MASTER PLAN DEVELOPMENT OF THE MONTEREY PENINSULA LANDFILL, MARINA, CALIFORNIA

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SUMMARY: The Monterey Peninsula Landfill (MPL) was operated under an existing landfill master plan prepared in 1997. The Monterey Regional Waste Management District (District) advertised a solicitation for proposals from landfill consulting firms to prepare an update to their existing Master Plan. The requested update to the Master Plan was completed and submitted to the District in 2004. The primary objective of the Updated Master Plan was to review the previous landfill capacity and sequencing plan and evaluate the potential to increase the overall waste capacity of the site. In addition, the Updated Master Plan would allow the District to plan capital outlay budgets for future module development and update closure and post-closure cost estimates. Finally, the proposed module-sequencing plan would be utilized as a "blue print" for future landfill development.

1. INTRODUCTION

The Monterey Peninsula Landfill (MPL) is a Class III sanitary landfill covering an area of approximately 126 hectares. The site is located in Northern Monterey County, California approximately 1.6 km east of State Highway 1 and 3.2 km north of the City of Marina. The MPL began accepting waste in 1966 and was constructed in a series of modules. The site currently receives approximately 209,000 metric tons of municipal solid waste per year delivered to the landfill by the general public and commercial haulers.

Disposal operations are currently focused in the Module 4 area, just to the east of the existing Materials Recovery Facility (MRF). Wastes are disposed of utilizing the area method of disposal, with waste lifts averaging 4.6 meters in thickness. Wastes are placed and compacted in thin layers on a working face sloped no steeper than 3:1 (horizontal:vertical). Soils for intermediate and working face cover, consisting generally of sands, are excavated from the upland plateau area south and east of the current landfill area. Sand has also been sold to local contractors by the District for off site use.

The MPL is located in the coastal region of Monterey County within 4.8 km of Monterey Bay. The site, which is adjacent to the Salinas River and north of the former Fort Ord Military

Reservation is influenced by marine weather conditions. Average annual temperature extremes range from a low of 5.5^o Celsius in January to a high of 22^o Celsius in September. Rainfall is seasonal, with 90 percent of the precipitation occurring from November through April. Annual average precipitation recorded at the MPL by the District from 1983 to 2003 is 40 cm. Wind speed and direction monitored at the former Fort Ord Army Base indicate that winds in the site area are most frequently from the west (21.1 percent of the time) and the west-southwest (11.3 percent of the time). Calm weather occurs 20.7 percent of the time.

The MPL lies at the northern end of the Salinas Valley adjacent to the modern floodplain of the Salinas River. The Salinas Valley is filled with a thick sequence of Quaternary sediments, which have been subdivided into several distinct geologic units. Three of the regional units occur at the site: older dune sand (Qod), younger floodplain deposits (Qfly), and older floodplain deposits (Qflo), listed in descending stratigraphic order. The floodplain deposits were formed primarily by overwash of the Salinas River during periodic floods. These floodplain deposits consist of interbedded sand, silt, and clay. Floodplain units near the site underlie the dune sand wherever the dune sand is present.

The MPL is currently operated under a Landfill Master Plan prepared in 1997. In July of 2002, the District awarded a contract to prepare an update to the existing Master Plan. The Updated Master Plan development included sections on soil excavation and management, liner and leachate collection systems, a perched groundwater removal system, site capacity and landfill service life, and closure and post-closure. Included with the development were the detailed sequencing drawings for 13 future landfill construction phases. For each of the phases, quantities of excavation, liner materials, and waste fill volumes were determined. Based on the quantities generated, the construction period was determined for each phase of development along with the associated construction costs. The Updated Master Plan will enable the District to prepare the appropriate capital budgets and plan for development well in advance of construction.

The primary goal of the Updated Master Plan was to review the previous landfill capacity and sequencing plan and evaluate the potential to increase the overall waste capacity of the site as well as providing a "blue print" for future development. Several modifications to the previous Master Plan development resulted in a significant increase in the overall site life and capacity of the MPL. The District is currently seeking permit approval for this new landfill configuration under a Joint Technical Document to be submitted to the regulatory agencies. The following paper describes the modifications to the Master Plan that lead to the significant increase in capacity and site life.

