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Geotechnical Modeling of Municipal Solid Waste Landfill Slope Stability: Two-Dimensional and Three-dimensional Limit Equilibrium Analyses

Modelagem Geotécnica da Estabilidade de Taludes de Aterros Sanitários de Resíduos Sólidos Urbanos: Análises de Equilíbrio Limite Bidimensional e Tridimensional

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Abstract: This study conducts a comparative evaluation of 2D and 3D slope stability analyses for landfill applications under varying geometric and hydrogeological conditions. Stability assessments were performed using Slide2 and Slide3 software, applying the limit equilibrium method with the Morgenstern-Price formulation to determine critical failure surfaces and corresponding factors of safety. two hydrogeological scenarios: (1) an unsaturated condition with zero pore-water pressure and (2) a saturated condition with a 17-meters piezometric level. Results indicate that 3D modeling enhances spatial resolution, enabling precise identification of localized instability zones. However, despite its geometric simplifications, the 2D approach remains reliable. These findings suggest that the decision between 2D and 3D analyses should account for factors such as landfill geometry, computational resources, and the required precision for risk assessment.
Keywords: Municipal solid waste; Landfill slope stability; Limit equilibrium method; Three-dimensional analysis; DEM modeling**.**

Resumo: Este estudo realiza uma avaliação comparativa de análises de estabilidade de taludes em 2D e 3D para aplicações em aterros sanitários sob diferentes condições geométricas e hidrogeológicas. As avaliações de estabilidade foram realizadas utilizando os softwares Slide2 e Slide3, aplicando o método do equilíbrio limite com a formulação de Morgenstern-Price para determinar as superfícies de ruptura críticas e os respectivos fatores de segurança. Foram considerados dois cenários hidrogeológicos: (1) condição não saturada com pressão da água nos poros nula e (2) condição saturada com nível piezométrico de 17 metros. Os resultados indicam que a modelagem 3D aprimora a resolução espacial, permitindo a identificação precisa de zonas de instabilidade localizadas. No entanto, apesar das simplificações geométricas, a abordagem 2D permanece confiável. Essas descobertas sugerem que a decisão entre análises 2D e 3D deve levar em consideração fatores como a geometria do aterro, os recursos computacionais disponíveis e a precisão necessária para a avaliação de riscos.
Palavras-chave: Resíduos Sólidos Urbanos; Estabilidade de taludes em aterros sanitários; Método do equilíbrio limite; Análise tridimensional; Modelagem de Modelo Digital de Elevação (MDE).

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1. Introduction

Slope stability is a crucial aspect of landfill design and operation, requiring comprehensive analysis to ensure structural integrity and long-term functionality. Several factors influence landfill slope behavior, including the composition and mechanical properties of waste, slope geometry, the characteristics of the soil used in the base and cover layers, pore pressure conditions and external loads acting on the slope (Qi et al., 2021). Accordingly, a comprehensive stability assessment is essential for mitigating risks such as landslides, erosion, and contamination (Bahia et al., 2025). For landfill stability analysis, it is necessary to evaluate shear stress distribution and other geotechnical parameters along potential failure surfaces to determine the Factor of Safety (FS). This parameter is a critical indicator of slope reliability and must be validated in accordance with established technical standards (Nasiri and Hajiazizi, 2020).

Slope stability analysis in landfill engineering employs both two-dimensional (2D) and three-dimensional (3D) methodologies, with persistent scholarly discussion regarding their respective advantages and limitations (Feng et al., 2018; Gitirana Jr et al., 2019; Santos et al., 2025; Wu et al., 2024). Historically, 2D analysis has dominated practice due to its simplified planar representation of landfill geometry, offering computational efficiency and procedural familiarity. Furthermore, the limited availability of three-dimensional geotechnical data and the increased computational demands associated with 3D modeling often restrict its application in landfill engineering (Rao et al., 2024).

In practical applications, 3D slope stability analyses are less frequently utilized, typically reserved for cases involving highly irregular geometries or complex failure mechanisms where lateral variations and topographic irregularities become critical. While a 2D approach is generally sufficient for analyzing symmetrical cross sections along the longitudinal direction, asymmetric conditions introduce additional complexities that require a more comprehensive evaluation. A two-dimensional model may not adequately capture the actual behavior of the soil or structural components, as it does not account for variations in geometry and material properties in all spatial directions (Chakraborty and Goswami, 2016; Leshchinsky and Baker, 1986).

The 3D approach enables more accurate characterization of topographic irregularities, terrain variations, and heterogeneous soil properties, enhancing the reliability of stability assessments compared to conventional 2D analyses (Rao et al., 2024). By providing a more comprehensive evaluation of slope behavior, 3D methods mitigate the excessive conservatism of 2D-derived factors of safety while identifying critical failure surfaces that may remain undetected in planar analyses (Zhang et al., 2022).

Three-dimensional stability analysis techniques rely on topographic models capable of accurately representing slope discontinuities, which are often obtained using digital photogrammetry techniques (Singh et al., 2022). In this context, the rapid advancement of image acquisition technologies has facilitated the use of Unmanned Aerial Vehicles (UAVs) for photogrammetric surveys, enabling the generation of high-precision Digital Elevation Models (DEMs). These models reconstruct the three-dimensional surface with exceptional accuracy (Baiocchi et al., 2019), allowing for a more precise evaluation of potential failure surfaces (Vemulapalli and Mesapam, 2021).

