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Assessments of Internal Erosion in a Landfill Due to Changes in Groundwater Level

Siamak Feizi, Gunvor Baardvik

Abstract**—**Soil erosion has special consequences for landfills that are more serious than those found at conventional construction sites. Different potential heads between two sides of a landfill and the subsequent movement of water through pores within the soil body could trigger the soil erosion and construction instability. Such condition was encountered in a landfill project in the southern part of Norway. To check the risk of internal erosion due changes in the groundwater level (because of seasonal flooding in the river), a series of numerical simulations by means of Geo-Seep software were conducted. Output of this study provides a total picture of the landfill stability, possibilities of erosions and necessary measures to prevent or reduce the risk for the landfill operator.

Keywords**—**Erosion, seepage, landfill, stability.

I. INTRODUCTION

LANDFILL sites are specified areas for the disposal of waste materials. According to [1], the continually growing human activities in the last decennia has accompanied a very rapid increase of any type of wastes. Thus, the need for disposal of wastes in a systematic way is very demanding in the 21st century.

In landfills and in any earth system, soil is the key element in controlling hydrological, erosional, and geochemical cycles. Therefore, it is important to study on human activities and pollution on soil. Land degradation caused by human activities has significant adverse effects on the environments and ecosystems worldwide, see [2]-[4]. The waste type, activities in and around landfills, subsidence of the waste over time and their post-closure care requirements are amongst parameters that should be considered in the design process and control of a landfill during the operational life. The soil particle movements under seepage flow are one of the main mechanisms for incidents and failure in dams and streambanks, also in landfills [5], [6]. Due to a very major consequence of a site failure, a landfill operator must be aware of any structural weaknesses that could lead to any instability.

According to the basic physics rule, water flows always occur from a higher potential location to a lower potential. This flow and water movement through pores can trigger the soil erosion and may cause some instability in the constructions. This phenomenon is especially important in landfills due to existence of water material. This potential difference and possible water movements were encountered in a landfill project in Norway. There is a potential existence of sand/gravel (which is called a core zone in this paper) under an old railroad which is located in front of the landfill. The soil in the landfill itself consists of coarse material. In absence of proper soil investigation, there is limited information regarding the conductivity properties of the landfill material compared to the filling part. In connection with the flood in 1995 at that region, the front of the landfill was secured against external erosion with an approximately 1 m thick layer of stone blocks. In the monitoring work under the closure of the landfill, there are however registered particles in the water at the measuring point. The stone blocks made it difficult to find out exactly where the water with particles comes from. It was therefore unclear whether the particles in the water come from the zone in front of the stone plaster or they are transported with the water out of the landfill which may increase the risk of erosion in the landfill.

The main goal of this study is to check development of internal erosion and water movements (which could be due to flooding in the river) through a series of numerical analysis in geo-Seep program. Findings will provide useful data such as possibility of erosions, risks locations and necessary measure to mitigate/reduce risks to the landfill operator.

The analyses were performed for the most realistic cases with a total head difference between external (upstream-UP) and internal (downstream-DS) water levels of up to 2.5 m.

II. CRITICAL GRADIENT

Flow current can lead erosion in the landfill body which is behind instability of several mechanisms. The onset of seepage erosion in soil is assessed on the basis of hydraulic criteria, especially in relation to the critical hydraulic gradient. This parameter is usually defined as the critical condition in which the soil's effective stress becomes negligible.

The critical gradient is usually calculated according to (1) as determined by [7]:

$$i_c = (\gamma_s-\gamma_w) / \gamma_w (1-n) \qquad (1)$$

In this equation, γ_s is the specific gravity of soil, γ_w is the specific gravity of water, and n is the porosity.

