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Design and Slope Stability Assessment of a Proposed Sanitary Landfill in the Philippines

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Abstract: *This study evaluates the performance and stability of a proposed design of a sanitary landfill for the municipality of La Trinidad, Benguet using Slide2 simulations. The primary objective of the study is to propose a sanitary landfill site that is adequate to the needs of the municipality. Parameters for the design of the sanitary landfill such as its volume, and the dimensions of the trenches were calculated using physical and socio-economic data from the municipality. From the analysis, it was found that the proposed dimensions for the landfill are stable under expected heavy rainfall or seismic events. However, extreme typhoon conditions on a completed landfill produced an FS of 0.811, which indicates that further optimization can be done. The study suggests that onsite testing of the soil must be conducted to verify the Slide2 analysis as the parameters used in the study were sourced from literature.*

Keywords: Landfill design; Slope stability

1. INTRODUCTION

The management of Municipal Solid Wastes (MSW) is important to ensure that the waste cannot pollute the surrounding environment through leachate infiltration. The amount of waste generated can be attributed to its level of urbanization, economic development, and population growth. Among these, population growth and GDP per capita are believed to be the primary variables in the increase of MSW [1]. The increasing rate of waste generation is also observed in the Philippines; as it is projected that the total waste generation of the country is expected to grow to 23.61M tons in 2025 [2]. If left on its own, improper management of MSW will present problems in the groundwater table due to leachate intrusions and would pose an environmental hazard to the local population.

Policies in the management and reduction of MSW have been issued to address the growing rate of waste generation in the country. These regulations are seen in the Ecological Solid Waste Management Act or RA 9003, which required Local government units (LGUs) to implement their own solid waste management plans [3]. For the LGUs to develop their MSW management infrastructure, it must adhere to the standards in developing a sanitary landfill as seen in DENR Administrative Order (DAO) 1998-50.

In the municipality of La Trinidad, Benguet, Philippines, there are existing waste management facilities in Barangay Alno, covering a total area of 9.85 hectares. Due to a change in regulation on these facilities, Open dump sites such as the Buyagan Open Dumpsite in Barangay Poblacion were closed in compliance with RA 9003. This led to the construction of the Alno-Induyan Engineered Sanitary Landfill (ESL) in Barangay Alno [4]. However, due to the high volume of waste generated, Cell 1 of the landfill filled up before its expected 10-year lifespan and would end its service earlier. The landfill currently spans 10.2 hectares. It is projected that by the end of the 2016-2025 planning period; an estimated 12.79 hectares of land is required to properly manage the waste of the municipality. This leaves a deficit of approximately 2 hectares of land that is required to service the area. Therefore, a proposal for a new sanitary landfill is essential to fully comply with RA 9003.

The aim of this study is to propose and site a sanitary landfill design that satisfies the projected demands of the study area, in this case, La Trinidad, Benguet, Philippines. The design of the proposed sanitary landfill will be analyzed using Rocscience's Slide2 to simulate its performance under heavy rainfall and seismic shaking.

2. Methods and Materials

2.1 Research Locale

The locale for the proposed sanitary landfill is the municipality of La Trinidad, Benguet, Philippines. It is known as the "Strawberry Capital of the Philippines" as it contains wide agricultural lands, which produce valuable agricultural crops and fruits such as strawberries and lettuce—all of which are specific to the region. The region is landlocked with Its total land area measuring to 70.04 km^2, which is 2.53% of the total area of the province of Benguet and houses a population of 137,404 spread throughout 16 barangays. The municipality experienced steady growth due to urbanization and its proximity to Baguio City, which is the province's economic hub. This growth nets the municipality an annual growth rate of 1.32% [5].

2.2 Data

Important data for calculation of landfill design parameters, such as daily waste generation, coverage of collection, was collected from the municipality's solid waste management plan [6].

Rainfall data, waste generation and other physical properties considered in the landfill design were provided by the municipality's Disaster risk plan and physical profile reports [6] [7].

The United States Geological Survey USGS provided the study area's Digital Terrain Model (DTM) for elevation profile of the proposed site of the sanitary landfill.

The primary parameters for analysis of the landfill design were set by identifying values from existing research papers in terms of the materials used [8] [9].

