Prepared for

Waste Management of Hawai'i, Inc.
71-1111 Queen Ka'ahumanu Highway
Waikoloa, Hawai'i 96738

MASTER PLAN REPORT

WEST HAWAII LANDFILL
Waikoloa, Hawai'i

Prepared by

Geosyntec consultants

1111 Broadway, Sixth Floor
Oakland, California 94607

Project Number: WG1339-06

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1. INTRODUCTION

Geosyntec Consultants, Inc. (Geosyntec) has prepared this master plan report for Cells 8B (Remainder) through 11B and Cells 12 through 23 of the West Hawaii Sanitary Landfill (WHSL) on behalf of Waste Management of Hawai'i, Inc. (WMH). The WHSL is an existing non-hazardous municipal solid waste (MSW) disposal facility located in north Kona, on the island of Hawai'i. The landfill is owned by the County of Hawai'i, Department of Public Works, Division of Solid Waste, and operated by WMH.

This report was prepared by Kim Huynh and Fabrizio Settepani, and was reviewed by Hari D. Sharma, Ph.D., P.E., all of Geosyntec, in accordance with the internal review policy of the firm.

1.1 Site Background

The WHSL is an active landfill located at 71-1111 Queen Ka'ahumanu Highway in Waikoloa, Hawai'i. Sheet 1 presents a vicinity map for the site. The entire facility covers approximately 300 acres, and includes a permitted 149-acre MSW landfill, an administration building, scale house, and maintenance shop are located at the northern end of the facility, near Queen Ka'ahumanu Highway (Sheet 2 of the Drawings).

The WHSL began operation in 1993 as an MSW disposal facility, and is regulated by the State of Hawai'i Department of Health, Environmental Management Division, Solid and Hazardous Waste Branch (DOH) under Permit LF0072-93. The landfill is divided into 23 cells, with each cell constructed in one or more phases. Cells 1 through 11A and Cell 8B (Partial) have been constructed and are currently receiving waste.

This Master Plan document presents the overall design for the future cells, Cells 8B (Remainder) through 11B and Cells 12 through 23, which represent more than half the entire landfill waste footprint.

1.2 Sequential Development

Existing Cells 1 through 11A and Cell 8B (Partial) occupy approximately 58 acres. Future development will occur primarily Cells 8B (Remainder) through 11B and Cells 12 through 23, covering roughly 91 acres. Sheet 2 presents the approximate cell

boundaries. Development will likely progress in approximately 2- to 5-acre phases to provide capacity as needed for ongoing operations.

1.3 Design Description

The master plan meets the design standards and performance criteria specified in Chapter 342H, *Hawai'i Revised Statutes*, and Title 11, Chapter 58.1, *Hawai'i Administrative Rules* that incorporate Title 40 (Protection of Environment), Part 258 (Criteria for Municipal Solid Waste Landfills) in the Code of Federal Regulations (CFR) (also known as Subtitle D). The future cells will be lined with a composite liner system consisting of a geosynthetic clay liner (GCL) overlain by a 60-mil double-sided-sided textured high-density polyethylene (HDPE) geomembrane. The final cover system will include a composite barrier layer consisting of a GCL overlain by a flexible membrane liner (FML); the FML will be overlain by a cushion geotextile. The cushion geotextile will be overlain by a protective rock layer. This top layer will be obtained from processed onsite excavation sources.

Two proposed base grading plans are presented in this report. WMH is evaluating potential markets for the native rock material in addition to that required for cell construction and cover. In preparation for this, WMH proposes to deepen the excavation of the cell base grades as these projects come up to generate sufficient rock material to meet their needs. However, since the level and timing of the demand are unknown at this time, WMH proposes two excavation plans that will define the "upper limit" and the "lower limit" of the future cell excavation. The actual base grades of each cell may be somewhere in between these plans, and will be determined at the time of detailed design based on offsite needs at the time the cell is excavated.

The upper and lower limit proposed base grading plans are shown on Sheets 3 and 4 of the Drawings. The currently permitted base grades represent the "upper limit" of excavation. Approximately 220,000 cubic yards (cy) of earthfill and 5,150,000 cy of excavation will be required to achieve these grades based on the 23 April 2011 topography. The proposed "lower limit" base grading plan will require approximately 220,000 cy of earthfill and 8,200,000 cy of excavation.

Leachate generated within the landfill will be collected within a leachate collection and removal system (LCRS) on the floor and side slopes of the cell consisting of a 1-ft thick blanket layer of drainage gravel overlain by a geotextile separator and graded to drain

toward a perforated pipe and sump. Additional sumps may be added on the east side of the landfill. In the event the east side sumps are constructed, one or more additional groundwater wells will be added. For planning purposes, the location of one additional well is shown on Sheet 4 of the Drawings. Specific well location(s) will be provided when detailed construction drawings are submitted.

Waste within the new Cells 9B through 11B and Cells 12 through 23 will be adjacent to and overlying the existing MSW. Stability calculations are presented in this report reflecting final build-out to elevation 262 feet above mean sea level (ft MSL) with lined floor slopes constructed at approximately 2.8%, and lined side slopes constructed at 4H:1V (horizontal to vertical). Both static and seismic slope stability analyses for the final fill configuration have also been completed, and the results are presented in Appendix B. The final cover slopes are 5H:1V (horizontal to vertical) or flatter.

1.4 Report Organization

The remainder of this report is organized as follows:

- Section 2 includes a description of geologic and hydrogeologic conditions at the site;
- Section 3 discusses the Master Plan details, including the landfill containment system for future Cells 9B through 11B and Cells 12 through 23 and slope stability considerations;
- Section 4 includes a list of references cited in the report; and
- Section 5 includes the limitations regarding the application of information presented in this report.

The tables, drawings, and appendices included at the end of the report text provide supporting information and data for the master plan report.

2. SUBSURFACE CONDITIONS

This section provides an overview of the regional and site geology, site seismicity, and the hydrogeology based on historical data for the WHSL. The subsurface conditions summarized below are from Geosyntec [2007].

2.1 Regional Geology

The island of Hawai'i is the youngest of the Hawaiian Islands. Like the other islands, Hawai'i was formed by volcanic activity and is still expanding due to current eruptions. Five volcanoes are on Hawai'i. Mauna Kea, the highest of the five and inactive, has a peak elevation of 13,796 ft MSL and is east of the site. Kohala (5,480 ft MSL) is inactive and is north of the site. Kilauea (4,093 ft MSL) and Mauna Loa (13,677 ft MSL) are both active volcanoes southeast of the site. Hualalai (8,271 ft MSL) is south and the closest volcano to the site (about 15 miles). Hualalai last erupted in about 1800. All six volcanoes of the "Big Island" share a common evolution through three petrological stages: a basaltic, mainly tholeiitic shield-building stage, a discontinuous period of alkaline volcanism, and a period of quiescence followed by a brief period of post-erosional volcanism.

The WHSL is located within the Mauna Loa volcano boundaries. The rocks of Mauna Loa have been divided into four formations: the Ninole and the Kahuku Basalts, the Pahala Ash, and the Kau Basalt [Stearns and Macdonald, 1964; Macdonald and Abbott, 1970].

Lavas of the Ninole Basalt are only exposed in a series of steep-sided hills along the east side of the southwest rift zone of Mauna Loa. The Kahuku Basalt includes older lavas of Mauna Loa that are exposed along the Kahuku Pali, along the south slope of Mauna Loa, along the Kaoiki Fault scarp, and in a large triangular kipuka between Kilauea and the northeast rift zone of Mauna Loa. Both the Ninole and and Kahuku Basalts are overlain by the Pahala Ash, a blanket deposit of fire-fountain debris and reworked ash and stream sediments derived mainly from Kilauea caldera [Fraser, 1960; Easton 1978]. The Pahala Ash is covered by more recent lavas on both Mauna Loa and Kilauea. Mauna Loa rocks younger than the Pahala Ash are grouped into the Kau Basalt, which includes the present-day lavas. The thickness section (600 feet) of Kau Basalt is exposed in the summit caldera of Mauna Loa. Mauna Loa has erupted 39

times (flank and summit eruptions) from 1832 to present [Macdonald, Abbott, Peterson, 1983]. Lava tubes, holes, and large cracks are known to exist in the region.

2.2 Site Geology

The site is on the leeward side of Hawai'i on the Kona coast. The Pacific Ocean is 1 ¼ miles northwest of the site. The Kona coast is an arid plain of lava flows shielded by the mountains from the rain of the prevailing trade winds. The site is situated on a barren 1859 Mauna Loa lava flow more than 1 ½ miles from any populated areas. The lava flow consists of basalt with little ash cover. Both types of lava, a'a and pahoehoe, are found at the site. Tumbled heaps of clinker-like and sharp a'a lava cover about 85 percent of the site while localized exposures of very hard basalt rock formation (older pahoehoe lava) covers the rest. Geological investigations indicate fractured basalt exists below the surface a'a lava.

The geology beneath the landfill consists largely of hard, gray vesicular basalt (fractured bluerock). Thin intermittent layers of reddish gray basalt fragments (clinker) lie widely spaced between the dense bluerock layers.

2.3 Regional Hydrogeology

On a regional scale, fresh groundwater in aquifers on Hawai'i is similar to other islands, and occurs as a lens floating above and displacing saline groundwater. Because of this relationship, groundwater wells that are drilled too deep or are over-pumped are susceptible to seawater intrusion. Generally, the fresh water lens is thickest at the center of the island and thins toward the edges of the island at sea level [Hufen and others, 1980].

Because rainfall tends to be greatest in the island's interior mountainous areas, recharge to the basal groundwater bodies is also greatest in these regions. As a result, groundwater levels are highest inland and groundwater flow is generally from inland areas outward toward the coast. The regional groundwater flows in a northwesterly direction toward the ocean.

According to the County of Hawaii Water Master Plan [R.W. Beck, Inc, 2006], the site is in Hydrographic Area 5, which covers portions of South Kohala, North Kohala, North

Kona, and Hamakua. This area receives the least rainfall of all hydrographic areas in the island of Hawai'i.

The quality of groundwater in the volcanic aquifers is generally good, except where proximity to the ocean results in elevated salinity [Takasaki, 1971]. Chloride concentration in the WHSL groundwater production well is approximately 1,000 milligrams per liter (mg/L).

2.4 Site Hydrogeology

The WHSL is located in the northwest Mauna Loa aquifer sector, within the limits of the Kiholo aquifer system and in close proximity to the boundaries of the Anaehoomalu aquifer system to the north. The shallow groundwater aquifer beneath the WHSL occurs within the underlying sequence of fractured basalt flows and clinker. This basal unconfined aquifer is modified by the Ghyben-Herzberg relationship of a freshwater lens floating on the underlying seawater. The permeability of the rock in this region (North Kona) is relatively high with estimated hydraulic conductivities ranging from 500 to 33,900 foot/day (ft/d) [Bauer, 2003]. The high permeabilities and lack of caprock (alluvium, clays, and fossilized coral reef with less permeability) at the coast prevent the buildup of a thick freshwater lens and provide a relative flat hydraulic gradient. The groundwater beneath the landfill is brackish with high values of sodium and chloride, and approximately 2,500 parts per million (ppm) of total dissolved solids (TDS).

Based on historical water level data from the site monitoring wells, groundwater is encountered from 150 to 250 feet below ground surface (bgs) (0.5 to 2.5 ft MSL). Since June 1996, the average groundwater flow direction at WHSL has historically been approximately to the west-southwest. In general, the groundwater gradient is relatively flat (less than 0.0005 feet per foot), and calculated groundwater velocities are generally on the order of 2 to 3 ft/dy.

The landfill operates a groundwater production well as a source for wash water and dust control. There are few potable water supplies in the hydrographic area. These are used by residences, ranchers and resort developments primarily for drinking and domestic purposes. There are no drinking water wells down-gradient of the landfill. Numerous wells used for irrigation and agricultural (nonpotable) purposes are reported in the

general vicinity [HLA, 1993]. The Waikoloa Resort owns and maintains all of the nearby wells.

2.4.1 Tidal Influence Evaluation and Apparent Groundwater Flow Direction

Water levels in monitoring wells at the WHSL are tidally influenced. A tidal influence study was conducted at the WHSL on 6 through 8 April 2001 during a period of moderate tidal events to assess the impact of tidal fluctuations on the groundwater beneath the vicinity of the WHSL and to further evaluate the groundwater flow conditions and the need for additional monitoring wells.

Based on the study, it was concluded that no significant barrier to groundwater flow exists between the WHSL and the coast. Results of the tidal influence study indicated that groundwater elevations at the site fluctuate moderately due to tidal effects. The magnitude of groundwater fluctuations ranges from 0.45 ft to 0.73 ft, with the largest amplitude of tidal response occurring in the northwest in closest proximity to the shoreline at the down-gradient portion of the site. The tidal amplitude recorded in the sea at Kawaihae, located 10 miles to the north, during the two-day tidal study is estimated to be around 2.0 feet. Based on this estimation, the tidal efficiency of the aquifer (ratio of tidal amplitude in the wells to that of the sea) is about 20 to 35 percent. The delay in response (or lag time) recorded in the wells compared to tidal fluctuation in the sea at Kawaihae range approximately from 1.5 to 2.5 hours.

In addition, the results of the evaluation also suggest that tidal influences have a moderate impact on overall groundwater flow direction at the site. The groundwater flow direction has historically been to the west-southwest. The initial twenty-four hour monitoring period recorded in 2002 during the tidal study indicated a westerly shift in flow direction when compared to historic monitoring events. The second twenty-four monitoring period suggested a southerly shift in flow direction. However, an average of the two 24 hour periods was consistent with previous monitoring events.

Based on the results of the study, an additional well was installed down-gradient along the western property margin in order to accommodate potential groundwater flow fluctuations due to tidal affects.

2.4.2 Surface Water Hydrology

Due to the arid nature of the site, little runoff is expected that needs to be managed in a surface water management system. The site receives between 10 to 20 inches of precipitation annually. The adjusted pan evaporation at the site is estimated at 100 inches per year [Ekern and Chang, 1985]. The 25-year, 24-hour design storm is 5.0 inches [Department of Commerce, 1962]. There are no natural drainage courses evident in the facility area indicating that runoff is minimal. This is expected due to the rough and porous nature of the a'a lava and the drainage capacity of the fractured basalt beneath the site.

The WHSL has been designed with a perimeter infiltration ditch to collect runoff from the landfill and any infiltration drainage from the granular layers in the final cover. Due to the porous nature of the soils used to construct the cover and ditch, runoff is expected to infiltrate into the subsurface.

3. MASTER PLAN

This section discusses the master plan details, including the proposed base and final grading plans, associated airspace volumes, liner system components, the proposed final cover system, and slope stability analyses.

3.1 Proposed Base Grading Plans

As described in Section 1.3, two base grading plans are proposed for the WHSL to accommodate potential future demand for the native rock material that will be excavated to construct the landfill base grades.

The permitted base grading plan (Sheet 3) represents the "upper limit" of future excavation and includes 4H:1V side slopes and floor grades sloping approximately 2.8% towards LCRS swales that drain at approximately 1.9% to three sumps located along the west side of the landfill.

The proposed "lower limit" base grading plan (Sheet 4) represents possible lower excavation expected in the future cells. The "lower limit" base grading plan includes 4H:1V side slopes and floor grades sloping approximately 2.8% towards LCRS swales that drain at approximately 1.9% to three sumps located along the west side and to four, newly proposed additional sumps located along the east side. With this configuration, a north-south trending ridge line is formed along the approximate middle of the landfill footprint. Depending on the actual depth excavated, the ridge could shift to the east.

The "lower limit" base grading plan is approximately 20 feet deeper than the permitted base grades within the cells sloping towards the west, and up to approximately 60 feet deeper than the permitted base grades within the cells sloping towards the east (due to proposed east sumps). Sheet 6 presents typical cross sections of the landfill in the north-south and east-west directions comparing the two base grading plans.

3.2 Proposed Final Grading Plan

The proposed final grading plan is shown on Sheet 5. The proposed final grades maintains the permitted maximum elevation of 262 ft MSL and the approximate 10H:1V north-facing waste slope. The south-, east-, and west-facing fill slopes are

generally 5H:1V except at the northwest and northeast corners where flatter slopes are controlled by stability. The top deck reaches a peak ridge at elevation of 262 ft MSL that slopes down 3% to the east and west.

3.3 Airspace Volumes

The maximum allowable final fill grades are shown on Sheet 5 of the Drawings. Based on the proposed base and final grades, the total net airspace volumes for currently permitted base grades and for the "lower limit" base grades are approximately 15.5 MCY and 18.5 MCY, respectively. The net airspace is the volume for waste and daily cover above the lining system and below the final cover system.

Estimates of the total net remaining airspace were made by comparing the final fill surface to a combination of the base grading surfaces (in future modules) and the 23 April 2011 topography (for existing modules) using computer drafting methods. The total remaining airspace ranges from approximately 12.2 MCY based on the permitted base grades to approximately 15.2 MCY based on the proposed "lower limit" base grades.

3.4 Slope Stability Analyses

Slope stability analyses were performed for the final build-out of the WHSL. Slope stability of each phase of development will be evaluated and analyses will be included as part of the design report for each phase.

3.4.1 Methodology

Two-dimensional slope stability analyses were performed using the software program SLOPE/W [GEO-SLOPE, 2007]. The program employs a user-directed search routine to determine the critical potential shear surface with the minimum factor of safety. Slope stability was evaluated using the limit equilibrium procedures based on the Spencer [1967] method of slices. Spencer's method satisfies all conditions of force and moment equilibrium.

3.4.2 Material Properties

The material properties used in the stability analyses and the sources of information for these properties are summarized in Table 1 and Appendix B. Four materials were modeled in the slope stability analyses: (1) waste fill, (2) the existing and proposed liner system, and (3) the subgrade. The strength parameters for each of these materials used in the analyses are included in Appendix B. Section 3.7 presents details of the proposed liner systems.

The shear strengths of the site specific geosynthetic materials used to construct each phase should meet or exceed those assumed in this report. Cell-specific technical specifications and Construction Quality Assurance (CQA) manuals will be developed for each phase. The shear strengths will be verified using site specific materials as part of CQA.

For the stability analyses, Geosyntec has assumed that leachate levels within the waste fill will be limited to less than 1 foot above the liner system. This will be confirmed during detailed cell design by performing the Hydrologic Evaluation of Landfill Performance (HELP) analyses for each cell to evaluate leachate generation at the landfill. As discussed in Section 2.5, the groundwater is sufficiently deep that there are no piezometric pressures acting on the underside of the liner, therefore, water was not modeled in the stability analyses.

3.5 Site Seismic Evaluation

Site-specific seismic evaluations were performed for the WHSL by Geosyntec as part of this master plan design. The evaluations included the seismic hazard evaluation and the site seismic response analyses, and are included in Appendix A of this report. The following sections describe these evaluations.

The seismic hazard assessment for the WHSL follows the requirements in Title 40, Part 257 and Part 258 Code of Federal Regulations (Subtitle D) that requires that an evaluation of the seismic hazard be performed. The design ground motion having 10 percent probability of being exceeded in 250 years (i.e., 2% PE in 50 yrs. or a 2,475-year return period). The results of this evaluation are presented in a form of acceleration response spectrum (target spectrum). The design ground motions were developed to conform to the target spectrum, but also to match and or exceed

deterministically-evaluated significant duration of strong ground shaking. The acceleration response spectrum for the hypothetical bedrock outcrop at geometric center of the site (5% viscous damping) yields a free-field peak horizontal ground acceleration (PHGA) of 0.60g. The design event is a Moment Magnitude 6.7 at an approximate site-to-source distance of 17 kilometers. Details of the site seismic evaluation can be found in Appendix A.

The site response analysis was conducted to assess the influence of landfill mass on design (i.e., bedrock) ground motions. The results of site response analysis served as an input into seismic deformation analysis. The results of seismic deformation analysis are presented in a form of site-specific seismic deformation charts.

For the one-dimensional seismic analysis of the landfill, Geosyntec developed representative MSW columns consisting of 30 ft thick and 80 ft thick columns of final cover, MSW, and liner system over bedrock.

Geosyntec selected the following time histories (accelerograms) to represent design ground motions in bedrock at the WHSL site. All three accelerograms were selected from the catalog of shallow crustal earthquakes in the western United States, including two Hawaii motions. These accelerograms are:

- The University of Hawaii (344 deg) accelerogram, recorded during the M_w 7.2 Island of Hawaii earthquake. The island of Hawaii earthquake occurred on 29 November 1975 at a depth of 3.1 miles (5 km).
- The Lucerne Valley (340 deg) accelerogram, recorded during the M_w 7.3 Landers earthquake. The Landers earthquake occurred on 28 June 1992 on a strike-slip fault. The estimated distance between the fault rupture plane and the recording station is 1.1 km.
- The Kiholo Bay (268 deg) accelerogram, recorded during the M_w 6.7 Hawaii earthquake. This earthquake occurred on 15 October 2006. The 2006 Hawaii earthquake was an offshore earthquake occurring 21 kilometres southwest from Puakō and 21 kilometres north of Kailua-Kona, Hawaii, just offshore of the Kona Airport, on Sunday October 15, 2006.

Each time history was scaled to 0.60g. One-dimensional equivalent-linear seismic response analyses of the characteristic columns through the landfill were conducted

using the computer program SHAKE2000. For additional information, refer to Appendix A.

The results of the SHAKE2000 one-dimensional seismic site response analysis were used as input for Newmark [Newmark, 1965] seismic deformation analysis to develop site-specific permanent seismic deformation charts for landfill cover and liner. The horizontal equivalent acceleration time history at the base of the landfill, which is equal to the shear stress time history at that elevation divided by the vertical effective stress, was calculated and was used as input in the analyses. Since the seismic deformation calculated by this method is a function of yield acceleration, the analyses were repeated for several yield acceleration levels and presented in the form of permanent seismic deformation charts which are included in Appendix A.

3.6 Slope Stability Results

Static Slope Stability: The generally accepted static factor of safety for long term static loading conditions is 1.5 [Duncan, 1992]. The static factor of safety for the sections analyzed (assuming final fill conditions) were higher than 1.5 (Appendix B). As described below, seismic stability requirements control the design.

Seismic Slope Stability: Pseudo-static stability analyses were performed to evaluate seismic stability of the final fill grades for the entire landfill using the results of the site seismic response analysis. The k_y for each of the critical cross-sections was evaluated for a factor of safety equal to 1.0, as listed in Table 2. The k_y was compared to the graphs presented in Appendix A that estimate the maximum anticipated displacement of the base of the landfill mass for various k_y. The acceptable seismic deformations for landfills are less than or equal to 12 inches [Seed and Bonaparte, 1992]. For the WHSL, it was assumed that the acceptable deformation at the liner level is 6 inches and that the acceptable deformation at the final cover level is 12 inches. The results indicate that seismic stability, not static stability, is the controlling condition for the landfill[1]. Details of the seismic slope stability analyses are presented in Appendix B.

[1] The estimated seismic deformations for landfill mass at the base liner level are on the order of 4 inches, while for the landfill cover system, the deformation is 12 inches. Both these deformations meet the seismic criterion of 12 inches or less.

3.7 Base Containment System

In accordance with Chapter 342H, *Hawai'i Revised Statutes*, and Title 11, Chapter 58.1, *Hawai'i Administrative Rules*. The composite base lining system at the WHSL consists of a GCL overlain by a FML. Also, starting with Cell 8B, an additional layer of GCL and FML is provided in the sump areas for improved performance and protection of the liner system. The base containment system details for existing and future cells at the WHSL are shown on Figure 1.

The base containment system for the future cells at WHSL consists (from top to bottom) of:

- 2-ft thick operations layer (soil protective layer);
- 16 oz/sy separator non-woven geotextile;
- 1-ft thick drainage gravel with a minimum hydraulic conductivity of 0.7 cm/sec and a perforated collection pipe buried within the drainage gravel layer;
- 16 oz/sy cushion non-woven geotextile;
- 60-mil double-sided-sided textured HDPE geomembrane;
- internally reinforced GCL (Bentofix NWL-35 or equivalent); and
- 1-foot thick soil cushion/leveling layer.

Calculations supporting the detailed design of the base lining system (i.e., liner stress and anchor trench calculations) will be performed for each cell as part of detailed cell design. The composite lining system, consisting of GCL and HDPE geomembrane, is further discussed below.

3.7.1 GCL

The GCL is the lower component of the composite liner system beneath the landfill. The primary function of the GCL is to reduce the flow rate of liquid caused by potential flaws in the overlying flexible membrane liner. The GCL is a manufactured product, consisting of a layer of unhydrated bentonite sandwiched between two non-woven geotextiles and reinforced. Bentonite is a clay mineral which, when wetted, is one of the least permeable, naturally occurring soil minerals.

3.7.2 Flexible Membrane Liner: HDPE Geomembrane

The HDPE geomembrane is the primary component of the composite liner system. HDPE is typically used for flexible membrane liners because of its compatibility with leachate, proven effectiveness, and relative cost. As required by Subtitle D, the HDPE geomembrane in the base liner in the proposed design will have a minimum thickness of 60 mil. A double-sided textured geomembrane will be used for improved interface shear strength.

3.8 Leachate Collection and Removal System

The LCRS will be designed to meet 40 CFR 258.2 (Subtitle D) requirements. Leachate will be collected at the base of the cells within the LCRS and the leachate collection sump. Consistent with current site operations, leachate will be pumped from the sump and either utilized for dust control over lined areas of the landfill, pumped to an onsite evaporation pond, or transported to a Publicly Owned Treatment Work (POTW).

Calculations supporting the design of the LCRS will be performed during detailed cell design. Consistent with previous cells, the leachate generation rate from the waste and maximum head on the liner, for use in designing the leachate collection system, will be modeled using the computer software Hydrologic Evaluation of Landfill Performance (HELP), version 3.07, developed by the U.S. Environmental Protection Agency (USEPA) [USAE, 1997; Schroeder et al., 1994a, b].

Based on analyses for previous cells, if similar drainage lengths are maintained, an LCRS with a hydraulic conductivity of 0.7 cm/sec should maintain less than one foot of head over the liner as required by Subtitle D. This will be confirmed during the detailed design for each cell.

3.8.1 LCRS Drainage Layer Materials

The LCRS drainage layer will consist of a blanket granular drainage layer on the floor and side slopes. The LCRS gravel will have a minimum hydraulic conductivity of 0.7 cm/sec. To protect against potential puncture of the underlying geomembrane, the

particle size of the drainage gravel has been limited to a maximum diameter of 3/4-inch, and a nonwoven cushion geotextile required between the gravel and the geomembrane.

The LCRS drainage gravel will be overlain by a sheet of nonwoven geotextile separator fabric. The geotextile functions to separate and reduce intrusion of fine materials from the overlying operations layer into the drainage gravel. This will allow the drainage gravel to retain its specified hydraulic conductivity.

3.8.2 LCRS Pipes

The perforated LCRS pipes will be designed to carry twice the peak daily leachate flow and to withstand the expected loads due to the future overlying waste and final cover. Calculations supporting the LCRS pipe design will be performed during detailed cell design.

3.8.3 LCRS Sumps

As discussed in Section 3.1, two sump configurations are proposed in the master plan design. The permitted base grading plan includes two new sumps along the west side of the landfill, in line with the existing sumps within Cells 8A and 8B (Partial). The configuration for the "lower limit" base grades includes the sumps on the west side plus four additional sumps mirrored on the east side. The new sumps will be sized during detailed cell design based on results of the HELP analyses.

Consistent with Cell 8B, the sump design also includes a secondary GCL overlain by a secondary 60-mil HDPE geomembrane, a primary GCL overlain by a primary 60-mil HDPE geomembrane, sump gravel, a side slope leachate collection clean-out riser pipe, and a pipe completion located at the top of the side slope just beyond the limit of the landfill containment system.

3.9 Operations Layer

The operations layer is placed over the drainage layer on the floor and the sideslopes to protect the composite liner and LCRS pipes during waste placement operations. The operations layer for future cells will consist of a minimum 2-foot-thick layer of

generally sandy material excavated from onsite stockpiles. The maximum particle size of the material will be limited to 2-inches when in contact with the separator geotextile.

3.10 Final Cover Design

The final cover system will consist of the following components (from top to bottom):

- 1-foot thick protective rock layer[2];
- 6-inch thick cushion layer[3];
- cushion geotextile;
- flexible membrane liner (either 60-mil HDPE geomembrane or 40 mil LLDPE geomembrane), textured on both sides;
- reinforced GCL (nonwoven geotextile/bentonite/nonwoven geotextile);
- 6-inch thick soil cushion layer; and
- 1-foot thick intermediate/daily cover soil layer.

A typical cover detail is shown on Sheet 8 of the Drawings.

Seismic slope stability analyses (Appendix B) for the cover system presents a range of internal soil strengths to limit deformations to 12 inches or less[4]. The soil and geosynthetics selected during detailed design must meet the strength criteria for the final grades presented in this report. Based on the static and seismic requirements, the minimum required strength[5] is between 22 and 23 degrees.

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[2] A drainage layer such as a drainage geocomposite or pipes may be needed to maintain stability of the final cover. This will be determined as part of the final design at the time of closure.

[3] May be omitted if the overlying protective rock layer consists of 2-inch minus within the lower 6 inches of the lift.

[4] The analyses assume that the protective rock layer is drained so that a water surface is not present; this may be achieved by a piping system or other means.

[5] Interface strength for the various soil/geosynthetic interfaces, soil components, and geosynthetic/geosynthetic interfaces.

3.11 Storm Water Management

Geosyntec understands that for previous cells, storm-water runoff sheet flows to the perimeter of the developed cells and that based on WMH's experience, the site is underlain by very porous materials and storm water infiltrates. Therefore, for the final build-out condition, storm water is expected to infiltrate into the subgrade surrounding the landfill, and its collection and pumping is not required.

With each cell development, temporary controls will be incorporated in the cell design to minimize run-on flows into the new cells from adjacent areas and also to contain any leachate or liquid that accumulates in the cell. During operations, appropriate storm-water controls and erosion control measures will be taken by WMH as a part of site operations in accordance with the site's Storm-Water Pollution Prevention Plan (SWPPP).

3.12 Technical Specifications and Construction Quality Assurance Plan

The construction specifications for the various liner system components and materials described in previous sections (e.g., geotextile, GCL, geomembrane, LCRS pipe, LCRS gravel, operations layer, etc.) have been developed for the site and will be revised as necessary for each new cell at the time of construction.

A CQA plan has also been developed for construction of previous cells at the site and will be revised for each cell to verify that the cell is constructed in accordance with the plans and technical specifications.

3.13 Groundwater Monitoring

The site currently has four groundwater monitoring wells. WHW-01 and WHW-02 are on east side of the Landfill and WHW-03 and WHW-04 are on the west side. The monitoring wells are sampled in accordance with the Groundater and Leachate Monitoring Plan (Geosyntec, 2007).

As described in Section 3.1, four additional LCRS sumps are proposed along the east side of the landfill for the "lower limit" base grading plan. If any of these sumps are constructed, WMH proposes to install at least one additional groundwater monitoring well. For planning purposes, the additional well is shown on Sheet 4 at approximately

800 ft west of the southeast corner of the landfill. Based on evaluation of monitoring data for the site, the average groundwater flow direction inferred from the hydraulic gradient direction is toward the southwest. The purpose of this well is to monitor the groundwater downgradient of the four proposed sumps along the eastern margin of the landfill.

4. REFERENCES

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5. LIMITATIONS

This report was prepared in general accordance with the accepted standard of practice existing in Hawai'i at the time the project was performed. It should be recognized that definition and evaluation of environmental conditions is a difficult and inexact art. The subsurface conditions (e.g., soil, rock, and ground water) only represent the location and type(s) of evaluations or tests performed. Judgments leading to conclusions and recommendations are generally made with a limited knowledge of the conditions present. Geosyntec Consultants, Inc. has prepared this report for Waste Management of Hawai'i, Inc.'s exclusive use for this particular project and in accordance with generally accepted engineering practices within the area at the time of our investigation and evaluation. No other representations, expressed or implied, and no warranty or guarantee is included or intended.

This report may be used only by Waste Management of Hawai'i, Inc. and only for the purposes stated, within a reasonable time from its issuance. Land use, site conditions (both on-site and off-site) or other factors may change over time, and additional work may be required with the passage of time. Any party other than Waste Management of Hawai'i, Inc. who wishes to use this report will notify Geosyntec Consultants of such intended use. Based on the intended use of the report, Geosyntec Consultants may require that additional work be performed and that an updated report be issued. Non-compliance with any of these requirements by Waste Management of Hawai'i, Inc. or anyone else will release Geosyntec Consultants from any liability resulting from the use of this report by any unauthorized party.

TABLES

Table 1: Material Properties Used in Slope Stability Analyses[1]

Material	Unit Weight (pcf)	Shear Strength Model
MSW	65	Bi-linear Strength Envelope [Kavazanjian et al. 1995]: • For normal stresses between 0 and 770 psf, cohesion = 500 psf and friction angle = 0°; • For normal stresses greater than 770 psf, cohesion = 0 psf and friction angle = 33°.
Existing Liner System		
Cells 1 -7	100	Shear-Normal Function Strength Envelope[1] based on review of liner system configurations.
Cells 8A & 9A (Partial)	100	Shear-Normal Function Strength Envelope[1] based on CQA data.
Cells 9A (Remainder) & 10A (Partial)		Shear-Normal Function Strength Envelope[1] based on CQA data.
Cells 10A (Remainder) & 11A		Bi-linear Strength Envelope based on CQA data: • For normal stresses between 0 and 8,000 psf, cohesion = 0 psf and friction angle = 7.8°; • For normal stresses greater than 8,000 psf, friction angle = 1.6°.
Cell 8B (Partial)	100	Shear-Normal Function Strength Envelope[1] based on CQA data.
Future Liner System		
Future Modules	100	Shear-Normal Function Strength Envelope[1]
Subgrade	NA	Bedrock (forces truncated circle along liner)

Note:

(1) Provided in Appendix B.

Table 2: Slope Stability Results for Waste Mass[1]

Section	Configuration	Base Grade	Factor of Safety	Yield Acceleration k_y[2]
A1	West Slope	Permit	3.5	0.17g
		Lower Limit	3.5	0.17g
	East Slope	Permit	3.7	0.22g
		Lower Limit	3.7	0.17g
A2	West Slope	As-Built	4.2	0.14g
	East Slope	Permit	3.9	0.22g
		Lower Limit	3.9	0.17g
B1	North Slope	As-Built	2.7	0.13g
	South Slope	Permit	2.8	0.17g
		Lower Limit	3.3	0.14g

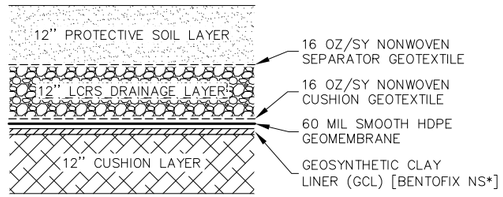
Note:

(1) Details of slope stability analyses are presented in Appendix B.

(2) Seismic yield accelerations were calculated under final fill conditions, and estimated seismic displacements were less than or equal to 6 inches.

FIGURE

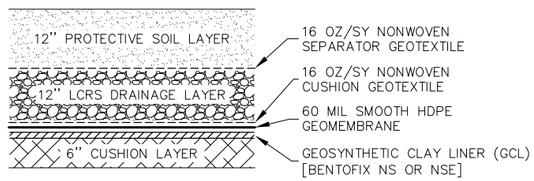
CELLS 1, 2, & 3



BASE LINER (FLOOR & SIDESLOPE)

SOURCES: "*QUALITY ASSURANCE REPORT, WEST HAWAII LANDFILL-CELL 1, PUUANAHULU, HAWAII*," BY HARDING LAWSON ASSOCIATES, 14 OCTOBER 1993; "*QUALITY ASSURANCE REPORT, WEST HAWAII SANITARY LANDFILL-CELL 1 (EAST) AND CELL 2 (WEST), PUUANAHULU, HAWAII*," BY HARDING LAWSON ASSOCIATES, 7 JULY 1994; AND "*WEST HAWAII SANITARY LANDFILL, CELL 3 GEOSYNTHETIC LINER CONSTRUCTION, CONSTRUCTION QUALITY ASSURANCE REPORT*," BY RUST ENVIRONMENT & INFRASTRUCTURE, INC., 9 MAY 1996.

CELLS 4, 5, 6, & 7

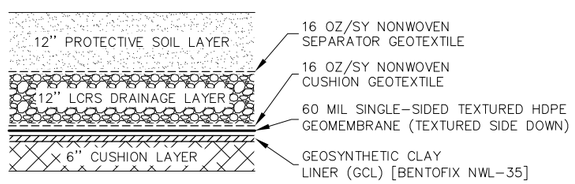


BASE LINER (FLOOR & SIDESLOPE)

NOTES: (1) CUSHION LAYER THICKNESS UNKNOWN FOR CELLS 4 AND 5A.
(2) PROTECTIVE SOIL COVER THICKNESS UNKNOWN FOR CELL 5A.
(3) CELLS 5 & 7: 12" LCRS DRAINAGE LAYER AND SEPARATOR GEOTEXILE INSTALLED 10 FT UP SIDESLOPE DURING CELL CONSTRUCTION. WMH EXTENDED THESE LAYERS DURING OPERATIONS AS FILLING PROGRESSED.

SOURCES: "*FINAL CONSTRUCTION QUALITY ASSURANCE REPORT, MSW CELL 4, COMPOSITE LINER & LEACHATE COLLECTION & REMOVAL SYSTEM*," BY RUST ENVIRONMENT & INFRASTRUCTURE, INC., 14 MAY 1998; "*CONSTRUCTION QUALITY ASSURANCE REPORT FOR WEST HAWAII SANITARY LANDFILL, CELL 5-A, WASTE MANAGEMENT OF HAWAII, WAIKOLOA, HAWAII*," BY A-MEHR, 1 JUNE 2000; "*CONSTRUCTION QUALITY ASSURANCE REPORT FOR WEST HAWAII SANITARY LANDFILL, CELL 5-B, WASTE MANAGEMENT OF HAWAII, WAIKOLOA, HAWAII*," BY A-MEHR, NOVEMBER 2001; "*CONSTRUCTION QUALITY ASSURANCE REPORT FOR WEST HAWAII SANITARY LANDFILL, CELL 6, WASTE MANAGEMENT OF HAWAII, WAIKOLOA, HAWAII*," BY A-MEHR, MARCH 2003; AND "*CONSTRUCTION QUALITY ASSURANCE REPORT FOR WEST HAWAII SANITARY LANDFILL, CELL 7, WASTE MANAGEMENT OF HAWAII, WAIKOLOA, HAWAII*," BY A-MEHR, INC., SEPTEMBER 2004; AND "CONSTRUCTION QUALITY ASSURANCE REPORT FOR CELL 7 REMAINDER, WEST HAWAII SANITARY LANDFILL, WAIKOLOA, HAWAII," BY EARTH TECH, INC., MAY 2007

CELLS 8A & 9A (PARTIAL)

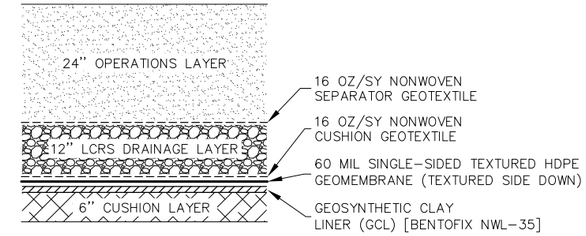


BASE LINER (FLOOR & SIDESLOPE)

NOTE: 12" LCRS DRAINAGE LAYER AND SEPARATOR GEOTEXILE INSTALLED 10 FT UP SIDESLOPE DURING CELL CONSTRUCTION. WMH EXTENDED THESE LAYERS DURING OPERATIONS AS FILLING PROGRESSED.

SOURCE: "*CONSTRUCTION QUALITY ASSURANCE REPORT FOR CELL 8A (REMAINDER) AND 9A (PARTIAL), WEST HAWAII SANITARY LANDFILL, WAIKOLOA, HAWAII*," BY EARTH TECH, INC., DECEMBER 2007.

CELL 9A (REMAINDER), 10A, & 11A

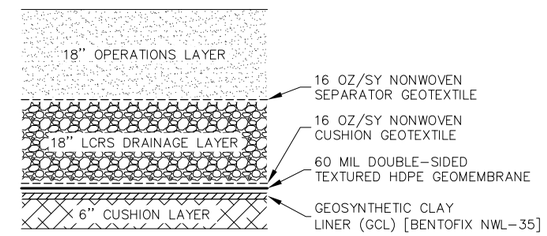


BASE LINER (FLOOR & SIDESLOPE)

NOTE: CELLS 9A (REMAINDER), 10A, AND 11A DO NOT HAVE SIDESLOPES.

SOURCES: "*REPORT OF CONSTRUCTION QUALITY ASSURANCE, CELLS 9A (REMAINDER) & 10A (PARTIAL) CONSTRUCTION, WEST HAWAII LANDFILL, WAIKOLOA, HAWAII*," BY GEOSYNTEC CONSULTANTS, INC., 22 JANUARY 2009; "*CONSTRUCTION QUALITY ASSURANCE REPORT FOR CELL 10A (REMAINDER) AND 11A (PARTIAL), WEST HAWAII SANITARY LANDFILL, WAIKOLOA, HAWAII*," BY AECOM TECHNICAL SERVICES, INC, APRIL 2010; AND "*CONSTRUCTION QUALITY ASSURANCE REPORT FOR CELL 11A (REMAINDER), WEST HAWAII SANITARY LANDFILL, WAIKOLOA, HAWAII*," BY AECOM TECHNICAL SERVICES, INC, FEBRUARY 2011.

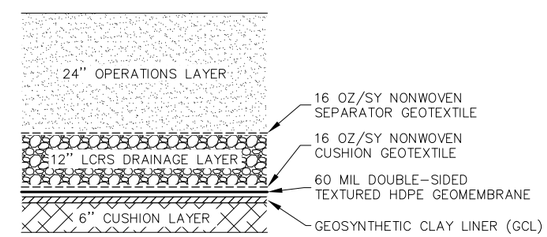
CELL 8B



FLOOR LINER

SOURCE: "*CONSTRUCTION QUALITY ASSURANCE REPORT FOR CELL 8B (PARTIAL), WEST HAWAII LANDFILL, WAIKOLOA, HAWAII*," BY AECOM TECHNICAL SERVICES, INC., NOVEMBER 2011, REVISED OCTOBER 2011.

FUTURE CELLS



BASE LINER (FLOOR & SIDESLOPE)

SOURCE: "*CONSTRUCTION DRAWINGS, CELL 8B, WEST HAWAII LANDFILL, WAIKOLOA, HAWAII*," BY GEOSYNTEC CONSULTANTS, INC., MAY 2011, REVISED OCTOBER 2011.

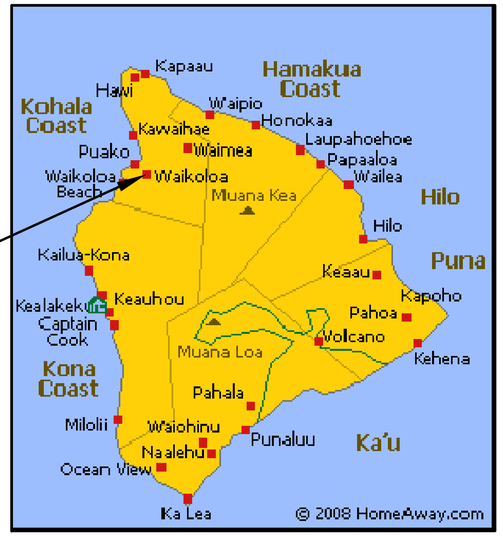
Geosyntec consultants

BASE CONTAINMENT SYSTEM DETAILS MASTER PLAN WEST HAWAII LANDFILL WAIKOLOA, HAWAII	FIGURE NO.	1
	PROJECT NO.	WG1339-06
	DATE:	12 MARCH 2012

P:\CADD\Land Projects 3\WM\West Hawaii\WG1339-06 (MasterPlan)\1339-06_MP FIG1.dwg 3-13-12 KHuynh

DRAWINGS

DRAWINGS
MASTER PLAN
WEST HAWAII LANDFILL
WAIKOLOA, HAWAII
MARCH 2012



VICINITY MAP

SHEET NO.	TITLE
1	COVER AND INDEX SHEET
2	SITE PLAN
3	CURRENTLY PERMITTED BASE GRADING PLAN
4	PROPOSED "LOWER LIMIT" BASE GRADING PLAN
5	PROPOSED FINAL GRADING PLAN
6	TYPICAL CROSS SECTIONS
7	DETAILS I
8	DETAILS II

PREPARED FOR:

WASTE MANAGEMENT OF HAWAII, INC.
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PREPARED BY:

Geosyntec consultants
engineers | scientists | innovators

1111 BROADWAY, SIXTH FLOOR
OAKLAND, CALIFORNIA 94607
PHONE: (510) 836-3034

PROJECT NO. WG1339-06

LEGEND

- 360 — EXISTING GROUND 10-FT CONTOUR (MSL)
- EXISTING GROUND 2-FT CONTOUR (MSL)
- APPROXIMATE CELL BOUNDARY
- PROPERTY LINE
- EXISTING LANDFILL
- APPROXIMATE LOCATION OF EXISTING MONITORING WELL
- △ HV-4 288.16 — EXISTING BENCHMARK

NOTES:

1. SITE TOPOGRAPHY BASED ON 23 APRIL 2011 AERIAL SURVEY PROVIDED BY AERO-METRIC, INC.

2. THE COORDINATES AND BEARINGS SHOWN ARE BASED ON THE HAWAII STATE PLANE COORDINATE SYSTEM, ZONE 1. THE VERTICAL DATUM IS BASED ON MEAN SEA LEVEL.

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250 125 0 250 500
SCALE IN FEET

REVISIONS

NO.	DESCRIPTION	DATE	BY

WASTE MANAGEMENT

Geosyntec consultants
1111 Broadway
Sixth Floor
Oakland, CA 94607

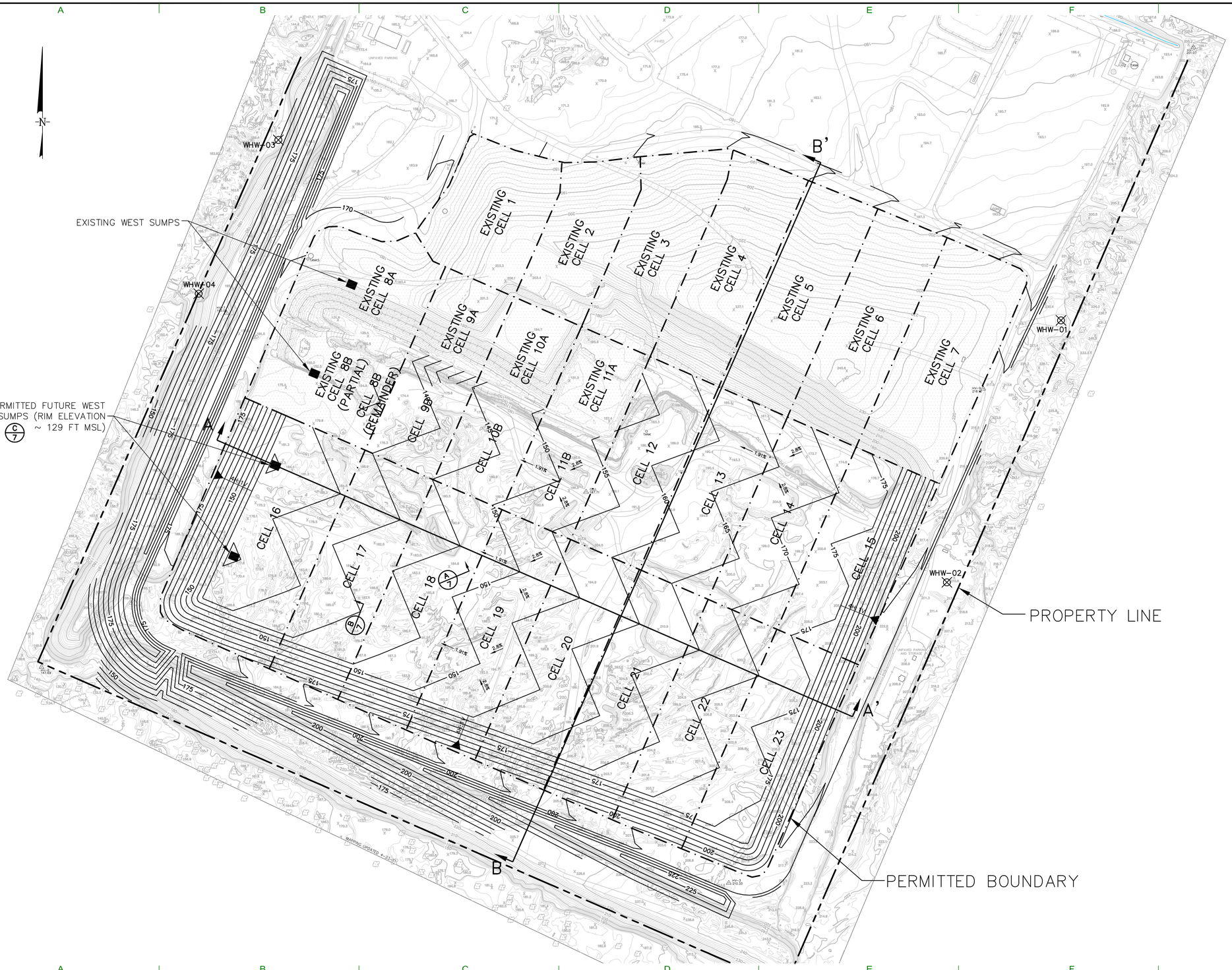
SITE PLAN

MASTER PLAN
WEST HAWAII LANDFILL
WAIKOLOA, HAWAII

NOT FOR CONSTRUCTION

DES BY: FWS	DATE: 12 MARCH 2012
DRN BY: LKH	SCALE: AS SHOWN
CHK BY: FWS	PROJECT: WG1339-06
REV BY: LKH	DOCUMENT:
APP BY: HDS	
FILE: 1339-06_MP C002-5.DWG	

SHEET NO.
2



LEGEND

- 200 — PERMITTED BASE GRADE 5-FT CONTOUR (MSL)
- 360 — EXISTING GROUND 10-FT CONTOUR (MSL)
- EXISTING GROUND 2-FT CONTOUR (MSL)
- APPROXIMATE CELL BOUNDARY
- PROPERTY LINE
- EXISTING LANDFILL
- APPROXIMATE LOCATION OF EXISTING MONITORING WELL
- HV-4 288.16 — EXISTING BENCHMARK

NOTES:

1. SITE TOPOGRAPHY BASED ON 23 APRIL 2011 AERIAL SURVEY PROVIDED BY AERO-METRIC, INC.

2. THE COORDINATES AND BEARINGS SHOWN ARE BASED ON NTHE HAWAII STATE PLANE COORDINATE SYSTEM, ZONE 1. THE VERTICAL DATUM IS BASED ON MEAN SEA LEVEL.