In the context of landfill engineering, the occurrence of slope failures over the past decade underscores the need for more advanced stability analyses in these structures (Datta and Sivakumar Babu, 2016; Li et al., 2019; Rao et al., 2024). Three-dimensional stability analyses are particularly relevant, as they account for complex scenarios involving significant variations in slope geometry and heterogeneous and/or anisotropic waste materials (Chen et al., 2024; Shiau et al., 2023). Given these factors, expanding the scope of stability assessments is essential to ensure a more accurate and reliable evaluation of landfill slope behavior.

Stark and Eid (1998) highlight the advantages of 3D stability analyses in slope designs characterized by complex topography, shear strength variations, or pore pressure conditions. Several studies have conducted stability assessments for landfills, predominantly employing 2D approaches, reinforcing a well-established tradition in the technical literature (Cirolini et al., 2020; Damasceno et al., 2020; Medeiros et al., 2020; Munwar Basha and Raviteja, 2018; Remédio, 2014; Silva, 2011; Strauss, 1998; Zhan et al., 2008). However, the limited number of studies focusing on 3D stability analyses in landfill engineering suggests a significant research gap in evaluating the influence of three-dimensional effects on slope behavior.

Therefore, this study aims to evaluate landfill slope Behavior using both 2D and 3D analyses to assess the effectiveness of these approaches in characterizing the geotechnical behavior of landfills under varying conditions. By integrating 2D and 3D methodologies, this research seeks to advance the scientific understanding of three-dimensional effects on landfill stability.

2. Methodology

2.1. Input data

The stability analysis of landfills relies on accurate geotechnical input data, including the mechanical properties of the solid waste layers (waste with varying degrees of decomposition) and soil layers, as well as the piezometric levels of leachate within the waste mass. In this study, the geotechnical parameters (friction angle, cohesion, and unit weight) of the Municipal Solid Waste (MSW) and surrounding soils, along with the leachate piezometric level, were obtained from Araújo Neto (2021).

The stability assessment considered two hydrogeological scenarios to evaluate the influence of leachate levels:

- Scenario 1 (Unsaturated Condition): No piezometric surface within the waste body, representing the most favorable stability condition.
- Scenario 2 (Saturated Condition): A piezometric surface at 17 m depth, corresponding to the maximum recorded level during monitoring and representing the most critical stability condition.

Table 1 summarizes the geotechnical parameters for MSW and soils under both scenarios.

Table 1 – Geotechnical parameters of MSW and soils for the two analyzed scenarios.

Material	Unit Weight (KN/m³)	Cohesion (kPa)		Friction Angle (°)	
		Scenario 1	Scenario 2	Scenario 1	Scenario 2
Recently deposited waste	10	1.4	5.2	28.3	21.6
One-year-old waste mass	15	41	52.7	35.6	27
Two-year-old waste mass	15	41.6	28.4	31.9	29.7
Cover layer	14.5	7.8		31	
Liner layer	18.8	1.7		26	
Subsoil	14.5	7.8		31	
Rock	26	-		-	

Source: Adapted from Araújo Neto (2021).

The piezometric level data were obtained through continuous monitoring of piezometers installed within the landfill cell, utilizing an electronic sensor. For the stability analysis, the most critical recorded level (17 meters) was selected, which remained below the maximum observed level of 30 meters at the landfill plateau.

2.2. Critical sections

The critical cross sections for the two-dimensional stability analyses were defined based on the landfill topography, following the direction from the highest to the lowest elevation of the waste body. This approach was adopted to ensure the selected cross sections represent the most unfavorable stability conditions. Figure 1 presents the geometric configuration and the designated cross sections utilized in the stability assessments.

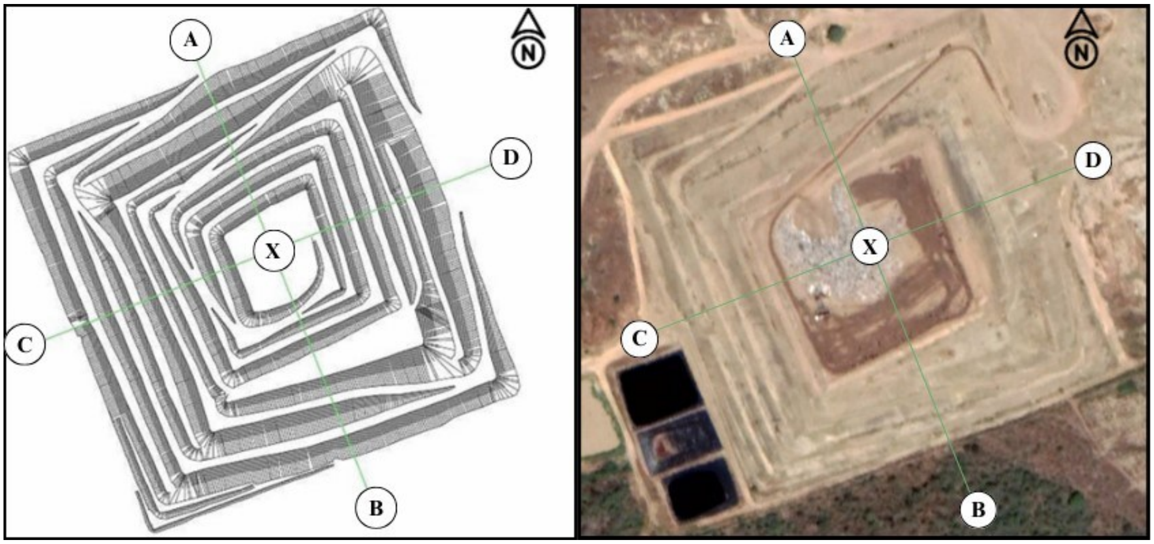

Figure 1 – Layout of critical cross sections for stability analysis (aerial view).
Source: Adapted from Araújo Neto (2021).