According to available laboratory data, for the mentioned landfill in Norway, a porosity range varies between 0.2-0.3 for the filling material, thus the critical gradient (according to [1]) varies from 0.7 to 0.8. Although Terzaghi [7] suggested that the critical gradient depends only on the porosity and the specific

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gravity, it is however in both the field and in the laboratory has been observed that seeping erosion can start in gradients in the much lower gradients than those determined by Terzaghi's classical approach. According to [8]-[10], the theoretical critical gradients i_c could be as low as shown in Table I, which generally indicate a greater risk of erosion if they are exceeded. So, parameters such as relative density, porosity, particle size distribution and especially d_{15} and material type are among those that have the greatest effect on critical gradients.

TABLE I
CRITICAL GRADIENT RANGE

Soil type	i_c [-]
Gravel	0.20-0.33
Coarse sand	0.15-0.20
Fine sand	0.12-017

Based on the discussions above and available data for the mentioned landfill in Norway (which is very limited), gradients above 0.5 are assumed to be critical gradients at this field.

III. METHODOLOGY

The modelling was carried out by means of Seep /W (GeoSlope Int. -2019), [11]. Because of the high heterogeneity of the landfill material, several properties and combinations were tested in the models. In all analysis, the "steady state" model with constant boundary conditions have been used, see Fig. 1.

A. Input Parameters

The main input parameters in seepage analysis are the soil density (γ_t) and hydraulic conductivity (permeability coefficient). Table II presents input parameters used in the seepage analysis.

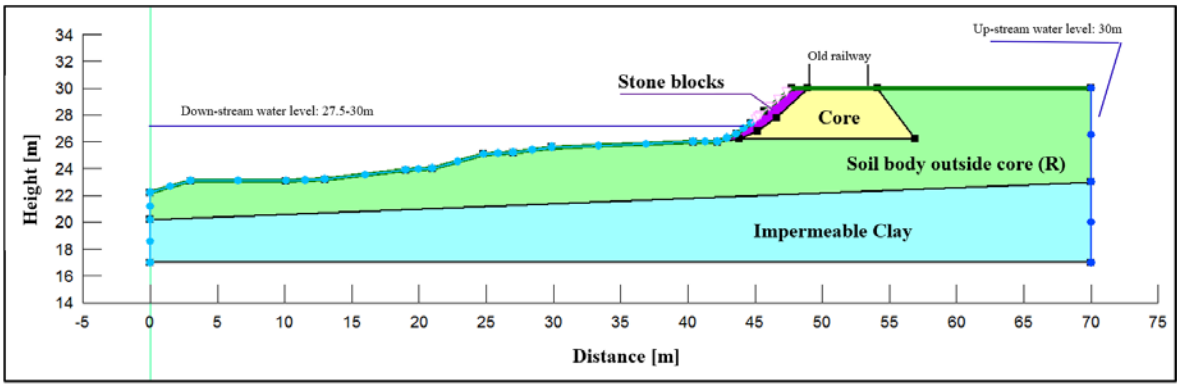

Fig. 1 2D section of the embankment with filling under the railway with coarse material corresponding to gravel and sand. Boundary conditions and other materials are indicated.

TABLE II
INPUT PARAMETERS

Soil type	γ_t [kN/m^3]	Permeability [m/s]
Clay (C)	18.5	~ 1e-9
Sand (M3)	19	~ 1e-4
Gravel (M4)	20	~ 1e-3
Stone block	21	~ 1e-2

B. Water Level at up/down Streams of Landfill

Two situations have been seen where height differences can occur in front of and behind the front of the landfill. One is the height difference that follows from the fact that the front is not very permeable and that it will therefore establish a high water level inside the landfill and low water level in front, at low tide in the river. Fig. 2 shows a section of a longitudinal profile where the water level from the front and inwards in the landfill is interpolated based on measurements in the wells. The water level in the wells in the length profile is from different years, when wells B107 and B112 were taken out of operation when the zoning of the landfill began in 2014/2015. In the summer of 2020, it became possible to re-measure water levels in well B104 in the middle of the landfill. It is located 175 m from well B109. The water level measured in 2020 in well B104 (elevation 31.6) harmonizes well with the measurements in wells B107 and B112 from 2013 and 2014. The estimated water line in Fig. 2 is therefore further selected as the basis for gradients for leachate flow from the landfill in the normal situation.

