

**SLOPE STABILITY ANALYSIS FOR WASTE LANDFILL IN
CENTRAL DISTRICT TEGUCIGALPA HONDURAS**

**HONDURAS TEGUCIGALPA MERKEZ BÖLGESİ ATIK
DEPOLAMA ALANI ŞEV STABİLİTE ANALİZİ**

José Miguel CAMINALS GUILLÉN

PROF. DR. BERNA UNUTMAZ

Supervisor

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ABSTRACT

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José Miguel CAMINALS GUILLÉN

Master of Science, Department of Civil Engineering

Supervisor: Prof. Dr. Berna UNUTMAZ

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Municipal solid waste (MSW) generation is an exponentially growing problem across the earth with increasing industries, population, and expansion of cities. Societies have created a consumerism culture from which every day waste is deposited in landfills. In the past years all around the world, a big effort and interest has been presented by companies, organizations and governments to reduce the MSW generation by promoting recycling methods and creating awareness of the problem. People may be aware of the increase in waste production but in general, the process behind the disposal of a daily meal residue containing plastic, paper, and organic material until it is buried in a landfill is mostly unknown. The use of open disposal dump areas to engineered landfills represents an important step for controlling the MSW generated by growing urbanizations and in some cases even benefiting from it by the generation of energy sources such as biogas. In every life situation, we are generally looking

forward to improvement which is the same scenario for MSW disposal facilities. In this thesis, the sanitary landfill in the city of Tegucigalpa Honduras will be discussed, which in the near future will transition from Section III to a Section IV disposal area in its recently acquired 211,320 m² premises. The objective of this thesis is to generate a supporting tool for the new fourth-stage engineered landfill design utilizing slope stability analyses as a geotechnical reference of both the virgin lands to be used for the new landfill and the finished engineered landfill model. With the use of collected surveying field data, landfill manager guidelines, GeoStudio SLOPE/W, and AutoCAD Civil 3D model assisting software an optimized engineered landfill is presented. Site selection, dimensioning and engineered characteristics of the landfill have been developed in accordance with local landfill management guidelines and regulations promoting health and engineering improvement. Results show that the new projected land area presents suitable topography, ground and slope stability conditions for this project to be executed as presented. It is to be clarified that the analyses and data unveiled in this study bestow a supporting instrument for the design to be accomplished and not an official municipality final design document.

Keywords: Slope Stability Analysis, Solid Waste Landfills, Limit Equilibrium Methods, El Crematorio Honduras Landfill Site

ÖZET

HONDURAS TEGUCİGALPA MERKEZ BÖLGESİ ATIK DEPOLAMA ALANI ŞEV STABİLİTE ANALİZİ

José Miguel CAMINALS GUILLÉN

Yüksek Lisans, İnşaat Mühendisliği Bölümü

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Evsel katı atık (MSW) üretimi, artan endüstriler, nüfus ve şehirlerin genişlemesi ile dünya genelinde katlanarak büyüyen bir sorundur. Biz insanlar, her gün çöplüklerdeki atık bileşiminin büyük bir bölümünü oluşturan plastik gibi atıklar ürettiğimiz bir tüketim kültürü yarattık. Geçtiğimiz yıllarda tüm dünyada farklı şirketler, kuruluşlar ve hükümetler tarafından geri dönüşüm yöntemlerini teşvik ederek ve sorun hakkında farkındalık yaratarak bu MSW üretimini azaltmak için büyük bir çaba ve ilgi gösterilmiştir. İnsanlar atık üretimindeki artışın farkında olabilir, ancak genel olarak plastik, kağıt ve organik maddeler içeren günlük yemek artıklarının bir çöplükte gömülene kadar bertaraf edilmesinin ardındaki tüm süreç çoğunlukla bilinmemektedir. Açık çöplük alanlarının mühendislik ürünü depolama sahalarında kullanılması, büyüyen şehirleşme tarafından üretilen farklı kontrol edilmesi ve hatta bazı durumlarda biyogaz enerji kaynaklarının üretilmesi yoluyla bundan faydalanılması için önemli bir adımı temsil eder. Her yaşam durumunda, MSW bertaraf tesisleri için aynı

senaryo olan, genellikle iyileştirmeyi dört gözle bekliyoruz. Bu tezde, yakın zamanda satın alınan 211.320 m² arazisinde yakın bir gelecekte 3. aşamadan 4. aşamaya geçiş yapacak olan Honduras Tegucigalpa şehrinde bulunan tek lisanslı düzenli depolama sahasını ele alacağız. Bu tezin amacı, hem yeni depolama sahası için kullanılacak bakir arazilerin hem de bitmiş mühendislik ürünü depolama sahası modelinin jeoteknik referansı olarak şev stabilitesi analizleri aracılığıyla yeni dördüncü aşama mühendislik ürünü depolama sahası tasarımı için destekleyici bir araç oluşturmaktır. Toplanan yerel ölçüm saha verileri, depolama yöneticisi yönergeleri, GeoStudio SLOPE/W ve AutoCAD Civil 3D model yardımcı yazılımının kullanımıyla, optimize edilmiş bir mühendislik ürünü depolama alanı sunulur. Düzenli depolama sahasının yer seçimi, boyutlandırılması ve mühendislik özellikleri, sağlık ve mühendislik iyileştirmelerini teşvik eden yerel depolama yönetimi yönergeleri ve düzenlemelerine uygun olarak geliştirilmiştir. Sonuçlar, projelendirilen yeni arazi alanının, bu projenin sunulduğu şekilde yürütülmesi için uygun bir topoğrafya, zemin ve şev stabilitesi koşulları sunduğunu göstermektedir. Açıklığa kavuşturulmalıdır ki, bu çalışmada ortaya konulan analizler ve veriler, resmi bir belediye nihai tasarım belgesi değil, gerçekleştirilecek tasarıma destekleyici bir araç sunmaktadır.

Anahtar Kelimeler: Şev Stabilite Analizi, Atık Depolama Alanları, Katı Atık Yönetimi, Limit Denge Yöntemleri, El Crematorio Honduras Depolama Sahası

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ABBREVIATIONS

Abbreviations

| | |
|-------------|--|
| AMDC | Alcaldía Municipal de Distrito Central (Municipal Central District Town Hall) |
| AGCI | Agencia de Cooperación Internacional de Chile (Chilean International Cooperation Agency) |
| BCH | Banco Central de Honduras (Central Bank of Honduras) |
| CABEI | The Central American Bank for Economic Integration |
| CHOC | Código Hondureño de la Construcción (Honduran Code of Construction) |
| CNP+LH | Centro Nacional de Producción Más Limpia de Honduras (National Center for Cleaner Production of Honduras) |
| FOS | Factor of Safety |
| GDP | Gross Domestic Product |
| GIRS | Gestion Integral de Residuos Sólidos (Solid Waste Integral Management) |
| GIZ | Deutsche Gesellschaft für Internationale Zusammenarbeit, (German Agency for International Cooperation) |
| IGN | Instituto Nacional de Geografía (National Geography Institute) |
| INE | Instituto Nacional de Estadística (National Institute of Statistics) |
| JICA | Japan International Cooperation Agency |
| MI AMBIENTE | Secretaría de Energía, Recursos Naturales, Ambiente y Minas (Secretariat of Natural Resources and Environment) |
| MSW | Municipal Solid Waste |
| PAHO | Pan American Health Organization |

| | |
|--------|---|
| RN-15 | Ruta Nacional 15 National Route 15 |
| RQD | Rock Quality Designation |
| SDHJGD | Secretaría de Derechos Humanos, Justicia, Gobernación y Descentralización (Secretariat of Human Rights, Justice, Governance and Decentralization) |
| SERNA | Secretaría de Recursos Naturales y Ambiente (Secretariat of Natural Resources and Environment) |
| SPT | Standard Penetration Test |
| TCD | Tegucigalpa Central District |
| UN | United Nations |
| VES | Vertical Electrical Sounding |

1. INTRODUCTION

Waste material is generated in urbanizations every second and at the same time it is being disposed and processed in nonstop working landfills. Having a destined place, methods and planning for this unwanted material is of great importance, reason why ahead planning must be done to handle this waste material in safe and socially responsible methods. The city of Tegucigalpa, like any other urban center in the world, is an important source of solid and hazardous waste generation, which is the product of commercial, industrial, institutional and residential activities that take place in this geographical area. The generation of MSW is directly associated with population growth and the development of commercial and industrial activities, showing an invariable trend towards increase and in this way propitiating a greater demand for new urban sanitation facilities. The objectives of this study are to provide a series of collected data with the addition of computerized slope stability analysis as supporting documentation for the landfill Section IV electability, improve the pre-planification standard processes used and provide proof of an engineered environmentally friendly waste disposal center in the most populous city of Honduras. The requirements for the new stage waste disposal landfill were analyzed in three important stages, understanding current landfill management, engineering geological investigation and finally site feasibility evaluation.

The main objective of this study is to prove the engineering suitability of the rock and soil masses at the proposed landfill site. These rock and soil properties to be required for landfill construction and design were identified as a priority, drainage, liner material, leachate collector system, final cover and gas venting system were also reviewed and proposed as needed. For these purposes borehole applications, in-situ and laboratory tests, scan-line topographies and seismic surveys were conducted to characterize the engineering properties of the site masses exposed at the proposed new landfill site. The methodology defined in the study proves to be an appropriate supporting tool for landfill Section IV area design and construction process apportioning for MSW site selection procedures to be considered in other growing urban regions in the country.

2. LITERATURE SURVEY

Trash disposal management has become an indispensable task for any city in the world and is known for the negative effects it can cause on health and living quality standards, especially suited places must be designated for this purpose. The awareness for securing the sanitation standards in the city of Tegucigalpa has an important role in the engineering area from which the new engineered landfill section will have considerable beneficial effects on the city from a sanitary point of view (Burgess, 1994).

The objective of the geotechnical tools applied to this study is to set the engineered parameters for leachate, gas, water, and drainage systems to comply with design and environmental regulations. A mechanically modified landfill proposal is analyzed by having a close look at its historic geological background, general lithologic stratigraphy, and geomorphology. The main subject of interest in this study is the analysis of failure mechanisms defining the geotechnical parameters to generate limit equilibrium methods on landfill slopes from which a properly engineered solution is detailed. Literature and relevant information are described in the following section.

2.1. Geographic Location and Country Background

Honduras, officially the Republic of Honduras, is one of the seven countries that conform to the isthmus of the Central American region which unites North America with South America. Mathematically it is located with geographic coordinates $15^{\circ}00'N$, $86^{\circ}30'W$ between Guatemala, and El Salvador to the west and Nicaragua to the south (Figure 2.1). The Caribbean Sea washes its northern coast and the Pacific Ocean its narrow southern coast. Its area includes the offshore Caribbean Bay Islands to the North, best known for its touristic attractions and second largest coral reef in the world (Honduras_and_Belize, n.d.). Honduras is politically divided into 18 departments with Spanish being the official language of the country. The two major cities in the territory are Tegucigalpa, the capital city, and San Pedro Sula the industrial city of Honduras (Clegern et al., 2022).



Figure 2. 1 Honduras location Encyclopaedia Britannica

Honduras has a total territory area of 112,492 km² (Ediciones Ramsés, 2000) which is ranked 103 in country area comparison to the rest of the world. The predominant climate in the area is mainly subtropical in the lowlands and temperate in the mountains. The morphology of the country consists mostly of mountains and rivers in its interior with narrow coastal plains at its sea borders. The elevations of topography range between 0 to 2,870 meters above sea level with a mean of 684 meters. Honduras explores natural resources such as timber, gold, silver, copper, lead, zinc, iron ore, antimony, coal, fish and hydropower (CIA, 2017). Even though natural hazard frequency is not high in the country, natural phenomena ranging from mild earthquake activity to occasional heavy tropical weather patterns like hurricanes and floods cause considerable damage due to the susceptibility of the country against these natural phenomena.

Honduras is a developing country with innumerable economic and social challenges which situate it among the poorest countries in Latin America with one of the lowest per capita incomes in the region where more than half of the population lives in poverty. These poverty rates are higher among rural and indigenous people settled at outskirts of north and central areas where most of the industries and infrastructure are concentrated. The persistent high poverty rate depends, in part, on the precarious educational system from which the drop-out rate and grade repetition remain high. The majority of the population lives in the mountainous western half of the country divided between the cities of Tegucigalpa and San Pedro Sula, the population growth rate has been decreasing since the 1990s and is now 1.2% annually from which according to the National Institute of Statistics (INE), Honduras has an estimated population of 9,636,510 (INE, 2022).

The major urban population areas consist of 1.527 million in the capital and 956,000 in San Pedro Sula (Central Intelligence Agency, 2022). Tegucigalpa as the main focus of this study contains an approximate territorial extension of 1,514 km², made up of 43 villages and 538 hamlets registered in the 2013 National Population and Housing Census (INE, 2019).

2.2. Waste Management in Honduras

Honduras is currently working on projects related to waste management, specific actions were carried out by the 2014-2018 government plan, from which promoting the institutional strategy of the Secretariat of Natural Resources and Environment (MI AMBIENTE) 2016-2026 plan was one of the primary objectives. An emphasis on the strategic axes of the policy environment of Honduras was revised in 2012, in this particular instance, the topic of waste disposal gained attention when the sectoral analysis of solid waste in Honduras was completed with Pan American Health Organization assistance (PAHO) in 2010. This allowed MÍ AMBIENTE to establish specific initiatives such as the creation of the Solid Waste Department adjudged to the General Environmental Management Directorate of Honduras. The creation of the Inter-institutional Commission for Integral Management of Solid Waste in 2012 was a key aspect of the additional participation of waste management experts in the institution. This strengthened the solid waste management issues in the country through the

execution of development plans which made it possible to generate an impact on local governments, and private and educational institutions (Ambiente, 2017). Elaboration and approval of reforms to the regulation of MSW was a successful task along with the development of technical instruments as supporting tools, such as the “Construction and Operation Manual of Sanitary Landfills” and the National Municipal Master Plan for Integral Management of Solid Waste (GIRS).

Another important point to take into consideration at the municipal waste management level was the establishment of the categorization of the municipalities established by the Secretariat of Human Rights, Justice, Governance and Decentralization (SDHJGD), which generated important information for the identification of the problems faced by municipalities, consequently providing a series of detailed study elements of interest areas to different expert analysts. This was done through the design of the categorization model, which is based on a mathematical-statistical system whose purpose is to classify municipalities into performance categories. This design implies a development index of the municipality, with which progress in coverage of needs is measured by unsatisfied basic needs, human development index, degree of urbanization and energy index, with a weighting of 45% on the scale. The other index of the municipality regards aspects of autonomy, capacity, financial dependence, municipal investments, expenses of operation and fiscal management, with a remaining weighting of 55%. The municipal categorization allows to get a perspective idea of the effort that municipalities make in the provision of general municipal services such as water, sewage, solid waste management, health, education and others. There are eleven (11) components reflected, four (4) indicators of municipality development, and seven (7) regarding financial administrative issues. The classification system is applied in all the 298 municipalities within the country, meaning that the highest values (equivalent to 100%) are used as a reference to compare with the lowest ones (see Appendix A.1) (Ambiente, 2017). The dynamic model is based on the estimation of municipal public management indicators that represents the administrative and financial capacities according to continuous data retrieved from the local government accountability platform that allows both a biannually and by government period measurement. The four measuring categories established by the model are:

| | | |
|--------------------------|-----|-----------------------|
| High performance | (A) | from 80 to 100% |
| Satisfactory performance | (B) | from 70 to 79.99% |
| Low performance | (C) | from 50 to 69.99% |
| Critical performance | (D) | from 49.99% and below |

It is important to highlight the lack of commitment of the population regarding waste management, evidenced in the different actions that are observed every day, people throwing garbage in open areas or unauthorized sites. There is a lack of strategy that links aspects of formal training with the inclusion of citizen participation, gender, and ethnicity. Process development and behavior change of the population in terms of habits should be promoted by the governing entities (Ambiente, 2017). The inter-institutional significance is a primary need, on the other hand, the existence of a market for certain types of waste that have a high market value, is already developed, with the existence of different companies dedicated to the purchase and commercialization of these wastes such as plastics, ferrous and non-ferrous metals as identified in the GDP contributors list from the Central Bank of Honduras (BCH).

2.2.1. Description of Tegucigalpa's Municipal Solid Waste Landfill

The capital city main waste disposal center according to the Central American Bank for Economic Integration (CABEI) is used approximately by 600,000 beneficiaries in the urban area of the Central District as registered users of the sanitation service plus 40,000 users from the areas surrounding the landfill. The rest of the population of the Central District (600,000 inhabitants) are considered indirect beneficiaries. An aerial view of the landfill can be seen in Figure 2.2.



Figure 2. 2 Aerial view from the Municipal Landfill in Tegucigalpa. Photograph by German R. Pavón

According to the article written by Rudi Mejía on STN Honduras, by 2020 more than 4 million metric tons of garbage had been received in Tegucigalpa's municipal landfill since 1978. The city mayor's office of the Central District announced on the 3rd of July 2021 the construction of another sanitary landfill in the capital, as the city demands and needs. German Pavón, the cleaning manager of the municipality explained that this new project will be located in an area next to the current municipal authorized landfill. The municipality added that its strategic plan includes future investment to carry out an environment-friendly project. The landfill will operate on a 21-ha property adjacent to the current landfill and is expected to have a service life of 24 years with the indicated management. For now, works continue on cell number three where the technical closure of the landfill has begun (Rudi Mejía, 2020). This cell is expected to receive MSW until the end of 2023 as explained by Hermes Guifarro, site landfill manager. The Municipal Central District Town Hall (AMDC) stated that improved operation expected for the new landfill will consist in handling the 850 daily tons of garbage that the facility receives which will be handled with better equipment designed

exclusively for this type of work, adding that compaction tasks and work fronts will be performed more efficiently.

At the north-easternmost part of the landfill, there is a small invasion neighborhood, as it is called to neighborhoods not formally designated by the municipality, which in its majority is occupied by extremely low-resourced people, who on a daily basis go into the landfill premises to scrape through the trash from the new coming trucks. Some collect plastic items which later sell to recycling companies for small amounts of money. Geologist José Arce stated that when performing pit excavations and boreholes people from the invasion community approached in an aggressive and unwelcoming way expressing their disapproval of the building of the new landfill. As expressed by the geologist most probable this north eastern part of the property acquired for the new landfill will not be used to keep a peace agreement with the people as relocating them will certainly not be an option. As a further matter, it is important to mention that this neighborhood possesses a candidate future access for the dump trucks which with some improvements such as enlarging its cross-section could become an alternative access for the trucks. (J. Arce, personal communication, July 19, 2022).

The operational management of the waste generated in the city has been in charge of the municipal authorities, disposing of the legal means, as well as the financial, administrative, and operational tasks to complying with the responsibility of municipal tax collection, street sweeping, garbage collection, transportation and adequate disposal of the MSW. The municipality of Tegucigalpa falls inside the high-performance “A” category of the municipal public management classification system.

The landfill located in the outer surroundings of Tegucigalpa began as a controlled or semi-controlled dump site. Since 1977, the solid waste generated by the areas of Tegucigalpa and Comayagua has been disposed of in an open-air dump belonging to the AMDC which after the devastating hurricane Mitch in 1998 received the attention and help of international organizations such as the Japan International Cooperation Agency (JICA) who evaluated and

prepared a study report on MSW management for the urban area of Tegucigalpa's Central District on March 1999. The landfill receives solid waste from the residential, commercial, institutional sectors and public areas (streets and parks), then transported by a fleet of dump trucks managed by the AMDC. Likewise, the site receives special waste, such as construction and hazardous waste, including agricultural, agro-industrial, industrial and hospital waste, among others. The method of MSW filling consists of the formation of terraces that can reach more than 10 meters in height. With the help of mechanical machinery, the covering material is compacted over the waste, this material is extracted from selected material pits within the landfill premises. The machinery used for the operation of the landfill consists of caterpillar tractors, backhoes, water tankers, front wheel loaders and dump trucks.

According to the "Sectoral Analysis of Solid Waste" report from the PAHO, it is clearly indicated that Honduras does not have quality service and efficiency in waste treatment. Among the deficiencies that it presents to exist the collection and transportation of solid and hospital waste which is partly carried out in private vehicles hired by the Ministry of Health or by the AMDC which are vehicles that do not meet the requirements for this garbage recollection. The incineration of waste is another deficiency that is carried out often without standardized technical criteria and at the same time is not separated or classified by material or waste type. Even though efforts are being carried out for separating materials (especially plastic), at the end of the day a dump site with mixed MSW is grouped in a disorderly way.

2.2.2. El Crematorio Landfill Geographic Location

Located in the Tusterique sector in the Guanábano village with 14° 8'41.55"N latitude; 87°13'27.93"W longitude coordinates, El Crematorio is the name given to the landfill located in the department of Francisco Morazán on the RN-15 road that leads from Tegucigalpa Central District (TCD) to the north eastern department of Olancho. The approximate station of the project is kilometer 3 where the main access to the sanitary landfill can be found with premises at a height above sea level between 1070 and 1150 meters. From Figure 2.3 a satellite geographical location of the landfill can be observed with the new land extension area delimited by the red polygonal.

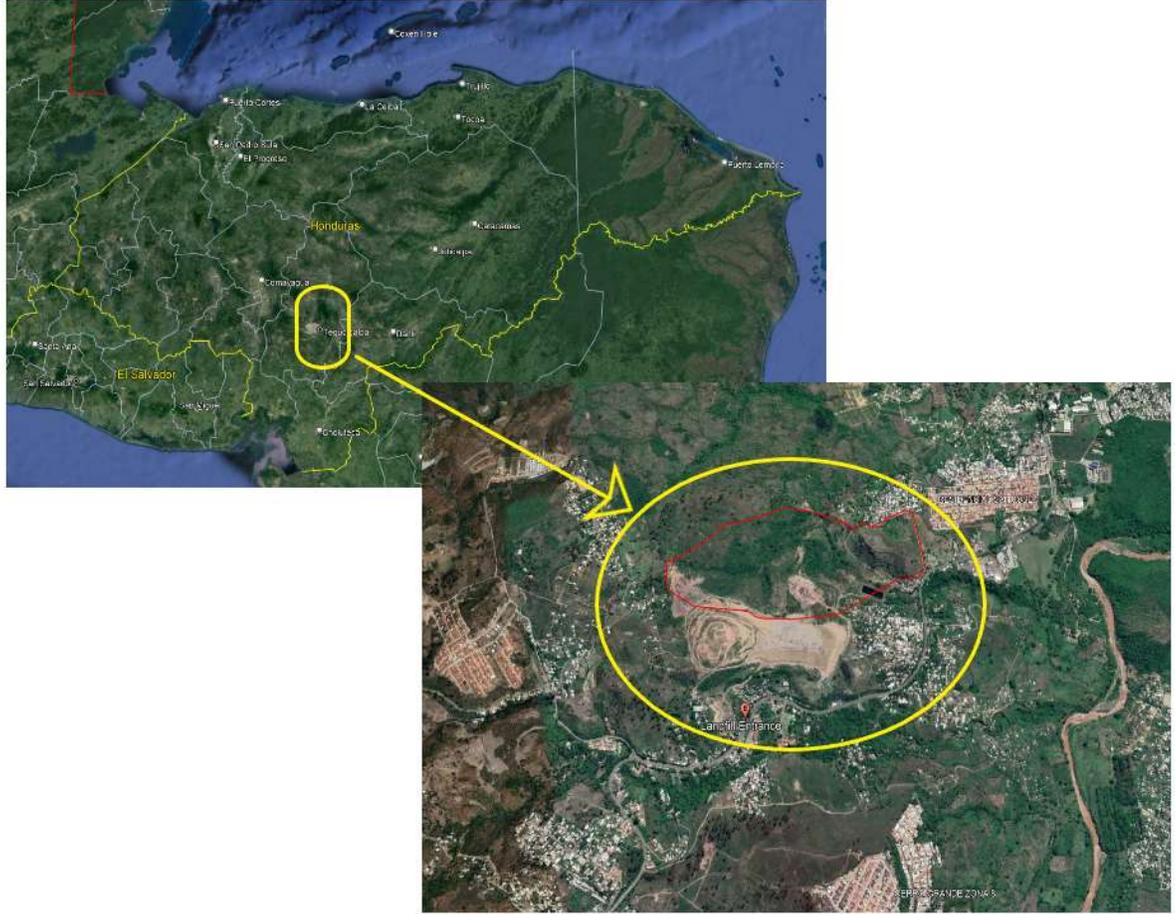


Figure 2.3 Location of the project

2.2.3. General Description of Working Area and Surroundings

The expansion of the landfill with the newly acquired 400,000 m² area by the AMDC is still to be defined while legal and environmental permission procedures take place. The new landfill areas are tentatively selected according to the topographic advantage that can be observed in the area, where slopes can contribute to the landfill constructive procedures and accessible drainage solutions can be performed. In general, the topography in El Crematorio presents a very irregular shape in both its natural and finished landfill landscape, when compared to other landfills in the country like for instance the sanitary landfill in Comayagua where flat valleys are easily found (Figure 2.4). The central geographic location of Tegucigalpa, characterized by its mountainous areas and irregular city urbanizations affects

as well El Crematorio, where apart from being surrounded by mountains on its north and western part, urbanizations like the Cerro Grande Zona 8 and San Jose residential 500 meters north-east and 900 meters south respectively from El Crematorio can be found. In the “Manual for Construction and Operation of Sanitary Landfills in Honduras,” there is no specification about landfill distancing restriction from urbanized areas rather than a general participatory process where the possible communities which may be affected by a landfill must be informed and measures intended to prevent and/or control possible health and environmental damage must be done (SERNA Honduras et al., 2014).



Figure 2. 4 Panoramic view of Sanitary Landfill in Comayagua. Source: General Directorate of Environmental Management (MI AMBIENTE).

El Crematorio is a mechanized sanitary landfill, meaning that it is designed to be the final disposal of MSW from the city of Tegucigalpa generating more than 850 tons of non-special solid waste per day. This type of landfill requires the use of heavy machinery for its operations of moving the waste, accommodation, compaction and final coverage layer. All these procedures are done with mechanical equipment such as bulldozers, front loaders, water

tanks, graders, and others. The mechanized sanitary system allows timely compaction and daily coverage of significant amounts of waste avoiding the generation of health and environmental hazards that could affect the local habitants and environment.

2.2.1. Waste Management Challenges

Waste management in Honduras faces numerous challenges for which the MI AMBIENTE with the collaboration of the United Nations (UN) 2030 agenda have set out a plan and measures to address them. The main issues with this problem are an increasing population and economy, which result in higher levels of waste production resulting in additional strain on the existing waste handling facilities, such as El Crematorio. The increased complexity of the waste composition because of urbanization and industrialization affects directly its management which is compounded when hazardous waste mixes with general waste. This inadequate waste disposal and management lead to unpleasant living conditions and a polluted, unhealthy environment. In Honduras understanding the main waste flows and national waste balance is a hard task when the submission of waste data is not an obligatory information mark for the municipalities. The available data is often unreliable and mostly approximated which in some cases end up being contradictory. The absence of a recycling infrastructure must also be pointed out in which MSW suffers underpricing management, which means that the costs of waste recycling are not fully appreciated by consumers and industry, whereas waste disposal is preferred over other options. Given that landfilling costs are lower than waste treatment options, compliant landfills and hazardous waste management facilities are needed to continue disposing of the different city wastes as is the case of Tegucigalpa where the actual disposal capacity is near being completed.

Honduras is part of the 2030 agenda for sustainable development, approved in September 2015 by the UN general assembly. This multi-governmental agreement which describes an improvement tool towards economic, social, and environmental sustainability topics, represents a guidance book for Latin America and Caribbean countries since it prioritizes issues such as decreasing poverty levels, reduction of inequality, economic growth, sustainable cities, and climate change issues among others (*Agenda 2030 Para El Desarrollo Sostenible | Agenda 2030 En América Latina y El Caribe*, n.d.).

2.3. Regional Geology

As its foundational rocks, Honduras regional geologic structure contains Paleozoic metamorphic rocks like the Cacaguapa schist. Underlying its territory together with its neighbor countries Nicaragua and El Salvador, a continental Chortis block fragment is located (Gordon, 1992). The Valle de Catacamas depression runs along the Guayape fault for 290 kilometers which is the longest and most continuous structure in Honduras and also one of the major tectonic elements in the Chortis block of the Caribbean plate (Finch & Ritchie, 1991). The large-scale regional geology must be characterized and discussed to locally identify the project site. Using a series of different geological disciplines, a pattern of Honduras past geological characteristics is detailed in this study.

2.3.1. Regional Tectonic Framework

The country is located in the northwestern corner of the Caribbean tectonic plate, just south of the contact zone between the latter and the North American plate. The contact between the Cocos (oceanic) and the Caribbean (continental) tectonic plates embodies an active tectonic margin in which subduction of the Cocos plate is taking place under the continental plate. These block rotation changes are observed in seismicity, gravity anomaly patterns, volume and composition of volcanic products, and topography. Therefore, the complex volcano-tectonic geology south of the main boundary faults may be explained by the interaction and rotation of crustal blocks in the overriding Caribbean plate above the magma production zone along the down-going Cocos Plate. This is a process derived from the difference in density between both plates where the denser oceanic crust sinks under the continental plate. The subduction of the Cocos plate under the North American and Caribbean plates produces the formation of the Mesoamerican Trench, the current Central American volcanic arcuate, and earthquake activity along the plate interface. The boundary between the North American and Caribbean tectonic plates is formed by the Motagua and Polochic fault systems of southern Guatemala on the terrestrial part and by the continuation of this system in the marine part, the Cayman Trench which is limited by the Swan Island fault consisting of a shear-type fault system sinister displacement. This plate margin is a tectonic setting that produces intraplate deformation (Burkart & Self, 1985)

From a geological point of view, the Republic of Honduras is situated on what has been called “Bloque Chortís”, used as a geographical term to describe the Neogene tectonic style south of the Motagua fault in Guatemala (Geólogos del Mundo et al., 2010), differentiating it from the northern regions of the fault, and the other southern Central American regions as Nicaragua, Costa Rica, and Panama. Its southern limit has been defined at latitude 12° 30’, due to the lack of a visible geological feature that serves as a boundary between the northern Continental and the southern Oceanic terrestrial crusts (Figure 2.5).

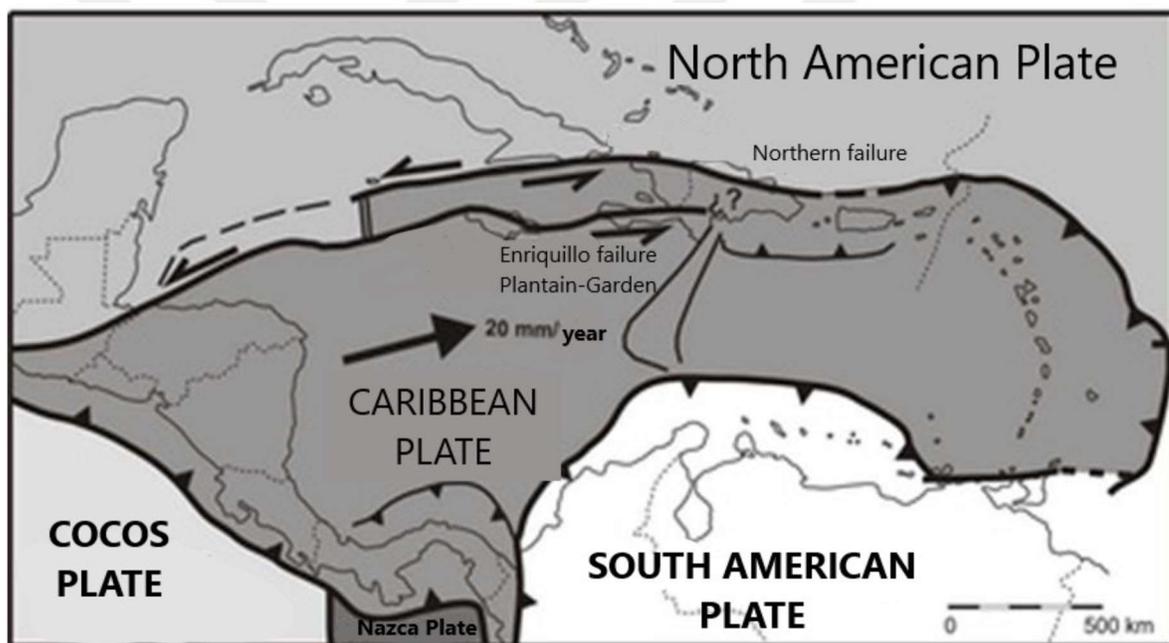


Figure 2. 5 Map of tectonic plates in the Caribbean

The materials of the Bloque Chortís correspond to Formations of Mesozoic and Cenozoic ages, which are discordantly located on a Paleozoic base of metamorphic rocks. The plinth rocks are mainly low-grade meta-sedimentary rocks. Intrusions of the Paleozoic age have been dated which in turn, have been metamorphosed. The crust of the Bloque Chortís which can be appreciated in Figure 2.6, is continental in type.

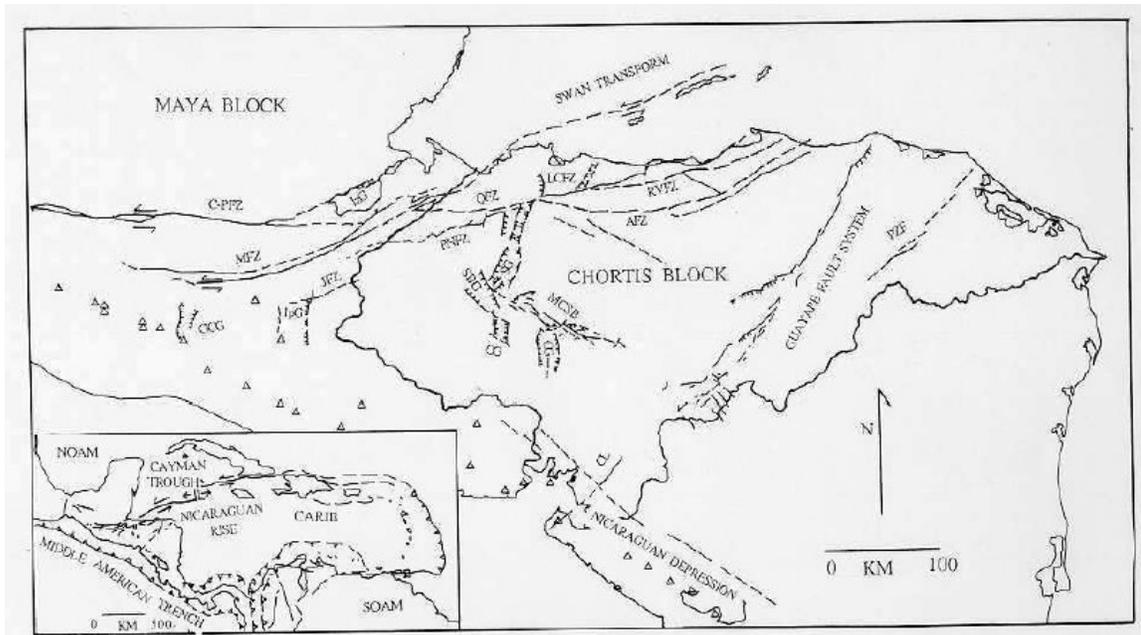


Figure 2. 6 Tectonic map of Honduras and bordering regions (modified by Rogers, et al., 1992).

2.3.2. Regional Stratigraphy

The stratigraphic study compiled by (Romonti & Peretti, 2007) describes the stratigraphic column at national level as a base of Paleozoic schists known as the Cacaguapa Group deposited discordantly within sedimentary formations under continental or shallow marine conditions. A Mesozoic stratum up to 4000 m. thick forms the basement of the stratigraphic column for the Central and Eastern Chortis Block. The southern Chortis and Maya Block record a Cretaceous–Early Cenozoic collision and eastward sinistral translation of the Greater Antilles arc. This block translation evidences the northward stepping of the plate boundary (Ratschbacher et al., 2009). The Agua Fría and the Todos los Santos formation make up the Honduras group were the Agua Fría formation deposited in the mid-Jurassic is exposed near to the southeast Guayape fault system. This formation was deformed and partially metamorphosed by the deposition of Cretaceous strata (Geólogos del Mundo et al., 2010).

The Tepemechín formation is a thin conglomerate base of carbonate stratigraphy of the Yojoa Group (Barremian-Albian, Lower Cretaceous) conformed by a series of carbonate rocks corresponding to reef limestone in shallow waters. The group is divided into two formations, the Cantarranas formation, a sequence of thin basal layers of black limestone and schist of Neociomian to Albian age and the Atima formation named after the rustic to dark gray limestone cliffs that form the town of Atima Santa Barbara composed of massive limestone from the late Cretaceous with calcareous conglomerates interstratified with limestone from the Cantarranas and Atima formations. At the end of the Cretaceous, the Valle de Angeles Group marks a change in the deposition of carbonate fragments, it contains an interval generally thicker in the upper part and finer in the lower part (Gerson Armando, 2021), separated by layers of marine carbonate of Cenomanian age, Jaitiques and Esquías formations. The upper and lower red layers are known as the superior and inferior Valle de Angeles Formation respectively, in the absence of the carbonate units separating the red layers, the general term Valle de Angeles Formation is used. In Figure 2.7 the location of the different depressions in Central America can be observed.

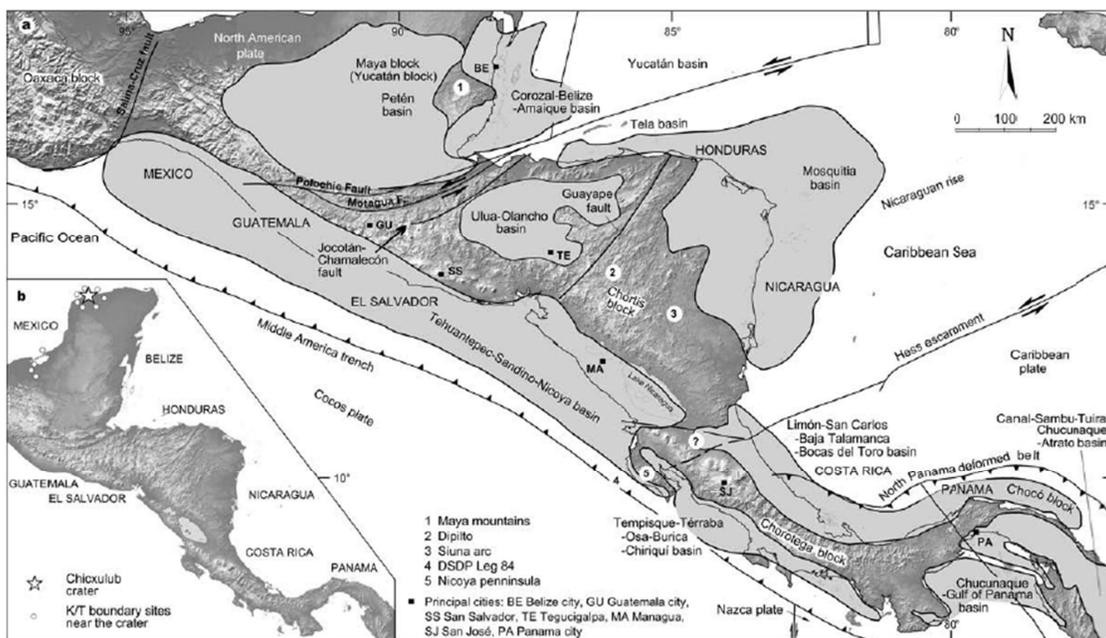


Figure 2. 7 (a) Location of sedimentary basins in Central America and major structural elements; (b) Location of Chicxulub crater, and related siliciclastic or breccia deposits in the Yucatán peninsula. Source: (Guillermo et al., 2007)

2.3.3. Seismicity

The countries of Central America are located within the boundaries of the Caribbean, North American, Cocos and Nazca plates. The Cocos-Caribbean contact is a convergence or subduction of the mentioned plates. The Nazca and Caribbean plates are bounded by the Southern Panama Deformed Belt, the Polochic-Motagua Chamelecón, Panama Fracture Zone, and Atrato Suture Zone strike-slip faults formation respectively. The North American-Caribbean, Cocos-Nazca, and Caribbean-Caribbean plate boundaries intraplate structures of earthquake-tectonic interest which are the Chortis Block, the Hess Escarpment, the Nicaraguan Depression and the Southern Panama Fault Zone (GEASA, 2021a).

According to the Honduran Code of Construction (CHOC), the Iso-acceleration maps valid for Honduras in the new landfill project area indicate a 3b zone corresponding to values of 0.25g which should be considered for design within this zone (see Figure 2.8).

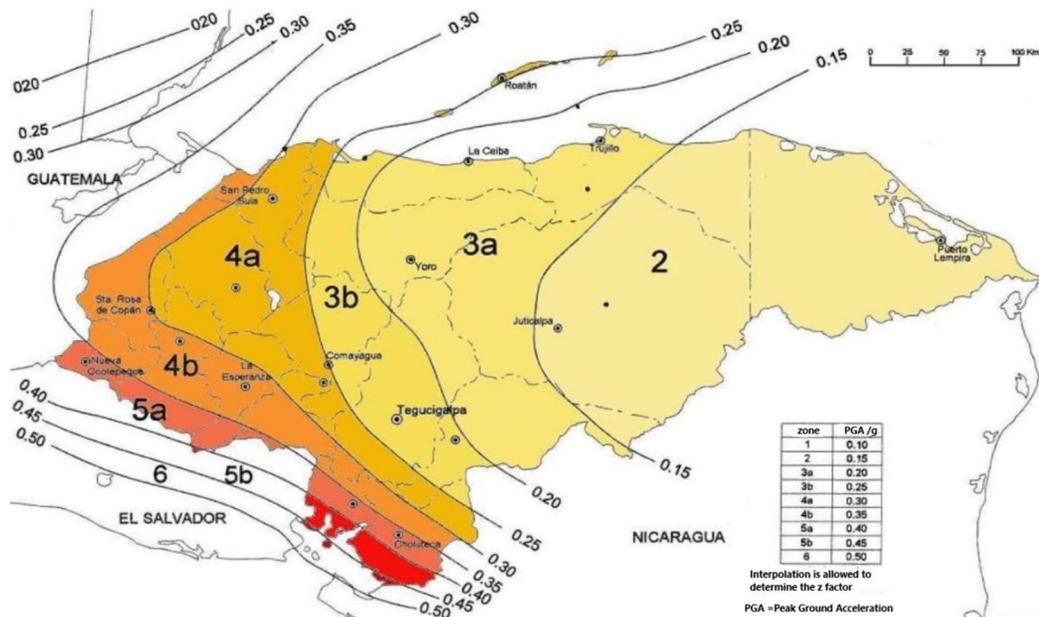


Figure 2. 8 Seismic zoning map of Honduras CHOC 2008

2.3.4. Lithology

The “Bloque Chortís” is formed by mainly sedimentary lowgrade metamorphic rocks. The dominant rock types are phyllites and granitic schists, even though rocks with variable materials are also present, such as the Cacaguapa Schists, or Cacaguapa Group whose age ranges from pre-Mesozoic to Paleozoic era, being possibly the oldest rocks identified in Honduras. Some sedimentary formations of the Mesozoic age (Jurassic and Lower Cretaceous) are discordantly located on the Paleozoic base, and deposited under continental or shallow marine conditions. These materials are called the Honduras Group and are subdivided into the Agua Fría Formation and an Upper Siliciclastic assemblage. In the upper Cretaceous, a powerful series of carbonate rocks were deposited, followed by some detrital rocks, molasse type with a well-marked purple-red color. The limestones have been called the Yojoa Group, and are distributed throughout a wide area of Honduras, northwestern El Salvador, and southwestern Guatemala. As for the detrital rocks, they form the so-called Valle de Ángeles Group, made up of conglomerates, sandstone, marl and limestone (GEASA, 2021a).

During the Tertiary, volcanic emissions were produced beginning with the Matagalpa formation, a pre-ignimbrite volcanic unit, with a predominance of andesite flows, basalts and pyroclastic sediments, resting unconformably on the Cretaceous rocks. Above this formation appears the Padre Miguel Group, extended to all the acidic volcanic deposits of Central America from the Oligocene and Miocene, and which consists of a group of ignimbrites, rhyolitic tuffs, and andesitic tuffs. Numerous intrusive bodies cut through all the rocks described, including granites, granodiorites, etc. At the end of the Tertiary, a global upheaval of the "Chortis Block" took place, causing the erosion of the materials described. The products of this erosion were transported and sedimented in basins and valleys. During the Quaternary, the most recent materials were deposited, which would be the current alluvial, deltaic and colluvial materials.

2.3.5. Geomorphology

Honduras is a mountainous region where approximately 80% of its land exhibits this terrain, with elevations of more than 1,000 meters above sea level and above 2,000 meters at specific points (Merrill, 1993). In its interior and near coast areas alternating high plateaus created by large valleys can be appreciated where steep slopes predominate; 60% of the soils have slopes greater than 30%. The country can be divided into numerous regions from a physiographic point of view. In the west with long valleys arranged in a north-south direction. High elevations and steep slopes with flat and abrupt limits, valleys that are sharply cut and rectilinear, a central mountainous region, a mountainous zone to the east, and flat regions close to the Atlantic and Pacific coasts.

In a general view, the mountainous region of the country is formed by the Sierras of northeastern Central America, tertiary volcanic ranges, mountains of southeastern Central America and the Pacific volcanic chain. Likewise, the lowlands are formed by the Petén and Yucatán peninsulas, the Gulf coastal plain, the Caribbean coastal plain, the Pacific coastal plain and the Nicaraguan depression. The sierras of northeastern Central America form an arc that opens to the north creating many ranges. Subparallel highlands extend from Mexico, Guatemala, Honduras, and northeastern Nicaragua to the Caribbean. The ranges are separated from each other by faults such as the Motagua, Valle of Polochic and the Valley of Chamelecón faults. The volcanic platforms and ranges that cover large areas of Nicaragua and Honduras, extended towards El Salvador which were built with lavas from the Oligocene period to the Pliocene, being found in pyroclastic rocks; most of them ignimbrites and volcanoclastic sediments, which vary in substance from rhyolites to basic andesites. In Honduras and Nicaragua, they form extensive plains and blocks of faulted mountains, which continue toward El Salvador (Dengo & Bohnenberger, 1969). The Pacific volcanic chain of the Quaternary period extends from the Mexican border to Costa Rica and continues, in a much more dispersed arrangement until Panama. The chain is very close, in the spatial sense, to the area of seismic activity on the Central American plate and is currently recognized as a decisive protagonist of subduction. The lowlands of El Petén and the Yucatán peninsula are built of limestone and evaporites from the Cretaceous period, also limestone from the Tertiary period. This zone is characterized by drainage and karst topography.

According to the position of the project, the geomorphology is complex. On one side, the hill of the current dump site has a cut where the current landfilling work is being carried out. This hill has steep slopes towards the foot contact zone of the new expansion area with tuff lithology. The existence of water ravines also procures attention for the relief solution associated with it.

2.3.6. Geology of Central America

Central America due to its location on the western margin of the Caribbean tectonic plate, has a particularly unstable crust. The land was raised from the sea by the subduction of the oceanic crust on this edge, which started in the Miocene 25 million years ago. A peninsula and an archipelago were formed in the initial stage. The scattered islands eventually combined to form a true land bridge, or isthmus, connecting North and South America, some 3 million years ago. Volcanic eruptions took place often at the same time as subduction and uplift (Dengo, 1967).

The North American Plate, the Caribbean Plate, and the Cocos Plate are the tectonic plates on which Central America is located. The author Richard Weyl in his work "Geology of Central America" defines Central America as "the terrestrial surface and the platform that extends towards the east of Guatemala and the south, until the Arato lowlands in Colombia. As a result, it encompasses seven countries: Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica, Panama, and Belize. Central America can be divided into two large units which are completely different from each other, both in geological history and structure (Sapper & Paap, 1981). These unit divisions were also recognized by Schuchert (1967), Stille (1960) and Dengo (1968 - 1973) in their more recent studies. Guatemala, Honduras, El Salvador, and northern Nicaragua make up the northeast region displaying a crust-type continental formation with paleozoic rocks. This formation has a presence of anatexite and plutonic metamorphic rocks older than the Paleozoic. In the Tertiary period, northeastern Central America was the scene of continental volcanism were extremely violent eruptions with large masses of ignimbrite were extruded. Gordon Andrew Macdonald explains that the

southeastern part of Nicaragua to Panama is formed from an oceanic-type Cretaceous crust, on which small marine and volcanic sediments were deposited during the tertiary period. This region has been transformed into crusts that sit between the oceanic and continental parts, using the controversial term “tectonic platform”. The Crustal structure and development of the two parts of Central America are contrasted with each other in a highly diagrammatic way.

2.3.7. Local Geology

According to the geological map sheet edited by the National Geographic Institute (IGN), the geology of the area corresponds to the Padre Miguel Group, more specifically to two formations. In the northern area of the project, the TPM unit member and in the southern zone of the Cerro Grande TCG unit (see Appendix A.2 Soil Units Chart). The TPM unit is a sequence of rhyolitic, andesitic, and dacitic ignimbrites with tuffs of different colors and resistances (GEASA, 2021a). This unit is very marked on Cerro Tusterique which is the name given to the mountain located in the project and next to the residential San Jose on the northeastern side where these sequences can be observed. From the geological map sheet 2758 II of Tegucigalpa (Appendix A.3 Geological Map of Project area) a focus area is made on the northern TCD area and Project location shown in Figures 2.9 and 2.10 respectively.



Figure 2. 9 The geological map of Tegucigalpa Honduras scale 1:50,000

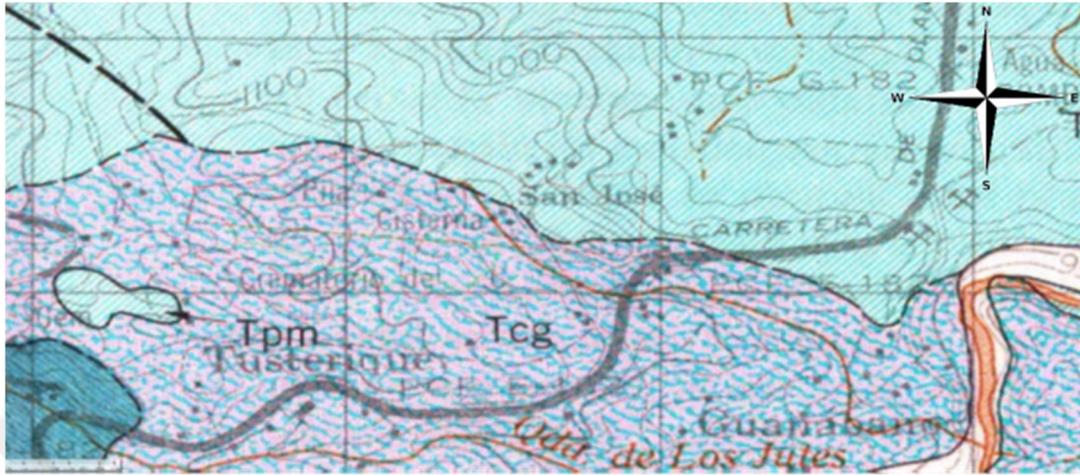


Figure 2. 10 GEOLOGICAL MAP 2758 II - Tegucigalpa Sheet – scale 1:12500 - edited by the National Geographic Institute with project location.