3. BASE GRADES SHOWN ARE FOR TOP OF SOIL CUSHION LAYER.

5. THE LOCATION OF TIE-IN TO EXISTING CONTAINMENT SYSTEM SHOWN IS APPROXIMATE. ACTUAL LOCATION OF TIE-IN SHALL BE FIELD VERIFIED PRIOR TO CONSTRUCTION.

6. GRADES ALONG TIE-IN TO EXISTING CELLS MAY BE ADJUSTED AS NEEDED TO MATCH EXISTING GRADES WITH PRIOR APPROVAL BY THE ENGINEER.

200 100 0 200 400
SCALE IN FEET

REVISIONS			
NO.	DESCRIPTION	DATE	BY

WASTE MANAGEMENT

Geosyntec consultants
1111 Broadway
Sixth Floor
Oakland, CA 94607

CURRENTLY PERMITTED BASE GRADING PLAN

MASTER PLAN
WEST HAWAII LANDFILL
WAIKOLOA, HAWAII

NOT FOR CONSTRUCTION

DES BY: FWS	DATE: 12 MARCH 2012
DRN BY: LKH	SCALE: AS SHOWN
CHK BY: FWS	PROJECT: WG1339-06
REV BY: LKH	DOCUMENT:
APP BY: HDS	
FILE: 1339-06_MP C002-5.DWG	

SHEET NO. 3

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LEGEND

- 200 — PROPOSED "LOWER LIMIT" BASE GRADE 5-FT CONTOUR (MSL)
- 360 — EXISTING GROUND 10-FT CONTOUR (MSL)
- EXISTING GROUND 2-FT CONTOUR (MSL)
- APPROXIMATE CELL BOUNDARY
- PROPERTY LINE
- EXISTING LANDFILL
- APPROXIMATE LOCATION OF MONITORING WELL
- HV-4 288.16 — EXISTING BENCHMARK

NOTES:

1. SITE TOPOGRAPHY BASED ON 23 APRIL 2011 AERIAL SURVEY PROVIDED BY AERO-METRIC, INC.

2. THE COORDINATES AND BEARINGS SHOWN ARE BASED ON NTHE HAWAII STATE PLANE COORDINATE SYSTEM, ZONE 1. THE VERTICAL DATUM IS BASED ON MEAN SEA LEVEL.

3. BASE GRADES SHOWN ARE FOR TOP OF SOIL CUSHION LAYER.

5. THE LOCATION OF TIE-IN TO EXISTING CONTAINMENT SYSTEM SHOWN IS APPROXIMATE. ACTUAL LOCATION OF TIE-IN SHALL BE FIELD VERIFIED PRIOR TO CONSTRUCTION.

6. GRADES ALONG TIE-IN TO EXISTING CELLS MAY BE ADJUSTED AS NEEDED TO MATCH EXISTING GRADES WITH PRIOR APPROVAL BY THE ENGINEER.

7. NEW GROUNDWATER MONITORING WELL WHW-05 WILL BE INSTALLED IF EASTERN LCRS SUMPS ARE CONSTRUCTED. PROPOSED LOCATION OF WHW-05 IS APPROXIMATE, AND IS SHOWN FOR PLANNING PURSOES ONLY. EXACT LOCATION WILL BE DETERMINED AT A FUTURE DATE IF THE WELL IS REQUIRED.

200 100 0 200 400
SCALE IN FEET

REVISIONS

NO.	DESCRIPTION	DATE	BY

WASTE MANAGEMENT

Geosyntec consultants
1111 Broadway
Sixth Floor
Oakland, CA 94607

PROPOSED "LOWER LIMIT" BASE GRADING PLAN

MASTER PLAN
WEST HAWAII LANDFILL
WAIKOLOA, HAWAII

NOT FOR CONSTRUCTION

DES BY: FWS	DATE: 12 MARCH 2012
DRN BY: LKH	SCALE: AS SHOWN
CHK BY: FWS	PROJECT: WG1339-06
REV BY: LKH	DOCUMENT:
APP BY: HDS	
FILE: 1339-06_MP C002-5.DWG	

SHEET NO. 4

F:\CADD\Local Projects 3\WA\West Hawai\WG1339-06 (MasterPlan)\1339-06_MP C002-6.dwg 3-13-12 KHuynh

LEGEND

- 262 — PROPOSED FINAL GRADE 25-FT CONTOUR (MSL)
- PROPOSED FINAL GRADE 5-FT CONTOUR (MSL)
- 360 — EXISTING GROUND 10-FT CONTOUR (MSL)
- EXISTING GROUND 2-FT CONTOUR (MSL)
- APPROXIMATE CELL BOUNDARY
- PROPERTY LINE
- EXISTING LANDFILL
- APPROXIMATE LOCATION OF MONITORING WELL
- HV-4 288.16 — EXISTING BENCHMARK

NOTES:

1. SITE TOPOGRAPHY BASED ON 23 APRIL 2011 AERIAL SURVEY PROVIDED BY AERO-METRIC, INC.

2. THE COORDINATES AND BEARINGS SHOWN ARE BASED ON NTHE HAWAII STATE PLANE COORDINATE SYSTEM, ZONE 1. THE VERTICAL DATUM IS BASED ON MEAN SEA LEVEL.

3. BASE GRADES SHOWN ARE FOR TOP OF SOIL CUSHION LAYER.

5. THE LOCATION OF TIE-IN TO EXISTING CONTAINMENT SYSTEM SHOWN IS APPROXIMATE. ACTUAL LOCATION OF TIE-IN SHALL BE FIELD VERIFIED PRIOR TO CONSTRUCTION.

6. GRADES ALONG TIE-IN TO EXISTING CELLS MAY BE ADJUSTED AS NEEDED TO MATCH EXISTING GRADES WITH PRIOR APPROVAL BY THE ENGINEER.

200 100 0 200 400
SCALE IN FEET

REVISIONS

NO.	DESCRIPTION	DATE	BY

WASTE MANAGEMENT

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1111 Broadway
Sixth Floor
Oakland, CA 94607

PROPOSED FINAL GRADING PLAN

MASTER PLAN
WEST HAWAII LANDFILL
WAIKOLOA, HAWAII

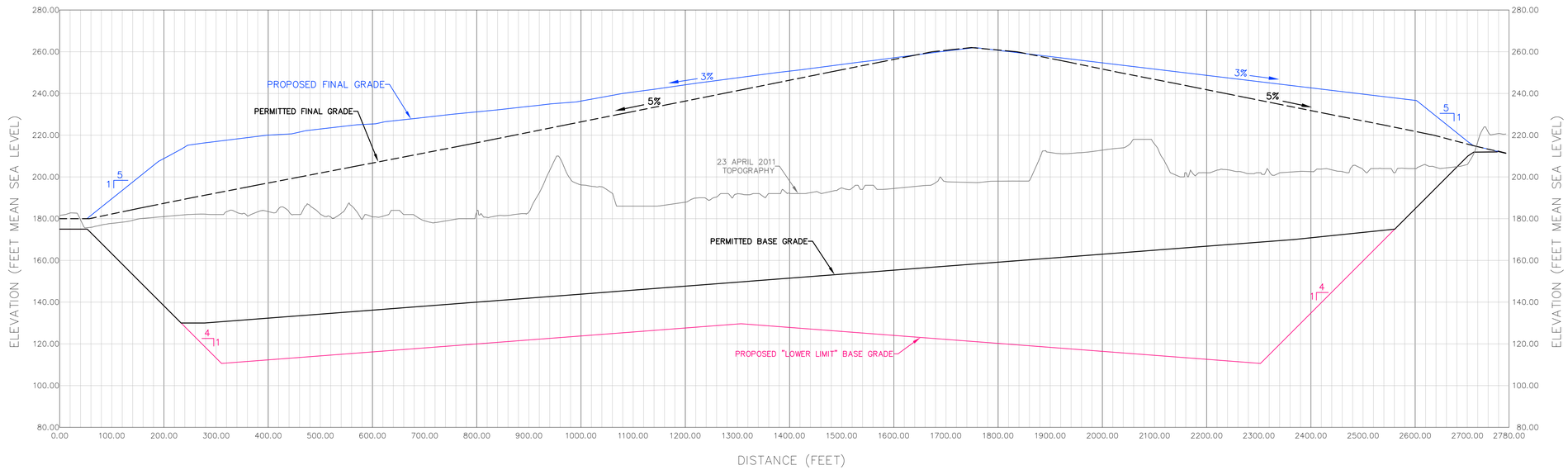
NOT FOR CONSTRUCTION

DES BY: FWS	DATE: 12 MARCH 2012
DRN BY: LKH	SCALE: AS SHOWN
CHK BY: FWS	PROJECT: WG1339-06
REV BY: LKH	DOCUMENT:
APP BY: HDS	
FILE: 1339-06_MP C002-5.DWG	

SHEET NO.
5

F:\CADD\Local Projects 3\WM\West Hawaii\WG1339-06 (Waterfront)\1339-06_MP C002-6.dwg 3-13-12 KHuynh

SECTION A–A'



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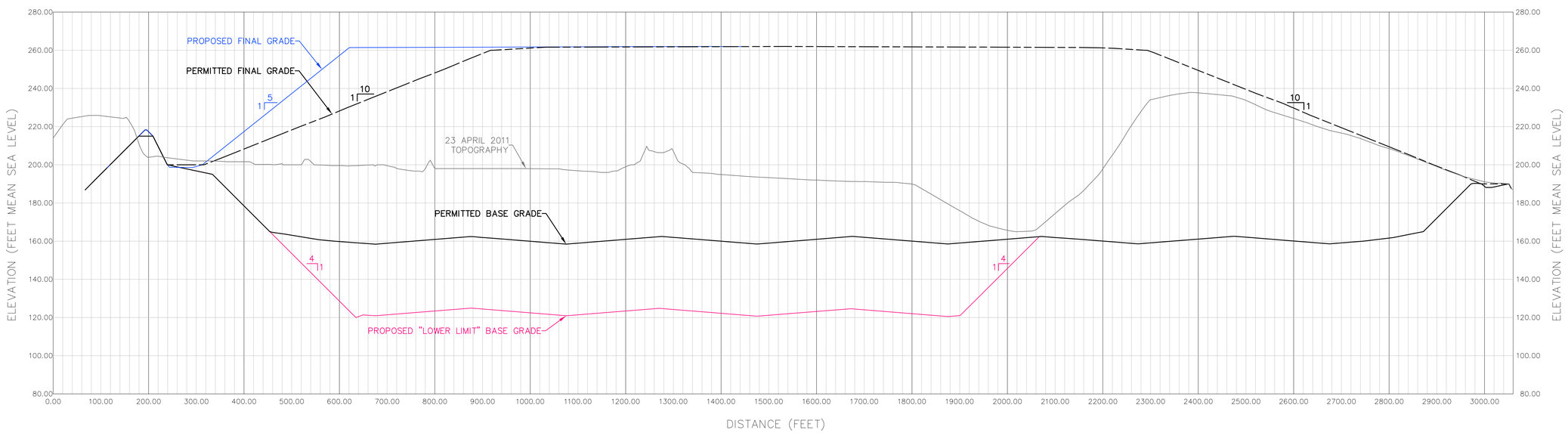

120 60 0 120 240
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30 15 0 30 60
VERTICAL SCALE IN FEET

REVISIONS			
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Geosyntec consultants

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Oakland, CA 94607

TYPICAL CROSS SECTIONS

MASTER PLAN
WEST HAWAII LANDFILL
WAIKOLOA, HAWAII

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DES BY: FWS	DATE: 12 MARCH 2012
DRN BY: LKH	SCALE: AS SHOWN
CHK BY: FWS	PROJECT: WG1339–06
REV BY: LKH	DOCUMENT:
APP BY: HDS	
FILE: 1339–06_MP C002–5.DWG	

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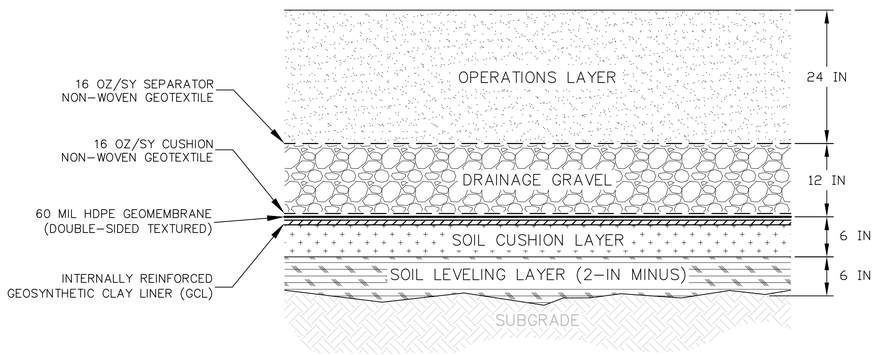

A 3,4 DETAIL (TYPICAL)
BASE CONTAINMENT SYSTEM CONFIGURATION
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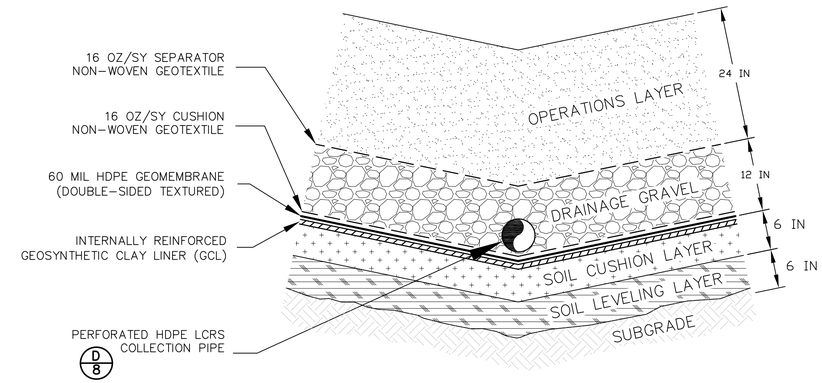
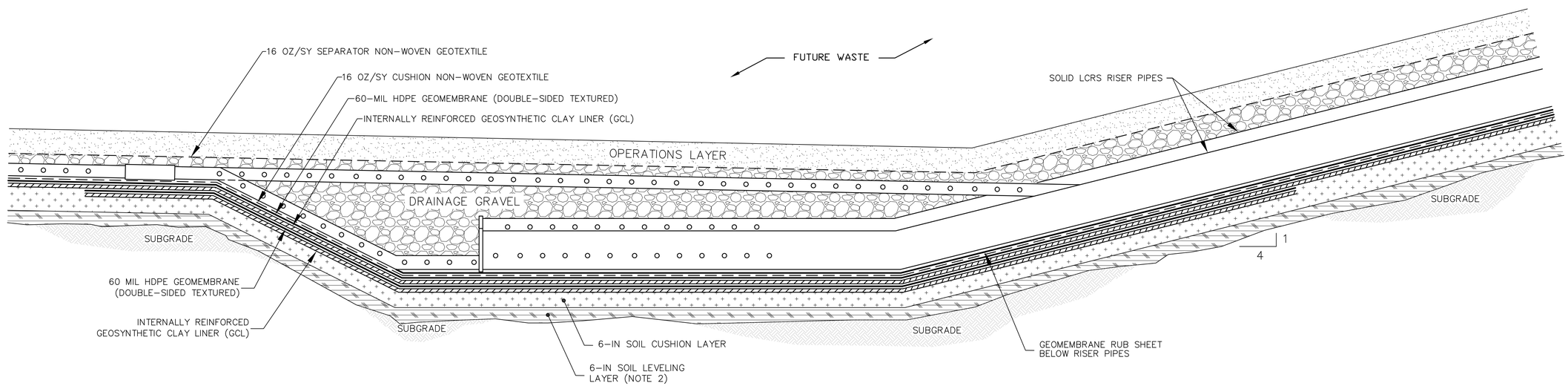


B 3,4 LCRS TRENCH (TYP.)
FLOOR
NOT TO SCALE



C 3,4 DETAIL (TYPICAL)
LCRS SUMP
NOT TO SCALE

NOTES:

1. SCREENED BACK LINES AND HATCHES DEPICT EXISTING ASSUMED CONDITIONS.
2. THICKNESS OF SOIL LEVELING LAYER BAY VARY BASED ON BLASTING BREAKAGE AND GRADES ACHIEVED AFTER BLASTING.

P:\CADD\Land Projects 3\WM\West Hawaii\WG1339-06 (MasterPlan)\1339-06_MP C007-8.dwg 3-13-12 KHuynh

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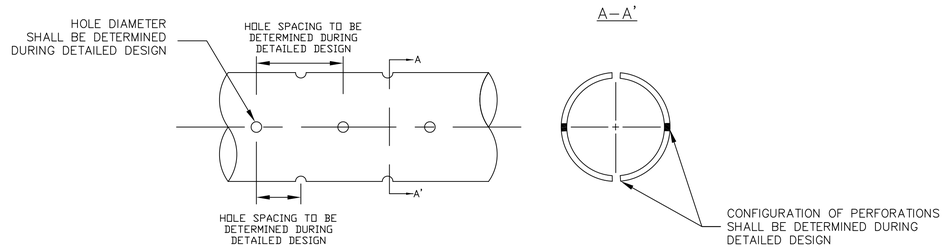
DETAILS I

MASTER PLAN
WEST HAWAII LANDFILL
WAIKOLOA, HAWAII

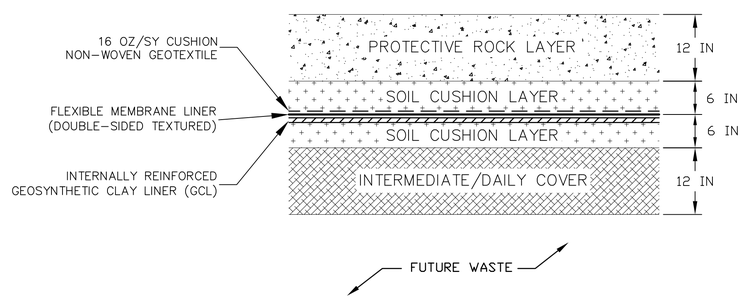
NOT FOR CONSTRUCTION

DES BY: FWS	DATE: 12 MARCH 2012
DRN BY: LKH	SCALE: AS SHOWN
CHK BY: FWS	PROJECT: WG1339-06
REV BY: LKH	DOCUMENT:
APP BY: HDS	
FILE: 1339-06_MP C007-8.DWG	

SHEET NO. 7



D/7 DETAIL (TYPICAL)
PIPE PERFORATION



E/5 DETAIL (TYPICAL)
FINAL COVER SYSTEM

P:\CADD\Land Projects 3\WM\West Hawaii\WG1339-06 (MasterPlan)\1339-06_MP C007-8.dwg 3-13-12 KHuynh

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NO.	DESCRIPTION	DATE	BY

WASTE MANAGEMENT

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Oakland, CA 94607

DETAILS II

MASTER PLAN
WEST HAWAII LANDFILL
WAIKOLOA, HAWAII

NOT FOR CONSTRUCTION

DES BY: FWS	DATE: 12 MARCH 2012
DRN BY: LKH	SCALE: AS SHOWN
CHK BY: FWS	PROJECT: WG1339-06
REV BY: LKH	DOCUMENT:
APP BY: HDS	
FILE: 1339-06_MP C007-8.DWG	

SHEET NO.
8

APPENDIX A

Geosyntec consultants

2100 Main Street, Suite 150
Huntington Beach, California 92648
PH 714.969.0800
FAX 714.969.0820
www.geosyntec.com

12 March 2012

Dr. Hari Sharma, P.E., G.E.
Principal
Geosyntec Consultants, Inc.
1111 Broadway, Sixth Floor
Oakland, California 94607

Subject: Seismic Site Response and Seismic Deformation Analyses
West Hawaii Sanitary Landfill
Waikoloa, Hawaii

Dear Dr. Sharma:

GENERAL

This letter report provides an input for performance-based seismic stability assessment of West Hawaii Sanitary Landfill (WHSL). The WHSL is near Waikoloa, Hawaii. The following evaluations were performed in order to develop necessary input: (i) seismic hazard assessment; (ii) development of design ground motions; (iii) site response analyses of representative landfill configurations; and (iv) seismic deformation analysis for representative landfill configurations. The input for evaluations documented herein is based upon the results of previous work at the site by Geosyntec Consultants, Inc. (Geosyntec) and information presented in Geosyntec [2012].

The seismic hazard assessment documented herein is probabilistic, with design ground motion having 10 percent probability of being exceeded in 250 years[1] (2% PE in 50 yrs.; 2,475-year return period) which is the requirement in Title 40, Part 257 and Part 258 of the Code of Federal Regulations (i.e., Subtitle D). The results of this evaluation are presented as an acceleration response spectrum (target spectrum). The design ground

[1] This probability of exceedance is the same as a 2 percent probability of being exceeded in 50 years (2,475-year return period) which is commonly used in building codes and is listed as such on the United States Geological Survey web page.

motions were developed to conform to the target spectrum and also to match and/or exceed the deterministically-evaluated significant duration of strong ground shaking.

The site response analysis was conducted to assess the influence of landfill mass on design (i.e., bedrock) ground motions. The results of site response analysis served as an input into seismic deformation analysis. The results of seismic deformation analysis are presented as site-specific seismic deformation charts. These charts may be used, in conjunction with the results of pseudostatic stability evaluations documented in Geosyntec [2012], to perform a performance-based seismic stability assessment of WHSL.

BACKGROUND

The WHSL is an active landfill located at 71-1111 Queen Ka'ahumanu Highway in Waikoloa, Hawai'i. The approximate coordinates of the geometric center of the site are, as shown in Figure 1, 19.89 degrees north latitude and -155.98 degrees west longitude. The entire facility covers approximately 300 acres, and includes a permitted 149-acre Municipal Solid Waste (MSW) landfill, an administration building, scale house, and maintenance shop are located at the northern end of the facility, near Queen Ka'ahumanu Highway.

The WHSL began operation in 1993 as an MSW disposal facility. The WSSL is regulated by the State of Hawai'i Department of Health, Environmental Management Division, Solid and Hazardous Waste Branch (DOH) under Permit LF0072-93. The landfill is divided into 23 cells, with each cell constructed in one or more phases. Cells 1 through 11A and Cell 8B (Partial) have been constructed and are currently receiving waste.

The overall design for the future cells, Cells 8B (Remainder) through 11B and Cells 12 through 23, which represents more than half the entire landfill waste footprint, is presented in Geosyntec [2012] along with the results of relevant static and pseudostatic stability evaluations. The results of pseudostatic evaluations of representative waste fill configurations (yield acceleration of sliding mass, k_y) is, along with site-specific seismic deformation charts, used for performance-based seismic stability assessment of WHSL which is documented in Geosyntec [2012].

Geosyntec consultants

SEISMIC HAZARD EVALUATION

The West Hawaii Sanitary Landfill is in an area of high seismicity. Epicenters of known historic earthquakes in the area are shown in Figure 2. Also shown in Figure 2 are the earthquake rupture areas delineated by Klein et al. [2001] from aftershock zones or were inferred from flank geometry and contemporary seismicity.

The M_w 6.7 Hawaii earthquake (epicenter not shown in Figure 2) occurred on 15 October 2006. This was an offshore earthquake with approximate epicentral coordinates of 19.820 degrees north latitude and -156.027 degrees west longitude, as reported on the United States Geological Survey (USGS) web site (www.usgs.org). This epicenter was approximately 17 kilometers southwest from the WHSL site.

Based upon review of historic seismicity, Geosyntec evaluated that seismic hazard at the WHSL site is dominated by a Moment Magnitude 6.7 event at an approximate site-to-source distance of 17 kilometers. Using this information, Geosyntec further evaluated that significant duration of strong ground shaking in hypothetical bedrock outcrop at geometric center of the site ranges from 6 to 13 seconds. The spreadsheet calculations of significant duration are enclosed in Appendix A.

The evaluation on the free-field Peak Horizontal Ground Acceleration (PHGA) and associated acceleration response spectrum (2% viscous damping) documented herein is, in accordance with the State of Hawaii requirements, probabilistic. The evaluation is performed for an event with 2% PE in 50 yrs. using the Java calculator tool posted on the USGS web site. The acceleration response spectrum for the hypothetical bedrock outcrop at geometric center of the site (5% viscous damping) is shown in Figure 3. The free-field PHGA is 0.60 g.

DEVELOPMENT OF DESIGN GROUD MOTIONS

Three design ground motions, described in a subsequent section "Representative Time Histories," were selected from a catalog (i.e., on-line database) of recorded ground motions and scaled to a PHGA of 0.60 g. The selection was made based upon the conformance of motion characteristics with the design significant duration of strong ground shaking and the target acceleration response spectrum.

SEISMIC SITE RESPONSE AND DEFORMATION ANALYSES

Method of Analysis

The seismic response and deformation analyses for WHSL were carried out in accordance with the methodology outlined below:

(i) select representative cross sections through landfill based upon cell base grade and waste fill geometries;

(ii) assign material properties to the selected cross sections based upon available information, past experience, and engineering judgment;

(iii) select representative one-dimensional (1-D) columns for seismic site response analysis;

(iv) perform 1-D equivalent-linear seismic site response analyses of the representative columns and express the results in terms of the average acceleration time history at landfill surface and at a depth corresponding to the top of the base liner system; and

(v) perform Newmark-type [Newmark, 1965] seismic deformation analyses for the landfill cover and for the landfill liner (waste mass) by processing the average acceleration time histories calculated in step (iv) and expressing the results in terms of site-specific seismic deformation charts.

The above-outlined methodology is essentially the *decoupled* approach to seismic deformation analyses. Lin and Whitman [1983] and Gazetas and Uddin [1994] have demonstrated that this decoupled approach is generally conservative and typically overestimates permanent displacements by at least a factor of two compared to more rigorous *fully coupled* seismic deformation analysis methods.

Representative Waste Fill Columns

West Hawaii Sanitary Landfill has rectangular geometry, and a large width to height ratio. Therefore, a one-dimensional analysis is appropriate, yet conservative, to evaluate the seismic response of the landfill. For the one-dimensional seismic analysis of the

landfill, Geosyntec developed representative MSW columns, referred to herein as *Columns 1* and 2. Column 1 is 30 ft thick and Column 2 is 80 ft thick.

Material Properties

For the seismic site response analysis of the waste mass, Geosyntec divided the on-site materials into the following characteristic groups:

(i) Municipal Solid Waste (MSW) material; and

(ii) basaltic rock underlying the site;

In the absence of site specific data, MSW materials disposed of at the site were characterized by the Kavazanjian et al. [1996] unit weight and shear wave velocity profiles for MSW. This set of generic material properties was based upon shear wave velocity measurements at the Operating Industries, Inc. (OII) landfill in southern California, but, as demonstrated in the same reference, is representative of a variety of solid waste landfills.

The Matasovic and Kavazanjian [1998] normalized shear modulus reduction (upper-bound) and material damping (lower-bound) curves were selected for the analyses. The shear modulus reduction and damping properties are based upon cyclic direct simple shear testing of municipal solid waste and back analysis of recorded strong motion data at the Operating Industries, Inc. (OII) landfill in southern California.

For consistency with information used to evaluate the bedrock acceleration response spectrum for development of design ground motions, shear wave velocity of 2,500 ft/second was assumed for bedrock underlying representative columns 1 and 2.

Representative Time Histories

Geosyntec selected the following time histories (accelerograms) to represent design ground motions in bedrock at the WHSL site. All three accelerograms were selected from the catalog of shallow crustal earthquakes in the western United States, including two Hawaii motions. These accelerograms are:

- The University of Hawaii (344 deg) accelerogram, recorded during the M_w 7.2 Island of Hawaii earthquake. The island of Hawaii earthquake occurred on 29 November 1975 at a depth of 3.1 miles (5 km).

- The Lucerne Valley (340 deg) accelerogram, recorded during the M_w 7.3 Landers earthquake. The Landers earthquake occurred on 28 June 1992 on a strike-slip fault. The estimated distance between the fault rupture plane and the recording station is 1.1 km.

- The Kiholo Bay (268 deg) accelerogram, recorded during the M_w 6.7 Hawaii earthquake. This earthquake occurred on 15 October 2006. The 2006 Hawaii earthquake was an offshore earthquake occurring 21 kilometres southwest from Puakō and 21 kilometres north of Kailua-Kona, Hawaii, just offshore of the Kona Airport, on Sunday October 15, 2006.

The acceleration response spectra (i.e. elastic 5% damped spectra) of scaled to 0.60 g accelerograms are plotted against the target acceleration response spectrum in Figure 3.

Figure 3 indicates that the acceleration response spectra of selected accelerograms scaled to PHGA of 0.60 g match and exceed the target acceleration response spectrum in the period range of 0.1 to 1.0 seconds which is of interest for seismic considerations at the site.

Seismic Site Response Analyses

One-dimensional equivalent-linear seismic response analyses of the characteristic columns through the landfill were conducted using the computer program SHAKE2000 [Ordonez, 2006; www.GeoMotions.com]. SHAKE2000 computes the response of a system of homogeneous, visco-elastic layers of infinite horizontal extent subjected to vertically propagating shear waves. The program is based on the continuous solution to the wave equation adapted for use with transient motions through the Fast Fourier Transform Algorithm. The nonlinearity of the shear modulus and damping is accounted for by the use of equivalent linear soil properties [Idriss and Seed, 1968] using an iterative procedure to obtain values for modulus and damping compatible with the effective strains in each layer.

The design accelerograms scaled to the design PHGA of 0.60 g were applied at the base of the characteristic columns in the SHAKE2000 analyses. Detailed seismic site response analysis computer outputs are enclosed in Appendix B. The average acceleration time histories from the above described SHAKE2000 seismic site response analyses were used in the Newmark seismic deformation analyses as described below.

The results of the seismic site response analyses indicate that the WHSL waste fill amplified input (i.e., bedrock) ground motions.

Newmark Seismic Deformation Analyses

The results of the SHAKE2000 one-dimensional seismic site response analysis were used as input for Newmark [Newmark, 1965] seismic deformation analysis to develop site-specific permanent seismic deformation charts for landfill cover and liner. The horizontal equivalent acceleration time history at the base of the landfill, which is equal to the shear stress time history at that elevation divided by the vertical effective stress, was calculated and was used as input in the analyses. Since the seismic deformation calculated by this method is a function of yield acceleration, the analyses were repeated for several yield acceleration levels and presented in the form of permanent seismic deformation charts. These charts are presented in Figures 4 through 7. The computer program outputs are enclosed in Appendix C.

CONCLUSIONS

This letter report presents the results of site-specific seismic hazard, site response, and seismic deformation potential analyses performed by Geosyntec for the West Hawaii Sanitary Landfill. The results of the seismic site response analysis are representative of 30 and 80 ft high waste columns. These results were used as an input into the seismic deformation analysis. The results of seismic deformation analysis are presented in a form of charts relating calculated permanent seismic deformation to yield acceleration (permanent displacement charts) and are presented in Figures 4 through 7.

For a known yield acceleration of critical failure mas, the permanent seismic displacement charts developed herein, can be used to perform a performance-based seismic stability evaluation of WHSL cover and liner.

Geosyntec consultants

CLOSURE

This letter report was prepared by Dr. Neven Matasovic, P.E., G.E. of Geosyntec. In accordance with the peer review policy of the firm, this report was reviewed by Mr. Fabrizio Settepani, P.E., G.E., also of Geosyntec.

If you have any questions regarding this report or require additional information, please do not hesitate to contact either of the undersigned.

Sincerely,

Neven Matasovic, Ph.D., P.E., G.E.
Associate

Attachments: Appendices A through C

REFERENCES

Gazetas, G. and Uddin, N. [1994], "Permanent Deformation on Pre-Existing Sliding Surfaces in Dams," *Journal of Geotechnical Engineering,* ASCE, Vol. 120, No. 11, pp. 2041-2061.

Geosyntec [2012], "Master Plan Report, West Hawaii Landfill, Waikoloa, Hawaii," Technical Report, Geosyntec Consultants, Oakland, California.

Idriss, I.M., and Seed, H.B. [1968], "Seismic response of horizontal soil layers", *Journal of the soil mechanics and Foundations Division,* ASCE, Vol. 94, No. SM4, July, pp. 1003-1031.

Kavazanjian, E., Jr., Matasovic, N., Stokoe, K. and Bray, J.D. [1996], "In-Situ Shear Wave Velocity of Solid Waste from Surface Wave Measurements," Proc. *2nd International Congress on Environmental Geotechnics,* Osaka, Japan, Vol. 1, pp. 97-102.

Klein, F.W., Frankel, A.D., Mueller, C.S., Wesson. R.L., and Okubo, P.G. [2001], "Seismic Hazard of Hawaii: High Rate of Large Earthquakes and Probabilistic Ground Motion-Maps," *Bulletin of the Seismological Society of America*, Vol. 91, No. 3, pp. 479-498.

Lin, J.S. and Whitman, R.V. [1983], "Decoupling Approximation to the Evaluation of Earthquake-Induced Plastic Slip in Earth Dams," *Earthquake Engineering and Structural Dynamics,* Vol. 11, pp. 667-678.

Matasovic, N. and Kavazanjian, E., Jr. [1998], "Cyclic Characterization of OII Landfill Solid Waste," *ASCE Journal of Geotechnical and Geoenvironmental Engineering,* Vol. 124, No. 3, pp. 197-210.

Newmark, N.M. [1965], "Effects of Earthquakes, on Dams and Embankments," *Geotechnique,* Vol. 15, No. 2, pp. 139-160.

Ordonez, G. [2006], "SHAKE2000 - A computer program for the 1-D analysis of geotechnical earthquake engineering problems", *User's manual,* www.GeoMotions.com.

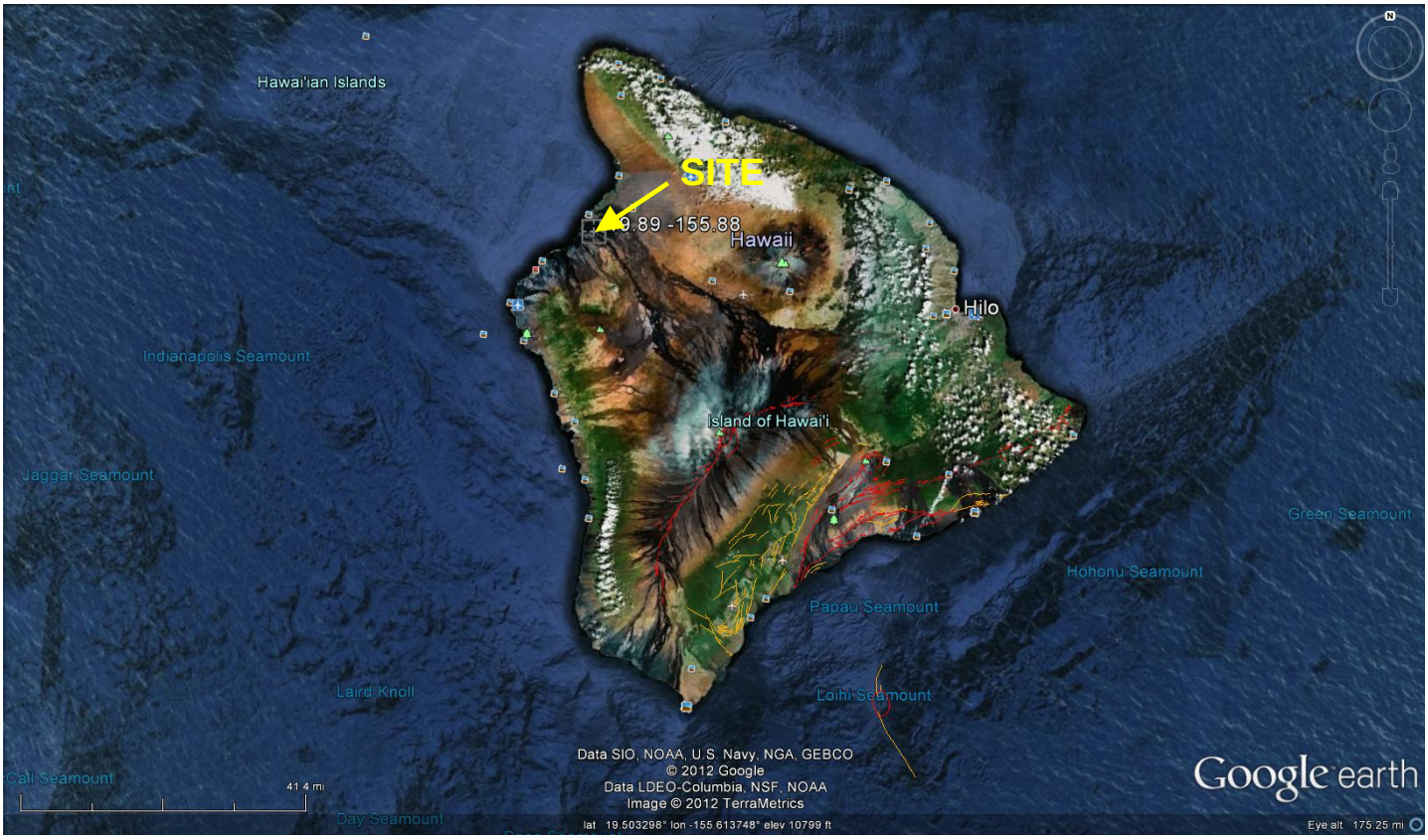

Figure 1: Site Location Map
West Hawaii Sanitary Landfill
Waikoloa, Hawaii

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Date: March 2012

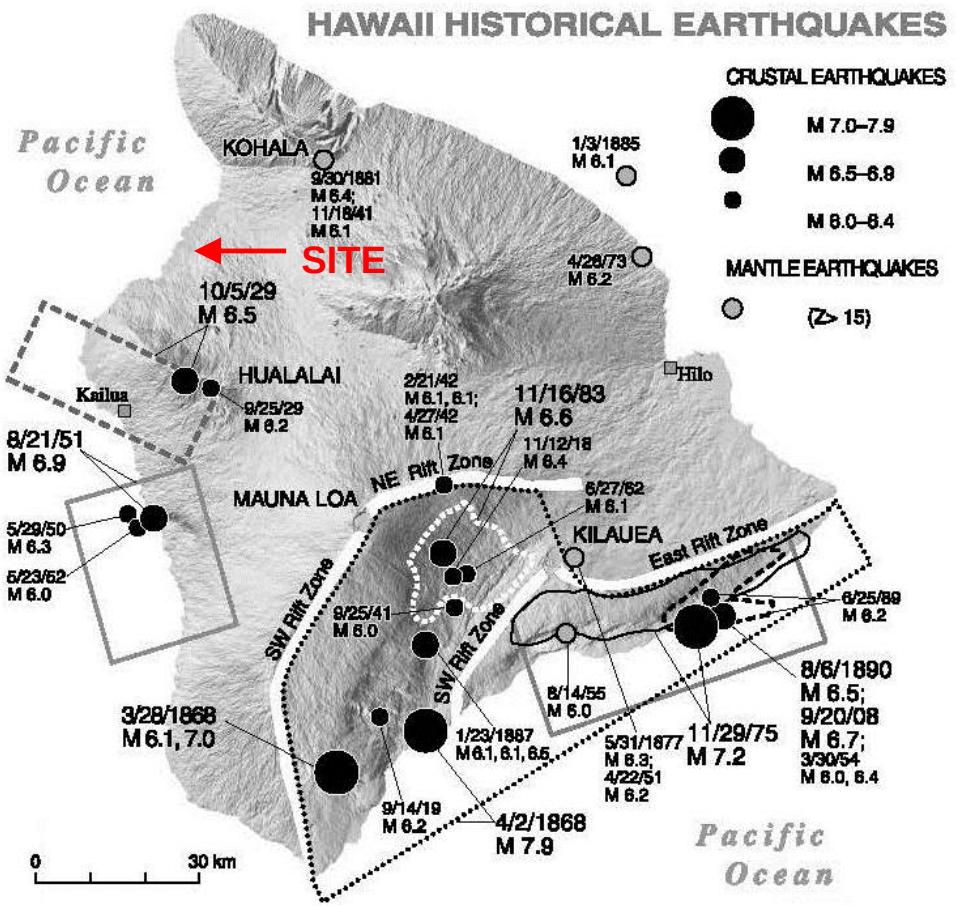

Figure 1. Large Hawaiian earthquakes and rupture zones. Circles are epicenters of the historical (1868–1998) $M \geqq 6.0$ Hawaiian earthquakes. Locations before the seismic network was established (about 1950) are from the isoseismal maps of Wyss and Koyanagi (1992a) and locations of Klein and Wright (2000). Many additional M 6 earthquakes are in the catalog before 1925 (Table 2) but are too poorly located to include on the map. Outlined areas are rupture areas from aftershock zones or inferred from flank geometry and contemporary seismicity. Ruptures of large earthquakes are on near-horizontal decollement faults at the base of seaward-slipping volcano flanks.