Table 1. Landfill layer parameters for slope stability

	Material	Unit weight (kN/m^3)	Φ	Cohesion, (kPa)
Bottom Layer	*Site soil*	17.83085	25	15
	Soil barrier	17.83085	25	25
	Secondary geomembrane	9.3	15	0
	Leak detection system	25	30	0
	Primary soil barrier	17.83085	25	25
	Primary geomembrane	9.3	15	0
	Leachate collection system	25	30	0
Top Layer	*MSW*	65	26.7	41.85
	Foundation Layer	25	30	0
	Gas vent layer	25	30	0
	Soil barrier	17.83085	25	25
	Top geomembrane	25	30	0
	Drainage layer	20	35	20
	Protection layer	15.1	37.5	0
	Control erosion layer	17.83085	25	15

Table 2. Landfill layer parameters for groundwater flow

	Material	k, (cm/sec)	Thickness, (m)
Bottom Layer	*Site soil*	1.00E-04	-
	Soil barrier	1.00E-07	0.3
	Secondary geomembrane	1.00E-08	0.05
	Leak detection system	5.01E-06	0.2
	Primary soil barrier	1.00E-07	0.3
	Primary geomembrane	1.00E-08	0.05
	Leachate collection system	5.00E-06	0.3
Top Layer	*MSW*	5.00E-05	-
	Foundation Layer	5.00E-06	0.3
	Gas vent layer	5.00E-06	0.15
	Soil barrier	1.00E-07	0.3
	Top geomembrane	5.00E-06	0.05
	Drainage layer	5.00E-06	0.3
	Protection layer	2.51E-06	0.6
	Control erosion layer	1.00E-04	0.15

2.3 Landfill Design Parameters and Calculations

To determine the parameters of the proposed landfill design, several considerations must first be considered. One of the primary factors is the volume of excavated land. It involves the utilization of various spatial requirements such as the total production of municipal solid waste (MSW), coverage of collection, volume and area of the landfill.

The primary variables that will be used to determine these requirements will be based on the population, daily waste generated by the municipality, coverage of collection, density of compacted and stabilized MSW, and the amount of cover material for the volume of the compacted MSW.

The general flow of computations for the volume of excavation will start at the waste production per capita (ppc) in the first year shown in Eq.1. It is assumed that the ppc will increase due to the municipality growing year by year. Once production per capita is calculated, the production of MSW can be obtained using Eq 2. MSW production is either expressed on a basis as seen in Eq. 1 and 4 or on a yearly basis seen in Eq.3. In this study, projected MSW production was generated in a period of 5 years.

$$ppc = \frac{DSr}{Cov*7*Pop} \tag{1}$$

$$DSd = Pop * ppc \tag{2}$$

$$DSy = \frac{DSd*365}{1000} \tag{3}$$

$$DSr = \frac{ppc*pop*7*Cov}{100} \tag{4}$$

Where:
DSd – Daily MSW generation
DSr – Weekly MSW generation
Cov – Coverage of waste collection services
Pop – population served in waste collection
DSy – Yearly MSW generation

Using these values and the established values in terms of the compacted MSW, stabilized MSW, and daily cover computation, the other requisite volumes can be computed to determine the accumulated sanitary landfill volume. The computation of the required volumes in terms of the compacted MSW, stabilized MSW, and the sanitary landfill is shown Eq. 5 - 7.

$$V_{daily} = \frac{DSd}{D_{msw}} \tag{5}$$

$$V_{cm,daily} = V_{daily} * cm \tag{6}$$

$$V_{SL} = V_{stabilized,annual} + V_{cm,annual} \tag{7}$$

$$A_{SL} = \frac{V_{SL}}{h} \tag{8}$$

Where:
V_{daily} – daily compacted volume of MSW
$V_{cm,daily}$ – daily compacted volume of cover material
V_{SL} – volume of sanitary landfill
A_{SL} – initial area of sanitary landfill
D_{msw} – Compacted density of MSW

With the established values for the volume of the MSW, the required area to be filled can be calculated by utilizing an assumed height for the sanitary landfill. This value is established to be 6 m, which is compliant with industry standards for landfill dimensions. Using the calculated volumes, the required initial fill area can be calculated using Eq 8.

After which, the initial required area is to be factored by a constant offset F = 0.35 to account for additional structures that will be placed in support of the designed landfill. The total area of sanitary landfill is illustrated in Eq. 9. Finally, by evaluating the existing data of the municipality's solid waste management, the volume of the trench can be computed as seen in equation 10. The calculated volume of the trench uses the area method.

$$A_T = A_{SL} * (1 + F) \qquad (9)$$

$$V_Z = \frac{t * DSr * (1 + cm)}{D_{msw}} \qquad (10)$$

Where:
A_T – total area of sanitary landfill
V_Z – volume of trench
t – useful life of sanitary landfill in days

The number of trenches that will be used in the landfill was computed. With the parameters of the trench established, it is important to consider how many possible trenches can be placed within the site. This is shown in Eq. 11 where n is the number of trenches.

$$n = \frac{A_T}{A_{Trench} * (1 + F)} \qquad (11)$$

Then, the dimensions of the trench must be selected. The bottom width of the trench was established to be 6 m, and the top of the trench was set at 20 m. The height of the trench was determined to be 4 m. These parameters are used to compute the length of the trench, which is determined to be 4,826.03 m.