The second is the situation where a big difference in the water head between upstream and downstream of the landfill occurs. Fig. 3 shows the elevations experience the flood in 1995 where the top elevation went up to 30 m. Normally high spring floods have a water level around elevation 27 to 27.5 m. Thus, in the simulations, two water level levels are used at downstream (DS); elevation 27.5 m and elevation 29.0 m, which give height differences of respectively 2.5 m and 1 m assuming the upstream (UP) elevation at 30 m. The groundwater level in the landfill's upstream is fixed to elevation 30 m and used in all cases. Elevation 30 m is the highest flood water level and is in line with the surface in front of the landfill along the road. The landfill is, as previously mentioned, erosion-protected by a layer with stone blocks of approximately 1 m which is simulated with a very high permeability coefficient.

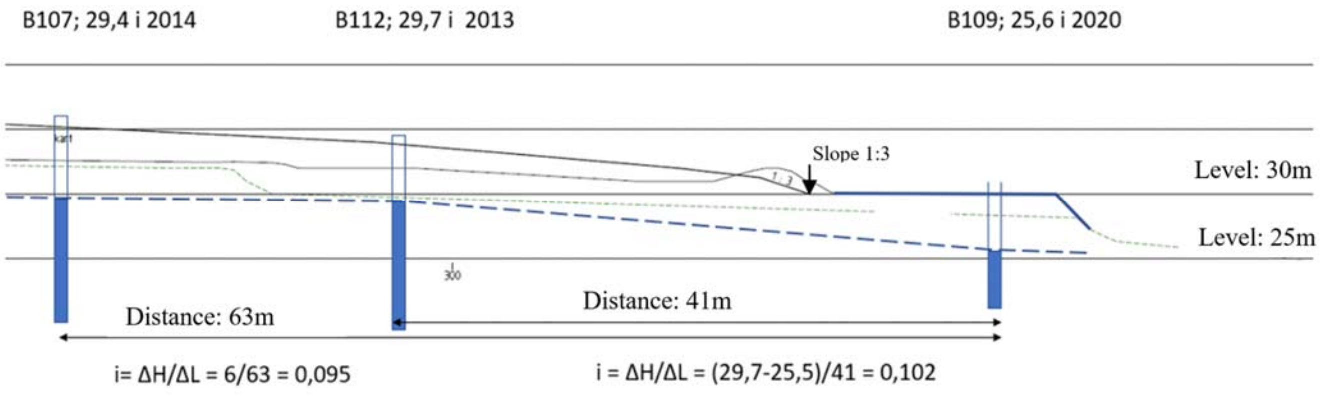

Fig. 2 Longitudinal profile with estimated water level and gradient towards the river

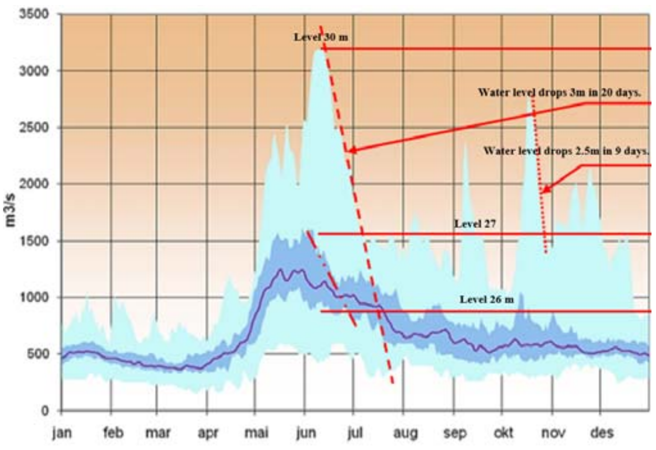

Fig. 3 The time it takes for the water flow in river to fall after flood periods [12]