Figure 2: Site Seismicity
West Hawaii Sanitary Landfill
Waikoloa, Hawaii

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Date: March 2012

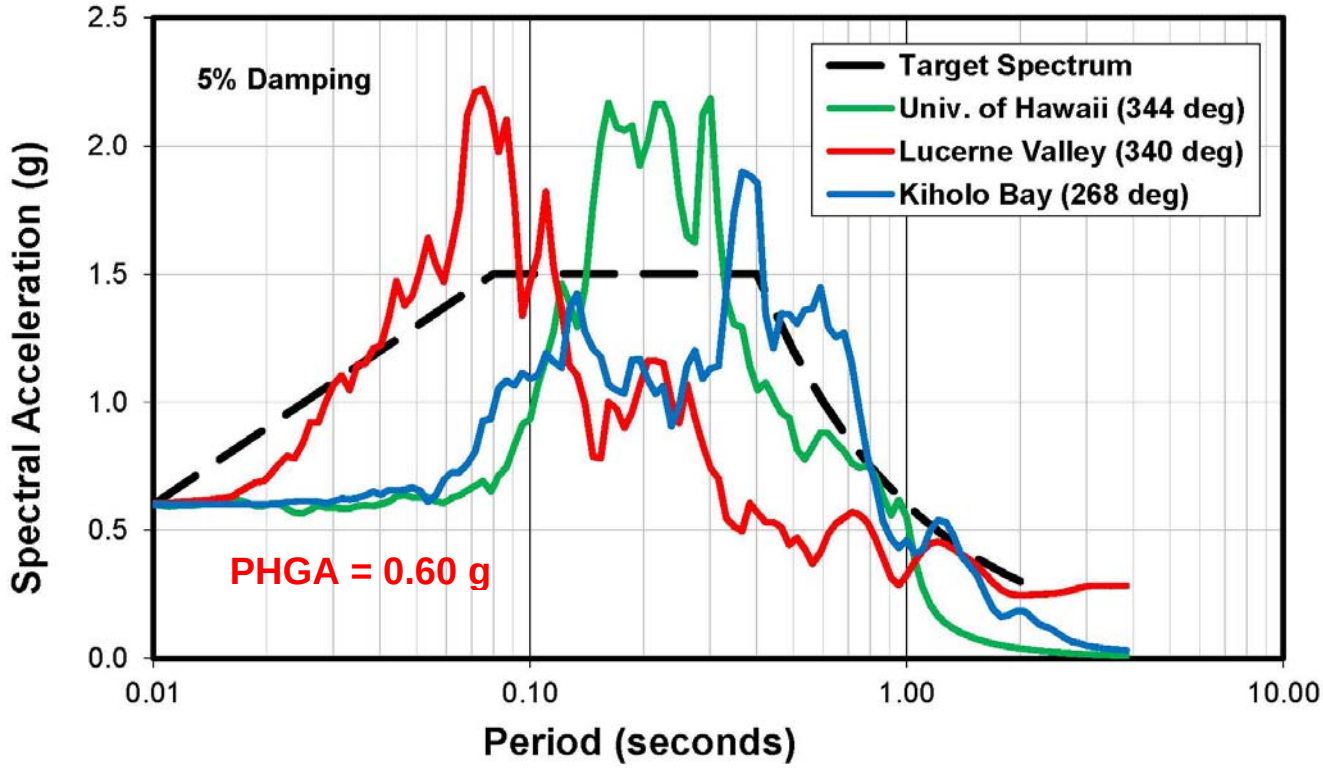

Figure 3: **Acceleration Response Spectra**
West Hawaii Sanitary Landfill
Waikoloa, Hawaii

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Date: March 2012

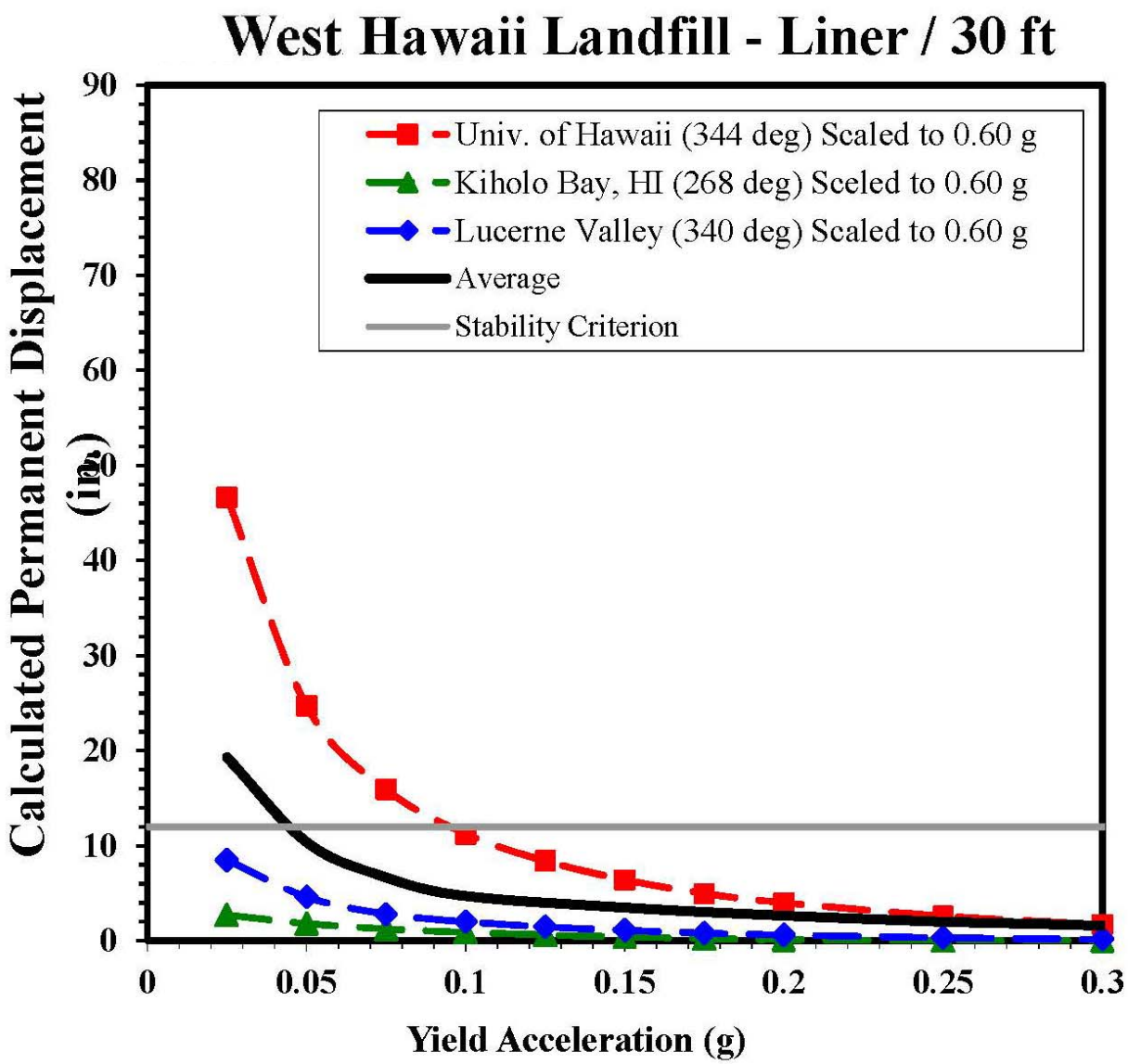

Figure 4: **Seismic Displacement Chart – Liner / 30 ft Column**
West Hawaii Sanitary Landfill
Waikoloa, Hawaii

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Date: March 2012

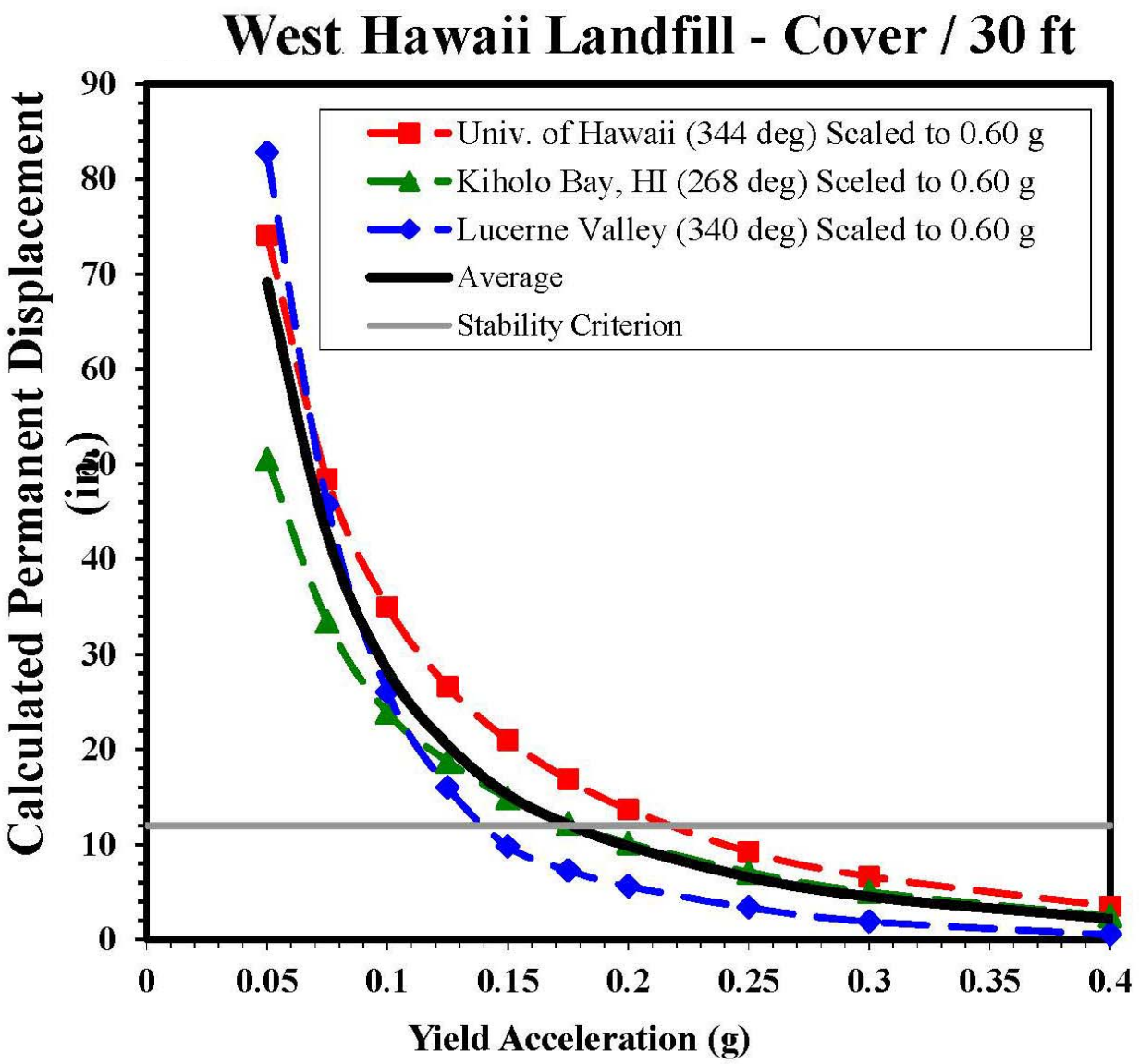

Figure 5: **Seismic Displacement Chart – Cover / 30 ft Column**
West Hawaii Sanitary Landfill
Waikoloa, Hawaii

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Project No.: WG1339-01

Date: March 2012

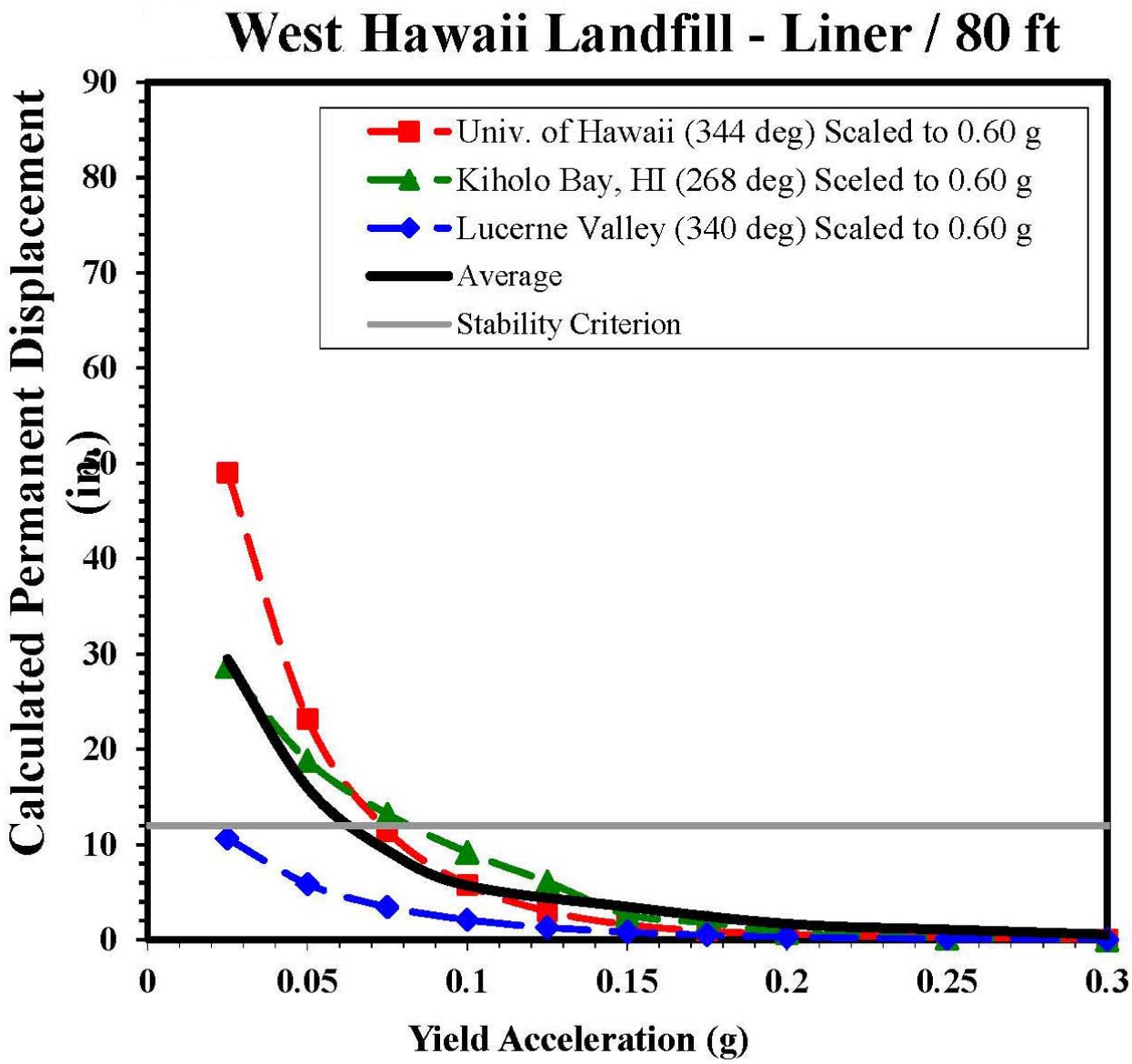

Figure 6: **Seismic Displacement Chart – Liner / 80 ft Column**
West Hawaii Sanitary Landfill
Waikoloa, Hawaii

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Project No.: WG1339-01

Date: March 2012

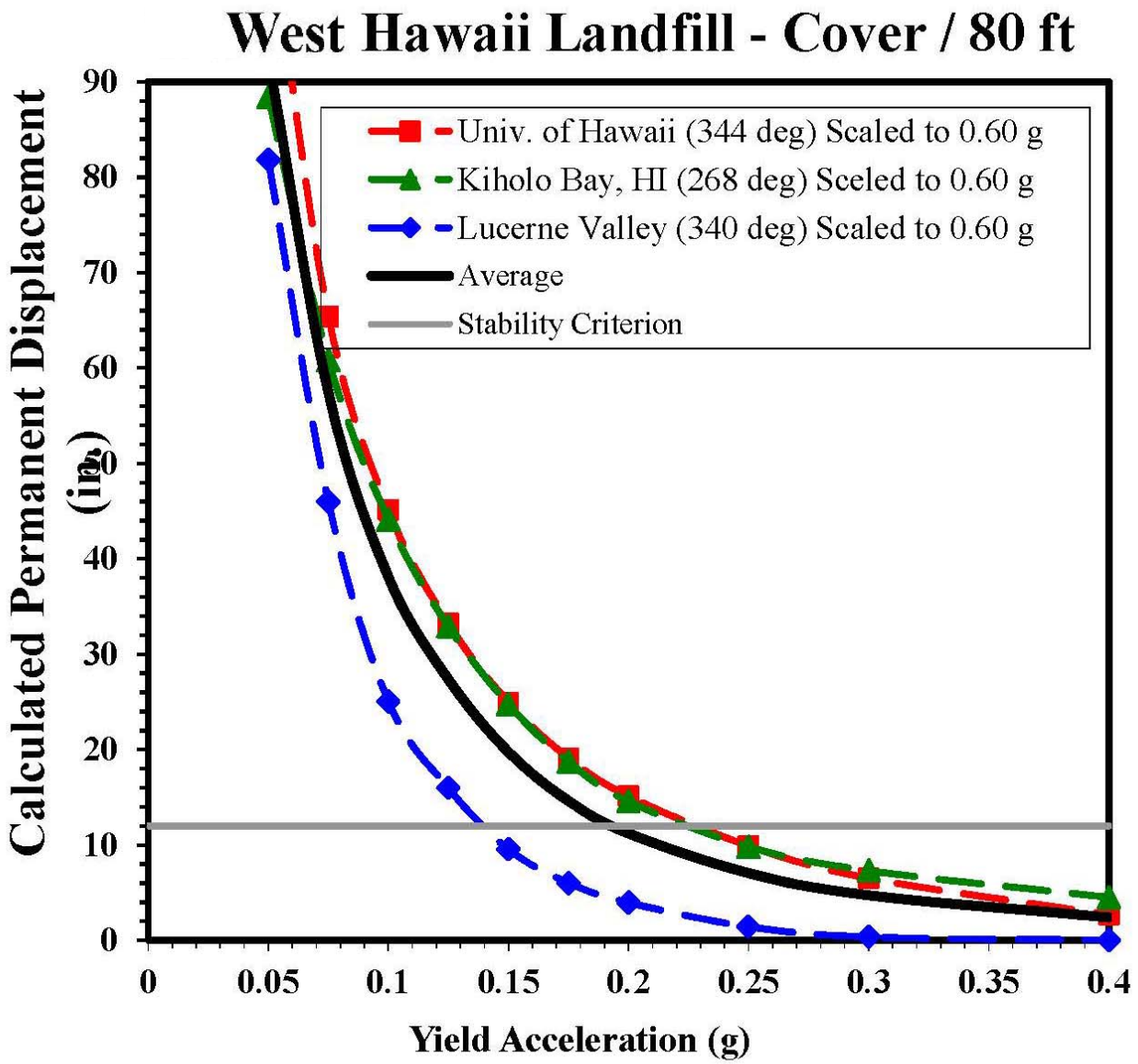

Figure 7: **Seismic Displacement Chart – Cover / 80 ft Column**
West Hawaii Sanitary Landfill
Waikoloa, Hawaii

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Project No.: WG1339-01

Date: March 2012

APPENDIX A
Duration of Shaking Evaluation

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Significant Duration of Strong Ground Shaking
Model: Kempton and Stewart (2006)

Site: **West Hawaii Landfill**

Fault: **2006 Hawaii Earthquake Epicentral Distance**

Model Parameter	**Value**
b1	2.79
b2	0.82
Moment Magnitude, M_w	6.7
δσ	29
β	3.2
c2	0.15
Site-to-Source Distance (km)	17
c4	3
c5	-0.0041
Vs30 (m/s)	2500
c6	-0.44
c7	0.0012
z1.5 (m) (assumed; assumption not critical)	1000
ln(Duration)	1.87

Calculated Significant Duration of Strong Ground Shaking, $D_{s(5\text{-}95)}$:

Mean	**6 sec**
Mean + one standard deviation	13 sec
Mean - one standard deviation	-1 sec

Reference: Kempton, J. J. and Stewart, J. P. (2006), "Prediction Equations for Significant Duration of Earthquake Ground Motions Considering Site and Near-Source Effects," Earthquake Spectra, Volume 22, No. 4, pp. 985-1013, November 2006, Earthquake Engineering Research Institute.

APPENDIX B
Site Response Analyses

APPENDIX B-1
30-ft Column

```
          ************************************************************
          * SHAKE  --   A COMPUTER PROGRAM FOR EARTHQUAKE RESPONSE   *
          *             ANALYSIS OF HORIZONTALLY LAYERED SITES       *
          *             by: Per B. Schnabel & John Lysmer -- 1970    *
          * ---------------------------------------------------------- *
          * Shake85   : IBM-PC version of SHAKE                      *
          *             by: S.S. (Willie) Lai, January 1985          *
          * ---------------------------------------------------------- *
          * Shake88   : New modulus reduction curves for clays       *
          *             added using results from Sun et al. (1988)   *
          *             by: J. I. Sun & Ramin Golesorkhi             *
          *             February 26, 1988                            *
          * ---------------------------------------------------------- *
          * Shake90/91: Adjust last iteration; Input now is either   *
          *             Gmax or max Vs; up to 13 material types can  *
          *             be specified by user; up to 50 Layers can    *
          *             be specified; object motion can be read in   *
          *             from a separate file and can have user       *
          *             specified format; Different periods for      *
          *             response spectral calculations; options      *
          *             are renumbered; and general cleanup          *
          *             by: J. I. Sun, I. M. Idriss & P. Dirrim      *
          *             June 1990 - February 1991                    *
          * ---------------------------------------------------------- *
          * Shake91   : General cleanup and finalization of input /  *
          *             output format ... etc                        *
          *             by: I. M. Idriss                             *
          *             December 1991                                *
          * ---------------------------------------------------------- *
          * Shake98   : Routine for direct calculation of average    *
          *             acceleration is added to the program. Out-   *
          *             put format is modified to enable the two -   *
          *             - page landscape printing.  The following    *
          *             modulus reduction and  damping curves are    *
          *             added:  Matasovic & Kavazanjian (1998) for   *
          *             municipal solid waste; Matasovic & Vucetic   *
          *             (1993) for SMB sand; and Vucetic and Dobry   *
          *             (1991) for clays of various plasticities.    *
          *             by: Neven Matasovic                          *
          *             August 1993 - May 1998                       *
          ************************************************************

 MAX. NUMBER OF TERMS IN FOURIER TRANSFORM  =      4096
 NECESSARY LENGTH OF BLANK COMMON X         =     25619

 ******   OPTION  1  ***  READ RELATION BETWEEN SOIL PROPERTIES AND STRAIN


 *********************
  MATERIAL TYPE NO. 1
 *********************

 CURVE NO.  1:      #1 Modulus - OII Waste (Matasovic & Kavazanjian, 1998)
 CURVE NO.  2:      #1 Damping - OII Waste (Matasovic & Kavazanjian, 1998)


      CURVE NO. 1              CURVE NO. 2
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001      1.13
```



```
     .0003     1.000          .0003      1.77
     .0010     1.000          .0010      2.58
     .0032      .994          .0032      4.03
     .0100      .983          .0100      5.89
     .0316      .959          .0316      8.97
     .1000      .881          .1000     12.91
     .3160      .655          .3160     17.63
    1.0000      .316         1.0000     21.92
    3.1600      .130         3.1600     25.17

 *********************
  MATERIAL TYPE NO. 6
 *********************

 CURVE NO. 11:      #6 Modulus for CL (PI=30) (Vucetic and Dobry, 1991)
 CURVE NO. 12:      #6 Damping for CL (PI=30) (Vucetic and Dobry, 1991)


      CURVE NO.11              CURVE NO.12
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001       .85
     .0003     1.000          .0003       .85
     .0010     1.000          .0010      1.36
     .0030      .976          .0030      2.18
     .0100      .901          .0100      3.82
     .0300      .743          .0320      6.00
     .1000      .538          .1000      8.72
     .3000      .332          .3160     12.41
    1.0000      .158         1.0000     16.90
    3.0000      .048         3.1600     21.26

 *********************
  MATERIAL TYPE NO. 3
 *********************

 CURVE NO.  5:   #3 Modulus for Gravel (Shibuya et al., 1990)
 CURVE NO.  6:   #3 Damping for Gravel (Shibuya et al., 1990)


      CURVE NO. 5              CURVE NO. 6
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001      2.50
     .0003      .986          .0003      2.56
     .0010      .951          .0010      2.73
     .0032      .903          .0032      2.94
     .0100      .847          .0100      3.32
     .0316      .792          .0316      4.14
     .1000      .722          .1000      5.00
    1.0000      .550         1.0000      7.40

 ******   OPTION  2  ***  READ SOIL / WASTE PROFILE

 SOIL PROFILE NO.      1   MSW - Matasovic & Kavazanjian (1998)

 NUMBER OF LAYERS      5
 DEPTH TO BEDROCK   30.0
```



```
  NO. TYPE  THICKNESS   DEPTH  TOT. PRESS.  MODULUS  DAMPING  UNIT WT. SH. VEL.
             (ft)       (ft)      (psf)       (ksf)    (%)      (pcf)     (fps)
   1    6     5.00       2.50    300.00       2507.   5.00    120.00     820.2
   2    1    10.00      10.00    969.50        745.   5.00     73.90     569.6
   3    1    10.00      20.00   1730.00        855.   5.00     78.20     593.2
   4    6     5.00      27.50   2446.00      13081.   5.00    130.00    1800.0
   5   BASE                                   26475.  10.00    136.40    2500.0

  PERIOD =  .146 sec  FROM AVERAGE SHEAR WAVE VELOCITY OF  824.3 ft/sec


 FREQUENCY  AMPLITUDE:
 MAXIMUM AMPLIFICATION =  12.29
 FOR FREQUENCY  (f)    =   5.29 c/sec
 FOR PERIOD (1 / f)    =    .19 sec

 ******   OPTION  3  ***  READ INPUT MOTION

  FILE NAME FOR INPUT MOTION =                hilohaw1.sar
  NO. OF INPUT ACCEL. POINTS =  3648
  NO. OF POINTS USED  IN FFT =  4096
      NO. OF  HEADING  LINES =     5
      NO. OF POINTS PER LINE =     8
  TIME STEP FOR INPUT MOTION =  .0200
  FORMAT FOR OF TIME HISTORY =  (8F9.6)


 ***** A C C E L E R O G R A M    H E A D E R *****

HILO, HAWAII, UNIVERSITY OF HAWAII, 11-1975; (N16W) (344 deg)
Island of Hawaii Eq. of 11-1975 Mw 7.2
Epic. Dist. = 43 km; Depth = 5 km
Uncorr. Max. = 0.197 g;  Max. in file = -0.173227 g; Ds = 56.10 s
3648 pts. @ 0.02 s

 **  FIRST & LAST 5 LINES OF INPUT MOTION *****

     1   .004905  .004782  .000347 -.002243 -.001744 -.001835 -.000235  .001897
     2   .000031  .000194 -.000887 -.002090 -.000989 -.002172 -.001948 -.000938
     3  -.002549 -.004303 -.001020  .001652  .001101 -.001448 -.001346 -.000020
     4   .003355  .002141 -.001652 -.001907 -.000663  .000928  .000734 -.000163
     5   .000326  .002233  .003691  .000795  .001703  .003263  .000438 -.001295
   ........ INPUT MOTION READ NOT ECHOED..........
   452  -.000500 -.000347 -.000275  .001275  .003885  .006954  .008586  .005965
   453   .003039 -.001346 -.004079 -.006710 -.006414 -.006608 -.006475 -.008484
   454  -.009238 -.006322 -.003171 -.000693 -.003181 -.004884 -.005445 -.001428
   455   .002825  .005649  .009065  .009371  .005506  .002723  .002090 -.000204
   456   .000632  .002692  .002366  .002274  .002152  .002070  .001978  .001968

 MAXIMUM ACCELERATION  =  .173227
 AT TIME               =     6.36 sec

 THE VALUES WILL BE MULTIPLIED BY A FACTOR  = 3.46366400
 TO GIVE NEW MAXIMUM ACCELERATION           =  .60000000

 MEAN SQUARE FREQUENCY =       3.78 c/sec
 MAXIMUM  ACCELERATION =    .600000 FOR FREQUENCIES REMOVED ABOVE 25.00 c/sec

 ******   OPTION  4  ***  READ WHERE OBJECT MOTION IS GIVEN

   OBJECT MOTION IN LAYER NUMBER   5 OUTCROPPING
```



```
 ******   OPTION  5  ***  OBTAIN STRAIN COMPATIBLE SOIL PROPERTIES

  MAXIMUM NUMBER OF ITERATIONS              =      7
  FACTOR FOR UNIFORM STRAIN IN TIME DOMAIN  =    .62

     ACCELEROGRAM   -                hilohaw1.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  1

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------   ------  -----
  1  6    2.5  .01079  .040   .050    -26.3    2231.5    2507.1    -12.3  1.000
  2  1   10.0  .11293  .134   .050     62.7     638.2     744.6    -16.7  1.000
  3  1   20.0  .15226  .146   .050     65.8     682.3     854.6    -25.2  1.000
  4  6   27.5  .01170  .041   .050    -21.6   11490.2   13080.7    -13.8  1.000


     ACCELEROGRAM   -                hilohaw1.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  2

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------   ------  -----
  1  6    2.5  .01055  .039   .040     -1.1    2239.6    2231.5      .4   .890
  2  1   10.0  .11243  .134   .134      -.1     638.9     638.2      .1   .857
  3  1   20.0  .16342  .149   .146      1.9     670.4     682.3     -1.8   .798
  4  6   27.5  .01162  .041   .041      -.3   11503.0   11490.2      .1   .878


     ACCELEROGRAM   -                hilohaw1.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  3

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------   ------  -----
  1  6    2.5  .01046  .039   .039      -.4    2242.7    2239.6      .1   .893
  2  1   10.0  .11248  .134   .134       .0     638.8     638.9      .0   .858
  3  1   20.0  .16477  .150   .149       .2     669.1     670.4     -.2   .785
  4  6   27.5  .01156  .041   .041      -.2   11512.7   11503.0      .1   .879


     ACCELEROGRAM   -                hilohaw1.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  4

  VALUES IN TIME DOMAIN
```

```
 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------   ------  -----
  1  6    2.5  .01044  .039   .039      -.1    2243.5    2242.7       .0   .895
  2  1   10.0  .11251  .134   .134       .0     638.8     638.8       .0   .858
  3  1   20.0  .16491  .150   .150       .0     668.9     669.1       .0   .783
  4  6   27.5  .01155  .041   .041      -.1   11515.3   11512.7       .0   .880


     ACCELEROGRAM   -               hilohaw1.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  5

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------   ------  -----
  1  6    2.5  .01043  .039   .039       .0    2243.6    2243.5       .0   .895
  2  1   10.0  .11252  .134   .134       .0     638.7     638.8       .0   .858
  3  1   20.0  .16492  .150   .150       .0     668.9     668.9       .0   .783
  4  6   27.5  .01154  .041   .041       .0   11515.9   11515.3       .0   .880


     ACCELEROGRAM   -               hilohaw1.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  6

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------   ------  -----
  1  6    2.5  .01043  .039   .039       .0    2243.6    2243.6       .0   .895
  2  1   10.0  .11253  .134   .134       .0     638.7     638.7       .0   .858
  3  1   20.0  .16492  .150   .150       .0     668.9     668.9       .0   .783
  4  6   27.5  .01154  .041   .041       .0   11516.0   11515.9       .0   .880


     ACCELEROGRAM   -               hilohaw1.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  7

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------   ------  -----
  1  6    2.5  .01043  .039   .039       .0    2243.6    2243.6       .0   .895
  2  1   10.0  .11253  .134   .134       .0     638.7     638.7       .0   .858
  3  1   20.0  .16492  .150   .150       .0     668.9     668.9       .0   .783
  4  6   27.5  .01154  .041   .041       .0   11516.0   11516.0       .0   .880

  VALUES IN TIME DOMAIN

  LAYER  MAT.  THICKNESS   DEPTH   MAX. STRAIN   MAX. STRESS   AVG. ACC.   TIME
         TYPE     (ft)      (ft)        (%)         (psf)         (g)      (sec)
```



```
     1     6       5.0       2.5        .01682      377.47     1.25825      6.52
     2     1      10.0      10.0        .18150     1159.28     1.19576      6.54
     3     1      10.0      20.0        .26601     1779.33     1.02852      6.52
     4     6       5.0      27.5        .01862     2143.79      .87645      6.52

  PERIOD =  .158 sec  FROM AVERAGE SHEAR WAVE VELOCITY OF  761.6 ft/sec


 FREQUENCY  AMPLITUDE:
 MAXIMUM AMPLIFICATION =   4.30
 FOR FREQUENCY  (f)    =   4.70 c/sec
 FOR PERIOD (1 / f)    =    .21 sec

 ******   OPTION  6  ***  COMPUTE MOTION IN NEW SUBLAYERS

  ACCELEROGRAM  -               hilohaw1.sar
  D E P O S I T - MSW - Matasovic & Kavazanjian (1998)

  LAYER        DEPTH    MAX. ACC.      TIME    MN.SQ.FR.   ACC. RATIO  TH SAVED
                (ft)       (g)         (sec)     (c/sec)    QUIET ZONE  ACC.REC.
  WITHIN          .0     1.26919        6.52       4.02         .146        512
  WITHIN         5.0     1.25286        6.52       3.99         .146          0
  WITHIN        15.0      .89446        6.52       3.33         .139          0
  WITHIN        25.0      .51173        6.38       3.55         .183          0
  WITHIN        30.0      .50098        6.38       3.57         .184          0
  OUTCR.        30.0      .60000        6.36       3.78         .178          0

 ******   OPTION  7  ***  COMPUTE STRESS/STRAIN HISTORY

 COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF  LAYER    6
 SCALE FOR PLOTTING      .0000
 IDENTIFICATION -  -- stress in level  4

 COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF  LAYER    6
 SCALE FOR PLOTTING      .0000
 IDENTIFICATION -  -- strain in level  4
```

```
          ************************************************************
          * SHAKE  --   A COMPUTER PROGRAM FOR EARTHQUAKE RESPONSE   *
          *             ANALYSIS OF HORIZONTALLY LAYERED SITES       *
          *             by: Per B. Schnabel & John Lysmer -- 1970    *
          * ---------------------------------------------------------- *
          * Shake85   : IBM-PC version of SHAKE                      *
          *             by: S.S. (Willie) Lai, January 1985          *
          * ---------------------------------------------------------- *
          * Shake88   : New modulus reduction curves for clays       *
          *             added using results from Sun et al. (1988)   *
          *             by: J. I. Sun & Ramin Golesorkhi             *
          *             February 26, 1988                            *
          * ---------------------------------------------------------- *
          * Shake90/91: Adjust last iteration; Input now is either   *
          *             Gmax or max Vs; up to 13 material types can  *
          *             be specified by user; up to 50 Layers can    *
          *             be specified; object motion can be read in   *
          *             from a separate file and can have user       *
          *             specified format; Different periods for      *
          *             response spectral calculations; options      *
          *             are renumbered; and general cleanup          *
          *             by: J. I. Sun, I. M. Idriss & P. Dirrim      *
          *             June 1990 - February 1991                    *
          * ---------------------------------------------------------- *
          * Shake91   : General cleanup and finalization of input /  *
          *             output format ... etc                        *
          *             by: I. M. Idriss                             *
          *             December 1991                                *
          * ---------------------------------------------------------- *
          * Shake98   : Routine for direct calculation of average    *
          *             acceleration is added to the program. Out-   *
          *             put format is modified to enable the two -   *
          *             - page landscape printing.  The following    *
          *             modulus reduction and  damping curves are    *
          *             added:  Matasovic & Kavazanjian (1998) for   *
          *             municipal solid waste; Matasovic & Vucetic   *
          *             (1993) for SMB sand; and Vucetic and Dobry   *
          *             (1991) for clays of various plasticities.    *
          *             by: Neven Matasovic                          *
          *             August 1993 - May 1998                       *
          ************************************************************

 MAX. NUMBER OF TERMS IN FOURIER TRANSFORM  =      4096
 NECESSARY LENGTH OF BLANK COMMON X         =     25619

 ******   OPTION  1  ***  READ RELATION BETWEEN SOIL PROPERTIES AND STRAIN


 *********************
  MATERIAL TYPE NO. 1
 *********************

 CURVE NO.  1:      #1 Modulus - OII Waste (Matasovic & Kavazanjian, 1998)
 CURVE NO.  2:      #1 Damping - OII Waste (Matasovic & Kavazanjian, 1998)


      CURVE NO. 1              CURVE NO. 2
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001      1.13
```



```
     .0003     1.000          .0003      1.77
     .0010     1.000          .0010      2.58
     .0032      .994          .0032      4.03
     .0100      .983          .0100      5.89
     .0316      .959          .0316      8.97
     .1000      .881          .1000     12.91
     .3160      .655          .3160     17.63
    1.0000      .316         1.0000     21.92
    3.1600      .130         3.1600     25.17

 *********************
  MATERIAL TYPE NO. 6
 *********************

 CURVE NO. 11:      #6 Modulus for CL (PI=30) (Vucetic and Dobry, 1991)
 CURVE NO. 12:      #6 Damping for CL (PI=30) (Vucetic and Dobry, 1991)


      CURVE NO.11              CURVE NO.12
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001       .85
     .0003     1.000          .0003       .85
     .0010     1.000          .0010      1.36
     .0030      .976          .0030      2.18
     .0100      .901          .0100      3.82
     .0300      .743          .0320      6.00
     .1000      .538          .1000      8.72
     .3000      .332          .3160     12.41
    1.0000      .158         1.0000     16.90
    3.0000      .048         3.1600     21.26

 *********************
  MATERIAL TYPE NO. 3
 *********************

 CURVE NO.  5:   #3 Modulus for Gravel (Shibuya et al., 1990)
 CURVE NO.  6:   #3 Damping for Gravel (Shibuya et al., 1990)


      CURVE NO. 5              CURVE NO. 6
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001      2.50
     .0003      .986          .0003      2.56
     .0010      .951          .0010      2.73
     .0032      .903          .0032      2.94
     .0100      .847          .0100      3.32
     .0316      .792          .0316      4.14
     .1000      .722          .1000      5.00
    1.0000      .550         1.0000      7.40

 ******   OPTION  2  ***  READ SOIL / WASTE PROFILE

 SOIL PROFILE NO.      1   MSW - Matasovic & Kavazanjian (1998)

 NUMBER OF LAYERS      5
 DEPTH TO BEDROCK   30.0
```



```
  NO. TYPE  THICKNESS   DEPTH  TOT. PRESS.  MODULUS  DAMPING  UNIT WT. SH. VEL.
             (ft)       (ft)      (psf)       (ksf)    (%)      (pcf)     (fps)
   1    6     5.00       2.50    300.00       2507.    5.00    120.00     820.2
   2    1    10.00      10.00    969.50        745.    5.00     73.90     569.6
   3    1    10.00      20.00   1730.00        855.    5.00     78.20     593.2
   4    6     5.00      27.50   2446.00      13081.    5.00    130.00    1800.0
   5   BASE                                  26475.   10.00    136.40    2500.0

  PERIOD =  .146 sec  FROM AVERAGE SHEAR WAVE VELOCITY OF  824.3 ft/sec


 FREQUENCY  AMPLITUDE:
 MAXIMUM AMPLIFICATION =  12.29
 FOR FREQUENCY  (f)    =   5.29 c/sec
 FOR PERIOD (1 / f)    =    .19 sec

 ******   OPTION  3  ***  READ INPUT MOTION

  FILE NAME FOR INPUT MOTION =                kiho_268.sar
  NO. OF INPUT ACCEL. POINTS =  5472
  NO. OF POINTS USED  IN FFT =  4096
      NO. OF  HEADING  LINES =     5
      NO. OF POINTS PER LINE =     8
  TIME STEP FOR INPUT MOTION =  .0050
  FORMAT FOR OF TIME HISTORY =  (8F9.6)


 ***** A C C E L E R O G R A M    H E A D E R *****

2006  10  15    1707 KIHOLO BAY, HAWAII, HI EARTHQUAKE
Moment Mag= 6.7; Max in File = 0.187210 g
station = HI:HI;Anaehoomalu,Waikoloa Htl component= 268
epicentral dist =     17.1       pk acc =  1.84E+2
684 x 8 = 5472 pts @ 0.005 sec

 **  FIRST & LAST 5 LINES OF INPUT MOTION *****

     1   .000119  .000154  .000182  .000134  .000064  .000118  .000362  .000678
     2   .000893  .000966  .000946  .000815  .000470 -.000081 -.000617 -.000858
     3  -.000690 -.000208  .000368  .000793  .000922  .000841  .000811  .000937
     4   .000999  .000786  .000495  .000505  .000712  .000472 -.000523 -.001620
     5  -.001847 -.001063 -.000061  .000471  .000618  .000710  .000636  .000119
   ........ INPUT MOTION READ NOT ECHOED..........
   680   .014128  .014194  .014311  .014465  .014287  .013532  .012320  .010972
   681   .009859  .009281  .009252  .009394  .009336  .009265  .009760  .010906
   682   .011866  .011630  .010134  .008317  .007094  .006527  .006042  .005167
   683   .003865  .002328  .000743 -.000754 -.002064 -.003137 -.003946 -.004475
   684  -.004799 -.005141 -.005703 -.006423 -.007008 -.007243 -.007204 -.007112

 MAXIMUM ACCELERATION  =  .187209
 AT TIME               =    11.22 sec

 THE VALUES WILL BE MULTIPLIED BY A FACTOR  = 3.20497400
 TO GIVE NEW MAXIMUM ACCELERATION           =  .60000000

 MEAN SQUARE FREQUENCY =       3.53 c/sec
 MAXIMUM  ACCELERATION =    .598253 FOR FREQUENCIES REMOVED ABOVE 25.00 c/sec

 ******   OPTION  4  ***  READ WHERE OBJECT MOTION IS GIVEN

   OBJECT MOTION IN LAYER NUMBER   5 OUTCROPPING
```



```
 ******   OPTION  5  ***  OBTAIN STRAIN COMPATIBLE SOIL PROPERTIES

  MAXIMUM NUMBER OF ITERATIONS              =      7
  FACTOR FOR UNIFORM STRAIN IN TIME DOMAIN  =    .62

     ACCELEROGRAM   -                kiho_268.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  1

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------   ------  -----
  1  6    2.5  .00699  .033   .050    -50.2    2314.7    2507.1     -8.3  1.000
  2  1   10.0  .07385  .119   .050     57.9     671.3     744.6    -10.9  1.000
  3  1   20.0  .09996  .129   .050     61.3     752.9     854.6    -13.5  1.000
  4  6   27.5  .00849  .036   .050    -39.1   11919.0   13080.7     -9.7  1.000


     ACCELEROGRAM   -                kiho_268.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  2

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------   ------  -----
  1  6    2.5  .00665  .033   .033     -2.1    2322.6    2314.7       .3   .923
  2  1   10.0  .06994  .117   .119     -1.6     674.0     671.3       .4   .902
  3  1   20.0  .10409  .131   .129      1.3     746.2     752.9      -.9   .881
  4  6   27.5  .00905  .037   .036      2.4   11867.1   11919.0      -.4   .911


     ACCELEROGRAM   -                kiho_268.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  3

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------   ------  -----
  1  6    2.5  .00662  .033   .033      -.2    2323.3    2322.6       .0   .926
  2  1   10.0  .06962  .117   .117      -.1     674.3     674.0       .0   .905
  3  1   20.0  .10508  .131   .131       .3     744.6     746.2      -.2   .873
  4  6   27.5  .00910  .037   .037       .2   11862.9   11867.1       .0   .907


     ACCELEROGRAM   -                kiho_268.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  4

  VALUES IN TIME DOMAIN
```

```
 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------   ------  -----
  1  6    2.5  .00661  .033   .033       .0    2323.4    2323.3       .0   .927
  2  1   10.0  .06957  .117   .117       .0     674.3     674.3       .0   .906
  3  1   20.0  .10531  .131   .131       .1     744.2     744.6       .0   .871
  4  6   27.5  .00910  .037   .037       .0   11862.5   11862.9       .0   .907


     ACCELEROGRAM   -               kiho_268.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  5

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------   ------  -----
  1  6    2.5  .00661  .033   .033       .0    2323.4    2323.4       .0   .927
  2  1   10.0  .06956  .117   .117       .0     674.3     674.3       .0   .906
  3  1   20.0  .10536  .131   .131       .0     744.1     744.2       .0   .871
  4  6   27.5  .00910  .037   .037       .0   11862.5   11862.5       .0   .907


     ACCELEROGRAM   -               kiho_268.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  6

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------   ------  -----
  1  6    2.5  .00661  .033   .033       .0    2323.4    2323.4       .0   .927
  2  1   10.0  .06956  .117   .117       .0     674.3     674.3       .0   .906
  3  1   20.0  .10537  .131   .131       .0     744.1     744.1       .0   .871
  4  6   27.5  .00910  .037   .037       .0   11862.5   11862.5       .0   .907


     ACCELEROGRAM   -               kiho_268.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  7

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------   ------  -----
  1  6    2.5  .00661  .033   .033       .0    2323.4    2323.4       .0   .927
  2  1   10.0  .06956  .117   .117       .0     674.3     674.3       .0   .906
  3  1   20.0  .10538  .131   .131       .0     744.1     744.1       .0   .871
  4  6   27.5  .00910  .037   .037       .0   11862.5   11862.5       .0   .907

  VALUES IN TIME DOMAIN

  LAYER  MAT.  THICKNESS   DEPTH   MAX. STRAIN   MAX. STRESS   AVG. ACC.   TIME
         TYPE     (ft)      (ft)        (%)         (psf)         (g)      (sec)
```



```
     1     6       5.0       2.5        .01067      247.82      .82608    11.46
     2     1      10.0      10.0        .11219      756.48      .78028    11.47
     3     1      10.0      20.0        .16996     1264.68      .73103    11.22
     4     6       5.0      27.5        .01468     1741.39      .71194    11.22

  PERIOD =  .153 sec  FROM AVERAGE SHEAR WAVE VELOCITY OF  782.5 ft/sec


 FREQUENCY  AMPLITUDE:
 MAXIMUM AMPLIFICATION =   4.95
 FOR FREQUENCY  (f)    =   4.96 c/sec
 FOR PERIOD (1 / f)    =    .20 sec

 ******   OPTION  6  ***  COMPUTE MOTION IN NEW SUBLAYERS

  ACCELEROGRAM  -               kiho_268.sar
  D E P O S I T - MSW - Matasovic & Kavazanjian (1998)

  LAYER        DEPTH    MAX. ACC.      TIME    MN.SQ.FR.   ACC. RATIO  TH SAVED
                (ft)       (g)         (sec)     (c/sec)    QUIET ZONE  ACC.REC.
  WITHIN          .0      .83389       11.45       3.64         .185        512
  WITHIN         5.0      .82160       11.45       3.57         .187          0
  WITHIN        15.0      .73268       11.22       2.92         .196          0
  WITHIN        25.0      .60457       11.22       3.34         .212          0
  WITHIN        30.0      .59728       11.22       3.34         .213          0
  OUTCR.        30.0      .59825       11.22       3.53         .214          0

 ******   OPTION  7  ***  COMPUTE STRESS/STRAIN HISTORY

 COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF  LAYER    6
 SCALE FOR PLOTTING      .0000
 IDENTIFICATION -  -- stress in level  4

 COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF  LAYER    6
 SCALE FOR PLOTTING      .0000
 IDENTIFICATION -  -- strain in level  4
```

```
         ************************************************************
         * SHAKE  --   A COMPUTER PROGRAM FOR EARTHQUAKE RESPONSE   *
         *             ANALYSIS OF HORIZONTALLY LAYERED SITES       *
         *             by: Per B. Schnabel & John Lysmer -- 1970    *
         * ---------------------------------------------------------- *
         * Shake85   : IBM-PC version of SHAKE                      *
         *             by: S.S. (Willie) Lai, January 1985          *
         * ---------------------------------------------------------- *
         * Shake88   : New modulus reduction curves for clays       *
         *             added using results from Sun et al. (1988)   *
         *             by: J. I. Sun & Ramin Golesorkhi             *
         *             February 26, 1988                            *
         * ---------------------------------------------------------- *
         * Shake90/91: Adjust last iteration; Input now is either   *
         *             Gmax or max Vs; up to 13 material types can  *
         *             be specified by user; up to 50 Layers can    *
         *             be specified; object motion can be read in   *
         *             from a separate file and can have user       *
         *             specified format; Different periods for      *
         *             response spectral calculations; options      *
         *             are renumbered; and general cleanup          *
         *             by: J. I. Sun, I. M. Idriss & P. Dirrim      *
         *             June 1990 - February 1991                    *
         * ---------------------------------------------------------- *
         * Shake91   : General cleanup and finalization of input /  *
         *             output format ... etc                        *
         *             by: I. M. Idriss                             *
         *             December 1991                                *
         * ---------------------------------------------------------- *
         * Shake98   : Routine for direct calculation of average    *
         *             acceleration is added to the program. Out-   *
         *             put format is modified to enable the two -   *
         *             - page landscape printing.  The following    *
         *             modulus reduction and  damping curves are    *
         *             added:  Matasovic & Kavazanjian (1998) for   *
         *             municipal solid waste; Matasovic & Vucetic   *
         *             (1993) for SMB sand; and Vucetic and Dobry   *
         *             (1991) for clays of various plasticities.    *
         *             by: Neven Matasovic                          *
         *             August 1993 - May 1998                       *
         ************************************************************

 MAX. NUMBER OF TERMS IN FOURIER TRANSFORM  =      4096
 NECESSARY LENGTH OF BLANK COMMON X         =     25619

 ******   OPTION  1  ***  READ RELATION BETWEEN SOIL PROPERTIES AND STRAIN


 *********************
  MATERIAL TYPE NO. 1
 *********************

 CURVE NO.  1:      #1 Modulus - OII Waste (Matasovic & Kavazanjian, 1998)
 CURVE NO.  2:      #1 Damping - OII Waste (Matasovic & Kavazanjian, 1998)


      CURVE NO. 1              CURVE NO. 2
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001      1.13
```



```
     .0003     1.000          .0003      1.77
     .0010     1.000          .0010      2.58
     .0032      .994          .0032      4.03
     .0100      .983          .0100      5.89
     .0316      .959          .0316      8.97
     .1000      .881          .1000     12.91
     .3160      .655          .3160     17.63
    1.0000      .316         1.0000     21.92
    3.1600      .130         3.1600     25.17

 *********************
  MATERIAL TYPE NO. 6
 *********************

 CURVE NO. 11:      #6 Modulus for CL (PI=30) (Vucetic and Dobry, 1991)
 CURVE NO. 12:      #6 Damping for CL (PI=30) (Vucetic and Dobry, 1991)


      CURVE NO.11              CURVE NO.12
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001       .85
     .0003     1.000          .0003       .85
     .0010     1.000          .0010      1.36
     .0030      .976          .0030      2.18
     .0100      .901          .0100      3.82
     .0300      .743          .0320      6.00
     .1000      .538          .1000      8.72
     .3000      .332          .3160     12.41
    1.0000      .158         1.0000     16.90
    3.0000      .048         3.1600     21.26

 *********************
  MATERIAL TYPE NO. 3
 *********************

 CURVE NO.  5:   #3 Modulus for Gravel (Shibuya et al., 1990)
 CURVE NO.  6:   #3 Damping for Gravel (Shibuya et al., 1990)


      CURVE NO. 5              CURVE NO. 6
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001      2.50
     .0003      .986          .0003      2.56
     .0010      .951          .0010      2.73
     .0032      .903          .0032      2.94
     .0100      .847          .0100      3.32
     .0316      .792          .0316      4.14
     .1000      .722          .1000      5.00
    1.0000      .550         1.0000      7.40

 ******   OPTION  2  ***  READ SOIL / WASTE PROFILE

 SOIL PROFILE NO.      1   MSW - Matasovic & Kavazanjian (1998)

 NUMBER OF LAYERS      5
 DEPTH TO BEDROCK   30.0
```



```
  NO. TYPE  THICKNESS   DEPTH  TOT. PRESS.  MODULUS  DAMPING  UNIT WT. SH. VEL.
             (ft)       (ft)      (psf)       (ksf)    (%)      (pcf)     (fps)
   1    6     5.00       2.50    300.00       2507.   5.00    120.00     820.2
   2    1    10.00      10.00    969.50        745.   5.00     73.90     569.6
   3    1    10.00      20.00   1730.00        855.   5.00     78.20     593.2
   4    6     5.00      27.50   2446.00      13081.   5.00    130.00    1800.0
   5   BASE                                   26475.  10.00    136.40    2500.0

  PERIOD =  .146 sec  FROM AVERAGE SHEAR WAVE VELOCITY OF  824.3 ft/sec


 FREQUENCY  AMPLITUDE:
 MAXIMUM AMPLIFICATION =  12.29
 FOR FREQUENCY  (f)    =   5.29 c/sec
 FOR PERIOD (1 / f)    =    .19 sec

 ******   OPTION  3  ***  READ INPUT MOTION

  FILE NAME FOR INPUT MOTION =                luc92-fn.sar
  NO. OF INPUT ACCEL. POINTS = 12320
  NO. OF POINTS USED  IN FFT =  4096
      NO. OF  HEADING  LINES =     6
      NO. OF POINTS PER LINE =     8
  TIME STEP FOR INPUT MOTION =  .0040
  FORMAT FOR OF TIME HISTORY =  (8F9.6)


 ***** A C C E L E R O G R A M    H E A D E R *****

1992 Mw 7.3 Landers Eq.
Lucerne Valley, strike=340 (fault normal), static set by Hudnut geodetic model
1.1 km from the fault; forward directivity; shallow soil over hard rock
Joyner and Boore Class A; Ds 13.38 s
Recorded PGA = 0.76 g; Max. in file = 0.713386 g
8*1540 = 12320 pts @ 0.004 sec

 **  FIRST & LAST 5 LINES OF INPUT MOTION *****

     1  -.002559 -.001864 -.000497  .000960  .002188  .002937  .003559  .004559
     2   .006875  .010655  .013843  .013571  .009311  .003739 -.000616 -.004028
     3  -.007629 -.010747 -.011340 -.008186 -.003105  .000159  .000479 -.000154
     4  -.000232 -.000200 -.001059 -.002337 -.002922 -.002914 -.002663 -.001387
     5   .002288  .007957  .012828  .013737  .009850  .003706 -.001560 -.005316
   ........ INPUT MOTION READ NOT ECHOED...........
  1536  -.002270 -.000138 -.000180 -.001377 -.001369  .001319  .007493  .012797
  1537   .012225  .006912 -.001391 -.006299 -.005603 -.002072  .001551  .001488
  1538  -.001153 -.004629 -.007524 -.007878 -.005594 -.003036 -.000427  .005550
  1539   .012066  .013607  .009276  .001987 -.003915 -.006354 -.006264 -.004182
  1540  -.002739 -.003270 -.004798 -.006062 -.005249 -.003910 -.003144 -.002500

 MAXIMUM ACCELERATION  =  .713386
 AT TIME               =    10.37 sec

 THE VALUES WILL BE MULTIPLIED BY A FACTOR  =  .84105940
 TO GIVE NEW MAXIMUM ACCELERATION           =  .60000000

 MEAN SQUARE FREQUENCY =       8.96 c/sec
 MAXIMUM  ACCELERATION =    .615271 FOR FREQUENCIES REMOVED ABOVE 25.00 c/sec

 ******   OPTION  4  ***  READ WHERE OBJECT MOTION IS GIVEN
```



```
   OBJECT MOTION IN LAYER NUMBER   5 OUTCROPPING

 ******   OPTION  5  ***  OBTAIN STRAIN COMPATIBLE SOIL PROPERTIES

  MAXIMUM NUMBER OF ITERATIONS               =      7
  FACTOR FOR UNIFORM STRAIN IN TIME DOMAIN  =    .62

     ACCELEROGRAM   -                luc92-fn.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  1

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW        USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------    -------   ------  -----
  1  6    2.5  .00619  .032   .050    -58.0    2333.8    2507.1     -7.4  1.000
  2  1   10.0  .06352  .114   .050     56.0     678.9     744.6     -9.7  1.000
  3  1   20.0  .08140  .122   .050     59.0     764.8     854.6    -11.7  1.000
  4  6   27.5  .00577  .031   .050    -63.0   12234.3   13080.7     -6.9  1.000


     ACCELEROGRAM   -                luc92-fn.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  2

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW        USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------    -------   ------  -----
  1  6    2.5  .00520  .029   .032     -8.0    2360.9    2333.8      1.1   .931
  2  1   10.0  .05585  .109   .114     -4.0     685.4     678.9       .9   .912
  3  1   20.0  .07409  .119   .122     -2.7     770.2     764.8       .7   .895
  4  6   27.5  .00540  .030   .031     -3.0   12288.2   12234.3       .4   .935


     ACCELEROGRAM   -                luc92-fn.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  3

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW        USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------    -------   ------  -----
  1  6    2.5  .00515  .029   .029      -.5    2362.6    2360.9       .1   .942
  2  1   10.0  .05542  .109   .109      -.2     685.8     685.4       .1   .920
  3  1   20.0  .07368  .119   .119      -.2     770.6     770.2       .0   .901
  4  6   27.5  .00539  .030   .030      -.1   12289.8   12288.2       .0   .939


     ACCELEROGRAM   -                luc92-fn.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  4

  VALUES IN TIME DOMAIN
```

```
 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------  ------  -----
  1  6    2.5  .00514  .029   .029       .0    2362.7    2362.6      .0   .942
  2  1   10.0  .05540  .109   .109       .0     685.8     685.8      .0   .921
  3  1   20.0  .07366  .119   .119       .0     770.6     770.6      .0   .902
  4  6   27.5  .00539  .030   .030       .0   12289.8   12289.8      .0   .940


     ACCELEROGRAM   -                 luc92-fn.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  5

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------  ------  -----
  1  6    2.5  .00514  .029   .029       .0    2362.7    2362.7      .0   .942
  2  1   10.0  .05540  .109   .109       .0     685.8     685.8      .0   .921
  3  1   20.0  .07366  .119   .119       .0     770.6     770.6      .0   .902
  4  6   27.5  .00539  .030   .030       .0   12289.8   12289.8      .0   .940


     ACCELEROGRAM   -                 luc92-fn.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  6

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------  ------  -----
  1  6    2.5  .00514  .029   .029       .0    2362.7    2362.7      .0   .942
  2  1   10.0  .05540  .109   .109       .0     685.8     685.8      .0   .921
  3  1   20.0  .07366  .119   .119       .0     770.6     770.6      .0   .902
  4  6   27.5  .00539  .030   .030       .0   12289.8   12289.8      .0   .940


     ACCELEROGRAM   -                 luc92-fn.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  7

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------   -------  ------  -----
  1  6    2.5  .00514  .029   .029       .0    2362.7    2362.7      .0   .942
  2  1   10.0  .05540  .109   .109       .0     685.8     685.8      .0   .921
  3  1   20.0  .07366  .119   .119       .0     770.6     770.6      .0   .902
  4  6   27.5  .00539  .030   .030       .0   12289.8   12289.8      .0   .940

  VALUES IN TIME DOMAIN

  LAYER  MAT.  THICKNESS   DEPTH   MAX. STRAIN   MAX. STRESS   AVG. ACC.   TIME
         TYPE     (ft)      (ft)        (%)         (psf)         (g)     (sec)
```



```
    1     6       5.0       2.5        .00830      195.99      .65329    10.75
    2     1      10.0      10.0        .08935      612.73      .63201    10.41
    3     1      10.0      20.0        .11880      915.44      .52916    10.40
    4     6       5.0      27.5        .00869     1067.88      .43658    10.72

 PERIOD =  .151 sec  FROM AVERAGE SHEAR WAVE VELOCITY OF  793.5 ft/sec


FREQUENCY  AMPLITUDE:
MAXIMUM AMPLIFICATION =   5.43
FOR FREQUENCY  (f)    =   5.03 c/sec
FOR PERIOD (1 / f)    =    .20 sec

******   OPTION  6  ***  COMPUTE MOTION IN NEW SUBLAYERS

 ACCELEROGRAM  -                 luc92-fn.sar
 D E P O S I T - MSW - Matasovic & Kavazanjian (1998)

 LAYER        DEPTH    MAX. ACC.      TIME    MN.SQ.FR.   ACC. RATIO  TH SAVED
               (ft)       (g)         (sec)     (c/sec)    QUIET ZONE  ACC.REC.
 WITHIN          .0      .66050       11.99       5.80         .942        512
 WITHIN         5.0      .64818       11.99       5.40         .896          0
 WITHIN        15.0      .61245       10.50       7.93         .687          0
 WITHIN        25.0      .56594       14.64       8.79        1.000          0
 WITHIN        30.0      .54478       14.64       8.54        1.000          0
 OUTCR.        30.0      .61527       14.64       8.96        1.000          0

******   OPTION  7  ***  COMPUTE STRESS/STRAIN HISTORY

COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF  LAYER    6
SCALE FOR PLOTTING      .0000
IDENTIFICATION -  -- stress in level  4

COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF  LAYER    6
SCALE FOR PLOTTING      .0000
IDENTIFICATION -  -- strain in level  4
```