2.3. Analysis Methods

The Limit Equilibrium Method (LEM) was selected for analyzing the stability of landfill slopes. This approach is widely recognized as the traditional and predominant technique for assessing the stability of soil slopes (Qi et al., 2021). Numerous studies have applied LEM in landfill stability assessments, including those by Seed et al. (1990), Zhan et al. (2008), Jahanfar et al. (2017), Munwar Basha and Raviteja (2018), Li et al. (2019), Damasceno et al. (2020), and Medeiros et al. (2020), reinforcing its reliability and extensive use.

Within the limit equilibrium framework, the Morgenstern-Price method was selected due to its ability to satisfy all static equilibrium conditions and its widespread adoption in professional practice. This method is recognized for its robustness and conservative nature (Moawwez et al., 2021), ensuring reliable stability assessments. Additionally, it accounts for the interaction between slices, leading to a more accurate representation of the landfill mass behavior (Rahardjo and Fredlund, 1984).

Advanced methods, such as the Morgenstern-Price method, require an iterative trial-and-error calculation process to achieve moment and force equilibrium in each slice, making manual computations impractical (Abramson et al., 2001). Consequently, various computational tools have been developed to facilitate slope stability analysis. These software programs can accommodate complex geometries, diverse shear strength parameters, varying pore pressure conditions, and external loading scenarios. Additionally, they enable the automated identification of the most critical failure surface associated with the lowest factor of safety (Duncan and Wright, 2005).

The slope stability analyses were conducted using Slide2 and Slide3 software from Rocscience, established tools in geotechnical engineering with demonstrated reliability in academic and professional applications (Jahanfar et al., 2017). Slide2 employs limit equilibrium methods to compute the FS for both circular and non-circular failure surfaces in soil or rock slopes (Rocscience, 2025a). Slide3 extends this capability to three-dimensional analyses, utilizing a 3D method of columns to assess 3D failure mechanisms (Rocscience, 2025b).

In this study, Slide3 was particularly valuable in overcoming computational constraints associated with processing complex 3D geometries, which often present challenges in conventional stability analysis software. Both programs employed automated failure surface detection to identify critical slip surfaces based on the input geotechnical parameters, with FS calculations conducted using rigorous limit equilibrium methods.

2.4. Development of a Three-Dimensional Slope Stability Model

A three-dimensional geotechnical model of the landfill was developed utilizing a high-resolution DEM as the primary topographic dataset, effectively depicting the layout of the landfill cells throughout the study period. The data acquisition was conducted through photogrammetry, with a DJI Phantom 2 UAV, allowing for a 3D surface reconstruction. This methodology facilitated robust numerical modeling and simulation, aligning with the approaches previously demonstrated by (Chand and Koner, 2023). Digital Elevation Models serve as essential tools, providing critical digital topographic data that is vital for spatial analyses and geotechnical assessments. These models represent the Earth's surface in three dimensions, enabling the extraction of essential terrain parameters such as slope and elevation (Gomes et al., 2022).

To streamline the integration of the 3D model into Slide3 while overcoming computational limitations, the DEM was converted to a point cloud format using QGIS (Version 3.28.6). The conversion process involved first vectorizing the DEM into a raster file, then extracting pixel values to generate a regularly spaced set of points, from which terrain coordinates and elevations were obtained.

This process results in a vector points layer containing elevation attributes. Subsequently, the geospatial dataset is imported into the Slide3 computational environment for the slope behavior analysis. The software performed surface triangulation of the point cloud to reconstruct a continuous representation of the landfill geometry (Figure 2a). This triangulated surface served as the basis for all subsequent stability calculations (Figure 2b). Ultimately, the generated model was validated through data consistency verification and interpolation error analysis. This involved verifying data consistency, calculating interpolation errors, and rectifying any identified discrepancies (Figure 2c).