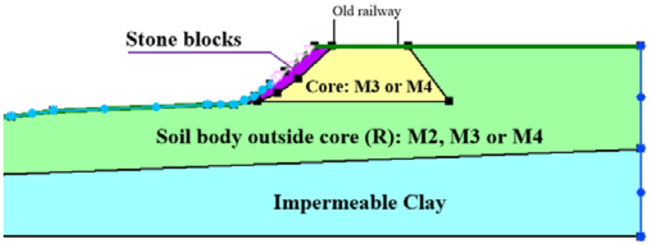

Fig. 4 Overview of the landfill zones: filling under railroad(C) and the outside the railroad area (R)

TABLE III
LIST OF ANALYZED SCENARIOS

Material type (R)	Material type (C)	Water level @ UP	Water level @ DS	Head difference [m]
M2	M3	30	27.5 to 29	2.5 to 1
M2	M4	30	27.5 to 29	2.5 to 1
M3	M3	30	27.5 to 29	2.5 to 1
M3	M4	30	27.5 to 29	2.5 to 1
M4	M3	30	27.5 to 29	2.5 to 1
M4	M4	30	27.5 to 29	2.5 to 1

C. Analysis Scenarios

In absence of detailed soil information about the landfill properties, the six most probable scenarios were considered in analysis which are listed in Table III. Fig. 4 introduces material zoning. In this figure, M2 stands for silt, M3 for sand and M4 for gravel. The zone under railway is called core zone (C) and it is expected to have filling material with higher permeabilities due to existence of old railroad (i.e M3 and M4). Areas outside of core under the railway are called with R and can consist of silty (M2), sandy (M3) or gravely (M4) materials.

IV. RESULTS

Results of simulations for the presented cases in Table III are shown in Figs. 5-10. In these figures, contours of gradations together with the flow vectors are illustrated. The first impression is that results are very depended on material properties under the railroad zone(core).

With a more permeable material under the railroad than the outside area, hydraulic gradients develop at the interface between the core and the outside core and therefore give less erosion risk. Due to higher local gradients (> 0.5), however, there is a risk of partial transport and the core clog with fine material, but it is not expected to have a major effect on the water movement in the landfill, see Figs. 5-7 and 9 (a). If the material outside the railroad (R) is coarser and more permeable than the core, the core itself will have little effect on gradients, and the high gradients will only develop towards the outside of the embankment just below the stone blocks, see Figs. 7 and 8 (a). In this case, the risk of erosion is high, and the water velocity can be much higher. However, such conditions can only exist for a short period of time before the groundwater level drops because of the groundwater level being lower naturally in coarse masses, and the gradients decrease after a short time. In addition, gradients are, in general, much lower in the case with the downstream (DS) water level on 29 m, and gradients are below the critical gradient (0.5), see Figs. 5-10 (a) and (b). Thus, in the case with DS water level at 29 m, no erosion occurs. The main reason for this is very small total head's (about 1 m) difference between upstream and downstream heads.

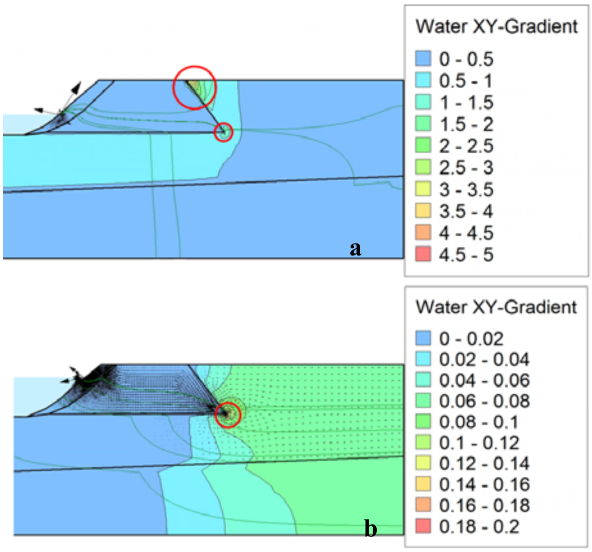

Fig. 5 Location of highest gradients for R: M2; C:M3, water level at DS is 27.5 m and 29 m for (a) and (b), respectively