2. MODIFICATIONS TO SITE CAPACITY AND LANDFILL SERVICE LIFE

The primary purpose of the Updated Master Plan for the MPL was to evaluate the potential of increasing the overall site waste capacity, thereby extending the service life of the landfill. To that end, the consultant focused on two primary issues. The first issue involved the placement of additional waste over areas of the existing modules that had undergone settlement to bring the external slopes to the proposed overall fill grade of 3:1 (horizontal-to-vertical). This process is called "sliver filling" and is discussed below. The second issue involved increasing the external design slopes of future landfill modules from 4:1 to 3:1, increasing the excavation cut slopes from 3:1 to 2:1, constructing a ridge and swale top deck closure configuration, and other factors that resulted in an increase in waste volume and extension of landfill service life.

2.1 Sliver Fill

Additional waste fill was proposed to be placed along the north slope of previously filled modules (Modules 1-3) increasing the external slopes from the existing 4 and 5:1 (horizontal-to-vertical) to 3:1. In addition to extending the life of the landfill, steeper external slopes will more readily promote surface water drainage from the slopes, thereby, decreasing the potential of infiltration of rainwater and possible leachate generation.

This construction will require the sequential removal of existing final cover soils(1.0 to 1.5 meters in thickness) within the sliver fill area prior to the placement of waste. Once additional waste materials are placed along these external slopes to a 3:1 grade, capping materials will be replaced over this newly constructed fill. The sequencing of construction will incorporate a careful process of delineating the area to be reconstructed, removal and stockpiling of the cover soils, temporarily decommissioning (LFG) wells, construction of access roads, route planning for waste haul trucks, and the placement and compaction of the waste on the slopes. Once the cover is placed over the additional waste, the LFG wells will be placed back into operation.

The north slope areas of the existing landfill to be reconstructed in this manner will be divided into discrete areas, each of which will be constructed in one continuous period, and then capped with final cover soils, with little or no interruption in the waste filling process. Depending on the size of the area to be reconstructed at any one time, the filling and recapping process may take several weeks to several months. At no time will this process be undertaken during the winter months when higher rainfall events are expected. The sliver fill construction process and general landfilling will continue until the ultimate fill elevations are reached for these modules

2.1.1 Site Life of Sliver Fill

The site loading estimates were calculated using information provided by the District, as well as the consultant’s airspace calculations. Based on recent volume estimates from previous fill surveys, a conservative in-place waste density was determined to be 0.77 grams per cubic centimeter. The net available airspace within the area of the landfill to undergo sliver filling was calculated to be 4,300,000 cubic meters, accounting for volumes of the prescriptive final cover system proposed for these modules, the interim cover that will be placed within the fill, and the removal of the existing final cover materials. With an annual waste generation growth rate of 1% per year, the service life of the sliver fill area (Modules 1-3) is estimated at slightly less than 13 years. This estimate allows the disposal of 6,900,000 metric tons of waste and 540,000 cubic meters of daily cover materials (on-site soils and alternative daily cover) at a waste-to-soil ratio of 7 parts waste to 1 part cover material.

2.2 Development of Future Expansion Modules

The previous Master Development Plan for the MPL consisted of 8 expansion modules with cut slopes excavated at 3:1 and final waste slopes constructed to 4:1 (EMCON 1997). With the objective of maximizing the available waste capacity and site life, an evaluation was conducted to determine the potential of steepening the existing cut slopes from 3:1 to 2:1 and the existing waste fill slopes from 4:1 to 3:1. Based on these modifications, the consultant prepared detailed cut and fill plans showing the complete future development of the MPL.

The District first proposed steepening the existing cut slopes during the development of Module 4. The stability of the 2:1 cut slope was discussed in the *Design Basis Memorandum for the Module*

4 Construction at the Monterey Peninsula Landfill (Vector, February 2002). In that document, the stability of the native cut slopes was found to be statically stable with a factor of safety of 1.4. In order to allow interim cut slopes with a factor of safety under 1.5, the regulatory agency required that waste be immediately placed against the base of the lined 2:1 slopes to act as a buttress. Following placement of approximately 3 meters of waste, the factor of safety of the cut slope increased to 1.6. As specified by the regulatory agency, the District placed a notation in their operating record stating that 3 meters of waste should be placed against all 2:1 cut slopes as soon as possible to act as a buttress.

The future area for landfill expansion was divided into new 12 modules (Modules 5 to 16) with a combined liner area of 82 hectares. Module sizes and limits were based on an approximate area of 6 to 8 hectares. Due to leachate control and construction issues, it was not possible to design all of the modules to the exact area criteria. The liner areas for each of the proposed development modules were determined along with the construction costs, site life, capacity, and construction period. Module 17 does not have a separate excavation plan because this module was designed to be built over previously lined modules. Table 1 shows each of the expansion modules along with the sliver fill and their corresponding construction sequencing.

