3D numerical modeling of a landslide in landfill site at Mila in Algeria

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KEYWORDS: Landslide, receptacle, 3D simulation, FLAC 3D

ABSTRACT: Usually actual slopes are not infinitely long and straight, but they are curved in both plan and elevation. The effect of slope curvature can really only be analysed with a three-dimensional model, therefore a 3D approach (by using the explicit finite difference code FLAC3D) is used to calculate the safety factor. Landslides were appeared in waste-land at Mila in Algeria, therefore a new shape of receptacle has been proposed using 3D simulation in order to test its slope stability. The new safety factor is calculated and compared with the former shape of waste-land. The stabilization technique used is based on the slope of the relief of discharge by the use of berm and the change of the shape of the discharge promoting three-dimensional effect of the slope. We have used the Mohr-Coulomb model for simulation and this robust model has the advantage of requiring little geotechnical parameters whose signification is well represented. The calculation of the safety factor is based on reducing the cohesion to a critical value causing the failure. The physical and mechanical properties used in the simulations are: the density 2t/m3, a friction angle 3° and cohesion 35 kPa. For these values of the parameters we find a safety factor equal to 1.87. We conclude that the new shape of the receptacle is more stable than the old one.

1 INTRODUCTION

Landslides occur in wide variety of circumstances. They affect structures built by man or natural slopes; they occur suddenly or with time. Failure affects a roughly circular in shape or without particular geometric feature (Costet and Sanglerat, 1983).
The shape of the sliding surface is not plan and thus becomes a three-dimensional problem. Through this study we model in 3D a landslide that took place in landfill site at Mila, in Algeria.

Climate change in recent years triggered landslides and weakened several cities in northern Algeria. Mila is one of these cities touched hardly by the activity of land. The soil layer is visibly with low resistance and very sensitive to water. The landfill site of Mila had activation slip affecting the slope of the receptacle and the land surrounding it.

2 PATHOLOGY OF THE SITE

2.1 Description: Photo 1 shows an overall view of the receptacle located on a low slope in the presence of two watercourse together downstream of receptacle by digging a deep trough.

After finalizing the digging of the receptacle, the works were stopped due to the appearance of signs of slippage jeopardizing the installation of the waterproofing geomembrane and drainage system and even the total departure of the receptacle down the trough.

2.2 Observed landslide: Figure1 summarizes the location of the cracks observed and highlights the sources and direction of ground movements.

Disorders detected can be classified into two types:

- **Instability of the receptacle:** Slopes South and East sides of the receptacle were affected by trigger signs of slippage manifested by ridges at the foot of the slope (Photo 2) and cracks on the crest of the upstream slope. These slides are currently low speed present a danger to the working of the geomembrane and can suddenly cause the ruin of the receptacle. A seepage face was located in the middle of the upstream slope. Water inflow infiltration can cause disorders after placement of the waterproof geomembrane.
- **Slip of the entourage of the receptacle:** Surrounding the receptacle of low slope was affected by several signs of slippage manifested by cracks. The length and opening of large cracks were signs of a massive shift of the soil layer.

Photo1. Overview of the receptacle

Photo2. Bead at the foot of the upstream slope of 14m in height

2.3 Interpretation of soil investigation: The geotechnical characteristics of the site given by the laboratory (results of five diamond drill holes: degrees of saturation: 95 to100%, liquid limit 43 to 71%, plasticity index 16 to 41) show that the ground seat is a plastic swelling clay and with low mechanical strength in the short term, an undrained cohesion Cu varied between 10 kPa and 70 kPa and a friction angle ϕ_u from 1 to 7. This variation of mechanical properties can be explained by the strong heterogeneity of the site and the presence of boulders in the field.