For the volume and dimensions of the daily cell, Eq. 12-14 will be used to determine the amount of MSW in a daily cell, volume, area, and length of each cell given a standard height of 1.5 meters [10].

$$V_c = \frac{DS_{SL}}{D_{msw}} * (1 + cm) \qquad (12)$$

$$A_c = \frac{V_c}{h_c} \qquad (13)$$

$$l = \frac{A_c}{w} \qquad (14)$$

2.4 Geomaterials

In the lining system of the landfill, high-density polyethylene or HDPE. was used for both in the top and bottom layer and was applied for the primary and secondary geomembrane, and the top membrane. HDPE was chosen as it is widely used as a geomembrane material in sanitary landfills due to its excellent chemical resistance, durability, and cost-effectiveness.

For the geotextiles used in the lining system. TenCate Mirafi PET 200-50 geotextile was used for its high strength and resistance to chemical attack.

2.5 Design Simulation Parameters

Using Slide2 under Rocscience, the proposed design of the landfill was simulated using a QCAD design of the cell together with the parameters of each material in tables 1 and 2 to simulate real-world conditions and scenarios.

The design was put through various scenarios and tests to calculate its Factor of Safety (FS), leachate and groundwater flow conditions, and a Magnitude 6.2 earthquake. For the stability of the landfill against rainfall, a rate of 0.005m/day was used to simulate heavy typhoon rains. The stability of the landfill due to earthquakes was also investigated as the proposed site is located about 5 km east of the Tuba fault line as well as the naturally sloped and mountainous terrain in the site makes the area susceptible to landslides.

3. Results and Discussion

3.1 Sanitary landfill site

The location of the proposed landfill site is located at Barangay Alno. This area was chosen as it is reported to have a comparatively gentle slope compared to the average slope of 40% in the whole municipality [7]. The soil in the area is categorized as "Halsema loam" where the internal drainage of the soil is moderately slow [6]. The type of soil present in the proposed site is favorable for a sanitary landfill as the base soil would prevent leachate discharge. The elevation of the selected area is reported to have an average elevation of 1150 meters. The Elevation profile of the proposed site (see Fig. 1) was conducted using QGIS. The location of the site is adjacent to the existing Sanitary landfill of the municipality and will be considered an expansion of the landfill.

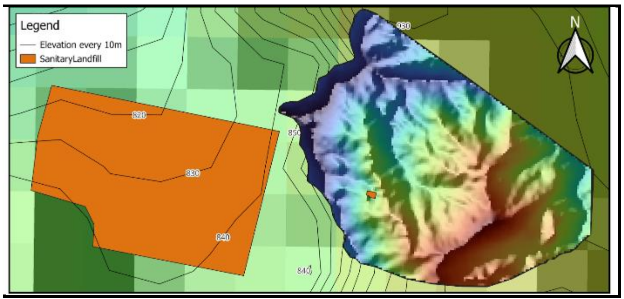

Fig. 1. Terrain Analysis of the Proposed Sanitary Landfill

3.2 Site Preparations and layout

To facilitate site preparation, vegetation clearance will be conducted, with primary removal targeting grasses and shrubs, as the area contains minimal large trees. Then, the terrain will be leveled by cutting to prevent slope failure and waste from running down the slopes.

After vegetation clearance, a ditch will be excavated on the sides of the sanitary landfill area with a width of 600 mm and a height of 500 mm for rainfall drainage. This would prevent the surface runoff from collecting in the landfill while it is not yet covered. Aside from this, drainage will also be constructed for the leachate collection system where perforated pipes are put in place with gravel.

For the components of the landfill site, other landfill infrastructures and support facilities were placed in conjunction with the main excavation. For the landfill infrastructures, internal leachate drainage will be constructed according to the layers of the sanitary landfill. In this case, the leak detection system and the primary leachate collection system will have perforated pipes and gravel, which will lead the leachate to a leachate pond and will be treated. A Gas and Venting system are also constructed to reduce the build-up of methane within the landfill.

Several monitoring wells will also be constructed around the sanitary landfill to monitor the groundwater table and the sub-surface water. It is a means of detecting pollution from the construction of sanitary landfill, wherein pollutants, pH, conductivity, and dissolved oxygen, are analyzed. Additionally, a monitoring pond will be constructed to analyze surface runoff and possible leachate contamination on surface water due to liner failure.

