# FINAL
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# GEOTECHNICAL AND SLOPE STABILITY ANALYSIS

# MALJAMAR PIPELINE RELEASE SITE

# MALJAMAR (LEA COUNTY), NEW MEXICO

## NMOCD 1-RP NO. 956

*Prepared for*
BP Pipelines (North America), Inc.
302 East Avenue A
Lovington, New Mexico 88260

And

Atlantic Richfield Company
(a BP Affiliate) Remediation Management
501 Westlake Park Boulevard
Houston, Texas 77079

July 2007

*Prepared by*

**URS**
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Project No. 41008426

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July 12, 2007

Mr. Glenn Von Gonten
New Mexico Oil Conservation Division
1220 S. St. Francis
Santa Fe, New Mexico 87505

**Re: Submittal of *Geotechnical and Slope Stability Analysis Technical Memorandum,* Maljamar Pipeline Release Site, Maljamar (Lea County), New Mexico, NMOCD 1-RP No. 956**

Dear Mr. Gonten,

On behalf of BP Pipelines (North America), Inc., enclosed please find the above-referenced technical memorandum. The *Geotechnical and Slope Stability Analysis Technical Memorandum* documents the results of the September 2006 geotechnical sampling activities and the subsequent slope stability analysis that established the safety conditions of the open North Site excavation and were used to support excavation management planning.

Please note that as of July 1, 2007, responsibility for this site has been transferred to Centurion Pipeline, L.P. Should you have any questions or require further assistance regarding the submittal of this report, please contact Mr. Bill Von Drehle at 713.215.7379.

Sincerely,
**URS Corporation**

Shannon A. Hoover
Senior Geologist

cc: Mr. Jimmy Humble, BP Pipelines (North America), Inc.,
Lovington, New Mexico

Mr. Michael Whelan, Atlantic Richfield Company (a BP Affiliate), Remediation Management, Houston, Texas

Mr. Larry Johnson, New Mexico Oil Conservation Division,
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## Certificate of Engineer

The technical material and data contained in this report were prepared under the supervision and direction of the undersigned, whose seal as a professional engineer is affixed below.

Donald T. Lopez, PE
New Mexico Registered
Professional Engineer,
License Number 5122
URS Corporation
July 6, 2007

DONALD T. LOPEZ
5122

## 1.0 INTRODUCTION

BP Pipelines (North America), Inc. (BP Pipeline NA) operated a 6-inch crude oil gathering line in Lea County, New Mexico (operated by Centurion Pipeline, L.P., a subsidiary of Occidental Petroleum Corporation as of July 1, 2007). Releases occurred at two locations along the line in December 2005, and are believed to have been the result of internal corrosion. The releases were discovered during aerial reconnaissance of the line. The two project sites (identified as the North and South Sites) are located within approximately 1,000 feet of each other, approximately 5 miles southeast of the town of Maljamar in Lea County (Figure 1). The North Site is located on State of New Mexico land, and the South Site is located on private property owned by Mr. Ross Caviness.

### 1.1 Background

BP Pipelines NA immediately repaired the lines at the two release locations and retained Conestoga-Rovers & Associates (CRA) to perform initial response activities. These activities included the excavation of impacted soils at each site to remove source area material and investigate the extent of the impacts. Excavation activities conducted at the North Site eventually reached an approximate depth of 50 feet below ground surface (bgs). Initial soil samples were collected during North Site excavation between approximately 33 to 50 feet bgs and submitted for benzene, toluene, ethylbenzene, and xylenes (BTEX) and total petroleum hydrocarbons (TPH) analysis. Concentrations of these chemicals of concern (COC) were detected in exceedence of the recommended remediation action levels listed in the New Mexico Oil Conservation Division's (NMOCD) *Guidelines for Remediation of Leaks, Spills and Releases* (August 1993). Limited exploratory excavation was performed at the South Site, but no soil samples were submitted for laboratory analysis. However, CRA indicated that PID readings were still elevated, and photographs of the excavation show residual staining.

Further response actions at the sites were performed to comply with NMOCD requirements and ensure that there is no remaining threat from the release to injure or be detrimental to public health, fresh waters, animal or plant life, or property or unreasonably interfere with the public welfare or use of the property. Following the initial response activities, and pursuant to the NMOCD's letter dated February 3, 2006, which directs that "BP shall vertically and horizontally delineate the vadose zone at each location according to OCD guidelines…," the primary objective of the project was to determine the horizontal and vertical extent of residual impacts, so that the next appropriate phase of response action could be evaluated. However, observations of the excavations at the sites indicated that minimum excavation safety conditions were not met.

Due to the nature of the loose fine sand and the presence of weak to no cementation, the Occupational Safety and Health Administration (OSHA) categorizes site soils as Class C (the worst class), and appropriate sloping of sidewalls for excavation safety would need to be or exceed 2 horizontal (H):1 vertical (V). Slope conditions of the open excavation sidewalls at the North Site were determined to be less than 2H:1V on three of the four sidewalls.

Empirical observations (staining and sampling during initial response actions and soil type) indicate that the crude oil migration pathway in the subsurface was predominantly vertical, with limited horizontal spread. Therefore, determination of the vertical extent of residual impacts necessitated that any investigative activities be conducted at and in the immediate vicinity of the release. But, since the excavation did not meet minimum standards for safety, URS recommended that workers or equipment not enter the area for further delineation investigation. The excavations would need to be managed before any subsurface investigation work could be performed.

An initial exploratory boring program was conducted in September 2006 to 1) collect data to support the development of a plan to appropriately and safely manage the excavations so that further delineation investigation could be pursued, and 2) to collect initial environmental data to provide an indication of potential extent of impacts in soil and groundwater. The initial exploratory boring program was performed in accordance with the August 2006 *Work Plan – Initial Exploratory Borings, Maljamar Pipeline Release Site* (Work Plan), which was approved by the NMOCD on September 5, 2006. A document entitled *Technical Memorandum – Initial Exploratory Soil Boring Program, Maljamar Pipeline Release Site* that documented the results of the environmental sampling was submitted to the NMOCD in December 2006.

The results of the geotechnical and slope stability analysis detailed in this document were used to evaluate different options for managing the North and South Site excavations. Ultimately, the North Site excavation was addressed by utilizing existing stockpiled soil that met allowable levels to return to the excavation per NMOCD approval, and backfilling the excavation remotely with a truck-mounted telescopic conveyor belt (tele-belt). The South Site was also backfilled but was shallow enough to accomplish the task with excavators and bulldozers. Upon completion of the backfilling activities, additional soil borings and monitoring wells were installed at both the North and South Sites to complete source area characterization, delineating both the vertical and horizontal extent of impacts. The backfilling and delineation activities were detailed in a document entitled *Technical Memorandum – Excavation Backfilling and Source Area Characterization, Maljamar Pipeline Release Site* that was submitted to the NMOCD in June 2007.

## 1.2 Objective

The objective of this technical memorandum is to document the results of the September 2006 geotechnical sampling activities and the subsequent slope stability analysis that established the safety conditions of the open North Site excavation and were used to support excavation management planning.

## 2.0 INVESTIGATION ACTIVITIES

To further evaluate and manage site conditions so that further investigation of residual impacts from the release could be pursued, URS proposed the initial exploratory soil boring program in the August 2006 Work Plan. This soil boring program was primarily intended to acquire geotechnical data to facilitate slope stability analysis and excavation management plan development for the North and South Site excavations. URS also utilized the initial soil borings for the purpose of investigating the horizontal extent of residual impacts and assessing groundwater conditions (e.g., presence of possible impacts), primarily at the North Site during the initial drilling mobilization (see Technical Memorandum dated December 2006).

In order to achieve the objectives of the August 2006 Work Plan, the following steps were conducted:

- Installation of four exploratory soil borings at the North Site to approximately 130 feet bgs, which were subsequently converted to groundwater monitoring wells;
- Installation of four exploratory soil borings at the South Site to 50 feet bgs (properly plugged and abandoned with cement grout after installation in accordance with New Mexico regulations);
- Collection of soil samples for geotechnical and environmental analysis;
- Collection of groundwater samples from the four North Site monitoring wells for groundwater assessment.

The results of the geotechnical analyses were then used to conduct a slope stability analysis of the North Site excavation and to support development of an appropriate excavation management plan. This technical memorandum describes only the geotechnical sampling activities and subsequent slope stability analysis.

URS retained the services of WDC Exploration, a State of New Mexico-licensed driller, for boring and monitoring well installation. Borings were installed at the locations shown on Figure 2 (North Site) and Figure 3 (South Site) utilizing hollow stem auger (HSA) drilling. Locations were selected to be close enough to the existing excavation edge to acquire geotechnical information from the adjacent area where heavy equipment operation and earth-moving were anticipated, but far enough away that monitoring wells were not likely to be jeopardized during future earth-moving activities. Boring logs, including well completion details, are included in Appendix A.

The initial exploratory soil boring program for the North and South Sites is discussed in the following subsections.

## 2.1 North Site

- Four monitoring wells (B-1/MW-1 through B-4/MW-4) were installed to approximately 10 feet within the first saturated zone (Figure 2). Total depths of exploration ranged from 128.5-132.5 feet bgs. Bedrock was not encountered in any of the borings installed at the site.
- Standard penetration testing (SPT) was performed every 5 feet.
- Split spoon samples were collected every 5 feet for lithologic description and field screening (i.e., headspace analysis) with a properly calibrated photoionization detector (PID) for the presence of volatile organic compound (VOC) vapors. One sample collected per 10-foot interval was submitted to AMEC in Albuquerque, New Mexico for analysis of grain size. Atterberg Limits were also proposed in the August 2006 Workplan; however, the samples did not contain sufficient amounts of clay, and Atterberg Limits testing was not performed.
- For additional geotechnical analysis, two undisturbed samples were collected from each soil boring for direct shear tests, with one sample representing the upper 50 feet bgs (representative of conditions associated with the excavation) and the second sample representing the interval between 50 and 75 feet bgs (in the event that future remedial action might include excavation beyond a depth of 50 feet bgs). These samples were submitted to AMEC in Albuquerque, New Mexico.

## 2.2 South Site

- Four soil borings (B-5 through B-8) were installed to total depths of 51.5 feet bgs (Figure 3). Neither bedrock nor groundwater was encountered in any of the borings installed at the South Site.
- SPT was performed every 5 feet.
- Split spoon samples were collected every 5 feet for lithologic description and field screening (i.e., headspace analysis) with a properly calibrated PID for the presence of VOC vapors. One sample collected per 10-foot interval was submitted to AMEC in Albuquerque, New Mexico for analysis of grain size.

Atterberg Limits were also proposed in the August 2006 Workplan; however, the samples did not contain sufficient amounts of clay, and Atterberg Limits testing was not performed.

- For geotechnical purposes, two undisturbed samples were collected per soil boring for direct shear tests, with one sample representing the upper 25 feet bgs and the second sample representing the interval between 25 and 50 feet bgs. These samples were submitted to AMEC in Albuquerque, New Mexico.

# 3.0 SITE CHARACTERISTICS

## 3.1 Geology

*Regional Geology*

According to the Hobbs Sheet of the Geologic Atlas of Texas (includes the southeast portion of New Mexico), the area is underlain by Quaternary-aged colluvial slopewash and talus deposits of sands, silts, and gravels from the Ogallala Formation of the caprock to the north. Caliche layers within the colluvial deposits are reportedly up to 20 feet thick. The Gatuña Formation, which consists primarily of fine friable sand, may underlie the area, with these surficial deposits ultimately overlying Triassic- or Permian-aged bedrock of claystone, siltstone, and sandstone.

*Site Geology*

Based on the lithology described during installation of the initial soil borings in September 2006, the North and South Sites were determined to be underlain by moderately well sorted very fine to fine sand with weak to poor calcareous cementation and lenses of caliche and caliche gravel. The moderately well sorted sand extends to depths of approximately 50-60 feet bgs, where alternating areas of poorly sorted and moderately well sorted sand are present. At depths of approximately 40-60 feet bgs, the sand includes pockets of well-cemented lithified sandstone. At approximately 120 feet bgs silty sand may be present above gravelly sand or sand with trace amounts of gravel. While removing the augers from MW-2/B-2, the bottom of the lead auger was observed to have dark red silty clay. An expanded description of site lithology, based on subsequent subsurface investigation, is included in the June 2007 document entitled *Technical Memorandum - Excavation Backfilling and Source Area Characterization, Maljamar Pipeline Release Site.*

Observations of lithology through the initial investigated depth of 132.5 feet bgs at the North Site and 51.5 feet bgs at the South Site are consistent with the colluvial deposits and Gatuña Formation. No bedrock was observed in the soil borings installed at the North and South Sites. The boring logs are provided in Appendix A.

## 3.2 Hydrogeology

State well records indicate that depth to water in registered water wells in the area are on the order of 170 to 190 feet bgs; however, the coordinates of these wells indicate they are located to the north of the site at positions atop the caprock, which appears to be approximately 75-100 feet higher in elevation than the site. State well records were also identified for the property to the south, owned by Mr. Caviness, but the well records did not include depth to water information. Mr. Caviness recalled that depth to groundwater in one of his water wells located approximately one mile south of the sites was approximately 125 feet bgs.

Based on the initial fluid levels measured on September 29, 2006, depth of groundwater beneath the North Site ranges from approximately 115-122 feet bgs (approximately 118-125 feet below the top of casing), with groundwater flow to the south-southwest. Fluid levels measured during subsequent investigation activities confirmed groundwater depths at the North Site and indicated depth to groundwater at the South Site ranges from approximately 108 to 110 feet bgs (approximately 111 to 113 feet below the top of casing), with groundwater flow to the south-southwest (see June 2007 Technical Memorandum). Therefore, groundwater was not anticipated within the immediate vicinity of the excavations.

## 4.0 GEOTECHNICAL SAMPLING

This section provides results for geotechnical samples collected during the initial exploratory soil borings installed in September 2006 and the subsequent slope stability analysis performed with the geotechnical data obtained.

### 4.1 Grain Size

Split-spoon samples were collected from soil borings B-1 through B-8 every 5 feet. One sample from every 10 foot interval was selected for submittal to AMEC in Albuquerque, New Mexico for grain size analysis. Samples were collected as summarized in Table 1.

**Table 1**
**Summary of Soil Samples Collected for Grain Size Analysis**
**Maljamar Pipeline Release Site**
**Maljamar, New Mexico**
**NMOCD 1-RP No. 956**

| *Boring* | | | | | | | |
|---|---|---|---|---|---|---|---|
| **North Site** | | | | **South Site** | | | |
| B-1 | B-2 | B-3 | B-4 | B-5 | B-6 | B-7 | B-8 |
| *Depth in feet bgs* | | | | | | | |
| 10-11.5 | 10-11.5 | 10-11.5 | 10-11.5 | 10-11.5 | 10-11.5 | 10-11.5 | 10-11.5 |
| 20-21.5 | 20-21.5 | 20-21.5 | 20-21.5 | 15-16.5 | 20-21.5 | 20-21.5 | 20-21.5 |
| 30-31.5 | 30-31.5 | 30-31.5 | 30-31.5 | 30-31.5 | 30-31.5 | 30-31.5 | 30-31.5 |
| 40-41.5 | 40-41.5 | 40-41.5 | 40-41.5 | 45-46.5 | 40-41.5 | 40-41.5 | 40-41.5 |
| 50-51.5 | 50-51.5 | 50-51.5 | 50-51.5 | 50-51.5 | 50-51.5 | 45-46.5 | 45-46.5 |
| 60-61.5 | 60-61.5 | 60-61.5 | 60-61.5 | | | | |
| 75-76.5 | 70-71.5 | 75-76.5 | 70-71.5 | | | | |
| 85-85.5 | 80-81.5 | 80-81.5 | 80-81.5 | | | | |
| 100-101.5 | 90-91.5 | 90-91.5 | 90-91.5 | | | | |
| 110-111.5 | 100-101.5 | 100-101.5 | 100-101.5 | | | | |
| 115-116.5 | 110-111.5 | 110-111.5 | 115-116.5 | | | | |
| | 120-121.5 | | 125-126.5 | | | | |

Samples collected from the borings indicated little change in the lithology encountered during the soil boring program (see Section 3.0 and boring logs in Appendix A).