The Cerro Grande formation that is found in the south area corresponds to ignimbrites with quartz (amorphous silica) and sanidine in a vitrified matrix with deep and vertical fracturing. In Figure 2.11 the lithology with the fire opal type can be observed.



Figure 2. 11 Amorphous silica. Source: GEASA studies for the new municipal landfill report.

Greenish tones are observed in some loose clasts in the area, indicating that outcrops of the Matagalpa formation may occasionally be found in the area. Given this, depending on the slope some areas may be found to contain colluvium-type materials with large rock fragments and a sandy matrix. A detailed description of the materials found in the tests is presented in the laboratory results section.

2.4. Climate Conditions

The local climate is characterized by a tropical Monsoon climate (Monroe Jr, 1965), which manifests a dry season from January to June and a rainy season between June and December, with climate transition stages in the intermediate months to the critical points. The orography of the Honduran territory plays a very important role in the diversification of its climate since when interacting with the circulation of the atmosphere and the systems of low and high pressure, troughs of surface, height and of mid-levels, tropical waves, cold fronts, tropical cyclones and tropical waves that affect the region, produce regimes of different rains on the Caribbean slope, the Pacific slope and in the central inter-mountainous zone (Pastrana, 1976).

Most of the Honduran territory, especially the intermountain zones and the coastline of the Gulf of Fonseca, have a climate with a precipitation regime that presents two well-marked season stations, the rainy and the dry stations. During the rainy season in these regions (May-October) there is a decrease in precipitation in a period known as the “Summer Canicula”. In contrast, on the Caribbean coast, it rains almost all the year registering a decrease in precipitation during the months of February to May. The region which receives the most annual precipitation is the Caribbean coast on the north and the region with the least precipitation is the central zone of the country as can be appreciated in Figure 2.12.

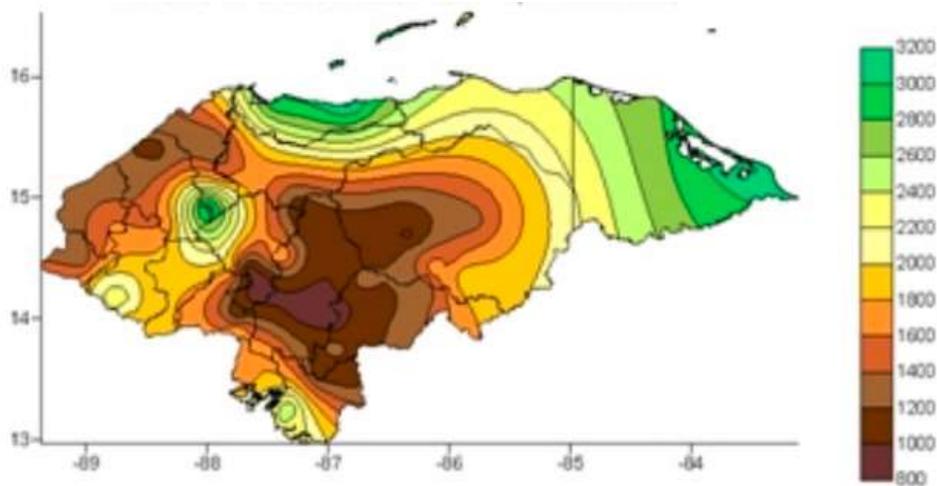


Figure 2. 12 Average annual rainfall totals, in millimeters, source: Climate Variability and Climate Change in Honduras, Francisco J. Argeñal 2010.

The Honduran precipitation regime is a direct and indirect consequence of the Intertropical Zone of Convergence (Z.I.T.C.) phenomena which undergoes different tropical cycles. In the west mid-latitudes with tropical waves of low atmospheric pressure in height and surface, sea-to-land breezes, valley breezes and mountain cold fronts may undergo sporadic tropical cyclones. According to Alfaro (2002), other factors that must be taken into account are the convergence of moisture and heat flow latent since these parameters increase during the rainy season having a positive influence on the convection over the region and which is reflected with an increase in evaporation and advection moisture. The dry season and the “Summer Canicula” (July-August), in the southern and inter-mountain regions, is a consequence of the strengthening westward shift of the North Atlantic anticyclone, located on the islands of Bermuda during this time of year, which causes an increase in the velocity of the trade winds (Hastenrath, 1991). The average low temperatures of Honduras occur in the month of December and range between 8°C in the high parts of the Celaque mountain range, up to 28°C in the southern plains, while the hottest month is April where average temperatures range from 10°C in the upper parts of Celaque up to 31°C on the southern plains of the country. In June the highest temperature of all Honduras is registered in the Sula Valley since until this month the rainy season begins in the northwestern region (Argenal, 2010).

3. STABILITY CONDITIONS IN LANDFILL DESIGN

Since the introduction of geosynthetics in liners as a regulation requirement more importance has been given to the slope stability topic (Omari, 2012). The geosynthetic materials may act as a triggering factor for waste movement in landfill excavated slopes. Therefore, assessing the stability of MSW excavation slopes is crucial for its final design. Additional factors must be taken into account for waste quantities to be managed, waste cell divisions, fluid and gas extraction systems, and expansion rates. To assess an MSW disposal site, slope stability analysis is a fundamental step followed by an engineered design on which as general an empirical slope height relation suggests that the slope angle should decrease as the slope height rises (Stark, 1999).

3.1. Landfill Slope Stability Assessment

Waste disposal sites acquaint with one of the highest potential sources of contamination made by humans. Risk assessment is necessary for landfill slope stability to determine the danger and impact of a potential failure. The failure hazard refers to its probability and triggering mechanisms such as rainfall. Historically and currently, landfills have been the main used structure for waste disposal. Non likewise all around the world catastrophic events have been recorded in which landfill slope failures have had lethal results as it occurred in the Leuwigajah dumpsite Bandung, Indonesia (2005) where 71 houses were buried and 147 people lost their lives (Lavigne et al., 2014). This is considered the second deadliest waste slide in history after the waste slope failure of the Payatas dumpsite in the Philippines (2000) where more than 200 were killed (Koelsch, 2007). In both exposed cases, the common triggering factor was rainfall, which combined with low-density waste allowed a higher water percolation rate which consequently reduced shear strength.

As for the cases presented one of the main objectives of this study is to prevent such fatalities by evaluating the variables affecting landfill stability like rainwater and leachate refusal which create the weakest shear strength interface at the bottom liner systems. Landfill operations including daily cell arrangements, coverage procedures, gas and leachate

drainages are critical points to maintain the stability for which it is purposely designed (Law, 2013). To simulate the performance of the landfill slope during normal landfill operation and final slope, a computerized design is run to obtain its factor of safety against instability where analytical and stability modeling experience is required. To ensure slope stability, landfill operations must be optimized to reduce leachate head build-up above the bottom liner system.

3.2. Slope Failure Modes

Determining a slope failure mechanism mode may result in a challenging task due to the lack of field data in the exact location of a study which makes it hard to fully comprehend the potential failure mechanism. Expertise and field experience are crucial criteria to assess a slope stability failure with the appropriate method. Field observation plays an important role in cataloging the possible initial failure mechanism of a slope taking into consideration the geological parameters, the geometry of the slope, joint structures, and behavior of the rock and rock mass as it is the scenario case for El Crematorio which presents a predominating ignimbrite lithology. The importance of identifying the failure mode is to provide the engineer or designer with a field phenomenon from which a particular analysis with a defined mechanical model can be made to manage or control landfill stability. (Stark, 1999) classified landfill failure into two major modes, translational and rotational, from which based on previous records like the tragic rotational failure in the Payatas landfill in the Philippines, the translational failure mode is more catastrophic and common than the rotational failure. Payatas tragedy highlighted the necessity of more research on failure modes. Thus, a year later, (Qian et al., 2001) published the six main general landfill failure modes within the cover liner, waste materials and foundation soil interfaces, illustrated in Figure 3.1. In the following sections, some of these typical slope failure mechanisms are discussed.

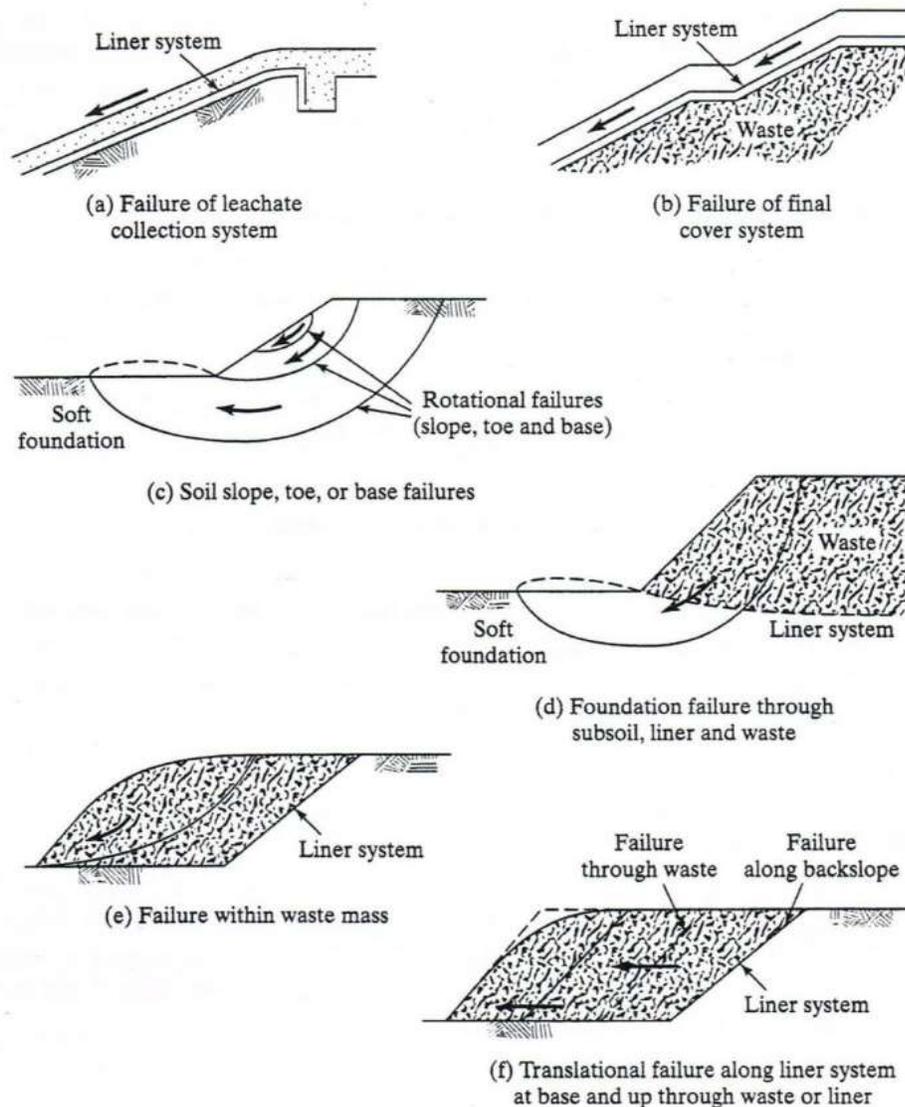


Figure 3. 1 Landfill failure modes (Qian et al., 2001).

3.2.1. Rotational Failure

Following the classification of rotational shear failures by (Qian et al., 2001), these types of failures are the most common type in landfill slopes and are also referred to as circular failures (Hoek & Bray, 1981). As the name implies the failure takes place along a circular arc normally occurring in slope discontinuities or weak planes. Rotational shear failure generally involves failure along pre-existing discontinuities sometimes going through intact rock and is prone to be relatively deep, even though shallow ones can also occur. There are a series of combinations that may occur in these circular failures with or without tension

cracks (Sjöberg, 1996). Failure due to rotation of the slopes at the base or through the soil as shown in Figure 2.14c is a failure where normally rotation of its weak plane occurs on steep slopes or through soft soil layers. This type of failure is local and does not involve the waterproofing system or the waste mass (Qian et al., 2001).

3.2.2. Rotational Failure of Sidewall Slope or Base

This failure occurs when the soil layers behind or beneath the waste mass are unstable and provoke a circular failure, see Figure 3.2. Failure plane can emerge from the slope, toe, or within the foundation. This geotechnical problem applies to steep side slopes and/or soft foundation soils and does not involve liner systems or their waste mass properties (Omari, 2012).

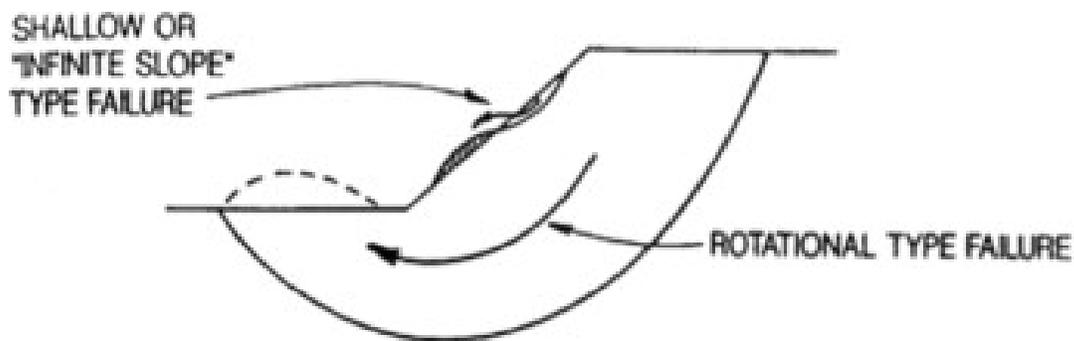


Figure 3. 2 Rotational failure of sidewall slope and base failure (Mitchell & Mitchell, 1993)

3.2.3. Rotational Foundation Failure through Waste, Liner, and Subsoil

Failure by rotation through waste, liner, and subsoil starts at the foundation as a sloping of waste on the upper part and continues through the MSW mass all the way to the liner and subsoil as shown in Figure 3.3 (Qian et al., 2001). This type of failure occurs within the waste mass and is common in steep slopes with high moisture content, and low compaction density. Such failures can be massive, involving over 50,0000 m³ of waste (Omari, 2012). The weight of the MSW may be one of the triggering factors of these failures.

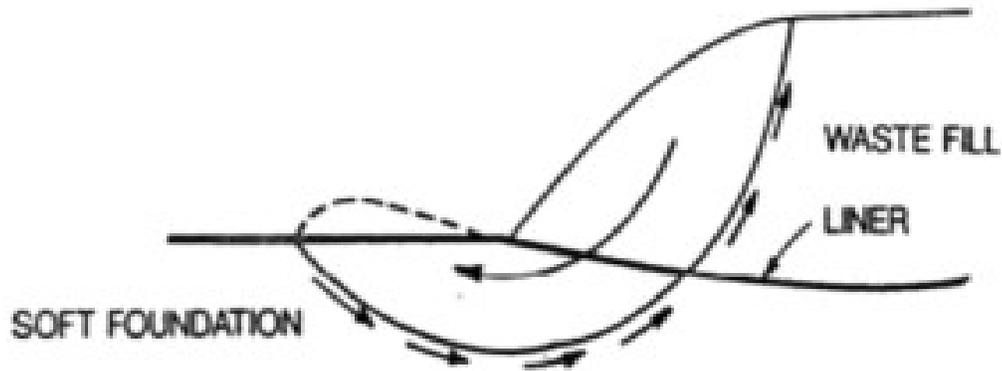


Figure 3. 3 Rotational failure through the landfill, liner, and foundation layer (Mitchell & Mitchell, 1993)

As an example of a failure by rotation within the waste mass, the “Göktürk” sanitary landfill located 8 km northwest of Istanbul Kemerburgaz in Turkey, started operating its 60-acre first-stage disposal site in 1993 which was completed two years later in 1995, where after its closure, suffered a landslide due to high pore water pressure in the subsoil associated with poor leachate management. The rise in pore water pressure was triggered by the heavy rains from the spring season. This event occurred on April 1995 as presented at the Middle European Conference on Landfill Technology Design (*A Case Study On Slope Failure in a Sanitary Landfill*, 1995) by authors Turan Durgunoğlu, Turhan Karadayılar and Guney Olgun. The investigations indicated that the rise in pore water pressure was the result of the gas collection pipes which had not been constructed as specified in the design project required by the Turkish Standards for clay liners. Therefore, marking the importance of gas and leachate collection systems to prevent failure by rotation within the waste mass.

3.2.4. Translational Failure Along the Bottom Liner System

Translational failure can occur with the waste sliding above, within, or beneath the liner system. The failure plane can extend from the toe up through the waste mass, or continue in the liner system along the back slope (Qian et al., 2001). This type of failure is mostly possible in landfills and starts with a huge sliding mass that deforms and breaks into several

independent pieces (Stark, 1999). Normally starting from the weak surfaces within the waste mass or liner interface as shown in Figure 3.4. Stark (1999) claimed that homogeneous materials such as soft soils and clays are more prone to failure.



Figure 3. 4 Failure by sliding along the landfill liner system (Mitchell & Mitchell, 1993).

Based on previous landfill failure records, translational failure is probably more catastrophic and common rather than rotational failure. This failure may as well be affected by seasonal changes in the waste composition (Blight, 2008). Different shear strengths between the waste components and liner can trigger a translational failure in the waste-liner interface. Translational failure can be significantly triggered by high leachate levels in landfills where leachate levels may decrease the FOS considerably more quickly for an interface with a high friction angle and low cohesiveness than it does for an interface with the opposite situation (Xuede, 2008). Such failures have resulted in the largest landfill failures involving up to over 1.000.000 m³ of waste material in both clay-lined and geosynthetic-lined sites as can be seen on case histories listed in Table 3.1.

Table 3. 1 Summary of 15 largest landfill failures causes in the world (Qian & Koerner, 2007; Qian & Koerner, 2007).

| Case history | Type of failure | Reason for low FS-values | Triggering mechanism |
|--------------|---------------------|--|--|
| U-3 | Translational | | Excessive buildup of leachate level due to ponding |
| U-4 | Translational | | Excessive buildup of leachate level due to ice formation |
| L-4 | Translational | | Excessive buildup of leachate level due to liquid waste |
| L-5 | Translational | Leachate buildup within waste mass | Excessive buildup of leachate level due to leachate injection |
| L-6 | Translational | | Excessive buildup of leachate level due to closed outlet valve |
| L-7 | Translational | | Excessive buildup of leachate level due to leachate injection |
| U-6 | Translational | | Excessive buildup of pore water pressure in waste |
| U-7 | Single rotational | | Excessive buildup of leachate level due to hurricane |
| L-1 | Translational | Wet clay beneath geomembrane, i.e., GM/CCL or GM/GCL composite | Excessive wetness of the GM/CCL interface |
| L-2 | Translational | | Excessive wetness of the GM/CCL interface |
| L-3 | Translational | | Excessive wetness of the bentonite in an unreinforced GCL |
| U-1 | Single rotational | | Rapid rise in leachate level within the waste mass |
| U-2 | Multiple rotational | Wet foundation or soft backfill soil | Foundation soil excavation exposing soft clay |
| U-5 | Single rotational | | Excessive buildup of perched leachate level on clay liner |
| U-8 | Translational | | Progressively weaker foundation soils |

U—unlined (or clay soil lined) sites; L—geomembrane or composite (GM/GCL or GM/CCL) lined sites.

3.2.5. Failure of the Final Cover System

Long and steep slopes in the final cover system formed of topsoil and a protective layer, may fail on the liner system. This failure surface plane is always planar (Omari, 2012), usually parallel to the surface ground as seen in Figure 3.5, and relatively at low depths of about 0.5–2 meters deep. The cover system failure normally happens when excessive precipitation occurs. If only soil is displaced, replacing the soil will fix the problem. However, the long-term stability issue may continue. The consequences are more serious if the liner system contains the failure surface.

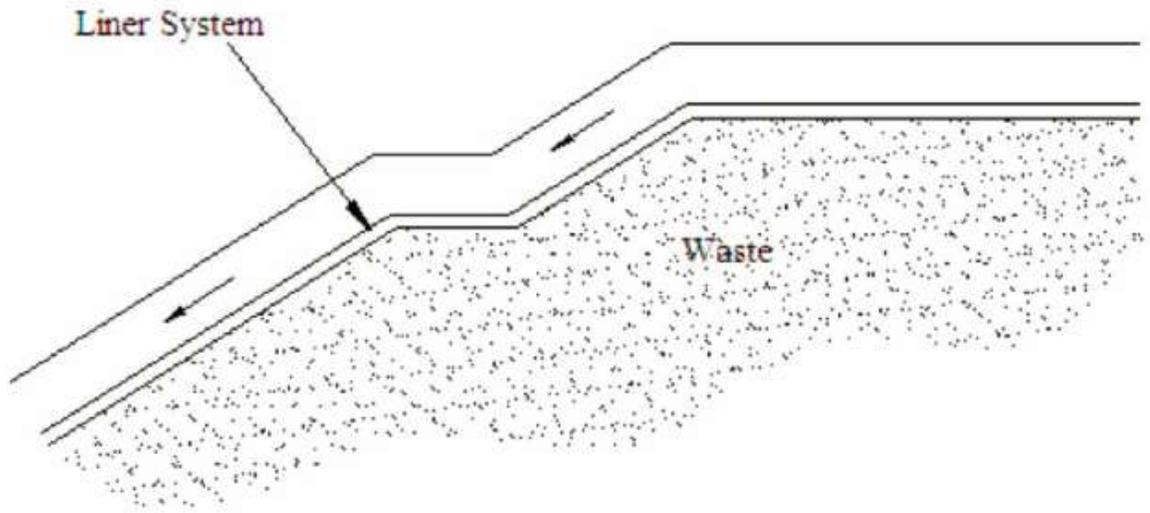


Figure 3. 5 Failure of a final cover system (Mitchell & Mitchell, 1993).

3.2.6. Rotational Failure of the Waste Mass

This failure occurs within the waste mass, completely independent of the bottom liner system, see Figure 3.6. It is assessed exactly in the same methods as the failures described before, except that the material composition is MSW instead of soil. It consists of a circular failure plane associated with large volumes of MSW movement from the face to the toe of the slope (Omari, 2012). These types of failures are commonly prompted by steep slopes, high water pore pressure, and deficiency of operation control.

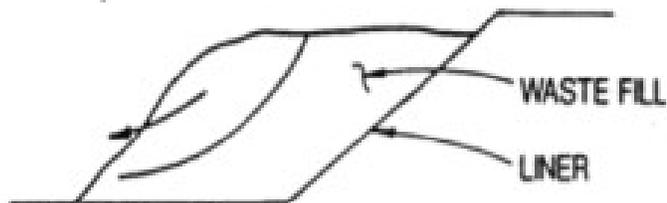


Figure 3. 6 Rotational failure of the waste pile (Mitchell & Mitchell, 1993).

3.3. Limit Equilibrium Methods

Two-dimensional (2D) and three-dimensional (3D) limit equilibrium stability models apply to stability analyses from which the 2D models present a more practical method given that it is easier to define circular and non-circular slip surfaces, soil properties, and fluid pressures in the slope. Duncan (1992, 1996) proved that limit equilibrium stability methods satisfy vertical, horizontal, and individual slice moment equilibrium conditions. Generally, the overall moment equilibrium yields a FOS within 5% of the correct solution indicating how crucial the definition of the slope geometry is. It is here where the majority of the time and effort should be spent when using these methods leaving the parameter inputs as remaining. The failure surfaces, unit weights, and shear strength parameters are inputted after selecting a suitable stability method that satisfies all conditions of equilibrium as stated by Janbu (1957), Morgenstern and Price (1965), and Spencer (1967).

3.3.1. Software Analysis Methods

When selecting a software program one of the most important factors is to make sure the stability methods within the software satisfy all conditions of equilibrium providing accurate results. Another important point to take into account are the slip surface geometries that can be analyzed as rotational and/or translational surfaces. Shear strength options and failure envelopes, options for incorporating fluid and gas pressures, and input and output techniques. Verification of the FOS computed by software can be done by using another slope stability program and confirming a reasonable comparison between the values of FOS. Hand calculations may also be performed even though they may require a longer time to assess. Most slope stability analyses are performed using a two-dimensional limit equilibrium method. These methods calculate the FOS assuming a plane-strain condition. Therefore, it is implicitly assumed that the slip surface is infinitely wide. The infinite 3D width of the slide mass is negligible as this assumption is not true. In general, the 2D analysis is the most appropriate method for slope design; both manually and by software because it provides a conservative estimation of the FOS (Duncan, 1992).

3.3.2. Assumptions for Limit Equilibrium Methods

Limit equilibrium methods are a simplification of the limit theory in continuum mechanics. This method is a standard use in soil and rock stability analyses where a slip-line assumption is made. In terms of simplicity, the limit equilibrium methods are based on the Mohr-Coulomb criteria which establishes a linear relationship between normal strength and shear strength. Different limit equilibrium analysis techniques have different failure criteria (Sjöberg, 1996), by instance methods like the Corps of Engineers, Modified Swedish, the Ordinary Method of Slices (OMS), the Simplified Bishop, and the Spencer, establish static equilibrium by splitting the soil mass above the selected slip surface into infinite vertical segments. Slice weight, the normal force on the sides, shear forces between slices, the normal force on the bottom, and so on are the forces needed to calculate. Likewise, the weight of the slice is the only one of these forces that are known, hence its calculation must satisfy static equilibrium (Eberhardt, 2003).

3.4. Definition of Shear Strength Parameters

A primary concern in evaluations of slope stability is the shear strength. Shear strength calculation is a delicate process, and to conduct a correct analysis a solid understanding of the parameters must be known. The strength parameters found on the landfill stability slopes are the foundation material's and bottom liner's internal shear strength and cohesion of soil. The total unit weight and internal shear strength of the waste mass, waste height from the bottom liner to the top of the foreseen slope, finished waste slope angle, and leachate levels along the liner, if considered, as normally the baseline analysis assumes zero leachate head above the liner.

3.5. Slope Stability Analysis Methods

Commonly limit equilibrium and finite element analyses are the two types of procedures followed to determine the slope stability of landfill structures. The latter one is based on stress and deformations, meanwhile, the limit equilibrium methods focus on force and moments. Regarding landfills, the MSW stress-strain parameters are difficult to access to perform a finite element analysis whereas the strength parameters of limit equilibrium are

easier to obtain from geotechnical field data. Most of the slope stability methods have been focused on limit equilibrium procedures (Omari, 2012) in which the FOS yields an approach value when contrasting its forces and moments summation compared with the resisting and moment forces as shown in the following formula.

$$FOS = \frac{\sum \text{Resisting forces, moments}}{\sum \text{Driving forces, moments}}$$

If the FOS is less than 1 it indicates slope failure is likely to occur, while naturally higher values would be acceptable in terms of safety, when speaking about landfills a suggested FOS value to guarantee reliable long-term slope stability is anywhere between 1.5-3.0 as suggested by (Datta & Sivakumar Babu, 2016; Kamien, 1997). However, all depends on the accuracy of the data which in terms of landfill sites may not be so precise (Kamien, 1997). The most useful limit equilibrium methods for analyzing slope stability are the Spencer, Bishop, and Fellenius methods of slicing. In these techniques, the normal stress on the analysis surface is mostly influenced by the mass above the slide surface (Lambe & Whitman, 1969).

To calculate FOS, the sliding masses must be separated into several vertical slices where the equilibrium of each slice is calculated in terms of force and moments. Given that this process needs to be repeated many times to obtain the most critical mass slide with the minimum FOS, the use of slope analysis software provides a great alternative for executing these procedures. Different assumptions for inter-slice forces generate different solutions as described by the method of slices (i.e., Ordinary, Simplified Bishop, Janbu Simplified, Spencer, and Morgenstern-Price). Except for the ordinary method which can vary up to 60%, the minimum FOS in the different methods varies slightly by 10% as explained by the authors (Whitman & Bailey, 1967). Table 3.2 describes the different assumptions, forces, and moments used in the different methods of slices.

Table 3. 2 Different method of slices for slope stability analysis

| Method | Assumptions | Equations used | Slip surface |
|----------------------------------|--|--|--------------|
| Ordinary method of slices (1936) | <ul style="list-style-type: none"> Resultant of side forces (E_i) is parallel to the base of the slice | <ul style="list-style-type: none"> Overall moment | Circular |
| Bishop (1955) | <ul style="list-style-type: none"> Resultant of side forces is horizontal | <ul style="list-style-type: none"> Overall moment Vertical forces | Circular |
| Janbu(1956) | <ul style="list-style-type: none"> Location of side force resultants on the sides of the slice (location can be varied) Uses a correction factor f_o To account for the effect of the inter-slice shear forces. | <ul style="list-style-type: none"> Overall moment Vertical forces Horizontal forces Slice moment | Any |
| Morgenstern and price(1965) | <ul style="list-style-type: none"> Inter-slice forces (X_i) related by $V = \lambda f(x) E$ form of $f(x)$ | <ul style="list-style-type: none"> Overall moment Vertical forces Horizontal forces Slice moment | Any |
| Spencer(1967) | <ul style="list-style-type: none"> Inter-slice forces are parallel | <ul style="list-style-type: none"> Overall moment Vertical forces Horizontal forces Slice moment | Any |
| Samani and Meidani(2003) | <ul style="list-style-type: none"> No Assumption | <ul style="list-style-type: none"> Overall moment Vertical forces Equilibrium of forces in tangential direction to the base of slices | Circular |

3.6. Factors Affecting Slope Stability of Landfills

Citing Terzaghi in reference to factors affecting slope stability, authors (Braja, 2001; Suárez, 1998) explain that the main factors affecting slopes is caused by human activities combined with natural effects. Identifying slope stability factors includes analyzing erosion, rainfall, seismicity, geological aspects, loads, and geometry of landfills. In addition, (Suárez, 1998) includes that the types of movements must be defined to obtain an accurate conclusion of the factors that affect its stability.

3.6.1. Geometry

The primary factor influencing the safety of landfills is the geometry of the site, which includes the boundaries, height, and side slopes usually causes a decrease in the FOS as the mentioned parameter values increase. The resisting forces come from the slope toe berms; therefore, it is important to design final landfill covers, bottom liners, and side slope liners with the minimum angle possible. A viable solution for erosion prevention in steep slopes is the use of vegetation layers. If the designed slope is steeper than the effective friction angles between the materials, sliding instability will be more likely to occur. Modern landfills

require the use of geosynthetic materials in the final cover resulting in flatter slope angles and more stable landfills (Omari, 2012).

3.6.2. Pore Water Pressure

Groundwater flow may be altered depending on rainfall and drainage patterns. If not correctly managed, the leachate and fluid recirculation inside the landfill might also have an impact on the pore pressure as it occurred in the Turkish landfill. As a result of the wet or saturated materials on the slope, their weight increases which consequently increases the pore water pressure, which in turn reduces effective stress and shear strength (Omari, 2012). In other words, the stability of the landfill increases as pore water pressure decreases whereas the stability decreases as water pore pressure builds up along the materials in the landfill.

3.6.3. Loading Conditions

Landfills due to their daily loading activities, naturally undergo an increase in waste unit load mass and vertical expansion of the landfill. The increase in the unit weight of the waste mass is caused by the external loads over the daily cover, final cover, and movement of dump trucks or machinery over the stacked layers of MSW. Areas exposed to seismicity are prone to experience stability issues (Omari, 2012).

3.6.4. Seismicity

Seismic activity significantly affects a landfill slope stability in which the tension in the waste mass increases substantially, in some cases stretching or tearing off the different materials and layers in a landfill. Tension cracks on the surface and displacement of the methane gas collection system may occur as well (Matasovic & Kavazanjian Jr, 2006). During the design procedures, it is important to consider the weight of the waste because this data is to be used for the analysis of liner puncture and pipe crushing calculations during seismic events (Choudhury & Savoikar, 2009). A major concern in landfill structures is the potential environmental contamination and human risk hazard it has which in a seismic event may unstable the landfill structure leading it to collapse (Krinitzsky et al., 1997).

3.6.5. Settlement

Settlement of a landfill affects positively the stability of a slope where the settlement of the waste mass increasing the unit weight causes the waste to densify, therefore improving the stability of the slope (Shafer et al., 2000). Settlement may also have a downside when happening in excess where tension cracks may be created in its surface allowing rainwater to percolate affecting the stability of the landfill by the increase in water pore pressure, thus the decreases the effective stress (Omari, 2012).

3.6.6. Leachate

The composition of leachate from a landfill is highly variable, depending on the stabilization stage in which the waste in the area is going through, the dilution of external water and the composition of the disposed waste in the filling. In general terms, the leachate coming from a sanitary landfill is characterized due to its high organic load, which can vary between 10 and 100 times the organic load of effluent sewerage (SERNA Honduras et al., 2014), which contains significant salt content, oxidizable chemical compounds, and heavy metals. El Crematorio has a leachate collection system that started to be in use in the 90s after it transitioned from an open-air dump to a controlled landfill site. This system partly collects the leachate generated from sections 1 through 3 and it takes them into an 8” collection pipe running all the way to the primary collection pond similar to the one shown in Figure 3.7.



Figure 3. 7 Leachate collection Pond in Potrerillos department of Cortes, Honduras

A leachate recirculation system is used to pump the leachate accumulated in the primary collection pond. The purpose of recirculating leachate is to prevent spillage in the first pond, especially during the rainy season. The recirculation of the leachate on the residues speeds up the process of decomposition, especially during the dry seasons. The leachate collection system has the basic function of transporting the leachate percolated from the disposal wastes towards the leachate pond which consequently is transported to a secondary bigger capacity drying lagoon (Figure 3.8).



Figure 3. 8 El Crematorio leachate pond 2019, source: Honduras and Spain fund CABEI

The existing leachate lagoons in El Crematorio have an approximate storage capacity of 300 m³ for the primary collection pond and 5,400 m³ for the secondary lagoon, and as they are currently in use, until now their capacity has been enough for the landfill site demand; as expressed by the landfill manager. The new landfill Section IV is considered to include both new primary and secondary leachate collection ponds which can have the capacity to manage the leachate from the upcoming new landfills. Following the technical procedures of the current landfill, the leachate will be collected through 6” perforated pipes in five rows, set 22 meters apart on each bottom liner terrace (Figure 3.9) which intercept an 8” collector pipe to a final main 10” landfill collection pipe that discharges on the primary collection pond. The space not occupied by the perforated tubes inside the drainage channels drainage is filled

with clean or washed gravel of 3.5 to 5 cm (Figure 3.10). These drainage pipes should have a slope of 0.5 to 1% towards the collector pipe.

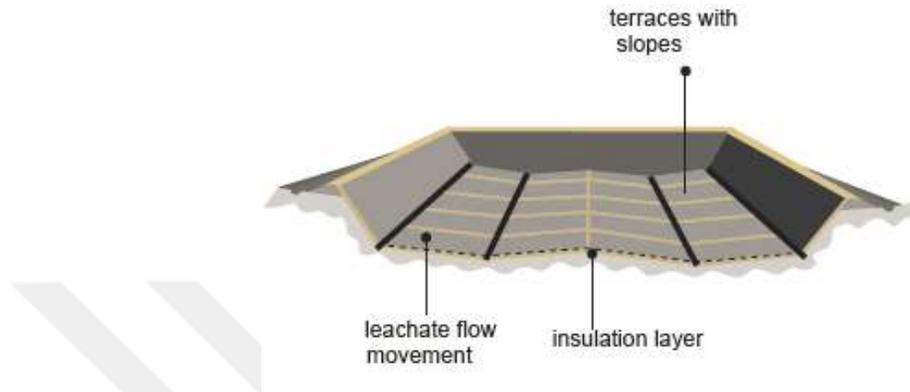


Figure 3. 9 Bottom drainage network arranged in the bottom liner.

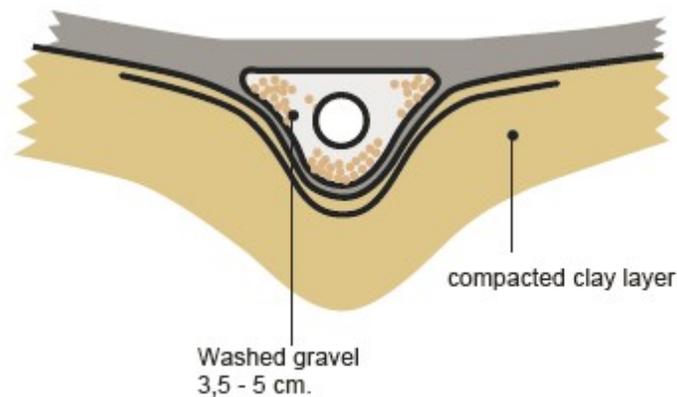


Figure 3. 10 Bottom leachate drain gutter detail.

Routine maintenance must be given to the lagoons, checking that the geomembrane is well placed and that they do not present cracks, otherwise, the respective repairs should be done. It must be avoided that the lagoon exceeds the design capacity in rainy weather and for this, it is necessary to recirculate the leachate on the primary pond, preferably in sunny hours.

4. SITE INVESTIGATION AND LABORATORY TESTING STUDIES IN THE LANDFILL

The AMDC requested a geological-geotechnical preliminary study to verify the general soil conditions of the area where the expansion of the Tegucigalpa new landfill is planned. For the study, ten (10) rotational geotechnical boreholes with a depth of 10 meters and ten (10) exploration test pits were requested and carried out in the area (GEASA, 2021a). The number and type of tests, as well as their location and supervision, were provided by the client. In addition to various laboratory tests, the purpose of the geotechnical study was to investigate the virgin terrain and provide enough data for specialists to complete the design of the structures that the project will require.

As described by the surveying engineer, the West area of the future landfill was not thoroughly tested due to a lack of road access and rough terrain conditions presented (J. Arce, personal communication, July 19, 2022). In Figure 4.1, the pits (calicata) and borehole (sondeo) locations are presented.



Figure 4. 1 Satellite location of the tests within the premises. Source (GEASA, 2021a)

4.1. Geotechnical Studies on Site

From the Geotechnical map of Honduras Figure 4.2, the Minas de Oro structural belt can be observed just below the site where the Central and Northern Chortis terrains meet.

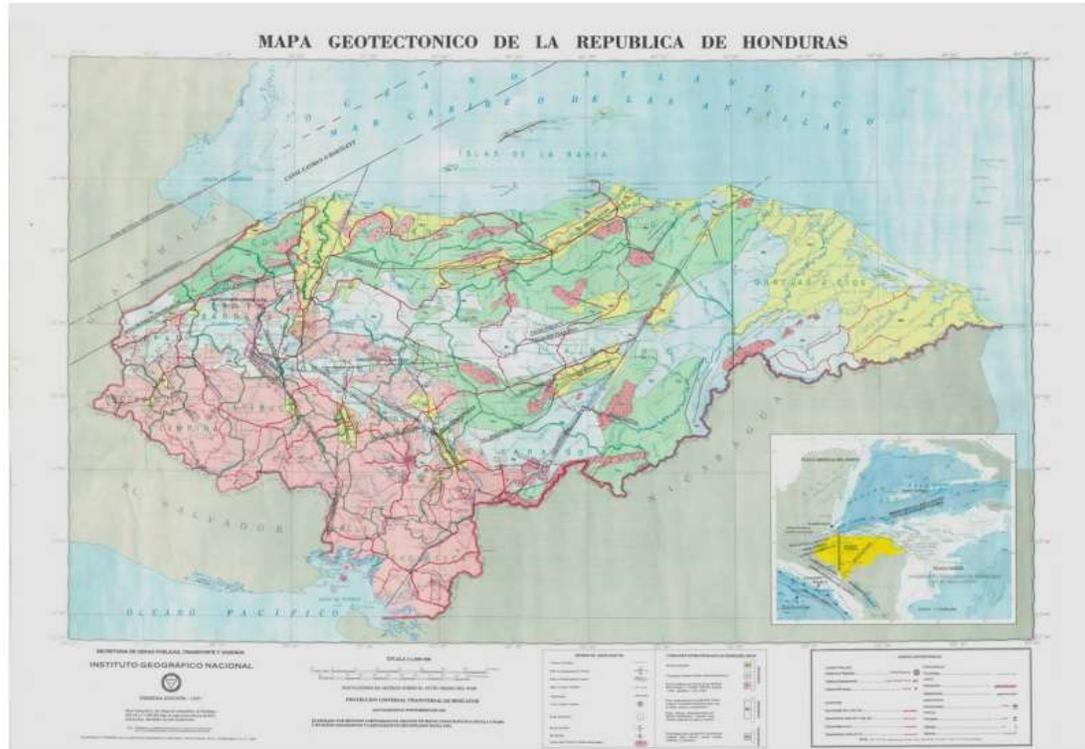


Figure 4. 2 Geotectónica Map from the Republic of Honduras. Author: Instituto Geográfico Nacional de Honduras 1997 1st Edition.

Geotechnical studies on the project area are very poor in terms of data gathering given that the client explicitly asked for a general condition report of the soil in the area where the expansion of the landfill is planned (J. Arce, personal communication, July 19, 2022). Small rainwater creeks identified in the site area are colluvium material. From tests and observation, a series of altered ignimbrite tuffs was found to be proliferating in the area with ignimbrite material in its deepest section of the perforations. As geotechnical tests were performed on the area, ten (10) borehole drillings were executed until a depth of 10 meters, and ten (10) exploration test pits for laboratory samples were made by hand using chisels and shovels. Results are shown in the laboratory and testing section of the document.

4.2. The Objective of the Analysis

To avoid a landfill collapse which could include human casualties and environmental contamination damage is the main objective of the analysis. The slope stability analysis is a quantitative tool from which the aim is to obtain a Factor of Safety (FOS) measurement that may give us an estimation of the available strength to the strength at failure ratio. There are extensive studies on the changes in FOS influenced by rainfall, vegetation, cracks in slopes and seismic activity such as (Ghani et al., 2020; Mukhlisin & Khiyon, 2018) describe in their works. The determination for an optimum analysis requires thorough research into each of the landfill collapse triggering variables mentioned which is not included in this study.

4.3. Laboratory Testing

Selected strata and soil samples were sent to the laboratory to determine their geomechanical properties. In general, the soils were restricted to the first 1.20 to 1.80 meters of the drillings altered in situ, or material from the slopes was found. These slopes correspond to the areas worked on the daily basis of the current landfill. It is important to indicate that there is a mixture of rubbish, debris, covering material, and in some cases fractured rock in these places. As can be seen in Table 4.1, samples from the different strata found were evaluated for testing in each survey (GEASA, 2021a).

Table 4. 1 Landfill project pits and testing September 2021

| Sample | Survey | Box | Interval | Tests |
|--------|---------|-----|----------|---|
| | Pit #1 | | | Granulometry, limits, density, specific weight and humidity |
| | Pit #2 | | | Granulometry, limits, density, specific weight and humidity |
| | Pit #3 | | | Granulometry, limits, density, specific weight and humidity |
| | Pit #4 | | | Granulometry, limits, density, specific weight and humidity |
| | Pit #5 | | | Granulometry, limits, density, specific weight and humidity |
| | Pit #6 | | | Granulometry, limits, density, specific weight and humidity |
| | Pit #7 | | | Granulometry, limits, density, specific weight and humidity |
| | Pit #8 | | | Granulometry, limits, density, specific weight and humidity |
| | Pit #9 | | | Granulometry, limits, density, specific weight and humidity |
| | Pit #10 | | | Granulometry, limits, density, specific weight and humidity |

Slightly altered tuff-type rock material was found in the pits, meanwhile, in the boreholes, cores were extracted from the rock for uniaxial compressions since it is the predominant material in the area. A summary of the test results carried out on the soil samples is shown in Appendix 4 and 5. Larger granulometry of andesite are shown for tests such as the direct cut since its grain size is greater than 1/3 of the height of the specimen. According to the laboratory report, this is because the sample corresponds to soils from the fragmented rock with little lateralization. The samples were evaluated for granulometry and limits to carry out consolidation tests. Given that this test requires soils of specific granulometries such as silty or clayey sands to clays, from the soil test summary below it can be stated that no such fine granulometries exist; therefore, not suitable for consolidation tests. As for rock compressions, values between 5,000.00 psi and 225.00 psi were obtained. The lowest values correspond to the tuffs and ignimbrites of the Padre Miguel Group found on the north side of the property. The rock compression tests summary is shown in Appendix 5.

4.4. Geotechnical Drilling

Drilling surveys performed at the site correspond to the best-fitted locations for the investigation of the soils and strata as wanted by the client. The coordinates were taken by GPS and their locations are described in Table 4.2.

Table 4. 2 Borehole drilling GPS coordinates

| | Latitude | Longitude | Depth (m) |
|--------------|---------------|---------------|--------------|
| Borehole #1 | 14° 8'56.76"N | 87°13'7.62"W | 10m vertical |
| Borehole #2 | 14° 9'5.72"N | 87°13'31.14"W | 10m vertical |
| Borehole #3 | 14° 9'1.39"N | 87°13'26.23"W | 6m vertical |
| Borehole #4 | 14° 9'2.92"N | 87°13'11.82"W | 10m vertical |
| Borehole #5 | 14° 8'58.45"N | 87°13'4.17"W | 10m vertical |
| Borehole #6 | 14° 9'2.74"N | 87°13'0.37"W | 10m vertical |
| Borehole #7 | 14° 9'1.38"N | 87°13'0.98"W | 10m vertical |
| Borehole #8 | 14° 9'11.93"N | 87°13'6.37"W | 10m vertical |
| Borehole #9 | 14° 9'8.78"N | 87°13'1.07"W | 10m vertical |
| Borehole #10 | 14° 9'10.16"N | 87°13'3.35"W | 10m vertical |

A detailed description of the materials found in the surveys is described in the drilling log included in Appendix A.6. The strata found can briefly be described as rocky coming from the Cerro Grande and Padre Miguel formations. According to the geological map of Honduras sheet 2758 II, Cerro Grande formations will prevail in the southern part of the area and Padre Miguel in the northern part. The borehole studies done on the project can be observed in Figure 4.3 located with GPS data.

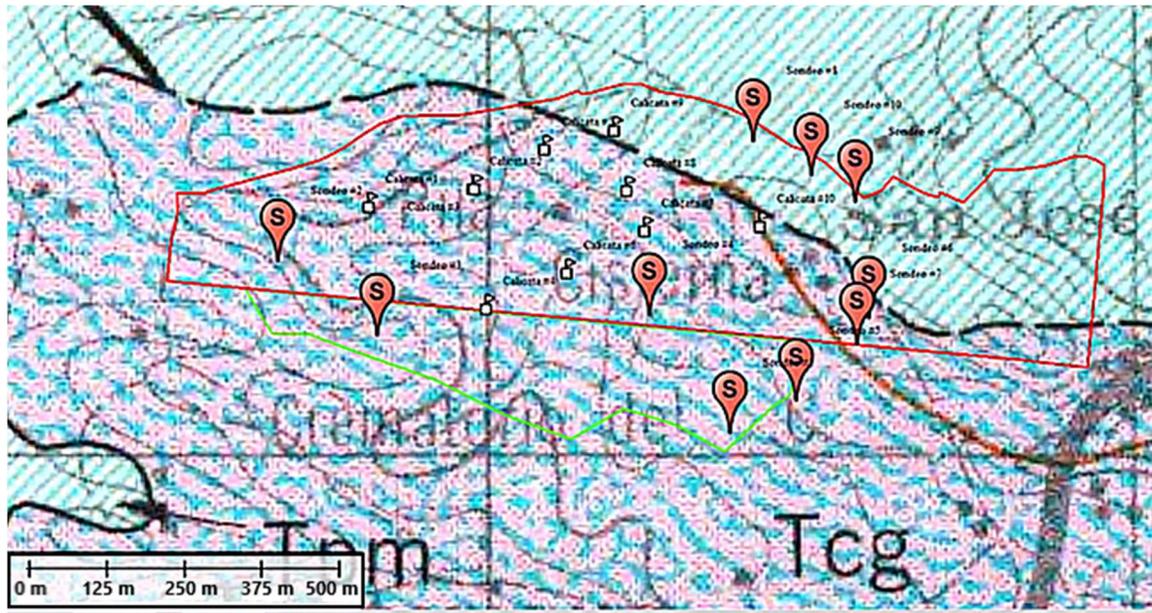


Figure 4. 3 Project area with the location of the boreholes.

This differentiation between the two formations indicates that the new project area is a volcanic contact zone. Thus, in the boreholes and pits in the Padre Miguel area (north), tuffs and ignimbrites with a higher degree of surface alteration were observed. On the other side, the Cerro Grande member exhibited ignimbrite rocks with opals and crystallized silica outcrop with few alterations. In that area where contact with the current dump site exists, various thicknesses of waste material with soil materials and debris from the hillside are found over the slopes. The standard penetration tests (SPT) performance within the boreholes was evaluated according to the standard (ASTM Standard D 1586–67) which dictates that the test must be performed in soil. According to the obtained samples, an organic residual

soil was identified in the first 1 to 1.5 meters in most of the boreholes and in some cases a highly weathered rock with an intact structure, therefore obtaining immediate refusal of the test. As the top layer of soil exhibited poor geomechanical properties, its evaluation was omitted. In the rest of the boreholes, the rock outcropped, so this type of test was not required (GEASA, 2021a).

4.5. Test Pits

Ten (10) manual pits were made to obtain unaltered samples. Their coordinates taken with a GPS device can be seen in Table 4.3 along with their characteristics.