For the support infrastructure, a perimeter fence and Buffer area are placed to ensure further protection of visual integrity as well as the surrounding community and geologic features, the buffer area is established 5 meters from the boundary line of the site.

Other support infrastructure includes a site identification board outside the landfill, a control building, and sanitary facilities would be located at the site. The proposed layout of the landfill is presented below (see Fig. 2).

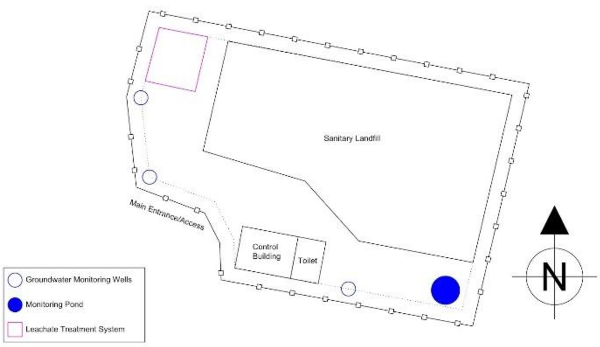

Fig. 2. Site development plan of the proposed landfill

3.3 Landfill Design parameters

Based on the primary variables needed to design a sanitary landfill, The following values were obtained. These values are established to be 137,404 inhabitants, 54956.10384 kg/day, 90% coverage, 472.44 kg/m^3, 630 kg/m^3, and a 20 percent offset to account for the cover material. The values mentioned above were primarily generated through various reports on the municipality and existing manuals on how to design a landfill [7] [10] [11]. In determining projected increase of MSW generated in a span of 5 years, the following values were calculated as summarized in Table 3.

Year	Pop, inhab	ppc kg/cap/day	Dsd, kg/day	Dsy, ton/year
2020	*137,404*	*0.4444*	*61062.34*	*22287.75*
2021	*139,218*	*0.4503*	*62685.02*	*22880.03*
2022	*141,055*	*0.4562*	*64350.83*	*23488.05*
2023	*142,917*	*0.4622*	*66060.90*	*24112.23*
2024	*144,804*	*0.4683*	*67816.42*	*24752.99*

Table 3. Daily and yearly MSW generation projection.

Next, the volumes of the compacted MSW and the cover are calculated. The summary of these values is shown in Table 4.

Compacted		Cover		Stabilized
Vdaily	Vannual	cm,daily	annual	yearly
m^3/day	m^3/year	m^3	m^3/year	m^3/year
129.2488731	47175.83868	25.84977462	9435.167735	35377.38607
132.6835637	48429.50073	26.53671273	9685.900147	36317.51322
136.2095285	49716.47791	27.2419057	9943.295582	37282.62353
139.8291932	51037.65553	27.96583864	10207.53111	38273.38092
143.5450478	52393.94243	28.70900955	10478.78849	39290.46693

Table 4. Annual and daily volumes for Compacted, cover and stabilized MSW.

Lastly, the volumes and area of the Sanitary landfill are summarized in Table 5.

Sanitary landfill		Area	
volume	accumulated	fill	total
m^3	m^3	m^2	m^2
44812.55381	44812.55381	7468.758968	9709.386658
46003.41336	90815.96717	7667.235561	10350.76801
47225.91911	138041.8863	7870.986519	10625.8318
48480.91202	186522.7983	8080.152004	10908.2052
49769.25541	236292.0537	8294.875902	11198.08247

Table 5. Volume and area for the sanitary landfill

From these results, it is found that the initial required area of the sanitary landfill is 8294.88 square meters. Using Eq. 9-11, the total adjusted area of the sanitary landfill, number of trenches and Volume of excavation is 11198.08 m^2, 104 trenches and 386,083 m^3 respectively. Lastly, the volume, area, and length of the daily cell is shown to be 246.81 m^3, 164.54 m^2/day, and 27.42 m.

3.4 Stability Analysis of the Landfill

Using the established parameters of the layers of the landfill design, various schemes of the landfill design were simulated to evaluate the stability of the structure in the different stages of its function. These are the base layer simulation, MSW-filled, and covered landfill.

For the base layer scheme, its simulation evaluates the stability of the bottom layer of the trench, which includes the soil barrier, secondary geomembrane, leak detection system, primary soil barrier, primary geomembrane and the leachate collection system. It is done to evaluate if the bottom section of the design can withstand the various loads placed in the landfill design. The condition of the base layer and its corresponding factor of safety are seen below.