Therefore, the selection of samples on 10-foot intervals is sufficient to characterize the variations in grain size throughout the investigated depth.

Results from the grain size analyses indicate that the site is predominantly underlain by cohesionless silty sand. The laboratory reports for the grain size analyses are included in Appendix B. (Note: The samples for boring B-4 appear to have been lost in transit to AMEC and have not been located. Due to the similarity of the lithology throughout all of the borings; however, any additional data from boring B-4 is not anticipated to have contributed to different results than provided by the remaining seven borings.)

## 4.2 Direct Shear Tests

Two undisturbed samples were also collected from each soil boring for direct shear tests using dedicated brass ring samplers composed of 6 one-inch rings. Samples collected from each boring for direct shear testing are summarized in Table 2.

**Table 2**
**Summary of Soil Samples Collected for Direct Shear Testing**
**Maljamar Pipeline Release Site**
**Maljamar, New Mexico**
**NMOCD 1-RP No. 956**

| *Boring* | | | | | | | |
|---|---|---|---|---|---|---|---|
| **North Site** | | | | **South Site** | | | |
| B-1 | B-2 | B-3 | B-4 | B-5 | B-6 | B-7 | B-8 |
| *Depth in feet bgs* | | | | | | | |
| 25-25.5 | 20-20.5 | 20-20.5 | 20-20.5 | 20-20.5 | 25-25.5 | 20-20.5 | 20-20.5 |
| 70-70.5 | 60-60.5 | 50-50.5 | 50-50.5 | 40-40.5 | 40-40.5 | 40-40.5 | 40-40.5 |

The results of the initial exploratory soil boring program indicated that the lithology throughout the investigated depth was similar. Therefore, the samples selected for direct shear testing are representative of those soils likely to be encountered at the open excavations. These samples are also representative of deeper soils should additional excavation be warranted for further response actions.

The results indicate that the final wet density of the samples ranged from 119.3 to 128.7 pounds per cubic foot (lbs/ft$^3$), the internal friction angle ranged from 21.6° to 34.5°, and cohesion ranged from 0 to 0.588 kips per square foot (ksf). The results of the shear tests on each of the samples are summarized in Table 3.

### Table 3
### Summary of Direct Shear Testing Results
### Maljamar Pipeline Release Site
### Maljamar, New Mexico
### NMOCD 1-RP No. 956

| *Boring* | *Final Wet Density (γ)* | *Sample Depth (feet bgs)* | *Soil Type* | *Internal Friction Angle (φ)* | *Cohesion (ksf)* |
|---|---|---|---|---|---|
| B-1 | 128.7 | 25.5 | silty sand | 33.8° | 0 |
| B-1 | 124.2 | 70.5 | silty clayey sand | 27.2° | 0.511 |
| B-2 | 122.69 | 20.5 | silty sand | 24.2° | 0.037 |
| B-2 | 124.2 | 60.5 | silty sand | 22.3° | 0.588 |
| B-3 | 124.2 | 20.5 | silty sand | 28.4° | 0.098 |
| B-3 | 128 | 50.5 | silty sand | 24.5° | 0.256 |
| B-5 | 130 | 20.5 | silty sand | 34.5° | 0 |
| B-5 | 122.5 | 40.5 | silty sand | 27.8° | 0.124 |
| B-6 | 120.6 | 25.5 | silty sand | 25.6° | 0.044 |
| B-6 | 122.4 | 40.5 | silty sand | 28.1° | 0.142 |
| B-7 | 126 | 20.5 | silty sand | 24.5° | 0.096 |
| B-7 | 123.4 | 40.5 | silty sand | 29.4° | 0 |
| B-8 | 124.3 | 20.5 | silty sand | 21.6° | 0.58 |
| B-8 | 119.3 | 40.5 | silty sand | 28.6° | 0.158 |

## 5.0 SLOPE STABILITY ANALYSIS

A slope stability analysis of the open North Site excavation was performed to determine the safety of the excavation and to ensure that the stability of the excavation was considered during the planning and execution of any approach to excavation management. A qualified registered professional engineer in the State of New Mexico must perform and evaluate the results of the slope stability analysis to ensure that work meets the standard of care for engineering practice. Considerable engineering judgment is required to properly evaluate the results so that excavation safety is always maintained.

Mr. Donald T. Lopez of the URS Albuquerque Office, a State of New Mexico Registered Professional Engineer (PE) highly qualified in geotechnical engineering, performed the slope stability analysis. Mr. Lopez is a key project team member as the Project Geotechnical Engineer, has been involved with the evaluation of site conditions and the development of the August 2006 Work Plan, and was involved with the evaluation of different management methods and ultimately the development and execution of the excavation management plan used to backfill the excavations.

The slope stability analysis was performed using the geotechnical investigation data and results acquired during the initial exploratory soil boring program performed in September 2006 and the computer modeling program entitled *GSLOPE* version 4.1, a Limit Equilibrium Slope Stability Analysis for Windows (copyright 2004 Mitre Software Corporation). Mr. Lopez has used this modeling software program for slope stability analyses for over 17 years, and *GSLOPE* is extensively used by various state agencies, numerous consultants, suppliers, and mining companies throughout the world. The soil at this site is classified predominantly as a silty sand, which is generally a cohesionless material. Therefore, the direct shear test, which determines the drained shear strength of a material, is appropriate for use in the slope stability analysis of the excavation.

The user's manual for *GSLOPE*, which provides technical specifications of this model, and the resulting cross-sections from the model, are included in Appendix C. The slope stability analysis steps and results are outlined below:

- Based on a topographic survey conducted by a State of New Mexico-licensed land surveyor, the steepest excavation slope from the North Site was identified. The steepest current slope was used in the slope stability analysis as the area representing the least safe conditions. A topographic plan and representative cross-sections of the existing North Site excavation are depicted on Figure 4.

- Initial visual observations of the excavation, the depth of the open excavation (greater than 20 feet bgs), and the understanding of the soil type (Class C), indicated that the sidewalls of the excavation would need to be sloped greater than a ratio of 2 H:1V to meet OSHA safety standards. The Project Engineer determined that the sidewalls would have to be sloped at a ratio of 3H:1V in order to meet minimum safety requirements.

- The shear strengths from all of the data obtained from borings B-1 through B-8 were plotted on a graph (see Appendix C). Representative values were selected from all of the direct shear strength data for use in *GSLOPE*. The values selected (internal friction angle of 24° and cohesion of 50 pounds per square foot) are not the lowest values derived from the direct shear testing, but industry standard recommends 2/3 of all of the values obtained should be above the selected values used in the slope stability analysis.

- The slope stability analysis was performed assuming that saturated conditions existed at the bottom of the current exaction. This assumption was chosen to be conservative and to understand factor of safety conditions if precipitation events contributed to higher water content in soils during excavation management activities.

- The model calculated the existing factor of safety for the steepest slope of the open North Site excavation. This factor of safety was determined to be approximately 1.082, indicating that the open excavation had the lowest factor of safety and confirmed previous observations that the slopes of the North Site excavation do not meet minimum safety conditions (Note: industry standards generally recommend a factor of safety on the order of 1.5 for similar types of excavation work). The initial model run also showed that no work should be conducted within 10 feet of the edge of the excavation. Therefore, a minimum safe work limit line of 10 feet from edge of the excavation was established. However, additional modeling was performed to assess the affects of weight and vibration from heavy equipment during excavation management work. The work limit line was adjusted farther from the edge of the excavation accordingly during backfilling activities at the direction and professional judgment of the Project

Geotechnical Engineer (e.g., 15 feet for personnel, 25 feet for excavators and bulldozers, and 40 feet for the tele-belt) to protect the safety of site workers. The cross-sections of the model that illustrate the factor of safety for the open North Site excavation and the effects of weight and vibration are included in Appendix C.

- No further analysis was performed for the South Site excavation. This excavation is much smaller relative to the North Site. The technical approach to address the South Site was to backfill the excavation in preparation for further source area characterization activities (i.e., soil boring and groundwater monitoring well installation). Based on survey data, the South Site excavation is approximately 10 feet in depth at its deepest point, and a 10-foot safe work zone from the edge of the excavation for heavy equipment and personnel were determined to be sufficient for safety.

## 6.0 CONCLUSIONS

The conclusions of the geotechnical and slope stability analysis are as follows:

- The site is predominantly underlain by a silty fine sand, with little variation in lithology from the surface to the groundwater table, where coarser grained materials were encountered (see boring logs in Appendix A and grain size reports in Appendix B).

- Depth to groundwater is approximately 120 feet bgs, not within or near the limits of the open excavations, and was not a consideration with regard to slope stability analysis. However, the slope stability analysis did assume possible saturated conditions at the bottom of the North Site excavation to account for higher potential water content in soils as a result of precipitation events.

- The results of the slope stability analysis demonstrated that the factor of safety for the steepest sidewall of the open excavation was approximately 1.082 (versus a minimum industry standard of 1.5), confirming that the excavation did not meet minimum safety conditions.

- Based on the results of the slope stability analysis, the Project Geotechnical Engineer set minimum work limit lines for personnel and heavy equipment to protect site workers during excavation management activities.

# FIGURES

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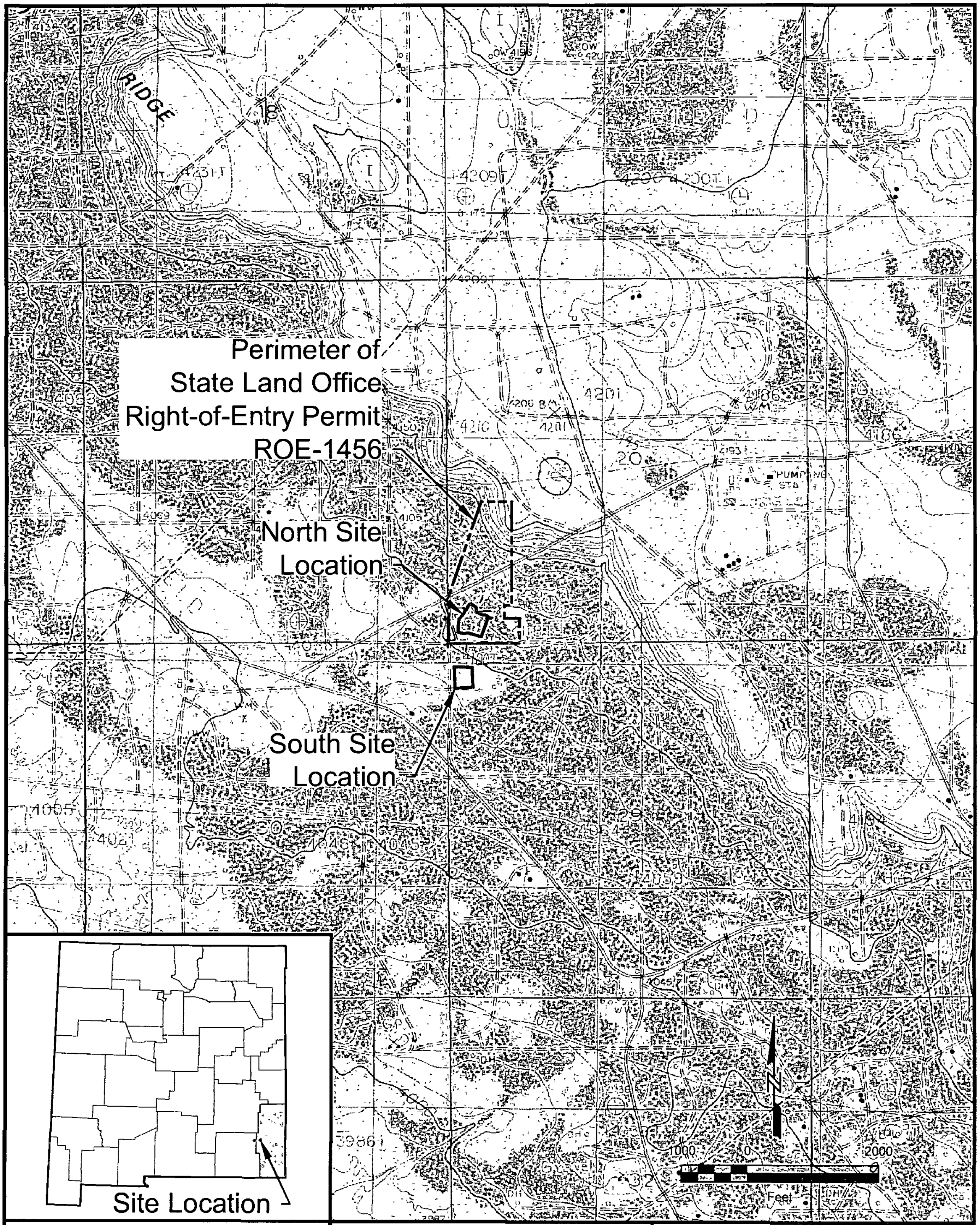

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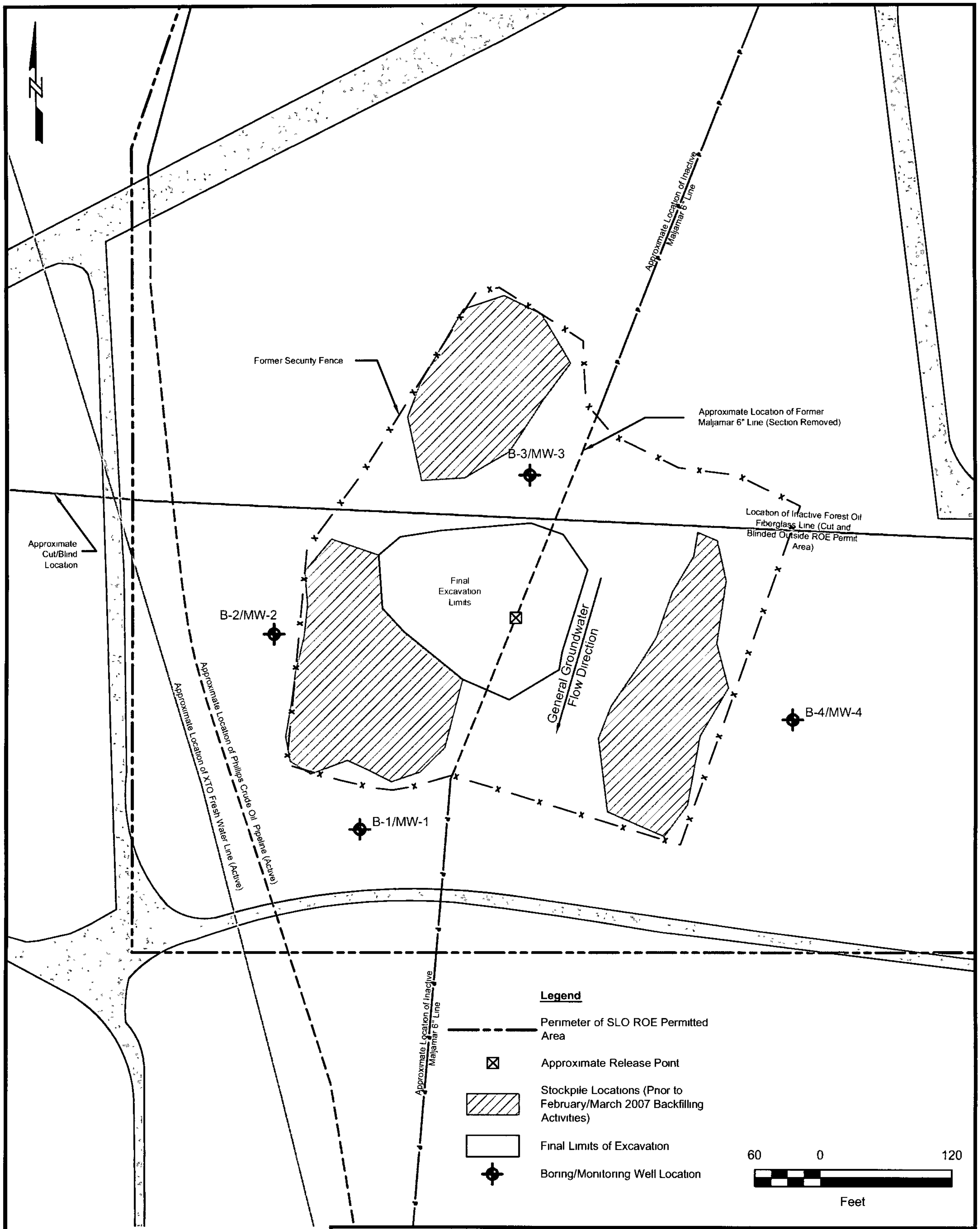
BP Pipeline (North America), Inc.
Maljamar Pipeline Release Site
NMOCD 1-RP No. 956
Maljamar, New Mexico