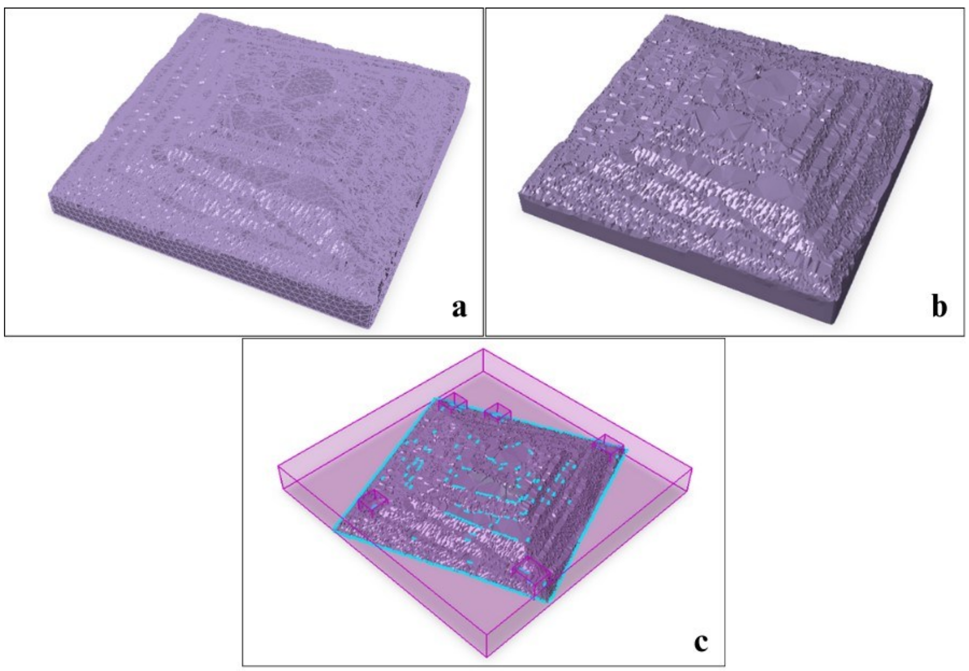

Figure 2 – DEM generation process in Slide3: a) Mesh generated after point set triangulation; b) Surface model after triangulation; c) Fault detection for surface correction.
Source: Authors (2026).

Following the generation of the elevation grid and resolution of any geometric inconsistencies, the DEM undergoes refinement through additional processing steps. These may include surface smoothing operations to enhance topographic representation where required. The finalized DEM is systematically documented, with particular attention to specifying elevation scales for distinct terrain segments (Figure 3). This processed dataset is then prepared for implementation in subsequent analyses, including the slope stability assessments central to this study.

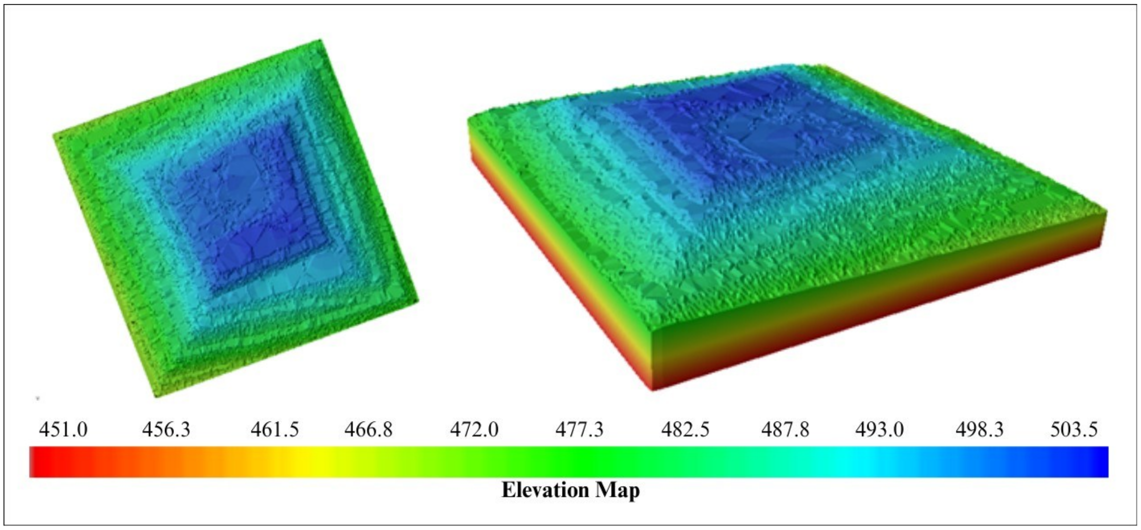

Figure 3 – MDE generated using Slide3 software.
Source: Authors (2026).

To enhance the geometric and geotechnical accuracy of the landfill model, the 3D modeling representation incorporated stratigraphic components, including the soil layers (liner and cover layers), waste body, and internal pore pressure. The stratification of the study area was modeled using the Borehole Manageri tool in Slide3, which facilitates the simulation of boreholes to define representative material layers within the 3D model. This process enabled the delineation of boundary surfaces corresponding to the various landfill components.

Using this tool, boreholes were assigned with data on the thickness configuration of the representative layers within the landfill cell in the 3D model. The borehole configuration was adapted from two-dimensional cross sections to accurately reproduce the stratigraphy of the landfill, incorporating information from Araújo Neto (2021). Subsequently, the software executed an interpolation process to delineate the layers, effectively characterizing the geotechnical properties of the waste and soil constituents within the landfill.

3. Results

3.1. Two-dimensional slope stability analysis

3.1.1. Two-dimensional analyses for Scenario 1

For Scenario 1, stability analyses were conducted on cross sections A-X, B-X, C-X, and D-X. Figure 4 presents the most critical factor of safety results for each section, as determined by the software used in the analysis.