APPENDIX B-2
80-ft Column

```
         ************************************************************
         * SHAKE  --   A COMPUTER PROGRAM FOR EARTHQUAKE RESPONSE   *
         *             ANALYSIS OF HORIZONTALLY LAYERED SITES       *
         *             by: Per B. Schnabel & John Lysmer -- 1970    *
         * ---------------------------------------------------------- *
         * Shake85   : IBM-PC version of SHAKE                      *
         *             by: S.S. (Willie) Lai, January 1985          *
         * ---------------------------------------------------------- *
         * Shake88   : New modulus reduction curves for clays       *
         *             added using results from Sun et al. (1988)   *
         *             by: J. I. Sun & Ramin Golesorkhi             *
         *             February 26, 1988                            *
         * ---------------------------------------------------------- *
         * Shake90/91: Adjust last iteration; Input now is either   *
         *             Gmax or max Vs; up to 13 material types can  *
         *             be specified by user; up to 50 Layers can    *
         *             be specified; object motion can be read in   *
         *             from a separate file and can have user       *
         *             specified format; Different periods for      *
         *             response spectral calculations; options      *
         *             are renumbered; and general cleanup          *
         *             by: J. I. Sun, I. M. Idriss & P. Dirrim      *
         *             June 1990 - February 1991                    *
         * ---------------------------------------------------------- *
         * Shake91   : General cleanup and finalization of input /  *
         *             output format ... etc                        *
         *             by: I. M. Idriss                             *
         *             December 1991                                *
         * ---------------------------------------------------------- *
         * Shake98   : Routine for direct calculation of average    *
         *             acceleration is added to the program. Out-   *
         *             put format is modified to enable the two -   *
         *             - page landscape printing.  The following    *
         *             modulus reduction and  damping curves are    *
         *             added:  Matasovic & Kavazanjian (1998) for   *
         *             municipal solid waste; Matasovic & Vucetic   *
         *             (1993) for SMB sand; and Vucetic and Dobry   *
         *             (1991) for clays of various plasticities.    *
         *             by: Neven Matasovic                          *
         *             August 1993 - May 1998                       *
         ************************************************************

 MAX. NUMBER OF TERMS IN FOURIER TRANSFORM  =      4096
 NECESSARY LENGTH OF BLANK COMMON X         =     25619

 ******   OPTION  1  ***  READ RELATION BETWEEN SOIL PROPERTIES AND STRAIN


 *********************
  MATERIAL TYPE NO. 1
 *********************

 CURVE NO.  1:      #1 Modulus - OII Waste (Matasovic & Kavazanjian, 1998)
 CURVE NO.  2:      #1 Damping - OII Waste (Matasovic & Kavazanjian, 1998)


      CURVE NO. 1              CURVE NO. 2
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001      1.13
```



```
     .0003     1.000          .0003      1.77
     .0010     1.000          .0010      2.58
     .0032      .994          .0032      4.03
     .0100      .983          .0100      5.89
     .0316      .959          .0316      8.97
     .1000      .881          .1000     12.91
     .3160      .655          .3160     17.63
    1.0000      .316         1.0000     21.92
    3.1600      .130         3.1600     25.17

 *********************
  MATERIAL TYPE NO. 6
 *********************

 CURVE NO. 11:      #6 Modulus for C  (PI=30) (Vucetic and Dobry, 1991)
 CURVE NO. 12:      #6 Damping for C  (PI=30) (Vucetic and Dobry, 1991)


      CURVE NO.11              CURVE NO.12
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001       .85
     .0003     1.000          .0003       .85
     .0010     1.000          .0010      1.36
     .0030      .976          .0030      2.18
     .0100      .901          .0100      3.82
     .0300      .743          .0320      6.00
     .1000      .538          .1000      8.72
     .3000      .332          .3160     12.41
    1.0000      .158         1.0000     16.90
    3.0000      .048         3.1600     21.26

 *********************
  MATERIAL TYPE NO. 3
 *********************

 CURVE NO.  5:   #3 Modulus for Gravel (Shibuya et al., 1990)
 CURVE NO.  6:   #3 Damping for Gravel (Shibuya et al., 1990)


      CURVE NO. 5              CURVE NO. 6
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001      2.50
     .0003      .986          .0003      2.56
     .0010      .951          .0010      2.73
     .0032      .903          .0032      2.94
     .0100      .847          .0100      3.32
     .0316      .792          .0316      4.14
     .1000      .722          .1000      5.00
    1.0000      .550         1.0000      7.40

 ******   OPTION  2  ***  READ SOIL / WASTE PROFILE

 SOIL PROFILE NO.      1   MSW - Matasovic & Kavazanjian (1998)

 NUMBER OF LAYERS     10
 DEPTH TO BEDROCK   80.0
```



```
  NO. TYPE  THICKNESS   DEPTH  TOT. PRESS.  MODULUS  DAMPING  UNIT WT. SH. VEL.
             (ft)       (ft)      (psf)       (ksf)    (%)     (pcf)     (fps)
   1    6     5.00      2.50    300.00       2507.    5.00   120.00     820.2
   2    1    10.00     10.00    969.50        745.    5.00    73.90     569.6
   3    1    10.00     20.00   1730.00        855.    5.00    78.20     593.2
   4    1    10.00     30.00   2528.50        963.    5.00    81.50     616.8
   5    1    10.00     40.00   3356.50       1071.    5.00    84.10     640.4
   6    1    10.00     50.00   4206.50       1176.    5.00    85.90     664.0
   7    1    10.00     60.00   5071.50       1279.    5.00    87.10     687.7
   8    1    10.00     70.00   5947.00       1383.    5.00    88.00     711.3
   9    6     5.00     77.50   6712.00      13081.    5.00   130.00    1800.0
  10   BASE                                 26475.   10.00   136.40    2500.0

  PERIOD =  .442 sec  FROM AVERAGE SHEAR WAVE VELOCITY OF  724.1 ft/sec


 FREQUENCY  AMPLITUDE:
 MAXIMUM AMPLIFICATION =  13.18
 FOR FREQUENCY  (f)    =   2.22 c/sec
 FOR PERIOD (1 / f)    =    .45 sec

 ******   OPTION  3  ***  READ INPUT MOTION

  FILE NAME FOR INPUT MOTION =                    Hilohaw1.sar
  NO. OF INPUT ACCEL. POINTS =  3648
  NO. OF POINTS USED  IN FFT =  4096
      NO. OF  HEADING  LINES =     5
      NO. OF POINTS PER LINE =     8
  TIME STEP FOR INPUT MOTION =  .0200
  FORMAT FOR OF TIME HISTORY =  (8F9.6)


 ***** A C C E L E R O G R A M    H E A D E R *****

HILO, HAWAII, UNIVERSITY OF HAWAII, 11-1975; (N16W) (344 deg)
Island of Hawaii Eq. of 11-1975 Mw 7.2
Epic. Dist. = 43 km; Depth = 5 km
Uncorr. Max. = 0.197 g;  Max. in file = -0.173227 g; Ds = 56.10 s
3648 pts. @ 0.02 s

 **  FIRST & LAST 5 LINES OF INPUT MOTION *****

     1   .004905  .004782  .000347 -.002243 -.001744 -.001835 -.000235  .001897
     2   .000031  .000194 -.000887 -.002090 -.000989 -.002172 -.001948 -.000938
     3  -.002549 -.004303 -.001020  .001652  .001101 -.001448 -.001346 -.000020
     4   .003355  .002141 -.001652 -.001907 -.000663  .000928  .000734 -.000163
     5   .000326  .002233  .003691  .000795  .001703  .003263  .000438 -.001295
   ........ INPUT MOTION READ NOT ECHOED...........
   452  -.000500 -.000347 -.000275  .001275  .003885  .006954  .008586  .005965
   453   .003039 -.001346 -.004079 -.006710 -.006414 -.006608 -.006475 -.008484
   454  -.009238 -.006322 -.003171 -.000693 -.003181 -.004884 -.005445 -.001428
   455   .002825  .005649  .009065  .009371  .005506  .002723  .002090 -.000204
   456   .000632  .002692  .002366  .002274  .002152  .002070  .001978  .001968

 MAXIMUM ACCELERATION  =  .173227
 AT TIME               =     6.36 sec

 THE VALUES WILL BE MULTIPLIED BY A FACTOR  = 3.46366400
 TO GIVE NEW MAXIMUM ACCELERATION           =  .60000000

 MEAN SQUARE FREQUENCY =       3.78 c/sec
```



```
 MAXIMUM  ACCELERATION =    .600000 FOR FREQUENCIES REMOVED ABOVE 25.00 c/sec

 ******   OPTION  4  ***  READ WHERE OBJECT MOTION IS GIVEN

   OBJECT MOTION IN LAYER NUMBER  10 OUTCROPPING

 ******   OPTION  5  ***  OBTAIN STRAIN COMPATIBLE SOIL PROPERTIES

  MAXIMUM NUMBER OF ITERATIONS                =      7
  FACTOR FOR UNIFORM STRAIN IN TIME DOMAIN  =    .62

     ACCELEROGRAM   -                    Hilohaw1.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  1

  VALUES  IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW        USED    ERROR  RATIO
--- ---- ----  -------  ----- ------  ------   -------    -------   ------  -----
  1  6    2.5  .00872  .036   .050    -37.7    2280.2    2507.1     -9.9  1.000
  2  1   10.0  .09148  .126   .050     60.3     660.5     744.6    -12.7  1.000
  3  1   20.0  .12494  .138   .050     63.8     715.5     854.6    -19.4  1.000
  4  1   30.0  .14730  .145   .050     65.5     775.1     962.9    -24.2  1.000
  5  1   40.0  .15642  .147   .050     66.1     849.5    1071.1    -26.1  1.000
  6  1   50.0  .15907  .148   .050     66.2     929.0    1176.2    -26.0  1.000
  7  1   60.0  .15610  .147   .050     66.1    1015.1    1279.3    -26.0  1.000
  8  1   70.0  .14844  .145   .050     65.6    1110.9    1382.7    -24.5  1.000
  9  6   77.5  .01563  .047   .050     -7.4   10945.4   13080.7    -19.5  1.000


     ACCELEROGRAM   -                    Hilohaw1.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  2

  VALUES  IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW        USED    ERROR  RATIO
--- ---- ----  -------  ----- ------  ------   -------    -------   ------  -----
  1  6    2.5  .00622  .032   .036    -14.5    2333.1    2280.2      2.3   .910
  2  1   10.0  .06549  .115   .126    -10.0     677.3     660.5      2.5   .887
  3  1   20.0  .10173  .130   .138     -6.5     750.0     715.5      4.6   .837
  4  1   30.0  .12559  .138   .145     -4.7     805.2     775.1      3.7   .805
  5  1   40.0  .13642  .142   .147     -4.0     878.3     849.5      3.3   .793
  6  1   50.0  .14152  .143   .148     -3.3     956.0     929.0      2.8   .790
  7  1   60.0  .13935  .143   .147     -3.3    1043.6    1015.1      2.7   .794
  8  1   70.0  .13397  .141   .145     -3.0    1138.7    1110.9      2.4   .803
  9  6   77.5  .01453  .045   .047     -3.0   11082.8   10945.4      1.2   .837


     ACCELEROGRAM   -                    Hilohaw1.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  3

  VALUES  IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
```

		(ft)	STRAIN	NEW	USED	ERROR	NEW	USED	ERROR	RATIO
1	6	2.5	.00625	.032	.032	.3	2332.2	2333.1	.0	.931
2	1	10.0	.06598	.115	.115	.2	677.0	677.3	-.1	.910
3	1	20.0	.09757	.128	.130	-1.2	754.3	750.0	.6	.878
4	1	30.0	.12112	.137	.138	-1.1	812.1	805.2	.8	.836
5	1	40.0	.13299	.141	.142	-.7	883.7	878.3	.6	.820
6	1	50.0	.13882	.143	.143	-.6	960.4	956.0	.5	.813
7	1	60.0	.13674	.142	.143	-.5	1048.4	1043.6	.5	.816
8	1	70.0	.13200	.140	.141	-.4	1142.8	1138.7	.4	.824
9	6	77.5	.01442	.045	.045	-.3	11096.6	11082.8	.1	.847

ACCELEROGRAM - Hilohaw1.sar
P R O F I L E - MSW - Matasovic & Kavazanjian (1998)

ITERATION NUMBER 4

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	6	2.5	.00629	.032	.032	.2	2331.4	2332.2	.0	.930
2	1	10.0	.06641	.115	.115	.2	676.6	677.0	.0	.909
3	1	20.0	.09772	.128	.128	.0	754.2	754.3	.0	.883
4	1	30.0	.12009	.137	.137	-.3	813.7	812.1	.2	.843
5	1	40.0	.13241	.141	.141	-.1	884.6	883.7	.1	.825
6	1	50.0	.13839	.142	.143	-.1	961.2	960.4	.1	.817
7	1	60.0	.13632	.142	.142	-.1	1049.2	1048.4	.1	.820
8	1	70.0	.13176	.140	.140	-.1	1143.3	1142.8	.0	.826
9	6	77.5	.01442	.045	.045	.0	11097.0	11096.6	.0	.848

ACCELEROGRAM - Hilohaw1.sar
P R O F I L E - MSW - Matasovic & Kavazanjian (1998)

ITERATION NUMBER 5

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	6	2.5	.00629	.032	.032	.0	2331.2	2331.4	.0	.930
2	1	10.0	.06649	.115	.115	.0	676.6	676.6	.0	.909
3	1	20.0	.09782	.128	.128	.0	754.2	754.2	.0	.883
4	1	30.0	.11985	.137	.137	-.1	814.1	813.7	.0	.845
5	1	40.0	.13231	.141	.141	.0	884.8	884.6	.0	.826
6	1	50.0	.13832	.142	.142	.0	961.3	961.2	.0	.817
7	1	60.0	.13625	.142	.142	.0	1049.3	1049.2	.0	.820
8	1	70.0	.13174	.140	.140	.0	1143.3	1143.3	.0	.827
9	6	77.5	.01442	.045	.045	.0	11096.7	11097.0	.0	.848

ACCELEROGRAM - Hilohaw1.sar
P R O F I L E - MSW - Matasovic & Kavazanjian (1998)

ITERATION NUMBER 6

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	6	2.5	.00629	.032	.032	.0	2331.2	2331.2	.0	.930
2	1	10.0	.06651	.115	.115	.0	676.6	676.6	.0	.909
3	1	20.0	.09784	.128	.128	.0	754.1	754.2	.0	.882
4	1	30.0	.11979	.137	.137	.0	814.2	814.1	.0	.845
5	1	40.0	.13229	.141	.141	.0	884.8	884.8	.0	.826
6	1	50.0	.13831	.142	.142	.0	961.3	961.3	.0	.817
7	1	60.0	.13623	.142	.142	.0	1049.3	1049.3	.0	.820
8	1	70.0	.13174	.140	.140	.0	1143.3	1143.3	.0	.827
9	6	77.5	.01442	.045	.045	.0	11096.6	11096.7	.0	.848

ACCELEROGRAM - Hilohaw1.sar
P R O F I L E - MSW - Matasovic & Kavazanjian (1998)

ITERATION NUMBER 7

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	6	2.5	.00629	.032	.032	.0	2331.2	2331.2	.0	.930
2	1	10.0	.06651	.115	.115	.0	676.6	676.6	.0	.909
3	1	20.0	.09784	.128	.128	.0	754.1	754.1	.0	.882
4	1	30.0	.11977	.137	.137	.0	814.2	814.2	.0	.846
5	1	40.0	.13228	.141	.141	.0	884.8	884.8	.0	.826
6	1	50.0	.13830	.142	.142	.0	961.3	961.3	.0	.817
7	1	60.0	.13623	.142	.142	.0	1049.3	1049.3	.0	.820
8	1	70.0	.13174	.140	.140	.0	1143.3	1143.3	.0	.827
9	6	77.5	.01442	.045	.045	.0	11096.6	11096.6	.0	.848

VALUES IN TIME DOMAIN

LAYER	MAT. TYPE	THICKNESS (ft)	DEPTH (ft)	MAX. STRAIN (%)	MAX. STRESS (psf)	AVG. ACC. (g)	TIME (sec)
1	6	5.0	2.5	.01015	236.67	.78889	61.98
2	1	10.0	10.0	.10728	725.79	.74863	61.98
3	1	10.0	20.0	.15781	1190.14	.68794	61.98
4	1	10.0	30.0	.19318	1572.87	.62206	53.80
5	1	10.0	40.0	.21336	1887.82	.56244	53.78
6	1	10.0	50.0	.22307	2144.36	.50977	53.78
7	1	10.0	60.0	.21973	2305.72	.45464	53.78
8	1	10.0	70.0	.21249	2429.35	.40850	53.76
9	6	5.0	77.5	.02326	2581.62	.38463	53.74

PERIOD = .479 sec FROM AVERAGE SHEAR WAVE VELOCITY OF 668.0 ft/sec

FREQUENCY AMPLITUDE:
MAXIMUM AMPLIFICATION = 4.72
FOR FREQUENCY (f) = 2.00 c/sec
FOR PERIOD (1 / f) = .50 sec

****** OPTION 6 *** COMPUTE MOTION IN NEW SUBLAYERS

ACCELEROGRAM - Hilohaw1.sar

D E P O S I T - MSW - Matasovic & Kavazanjian (1998)

LAYER	DEPTH (ft)	MAX. ACC. (g)	TIME (sec)	MN.SQ.FR. (c/sec)	ACC. RATIO QUIET ZONE	TH SAVED ACC.REC.
WITHIN	.0	.79411	61.98	2.75	.198	512
WITHIN	5.0	.78790	61.98	2.72	.197	0
WITHIN	15.0	.65520	61.98	2.24	.181	0
WITHIN	25.0	.57142	53.76	2.21	.149	0
WITHIN	35.0	.50499	53.74	2.75	.202	0
WITHIN	45.0	.53180	6.68	3.21	.195	0
WITHIN	55.0	.54520	6.38	3.38	.162	0
WITHIN	65.0	.57129	6.38	3.50	.151	0
WITHIN	75.0	.54213	6.38	3.75	.166	0
WITHIN	80.0	.53485	6.38	3.74	.166	0
OUTCR.	80.0	.60000	6.36	3.78	.178	0

****** OPTION 7 *** COMPUTE STRESS/STRAIN HISTORY

COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF LAYER 9
SCALE FOR PLOTTING .0000
IDENTIFICATION - -- stress in level 9

COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF LAYER 9
SCALE FOR PLOTTING .0000
IDENTIFICATION - -- strain in level 9

```
         ************************************************************
         * SHAKE  --   A COMPUTER PROGRAM FOR EARTHQUAKE RESPONSE   *
         *             ANALYSIS OF HORIZONTALLY LAYERED SITES       *
         *             by: Per B. Schnabel & John Lysmer -- 1970    *
         * ---------------------------------------------------------- *
         * Shake85   : IBM-PC version of SHAKE                      *
         *             by: S.S. (Willie) Lai, January 1985          *
         * ---------------------------------------------------------- *
         * Shake88   : New modulus reduction curves for clays       *
         *             added using results from Sun et al. (1988)   *
         *             by: J. I. Sun & Ramin Golesorkhi             *
         *             February 26, 1988                            *
         * ---------------------------------------------------------- *
         * Shake90/91: Adjust last iteration; Input now is either   *
         *             Gmax or max Vs; up to 13 material types can  *
         *             be specified by user; up to 50 Layers can    *
         *             be specified; object motion can be read in   *
         *             from a separate file and can have user       *
         *             specified format; Different periods for      *
         *             response spectral calculations; options      *
         *             are renumbered; and general cleanup          *
         *             by: J. I. Sun, I. M. Idriss & P. Dirrim      *
         *             June 1990 - February 1991                    *
         * ---------------------------------------------------------- *
         * Shake91   : General cleanup and finalization of input /  *
         *             output format ... etc                        *
         *             by: I. M. Idriss                             *
         *             December 1991                                *
         * ---------------------------------------------------------- *
         * Shake98   : Routine for direct calculation of average    *
         *             acceleration is added to the program. Out-   *
         *             put format is modified to enable the two -   *
         *             - page landscape printing.  The following    *
         *             modulus reduction and  damping curves are    *
         *             added:  Matasovic & Kavazanjian (1998) for   *
         *             municipal solid waste; Matasovic & Vucetic   *
         *             (1993) for SMB sand; and Vucetic and Dobry   *
         *             (1991) for clays of various plasticities.    *
         *             by: Neven Matasovic                          *
         *             August 1993 - May 1998                       *
         ************************************************************

 MAX. NUMBER OF TERMS IN FOURIER TRANSFORM  =      4096
 NECESSARY LENGTH OF BLANK COMMON X         =     25619

 ******   OPTION  1  ***  READ RELATION BETWEEN SOIL PROPERTIES AND STRAIN


 *********************
  MATERIAL TYPE NO. 1
 *********************

 CURVE NO.  1:      #1 Modulus - OII Waste (Matasovic & Kavazanjian, 1998)
 CURVE NO.  2:      #1 Damping - OII Waste (Matasovic & Kavazanjian, 1998)


      CURVE NO. 1              CURVE NO. 2
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001      1.13
```



```
     .0003     1.000          .0003      1.77
     .0010     1.000          .0010      2.58
     .0032      .994          .0032      4.03
     .0100      .983          .0100      5.89
     .0316      .959          .0316      8.97
     .1000      .881          .1000     12.91
     .3160      .655          .3160     17.63
    1.0000      .316         1.0000     21.92
    3.1600      .130         3.1600     25.17

 *********************
  MATERIAL TYPE NO. 6
 *********************

 CURVE NO. 11:      #6 Modulus for C  (PI=30) (Vucetic and Dobry, 1991)
 CURVE NO. 12:      #6 Damping for C  (PI=30) (Vucetic and Dobry, 1991)


      CURVE NO.11              CURVE NO.12
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001       .85
     .0003     1.000          .0003       .85
     .0010     1.000          .0010      1.36
     .0030      .976          .0030      2.18
     .0100      .901          .0100      3.82
     .0300      .743          .0320      6.00
     .1000      .538          .1000      8.72
     .3000      .332          .3160     12.41
    1.0000      .158         1.0000     16.90
    3.0000      .048         3.1600     21.26

 *********************
  MATERIAL TYPE NO. 3
 *********************

 CURVE NO.  5:   #3 Modulus for Gravel (Shibuya et al., 1990)
 CURVE NO.  6:   #3 Damping for Gravel (Shibuya et al., 1990)


      CURVE NO. 5              CURVE NO. 6
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001      2.50
     .0003      .986          .0003      2.56
     .0010      .951          .0010      2.73
     .0032      .903          .0032      2.94
     .0100      .847          .0100      3.32
     .0316      .792          .0316      4.14
     .1000      .722          .1000      5.00
    1.0000      .550         1.0000      7.40

 ******   OPTION  2  ***  READ SOIL / WASTE PROFILE

 SOIL PROFILE NO.      1   MSW - Matasovic & Kavazanjian (1998)

 NUMBER OF LAYERS     10
 DEPTH TO BEDROCK   80.0
```



```
  NO. TYPE  THICKNESS   DEPTH  TOT. PRESS.  MODULUS  DAMPING  UNIT WT. SH. VEL.
             (ft)       (ft)      (psf)       (ksf)    (%)      (pcf)     (fps)
   1    6     5.00       2.50    300.00       2507.   5.00    120.00     820.2
   2    1    10.00      10.00    969.50        745.   5.00     73.90     569.6
   3    1    10.00      20.00   1730.00        855.   5.00     78.20     593.2
   4    1    10.00      30.00   2528.50        963.   5.00     81.50     616.8
   5    1    10.00      40.00   3356.50       1071.   5.00     84.10     640.4
   6    1    10.00      50.00   4206.50       1176.   5.00     85.90     664.0
   7    1    10.00      60.00   5071.50       1279.   5.00     87.10     687.7
   8    1    10.00      70.00   5947.00       1383.   5.00     88.00     711.3
   9    6     5.00      77.50   6712.00      13081.   5.00    130.00    1800.0
  10   BASE                                  26475.  10.00    136.40    2500.0

  PERIOD =  .442 sec  FROM AVERAGE SHEAR WAVE VELOCITY OF  724.1 ft/sec


 FREQUENCY  AMPLITUDE:
 MAXIMUM AMPLIFICATION =  13.18
 FOR FREQUENCY  (f)    =   2.22 c/sec
 FOR PERIOD (1 / f)    =    .45 sec

 ******   OPTION  3  ***  READ INPUT MOTION

  FILE NAME FOR INPUT MOTION =                    Kiho_268.sar
  NO. OF INPUT ACCEL. POINTS =  5472
  NO. OF POINTS USED  IN FFT =  4096
      NO. OF  HEADING  LINES =     5
      NO. OF POINTS PER LINE =     8
  TIME STEP FOR INPUT MOTION =  .0050
  FORMAT FOR OF TIME HISTORY =  (8F9.6)


 ***** A C C E L E R O G R A M    H E A D E R *****

2006  10  15    1707 KIHOLO BAY, HAWAII, HI EARTHQUAKE
Moment Mag= 6.7; Max in File = 0.187210 g
station = HI:HI;Anaehoomalu,Waikoloa Htl component= 268
epicentral dist =     17.1       pk acc =  1.84E+2
684 x 8 = 5472 pts @ 0.005 sec

 **  FIRST & LAST 5 LINES OF INPUT MOTION *****

     1   .000119  .000154  .000182  .000134  .000064  .000118  .000362  .000678
     2   .000893  .000966  .000946  .000815  .000470 -.000081 -.000617 -.000858
     3  -.000690 -.000208  .000368  .000793  .000922  .000841  .000811  .000937
     4   .000999  .000786  .000495  .000505  .000712  .000472 -.000523 -.001620
     5  -.001847 -.001063 -.000061  .000471  .000618  .000710  .000636  .000119
   ........ INPUT MOTION READ NOT ECHOED..........
   680   .014128  .014194  .014311  .014465  .014287  .013532  .012320  .010972
   681   .009859  .009281  .009252  .009394  .009336  .009265  .009760  .010906
   682   .011866  .011630  .010134  .008317  .007094  .006527  .006042  .005167
   683   .003865  .002328  .000743 -.000754 -.002064 -.003137 -.003946 -.004475
   684  -.004799 -.005141 -.005703 -.006423 -.007008 -.007243 -.007204 -.007112

 MAXIMUM ACCELERATION  =  .187209
 AT TIME               =    11.22 sec

 THE VALUES WILL BE MULTIPLIED BY A FACTOR  = 3.20497400
 TO GIVE NEW MAXIMUM ACCELERATION           =  .60000000

 MEAN SQUARE FREQUENCY =       3.53 c/sec
```



```
 MAXIMUM  ACCELERATION =    .598253 FOR FREQUENCIES REMOVED ABOVE 25.00 c/sec

 ******   OPTION  4  ***  READ WHERE OBJECT MOTION IS GIVEN

   OBJECT MOTION IN LAYER NUMBER  10 OUTCROPPING

 ******   OPTION  5  ***  OBTAIN STRAIN COMPATIBLE SOIL PROPERTIES

  MAXIMUM NUMBER OF ITERATIONS                =      7
  FACTOR FOR UNIFORM STRAIN IN TIME DOMAIN  =    .57

     ACCELEROGRAM   -                    Kiho_268.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  1

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  -------  ----- ------  ------   -------   -------  ------  -----
  1  6    2.5  .01018  .038   .050    -29.9    2252.6    2507.1    -11.3  1.000
  2  1   10.0  .10889  .133   .050     62.3     643.5     744.6    -15.7  1.000
  3  1   20.0  .15762  .148   .050     66.2     676.5     854.6    -26.3  1.000
  4  1   30.0  .18686  .155   .050     67.7     730.1     962.9    -31.9  1.000
  5  1   40.0  .20272  .158   .050     68.4     795.0    1071.1    -34.7  1.000
  6  1   50.0  .21167  .160   .050     68.7     863.0    1176.2    -36.3  1.000
  7  1   60.0  .21316  .160   .050     68.8     936.8    1279.3    -36.6  1.000
  8  1   70.0  .20577  .159   .050     68.5    1022.2    1382.7    -35.3  1.000
  9  6   77.5  .02191  .053   .050      5.5   10309.8   13080.7    -26.9  1.000


     ACCELEROGRAM   -                    Kiho_268.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  2

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW       USED    ERROR  RATIO
--- ---- ----  -------  ----- ------  ------   -------   -------  ------  -----
  1  6    2.5  .00773  .035   .038    -11.0    2299.1    2252.6      2.0   .898
  2  1   10.0  .08031  .122   .133     -9.0     667.1     643.5      3.5   .864
  3  1   20.0  .13318  .141   .148     -4.9     704.8     676.5      4.0   .792
  4  1   30.0  .17591  .152   .155     -1.6     741.5     730.1      1.5   .758
  5  1   40.0  .20605  .159   .158      .4      791.6     795.0     -.4    .742
  6  1   50.0  .22453  .162   .160     1.5      849.3     863.0     -1.6   .734
  7  1   60.0  .23123  .163   .160     2.0      916.4     936.8     -2.2   .732
  8  1   70.0  .22725  .163   .159     2.5      995.2    1022.2     -2.7   .739
  9  6   77.5  .02272  .054   .053     1.3    10241.9   10309.8      -.7   .788


     ACCELEROGRAM   -                    Kiho_268.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  3

  VALUES IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
```

		(ft)	STRAIN	NEW	USED	ERROR	NEW	USED	ERROR	RATIO
1	6	2.5	.00748	.034	.035	-1.3	2304.2	2299.1	.2	.917
2	1	10.0	.07690	.120	.122	-1.2	669.2	667.1	.3	.896
3	1	20.0	.12693	.139	.141	-1.4	712.9	704.8	1.1	.825
4	1	30.0	.17243	.151	.152	-.5	745.3	741.5	.5	.770
5	1	40.0	.20650	.159	.159	.1	791.1	791.6	-.1	.739
6	1	50.0	.22807	.163	.162	.4	845.7	849.3	-.4	.722
7	1	60.0	.23656	.164	.163	.6	910.7	916.4	-.6	.716
8	1	70.0	.23367	.164	.163	.7	987.7	995.2	-.8	.720
9	6	77.5	.02286	.054	.054	.2	10230.0	10241.9	-.1	.783

ACCELEROGRAM - Kiho_268.sar
P R O F I L E - MSW - Matasovic & Kavazanjian (1998)

ITERATION NUMBER 4

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	6	2.5	.00744	.034	.034	-.2	2305.1	2304.2	.0	.919
2	1	10.0	.07642	.120	.120	-.2	669.6	669.2	.0	.899
3	1	20.0	.12525	.138	.139	-.4	715.1	712.9	.3	.834
4	1	30.0	.17133	.151	.151	-.2	746.5	745.3	.2	.774
5	1	40.0	.20649	.159	.159	.0	791.1	791.1	.0	.739
6	1	50.0	.22899	.163	.163	.1	844.8	845.7	-.1	.719
7	1	60.0	.23807	.165	.164	.2	909.1	910.7	-.2	.712
8	1	70.0	.23549	.164	.164	.2	985.5	987.7	-.2	.714
9	6	77.5	.02289	.054	.054	.0	10228.2	10230.0	.0	.782

ACCELEROGRAM - Kiho_268.sar
P R O F I L E - MSW - Matasovic & Kavazanjian (1998)

ITERATION NUMBER 5

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	6	2.5	.00743	.034	.034	-.1	2305.3	2305.1	.0	.919
2	1	10.0	.07631	.120	.120	.0	669.6	669.6	.0	.899
3	1	20.0	.12480	.138	.138	-.1	715.7	715.1	.1	.837
4	1	30.0	.17100	.151	.151	-.1	746.9	746.5	.1	.775
5	1	40.0	.20645	.159	.159	.0	791.2	791.1	.0	.739
6	1	50.0	.22924	.163	.163	.0	844.6	844.8	.0	.718
7	1	60.0	.23849	.165	.165	.0	908.6	909.1	.0	.711
8	1	70.0	.23601	.164	.164	.1	984.9	985.5	-.1	.713
9	6	77.5	.02289	.054	.054	.0	10227.9	10228.2	.0	.782

ACCELEROGRAM - Kiho_268.sar
P R O F I L E - MSW - Matasovic & Kavazanjian (1998)

ITERATION NUMBER 6

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	6	2.5	.00742	.034	.034	.0	2305.4	2305.3	.0	.920
2	1	10.0	.07628	.120	.120	.0	669.6	669.6	.0	.899
3	1	20.0	.12468	.138	.138	.0	715.9	715.7	.0	.837
4	1	30.0	.17089	.151	.151	.0	747.0	746.9	.0	.776
5	1	40.0	.20642	.159	.159	.0	791.2	791.2	.0	.739
6	1	50.0	.22930	.163	.163	.0	844.5	844.6	.0	.718
7	1	60.0	.23861	.165	.165	.0	908.5	908.6	.0	.710
8	1	70.0	.23616	.164	.164	.0	984.8	984.9	.0	.712
9	6	77.5	.02289	.054	.054	.0	10227.9	10227.9	.0	.782

ACCELEROGRAM - Kiho_268.sar
P R O F I L E - MSW - Matasovic & Kavazanjian (1998)

ITERATION NUMBER 7

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	6	2.5	.00742	.034	.034	.0	2305.4	2305.4	.0	.920
2	1	10.0	.07627	.120	.120	.0	669.7	669.6	.0	.899
3	1	20.0	.12464	.138	.138	.0	715.9	715.9	.0	.838
4	1	30.0	.17086	.151	.151	.0	747.0	747.0	.0	.776
5	1	40.0	.20641	.159	.159	.0	791.2	791.2	.0	.739
6	1	50.0	.22932	.163	.163	.0	844.5	844.5	.0	.718
7	1	60.0	.23864	.165	.165	.0	908.5	908.5	.0	.710
8	1	70.0	.23620	.164	.164	.0	984.7	984.8	.0	.712
9	6	77.5	.02289	.054	.054	.0	10227.9	10227.9	.0	.782

VALUES IN TIME DOMAIN

LAYER	MAT. TYPE	THICKNESS (ft)	DEPTH (ft)	MAX. STRAIN (%)	MAX. STRESS (psf)	AVG. ACC. (g)	TIME (sec)
1	6	5.0	2.5	.01302	300.27	1.00089	11.56
2	1	10.0	10.0	.13382	896.10	.92429	11.57
3	1	10.0	20.0	.21867	1565.38	.90484	11.37
4	1	10.0	30.0	.29976	2239.12	.88555	11.38
5	1	10.0	40.0	.36213	2865.11	.85360	11.37
6	1	10.0	50.0	.40231	3397.47	.80767	11.36
7	1	10.0	60.0	.41867	3803.63	.75000	11.36
8	1	10.0	70.0	.41439	4080.78	.68619	11.35
9	6	5.0	77.5	.04016	4107.21	.31192	11.33

PERIOD = .501 sec FROM AVERAGE SHEAR WAVE VELOCITY OF 638.5 ft/sec

FREQUENCY AMPLITUDE:
MAXIMUM AMPLIFICATION = 4.08
FOR FREQUENCY (f) = 1.88 c/sec
FOR PERIOD (1 / f) = .53 sec

****** OPTION 6 *** COMPUTE MOTION IN NEW SUBLAYERS

ACCELEROGRAM - Kiho_268.sar

D E P O S I T - MSW - Matasovic & Kavazanjian (1998)

LAYER	DEPTH (ft)	MAX. ACC. (g)	TIME (sec)	MN.SQ.FR. (c/sec)	ACC. RATIO QUIET ZONE	TH SAVED ACC.REC.
WITHIN	.0	1.02511	11.56	2.25	.164	512
WITHIN	5.0	1.01784	11.56	2.23	.164	0
WITHIN	15.0	.89224	11.58	2.02	.181	0
WITHIN	25.0	.78975	11.60	2.09	.193	0
WITHIN	35.0	.70491	11.35	2.24	.193	0
WITHIN	45.0	.60200	11.34	2.41	.195	0
WITHIN	55.0	.49253	11.32	2.74	.195	0
WITHIN	65.0	.49643	11.23	3.22	.196	0
WITHIN	75.0	.51173	11.22	3.56	.226	0
WITHIN	80.0	.50873	11.22	3.52	.227	0
OUTCR.	80.0	.59825	11.22	3.53	.214	0

****** OPTION 7 *** COMPUTE STRESS/STRAIN HISTORY

COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF LAYER 9
SCALE FOR PLOTTING .0000
IDENTIFICATION - -- stress in level 9

COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF LAYER 9
SCALE FOR PLOTTING .0000
IDENTIFICATION - -- strain in level 9

```
         ************************************************************
         * SHAKE  --   A COMPUTER PROGRAM FOR EARTHQUAKE RESPONSE   *
         *             ANALYSIS OF HORIZONTALLY LAYERED SITES       *
         *             by: Per B. Schnabel & John Lysmer -- 1970    *
         * ---------------------------------------------------------*
         * Shake85   : IBM-PC version of SHAKE                      *
         *             by: S.S. (Willie) Lai, January 1985          *
         * ---------------------------------------------------------*
         * Shake88   : New modulus reduction curves for clays       *
         *             added using results from Sun et al. (1988)   *
         *             by: J. I. Sun & Ramin Golesorkhi             *
         *             February 26, 1988                            *
         * ---------------------------------------------------------*
         * Shake90/91: Adjust last iteration; Input now is either   *
         *             Gmax or max Vs; up to 13 material types can  *
         *             be specified by user; up to 50 Layers can    *
         *             be specified; object motion can be read in   *
         *             from a separate file and can have user       *
         *             specified format; Different periods for      *
         *             response spectral calculations; options      *
         *             are renumbered; and general cleanup          *
         *             by: J. I. Sun, I. M. Idriss & P. Dirrim      *
         *             June 1990 - February 1991                    *
         * ---------------------------------------------------------*
         * Shake91   : General cleanup and finalization of input /  *
         *             output format ... etc                        *
         *             by: I. M. Idriss                             *
         *             December 1991                                *
         * ---------------------------------------------------------*
         * Shake98   : Routine for direct calculation of average    *
         *             acceleration is added to the program. Out-   *
         *             put format is modified to enable the two -   *
         *             - page landscape printing.  The following    *
         *             modulus reduction and  damping curves are    *
         *             added:  Matasovic & Kavazanjian (1998) for   *
         *             municipal solid waste; Matasovic & Vucetic   *
         *             (1993) for SMB sand; and Vucetic and Dobry   *
         *             (1991) for clays of various plasticities.    *
         *             by: Neven Matasovic                          *
         *             August 1993 - May 1998                       *
         ************************************************************

 MAX. NUMBER OF TERMS IN FOURIER TRANSFORM  =      4096
 NECESSARY LENGTH OF BLANK COMMON X         =     25619

 ******   OPTION  1  ***  READ RELATION BETWEEN SOIL PROPERTIES AND STRAIN


 *********************
  MATERIAL TYPE NO. 1
 *********************

 CURVE NO.  1:      #1 Modulus - OII Waste (Matasovic & Kavazanjian, 1998)
 CURVE NO.  2:      #1 Damping - OII Waste (Matasovic & Kavazanjian, 1998)


      CURVE NO. 1              CURVE NO. 2
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001      1.13
```



```
     .0003     1.000          .0003      1.77
     .0010     1.000          .0010      2.58
     .0032      .994          .0032      4.03
     .0100      .983          .0100      5.89
     .0316      .959          .0316      8.97
     .1000      .881          .1000     12.91
     .3160      .655          .3160     17.63
    1.0000      .316         1.0000     21.92
    3.1600      .130         3.1600     25.17

 *********************
  MATERIAL TYPE NO. 6
 *********************

 CURVE NO. 11:      #6 Modulus for C  (PI=30) (Vucetic and Dobry, 1991)
 CURVE NO. 12:      #6 Damping for C  (PI=30) (Vucetic and Dobry, 1991)


      CURVE NO.11              CURVE NO.12
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001       .85
     .0003     1.000          .0003       .85
     .0010     1.000          .0010      1.36
     .0030      .976          .0030      2.18
     .0100      .901          .0100      3.82
     .0300      .743          .0320      6.00
     .1000      .538          .1000      8.72
     .3000      .332          .3160     12.41
    1.0000      .158         1.0000     16.90
    3.0000      .048         3.1600     21.26

 *********************
  MATERIAL TYPE NO. 3
 *********************

 CURVE NO.  5:   #3 Modulus for Gravel (Shibuya et al., 1990)
 CURVE NO.  6:   #3 Damping for Gravel (Shibuya et al., 1990)


      CURVE NO. 5              CURVE NO. 6
   =================        =================
    STRAIN    G/Gmax         STRAIN   DAMPING
   -------   -------        --------  -------
     .0001     1.000          .0001      2.50
     .0003      .986          .0003      2.56
     .0010      .951          .0010      2.73
     .0032      .903          .0032      2.94
     .0100      .847          .0100      3.32
     .0316      .792          .0316      4.14
     .1000      .722          .1000      5.00
    1.0000      .550         1.0000      7.40

 ******   OPTION  2  ***  READ SOIL / WASTE PROFILE

 SOIL PROFILE NO.      1   MSW - Matasovic & Kavazanjian (1998)

 NUMBER OF LAYERS     10
 DEPTH TO BEDROCK   80.0
```



```
  NO. TYPE  THICKNESS   DEPTH  TOT. PRESS.  MODULUS  DAMPING  UNIT WT. SH. VEL.
             (ft)       (ft)      (psf)       (ksf)    (%)      (pcf)     (fps)
   1    6     5.00       2.50    300.00       2507.   5.00    120.00    820.2
   2    1    10.00      10.00    969.50        745.   5.00     73.90    569.6
   3    1    10.00      20.00   1730.00        855.   5.00     78.20    593.2
   4    1    10.00      30.00   2528.50        963.   5.00     81.50    616.8
   5    1    10.00      40.00   3356.50       1071.   5.00     84.10    640.4
   6    1    10.00      50.00   4206.50       1176.   5.00     85.90    664.0
   7    1    10.00      60.00   5071.50       1279.   5.00     87.10    687.7
   8    1    10.00      70.00   5947.00       1383.   5.00     88.00    711.3
   9    6     5.00      77.50   6712.00      13081.   5.00    130.00   1800.0
  10   BASE                                  26475.  10.00    136.40   2500.0

  PERIOD =  .442 sec  FROM AVERAGE SHEAR WAVE VELOCITY OF  724.1 ft/sec


 FREQUENCY  AMPLITUDE:
 MAXIMUM AMPLIFICATION =  13.18
 FOR FREQUENCY  (f)    =   2.22 c/sec
 FOR PERIOD (1 / f)    =    .45 sec

 ******   OPTION  3  ***  READ INPUT MOTION

  FILE NAME FOR INPUT MOTION =                    Luc92-fn.sar
  NO. OF INPUT ACCEL. POINTS = 12320
  NO. OF POINTS USED  IN FFT =  4096
      NO. OF  HEADING  LINES =     6
      NO. OF POINTS PER LINE =     8
  TIME STEP FOR INPUT MOTION =  .0040
  FORMAT FOR OF TIME HISTORY =  (8F9.6)


 ***** A C C E L E R O G R A M    H E A D E R *****

1992 Mw 7.3 Landers Eq.
Lucerne Valley, strike=340 (fault normal), static set by Hudnut geodetic model
1.1 km from the fault; forward directivity; shallow soil over hard rock
Joyner and Boore Class A; Ds 13.38 s
Recorded PGA = 0.76 g; Max. in file = 0.713386 g
8*1540 = 12320 pts @ 0.004 sec

 **  FIRST & LAST 5 LINES OF INPUT MOTION *****

     1  -.002559 -.001864 -.000497  .000960  .002188  .002937  .003559  .004559
     2   .006875  .010655  .013843  .013571  .009311  .003739 -.000616 -.004028
     3  -.007629 -.010747 -.011340 -.008186 -.003105  .000159  .000479 -.000154
     4  -.000232 -.000200 -.001059 -.002337 -.002922 -.002914 -.002663 -.001387
     5   .002288  .007957  .012828  .013737  .009850  .003706 -.001560 -.005316
   ........ INPUT MOTION READ NOT ECHOED..........
  1536  -.002270 -.000138 -.000180 -.001377 -.001369  .001319  .007493  .012797
  1537   .012225  .006912 -.001391 -.006299 -.005603 -.002072  .001551  .001488
  1538  -.001153 -.004629 -.007524 -.007878 -.005594 -.003036 -.000427  .005550
  1539   .012066  .013607  .009276  .001987 -.003915 -.006354 -.006264 -.004182
  1540  -.002739 -.003270 -.004798 -.006062 -.005249 -.003910 -.003144 -.002500

 MAXIMUM ACCELERATION  =  .713386
 AT TIME               =    10.37 sec

 THE VALUES WILL BE MULTIPLIED BY A FACTOR  =  .84105940
 TO GIVE NEW MAXIMUM ACCELERATION           =  .60000000
```



```
 MEAN SQUARE FREQUENCY =       8.96 c/sec
 MAXIMUM  ACCELERATION =    .615271 FOR FREQUENCIES REMOVED ABOVE 25.00 c/sec

 ******   OPTION  4  ***  READ WHERE OBJECT MOTION IS GIVEN

   OBJECT MOTION IN LAYER NUMBER  10 OUTCROPPING

 ******   OPTION  5  ***  OBTAIN STRAIN COMPATIBLE SOIL PROPERTIES

  MAXIMUM NUMBER OF ITERATIONS                =      7
  FACTOR FOR UNIFORM STRAIN IN TIME DOMAIN  =     .62

     ACCELEROGRAM   -                   Luc92-fn.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  1

  VALUES  IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW        USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------    -------   ------  -----
  1  6    2.5  .00614  .032   .050   -58.6    2335.0     2507.1     -7.4  1.000
  2  1   10.0  .05841  .111   .050    54.8     683.1      744.6     -9.0  1.000
  3  1   20.0  .06723  .116   .050    56.7     775.9      854.6    -10.1  1.000
  4  1   30.0  .07039  .117   .050    57.3     871.2      962.9    -10.5  1.000
  5  1   40.0  .07471  .119   .050    58.0     964.8     1071.1    -11.0  1.000
  6  1   50.0  .08071  .122   .050    58.9    1053.3     1176.2    -11.7  1.000
  7  1   60.0  .08738  .124   .050    59.8    1138.7     1279.3    -12.3  1.000
  8  1   70.0  .09811  .128   .050    61.1    1220.0     1382.7    -13.3  1.000
  9  6   77.5  .01194  .041   .050   -20.5   11451.6    13080.7    -14.2  1.000


     ACCELEROGRAM   -                   Luc92-fn.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  2

  VALUES  IN TIME DOMAIN

 NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR MODULUS ----->   G/Go
         (ft)   STRAIN  NEW    USED   ERROR      NEW        USED    ERROR  RATIO
--- ---- ----  ------- ----- ------  ------   -------    -------   ------  -----
  1  6    2.5  .00405  .026   .032   -21.8    2399.9     2335.0      2.7   .931
  2  1   10.0  .04509  .102   .111    -8.7     696.2      683.1      1.9   .917
  3  1   20.0  .06023  .112   .116    -3.4     782.2      775.9       .8   .908
  4  1   30.0  .06546  .115   .117    -2.2     876.0      871.2       .5   .905
  5  1   40.0  .07508  .119   .119      .1     964.5      964.8       .0   .901
  6  1   50.0  .08071  .122   .122      .0    1053.3     1053.3       .0   .896
  7  1   60.0  .08700  .124   .124     -.1    1139.1     1138.7       .0   .890
  8  1   70.0  .09418  .127   .128    -1.1    1223.8     1220.0       .3   .882
  9  6   77.5  .01201  .042   .041      .2   11441.8    11451.6      -.1   .875


     ACCELEROGRAM   -                   Luc92-fn.sar
     P R O F I L E  - MSW - Matasovic & Kavazanjian (1998)

  ITERATION NUMBER  3

  VALUES  IN TIME DOMAIN
```