The site life calculations for the expansion modules (Modules 5 to 17) were developed using similar design and growth parameters as the sliver fill, specifically a 7:1 waste to soil ratio, a yearly waste generation growth rate of 1%, and an in-place waste density of 0.77 grams per cubic centimeter. Following completion of the sliver filling, the initial year for filling the first expansion module (Module 5) was estimated to be 2015, at which point the incoming waste rate is 233,000 metric tons per year. For expansion Modules 5 through 17, the gross design capacity of 56,000,000 cubic meters is decreased by 2,000,000 cubic meters to account for the closure cap volume and by 480,000 cubic meters for the protective cover on the bottom liner system.

Table 1 - Construction Sequencing

	Life	**(Cubic Meters)**	**Construction**	**Construction**	**Cost Estimate**	**Filling**	**Filling**
Modules 1-4	13	4,084,000	NA	NA	NA	2003	2015
Module 5	5	1,666,000	2012	2014	$1,492,000	2015	2019
Module 6	6	1,634,000	2017	2019	$4,700,000	2019	2024
Module 7	22	9,077,000	2022	2024	$4,904,000	2024	2045
Module 8	6	2,619,000	2043	2045	$4,101,000	2045	2050
Module 9	8	3,883,000	2048	2050	$6,636,000	2050	2057
Module 10	6	2,788,000	2055	2057	$4,076,000	2057	2062
Module 11	8	4,005,000	2060	2062	$3,251,000	2062	2069
Module 12	23	15,143,000	2067	2069	$2,246,000	2069	2091
Module 13	3	1,305,000	2089	2091	$4,665,000	2091	2093
Module 14	2	983,000	2091	2093	$5,109,000	2093	2094
Module 15	4	2,663,000	2092	2094	$4,231,000	2094	2097
Module 16	10	7,205,000	2095	2097	$4,677,000	2097	2106
Module 17	4	2,993,000	NA	NA	$0	2106	2109

2.3 Maximum Landfill Height Increase

The primary objective of the Updated Master Plan was to increase the site capacity and service life of the MPL within the total permitted landfill elevation limits. By increasing the external slope angle, cut slope angle, and overall configuration, the consultant succeeded in this objective. The consultant was also requested by the District to determine the maximum potential waste capacity at the MPL that could be obtained by increasing the final fill elevation to the highest level possible. To that end, the 3:1 external waste slopes were continued up to a small 5% sloping top deck. A maximum elevation of 136 meters was obtained with this new configuration. At the current time, the District is not pursuing a height increase to 136 meters; however this possibility remains in the future.

In order for the regulatory agencies to permit the future development modules with 3:1 external waste slopes, the consultant prepared a stability analysis for the maximum build-out. Failure surfaces were evaluated utilizing limit equilibrium methods to determine the factor of safety for stability. The factor of safety was defined as the ratio of total equilibrium shear stress to available shear strength. The site was evaluated under both static and pseudo-static (earthquake) conditions.

2.3.1 Determination of Critical Sections and Geometry Evaluated

Slopes where stability is critical within landfills typically occur in areas that contain relatively weak geomembrane or soil liner interfaces (Benson et. al, 2003). Stability is also more critical where excavations are shallow and the external waste slopes are not buttressed by an opposing embankment. Under the Updated Master Plan, the new modules will be constructed with relatively low strength composite liners, however, they will each be constructed (buttressed) in excavations that range from 24 meters to 37 meters below the surrounding ground surface.

The shallowest excavations for geomembrane lined portions of the MPL occur in the existing Module 3 area. The weakest liner interface lies beneath Phase I of Module 3. This portion of Module 3 is located at the northeastern corner of the site. Phase I was constructed about 1.5 meters below the existing ground surface and excavated soils from the site were used to construct a perimeter berm (levy) on the north and east sides to form a small buttress approximately 3 to 4 meters high. The liner was constructed with a smooth HDPE geomembrane overlying a compacted clay liner. The bottom of the module was sloped to the northeast at a 1% percent grade to aid in the collection and removal of leachate.

The bottom liners for Phases II and III of Module 3 were constructed with higher shear strength textured HDPE geomembrane. Overlying waste has been placed throughout the Module 3 area to its original planned configuration. Under the Updated Master Plan, additional waste filling in the Phase I area will occur above an existing access road about 12 meters above the perimeter berm. In the remaining portions of Module 3 (Phases II and III), new waste sliver fills will be extended from the berm up to the crest of the landfill eliminating the referenced access road. The new waste for the future modules will be placed at a slope of 3:1 to the final proposed build-out.