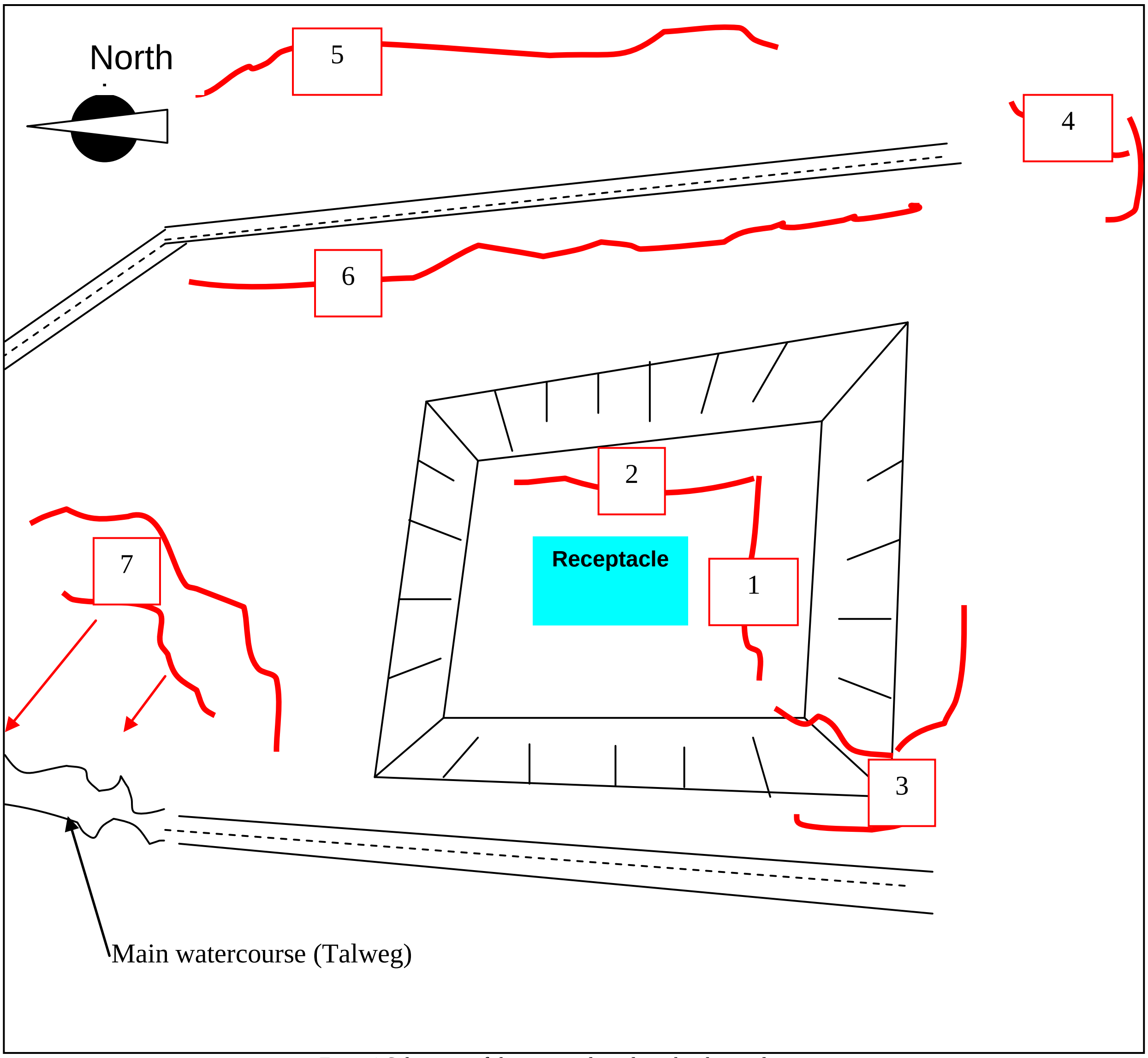

Figure1.Schematic of the receptacle and cracks observed

3 FACTORS PROMOTING THE SLIP

The state of the site and the analysis of the soil investigation have allowed to draw the following:

- The soil layer is obviously very sensitive clay to water. Resistant at intact state and plastic when wet.
- The excavation of the receptacle with a depth of up to 14 m with a single slope of 1/2.5 to 1/3 in a field of low resistance as indicated in the report of the soil study presents a slipping hazard. Calculations have shown that the slope of 14 m in height is very close to the critical balance (safety factor close to 1).
- The landslide of the entourage of the receptacle is probably initiated before the excavation of the receptacle but it is accelerated by the earthworks.
- The landslide of the entourage is due to the depth of the main watercourse just downstream of the receptacle.

4 PROPOSED SOLUTION

The sources of this landslide receptacle are:

- ✓ The main slope is very close to the critical balance according to the mechanical characteristics of soil and confirmed by the shape of slip observed in situ.
- ✓ Increasing the depth of the main watercourse caused by water flow over the years is the generator of massive landslides by regression of the watercourse to the installation areas of major receptacles of the landfill

Solutions have been proposed to stabilize the receptacle dug based on the elimination of the sources indicated above. The stabilization technique of sliding used is based on the relief of slopes by the use of berm of 5 to 12 m wide, with real slope of bank not exceeding 1/3. Varying the shape of the receptacle promotes the three-dimensional effect of the bank.