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	6	2.5	.00402	.026	.026	-.4	2401.1	2399.9	.1	.957
2	1	10.0	.04412	.101	.102	-.7	697.3	696.2	.2	.935
3	1	20.0	.05989	.112	.112	-.2	782.5	782.2	.0	.915
4	1	30.0	.06514	.114	.115	-.1	876.3	876.0	.0	.910
5	1	40.0	.07525	.119	.119	.1	964.3	964.5	.0	.900
6	1	50.0	.08080	.122	.122	.0	1053.2	1053.3	.0	.896
7	1	60.0	.08701	.124	.124	.0	1139.1	1139.1	.0	.890
8	1	70.0	.09415	.127	.127	.0	1223.8	1223.8	.0	.885
9	6	77.5	.01204	.042	.042	.1	11435.9	11441.8	-.1	.875

ACCELEROGRAM - Luc92-fn.sar
P R O F I L E - MSW - Matasovic & Kavazanjian (1998)

ITERATION NUMBER 4

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	6	2.5	.00402	.026	.026	.0	2401.1	2401.1	.0	.958
2	1	10.0	.04402	.101	.101	-.1	697.4	697.3	.0	.936
3	1	20.0	.05987	.112	.112	.0	782.6	782.5	.0	.916
4	1	30.0	.06512	.114	.114	.0	876.3	876.3	.0	.910
5	1	40.0	.07527	.119	.119	.0	964.3	964.3	.0	.900
6	1	50.0	.08081	.122	.122	.0	1053.2	1053.2	.0	.895
7	1	60.0	.08701	.124	.124	.0	1139.1	1139.1	.0	.890
8	1	70.0	.09415	.127	.127	.0	1223.8	1223.8	.0	.885
9	6	77.5	.01205	.042	.042	.0	11434.9	11435.9	.0	.874

ACCELEROGRAM - Luc92-fn.sar
P R O F I L E - MSW - Matasovic & Kavazanjian (1998)

ITERATION NUMBER 5

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	6	2.5	.00402	.026	.026	.0	2401.0	2401.1	.0	.958
2	1	10.0	.04401	.101	.101	.0	697.4	697.4	.0	.937
3	1	20.0	.05987	.112	.112	.0	782.6	782.6	.0	.916
4	1	30.0	.06512	.114	.114	.0	876.3	876.3	.0	.910
5	1	40.0	.07527	.119	.119	.0	964.3	964.3	.0	.900
6	1	50.0	.08081	.122	.122	.0	1053.2	1053.2	.0	.895
7	1	60.0	.08701	.124	.124	.0	1139.1	1139.1	.0	.890
8	1	70.0	.09415	.127	.127	.0	1223.8	1223.8	.0	.885
9	6	77.5	.01205	.042	.042	.0	11434.7	11434.9	.0	.874

ACCELEROGRAM - Luc92-fn.sar
P R O F I L E - MSW - Matasovic & Kavazanjian (1998)

ITERATION NUMBER 6

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	6	2.5	.00402	.026	.026	.0	2401.0	2401.0	.0	.958
2	1	10.0	.04401	.101	.101	.0	697.4	697.4	.0	.937
3	1	20.0	.05987	.112	.112	.0	782.6	782.6	.0	.916
4	1	30.0	.06512	.114	.114	.0	876.3	876.3	.0	.910
5	1	40.0	.07527	.119	.119	.0	964.3	964.3	.0	.900
6	1	50.0	.08081	.122	.122	.0	1053.2	1053.2	.0	.895
7	1	60.0	.08701	.124	.124	.0	1139.1	1139.1	.0	.890
8	1	70.0	.09415	.127	.127	.0	1223.8	1223.8	.0	.885
9	6	77.5	.01205	.042	.042	.0	11434.6	11434.7	.0	.874

ACCELEROGRAM - Luc92-fn.sar
P R O F I L E - MSW - Matasovic & Kavazanjian (1998)

ITERATION NUMBER 7

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	6	2.5	.00402	.026	.026	.0	2401.0	2401.0	.0	.958
2	1	10.0	.04401	.101	.101	.0	697.4	697.4	.0	.937
3	1	20.0	.05987	.112	.112	.0	782.6	782.6	.0	.916
4	1	30.0	.06512	.114	.114	.0	876.3	876.3	.0	.910
5	1	40.0	.07527	.119	.119	.0	964.3	964.3	.0	.900
6	1	50.0	.08081	.122	.122	.0	1053.2	1053.2	.0	.895
7	1	60.0	.08701	.124	.124	.0	1139.1	1139.1	.0	.890
8	1	70.0	.09415	.127	.127	.0	1223.8	1223.8	.0	.885
9	6	77.5	.01205	.042	.042	.0	11434.6	11434.6	.0	.874

VALUES IN TIME DOMAIN

LAYER	MAT. TYPE	THICKNESS (ft)	DEPTH (ft)	MAX. STRAIN (%)	MAX. STRESS (psf)	AVG. ACC. (g)	TIME (sec)
1	6	5.0	2.5	.00649	155.82	.51940	14.76
2	1	10.0	10.0	.07099	495.06	.51064	10.49
3	1	10.0	20.0	.09656	755.67	.43680	10.48
4	1	10.0	30.0	.10503	920.38	.36400	10.80
5	1	10.0	40.0	.12140	1170.64	.34877	10.79
6	1	10.0	50.0	.13034	1372.75	.32634	10.77
7	1	10.0	60.0	.14034	1598.54	.31520	10.76
8	1	10.0	70.0	.15186	1858.47	.31251	10.74
9	6	5.0	77.5	.01944	2222.72	.33116	10.72

PERIOD = .465 sec FROM AVERAGE SHEAR WAVE VELOCITY OF 688.0 ft/sec

FREQUENCY AMPLITUDE:
MAXIMUM AMPLIFICATION = 5.46
FOR FREQUENCY (f) = 2.09 c/sec
FOR PERIOD (1 / f) = .48 sec

****** OPTION 6 *** COMPUTE MOTION IN NEW SUBLAYERS

ACCELEROGRAM - Luc92-fn.sar
D E P O S I T - MSW - Matasovic & Kavazanjian (1998)

LAYER	DEPTH (ft)	MAX. ACC. (g)	TIME (sec)	MN.SQ.FR. (c/sec)	ACC. RATIO QUIET ZONE	TH SAVED ACC.REC.
WITHIN	.0	.52696	14.76	4.11	.613	512
WITHIN	5.0	.50026	14.76	3.88	.618	0
WITHIN	15.0	.43918	10.80	3.68	.565	0
WITHIN	25.0	.48446	10.79	4.84	.501	0
WITHIN	35.0	.45213	10.77	5.09	.557	0
WITHIN	45.0	.48047	10.76	5.87	.873	0
WITHIN	55.0	.54112	10.74	6.73	.740	0
WITHIN	65.0	.56100	10.72	7.68	.887	0
WITHIN	75.0	.51035	10.71	8.58	.997	0
WITHIN	80.0	.50121	10.71	8.30	.991	0
OUTCR.	80.0	.61527	14.64	8.96	1.000	0

****** OPTION 7 *** COMPUTE STRESS/STRAIN HISTORY

COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF LAYER 9
SCALE FOR PLOTTING .0000
IDENTIFICATION - -- stress in level 9

COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF LAYER 9
SCALE FOR PLOTTING .0000
IDENTIFICATION - -- strain in level 9

APPENDIX C

Seismic Deformation Analysis

APPENDIX C-1

Seismic Deformation Analysis – 30 ft

```
          ************************************************
          **                                            **
          **                 YSLIP_PM                   **
          **        (VERSION 2.2, JANUARY 1996)         **
          **                                            **
          **   A COMPUTER PROGRAM FOR SIMULATION OF     **
          **   DYNAMIC BEHAVIOR OF A RIGID BLOCK ON     **
          **   AN INCLINED PLANE AND CALCULATION OF     **
          **   PERMANENT DISPLACEMENTS OF THE BLOCK     **
          **                                            **
          **                    BY                      **
          **                                            **
          **               Liping Yan                   **
          **            Neven Matasovic                 **
          **         Edward Kavazanjian, Jr.            **
          **                                            **
          ************************************************

          ***************REPRINT INPUT DATA**************

TITLE
Classical Newmark Analysis
SUBTITLE
Liner / Western Hawaii Lfd. / 30 ft MSW @ 0.60 g
KPAR   N    KACC  KCOM   g(m/s/s)  KOUT   KSLIP  KDIR
0     10    1     1      386.20    0      0      0
Ky(1), ..., Ky(N)
0.025 0.05 0.075 0.10 0.125 0.15 0.175 0.20 0.25 0.30
YIELD ACCELERATION DEGRADATION DATA
Ky is constant.
FILE NAME OF INPUT HORIZONTAL ACC.
30ft-h.pun
NIDH  KREAD     NP        NLINE     DT       APH
1     2         2048      256       0.02     0.877
FILE NAME OF INPUT VERTICAL ACC.
NO Av
NIDV  KREAD     NP        NLINE     DT       APV       TSHIFT
NO INPUT
FILE NAME FOR OUTPUT OF SLIDING MOTION
YEX0.OUS
FILE NAME FOR OUTPUT OF ABSOLUTE MOTION
YEX0.OUA

MAX. VALUE OF INPUT HORI. ACC. = 2.045573
INPUT HORI. ACC. TIMES A FACTOR =  .428731 TO GET APH =  .877000


          *****************RESULTS*****************

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .025000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 23.4687
        PERMANENT SLIDING DISPLACEMENT = 43.3213

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 23.0793
        PERMANENT SLIDING DISPLACEMENT = 46.6528

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .050000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 22.3315
        PERMANENT SLIDING DISPLACEMENT = 22.6477

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 19.8346
        PERMANENT SLIDING DISPLACEMENT = 24.6799

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .075000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 21.2057
        PERMANENT SLIDING DISPLACEMENT = 14.3463

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 18.1157
        PERMANENT SLIDING DISPLACEMENT = 15.9225

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .100000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 20.0912
        PERMANENT SLIDING DISPLACEMENT = 10.2347

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 16.9799
        PERMANENT SLIDING DISPLACEMENT = 11.2426

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .125000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 18.9882
        PERMANENT SLIDING DISPLACEMENT =  7.8222

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 15.8614
        PERMANENT SLIDING DISPLACEMENT =  8.3912

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .150000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 17.8966
        PERMANENT SLIDING DISPLACEMENT =  6.1796

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 14.7602
        PERMANENT SLIDING DISPLACEMENT =  6.3950

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .175000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 16.8165
        PERMANENT SLIDING DISPLACEMENT =  4.9641

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 13.6764
        PERMANENT SLIDING DISPLACEMENT =  4.9076

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .200000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 15.7683
        PERMANENT SLIDING DISPLACEMENT =  3.9950

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 12.6100
        PERMANENT SLIDING DISPLACEMENT =  3.7770

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .250000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 14.0512
        PERMANENT SLIDING DISPLACEMENT =  2.5905

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 10.8603
        PERMANENT SLIDING DISPLACEMENT =  2.2016

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .300000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 12.3798
        PERMANENT SLIDING DISPLACEMENT =  1.6869

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  9.2351
        PERMANENT SLIDING DISPLACEMENT =  1.2507
```

```
          ************************************************
          **                                            **
          **                 YSLIP_PM                   **
          **        (VERSION 2.2, JANUARY 1996)         **
          **                                            **
          **   A COMPUTER PROGRAM FOR SIMULATION OF     **
          **   DYNAMIC BEHAVIOR OF A RIGID BLOCK ON     **
          **   AN INCLINED PLANE AND CALCULATION OF     **
          **   PERMANENT DISPLACEMENTS OF THE BLOCK     **
          **                                            **
          **                    BY                      **
          **                                            **
          **               Liping Yan                   **
          **            Neven Matasovic                 **
          **         Edward Kavazanjian, Jr.            **
          **                                            **
          ************************************************

          ***************REPRINT INPUT DATA**************

TITLE
Classical Newmark Analysis
SUBTITLE
Liner / Western Hawaii Lfd. / 30 ft MSW @ 0.60 g
KPAR   N    KACC  KCOM   g(m/s/s)  KOUT   KSLIP  KDIR
0     10    1     1      386.20    0      0      0
Ky(1), ..., Ky(N)
0.025 0.05 0.075 0.10 0.125 0.15 0.175 0.20 0.25 0.30
YIELD ACCELERATION DEGRADATION DATA
Ky is constant.
FILE NAME OF INPUT HORIZONTAL ACC.
30ft-k.pun
NIDH  KREAD     NP        NLINE     DT       APH
1     2         1048      256       0.005    0.711
FILE NAME OF INPUT VERTICAL ACC.
NO Av
NIDV  KREAD     NP        NLINE     DT       APV       TSHIFT
NO INPUT
FILE NAME FOR OUTPUT OF SLIDING MOTION
YEX0.OUS
FILE NAME FOR OUTPUT OF ABSOLUTE MOTION
YEX0.OUA

MAX. VALUE OF INPUT HORI. ACC. = 1.044241
INPUT HORI. ACC. TIMES A FACTOR =  .680877 TO GET APH =  .711000


          *****************RESULTS*****************

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .025000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  6.5610
        PERMANENT SLIDING DISPLACEMENT =  1.3778

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 11.0732
        PERMANENT SLIDING DISPLACEMENT =  2.7710

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .050000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  4.8065
        PERMANENT SLIDING DISPLACEMENT =   .6782

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  9.3083
        PERMANENT SLIDING DISPLACEMENT =  1.7849

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .075000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  3.1765
        PERMANENT SLIDING DISPLACEMENT =   .3628

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  7.6730
        PERMANENT SLIDING DISPLACEMENT =  1.2468

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .100000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  1.6807
        PERMANENT SLIDING DISPLACEMENT =   .1524

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  6.1691
        PERMANENT SLIDING DISPLACEMENT =   .8753

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .125000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =   .4377
        PERMANENT SLIDING DISPLACEMENT =   .0172

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  4.8180
        PERMANENT SLIDING DISPLACEMENT =   .6013

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .150000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =   .0801
        PERMANENT SLIDING DISPLACEMENT =   .0017

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  3.6146
        PERMANENT SLIDING DISPLACEMENT =   .3940

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .175000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =   .0000
        PERMANENT SLIDING DISPLACEMENT =   .0000

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  2.5671
        PERMANENT SLIDING DISPLACEMENT =   .2390

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .200000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =   .0000
        PERMANENT SLIDING DISPLACEMENT =   .0000

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  1.6730
        PERMANENT SLIDING DISPLACEMENT =   .1278

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .250000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =   .0000
        PERMANENT SLIDING DISPLACEMENT =   .0000

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =   .3529
        PERMANENT SLIDING DISPLACEMENT =   .0141

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .300000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =   .0000
        PERMANENT SLIDING DISPLACEMENT =   .0000

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =   .0000
        PERMANENT SLIDING DISPLACEMENT =   .0000
```

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          ************************************************
          **                                            **
          **                 YSLIP_PM                   **
          **        (VERSION 2.2, JANUARY 1996)         **
          **                                            **
          **   A COMPUTER PROGRAM FOR SIMULATION OF     **
          **   DYNAMIC BEHAVIOR OF A RIGID BLOCK ON     **
          **   AN INCLINED PLANE AND CALCULATION OF     **
          **   PERMANENT DISPLACEMENTS OF THE BLOCK     **
          **                                            **
          **                    BY                      **
          **                                            **
          **                Liping Yan                  **
          **             Neven Matasovic                **
          **          Edward Kavazanjian, Jr.           **
          **                                            **
          ************************************************

          ***************REPRINT INPUT DATA**************

TITLE
Classical Newmark Analysis
SUBTITLE
Liner / Western Hawaii Lfd. / 30 ft MSW @ 0.60 g
KPAR   N    KACC  KCOM   g(m/s/s)  KOUT   KSLIP  KDIR
0     10    1     1      386.20    0      0      0
Ky(1), ..., Ky(N)
0.025 0.05 0.075 0.10 0.125 0.15 0.175 0.20 0.25 0.30
YIELD ACCELERATION DEGRADATION DATA
Ky is constant.
FILE NAME OF INPUT HORIZONTAL ACC.
30ft-l.pun
NIDH  KREAD     NP        NLINE     DT       APH
1     2         2048      256       0.004    0.436
FILE NAME OF INPUT VERTICAL ACC.
NO Av
NIDV  KREAD     NP        NLINE     DT       APV       TSHIFT
NO INPUT
FILE NAME FOR OUTPUT OF SLIDING MOTION
YEX0.OUS
FILE NAME FOR OUTPUT OF ABSOLUTE MOTION
YEX0.OUA

MAX. VALUE OF INPUT HORI. ACC. =  .447527
INPUT HORI. ACC. TIMES A FACTOR =  .974243 TO GET APH =  .436000


          *****************RESULTS*****************

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .025000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 13.6169
        PERMANENT SLIDING DISPLACEMENT =  8.4786

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  8.8062
        PERMANENT SLIDING DISPLACEMENT =  5.9517

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .050000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 12.3036
        PERMANENT SLIDING DISPLACEMENT =  4.6193

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  7.5204
        PERMANENT SLIDING DISPLACEMENT =  3.2541

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .075000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 11.0641
        PERMANENT SLIDING DISPLACEMENT =  2.7868

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  6.3601
        PERMANENT SLIDING DISPLACEMENT =  1.9324

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .100000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  9.8938
        PERMANENT SLIDING DISPLACEMENT =  1.9897

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  5.3574
        PERMANENT SLIDING DISPLACEMENT =  1.1485

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .125000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  8.7860
        PERMANENT SLIDING DISPLACEMENT =  1.4575

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  4.4580
        PERMANENT SLIDING DISPLACEMENT =   .6693

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .150000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  7.7342
        PERMANENT SLIDING DISPLACEMENT =  1.0752

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  3.6320
        PERMANENT SLIDING DISPLACEMENT =   .3971

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .175000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  6.7419
        PERMANENT SLIDING DISPLACEMENT =   .7932

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  2.8719
        PERMANENT SLIDING DISPLACEMENT =   .2496

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .200000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  5.8084
        PERMANENT SLIDING DISPLACEMENT =   .5876

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  2.1789
        PERMANENT SLIDING DISPLACEMENT =   .1547

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .250000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  4.0928
        PERMANENT SLIDING DISPLACEMENT =   .3196

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  1.0044
        PERMANENT SLIDING DISPLACEMENT =   .0463

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .300000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  2.5933
        PERMANENT SLIDING DISPLACEMENT =   .1606

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =   .1748
        PERMANENT SLIDING DISPLACEMENT =   .0048
```

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          ************************************************
          **                                            **
          **                YSLIP_PM                    **
          **        (VERSION 2.2, JANUARY 1996)         **
          **                                            **
          **   A COMPUTER PROGRAM FOR SIMULATION OF     **
          **   DYNAMIC BEHAVIOR OF A RIGID BLOCK ON     **
          **   AN INCLINED PLANE AND CALCULATION OF     **
          **   PERMANENT DISPLACEMENTS OF THE BLOCK     **
          **                                            **
          **                    BY                      **
          **                                            **
          **               Liping Yan                   **
          **            Neven Matasovic                 **
          **         Edward Kavazanjian, Jr.            **
          **                                            **
          ************************************************

          ***************REPRINT INPUT DATA**************

TITLE
Classical Newmark Analysis
SUBTITLE
COVER / Western Hawaii Lfd. / 30 ft MSW @ 0.60 g
KPAR   N    KACC  KCOM   g(m/s/s)  KOUT   KSLIP  KDIR
0     10    1     1      386.20    0      0      0
Ky(1), ..., Ky(N)
0.05 0.075 0.10 0.125 0.15 0.175 0.20 0.25 0.30 0.40
YIELD ACCELERATION DEGRADATION DATA
Ky is constant.
FILE NAME OF INPUT HORIZONTAL ACC.
30ft-h.pun
NIDH  KREAD     NP        NLINE     DT       APH
2     2         4096      512       0.020    1.258
FILE NAME OF INPUT VERTICAL ACC.
NO Av
NIDV  KREAD     NP        NLINE     DT       APV       TSHIFT
NO INPUT
FILE NAME FOR OUTPUT OF SLIDING MOTION
YEX0.OUS
FILE NAME FOR OUTPUT OF ABSOLUTE MOTION
YEX0.OUA

MAX. VALUE OF INPUT HORI. ACC. = 1.269187
INPUT HORI. ACC. TIMES A FACTOR =  .991186 TO GET APH = 1.258000


          ******************RESULTS*****************

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .050000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 33.9139
        PERMANENT SLIDING DISPLACEMENT = 71.1789

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 28.9282
        PERMANENT SLIDING DISPLACEMENT = 74.1284

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .075000
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*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 32.7869
        PERMANENT SLIDING DISPLACEMENT = 46.3261

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 26.3784
        PERMANENT SLIDING DISPLACEMENT = 48.3925

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .100000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 31.6671
        PERMANENT SLIDING DISPLACEMENT = 32.8323

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 25.2845
        PERMANENT SLIDING DISPLACEMENT = 34.9980

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .125000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 30.5545
        PERMANENT SLIDING DISPLACEMENT = 24.3874

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 24.2024
        PERMANENT SLIDING DISPLACEMENT = 26.6048

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .150000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 29.4491
        PERMANENT SLIDING DISPLACEMENT = 18.8229

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 23.1323
        PERMANENT SLIDING DISPLACEMENT = 20.9522

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .175000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 28.3509
        PERMANENT SLIDING DISPLACEMENT = 15.3070

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 22.0742
        PERMANENT SLIDING DISPLACEMENT = 16.8430

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .200000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 27.2598
        PERMANENT SLIDING DISPLACEMENT = 12.8126

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 21.0279
        PERMANENT SLIDING DISPLACEMENT = 13.6948

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .250000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 25.0993
        PERMANENT SLIDING DISPLACEMENT =  9.1593

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 18.9712
        PERMANENT SLIDING DISPLACEMENT =  9.2212

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .300000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 22.9676
        PERMANENT SLIDING DISPLACEMENT =  6.6386

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 16.9622
        PERMANENT SLIDING DISPLACEMENT =  6.3480

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .400000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 19.5314
        PERMANENT SLIDING DISPLACEMENT =  3.5068

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 13.2705
        PERMANENT SLIDING DISPLACEMENT =  2.9602
```

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          ************************************************
          **                                            **
          **                YSLIP_PM                    **
          **        (VERSION 2.2, JANUARY 1996)         **
          **                                            **
          **   A COMPUTER PROGRAM FOR SIMULATION OF     **
          **   DYNAMIC BEHAVIOR OF A RIGID BLOCK ON     **
          **   AN INCLINED PLANE AND CALCULATION OF     **
          **   PERMANENT DISPLACEMENTS OF THE BLOCK     **
          **                                            **
          **                    BY                      **
          **                                            **
          **               Liping Yan                   **
          **            Neven Matasovic                 **
          **         Edward Kavazanjian, Jr.            **
          **                                            **
          ************************************************

          ***************REPRINT INPUT DATA**************

TITLE
Classical Newmark Analysis
SUBTITLE
COVER / Western Hawaii Lfd. / 30 ft MSW @ 0.60 g
KPAR   N    KACC  KCOM   g(m/s/s)  KOUT   KSLIP  KDIR
0     10    1     1      386.20    0      0      0
Ky(1), ..., Ky(N)
0.05 0.075 0.10 0.125 0.15 0.175 0.20 0.25 0.30 0.40
YIELD ACCELERATION DEGRADATION DATA
Ky is constant.
FILE NAME OF INPUT HORIZONTAL ACC.
30ft-k.pun
NIDH  KREAD     NP        NLINE     DT       APH
2     2         4096      512       0.005    0.826
FILE NAME OF INPUT VERTICAL ACC.
NO Av
NIDV  KREAD     NP        NLINE     DT       APV       TSHIFT
NO INPUT
FILE NAME FOR OUTPUT OF SLIDING MOTION
YEX0.OUS
FILE NAME FOR OUTPUT OF ABSOLUTE MOTION
YEX0.OUA

MAX. VALUE OF INPUT HORI. ACC. =  .833889
INPUT HORI. ACC. TIMES A FACTOR =  .990540 TO GET APH =  .826000


          ******************RESULTS*****************

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .050000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY = 38.6845
        PERMANENT SLIDING DISPLACEMENT = 44.7236

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY = 24.2316
        PERMANENT SLIDING DISPLACEMENT = 50.5036

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .075000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY = 36.4614
        PERMANENT SLIDING DISPLACEMENT = 32.4262

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY = 22.8249
        PERMANENT SLIDING DISPLACEMENT = 33.4456

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .100000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY = 34.2875
        PERMANENT SLIDING DISPLACEMENT = 23.8599

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY = 21.4740
        PERMANENT SLIDING DISPLACEMENT = 23.1057

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .125000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY = 32.1705
        PERMANENT SLIDING DISPLACEMENT = 18.7259

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY = 20.1762
        PERMANENT SLIDING DISPLACEMENT = 16.1139

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .150000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY = 30.0895
        PERMANENT SLIDING DISPLACEMENT = 14.8939

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY = 18.9136
        PERMANENT SLIDING DISPLACEMENT = 11.4179

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .175000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY = 28.0694
        PERMANENT SLIDING DISPLACEMENT = 12.2230

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY = 17.7199
        PERMANENT SLIDING DISPLACEMENT =  8.2647

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .200000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY = 26.0932
        PERMANENT SLIDING DISPLACEMENT = 10.1556

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY = 16.5527
        PERMANENT SLIDING DISPLACEMENT =  6.1269

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .250000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY = 22.2985
        PERMANENT SLIDING DISPLACEMENT =  7.0905

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY = 14.3720
        PERMANENT SLIDING DISPLACEMENT =  3.6602

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .300000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY = 19.0096
        PERMANENT SLIDING DISPLACEMENT =  4.9977

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY = 12.3492
        PERMANENT SLIDING DISPLACEMENT =  2.2668

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .400000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY = 13.5611
        PERMANENT SLIDING DISPLACEMENT =  2.4633

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY =  8.7645
        PERMANENT SLIDING DISPLACEMENT =   .8773
```

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          ************************************************
          **                                            **
          **                 YSLIP_PM                   **
          **        (VERSION 2.2, JANUARY 1996)         **
          **                                            **
          **   A COMPUTER PROGRAM FOR SIMULATION OF     **
          **   DYNAMIC BEHAVIOR OF A RIGID BLOCK ON     **
          **   AN INCLINED PLANE AND CALCULATION OF     **
          **   PERMANENT DISPLACEMENTS OF THE BLOCK     **
          **                                            **
          **                    BY                      **
          **                                            **
          **               Liping Yan                   **
          **            Neven Matasovic                 **
          **         Edward Kavazanjian, Jr.            **
          **                                            **
          ************************************************

          ***************REPRINT INPUT DATA**************

TITLE
Classical Newmark Analysis
SUBTITLE
COVER / Western Hawaii Lfd. / 30 ft MSW @ 0.60 g
KPAR   N    KACC  KCOM   g(m/s/s)  KOUT   KSLIP  KDIR
0     10    1     1      386.20    0      0      0
Ky(1), ..., Ky(N)
0.05 0.075 0.10 0.125 0.15 0.175 0.20 0.25 0.30 0.40
YIELD ACCELERATION DEGRADATION DATA
Ky is constant.
FILE NAME OF INPUT HORIZONTAL ACC.
30ft-l.pun
NIDH  KREAD     NP        NLINE     DT       APH
2     2         4096      512       0.004    0.653
FILE NAME OF INPUT VERTICAL ACC.
NO Av
NIDV  KREAD     NP        NLINE     DT       APV       TSHIFT
NO INPUT
FILE NAME FOR OUTPUT OF SLIDING MOTION
YEX0.OUS
FILE NAME FOR OUTPUT OF ABSOLUTE MOTION
YEX0.OUA

MAX. VALUE OF INPUT HORI. ACC. =  .660504
INPUT HORI. ACC. TIMES A FACTOR =  .988639 TO GET APH =  .653000


          *****************RESULTS*****************

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .050000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 40.4814
        PERMANENT SLIDING DISPLACEMENT = 82.7577

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 13.4110
        PERMANENT SLIDING DISPLACEMENT = 24.2835

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .075000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 30.4762
        PERMANENT SLIDING DISPLACEMENT = 45.7859

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 11.8837
        PERMANENT SLIDING DISPLACEMENT = 13.9230

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .100000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 24.8654
        PERMANENT SLIDING DISPLACEMENT = 26.0540

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 11.0323
        PERMANENT SLIDING DISPLACEMENT =  9.2925

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .125000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 19.2648
        PERMANENT SLIDING DISPLACEMENT = 16.0269

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 10.1936
        PERMANENT SLIDING DISPLACEMENT =  6.4520

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .150000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 13.7078
        PERMANENT SLIDING DISPLACEMENT =  9.8177

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  9.3971
        PERMANENT SLIDING DISPLACEMENT =  4.7950

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .175000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 10.3669
        PERMANENT SLIDING DISPLACEMENT =  7.2799

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  8.6224
        PERMANENT SLIDING DISPLACEMENT =  3.5960

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .200000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  9.4325
        PERMANENT SLIDING DISPLACEMENT =  5.6044

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  7.8611
        PERMANENT SLIDING DISPLACEMENT =  2.7114

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .250000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  7.7089
        PERMANENT SLIDING DISPLACEMENT =  3.3525

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  6.4183
        PERMANENT SLIDING DISPLACEMENT =  1.5888

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .300000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  6.3049
        PERMANENT SLIDING DISPLACEMENT =  1.8793

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  5.0746
        PERMANENT SLIDING DISPLACEMENT =   .9087

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .400000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  3.8754
        PERMANENT SLIDING DISPLACEMENT =   .5153

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  2.8009
        PERMANENT SLIDING DISPLACEMENT =   .2601
```

APPENDIX C-2

Seismic Deformation Analysis – 80 ft

```
          ************************************************
          **                                            **
          **                 YSLIP_PM                   **
          **        (VERSION 2.2, JANUARY 1996)         **
          **                                            **
          **   A COMPUTER PROGRAM FOR SIMULATION OF     **
          **   DYNAMIC BEHAVIOR OF A RIGID BLOCK ON     **
          **   AN INCLINED PLANE AND CALCULATION OF     **
          **   PERMANENT DISPLACEMENTS OF THE BLOCK     **
          **                                            **
          **                    BY                      **
          **                                            **
          **               Liping Yan                   **
          **            Neven Matasovic                 **
          **         Edward Kavazanjian, Jr.            **
          **                                            **
          ************************************************

          ***************REPRINT INPUT DATA**************

TITLE
Classical Newmark Analysis
SUBTITLE
Liner / Western Hawaii Lfd. / 80 ft MSW @ 0.60 g
KPAR   N    KACC  KCOM   g(m/s/s)  KOUT   KSLIP  KDIR
0     10    1     1      386.20    0      0      0
Ky(1), ..., Ky(N)
0.025 0.05 0.075 0.10 0.125 0.15 0.175 0.20 0.25 0.30
YIELD ACCELERATION DEGRADATION DATA
Ky is constant.
FILE NAME OF INPUT HORIZONTAL ACC.
80ft-h.pun
NIDH  KREAD     NP        NLINE     DT       APH
1     2         2048      256       0.02     0.385
FILE NAME OF INPUT VERTICAL ACC.
NO Av
NIDV  KREAD     NP        NLINE     DT       APV       TSHIFT
NO INPUT
FILE NAME FOR OUTPUT OF SLIDING MOTION
YEX0.OUS
FILE NAME FOR OUTPUT OF ABSOLUTE MOTION
YEX0.OUA

MAX. VALUE OF INPUT HORI. ACC. = 2.228650
INPUT HORI. ACC. TIMES A FACTOR =  .172750 TO GET APH =  .385000


          *****************RESULTS*****************

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .025000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 12.0328
        PERMANENT SLIDING DISPLACEMENT = 48.0051

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 16.7908
        PERMANENT SLIDING DISPLACEMENT = 48.9903

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .050000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  9.4120
        PERMANENT SLIDING DISPLACEMENT = 20.8261

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 14.3942
        PERMANENT SLIDING DISPLACEMENT = 23.2268

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .075000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  7.3868
        PERMANENT SLIDING DISPLACEMENT =  8.9212

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 12.4020
        PERMANENT SLIDING DISPLACEMENT = 11.4365

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .100000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  5.4282
        PERMANENT SLIDING DISPLACEMENT =  4.0421

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 10.6373
        PERMANENT SLIDING DISPLACEMENT =  5.7796

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .125000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  3.9610
        PERMANENT SLIDING DISPLACEMENT =  1.8035

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  8.9801
        PERMANENT SLIDING DISPLACEMENT =  2.9987

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .150000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  3.1244
        PERMANENT SLIDING DISPLACEMENT =   .7714

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  7.6008
        PERMANENT SLIDING DISPLACEMENT =  1.5772

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .175000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  2.3775
        PERMANENT SLIDING DISPLACEMENT =   .3216

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  6.3021
        PERMANENT SLIDING DISPLACEMENT =   .9135

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .200000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  1.6826
        PERMANENT SLIDING DISPLACEMENT =   .1219

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  5.0732
        PERMANENT SLIDING DISPLACEMENT =   .5873

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .250000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =   .5419
        PERMANENT SLIDING DISPLACEMENT =   .0229

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  2.9803
        PERMANENT SLIDING DISPLACEMENT =   .2503

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .300000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =   .0024
        PERMANENT SLIDING DISPLACEMENT =   .0001

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  1.3762
        PERMANENT SLIDING DISPLACEMENT =   .0845
```

```
          ************************************************
          **                                            **
          **                 YSLIP_PM                   **
          **        (VERSION 2.2, JANUARY 1996)         **
          **                                            **
          **   A COMPUTER PROGRAM FOR SIMULATION OF     **
          **   DYNAMIC BEHAVIOR OF A RIGID BLOCK ON     **
          **   AN INCLINED PLANE AND CALCULATION OF     **
          **   PERMANENT DISPLACEMENTS OF THE BLOCK     **
          **                                            **
          **                    BY                      **
          **                                            **
          **                Liping Yan                  **
          **             Neven Matasovic                **
          **          Edward Kavazanjian, Jr.           **
          **                                            **
          ************************************************

          ***************REPRINT INPUT DATA**************

TITLE
Classical Newmark Analysis
SUBTITLE
Liner / Western Hawaii Lfd. / 80 ft MSW @ 0.60 g
KPAR   N    KACC  KCOM   g(m/s/s)  KOUT   KSLIP  KDIR
0     10    1     1      386.20    0      0      0
Ky(1), ..., Ky(N)
0.025 0.05 0.075 0.10 0.125 0.15 0.175 0.20 0.25 0.30
YIELD ACCELERATION DEGRADATION DATA
Ky is constant.
FILE NAME OF INPUT HORIZONTAL ACC.
80ft-k.pun
NIDH  KREAD     NP        NLINE     DT       APH
1     2         2048      256       0.005    0.311
FILE NAME OF INPUT VERTICAL ACC.
NO Av
NIDV  KREAD     NP        NLINE     DT       APV       TSHIFT
NO INPUT
FILE NAME FOR OUTPUT OF SLIDING MOTION
YEX0.OUS
FILE NAME FOR OUTPUT OF ABSOLUTE MOTION
YEX0.OUA

MAX. VALUE OF INPUT HORI. ACC. = 1.502630
INPUT HORI. ACC. TIMES A FACTOR =  .206970 TO GET APH =  .311000


          ******************RESULTS*****************

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .025000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 24.0156
        PERMANENT SLIDING DISPLACEMENT = 28.1852

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 19.3842
        PERMANENT SLIDING DISPLACEMENT = 28.6907

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .050000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 19.6212
        PERMANENT SLIDING DISPLACEMENT = 18.8160

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 16.4309
        PERMANENT SLIDING DISPLACEMENT = 18.5425

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .075000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 15.5796
        PERMANENT SLIDING DISPLACEMENT = 13.1934

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 13.6682
        PERMANENT SLIDING DISPLACEMENT = 11.6166

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .100000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 12.4479
        PERMANENT SLIDING DISPLACEMENT =  9.1833

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 11.0953
        PERMANENT SLIDING DISPLACEMENT =  6.5323

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .125000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  9.6706
        PERMANENT SLIDING DISPLACEMENT =  6.0770

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  8.7203
        PERMANENT SLIDING DISPLACEMENT =  3.8184

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .150000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  7.2717
        PERMANENT SLIDING DISPLACEMENT =  3.6417

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  6.5771
        PERMANENT SLIDING DISPLACEMENT =  2.1834

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .175000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  5.4013
        PERMANENT SLIDING DISPLACEMENT =  1.8123

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  4.7295
        PERMANENT SLIDING DISPLACEMENT =  1.3161

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .200000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  3.8154
        PERMANENT SLIDING DISPLACEMENT =   .7484

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  3.2702
        PERMANENT SLIDING DISPLACEMENT =   .7573

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .250000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  1.2984
        PERMANENT SLIDING DISPLACEMENT =   .1080

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  1.2139
        PERMANENT SLIDING DISPLACEMENT =   .1543

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .300000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =   .0126
        PERMANENT SLIDING DISPLACEMENT =   .0002

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =   .0839
        PERMANENT SLIDING DISPLACEMENT =   .0023
```

```
          ************************************************
          **                                            **
          **                YSLIP_PM                    **
          **        (VERSION 2.2, JANUARY 1996)         **
          **                                            **
          **   A COMPUTER PROGRAM FOR SIMULATION OF     **
          **   DYNAMIC BEHAVIOR OF A RIGID BLOCK ON     **
          **   AN INCLINED PLANE AND CALCULATION OF     **
          **   PERMANENT DISPLACEMENTS OF THE BLOCK     **
          **                                            **
          **                    BY                      **
          **                                            **
          **               Liping Yan                   **
          **            Neven Matasovic                 **
          **         Edward Kavazanjian, Jr.            **
          **                                            **
          ************************************************

          ***************REPRINT INPUT DATA**************

TITLE
Classical Newmark Analysis
SUBTITLE
Liner / Western Hawaii Lfd. / 80 ft MSW @ 0.60 g
KPAR   N    KACC  KCOM   g(m/s/s)  KOUT   KSLIP  KDIR
0     10    1     1      386.20    0      0      0
Ky(1), ..., Ky(N)
0.025 0.05 0.075 0.10 0.125 0.15 0.175 0.20 0.25 0.30
YIELD ACCELERATION DEGRADATION DATA
Ky is constant.
FILE NAME OF INPUT HORIZONTAL ACC.
80ft-l.pun
NIDH  KREAD     NP        NLINE     DT       APH
1     2         2048      256       0.004    0.331
FILE NAME OF INPUT VERTICAL ACC.
NO Av
NIDV  KREAD     NP        NLINE     DT       APV       TSHIFT
NO INPUT
FILE NAME FOR OUTPUT OF SLIDING MOTION
YEX0.OUS
FILE NAME FOR OUTPUT OF ABSOLUTE MOTION
YEX0.OUA

MAX. VALUE OF INPUT HORI. ACC. =  .701095
INPUT HORI. ACC. TIMES A FACTOR =  .472119 TO GET APH =  .331000


          ******************RESULTS*****************

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .025000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 15.4661
        PERMANENT SLIDING DISPLACEMENT = 10.6374

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  9.5538
        PERMANENT SLIDING DISPLACEMENT = 10.5821

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .050000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 13.2136
        PERMANENT SLIDING DISPLACEMENT =  5.8482

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  7.7468
        PERMANENT SLIDING DISPLACEMENT =  5.0595

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .075000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 11.0690
        PERMANENT SLIDING DISPLACEMENT =  3.4568

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  6.1381
        PERMANENT SLIDING DISPLACEMENT =  2.6529

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .100000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  9.0410
        PERMANENT SLIDING DISPLACEMENT =  2.0938

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  4.7082
        PERMANENT SLIDING DISPLACEMENT =  1.2758

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .125000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  7.1322
        PERMANENT SLIDING DISPLACEMENT =  1.2981

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  3.4276
        PERMANENT SLIDING DISPLACEMENT =   .5125

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .150000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  5.4771
        PERMANENT SLIDING DISPLACEMENT =   .8034

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  2.3050
        PERMANENT SLIDING DISPLACEMENT =   .2438

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .175000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  4.1094
        PERMANENT SLIDING DISPLACEMENT =   .4873

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  1.4273
        PERMANENT SLIDING DISPLACEMENT =   .1209

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .200000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  3.0820
        PERMANENT SLIDING DISPLACEMENT =   .3063

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =   .7814
        PERMANENT SLIDING DISPLACEMENT =   .0466

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .250000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =  1.4331
        PERMANENT SLIDING DISPLACEMENT =   .0888

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =   .0182
        PERMANENT SLIDING DISPLACEMENT =   .0002

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .300000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =   .3175
        PERMANENT SLIDING DISPLACEMENT =   .0109

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =   .0000
        PERMANENT SLIDING DISPLACEMENT =   .0000
```

```
          ************************************************
          **                                            **
          **                YSLIP_PM                    **
          **        (VERSION 2.2, JANUARY 1996)         **
          **                                            **
          **   A COMPUTER PROGRAM FOR SIMULATION OF     **
          **   DYNAMIC BEHAVIOR OF A RIGID BLOCK ON     **
          **   AN INCLINED PLANE AND CALCULATION OF     **
          **   PERMANENT DISPLACEMENTS OF THE BLOCK     **
          **                                            **
          **                    BY                      **
          **                                            **
          **               Liping Yan                   **
          **            Neven Matasovic                 **
          **         Edward Kavazanjian, Jr.            **
          **                                            **
          ************************************************

          ***************REPRINT INPUT DATA**************

TITLE
Classical Newmark Analysis
SUBTITLE
COVER / Western Hawaii Lfd. / 80 ft MSW @ 0.60 g
KPAR   N    KACC  KCOM   g(m/s/s)  KOUT   KSLIP  KDIR
0     10    1     1      386.20    0      0      0
Ky(1), ..., Ky(N)
0.05 0.075 0.10 0.125 0.15 0.175 0.20 0.25 0.30 0.40
YIELD ACCELERATION DEGRADATION DATA
Ky is constant.
FILE NAME OF INPUT HORIZONTAL ACC.
80ft-h.pun
NIDH  KREAD     NP        NLINE     DT       APH
2     2         4096      512       0.02     0.789
FILE NAME OF INPUT VERTICAL ACC.
NO Av
NIDV  KREAD     NP        NLINE     DT       APV       TSHIFT
NO INPUT
FILE NAME FOR OUTPUT OF SLIDING MOTION
YEX0.OUS
FILE NAME FOR OUTPUT OF ABSOLUTE MOTION
YEX0.OUA

MAX. VALUE OF INPUT HORI. ACC. =  .794107
INPUT HORI. ACC. TIMES A FACTOR =  .993569 TO GET APH =  .789000


          ******************RESULTS*****************

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .050000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 32.5296
        PERMANENT SLIDING DISPLACEMENT =107.3578

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 32.3802
        PERMANENT SLIDING DISPLACEMENT = 99.4248

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .075000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 30.5120
        PERMANENT SLIDING DISPLACEMENT = 65.4129

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 30.1232
        PERMANENT SLIDING DISPLACEMENT = 63.9137

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .100000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 28.5141
        PERMANENT SLIDING DISPLACEMENT = 45.1393

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 27.9418
        PERMANENT SLIDING DISPLACEMENT = 42.4591

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .125000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 26.6353
        PERMANENT SLIDING DISPLACEMENT = 33.2052

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 25.8291
        PERMANENT SLIDING DISPLACEMENT = 29.2900

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .150000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 24.8697
        PERMANENT SLIDING DISPLACEMENT = 24.9359

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 23.8718
        PERMANENT SLIDING DISPLACEMENT = 20.8999

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .175000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 23.1236
        PERMANENT SLIDING DISPLACEMENT = 19.0759

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 22.0549
        PERMANENT SLIDING DISPLACEMENT = 15.0457

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .200000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 21.4797
        PERMANENT SLIDING DISPLACEMENT = 15.0927

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 20.2889
        PERMANENT SLIDING DISPLACEMENT = 11.1462

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .250000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 18.4740
        PERMANENT SLIDING DISPLACEMENT =  9.8759

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 16.8989
        PERMANENT SLIDING DISPLACEMENT =  6.4524

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .300000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 15.5802
        PERMANENT SLIDING DISPLACEMENT =  6.4831

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 13.6896
        PERMANENT SLIDING DISPLACEMENT =  4.0730

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .400000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 10.7437
        PERMANENT SLIDING DISPLACEMENT =  2.6600

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =  8.3773
        PERMANENT SLIDING DISPLACEMENT =  1.8103
```

```
          ************************************************
          **                                            **
          **                YSLIP_PM                    **
          **        (VERSION 2.2, JANUARY 1996)         **
          **                                            **
          **   A COMPUTER PROGRAM FOR SIMULATION OF     **
          **   DYNAMIC BEHAVIOR OF A RIGID BLOCK ON     **
          **   AN INCLINED PLANE AND CALCULATION OF     **
          **   PERMANENT DISPLACEMENTS OF THE BLOCK     **
          **                                            **
          **                    BY                      **
          **                                            **
          **               Liping Yan                   **
          **            Neven Matasovic                 **
          **         Edward Kavazanjian, Jr.            **
          **                                            **
          ************************************************

          ***************REPRINT INPUT DATA**************

TITLE
Classical Newmark Analysis
SUBTITLE
COVER / Western Hawaii Lfd. / 80 ft MSW @ 0.60 g
KPAR   N    KACC  KCOM   g(m/s/s)  KOUT   KSLIP  KDIR
0     10    1     1      386.20    0      0      0
Ky(1), ..., Ky(N)
0.05 0.075 0.10 0.125 0.15 0.175 0.20 0.25 0.30 0.40
YIELD ACCELERATION DEGRADATION DATA
Ky is constant.
FILE NAME OF INPUT HORIZONTAL ACC.
80ft-k.pun
NIDH  KREAD     NP        NLINE     DT       APH
2     2         4096      512       0.005    0.974
FILE NAME OF INPUT VERTICAL ACC.
NO Av
NIDV  KREAD     NP        NLINE     DT       APV       TSHIFT
NO INPUT
FILE NAME FOR OUTPUT OF SLIDING MOTION
YEX0.OUS
FILE NAME FOR OUTPUT OF ABSOLUTE MOTION
YEX0.OUA

MAX. VALUE OF INPUT HORI. ACC. =  .999449
INPUT HORI. ACC. TIMES A FACTOR =  .974537 TO GET APH =  .974000


          ******************RESULTS*****************

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .050000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 55.2328
        PERMANENT SLIDING DISPLACEMENT = 60.0359

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 52.6395
        PERMANENT SLIDING DISPLACEMENT = 88.3823

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .075000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 52.7401
        PERMANENT SLIDING DISPLACEMENT = 43.4085

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 50.3015
        PERMANENT SLIDING DISPLACEMENT = 60.8437

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .100000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 50.2773
        PERMANENT SLIDING DISPLACEMENT = 33.3901

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 48.0059
        PERMANENT SLIDING DISPLACEMENT = 44.0547

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .125000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 47.8581
        PERMANENT SLIDING DISPLACEMENT = 26.0064

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 45.7602
        PERMANENT SLIDING DISPLACEMENT = 32.8919

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .150000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 45.5014
        PERMANENT SLIDING DISPLACEMENT = 20.4264

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 43.5465
        PERMANENT SLIDING DISPLACEMENT = 24.7136

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .175000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 43.1727
        PERMANENT SLIDING DISPLACEMENT = 16.3172

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 41.3928
        PERMANENT SLIDING DISPLACEMENT = 18.7234

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .200000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 40.9020
        PERMANENT SLIDING DISPLACEMENT = 13.1098

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 39.2662
        PERMANENT SLIDING DISPLACEMENT = 14.5550

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .250000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 36.4778
        PERMANENT SLIDING DISPLACEMENT =  8.8956

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 35.1645
        PERMANENT SLIDING DISPLACEMENT =  9.8314

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .300000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 32.2484
        PERMANENT SLIDING DISPLACEMENT =  6.4442

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 31.2368
        PERMANENT SLIDING DISPLACEMENT =  7.3259

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .400000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY = 24.3092
        PERMANENT SLIDING DISPLACEMENT =  3.9904

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY = 23.9074
        PERMANENT SLIDING DISPLACEMENT =  4.5043
```

```
          ************************************************
          **                                            **
          **                YSLIP_PM                    **
          **        (VERSION 2.2, JANUARY 1996)         **
          **                                            **
          **   A COMPUTER PROGRAM FOR SIMULATION OF     **
          **   DYNAMIC BEHAVIOR OF A RIGID BLOCK ON     **
          **   AN INCLINED PLANE AND CALCULATION OF     **
          **   PERMANENT DISPLACEMENTS OF THE BLOCK     **
          **                                            **
          **                    BY                      **
          **                                            **
          **               Liping Yan                   **
          **            Neven Matasovic                 **
          **         Edward Kavazanjian, Jr.            **
          **                                            **
          ************************************************

          ***************REPRINT INPUT DATA**************

TITLE
Classical Newmark Analysis
SUBTITLE
COVER / Western Hawaii Lfd. / 80 ft MSW @ 0.60 g
KPAR   N    KACC  KCOM   g(m/s/s)  KOUT   KSLIP  KDIR
0     10    1     1      386.20    0      0      0
Ky(1), ..., Ky(N)
0.05 0.075 0.10 0.125 0.15 0.175 0.20 0.25 0.30 0.40
YIELD ACCELERATION DEGRADATION DATA
Ky is constant.
FILE NAME OF INPUT HORIZONTAL ACC.
80ft-l.pun
NIDH  KREAD     NP        NLINE     DT       APH
2     2         4096      512       0.004    0.519
FILE NAME OF INPUT VERTICAL ACC.
NO Av
NIDV  KREAD     NP        NLINE     DT       APV       TSHIFT
NO INPUT
FILE NAME FOR OUTPUT OF SLIDING MOTION
YEX0.OUS
FILE NAME FOR OUTPUT OF ABSOLUTE MOTION
YEX0.OUA

MAX. VALUE OF INPUT HORI. ACC. =  .526964
INPUT HORI. ACC. TIMES A FACTOR =  .984887 TO GET APH =  .519000


          ******************RESULTS*****************

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .050000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY = 39.1926
        PERMANENT SLIDING DISPLACEMENT = 81.8054

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY = 12.9391
        PERMANENT SLIDING DISPLACEMENT = 22.6289

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .075000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY = 30.3582
        PERMANENT SLIDING DISPLACEMENT = 45.9554

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY =  9.5205
        PERMANENT SLIDING DISPLACEMENT = 12.5214

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .100000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY = 24.8251
        PERMANENT SLIDING DISPLACEMENT = 25.0400

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY =  8.3001
        PERMANENT SLIDING DISPLACEMENT =  7.3975

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .125000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY = 19.8654
        PERMANENT SLIDING DISPLACEMENT = 15.9554

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY =  7.3430
        PERMANENT SLIDING DISPLACEMENT =  4.3706

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .150000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY = 16.4787
        PERMANENT SLIDING DISPLACEMENT =  9.5517

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY =  6.4631
        PERMANENT SLIDING DISPLACEMENT =  2.5176

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .175000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY = 13.8843
        PERMANENT SLIDING DISPLACEMENT =  6.0127

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY =  5.6328
        PERMANENT SLIDING DISPLACEMENT =  1.3854

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .200000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY = 11.3413
        PERMANENT SLIDING DISPLACEMENT =  3.9494

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY =  4.8398
        PERMANENT SLIDING DISPLACEMENT =   .7955

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .250000
```



```
*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY =  6.3347
        PERMANENT SLIDING DISPLACEMENT =  1.4240

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY =  3.4236
        PERMANENT SLIDING DISPLACEMENT =   .3080

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .300000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY =  2.1312
        PERMANENT SLIDING DISPLACEMENT =   .3517

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY =  2.1928
        PERMANENT SLIDING DISPLACEMENT =   .1078

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .400000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                MAX. SLIDING VELOCITY =   .8099
        PERMANENT SLIDING DISPLACEMENT =   .0362

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                MAX. SLIDING VELOCITY =   .5104
        PERMANENT SLIDING DISPLACEMENT =   .0113
```