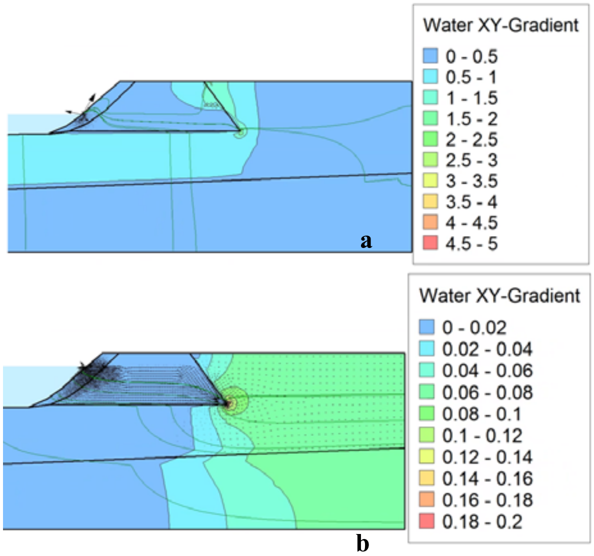

Fig. 6 Location of highest gradients for R: M2; C:M4, water level at DS is 27.5 m and 29 m for (a) and (b), respectively

V. SUMMARY AND CONCLUSIONS

Analysis shows that there are certain risks of erosion when the material around the core is coarser and more permeable than the core material. In such case, the core itself has little effect on gradients, and the high gradients develop towards the outside of the embankment, and just below the boulders. However, as emphasized before, such conditions will only exist for a short period of time before the groundwater level drops due to high permeability in coarse masses.

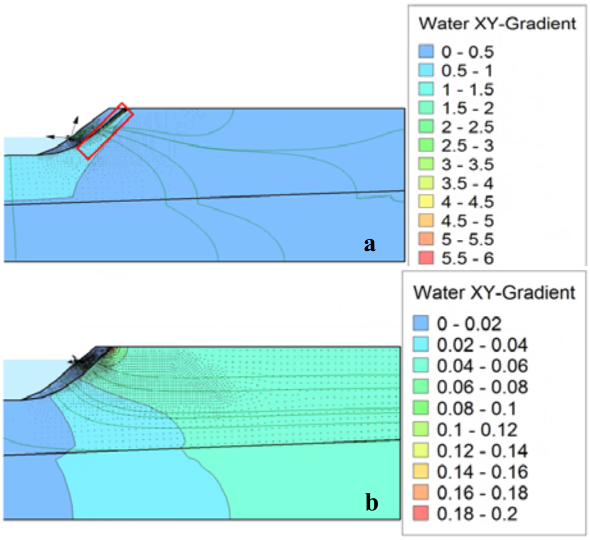

Fig. 7 Location of highest gradients for R: M3; C:M3, water level at DS is 27.5 m and 29 m for (a) and (b), respectively