The use of the berm gives a slope more stable by increasing the potential sliding surface and reduces the loads acting on the sliding triggered surface which resists with the residual mechanical characteristics (characteristics lower than the natural characteristics of the site). In addition, the berm allows the movements of equipments during operation and construction phases. In conclusion, the berm allows to fixe better the geomembrane on banks particularly tall.

Seepage observed on the main bank fed by ground water or rain water stagnated at the crest of the slope must be drained to prevent water pressure destabilizing the geomembrane. The proposed solution is treated with a mask and a drainage trench running along the berm taking advantage of the existing bank. The three-dimensional effect of the bank allows to improve slope stability by discriminating against the creation of a sliding surface (Hoek and Bray 1981).

5 MODELING 3D OF THE RECEPTACLE WITH FLAC3D

Numerical simulations of the receptacle to calculate the safety factor have been carried out in this paper using the commercially available three-dimensional code FLAC3D (2000), Fast Lagrangian Analyses of Continua. This code uses an explicit finite difference program to study numerically the mechanical behaviour of a continuous 3D medium as it reaches equilibrium or steady plastic flow. The explicit Lagrangian calculation scheme and the mixed-discretization zoning technique (Cundall PA., 1987) used in FLAC3D ensure that plastic failure and flow are modelled very accurately (Benmebarek et al, 2008).

For the soil behavior, a linear elastic-perfectly plastic associative Mohr–Coulomb model encoded in FLAC3D is adopted. This robust model widely known and used in the simulations of geotechnical structures was selected and it has the advantage of requiring few parameters whose meaning is well represented, requiring the specification of a shear modulus G = 22 MPa, a bulk modulus K = 60 MPa, a unit weight γ = 20 kN/m3, a friction angle φ, and an angle of dilation $\psi = \varphi$ (Benmebarek et al, 2008, Khelifa T., 2008). In the code FLAC3D, it is preferable for the elastic properties of geomaterials to use the bulk modulus K and shear modulus G as the Young's modulus E and Poisson's ratio ν and the relationship between these coefficients is (1)

$$K = \frac{E}{3(1-2\nu)} \qquad G = \frac{E}{2(1+\nu)} \qquad (1)$$

The physical and mechanical properties used for numerical simulations are as follows: a density of 2 t/m3, a friction angle of 3 ° and a cohesion of 35 kPa. Visual inspection of the sliding bank of the receptacle (bead at the foot of the talus and cracks a few meters from the crest) corresponds to a friction angle of soil close to 3°. Computation of the safety factor is based on reducing cohesion C_u until a critical value causing failure (Cu^{cal} = Cu / Fs with Fs safety factor).

Effect of berm: Simulation results in 2D with FLAC (2000) have given a safety factor of 1.22 for the original form (without berm) and 1.57 for the proposed form (with berm) which corresponds to an improvement of 29% on safety factor.
three-dimensional effect: In order to relieve the current sliding surface and improve slope stability of a receptacle a change of shape was proposed to benefit from the three-dimensional effect of favoring bank stability

Landslides occurred in the bank of receptacle lead us to seek a new shape more stable. The use of a berm allows relief of side slope and thus reduce the risk of landslides. Figure 2 schematizes the proposed form and an overlay with the former. For the modelisation we have used the mesh shown in Figure 3 (7808 elements and 9093 nodes), which represents part of the receptacle. On the mesh we clearly see the berm slope 1/3