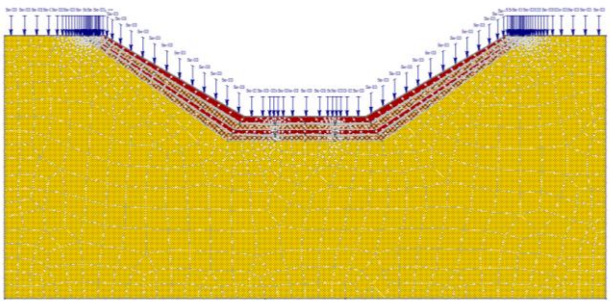

Fig. 3. Conditions of the base layer

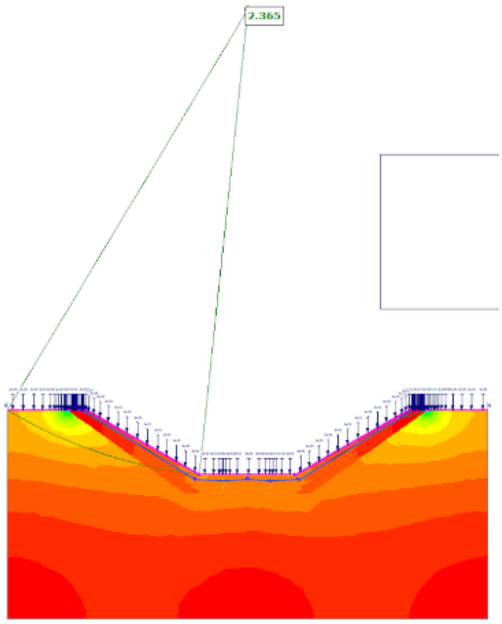

Fig. 4. Factor of safety of the base layer

From the simulations, it was found that the base layer was able to have Factor of Safety of 2.365, when given the conditions of the parameters of the soil used along with the rainfall conditions. This FS was found to be relatively high as generally, a FS of 1.5 is established to be used for the design of slopes in landfill cover systems, which was taken from the design of dam embankments [12]. On analyzing the results of the simulation, it can be assumed that the relatively high FS was due to the geotextile placed over and under the layer of gravel acting as the primary leachate collection system.

For the MSW-filled scheme of the simulations, MSW is added into the landfill design to further evaluate the stability of landfill under operating conditions, where the MSW exerts additional load into the base liner system.

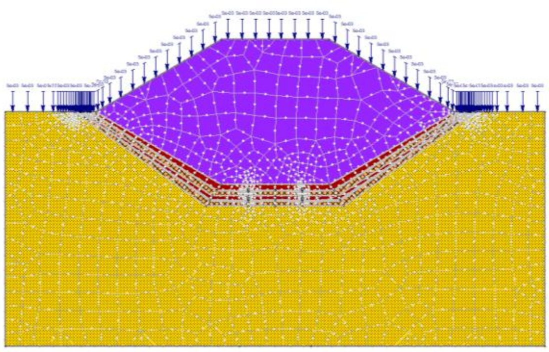

Fig. 5. Conditions of the MSW-filled trench

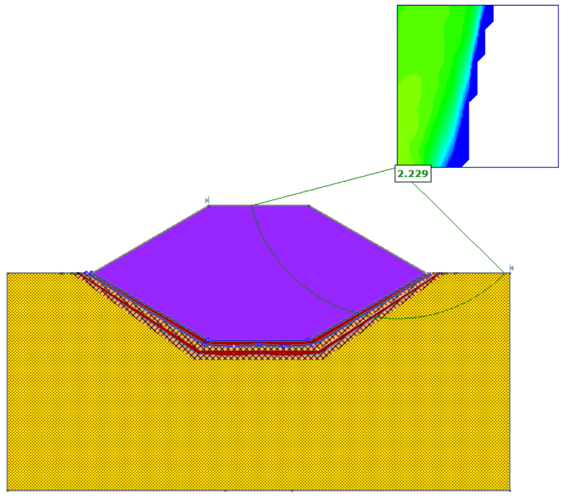

Fig. 6. Factor of safety of the MSW-filled trench

The MSW-filled trench has a calculated FS of 2.229, which indicates that the designed slope dimensions for the landfill remain stable even under full loading conditions displaced upon by the MSW. This satisfactory result also indicates that the trench is safe and could be covered. This also means the design can fit as much MSW as its volume can hold without having much of a gradual slope that the cross-sectional area cannot accommodate for the desired volume. However, it is important to note that while the current design can contain the waste mass without reducing capacity; the decrease in FS indicates that there was added stress due to the waste loading and the potential core building in the leachate collection system.

Following the evaluation of the MSW-filled condition of the landfill design, the final simulated phase would be the covered landfill. This simulation incorporates the top and bottom layers of the landfill (20 m top and 6 m bottom for both layers). This phase examines the performance of the designed landfill when subject to the Philippine's worst case rainfall scenario of 0.005 m/day, which was the rainfall conditions during Typhoon Ondoy or Ketsana in 2009. The results of the simulation are shown (see Fig. 7 - 9.)