Table 4. 3 Location and characteristics of the trial pits

| | coordinates | Size (approx.) | Sample |
|---------|-----------------------|-----------------------|---------------|
| Pit #1 | 16P 1564597 / 0475827 | 1X1X1 meter | 1m |
| Pit #2 | 16P 1564627 / 0475990 | 1X1X1 meter | 1m |
| Pit #3 | 16P 1564544/0476003 | 1X1X1 meter | 1m |
| Pit #4 | 16P 1564433/0476010 | 1X1X1 meter | 1m |
| Pit #5 | 16P 1564673/ 0476091 | 1X1X1 meter | 1m |
| Pit #6 | 16P 1564491 / 0476136 | 1X1X1 meter | 1m |
| Pit #7 | 16P 1564557 / 0476258 | 1X1X1 meter | 1m |
| Pit #8 | 16P 1564623/0476230 | 1X1X1 meter | 1m |
| Pit #9 | 16P 1564719/ 0476210 | 1X1X1 meter | 1m |
| Pit #10 | 16P 1564565/ 0476438 | 1X1X1 meter | 1m |

Samples of the existing material at the bottom of the pits were analyzed in the laboratory. In general, the samples obtained correspond to altered or weathered material of the basement rock, being those of the north zone tuffs and ignimbrites (GEASA, 2021a). This material does not present plasticity and was easily obtained with the use of pikes and bars, see Appendix A.7 pit logs 1-10. Being able to state that the altered basement rock is located one meter from the surface. The location of the tested pits can be seen in Figure 4.4.



Figure 4. 4 Location of testing pits in El Crematorio premises.

4.6. Electric Tomography

As part of the studies made by GEASA, a geophysical study was carried out using the method of electrical tomography and Vertical Electrical Soundings (VES), to characterize and estimate the quality of the soil, as well as determine the geometry of the subsoil and other characteristics such as the presence of groundwater. Figure 4.5 shows the approximate study area and the spatial distribution of the tomography profiles made indicating the starting direction of each tomography.

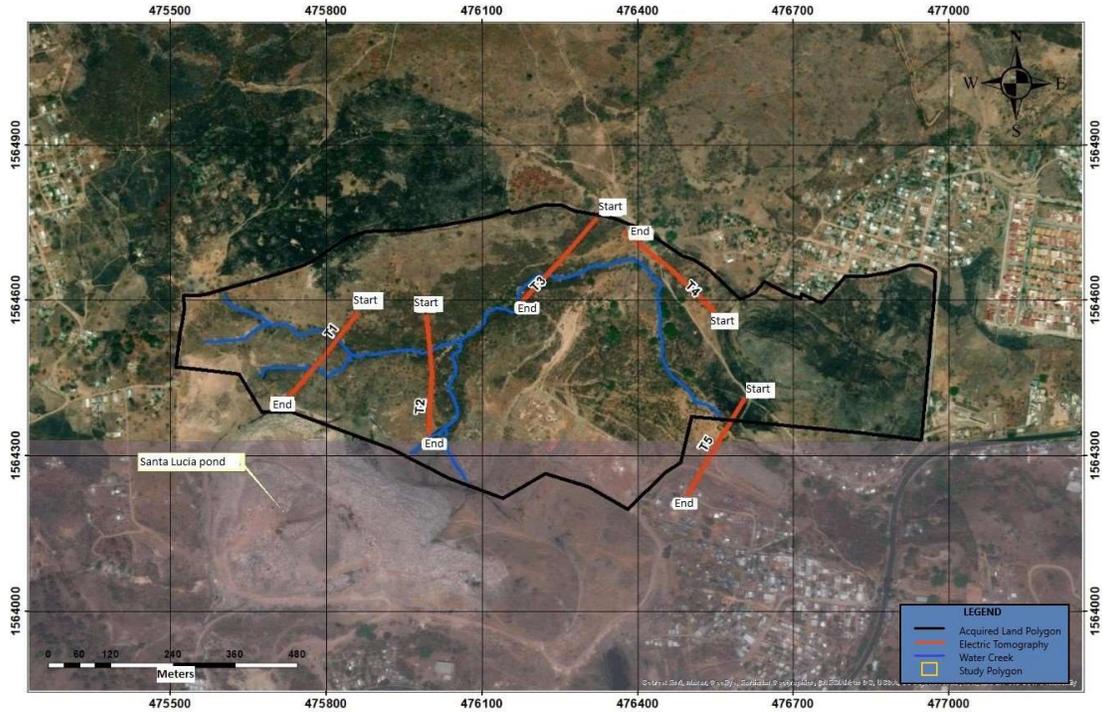


Figure 4. 5 Spatial distribution of the electrical tomography profiles raised (in red). Satellite image

A total of 5 electrical tomography profiles were performed in the study area for which details and coordinates about the profiles are shown in Tables 4.4 and 4.5, respectively.

Table 4. 4 Electrical tomography profiles performed in the study area.

| Profile | Approximate Orientation | Length Profile (m) | Separation between Electrodes | Maximum Depth reached |
|---------|-------------------------|--------------------|-------------------------------|-----------------------|
| T1 | NE-SW | 235 | 5 | 45 |
| T2 | N-S | 235 | 5 | 45 |
| T3 | NE-SW | 235 | 5 | 45 |
| T4 | SE-NW | 235 | 5 | 45 |
| T5 | NE-SW | 235 | 5 | 45 |

Table 4. 5 Approximate coordinates (UTM WGS84) of the initial and final test points of the electrical tomography profiles

| Profile | Spot | Description | Orientation | Easting(m) | Northing(m) |
|---------|------|---------------|-------------|------------|-------------|
| 1 | TM1i | Initial point | NE | 475860.00 | 1564576.00 |
| 1 | TM1f | Final point | SW | 475721.00 | 1564407.00 |
| 2 | TM2i | Initial point | N | 475993.00 | 1564572.00 |
| 2 | TM2f | Final point | S | 475997.00 | 1564339.00 |
| 3 | TM3i | Initial point | NE | 476321.00 | 1564760.00 |
| 3 | TM3f | Final point | SW | 476173.00 | 1564595.00 |
| 4 | TM4i | Initial point | SE | 476550.00 | 1564577.00 |
| 4 | TM4f | Final point | NW | 476374.00 | 1564731.00 |
| 5 | TM5i | Initial point | NE | 476607.00 | 1564412.00 |
| 5 | TM5f | Final point | SW | 476496.00 | 1564224.00 |

Figures 4.6 to 4.10 show the profile sections obtained from the surveys with the best statistical fit for the area of interest. In general, for each figure, the color represents a different value of resistivity, measured in ohm-m.

Figure 4.6 shows Profile 1. This profile was surveyed in a NE-SW direction, at the extreme west of the study area, with a length of 235m and reaching a maximum exploration depth of 45m. The endpoint is located on the edge of an access road in the area, and a water slide is located between points 70m and 80m. Materials with resistivities between 10 to 20 Ohm-m are observed in the initial part of the profile, continuing to the area around the ravine with materials having resistivities between 20 to 90 Ohm-m. From this point until the end of the profile the behavior changes, a small initial layer between 5m to 10m thick appears with materials with resistivities between 90 to 500 Ohm-m, and in some parts above 1,000 Ohm - m. These values can be associated with fractured rock and loose soils. Below these depths, the resistivity of the materials drops to less than 5 Ohm-m (materials in blue tones in the figure), which can be associated with the presence of groundwater (GEASA, 2021b).

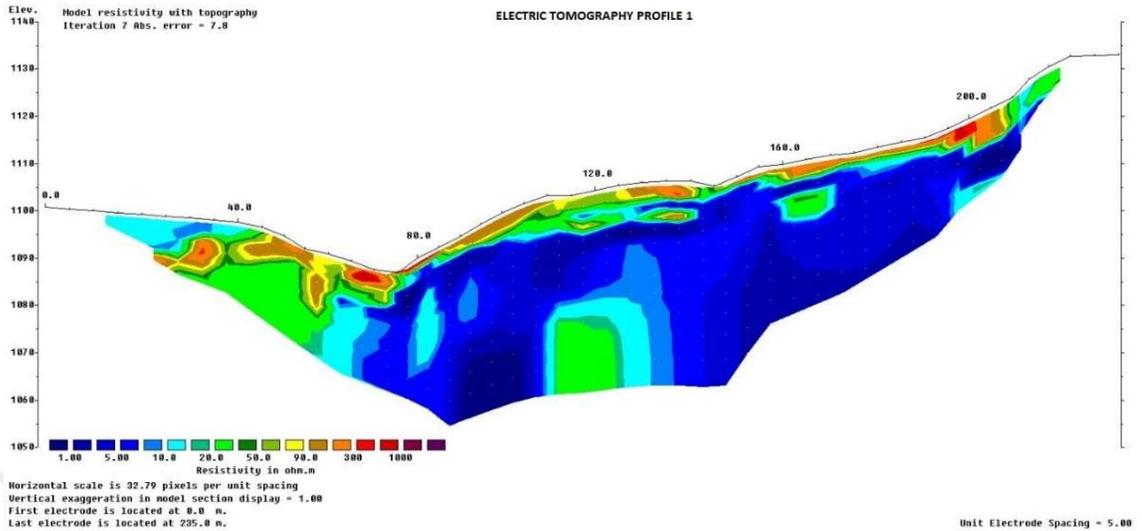


Figure 4. 6 Profile 1 Electric tomography. The different colors represent the resistivity of the material in ohm-m.

Figure 4.7 shows Profile 2. This profile was surveyed in an N-S direction, with the initial point approximately 130m to the east of the initial point of profile 1, with a length of 235m and reaching a maximum exploration depth of 45m. A first layer with materials between 90 and 300 Ohm-m (in brown to red tones) is observed in this profile and some points reach up to 1,000 Ohm-m. This layer appears quite irregular, varying in thickness from 5m to 20m. Below this layer appear materials with resistivities below 5 Ohm-m that can be associated with the presence of groundwater (GEASA, 2021b).

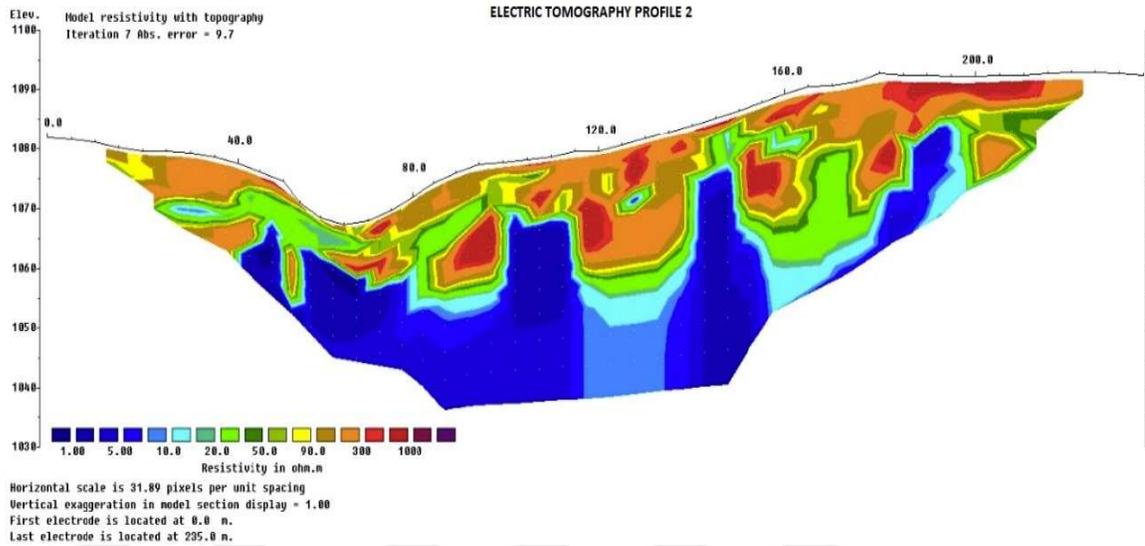


Figure 4. 7 Profile 2 Electric tomography. The different colors represent the resistivity of the material in ohm-m.

Figure 4.8 shows Profile 3. This profile was surveyed in a NE-SW direction, in the northern part of the study area, with a length of 235m and reaching a maximum exploration depth of 45m. The profile cuts the ravine in the area at approximately the 155m point. Materials with resistivities between 20 to 100 Ohm-m are observed in this profile in the initial part. An area stands out with materials with resistivities of less than 5 Ohm-m that can be associated with the presence of groundwater. Unlike profiles 1 and 2 where the materials with low resistivity extend to at least the maximum depth of exploration of the profiles (45m) in this profile 3 the low resistivities are concentrated on the surface and up to 15m to 20m deep. From the 170m point, there is an increase in the resistivity of the materials, increasing above 300 Ohm-m and reaching up to 1,000 Ohm-m. This may be indicating a contact with rock in the area (GEASA, 2021b).

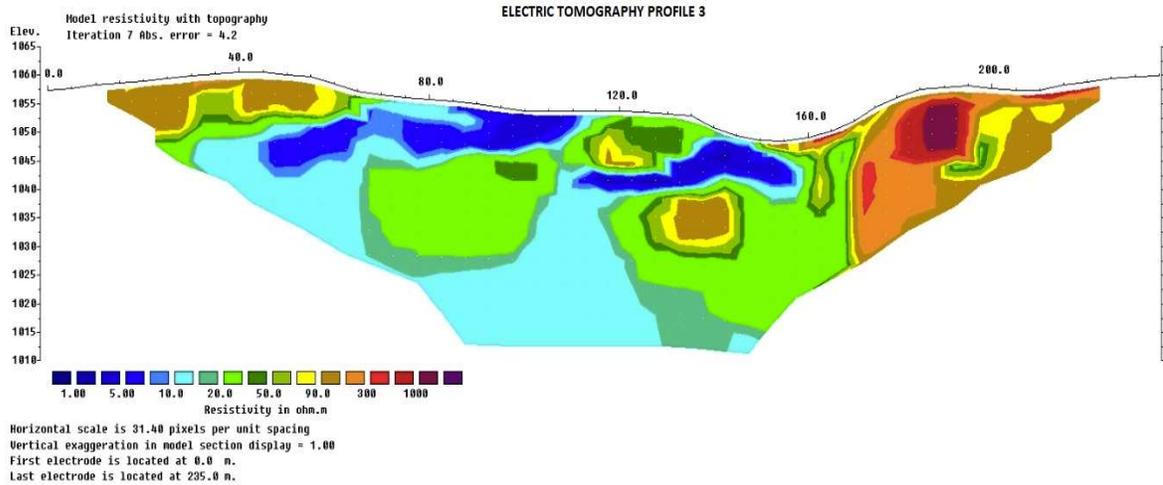


Figure 4. 8 Profile 3 Electric tomography. The different colors represent the resistivity of the material in ohm-m.

Figure 4.9 shows Profile 4. This profile was surveyed in a SE-NW direction, in the northern part of the study area, with a length of 235m and reaching a maximum exploration depth of 45m. The profile cuts the end of a water slide in the area at approximately the 175m point. It is observed in the central part of the profile a hill that stands out in the area, materials with resistivities above 300 Ohm-m, and extends to at least 20m depth. Towards the end of the profile, materials with low resistivity appear, which are associated with the presence of groundwater in the area (GEASA, 2021b).

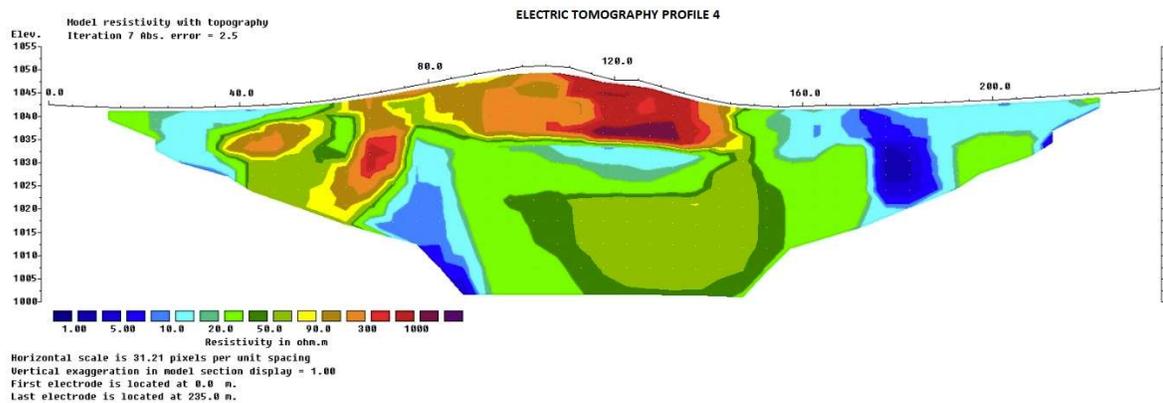


Figure 4. 9 Profile 4 Electric tomography. The different colors represent the resistivity of the material in ohm-m.

Figure 4.10 shows Profile 5. This profile was surveyed in a NE-SW direction, at the eastern end of the study area, with a length of 235m and reaching a maximum exploration depth of 45m. The profile passes approximately 25m next to an oxidation pond in the area and ends between some houses in a sector outside the study area. An access road cuts the profile around the 150m point. It is observed in the profile up to 150m that materials in green tones with resistivities between 20 to 90 Ohm-m predominate. with some areas with materials with blue tones that are associated with the presence of groundwater. The area around the 70 m point, where a water slide crosses the profile, had water on the surface, behaving like a swampy area. From the 150m point and towards the end of the profile, there is an increase in resistivity that is associated with the presence of rock that was observed to outcrop in the area. Water filtration can also be seen in this area denoted by areas in blue tones (GEASA, 2021b).

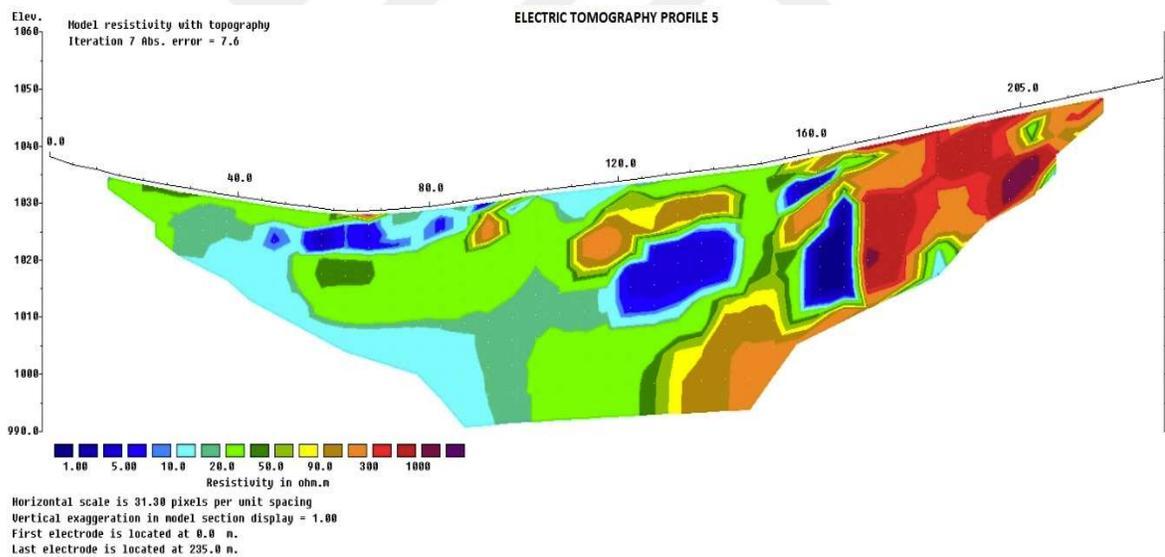


Figure 4. 10 Profile 5 Electric tomography. The different colors represent the resistivity of the material in ohm-m.

Next, a description of the data collection methodology and results of the analysis as well as their interpretation is presented.

4.6.1. Methodology

The electrical resistivity method consists of applying a flow of electricity on the surface of the earth and then measuring the potential differences at specific points. This leads us to determine the resistivity distribution at the surface and to an interpretation of subsurface materials. It is carried out by placing four electrodes aligned at equal distances from each other (Figure 4.11a). A battery is connected to the outer electrodes, measuring the intensity that circulates between them, as well as the voltage between the intermediate electrodes. The resistivity is defined by the following expression:

$$R = \frac{V}{I} 2\pi d$$

Where R is the resistivity in ohm-m, V is the voltage, I is current, and d is a factor of the distance between the electrodes, which varies depending on the electrode arrangement used. The obtained resistivity value represents the average of a large volume of soil since the current network extends in depth. To explore the resistivity of the soil at different depths, this procedure is repeated with different separations between electrodes, to perform what is known as a vertical electrical sounding or SEV (Figure 4.11b). If this procedure is repeated with the electrodes both at different separations and at different points, information can be obtained both along a profile and in-depth to perform an electrical tomography that is a 2D model (Figure 4.11c).

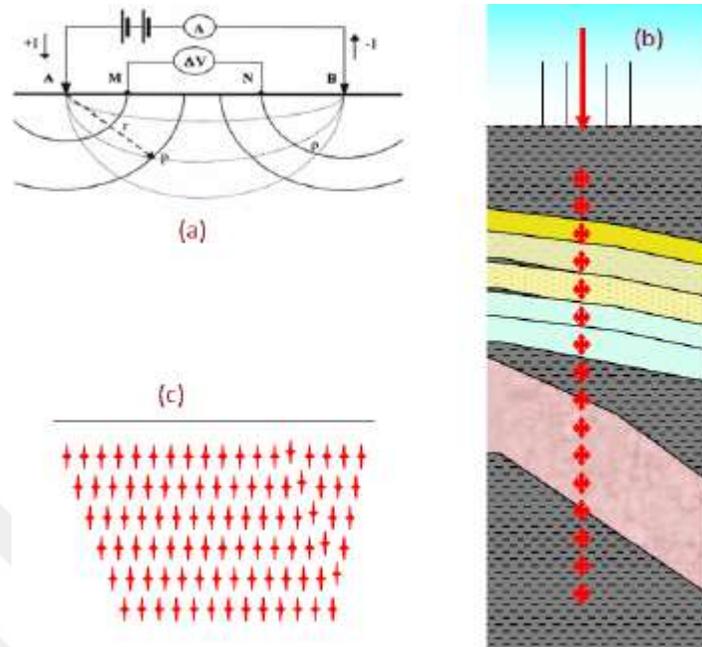


Figure 4. 11 a) Schematic of the electrical resistivity method. A, B, M, and N represent the different electrodes. b) Schematic of a Vertical Electrical Sounding (SEV) as it increases the separation of the electrodes increases the depth of exploration. c)

The tomography data collected in the tests made by GEASA were performed with the TERRAMETER LS-2 electrical resistivity prospecting equipment from ABEM, which allows the connection of up to 48 electrodes. Cables with a maximum separation between electrodes of 5m were used. With this configuration, up to 235m were able to be covered on the surface per profile, and maximum depths of between 40m and 50m were reached. The data from Vertical Electrical Surveys was stored in the GEOAMP 303 equipment of the Colombian brand Subsuelo 3D. The configuration chosen for the tests due to its versatility was the Schlumberger, being an arrangement consisting of four electrodes aligned symmetrical with respect to the center of the probe, using a relatively small separation between the potential electrodes ($AB/5 > MN > AB/20$). The data is then transferred to a computer using the manufacturer's software and processed by the specialist.

4.7. Waste Properties and General Information

Based on the information obtained from the “Diagnosis of the Situation of Waste Management in Honduras 2016”, the general waste composition in Honduran waste disposal sites consists of cardboard and paper used as the packaging of raw materials from which around 75% are recycled and reused in companies when they have not been contaminated. In the case of plastics, the reported waste is made up of polyethylene terephthalate (PET), for high- and low-density polyethylene type plastic waste (PAD, PLD) and polypropylene (PP), which mainly comes from raw material packaging and food packaging. Mainly PET, polyethylene, and polypropylene are recycled. The data shows that an estimate of about 20% of total plastic waste is going to final disposal sites in the municipality due to a lack of comprehensive waste treatment methods.

In many cases, materials contaminated with oils and lubricants are destined for controlled incineration with authorized supervision, alternatively in other cases mixed with organic waste into the disposal site. The chemical and hazardous residue percentage of adequate treatment is low when compared to the whole generation of this waste type. This is mostly due to elevated disposal costs in treatment and a lack of awareness about the impact of this kind of waste. Ferrous waste materials constitute scrap coming from machinery structures and obsolete buildings that are demolished, meanwhile, the non-ferrous materials are mostly made up of electrical wiring aluminum, copper, bronze, and beverage containers. Tire waste generated in representative amounts by different companies is part of collection and disposal alliances through which cogeneration processes in cement kilns with cement companies are done for example with Argos cement company. The waste which represents the fewer solutions regarding its treatment is industrial waste from which a mixture of waste is not classified and is contaminated with food residues and sanitary waste products. A chart resume of waste composition is shown in Figure 4.12.

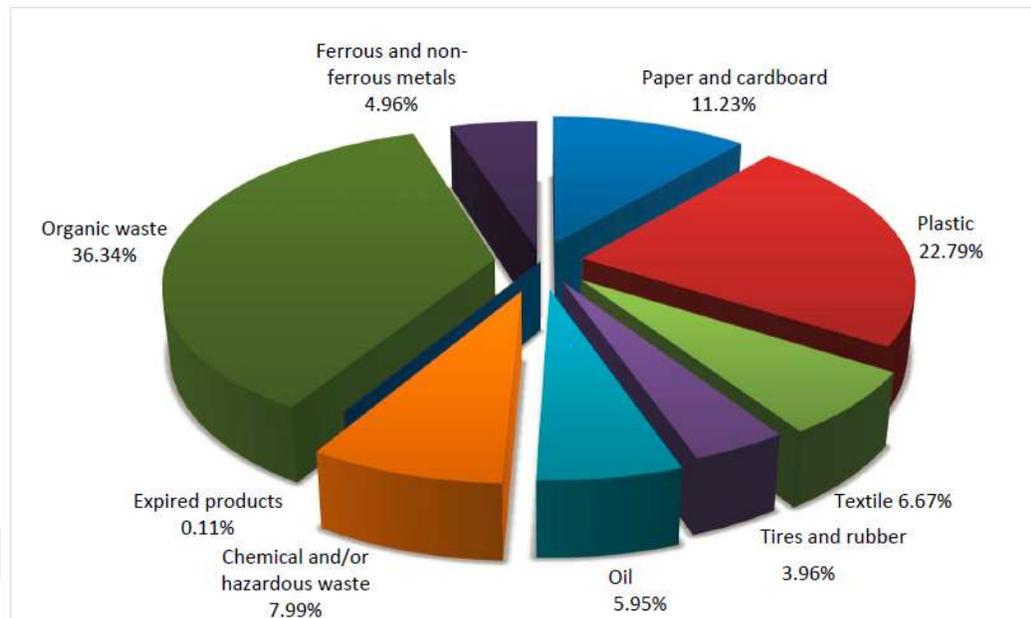


Figure 4. 12 Percentage representation of waste generated at industrial level. Source: Diagnosis of the situation of waste management in Honduras 2016

4.7.1. Composition of Waste

Due to the lack of updated information and difficulty in characterizing the waste composition of residues in the municipalities of Honduras, the information gathered by the different municipalities consists of an estimation of the residues characterization presented in the diagnostic report (Ambiente, 2017). This estimation was carried out taking into account the data of 10 municipalities (Villanueva, Choloma, Comayagua, San Pedro Sula, Tegucigalpa, Siguatepeque, Danlí, Puerto Cortes, Santa Rosa de Copan, and Choluteca) and four associations made up of 12 municipalities (Lenca Eramaní Commonwealth, AMVAS MANVASSEN and the Commonwealth of Güisayote). It is important to indicate that the information is based on 22 municipalities, among which 40.4% of the population at the national level is concentrated. As described in the report a critical difficulty was the different way municipalities carry out the characterization; in some cases, using four (4) and in others up to ten (10) different characterization types. According to the data of the municipalities that could be evaluated, the characterization presents a mixture of common hazardous and special waste. Figure 4.13 shows the compositions, being the highest proportion of waste of organic origin (food and garden waste) a 57.90%, plastic waste at 14.41%, paper and

cardboard at 17.36%, metal waste at 2.11%, textile waste at 3.33%, glass at 1.27%, forestry waste at 1.09%, leather at 0.33%, others (not reported accurately) at 1.98% and sanitary waste at 0.22%.

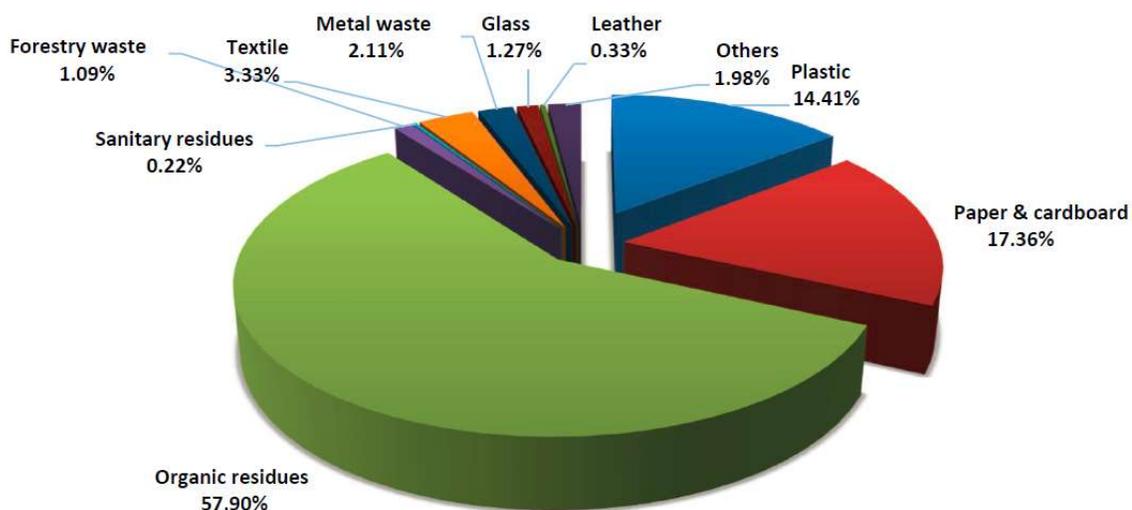


Figure 4. 13 Municipal wastes characterization, source: Diagnosis of the situation of waste management in Honduras 2016.

It was found that the final disposal sites of the municipalities, in addition to receiving nonspecial waste, receive special and hazardous waste as normal sanitary waste. This situation is common in municipal service systems since companies in the commercial and industrial sectors deliver their waste directly to municipal collection systems.

4.7.2. Unit Weight

The unit weight of the solid waste mass is a useful parameter to be known when applied it to surcharge excavated models. From the laboratory sampling database in CINSa no apparent data exists about this parameter, the reason for which citing the data of Fassett (1993) and other study reports, values of 3 and 17 kN/m³ for uncompacted and compacted landfills were reported respectively. Other researchers pointed out data from 37 different landfills varying between 3–20 kN/m³ (Zekkos et al., 2006). As for the analysis with MSW surcharge in Section IV performed on this study, the value of 17 kN/m³ was used as input value on the

software. In Figure 4.14 the most critical profile of the landfill (profile 4) was modeled simulating the excavated scenario 2 ground profile with the MSW mass as a surcharge from which the most critical value obtained was a 1.04 FOS that is not even a representative slip surface, meaning that the higher values as 1.34 may be more accurate.

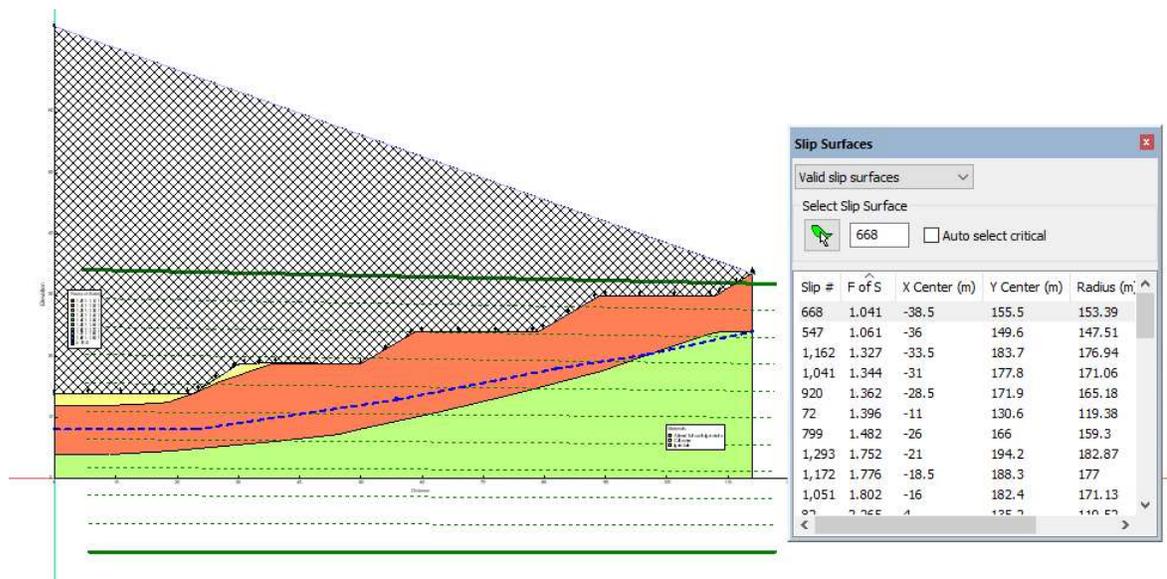


Figure 4. 14 Section IV excavated modeled profile 4 with waste mass surcharge analysis.

From the grid radius analysis performed on the excavated Profile 4 a 50-meter-high waste disposal section was achieved where the model assumes a 3:1 slope used as the filling closing cover and 3:1 excavation terraces to decrease slope, toe, and base rotational failure. It is to be stated that the liner and geomembrane characteristics have not been taken into account for this analysis.

4.7.3. Distribution and Compaction of Waste Cells

Once the MSW is located at the assigned working front for that day, the process done with the waste material is described in Figure 4.15, and a daily 30 cm cover of the site is shown in Figure 4.16.

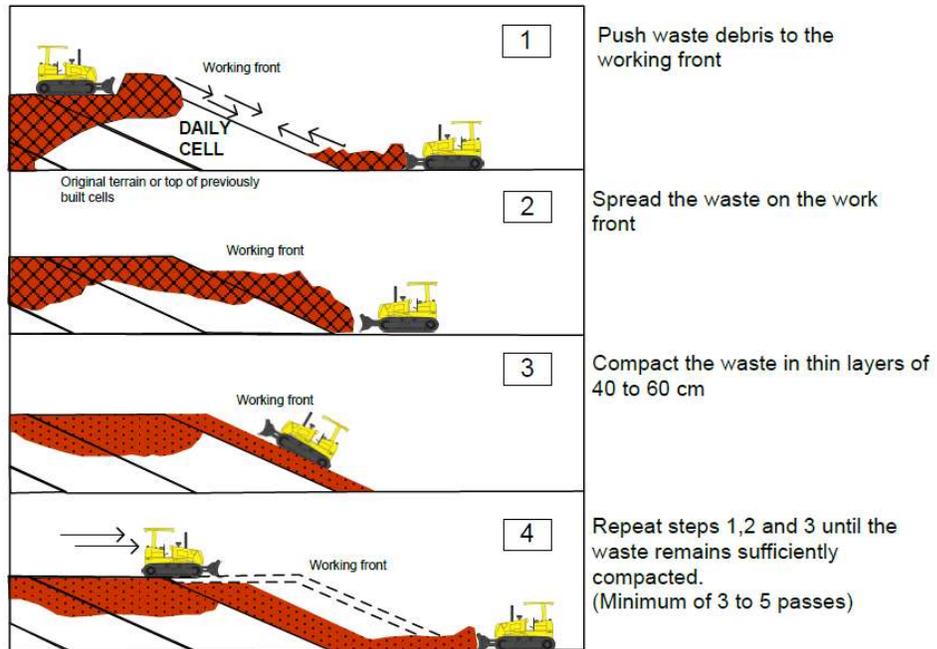


Figure 4. 15 Spreading and compaction of waste material cells, source: Manual de Operaciones Relleno Sanitario de Potrerillos Honduras 2013

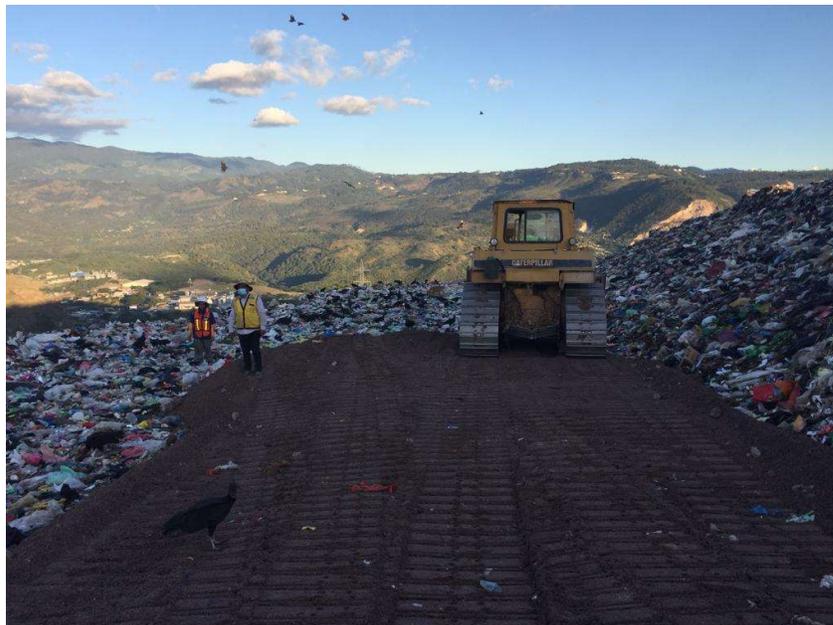


Figure 4. 16 30 cm daily cover layer in El Crematorio with material from site. Photograph provided by CINSA.

4.7.4. Closure Criteria

The appropriate level of closure for the area phase should be the level that allows for a 3:1 slope (Figure 4.17). After the final cover a water drainage system around the site, dikes, controlled slope, and gas fireplaces are required. The final soil cover should be provided for environmental protection measures such as minimizing leachate production, preventing waste spreading, minimizing odors, and preventing fires. The recommended thickness for the final cover by the Honduras sanitary landfill manual is 60 cm of cover material plus 20 cm of organic soil from which El Crematorio is using a 1 m thickness closure layer and then installing a vegetative layer (see Figure 4.18) over this one. Final cover material compaction results from sections 1 and 2 are presented in Appendix A.8.



Figure 4. 17 Municipal Landfill in Tegucigalpa 3:1 slope closure. Photograph by German R. Pavón



Figure 4. 18 Municipal Landfill in Tegucigalpa section 1 and 2 vegetative layer. Photograph by German R. Pavón.

4.8. Defining the Slope Model

To execute the slope analysis parameters such as the topography, water table, lithology and soil mechanical characteristics had to be defined. As a start, the topography data was obtained and modeled in the Civil CAD software (Figure 4.19), from which different areas were analyzed for the new landfill. In the location of the landfill, the four (4) most critical slope areas were selected and their natural terrain profile coordinates were obtained for its posterior use in the slope analysis software.



Figure 4. 19 Tegucigalpa El Crematorio landfill extension area topographic curves.

4.8.1. Section IV Cross Sections

For the soil profiles to be taken on the analysis, the tomographic profiles selected from the hydrogeological identification study were used as guidelines with the borehole drilling information to define the stratigraphic profiles. The electric tomography profiles performed were scaled into the Civil CAD software in which a grid was defined to extract an X-Y coordinate table for its posterior use in the slope analysis software.

Inside the landfill Section IV defined area, four (4) profiles were generated from the topography model created in Civil CAD; the profiles were located in such a way that the most irregular areas or slopes could be visualized and respectively analyzed. The profiles are shown in Figures 4.20,4.21,4.22 and 4.23 on which the white boundary represents the natural terrain, orange the landfill geometry, green for fill areas, red for excavation areas, and blue the waste cell areas.

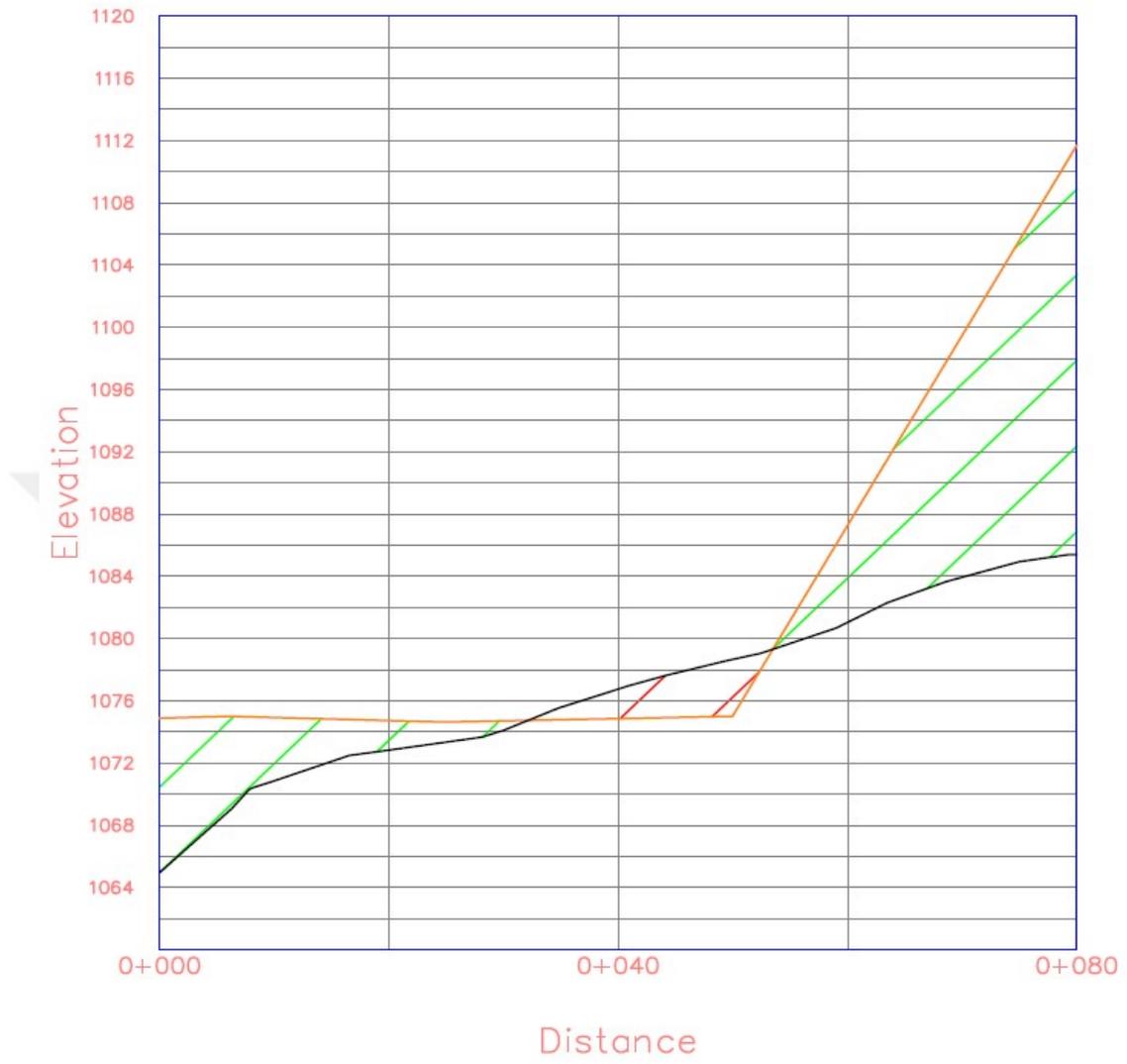


Figure 4. 20 Profile 1 green for fill, red for excavation, and orange for the engineered landfill.

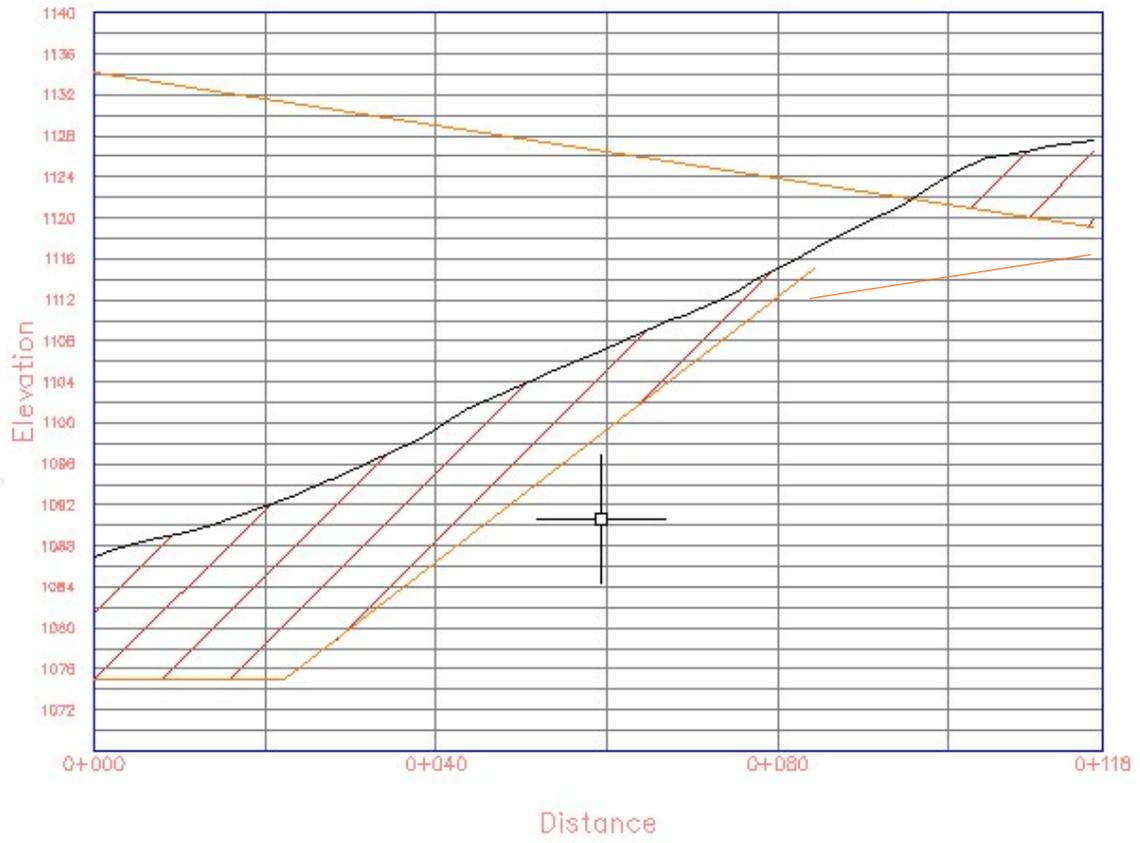


Figure 4. 21 Profile 2 red for excavation and orange for the engineered landfill.

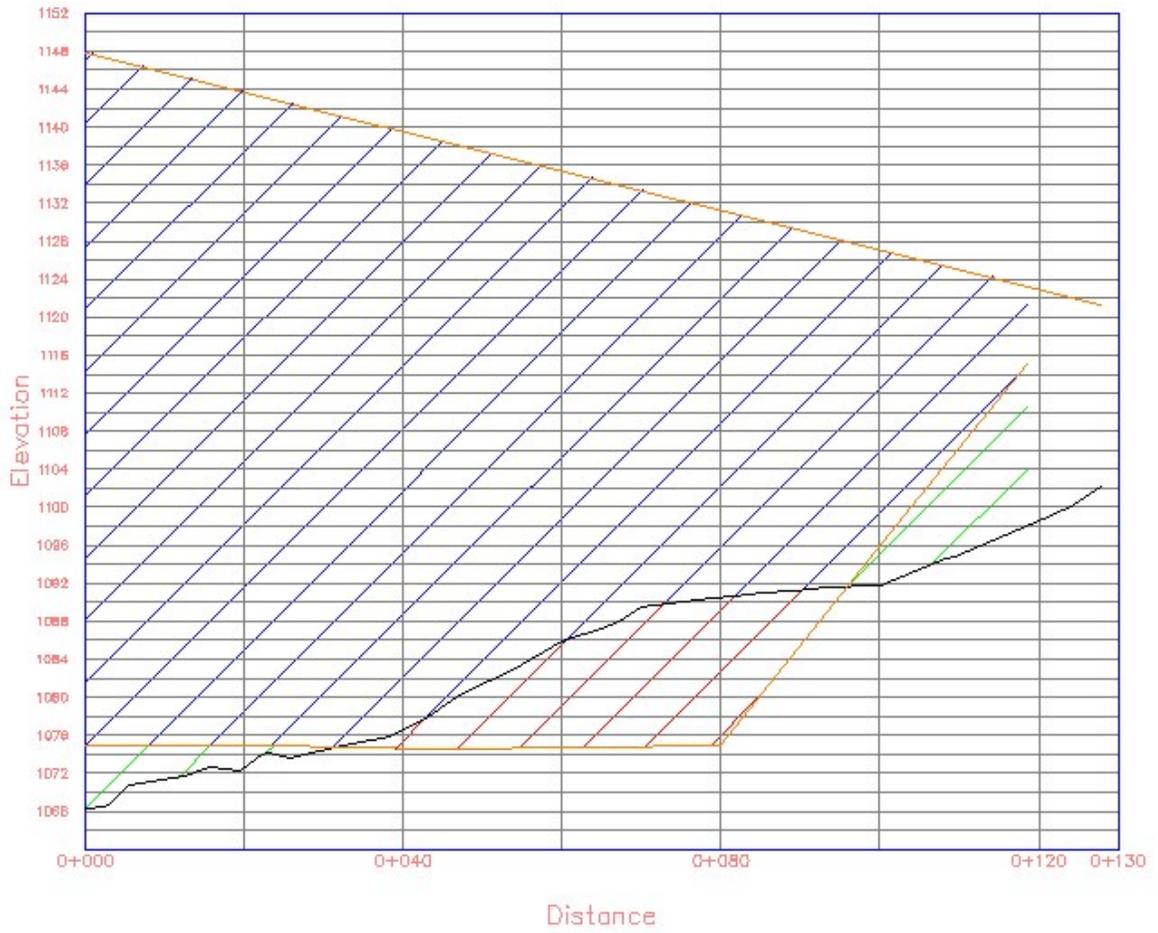


Figure 4. 22 Profile 3 green for fill, red for excavation, and orange for the engineered landfill.