DATE:
DRWN:

**Site Location Map**
**Geotechnical and Slope Stability Analysis**

**Figure 1**



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BP Pipeline (North America), Inc.
Maljamar Pipeline Release Site
NMOCD 1-RP No. 956
Maljamar, New Mexico

**Soil Boring/Monitoring Well Locations**
**North Site**
**Geotechnical and Slope Stability Analysis Technical Memorandum**

DATE:
DRWN:

**Figure 2**

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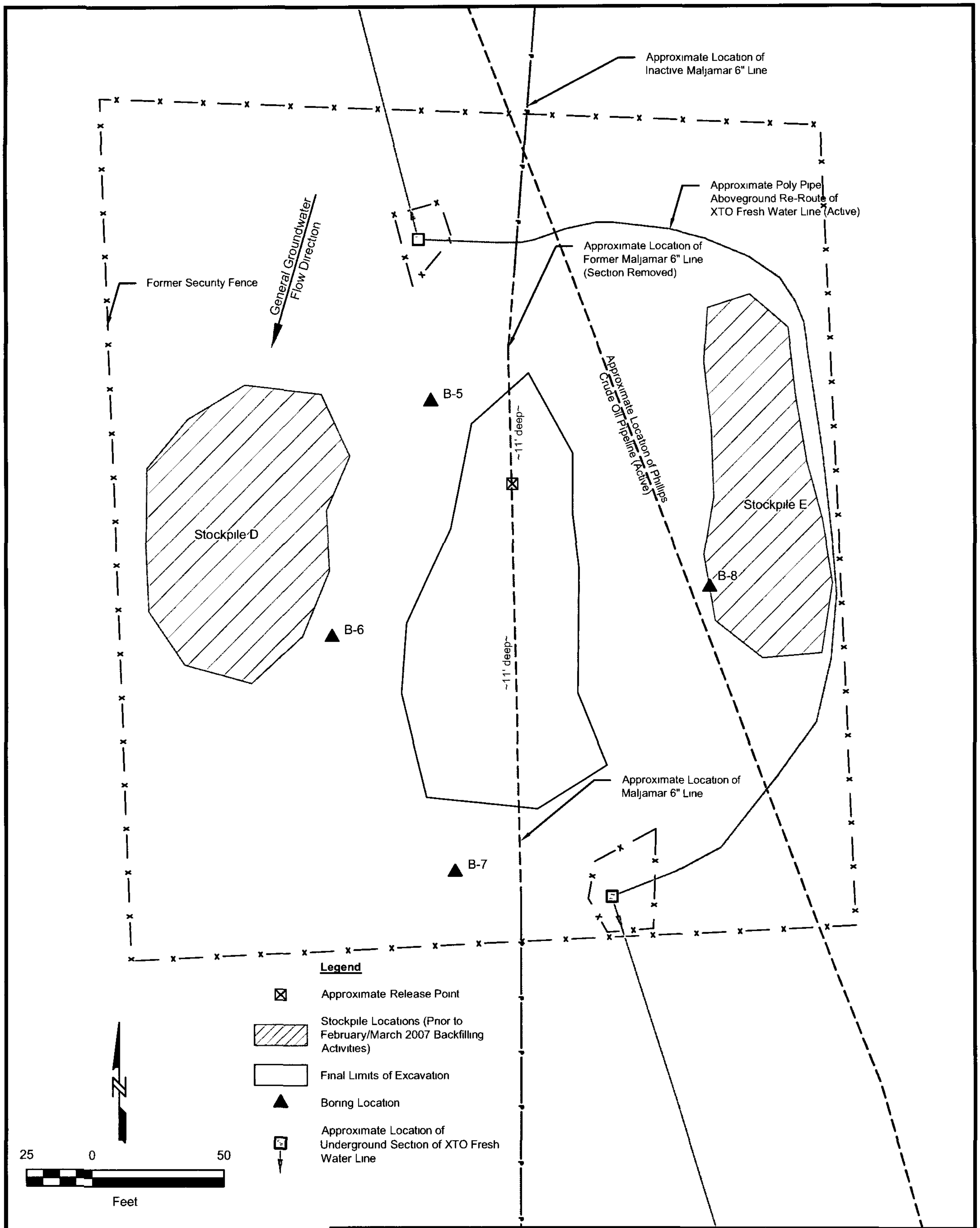

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BP Pipeline (North America), Inc.
Maljamar Pipeline Release Site
NMOCD 1-RP No. 956
Maljamar, New Mexico

**Soil Boring Locations**
**South Site**
**Geotechnical and Slope Stability Analysis Technical Memorandum**

DATE:
DRWN:

**Figure 3**

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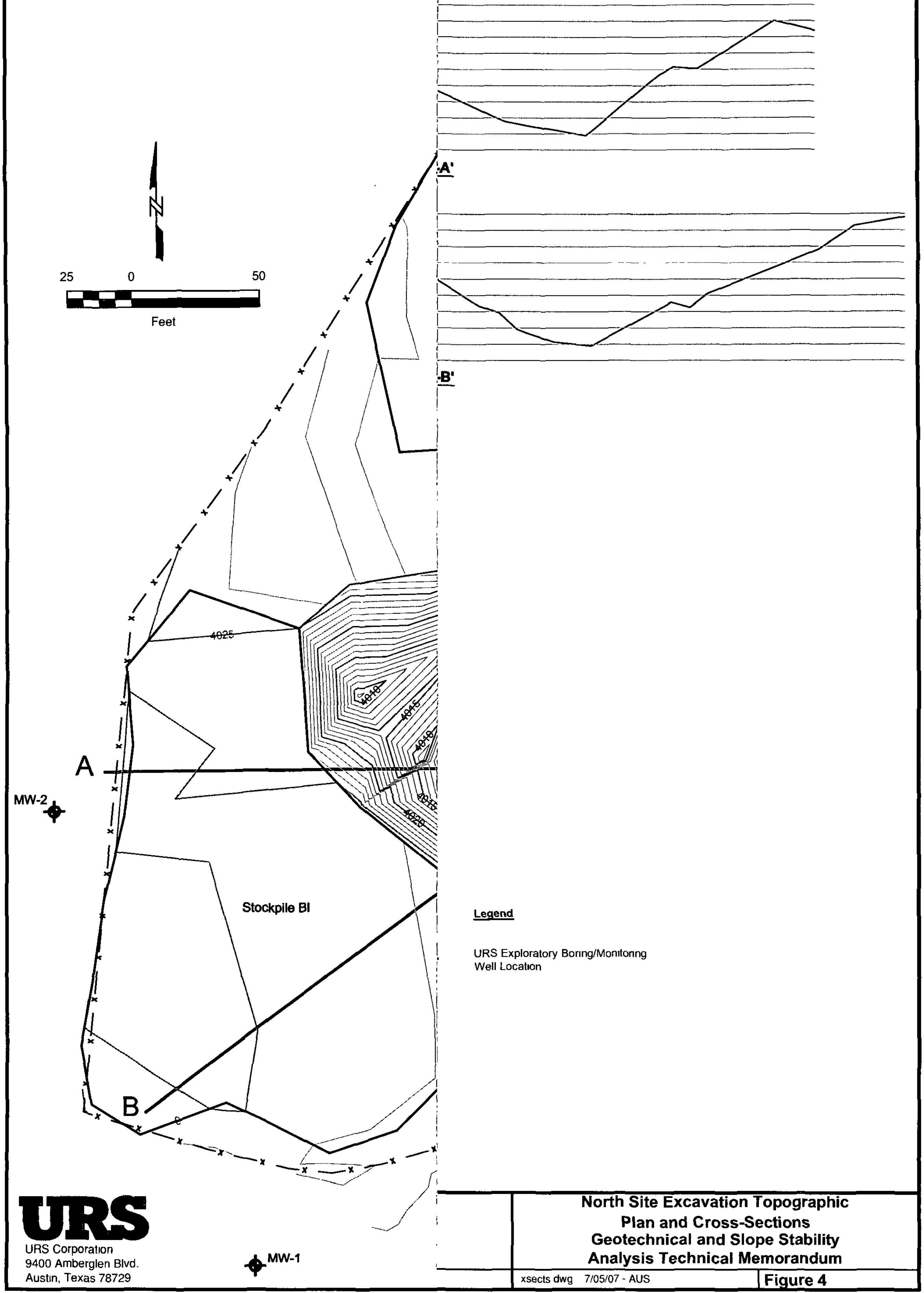

**Legend**

URS Exploratory Boring/Monitoring Well Location

**URS**

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## North Site Excavation Topographic Plan and Cross-Sections Geotechnical and Slope Stability Analysis Technical Memorandum

xsects dwg 7/05/07 - AUS

**Figure 4**

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# APPENDIX A
# SOIL BORING LOGS

URS

## SOIL BORING AND WELL LOG

| | |
|---|---|
| **Boring/Well ID:** B-1 / MW-1 | **Total Depth:** 130 feet bgs |

| PROJECT INFORMATION | DRILLING INFORMATION |
|---|---|
| **Project:** BP Pipeline | **Drilling Company:** WDC |
| **Location:** Maljamar, New Mexico | **Drilling Equipment:** CME 85 |
| **Site Name:** North Excavation | **Drilling Method:** Hollow Stem Auger |
| **Project Number:** 41008243.00005 | **Sampling Method:** Split Spoon |
| **Logged By:** Rita Krebs | **Driller:** George Guzman |
| **Project Manager:** Shannon Hoover, P.G. | **Dates Drilled:** September 13-14, 2006 |

| Depth (feet bgs) | Sample Recovery (inches) | Blow Counts (per 6 inches) | PID (ppmv) | USCS Symbol | Lithology Symbol | Lithology Description and Notes | Well Construction |
|---|---|---|---|---|---|---|---|
| 0<br>2<br>4<br>6<br>8 | | | | SP | ░ | SAND<br>Potholed upper 6', logged from surface, pale brown (10 YR 6/3), tan fine loose sand, soft, friable, nonplastic, some silt, trace caliche nodules, moderately well sorted, dry, no odor, no staining | 2" PVC well (extends above grade inside 3" steel casing)<br>Grout to 110.5' |
| 10<br>12 | 18/18 | 5<br>7<br>10 | 0 | SP | ░ | SAND<br>Very pale brown (10 YR 7/3), loose, dry, moderately well sorted, very fine to fine sand with some silt, no odor, no staining | |
| 14<br>16<br>18 | 17/18 | 6<br>9<br>15 | 0 | SP | ░ | SAND<br>Same as above, no odor, no staining | |
| 20<br>22 | 18/18 | 4<br>20<br>28 | 0 | SP | ░ | SAND<br>As above, trace silt, slightly moist, no odor, no staining | |
| 24<br>26<br>28 | 12/12 | 19<br>50 | 0 | SP | ░ | SAND<br>As above with caliche nodules, slightly moist, no odor, no staining | |
| 30<br>32 | 17/18 | 17<br>50 | 0 | SP | ░ | SAND<br>As above, slightly moist, no odor, no staining | |
| 34<br>36<br>38 | 18/18 | 15<br>29<br>50 | 0 | SP | ░ | SAND<br>35.5', 1" Caliche gravel<br>36.0', 2" White caliche<br>38', Hard caliche layer (driller note) | |
| 40<br>42 | 12/18 | 50 | 0 | SP | ░ | SAND<br>Same as above, no odor, no staining | |
| 44<br>46<br>48 | 9/18 | 42<br>50 | 0 | SP | ░ | SAND<br>As above, trace 1" gravel, no odor, no staining | |
| 50<br>52<br>54 | 16/18 | 40<br>50 | 0 | SW | ░ | SAND<br>Light yellowish brown (10 YR 5/4), dense, some silt, trace (2%) fine to medium gravel, subangular sand is fine to medium with trace coarse sand, poorly sorted, slightly moist<br>50.5', Color change to brown (7 5 YR 5/4), no odor, no staining | |
| 56<br>58 | 0/18 | 34<br>50 | 0 | | | No recovery<br>56-57', Caliche layer (driller note)<br>58-59', Caliche layer (driller note) | |
| 60<br>62 | 9/18 | 50 | 0 | SW | ░ | SAND<br>Brown (7.5 YR 5/4), some silt, some friable sandstone, fine to medium sand, dense, trace fine subangular gravel, poorly sorted | |