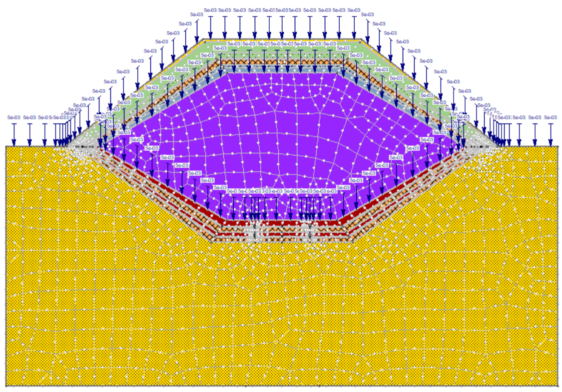

Fig. 7. Conditions of the covered trench

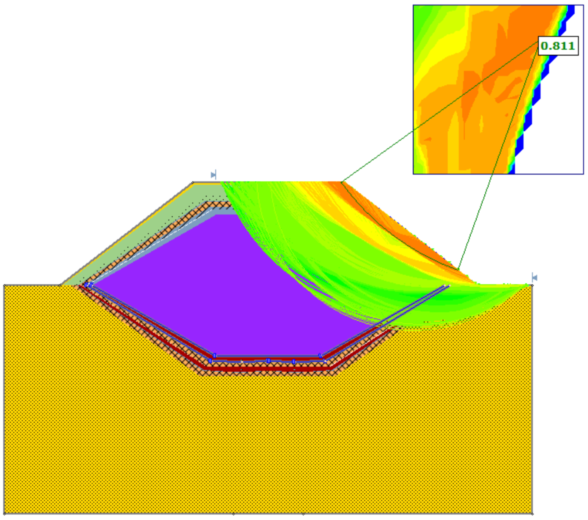

Fig. 8. Factor of Safety for the covered trench.

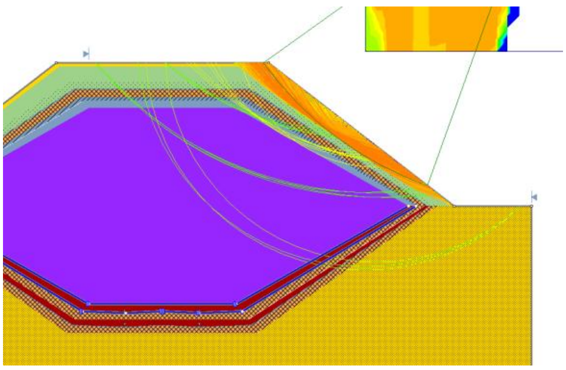

Fig. 9. Failure curves with FS < 1; transitioning of aggressive slope to gradually decreasing.

The landfill cover layer, exposed to rainfall as well as the parameters of each of its respective layers, has presented a factor of safety of 0.811, where suspected failure is seen in the control soil layer mainly due to the aggressive sharpness of the slope. It generates excessive shear stress during saturation events, which highlights the failure mechanism that is evident within the landfill system as the gradual sloughing of the cover soil towards the bottom end of the landfill system (see Fig. 9). This does not necessarily translate to the total failure of the landfill, but rather the sharpness of the cover soil from the top to the side turning into a more gradual slope down to the base of the landfill. However, it is important to note that the geomembrane and the drainage layers were found to be fully functional still as it was able to prevent leachate from breaking out on the sides of the landfill.

3.5 Leachate Flow Simulations

For the simulation of leachate, all three scenarios were put through the same rainfall conditions, assuming the worst-case scenario of the average rainfall during a typhoon. The flowlines in each scenario (see Fig. 10-12) present the flow of water to accumulate to the sides of the trench and down towards two points at the center. Drainages are found on both sides of the trench, as well as a leachate drainage pipe in the center of both the primary leachate collection system and the leak detection system. This is also seen in Figure 18 where groundwater flows down along the slope, penetrating down to the protection layer, meaning that the design is also impervious and discourages any water seeping into the MSW layer. Any leachate that may be accumulated in the MSW layer will also be funneled down into the leachate drainage pipes. Any flow lines seen in the site soil layer of the diagram are too little to consider.