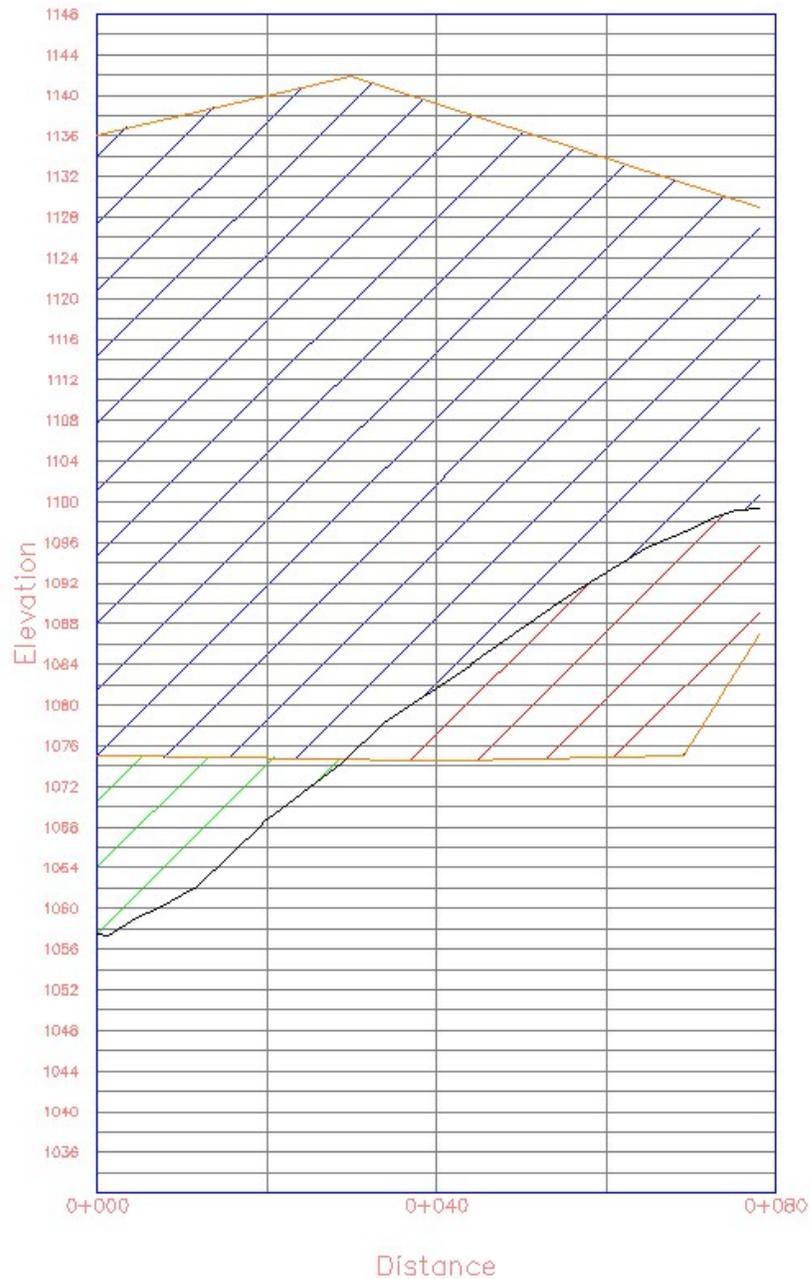


Figure 4. 23 Profile 4 green for fill, red for excavation, and orange for the engineered landfill.

From the data presented the profiles retrieved were set as the study point for the upcoming analysis, excavation area, and landfill shape. The Geo Studio analysis software features, soil parameters selection, and analysis type are described in the following sections of this chapter.

4.8.2. GeoStudio Computer Software Analysis

Geostudio SLOPE/W software tool uses limit equilibrium methods to solve slope stability problems. The software gives liberty to model heterogeneous soil types, different stratigraphic layers, slip surface geometry, pore-water pressure conditions and external loads. The interface in the software is user-friendly and practical to understand its operating features. During an analysis, after the 2-D model is drawn and the material parameters defined, the numerical analysis is quickly executed with various methodologies included in the software. The input data may be used to compute both finite element and limit equilibrium calculations. Therefore, making SLOPE/W a proper and versatile program.

To mention some of the methods included in SLOPE/W, the ordinary (Fellenius), Bishop Simplified, Spencer, Janbu Simplified, Morgenstern-Price and Corps of Engineers are among the options available in the software package. Due to the variability and uncertainty of the data input in the program, SLOPE/W automatically performs a probabilistic analysis to statistically quantify the failure probability of a slope. This is achieved through the Monte Carlo Method which performs a sensibility analysis by checking over different parameters such as unit weight, cohesion, and friction angle (Omari, 2012).

4.8.3. Material Parameters

Given the general lithography and soil parameters obtained from the geotechnical survey in the landfill, these results have been compared with different literature sources to obtain the most critical parameters for the analysis. From the site, the electric tomographies T1 and T2, the nearest to the interest zone of the study, showed an irregular material resistance layer near the creek areas for which a 5 to 10 m thickness is observed, associated with fractured rock and loose soils. Below this layer resistivity indicated the presence of groundwater. The study area is mostly made up of granular materials and fractured rocks, the uppermost layers have been defined as an unsaturated material in which the westernmost area of the landfill is made up of colluvium material that varied irregularly between 10 to 25 m, found after this a series of fractured rocks or altered ignimbrite tuffs. The Vertical Electrical sounding (VES) indicated 4 different material deposits corresponding to altered tuffs from the Padre Miguel

group, colluvium material mixed with altered in situ material and garbage, a third saturated material layer, and the fourth a solid rock at depth. The VES models detailed 3 to 5 differentiated layers, but all mark an intermediate layer of low resistivity which may correspond to a saturated level since all the lines are related to the creek that crosses the area and therefore dictates a slope in favor of it.

Data from boreholes 3 and 4 indicate an average 0-6 m. altered tuffs and ignimbrites of Cerro Grande formation and an ignimbrite rhyolitic tuff layer up to 10 m. depth. In borehole 4 the survey finished at 6 m. depth due to failure in the drilling process because of the fine colluvium material on the hillside. Inside Section IV, the 1x1x1 m. trial pits with numbers 2,3,4,7, and 8 resulted in predominant altered tuffs. Collected studies from the previously mentioned materials in other parts of the world is included as supporting material. The tuff material literature presents the following geotechnical properties; 18-25 kN/m³ unit weight, highly varied compressive strengths, 0-1.45 MPa cohesion, and 24°-45° of friction angle. In the specific case of Indonesia, unit weight varies from 10 to 30 kN/m³, compressive strength from 0 - 0.2 MPa, 0 to 0.1 MPa cohesion, and 10° - 40° friction angle (Asniar et al., 2019). Other data found shows cohesive strength of 90 kPa and 20° friction angle for tuff material under natural moisture content (Rotonda et al., 2015).

For ignimbrite, the supporting literature indicated an overall low density and high porosity characteristics resulting in weak compression, low tensile stress, 0.06–9.0MPa cohesion, and 27°–38° angle of friction. Ignimbrite has a high plastic deformation prior its failure point (Moon, 1993). Regarding colluvium material, Taiwan possesses a very similar tropical climate as Honduras, the colluvium soils in Taiwan slope surfaces describe characteristics such as porosity, loose material and high permeability. The colluvium soils found in Taiwan are usually close to the water table, which is similar to the colluvium found near the creek areas of the Section IV landfill site (Jeng & Sue, 2016). Some of the, mechanical properties found on the tests performed in Taiwan are included in the Appendix A.9.

4.8.4. Analysis Type

The limit equilibrium analysis was performed with the Janbu and Bishops method. The Janbu method is very similar to the Bishops method except that the first one satisfies overall horizontal forces but not the overall moments. Between the 2 methods, Janbu is significantly lower due to the sensitivity of the interslice shear force which is ignored in this method making the FOS lower for circular slip surfaces. The Janbu analysis performed in this study was divided into two (2) scenarios in which scenario 1 considers a water table 15 meters below the surface as presumed in the geotechnical report and scenario 2 represents an elevated water table from 1-10 meters below the surface level. The Scenario 2 assumptions were created to perform the most critical landfill conditions analysis.

4.9. Landfill Results

The results obtained from the laboratory and field data result in the Section IV engineered landfill which includes a leachate and methane gas systems concept idea. A considerable waste filling space was obtained after different elevations and configurations were attempted taking as a base point the current stage II and III dirt road cote at 1,110 meters above sea level was a key aspect for the rest of the landfill geometry design. The proposed landfill area presents a great accident terrain in which slopes from 28% to 64% are found, however, the implemented model focuses on taking the most advantage of this section giving order and place for future landfill stages to be executed.

Taking into account that the northern section of the acquired land running 900 meters across the center represents harder access in construction terms, its steep hill represents 125,000 m² of the site area in which more vigorous work to be shaped and landfilled is needed. The location of the new area would serve as a starting point from which as its filling activities start, determined excavation works of the northern hill will be able to be done. As indicated in the geotechnical studies for the new landfill, the SPT samples recovered an organic soil identified in the first 1 to 1.5 meters in most of the boreholes and in others, a highly weathered rock with an intact structure causing a refusal of the SPT test was found. Test pits samples obtained correspond to altered or weathered material of the basement rock, defining those of

the north zone as tuffs and ignimbrites. This material does not present plasticity characteristics reason why with the use of pikes and bars it could be obtained. As a result, it can be stated that one meter beneath the surface the alternated basement rock is located.

The 21 ha of virgin land is estimated to be the main waste disposal for the next 24 years in Tegucigalpa, meaning that the proposed Section IV landfill would account for 37.5% of the landfill expected lifespan. In addition to having a good start margin for the El Crematorio landfill the implementation of new leachate pond structures and drainages will have a positive impact on the environment and nearby areas, therefore this thesis study incorporates a fundamental base analysis study of the area with a possible solution for the new landfill distribution.

Consequently, it can be clearly stated that the El Crematorio landfill has suffered positive improvements since its beginnings in 1978 and can safely be used as the new landfill center for the disposal of waste in the city of Tegucigalpa. Although it was possible to obtain the desired design capacities utilizing topographic advantage, it is also necessary to focus on and improvement of the leachate and gas collection systems. The results of these achievements are detailed in the following section.

4.9.1. Field Data Results

According to the SPT and electric tomography tests carried out, the thickness of the existing colluvium soils in the project is minimal and cannot be used as a foundation for structures. Below this level, a slightly weathered rock and sound rock is found. In the southern area of the project, tuff-type rock and ignimbrites are observed. At ground level garbage residual and hillside soils with porous and permeable characteristics are found. As evidenced in surveys and pits, the thickness of these materials is small, between 1 and 3 meters. Therefore, according to the slopes and the areas, it would be material to remobilize due to its low geotechnical characteristics.

The depth extension of these soils is not uniform since the SPT tests show that the slopes of the northern area outcrop with layers of tuff and ignimbrites. Two types of rock have been evidenced in the area. In the southern zone, close to the current fill area, there are ignimbrites from the Cerro Grande formation, which include significantly compact and resistant diaclose fissured rocks filled with amorphous crystallized silica (opals).

On the other side of the ravine landform dividing the project area, tuff and ignimbrite rocks from the Padre Miguel group outcrop as the second evidenced rock type. Uniaxial compression tests to evaluate resistance of the rocks have been performed. These parameter results together with RQD data are included in the probe logs. For more information, see Appendices A.6 Drilling Log and A.10 Laboratory Tests.

4.9.2. Input Parameter Results for Analysis

The analysis in this study is comprised of three main materials forming the slopes at section IV landfill for which their parameter characteristics are defined as follows. See table 4.6.

Table 4. 6 Input design parameters for El Crematorio

| Description | Cohesion (kN/m ²) | Friction Angle ϕ | Unit Weight γ (kN/m ³) |
|----------------------------|-------------------------------|-----------------------|---|
| 1. Colluvium | 0 | 27 | 19.31 |
| 2. Altered ignimbrite tuff | 300 | 29 | 23.09 |
| 3. Ignimbrite | 403 | 27 | 18.33 |

4.10. Slope Stability Analysis

This analysis objective is to generate a stability conception of the slopes found inside the future landfill section IV. The study includes a discussion about the impact on the variation of the water table and analyses the slopes FS modulating them in the Geostudio 2021.4 version software. In addition, comments for reduced slope stability risk and recommendations are presented.

4.10.1. Water Table Scenarios

Uncertainty in the level and potential variation of the water table is affected by different factors such as excessive rainfall, hurricanes, and permeability of soil surrounding the landfill. With two different potential piezometric line scenarios for the analysis, this information interpreted from the site study electric tomography approximations is defined as the first scenario, on the other hand, the second scenario resembles a higher piezometric line nearer to the sliding surface being this the worst-case scenario.

4.10.2. Stability of the Slope

Before discussing the analysis made with Geostudio the methodology of slope stability and methods used in the analysis must be understood. The methodology is based on the measurement of the critical surface, the most likely to fail, compared with the shear strength of the soil. This critical surface represents the minimum FS in the slope. A slope's FS is determined by the soil properties, angle of the slope, depth of excavations, height of the slope, loads on the slope and water table (Mahammedi, 2015). Multiple aspects intervene inside a stability analysis plus the uncertainty of some data which is highly probable to occur. The use of slope stability analysis as a description is a short sentence to describe the complex calculation that this process withholds.

4.10.3. Methods for calculating slope stability

Normally two methods are used for performing slope stability calculations. These are the limit equilibrium methods and finite element methods (Chen & Snitbhan, 1975) The limit equilibrium is the most commonly used for this calculation in heterogenous soils where the basic principle is to decompose the slope's soil mass into slices considering the resulting inter-sliding forces acting on each slice (Chowdury, 2012).

4.10.4. Software analysis

The results from the Geostudio software performed with the Janbu method pointed out the most critical FS results given by the slip circles. The analyses are based on four parameters for their calculation; geometry of the slope, piezometric line, shear strength, and soil

parameters. Geostudio analyses these circular slips at different depths calculating the minimal FS in the expected slope sliding behavior. The results taken from the two different scenarios represent soil parameters taken from soil testing and literature sources from which the following data is presented in Table 4.7.

Table 4. 7 Soil parameters used in the software

| Description | Cohesion (kN/m ²) | The angle of friction ϕ | Unit weight γ (kN/m ³) |
|-------------------------|-------------------------------|------------------------------|---|
| Colluvium | 0 | 27 | 19.31 |
| Altered Ignimbrite Tuff | 300 | 29 | 23.09 |
| Ignimbrite | 403 | 27 | 18.33 |

Scenario 1 Profile analyses

Located in the north-western area of Section IV, profile 1 with a 1.145 FS has an 80 meter length slope whose results show safe conditions for its natural slope geometry. Figure 4.24.

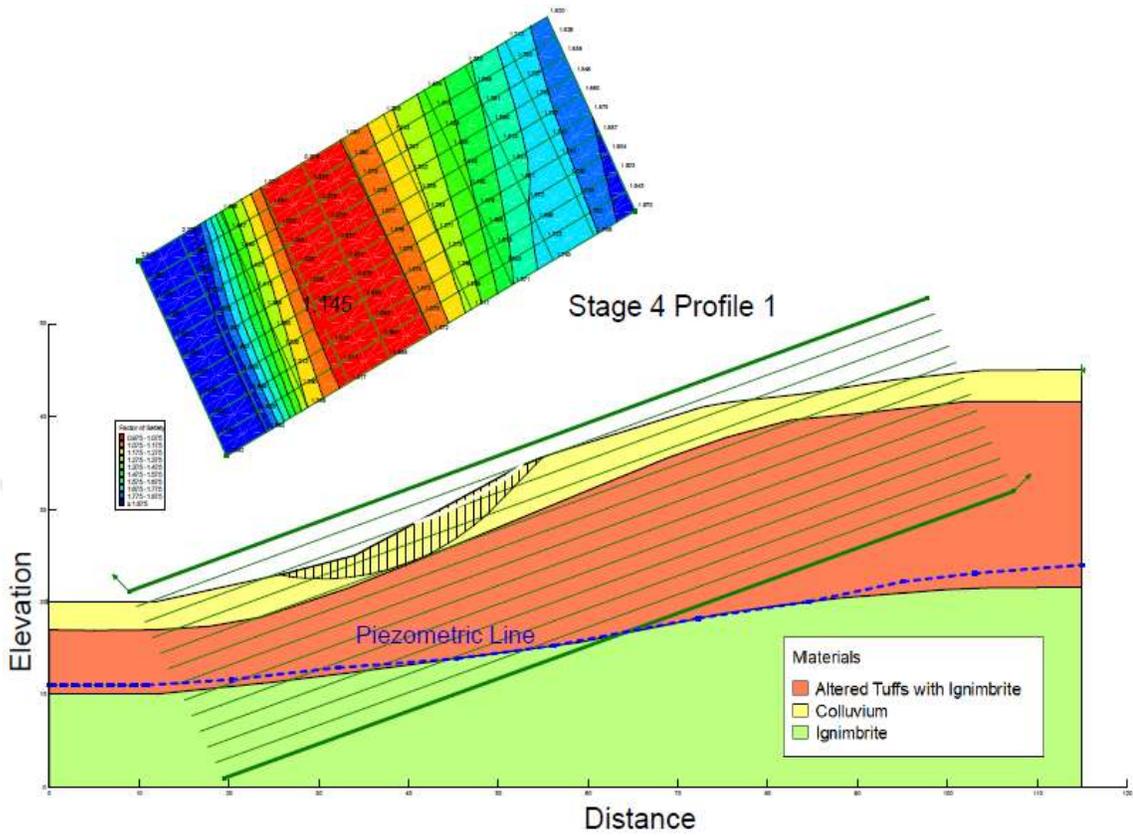


Figure 4. 24 Profile 1 Section IV scenario 1

With an FS of 1.637 profile 2 does not represent an imminent danger to the southwestern area of the future landfill given its average 38% inclination slope on a horizontal 70 meter long-run. Figure 4.25.

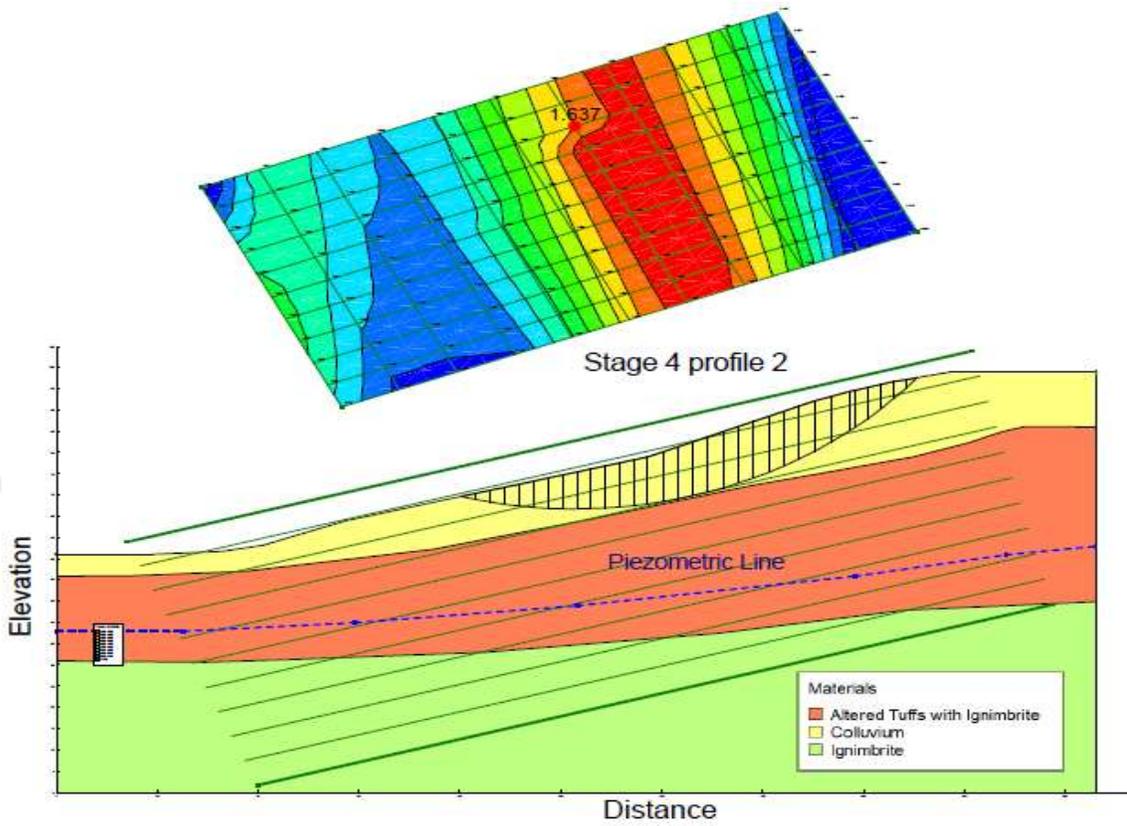


Figure 4. 25 Profile 2 section IV scenario 1

Profile 3 contains the highest FS of all the profiles in this analysis with a value of 1.859, given its horizontal 100 meter long and light slope geometry. Figure 4.26.

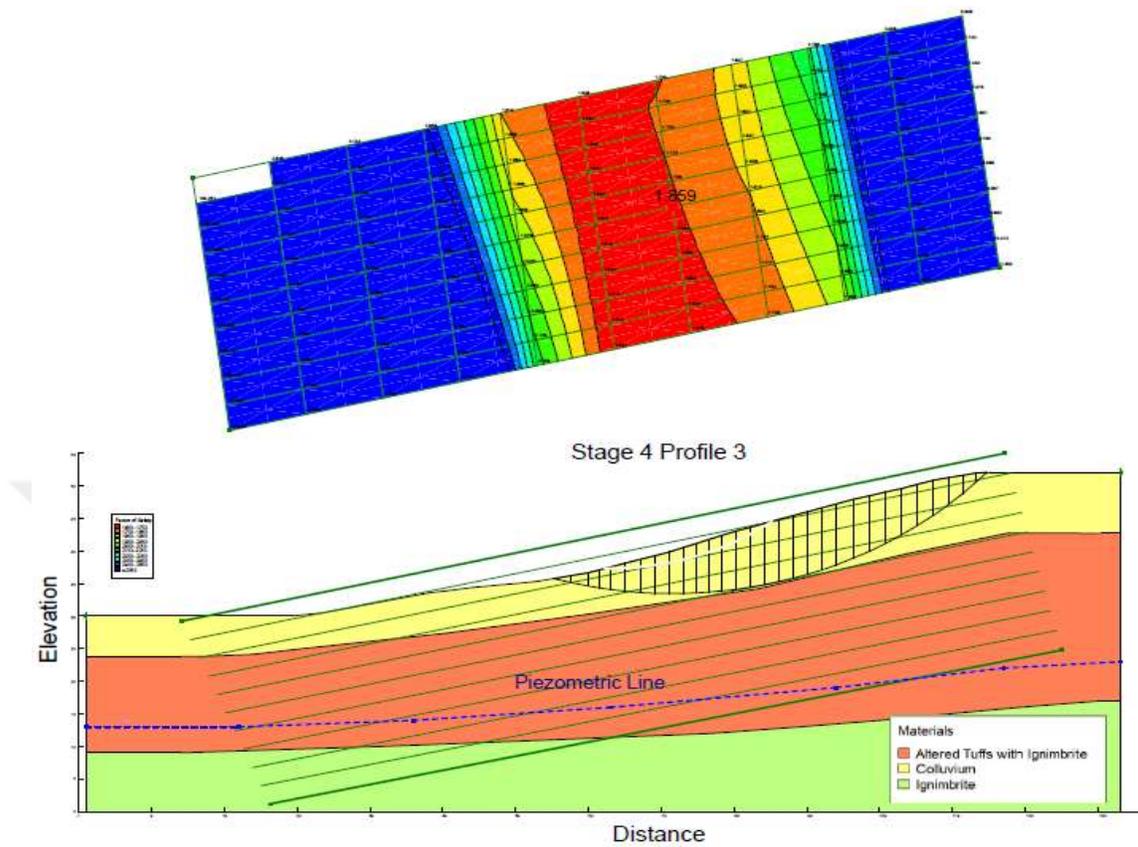


Figure 4. 26 Profile 3 section IV scenario 1

With an FS of 0.895 slope profile 4 represents the highest instability slope from the area. Located on the northeastern part from where the slope continues to prolong and rainwater is most probable to run. Figure 4.27.

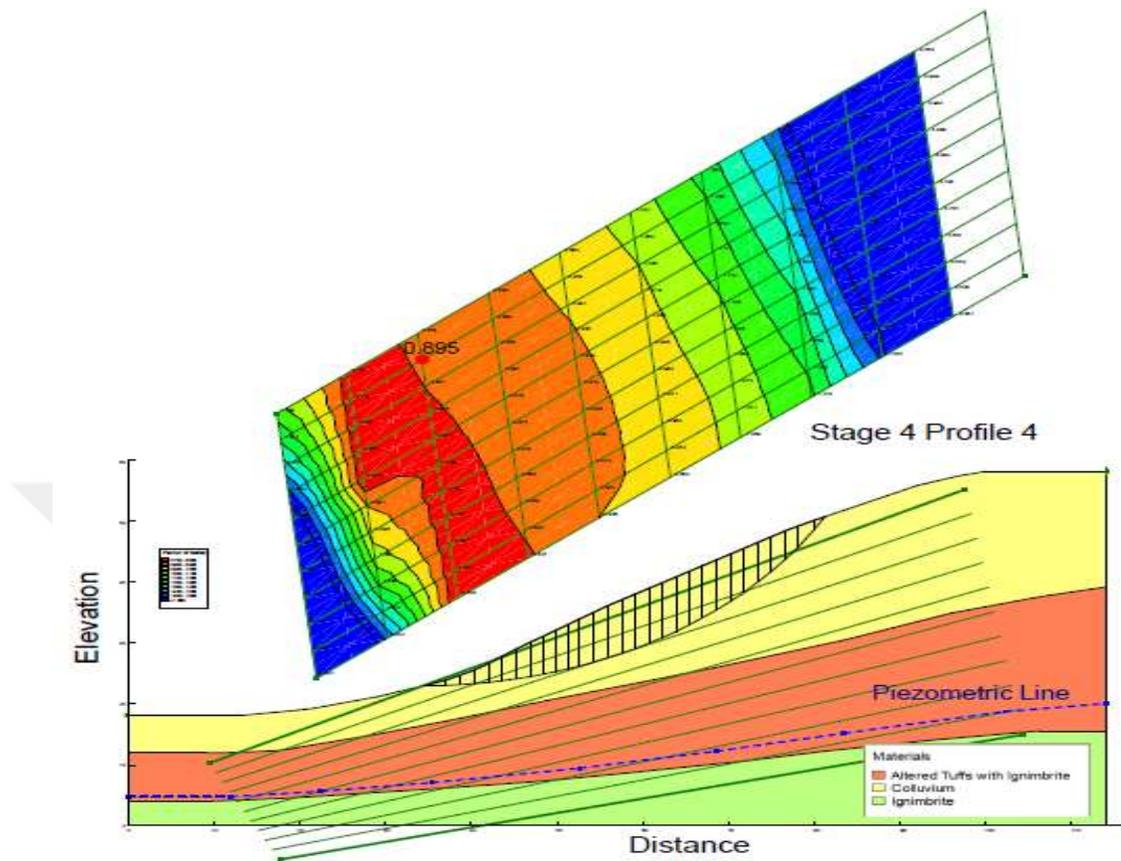


Figure 4. 27 Profile 4 section IV scenario 1

Scenario 2 Profile Analyses

The elevated piezometric line decreased the FS by only 0.01 compared to scenario 1. From all scenario 2 this represents the lowest and most negligible result. Figure 4.28.

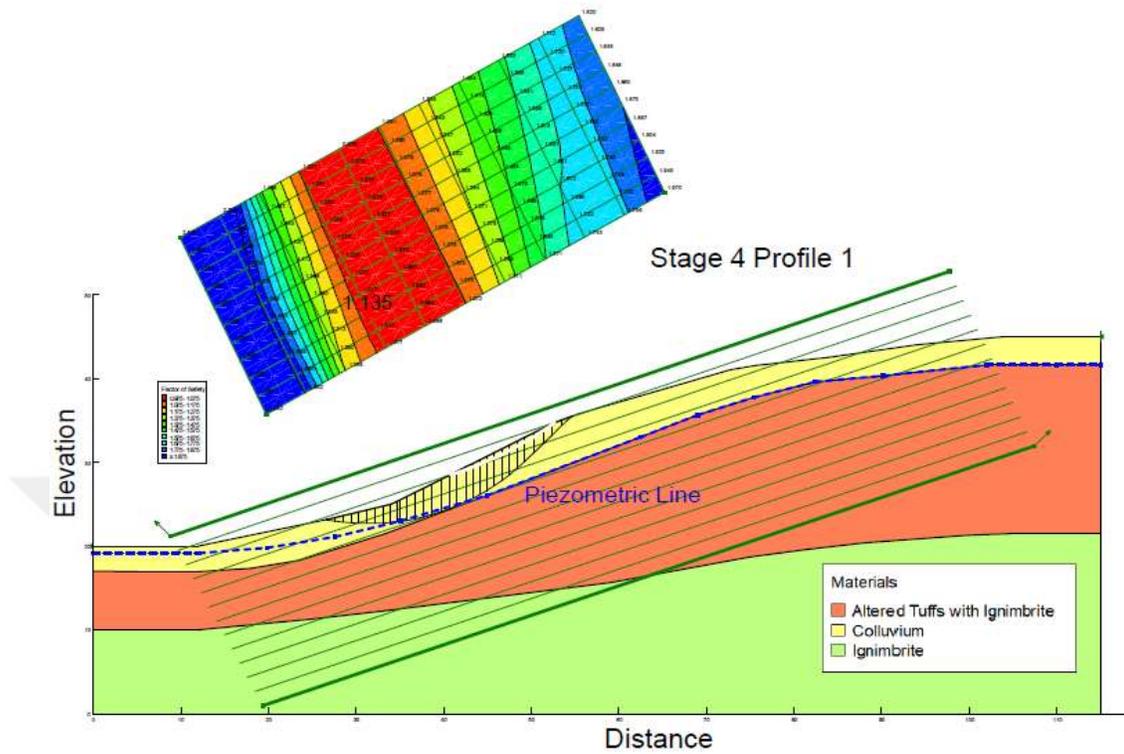


Figure 4. 28 Profile 1 section IV scenario 2

With a 0.118 lower FS compared to scenario 1, the difference is almost negligible, which is expected from colluvium material represents a good water-draining material. Figure 4.29.

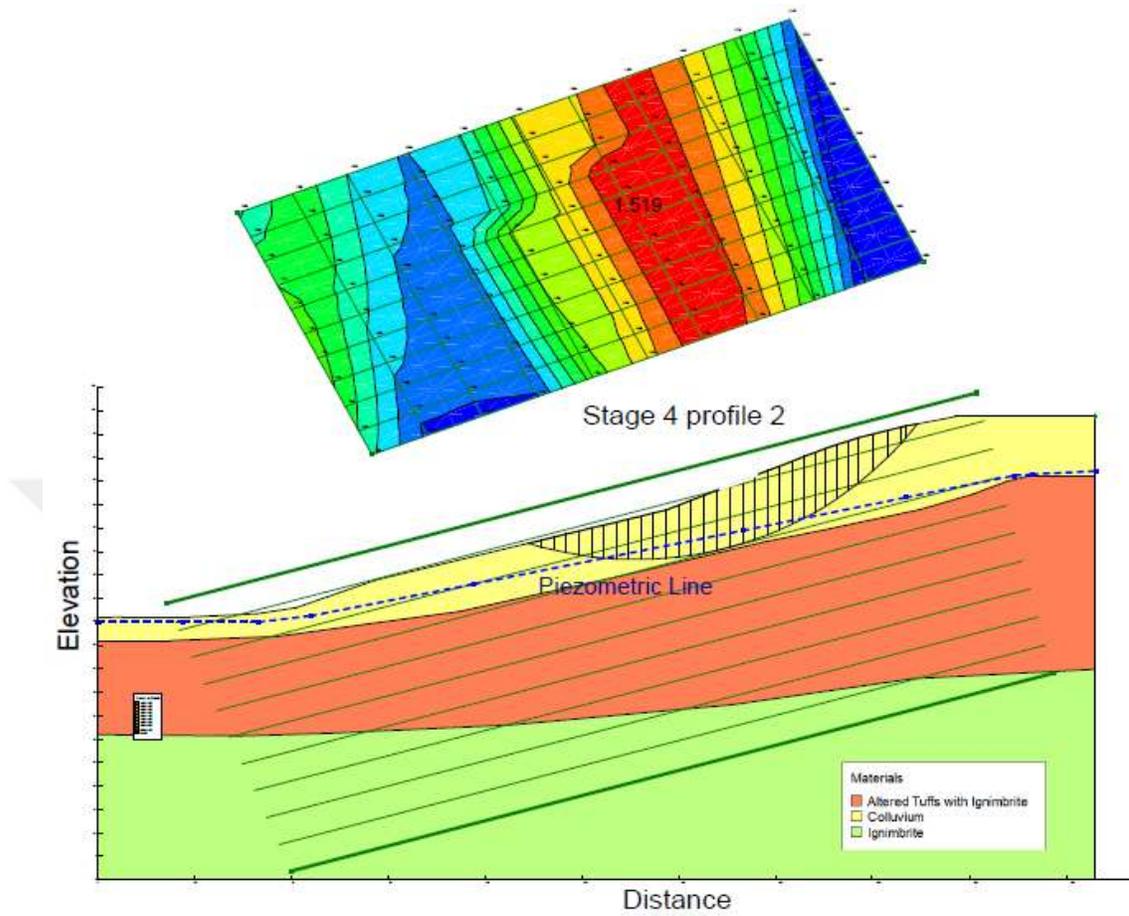


Figure 4. 29 Profile 2 section IV scenario 2

Only a 0.014 lower FS was achieved on this profile. Figure 4.30.

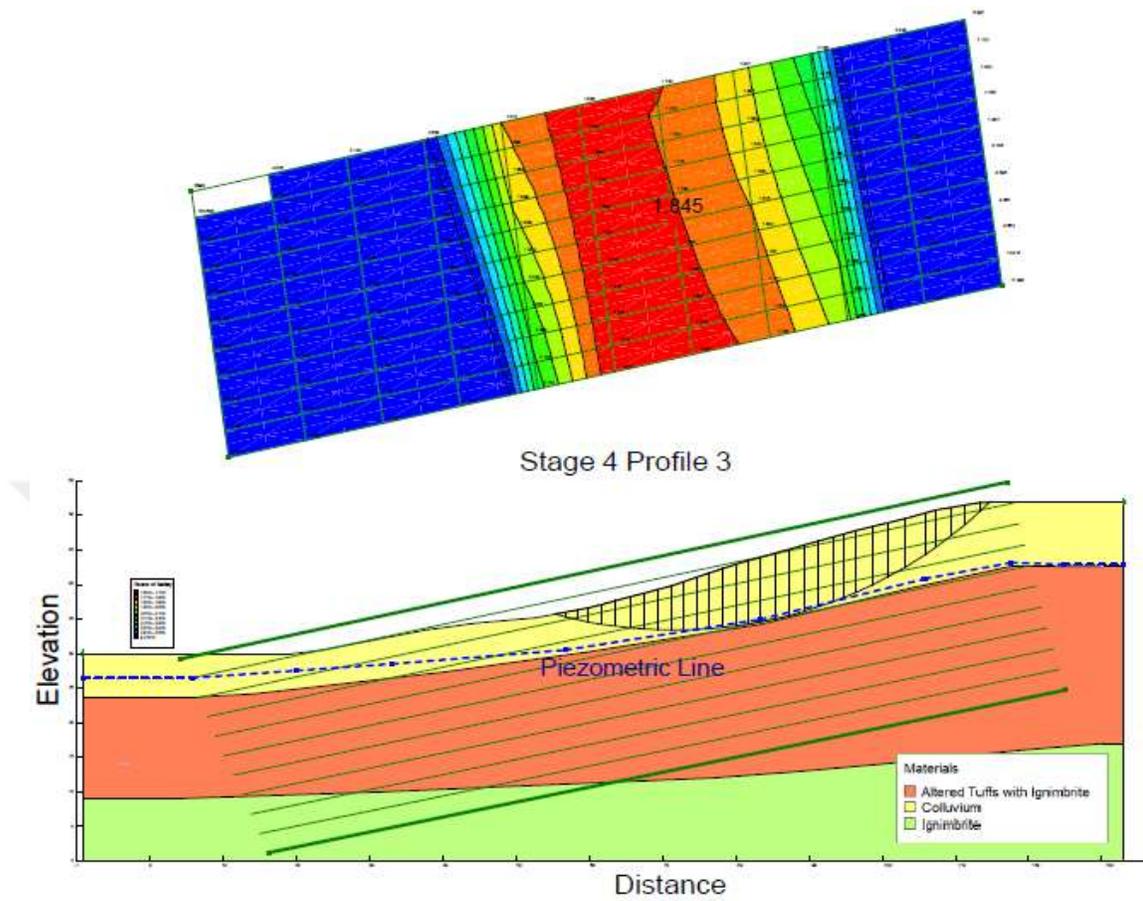


Figure 4.30 Profile 3 section IV scenario 2

With a 0.865 FS, this scenario 2 profile 4 is identified as the most critical slope in this analysis study indicating where the most attention should be centered from a safety point of view. Figure 4.31.

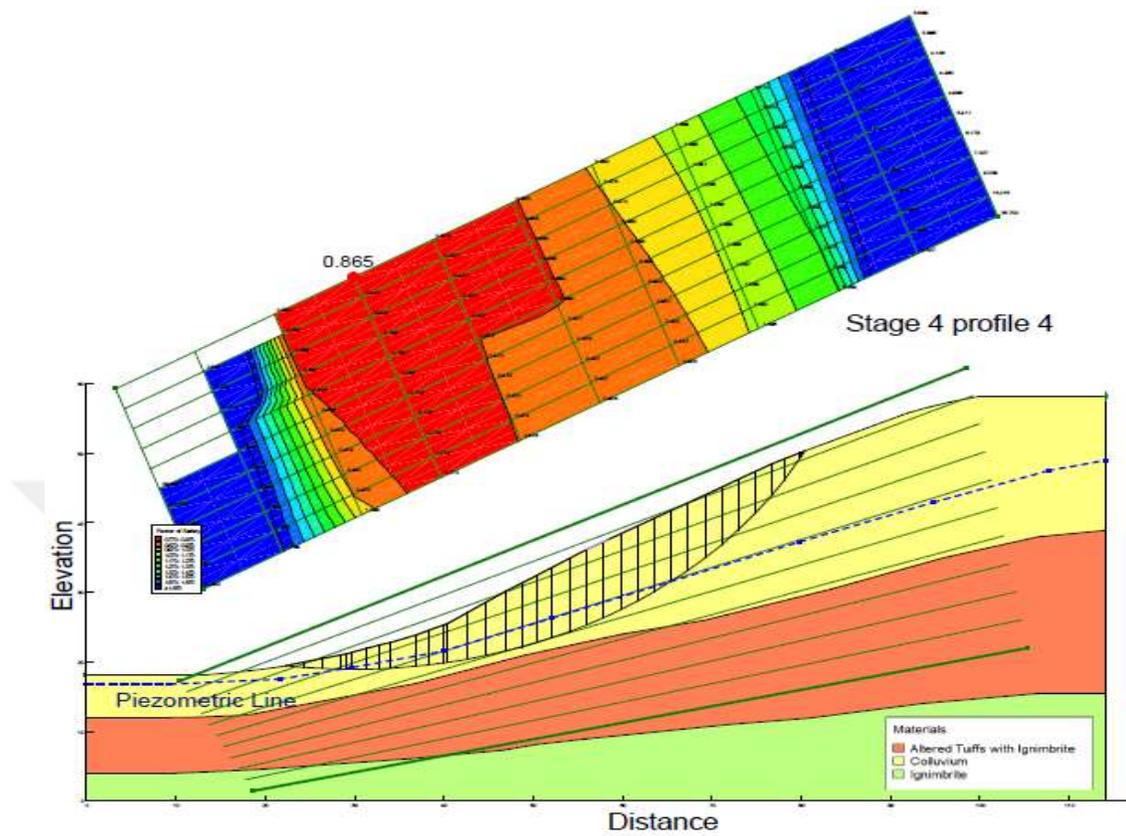


Figure 4. 31 Profile 4 section IV scenario 2

From the available data and presented analysis it was able to be determined that even though the two scenarios presented different water table inputs, as a general the area of study does not represent a dangerous sliding area except for Profile 4 which compared to the others presented the most instability of the slopes. This risk is expected to disappear as the area will be excavated into a cone-shaped opened pit modifying its geometry.

4.11. Landfill Section Design and Remediation

The section landfill design is foreseen to comply with all modern waste facility characteristics in which the leachate collection and gas management systems must be designed appropriately to receive approval from the AMDC before the construction of this facility extension may begin. A satellite view of the working area is shown in Figure 4.32 consequently,

management operation details and general element characteristics have been taken into consideration which are found in the following sections.

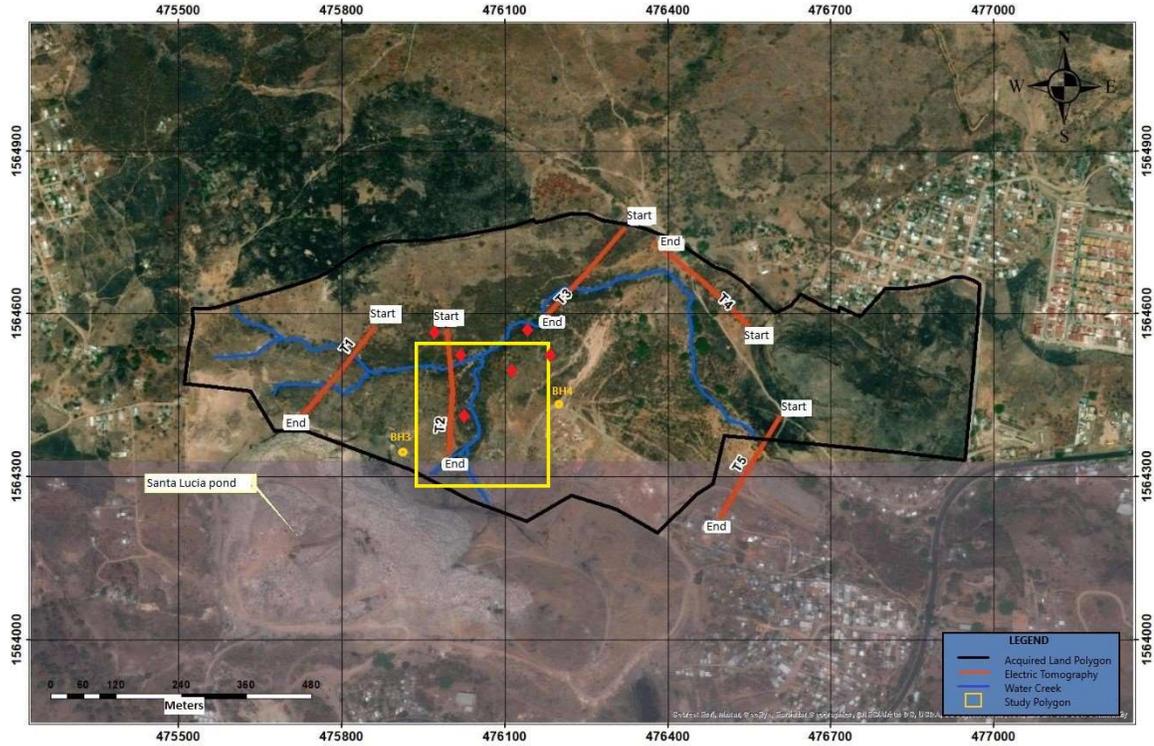


Figure 4. 32 Satellite view of proposed Section IV working area.

4.11.1. Proposed Location

The proposed landfill location is overseen to be located next to the old section and current landfill works in the northern part of the sanitary complex. Similar to the old sections, the new landfill is expected to cover more than 100,000 m² of land, as represented in Figure 4.33, on which its construction and activities will be developed.

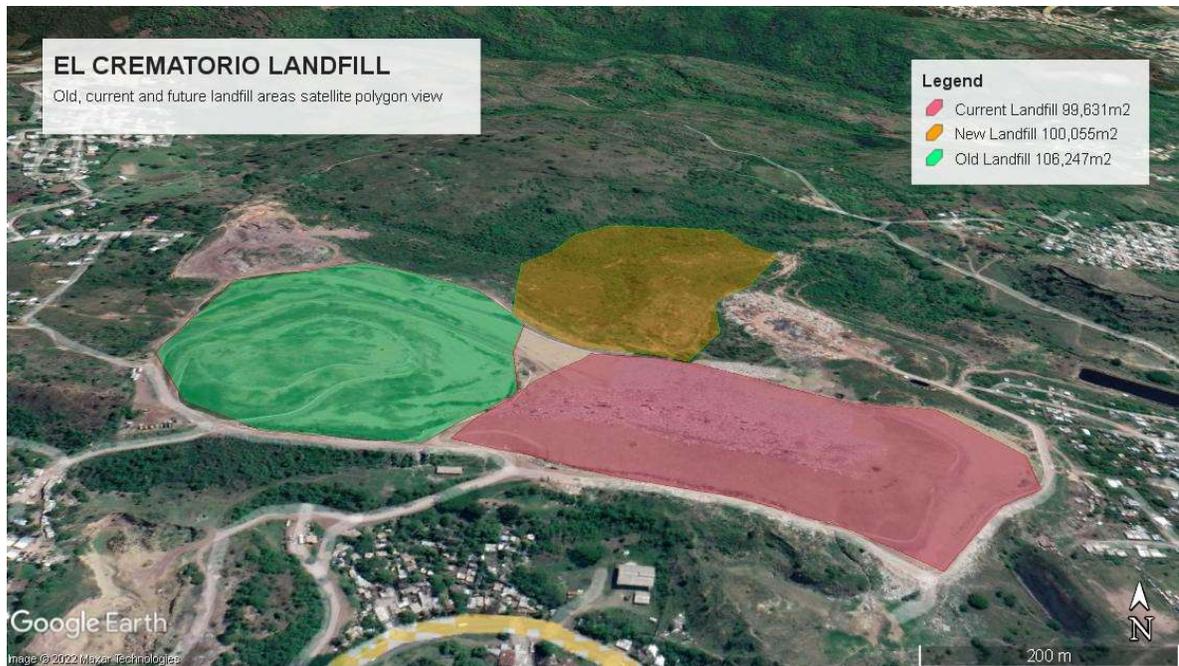


Figure 4. 33 Old, current and proposed landfill area views from satellite imagery.

4.11.2. 3D Model Construction

Modeling the new landfill with AutoCAD Civil 3D built in tools enabled the modeling for natural terrain topography, landfill excavation area, cross sections and earth movements. As a start the topography obtained from site was inserted into the software and later created into a surface element with triangulation points obtaining as a result a topographical view of the Section IV terrain area as can be seen in Figures 4.34 and 4.35

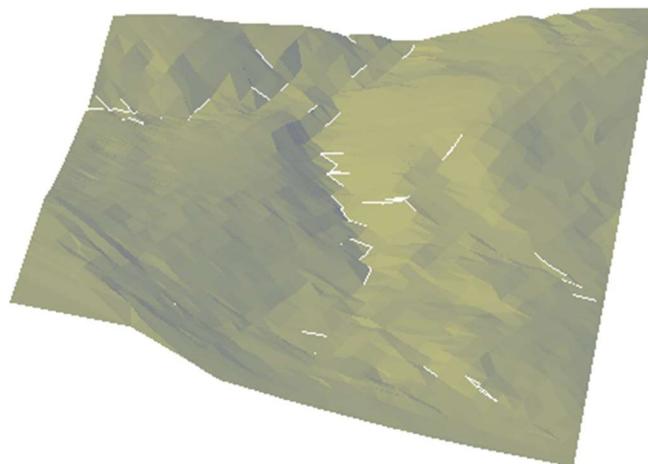


Figure 4. 34 Rendered realistic topographic view of the Section IV area in El Crematorio



Figure 4. 35 Rendered shaded topographic view of the Section IV area in El Crematorio

After defining the most suitable landfill location, the bottom liner depth and length were created using featured lines enabling the 3D visualization of the model. Proceeding with grading the landfill excavation areas the bottom liner was defined at a depth of 1,074.56 m. at the lowest point. Starting from the lowest point a mid-point filling height is calculated at 1,115 m. (Figures 4.36 a and b) point from which the landfill is to be filled respecting a 3:1 relation slope until reaching a maximum closure elevation of 1,153 m. as shown in Figure 4.37.

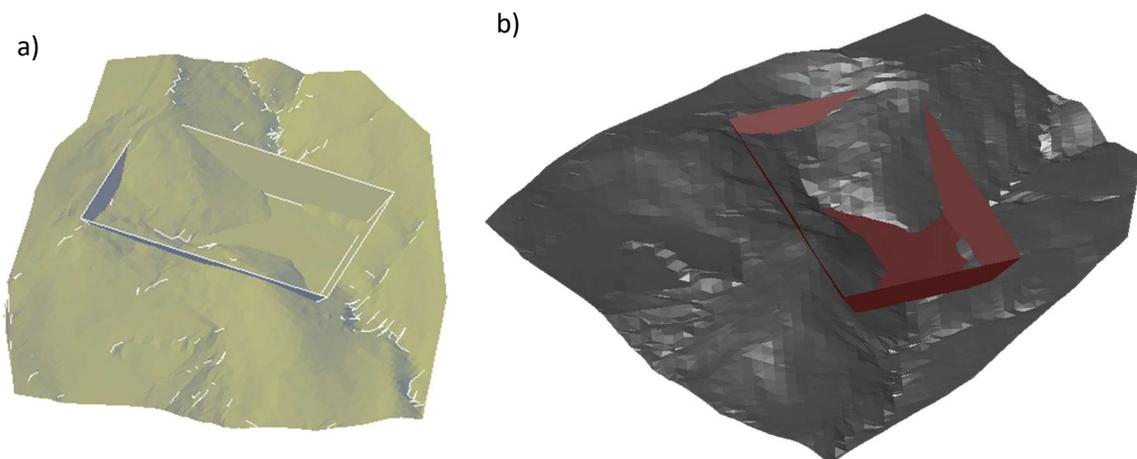


Figure 4. 36 a) Realistic render of the bottom liner; b) shaded render view of the bottom liner

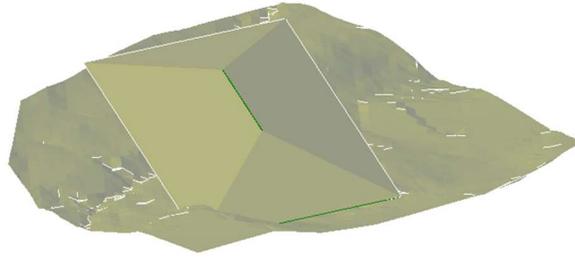


Figure 4. 37 Realistic rendered view of final closure 3:1 slope relation

The general model was constructed following location and height references from other points in the old landfill stages likewise, the leachate system draining slope was defined with a 1.5% slope running from the farthest most external points of the bottom liner until the center, place where the main leachate collection in the pipe will be located. The 3D model is an advantageous tool from which the most critical slope profiles could be selected and their natural terrain elevation data was retrieved for a posterior slope analysis. These analyses are presented in the testing and studies of the landfill section of the document.