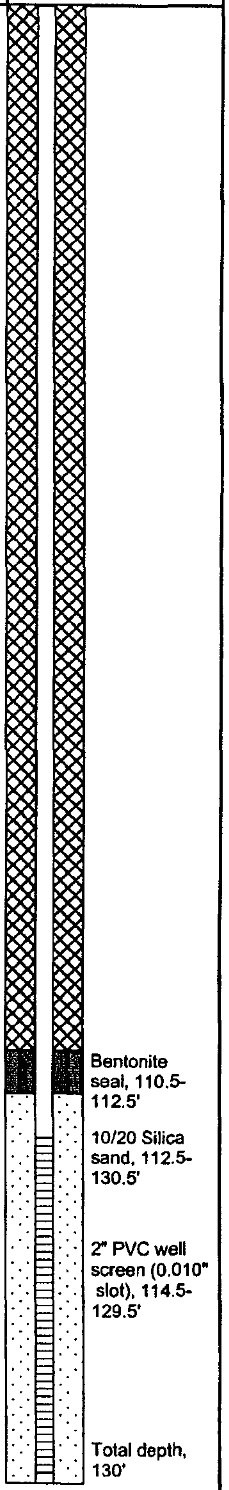
**URS**

## SOIL BORING AND WELL LOG

**Boring/Well ID:** B-1 / MW-1 | **Total Depth:** 130 feet bgs

| Depth (feet bgs) | Sample Recovery (inches) | Blow Counts (per 6 inches) | PID (ppmv) | USCS Symbol | Lithology Symbol | Lithology Description and Notes | |
|---|---|---|---|---|---|---|---|
| 64 | | | | | | | |
| 66 | 4/18 | 50 | 0 | SW | | SAND | As above, no odor, no staining, slightly moist |
| 68 | | | | | | | |
| 70 | 12/12 | 31<br>50 | 0 | SW | | SAND | Yellow (10 YR 7/6), very dense, slightly moist, 15% fine to medium angular to subrounded gravel, 10% silt, no odor, no staining, sand is very fine to very coarse, very poorly sorted. 70.25', Color change to brownish yellow (10 YR 6/6,) no staining, no odor. 71', <1" Green sandstone, friable, slightly moist |
| 72 | | | | | | | |
| 74 | | | | | | | |
| 76 | 6/18 | 50 | 0 | SW | | SAND | Brownish yellow (10 YR 6/6), dense, slightly moist, no staining, no odor, fine to medium sand, trace silt, trace fine subrounded gravel<br>76-77.5', Caliche layer (driller note) |
| 78 | | | | | | | |
| 80 | 6/18 | 50 | 0 | SW | | SAND | As above<br>81', Hard drilling with augers |
| 82 | | | | | | | |
| 84 | | | | | | | |
| 86 | 15/18 | 27<br>50 | 0 | SP | | SAND | Pinkish gray (7.5 YR 7/2), slightly moist, weakly cemented, very dense, moderately well sorted very fine to fine sand, trace silt |
| 88 | | | | | | | |
| 90 | 2/18 | 50 | | SP | | SAND | As above |
| 92 | | | | | | | |
| 94 | | | | | | | |
| 96 | 13/18 | 30<br>50 | 0 | SP | | SAND | As above except sand is fine to medium, trace fine rounded gravel, no odor, no staining, slightly moist |
| 98 | | | | | | | |
| 100 | 9/18 | 30<br>50 | 0 | SP<br>SW | | SAND | As above, slightly moist, no odor, no staining<br>100.5', Light brown (7.5 YR 6/4) very dense, slightly moist, very fine to very coarse sand, trace fine subangular gravel, very poorly sorted |
| 102 | | | | | | | |
| 104 | | | | | | | |
| 106 | 14/18 | 39<br>50 | 0 | SP | | SAND | Light brown (7.5 YR 6/4), slightly moist, dense very fine to fine sand with some silt, moderately well sorted, no odor, no staining |
| 108 | | | | | | | |
| 110 | 9/18 | 48<br>50 | 0 | SP | | SAND | As above, except color is light reddish brown (5 YR 6/4), moist |
| 112 | | | | | | | |
| 114 | | | | | | | |
| 116 | 13/18 | 46<br>50 | 0 | SP | | SAND | As above except nodules of hard friable lithified sandstone (2%) |
| 118 | | | | | | | |
| 120 | 9/18 | 100 | 0 | SW | | GRAVELLY SAND | Brown (7.5 YR 5/4), dense, wet, some clay and silt, fine subangular to subrounded gravel (up to 0.5 inch), no odor, no staining<br>120.5', Clay layer, reddish brown (5 YR 5/4), moist, stiff, trace subrounded fine gravel, no odor, no staining |
| 122 | | | | | | | |
| 124 | | | | | | | |
| 126 | 6/18 | NA | | SW | | SAND | As above, except saturated |
| 128 | | | | | | | |
| 130 | | | | | | | |
| 132 | | | | | | | |
| 134 | | | | | | | |
| 136 | | | | | | | |
| 138 | | | | | | | |

**Well Construction**



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## SOIL BORING AND WELL LOG

**Boring/Well ID:** B-2 / MW-2

**Total Depth:** 135 feet bgs

### PROJECT INFORMATION

**Project:** BP Pipeline

**Location:** Maljamar, New Mexico

**Site Name:** North Excavation

**Project Number:** 41008243.00005

**Logged By:** Rita Krebs

**Project Manager:** Shannon Hoover, P.G.

### DRILLING INFORMATION

**Drilling Company:** WDC

**Drilling Equipment:** CME 85

**Drilling Method:** Hollow Stem Auger

**Sampling Method:** Split Spoon

**Driller:** George Guzman

**Dates Drilled:** September 16-25, 2006

| Depth (feet bgs) | Sample Recovery (inches) | Blow Counts (per 6 inches) | PID (ppmv) | USCS Symbol | Lithology Symbol | Lithology Description and Notes | Well Construction |
|---|---|---|---|---|---|---|---|
| 0<br>2<br>4<br>6<br>8 | | | | SP | | SAND<br>0-6' Air knife for utility clearance, sand, light brown (7.5 YR 6/3), loose, moderately well sorted, very fine to medium sand, trace silt and clay, dry, no odor, no staining | 2" PVC well (extends above grade inside 3" steel casing)<br>Grout to 109 5' |
| 10<br>12 | 18/18 | 8<br>12<br>17 | 0 | SP | | SAND<br>Pink (7.5 YR 7/3), loose, moderately well sorted, very fine to medium sand (mostly fine sized). Caliche nodules, trace manganese nodules (1 cm) and FeOx staining, trace silt, no odor, no staining | |
| 14<br>16<br>18 | 18/18 | 13<br>24<br>31 | 0 | SP | | SAND<br>As above, except increased caliche and manganese nodules. Manganese nodules *are 2 cm, weak cement*, dense, slightly moist, no odor, no staining | |
| 20<br>22 | 12/12 | 22<br>43 | 0 | SP | | SAND<br>As above, no odor, no staining | |
| 24<br>26<br>28 | 18/18 | 24<br>50 | 0 | SP | | SAND<br>As above, very fine to medium sand (mostly medium sized) | |
| 30<br>32 | 18/18 | 22<br>50 | 0 | SP | | SAND<br>As above, no odor, no staining | |
| 34<br>36<br>38 | 18/18 | 13<br>15<br>31 | 0 | SP | | SAND<br>As above, except very dense, increased caliche cement, no odor, no staining | |
| 40<br>42 | 18/18 | 18<br>30<br>50 | 0 | SP | | SAND<br>As above with trace fine caliche gravel, no odor, no staining | |
| 44<br>46<br>48 | 18/18 | 32<br>50 | 0 | SW | | SAND<br>Pink (7.5 YR 7/4), very dense, slightly moist, poorly sorted, very fine to very coarse subangular sand, trace (2%) fine subangular gravel, 1 cm pockets of strongly cemented lithified sandstone | |
| 50<br>52 | 18/18 | 36<br>42<br>50 | 0 | SW | | SAND<br>As above, except no *gravel, yellow* FeOx staining, sand is mostly fine sized, ranging from very fine to coarse with little silt, no odor, no staining<br>51.5', 0.5" hard white caliche, | |
| 54<br>56<br>58 | 18/18 | 37<br>47<br>50 | 0 | SW | | SAND<br>As above with two 0.5" white hard caliche layers at 55'<br>55.75', 2" gravelly sand, fine to medium angular gravel (up to 1.5 cm)<br>56.0', sand is very fine to very coarse, subangular, mostly medium sized trace fine subangular gravel, no odor, no staining | |
| 60<br>62 | 12/12 | 43<br>50 | 0 | SP | | SAND<br>Pinkish gray (7.5 YR 7/2), moderately well sorted, dense, slightly moist, weakly cemented, very fine to medium sand (mostly fine), trace silt, thinly bedded (1cm bedding layers) | |

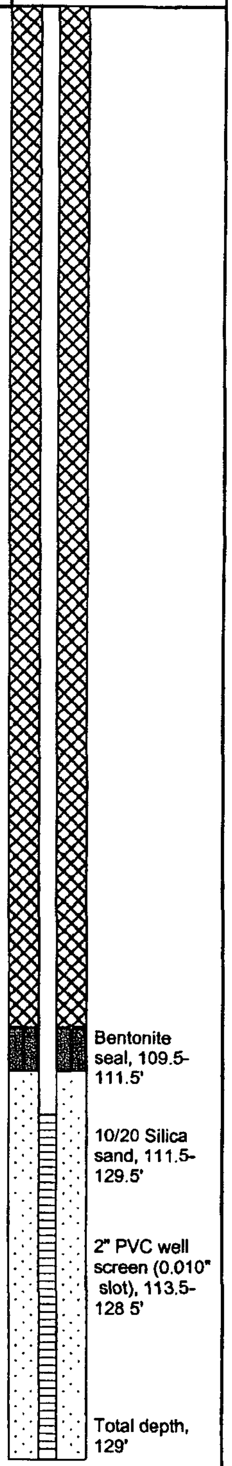
URS

## SOIL BORING AND WELL LOG

**Boring/Well ID:** B-2 / MW-2 | **Total Depth:** 135 feet bgs

| Depth (feet bgs) | Sample Recovery (inches) | Blow Counts (per 6 inches) | PID (ppmv) | USCS Symbol | Lithology Symbol | Lithology Description and Notes | |
|---|---|---|---|---|---|---|---|
| 64 | | | | | | | |
| 66 | 18/18 | 43<br>50 | 0 | SP | ░ | SAND | As above with trace yellow FeOx staining, trace fine subrounded gravel (green rhyolite porphyry) |
| 68 | | | | | | | |
| 70 | 18/18 | 15<br>24<br>47 | | SP | ░ | SAND | As above, coarsening with depth, sand is mostly medium sized |
| 72 | | | | | | | |
| 74 | | | | | | | |
| 76 | 18/18 | 34<br>41<br>50 | 0 | SP | ░ | SAND | As above, except sand is very fine to fine (mostly fine), three 1 cm white hard caliche layers between 75-75.5', very dense, no odor, no staining |
| 78 | | | | | | | |
| 80 | 18/18 | 20<br>25<br>44 | 0 | SP<br>CL<br>SP | ░<br>▨<br>░ | SAND<br>CLAY<br>SAND | 80-81 as above, coarsening to very fine to medium<br>81-81.3 clay, reddish brown, very stiff, medium plasticity, moist, no odor, no staining<br>81 3' sand, pink (7.5 YR 8/3) dense, slightly moist, moderately well sorted, very fine to fine sand, little silt, no odor, no staining |
| 82 | | | | | | | |
| 84 | | | | | | | |
| 86 | 18/18 | 37<br>35<br>50 | 0 | SP | ░ | SAND | As above, no odor, no staining |
| 88 | | | | | | | |
| 90 | 12/18 | 50 | 0 | SP | ░ | SAND | As above, with 1 cm pockets of lithified sandstone, moist |
| 92 | | | | | | | |
| 94 | | | | | | | |
| 96 | | | | | | | No split spoon sample |
| 98 | | | | | | | |
| 100 | 12/18 | 27<br>50 | 0 | SP | ░ | SAND | Light reddish brown (5 YR 6/4), slightly moist, fine to medium sand, trace silt, trace white rounded caliche gravel, no odor, no staining |
| 102 | | | | | | | |
| 104 | | | | | | | |
| 106 | 15/18 | 41<br>50 | 0 | SP | ░ | SAND | Coarsening with depth, fine to medium sand, moist, no caliche nodules, pockets of strongly cemented sandstone |
| 108 | | | | | | | |
| 110 | 18/18 | 23<br>50 | 0 | SM | ▥ | SILTY SAND | Reddish yellow (5 YR 6/6), moist, dense poorly sorted very fine to medium sand, trace white caliche, no odor, no staining |
| 112 | | | | | | | |
| 114 | | | | | | | |
| 116 | 11/18 | 27<br>50 | 0 | SM | ▥ | SILTY SAND | As above except wet<br>116', Saturated gravel (driller note)<br>117', Gravel (driller note) |
| 118 | | | | | | | |
| 120 | 8/18 | 60 | 0 | SW | ░ | SAND | Light brown (7.5 YR 6/3), dense, saturated, poorly sorted, very fine to very coarse sand, little subangular to subrounded fine gravel, little silt and clay |
| 122 | | | | | | | |
| 124 | | | | | | | |
| 126 | | | | | | | |
| 128 | | | | | | | |
| 130 | | | | | | | |
| 132 | | | | | | | |
| 134 | | | | | | | |
| 136 | | | | | | | |
| 138 | | | | | | | |

Well Construction



**URS**

## SOIL BORING AND WELL LOG

**Boring/Well ID:** B-3 / MW-3
**Total Depth:** 133 feet bgs

| PROJECT INFORMATION | DRILLING INFORMATION |
|---|---|
| **Project:** BP Pipeline | **Drilling Company:** WDC |
| **Location:** Maljamar, New Mexico | **Drilling Equipment:** CME 85 |
| **Site Name:** North Excavation | **Drilling Method:** Hollow Stem Auger |
| **Project Number:** 41008243.00005 | **Sampling Method:** Split Spoon |
| **Logged By:** Rita Krebs | **Driller:** George Guzman |
| **Project Manager:** Shannon Hoover, P.G. | **Dates Drilled:** September 26-27, 2006 |

| Depth (feet bgs) | Sample Recovery (inches) | Blow Counts (per 6 inches) | PID (ppmv) | USCS Symbol | Lithology Symbol | Lithology Description and Notes | Well Construction |
|---|---|---|---|---|---|---|---|
| 0 | | | | SP | | SAND 0-6' Air knife for utility clearance, sand, light brown (7.5 YR 6/3), dry, loose, moderately well sorted very fine to medium sand, no odor, no staining | 2" PVC well (extends above grade inside 3" steel casing) |
| 2 | | | | | | | |
| 4 | | | | | | | |
| 6 | | | | | | | Grout to 113' |
| 8 | | | | | | | |
| 10 | 18/18 | 12<br>13<br>24 | 5.5 | SP | | SAND Pink (7.5 YR 7/3), dry, loose moderately well sorted very fine to fine sand, trace silt, white caliche nodules, no odor, no staining<br>11', black 1 cm manganese nodules | |
| 12 | | | | | | | |
| 14 | | | | | | | |
| 16 | 18/18 | 20<br>43<br>50 | 4.0 | SP | | SAND As above, with increased caliche, weak cement, dense | |
| 18 | | | | | | | |
| 20 | 12/12 | 12<br>50 | 0 | SP | | SAND As above | |
| 22 | | | | | | | |
| 24 | | | | | | | |
| 26 | 18/18 | 18<br>50 | 0 | SP | | SAND As above, except less cement, less caliche, increase manganese nodules, slightly moist, no odor, no staining | |
| 28 | | | | | | | |
| 30 | 18/18 | 24<br>41<br>50 | 0.7 | SP | | SAND As above, except sand is fine to medium, dense, no odor, no staining | |
| 32 | | | | | | | |
| 34 | | | | | | | |
| 36 | 18/18 | 24<br>50 | 0.7 | SP | | SAND As above, no odor, no staining | |
| 38 | | | | | | | |
| 40 | 18/18 | 24<br>50 | 0 | SP | | SAND As above, slightly moist, no odor, no staining | |
| 42 | | | | | | | |
| 44 | | | | | | | |
| 46 | 18/18 | 21<br>40<br>50 | 0 | SP | | SAND As above with increased caliche, fine white caliche gravel | |
| 48 | | | | | | | |
| 50 | 12/12 | 15<br>50 | 0 | SP | | SAND As above, with 1 cm pockets of well cemented lithified sandstone | |
| 52 | | | | | | | |
| 54 | | | | | | | |
| 56 | 10/18 | 50 | 0 | SP | | SAND As above, except sand is very fine to fine, no odor, no staining | |
| 58 | | | | | | | |
| 60 | 6/18 | 50 | 0 | SW | | SAND 60.25', Pink (7.5 YR 7/3), dense, poorly sorted, very fine to very coarse subangular to subrounded sand, trace silt, slightly moist, no odor, no staining | |
| 62 | | | | | | | |