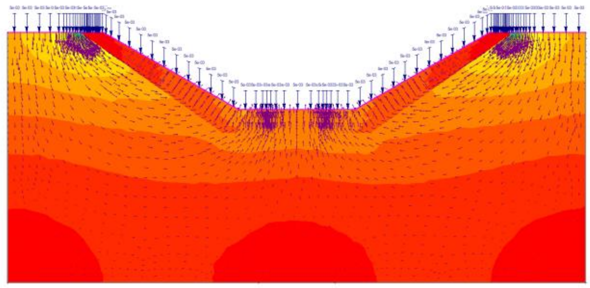

Fig. 10. Groundwater flow of the base trench layer.

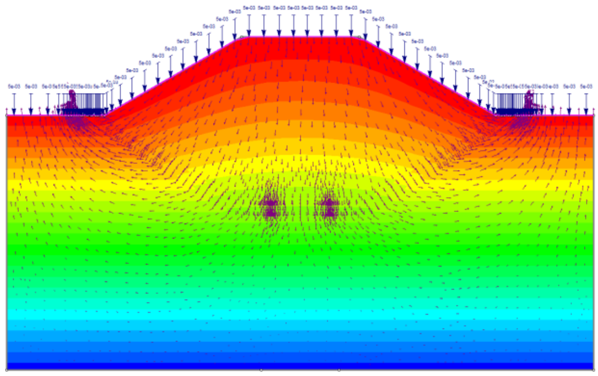

Fig. 11. Leachate and groundwater flow of the MSW-filled trench.

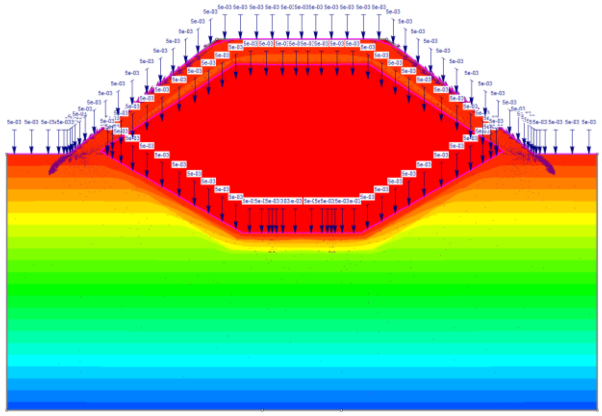

Fig. 12. Leachate and groundwater flow of the covered trench.

3.6 Seismic Event Simulations

For the seismic event simulation, the method used to estimate the displacement of the slope is Newmark's sliding block analysis. At post-earthquake, the design presented a Newmark displacement of 0.619cm when put through a magnitude 6.2 earthquake (see Fig. 12). This implies that, despite the presence of soil displacement in the landfill design, this does not result in the total failure of the landfill, where contamination of the site would occur.

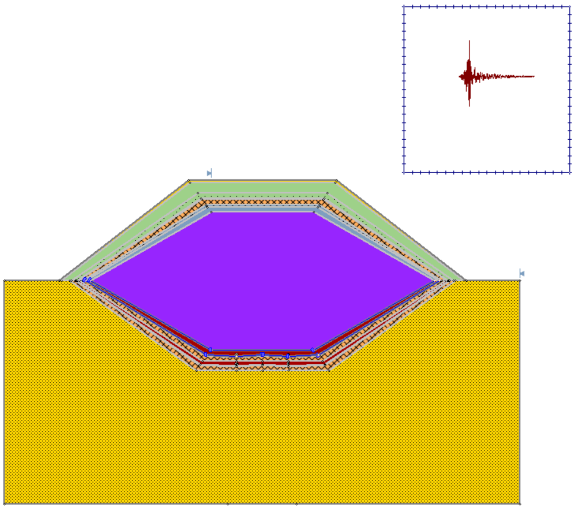

Fig. 11. Pre-earthquake conditions of the landfill.

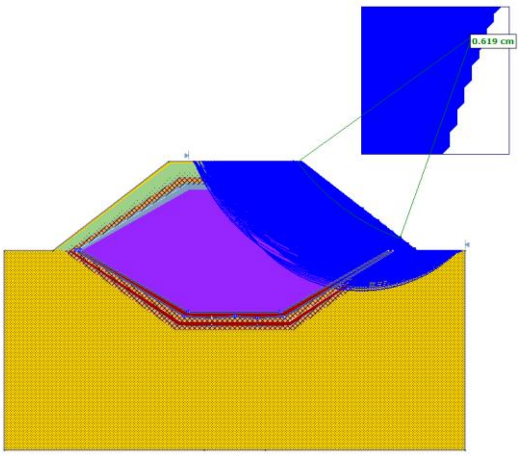

Fig. 12. Calculated displacement after a simulated earthquake.