4.11.3. Liner

In compliance with the criteria for the disposal of solid wastes, the proper approaches must be used to reduce the impact on the environment. Leachate from waste disposal facilities have the potential to contaminate soil, groundwater, and surface waters, a reason why before installing the geomembrane liner, a permeability barrier made from a combination of clays is used. According to the standards mentioned in the Honduran landfill waste manual, the thickness of the clay layer to be used as an impermeable material must be 60 cm which is the same indicated by Turkish landfill standards (Eberhardt, 2003). This protection layer or liner is constructed in two 30 cm thick compacted layers.

4.11.4. Geomembrane

The objective of geomembrane is to avoid seepage of leachate into groundwater and surface. It should be noted that the waterproofing must comply with a coefficient of 10^{-7} cm/sec. As described in the Honduras landfill guidelines. The sanitary landfills in the country are

required to use 1.5 mm HDPE waterproofing geomembrane. For its correct use, a field assistant must check the area of the cells where the work fronts are being made to verify that heavy machinery does not cause any damage to it. Geomembranes must fulfill a series of strict quality controls with HDPE resin, carbon black as a stabilizer against UV rays, antioxidant additives, thermal stabilizers and appropriate thickness. A table with the reference characteristics is included in the Appendix A.11. Anchorage trenching is a fundamental constructive process in the installation of a geomembrane, where the geomembrane should extend over a rounded corner to a trench which is to be backfilled with compacted soil. An example of anchorage made in a leachate pond of El Crematorio is shown in Figure 4.38.



Figure 4. 38 Geomembrane and anchorage in El Crematorio leachate pond.

4.11.5. Drainage

Managing the surface rainwater during the landfill operations and after its technical closure must be included as part of the design given the importance it represents for the safety and efficiency of the landfill. The main function of the surface drainage is to prevent rain water

from entering the landfill area. As explained before in the document the excessive percolation of water increases the unit weight of the waste mass therefore increasing the pore water pressure which may lead to the failure of the landfill. Rainwater is collected in the superficial drains (Figure 4.39) and transported to either water drains located outside the landfill or bigger natural running water bodies near the zone (Figure 4.40). The second case applies to El Crematorio which contains a series of ravines that collect rainwater and transport it for about 1.2 km until the Choluteca River. In Sections 1 and 3 of the landfill, gutters have been built on the natural ground with stone and concrete. These gutters need maintenance checks, especially during rainy seasons where any residues or dirt on them should be removed for their effective operation (Mi Ambiente Honduras, 2013).



Figure 4.39 El Crematorio stage 1 and 2 gutters construction February 2020, Source: CINSAs landfill maintenance for section 1 and 3 photographic gallery.



Figure 4. 40 El Crematorio stage 1 and 2 rainwater discharge tube construction February 2020, Source: Cinsa landfill maintenance for Sections 1 and 3 photographic galleries.

4.11.6. Gas Collection

Safety and environmental purposes require the gas collection and management system. To emphasize the importance of gas collection in a landfill the following case is presented. The “Rumpke” landfill in the town of Colerain, Ohio USA occupied an area of 30 ha receiving around 1.6 million tons of waste per year. The landfill reached a height of 75 m and on March 9, 1996, a huge landslide occurred triggered by the gases in the landfill as Rumpke did not have a gas collection system and the deficient leachate extraction system. The landfill reached such high levels of internal pressure that days before the landslide tension cracks and leachate could be seen on the surface of the slopes (Koelsch & Reynolds, 1999). El Crematorio has operated a gas collection system using chimneys from which later the gas is flared. The chimneys are vertically installed gas fireplaces that remove the gas generated by the landfill during the decomposition of its waste. The chimneys also introduce air into the waste mass which helps ease the decomposition process. As landfill activities progress and disposed waste increases, it is necessary to increase the height of gas fireplaces as well.

The gas chimneys start directly placed on the leachate pipe (Figure 4.41), in such a way that they start from the base of the landfill and can evacuate as many gases as possible. The proper functioning of this system will depend on the speed of how the solid waste deposited is decomposed, which happens in the presence of oxygen. These chimneys are built with wood casing siding, lined with 1 ½" x 72" mesh, known as chicken coop mesh and filled with stone. As shown in the respective figure, in order for the gases circulate easily, a perforated 4" PVC pipe will be placed or grooved in the center to complete the fireplace. When finishing the chimney, a layer of 10 cm soil-cement is be placed with an area of 60 x 60 cm, placing a 6-inch concrete pipe that will protrude to the ground for its final flaring. See Figure 4.42 (Mi Ambiente Honduras, 2013).

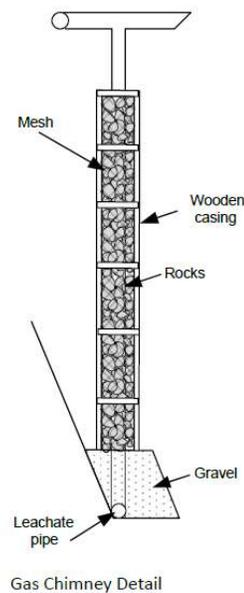


Figure 4. 41 Gas chimney detail.

CHIMNEY PIPE DETAIL

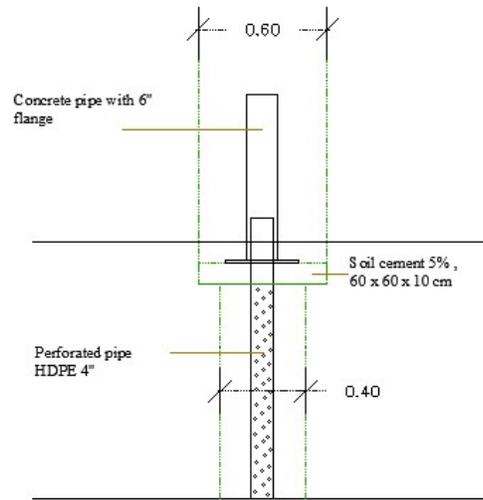


Figure 4. 42 Gas chimney pipe detail.

4.12. Risk Assessment

Slope stability risk assessments have been made possible by probabilistic assessment techniques (Chi et al., 2011; Christian et al., 1994; Lacasse et al., 2007a). However, Lacasse et al. (2007) defined risk as a measure of the adverse effects on lives, health, property, or environmental damage. Until now El Crematorio has not had any historic major accident indicating that the management and operating controls have been done properly. To mention the major risks to deal with the proposed Section IV, toxins, leachate and methane gas generated by the landfill MSW will always be the signature risk factors for a new landfill and particularly on the IV stage landfill a special consideration must be done regarding its low topographic location from where any type of running surface water must be controlled and diverted out of this landfill. Given that the landfill will be expected to grow in a feature, the geographical location of this landfill is expected to be a transition point of leachate and surface water evacuation which will most probably be carried to its leachate ponds and natural rainwater courses from western to eastern part of the site.

The level of risk assessment importance required for this landfill lies in the collateral effect this landfill could have on the existing closed landfill property on the southern site. There are no villages or settlements near the expected working area of this landfill which implies the landfill is not a direct risk for human settlements but as mentioned before there are always garbage scavengers around the working landfill from which the greatest human risk factor can be pointed out. As for environmental risks, the protection measures to be taken for this new stage will mark a lead, especially for the protection of the subsoil condition which as discussed with landfill management due to its opened dump site origin back in the 70's has not had the best methodology regarding this topic.

4.13. Capacity and Future Concept

As part of the designing tasks of any engineering project, a futuristic concept view must be made for the structures to be built and their functionality in the future. El Crematorio management officials stated that this new site area should be enough to cover 24 years of service in terms of MSW quantification when based on the kg/capita/day of waste data obtained from the World Bank Group urban development series “What a Waste”, in 2010 and 2016 the kg/capita/day was 0.61 and 0.65 respectively (Kaza et al., 2018; SERNA Honduras et al., 2014); obtaining an increased rate value of 0.69 kg/capita/day for the year 2022. This value was compared to the landfill daily entry registry of 850 tons/day and as a result, a value of 890 tons/day is obtained which is just a 4.49% above the actual value, proving that the yearly 50-70 ton/day increase calculation is more or less near the actual value. Following the same calculation methodology, the proposed landfill Section IV expected capacity of 2.8 million m³ is estimated to be enough for the following 8 years meaning that at least two more landfills with similar or greater capacities will be needed to cover the 24 years of service as expected by the AMDC. A concept design is shown in Figure 4.43 which includes two more engineered landfills and 2 secondary major leachate ponds. As for Section IV, an estimate cut and fill calculation from the Civil CAD 3D model is presented in Table 4.8.



Figure 4. 43 Future landfill division concept of El Crematorio.

Table 4. 8 Cut/Fill report of proposed Section IV generated with Civil CAD 3D.

| Volume Summary | | | | | | | |
|----------------------|------|------------|-------------|----------------|-------------|---------------|------------------|
| Name | Type | Cut Factor | Fill Factor | 2d Area (sq.m) | Cut (Cu.M.) | Fill (Cu. M.) | Net (Cu. M.) |
| complete fill volume | full | 1.000 | 1.000 | 54000.00 | 0.00 | 2830338.43 | 2830338.43<Fill> |

| Totals | | | | |
|--------|----------------|-------------|---------------|------------------|
| | 2d Area (sq.m) | Cut (Cu.M.) | Fill (Cu. M.) | Net (Cu. M.) |
| Total | 54000.00 | 0.00 | 2830338.43 | 2830338.43<Fill> |

Value adjusted by cut or fill factor other than 1.0

4.14. Summary of Results and New Landfill Proposal

Normally when choosing a landfill site, areas with high water table or high bedrock formations are not wanted and more importance is given to the soil characteristics. Given that the site to be used for the proposed landfill is already determined, from the tests and surveys performed at the site these requirements are confirmed. According to the investigations carried out, the thickness of the first existing soils in the project area is ranging up to 3m depth and cannot be used as a foundation for structures. Below this layer, a slightly weathered rock is found in most of the area, especially in the southern area where a tuff-type rock and ignimbrites formation proliferate.

Landfill Section IV is located in a suitable place which will facilitate the transition of Landfill Section III on which work is currently undergoing. Regarding rainwater drainages, the new location has the facility that the main water ravine crosses but the importance has to be given to this issue having in mind that future landfill expansions east of the proposed Section IV may also use this same drainage. The computed factor of safety will be significantly impacted by the leachate level above the liner system. Although not covered in this work, the other elements stated above are still important and should be considered when determining the FOS.

5. CONCLUSION AND RECOMMENDATIONS

The following conclusions and recommendations summarize the work presented in this study which relates the collected laboratory data, digitalized slope analysis models, field surveying data and local site engineer interviews related to this landfill. Accordingly, the following conclusions and recommendations are stated.

5.1. Conclusions

In the frame of reference of this study, the suggested El Crematorio Section IV as a new landfill area was analyzed and evaluated giving as a result a viable design solution for the projected expansion of the site. In terms of influence, this project has an important social responsibility over the 1.2 million habitants of the urbanization. For instance, the topography of the area represents a major issue due to the different slopes converging inside the terrain. However, the project area has a very defined geology markedly divided by a rainwater ravine, located between two formations of tertiary age and volcanic origin limited by it. In the northern zone, tuffs and ignimbrites of the Padre Miguel Formation outcrop. In the southern area and close to the current fill, the ignimbrites with veins of amorphous silica from the Cerro Grande formation. The tuffs of the Padre Miguel group are significantly softer or less resistant than those of the Cerro Grande formation on the surface which are more weatherable and alterable. The soils found are generally limited to minimal thicknesses (< 3.0 meters) in the flat areas of the north and in some points on the slopes. These slopes have a thin thickness of colluvium and poorly developed soils. Both the test pits and the boreholes have a short survey investigation length, so the water table has not been found with certainty. Much of the water measured in the geological was cataloged as drilling residual water. No foundations or constructions are estimated, but if any are located, they can be executed by eliminating the poor mechanically detected soils.

El Crematorio landfill works according to construction and operation manuals which are followed as required. These manuals have been created with the support of international helping organizations such as JICA, AGCI and GIZ cooperation agencies. Design and

location have been done according to the current landfill construction criteria used along the landfill with the support of engineering software models creating the most efficient waste disposal filling space comprehending safe slope conditions and landfill Section IV area is viable given the current dirt road access, near location to the main leachate 24" diameter drainage pipeline and topographic advantage of the area. The necessary geotechnical investigation importance has not been given to the area of study for which a poor amount of laboratory data has been gathered compared to the importance and transcendence of the project.

The presented study has been done as an approach to model the El Crematorio landfill newly acquired area conditions using the available limited geotechnical testing data performed, local landfill manager and site testing geologist experience and knowledge plus the gathering of laboratory reports of nearby tested sites as supporting data. Rhyolitic ignimbrite rock formations are predominant in all the sites starting from depths of 6 meters and on. Also, predominant volcanic tuffs from the Cerro Grande formation are observed in the surface area where cohesion values of 150 kN/m² are found. The porous soft pyroclastic rock can be excavated with vertical side slopes having a plastic behavior when moist and hard to break up when dry. Slope analysis using the GeoSlope software has been performed using the grid and surface slips. The material data input on this software is based on literature collected data simulating the most critical scenario possible. The estimated utility life for the stage four landfill is of 5 years taking into consideration a 7% annual increase in the garbage disposal each year. Landfill dimensions were done with existing topography data and information from existing leachate pipe and leachate pond characteristics for its design to comply with a minimum 2% slope on the bottom liner for evacuation of leachate.

In Honduras, the environmental impacts caused by dumps denote relevant impacts on soils, surface, and underground water bodies with a loss of surplus value of the areas. Poor solid waste management extends from domiciliary to local and regional levels. El Crematorio is working effectively on handling the waste but there are no environmental monitoring programs in the stages of management, collection, transportation and final disposal of solid

waste. There is not a well-defined requirement for new urbanization that can be done near landfill areas, the requirements regarding this issue are very general and open to interpretation. Health and environmental protection should always be a main concern. As a conclusion the study presented presents an overall draft concept design and does not contain the complete design considerations for the landfill, which can be taken step by step from the “Manual de Construcción y Operación de Rellenos Sanitarios en Honduras”.

5.2. Recommendations

Different from the previous sections which at their beginning in the 70's were used as semi-controlled open-air dumps, this new section is to be constructed from ground zero opening the path to constructing an improved standardized sanitary landfill. Special attention is recommended to the liner which must be waterproofed with the use of geomembrane plastic liners and also protected from external incoming water given its low altitude location. Mitigation works such as channeling rainwater from the northern hillside and adequate rainwater extracting channels or pipes on the lower ravine must be taken into consideration.

This study presents a slope analysis with estimated material parameter values for which performing a complete local soil analysis of the area comprehended in the design is suggested. Hydraulic conductivity tests on the clay material to be used as a base of the landfill would be an interesting value to obtain to learn the coefficient of permeability from this material. As there is no solid data on the location of the water table in the landfill, in case of an event where more accurate data is retrieved, the distance from the bottom of the landfill to the highest point of the water table must not be less than 3 m, and must exist between both a layer of soil with a coefficient of equivalent hydraulic conductivity not exceeding 10-5 cm/second. The landfill will continue to expand in the future for which leachate treatment methods for the use of watering the vegetative support layers in the finished landfills could be taken into consideration. The installation of a fence around the perimeter of the landfill premises should be managed to control the entrance of incoming garbage scavengers, and people unrelated to the landfill tasks and also to prevent incoming animals like cattle and horses which on a daily basis come into the landfill from the northern section. The fence is a

must-perimetral structure with a minimum height of 1.80 m as indicated in the sanitary landfill of Honduras guidelines. El Crematorio has been in use for over 45 years and the 211,320 m² acquisition of new lands indicates its utility lifetime expansion, the implementation of landfill gas collection systems for biogas or other usages could be considered having in mind that in the long term, the amount of biogas generated could be considerable. Early paperwork and environmental administrative procedures to get the required permissions for coordination and development of the works on time and avoid short deadlines. More effort and interest should be given to the separation of waste materials rather than disposing of them in a big mixture of MSW, continue to encourage a recycling culture, and create indirect works for the people in need.

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APPENDIX

| No. | Municipality | Department | Population 2013 | Estimate for waste generation (t/day) | Municipal Category | Description of Infrastructure available at Final Disposal sites |
|--|---|-------------------|-----------------|---------------------------------------|--------------------|---|
| 1 | Santa Bárbara | Santa Bárbara | 44 182 | 74 | A | Open air dump |
| 2 | La Lima | Cortés | 76 823 | 10 | A | Open air dump |
| 3 | Tocoa | Colón | 96 360 | 150 | A | Open air dump |
| 4 | Roatán | Islas de la Bahía | 46 133 | 150 | A | Open air dump |
| 5 | Santa Rosa de Copán | Copán | 65 233 | 45 | A | Sanitary landfill |
| 6 | Siguatepeque | Comayagua | 101 316 | 44 | A | Open air dump |
| 7 | Tela | Atlántida | 100 650 | 50 | A | Open air dump |
| 8 | Distrito Central | Francisco Morazán | 1 207 640 | 800 | A | Controlled dump |
| 9 | San Pedro Sula | Cortés | 874 561 | 793,66 | A | Controlled dump |
| 10 | Choloma | Cortés | 305 272 | 144 | A | Open air dump |
| 11 | Villanueva* | Cortés | 161 609 | 67 | A | Open air dump |
| 12 | El Progreso | Yoro | 193 567 | 100 | A | Improved Technical closure |
| 13 | La Ceiba | Atlántida | 207 733 | 130 | A | Open air dump |
| 14 | Choluteca | Choluteca | 159 739 | 99 | A | Open air dump |
| 15 | Comayagua | Comayagua | 155 948 | 75 | A | Sanitary landfill |
| 16 | Quimistán | Santa Bárbara | 52 884 | 40 | B | Open air dump |
| 17 | Omoa | Cortés | 48 495 | 34,29 | B | Open air dump |
| 18 | San Manuel* | Cortés | 58 927 | 30 | B | Open air dump |
| 19 | Santa Cruz | Cortés | 86 590 | 22 | B | Open air dump |
| 20 | El Paraíso | El Paraíso | 45 638 | 25 | B | Open air dump |
| 21 | El Negrito | Yoro | 47 104 | 30 | B | Open air dump |
| 22 | Yoro | Yoro | 91 751 | 50 | B | Open air dump |
| 23 | Trujillo | Colón | 63 622 | 10 | B | Open air dump |
| 24 | La Paz | La Paz | 47 452 | 20 | B | Open air dump |
| 25 | Puerto Cortés | Cortés | 127 968 | 80 | B | Sanitary landfill |
| 26 | Olancho | Yoro | 110 437 | 50 | B | Open air dump |
| 27 | Juticalpa | Olancho | 132 484 | 50 | B | Open air dump |
| 28 | Catacamas | Olancho | 124 599 | 60 | B | Open air dump |
| 29 | Danlí | El Paraíso | 206 922 | 110 | B | Open air dump |
| 30 | Taulabé | Comayagua | 24 930 | 15 | B | Open air dump |
| 31 | Potrerosillos | Cortés | 24 626 | 36 | B | Sanitary landfill |
| 32 | Nacaome | Valle | 59 291 | 53 | C | Open air dump |
| 33 | Trojes | El Paraíso | 50 047 | 8 | C | Open air dump |
| 34 | Gracias | Lempira | 51 635 | 25 | C | Technical closure |
| 35 | Puerto Lempira | Gracias a Dios | 51 702 | 10 | D | Open air dump |
| TOTAL | | | | 5 303 870 | 3 489,95 | |
| Total population of the country | | | | 8 725 111 | | |
| Note: | *These municipalities make up a commonwealth for the administration of the water and waste service; however, all have final disposal sites (dumps) and the company Aguas del Valle, whose headquarters are in the municipality of Villanueva, administratively collects the finances. | | | | | |

Figure A.1 Daily estimate of collected waste: Residential/Urban and Commercial in evaluated municipalities. Sources: Consultation to evaluated municipalities, reviews of AMDC and SPS studies of 2016, studies from CNP+LH 2013

| Age/Edad | Unit/Unidad | Descripción | Description | |
|-----------|-------------|--|--|--|
| Cenozoico | Cuaternario | Qal | Depósitos recientes de aluvión | Recent alluvium deposits |
| | | Qe | Depósitos antiguos de arena, grava, guijarros de terrazas y abanico aluvial. | Older deposits of sand, gravel, terrace deposits and alluvial fans. |
| | | Qb | Coladas de basálto obscuro de olivino, plagioclasa y escoria. | Dark, olivine and plagioclase bearing basalt flows and scoria. |
| | | Grupo Padre Miguel | Padre Miguel Group | |
| | Terciario | Tep | Miembro el Periodista: Sedimentos volcanoclastos de arenisca, grava y limonita . | El Periodista member: Volcanoclastic sediments of sandstone, gravel, and shale. |
| | | Tpm | Secuencia ignimbritas principales de tobas riolíticas, dacíticas y andesíticas de varios colores. Algunas rocas sedimentarias de clastos volcánicos y tobas bien estratificadas. | The principal ignimbrite sequence of multicolored rhyolitic, dacitic, and andesitic tuffs. Includes volcanoclastic sedimentary rocks and stratified tuffs. |
| | | Tpml | Lahares con clásticos de rocas volcánicas terciarias y sedimentos cretácicos. | Lahars containing clasts of Tertiary volcanic and Cretaceous sedimentary rocks. |
| | | Teg | Miembro Cerro Grande: Ignimbritas con cristales de cuarzo y sanidino en una matriz vitrificada de color violeta con fracturación intensa y vertical. | Cerro Grande member: Light purple ignimbrite with quartz and sanidine crystals in a vitreous matrix with vertical and intense fractures. |
| | | | Formación Matagalpa | Matagalpa Formation |
| | | Tm | Coladas máficas de basaltos y andesitas de apfíbulas y feldspato cálcico o plagioclasa de color gris intensamente alterada a clorita, sericita y epidota. | Mafic flows of gray, amphibole, calcic feldspar or plagioclase that has been intensely altered to chlorite, sericite and epidote. |
| | Ti | Intrusivos y diques de composición intermedia. | Intrusives and dikes of intermediate composition. | |
| | | Grupo Valle de Angeles | Valle de Angeles Group | |

| | | | | |
|-----------|-----------|--|--|--|
| Mesozoico | Cretacico | Krc | Formación Río Chiquito: Lutitas , limonitas, areniscas, rosadas y algunas capas de conglomerado de cuarzo. | Río Chiquito Formation: Reddish siltstone, shale and sandstone with beds of quartz conglomerates. |
| | | Kvac | Pequeño afloramiento de caliza gris dentro la formación río chiquito. | Small outcrop of gray limestone within the Río Chiquito Formation. |
| | | Kvn | Formación Villa Nueva: estratos silicásticos de grano grueso conglomerados de cuarzo y clastos de rocas (metamórficas, volcánicas, y calizas) areniscas de color rojo claro hasta café claro y algunas tobas volcánicas. | Villa Nueva Formation: Light red to light brown coarse grained siliclastic strata of quartz and lithic (metamorphic, volcanic and limestone) clast conglomerate, sandstone and minor beds of volcanic tuffs. |
| | | Grupo Honduras | Honduras Group | |
| Juracico | JKhg | Lutitas y areniscas oscuras bien alteradas con algunas rocas volcánicas. | Dark siltstone and sandstone well altered containing some volcanic rocks. | |

Figure A.2 Soil Units Chart Honduras Geology March, 1997, Edition 1.3 1:50,000 Source: Robert D. Rogers, 1993, Mapa Geologico de Honduras, Hoja de Tegucigalpa, Translated into English by R.D. Rogers.

| | | | | | |
|--------------------------|-----|------------------|-----------|--------------|-----------|
| SOIL TEST SUMMARY | | | | Code | LA-F0019 |
| | | | | Version | 2 |
| | | | | Approved: | MAF |
| Elaborated by: | RAF | Elaboration Date | 20-Jan-15 | Last Version | 12-jun-17 |

Project: Sanitary Landfill Lab. Code : L C

| N.º | TESTS PERFORMED | TEST 1 | TEST 2 | TEST 3 | TEST 4 | TEST 5 | TEST 6 |
|-----|---------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1 | Sample Number | 1173 | 1177 | 1169 | 1171 | 1178 | 1176 |
| 2 | Station | Pit N.º 1 | Pit N.º 2 | Pit N.º 3 | Pit N.º 4 | Pit N.º 5 | Pit N.º 6 |
| 3 | Material Type | Existent | Existent | Existent | Existent | Existent | Existent |
| 4 | Date | 16-sep-21 | 16-sep-21 | 16-sep-21 | 16-sep-21 | 16-sep-21 | 16-sep-21 |
| 5 | Depth in Meters | N/A | N/A | N/A | N/A | N/A | N/A |
| 6 | Side | N/A | N/A | N/A | N/A | N/A | N/A |
| 7 | Location or Section | N/A | N/A | N/A | N/A | N/A | N/A |

| N.º | GRANULOMETRY (% SIEVE PASS) | | | | | | |
|-----|------------------------------|-----|-----|-----|-----|-----|-----|
| 9 | Sieve N.º 3" | | | | | | |
| 10 | Sieve N.º 2½" | | | | | | |
| 11 | Sieve N.º 2" | 100 | | | | | |
| 12 | Sieve N.º 1½" | 93 | 100 | | 100 | 100 | |
| 13 | Sieve N.º 1" | 86 | 95 | | 98 | 93 | 100 |
| 14 | Sieve N.º ¾" | 75 | 79 | 100 | 96 | 90 | 98 |
| 15 | Sieve N.º ½" | 67 | 75 | 95 | 89 | 86 | 91 |
| 15 | Sieve: N.º 3/8" | 63 | 72 | 90 | 82 | 84 | 81 |
| 16 | Sieve N.º 4 | 52 | 65 | 66 | 53 | 78 | 43 |
| 17 | Sieve N.º 8 | 43 | 60 | 42 | 30 | 72 | 22 |
| 18 | Sieve N.º 10 | 41 | 58 | 38 | 26 | 70 | 20 |
| 19 | Sieve N.º 40 | 26 | 48 | 20 | 12 | 56 | 12 |
| 20 | Sieve N.º 100 | 20 | 35 | 14 | 9 | 45 | 10 |
| 21 | Sieve N.º 200 | 18 | 30 | 11 | 8 | 41 | 8 |

| | | | | | | | |
|----|---------------------------------------|-----------|-----------|-----------|----------|-----------|-----------|
| 22 | Liquid Limit | 56 | 78 | 37 | 32 | 61 | 40 |
| 23 | Plasticity Index | 25 | 45 | 8 | 6 | 31 | 11 |
| 24 | AASHTO Classification | A-2-7 (0) | A-2-7 (3) | A-2-4 (0) | A-1a (0) | A-7-5 (7) | A-2-6 (0) |
| 25 | Unified Classification | SM | SC | SP-SM | SP-SM | SC | GP-GM |
| 26 | Maximum Density, Lbs./Ft ³ | | | | | | |
| 27 | % of Optimal Humidity | | | | | | |
| 28 | % of Natural Humidity | 12.0 | 4.7 | 9.6 | 8.1 | 10.9 | 8.0 |
| 29 | Humid Density , Kg/m ³ | 1,445.99 | 1,309.95 | 1,674.85 | 1,576.17 | 1,742.33 | 1,640.10 |
| 30 | Dry Density , Kg/m ³ | 1,178.77 | 1,103.65 | 1,493.86 | 1,431.39 | 1,310.87 | 1,482.23 |
| 31 | Specific Gravity with Picnometer | 2.678 | 2.525 | 2.505 | 2.558 | 2.632 | 2.554 |
| 32 | CBR at 90% | | | | | | |
| 33 | CBR at 95% | | | | | | |
| 34 | CBR at 100% | | | | | | |
| 35 | Swelling % | | | | | | |
| 36 | Bulking Factor % | | | | | | |

Observations page 1 of 2

24-sep-21
Date

Approved by

Figure A.4 Soil test summary pits 1-6 and Landfill compression strength of rock specimen summary

| | | | | | |
|---|--|--|--|--------------|-----------|
| SOIL TEST SUMMARY | | | | Code | LA-FO019 |
| | | | | Version | 2 |
| Elaborated by: RAF Elaboration Date: 20-Jan-15 | | | | Approved | MAF |
| | | | | Last Version | 12-jun-17 |

Project: Sanitary Landfill Lab. Code : LC

| N.º | TESTS PERFORMED | TEST 1 | TEST 2 | TEST 3 | TEST 4 | TEST 5 | TEST 6 |
|-----|---------------------|-----------|-----------|-----------|------------|--------|--------|
| 1 | Sample Number | 1172 | 1170 | 1174 | 1175 | | |
| 2 | Station | Pit N.º 7 | Pit N.º 8 | Pit N.º 9 | Pit N.º 10 | | |
| 3 | Material Type | Existent | Existent | Existent | Existent | | |
| 4 | Date | 16-sep-21 | 16-sep-21 | 16-sep-21 | 16-sep-21 | | |
| 5 | Depth in Meters | N/A | N/A | N/A | N/A | | |
| 6 | Side | N/A | N/A | N/A | N/A | | |
| 7 | Location or Section | N/A | N/A | N/A | N/A | | |

| N.º | GRANULOMETRY (% SIEVE PASS) | | | | | |
|-----|------------------------------|-----|-----|-----|-----|--|
| 9 | Sieve N.º 3" | | | | | |
| 10 | Sieve N.º 2½" | | | | | |
| 11 | Sieve N.º 2" | | | | | |
| 12 | Sieve N.º 1½" | | 100 | | | |
| 13 | Sieve N.º 1" | 100 | 82 | 100 | | |
| 14 | Sieve N.º ¾" | 97 | 71 | 93 | 100 | |
| 15 | Sieve N.º ½" | 91 | 49 | 80 | 96 | |
| 16 | Sieve N.º 3/8" | 85 | 39 | 73 | 92 | |
| 17 | Sieve N.º 4 | 58 | 24 | 53 | 67 | |
| 18 | Sieve N.º 8 | 37 | 18 | 38 | 42 | |
| 19 | Sieve N.º 10 | 33 | 17 | 34 | 37 | |
| 20 | Sieve N.º 40 | 16 | 11 | 20 | 19 | |
| 21 | Sieve N.º 100 | 11 | 8 | 15 | 15 | |
| 21 | Sieve N.º 200 | 10 | 7 | 13 | 13 | |

| | | | | | | | |
|----|----------------------------------|----------|-----------|-----------|-----------|--|--|
| 22 | Liquid Limit | 31 | 43 | 43 | 35 | | |
| 23 | Plasticity Index | 4 | 9 | 15 | 8 | | |
| 24 | AASHTO Classification | A-1a (0) | A-2-5 (0) | A-2-7 (0) | A-2-4 (0) | | |
| 25 | Unified Classification | SP-SM | GP-GM | SM | SM | | |
| 26 | Maximum Density, Lbs./Ft ³ | | | | | | |
| 27 | % of Optimal Humidity | | | | | | |
| 28 | % of Natural Humidity | 10.9 | 9.3 | 10.5 | 9.4 | | |
| 29 | Humid Density , Kg/m³ | 1,518.61 | 1,478.57 | 1,433.54 | 1,590.21 | | |
| 30 | Dry Density , Kg/m³ | 1,336.89 | 1,259.19 | 1,247.44 | 1,417.18 | | |
| 31 | Specific Gravity with Picnometer | 2.513 | 2.493 | 2.565 | 2.556 | | |
| 32 | CBR at 90% | | | | | | |
| 33 | CBR at 95% | | | | | | |
| 34 | CBR at 100% | | | | | | |
| 35 | Swelling % | | | | | | |
| 36 | Bulking Factor % | | | | | | |

Observations page 2 of 2

24-sep-21 Date Approved by:

Figure A.4 Soil test summary pits 7-10 and Landfill compression strength of rock specimen summary

| | | | | | | | |
|--------------------|--|-------------------------------|--|---|--|--|--|
| PROJECT | | CREMATORIO MUNICIPAL | | LOCATION | | CENTRAL DISTRICT | |
| DATE | | 10 NOVEMBER 2017 | | PERFORATED / SUPERVISED / APPROVED | | ENRI PEREZ / ING. BURIAS / GEOLOGIST JOSE ARCE | |
| WATER TABLE | | 10 NOVEMBER 2017 | | REPORTED BY | | JAD | |
| COORDINATES | | 16P 14 8758.07N / 87 137.827W | | LAST VERSION | | 1.00-01 | |

| | | | | | |
|---------------------------|-----------|------------------------------|------------|-----------------------------|------------|
| Borehole Lithology | | NO. OF SAMPLES COLLECTED: 13 | | NO. OF SAMPLES ANALYZED: 13 | |
| DEPTH (M) | LITHOLOGY | CORRECTION | CORRECTION | CORRECTION | CORRECTION |
| | | | | | |
| 0.0 | | | | | |
| 0.5 | | | | | |
| 1.0 | | | | | |
| 1.5 | | | | | |
| 2.0 | | | | | |
| 2.5 | | | | | |
| 3.0 | | | | | |
| 3.5 | | | | | |
| 4.0 | | | | | |
| 4.5 | | | | | |
| 5.0 | | | | | |
| 5.5 | | | | | |
| 6.0 | | | | | |
| 6.5 | | | | | |
| 7.0 | | | | | |
| 7.5 | | | | | |
| 8.0 | | | | | |
| 8.5 | | | | | |
| 9.0 | | | | | |

| | |
|--|--|
| BOREHOLE #1 | |
|  | |

| | |
|---------------------|---|
| OBSERVATIONS | LOSS OF PERFORATION WATER AT 3.0 METERS |
|---------------------|---|

| | | | | | | | | | |
|--------------|--|----------------------|--|----------------------------------|--|--|--|--------------|--|
| PROJECT | | CREMATORIO MUNICIPAL | | LOCATION | | CENTRAL DISTRICT | | SITE CAMP ID | |
| DATE | | DRILLING RIG | | IONOSPHERE #2 | | PERFORATED / SUPERVISED / APPROVED | | MEXICO | |
| WATER TABLE | | COORDINATES | | 146° 45' 25.775" W / 21° 0' 0" N | | EDIL PEREZ / ING. BORJAS / GEOLOGIST OSCAR ACE | | MAD | |
| BOREHOLE ID | | BOREHOLE #2 | | BOREHOLE #2 | | BOREHOLE #2 | | BOREHOLE #2 | |
| DEPTH (M) | | DEPTH (M) | | DEPTH (M) | | DEPTH (M) | | DEPTH (M) | |
| 0.0 | | 0.0 | | 0.0 | | 0.0 | | 0.0 | |
| 1.0 | | 1.0 | | 1.0 | | 1.0 | | 1.0 | |
| 2.0 | | 2.0 | | 2.0 | | 2.0 | | 2.0 | |
| 3.0 | | 3.0 | | 3.0 | | 3.0 | | 3.0 | |
| 4.0 | | 4.0 | | 4.0 | | 4.0 | | 4.0 | |
| 5.0 | | 5.0 | | 5.0 | | 5.0 | | 5.0 | |
| 6.0 | | 6.0 | | 6.0 | | 6.0 | | 6.0 | |
| 7.0 | | 7.0 | | 7.0 | | 7.0 | | 7.0 | |
| 8.0 | | 8.0 | | 8.0 | | 8.0 | | 8.0 | |
| 9.0 | | 9.0 | | 9.0 | | 9.0 | | 9.0 | |
| 10.0 | | 10.0 | | 10.0 | | 10.0 | | 10.0 | |
| 11.0 | | 11.0 | | 11.0 | | 11.0 | | 11.0 | |
| 12.0 | | 12.0 | | 12.0 | | 12.0 | | 12.0 | |
| 13.0 | | 13.0 | | 13.0 | | 13.0 | | 13.0 | |
| 14.0 | | 14.0 | | 14.0 | | 14.0 | | 14.0 | |
| 15.0 | | 15.0 | | 15.0 | | 15.0 | | 15.0 | |
| 16.0 | | 16.0 | | 16.0 | | 16.0 | | 16.0 | |
| 17.0 | | 17.0 | | 17.0 | | 17.0 | | 17.0 | |
| 18.0 | | 18.0 | | 18.0 | | 18.0 | | 18.0 | |
| 19.0 | | 19.0 | | 19.0 | | 19.0 | | 19.0 | |
| 20.0 | | 20.0 | | 20.0 | | 20.0 | | 20.0 | |
| 21.0 | | 21.0 | | 21.0 | | 21.0 | | 21.0 | |
| 22.0 | | 22.0 | | 22.0 | | 22.0 | | 22.0 | |
| 23.0 | | 23.0 | | 23.0 | | 23.0 | | 23.0 | |
| 24.0 | | 24.0 | | 24.0 | | 24.0 | | 24.0 | |
| 25.0 | | 25.0 | | 25.0 | | 25.0 | | 25.0 | |
| 26.0 | | 26.0 | | 26.0 | | 26.0 | | 26.0 | |
| 27.0 | | 27.0 | | 27.0 | | 27.0 | | 27.0 | |
| 28.0 | | 28.0 | | 28.0 | | 28.0 | | 28.0 | |
| 29.0 | | 29.0 | | 29.0 | | 29.0 | | 29.0 | |
| 30.0 | | 30.0 | | 30.0 | | 30.0 | | 30.0 | |
| 31.0 | | 31.0 | | 31.0 | | 31.0 | | 31.0 | |
| 32.0 | | 32.0 | | 32.0 | | 32.0 | | 32.0 | |
| 33.0 | | 33.0 | | 33.0 | | 33.0 | | 33.0 | |
| 34.0 | | 34.0 | | 34.0 | | 34.0 | | 34.0 | |
| 35.0 | | 35.0 | | 35.0 | | 35.0 | | 35.0 | |
| 36.0 | | 36.0 | | 36.0 | | 36.0 | | 36.0 | |
| 37.0 | | 37.0 | | 37.0 | | 37.0 | | 37.0 | |
| 38.0 | | 38.0 | | 38.0 | | 38.0 | | 38.0 | |
| 39.0 | | 39.0 | | 39.0 | | 39.0 | | 39.0 | |
| 40.0 | | 40.0 | | 40.0 | | 40.0 | | 40.0 | |
| 41.0 | | 41.0 | | 41.0 | | 41.0 | | 41.0 | |
| 42.0 | | 42.0 | | 42.0 | | 42.0 | | 42.0 | |
| 43.0 | | 43.0 | | 43.0 | | 43.0 | | 43.0 | |
| 44.0 | | 44.0 | | 44.0 | | 44.0 | | 44.0 | |
| 45.0 | | 45.0 | | 45.0 | | 45.0 | | 45.0 | |
| 46.0 | | 46.0 | | 46.0 | | 46.0 | | 46.0 | |
| 47.0 | | 47.0 | | 47.0 | | 47.0 | | 47.0 | |
| 48.0 | | 48.0 | | 48.0 | | 48.0 | | 48.0 | |
| 49.0 | | 49.0 | | 49.0 | | 49.0 | | 49.0 | |
| 50.0 | | 50.0 | | 50.0 | | 50.0 | | 50.0 | |
| 51.0 | | 51.0 | | 51.0 | | 51.0 | | 51.0 | |
| 52.0 | | 52.0 | | 52.0 | | 52.0 | | 52.0 | |
| 53.0 | | 53.0 | | 53.0 | | 53.0 | | 53.0 | |
| 54.0 | | 54.0 | | 54.0 | | 54.0 | | 54.0 | |
| 55.0 | | 55.0 | | 55.0 | | 55.0 | | 55.0 | |
| 56.0 | | 56.0 | | 56.0 | | 56.0 | | 56.0 | |
| 57.0 | | 57.0 | | 57.0 | | 57.0 | | 57.0 | |
| 58.0 | | 58.0 | | 58.0 | | 58.0 | | 58.0 | |
| 59.0 | | 59.0 | | 59.0 | | 59.0 | | 59.0 | |
| 60.0 | | 60.0 | | 60.0 | | 60.0 | | 60.0 | |
| 61.0 | | 61.0 | | 61.0 | | 61.0 | | 61.0 | |
| 62.0 | | 62.0 | | 62.0 | | 62.0 | | 62.0 | |
| 63.0 | | 63.0 | | 63.0 | | 63.0 | | 63.0 | |
| 64.0 | | 64.0 | | 64.0 | | 64.0 | | 64.0 | |
| 65.0 | | 65.0 | | 65.0 | | 65.0 | | 65.0 | |
| 66.0 | | 66.0 | | 66.0 | | 66.0 | | 66.0 | |
| 67.0 | | 67.0 | | 67.0 | | 67.0 | | 67.0 | |
| 68.0 | | 68.0 | | 68.0 | | 68.0 | | 68.0 | |
| 69.0 | | 69.0 | | 69.0 | | 69.0 | | 69.0 | |
| 70.0 | | 70.0 | | 70.0 | | 70.0 | | 70.0 | |
| 71.0 | | 71.0 | | 71.0 | | 71.0 | | 71.0 | |
| 72.0 | | 72.0 | | 72.0 | | 72.0 | | 72.0 | |
| 73.0 | | 73.0 | | 73.0 | | 73.0 | | 73.0 | |
| 74.0 | | 74.0 | | 74.0 | | 74.0 | | 74.0 | |
| 75.0 | | 75.0 | | 75.0 | | 75.0 | | 75.0 | |
| 76.0 | | 76.0 | | 76.0 | | 76.0 | | 76.0 | |
| 77.0 | | 77.0 | | 77.0 | | 77.0 | | 77.0 | |
| 78.0 | | 78.0 | | 78.0 | | 78.0 | | 78.0 | |
| 79.0 | | 79.0 | | 79.0 | | 79.0 | | 79.0 | |
| 80.0 | | 80.0 | | 80.0 | | 80.0 | | 80.0 | |
| 81.0 | | 81.0 | | 81.0 | | 81.0 | | 81.0 | |
| 82.0 | | 82.0 | | 82.0 | | 82.0 | | 82.0 | |
| 83.0 | | 83.0 | | 83.0 | | 83.0 | | 83.0 | |
| 84.0 | | 84.0 | | 84.0 | | 84.0 | | 84.0 | |
| 85.0 | | 85.0 | | 85.0 | | 85.0 | | 85.0 | |
| 86.0 | | 86.0 | | 86.0 | | 86.0 | | 86.0 | |
| 87.0 | | 87.0 | | 87.0 | | 87.0 | | 87.0 | |
| 88.0 | | 88.0 | | 88.0 | | 88.0 | | 88.0 | |
| 89.0 | | 89.0 | | 89.0 | | 89.0 | | 89.0 | |
| 90.0 | | 90.0 | | 90.0 | | 90.0 | | 90.0 | |
| 91.0 | | 91.0 | | 91.0 | | 91.0 | | 91.0 | |
| 92.0 | | 92.0 | | 92.0 | | 92.0 | | 92.0 | |
| 93.0 | | 93.0 | | 93.0 | | 93.0 | | 93.0 | |
| 94.0 | | 94.0 | | 94.0 | | 94.0 | | 94.0 | |
| 95.0 | | 95.0 | | 95.0 | | 95.0 | | 95.0 | |
| 96.0 | | 96.0 | | 96.0 | | 96.0 | | 96.0 | |
| 97.0 | | 97.0 | | 97.0 | | 97.0 | | 97.0 | |
| 98.0 | | 98.0 | | 98.0 | | 98.0 | | 98.0 | |
| 99.0 | | 99.0 | | 99.0 | | 99.0 | | 99.0 | |
| 100.0 | | 100.0 | | 100.0 | | 100.0 | | 100.0 | |
| OBSERVATIONS | | OBSERVATIONS | | OBSERVATIONS | | OBSERVATIONS | | OBSERVATIONS | |

| | | | | | | | | | | | |
|-------------|--|----------------------|--|------------------------------------|--|------------------------------------|--|--|--|--------|--|
| PROJECT | | CREMATORIO MUNICIPAL | | LOCATION | | CENTRAL DISTRICT | | SERIAL# | | 20 | |
| DATE | | DRILLING RIG | | LONCYEAR 42 | | PERFORATED / SUPERVISED / APPROVED | | EDIL PEREZ / ING. BURNAS / GEOLOGIST JOSE ARCE | | 202001 | |
| WATER TABLE | | COORDINATES | | 16° 11' 0" S 77° W / 87 15 33.45 W | | APPROVED BY | | JAD | | 2020 | |

| DEPTH (M) | LITHOLOGY | SPT | MEASURED BOREHOLE PARAMETERS WITH SPT TESTING | | | PERFORATION RESULTS (NOISE) | BOB | DEPTH (M) | BOREHOLE # 2 |
|-----------|-----------|-----|---|-------------|------------|-----------------------------|-----|-----------|--------------|
| | | | N (SPT) | Q (kgf/cm²) | f (kgf/cm) | | | | |
| 0.0 | GRAVELL | | | | | | | | |
| 0.5 | GRAVELL | | | | | | | | |
| 1.0 | GRAVELL | | | | | | | | |
| 1.5 | GRAVELL | | | | | | | | |
| 2.0 | GRAVELL | | | | | | | | |
| 2.5 | GRAVELL | | | | | | | | |
| 3.0 | GRAVELL | | | | | | | | |
| 3.5 | GRAVELL | | | | | | | | |
| 4.0 | GRAVELL | | | | | | | | |
| 4.5 | GRAVELL | | | | | | | | |
| 5.0 | GRAVELL | | | | | | | | |
| 5.5 | GRAVELL | | | | | | | | |
| 6.0 | GRAVELL | | | | | | | | |
| 6.5 | GRAVELL | | | | | | | | |
| 7.0 | GRAVELL | | | | | | | | |
| 7.5 | GRAVELL | | | | | | | | |
| 8.0 | GRAVELL | | | | | | | | |
| 8.5 | GRAVELL | | | | | | | | |
| 9.0 | GRAVELL | | | | | | | | |