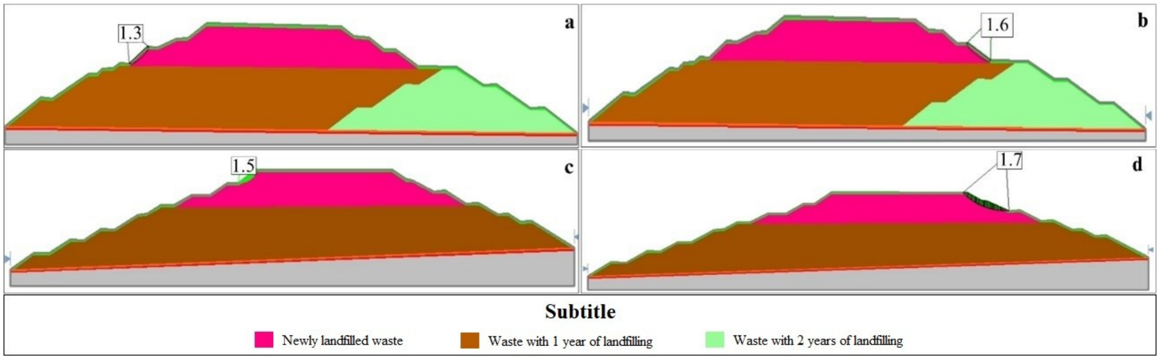

Figure 4 – Distribution of factors of safety in the most critical cross sections of Scenario 1: (a) Cross section A-X (profile AB); (b) Cross section B-X (profile AB); (c) Cross section C-X (profile CD); (d) Cross section D-X (profile CD). Source: Authors (2026).

The stability analyses identified minimum factors of safety along critical failure surfaces within the upper regions of the waste cell (Figures 4a-4c). These reduced stability conditions correlate directly with zones containing recently deposited waste, where limited backfill duration has diminished shear strength characteristics. The geotechnical behavior of MSW exhibits significant temporal variability, with recently placed waste demonstrating inferior mechanical properties compared to material undergoing one to two years of backfilling. This strength discrepancy arises from differential consolidation histories. Older landfilled waste (1-2 years) benefits from progressive overburden loading as subsequent waste layers are placed, inducing substantial consolidation and consequent strength enhancement. Conversely, recently backfilled MSW layers had not yet been exposed to significant overburden pressure and remain in the preliminary stages of biodegradation, resulting in both lower density and reduced shear resistance.

The unit weight of MSW is directly influenced by overburden pressure, which refers to the load exerted by the overlying waste and soil layers. In deeper layers of landfills, the increased overburden pressure results in heightened waste density, particularly following a certain stage of stabilization induced by biodegradation (Townsend et al., 2015). Consequently, MSW in deeper layers tends to be denser than recently compacted waste near the surface. In the context of Scenario 1, waste profiles characterized by elevated unit weights and located in deeper layers demonstrated higher factors of safety. In contrast, profiles exhibiting lower specific weights, typically linked to recently deposited waste, revealed lower factor of safety values.

Supporting these findings, Feng et al. (2017) examined the geotechnical properties of MSW and observed that waste density increased while compressibility decreased with depth, based on unit weight measurements from both surface samples and samples collected at a depth of 16 meters. Similarly, Awad-Allah (2022) investigated the stability of landfills using geotechnical parameters obtained from field tests, concluding that factor of safety values were significantly influenced by the inclination of side slopes and shear strength parameters.

A significant observation from Scenario 1 is the absence of pore pressure development within the waste mass, as no liquid or gas accumulation was detected. Under these conditions, the spatial distribution of critical failure surfaces was predominantly controlled by the shear strength and unit weight of the waste layers, which aligns with the identification of failure surfaces in the upper landfill layers. Furthermore, temporal fluctuations in FS may be attributed to several factors such as climatic conditions, sampling depth, and waste degradation extent (Cox et al., 2015).

3.1.2. Two-dimensional analyses for Scenario 2

For Scenario 2, the factor of safety results for each analyzed cross section are presented in Figure 5.

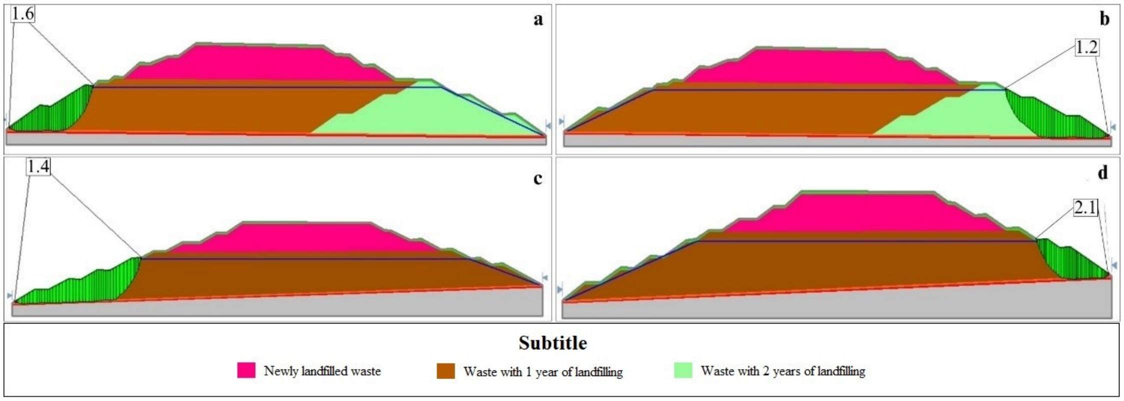

Figure 5 – Distribution of factors of safety in the most critical cross sections of Scenario 2: a) Cross section A-X (profile AB); b) Cross section B-X (profile AB); c) Cross section C-X (profile CD); d) Cross section D-X (profile CD).
Source: Authors (2026).