Since the Phase I area of Module 3 is located at the corner of the landfill, the maximum elevation that the waste will achieve over most of this portion of the liner will be 87 meters. The maximum height of waste could be achieved along a section that traverses directly up the corner. The maximum height will also be achieved over the Phase II area of Module 3. Each of these two sections was analyzed for sliding failure.

2.3.2 Geology and Material Properties

Except for the waste properties, the other material properties and thicknesses of the soils underlying Module 3 in the evaluation are based on the information from the previous Master Plan (EMCON 1997). The geologic data, subgrade material, and interface shear strength properties used in that report were utilized for the current evaluation.

The following cross-section was assumed for the analysis, from top to bottom:

- Waste material with an average density of 1 gram per cubic centimeter (consistent with all previous analyses), and a shear strength of 32°. The bottom of the waste was assumed to be at an average elevation 3 meters msl.
- Composite liner (HDPE/compacted clay) with a density of 1.6 grams per cubic centimeter and shear strengths of 9° and 14° for the smooth liner and textured liner, respectively.
- A 15-meter thick layer of "upper sand" was presumed to exist immediately below the waste. This assumption was also consistent with the assumptions for the slope stability analyses previously performed for Module 3 (EMCON 1995).
- A 15-meter thick layer of "lower clay" having a density of 1.8 grams per cubic centimeter, and shear strength parameters of 13° friction and 2,929 kilograms per square meter cohesion.
- "Lower sand" was assumed to underlie the clay, having a (saturated) density of 2 grams per cubic centimeter and a shear strength of 35°. Given the depth and higher density of the lower sand, this material was assumed not to be susceptible to liquefaction.

2.3.3 Analysis and Results

The stability of the sections was evaluated utilizing limit equilibrium slope stability methods using the computer program PCSTABL5M. For overall landfill stability, the computer program calculated a factor of safety for shear failure surfaces that ran along the bottom liner for some distance before going up through the waste. The search for the critical block failure surfaces for the static stability was initially performed using the modified Janbu method. The program was used to evaluate 1,000 potential failure surfaces. Once the critical failure surface was located, the final factor of safety was determined using Spencer's method of slices.

Static factors of safety of 1.5 are generally considered acceptable for landfill slope stability. Therefore, based on the initial results for the unbuttressed landfill, the proposed 3:1 waste fill configuration would need to be modified in the area of Module 3 where a static factor of safety of 1.4 was determined. It was decided that the waste fill slope could be further stabilized with a soil berm. For this study, a berm height up to elevation 20 meters (approximately the location of the existing mid-slope access road) was selected. This berm was assumed to be constructed with a 2:1 external slope with the toe of the soil fill starting at the same location as the outer toe of the existing levy. Under this berm configuration, the stability was increased to 1.7 for each of the build-out heights.

An iterative approach similar to that used for the static analysis was used to find the yield-acceleration for the critical slip surface. Various yield accelerations were input into the program until a factor of safety approximately equal to 1.0 was obtained. The lowest yield acceleration was determined to be 0.12g. This was the same value obtained in the previous Module 4 analysis (Vector 2002). Based on this result, it can be assumed that similar displacement may occur during an earthquake as those calculated for Module 4. However, a dynamic analysis was performed to confirm this assumption.

2.3.4 Dynamic Analysis

A dynamic analysis was performed to estimate the potential displacement of the landfill mass of the MPL as a result of sliding along the base liner during a large earthquake. An earthquake with a magnitude of 8.25 was used for the analysis, based on an earthquake originating on the San Andreas Fault, located approximately 24 km to the northeast. The analysis was performed using a simplified procedure developed by Bray et al, 1998. This method utilizes site specific information (bedrock acceleration, landfill depth, etc.) and predetermined seismic response tables that were developed from observed performance of California landfills during recent earthquakes to allow the designer to calculate the potential displacement without the use of a complicated computer simulation. One of the landfills used for the development of the procedure was the MPL.

In this procedure, the designer first must calculate the yield acceleration (k_y) of the landfill mass using standard equilibrium analyses. The yield acceleration is defined as the horizontal acceleration that, when applied to the landfill section in the limit equilibrium analyses, resulted in a pseudo-static factor of safety essentially equal to one. The lowest value of 0.12 g was used to examine the potential maximum displacement.

In the next step, the designer determines the maximum horizontal acceleration (MHA), the period (T_m), and the significant duration ($D_{5\text{-}95}$) of the earthquake at the bedrock contact of the site. The MHA was previously determined to be 0.35g (EMCON, 1992). The T_m and $D_{5\text{-}95}$ are based on the magnitude of the earthquake and the distance that it will occur from the site. These values were obtained from a graph contained within the referenced paper, based on a magnitude M=8 earthquake, occurring along the San Andreas Fault 24 km from the MPL.