**URS**

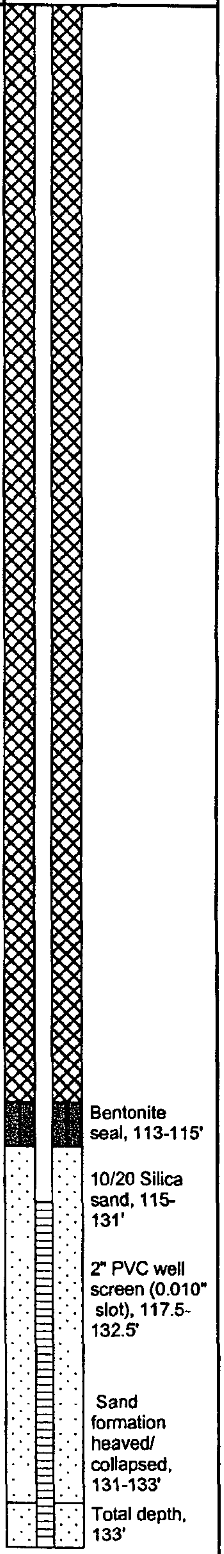
## SOIL BORING AND WELL LOG

**Boring/Well ID:** B-3 / MW-3

**Total Depth:** 133 feet bgs

| Depth (feet bgs) | Sample Recovery (inches) | Blow Counts (per 6 inches) | PID (ppmv) | USCS Symbol | Lithology Symbol | Lithology Description and Notes | |
|---|---|---|---|---|---|---|---|
| 64 | | | | | | | |
| 66 | 18/18 | 27<br>43<br>50 | 0 | SW | ░ | SAND | As above with FeOx staining, sand is mostly medium sized |
| 68 | | | | | | | |
| 70 | 8/18 | 50 | 0 | SW | ░ | SAND | As above, with increased caliche |
| 72 | | | | | | | |
| 74 | | | | | | | |
| 76 | 7/18 | 45<br>50 | 0 | SP | ░ | SAND | Light brown (7.5 YR 6/3), slightly moist, dense, moderately well sorted, very fine to fine sand, no odor, no staining |
| 78 | | | | | | | |
| 80 | 18/18 | 13<br>43<br>50 | 0 | SP | ░ | SAND | As above, except sand is fine to medium (mostly medium), red and yellow FeOx staining, no odor, no staining |
| 82 | | | | | | | |
| 84 | | | | | | | |
| 86 | 18/18 | 44<br>50 | 0 | SP | ░ | SAND | Same as above |
| 88 | | | | | | | |
| 90 | 18/18 | 34<br>50 | 0 | SW | ░ | SAND | Pink (7.5 YR 7/4), moist, very fine to very coarse sand, (mostly medium), trace silt, trace fine subangular gravel, no odor, no staining, poorly sorted |
| 92 | | | | | | | |
| 94 | | | | | | | |
| 96 | 18/18 | 21<br>30<br>50 | 0 | SW | ░ | SAND | As above |
| 98 | | | | | | | |
| 100 | 18/18 | 28<br>37<br>50 | 0 | SW | ░ | SAND | As above, no odor, no staining |
| 102 | | | | | | | |
| 104 | | | | | | | |
| 106 | 18/18 | 30<br>50 | 0 | SW | ░ | SAND | As above, no odor, no staining |
| 108 | | | | | | | |
| 110 | 6/18 | 50 | 0 | SP | ░ | SAND | Strong brown (7.5 YR 5/6), moist, dense, moderately well sorted, very fine to fine sand, trace silt, no odor, no staining |
| 112 | | | | | | | |
| 114 | | | | | | | |
| 116 | 9/18 | 50 | 0 | SP | ░ | SAND | As above, except color is reddish yellow (7.5 YR 6/6), sand is fine to medium (mostly medium sized), no odor, no staining |
| 118 | | | | | | | |
| 120 | 18/18 | 50 | | SM | ▥ | SILTY SAND | Yellowish red (5 YR 5/6), very moist, dense, poorly sorted, very fine to very course, subangular to subrounded sand (mostly very fine sized), no odor, no staining |
| 122 | | | | | | | |
| 124 | | | | | | | |
| 126 | 5/18 | 75 | 0 | SW | ○ | GRAVELLY SAND | Reddish brown (5 YR 4/4), saturated, dense, very fine to very coarse sand, fine subangular to subrounded gravel (up to 1 inch), no odor, no staining, estimated depth to water is 124' (driller note) |
| 128 | | | | | | | |
| 130 | | | | | | | |
| 132 | | | | | | | |
| 134 | | | | | | | |
| 136 | | | | | | | |
| 138 | | | | | | | |

**Well Construction**



URS

## SOIL BORING AND WELL LOG

| | |
|---|---|
| **Boring/Well ID:** B-4 / MW-4 | **Total Depth:** 135 feet bgs |

| PROJECT INFORMATION | DRILLING INFORMATION |
|---|---|
| **Project:** BP Pipeline | **Drilling Company:** WDC |
| **Location:** Maljamar, New Mexico | **Drilling Equipment:** CME 85 |
| **Site Name:** North Excavation | **Drilling Method:** Hollow Stem Auger |
| **Project Number:** 41008243.00005 | **Sampling Method:** Split Spoon |
| **Logged By:** Rita Krebs | **Driller:** George Guzman |
| **Project Manager:** Shannon Hoover, P.G. | **Dates Drilled:** September 27-28, 2006 |

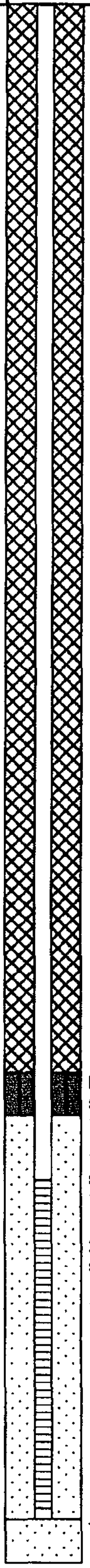
| Depth (feet bgs) | Sample Recovery (inches) | Blow Counts (per 6 inches) | PID (ppmv) | USCS Symbol | Lithology Symbol | Lithology Description and Notes | | Well Construction |
|---|---|---|---|---|---|---|---|---|
| 0<br>2<br>4<br>6<br>8 | | | | SP | | SAND | 0-6' Air knife for utility clearance, sand, brown (7.5 YR 5/4), dry, loose, moderately well sorted, very fine to fine sand with little silt, no odor, no staining | 2" PVC well (extends above grade inside 3" steel casing)<br>Grout to 112.5' |
| 10<br>12<br>14 | 18/18 | 4<br>4<br>7 | 0 | SP | | SAND | Pink (7.5 YR 7/3), dry, loose, moderately well sorted, very fine to fine sand, trace fines, white caliche, 1 cm black manganese nodules, no odor, no staining | |
| 16<br>18 | 18/18 | 15<br>30<br>40 | 0 | SP | | SAND | As above, except slightly moist, medium dense, increased white caliche gravel | |
| 20<br>22<br>24 | 12/12 | 17<br>38 | 0 | SP | | SAND | As above, except sand is very fine to medium | |
| 26<br>28 | 18/18 | 11<br>23<br>40 | 0 | SP | | SAND | As above, with weak cement, no odor, no staining, dense | |
| 30<br>32<br>34 | 18/18 | 17<br>34<br>50 | 0 | SP | | SAND | As above, decrease in fines, no odor, no staining | |
| 36<br>38 | 18/18 | 31<br>50 | 0 | SP | | SAND | As above<br>36', sand is very fine to fine with little fines, no odor, no staining | |
| 40<br>42<br>44 | 18/18 | 27<br>50 | 0 | SP | | SAND | As above, except sand is very fine to medium (mostly medium), 1" pockets of strongly cemented lithified sandstone | |
| 46<br>48 | 18/18 | 37<br>50 | 0 | SP | | SAND | As above, no odor, no staining | |
| 50<br>52<br>54 | 12/12 | 20<br>50 | 0 | SP | | SAND | As above | |
| 56<br>58 | 9/18 | 43<br>50 | 0 | SP | | SAND | As above, gradual color change to light brown (7.5 YR 6/4), slightly moist, no odor, no staining | |
| 60<br>62 | 18/18 | 18<br>38<br>50 | 0 | SP | | SAND | As above, no odor, no staining | |

## SOIL BORING AND WELL LOG

**Boring/Well ID:** B-4 / MW-4 | **Total Depth:** 135 feet bgs

| Depth (feet bgs) | Sample Recovery (inches) | Blow Counts (per 6 inches) | PID (ppmv) | USCS Symbol | Lithology Symbol | Lithology Description and Notes | |
|---|---|---|---|---|---|---|---|
| 64 | | | | | | | |
| 66 | 18/18 | 19<br>41<br>50 | 0 | SW | | SAND | Very pale brown (10 YR 7/3), slightly moist, very dense, very fine to very coarse, subangular to subrounded sand (mostly fine sized), 1.5" caliche layer at 65', poorly sorted, coarsening with depth<br>66.5', sand is hard and strongly cemented, little fine subrounded gravel (18%), gravel includes strong brown (7.5 YR 4/6) silty clay, poorly sorted |
| 68 | | | | | | | |
| 70 | 11/18 | 50 | 0 | SP | | SAND | Pink (7.5 YR 7/3), dense, moderately well sorted, very fine to medium sand (mostly fine sized), trace silt, slightly moist, no odor, no staining<br>70.5', 1 5" hard, strongly cemented lithified sandstone |
| 72 | | | | | | | |
| 74 | | | | | | | |
| 76 | 18/18 | 40<br>50 | 0 | SP | | SAND | As above, with trace very course subangular sand (4%)<br>76', strong brown (7.5 YR 4/6) silty clay nodule (1"), no odor, no staining |
| 78 | | | | | | | |
| 80 | 18/18 | 26<br>50 | 0 | SP | | SAND | Light brown (7.5 YR 6/3), slightly moist, moderately well sorted, very fine to medium sand (mostly fine), no odor, no staining |
| 82 | | | | | | | |
| 84 | | | | | | | |
| 86 | 18/18 | 25/50 | inoper-able | SW | | SAND | Pale brown (10 YR 6/3), slightly moist, dense very find to very coarse subrounded sand, trace fines, subrounded gravel, trace silt, no odor, no staining |
| 88 | | | | | | | |
| 90 | 18/18 | 31<br>50 | | SW | | SAND | As above, sand is mostly medium sized, gravel up to 1 cm, includes quartzite and red clay |
| 92 | | | | | | | |
| 94 | | | | | | | |
| 96 | 13/18 | 50 | | SW | | SAND | As above, decrease in gravel |
| 98 | | | | | | | |
| 100 | 18/18 | 31<br>50 | | SW<br>SP | | SAND | As above, 100.6-100.8', sandstone, light gray (10 YR 7/2), moist, friable, no odor, no staining, 100.8-100.9', silty sand, brown (7 5 YR 5/3), loose, poorly sorted, very fine to fine sand, moist, no odor, no staining, 100.9', sand, light brown (7.5 YR 6/3), dense, moderately well sorted, very fine to fine sand, trace silt, moist, no odor, no staining, weak cement |
| 102 | | | | | | | |
| 104 | | | | | | | |
| 106 | 10/18 | 36<br>50 | | SW | | SAND | 105-105.3', sandstone, light brown (7.5 YR 6/3), hard, dry very fine to very coarse subrounded sand, yellow FeOx staining, some fine subrounded gravel (25%), gravel is quartz, red clay, 105.3', sand, light brown, dense, moist, poorly sorted, very fine to very coarse, subrounded sand, (mostly fine sized), trace silt, no odor, no staining, yellow and red FeOx staining |
| 108 | | | | | | | |
| 110 | 7/18 | 50 | | SP | | SAND | Brown (7.5 YR 5/4), dense, moderately well sorted, very fine to fine sand, trace silt, no odor, no staining |
| 112 | | | | | | | |
| 114 | | | | | | | |
| 116 | 8/18 | 50 | | SP | | SAND | As above, with increasing moisture |
| 118 | | | | | | | |
| 120 | 11/18 | 40<br>50 | | SP | | SAND | As above, color change to strong brown (7.5 YR 4/6), increasing moisture, no odor, no staining |
| 122 | | | | | | | |
| 124 | | | | | | | |
| 126 | 7/18 | 60 | | SP | | SAND | As above, except saturated. Trace fine subrounded gravel |
| 128 | | | | | | | |
| 130 | | | | | | | |
| 132 | | | | | | | |
| 134 | | | | | | | |
| 136 | | | | | | | |
| 138 | | | | | | | |

Well Construction



Bentonite seal, 112.5-114.5'

10/20 Silica sand, 114.5-135'

2" PVC well screen (0.010" slot), 117.5-132.5'

Total depth, 135'

**URS**

## SOIL BORING LOG

**Boring/Well ID:** B-5 | **Total Depth:** 51.5 feet bgs

| PROJECT INFORMATION | DRILLING INFORMATION |
|---|---|
| **Project:** BP Pipeline | **Drilling Company:** WDC |
| **Location:** Maljamar, New Mexico | **Drilling Equipment:** CME 85 |
| **Site Name:** South Excavation | **Drilling Method:** Hollow Stem Auger |
| **Project Number:** 41008243.00005 | **Sampling Method:** Split Spoon |
| **Logged By:** Rita Krebs | **Driller:** George Guzman |
| **Project Manager:** Shannon Hoover, P.G. | **Dates Drilled:** September 14, 2006 |

| Depth (feet bgs) | Sample Recovery (inches) | Blow Counts (per 6 inches) | PID (ppmv) | USCS Symbol | Lithology Symbol | Lithology Description and Notes |
|---|---|---|---|---|---|---|
| 0 | | | | SP | ░ | SAND Air knife 0-6', sand, brown (7.5 YR 5/4), loose, moderately well sorted very fine to fine sand, white caliche nodules, dry |
| 2 | | | | | ░ | |
| 4 | | | | | ░ | |
| 6 | | | | | | |
| 8 | | | | | | |
| 10 | 18/18 | 3<br>8<br>12 | 0 | SP | ░ | SAND Pink (7.5 YR 7/4), loose, moderately well sorted, very fine to fine sand, trace silt, dry, no odor, no staining, caliche nodules |
| 12 | | | | | | |
| 14 | | | | | | |
| 16 | 18/18 | 8<br>19<br>35 | 0 | SP | ░ | SAND As above, very weakly cemented, increased caliche nodules |
| 18 | | | | | | |
| 20 | 12/12 | 24<br>38 | 0 | SP | ░ | SAND As above, gradational color change to light brown (7 5 YR 6/4), trace black (2 mm) nodules, possibly manganese nodules |
| 22 | | | | | | |
| 24 | | | | | | |
| 26 | 18/18 | 19<br>40<br>50 | 0 | SP | ░ | SAND As above, except dense |
| 28 | | | | | | |
| 30 | 18/18 | 37<br>50 | 0 | SP | ░ | SAND As above<br>30.5', 1" hard caliche layer, slightly moist |
| 32 | | | | | | |
| 34 | | | | | | |
| 36 | 18/18 | 30<br>50 | 0 | SP | ░ | SAND As above, except color is reddish yellow (7.5 YR 6/6)<br>30.5', 1" white hard caliche layer<br>31.0', color is pink (7.5 YR 7/3), fine caliche gravel |
| 38 | | | | | | |
| 40 | 12/12 | 50 | 0 | SW | ░ | SAND Pink (7.5 YR 7/3), dense, slightly moist, poorly sorted, very fine to very coarse sand (mostly medium), trace silt, trace fine subrounded gravel, some nodules of sand are hard and strongly cemented, no odor, no staining |
| 42 | | | | | | |
| 44 | | | | | | |
| 46 | 18/18 | 27<br>50 | 0 | SW | ░ | SAND As above<br>45.5', 1-cm white hard caliche layer |
| 48 | | | | | | |
| 50 | 18/18 | 20<br>30<br>50 | 0 | SW | ░ | SAND As above<br>50.2', reddish brown (5 YR 4/4) clay nodule<br>Total depth, 51.5' |
| 52 | | | | | | |
| 54 | | | | | | |
| 56 | | | | | | |
| 58 | | | | | | |
| 60 | | | | | | |
| 62 | | | | | | |