APPENDIX B

Geosyntec consultants

COMPUTATION COVER SHEET

Client: **WMH** Project: **West Hawaii Landfill** Project/ Proposal No.: Task No. **WG1339-06**

Title of Computations **Slope Stability Analyses for Master Plan Design**

Computations by:	Signature	Kim Huynh	6 MARCH 2012
	Printed Name	Kim Huynh	Date
	Title	Project Engineer	
Assumptions and Procedures Checked by: (peer reviewer)	Signature	F. Settepani	8 MAR 12
	Printed Name	F. SETTEPANI	Date
	Title		
Computations Checked by:	Signature	Amy Padovani	03/08/12
	Printed Name	Amy Padovani	Date
	Title	Project Engineer	
Computations backchecked by: (originator)	Signature	Kim Huynh	9 MARCH 2012
	Printed Name	Kim Huynh	Date
	Title	Project Engineer	
Approved by: (pm or designate)	Signature		
	Printed Name		Date
	Title		

Approval notes:

Revisions (number and initial all revisions)

No.	Sheet	Date	By	Checked by	Approval

Written by:	**K. Huynh**	Date:	**03/06/12**	Reviewed by:		Date:	
Client:	**WMH**	Project:	**West Hawaii Landfill, Master Plan**	Project No.	**WG1339**	Task No.:	**06**

SLOPE STABILITY ANALYSES FOR MASTER PLAN WEST HAWAII LANDFILL

PURPOSE

This calculation package presents the slope stability analyses performed for the Master Plan design at the West Hawaii Sanitary Landfill (WHSL). The WHSL, located in North Kona on the island of Hawaii, is owned by the County of Hawaii, Department of Public Works, Division of Solid Waste, and is operated by Waste Management of Hawaii, Inc. (WMH). The 149-acre permitted landfill comprises 23 planned cells, of which Cells 1 through 8 and approximately half of Cells 9, 10, and 11 have been constructed and are receiving waste.

ASSUMPTIONS

The following assumptions were made for the analyses:

- Two base grading plans are considered in the Master Plan:
  i. The permitted base grading plan (Figure 1) represents the "upper limit" of the bottom of the landfill (surface upon which geosynthetics are placed).
  ii. The proposed "lower" base grading plan (Figure 2) represents the "lower limit" grade of the bottom of the landfill.

  The actual bottom will be determined during detailed design of each cell, and will likely be located somewhere between the permitted base grades and the proposed "lower limit" base grades.

- the proposed final grades (Figure 3) consist of:
  i. peak elevation of 262 feet mean sea level (ft MSL);
  ii. a minimum 3% grade on the top deck for drainage; and
  iii. side slopes of 10 horizontal to 1 vertical (10H:1V) within the existing Cells 1 through 8A and up to 5H:1V within the future cells.
- both static and seismic stability analyses were performed in the analyses;

- typical liner systems and details assumed in analyses are presented on Figure 4; and
- leachate is assumed to be maintained below the permitted 1-ft maximum head above the liner and was therefore excluded from the analyses.

ANALYSES

Static slope stability was analyzed using the Spencer Method (1967) employed in the Slope/W software (GEO-SLOPE 2007). The Spencer method satisfies both moment and force equilibrium conditions (Duncan, 1992). The program generates potential slip surfaces using a grid of circle centers and a series of tangent lines.

Seismic deformations were estimated based on the site response and seismic deformation analyses performed for the WHSL (Geosyntec, 2012). Figures 4-7 from these analyses presents plots of the seismically-induced deformation of the landfill mass versus yield acceleration k_y and landfill cover versus k_y, respectively. The pseudo-static stability of the final grade was evaluated to estimate the k_y that results in a static factor of safety equal to 1. Figures 4-7 were then used to estimate the seismic deformation from the resulting k_y.

Three cross sections (Figures 1-3) were evaluated in these analyses: two sections, A1 and A2, in the east-to-west direction, and one section B1 in the general north-to-south direction. All sections were evaluated assuming final fill conditions (Figure 3).

For each section, the future cells were modeled with two base configurations: (i) permitted base grades and (ii) proposed “lower limit” base grades. The base of existing Cells 8A-11A and 8B were modeled based on as-built information. The base of existing Cells 1-7 was based on permit information because as-built information was not available. The cross sections are presented on Figures 5 through 8.

MATERIAL PROPERTIES

The material properties assumed in analyses are described below.

Municipal Solid Waste (MSW) [Kavazanjian et al., 1995]

Unit weight $\gamma = 65$ pcf

Bilinear strength envelope:

$\phi_1 = 0°$ and cohesion (c) of 500 psf for normal stress $\sigma_n \leq 770$ psf, and

$\phi_2 = 33°$ for $\sigma_n \geq 770$ psf

Base Liner System for Cells 1-7

The composite liner systems for Cells 1-7 consist of a nonwoven cushion geotextile overlying a 60 mil smooth HDPE geomembrane overlying a geosynthetic clay liner (GCL). Interface strengths for the site-specific materials are not available for these cells. Therefore, based on Geosyntec's experience with similar liner systems, the following interface strengths were assumed:

Cells 1 through 7	
Normal Stress (psf)	Assumed Shear Strength (psf)
0	0
1,000	141
4,000	562
8,000	1,124
10,000	1,204
15,000	1,405

Base Liner System for Cells 8A-11A

The composite liner systems for Cells 8A-11A consist of a nonwoven cushion geotextile overlying a 60 mil single-sided textured HDPE geomembrane (textured side down) overlying a GCL. Based on the available CQA data the assumed strength envelopes for Cells 8A-11A are tabulated/listed below:

Cells 8A & 9A (Partial)	
Normal Stress (psf)	Assumed Shear Strength (psf)
0	0
1,000	157
3,500	403
5,000	736
10,000	1,269
15,000	1,747

Cells 9A (Remainder) & 10A (Partial)	
Normal Stress (psf)	Assumed Shear Strength (psf)
0	0
1,000	214
4,000	741
8,000	957
10,000	1,040
15,000	1,291

For Cells 10A (Remainder) & 11A, a bilinear strength envelope having the following characteristics was assumed:

$\phi_1 = 7.8°$ and cohesion (c) of 0 psf for normal stress $\sigma_n \leq 8{,}000$ psf, and
$\phi_2 = 1.6°$ for $\sigma_n \geq 8{,}000$ psf

Cell 8B	
Normal Stress (psf)	Assumed Shear Strength (psf)
0	0
1,000	354
2,500	754
10,000	1,027

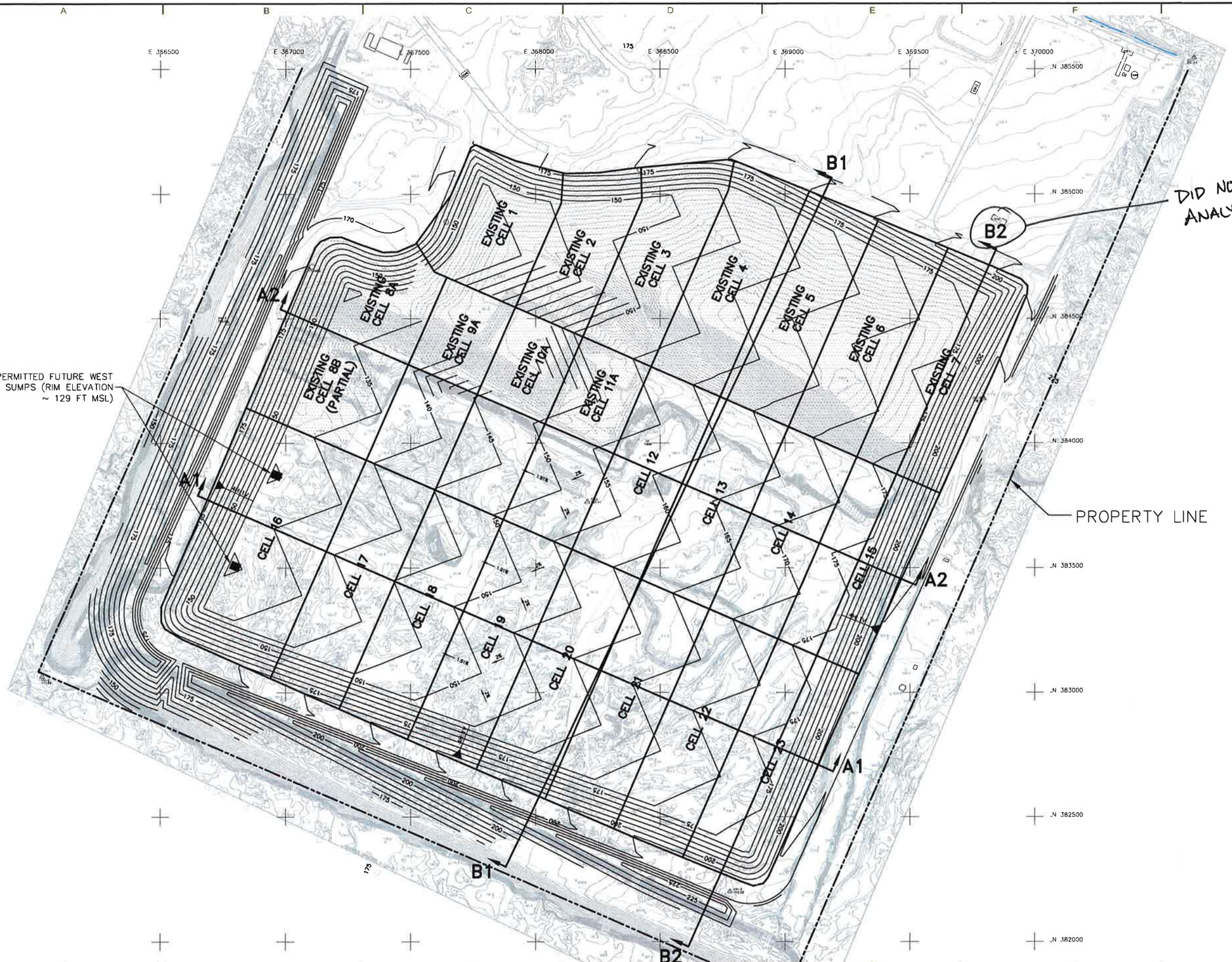
Base Liner System for Future Cells

The composite liner system for future cells consists of a nonwoven cushion geotextile overlying a 60 mil double-sided textured HDPE geomembrane overlying a geosynthetic clay liner (GCL). For these cells, the following design strength envelope was assumed:

Normal Stress (psf)	Assumed Shear Strength (psf)
0	0
1,000	350
2,500	950
5,000	1,000
10,000	1,200

RESULTS

The results of the slope stability analyses are summarized on Table 1 below. All sections achieved the minimum acceptable 1.5 static factor of safety. Seismic deformations at the liner level were estimated to be less than 6 inches. Slope stability outputs are provided in Attachment 1.



NOTES:

1. SITE TOPOGRAPHY BASED ON AERIAL PHOTOGRAPHY PERFORMED ON 23 APRIL 2011 BY AERO-METRIC, INC.

2. THE COORDINATES AND BEARINGS SHOWN ARE BASED ON THE HAWAII STATE PLANE COORDINATE SYSTEM, ZONE 1. THE VERTICAL DATUM BASED ON MEAN SEA LEVEL.

LEGEND

- GROUND SURFACE CONTOUR (10 FT)
- GROUND SURFACE CONTOUR (2 FT)
- PERMITTED BASE GRADE CONTOUR (5 FT)
- APPROXIMATE LIMITS OF EXISTING CELLS
- APPROXIMATE CELL LIMIT
- PROPERTY BOUNDARY
- HV-7 — SURVEY CONTROL POINT NO.
- 193.02 — ELEVATION

200 100 0 200 400
SCALE IN FEET

REVISIONS			
NO.	DESCRIPTION	DATE	BY

WASTE MANAGEMENT

Geosyntec consultants

1111 Broadway
Sixth Floor
Oakland, CA 94607

PERMITTED BASE GRADING PLAN "UPPER LIMIT"

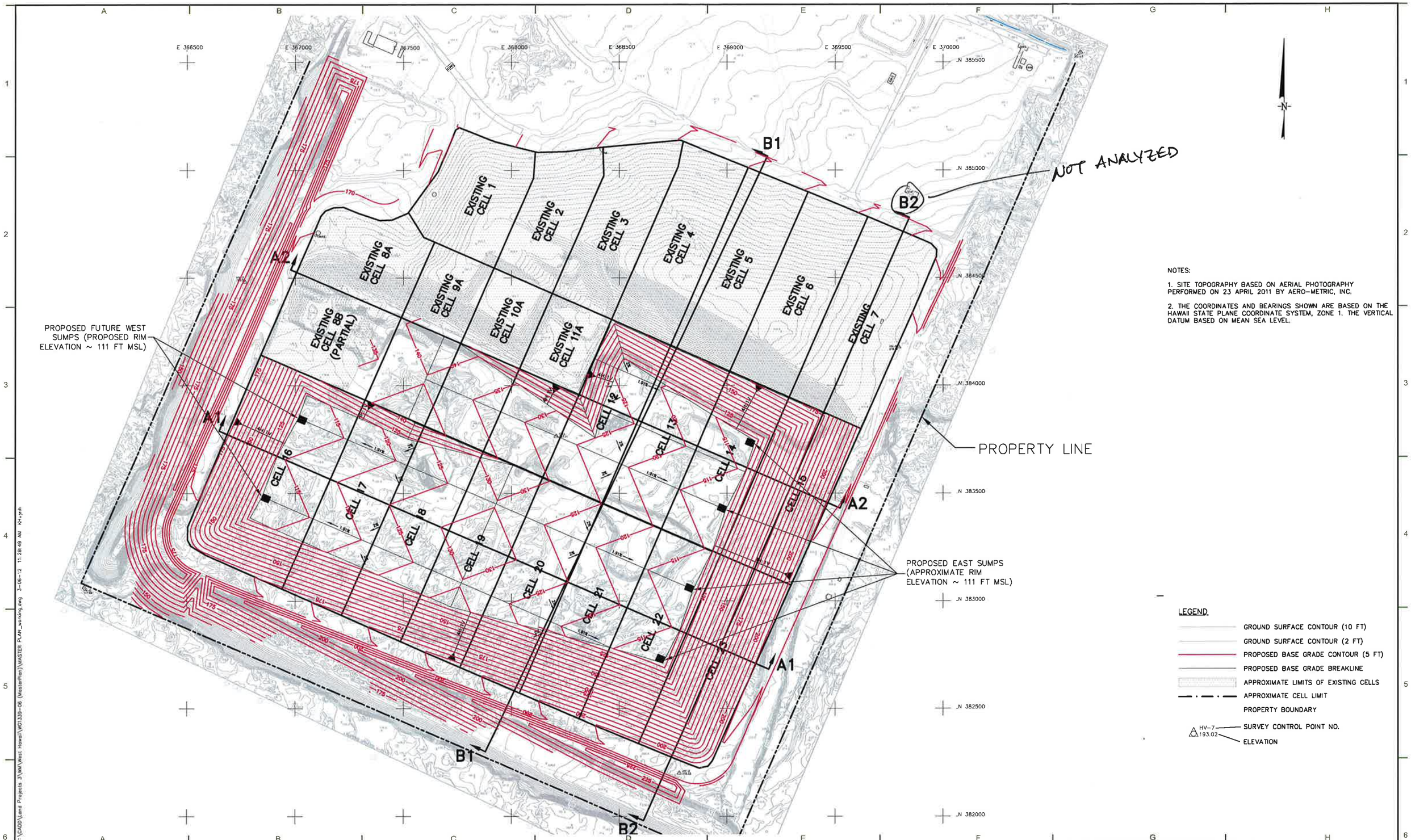
MASTER PLAN
WEST HAWAII LANDFILL
WAIKOLOA, HAWAII

NOT FOR CONSTRUCTION

DES BY: FWS	DATE: 28 FEBRUARY 2012
DRN BY: LKH	SCALE: AS SHOWN
CHK BY: FWS	PROJECT: WG1339-06
REV BY: HDS	DOCUMENT:
APP BY: HDS	
FILE: master plan.dwg	

FIGURE NO. 1

P:\CADD\Land Projects 3\WM\West Hawaii\WG1339-06 (MasterPlan)\MASTER PLAN_working.dwg 3-06-12 11:26:54 AM Khuynh



NOTES:

1. SITE TOPOGRAPHY BASED ON AERIAL PHOTOGRAPHY PERFORMED ON 23 APRIL 2011 BY AERO-METRIC, INC.

2. THE COORDINATES AND BEARINGS SHOWN ARE BASED ON THE HAWAII STATE PLANE COORDINATE SYSTEM, ZONE 1. THE VERTICAL DATUM BASED ON MEAN SEA LEVEL.

LEGEND

- GROUND SURFACE CONTOUR (10 FT)
- GROUND SURFACE CONTOUR (2 FT)
- PROPOSED BASE GRADE CONTOUR (5 FT)
- PROPOSED BASE GRADE BREAKLINE
- APPROXIMATE LIMITS OF EXISTING CELLS
- APPROXIMATE CELL LIMIT
- PROPERTY BOUNDARY
- HV-7 / 193.02 — SURVEY CONTROL POINT NO. / ELEVATION

P:\CADD\Land Projects 3\WM\West Hawaii\WG1339-06 (MasterPlan)\MASTER PLAN_working.dwg 3-06-12 11:28:49 AM KHuynh

200 100 0 200 400
SCALE IN FEET

REVISIONS			
NO.	DESCRIPTION	DATE	BY

WASTE MANAGEMENT

Geosyntec consultants

1111 Broadway
Sixth Floor
Oakland, CA 94607

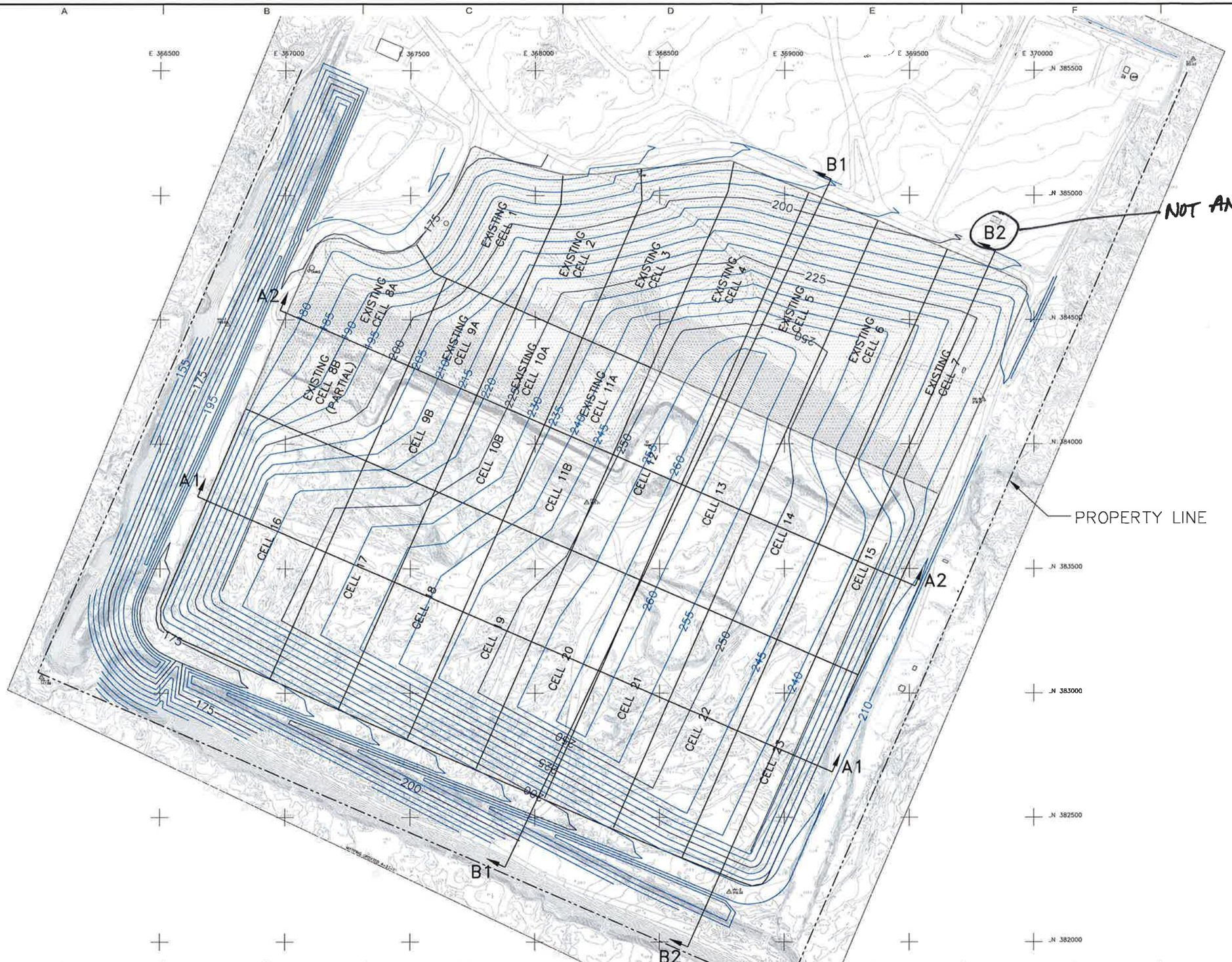
PROPOSED BASE GRADING PLAN "LOWER LIMIT"

MASTER PLAN
WEST HAWAII LANDFILL
WAIKOLOA, HAWAII

NOT FOR CONSTRUCTION

DES BY: FWS	DATE: 28 FEBRUARY 2012
DRN BY: LKH	SCALE: AS SHOWN
CHK BY: FWS	PROJECT: WG1339-06
REV BY: HDS	DOCUMENT:
APP BY: HDS	
FILE: master plan.dwg	

FIGURE NO.
2



NOTES:

1. SITE TOPOGRAPHY BASED ON AERIAL PHOTOGRAPHY PERFORMED ON 23 APRIL 2011 BY AERO-METRIC, INC.

2. THE COORDINATES AND BEARINGS SHOWN ARE BASED ON THE HAWAII STATE PLANE COORDINATE SYSTEM, ZONE 1. THE VERTICAL DATUM BASED ON MEAN SEA LEVEL.

LEGEND

- GROUND SURFACE CONTOUR (10 FT)
- GROUND SURFACE CONTOUR (2 FT)
- PROPOSED FINAL GRADE CONTOUR (25 FT)
- PROPOSED FINAL GRADE CONTOUR (5 FT)
- APPROXIMATE LIMITS OF EXISTING CELLS
- APPROXIMATE CELL LIMIT
- PROPERTY BOUNDARY
- HV-7 — SURVEY CONTROL POINT NO.
- 193.02 — ELEVATION

200 100 0 200 400
SCALE IN FEET

REVISIONS			
NO.	DESCRIPTION	DATE	BY

WASTE MANAGEMENT

Geosyntec consultants

1111 Broadway
Sixth Floor
Oakland, CA 94607

PROPOSED FINAL GRADING PLAN

MASTER PLAN
WEST HAWAII LANDFILL
WAIKOLOA, HAWAII

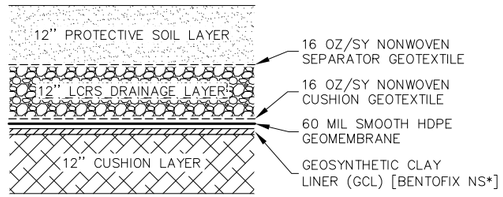
NOT FOR CONSTRUCTION

DES BY: FWS	DATE: 28 FEBRUARY 2012
DRN BY: LKH	SCALE: AS SHOWN
CHK BY: FWS	PROJECT: WG1339-06
REV BY: HDS	DOCUMENT:
APP BY: HDS	
FILE: master plan.dwg	

FIGURE NO.
3

P:\CADD\Land Projects 3\WM\West Hawaii\WG1339-06 (MasterPlan)\MASTER PLAN_working.dwg 3-12-12 09:32:07 AM klnguyen

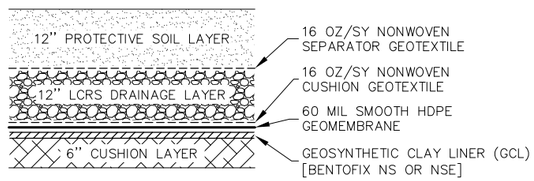
CELLS 1, 2, & 3



BASE LINER (FLOOR & SIDESLOPE)

SOURCES: "*QUALITY ASSURANCE REPORT, WEST HAWAII LANDFILL-CELL 1, PUUANAHULU, HAWAII*," BY HARDING LAWSON ASSOCIATES, 14 OCTOBER 1993; "*QUALITY ASSURANCE REPORT, WEST HAWAII SANITARY LANDFILL-CELL 1 (EAST) AND CELL 2 (WEST), PUUANAHULU, HAWAII*," BY HARDING LAWSON ASSOCIATES, 7 JULY 1994; AND "*WEST HAWAII SANITARY LANDFILL, CELL 3 GEOSYNTHETIC LINER CONSTRUCTION, CONSTRUCTION QUALITY ASSURANCE REPORT*," BY RUST ENVIRONMENT & INFRASTRUCTURE, INC., 9 MAY 1996.

CELLS 4, 5, 6, & 7

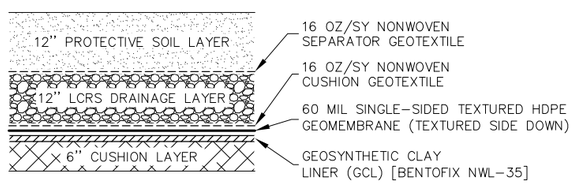


BASE LINER (FLOOR & SIDESLOPE)

NOTES: (1) CUSHION LAYER THICKNESS UNKNOWN FOR CELLS 4 AND 5A.
(2) PROTECTIVE SOIL COVER THICKNESS UNKNOWN FOR CELL 5A.
(3) CELLS 5 & 7: 12" LCRS DRAINAGE LAYER AND SEPARATOR GEOTEXILE INSTALLED 10 FT UP SIDESLOPE DURING CELL CONSTRUCTION. WMH EXTENDED THESE LAYERS DURING OPERATIONS AS FILLING PROGRESSED.

SOURCES: "*FINAL CONSTRUCTION QUALITY ASSURANCE REPORT, MSW CELL 4, COMPOSITE LINER & LEACHATE COLLECTION & REMOVAL SYSTEM*," BY RUST ENVIRONMENT & INFRASTRUCTURE, INC., 14 MAY 1998; "*CONSTRUCTION QUALITY ASSURANCE REPORT FOR WEST HAWAII SANITARY LANDFILL, CELL 5-A, WASTE MANAGEMENT OF HAWAII, WAIKOLOA, HAWAII*," BY A-MEHR, 1 JUNE 2000; "*CONSTRUCTION QUALITY ASSURANCE REPORT FOR WEST HAWAII SANITARY LANDFILL, CELL 5-B, WASTE MANAGEMENT OF HAWAII, WAIKOLOA, HAWAII*," BY A-MEHR, NOVEMBER 2001; "*CONSTRUCTION QUALITY ASSURANCE REPORT FOR WEST HAWAII SANITARY LANDFILL, CELL 6, WASTE MANAGEMENT OF HAWAII, WAIKOLOA, HAWAII*," BY A-MEHR, MARCH 2003; AND "*CONSTRUCTION QUALITY ASSURANCE REPORT FOR WEST HAWAII SANITARY LANDFILL, CELL 7, WASTE MANAGEMENT OF HAWAII, WAIKOLOA, HAWAII*," BY A-MEHR, INC., SEPTEMBER 2004; AND "CONSTRUCTION QUALITY ASSURANCE REPORT FOR CELL 7 REMAINDER, WEST HAWAII SANITARY LANDFILL, WAIKOLOA, HAWAII," BY EARTH TECH, INC., MAY 2007

CELLS 8A & 9A (PARTIAL)

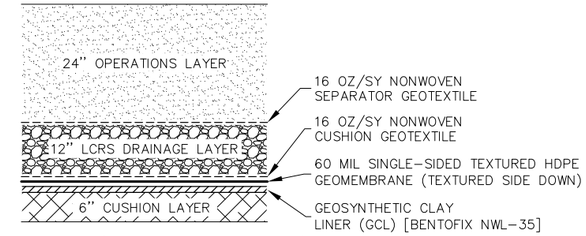


BASE LINER (FLOOR & SIDESLOPE)

NOTE: 12" LCRS DRAINAGE LAYER AND SEPARATOR GEOTEXILE INSTALLED 10 FT UP SIDESLOPE DURING CELL CONSTRUCTION. WMH EXTENDED THESE LAYERS DURING OPERATIONS AS FILLING PROGRESSED.

SOURCE: "*CONSTRUCTION QUALITY ASSURANCE REPORT FOR CELL 8A (REMAINDER) AND 9A (PARTIAL), WEST HAWAII SANITARY LANDFILL, WAIKOLOA, HAWAII*," BY EARTH TECH, INC., DECEMBER 2007.

CELL 9A (REMAINDER), 10A, & 11A

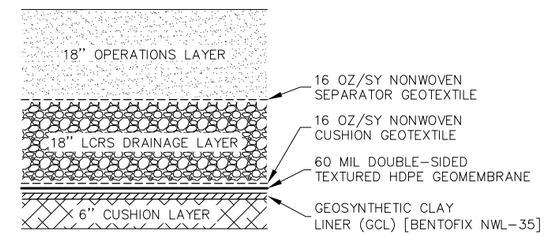


BASE LINER (FLOOR & SIDESLOPE)

NOTE: CELLS 9A (REMAINDER), 10A, AND 11A DO NOT HAVE SIDESLOPES.

SOURCES: "*REPORT OF CONSTRUCTION QUALITY ASSURANCE, CELLS 9A (REMAINDER) & 10A (PARTIAL) CONSTRUCTION, WEST HAWAII LANDFILL, WAIKOLOA, HAWAII*," BY GEOSYNTEC CONSULTANTS, INC., 22 JANUARY 2009; "*CONSTRUCTION QUALITY ASSURANCE REPORT FOR CELL 10A (REMAINDER) AND 11A (PARTIAL), WEST HAWAII SANITARY LANDFILL, WAIKOLOA, HAWAII*," BY AECOM TECHNICAL SERVICES, INC, APRIL 2010; AND "*CONSTRUCTION QUALITY ASSURANCE REPORT FOR CELL 11A (REMAINDER), WEST HAWAII SANITARY LANDFILL, WAIKOLOA, HAWAII*," BY AECOM TECHNICAL SERVICES, INC, FEBRUARY 2011.

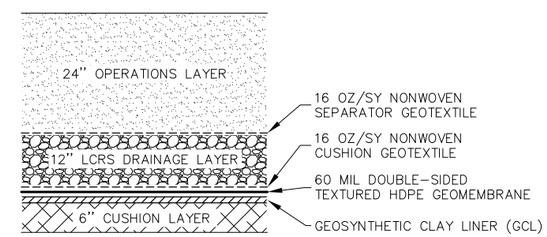
CELL 8B



FLOOR LINER

SOURCE: "*CONSTRUCTION QUALITY ASSURANCE REPORT FOR CELL 8B (PARTIAL), WEST HAWAII LANDFILL, WAIKOLOA, HAWAII*," BY AECOM TECHNICAL SERVICES, INC., NOVEMBER 2011, REVISED OCTOBER 2011.

FUTURE CELLS



BASE LINER (FLOOR & SIDESLOPE)

SOURCE: "*CONSTRUCTION DRAWINGS, CELL 8B, WEST HAWAII LANDFILL, WAIKOLOA, HAWAII*," BY GEOSYNTEC CONSULTANTS, INC., MAY 2011, REVISED OCTOBER 2011.

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BASE CONTAINMENT SYSTEM DETAILS MASTER PLAN WEST HAWAII LANDFILL WAIKOLOA, HAWAII	FIGURE NO.	4
	PROJECT NO.	WG1339-06
	DATE:	12 MARCH 2012

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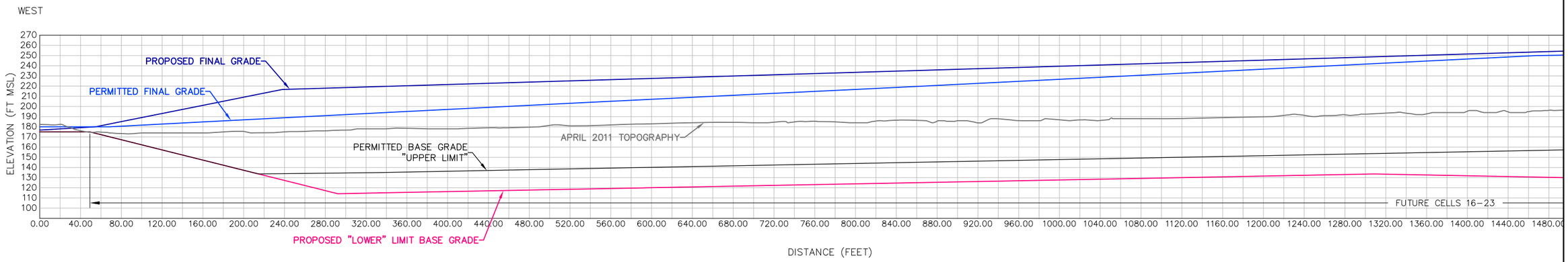
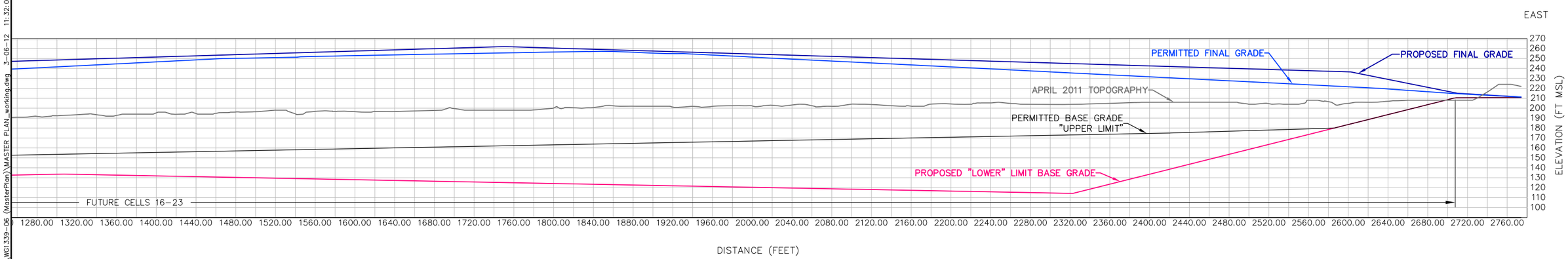
SECTION A1 – WEST SIDE



SECTION A1 – EAST SIDE



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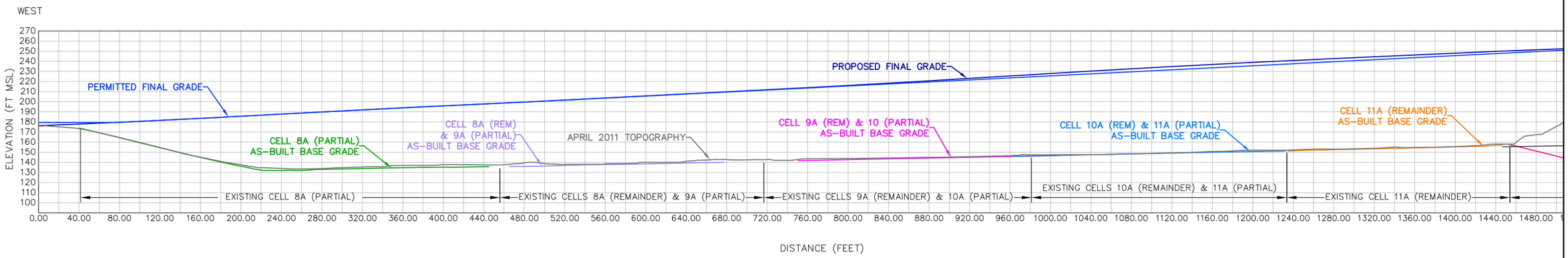
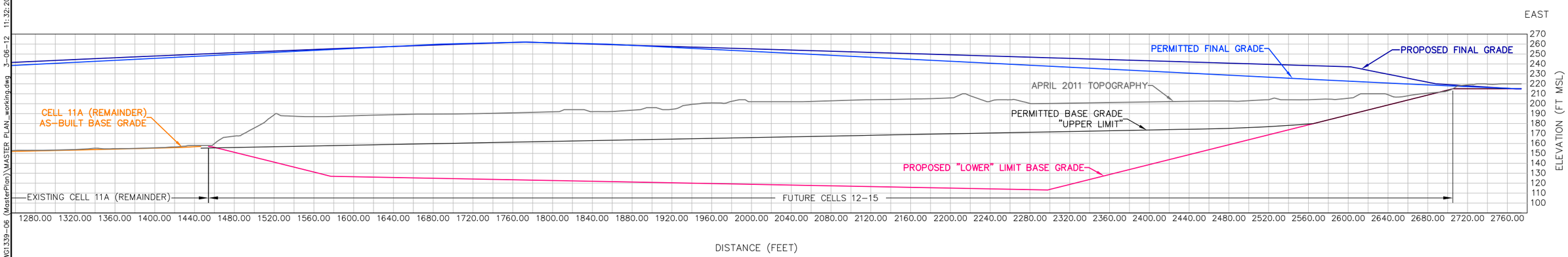
STABILITY SECTION A1 WEST HAWAII LANDFILL WAIKOLOA, HAWAII	FIGURE NO.	5
	PROJECT NO.	WG1339
	DATE:	5 MARCH 2012

SECTION A2 – WEST SIDE



SECTION A2 – EAST SIDE



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STABILITY SECTION A2 WEST HAWAII LANDFILL WAIKOLOA, HAWAII	FIGURE NO.	6
	PROJECT NO.	WG1339
	DATE:	5 MARCH 2012

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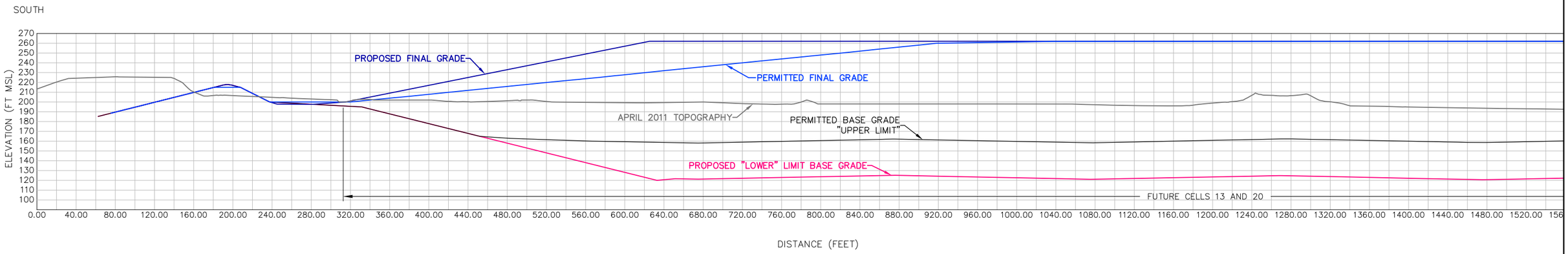
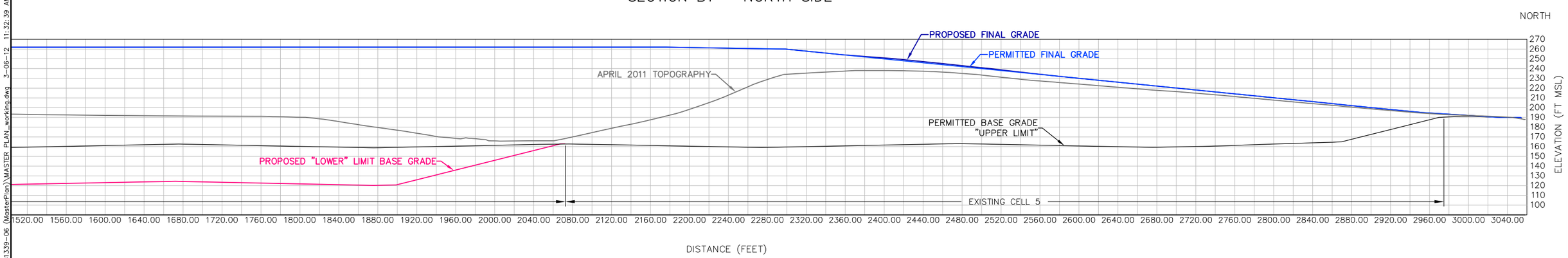
SECTION B1 – SOUTH SIDE



SECTION B1 – NORTH SIDE



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STABILITY SECTION B1 WEST HAWAII LANDFILL WAIKOLOA, HAWAII	FIGURE NO.	7
	PROJECT NO.	WG1339
	DATE:	5 MARCH 2012

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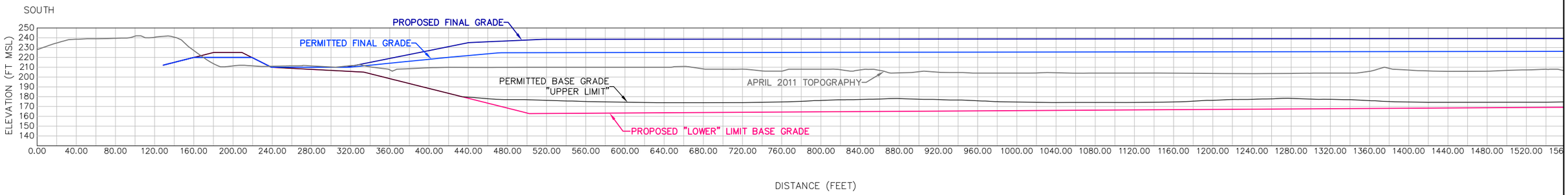
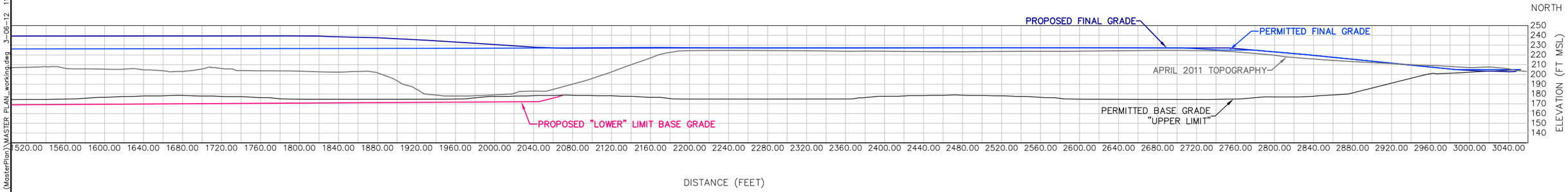
SECTION B2 – SOUTH SIDE



SECTION B2 – NORTH SIDE



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STABILITY SECTION B2 WEST HAWAII LANDFILL WAIKOLOA, HAWAII	FIGURE NO.	8
	PROJECT NO.	WG1339
	DATE:	5 MARCH 2012

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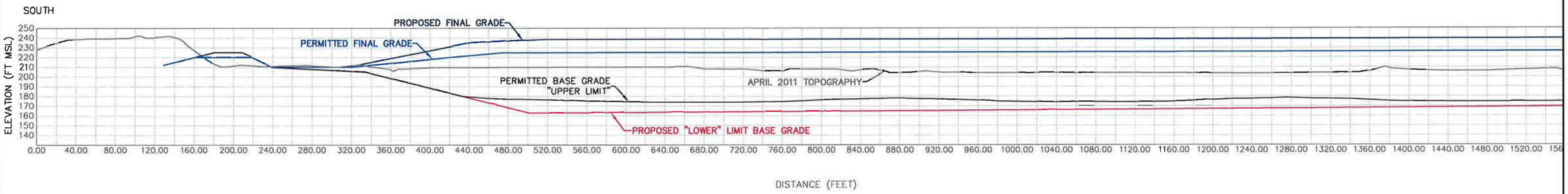
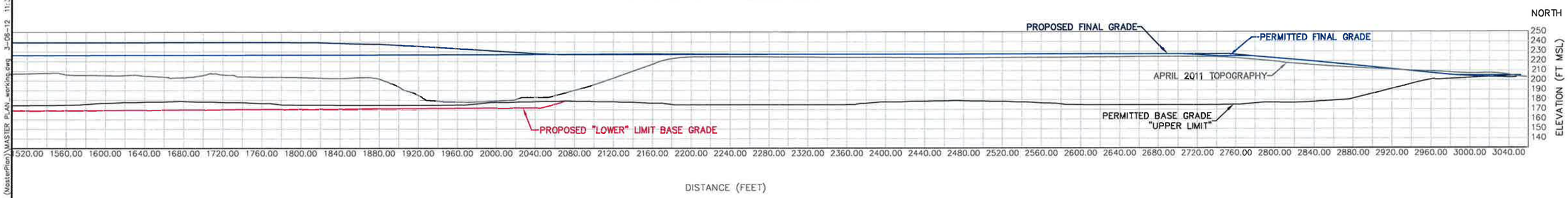
SECTION B2 – SOUTH SIDE



SECTION B2 – NORTH SIDE



SECTION B2 NOT ANALYZED FOR STABILITY ; DOES NOT APPEAR TO BE CRITICAL BASED ON INSPECTION.