| | |
|--------------|---|
| OBSERVATIONS | LOSS OF PERFORATION WATER AT 3.0 METERS |
|--------------|---|

| PROJECT | | CREMATORIO MUNICIPAL | | LOCATION | | CENTRAL DISTRICT | | CELL: CA-1P-01 | |
|---|-----------|-------------------------------|-----------|--|-----------|------------------------------------|-----------|----------------|-----------|
| DATE | | DRILLING RIG | | LOG NUMBER | | PERFORATED / SUPERVISED / APPROVED | | PERSON | |
| WATER TABLE | | COORDINATES | | EQUIPMENT | | APPROVED BY | | DATE | |
| | | 10615748.47 | | EDIL PEREZ / ING. BORJAS / GEOLOGIST JOSE ARCE | | JAD | | JUN-21 | |
| | | 10P XXXXXXX N E / XXXXXXX N N | | | | LAB VERBOS | | | |
| <p>MEASURED BOREHOLE PARAMETERS WITH SPT TESTING</p> <p>BOREHOLE # 3</p> | | | | | | | | | |
| MEASUREMENT | DEPTH (M) | DEPTH (FT) | DEPTH (M) | DEPTH (FT) | DEPTH (M) | DEPTH (FT) | DEPTH (M) | DEPTH (FT) | DEPTH (M) |
| 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.0 | 0.95 | 3.12 | 0.95 | 3.12 | 0.95 | 3.12 | 0.95 | 3.12 | 0.95 |
| 2.0 | 1.90 | 6.24 | 1.90 | 6.24 | 1.90 | 6.24 | 1.90 | 6.24 | 1.90 |
| 3.0 | 2.85 | 9.36 | 2.85 | 9.36 | 2.85 | 9.36 | 2.85 | 9.36 | 2.85 |
| 4.0 | 3.80 | 12.48 | 3.80 | 12.48 | 3.80 | 12.48 | 3.80 | 12.48 | 3.80 |
| 5.0 | 4.75 | 15.60 | 4.75 | 15.60 | 4.75 | 15.60 | 4.75 | 15.60 | 4.75 |
| 6.0 | 5.70 | 18.72 | 5.70 | 18.72 | 5.70 | 18.72 | 5.70 | 18.72 | 5.70 |
| 7.0 | 6.65 | 21.84 | 6.65 | 21.84 | 6.65 | 21.84 | 6.65 | 21.84 | 6.65 |
| 8.0 | 7.60 | 24.96 | 7.60 | 24.96 | 7.60 | 24.96 | 7.60 | 24.96 | 7.60 |
| 9.0 | 8.55 | 28.08 | 8.55 | 28.08 | 8.55 | 28.08 | 8.55 | 28.08 | 8.55 |
| 10.0 | 9.50 | 31.20 | 9.50 | 31.20 | 9.50 | 31.20 | 9.50 | 31.20 | 9.50 |
| 11.0 | 10.45 | 34.32 | 10.45 | 34.32 | 10.45 | 34.32 | 10.45 | 34.32 | 10.45 |
| 12.0 | 11.40 | 37.44 | 11.40 | 37.44 | 11.40 | 37.44 | 11.40 | 37.44 | 11.40 |
| 13.0 | 12.35 | 40.56 | 12.35 | 40.56 | 12.35 | 40.56 | 12.35 | 40.56 | 12.35 |
| 14.0 | 13.30 | 43.68 | 13.30 | 43.68 | 13.30 | 43.68 | 13.30 | 43.68 | 13.30 |
| 15.0 | 14.25 | 46.80 | 14.25 | 46.80 | 14.25 | 46.80 | 14.25 | 46.80 | 14.25 |
| 16.0 | 15.20 | 49.92 | 15.20 | 49.92 | 15.20 | 49.92 | 15.20 | 49.92 | 15.20 |
| 17.0 | 16.15 | 53.04 | 16.15 | 53.04 | 16.15 | 53.04 | 16.15 | 53.04 | 16.15 |
| 18.0 | 17.10 | 56.16 | 17.10 | 56.16 | 17.10 | 56.16 | 17.10 | 56.16 | 17.10 |
| 19.0 | 18.05 | 59.28 | 18.05 | 59.28 | 18.05 | 59.28 | 18.05 | 59.28 | 18.05 |
| 20.0 | 19.00 | 62.40 | 19.00 | 62.40 | 19.00 | 62.40 | 19.00 | 62.40 | 19.00 |
| 21.0 | 20.00 | 65.60 | 20.00 | 65.60 | 20.00 | 65.60 | 20.00 | 65.60 | 20.00 |
| 22.0 | 21.00 | 68.80 | 21.00 | 68.80 | 21.00 | 68.80 | 21.00 | 68.80 | 21.00 |
| 23.0 | 22.00 | 72.00 | 22.00 | 72.00 | 22.00 | 72.00 | 22.00 | 72.00 | 22.00 |
| 24.0 | 23.00 | 75.20 | 23.00 | 75.20 | 23.00 | 75.20 | 23.00 | 75.20 | 23.00 |
| 25.0 | 24.00 | 78.40 | 24.00 | 78.40 | 24.00 | 78.40 | 24.00 | 78.40 | 24.00 |
| 26.0 | 25.00 | 81.60 | 25.00 | 81.60 | 25.00 | 81.60 | 25.00 | 81.60 | 25.00 |
| 27.0 | 26.00 | 84.80 | 26.00 | 84.80 | 26.00 | 84.80 | 26.00 | 84.80 | 26.00 |
| 28.0 | 27.00 | 88.00 | 27.00 | 88.00 | 27.00 | 88.00 | 27.00 | 88.00 | 27.00 |
| 29.0 | 28.00 | 91.20 | 28.00 | 91.20 | 28.00 | 91.20 | 28.00 | 91.20 | 28.00 |
| 30.0 | 29.00 | 94.40 | 29.00 | 94.40 | 29.00 | 94.40 | 29.00 | 94.40 | 29.00 |
| 31.0 | 30.00 | 97.60 | 30.00 | 97.60 | 30.00 | 97.60 | 30.00 | 97.60 | 30.00 |
| 32.0 | 31.00 | 100.80 | 31.00 | 100.80 | 31.00 | 100.80 | 31.00 | 100.80 | 31.00 |
| 33.0 | 32.00 | 104.00 | 32.00 | 104.00 | 32.00 | 104.00 | 32.00 | 104.00 | 32.00 |
| 34.0 | 33.00 | 107.20 | 33.00 | 107.20 | 33.00 | 107.20 | 33.00 | 107.20 | 33.00 |
| 35.0 | 34.00 | 110.40 | 34.00 | 110.40 | 34.00 | 110.40 | 34.00 | 110.40 | 34.00 |
| 36.0 | 35.00 | 113.60 | 35.00 | 113.60 | 35.00 | 113.60 | 35.00 | 113.60 | 35.00 |
| 37.0 | 36.00 | 116.80 | 36.00 | 116.80 | 36.00 | 116.80 | 36.00 | 116.80 | 36.00 |
| 38.0 | 37.00 | 120.00 | 37.00 | 120.00 | 37.00 | 120.00 | 37.00 | 120.00 | 37.00 |
| 39.0 | 38.00 | 123.20 | 38.00 | 123.20 | 38.00 | 123.20 | 38.00 | 123.20 | 38.00 |
| 40.0 | 39.00 | 126.40 | 39.00 | 126.40 | 39.00 | 126.40 | 39.00 | 126.40 | 39.00 |
| 41.0 | 40.00 | 129.60 | 40.00 | 129.60 | 40.00 | 129.60 | 40.00 | 129.60 | 40.00 |
| 42.0 | 41.00 | 132.80 | 41.00 | 132.80 | 41.00 | 132.80 | 41.00 | 132.80 | 41.00 |
| 43.0 | 42.00 | 136.00 | 42.00 | 136.00 | 42.00 | 136.00 | 42.00 | 136.00 | 42.00 |
| 44.0 | 43.00 | 139.20 | 43.00 | 139.20 | 43.00 | 139.20 | 43.00 | 139.20 | 43.00 |
| 45.0 | 44.00 | 142.40 | 44.00 | 142.40 | 44.00 | 142.40 | 44.00 | 142.40 | 44.00 |
| 46.0 | 45.00 | 145.60 | 45.00 | 145.60 | 45.00 | 145.60 | 45.00 | 145.60 | 45.00 |
| 47.0 | 46.00 | 148.80 | 46.00 | 148.80 | 46.00 | 148.80 | 46.00 | 148.80 | 46.00 |
| 48.0 | 47.00 | 152.00 | 47.00 | 152.00 | 47.00 | 152.00 | 47.00 | 152.00 | 47.00 |
| 49.0 | 48.00 | 155.20 | 48.00 | 155.20 | 48.00 | 155.20 | 48.00 | 155.20 | 48.00 |
| 50.0 | 49.00 | 158.40 | 49.00 | 158.40 | 49.00 | 158.40 | 49.00 | 158.40 | 49.00 |
| 51.0 | 50.00 | 161.60 | 50.00 | 161.60 | 50.00 | 161.60 | 50.00 | 161.60 | 50.00 |
| 52.0 | 51.00 | 164.80 | 51.00 | 164.80 | 51.00 | 164.80 | 51.00 | 164.80 | 51.00 |
| 53.0 | 52.00 | 168.00 | 52.00 | 168.00 | 52.00 | 168.00 | 52.00 | 168.00 | 52.00 |
| 54.0 | 53.00 | 171.20 | 53.00 | 171.20 | 53.00 | 171.20 | 53.00 | 171.20 | 53.00 |
| 55.0 | 54.00 | 174.40 | 54.00 | 174.40 | 54.00 | 174.40 | 54.00 | 174.40 | 54.00 |
| 56.0 | 55.00 | 177.60 | 55.00 | 177.60 | 55.00 | 177.60 | 55.00 | 177.60 | 55.00 |
| 57.0 | 56.00 | 180.80 | 56.00 | 180.80 | 56.00 | 180.80 | 56.00 | 180.80 | 56.00 |
| 58.0 | 57.00 | 184.00 | 57.00 | 184.00 | 57.00 | 184.00 | 57.00 | 184.00 | 57.00 |
| 59.0 | 58.00 | 187.20 | 58.00 | 187.20 | 58.00 | 187.20 | 58.00 | 187.20 | 58.00 |
| 60.0 | 59.00 | 190.40 | 59.00 | 190.40 | 59.00 | 190.40 | 59.00 | 190.40 | 59.00 |
| 61.0 | 60.00 | 193.60 | 60.00 | 193.60 | 60.00 | 193.60 | 60.00 | 193.60 | 60.00 |
| 62.0 | 61.00 | 196.80 | 61.00 | 196.80 | 61.00 | 196.80 | 61.00 | 196.80 | 61.00 |
| 63.0 | 62.00 | 200.00 | 62.00 | 200.00 | 62.00 | 200.00 | 62.00 | 200.00 | 62.00 |
| 64.0 | 63.00 | 203.20 | 63.00 | 203.20 | 63.00 | 203.20 | 63.00 | 203.20 | 63.00 |
| 65.0 | 64.00 | 206.40 | 64.00 | 206.40 | 64.00 | 206.40 | 64.00 | 206.40 | 64.00 |
| 66.0 | 65.00 | 209.60 | 65.00 | 209.60 | 65.00 | 209.60 | 65.00 | 209.60 | 65.00 |
| 67.0 | 66.00 | 212.80 | 66.00 | 212.80 | 66.00 | 212.80 | 66.00 | 212.80 | 66.00 |
| 68.0 | 67.00 | 216.00 | 67.00 | 216.00 | 67.00 | 216.00 | 67.00 | 216.00 | 67.00 |
| 69.0 | 68.00 | 219.20 | 68.00 | 219.20 | 68.00 | 219.20 | 68.00 | 219.20 | 68.00 |
| 70.0 | 69.00 | 222.40 | 69.00 | 222.40 | 69.00 | 222.40 | 69.00 | 222.40 | 69.00 |
| 71.0 | 70.00 | 225.60 | 70.00 | 225.60 | 70.00 | 225.60 | 70.00 | 225.60 | 70.00 |
| 72.0 | 71.00 | 228.80 | 71.00 | 228.80 | 71.00 | 228.80 | 71.00 | 228.80 | 71.00 |
| 73.0 | 72.00 | 232.00 | 72.00 | 232.00 | 72.00 | 232.00 | 72.00 | 232.00 | 72.00 |
| 74.0 | 73.00 | 235.20 | 73.00 | 235.20 | 73.00 | 235.20 | 73.00 | 235.20 | 73.00 |
| 75.0 | 74.00 | 238.40 | 74.00 | 238.40 | 74.00 | 238.40 | 74.00 | 238.40 | 74.00 |
| 76.0 | 75.00 | 241.60 | 75.00 | 241.60 | 75.00 | 241.60 | 75.00 | 241.60 | 75.00 |
| 77.0 | 76.00 | 244.80 | 76.00 | 244.80 | 76.00 | 244.80 | 76.00 | 244.80 | 76.00 |
| 78.0 | 77.00 | 248.00 | 77.00 | 248.00 | 77.00 | 248.00 | 77.00 | 248.00 | 77.00 |
| 79.0 | 78.00 | 251.20 | 78.00 | 251.20 | 78.00 | 251.20 | 78.00 | 251.20 | 78.00 |
| 80.0 | 79.00 | 254.40 | 79.00 | 254.40 | 79.00 | 254.40 | 79.00 | 254.40 | 79.00 |
| 81.0 | 80.00 | 257.60 | 80.00 | 257.60 | 80.00 | 257.60 | 80.00 | 257.60 | 80.00 |
| 82.0 | 81.00 | 260.80 | 81.00 | 260.80 | 81.00 | 260.80 | 81.00 | 260.80 | 81.00 |
| 83.0 | 82.00 | 264.00 | 82.00 | 264.00 | 82.00 | 264.00 | 82.00 | 264.00 | 82.00 |
| 84.0 | 83.00 | 267.20 | 83.00 | 267.20 | 83.00 | 267.20 | 83.00 | 267.20 | 83.00 |
| 85.0 | 84.00 | 270.40 | 84.00 | 270.40 | 84.00 | 270.40 | 84.00 | 270.40 | 84.00 |
| 86.0 | 85.00 | 273.60 | 85.00 | 273.60 | 85.00 | 273.60 | 85.00 | 273.60 | 85.00 |
| 87.0 | 86.00 | 276.80 | 86.00 | 276.80 | 86.00 | 276.80 | 86.00 | 276.80 | 86.00 |
| 88.0 | 87.00 | 280.00 | 87.00 | 280.00 | 87.00 | 280.00 | 87.00 | 280.00 | 87.00 |
| 89.0 | 88.00 | 283.20 | 88.00 | 283.20 | 88.00 | 283.20 | 88.00 | 283.20 | 88.00 |
| 90.0 | 89.00 | 286.40 | 89.00 | 286.40 | 89.00 | 286.40 | 89.00 | 286.40 | 89.00 |
| 91.0 | 90.00 | 289.60 | 90.00 | 289.60 | 90.00 | 289.60 | 90.00 | 289.60 | 90.00 |
| 92.0 | 91.00 | 292.80 | 91.00 | 292.80 | 91.00 | 292.80 | 91.00 | 292.80 | 91.00 |
| 93.0 | 92.00 | 296.00 | 92.00 | 296.00 | 92.00 | 296.00 | 92.00 | 296.00 | 92.00 |
| 94.0 | 93.00 | 299.20 | 93.00 | 299.20 | 93.00 | 299.20 | 93.00 | 299.20 | 93.00 |
| 95.0 | 94.00 | 302.40 | 94.00 | 302.40 | 94.00 | 302.40 | 94.00 | 302.40 | 94.00 |
| 96.0 | 95.00 | 305.60 | 95.00 | 305.60 | 95.00 | 305.60 | 95.00 | 305.60 | 95.00 |
| 97.0 | 96.00 | 308.80 | 96.00 | 308.80 | 96.00 | 308.80 | 96.00 | 308.80 | 96.00 |
| 98.0 | 97.00 | 312.00 | 97.00 | 312.00 | 97.00 | 312.00 | 97.00 | 312.00 | 97.00 |
| 99.0 | 98.00 | 315.20 | 98.00 | 315.20 | 98.00 | 315.20 | 98.00 | 315.20 | 98.00 |
| 100.0 | 99.00 | 318.40 | | | | | | | |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|------|---|------|----------------------|---------|----------|------|-------------|------|-------|------|------|-------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------------|---|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|--|--|---------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|---------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|---|--|------|------|--------|------|------|---------|----------|------|-------------|-----|-------|------|------|-------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|---|--|
| PROJECT CREMATARIO MUNICIPAL | | LOCATION CENTRAL DISTRICT | | D.S. 0097-01 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| DATE DRILLING RIG LONGYEAR 42 | | DRILLER EDI PEREZ / INC. BORJAS / GEOLOGIST JOE ARCE | | PROJ. NO. 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| WATER TABLE | | COORDINATES 87° 16' 02.02" N / 87° 13' 11.82" W | | PROJ. NO. JAD | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| MEASURED BOREHOLE PARAMETERS (MTH-8PT TEST) | | | | BOREHOLE # 4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| <table border="1" style="width:100%; border-collapse: collapse;"> <tr> <td>DEPTH (M)</td> <td>0.00</td> <td>0.30</td> <td>0.60</td> <td>0.90</td> <td>1.20</td> <td>1.50</td> <td>1.80</td> <td>2.10</td> <td>2.40</td> <td>2.70</td> <td>3.00</td> <td>3.30</td> <td>3.60</td> <td>3.90</td> <td>4.20</td> <td>4.50</td> <td>4.80</td> <td>5.10</td> <td>5.40</td> <td>5.70</td> <td>6.00</td> <td>6.30</td> <td>6.60</td> <td>6.90</td> <td>7.20</td> <td>7.50</td> <td>7.80</td> <td>8.10</td> <td>8.40</td> <td>8.70</td> <td>9.00</td> </tr> <tr> <td>DEPTH (FT)</td> <td>0</td> <td>1</td> <td>2</td> <td>3</td> <td>4</td> <td>5</td> <td>6</td> <td>7</td> <td>8</td> <td>9</td> <td>10</td> <td>11</td> <td>12</td> <td>13</td> <td>14</td> <td>15</td> <td>16</td> <td>17</td> <td>18</td> <td>19</td> <td>20</td> <td>21</td> <td>22</td> <td>23</td> <td>24</td> <td>25</td> <td>26</td> <td>27</td> <td>28</td> <td>29</td> <td>30</td> </tr> </table> | | DEPTH (M) | 0.00 | 0.30 | 0.60 | 0.90 | 1.20 | 1.50 | 1.80 | 2.10 | 2.40 | 2.70 | 3.00 | 3.30 | 3.60 | 3.90 | 4.20 | 4.50 | 4.80 | 5.10 | 5.40 | 5.70 | 6.00 | 6.30 | 6.60 | 6.90 | 7.20 | 7.50 | 7.80 | 8.10 | 8.40 | 8.70 | 9.00 | DEPTH (FT) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | <table border="1" style="width:100%; border-collapse: collapse;"> <tr> <td>DIAMETER (CM)</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> <td>10.0</td> </tr> <tr> <td>DIAMETER (IN)</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> <td>0.39</td> </tr> </table> | | DIAMETER (CM) | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | DIAMETER (IN) | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | <table border="1" style="width:100%; border-collapse: collapse;"> <tr> <td>ROCK</td> <td>SOIL</td> <td>GRAVEL</td> <td>CLAY</td> <td>SAND</td> <td>COBBLES</td> <td>CONCRETE</td> <td>PIPE</td> <td>REINFORCING</td> <td>BAR</td> <td>STEEL</td> <td>WIRE</td> <td>ROPE</td> <td>OTHER</td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </table> | | ROCK | SOIL | GRAVEL | CLAY | SAND | COBBLES | CONCRETE | PIPE | REINFORCING | BAR | STEEL | WIRE | ROPE | OTHER | | | | | | | | | | | | | | |  | |
| DEPTH (M) | 0.00 | 0.30 | 0.60 | 0.90 | 1.20 | 1.50 | 1.80 | 2.10 | 2.40 | 2.70 | 3.00 | 3.30 | 3.60 | 3.90 | 4.20 | 4.50 | 4.80 | 5.10 | 5.40 | 5.70 | 6.00 | 6.30 | 6.60 | 6.90 | 7.20 | 7.50 | 7.80 | 8.10 | 8.40 | 8.70 | 9.00 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| DEPTH (FT) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| DIAMETER (CM) | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| DIAMETER (IN) | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| ROCK | SOIL | GRAVEL | CLAY | SAND | COBBLES | CONCRETE | PIPE | REINFORCING | BAR | STEEL | WIRE | ROPE | OTHER | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| OBSERVATIONS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

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|--------------------------------------|--|---|--|---------------------|--|
| PROJECT CREMATOPIO MUNICIPAL | | LOCATION CENTRAL DISTRICT | | SHA DRAWING | |
| DATE DRILLING RIG LOWEYEAR 22 | | COORDINATES | | SECTION 3 | |
| WATER TABLE | | INVESTIGATED / SUPERVISED / APPROVED DON PEREZ / ING. BORJAS / GEO. DO ST. JOSE ARCE | | DRAWN BY JMD | |
| COORDINATES | | 16° 10' 8.58" N / 81° 13' 11.72" W | | DATE 2022 | |

| | | | | | |
|---------------------------|-------------------|---|-------------------|---------------------|-------------------|
| Geological Profile | | MEASURED BOREHOLE PARAMETERS (SPT TESTING) | | BOREHOLE # 5 | |
| DEPTH (M) | DEPTH (FT) | DEPTH (M) | DEPTH (FT) | DEPTH (M) | DEPTH (FT) |
| | | | | | |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.0 | 3.3 | 1.0 | 3.3 | 1.0 | 3.3 |
| 2.0 | 6.6 | 2.0 | 6.6 | 2.0 | 6.6 |
| 3.0 | 9.8 | 3.0 | 9.8 | 3.0 | 9.8 |
| 4.0 | 13.1 | 4.0 | 13.1 | 4.0 | 13.1 |
| 5.0 | 16.4 | 5.0 | 16.4 | 5.0 | 16.4 |
| 6.0 | 19.7 | 6.0 | 19.7 | 6.0 | 19.7 |
| 7.0 | 23.0 | 7.0 | 23.0 | 7.0 | 23.0 |
| 8.0 | 26.2 | 8.0 | 26.2 | 8.0 | 26.2 |
| 9.0 | 29.5 | 9.0 | 29.5 | 9.0 | 29.5 |
| 10.0 | 32.8 | 10.0 | 32.8 | 10.0 | 32.8 |
| 11.0 | 36.1 | 11.0 | 36.1 | 11.0 | 36.1 |
| 12.0 | 39.4 | 12.0 | 39.4 | 12.0 | 39.4 |
| 13.0 | 42.7 | 13.0 | 42.7 | 13.0 | 42.7 |
| 14.0 | 46.0 | 14.0 | 46.0 | 14.0 | 46.0 |
| 15.0 | 49.3 | 15.0 | 49.3 | 15.0 | 49.3 |
| 16.0 | 52.6 | 16.0 | 52.6 | 16.0 | 52.6 |
| 17.0 | 55.9 | 17.0 | 55.9 | 17.0 | 55.9 |
| 18.0 | 59.2 | 18.0 | 59.2 | 18.0 | 59.2 |
| 19.0 | 62.5 | 19.0 | 62.5 | 19.0 | 62.5 |
| 20.0 | 65.8 | 20.0 | 65.8 | 20.0 | 65.8 |
| 21.0 | 69.1 | 21.0 | 69.1 | 21.0 | 69.1 |
| 22.0 | 72.4 | 22.0 | 72.4 | 22.0 | 72.4 |
| 23.0 | 75.7 | 23.0 | 75.7 | 23.0 | 75.7 |
| 24.0 | 79.0 | 24.0 | 79.0 | 24.0 | 79.0 |
| 25.0 | 82.3 | 25.0 | 82.3 | 25.0 | 82.3 |
| 26.0 | 85.6 | 26.0 | 85.6 | 26.0 | 85.6 |
| 27.0 | 88.9 | 27.0 | 88.9 | 27.0 | 88.9 |
| 28.0 | 92.2 | 28.0 | 92.2 | 28.0 | 92.2 |
| 29.0 | 95.5 | 29.0 | 95.5 | 29.0 | 95.5 |
| 30.0 | 98.8 | 30.0 | 98.8 | 30.0 | 98.8 |

| | |
|---------------------|---|
| OBSERVATIONS | LOSS OF PERFORATION WATER AT 3.0 METERS |
|---------------------|---|

| | | | | | |
|-------------------------------------|--|---|--|--------------------------|--|
| PROJECT CREMATOPIO MUNICIPAL | | LOCATION CENTRAL DISTRICT | | DTA. CAP. C. | |
| DATE DRILLING RIG LUNGSAM 43 | | | | SECTOR 3 | |
| WATER TABLE | | PERFORATED / SUPERFICIO / APPROVED CDL PEREZ / ING. BONIAS / GEOLOGIST JOSÉ ARCE | | PREPARED BY JAD | |
| COORDINATES | | 18° 14' 2.22" N / 87° 13' 37" W | | LAST VERSION 2022 | |

| | | | | | |
|-------------------------|-------------------|---|----------------|--------------------|----------------|
| Soilhole Geology | | MEASURED BOREHOLE PARAMETER WITH SPT TESTING | | BOREHOLE# 6 | |
| DEPTH (M) | DEPTH (FT) | IS | N (SPT) | ROD | REMARKS |
| 0.0 | 0.0 | | | | |
| 0.5 | 1.5 | | | | |
| 1.0 | 3.0 | | | | |
| 1.5 | 4.5 | | | | |
| 2.0 | 6.0 | | | | |
| 2.5 | 7.5 | | | | |
| 3.0 | 9.0 | | | | |
| 3.5 | 10.5 | | | | |
| 4.0 | 12.0 | | | | |
| 4.5 | 13.5 | | | | |
| 5.0 | 15.0 | | | | |
| 5.5 | 16.5 | | | | |
| 6.0 | 18.0 | | | | |
| 6.5 | 19.5 | | | | |
| 7.0 | 21.0 | | | | |
| 7.5 | 22.5 | | | | |
| 8.0 | 24.0 | | | | |
| 8.5 | 25.5 | | | | |
| 9.0 | 27.0 | | | | |

| | |
|---|---|
| BOREHOLE LOG | NOT REACHED |
| <p>0.0 - 0.5 m: GRAVELLY SOIL</p> <p>0.5 - 1.0 m: GRAVELLY SOIL</p> <p>1.0 - 1.5 m: GRAVELLY SOIL</p> <p>1.5 - 2.0 m: GRAVELLY SOIL</p> <p>2.0 - 2.5 m: GRAVELLY SOIL</p> <p>2.5 - 3.0 m: GRAVELLY SOIL</p> <p>3.0 - 3.5 m: GRAVELLY SOIL</p> <p>3.5 - 4.0 m: GRAVELLY SOIL</p> <p>4.0 - 4.5 m: GRAVELLY SOIL</p> <p>4.5 - 5.0 m: GRAVELLY SOIL</p> <p>5.0 - 5.5 m: GRAVELLY SOIL</p> <p>5.5 - 6.0 m: GRAVELLY SOIL</p> <p>6.0 - 6.5 m: GRAVELLY SOIL</p> <p>6.5 - 7.0 m: GRAVELLY SOIL</p> <p>7.0 - 7.5 m: GRAVELLY SOIL</p> <p>7.5 - 8.0 m: GRAVELLY SOIL</p> <p>8.0 - 8.5 m: GRAVELLY SOIL</p> <p>8.5 - 9.0 m: GRAVELLY SOIL</p> | <p>0.0 - 0.5 m: GRAVELLY SOIL</p> <p>0.5 - 1.0 m: GRAVELLY SOIL</p> <p>1.0 - 1.5 m: GRAVELLY SOIL</p> <p>1.5 - 2.0 m: GRAVELLY SOIL</p> <p>2.0 - 2.5 m: GRAVELLY SOIL</p> <p>2.5 - 3.0 m: GRAVELLY SOIL</p> <p>3.0 - 3.5 m: GRAVELLY SOIL</p> <p>3.5 - 4.0 m: GRAVELLY SOIL</p> <p>4.0 - 4.5 m: GRAVELLY SOIL</p> <p>4.5 - 5.0 m: GRAVELLY SOIL</p> <p>5.0 - 5.5 m: GRAVELLY SOIL</p> <p>5.5 - 6.0 m: GRAVELLY SOIL</p> <p>6.0 - 6.5 m: GRAVELLY SOIL</p> <p>6.5 - 7.0 m: GRAVELLY SOIL</p> <p>7.0 - 7.5 m: GRAVELLY SOIL</p> <p>7.5 - 8.0 m: GRAVELLY SOIL</p> <p>8.0 - 8.5 m: GRAVELLY SOIL</p> <p>8.5 - 9.0 m: GRAVELLY SOIL</p> |



| |
|---------------------|
| OBSERVATIONS |
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| | | | | | | | | | |
|-------------|--|----------------------|--|---------------------------------|--|---|--|-------------|--|
| PROJECT | | CREMATORIO MUNICIPAL | | LOCATION | | CENTRAL DISTRICT | | CSA-CAMP-28 | |
| DATE | | DRILLING RIG | | LONGICAL 42 | | PERFORMED / SUPERVISED / APPROVED | | CLASSIFIED | |
| WATER TABLE | | COORDINATES | | 16° 14' 1.32" N 87° 13' 0.82" W | | EDIL PEREZ / ING. BORJAS / GEOLOGIST JOSAFACE | | APPROVED BY | |
| | | | | | | | | JAD | |
| | | | | | | | | DATE | |
| | | | | | | | | DATE | |

| | | | | | |
|--------------------|------------|--|-----|--------------|---------|
| Borehole Lithology | | MEASURED BOREHOLE PARAMETER WITH SPT TESTING | | BOREHOLE # 7 | |
| DEPTH (m) | DEPTH (ft) | DESCRIPTION | IS | N (SPT) | REMARKS |
| 0.0 | 0.0 | VEGETACION | 15 | | |
| 0.2 | 0.7 | MANEJER #1 | 30 | | |
| 0.5 | 1.6 | MANEJER #2 | 45 | | |
| 1.0 | 3.3 | MANEJER #3 | 60 | | |
| 1.5 | 5.0 | MANEJER #4 | 75 | | |
| 2.0 | 6.6 | MANEJER #5 | 90 | | |
| 2.5 | 8.2 | MANEJER #6 | 105 | | |
| 3.0 | 9.8 | NOT REACHED | 120 | | |
| 3.5 | 11.5 | | 135 | | |
| 4.0 | 13.1 | | 150 | | |
| 4.5 | 14.8 | | 165 | | |
| 5.0 | 16.4 | | 180 | | |
| 5.5 | 18.0 | | 195 | | |
| 6.0 | 19.7 | | 210 | | |
| 6.5 | 21.3 | | 225 | | |
| 7.0 | 23.0 | | 240 | | |
| 7.5 | 24.6 | | 255 | | |
| 8.0 | 26.2 | | 270 | | |
| 8.5 | 27.9 | | 285 | | |
| 9.0 | 29.5 | | 300 | | |



| | |
|--------------|--|
| OBSERVATIONS | |
| | |

| PROJECT | | CREMATORIO MUNICIPAL | | LOCATION | | CENTRAL DISTRICT | | STA. CAMP. # | |
|--------------|------------|--|------------|---------------------------------------|------------|---|------------|--------------|------------|
| DATE | | DRILLING RIG | | LONG. (M. 42) | | PERFORATED / SUPPLYED / APPROVED | | SERIES | |
| WATER TABLE | | COORDINATES | | 18P 14° 8' 11.85" N / 87° 10' 8.37" W | | EDIL. PEREZ / ING. BONIAS / GEOLOGIST JOS. ARCE | | DISEÑO: JAD | |
| BOREHOLE # 8 | | MEASURED BOREHOLE PARAMETER WITH SPT TESTING | | LAST SETTING | | 30421 | | | |
| DEPTH (M) | DEPTH (FT) | CORRECTION | CORRECTION | DEPTH (M) | DEPTH (FT) | CORRECTION | CORRECTION | CORRECTION | CORRECTION |
| | | | | | | | | | |
| 0.0 | 0.0 | | | 0.0 | 0.0 | | | | |
| 1.2 | 1.2 | | | 1.2 | 1.2 | | | | |
| 1.5 | 1.5 | | | 1.5 | 1.5 | | | | |
| 2.0 | 2.0 | | | 2.0 | 2.0 | | | | |
| 2.5 | 2.5 | | | 2.5 | 2.5 | | | | |
| 3.0 | 3.0 | | | 3.0 | 3.0 | | | | |
| 3.5 | 3.5 | | | 3.5 | 3.5 | | | | |
| 4.0 | 4.0 | | | 4.0 | 4.0 | | | | |
| 4.5 | 4.5 | | | 4.5 | 4.5 | | | | |
| 5.0 | 5.0 | | | 5.0 | 5.0 | | | | |
| 5.5 | 5.5 | | | 5.5 | 5.5 | | | | |
| 6.0 | 6.0 | | | 6.0 | 6.0 | | | | |
| 6.5 | 6.5 | | | 6.5 | 6.5 | | | | |
| 7.0 | 7.0 | | | 7.0 | 7.0 | | | | |
| 7.5 | 7.5 | | | 7.5 | 7.5 | | | | |
| 8.0 | 8.0 | | | 8.0 | 8.0 | | | | |
| 8.5 | 8.5 | | | 8.5 | 8.5 | | | | |
| 9.0 | 9.0 | | | 9.0 | 9.0 | | | | |

VERY CLAYEY
SANDY SILT
AND SILTY SAND
SOME FINE GRAIN
SHELLS

NOT REACHED

OBSERVATIONS

| | | | | | | | | | | | |
|--------------------|--|----------------------|--|------------------|--|--|--|-----------------------------------|--|--------------------|--|
| PROJECT | | CREMATORIO MUNICIPAL | | LOCATION | | CENTRAL DISTRICT | | SCALE | | 1:1 | |
| DATE | | DRILLING RIG | | LONGYCAL 42 | | PERFORMED / SUPERVISED / APPROVED | | ING. BORJAS / GEOLOGIST JOS. ARCE | | REVISIONS | |
| WATER TABLE | | | | | | | | | | 3 | |
| COORDINATES | | 18° 16' 11.85" N | | 87° 13' 32.37" W | | | | | | APPROVED BY | |
| | | | | | | | | | | JAD | |
| | | | | | | | | | | LAST UPDATE | |
| | | | | | | | | | | JUL 12 | |

| | | | | | | | | | | | |
|--------------------------------|--|----------------------|--|--------------------|--|----------------------|--|--------------------|--|----------------------|--|
| Stratigraphic Lithology | | WATER TABLE | | WATER TABLE | | WATER TABLE | | WATER TABLE | | WATER TABLE | |
| DEPTH (M) | | DIAMETER (CM) | | DEPTH (M) | | DIAMETER (CM) | | DEPTH (M) | | DIAMETER (CM) | |
| 0.0 | | 10.0 | | 0.00 | | 10.00 | | 0.00 | | 10.00 | |
| 0.5 | | 10.5 | | 0.30 | | 10.30 | | 0.30 | | 10.30 | |
| 1.0 | | 11.0 | | 0.60 | | 10.60 | | 0.60 | | 10.60 | |
| 1.5 | | 11.5 | | 0.90 | | 10.90 | | 0.90 | | 10.90 | |
| 2.0 | | 12.0 | | 1.20 | | 11.20 | | 1.20 | | 11.20 | |
| 2.5 | | 12.5 | | 1.50 | | 11.50 | | 1.50 | | 11.50 | |
| 3.0 | | 13.0 | | 1.80 | | 11.80 | | 1.80 | | 11.80 | |
| 3.5 | | 13.5 | | 2.10 | | 12.10 | | 2.10 | | 12.10 | |
| 4.0 | | 14.0 | | 2.40 | | 12.40 | | 2.40 | | 12.40 | |
| 4.5 | | 14.5 | | 2.70 | | 12.70 | | 2.70 | | 12.70 | |
| 5.0 | | 15.0 | | 3.00 | | 13.00 | | 3.00 | | 13.00 | |
| 5.5 | | 15.5 | | 3.30 | | 13.30 | | 3.30 | | 13.30 | |
| 6.0 | | 16.0 | | 3.60 | | 13.60 | | 3.60 | | 13.60 | |
| 6.5 | | 16.5 | | 3.90 | | 13.90 | | 3.90 | | 13.90 | |
| 7.0 | | 17.0 | | 4.20 | | 14.20 | | 4.20 | | 14.20 | |
| 7.5 | | 17.5 | | 4.50 | | 14.50 | | 4.50 | | 14.50 | |
| 8.0 | | 18.0 | | 4.80 | | 14.80 | | 4.80 | | 14.80 | |
| 8.5 | | 18.5 | | 5.10 | | 15.10 | | 5.10 | | 15.10 | |
| 9.0 | | 19.0 | | 5.40 | | 15.40 | | 5.40 | | 15.40 | |

BOREHOLE # 8

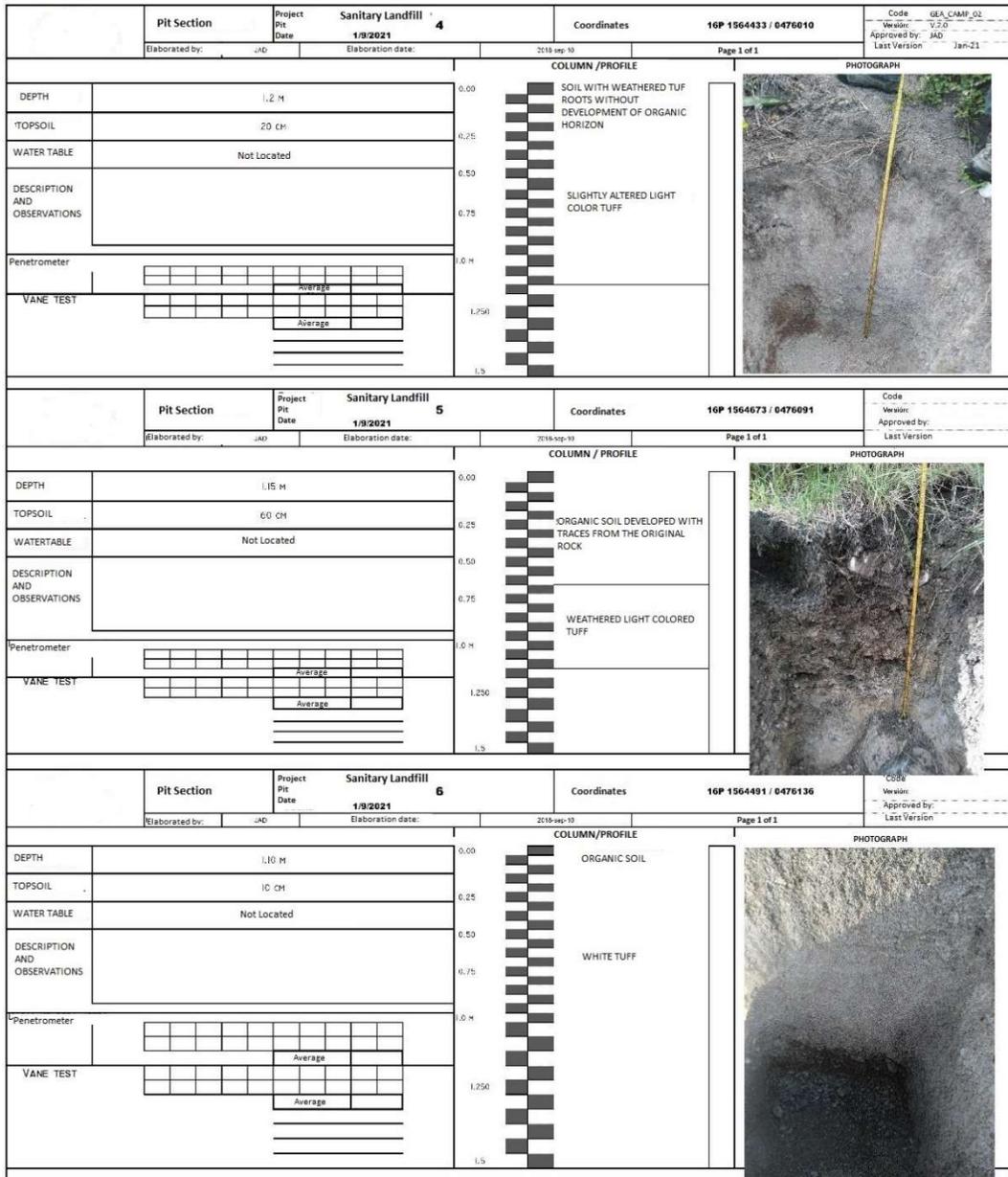
Observations: LOSS OF PERFORATION WATER AT 5.0 METERS





Figure A.6 Drilling Log performed for the study of the new landfill in the Central District Municipality by GEASA.

| Pit Section | | Project Pit Date | Sanitary Landfill 1 | Coordinates | 16P 1564597 / 6475827 | Code: CEA-CAMP_02 |
|------------------------------|--|-------------------------------|---------------------|---|--|----------------------|
| Elaborated by: JAD | | Elaboration date: 2019-Jul-19 | | Page 1 of 1 | | Version: V.2.0 |
| | | | | | | Approved: _____ |
| | | | | | | Last version: Jan-21 |
| Depth | 1.0 M | 0.00 | | COLUMN/PROFILE Organic Soil TUFF OF DIFFERENT COLORS SLIGHTLY ALTERED. HEALTHIER IN DEPTH. | PHOTOGRAPH  | |
| Topsoil | 10 CM | 0.25 | | | | |
| water table | Not located | 0.50 | | | | |
| Description and Observations | | 0.75 | | | | |
| Penetrometer | | 1.0 M | | | | |
| VANE TEST | | 1.250 | | | | |
| | | 1.5 | | | | |
| Pit Section | | Project Pit Date | Sanitary Landfill 2 | Coordinates | 16P 1564627 / 6475890 | Code: _____ |
| Elaborated by: JAD | | Elaboration date: 2019-Jul-19 | | Page 1 of 1 | | Version: _____ |
| | | | | | | Approved: _____ |
| | | | | | | Last version: _____ |
| Depth | 1.0 M | 0.00 | | COLUMN/PROFILE ORGANIC SOIL OF MEDIUM THICKNESS WITH SLIGHT SHRINKAGE LIGHT COLORED ALTERED TUF | PHOTOGRAPH  | |
| Topsoil | 60 CM | 0.25 | | | | |
| water table | Not located. Moisture in the photo product of rain and infiltration test. low permeability | 0.50 | | | | |
| Description and Observations | | 0.75 | | | | |
| Penetrometer | | 1.0 M | | | | |
| VANE TEST | | 1.250 | | | | |
| | | 1.5 | | | | |
| Pit Section | | Project Pit Date | Sanitary Landfill 3 | Coordinates | 16P 1564544 / 6476003 617 m (According to GPS) | Code: _____ |
| Elaborated by: JAD | | Elaboration date: 2019-Jul-19 | | Page 1 of 1 | | Version: _____ |
| | | | | | | Approved: _____ |
| | | | | | | Last version: _____ |
| Depth | 1.0 M | 0.00 | | COLUMN/PROFILE VERY ALTERED TUFF SOIL. ORGANIC MATTER ONLY IN ROOTS WITHOUT DEVELOPMENT OF ORGANIC HORIZON LIGHT COLORED TUFF SLIGHTLY ALTERED | PHOTOGRAPH  | |
| Topsoil | 5 CM | 0.25 | | | | |
| water table | Not Located | 0.50 | | | | |
| Description and Observations | | 0.75 | | | | |
| Penetrometer | | 1.0 M | | | | |
| VANE TEST | | 1.250 | | | | |
| | | 1.5 | | | | |



| Pit Section | | Project Pit Date | Sanitary Landfill | Coordinates | Code |
|------------------------------|------------|-------------------|--|-----------------------|--|
| | | 1/9/2021 | 7 | 16P 1564557 / 0476258 | GEA_CAMP_02 |
| Elaborated by: JAD | | Elaboration Date: | 2018-sep-10 | Page 1 of 1 | Version: V2.0 Approved: JAD Last version: sep-21 |
| Depth | 1.0 M | 0.00 | Column / Profile ALTERED TUFFS WITHOUT DEVELOPMENT OF ORGANIC HORIZON | Photograph | |
| Topsoil | 0 CM | 0.25 | | | |
| Water Table | NO. | 0.50 | | | |
| Description and Observations | | 0.75 | | | |
| Penetrometer Data | | 1.0 M | | | |
| VANE TEST | | 1.250 | | | |
| | | | 1.5 | | |
| Pit Section | | Project Pit Date | Sanitary Landfill | Coordinates | Code |
| | | 1/9/2021 | 8 | 16P 1564623 / 0476230 | GEA_CAMP_02 |
| Elaborated by: JAD | | Elaboration Date: | 2018-sep-10 | Page 1 of 1 | Version: V2.0 Approved: JAD Last version: sep-21 |
| Depth | 1.0 M | 0.00 | Column / Profile ALTERED TUFFS WITHOUT DEVELOPMENT OF ORGANIC HORIZON | Photograph | |
| Topsoil | 0 CM | 0.25 | | | |
| Water Table | NO. | 0.50 | | | |
| Description and Observations | | 0.75 | | | |
| Penetrometer Data | | 1.0 M | | | |
| VANE TEST | | 1.250 | | | |
| | | | 1.5 | | |
| Pit Section | | Project Pit Date | Sanitary Landfill | Coordinates | Code |
| | | 1/9/2021 | 9 | 16P 1564719 / 0476210 | GEA_CAMP_02 |
| Elaborated by: JAD | | Elaboration Date: | 2018-sep-10 | Page 1 of 1 | Version: V2.0 Approved: JAD Last version: sep-21 |
| Depth | 1.2 | 0.00 | Column / Profile ORGANIC SOIL TUFF/ LIGHT COLOR IGIMBRITE | Photograph | |
| Topsoil | 45 CM | 0.25 | | | |
| Water Table | NO UBICADO | 0.50 | | | |
| Description and Observations | | 0.75 | | | |
| Penetrometer Data | | 1.0 M | | | |
| VANE TEST | | 1.250 | | | |
| | | | 1.5 | | |

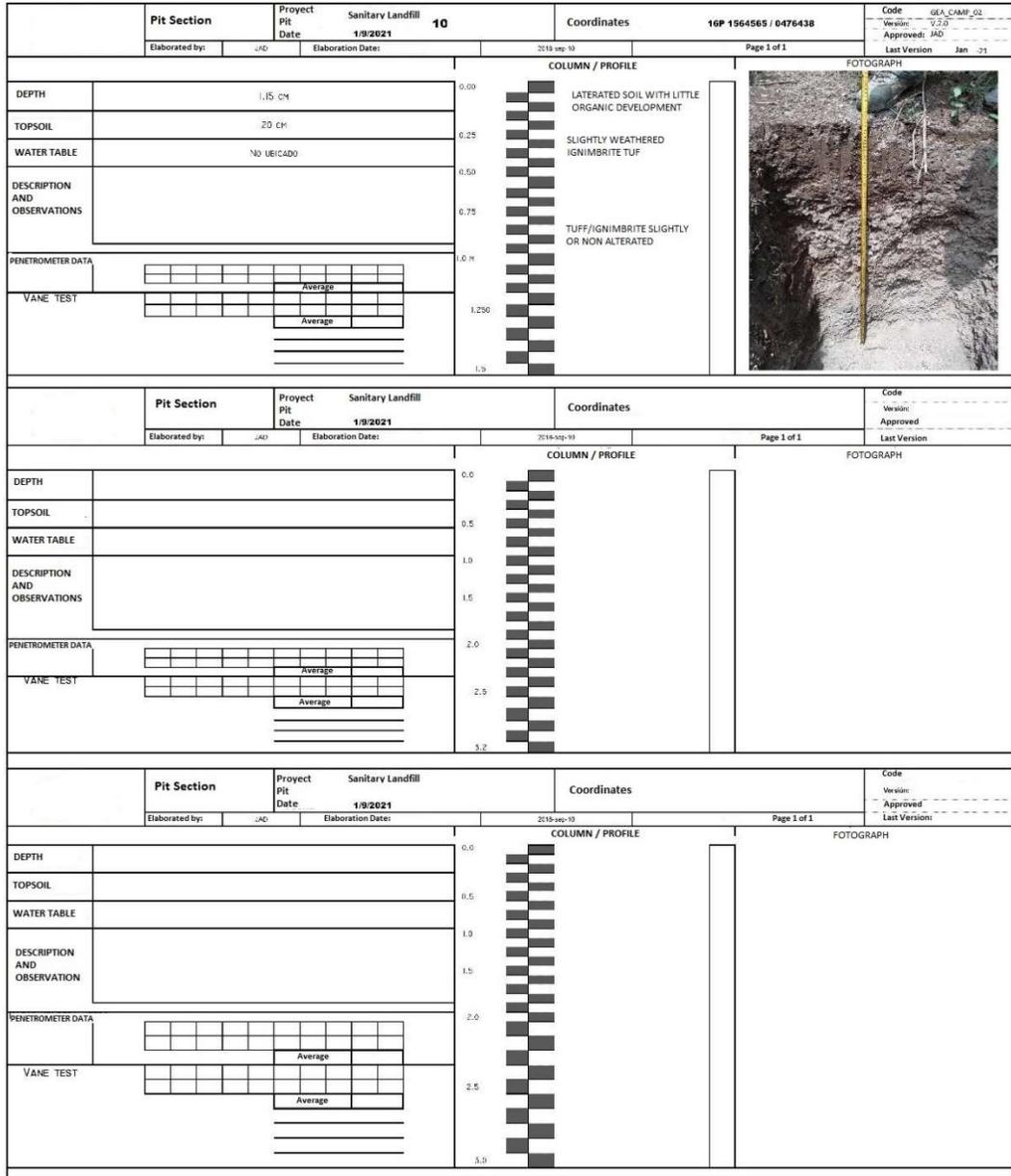


Figure A.7 Test Pits 1-10 performed for the study of the new landfill in the Central District Municipality by GEASA.

| | | | | |
|---|---|--|---------------------------------------|----|
|  cinsa@amnettg.com cinsasp@sulanet.com | Soils, Concrete, Asphalt and Materials Laboratory Summary of Results in Compaction Tests | Code RO-PCO-11 | Date of Last version of February 2007 | 26 |
| | | Laboratory: Central office Tegucigalpa | | |
| | | Version 3 | Page 1 of 1 Registration No. 506 | |
| Tegucigalpa Tel. 2232-6563, Fax 2232-6563, San Pedro Sula Tel. 2566-2424, Fax. 2566-2345 | | | | |

Project: MAINTENANCE OF SANITARY LANDFILL, CODE 2808
 Location: EXIT ROAD TO OLANCHO, DEPT. OF FCO. MORAZÁN Tests made in: FILLING OF DIRT WORKS
 Tests performed by: FERNANDO ERAZO Date: 06/SEPTEMBER/2021

| No. | Station | Location | % of compaction | % of humidity on Site | Maximum Density | Optimum Humidity | Specification | Observations |
|-----|---------|--|-----------------|-----------------------|-----------------|------------------|---------------|------------------------|
| 1 | ----- | Taken from the lines of solid residues | 95.3 | 27.5 | 85.0 | 30.0 | 95 % minimum | Compaction made |
| 2 | ----- | , in cell 1-A, cover of 30 cms | 95.7 | 28.0 | 85.0 | 30.0 | " " " | with vibratory |
| 3 | ----- | " " " " " | 95.9 | 27.7 | 85.0 | 30.0 | " " " | smooth metallic roller |
| | | **L.L ** | | | | | | |
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Testing Method: [AASHTO T 191-02 DENSITIES ON SITE] (AASHTO T99-04 STANDARD PROCTOR)
 Responsible: ESTEBAN MARIN MATAMOROS
 Approved by: Ing. Manuel Ángel Sánchez Date: 06/SEPTEMBER/2021

| | | | | |
|---|---|--|---------------------------------------|----|
|  cinsa@amnettg.com cinsasp@sulanet.com | Soils, Concrete, Asphalt and Materials Laboratory Summary of Results in Compaction Tests | Code RO-PCO-11 | Date of Last version of February 2007 | 26 |
| | | Laboratory: Central office Tegucigalpa | | |
| | | Version 3 | Page 1 of 1 Registration No. 509 | |
| Tegucigalpa Tel. 2232-6563, Fax 2232-6563, San Pedro Sula Tel. 2566-2424, Fax. 2566-2345 | | | | |

Project: MAINTENANCE OF SANITARY LANDFILL, CODE 2808
 Location: EXIT ROAD TO OLANCHO, DEPT. OF FCO. MORAZÁN Tests made in: FILLING OF DIRT WORKS
 Tests performed by: FERNANDO ERAZO Date: 13/SEPTEMBER/2021

| No. | Station | Location | % of compaction | % of humidity on Site | Maximum Density | Optimum Humidity | Specification | Observations |
|-----|---------|--|-----------------|-----------------------|-----------------|------------------|---------------|------------------------|
| 1 | ----- | Taken from the lines of solid residues | 96.6 | 26.8 | 85.0 | 30.0 | 95 % minimum | Compaction made |
| 2 | ----- | , in cell 1-A, cover of 30 cms | 95.5 | 27.5 | 85.0 | 30.0 | " " " | with vibratory |
| 3 | ----- | " " " " " | 96.0 | 26.7 | 85.0 | 30.0 | " " " | smooth metallic roller |
| | | **L.L ** | | | | | | |
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Testing Method: [AASHTO T 191-02 DENSITIES ON SITE] (AASHTO T99-04 STANDARD PROCTOR)
 Responsible: ESTEBAN MARIN MATAMOROS
 Approved by: Ing. Manuel Ángel Sánchez Date: 13/SEPTEMBER/2021

| | | | | |
|--|---|--|---------------------------------------|----------------------|
|  cinsa@amnettg.com cinsasps@sulanet.com | Soils, Concrete, Asphalt and Materials Laboratory Summary of Results in Compaction Tests | Code RO-PCO-11 | Date of Last version of February 2007 | 26 |
| | | Laboratory: Central office Tegucigalpa | | |
| | | Version 3 | Page 1 of 1 | Registration No. 511 |
| Tegucigalpa Tel. 2232-6563, Fax 2232-6563, San Pedro Sula Tel. 2566-2424, Fax. 2566-2345 | | | | |