Figure 5 illustrates the critical sections and the variations in FS across them, ranging from 1.2 to 2.1. The Scenario 2 analysis reveals that when incorporating excess pore pressure conditions in the computational model, Slide2 consistently locates the most critical failure surfaces beneath the piezometric line. The comparative stability performance for both scenarios is quantitatively summarized in Table 2.

Table 2 – Factor of safety classification from two-dimensional stability analyses for each cross section.

Cross Section	Scenario	Factor of Safety	Scenario	Factor of Safety
A-X	1	1.3	2	1.6
B-X		1.6		1.2
C-X		1.5		1.4
D-X		1.7		2.1
		Mean FS = 1.5		Mean FS = 1.6

Source: Authors (2026).

3.2.1. Three-dimensional analysis for Scenario 1

Figure 6 presents the distribution of FS obtained from the three-dimensional stability analyses conducted for Scenario 1.

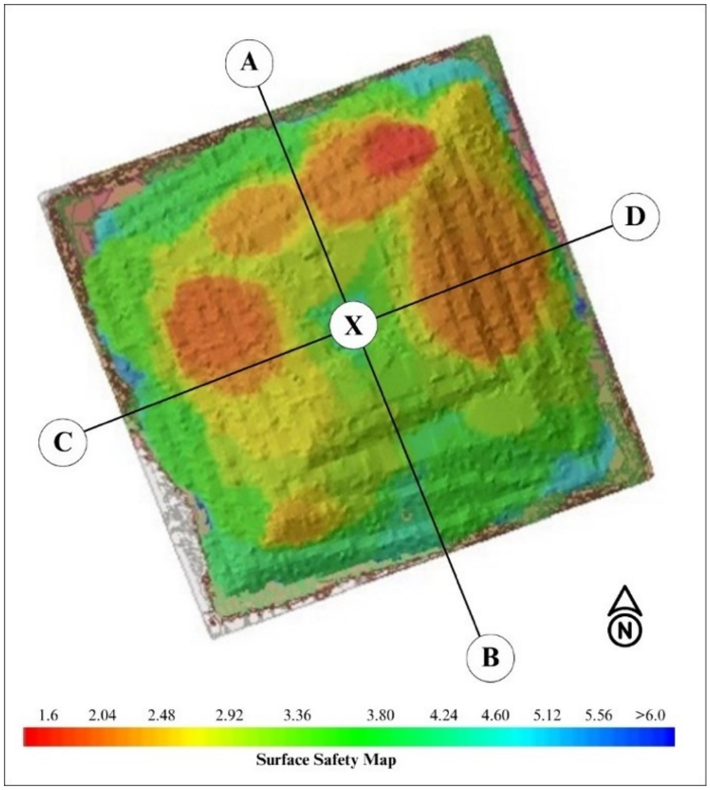

Figure 6 – Three-dimensional stability model for Scenario 1 illustrating factor of safety distribution.
Source: Authors (2026).

For Scenario 1, the computed FS of 1.6 satisfied the minimum stability requirement established by NBR 11682 (ABNT, 2009). The three-dimensional analysis revealed that the critical failure surface extended beyond the limits identified in two-dimensional cross sections (Figure 6). This divergence stems from the enhanced representational capacity of 3D modeling, which incorporates complete topographic geometry and spatial variability along all axes. Figure 7 presents perspective views of the factor of safety distribution, with particular emphasis on the zone exhibiting critical stability conditions.

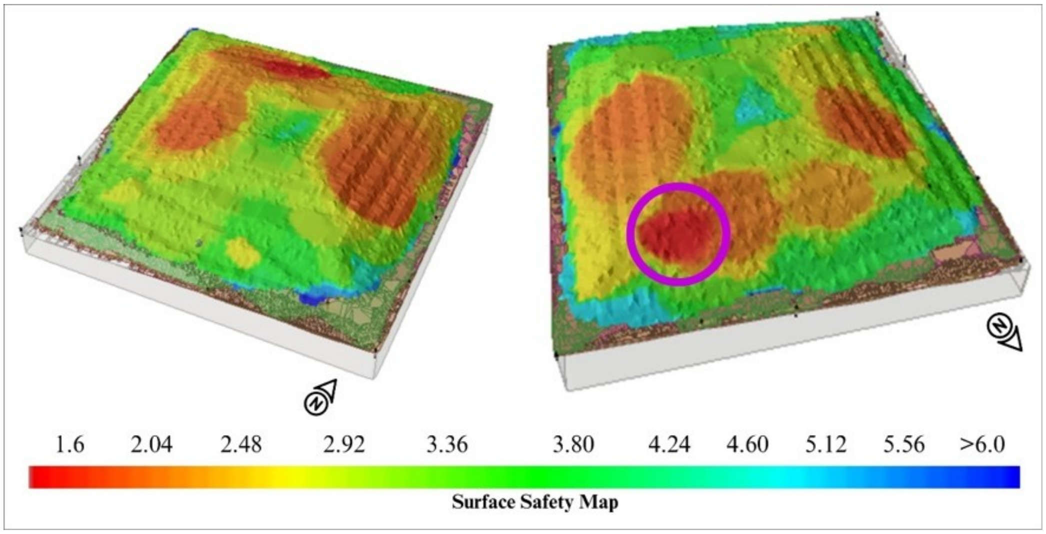

Figure 7 – Perspective view of the spatialized factor of safety on the 3D surface highlighting minimum FS locations in Scenario 1.
Source: Authors (2026).