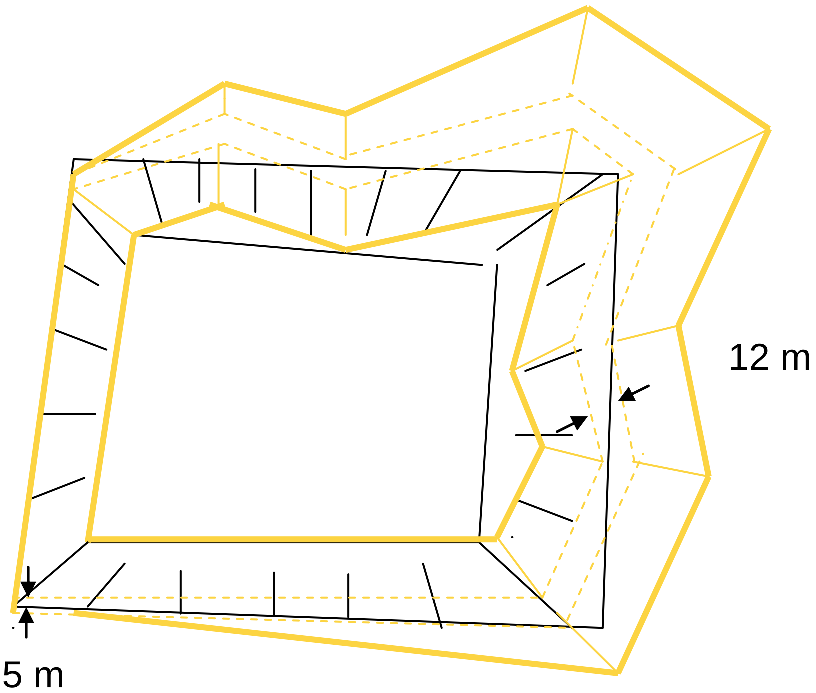

Figure 2. Superposition of the new form of receptacle with the old (solution with berm)

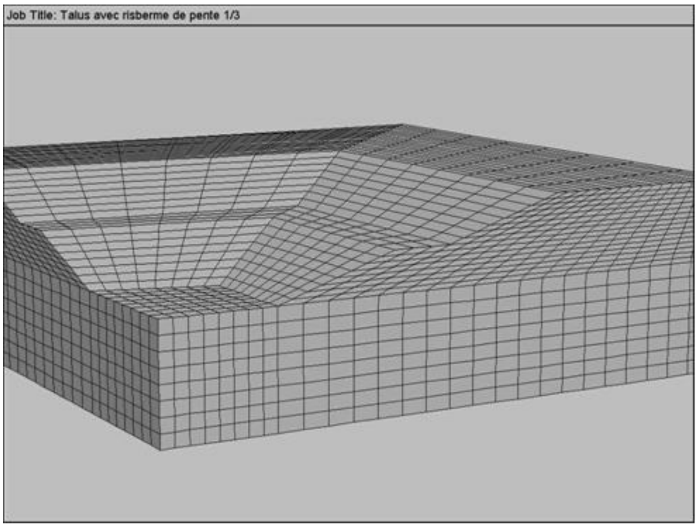

Figure 3. Mesh used 7808 elements and 9093 nodes (part of receptacle)

6 PRESENTATIONS OF RESULTS

In Figure 4 and 5 we have presented the vectors and contour displacements and on figure 6 form of the receptacle in case of slippage has been presented. Calculating the safety factor is based on reducing cohesion until a critical value causing rupture. For selected values we find a safety factor equal to 1.87. The sliding surface is slightly below the bottom of the receptacle. Photo 3 represents the receptacle in construction taking into considerations the new solutions proposed and on figure 7 an overview diagram of the site of discharge is shown.

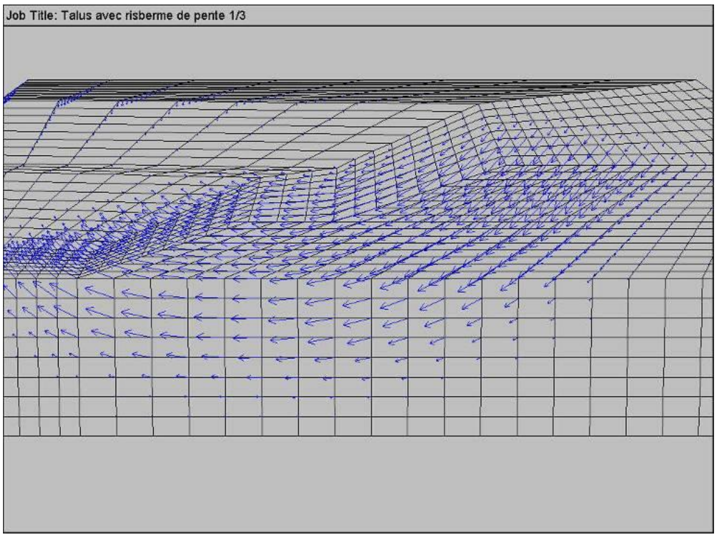

Figure 4. Vectors of displacements (φu =3°, Cu = 35 kPa)