Project: MAINTENANCE OF SANITARY LANDFILL, CODE 2808
 Location: EXIT ROAD TO OLANCHO, DEPT. OF FCO. MORAZÁN Tests made in: FILLING OF DIRT WORKS
 Tests performed by: FERNANDO ERAZO Date: 21/SEPTEMBER/2021

| No. | Station | Location | % of compaction | % of humidity on Site | Maximum Density | Optimum Humidity | Specification | Observations |
|-----|---------|--|-----------------|-----------------------|-----------------|------------------|---------------|------------------------|
| 1 | ----- | Taken from the lines of solid residues | 97.3 | 27.3 | 85.0 | 30.0 | 95 % minimum | Compaction made |
| 2 | ----- | , in cell 1-A, cover of 30 cms | 97.1 | 28.3 | 85.0 | 30.0 | " " " | with vibratory |
| 3 | ----- | " " " " " | 96.8 | 26.3 | 85.0 | 30.0 | " " " | smooth metallic roller |
| | | **L,L** | | | | | | |
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Testing Method: (AASHTO T 191-02 DENSITIES ON SITE) (AASHTO T99-04 STANDARD PROCTOR)
 Responsible: ESTEBAN MARIN MATAMOROS
 Approved by: Ing. Manuel Ángel Sánchez Date: 21/SEPTEMBER/2021

| | | | | |
|---|---|--|---------------------------------------|----------------------|
|  cinsa@amnettg.com cinsasps@sulanet.com | Soils, Concrete, Asphalt and Materials Laboratory Summary of Results in Compaction Tests | Code RO-PCO-11 | Date of Last version of February 2007 | 26 |
| | | Laboratory: Central office Tegucigalpa | | |
| | | Version 3 | Page 1 of 1 | Registration No. 516 |
| Tegucigalpa Tel. 2232-6563, Fax 2232-6563, San Pedro Sula Tel. 2566-2424, Fax. 2566-2345 | | | | |

Project: MAINTENANCE OF SANITARY LANDFILL, CODE 2808
 Location: EXIT ROAD TO OLANCHO, DEPT. OF FCO. MORAZÁN Tests made in: FILLING OF DIRT WORKS
 Tests performed by: FERNANDO ERAZO Date: 28/SEPTEMBER/2021

| No. | Station | Location | % of compaction | % of humidity on Site | Maximum Density | Optimum Humidity | Specification | Observations |
|-----|---------|--|-----------------|-----------------------|-----------------|------------------|---------------|------------------------|
| 1 | ----- | Taken from the lines of solid residues | 97.8 | 29.0 | 85.0 | 30.0 | 95 % minimum | Compaction made |
| 2 | ----- | , in cell 1-A, cover of 30 cms | 98.0 | 28.0 | 85.0 | 30.0 | " " " | with vibratory |
| 3 | ----- | " " " " " | 98.2 | 27.6 | 85.0 | 30.0 | " " " | smooth metallic roller |
| | | **L,L** | | | | | | |
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Testing Method: (AASHTO T 191-02 DENSITIES ON SITE) (AASHTO T99-04 STANDARD PROCTOR)
 Responsible: ESTEBAN MARIN MATAMOROS
 Approved by: Ing. Manuel Ángel Sánchez Date: 28/SEPTEMBER/2021

Figure A.8 Final cover layer compaction test laboratory results performed by CINSA 2021

| Layer | Cohesion (kPa) | Friction angle (°) | Unit weight (kN m ⁻³) |
|---------------------|-------------------|-----------------------|--------------------------------------|
| Colluvium | 18.5 | 29.6 | 19.31 |
| Sandstone and shale | 41.8 | 32.1 | 25.52 |
| Sandstone | 38.7 | 32.7 | 23.86 |
| Fracture zone | 0 | 22.6 | 22.60 |

Figure A.9 Soil and Rock Parameters Tests in Taiwan (Jeng & Sue, 2016)



| | | | | | | |
|---|--|--|--|--|---------------|-----------|
| GRANULOMETRIC ANALYSIS, ATTERBERG LIMITS AND SOIL CLASSIFICATION | | | | | Code: | LA-F0001 |
| | | | | | Version: | 7 |
| Produced by: RAA Date of elaboration: 24-Sep-05 page 1 of 1 | | | | | Passed: | RAF |
| | | | | | Last version: | 10-Jul-20 |

Draft: _____ Landfill _____ Sample # 1169

Station or precedence: _____ Pit #3 _____ Lab Code: LC

Hole or pit: 3 Gauge: N/A Depth in meters: N/A a N/A

Taken by: The interested Date taken: 16-Sep-21

Tested by: Peter Funes Rehearsed date: 20-Sep-21

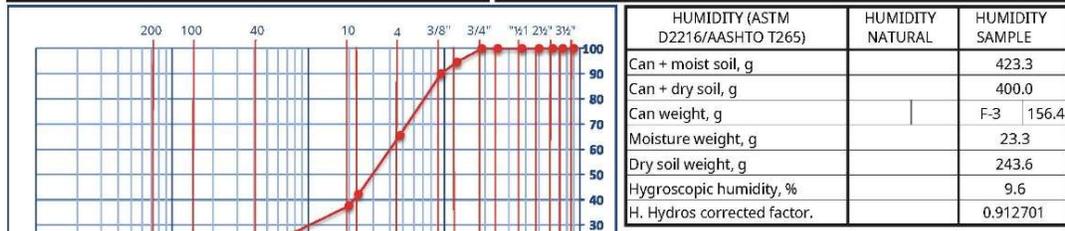
Material designation: _____ Existing soil _____ Side: N/A

SOIL SIZE ANALYSIS BY SIEVE (ASTM D422/AASHTO T88)

| Sieve No. | Weight | Percentage | | | Corduroy # <u>my</u> | Total air dried sample: <u>1253.1</u> | Total dry sample: <u>1143.7</u> |
|-----------|--------|-------------|----------|-------|----------------------|---------------------------------------|---------------------------------|
| in. | mm | Accum. Ret. | Retained | Pass | | | |
| 3 1/2" | 90.00 | | | | | | |
| 3" | 75.00 | | | | | | |
| 2 1/2" | 63.00 | | | | | | |
| 2" | 50.00 | | | | | | |
| 1 1/2" | 37.50 | | | | | | |
| 1" | 25.00 | | | | | | |
| 3/4" | 19.00 | 0.0 | 0.0 | 100.0 | | | |
| 1/2" | 12.50 | 61.2 | 5.4 | 94.6 | | | |
| 3/8" | 9.50 | 114.3 | 10.0 | 90.0 | | | |
| #4 | 4.75 | 392.8 | 34.3 | 65.7 | | | |
| Bottom | | | | | | | |
| Total | | | | | | | |

| Sieve No. | Weight | Percentage | | | Corduroy # <u>my</u> | Total air dried sample: <u>1253.1</u> | Total dry sample: <u>1143.7</u> |
|-----------|--------|-------------|----------|-------|----------------------|---------------------------------------|---------------------------------|
| in. | mm | Ret. Accum. | Retained | Pass | | | |
| #8 | 2.36 | 660.7 | 57.77 | 42.23 | | | 42.23 |
| #10 | 2.00 | 713.4 | 62.38 | 37.62 | | | 37.62 |
| #40 | 0.425 | 915.9 | 80.08 | 19.92 | | | 19.92 |
| #100 | 0.150 | 987.4 | 86.33 | 13.67 | | | 13.67 |
| #200 | 0.075 | 1,014.0 | 88.66 | 11.34 | | | 11.34 |
| Bottom | | | | | | | |
| Total | | | | | | | |

| | | | |
|--------------------------------------|--|----------------|-------------------------------------|
| DESCRIPTIVE INFORMATION OF THE SOILS | | organic soil | <input type="checkbox"/> |
| | | inorganic soil | <input checked="" type="checkbox"/> |



| SOIL CLASSIFICATION | | |
|---------------------|-------------------------------------|-----------|
| 1 | AASHTO classification (AASHTO M145) | A-2-4 (0) |
| 2 | SUCS Classification (ASTM D2487) | SP-SM |

| DIAMETERS (mm) and COEFFICIENTS | | | | | | | | |
|---------------------------------|-----------------|-------|---|-----------------|-------|---|-----------------|---|
| 1 | D ₁₀ | 0,000 | 3 | D ₆₀ | 4,173 | 5 | C _{OR} | - |
| 2 | D ₃₀ | 1,322 | 4 | D ₅₀ | 9,499 | 6 | C _c | - |

ATTERBERG LIMITS (ASTM D4318/AASHTO T89-T90)

Tested by: Yelson Ramirez Test date: 21-Sep-21

| # | DESCRIPTION | LIQUID LIMIT | | PLASTIC LIMIT | | Liquid limit: <u>37</u> | Plastic limit: <u>29</u> | Plasticity index: <u>8</u> |
|---|---------------------|--------------|-------|---------------|-------|-------------------------|--------------------------|----------------------------|
| | | HN-8 | 1-L | C-1 | 22-L | | | |
| 1 | Can # | | | | | | | |
| 2 | # of hits | 28 | 28 | - | - | | | |
| 3 | Can + moist soil, g | 38.18 | 41.83 | 31.44 | 30.50 | | | |
| 4 | Can + dry soil, g | 33.79 | 36.71 | 29.50 | 28.70 | | | |
| 5 | Moisture weight, g | 4.39 | 5.12 | 1.94 | 1.80 | | | |
| 6 | Can weight, g | 21.76 | 22.65 | 22.85 | 22.46 | | | |
| 7 | Dry soil weight, g | 12.03 | 14.06 | 6.65 | 6.24 | | | |
| 8 | % moisture | 36.49 | 36.42 | 29.17 | 28.85 | | | |

| | | | | | |
|--|-----|-----------------------------|-----------|----------------------|-----------|
| SPECIFIC GRAVITY OF SOILS WITH PYCNOMETER | | | | Code: | LA-FO010 |
| | | | | Version: | 3 |
| Produced by: | RAF | Date of elaboration: | 07-Apr-16 | Approved: | RAF |
| | | | | Last version: | 15-Feb-19 |

Draft: _____ Landfill _____ Sample # 1169
Origin of the sample: _____ Pit #3 _____ Lab Code: LC
Tested by: _____ Peter Funes _____ Probe: N/A SPT: N/A Date: 23-Sep-21
Material designation: _____ Existing Soil _____ Depth, m: -

| | | | | |
|--|--|--|--|--|
| SPECIFIC GRAVITY OF SOILS USING A PYCNOMETER WITH WATER (ASTM D854/AASHTO T100) | | | | |
|--|--|--|--|--|

| # | TEST STEPS | 1 | 2 | 3 |
|---|--|--------|--------|--------|
| 1 | Pycnometer number | 5 | 6 | 7 |
| 2 | Weight of pycnometer + water, g | 652.20 | 647.90 | 649.64 |
| 3 | Weight of material in air, g | 100.00 | 100.00 | 100.00 |
| 4 | Pycnometer + water + material after test, g | 712.20 | 708.00 | 709.80 |
| 5 | Material weight in water (4 - 2), g | 60.00 | 60.10 | 60.16 |
| 6 | Weight of material in air - weight of material in water (3 - 5), g | 40.00 | 39.90 | 39.84 |
| 7 | Specific gravity filler (3/6) | 2,500 | 2,506 | 2,510 |
| 8 | Average Specific Gravity | 2,505 | | |

| | | | | |
|--------------------------------------|--|--|--|--|
| DENSITY OF THE TESTED SAMPLES | | | | |
|--------------------------------------|--|--|--|--|

| # | WET DENSITY | | | # | DRY DENSITY | | |
|----|-----------------------------------|---------|---------|----|-----------------------------------|-------------|---------|
| 9 | can number | Z-1 | PS-7 | 25 | can number | Z-1 | PS-7 |
| 10 | Can + moist soil, g | 128.20 | 130.40 | 26 | Can + moist soil, g | 128.20 | 130.40 |
| 11 | Can weight, g | 13.70 | 13.57 | 27 | Can + dry soil, g | 115.90 | 117.70 |
| 12 | Wet soil weight, g | 114.50 | 116.83 | 28 | Moisture weight, g | 12.30 | 12.70 |
| 13 | Container volume, cm ³ | 69.06 | 69.06 | 29 | Container volume, cm ³ | 69.06 | 69.06 |
| 14 | Wet density, g/cm ³ | 1.66 | 1.69 | 30 | Can weight, g | 13.70 | 13.57 |
| 15 | Wet density, kg/m ³ | 1657.98 | 1691.72 | 31 | Dry soil weight, g | 102.20 | 104.13 |
| 16 | Avg Wet Density kg/m ³ | 1674.85 | | 32 | % moisture | 12.03522505 | 12,196 |
| | | | | 33 | Dry density, kg/m ³ | 1494.929793 | 1492.78 |
| | | | | 34 | Avg dry density kg/m ³ | 1493.86 | |

| # | NATURAL HUMIDITY | | |
|----|---------------------|--|--|
| 17 | can number | | |
| 18 | Can + moist soil, g | | |
| 19 | Can + dry soil, g | | |
| 20 | Moisture weight, g | | |
| 21 | Can weight, g | | |
| 22 | Dry soil weight, g | | |
| 23 | % moisture | | |
| 24 | Average Moisture % | | |

Observations:

| | | | | | | |
|---|-----|-----------------------------|-----------|-------------|----------------------|-----------|
| GRANULOMETRIC ANALYSIS, ATTERBERG LIMITS AND SOIL CLASSIFICATION | | | | | Code: | LA-F0001 |
| | | | | | Version: | 7 |
| Produced by: | RAA | Date of elaboration: | 24-Sep-05 | page 1 of 1 | Passed: | RAF |
| | | | | | Last version: | 10-Jul-20 |

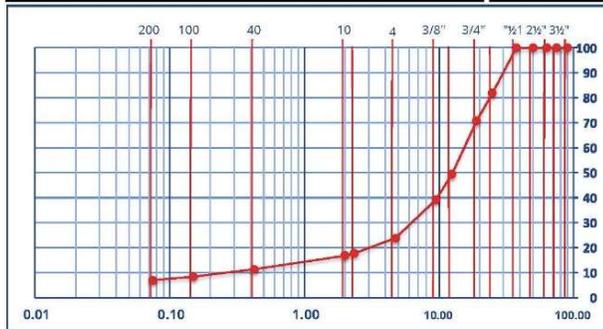
Draft: _____ Landfill _____ Sample # 1170
 Station or precedence: _____ Pit No. 8 _____ Lab Code: LC
 Hole or pit: 8 Gauge: N/A Depth in meters: N/A a N/A
 Taken by: _____ The interested _____ Date taken: 16-Sep-21
 Tested by: _____ Jorge Gomez _____ Rehearsed date: 22-Sep-21
 Material designation: _____ Existing soil _____ Side: N/A

SOIL SIZE ANALYSIS BY SIEVE (ASTM D422/AASHTO T88)

| Sieve No. | Weight | Percentage | | | Corduroy # | Total air dried sample: | Total dry sample: |
|-----------|--------|-------------|----------|-------|------------|-------------------------|-------------------|
| in. | mm | Ret. Accum. | Retained | Pass | | | |
| 3 1/2" | 90.00 | | | | | | |
| 3" | 75.00 | | | | | | |
| 2 1/2" | 63.00 | | | | | | |
| 2" | 50.00 | | | | | | |
| 1 1/2" | 37.50 | 0.0 | 0.0 | 100.0 | | | |
| 1" | 25.00 | 311.2 | 18.1 | 81.9 | | | |
| 3/4" | 19.00 | 503.6 | 29.3 | 70.7 | | | |
| 1/2" | 12.50 | 870.7 | 50.6 | 49.4 | | | |
| 3/8" | 9.50 | 1,045.5 | 60.7 | 39.3 | | | |
| #4 | 4.75 | 1,311.7 | 76.2 | 23.8 | | | |
| Bottom | | | | | | | |
| Total | | | | | | | |

| Sieve No. | Weight | Percentage | | | |
|-----------|--------|-------------|----------|-------|-----------|
| in. | mm | Ret. Accum. | Retained | Pass | corrected |
| #8 | 2.36 | 1,415.3 | 82.23 | 17.77 | 17.77 |
| #10 | 2.00 | 1,432.3 | 83.22 | 16.78 | 16.78 |
| #40 | 0.425 | 1,526.2 | 88.68 | 11.32 | 11.32 |
| #100 | 0.150 | 1,576.2 | 91.58 | 8.42 | 8.42 |
| #200 | 0.075 | 1,601.2 | 93.03 | 6.97 | 6.97 |
| Bottom | | | | | |
| Total | | | | | |

| | | |
|--------------------------------------|----------------|-------------------------------------|
| DESCRIPTIVE INFORMATION OF THE SOILS | organic soil | <input type="checkbox"/> |
| | inorganic soil | <input checked="" type="checkbox"/> |



| HUMIDITY (ASTM D2216/AASHTO T265) | HUMIDITY NATURAL | HUMIDITY SAMPLE |
|-----------------------------------|------------------|-----------------|
| Can + moist soil, g | | 659.7 |
| Can + dry soil, g | | 611.7 |
| Can weight, g | | Z-7 96.1 |
| Moisture weight, g | | 48 |
| Dry soil weight, g | | 515.6 |
| Hygroscopic humidity, % | | 9.3 |
| H. Hydros corrected factor. | | 0.914833 |

| SOIL CLASSIFICATION | | |
|---------------------|-------------------------------------|-----------|
| 1 | AASHTO classification (AASHTO M145) | A-2-5 (0) |
| 2 | SUCS Classification (ASTM D2487) | GP-GM |

| DIAMETERS (mm) and COEFFICIENTS | | | | | | | | |
|---------------------------------|-----------------|-------|---|-----------------|--------|---|----------------|-------|
| 1 | D ₁₀ | 0.300 | 3 | D ₆₀ | 15,727 | 5 | C _u | 52.46 |
| 2 | D ₃₀ | 6,658 | 4 | D ₉₀ | 30,587 | 6 | C _c | 9.40 |

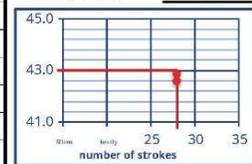
| SLIME AND/OR CLAY | SAND | | | GRAVEL |
|-------------------|------|------|-------|--------|
| | FINE | HALF | GROSS | |
| | | | | |

ATTERBERG LIMITS (ASTM D4318/AASHTO T89-T90)

Tested by: _____ Yelson Ramirez _____ Test date: 21-Sep-21

| # | DESCRIPTION | LIQUID LIMIT | | PLASTIC LIMIT | |
|---|---------------------|--------------|-------|---------------|-------|
| | | DC-2 | 2-L | 22-L | C-1 |
| 1 | Can # | | | | |
| 2 | # of hits | 28 | 28 | - | - |
| 3 | Can + moist soil, g | 37.03 | 36.07 | 33.15 | 33.32 |
| 4 | Can + dry soil, g | 32.52 | 32.02 | 30.40 | 30.65 |
| 5 | Moisture weight, g | 4.51 | 4.05 | 2.75 | 2.67 |
| 6 | Can weight, g | 21.93 | 22.57 | 22.46 | 22.85 |
| 7 | Dry soil weight, g | 10.59 | 9.45 | 7.94 | 7.80 |
| 8 | % moisture | 42.59 | 42.86 | 34.63 | 34.23 |

Liquid limit: 43
 Plastic limit: 3.4
 Plasticity index: 9



| SPECIFIC GRAVITY OF SOILS WITH PYCNOMETER | | | | Code: | LA-FO010 |
|--|-----|-----------------------------|-----------|----------------------|-----------|
| | | | | Version: | 3 |
| | | | | Approved: | RAF |
| Produced by: | RAF | Date of elaboration: | 07-Apr-16 | Last version: | 15-Feb-19 |

Draft: _____ Landfill _____ Sample # 1170
 Origin of the sample: _____ Pit No. 8 Lab Code: LC
 Tested by: _____ Peter Funes _____ Probe: N/A SPT: N/A Date: 23-Sep-21
 Material designation: _____ Existing Soil _____ Depth, m: -

| | | | |
|--|--|--|--|
| SPECIFIC GRAVITY OF SOILS USING A PYCNOMETER WITH WATER (ASTM D854/AASHTO T100) | | | |
|--|--|--|--|

| # | TEST STEPS | 1 | 2 | 3 |
|---|--|--------|--------|--------|
| 1 | Pycnometer number | 3 | 5 | 6 |
| 2 | Weight of pycnometer + water, g | 342.14 | 340.72 | 341.21 |
| 3 | Weight of material in air, g | 50.00 | 50.00 | 50.00 |
| 4 | Pycnometer + water + material after test, g | 372.10 | 370.70 | 371.10 |
| 5 | Material weight in water (4 - 2), g | 29.96 | 29.98 | 29.89 |
| 6 | Weight of material in air - weight of material in water (3 - 5), g | 20.04 | 20.02 | 20.11 |
| 7 | Specific gravity filler (3/6) | 2,495 | 2,498 | 2,486 |
| 8 | Average Specific Gravity | | 2,493 | |

| | | | |
|--------------------------------------|--|--|--|
| DENSITY OF THE TESTED SAMPLES | | | |
|--------------------------------------|--|--|--|

| # | WET DENSITY | | |
|----|-----------------------------------|---------|---------|
| 9 | can number | Z-14 | I |
| 10 | Can + moist soil, g | 115.40 | 115.90 |
| 11 | Can weight, g | 13.40 | 13.68 |
| 12 | Wet soil weight, g | 102.00 | 102.22 |
| 13 | Container volume, cm ³ | 69.06 | 69.06 |
| 14 | Wet density, g/cm ³ | 1.48 | 1.48 |
| 15 | Wet density, kg/m ³ | 1476.98 | 1480.16 |
| 16 | Avg Wet Density kg/m ³ | 1478.57 | |

| # | DRY DENSITY | | |
|----|-----------------------------------|---------|---------|
| 25 | can number | Z-14 | I |
| 26 | Can + moist soil, g | 115.40 | 115.90 |
| 27 | Can + dry soil, g | 99.90 | 101.10 |
| 28 | Moisture weight, g | 15.50 | 14.80 |
| 29 | Container volume, cm ³ | 69.06 | 69.06 |
| 30 | Can weight, g | 13.40 | 13.68 |
| 31 | Dry soil weight, g | 86.50 | 87.42 |
| 32 | % moisture | 17.92 | 16.93 |
| 33 | Dry density, kg/m ³ | 1253.88 | 1264.49 |
| 34 | Avg dry density kg/m ³ | 1259.19 | |

| # | NATURAL HUMIDITY | | |
|----|---------------------|--|--|
| 17 | can number | | |
| 18 | Can + moist soil, g | | |
| 19 | Can + dry soil, g | | |
| 20 | Moisture weight, g | | |
| 21 | Can weight, g | | |
| 22 | Dry soil weight, g | | |
| 23 | % moisture | | |
| 24 | Average Moisture % | | |

Observations:

| | | | | | | |
|---|-----|-----------------------------|-----------|-------------|----------------------|-----------|
| GRANULOMETRIC ANALYSIS, ATTERBERG LIMITS AND SOIL CLASSIFICATION | | | | | Code: | LA-F0001 |
| | | | | | Version: | 7 |
| Produced by: | RAA | Date of elaboration: | 24-Sep-05 | page 1 of 1 | Passed: | RAF |
| | | | | | Last version: | 10-Jul-20 |

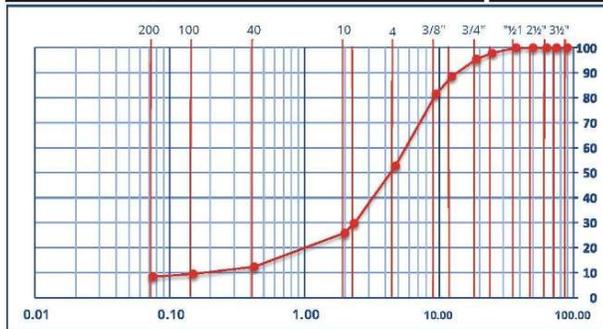
Draft: _____ Landfill Sample # 1171
 Station or precedence: _____ Pit No. 4 Lab Code: LC
 Hole or pit: 4 Gauge: N/A Depth in meters: N/A a N/A
 Taken by: The interested Date taken: 16-Sep-21
 Tested by: Jorge Gomez Rehearsed date: 22-Sep-21
 Material designation: Existing soil Side: N/A

SOIL SIZE ANALYSIS BY SIEVE (ASTM D422/AASHTO T88)

| Sieve No. | | Weight | | Percentage | | Corduroy # | XY | Total air dried sample: | |
|-----------|-------|-------------|----------|------------|-------|------------|----|-------------------------|-------------------|
| in. | mm | Ret. Accum. | Retained | | | | | 1510.3 | Total dry sample: |
| 3 1/2" | 90.00 | | | | | | | | |
| 3" | 75.00 | | | | | | | | |
| 2 1/2" | 63.00 | | | | | | | | |
| 2" | 50.00 | | | | | | | | |
| 1 1/2" | 37.50 | 0.0 | 0.0 | | 100.0 | | | | |
| 1" | 25.00 | 28.5 | 2.0 | | 98.0 | | | | |
| 3/4" | 19.00 | 63.0 | 4.5 | | 95.5 | | | | |
| 1/2" | 12.50 | 159.2 | 11.4 | | 88.6 | | | | |
| 3/8" | 9.50 | 258.8 | 18.5 | | 81.5 | | | | |
| #4 | 4.75 | 661.2 | 47.3 | | 52.7 | | | | |
| Bottom | | | | | | | | | |
| Total | | | | | | | | | |

| Sieve No. | Weight | Percentage | | | |
|-----------|--------|-------------|----------|-------|-----------|
| in. | mm | Ret. Accum. | Retained | Pass | corrected |
| #8 | 2.36 | 981.3 | 70.22 | 29.78 | 29.78 |
| #10 | 2.00 | 1,035.3 | 74.09 | 25.91 | 25.91 |
| #40 | 0.425 | 1,225.1 | 87.67 | 12.33 | 12.33 |
| #100 | 0.150 | 1,265.7 | 90.58 | 9.42 | 9.42 |
| #200 | 0.075 | 1,280.8 | 91.66 | 8.34 | 8.34 |
| Bottom | | | | | |
| Total | | | | | |

| | | | |
|--------------------------------------|--|----------------|-------------------------------------|
| DESCRIPTIVE INFORMATION OF THE SOILS | | organic soil | <input type="checkbox"/> |
| | | inorganic soil | <input checked="" type="checkbox"/> |



| HUMIDITY (ASTM D2216/AASHTO T265) | | HUMIDITY NATURAL | HUMIDITY SAMPLE |
|-----------------------------------|--|------------------|-----------------|
| Can + moist soil, g | | | 499.3 |
| Can + dry soil, g | | | 473.6 |
| Can weight, g | | X-3 | 155.5 |
| Moisture weight, g | | | 25.7 |
| Dry soil weight, g | | | 318.1 |
| Hygroscopic humidity, % | | | 8.1 |
| H. Hydros corrected factor. | | | 0.925247 |

| SOIL CLASSIFICATION | | |
|---------------------|-------------------------------------|----------|
| 1 | AASHTO classification (AASHTO M145) | A-1a (0) |
| 2 | SUCS Classification (ASTM D2487) | SP-SM |

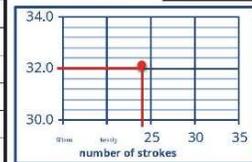
| DIAMETERS (mm) and COEFFICIENTS | | | | | | | | |
|---------------------------------|-----------------|-------|---|-----------------|--------|---|----------------|-------|
| 1 | D ₁₀ | 0.204 | 3 | D ₆₀ | 5,957 | 5 | C _u | 29.14 |
| 2 | D ₃₀ | 2,383 | 4 | D ₉₀ | 13,815 | 6 | C _c | 4.66 |

ATTERBERG LIMITS (ASTM D4318/AASHTO T89-T90)

Tested by: Yelson Ramirez Test date: 22-Sep-21

| # | DESCRIPTION | LIQUID LIMIT | | PLASTIC LIMIT | |
|---|---------------------|--------------|-------|---------------|-------|
| | | MH | HN-8 | XL | A-2 |
| 1 | Can # | | | | |
| 2 | # of hits | 24 | 24 | - | - |
| 3 | Can + moist soil, g | 37.22 | 37.34 | 31.11 | 30.05 |
| 4 | Can + dry soil, g | 33.55 | 33.55 | 29.21 | 28.51 |
| 5 | Moisture weight, g | 3.67 | 3.79 | 1.90 | 1.54 |
| 6 | Can weight, g | 22.13 | 21.76 | 22.05 | 22.50 |
| 7 | Dry soil weight, g | 11.42 | 11.79 | 7.16 | 6.01 |
| 8 | % moisture | 32.14 | 32.15 | 26.54 | 25.62 |

Liquid limit: 32
 Plastic limit: 26
 Plasticity index: 6



| | | | | | |
|--|-----|-----------------------------|-----------|----------------------|-----------|
| SPECIFIC GRAVITY OF SOILS WITH PYCNOMETER | | | | Code: | LA-FO010 |
| | | | | Version: | 3 |
| | | | | Approved: | RAF |
| Produced by: | RAF | Date of elaboration: | 07-Apr-16 | Last version: | 15-Feb-19 |

Draft: _____ Landfill _____ Sample # _____ 1171
Origin of the sample: _____ Pit No. 4 _____ Lab Code: _____ LC
Tested by: _____ Peter Funes _____ Probe: _____ N/A _____ SPT: _____ N/A _____ Date: _____ 23-Sep-21
Material designation: _____ Existing Soil _____ Depth, m: _____ -

| SPECIFIC GRAVITY OF SOILS USING A PYCNOMETER WITH WATER (ASTM D854/AASHTO T100) | | | | |
|---|--|--------|--------|--------|
| # | TEST STEPS | 1 | 2 | 3 |
| 1 | Pycnometer number | 10 | | 12 |
| 2 | Weight of pycnometer + water, g | 645.06 | 641.24 | 648.36 |
| 3 | Weight of material in air, g | 100.00 | 100.00 | 100.00 |
| 4 | Pycnometer + water + material after test, g | 705.90 | 702.20 | 709.30 |
| 5 | Material weight in water (4 - 2), g | 60.84 | 60.96 | 60.94 |
| 6 | Weight of material in air - weight of material in water (3 - 5), g | 39.16 | 39.04 | 39.06 |
| 7 | Specific gravity filler (3/6) | 2,554 | 2,561 | 2,560 |
| 8 | Average Specific Gravity | | 2,558 | |

| DENSITY OF THE TESTED SAMPLES | | | | | | | |
|-------------------------------|-----------------------------------|---------|---------|----|-----------------------------------|---------|---------|
| # | WET DENSITY | | | # | DRY DENSITY | | |
| 9 | can number | LI | ND-2 | 25 | can number | LI | ND-2 |
| 10 | Can + moist soil, g | 122.90 | 121.60 | 26 | Can + moist soil, g | 122.90 | 121.60 |
| 11 | Can weight, g | 13.30 | 13.50 | 27 | Can + dry soil, g | 112.60 | 111.90 |
| 12 | Wet soil weight, g | 109.60 | 108.10 | 28 | Moisture weight, g | 10.30 | 9.70 |
| 13 | Container volume, cm ³ | 69.06 | 69.06 | 29 | Container volume, cm ³ | 69.06 | 69.06 |
| 14 | Wet density, g/cm ³ | 1.59 | 1.57 | 30 | Can weight, g | 13.30 | 13.50 |
| 15 | Wet density, kg/m ³ | 1587.03 | 1565.31 | 31 | Dry soil weight, g | 99.30 | 98.40 |
| 16 | Avg Wet Density kg/m ³ | 1576.17 | | 32 | % moisture | 10.37 | 9.86 |
| | | | | 33 | Dry density, kg/m ³ | 1428.04 | 1434.73 |
| | | | | 34 | Avg dry density kg/m ³ | 1431.39 | |

| # | NATURAL HUMIDITY | | |
|----|---------------------|--|--|
| 17 | can number | | |
| 18 | Can + moist soil, g | | |
| 19 | Can + dry soil, g | | |
| 20 | Moisture weight, g | | |
| 21 | Can weight, g | | |
| 22 | Dry soil weight, g | | |
| 23 | % moisture | | |
| 24 | Average Moisture % | | |

Observations:

| | | | | | | |
|---|--|--|--|--|---------------|-----------|
| GRANULOMETRIC ANALYSIS, ATTERBERG LIMITS AND SOIL CLASSIFICATION | | | | | Code: | LA-FO001 |
| | | | | | Version: | 7 |
| Produced by: RAA Date of elaboration: 24-Sep-05 page 1 of 1 | | | | | Passed: | RAF |
| | | | | | Last version: | 10-Jul-20 |

Draft: _____ Landfill Sample # 1172
 Station or precedence: _____ Pit No. 7 Lab Code: LC
 Hole or pit: 7 Gauge: N/A Depth in meters: N/A a N/A
 Taken by: The interested Date taken: 16-Sep-21
 Tested by: Jorge Gomez Rehearsed date: 22-Sep-21
 Material designation: Existing soil Side: N/A

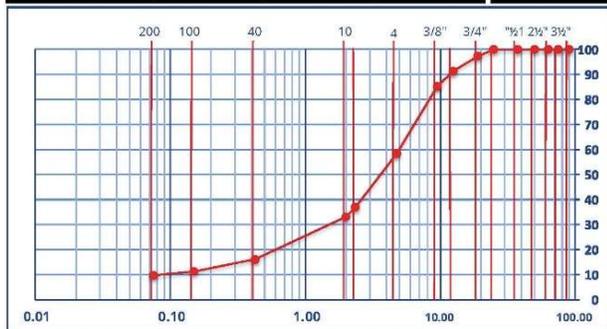
SOIL SIZE ANALYSIS BY SIEVE (ASTM D422/AASHTO T88)

| Sieve No. | Weight | Percentage | | |
|-----------|--------|-------------|----------|-------|
| in. | mm | Ret. Accum. | Retained | Pass |
| 3 1/2" | 90.00 | | | |
| 3" | 75.00 | | | |
| 2 1/2" | 63.00 | | | |
| 2" | 50.00 | | | |
| 1 1/2" | 37.50 | | | |
| 1" | 25.00 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.00 | 26.7 | 2.7 | 97.3 |
| 1/2" | 12.50 | 86.0 | 8.7 | 91.3 |
| 3/8" | 9.50 | 146.2 | 14.7 | 85.3 |
| #4 | 4.75 | 413.6 | 41.7 | 58.3 |
| Bottom | | | | |
| Total | | | | |

Conduroy # P5 Total air dried sample: 1101.2
Total dry sample: 992.6

| Sieve No. | Weight | Percentage | | | |
|-----------|--------|-------------|----------|-------|-----------|
| in. | mm | Ret. Accum. | Retained | Pass | corrected |
| #8 | 2.36 | 625.7 | 63.04 | 36.96 | 36.96 |
| #10 | 2.00 | 663.8 | 66.88 | 33.12 | 33.12 |
| #40 | 0.425 | 832.6 | 83.88 | 16.12 | 16.12 |
| #100 | 0.150 | 880.6 | 88.72 | 11.28 | 11.28 |
| #200 | 0.075 | 896.2 | 90.29 | 9.71 | 9.71 |
| Bottom | | | | | |
| Total | | | | | |

| | | |
|--------------------------------------|----------------|-------------------------------------|
| DESCRIPTIVE INFORMATION OF THE SOILS | organic soil | <input type="checkbox"/> |
| | inorganic soil | <input checked="" type="checkbox"/> |



| HUMIDITY (ASTM D2216/AASHTO T265) | HUMIDITY NATURAL | HUMIDITY SAMPLE |
|-----------------------------------|------------------|-----------------|
| Can + moist soil, g | | 333.8 |
| Can + dry soil, g | | 306.6 |
| Can weight, g | | B-4 58.1 |
| Moisture weight, g | | 27.2 |
| Dry soil weight, g | | 248.5 |
| Hygroscopic humidity, % | | 10.9 |
| H. Hydros corrected factor. | | 0.901342 |

| SOIL CLASSIFICATION | |
|---------------------|--|
| 1 | AASHTO classification (AASHTO M145) A-1a (0) |
| 2 | SUCS Classification (ASTM D2487) SP-SM |

| DIAMETERS (mm) and COEFFICIENTS | | | | | |
|---------------------------------|-----------------|-------|---|-----------------|--------|
| 1 | D ₁₀ | 0.089 | 3 | D ₆₀ | 5.044 |
| 2 | D ₃₀ | 1,711 | 4 | D ₉₀ | 11,839 |
| | | | 5 | C _{OR} | 56.72 |
| | | | 6 | C _c | 6.52 |

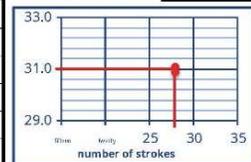
| SLIME AND/OR CLAY | SAND | | | GRAVEL |
|-------------------|------|------|-------|--------|
| | FINE | HALF | GROSS | |
| | | | | |

ATTERBERG LIMITS (ASTM D4318/AASHTO T89-T90)

Tested by: Yelson Ramirez Test date: 22-Sep-21

| # | DESCRIPTION | LIQUID LIMIT | | PLASTIC LIMIT | |
|---|---------------------|--------------|-------|---------------|-------|
| | | 22-L | C-1 | HN-4 | H-10 |
| 1 | Can # | | | | |
| 2 | # of hits | 28 | 28 | - | - |
| 3 | Can + moist soil, g | 38.06 | 41.62 | 31.00 | 30.59 |
| 4 | Can + dry soil, g | 34.38 | 37.17 | 29.25 | 28.92 |
| 5 | Moisture weight, g | 3.68 | 4.45 | 1.75 | 1.67 |
| 6 | Can weight, g | 22.46 | 22.85 | 22.71 | 22.73 |
| 7 | Dry soil weight, g | 11.92 | 14.32 | 6.54 | 6.19 |
| 8 | % moisture | 30.87 | 31.08 | 26.76 | 26.98 |

Liquid limit: 31
 Plastic limit: 27
 Plasticity index: 4



| | | | | | |
|--|-----|-----------------------------|-----------|----------------------|-----------|
| SPECIFIC GRAVITY OF SOILS WITH PYCNOMETER | | | | Code: | LA-FO010 |
| | | | | Version: | 3 |
| Produced by: | RAF | Date of elaboration: | 07-Apr-16 | Approved: | RAF |
| | | | | Last version: | 15-Feb-19 |

Draft: _____ Landfill _____ Sample # _____ 1172
Origin of the sample: _____ Pit No. 7 _____ Lab Code: _____ LC
Tested by: _____ Peter Funes _____ Probe: _____ N/A _____ SPT: _____ N/A _____ Date: _____ 23-Sep-21
Material designation: _____ Existing Soil _____ Depth, m: _____ -

| SPECIFIC GRAVITY OF SOILS USING A PYCNOMETER WITH WATER (ASTM D854/AASHTO T100) | | | | |
|---|--|--------|--------|--------|
| # | TEST STEPS | 1 | 2 | 3 |
| 1 | Pycnometer number | 1 | 3 | 4 |
| 2 | Weight of pycnometer + water, g | 642.18 | 651.80 | 651.50 |
| 3 | Weight of material in air, g | 100.00 | 100.00 | 100.00 |
| 4 | Pycnometer + water + material after test, g | 702.50 | 711.90 | 711.70 |
| 5 | Material weight in water (4 - 2), g | 60.32 | 60.10 | 60.20 |
| 6 | Weight of material in air - weight of material in water (3 - 5), g | 39.68 | 39.90 | 39.80 |
| 7 | Specific gravity filler (3/6) | 2,520 | 2,506 | 2,513 |
| 8 | Average Specific Gravity | 2,513 | | |

| DENSITY OF THE TESTED SAMPLES | | | | | | | |
|-------------------------------|-----------------------------------|---------|---------|----|-----------------------------------|---------|---------|
| # | WET DENSITY | | | # | DRY DENSITY | | |
| 9 | can number | J-2 | I | 25 | can number | J-2 | ND-2 |
| 10 | Can + moist soil, g | 117.70 | 119.00 | 26 | Can + moist soil, g | 117.70 | 119.00 |
| 11 | Can weight, g | 13.30 | 13.65 | 27 | Can + dry soil, g | 105.30 | 106.30 |
| 12 | Wet soil weight, g | 104.40 | 105.35 | 28 | Moisture weight, g | 12.40 | 12.70 |
| 13 | Container volume, cm ³ | 69.06 | 69.06 | 29 | Container volume, cm ³ | 69.06 | 69.06 |
| 14 | Wet density, g/cm ³ | 1.51 | 1.53 | 30 | Can weight, g | 13.30 | 13.65 |
| 15 | Wet density, kg/m ³ | 1511.73 | 1525.49 | 31 | Dry soil weight, g | 92.00 | 92.65 |
| 16 | Avg Wet Density kg/m ³ | 1518.61 | | 32 | % moisture | 13.48 | 13.71 |
| | | | | 33 | Dry density, kg/m ³ | 1338.24 | 1335.54 |
| | | | | 34 | Avg dry density kg/m ³ | 1336.89 | |

| # | NATURAL HUMIDITY | | |
|----|---------------------|--|--|
| 17 | can number | | |
| 18 | Can + moist soil, g | | |
| 19 | Can + dry soil, g | | |
| 20 | Moisture weight, g | | |
| 21 | Can weight, g | | |
| 22 | Dry soil weight, g | | |
| 23 | % moisture | | |
| 24 | Average Moisture % | | |

Observations:

| | | | | | | |
|---|--|--|--|--|----------------------|-----------|
| GRANULOMETRIC ANALYSIS, ATTERBERG LIMITS AND SOIL CLASSIFICATION | | | | | Code: | LA-F0001 |
| | | | | | Version: | 7 |
| Produced by: RAA Date of elaboration: 24-Sep-05 page 1 of 1 | | | | | Passed: | RAF |
| | | | | | Last version: | 10-Jul-20 |

Draft: _____ Landfill Sample # 1173

Station or precedence: _____ Pit No. 1 Lab Code: LC

Hole or pit: one Gauge: N/A Depth in meters: N/A a N/A

Taken by: _____ The interested Date taken: 16-Sep-21

Tested by: Jorge Gomez Rehearsed date: 22-Sep-21

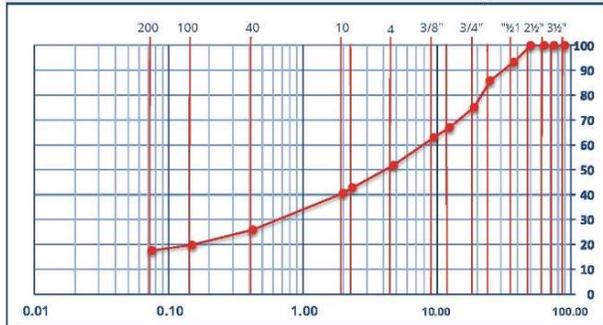
Material designation: _____ Existing soil Side: N/A

SOIL SIZE ANALYSIS BY SIEVE (ASTM D422/AASHTO T88)

| Sieve No. | Weight | Percentage | | | Corduroy # | Total air dried sample | Total dry sample |
|-----------|--------|-------------|----------|-------|------------|------------------------|------------------|
| in. | mm | Ret. Accum. | Retained | Pass | | | |
| 3 1/2" | 90.00 | | | | FZ | 1544.3 | 1378.4 |
| 3" | 75.00 | | | | | | |
| 2 1/2" | 63.00 | | | | | | |
| 2" | 50.00 | 0.0 | 0.0 | 100.0 | | | |
| 1 1/2" | 37.50 | 91.6 | 6.6 | 93.4 | | | |
| 1" | 25.00 | 195.0 | 14.1 | 85.9 | | | |
| 3/4" | 19.00 | 341.2 | 24.8 | 75.2 | | | |
| 1/2" | 12.50 | 453.3 | 32.9 | 67.1 | | | |
| 3/8" | 9.50 | 510.0 | 37.0 | 63.0 | | | |
| #4 | 4.75 | 663.8 | 48.2 | 51.8 | | | |
| Bottom | | | | | | | |
| Total | | | | | | | |

| Sieve No. | Weight | Percentage | | | |
|-----------|--------|-------------|----------|-------|-----------|
| in. | mm | Ret. Accum. | Retained | Pass | corrected |
| #8 | 2.36 | 787.9 | 57.16 | 42.84 | 42.84 |
| #10 | 2.00 | 819.0 | 59.42 | 40.58 | 40.58 |
| #40 | 0.425 | 1,021.8 | 74.13 | 25.87 | 25.87 |
| #100 | 0.150 | 1,105.7 | 80.22 | 19.78 | 19.78 |
| #200 | 0.075 | 1,136.6 | 82.46 | 17.54 | 17.54 |
| Bottom | | | | | |
| Total | | | | | |

| | | |
|--------------------------------------|----------------|-------------------------------------|
| DESCRIPTIVE INFORMATION OF THE SOILS | organic soil | <input type="checkbox"/> |
| | inorganic soil | <input checked="" type="checkbox"/> |



| | HUMIDITY (ASTM D2216/AASHTO T265) | HUMIDITY NATURAL | HUMIDITY SAMPLE |
|-----------------------------|-----------------------------------|------------------|-----------------|
| Can + moist soil, g | | | 424.7 |
| Can + dry soil, g | | | 395.8 |
| Can weight, g | | | F-13 155.7 |
| Moisture weight, g | | | 28.9 |
| Dry soil weight, g | | | 240.1 |
| Hygroscopic humidity, % | | | 12.0 |
| H. Hydros corrected factor. | | | 0.892565 |

| SOIL CLASSIFICATION | | |
|---------------------|-------------------------------------|-----------|
| 1 | AASHTO classification (AASHTO M145) | A-2-7 (0) |
| 2 | SUCS Classification (ASTM D2487) | YE |

| DIAMETERS (mm) and COEFFICIENTS | | | | | | | | |
|---------------------------------|-----------------|-------|---|-----------------|--------|---|----------------|---|
| 1 | D ₁₀ | 0.000 | 3 | D ₆₀ | 8,223 | 5 | C _u | - |
| 2 | D ₃₀ | 0.867 | 4 | D ₅₀ | 31,910 | 6 | C _c | - |

ATTERBERG LIMITS (ASTM D4318/AASHTO T89-T90)

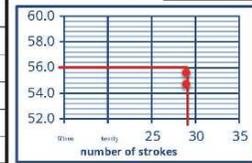
Tested by: Yelson Ramirez Test date: 22-Sep-21

| # | DESCRIPTION | LIQUID LIMIT | | | PLASTIC LIMIT | |
|---|---------------------|--------------|-------|--|---------------|-------|
| | | MH | HN-8 | | H-10 | HN-4 |
| 1 | Can # | | | | | |
| 2 | # of hits | 29 | 29 | | - | - |
| 3 | Can + moist soil, g | 33.10 | 34.12 | | 32.08 | 32.37 |
| 4 | Can + dry soil, g | 29.18 | 29.75 | | 29.84 | 30.08 |
| 5 | Moisture weight, g | 3.92 | 4.37 | | 2.24 | 2.29 |
| 6 | Can weight, g | 22.13 | 21.76 | | 22.73 | 22.71 |
| 7 | Dry soil weight, g | 7.05 | 7.99 | | 7.11 | 7.37 |
| 8 | % moisture | 55.60 | 54.69 | | 31.50 | 31.07 |

Liquid limit: 56

Plastic limit: 31

Plasticity index: 25



| | | | | | |
|--|--|--|--|---------------------|----------|
| SPECIFIC GRAVITY OF SOILS WITH PYCNOMETER | | | | Code: | LA-FO010 |
| | | | | Version: | 3 |
| | | | | Approved: | RAF |
| | | | | Produced by: | RAF |

Draft: _____ Landfill _____ Sample # 1173
 Origin of the sample: _____ Pit No. 1 _____ Lab Code: LC
 Tested by: _____ Peter Funes _____ Probe: N/A SPT: N/A Date: 23-Sep-21
 Material designation: _____ Existing Soil _____ Depth, m: -

| | | | |
|--|--|--|--|
| SPECIFIC GRAVITY OF SOILS USING A PYCNOMETER WITH WATER (ASTM D854/AASHTO T100) | | | |
|--|--|--|--|

| # | TEST STEPS | 1 | 2 | 3 |
|---|--|--------|--------|--------|
| 1 | Pycnometer number | 5 | 6 | 7 |
| 2 | Weight of pycnometer + water, g | 652.20 | 647.90 | 649.64 |
| 3 | Weight of material in air, g | 100.00 | 100.00 | 100.00 |
| 4 | Pycnometer + water + material after test, g | 714.80 | 710.60 | 712.30 |
| 5 | Material weight in water (4 - 2), g | 62.60 | 62.70 | 62.66 |
| 6 | Weight of material in air - weight of material in water (3 - 5), g | 37.40 | 37.30 | 37.34 |
| 7 | Specific gravity filler (3/6) | 2,674 | 2,681 | 2,678 |
| 8 | Average Specific Gravity | | 2,678 | |

| | | | |
|--------------------------------------|--|--|--|
| DENSITY OF THE TESTED SAMPLES | | | |
|--------------------------------------|--|--|--|

| WET DENSITY | | | | DRY DENSITY | | | |
|-------------|-----------------------------------|---------|---------|-------------|-----------------------------------|---------|---------|
| # | | B-5 | B-13 | # | | B-5 | B-13 |
| 9 | can number | B-5 | B-13 | 25 | can number | B-5 | B-13 |
| 10 | Can + moist soil, g | 114.80 | 112.10 | 26 | Can + moist soil, g | 114.80 | 112.10 |
| 11 | Can weight, g | 13.60 | 13.58 | 27 | Can + dry soil, g | 96.40 | 93.60 |
| 12 | Wet soil weight, g | 101.20 | 98.52 | 28 | Moisture weight, g | 18.40 | 18.50 |
| 13 | Container volume, cm ³ | 69.06 | 69.06 | 29 | Container volume, cm ³ | 69.06 | 69.06 |
| 14 | Wet density, g/cm ³ | 1.47 | 1.43 | 30 | Can weight, g | 13.60 | 13.58 |
| 15 | Wet density, kg/m ³ | 1465.39 | 1426.59 | 31 | Dry soil weight, g | 82.80 | 80.02 |
| 16 | Avg Wet Density kg/m ³ | 1445.99 | | 32 | % moisture | 22.22 | 23.12 |
| | | | | 33 | Dry density, kg/m ³ | 1183.08 | 1174.46 |
| | | | | 34 | Avg dry density kg/m ³ | 1178.77 | |

| # | NATURAL HUMIDITY | | |
|----|---------------------|--|--|
| 17 | can number | | |
| 18 | Can + moist soil, g | | |
| 19 | Can + dry soil, g | | |
| 20 | Moisture weight, g | | |
| 21 | Can weight, g | | |
| 22 | Dry soil weight, g | | |
| 23 | % moisture | | |
| 24 | Average Moisture % | | |