		Geosyntec consultants
STABILITY SECTION B2 WEST HAWAII LANDFILL WAIKOLOA, HAWAII	FIGURE NO.	8
	PROJECT NO.	WG1339
	DATE:	5 MARCH 2012

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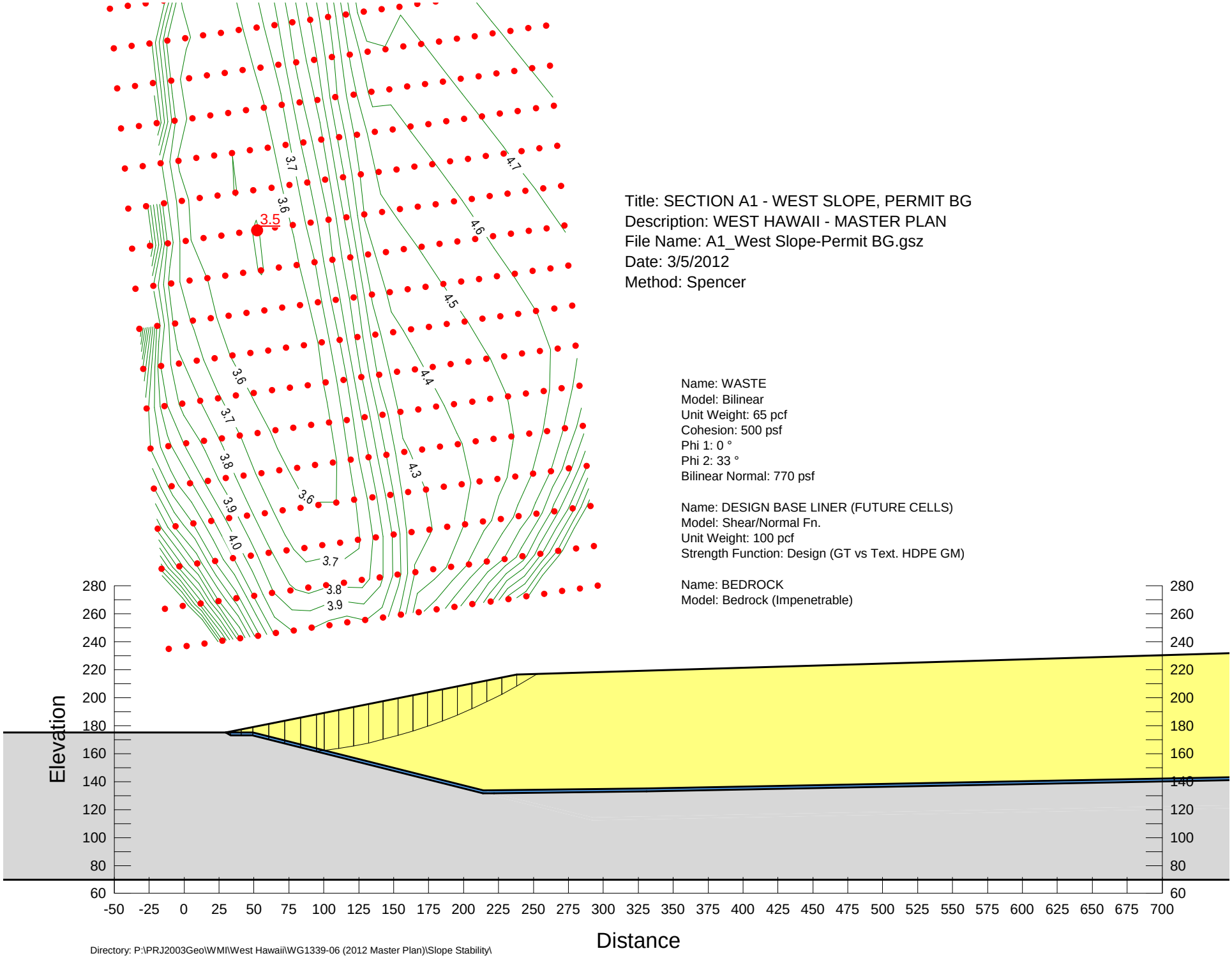
Attachment 1
Slope Stability Outputs



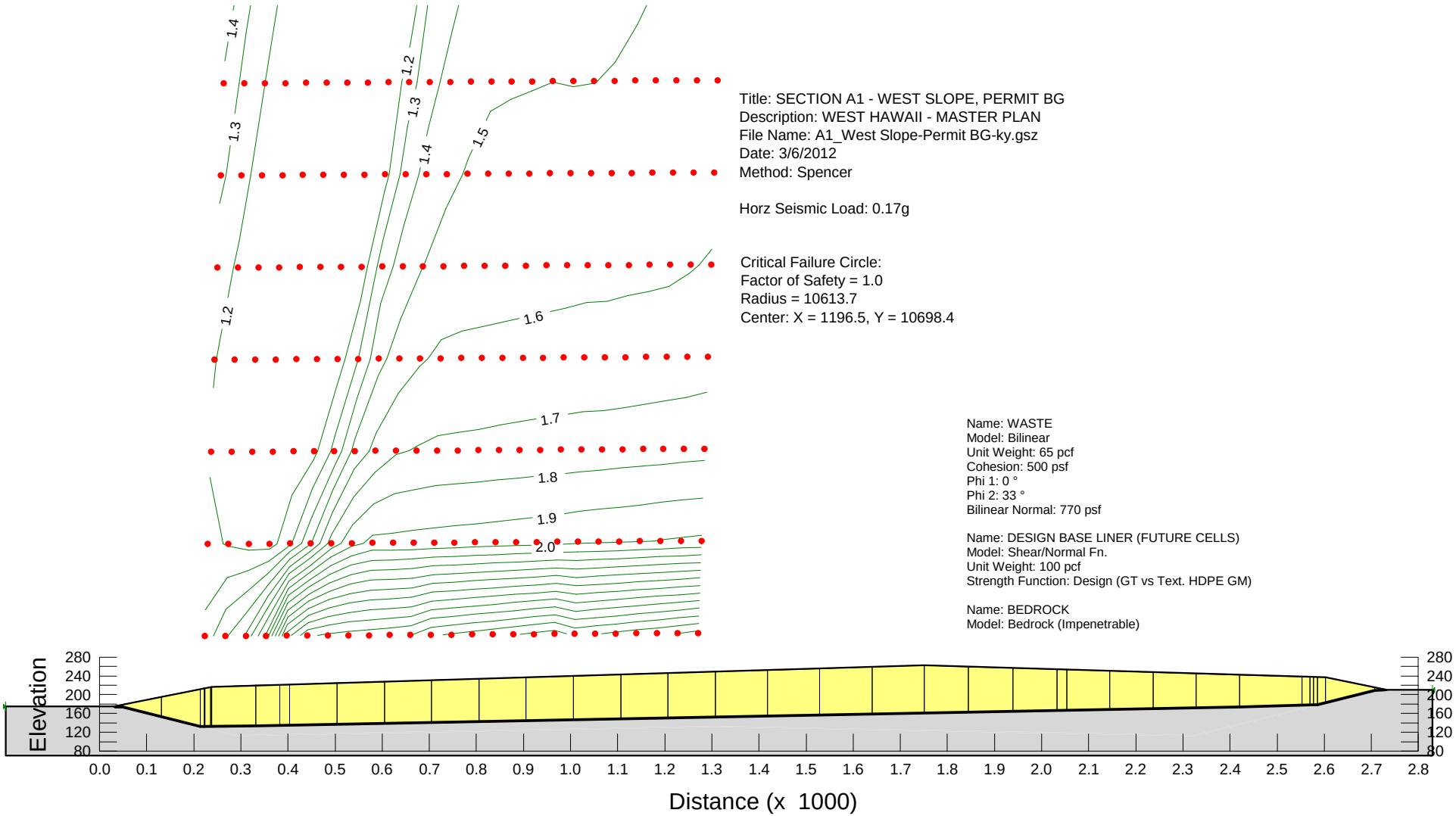
Title: SECTION A1 - WEST SLOPE, PERMIT BG
Description: WEST HAWAII - MASTER PLAN
File Name: A1_West Slope-Permit BG.gsz
Date: 3/5/2012
Method: Spencer

Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

Name: DESIGN BASE LINER (FUTURE CELLS)
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Design (GT vs Text. HDPE GM)

Name: BEDROCK
Model: Bedrock (Impenetrable)

Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\



Title: SECTION A1 - WEST SLOPE, PERMIT BG
Description: WEST HAWAII - MASTER PLAN
File Name: A1_West Slope-Permit BG-ky.gsz
Date: 3/6/2012
Method: Spencer

Horz Seismic Load: 0.17g

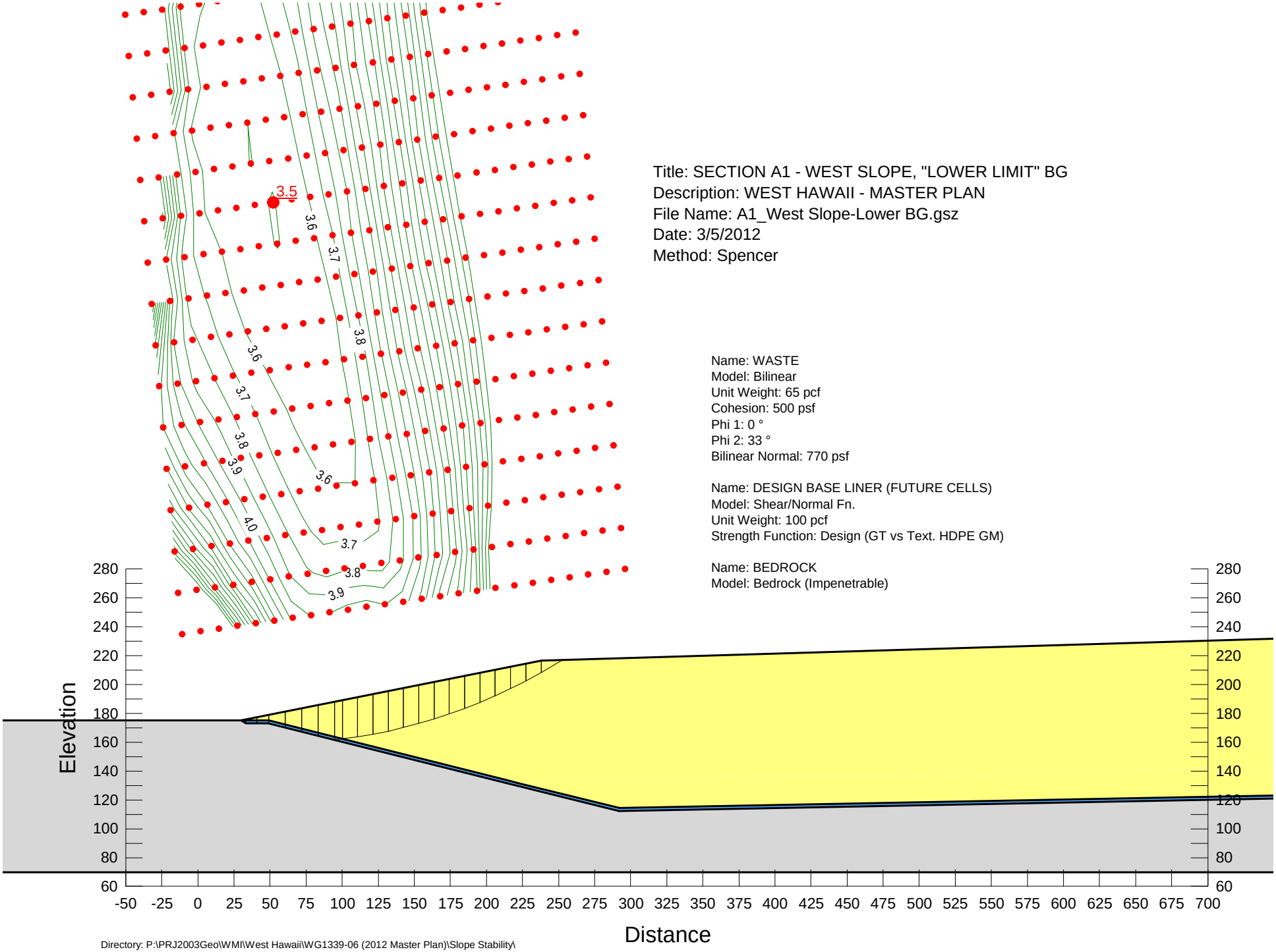
Critical Failure Circle:
Factor of Safety = 1.0
Radius = 10613.7
Center: X = 1196.5, Y = 10698.4

Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

Name: DESIGN BASE LINER (FUTURE CELLS)
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Design (GT vs Text. HDPE GM)

Name: BEDROCK
Model: Bedrock (Impenetrable)

Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\



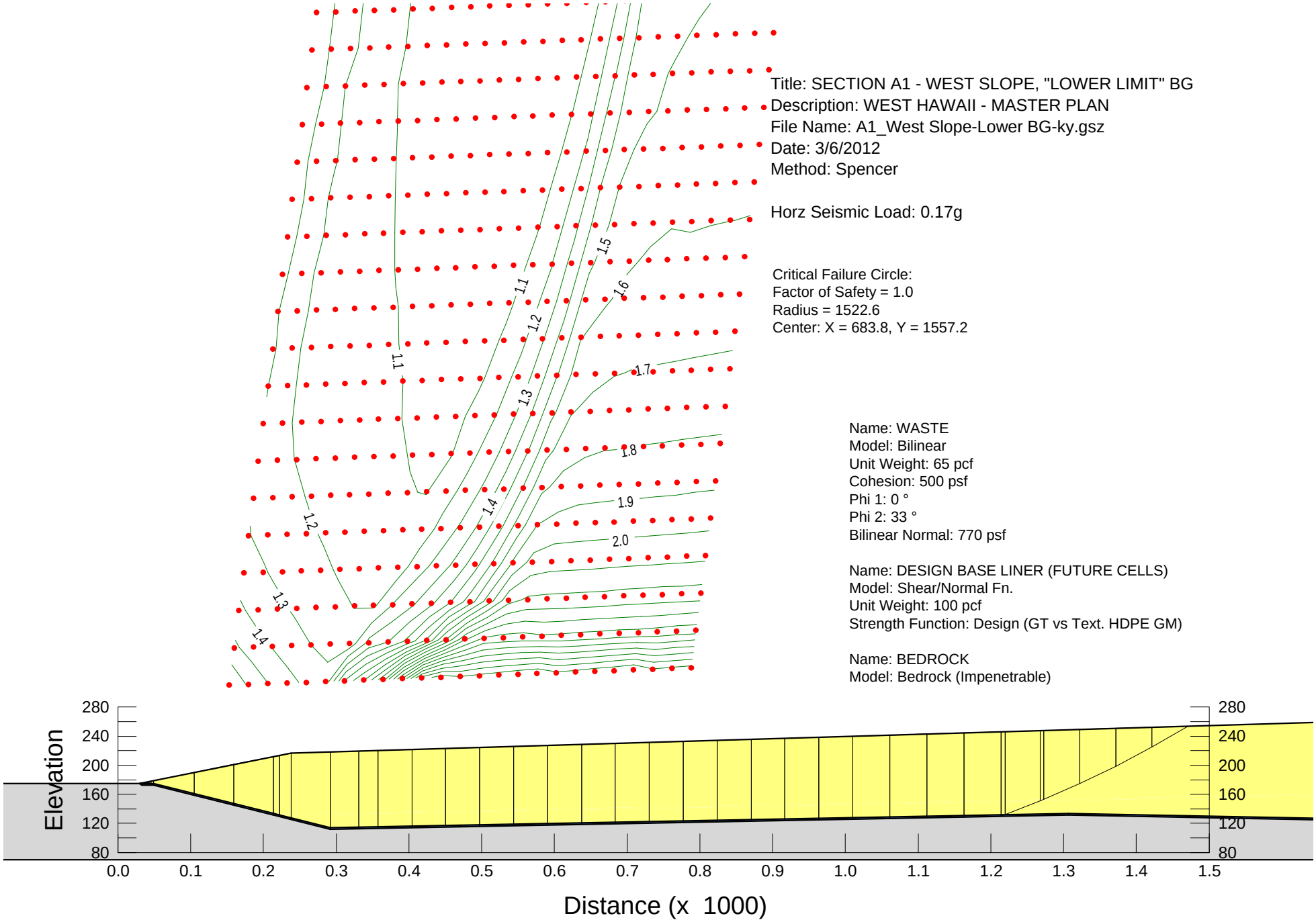
Title: SECTION A1 - WEST SLOPE, "LOWER LIMIT" BG
Description: WEST HAWAII - MASTER PLAN
File Name: A1_West Slope-Lower BG.gsz
Date: 3/5/2012
Method: Spencer

Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

Name: DESIGN BASE LINER (FUTURE CELLS)
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Design (GT vs Text. HDPE GM)

Name: BEDROCK
Model: Bedrock (Impenetrable)

Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\



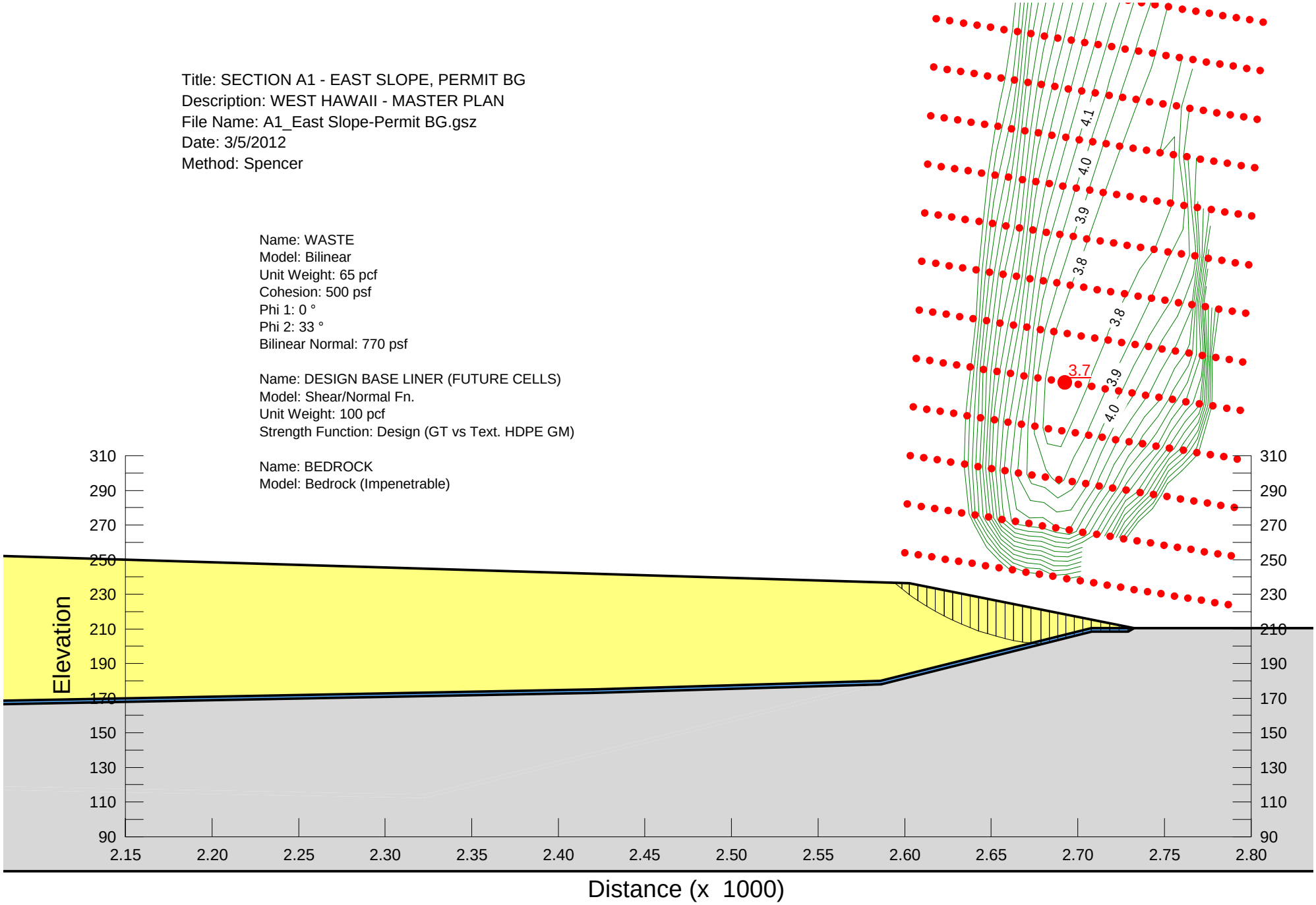
Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\

Title: SECTION A1 - EAST SLOPE, PERMIT BG
Description: WEST HAWAII - MASTER PLAN
File Name: A1_East Slope-Permit BG.gsz
Date: 3/5/2012
Method: Spencer

Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

Name: DESIGN BASE LINER (FUTURE CELLS)
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Design (GT vs Text. HDPE GM)

Name: BEDROCK
Model: Bedrock (Impenetrable)



Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\

Title: SECTION A1 - EAST SLOPE, PERMIT BG
Description: WEST HAWAII - MASTER PLAN
File Name: A1_East Slope-Permit BG-ky.gsz
Date: 3/6/2012
Method: Spencer

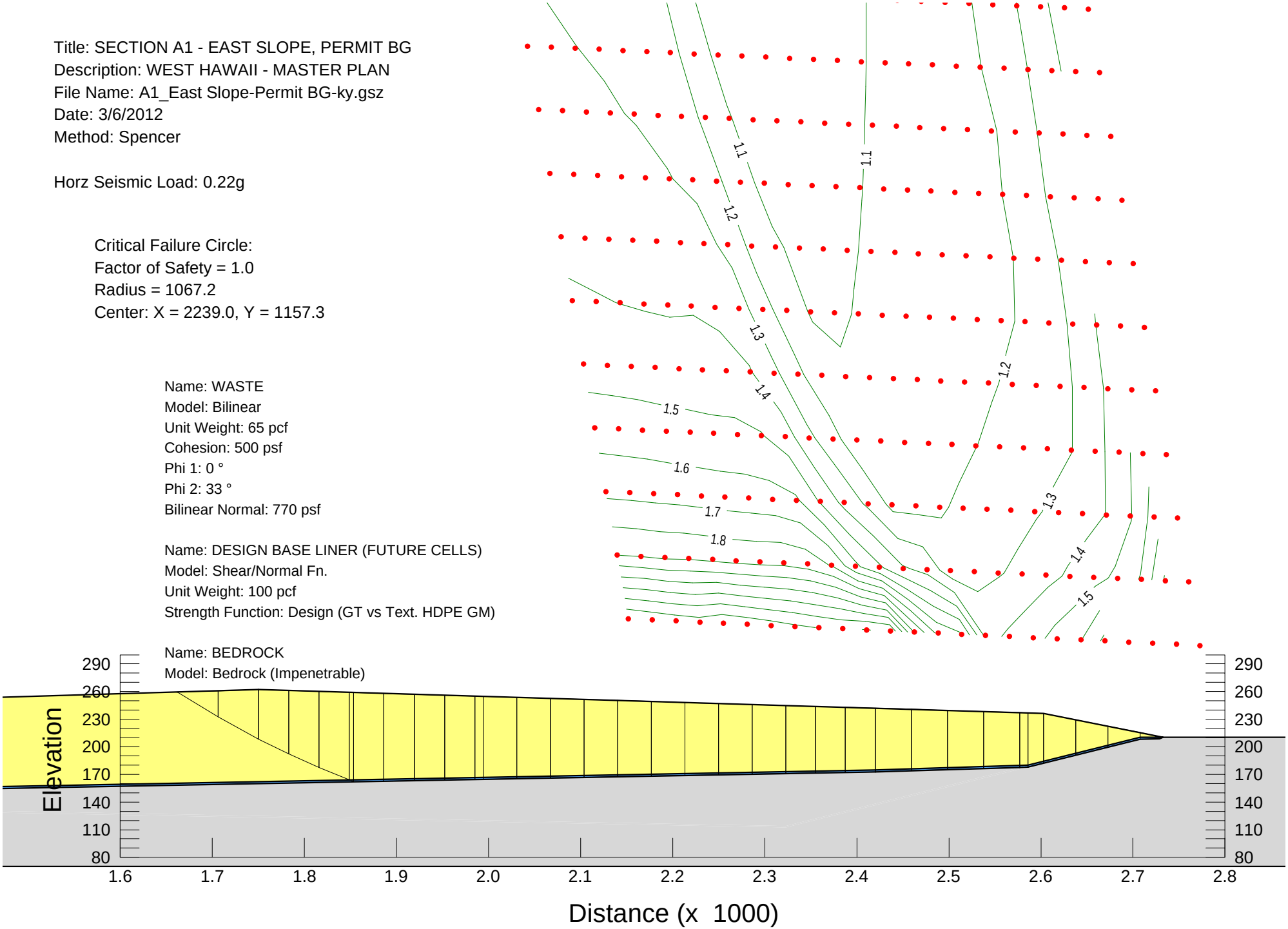
Horz Seismic Load: 0.22g

Critical Failure Circle:
Factor of Safety = 1.0
Radius = 1067.2
Center: X = 2239.0, Y = 1157.3

Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

Name: DESIGN BASE LINER (FUTURE CELLS)
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Design (GT vs Text. HDPE GM)

Name: BEDROCK
Model: Bedrock (Impenetrable)



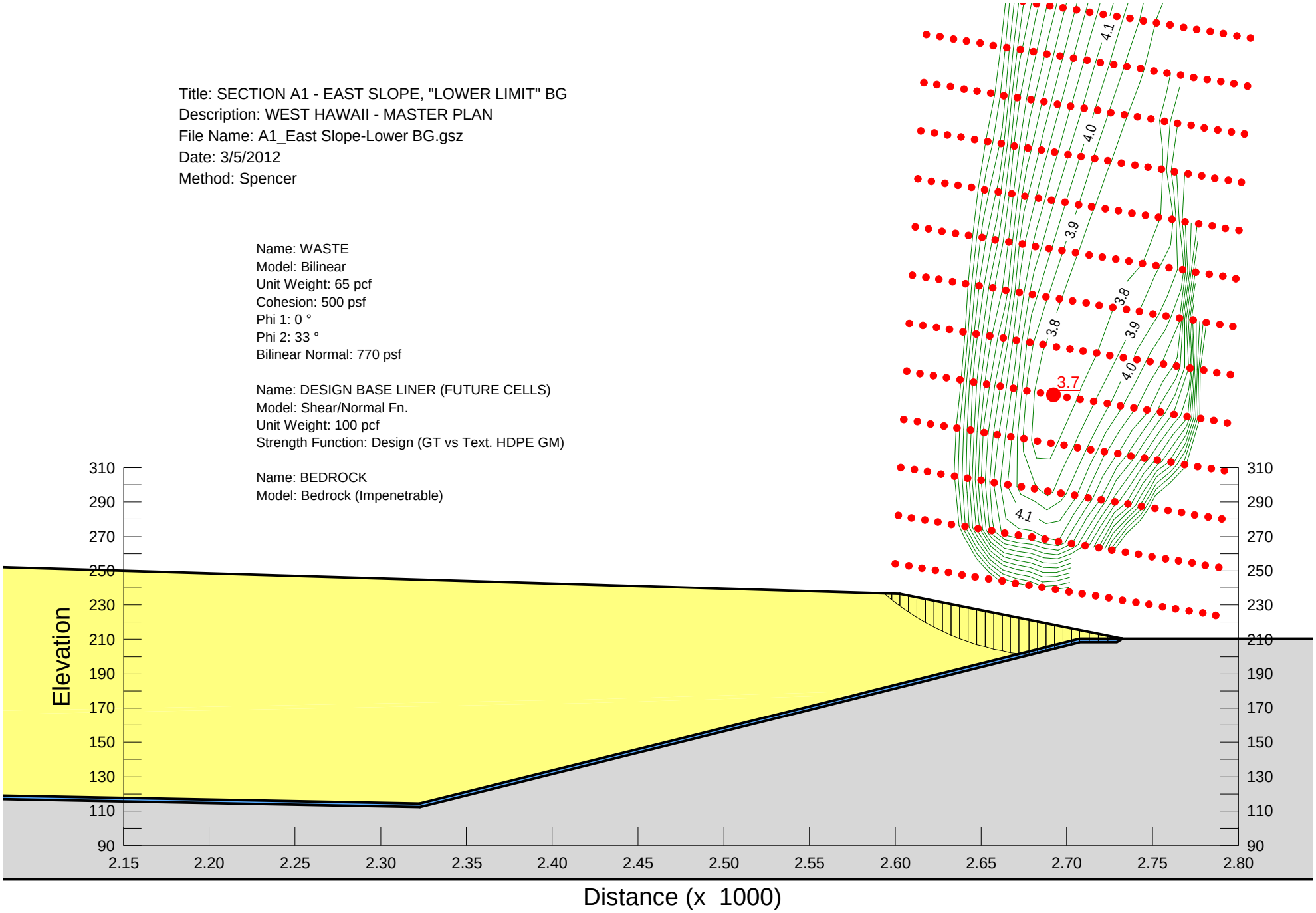
Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\

Title: SECTION A1 - EAST SLOPE, "LOWER LIMIT" BG
Description: WEST HAWAII - MASTER PLAN
File Name: A1_East Slope-Lower BG.gsz
Date: 3/5/2012
Method: Spencer

Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

Name: DESIGN BASE LINER (FUTURE CELLS)
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Design (GT vs Text. HDPE GM)

Name: BEDROCK
Model: Bedrock (Impenetrable)



Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\

Title: SECTION A1 - EAST SLOPE, "LOWER LIMIT" BG
Description: WEST HAWAII - MASTER PLAN
File Name: A1_East Slope-Lower BG-ky.gsz
Date: 3/6/2012
Method: Spencer

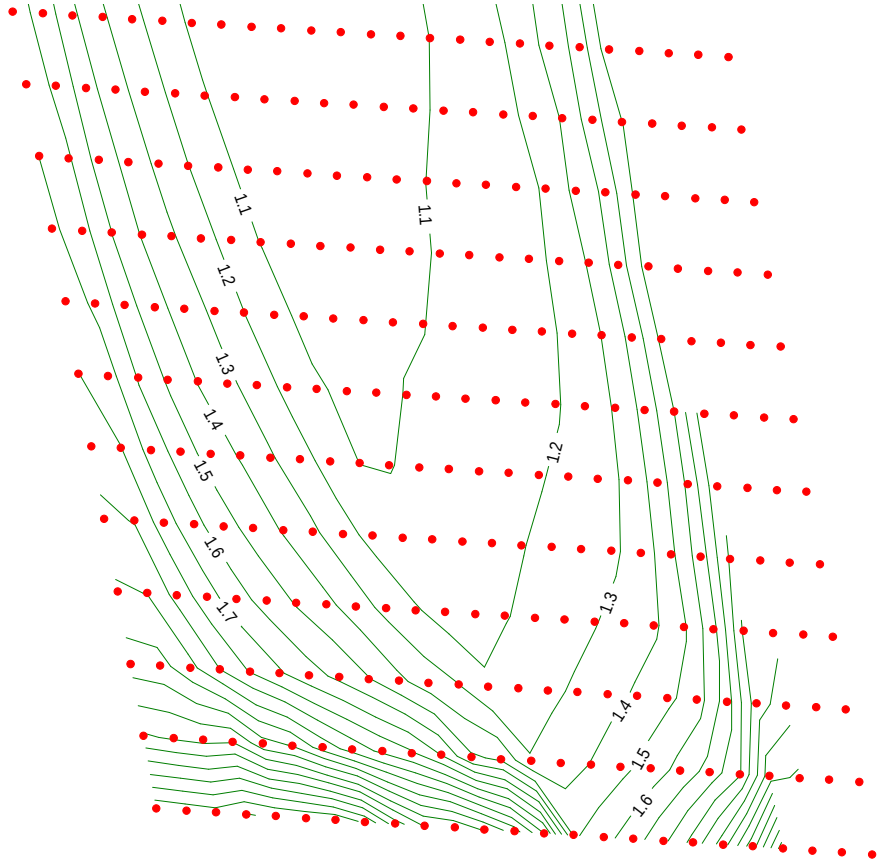
Horz Seismic Load: 0.173g

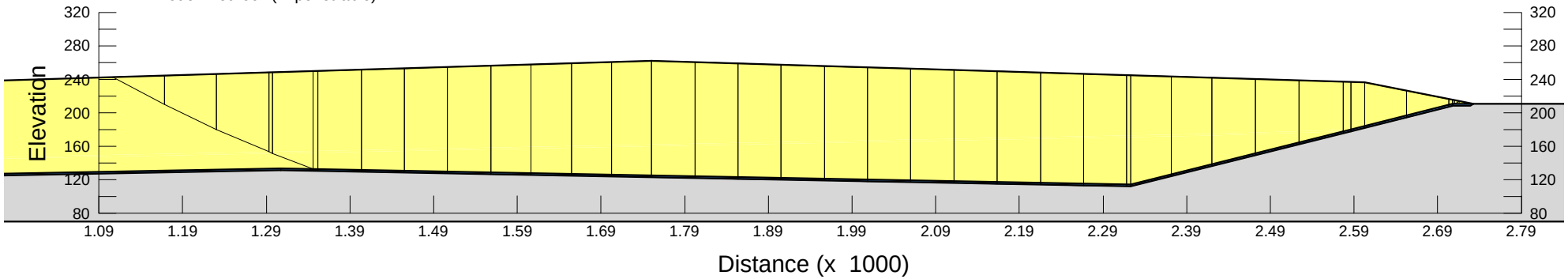
Critical Failure Circle:
Factor of Safety = 1.0
Radius = 1715.5
Center: X = 1938.4, Y = 1742.9

Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

Name: DESIGN BASE LINER (FUTURE CELLS)
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Design (GT vs Text. HDPE GM)

Name: BEDROCK
Model: Bedrock (Impenetrable)





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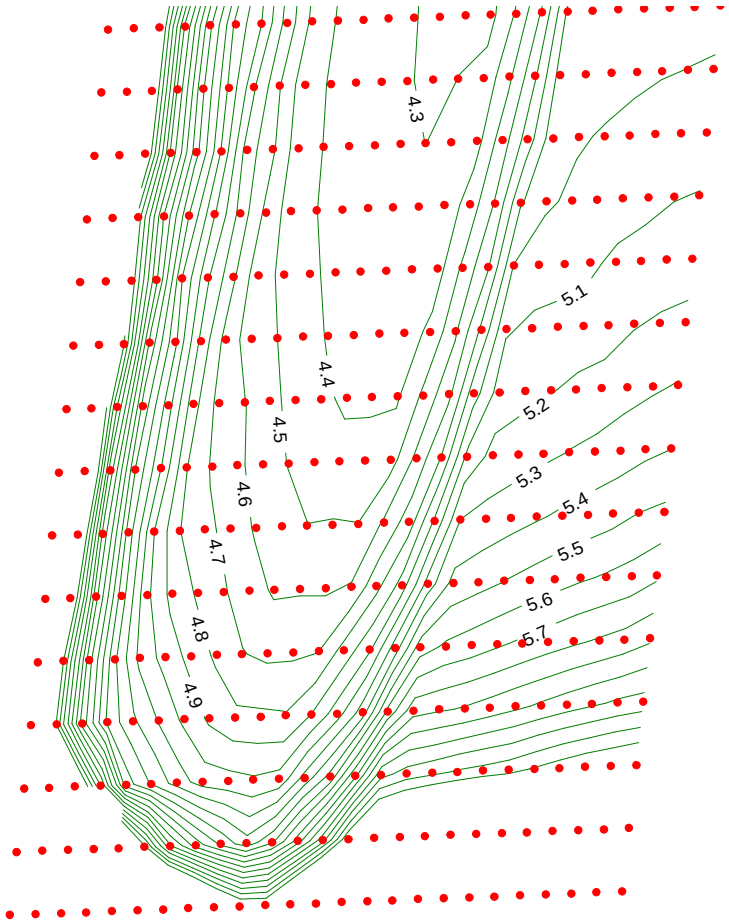


Title: SECTION A2 - WEST SLOPE, AS-BUILT BG
Description: WEST HAWAII - MASTER PLAN
File Name: A2_West Slope-AsBuilt BG.gsz
Date: 3/5/2012
Method: Spencer

Critical Failure Circle:
Factor of Safety = 4.2
Radius = 1494
Center: X = 581.1, Y = 1561.1

Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

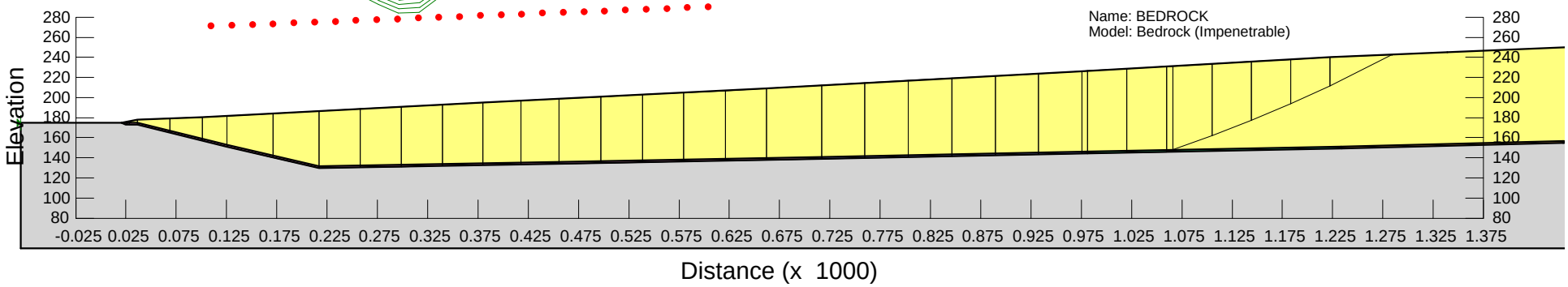
Name: CELLS 8A & 9A (PARTIAL) BASE LINER
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: 8A-9A Partial (GT vs Smooth HDPE GM)

Name: CELLS 9A (REMAINDER) & 10A (PARTIAL) BASE LINER
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: 9A Rem-10A Part

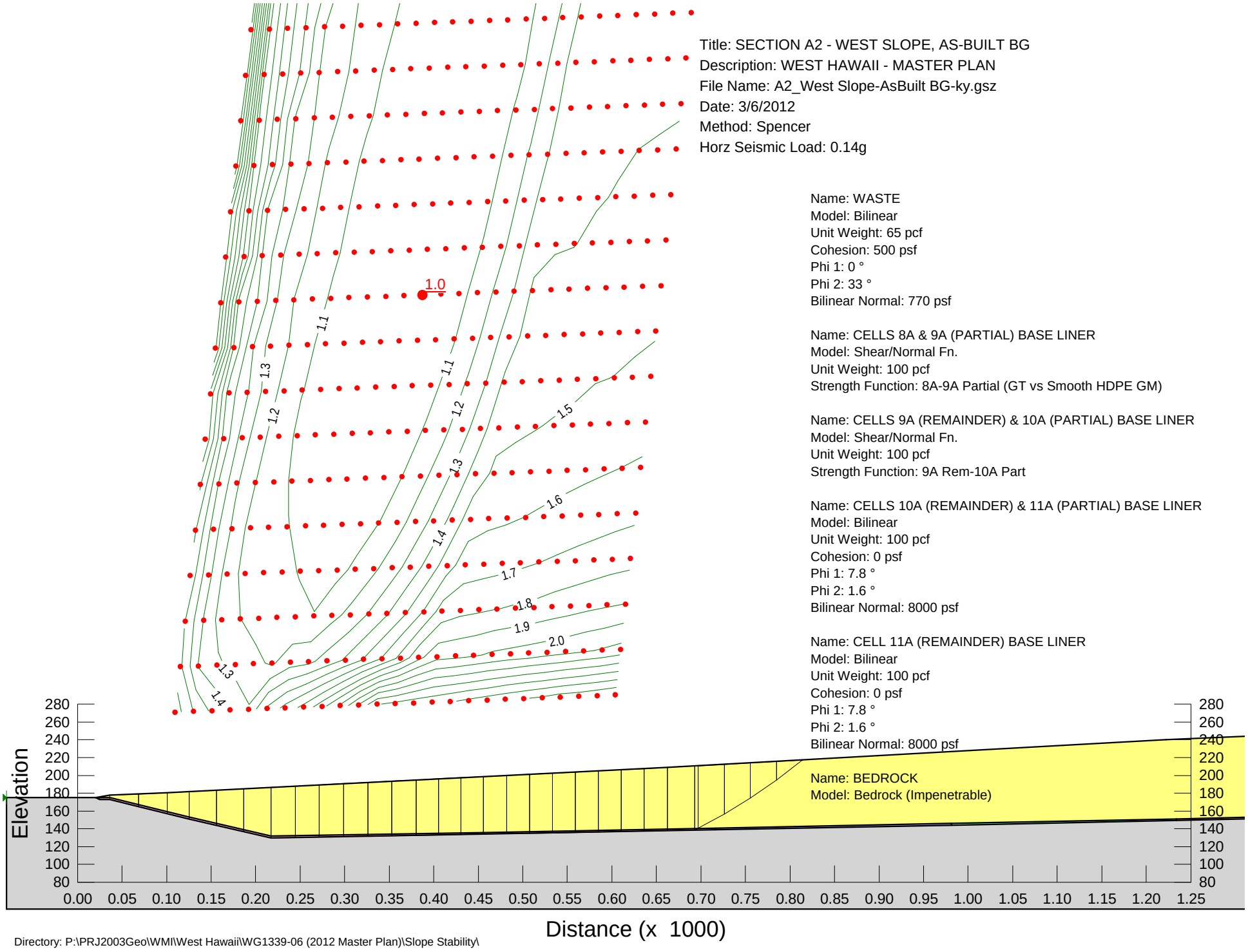
Name: CELLS 10A (REMAINDER) & 11A (PARTIAL) BASE LINER
Model: Bilinear
Unit Weight: 100 pcf
Cohesion: 0 psf
Phi 1: 7.8 °
Phi 2: 1.6 °
Bilinear Normal: 8000 psf

Name: CELL 11A (REMAINDER) BASE LINER
Model: Bilinear
Unit Weight: 100 pcf
Cohesion: 0 psf
Phi 1: 7.8 °
Phi 2: 1.6 °
Bilinear Normal: 8000 psf

Name: BEDROCK
Model: Bedrock (Impenetrable)



Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\



Title: SECTION A2 - WEST SLOPE, AS-BUILT BG
Description: WEST HAWAII - MASTER PLAN
File Name: A2_West Slope-AsBuilt BG-ky.gsz
Date: 3/6/2012
Method: Spencer
Horz Seismic Load: 0.14g

Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

Name: CELLS 8A & 9A (PARTIAL) BASE LINER
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: 8A-9A Partial (GT vs Smooth HDPE GM)

Name: CELLS 9A (REMAINDER) & 10A (PARTIAL) BASE LINER
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: 9A Rem-10A Part

Name: CELLS 10A (REMAINDER) & 11A (PARTIAL) BASE LINER
Model: Bilinear
Unit Weight: 100 pcf
Cohesion: 0 psf
Phi 1: 7.8 °
Phi 2: 1.6 °
Bilinear Normal: 8000 psf

Name: CELL 11A (REMAINDER) BASE LINER
Model: Bilinear
Unit Weight: 100 pcf
Cohesion: 0 psf
Phi 1: 7.8 °
Phi 2: 1.6 °
Bilinear Normal: 8000 psf

Name: BEDROCK
Model: Bedrock (Impenetrable)