URS

## SOIL BORING LOG

**Boring/Well ID:** B-6

**Total Depth:** 51.5 feet bgs

## PROJECT INFORMATION

**Project:** BP Pipeline

**Location:** Maljamar, New Mexico

**Site Name:** South Excavation

**Project Number:** 41008243.00005

**Logged By:** Rita Krebs

**Project Manager:** Shannon Hoover, P.G.

## DRILLING INFORMATION

**Drilling Company:** WDC

**Drilling Equipment:** CME 85

**Drilling Method:** Hollow Stem Auger

**Sampling Method:** Split Spoon

**Driller:** George Guzman

**Dates Drilled:** September 15, 2006

| Depth (feet bgs) | Sample Recovery (inches) | Blow Counts (per 6 inches) | PID (ppmv) | USCS Symbol | Lithology Symbol | Lithology Description and Notes |
|---|---|---|---|---|---|---|
| 0<br>2<br>4<br>6<br>8 | | | | SP | ░ | SAND 0-6' air knife for utility clearance, sand, brown (7.5 YR 5/4), loose, moderately well sorted, very fine to fine sand, trace silt, caliche nodules, dry |
| 10<br>12<br>14 | 18/18 | 4<br>4<br>7 | 0 | SP | ░ | SAND Pink (7.5 YR 7/3), loose, moderately well sorted, very fine to fine sand, with some silt, fine caliche gravel, dry, no odor, no staining |
| 16<br>18 | 18/18 | 3<br>4<br>7 | 0 | SP | ░ | SAND As above, except reddish yellow (7.5YR 6/6), very slightly cemented, dense, increased caliche nodules, no odor, no staining |
| 20<br>22<br>24 | 12/12 | 25<br>50 | 0 | SP | ░ | SAND As above, with black manganese nodules, slightly moist, no odor, no staining |
| 26<br>28 | 12/12 | 21<br>37 | 0 | SP | ░ | SAND As above, with 1" nodules of hard, strongly cemented sandstone |
| 30<br>32<br>34 | 18/18 | 25<br>37<br>50 | 0 | SP | ░ | SAND As above<br>30.5, caliche layer (1"), hard, no odor, no staining |
| 36<br>38 | 14/18 | 29<br>50 | 0 | SW | ░ | SAND As above, poorly sorted, very fine to medium, with trace coarse to very coarse sand, trace silt, slightly moist, no odor, no staining |
| 40<br>42<br>44 | 10/12 | 45<br>50 | 0 | SW | ░ | SAND Coarsening with depth, color gradually changed to light brown (7.5 YR 6/3), slightly moist, no odor, no staining, sand is very fine to very coarse, trace fine subangular gravel, sand is subangular to subrounded, dense |
| 46<br>48 | 18/18 | 20<br>39<br>50 | 0 | SW | ░ | SAND As above, except sand is mostly medium sized<br>46', very dense, slightly lithified |
| 50<br>52<br>54<br>56<br>58<br>60<br>62 | 18/18 | 30<br>50 | | SW | ░ | SAND As above, except no gravel<br>Total depth, 51.5' |

URS

## SOIL BORING LOG

| | |
|---|---|
| **Boring/Well ID:** B-7 | **Total Depth:** 51.5 feet bgs |

| **PROJECT INFORMATION** | **DRILLING INFORMATION** |
|---|---|
| **Project:** BP Pipeline | **Drilling Company:** WDC |
| **Location:** Maljamar, New Mexico | **Drilling Equipment:** CME 85 |
| **Site Name:** South Excavation | **Drilling Method:** Hollow Stem Auger |
| **Project Number:** 41008243.00005 | **Sampling Method:** Split Spoon |
| **Logged By:** Rita Krebs | **Driller:** George Guzman |
| **Project Manager:** Shannon Hoover, P.G. | **Dates Drilled:** September 15, 2006 |

| Depth (feet bgs) | Sample Recovery (inches) | Blow Counts (per 6 inches) | PID (ppmv) | USCS Symbol | Lithology Symbol | Lithology Description and Notes | |
|---|---|---|---|---|---|---|---|
| 0<br>2<br>4<br>6<br>8 | | | | SP | ∴ | SAND | Air knife 0-6' for utility clearance, sand, brown (7.5 YR 5/4), dry, loose, moderately well sorted, very fine to fine sand, trace silt, hard white caliche gravel |
| 10<br>12<br>14 | 18/18 | 5<br>4<br>5 | 0 | SP | ∴ | SAND | Pink (7.5 YR 7/3), loose, dry, moderately well sorted, very fine to fine sand, some silt, white hard 1-cm caliche gravel nodules |
| 16<br>18 | 18/18 | 5<br>10<br>13 | 0 | SP | ∴ | SAND | As above, except decrease to trace silt, black 2-cm manganese nodules, sand is very fine to fine, no odor, no staining, very weakly cemented |
| 20<br>22<br>24 | 12/12 | 15<br>44 | | SP | ∴ | SAND | As above, except color is reddish yellow (7.5 YR 6/6), slightly moist, no odor, no staining |
| 26<br>28 | 18/18 | 17<br>30<br>50 | 0 | SP | ∴ | SAND | As above |
| 30<br>32<br>34 | 12/18 | 29<br>50 | 0 | SP | ∴ | SAND | As above,<br>30.5', color abruptly changes to light brown (1.5 YR 6/3), 1- to 2-cm nodules of hard, strongly cemented sandstone, no odor, no staining |
| 36<br>38 | 14/18 | 25<br>50 | 0 | SP | ∴ | SAND | As above<br>36.0', 2-cm white hard caliche layer, no odor, no staining |
| 40<br>42<br>44 | 12/12 | 37<br>50 | 0 | SW | ∴ | SAND | Light brown (7.5 YR 6/4), dense, poorly sorted, very fine to very coarse sand (mostly medium sized), trace fine subrounded to angular gravel, trace silt, no odor, no staining, slightly moist |
| 46<br>48 | 18/18 | 17<br>40<br>50 | 0 | SW | ∴ | SAND | As above, except no gravel<br>46.25', 1" hard lithified, cemented sandstone |
| 50<br>52<br>54<br>56<br>58<br>60<br>62 | 11/18 | 50 | 0 | SW | ∴ | SAND | As above, with trace FeOx staining, slightly moist, no odor, no staining<br>Total depth 51.5' |

URS

# SOIL BORING LOG

**Boring/Well ID:** B-8 | **Total Depth:** 51.5 feet bgs

## PROJECT INFORMATION

**Project:** BP Pipeline

**Location:** Maljamar, New Mexico

**Site Name:** South Excavation

**Project Number:** 41008243.00005

**Logged By:** Rita Krebs

**Project Manager:** Shannon Hoover, P.G.

## DRILLING INFORMATION

**Drilling Company:** WDC

**Drilling Equipment:** CME 85

**Drilling Method:** Hollow Stem Auger

**Sampling Method:** Split Spoon

**Driller:** George Guzman

**Dates Drilled:** September 15, 2006

| Depth (feet bgs) | Sample Recovery (inches) | Blow Counts (per 6 inches) | PID (ppmv) | USCS Symbol | Lithology Symbol | Lithology Description and Notes | |
|---|---|---|---|---|---|---|---|
| 0<br>2<br>4<br>6<br>8 | | | | SP | | SAND | 0-6' Air knife for utility clearance, sand, (7 5 YR 5/4), dry, loose, moderately well sorted, very fine to fine sand, trace silt, hard, white caliche gravel |
| 10<br>12<br>14 | 18/18 | 6<br>10<br>15 | 0 | SP | | SAND | Pink (7.5 YR 7/3), dry, loose, moderately well sorted, very fine to medium, mostly fine sized, no odor, no staining, hard, white caliche nodules<br>11.25', slightly moist |
| 16<br>18 | 18/18 | 9<br>16<br>26 | 0 | SP | | SAND | 15', color is light brown (7.5 YR 6/3), 2-cm manganese nodules |
| 20<br>22<br>24 | 12/12 | 29<br>50 | 0 | SP | | SAND | As above, except weakly cemented, sand is mostly medium sized |
| 26<br>28 | 16/18 | 28<br>50 | 0 | SP | | SAND | As above, slightly moist, no odor, no staining |
| 30<br>32<br>34 | 18/18 | 22<br>31<br>50 | 0 | SP | | SAND | Pale brown (10 YR 7/3), moderately well sorted, very fine to fine sand, little silt, fine caliche gravel, no odor, no staining |
| 36<br>38 | 18/18 | 30<br>38<br>49 | 0 | SW | | SAND | Pink (7.5 YR 7/3), slightly moist, dense, poorly sorted, very fine to very coarse subangular to subrounded sand, weakly cemented, mostly medium sized sand, no odor, no staining, trace subangular gravel |
| 40<br>42<br>44 | 12/12 | 50 | 0 | SW | | GRAVELLY SAND | Light brown (7.5 YR 6/4), very fine to very coarse subangular sand, fine to medium subangular to rounded gravel, trace silt, gravel up to 3-cm, little cementation, no odor, no staining |
| 46<br>48 | 18/18 | 30<br>44<br>48 | 0 | SP | | SAND | Light brown (7 5 YR 6/3), slightly moist, dense, moderately well sorted, very fine to coarse sand, (mostly medium sized), no odor, no staining, weakly cemented trace pockets of strongly cemented sandstone |
| 50<br>52<br>54<br>56<br>58<br>60<br>62 | 2/18 | 25<br>50 | | SP | | SAND | As above, very fine to coarse sand, (mostly medium sized), no odor, no staining<br>Total depth, 51.5' |

# APPENDIX B
# LABORATORY REPORTS

September 29, 2006

URS-Austin
9400 Amberglen Blvd.
Austin, TX 78729

AMEC Job No.: 6-519-004192
Lab #6-1314

Attn: Shannon Hoover

Project: Maljamar Pipeline Release Project

Re: Results of Lab Testing (B-1) Performed by AMEC.

Robert Romero
Manager of Technical Services

Copies: Addressee (2)

amec

**Client:** URS - Austin
9400 Amberglen Blvd.
Austin, TX 78729-

**Report Date:** September 29, 2006

**Project #:** 6-519-004192
**Work Order #:** 5
**Sampled By:** Client
**Date Sampled:**

**Attention:** Shannon Hoover
**Project Name:** Maljamar Pipeline Release Project

Albuquerque, NM

**Sieve Analaysis (ASTM C117/C136)**
**Plasticity Index (ASTM D4318)**
**Soil Classification (ASTM D2487)**

**Project Manager:** Robert Romero

SOILS / AGGREGATES

| Sample Location | Soil Class. | L.L. | P.I. | #200 | #100 | #50 | #40 | #30 | #16 | #10 | #8 | #4 | 1/4" | 3/8" | 1/2" | 3/4' | 1" | 1 1/4" | 1 1/2" | 2" | 2 1/2" | 3" | 6" | 12" | Lab Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B-1 @ 10 - 11.5' | | | | 14 | 59 | 96 | 99 | 100 | | | | | | | | | | | | | | | | | 6-1314-01 |
| B-1 @ 20 - 21.5' | | | | 13 | 53 | 95 | 100 | | | | | | | | | | | | | | | | | | 6-1314-02 |
| B-1 @ 30 - 31.5' | | | | 8.2 | 42 | 94 | 100 | | | | | | | | | | | | | | | | | | 6-1314-03 |
| B-1 @ 40 - 41.5' | | | | 10 | 38 | 90 | 93 | 94 | 94 | 94 | 95 | 96 | | 99 | 100 | | | | | | | | | | 6-1314-04 |
| B-1 @ 50- 51.5' | | | | 14 | 31 | 64 | 75 | 80 | 85 | 88 | 88 | 92 | | 96 | 99 | 100 | | | | | | | | | 6-1314-05 |
| B-1 @ 60- 61.5' | | | | 16 | 23 | 26 | 68 | 87 | 96 | 99 | 99 | 99 | | 100 | | | | | | | | | | | 6-1314-06 |
| B-1 @ 75 - 76.5' | | | | 13 | 24 | 70 | 90 | 97 | 99 | 99 | 99 | 100 | | | | | | | | | | | | | 6-1314-07 |
| B-1 @ 85 - 86.5' | | | | 13 | 26 | 87 | 97 | 99 | 100 | | | | | | | | | | | | | | | | 6-1314-08 |
| B-1 @ 100 - 101.5' | | | | 10 | 19 | 55 | 72 | 82 | 90 | 94 | 95 | 99 | | 100 | | | | | | | | | | | 6-1314-09 |
| B-1 @ 110 - 111.5' | | | | 15 | 51 | 93 | 97 | 98 | 98 | 99 | 99 | 100 | | | | | | | | | | | | | 6-1314-10 |
| B-1 @ 115 - 116.5' | | | | 17 | 52 | 94 | 97 | 98 | 98 | 99 | 99 | 100 | | | | | | | | | | | | | 6-1314-11 |

Reviewed By:____________________________________

**Distribution:** Client: ☑ File: ☑ Supplier: ☑ Other: Addressee (1)
Email: ☐ Don Lopez / URS - Albuquerque (1)

AMEC Earth Environmental, Inc.
8519 Jefferson NE
Albuquerque, NM 87113
Tel 5058211801
Fax 5058217371

www.amec com

amec

**PROJECT:** Maljamar Pipeline Release Project
**LOCATION:** Maljamar, NM
**MATERIAL:** Silty Sand
**SAMPLE SOURCE:** B-1 at 25.5 ft
**SAMPLE PREPARATION:** In Situ, Inundated

**PROJECT NO:** 6-519-004192
**LAB NO:** 6-1314-12
**DATE SAMPLED:** 09/21/06

Reviewed By: ____________________

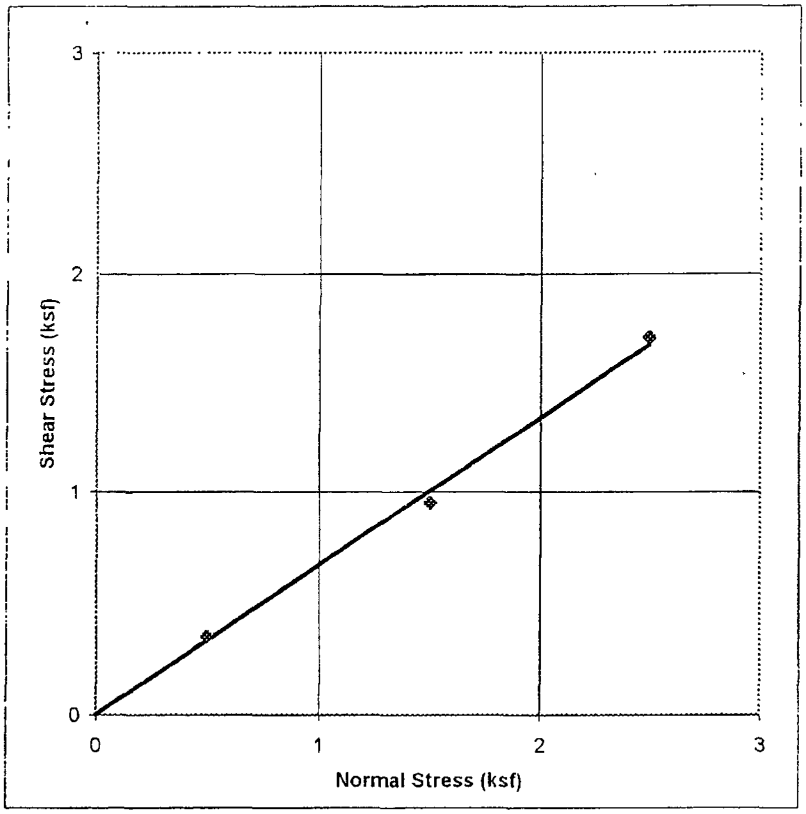
## DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED DRAINED CONDITIONS(ASTM D3080)