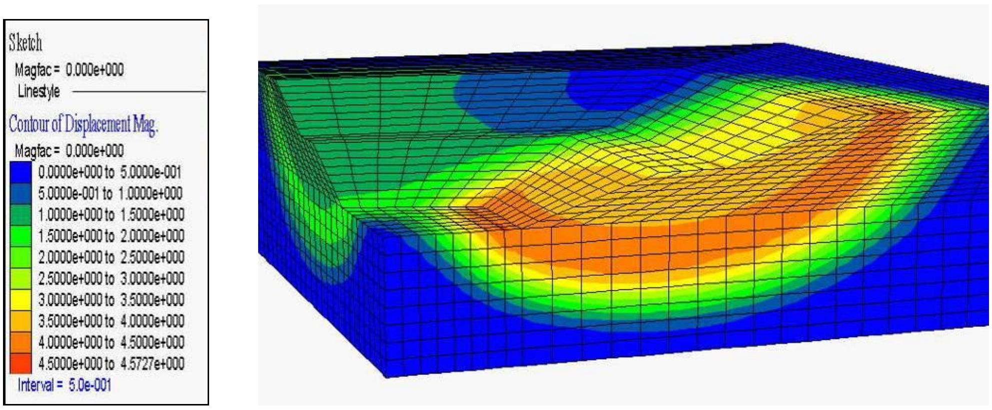

Figure 5: Contour of displacements (φu =3°, Cu = 35 kPa)

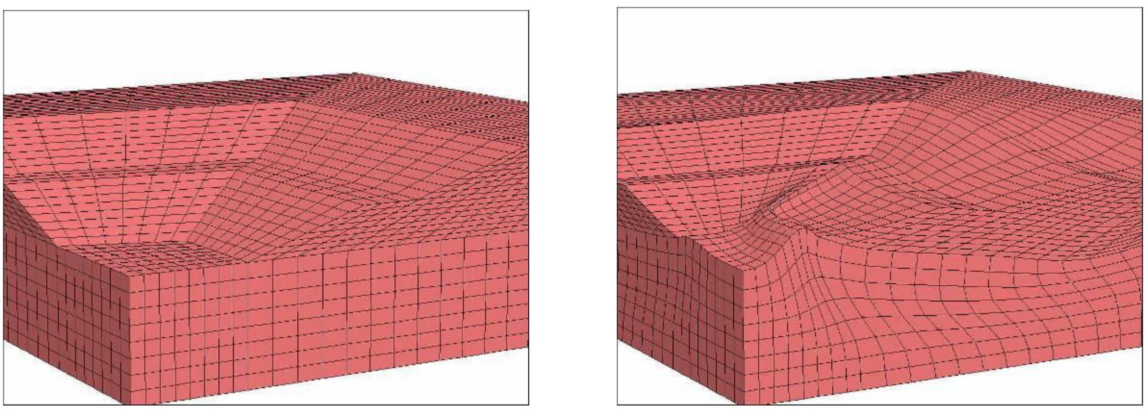

Figure 6.Form of the receptacle, stable and in case of slippage

Photo 3. Receptacle with berm in construction

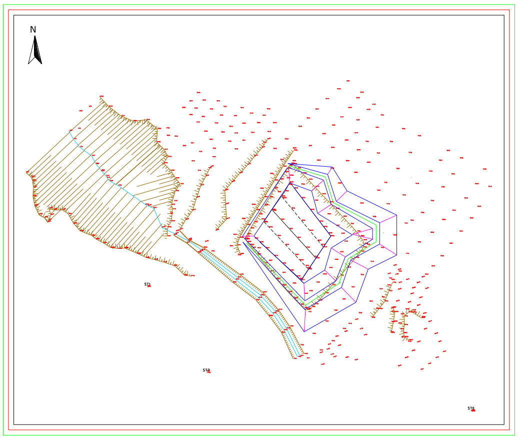

Figure7. Diagram of a global view of the receptacle by taking the new form more stable

7 SUMMARIES AND CONCLUSION

Through these three-dimensional numerical simulations we can draw the following conclusions:

- The site and the bank of the landfill present emanating global risk of landslide;
- Some mechanical properties of various core samples indicate a risk of slippage of the receptacle ground dug with a bank of 14 m high with a single slope;
- The proposed solution improves stability by increasing the volume of the discharge. It is based on the relief and improving the slope stability of the landfill using a berm, and a change in the geometry of the receptacle engaging three-dimensional effect;
- Modeling in 2D with the software Flac underestimates the safety factor of this receptacle.

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