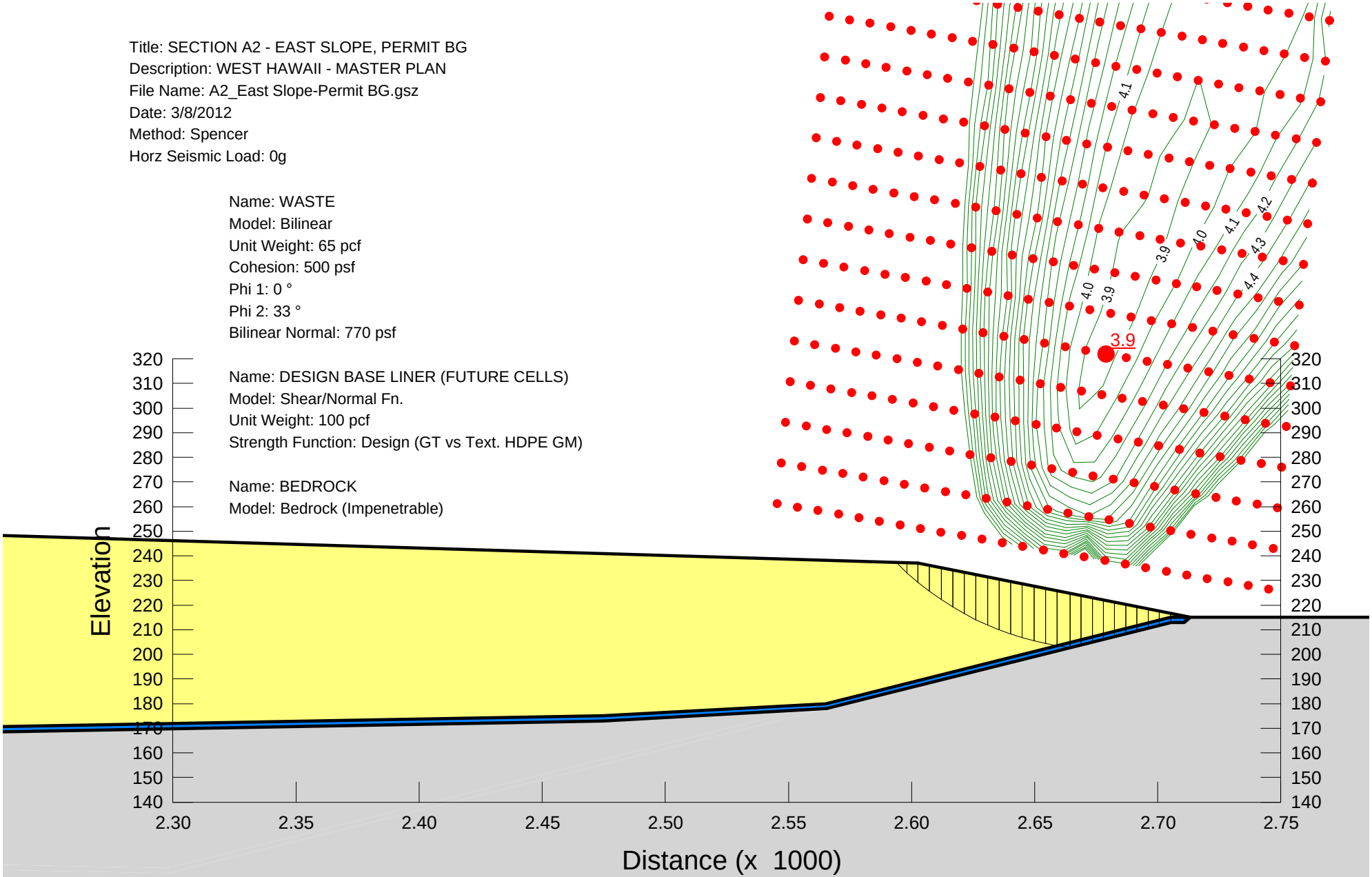
Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\

Title: SECTION A2 - EAST SLOPE, PERMIT BG
Description: WEST HAWAII - MASTER PLAN
File Name: A2_East Slope-Permit BG.gsz
Date: 3/8/2012
Method: Spencer
Horz Seismic Load: 0g

Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

Name: DESIGN BASE LINER (FUTURE CELLS)
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Design (GT vs Text. HDPE GM)

Name: BEDROCK
Model: Bedrock (Impenetrable)



Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\

Title: SECTION A2 - EAST SLOPE, PERMIT BG
Description: WEST HAWAII - MASTER PLAN
File Name: A2_East Slope-Permit BG-ky.gsz
Date: 3/8/2012
Method: Spencer
Horz Seismic Load: 0.22g

Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

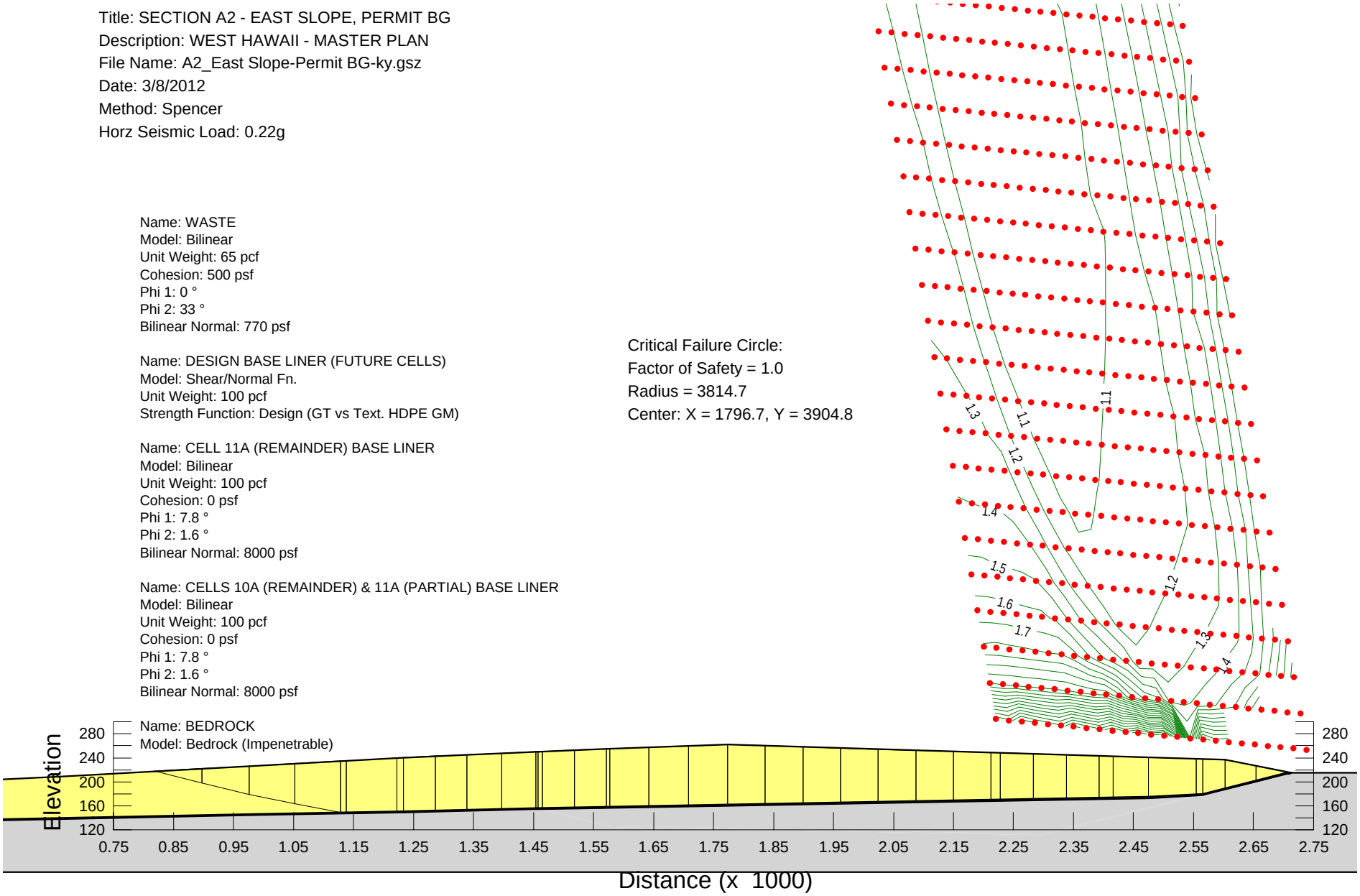
Name: DESIGN BASE LINER (FUTURE CELLS)
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Design (GT vs Text. HDPE GM)

Name: CELL 11A (REMAINDER) BASE LINER
Model: Bilinear
Unit Weight: 100 pcf
Cohesion: 0 psf
Phi 1: 7.8 °
Phi 2: 1.6 °
Bilinear Normal: 8000 psf

Name: CELLS 10A (REMAINDER) & 11A (PARTIAL) BASE LINER
Model: Bilinear
Unit Weight: 100 pcf
Cohesion: 0 psf
Phi 1: 7.8 °
Phi 2: 1.6 °
Bilinear Normal: 8000 psf

Name: BEDROCK
Model: Bedrock (Impenetrable)

Critical Failure Circle:
Factor of Safety = 1.0
Radius = 3814.7
Center: X = 1796.7, Y = 3904.8



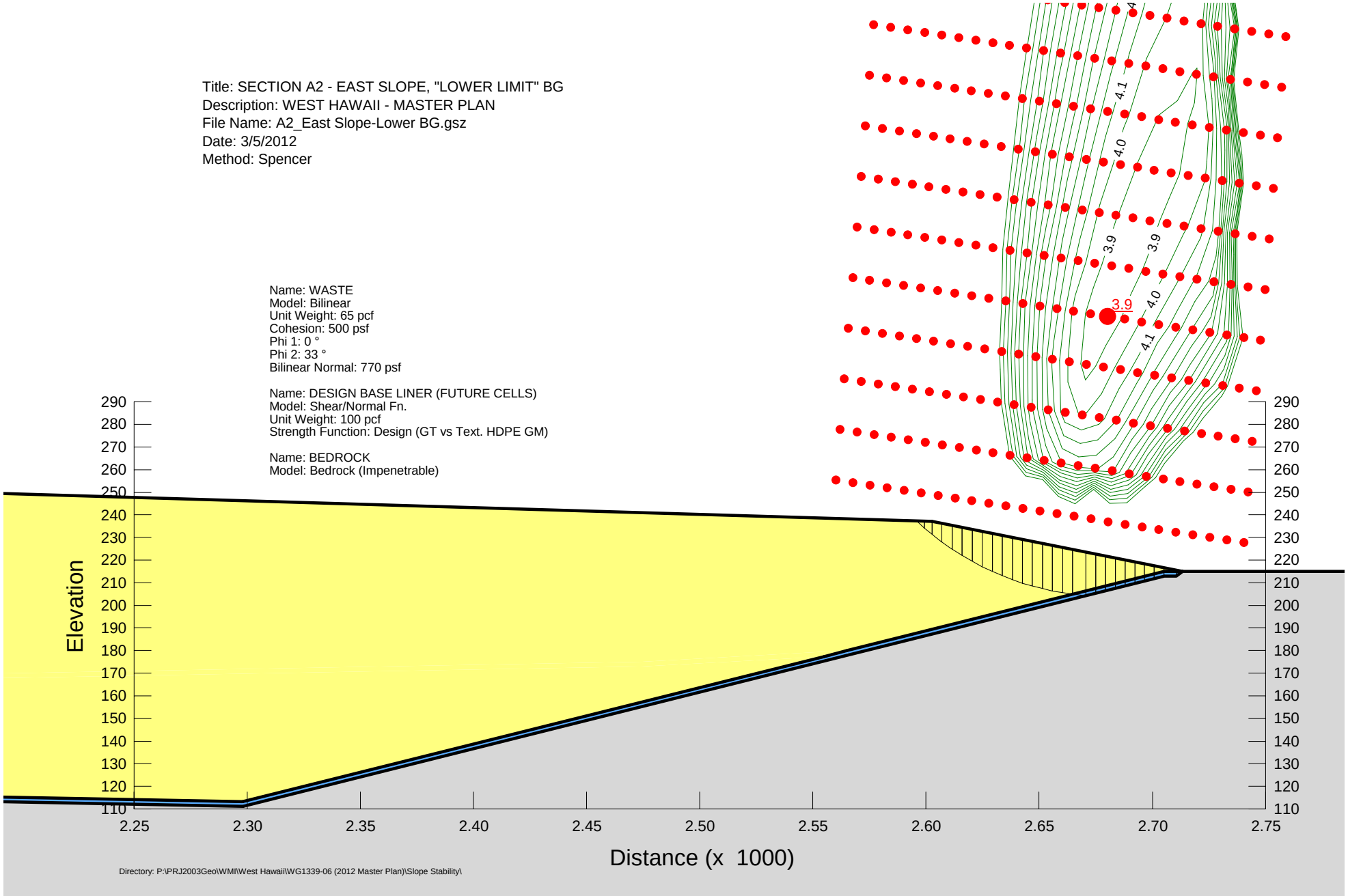
Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\

Title: SECTION A2 - EAST SLOPE, "LOWER LIMIT" BG
Description: WEST HAWAII - MASTER PLAN
File Name: A2_East Slope-Lower BG.gsz
Date: 3/5/2012
Method: Spencer

Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

Name: DESIGN BASE LINER (FUTURE CELLS)
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Design (GT vs Text. HDPE GM)

Name: BEDROCK
Model: Bedrock (Impenetrable)



Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\

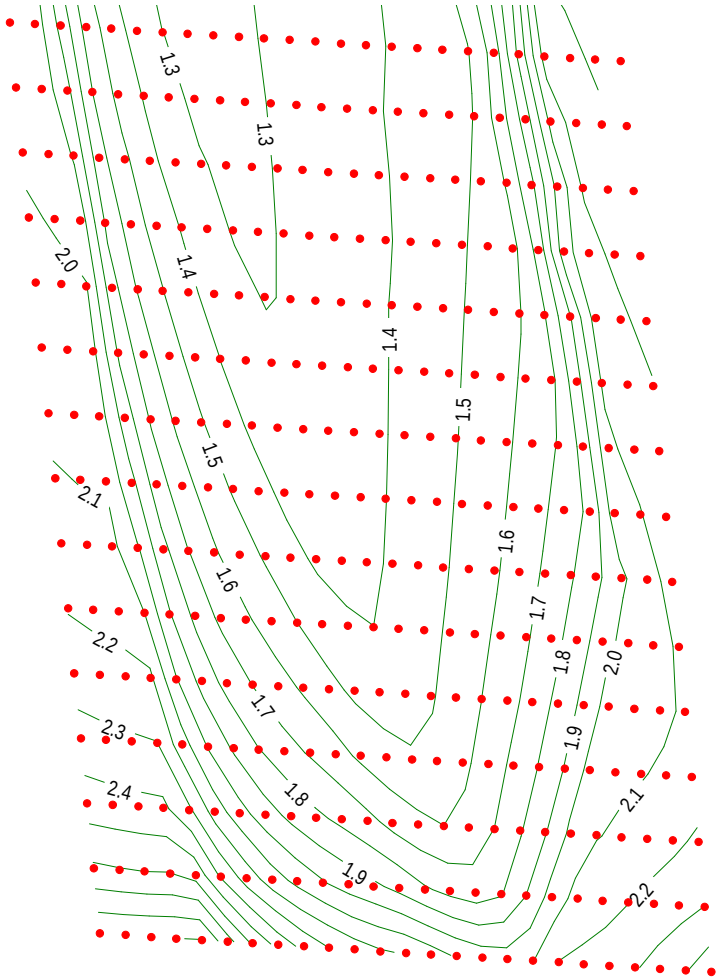
Title: SECTION A2 - EAST SLOPE, "LOWER LIMIT" BG
Description: WEST HAWAII - MASTER PLAN
File Name: A2_East Slope-Lower BG-ky.gsz
Date: 3/6/2012
Method: Spencer
Horz Seismic Load: 0.17g

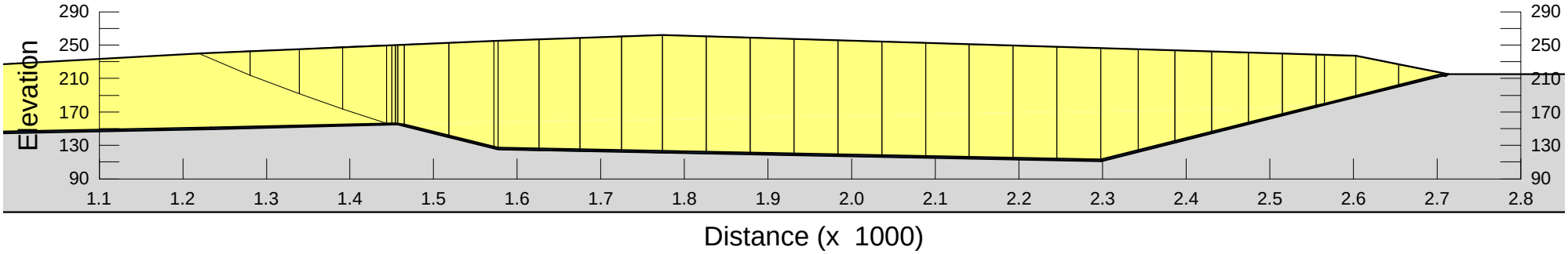
Critical Failure Circle:
Factor of Safety = 1.0
Radius = 1913.2
Center: X = 2000.2, Y = 1986.9

Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

Name: DESIGN BASE LINER (FUTURE CELLS)
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Design (GT vs Text. HDPE GM)

Name: BEDROCK
Model: Bedrock (Impenetrable)





Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\

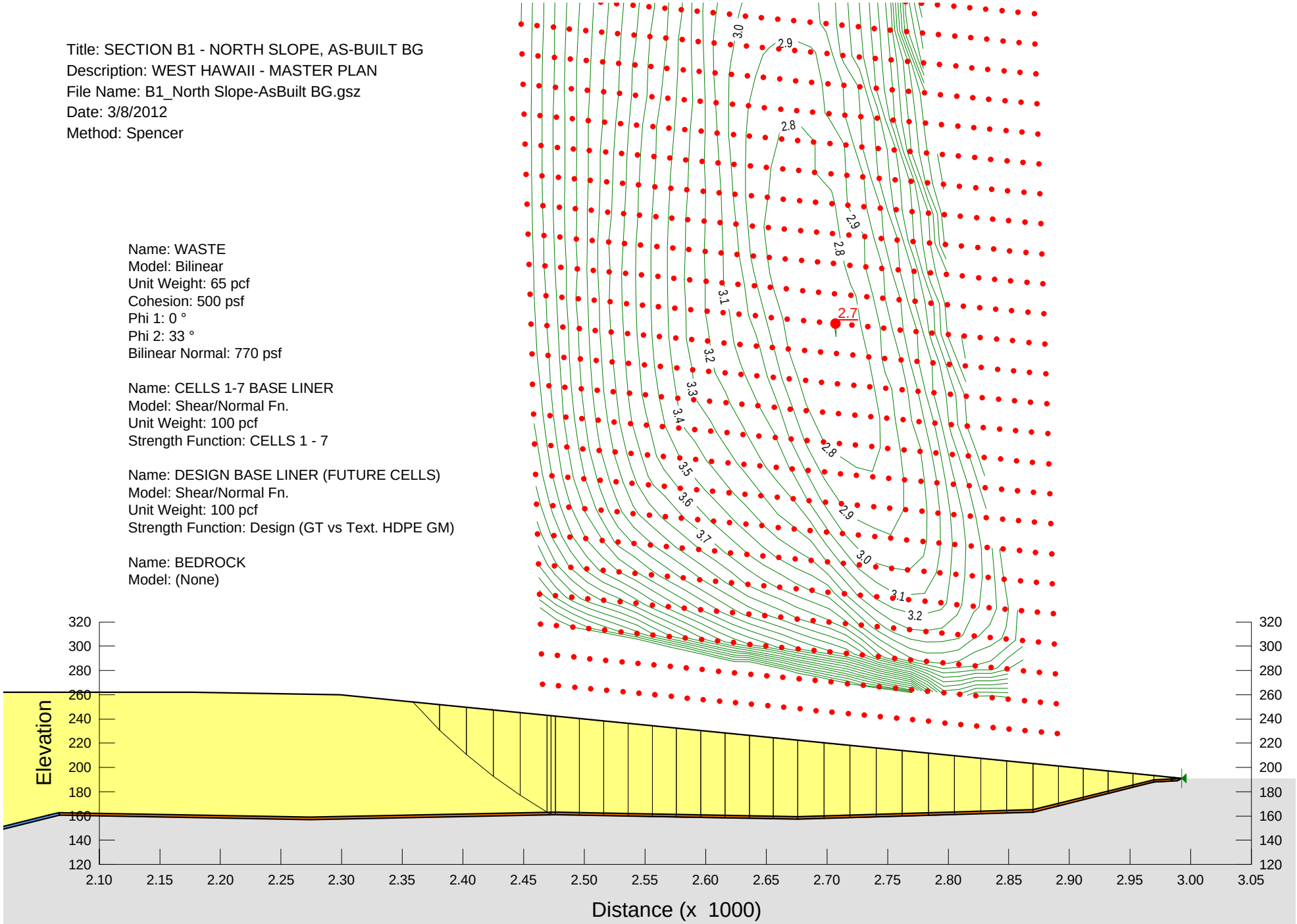
Title: SECTION B1 - NORTH SLOPE, AS-BUILT BG
Description: WEST HAWAII - MASTER PLAN
File Name: B1_North Slope-AsBuilt BG.gsz
Date: 3/8/2012
Method: Spencer

Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

Name: CELLS 1-7 BASE LINER
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: CELLS 1 - 7

Name: DESIGN BASE LINER (FUTURE CELLS)
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Design (GT vs Text. HDPE GM)

Name: BEDROCK
Model: (None)



Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\

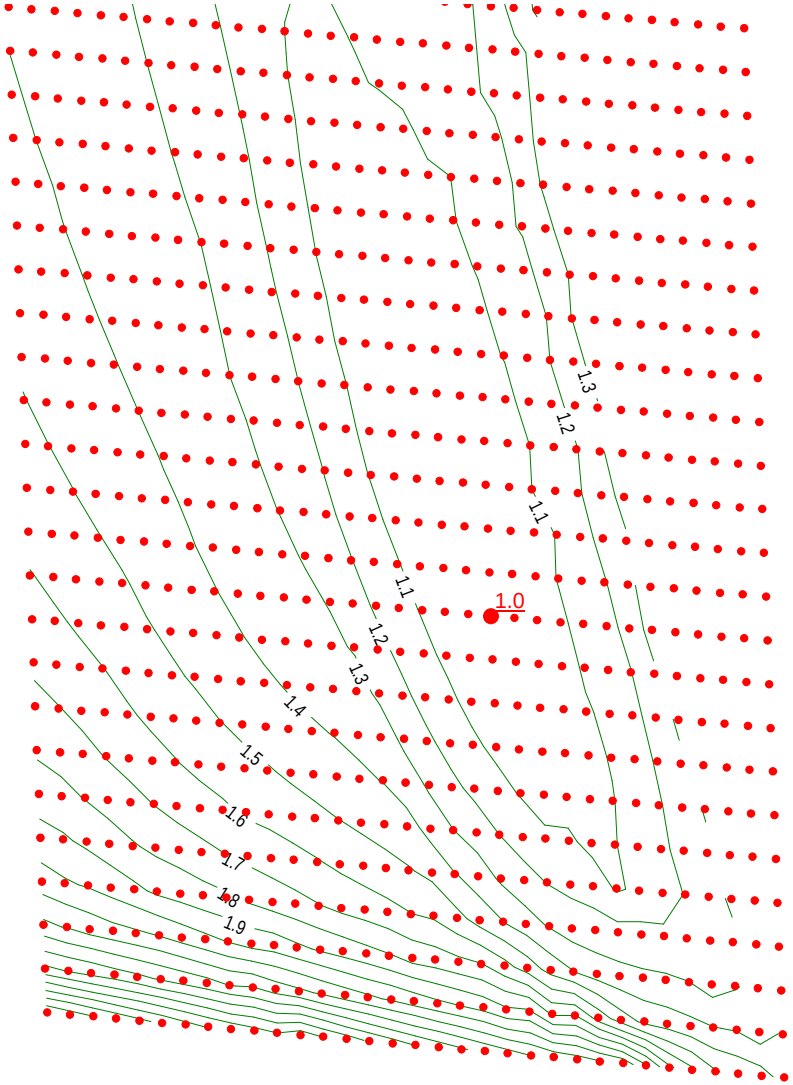
Title: SECTION B1 - NORTH SLOPE, AS-BUILT BG
Description: WEST HAWAII - MASTER PLAN
File Name: B1_North Slope-AsBuilt BG-ky.gsz
Date: 3/8/2012
Method: Spencer
Horz Seismic Load: 0.13g

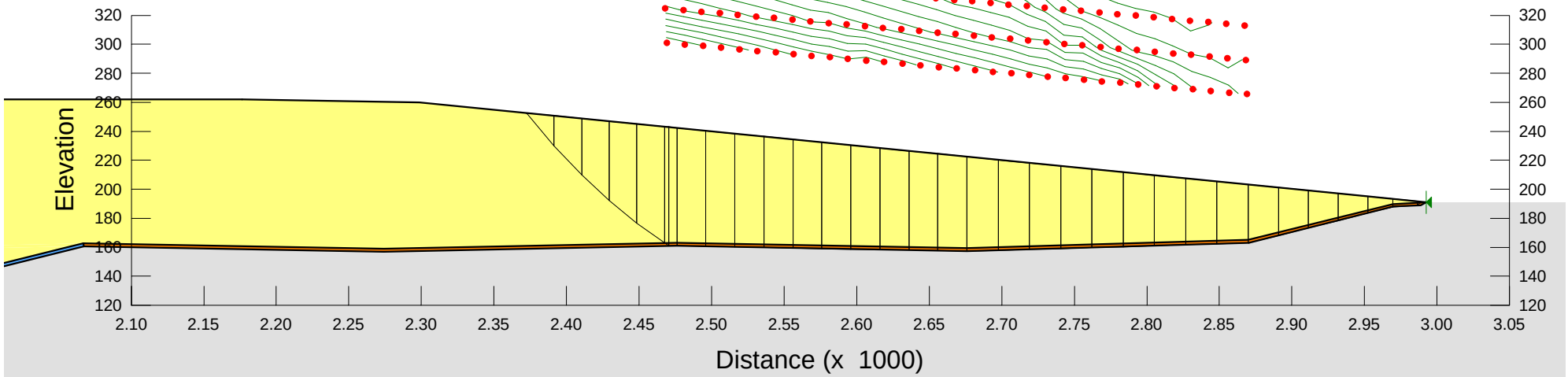
Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

Name: CELLS 1-7 BASE LINER
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: CELLS 1 - 7

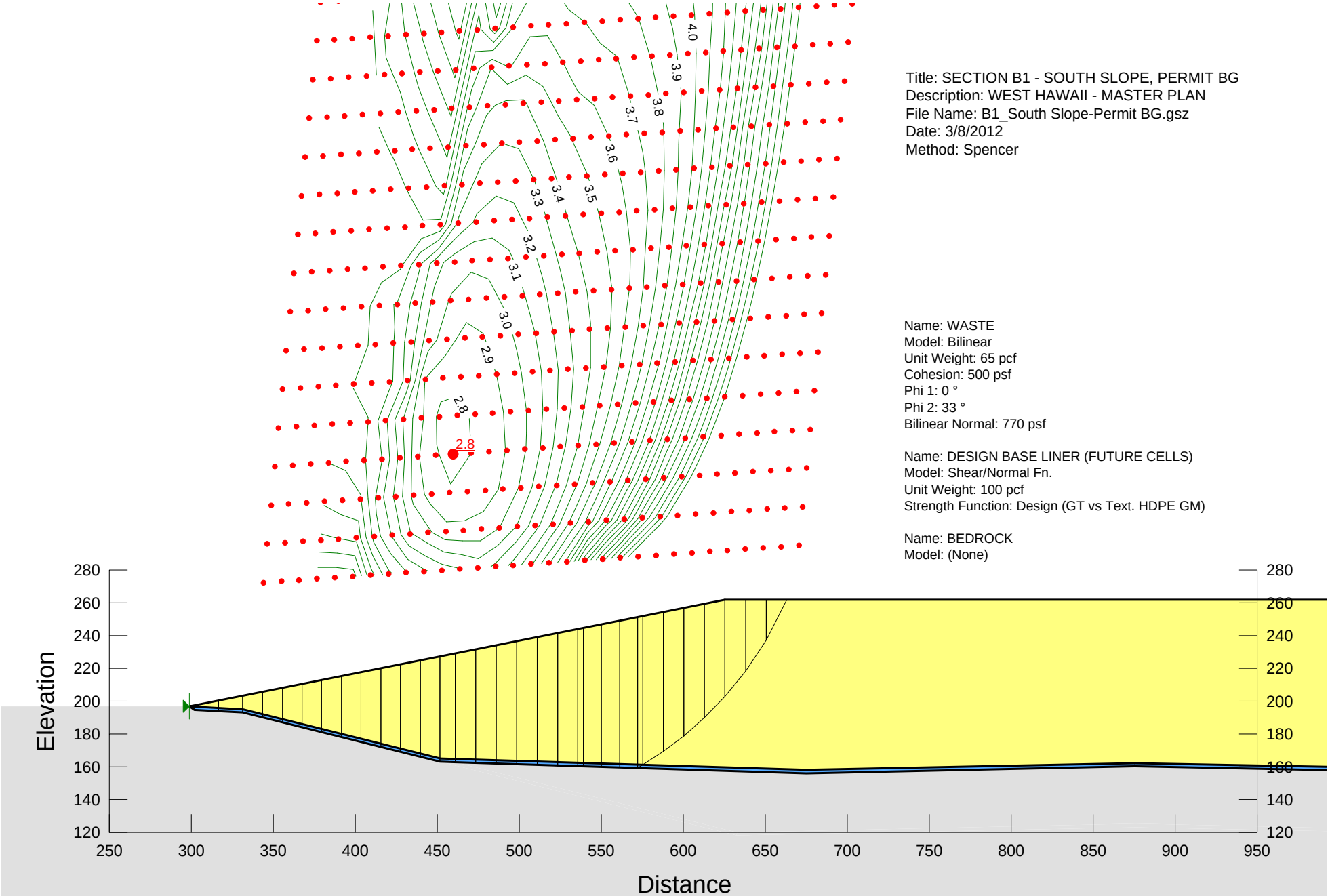
Name: DESIGN BASE LINER (FUTURE CELLS)
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Design (GT vs Text. HDPE GM)

Name: BEDROCK
Model: (None)





Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\



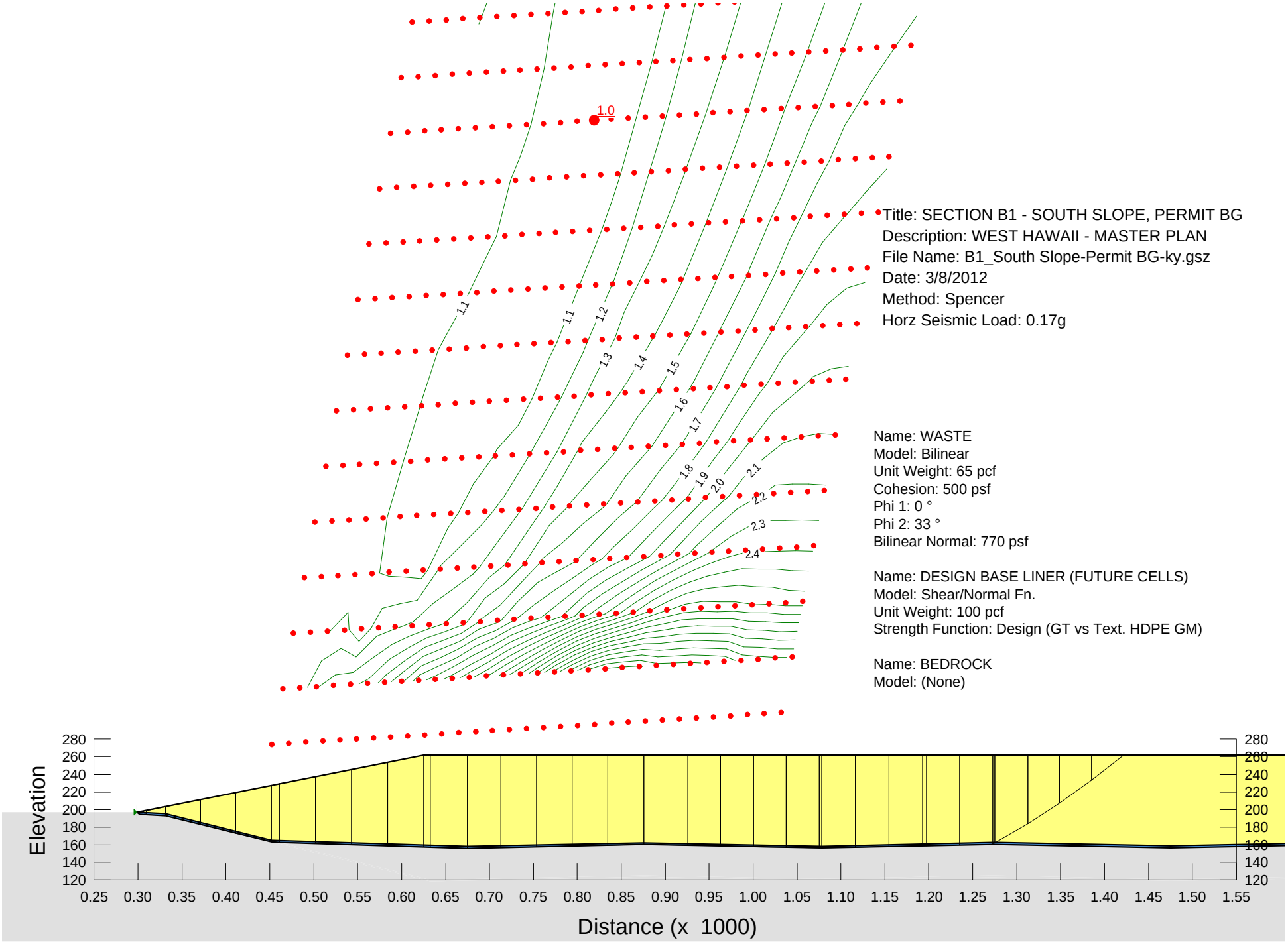
Title: SECTION B1 - SOUTH SLOPE, PERMIT BG
Description: WEST HAWAII - MASTER PLAN
File Name: B1_South Slope-Permit BG.gsz
Date: 3/8/2012
Method: Spencer

Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

Name: DESIGN BASE LINER (FUTURE CELLS)
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Design (GT vs Text. HDPE GM)

Name: BEDROCK
Model: (None)

Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\



Title: SECTION B1 - SOUTH SLOPE, PERMIT BG
Description: WEST HAWAII - MASTER PLAN
File Name: B1_South Slope-Permit BG-ky.gsz
Date: 3/8/2012
Method: Spencer
Horz Seismic Load: 0.17g

Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

Name: DESIGN BASE LINER (FUTURE CELLS)
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Design (GT vs Text. HDPE GM)

Name: BEDROCK
Model: (None)

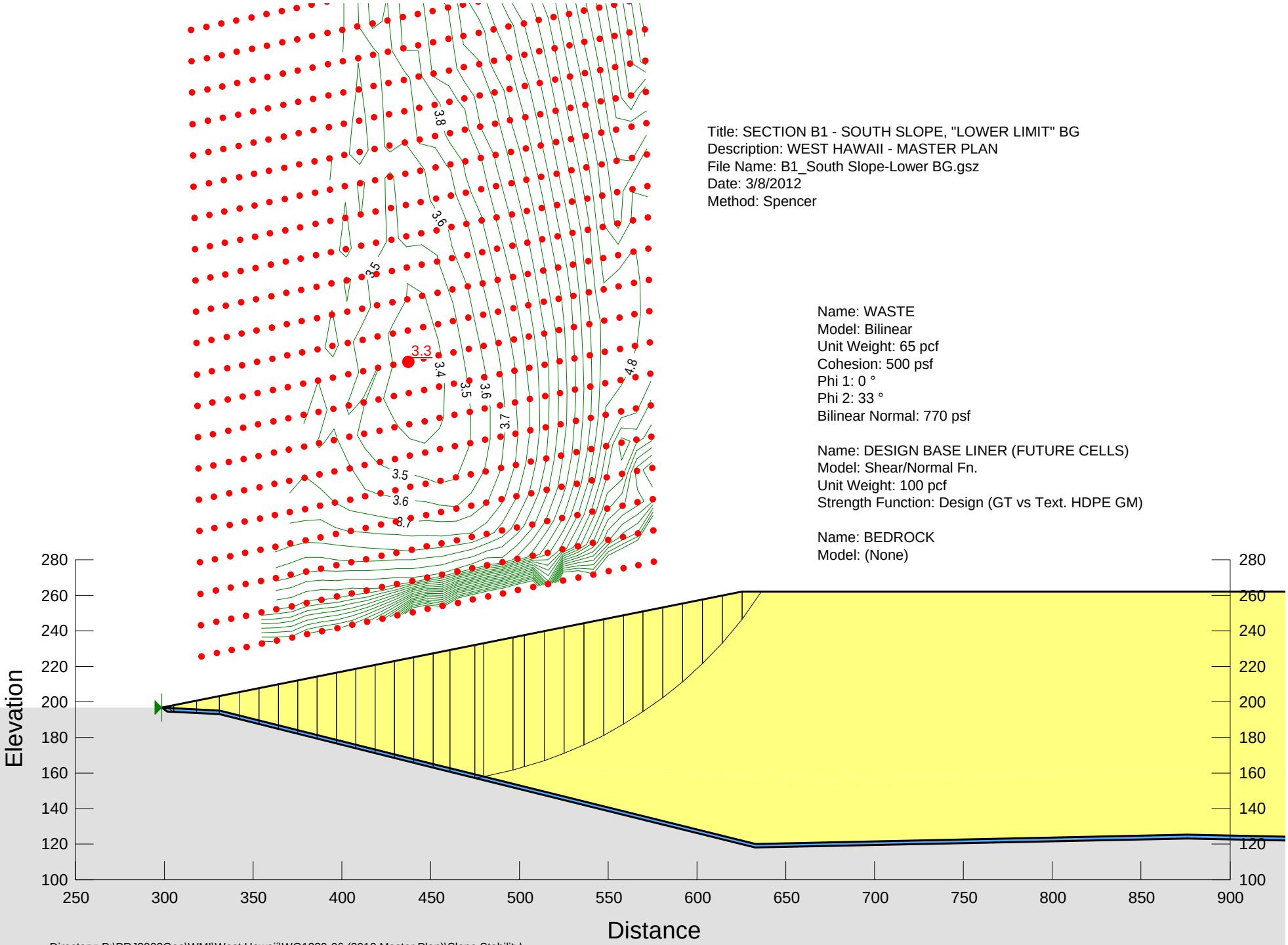
Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\

Title: SECTION B1 - SOUTH SLOPE, "LOWER LIMIT" BG
Description: WEST HAWAII - MASTER PLAN
File Name: B1_South Slope-Lower BG.gsz
Date: 3/8/2012
Method: Spencer

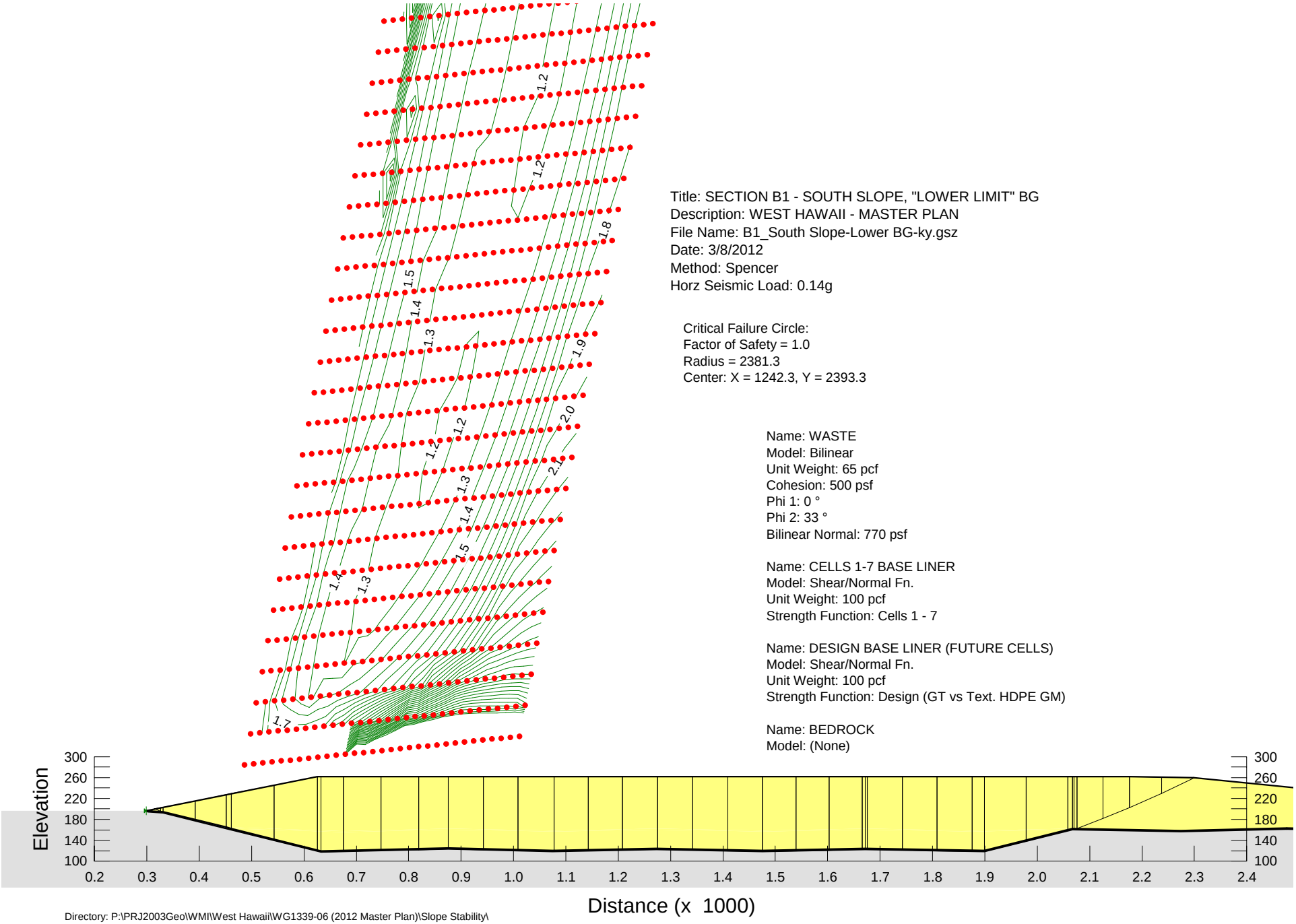
Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

Name: DESIGN BASE LINER (FUTURE CELLS)
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Design (GT vs Text. HDPE GM)

Name: BEDROCK
Model: (None)



Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\



Title: SECTION B1 - SOUTH SLOPE, "LOWER LIMIT" BG
Description: WEST HAWAII - MASTER PLAN
File Name: B1_South Slope-Lower BG-ky.gsz
Date: 3/8/2012
Method: Spencer
Horz Seismic Load: 0.14g

Critical Failure Circle:
Factor of Safety = 1.0
Radius = 2381.3
Center: X = 1242.3, Y = 2393.3

Name: WASTE
Model: Bilinear
Unit Weight: 65 pcf
Cohesion: 500 psf
Phi 1: 0 °
Phi 2: 33 °
Bilinear Normal: 770 psf

Name: CELLS 1-7 BASE LINER
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Cells 1 - 7

Name: DESIGN BASE LINER (FUTURE CELLS)
Model: Shear/Normal Fn.
Unit Weight: 100 pcf
Strength Function: Design (GT vs Text. HDPE GM)

Name: BEDROCK
Model: (None)

Directory: P:\PRJ2003Geo\WMI\West Hawaii\WG1339-06 (2012 Master Plan)\Slope Stability\

Cover Stability Analyses

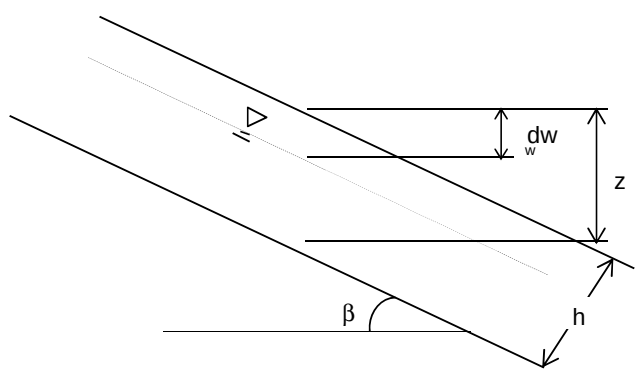
The cover stability analyses is performed using the infinite slope approach. The expression for the factor of safety is provided by Matasovic [1991] as follows:

$$FS = \frac{\left(\frac{c}{\gamma\ z\cos^2\beta}\right) + \tan\phi\left[1 - \left(\frac{\gamma_w(z - d_w)}{\gamma\ z}\right)\right] - k_s\tan\beta\ \tan\phi}{k_s + \tan\beta} \qquad \text{Equation (1)}$$

where:

- c = cohesion / adhesion (psf)
- γ = unit weight of cover soil (pcf)
- γ_w = unit weight of water (pcf)
- z = vertical thickness of the layer (ft)
- β = slope angle (degrees)
- ϕ = friction angle (degrees)
- d_w = vertical depth to water table (ft)
- k_s = seismic coefficient
- FS = factor of safety

The expressions are explained in the figure.



And based on geometry:

$$z = \frac{h}{\cos\beta} \qquad \text{Equation (2)}$$

Static Condition:

Under static conditions, the value of $k_s = 0$. Therefore, equation (1) can be modified to the following form:

$$FS = \frac{\left(\frac{c}{\gamma \ z \cos^2 \beta}\right) + \tan \phi \left[1 - \left(\frac{\gamma_w (z - d_w)}{\gamma \ z}\right)\right]}{\tan \beta} \qquad \text{Equation (3)}$$

<u>Case A:</u> No water table is present on the slope, i.e. dw = z. This is considered to be a long-term condition. Consequently, equation (3) is modified to the following form:

$$FS = \frac{\left(\frac{c}{\gamma \ z \cos^2 \beta}\right) + \tan \phi}{\tan \beta} \qquad \text{Equation (4)}$$

<u>Case B:</u> Water table is assumed to be at depth dw = 0.5 ft. This is considered to be a short-term condition, therefore, Equation (3) is used.

Seismic Condition:

The value of seismic coeffcient, k_s is estimated considering factor of safety, FS = 1. (Note: seismic coefficient = yield acceleration, i.e. $k_s = k_y$). The seismic coefficient is calculated only for the long-term condition, i.e. it has been assumed that seismicity and seepage will not occur simultaneously. Therefore, equation (1) can be modified to provide an expression for k_s, as follows:

$$k_s = \frac{\left(\frac{c}{\gamma \ z \cos^2 \beta}\right) + \tan \phi - \tan \beta}{1 + \tan \phi \ \tan \beta} \qquad \text{Equation (5)}$$

<u>Reference:</u>

Matasovic, N., "Selection of Method for Seismic Slope Stability Analyses", *Proceedings of Second International Conference on Recent Advances in Geotechnical Engineering and Soil Dynamics,* St. Louis, Missouri, Paper No. 7.20, 1991, pp. 1057-1062.

Calculations

The following values have been assumed in the analyses:

γ =	130	pcf
γ_w =	62.4	pcf
h =	1.5	ft
dw =	0	ft
c =	0 to 50	psf
ϕ =	19 to 24	degrees

Calculation of slope angle

Horizontal	Vertical	tanβ	Slope Angle (β)		z
			rad	degrees	ft
5	1	0.2	0.1974	11.310	1.530

Static Conditions:

Case A: No seepage (long-term condition). Equation (4) is used to calculate FS:

c		Factor of Safety					
(psf)	ϕ =	19	20	21	22	23	24
0		1.72	1.82	1.92	2.02	2.12	2.23
10		1.98	2.08	2.18	2.28	2.38	2.49
20		2.24	2.34	2.44	2.54	2.65	2.75
30		2.51	2.60	2.70	2.80	2.91	3.01
40		2.77	2.87	2.97	3.07	3.17	3.27
50		3.03	3.13	3.23	3.33	3.43	3.53

Case B: Seepage (water at final cover surface) (short-term condition). Equation (3) is used to calculate FS:

c		Factor of Safety					
(psf)	ϕ =	19	20	21	22	23	24
0		0.90	0.95	1.00	1.05	1.10	1.16
10		1.16	1.21	1.26	1.31	1.37	1.42
20		1.42	1.47	1.52	1.57	1.63	1.68
30		1.68	1.73	1.78	1.83	1.89	1.94
40		1.94	1.99	2.04	2.10	2.15	2.20
50		2.20	2.25	2.31	2.36	2.41	2.47

Note: A drainage layer such as a drainage geocomposite or pipes may be needed to maintain stability of the final cover. The analyses assume that no water will present within the soils overlying the geosynthetics. The final cover drainage system will be designed as part of final closure.

Seismic Condition:

Only long-term condition is considered (it is assumed that seepage and seismicity do not occur simultaneously). Equation (5) is used to calculate ks:

c		k_s					
(psf)	ϕ =	19	20	21	22	23	24
0		0.14	0.15	0.17	0.19	0.21	0.23
10		0.18	0.20	0.22	0.24	0.26	0.27
20		0.23	0.25	0.27	0.29	0.30	0.32
30		0.28	0.30	0.32	0.33	0.35	0.37
40		0.33	0.35	0.37	0.38	0.40	0.42
50		0.38	0.40	0.41	0.43	0.45	0.47