Observations:

| | | | | | | | |
|---|-----|-----------------------------|-----------|-------------|----------------------|-----------------|----------|
| GRANULOMETRIC ANALYSIS, ATTERBERG LIMITS AND SOIL CLASSIFICATION | | | | | | Code: | LA-F0001 |
| | | | | | | Version: | 7 |
| Produced by: | RAA | Date of elaboration: | 24-Sep-05 | page 1 of 1 | Last version: | 10-Jul-20 | |

Draft: _____ Landfill _____ Sample # 1174
 Station or precedence: _____ Pit No. 9 _____ Lab Code: LC
 Hole or pit: 9 Gauge: N/A Depth in meters: N/A a N/A
 Taken by: The interested Date taken: 16-Sep-21
 Tested by: Jorge Gomez Rehearsed date: 22-Sep-21
 Material designation: _____ Existing soil _____ Side: N/A

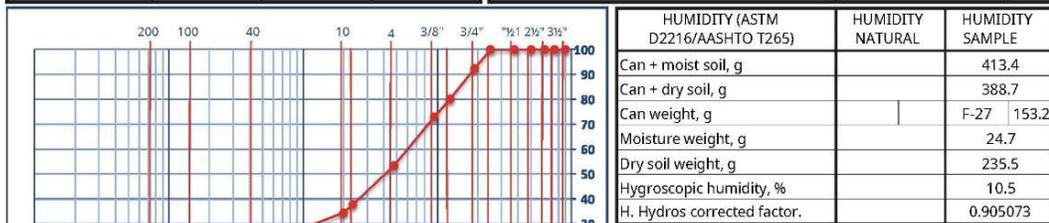
SOIL SIZE ANALYSIS BY SIEVE (ASTM D422/AASHTO T88)

| Sieve No. | Weight | Percentage | | |
|-----------|--------|-------------|----------|-------|
| in. | mm | Ret. Accum. | Retained | Pass |
| 3 1/2" | 90.00 | | | |
| 3" | 75.00 | | | |
| 2 1/2" | 63.00 | | | |
| 2" | 50.00 | | | |
| 1 1/2" | 37.50 | | | |
| 1" | 25.00 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.00 | 77.7 | 7.5 | 92.5 |
| 1/2" | 12.50 | 205.2 | 19.9 | 80.1 |
| 3/8" | 9.50 | 278.9 | 27.0 | 73.0 |
| #4 | 4.75 | 482.3 | 46.7 | 53.3 |
| Bottom | | | | |
| Total | | | | |

Conduity # EA-5 Total air dried sample: 1141.6
 Total dry sample: 1033.2

| Sieve No. | Weight | Percentage | | |
|-----------|--------|-------------|----------|-------|
| in. | mm | Ret. Accum. | Retained | Pass |
| #8 | 2.36 | 643.1 | 62.24 | 37.76 |
| #10 | 2.00 | 677.2 | 65.54 | 34.46 |
| #40 | 0.425 | 822.8 | 79.63 | 20.37 |
| #100 | 0.150 | 875.4 | 84.72 | 15.28 |
| #200 | 0.075 | 899.5 | 87.06 | 12.94 |
| Bottom | | | | |
| Total | | | | |

| | | |
|--------------------------------------|----------------|-------------------------------------|
| DESCRIPTIVE INFORMATION OF THE SOILS | organic soil | <input type="checkbox"/> |
| | inorganic soil | <input checked="" type="checkbox"/> |



| SOIL CLASSIFICATION | | |
|---------------------|-------------------------------------|-----------|
| 1 | AASHTO classification (AASHTO M145) | A-2-7 (0) |
| 2 | SUCS Classification (ASTM D2487) | YE |

| DIAMETERS (mm) and COEFFICIENTS | | | | | |
|---------------------------------|-----------------|-------|---|-----------------|--------|
| 1 | D ₁₀ | 0,000 | 3 | D ₆₀ | 6,362 |
| 2 | D ₃₀ | 1,502 | 4 | D ₈₀ | 17,694 |
| 5 | C _U | - | 6 | C _c | - |

ATTERBERG LIMITS (ASTM D4318/AASHTO T89-T90)

Tested by: Yelson Ramirez Test date: 21-Sep-21

| # | DESCRIPTION | LIQUID LIMIT | | PLASTIC LIMIT | |
|---|---------------------|--------------|-------|---------------|-------|
| | | C-13 | MH | HN-7 | A-2 |
| 1 | Can # | | | | |
| 2 | # of hits | 25 | 25 | - | - |
| 3 | Can + moist soil, g | 34.15 | 34.05 | 33.74 | 34.13 |
| 4 | Can + dry soil, g | 30.47 | 30.47 | 31.18 | 31.58 |
| 5 | Moisture weight, g | 3.68 | 3.58 | 2.56 | 2.55 |
| 6 | Can weight, g | 21.80 | 22.13 | 22.13 | 22.50 |
| 7 | Dry soil weight, g | 8.67 | 8.34 | 9.05 | 9.08 |
| 8 | % moisture | 42.45 | 42.93 | 28.29 | 28.08 |

Liquid limit: 43
 Plastic limit: 28
 Plasticity index: _____

| | | | | | |
|--|-----|-----------------------------|-----------|----------------------|-----------|
| SPECIFIC GRAVITY OF SOILS WITH PYCNOMETER | | | | Code: | LA-FO010 |
| | | | | Version: | 3 |
| | | | | Approved: | RAF |
| Produced by: | RAF | Date of elaboration: | 07-Apr-16 | Last version: | 15-Feb-19 |

Draft: _____ Landfill _____ Sample # _____ 1174
Origin of the sample: _____ Pit No. 9 _____ Lab Code: _____ LC
Tested by: _____ Peter Funes _____ Probe: _____ N/A _____ SPT: _____ N/A _____ Date: _____ 22-Sep-21
Material designation: _____ Existing Soil _____ Depth, m: _____ -

| SPECIFIC GRAVITY OF SOILS USING A PYCNOMETER WITH WATER (ASTM D854/AASHTO T100) | | | | |
|---|--|--------|--------|--------|
| # | TEST STEPS | 1 | 2 | 3 |
| 1 | Pycnometer number | 3 | 5 | 6 |
| 2 | Weight of pycnometer + water, g | 342.14 | 340.72 | 341.21 |
| 3 | Weight of material in air, g | 50.00 | 50.00 | 50.00 |
| 4 | Pycnometer + water + material after test, g | 372.70 | 371.20 | 371.70 |
| 5 | Material weight in water (4 - 2), g | 30.56 | 30.48 | 30.49 |
| 6 | Weight of material in air - weight of material in water (3 - 5), g | 19.44 | 19.52 | 19.51 |
| 7 | Specific gravity filler (3/6) | 2,572 | 2,561 | 2,563 |
| 8 | Average Specific Gravity | 2,565 | | |

| DENSITY OF THE TESTED SAMPLES | | | | | | |
|-------------------------------|-----------------------------------|---------|---------|------|-----------------------------------|-----------------|
| # | WET DENSITY | | | # | DRY DENSITY | |
| 9 | can number | 9-136 | X-5 | 25 | can number | 9136 X-5 |
| 10 | Can + moist soil, g | 115.90 | 109.50 | 26 | Can + moist soil, g | 115.90 109.50 |
| 11 | Can weight, g | 13.80 | 13.60 | 27 | Can + dry soil, g | 102.70 97.00 |
| 12 | Wet soil weight, g | 102.10 | 95.90 | 28 | Moisture weight, g | 13.20 12.50 |
| 13 | Container volume, cm ³ | 69.06 | 69.06 | 29 | Container volume, cm ³ | 69.06 69.06 |
| 14 | Wet density, g/cm ³ | 1.48 | 1.39 | 30 | Can weight, g | 13.80 13.60 |
| 15 | Wet density, kg/m ³ | 1478.42 | 1388.65 | 31 | Dry soil weight, g | 88.90 83.40 |
| 16 | Avg Wet Density kg/m ³ | 1433.54 | | 32 | % moisture | 14.85 14.99 |
| | | | | 33 | Dry density, kg/m ³ | 1248.20 1246.68 |
| | | | | 3. 4 | Avg dry density kg/m ³ | 1247.44 |

| # | NATURAL HUMIDITY | | |
|----|---------------------|--|--|
| 17 | can number | | |
| 18 | Can + moist soil, g | | |
| 19 | Can + dry soil, g | | |
| 20 | Moisture weight, g | | |
| 21 | Can weight, g | | |
| 22 | Dry soil weight, g | | |
| 23 | % moisture | | |
| 24 | Average Moisture % | | |

Observations:

| | | | | | | |
|---|--|--|--|--|----------------------|-----------|
| GRANULOMETRIC ANALYSIS, ATTERBERG LIMITS AND SOIL CLASSIFICATION | | | | | Code: | LA-F0001 |
| | | | | | Version: | 7 |
| Produced by: RAA Date of elaboration: 24-Sep-05 page 1 of 1 | | | | | Passed: | RAF |
| | | | | | Last version: | 10-Jul-20 |

Draft: _____ Landfill _____ Sample # 1175

Station or procedure: _____ Pit No. 10 _____ Lab Code: LC

Hole or pit: 10 Gauge: N/A Depth in meters: N/A a N/A

Taken by: _____ The interested _____ Date taken: 16-Sep-21

Tested by: Jorge Gomez Rehearsed date: 22-Sep-21

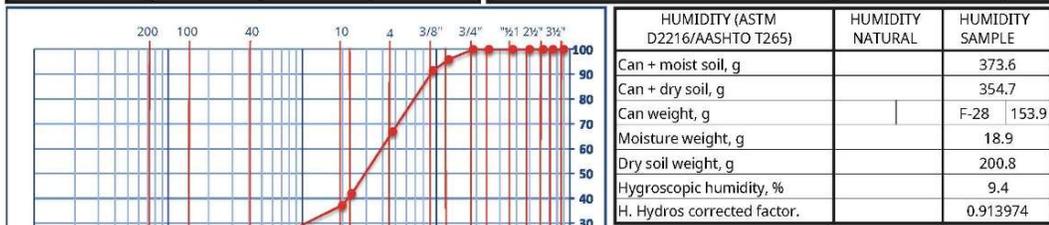
Material designation: _____ Existing soil _____ Side: N/A

SOIL SIZE ANALYSIS BY SIEVE (ASTM D422/AASHTO T88)

| Sieve No. | | Weight | | Percentage | | | Corduroy # <u>JG-8</u> | Total air dried sample: <u>1463.9</u> | |
|-----------|-------|-------------|----------|------------|--|--|------------------------|---------------------------------------|---------------|
| in. | mm | Ret. Accum. | Retained | Pass | | | | Total dry sample: | <u>1338.0</u> |
| 3 1/2" | 90.00 | | | | | | | | |
| 3" | 75.00 | | | | | | | | |
| 2 1/2" | 63.00 | | | | | | | | |
| 2" | 50.00 | | | | | | | | |
| 1 1/2" | 37.50 | | | | | | | | |
| 1" | 25.00 | | | | | | | | |
| 3/4" | 19.00 | 0.0 | 0.0 | 100.0 | | | | | |
| 1/2" | 12.50 | 54.1 | 4.0 | 96.0 | | | | | |
| 3/8" | 9.50 | 114.3 | 8.5 | 91.5 | | | | | |
| #4 | 4.75 | 442.1 | 33.0 | 67.0 | | | | | |
| Bottom | | | | | | | | | |
| Total | | | | | | | | | |

| Sieve No. | | Weight | | Percentage | | |
|-----------|-------|-------------|----------|------------|-----------|--|
| in. | mm | Ret. Accum. | Retained | Pass | corrected | |
| #8 | 2.36 | 776.8 | 58.06 | 41.94 | 41.94 | |
| #10 | 2.00 | 839.3 | 62.73 | 37.27 | 37.27 | |
| #40 | 0.425 | 1,079.8 | 80.70 | 19.30 | 19.30 | |
| #100 | 0.150 | 1,135.9 | 84.90 | 15.10 | 15.10 | |
| #200 | 0.075 | 1,160.1 | 86.71 | 13.29 | 13.29 | |
| Bottom | | | | | | |
| Total | | | | | | |

| | | | |
|--------------------------------------|--|----------------|-------------------------------------|
| DESCRIPTIVE INFORMATION OF THE SOILS | | organic soil | <input type="checkbox"/> |
| | | inorganic soil | <input checked="" type="checkbox"/> |



| SOIL CLASSIFICATION | | |
|---------------------|-------------------------------------|-----------|
| 1 | AASHTO classification (AASHTO M145) | A-2-4 (0) |
| 2 | UCS Classification (ASTM D2487) | YE |

| DIAMETERS (mm) and COEFFICIENTS | | | | | | | | |
|---------------------------------|-----------------|-------|---|-----------------|-------|---|----------------|---|
| 1 | D ₁₀ | 0,000 | 3 | D ₆₀ | 4,085 | 5 | C _u | - |
| 2 | D ₃₀ | 1,363 | 4 | D ₅₀ | 9,217 | 6 | C _c | - |

ATTERBERG LIMITS (ASTM D4318/AASHTO T89-T90)

Tested by: Yelson Ramirez Test date: 22-Sep-21

| # | DESCRIPTION | LIQUID LIMIT | | PLASTIC LIMIT | | Liquid limit: <u>35</u> | Plastic limit: <u>27</u> | Plasticity index: <u>8</u> |
|---|---------------------|--------------|-------|---------------|-------|-------------------------|--------------------------|----------------------------|
| | | hn | HN-80 | HN-7 | LC | | | |
| 1 | Can # | | | | | | | |
| 2 | # of hits | 28 | 28 | - | - | | | |
| 3 | Can + moist soil, g | 37.22 | 38.64 | 29.75 | 30.56 | | | |
| 4 | Can + dry soil, g | 33.48 | 34.58 | 28.15 | 28.86 | | | |
| 5 | Moisture weight, g | 3.74 | 4.06 | 1.60 | 1.70 | | | |
| 6 | Can weight, g | 22.60 | 22.80 | 22.13 | 22.60 | | | |
| 7 | Dry soil weight, g | 10.88 | 11.78 | 6.02 | 6.26 | | | |
| 8 | % moisture | 34.38 | 34.47 | 26.58 | 27.16 | | | |

| | | | | | |
|--|-----|-----------------------------|-----------|----------------------|-----------|
| SPECIFIC GRAVITY OF SOILS WITH PYCNOMETER | | | | Code: | LA-FO010 |
| | | | | Version: | 3 |
| Produced by: | RAF | Date of elaboration: | 07-Apr-16 | Approved: | RAF |
| | | | | Last version: | 15-Feb-19 |

Draft: _____ Landfill Sample # 1175
Origin of the sample: _____ Pit No. 10 Lab Code: LC
Tested by: Peter Funes Probe: N/A SPT: N/A Date: 22-Sep-21
Material designation: Existing Soil Depth, m: -

| SPECIFIC GRAVITY OF SOILS USING A PYCNOMETER WITH WATER (ASTM D854/AASHTO T100) | | | | |
|---|--|--------|--------|--------|
| # | TEST STEPS | 1 | 2 | 3 |
| 1 | Pycnometer number | 1 | 3 | 4 |
| 2 | Weight of pycnometer + water, g | 642.18 | 651.80 | 651.50 |
| 3 | Weight of material in air, g | 100.00 | 100.00 | 100.00 |
| 4 | Pycnometer + water + material after test, g | 703.00 | 712.60 | 712.50 |
| 5 | Material weight in water (4 - 2), g | 60.82 | 60.80 | 61.00 |
| 6 | Weight of material in air - weight of material in water (3 - 5), g | 39.18 | 39.20 | 39.00 |
| 7 | Specific gravity filler (3/6) | 2,552 | 2,551 | 2,564 |
| 8 | Average Specific Gravity | 2,556 | | |

| DENSITY OF THE TESTED SAMPLES | | | | | | | |
|-------------------------------|-----------------------------------|---------|---------|------|-----------------------------------|---------|---------|
| # | WET DENSITY | | | # | DRY DENSITY | | |
| 9 | can number | XX-2 | density | 25 | can number | XX-2 | 20 |
| 10 | Can + moist soil, g | 123.20 | 125.10 | 26 | Can + moist soil, g | 123.20 | 125.10 |
| 11 | Can weight, g | 13.60 | 15.06 | 27 | Can + dry soil, g | 111.40 | 113.00 |
| 12 | Wet soil weight, g | 109.60 | 110.04 | 28 | Moisture weight, g | 11.80 | 12.10 |
| 13 | Container volume, cm ³ | 69.06 | 69.06 | 29 | Container volume, cm ³ | 69.06 | 69.06 |
| 14 | Wet density, g/cm ³ | 1.59 | 1.59 | 30 | Can weight, g | 13.60 | 15.06 |
| 15 | Wet density, kg/m ³ | 1587.03 | 1593.40 | 31 | Dry soil weight, g | 97.80 | 97.94 |
| 16 | Avg Wet Density kg/m ³ | 1590.21 | | 32 | % moisture | 12.07 | 12.35 |
| | | | | 33 | Dry density, kg/m ³ | 1419.00 | 1415.35 |
| | | | | 3. 4 | Avg dry density kg/m ³ | 1417.18 | |

| # | NATURAL HUMIDITY | | |
|----|---------------------|--|--|
| 17 | can number | | |
| 18 | Can + moist soil, g | | |
| 19 | Can + dry soil, g | | |
| 20 | Moisture weight, g | | |
| 21 | Can weight, g | | |
| 22 | Dry soil weight, g | | |
| 23 | % moisture | | |
| 24 | Average Moisture % | | |

Observations:

| | | | | | | |
|---|-----|-----------------------------|-----------|-------------|----------------------|-----------|
| GRANULOMETRIC ANALYSIS, ATTERBERG LIMITS AND SOIL CLASSIFICATION | | | | | Code: | LA-FO001 |
| | | | | | Version: | 7 |
| | | | | | Passed: | RAF |
| | | | | | Last version: | 10-Jul-20 |
| Produced by: | RAA | Date of elaboration: | 24-Sep-05 | page 1 of 1 | Last version: | 10-Jul-20 |

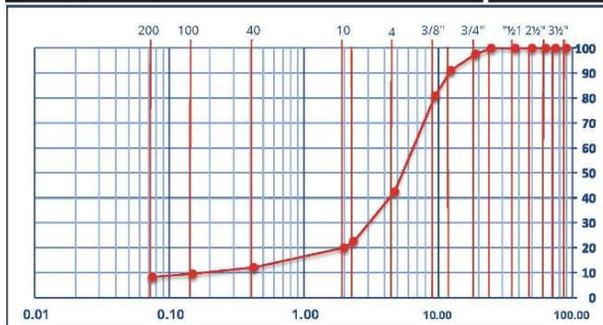
Draft: _____ Landfill _____ Sample # 1176
 Station or precedence: _____ Pit No. 6 _____ Lab Code: LC
 Hole or pit: 6 Gauge: N/A Depth in meters: N/A a N/A
 Taken by: _____ The interested _____ Date taken: 16-Sep-21
 Tested by: _____ Jorge Gomez _____ Rehearsed date: 22-Sep-21
 Material designation: _____ Existing soil _____ Side: N/A

SOIL SIZE ANALYSIS BY SIEVE (ASTM D422/AASHTO T88)

| Sieve No. | Weight | Percentage | | Conduroy # | Total air dried sample: | Total dry sample: |
|-----------|--------|------------|------|------------|-------------------------|-------------------|
| in. | mm | Retained | Pass | | | |
| 3 1/2" | 90.00 | | | | | |
| 3" | 75.00 | | | | | |
| 2 1/2" | 63.00 | | | | | |
| 2" | 50.00 | | | | | |
| 1 1/2" | 37.50 | | | | | |
| 1" | 25.00 | 0.0 | 0.0 | | | 100.0 |
| 3/4" | 19.00 | 24.2 | 2.4 | | | 97.6 |
| 1/2" | 12.50 | 91.0 | 8.9 | | | 91.1 |
| 3/8" | 9.50 | 196.2 | 19.1 | | | 80.9 |
| #4 | 4.75 | 590.8 | 57.5 | | | 42.5 |
| Bottom | | | | | | |
| Total | | | | | | |

| Sieve No. | Weight | Percentage | | | |
|-----------|--------|-------------|----------|-------|-----------|
| in. | mm | Ret. Accum. | Retained | Pass | corrected |
| #8 | 2.36 | 796.4 | 77.55 | 22.45 | 22.45 |
| #10 | 2.00 | 821.4 | 79.99 | 20.01 | 20.01 |
| #40 | 0.425 | 903.0 | 87.93 | 12.07 | 12.07 |
| #100 | 0.150 | 928.7 | 90.43 | 9.57 | 9.57 |
| #200 | 0.075 | 942.3 | 91.76 | 8.24 | 8.24 |
| Bottom | | | | | |
| Total | | | | | |

| | | |
|--------------------------------------|----------------|-------------------------------------|
| DESCRIPTIVE INFORMATION OF THE SOILS | organic soil | <input type="checkbox"/> |
| | inorganic soil | <input checked="" type="checkbox"/> |



| HUMIDITY (ASTM D2216/AASHTO T265) | HUMIDITY NATURAL | HUMIDITY SAMPLE |
|-----------------------------------|------------------|-----------------|
| Can + moist soil, g | | 382.9 |
| Can + dry soil, g | | 359.9 |
| Can weight, g | | AD-3 72.1 |
| Moisture weight, g | | 23 |
| Dry soil weight, g | | 287.8 |
| Hygroscopic humidity, % | | 8.0 |
| H. Hydros corrected factor. | | 0.925997 |

| SOIL CLASSIFICATION | | |
|---------------------|-------------------------------------|-----------|
| 1 | AASHTO classification (AASHTO M145) | A-2-6 (0) |
| 2 | SUCS Classification (ASTM D2487) | GP-GM |

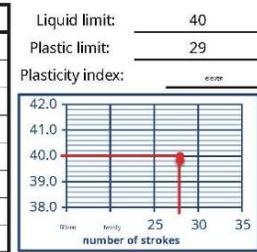
| DIAMETERS (mm) and COEFFICIENTS | | | | | | | | |
|---------------------------------|-----------------|-------|---|-----------------|--------|---|----------------|-------|
| 1 | D ₁₀ | 0,198 | 3 | D ₆₀ | 6,917 | 5 | C _u | 34,98 |
| 2 | D ₃₀ | 3,261 | 4 | D ₈₀ | 12,167 | 6 | C _c | 7,78 |

| SLIME AND/OR CLAY | SAND | | | GRAVEL |
|-------------------|------|------|-------|--------|
| | FINE | HALF | GROSS | |
| | | | | |

ATTERBERG LIMITS (ASTM D4318/AASHTO T89-T90)

Tested by: _____ Yelson Ramirez _____ Test date: _____ 21-Sep-21 _____

| # | DESCRIPTION | LIQUID LIMIT | | PLASTIC LIMIT | |
|---|---------------------|--------------|-------|---------------|-------|
| | | P-1 | C-2 | 2-L | DC-2 |
| 1 | Can # | P-1 | C-2 | 2-L | DC-2 |
| 2 | # of hits | 28 | 28 | - | - |
| 3 | Can + moist soil, g | 39.02 | 39.14 | 30.47 | 31.53 |
| 4 | Can + dry soil, g | 34.24 | 34.41 | 28.72 | 29.38 |
| 5 | Moisture weight, g | 4.78 | 4.73 | 1.75 | 2.15 |
| 6 | Can weight, g | 22.24 | 22.58 | 22.57 | 21.93 |
| 7 | Dry soil weight, g | 12.00 | 11.83 | 6.15 | 7.45 |
| 8 | % moisture | 39.83 | 39.98 | 28.46 | 28.86 |



| | | | | | |
|--|-----|-----------------------------|-----------|----------------------|-----------|
| SPECIFIC GRAVITY OF SOILS WITH PYCNOMETER | | | | Code: | LA-FO010 |
| | | | | Version: | 3 |
| | | | | Approved: | RAF |
| | | | | Last version: | 15-Feb-19 |
| Produced by: | RAF | Date of elaboration: | 07-Apr-16 | Last version: | 15-Feb-19 |

Draft: _____ Landfill _____ Sample # 1176
Origin of the sample: _____ Pit No. 6 _____ Lab Code: LC
Tested by: Peter Funes _____ Probe: N/A _____ SPT: N/A _____ Date: 22-Sep-21
Material designation: _____ Existing Soil _____ Depth, m: -

| SPECIFIC GRAVITY OF SOILS USING A PYCNOMETER WITH WATER (ASTM D854/AASHTO T100) | | | | |
|---|--|--------|--------|--------|
| # | TEST STEPS | 1 | 2 | 3 |
| 1 | Pycnometer number | 10 | 11 | 12 |
| 2 | Weight of pycnometer + water, g | 645.06 | 641.24 | 648.36 |
| 3 | Weight of material in air, g | 100.00 | 100.00 | 100.00 |
| 4 | Pycnometer + water + material after test, g | 706.00 | 702.00 | 709.20 |
| 5 | Material weight in water (4 - 2), g | 60.94 | 60.76 | 60.84 |
| 6 | Weight of material in air - weight of material in water (3 - 5), g | 39.06 | 39.24 | 39.16 |
| 7 | Specific gravity filler (3/6) | 2,560 | 2,548 | 2,554 |
| 8 | Average Specific Gravity | 2,554 | | |

| DENSITY OF THE TESTED SAMPLES | | | | | | | |
|-------------------------------|-----------------------------------|---------|---------|----|-----------------------------------|---------|---------|
| # | WET DENSITY | | | # | DRY DENSITY | | |
| 9 | can number | 29 | dws | 25 | can number | 29 | dws |
| 10 | Can + moist soil, g | 128.20 | 125.70 | 26 | Can + moist soil, g | 128.20 | 125.70 |
| 11 | Can weight, g | 13.27 | 14.10 | 27 | Can + dry soil, g | 117.30 | 114.80 |
| 12 | Wet soil weight, g | 114.93 | 111.60 | 28 | Moisture weight, g | 10.90 | 10.90 |
| 13 | Container volume, cm ³ | 69.06 | 69.06 | 29 | Container volume, cm ³ | 69.06 | 69.06 |
| 14 | Wet density, g/cm ³ | 1.66 | 1.62 | 30 | Can weight, g | 13.27 | 14.10 |
| 15 | Wet density, kg/m ³ | 1664.21 | 1615.99 | 31 | Dry soil weight, g | 104.03 | 100.70 |
| 16 | Avg Wet Density kg/m ³ | 1640.10 | | 32 | % moisture | 10.48 | 10.82 |
| | | | | 33 | Dry density, kg/m ³ | 1484.55 | 1479.91 |
| | | | | 34 | Avg dry density kg/m ³ | 1482.23 | |

| # | NATURAL HUMIDITY | | |
|----|---------------------|--|--|
| 17 | can number | | |
| 18 | Can + moist soil, g | | |
| 19 | Can + dry soil, g | | |
| 20 | Moisture weight, g | | |
| 21 | Can weight, g | | |
| 22 | Dry soil weight, g | | |
| 23 | % moisture | | |
| 24 | Average Moisture % | | |

Observations:

| | | | | | | |
|---|--|--|--|--|----------------------|-----------|
| GRANULOMETRIC ANALYSIS, ATTERBERG LIMITS AND SOIL CLASSIFICATION | | | | | Code: | LA-F0001 |
| | | | | | Version: | 7 |
| Produced by: RAA Date of elaboration: 24-Sep-05 page 1 of 1 | | | | | Passed: | RAF |
| | | | | | Last version: | 10-Jul-20 |

Draft: _____ Landfill Sample # 1177
 Station or precedence: _____ Pit No. 2 Lab Code: LC
 Hole or pit: two Gauge: N/A Depth in meters: N/A a N/A
 Taken by: _____ The interested Date taken: 16-Sep-21
 Tested by: Jorge Gomez Rehearsed date: 23-Sep-21
 Material designation: _____ Existing soil Side: N/A

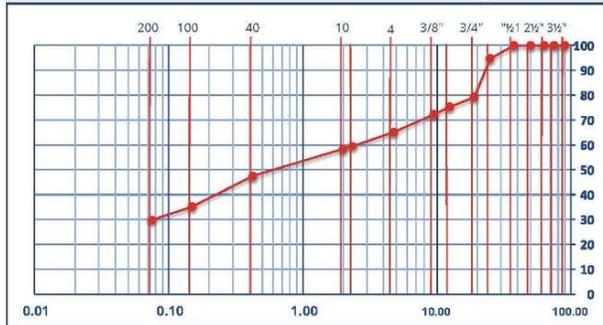
SOIL SIZE ANALYSIS BY SIEVE (ASTM D422/AASHTO T88)

| Sieve No. | Weight | Percentage | | | Corrected |
|-----------|-------------|------------|------|-------|-----------|
| in. mm | Ret. Accum. | Retained | Pass | | |
| 3 1/2" | 90.00 | | | | |
| 3" | 75.00 | | | | |
| 2 1/2" | 63.00 | | | | |
| 2" | 50.00 | | | | |
| 1 1/2" | 37.50 | 0.0 | 0.0 | 100.0 | |
| 1" | 25.00 | 74.1 | 5.3 | 94.7 | |
| 3/4" | 19.00 | 290.5 | 20.7 | 79.3 | |
| 1/2" | 12.50 | 346.3 | 24.7 | 75.3 | |
| 3/8" | 9.50 | 388.4 | 27.7 | 72.3 | |
| #4 | 4.75 | 489.4 | 34.9 | 65.1 | |
| Bottom | | | | | |
| Total | | | | | |

Corrosion # AC-100 Total air dried sample: 1468.3
 Total dry sample: 1401.8

| Sieve No. | Weight | Percentage | | | corrected |
|-----------|-------------|------------|-------|-------|-----------|
| in. mm | Ret. Accum. | Retained | Pass | | |
| #8 | 2.36 | 567.3 | 40.47 | 59.53 | 59.53 |
| #10 | 2.00 | 583.6 | 41.63 | 58.37 | 58.37 |
| #40 | 0.425 | 735.3 | 52.45 | 47.55 | 47.55 |
| #100 | 0.150 | 907.9 | 64.77 | 35.23 | 35.23 |
| #200 | 0.075 | 983.3 | 70.14 | 29.86 | 29.86 |
| Bottom | | | | | |
| Total | | | | | |

| | | |
|--------------------------------------|----------------|-------------------------------------|
| DESCRIPTIVE INFORMATION OF THE SOILS | organic soil | <input type="checkbox"/> |
| | inorganic soil | <input checked="" type="checkbox"/> |



| HUMIDITY (ASTM D2216/AASHTO T265) | HUMIDITY NATURAL | HUMIDITY SAMPLE |
|-----------------------------------|------------------|-----------------|
| Can + moist soil, g | | 492.2 |
| Can + dry soil, g | | 473.4 |
| Can weight, g | | YW 77.0 |
| Moisture weight, g | | 18.8 |
| Dry soil weight, g | | 396.4 |
| Hygroscopic humidity, % | | 4.7 |
| H. Hydros corrected factor. | | 0.954721 |

| SOIL CLASSIFICATION | | |
|---------------------|-------------------------------------|-----------|
| 1 | AASHTO classification (AASHTO M145) | A-2-7 (3) |
| 2 | SUCS Classification (ASTM D2487) | SC |

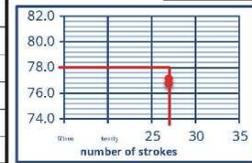
| DIAMETERS (mm) and COEFFICIENTS | | | | | | | | |
|---------------------------------|-----------------|-------|---|-----------------|--------|---|----------------|---|
| 1 | D ₁₀ | 0.000 | 3 | D ₆₀ | 2,562 | 5 | C _u | - |
| 2 | D ₃₀ | 0.077 | 4 | D ₅₀ | 23,168 | 6 | C _c | - |

ATTERBERG LIMITS (ASTM D4318/AASHTO T89-T90)

Tested by: Yelson Ramirez Test date: 21-Sep-21

| # | DESCRIPTION | LIQUID LIMIT | | PLASTIC LIMIT | |
|---|---------------------|--------------|-------|---------------|-------|
| | | HN-7 | 2-A | HN-8 | MH |
| 1 | Can # | | | | |
| 2 | # of hits | 27 | 27 | - | - |
| 3 | Can + moist soil, g | 31.18 | 34.21 | 31.43 | 31.17 |
| 4 | Can + dry soil, g | 27.25 | 29.11 | 29.03 | 28.94 |
| 5 | Moisture weight, g | 3.93 | 5.10 | 2.40 | 2.23 |
| 6 | Can weight, g | 22.13 | 22.50 | 21.76 | 22.13 |
| 7 | Dry soil weight, g | 5.12 | 6.61 | 7.27 | 6.81 |
| 8 | % moisture | 76.76 | 77.16 | 33.01 | 32.75 |

Liquid limit: 78
 Plastic limit: 33
 Plasticity index: _____



| | | | | | |
|--|-----|-----------------------------|-----------|----------------------|-----------|
| SPECIFIC GRAVITY OF SOILS WITH PYCNOMETER | | | | Code: | LA-FO010 |
| | | | | Version: | 3 |
| Produced by: | RAF | Date of elaboration: | 07-Apr-16 | Approved: | RAF |
| | | | | Last version: | 15-Feb-19 |

Draft: _____ Landfill _____ Sample # _____ 1177
Origin of the sample: _____ Pit No. 2 _____ Lab Code: _____ LC
Tested by: _____ Peter Funes _____ Probe: _____ N/A _____ SPT: _____ N/A _____ Date: _____ 22-Sep-21
Material designation: _____ Existing Soil _____ Depth, m: _____ -

| SPECIFIC GRAVITY OF SOILS USING A PYCNOMETER WITH WATER (ASTM D854/AASHTO T100) | | | | |
|---|--|--------|--------|--------|
| # | TEST STEPS | 1 | 2 | 3 |
| 1 | Pycnometer number | 5 | 6 | 7 |
| 2 | Weight of pycnometer + water, g | 652.20 | 647.90 | 649.64 |
| 3 | Weight of material in air, g | 100.00 | 100.00 | 100.00 |
| 4 | Pycnometer + water + material after test, g | 712.70 | 708.20 | 710.01 |
| 5 | Material weight in water (4 - 2), g | 60.50 | 60.30 | 60.37 |
| 6 | Weight of material in air - weight of material in water (3 - 5), g | 39.50 | 39.70 | 39.63 |
| 7 | Specific gravity filler (3/6) | 2,532 | 2,519 | 2,523 |
| 8 | Average Specific Gravity | 2,525 | | |

| DENSITY OF THE TESTED SAMPLES | | | | | | | |
|-------------------------------|-----------------------------------|---------|---------|------|-----------------------------------|---------|---------|
| # | WET DENSITY | | | # | DRY DENSITY | | |
| 9 | can number | T | 47 | 25 | can number | T | 47 |
| 10 | Can + moist soil, g | 102.10 | 105.90 | 26 | Can + moist soil, g | 102.10 | 105.90 |
| 11 | Can weight, g | 13.43 | 13.64 | 27 | Can + dry soil, g | 88.30 | 91.20 |
| 12 | Wet soil weight, g | 88.67 | 92.26 | 28 | Moisture weight, g | 13.80 | 14.70 |
| 13 | Container volume, cm ³ | 69.06 | 69.06 | 29 | Container volume, cm ³ | 69.06 | 69.06 |
| 14 | Wet density, g/cm ³ | 1.28 | 1.34 | 30 | Can weight, g | 13.43 | 13.64 |
| 15 | Wet density, kg/m ³ | 1283.96 | 1335.94 | 31 | Dry soil weight, g | 74.87 | 77.56 |
| 16 | Avg Wet Density kg/m ³ | 1309.95 | | 32 | % moisture | 18.43 | 18.95 |
| | | | | 33 | Dry density, kg/m ³ | 1106.08 | 1101.23 |
| | | | | 3. 4 | Avg dry density kg/m ³ | 1103.65 | |

| # | NATURAL HUMIDITY | | |
|----|---------------------|--|--|
| 17 | can number | | |
| 18 | Can + moist soil, g | | |
| 19 | Can + dry soil, g | | |
| 20 | Moisture weight, g | | |
| 21 | Can weight, g | | |
| 22 | Dry soil weight, g | | |
| 23 | % moisture | | |
| 24 | Average Moisture % | | |

Observations:

| | | | | | | | |
|---|-----|-----------------------------|-----------|-------------|----------------------|----------------------|-----------|
| GRANULOMETRIC ANALYSIS, ATTERBERG LIMITS AND SOIL CLASSIFICATION | | | | | | Code: | LA-F0001 |
| | | | | | | Version: | 7 |
| | | | | | | Passed: | RAF |
| | | | | | | Last version: | 10-Jul-20 |
| Produced by: | RAA | Date of elaboration: | 24-Sep-05 | page 1 of 1 | Last version: | 10-Jul-20 | |

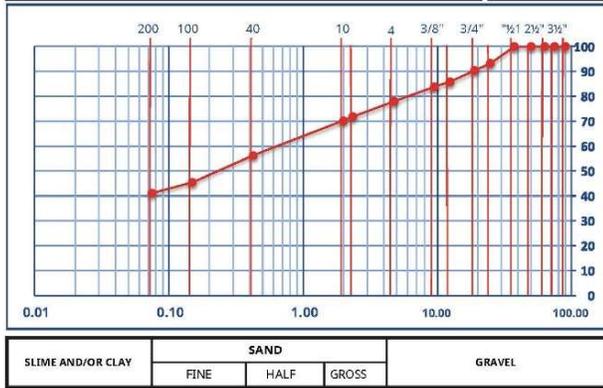
Draft: _____ Landfill _____ Sample # 1178
 Station or precedence: _____ Pit No. 5 _____ Lab Code: LC
 Hole or pit: 5 Gauge: N/A Depth in meters: N/A a N/A
 Taken by: The interested Date taken: 16-Sep-21
 Tested by: Jorge Gomez Rehearsed date: 23-Sep-21
 Material designation: _____ Existing soil _____ Side: N/A

SOIL SIZE ANALYSIS BY SIEVE (ASTM D422/AASHTO T88)

| Sieve No. | Weight | Percentage | | | Corduroy # | Total air dried sample: | Total dry sample: |
|-----------|--------|-------------|----------|-------|------------|-------------------------|-------------------|
| in. | mm | Ret. Accum. | Retained | Pass | | | |
| 3 1/2" | 90.00 | | | | | | |
| 3" | 75.00 | | | | | | |
| 2 1/2" | 63.00 | | | | | | |
| 2" | 50.00 | | | | | | |
| 1 1/2" | 37.50 | 0.0 | 0.0 | 100.0 | | | |
| 1" | 25.00 | 91.5 | 6.7 | 93.3 | | | |
| 3/4" | 19.00 | 131.0 | 9.6 | 90.4 | | | |
| 1/2" | 12.50 | 192.8 | 14.1 | 85.9 | | | |
| 3/8" | 9.50 | 220.8 | 16.1 | 83.9 | | | |
| #4 | 4.75 | 301.4 | 22.0 | 78.0 | | | |
| Bottom | | | | | | | |
| Total | | | | | | | |

| Sieve No. | Weight | Percentage | | | | |
|-----------|--------|-------------|----------|-------|-----------|--|
| in. | mm | Ret. Accum. | Retained | Pass | corrected | |
| #8 | 2.36 | 384.7 | 28.13 | 71.87 | 71.87 | |
| #10 | 2.00 | 407.1 | 29.77 | 70.23 | 70.23 | |
| #40 | 0.425 | 597.9 | 43.72 | 56.28 | 56.28 | |
| #100 | 0.150 | 746.3 | 54.57 | 45.43 | 45.43 | |
| #200 | 0.075 | 805.2 | 58.87 | 41.13 | 41.13 | |
| Bottom | | | | | | |
| Total | | | | | | |

| | | | |
|--------------------------------------|--|----------------|-------------------------------------|
| DESCRIPTIVE INFORMATION OF THE SOILS | | organic soil | <input type="checkbox"/> |
| | | inorganic soil | <input checked="" type="checkbox"/> |



| HUMIDITY (ASTM D2216/AASHTO T265) | | HUMIDITY NATURAL | HUMIDITY SAMPLE |
|-----------------------------------|--|------------------|-----------------|
| Can + moist soil, g | | | 317.4 |
| Can + dry soil, g | | | 293.1 |
| Can weight, g | | J-3 | 70.7 |
| Moisture weight, g | | | 24.3 |
| Dry soil weight, g | | | 222.4 |
| Hygroscopic humidity, % | | | 10.9 |
| H. Hydros corrected factor. | | | 0.901500 |

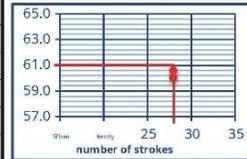
| SOIL CLASSIFICATION | | |
|---------------------|-------------------------------------|-----------|
| 1 | AASHTO classification (AASHTO M145) | A-7-5 (7) |
| 2 | SUCS Classification (ASTM D2487) | SC |

ATTERBERG LIMITS (ASTM D4318/AASHTO T89-T90)

Tested by: Yelson Ramirez Test date: 23-Sep-21

| # | DESCRIPTION | LIQUID LIMIT | | PLASTIC LIMIT | |
|---|---------------------|--------------|-------|---------------|-------|
| | | H-10 | HN-4 | A-2 | XL |
| 1 | Can # | | | | |
| 2 | # of hits | 28 | 28 | - | - |
| 3 | Can + moist soil, g | 33.57 | 34.09 | 31.88 | 30.35 |
| 4 | Can + dry soil, g | 29.45 | 29.82 | 29.71 | 28.43 |
| 5 | Moisture weight, g | 4.12 | 4.27 | 2.17 | 1.92 |
| 6 | Can weight, g | 22.65 | 22.71 | 22.50 | 22.05 |
| 7 | Dry soil weight, g | 6.80 | 7.11 | 7.21 | 6.38 |
| 8 | % moisture | 60.59 | 60.06 | 30.10 | 30.09 |

Liquid limit: 61
 Plastic limit: 30
 Plasticity index: 31



| | | | | | |
|--|-----|-----------------------------|-----------|----------------------|-----------|
| SPECIFIC GRAVITY OF SOILS WITH PYCNOMETER | | | | Code: | LA-FO010 |
| | | | | Version: | 3 |
| Produced by: | RAF | Date of elaboration: | 07-Apr-16 | Approved: | RAF |
| | | | | Last version: | 15-Feb-19 |

Draft: _____ Landfill _____ Sample # _____ 1178
Origin of the sample: _____ Pit No. 5 _____ Lab Code: _____ LC
Tested by: _____ Peter Funes _____ Probe: _____ N/A _____ SPT: _____ N/A _____ Date: _____ 23-Sep-21
Material designation: _____ Existing Soil _____ Depth, m: _____ -

| |
|--|
| SPECIFIC GRAVITY OF SOILS USING A PYCNOMETER WITH WATER (ASTM D854/AASHTO T100) |
|--|

| # | TEST STEPS | 1 | 2 | 3 |
|---|--|--------|--------|--------|
| 1 | Pycnometer number | 1 | 3 | 4 |
| 2 | Weight of pycnometer + water, g | 642.18 | 651.80 | 651.50 |
| 3 | Weight of material in air, g | 100.00 | 100.00 | 100.00 |
| 4 | Pycnometer + water + material after test, g | 704.20 | 713.90 | 713.40 |
| 5 | Material weight in water (4 - 2), g | 62.02 | 62.10 | 61.90 |
| 6 | Weight of material in air - weight of material in water (3 - 5), g | 37.98 | 37.90 | 38.10 |
| 7 | Specific gravity filler (3/6) | 2,633 | 2,639 | 2,625 |
| 8 | Average Specific Gravity | 2,632 | | |

| |
|--------------------------------------|
| DENSITY OF THE TESTED SAMPLES |
|--------------------------------------|

| # | WET DENSITY | | |
|----|-----------------------------------|---------|---------|
| 9 | can number | DW-4 | F |
| 10 | Can + moist soil, g | 132.90 | 134.90 |
| 11 | Can weight, g | 13.65 | 13.50 |
| 12 | Wet soil weight, g | 119.25 | 121.40 |
| 13 | Container volume, cm ³ | 69.06 | 69.06 |
| 14 | Wet density, g/cm ³ | 1.73 | 1.76 |
| 15 | Wet density, kg/m ³ | 1726.76 | 1757.89 |
| 16 | Avg Wet Density kg/m ³ | 1742.33 | |

| # | DRY DENSITY | | |
|----|-----------------------------------|---------|---------|
| 25 | can number | DW-4 | F |
| 26 | Can + moist soil, g | 132.90 | 134.90 |
| 27 | Can + dry soil, g | 103.80 | 104.40 |
| 28 | Moisture weight, g | 29.10 | 30.50 |
| 29 | Container volume, cm ³ | 69.06 | 69.06 |
| 30 | Can weight, g | 13.65 | 13.50 |
| 31 | Dry soil weight, g | 90.15 | 90.90 |
| 32 | % moisture | 32.28 | 33.55 |
| 33 | Dry density, kg/m ³ | 1317.15 | 1304.59 |
| 34 | Avg dry density kg/m ³ | 1310.87 | |

| # | NATURAL HUMIDITY | | |
|----|---------------------|--|--|
| 17 | can number | | |
| 18 | Can + moist soil, g | | |
| 19 | Can + dry soil, g | | |
| 20 | Moisture weight, g | | |
| 21 | Can weight, g | | |
| 22 | Dry soil weight, g | | |
| 23 | % moisture | | |
| 24 | Average Moisture % | | |

Observations:

Figure A.10 Laboratory Tests10 performed for the study of the new landfill in the Central District Municipality by GEASA.

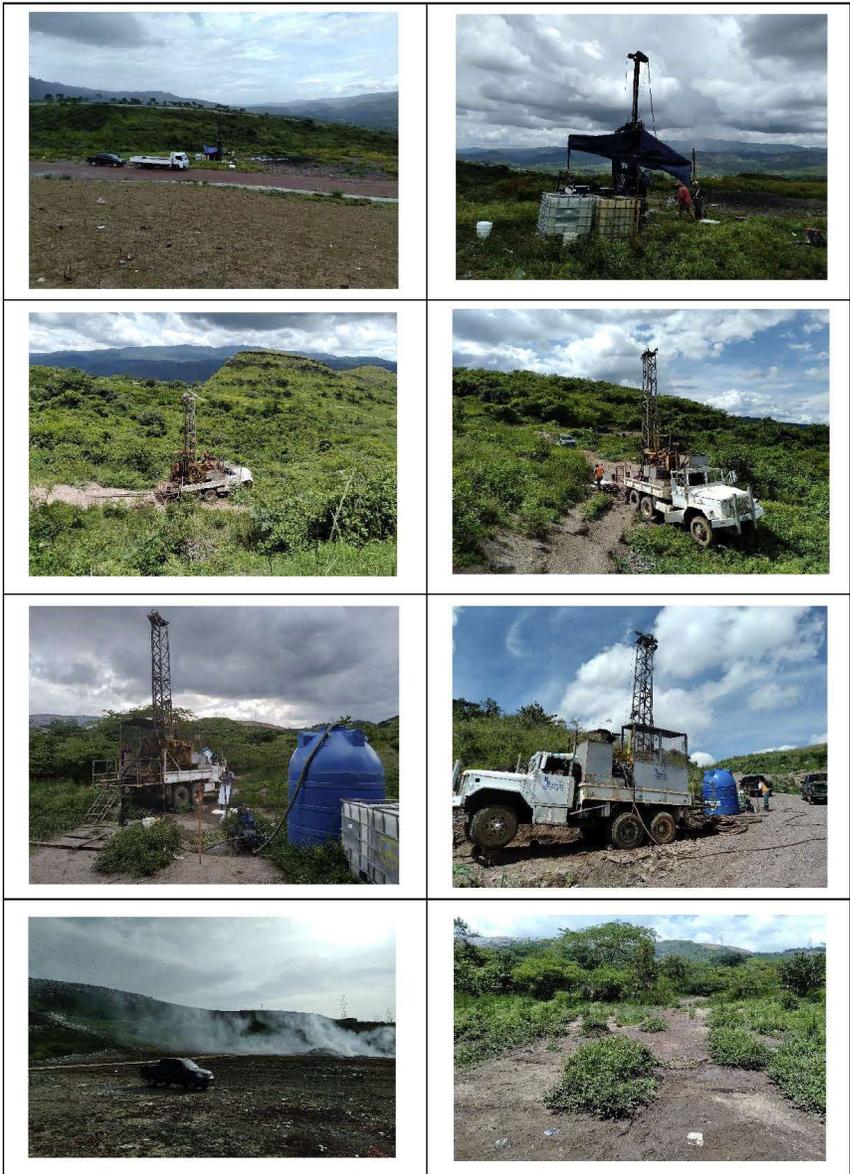
| RELEVANT PROPERTIES | RULE | UND | WORTH | FREQUENCY OF TESTING |
|--|---------------------------------------|------------------------|-----------------------|----------------------|
| Average thickness | ASTM D5199 | hmm | 1.50 | per roll |
| Minimal thickness | | hmm | 1.35 | |
| Density (minimum) | ASTM 1505 ASTM D792 | g/cc | 0.94 | 90,000kg |
| Tensile Strength (MV Minimum) (1) - Breaking strength - Yield Resistance - Elongation at Break - Elongation at Frequency | ASTM D6693 Type IV | KN/m KN/m % % | 40 22 700 12 | 9,000kg |
| Tear Resistance (MV Minimum) | ASTM D1004 | N | 191 | 20,000kg |
| Puncture Resistance (MV Minimum) ASTM D 4833 | | N | 480 | 20,000kg |
| Environmental Aging (SCR) ASTM D 5397 | | hr | 300 | By GRI GM-10 |
| Carbon black content | ASTM D4218 % 2.0 - 3.0 | | | 9,000kg |
| Carbon black dispersion (2) | ASTM D5596 | - | Category 1 or 2 | - |
| OIT Induced Oxidation Time High Pressure (3) | ASTM D5885 | min | > 400 | by formulation |
| Oven Aging at 85°C (% Min Ret of OIT at High Pressure after 90 days) | ASTM D5721 ASTM D5885 | min | > 80 | by formulation |
| UV resistance (% Min Ret of OIT at High Pressure after 1600 hours) | ASTM D7238 ASTM G154 ASTM D5885 | min | > 50 | by formulation |
| Wide Roll (4) | - | m | 7.00 | - |
| long roll | - | m | 150 | - |
| roll area | - | m2 | 1050 | - |
| Sales unit | - | m2 | - | - |

Figure A.11 Reference Geomembrane characteristics

Photographic Gallery









Photographic gallery Studies for the New Landfill of the Central District, GEASA Honduras report September 9 2021