The procedure then follows a step by step method of determining input values through calculations and the use of other graphs that are contained in the technical paper. The various parameters that are determined include the average shear wave velocity (V_{savg}) and period (T_s) of the waste as well as the maximum seismic loading (k_{max}) along the sliding surface. In the simplified method, the displacement is dependent upon the relationship of the yield acceleration for the slope to k_{max} for the sliding mass. The value of k_{max} for the final fill configuration was determined to be 0.13g. This value is considered the upper limit, 16^{th} percentile, figures from the procedure. Based on this value, the estimated displacement would be less than 1 cm for the final fill configuration.

2.3.5 Findings of Stability Analyses

The results of the static stability analyses indicate that the proposed build-out of external slopes at the steeper 3:1 waste configuration are stable to elevations up to 136 meters. However, in the Module 3 area, a soil berm is needed to buttress the waste and provide acceptable factors of safety against sliding. The pseudo-static and displacement analyses also indicate that movement during an earthquake should be within industry standards.

3. PERCHED GROUNDWATER REMOVAL (UNDERDRAIN) SYSTEM

A 3-meter thick *in situ* clay zone underlies the MPL at an elevation of approximately 4.5 meters msl. This clay zone acts as a secondary layer of containment and the floor of the expansion modules are all designed to be within the clay zone. The presence of a perched aquifer at approximately 10.7 meters msl required an underdrain to be constructed to relieve any stresses on the liner system and allow the excavation to be constructed within the *in situ* clay at an elevation of 4.5 meters msl. By constructing an underdrain system, the District was able to maximize the site capacity while taking advantage of the secondary geologic containment.

The primary groundwater flow direction of the perched aquifer is from the south, with the potential for some residual flow from the west. The underdrain system will consist of a series of horizontal pipes that will intercept the flow of groundwater and direct it into vertical risers where the water can be withdrawn. Once the module is filled with waste, it should be feasible to remove the pump and reposition it in the next module's underdrain sump.

The underdrain system will be constructed by temporarily over-steepening the sands directly above the *in situ* clay layer and placing four, 30 cm perforated pipes at even intervals between the existing clay layer and the perched aquifer. The underdrain system will be capped with compacted clay along the entire exposed face of the underdrain system to construct the slope to its final configuration. The horizontal pipes will terminate just beyond the edge of each module and will be welded to the vertical risers. A submersible pump will be used to remove water from the risers until the module is filled to native grades.

4. CONCLUSION

The objectives of the Updated Master Plan were to maximize the permitted waste capacity, provide a "blue print" for future landfill development, provide for capital outlay budget planning, and update the closure and post-closure cost estimates for the site. Although not discussed in great detail in this paper, the Updated Master Plan contained a set of 27 drawings showing the phased excavation and waste filling of each of the proposed expansion modules as well as the closure configuration at final build-out. Along with the drawings, details were provided on the liner, leachate, and final cover system configurations, the quantities of excavation and liner materials and associated costs, and the site life of each module. These drawings will enable the District operations personnel to plan for the construction and development of each future phase of the site expansion.

The primary goal of maximizing the available waste capacity and site life was achieved. The original capacity and site life of the MPL determined from the 1997 Master Plan (EMCON 1997) was 30 million metric tons with closure in the year 2090 (85 years remaining site life). The modifications discussed in this paper (sliver filling, steeper 3:1 waste fill slopes, steeper 2:1 excavation cut slopes, and maximizing the permitted final waste elevation) resulted in a major increase in the waste capacity and site life. By placing additional waste as a "sliver fill" over previously fill waste slopes, an additional 6.9 million metric tons of waste and almost 13 years of additional site life were realized. Maximizing the permitted waste capacity by building 3:1 fill slopes over the entire expansion area resulted in 31.7 million metric tons of capacity and 13 years of additional site life. Finally, should the District decide to permit the site to its maximum potential fill height, an additional 8 million metric tons and 13 years of additional site life (at 2109 disposal volumes) would be achieved. Overall, the modifications to the Master Plan for the MPL resulted in an increase in waste capacity of 16.6 million metric tons and an increase in site life of 31 years.

Looking at the future development and sequencing of landfills with a "fresh set of eyes" can often lead to modifications that can extend the capacity and life of a landfill, generating significant revenue for the operating agency. At the current fee of US $27 per metric ton, the 16.6 million metric tons of additional waste capacity realized in the Updated Master Plan for the MPL will result in US $448 million in additional revenue.

5. REFERENCES

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