Analyzing the perspective views of the landfill (Figure 7), the factor of safety varies depending on the location of the critical cross section, with lower values (1.6–2.4) observed in elevated regions where recently deposited waste exhibits lower unit weight and shear strength. These findings align with the two-dimensional analyses for Scenario 1 (Figures 4a–4d), which also identified the lowest FS values in the upper layers of the landfill.

However, when comparing the critical slip surfaces identified in the 2D and 3D stability analyses of Scenario 1, both versions of the Slide software exhibit convergences in certain areas and divergences in others. Despite these variations, the analyses yield statistically similar mean values, as shown in Table 3. The factors of safety values for the 3D analysis were derived from Figure 6, extracted from profiles matching those analyzed in the 2D assessments. These values, representing identical critical failure surfaces in both modeling approaches, were used for hypothesis testing at a 0.05 significance level.

Table 3 – Student's t-test for comparing the mean safety factor in the critical sections of Scenario 1.

		t-value	p
Critical Failure Surfaces (AX-BX; CX-DX)	Student's *t*-test	-0.289	0.821

Note. $H_0\ \mu_{bidimensional} = \mu_{tridimensional}$
$H'\ \mu_{bidimensional} \neq \mu_{tridimensional}$
Source: Authors (2026).

Statistical analysis of Table 3 shows no statistically significant difference between 2D and 3D mean factors of safety ($p > 0.05$), supporting the null hypothesis of equivalent stability assessments across modeling approaches. This suggests no statistically significant difference exists between the mean factors of safety obtained from two-dimensional analyses and those derived from corresponding three-dimensional profile assessments. While the 2D stability assessments offer a detailed understanding of specific sections, the 3D analysis provides a more comprehensive evaluation of the entire slope system, accounting for three-dimensional interactions across the terrain, including areas not captured in the two-dimensional models.

3.2.2. Three-dimensional analysis for Scenario 2

Figure 8 presents the spatial distribution of factors of safety derived from the 3D stability analysis for Scenario 2.

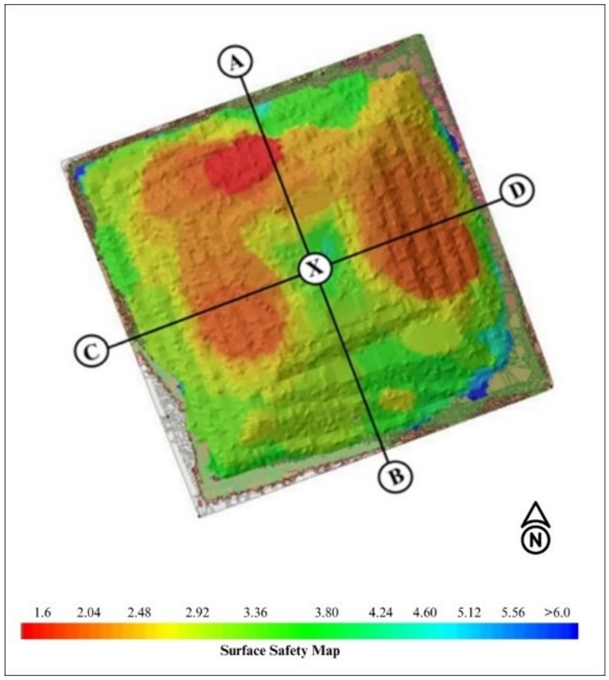

Figure 8 – Cross sections AB and CD in the 3D model for Scenario 2 showing spatial distribution of the factor of safety. Source: Authors (2026).

Figure 8 illustrates the spatial distribution of FSs for Scenario 2, revealing a minimum value of approximately 1.6 in a region adjacent to the critical zone identified in the three-dimensional analysis of Scenario 1. A comparative evaluation of the 2D and 3D results for Scenario 2 highlights methodological divergence in cross section C–X, where the critical failure surface varies significantly between the dimensional approaches. This discrepancy arises from the capacity of the 3D model to capture complex terrain features not represented in the 2D analysis. In contrast, cross section D–X exhibits strong spatial agreement between both methods, with consistent localization of the critical failure surface.

Thus, the comparative analysis reveals partial convergence between 2D and 3D-derived critical slip surfaces under Scenario 2 conditions, exhibiting both spatial correspondence in certain sectors and significant divergence in others. Figure 9 provides three-dimensional visualizations of factor of safety distributions, with the most critical stability zone distinctly highlighted in purple.