Initial thickness of specimen (in): 1.00
Initial diameter of specimen (in): 2.42
Shearing device used: Geomatic Direct Shear Apparatus, Model 8914
Rate of displacement (in/min): 0.02

| | | | |
|---|---|---|---|
| Direct shear point: | 1 | 2 | 3 |
| Dry mass of specimen (g) | 128.4 | 131.1 | 130.1 |
| Initial Moisture Content (g/g) | 4.1% | 4.0% | 5.1% |
| Initial Wet Density (lb/ft$^3$): | 111.0 | 113.2 | 113.6 |
| Initial Dry Density (lb/ft$^3$): | 106.7 | 108.9 | 108.1 |
| Final Moisture Content (g/g): | 19.0% | 17.2% | 18.1% |
| Final Wet Density (lb/ft$^3$): | 127.1 | 129.3 | 129.7 |
| Final Dry Density (lb/ft$^3$): | 106.8 | 110.3 | 109.9 |
| Normal Stress (kips/ft$^2$): | 0.50 | 1.50 | 2.50 |
| Maximum Shearing Stress (kips/ft$^2$): | 0.3 | 0.9 | 1.7 |
| Vertical Deformation @ Max Shear (in): | 0.003 | 0.002 | 0.004 |
| Horizontal Deformation @ Max Shear (in): | 0.046 | 0.074 | 0.076 |

**Internal Friction Angle ϕ** 33.8°
**Cohesion (kips/ft$^2$)** 0.0000

Notes:



AMEC Earth Environmental, Inc
8519 Jefferson NE
Albuquerque, NM 87113
Tel (505) 821-1801
Fax (505) 821-7371
www.amec.com

|  |  |
|---|---|
| **PROJECT:** | Maljamar Pipeline Release Project |
| **LOCATION:** | Maljamar, NM |
| **MATERIAL:** | Silty Clayey Sand |
| **SAMPLE SOURCE:** | B-1 at 70.5 ft |
| **SAMPLE PREPARATION:** | In Situ, Inundated |

|  |  |
|---|---|
| **PROJECT NO:** | 6-519-004192 |
| **LAB NO:** | 6-1314-13 |
| **DATE SAMPLED:** | 09/21/06 |

Reviewed By: ____________________

---

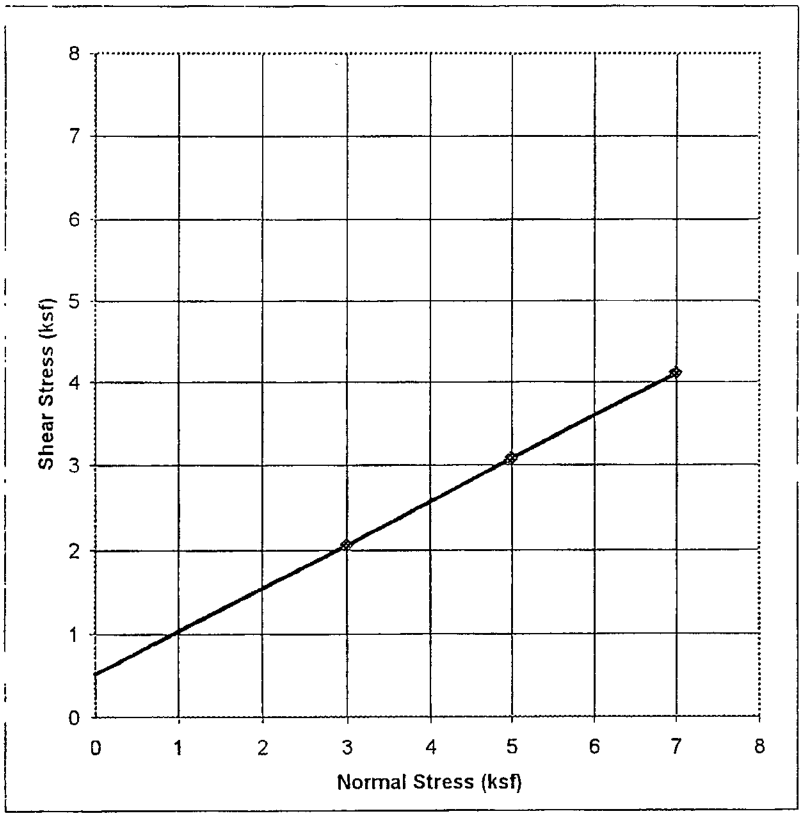
## DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED DRAINED CONDITIONS(ASTM D3080)

---

|  |  |  |  |
|---|---|---|---|
| Initial thickness of specimen (in): | 1.00 |  |  |
| Initial diameter of specimen (in): | 2.42 |  |  |
| Shearing device used: | Geomatic Direct Shear Apparatus, Model 8914 |  |  |
| Rate of displacement (in/min): | 0.015 |  |  |
| Direct shear point: | 1 | 2 | 3 |
| Dry mass of specimen (g): | 117.6 | 118.4 | 120.4 |
| Initial Moisture Content (g/g) | 10.0% | 13.6% | 12.2% |
| Initial Wet Density (lb/ft$^3$). | 107.4 | 111.7 | 112.1 |
| Initial Dry Density (lb/ft$^3$) | 97.7 | 98.4 | 100.0 |
| Final Moisture Content (g/g) | 20.8% | 23.1% | 22.8% |
| Final Wet Density (lb/ft$^3$): | 120.4 | 124.6 | 127.6 |
| Final Dry Density (lb/ft$^3$): | 99.6 | 101.2 | 103.9 |
| Normal Stress (kips/ft$^2$): | 3.00 | 5.00 | 7.00 |
| Maximum Shearing Stress (kips/ft$^2$) | 2.1 | 3.1 | 4.1 |
| Vertical Deformation @ Max Shear (in) | 0.002 | 0.001 | 0.001 |
| Horizontal Deformation @ Max Shear (in): | 0.080 | 0.090 | 0.110 |

|  |  |
|---|---|
| **Internal Friction Angle $\phi$** | **27.2°** |
| **Cohesion (kips/ft$^2$)** | **0.5110** |

Notes.



AMEC Earth Environmental, Inc
8519 Jefferson NE
Albuquerque, NM 87113
Tel (505) 821-1801
Fax (505) 821-7371
www.amec.com

October 2, 2006

URS-Austin
9400 Amberglen Blvd.
Austin, TX 78729

AMEC Job No.: 6-519-004192
Lab #6-1370

Attn: Shannon Hoover

Project: Maljamar Pipeline Release Project

Re: Results of Lab Testing (B-2) Performed by AMEC.

Robert Romero
Manager of Technical Services

Copies: Addressee (2)

amec

**Client:** URS - Austin
9400 Amberglen Blvd.
Austin, TX 78729-

**Attention:** Shannon Hoover
**Project Name:** Maljamar Pipeline Release Project

Albuqurque, NM

**Project Manager:** Robert Romero

**Report Date:** October 02, 2006

**Project #:** 6-519-004192
**Work Order #:** 7
**Sampled By:** Client
**Date Sampled:** 09/25/2006

**Sieve Analaysis (ASTM C117/C136)**
**Plasticity Index (ASTM D4318)**
**Soil Classification (ASTM D2487)**

SOILS / AGGREGATES

| Sample Location | Soil Class. | L.L. | P.I. | #200 | #100 | #50 | #40 | #30 | #16 | #10 | #8 | #4 | 1/4" | 3/8" | 1/2" | 3/4' | 1" | 1 1/4" | 1 1/2" | 2" | 2 1/2" | 3" | 6" | 12" | Lab Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B-2 @ 100 - 101.5' | | | | 23 | 52 | 89 | 95 | 95 | 96 | 96 | 96 | 96 | | 99 | 100 | | | | | | | | | | 6-1370-01 |
| B-2 @ 110 - 111.5' | | | | 12 | 43 | 86 | 94 | 97 | 98 | 98 | 98 | 98 | | 99 | 100 | | | | | | | | | | 6-1370-02 |
| B-2 @ 120 - 121.5' | | | | 15 | 28 | 59 | 74 | 81 | 86 | 88 | 89 | 91 | | 93 | 93 | 93 | 93 | | 100 | | | | | | 6-1370-03 |

Reviewed By:

**Distribution:** Client: ☑ File: ☑ Supplier: ☑ Other: Addressee (1)
Email: ☐ Don Lopez / URS - Albuquerque (1)

AMEC Earth .Environmental, Inc.
8519 Jefferson NE
Albuquerque, NM 87113
Tel 5058211801
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www.amec.com

October 2, 2006

URS-Austin
9400 Amberglen Blvd.
Austin, TX 78729

AMEC Job No.: 6-519-004192
Lab #6-1304

Attn: Shannon Hoover

Project: Maljamar Pipeline Release Project

Re: Results of Lab Testing (B-2) Performed by AMEC.

Robert Romero
Manager of Technical Services

Copies: Addressee (2)

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**Client:** URS - Austin
9400 Amberglen Blvd.
Austin, TX 78729-

**Report Date:** September 29, 2006

**Project #:** 6-519-004192
**Work Order #:** 1
**Sampled By:** Client
**Date Sampled:** 09/16/2006

**Attention:** Shannon Hoover
**Project Name:** Maljamar Pipeline Release Project

Albuquerque, NM

**Sieve Analaysis (ASTM C117/C136)**
**Plasticity Index (ASTM D4318)**
**Soil Classification (ASTM D2487)**

**Project Manager:** Robert Romero

SOILS / AGGREGATES

| Sample Location | Soil Class. | L.L. | P.I. | #200 | #100 | #50 | #40 | #30 | #16 | #10 | #8 | #4 | 1/4" | 3/8" | 1/2" | 3/4' | 1" | 1 1/4" | 1 1/2" | 2" | 2 1/2" | 3" | 6" | 12" | Lab Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B-2 @ 10-11.5' | | | | 11 | 52 | 93 | 99 | 100 | | | | | | | | | | | | | | | | | 6-1304-01 |
| B-2 @ 20-21.5' | | | | 4.5 | 36 | 97 | 100 | | | | | | | | | | | | | | | | | | 6-1304-02 |
| B-2 @ 30-31.5' | | | | 8.0 | 34 | 93 | 99 | 100 | | | | | | | | | | | | | | | | | 6-1304-03 |
| B-2 @ 60-61 5' | | | | 8.5 | 27 | 84 | 94 | 97 | 100 | | | | | | | | | | | | | | | | 6-1304-06 |
| B-2 @ 70-71.5' | | | | 13 | 23 | 62 | 83 | 96 | 100 | | | | | | | | | | | | | | | | 6-1304-07 |
| B-2 @ 80-81.5' | | | | 20 | 41 | 76 | 91 | 97 | 99 | 99 | 99 | 99 | | 100 | | | | | | | | | | | 6-1304-08 |
| B-2 @ 90-91.5' | | | | 13 | 36 | 74 | 88 | 94 | 99 | 99 | 99 | 100 | | | | | | | | | | | | | 6-1304-09 |

Reviewed By: ____________________

**Distribution:** Client: ☑ File: ☑ Supplier: ☑ Other: Addressee (1)
Email: ☐ Don Lopez / URS - Albuquerque (1)

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www.amec.com

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| | | | |
|---|---|---|---|
| **PROJECT:** | Majamar Pipeline Release Project | **JOB NO:** | 6-519-004192 |
| **CLIENT:** | URS | **WORK ORDER NO:** | 1 |
| **MATERIAL:** | | **LAB NO:** | 6-1304-04 |
| **SAMPLE SOURCE:** | B-2 @ 40 - 41.5' | **SAMPLED BY:** | Client |
| | | **DATE SAMPLED:** | 09/16/2006 |

---

## PARTICLE-SIZE ANALYSIS OF SOILS (AASHTO T88)

---

| | | | |
|---|---|---|---|
| WEIGHT OF SAMPLE DISPERSE | 61.24 | SPECIFIC GRAVITY OF SOILS (AASHTO T100) | 2.638 |
| PERCENT PASSING #10 SIEVE | 100.0 | | |

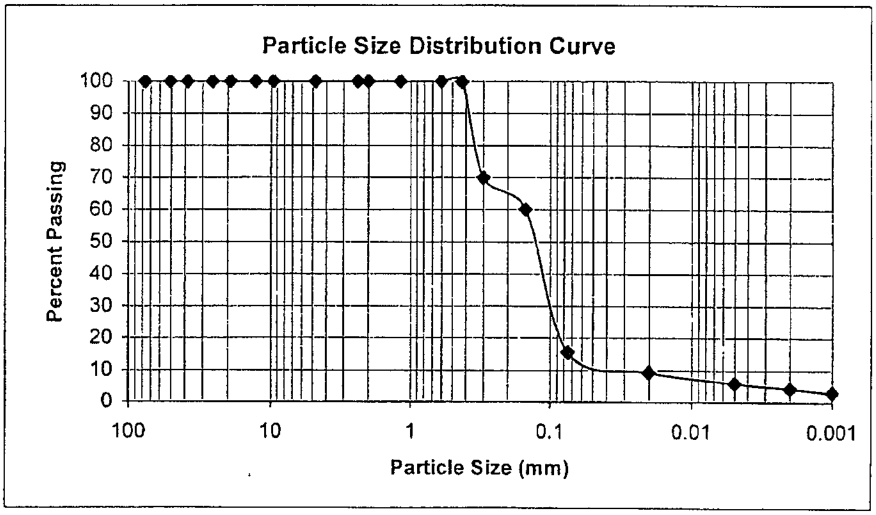
HYDROMETER RESULTS (% PASSING)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| PARTICLE SIZE DIAMETER (mm) | 0.0356 | 0.0226 | 0.0131 | 0.0093 | 0.0066 | 0.0032 | 0.0014 | 0.0010 |
| PERCENT OF TEST SAMPLE | 10.6 | 9.8 | 8.2 | 7.4 | 6.5 | 5.4 | 3.8 | 3.0 |
| PERCENT OF TOTAL SAMPLE | 10.6 | 9.8 | 8.2 | 7.4 | 6.5 | 5.4 | 3.8 | 3.0 |

| Size Classification | Gravel | Coarse Sand | Medium Sand | Fine Sand | Silt | Clay | Colloids |
|---|---|---|---|---|---|---|---|
| Percent | 0.0 | 0.0 | 30.0 | 60.7 | 5.0 | 4.3 | 3.0 |

SIEVE ANALYSIS
(AASHTO T27/T11)
(% PASSING)

| | |
|---|---|
| 3" | 100.0 |
| 2" | 100.0 |
| 1 1/2" | 100.0 |
| 1" | 100.0 |
| 3/4" | 100.0 |
| 1/2" | 100.0 |
| 3/8" | 100.0 |
| #4 | 100.0 |
| #8 | 100.0 |
| #10 | 100.0 |
| #16 | 100.0 |
| #30 | 100.0 |
| #40 | 99.8 |
| #50 | 70.0 |
| #100 | 60.2 |
| #200 | 15.6 |
| 0.02 mm | 9.3 |
| 0.005 mm | 6.0 |
| 0.002 mm | 4.3 |
| 0.001 mm | 3.0 |



| | | | |
|---|---|---|---|
| **PROJECT:** | Majamar Pipeline Release Project | **JOB NO:** | 6-519-004192 |
| **CLIENT:** | URS | **WORK ORDER NO:** | 1 |
| **MATERIAL:** | | **LAB NO:** | 6-1304-05 |
| **SAMPLE SOURCE:** | B-2 @ 50 - 51.5' | **SAMPLED BY:** | Client |
| | | **DATE SAMPLED:** | 09/16/2006 |