4. Conclusions

This study has designed a landfill system composed of the complete components found in a landfill. After designing the landfill dimensions and collecting information on the parameters of each material used in the construction of the landfill, as well as the conditions that the landfill may experience in the proposed study area, it can be concluded that the design is relatively safe for construction with a few recommendations to be made. It was found that the designed bottom layer achieved a factor of safety of 2.365, meanwhile the MSW-filled bottom layer was able to achieve an FS of 2.229. This validates the computations that were conducted, indicating that the 20 m top width and 6 m bottom width of the landfill is a feasible design for the proposed landfill. However, it was reported that the complete landfill design under extreme typhoon conditions produced an FS of 0.811, which indicates that further optimization can be done to produce a better FS for the landfill design.

5. Recommendations

Given the results of the analysis, it is recommended that the parameters were to be collected onsite such as specific gravity and Atterberg limits [13] to validate the results of the Slide2 analysis, as the parameters used in this design proposal were collected from available literature of the materials used in the analysis. Collecting borehole data and an assessment of the topology through surveying and onsite measurements will help guarantee a thorough design process that could consider more factors that may affect the stability of the landfill, especially given the possible uncertainties the landfill may encounter in its construction or during its useful life [14]. Furthermore, possible design considerations for the landfill may also include the optimization of the slope to prevent erosion within the proposed landfill [15].

6. REFERENCES

[1] Bilgilioglu, S. S., Gezgin, C., Orhan, O., & Karakus, P. (2022). A GIS-based multi-criteria decision-making method for the selection of potential municipal solid waste disposal sites in Mersin, Turkey. Environmental Science and Pollution Research, 29(4), 5313–5329.

[2] Climate Transparency platform: https://climate-transparency-platform.org/sites/default/files/2024-06/D4_Overview%20of%20waste%20sector%20and%20solid%20waste_CBIT%20GSP.pdf (accessed 15.04.25).

[3] Philippines official gazette: https://www.officialgazette.gov.ph/2001/01/26/republic-act-no-9003-s-2001/ (accessed 15.04.25).

[4] Lubrica, N. V. (2012). Breaking the Dichotomy: Combining Geographic Information System (GIS) and Participatory Approach in Identifying Suitable Landfill Sites in La Trinidad, Benguet. Tangkoyob. Volume 6. 74-87.

[5] PhilAtlas Website: https://www.philatlas.com/luzon/car/benguet/la-trinidad.html (accessed 15.04.25).

[6] La Trinidad DRMMO website: https://ltdrrmo.ph/wp-content/uploads/2024/05/La-Trinidad-MDRRM-Plan-2020.pdf (accessed 10.04.25).

[7] La Trinidad Socio-Economic & Physical Profile. (2016). La Trinidad DRMMO website: https://latrinidad.gov.ph/wp-content/uploads/2015/09/Profile-2016.pdf (accessed 10.04.25)

[8] Ng, H., & Qi, C. (2012). HDPE geomembrane applications in high-altitude region. *Geosynthetics Conference 2012*. Geosynthetics Society. https://library.geosyntheticssociety.org/wp-content/uploads/resources/proceedings/122021/Case%20History_2.pdf

[9] Almeida, T. L., & Schalch, V. (2008). *Considerations on soil permeability in landfill*. https://www.cabidigitallibrary.org/doi/pdf/10.5555/20093287795

[10] Jaramillo, J. (2003) Guidelines for the Design, Construction and Operation of Manual Sanitary Landfills. Pan American Center for Sanitary Engineering and Environmental Science.

[11] Alos, G. (2023). A case study of solid waste management in the central business district of La Trinidad, Benguet. *Global Scientific Journal, 11*(5)

[12] Liu, J., Gilbert, M., Thiel, R. P., & Wright, R. (1997). What is an appropriate factor of safety for landfill cover slopes.

https://www.rthiel.com/uploads/ngrey/067%201997%20Liu%20Gilbert%20Thiel%20Wright.pdf
[13] Dimalanta, J. B., Garcia, V. R., Lao, W., Galupino, J., Adajar, M. A. “Investigation of the Effects of Waste Stone Powder as an Additive for Alluvial Soil” in International Exchange and Innovation Conference on Engineering and Sciences, pp. 99-104, Kyushu University, 2024.
[14] Galupino, J., Dungca, J. "Estimating Ground Elevation using Borehole Information: A Case of Metro Manila, Philippines", in International Exchange and Innovation Conference on Engineering and Sciences, pp. 25-30, Kyushu University, 2022.
[15] Chihi, F. & Varga, G. (2023). Optimizing Landfill Capacity: A Numerical Study of the Slope Inclination Variation Impact on Landfill Storage Capacity and Its influence on the Safety Factors under Different Models. Periodica Polytechnica Civil Engineering. 68. 10.3311/PPci.22790.