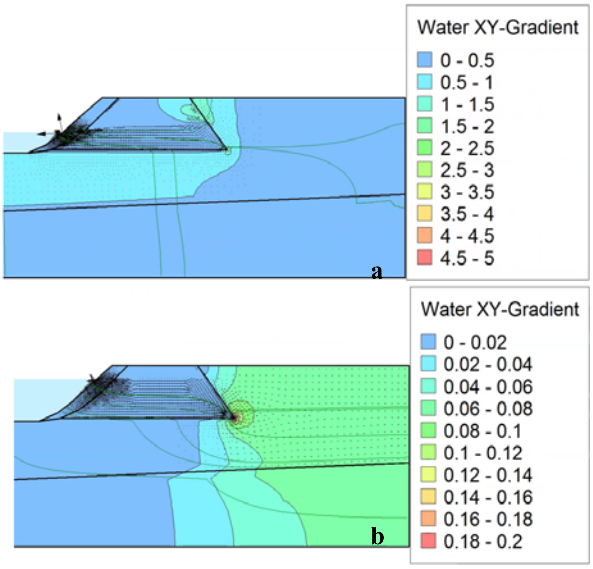

Fig. 8 Location of highest gradients for R: M3; C:M4, water level at DS is 27.5 m and 29 m for (a) and (b), respectively

Gradients are much lower when the DS water level is at 29 m where the total head between upstream and downstream is very small (1 m). In this case, no erosion is expected in any of the cases. To limit the effect of such high flow velocities and gradients in some possible scenarios, a boulder material (known as a "rip-rap") might be an alternative near the slope toe to cover the entire area below the level of protected rock paving from the last phase. This material is used to stabilize slopes that are unstable due to flow, also used to reduce the rate of concentrated runoff, which in turn increases the potential for infiltration. The filter between the boulders and the core with the right material and using filter material might be an option, however the costs and installation time are parameters should be considered by the landfill operator.

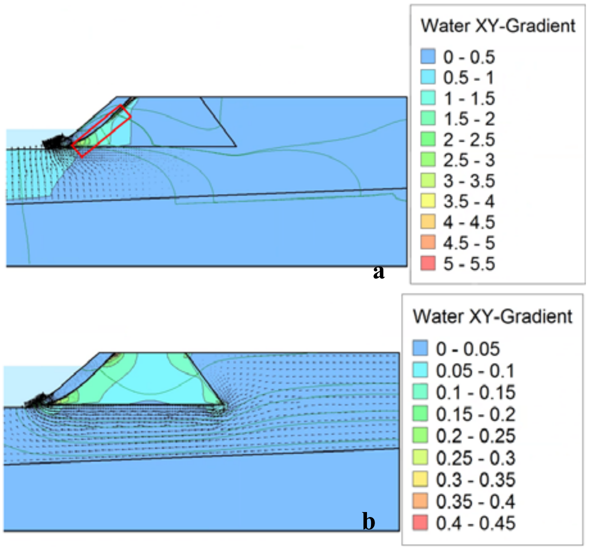

Fig. 9 Location of highest gradients for R: M4; C:M3, water level at DS is 27.5 m and 29 m for (a) and (b), respectively

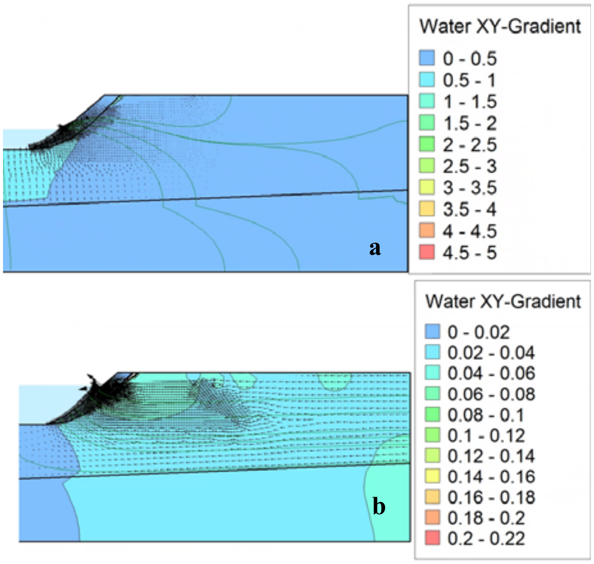

Fig. 10 Location of highest gradients for R: M4; C:M4, water level at DS is 27.5 m and 29 m for (a) and (b), respectively

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