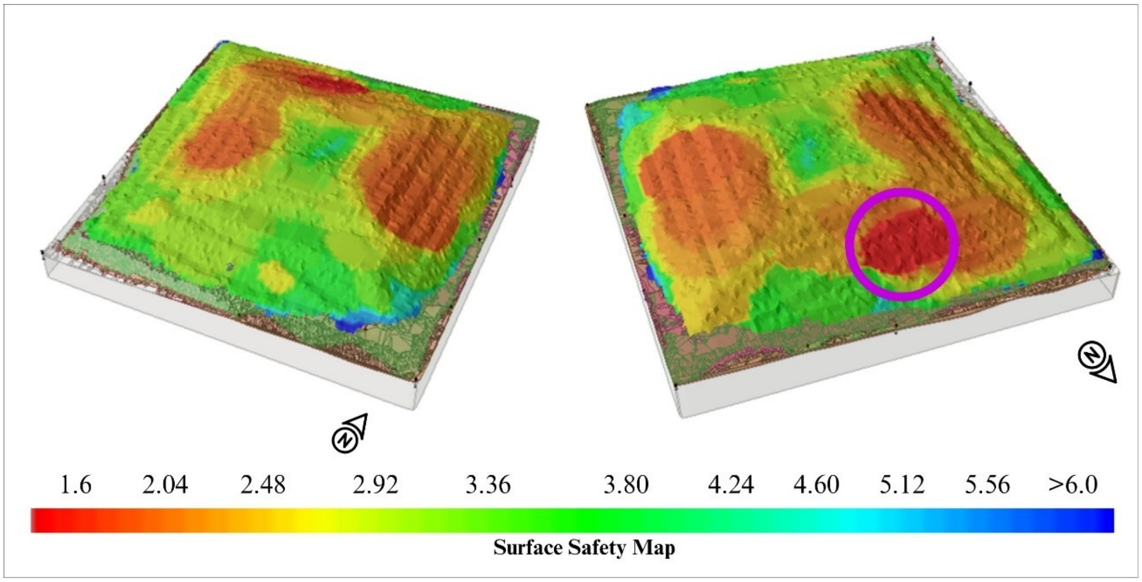

Figure 9 – Perspective view of 3D factor of safety spatialization highlighting the lowest value – Scenario 2.
Source: Authors (2026).

Figure 9 presents a comprehensive evaluation of the FS distribution patterns and the region corresponding to the most critical failure surface within the waste body under pore pressure-influenced conditions. To facilitate a direct comparison between the two-dimensional and three-dimensional analyses, FS values were extracted from identical regions across both models. Consistent with Scenario 1 findings, the mean FS values derived from the 3D simulation in Scenario 2 were closely aligned with those derived from the 2D analyses, as presented in Table 4.

Table 4 – Student's t-test for comparing the mean safety factor in the critical sections of Scenario 2.

		t-value	p
Critical Failure Surfaces (AX-BX; CX-DX)	Student's *t*-test	-1.396	0.212

Note. $H_0\ \mu_{bidimensional} = \mu_{tridimensional}$
$H'\ \mu_{bidimensional} \neq \mu_{tridimensional}$
Source: Authors (2026).

As evidenced by the statistical analysis in Table 4, the p-value exceeds the significance level of 0.05, thereby supporting the acceptance of the null hypothesis. These results demonstrate that no statistically significant difference exists between the mean factors of safety of critical failure surfaces derived from two-dimensional and three-dimensional analyses. Chang (2005) reanalyzed the Kettleman Hills landfill failure (1988) and reported that the factors of safety obtained from 3D analyses were slightly higher than those derived from plane strain conditions. These observed variations highlight the influence of differing modeling assumptions and analytical approaches.

Mitchell et al. (1990) and Qi et al. (2021) conducted landfill stability assessments using two-dimensional and three-dimensional analyses. Mitchell et al. (1990) reported FS ranges of 1.2-1.25 (2D) versus 1.08 (3D) for minimum wetting case, and 1.1-1.15 (2D) versus 1.01 (3D) for full-base-wetting case scenarios. On the other hand, Qi et al. (2020) observed divergent patterns, with 2D analyses yielding FS values of 1.5 (minimum pore water pressure coefficient) and 0.5 (maximum pore water pressure coefficient), compared to corresponding 3D results of 1.7 and 0.5. These literature findings support the statistical evidence presented in this study (Tables 3 and 4), demonstrating comparable mean factors of safety between the 2D and 3D approaches.

In this context, three-dimensional modeling offers distinct advantages for stability assessment by incorporating the full topographic complexity of the waste body, thereby enabling more accurate identification of zones with elevated instability potential. However, while 3D analyses provide superior spatial resolution for critical area detection, two-dimensional methods remain statistically reliable for factor of safety estimation, despite their inherent geometric simplifications.

4. Conclusions

The application of limit equilibrium methods in slope stability analyses significantly enhances the accuracy and reliability of stability assessment. When integrated with DEMs acquired through UAV photogrammetry, these methods enable three-dimensional surface reconstruction that represents actual landfill geometry. This combined approach provides a complete analytical framework for comprehensive slope stability evaluation.

This study compared two-dimensional and three-dimensional slope stability analyses of a landfill under two pore pressure conditions, considering the presence and absence of leachate saturation. The 3D analyses consistently produced higher factors of safety than the 2D assessments. This systematic difference is attributed to the ability of the three-dimensional method to offer a more comprehensive and detailed perspective, as it allows for the consideration of spatial variability, material heterogeneities, and the identification of geometric complexities within the landfill topography.

Nevertheless, the selection between 2D and 3D approaches must be carefully considered, as it hinges on multiple factors, such as project complexity, available resources, required precision, and the specific characteristics of the landfill under analysis.

While two-dimensional analysis offers an efficient primary tool for identifying potential critical zones, three-dimensional analysis provides a more precise assessment of stability conditions by incorporating spatial variations and material heterogeneities within the waste body. Consequently, integrating both methods can significantly enhance the accuracy and reliability of slope stability evaluations in landfill engineering.

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