In this case the safety factor is higher than 1.5; v) friction angles at the interface between the big bags and the base surface play a key role in stability analyses and must be taken into consideration during the design of the intermediate barrier separating the two cells. All these outcomes allow the landfill operator to define an efficient filling methodology of the new landfill cell taking into account the needed safety margins during the operations.

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