---

## PARTICLE-SIZE ANALYSIS OF SOILS (AASHTO T88)

---

| | | | |
|---|---|---|---|
| WEIGHT OF SAMPLE DISPERSEI | 60.05 | SPECIFIC GRAVITY OF SOILS (AASHTO T100) | 2.659 |
| PERCENT PASSING #10 SIEVE | 100.0 | | |

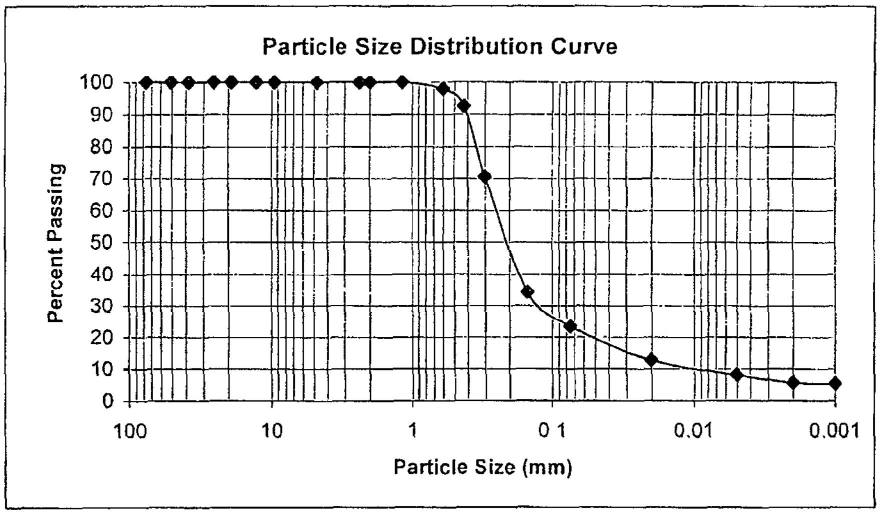
HYDROMETER RESULTS (% PASSING)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| PARTICLE SIZE DIAMETER (mm) | 0.0350 | 0.0222 | 0.0129 | 0.0091 | 0.0065 | 0.0032 | 0 0013 | 0 0009 |
| PERCENT OF TEST SAMPLE | 14.1 | 13.3 | 11.6 | 10.8 | 10.0 | 6.3 | 5.5 | 5.5 |
| PERCENT OF TOTAL SAMPLE | 14.1 | 13.3 | 11.6 | 10.8 | 10.0 | 6.3 | 5.5 | 5.5 |

| Size Classification | Gravel | Coarse Sand | Medium Sand | Fine Sand | Silt | Clay | Colloids |
|---|---|---|---|---|---|---|---|
| Percent | 0.0 | 0.0 | 29 4 | 57.8 | 7 1 | 5.8 | 5.5 |

SIEVE ANALYSIS
(AASHTO T27/T11)
(% PASSING)

| | |
|---|---|
| 3" | 100.0 |
| 2" | 100.0 |
| 1 1/2" | 100.0 |
| 1" | 100.0 |
| 3/4" | 100 0 |
| 1/2" | 100 0 |
| 3/8" | 100.0 |
| #4 | 100.0 |
| #8 | 100.0 |
| #10 | 100.0 |
| #16 | 100.0 |
| #30 | 98 0 |
| #40 | 92.6 |
| #50 | 70.6 |
| #100 | 34.3 |
| #200 | 23.6 |
| 0.02 mm | 12.8 |
| 0.005 mm | 8.2 |
| 0.002 mm | 5.8 |
| 0.001 mm | 5.5 |



amec

PROJECT: Maljamar Pipeline Release Project
LOCATION: Maljamar, NM
MATERIAL: Silty Sand
SAMPLE SOURCE: B-2 at 20.5 ft
SAMPLE PREPARATION: In Situ, Inundated

PROJECT NO: 6-519-004192
LAB NO: 6-1304-10
DATE SAMPLED: 09/21/06

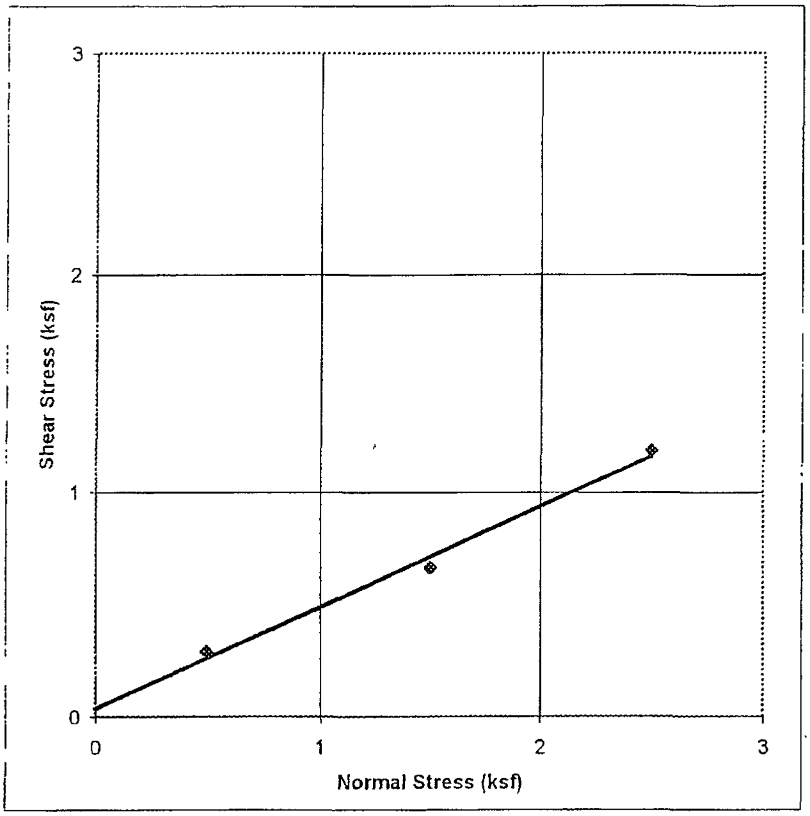
Reviewed By:

## DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED DRAINED CONDITIONS(ASTM D3080)

| | | | |
|---|---|---|---|
| Initial thickness of specimen (in): | 1.00 | | |
| Initial diameter of specimen (in): | 2.42 | | |
| Shearing device used. | Geomatic Direct Shear Apparatus, Model 8914 | | |
| Rate of displacement (in/min): | 0.01 | | |
| Direct shear point. | 1 | 2 | 3 |
| Dry mass of specimen (g): | 119.7 | 118.3 | 118.2 |
| Initial Moisture Content (g/g). | 2.8% | 2.6% | 3.8% |
| Initial Wet Density (lb/ft$^3$). | 102.2 | 100.8 | 101.9 |
| Initial Dry Density (lb/ft$^3$) | 99.4 | 98.3 | 98.2 |
| Final Moisture Content (g/g) | 20.8% | 21.4% | 20.2% |
| Final Wet Density (lb/ft$^3$): | 121.9 | 124.4 | 121.5 |
| Final Dry Density (lb/ft$^3$): | 100.9 | 102.5 | 101.1 |
| Normal Stress (kips/ft$^2$): | 0.50 | 1.50 | 2.50 |
| Maximum Shearing Stress (kips/ft$^2$): | 0.3 | 0.7 | 1.2 |
| Vertical Deformation @ Max Shear (in): | 0.000 | -0.006 | -0.001 |
| Horizontal Deformation @ Max Shear (in): | 0.064 | 0.234 | 0.146 |

**Internal Friction Angle $\phi$** 24.2°
**Cohesion (kips/ft$^2$)** 0.0370

Notes:



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www.amec.com

|  |  |  |  |
|---|---|---|---|
| PROJECT: | Maljamar Pipeline Release Project |  |  |
| LOCATION: | Maljamar, NM | PROJECT NO: | 6-519-004192 |
| MATERIAL: | Silty Sand | LAB NO: | 6-1304-11 |
| SAMPLE SOURCE: | B-2 at 60.5 ft | DATE SAMPLED: | 09/21/06 |
| SAMPLE PREPARATION: | In Situ, Inundated |  |  |

Reviewed By:

---

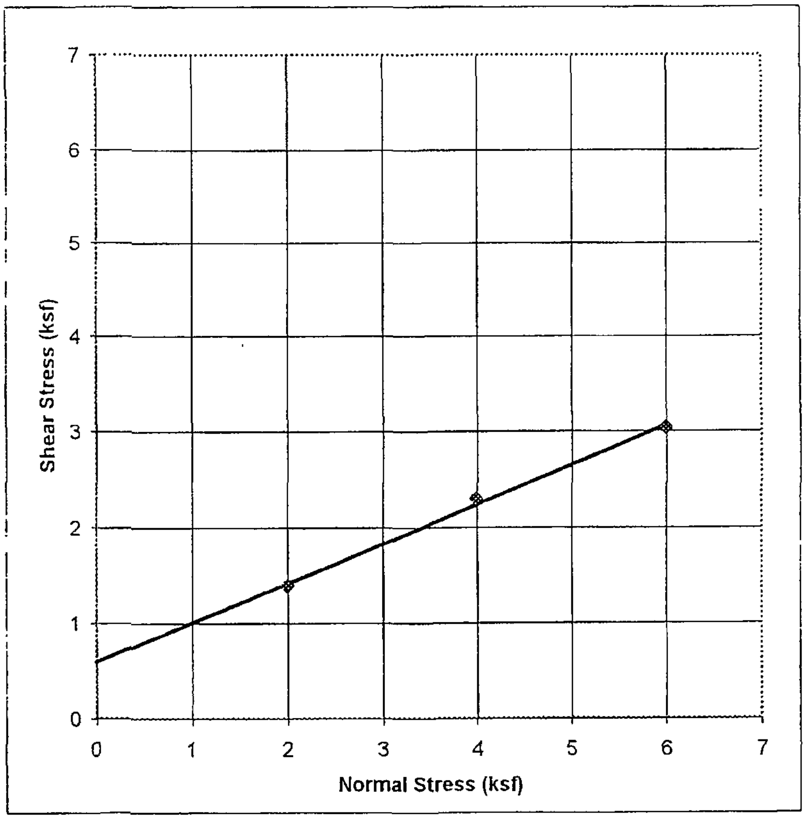
## DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED DRAINED CONDITIONS(ASTM D3080)

---

|  |  |  |  |
|---|---|---|---|
| Initial thickness of specimen (in): | 1.00 |  |  |
| Initial diameter of specimen (in): | 2.42 |  |  |
| Shearing device used: | Geomatic Direct Shear Apparatus, Model 8914 |  |  |
| Rate of displacement (in/min): | 0.02 |  |  |
| Direct shear point: | 1 | 2 | 3 |
| Dry mass of specimen (g): | 125.8 | 120 5 | 119.0 |
| Initial Moisture Content (g/g). | 4.0% | 4 2% | 4 2% |
| Initial Wet Density ($lb/ft^3$): | 108.6 | 104 3 | 103.0 |
| Initial Dry Density ($lb/ft^3$): | 104 5 | 100 1 | 98 9 |
| Final Moisture Content (g/g): | 18 8% | 19.4% | 20 0% |
| Final Wet Density ($lb/ft^3$). | 126.0 | 123.3 | 123 2 |
| Final Dry Density ($lb/ft^3$): | 106.0 | 103 3 | 102.6 |
| Normal Stress ($kips/ft^2$): | 2.00 | 4.00 | 6.00 |
| Maximum Shearing Stress ($kips/ft^2$): | 1.4 | 2 3 | 3.0 |
| Vertical Deformation @ Max Shear (in): | 0.002 | 0 003 | -0.001 |
| Horizontal Deformation @ Max Shear (in). | 0.064 | 0 110 | 0 138 |

|  |  |
|---|---|
| **Internal Friction Angle ϕ** | **22.3°** |
| **Cohesion ($kips/ft^2$)** | **0.5880** |

Notes



October 9, 2006

URS-Austin
9400 Amberglen Blvd.
Austin, TX 78729

AMEC Job No.: 6-519-004192
Lab #6-1371

Attn: Shannon Hoover

Project: Maljamar Pipeline Release Project

Re: Results of Lab Testing (B-3) Performed by AMEC.

Robert Romero
Manager of Technical Services

Copies: Addressee (2)

**Client:** URS - Austin
9400 Amberglen Blvd.
Austin, TX 78729-

**Report Date:** October 02, 2006

**Project #:** 6-519-004192
**Work Order #:** 8
**Sampled By:** Client
**Date Sampled:** 09/26/2006

**Attention:** Shannon Hoover
**Project Name:** Maljamar Pipeline Release Project

Albuquqrque, NM

**Sieve Analaysis (ASTM C117/C136)**
**Plasticity Index (ASTM D4318)**
**Soil Classification (ASTM D2487)**

**Project Manager:** Robert Romero

SOILS / AGGREGATES

| Sample Location | Soil Class. | L.L. | P.I. | #200 | #100 | #50 | #40 | #30 | #16 | #10 | #8 | #4 | 1/4" | 3/8" | 1/2" | 3/4' | 1" | 1 1/4" | 1 1/2" | 2" | 2 1/2" | 3" | 6" | 12" | Lab Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B-3 @ 10 - 11.5' | | | | 23 | 62 | 95 | 99 | 100 | | | | | | | | | | | | | | | | | 6-1371-01 |
| B-3 @ 20 - 21 5' | | | | 20 | 66 | 94 | 100 | | | | | | | | | | | | | | | | | | 6-1371-02 |
| B-3 @ 30 - 31.5' | | | | 14 | 51 | 93 | 100 | | | | | | | | | | | | | | | | | | 6-1371-03 |
| B-3 @ 40 - 41.5' | | | | 15 | 41 | 89 | 96 | 96 | 97 | 97 | 97 | 98 | | 99 | 100 | | | | | | | | | | 6-1371-04 |
| B-3 @ 50 - 51 5' | | | | 8 6 | 44 | 92 | 96 | 96 | 96 | 96 | 97 | 97 | | 98 | 98 | 100 | | | | | | | | | 6-1371-05 |
| B-3 @ 60 - 61.5' | | | | 16 | 42 | 80 | 89 | 92 | 94 | 95 | 95 | 96 | | 98 | 100 | | | | | | | | | | 6-1371-06 |
| B-3 @ 75 - 76.5' | | | | 13 | 43 | 89 | 97 | 99 | 100 | | | | | | | | | | | | | | | | 6-1371-07 |
| B-3 @ 80 - 81.5' | | | | 13 | 30 | 72 | 87 | 95 | 99 | 99 | 99 | 100 | | | | | | | | | | | | | 6-1371-08 |
| B-3 @ 90 - 91.5' | | | | 15 | 27 | 70 | 88 | 95 | 99 | 100 | | | | | | | | | | | | | | | 6-1371-09 |
| B-3 @ 100 - 101.5' | | | | 11 | 25 | 56 | 75 | 90 | 98 | 99 | 99 | 100 | | | | | | | | | | | | | 6-1371-10 |
| B-3 @ 110 - 111.5' | | | | 7.0 | 31 | 90 | 99 | 100 | | | | | | | | | | | | | | | | | 6-1371-11 |

Reviewed By:

**Distribution:** Client: ✓ File: ✓ Supplier: ☑ Other: Addressee (1)
Email:
Don Lopez / URS - Albuquerque (1)

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| | |
|---|---|
| **PROJECT:** | Maljamar Pipeline Release Project |
| **LOCATION:** | Maljamar, NM |
| **MATERIAL:** | Silty Sand |
| **SAMPLE SOURCE:** | B-3 at 20.5 ft |
| **SAMPLE PREPARATION:** | In Situ, Inundated |

| | |
|---|---|
| **PROJECT NO:** | 6-519-004192 |
| **LAB NO:** | 6-1371-12 |
| **DATE SAMPLED:** | 09/21/06 |

**Reviewed By:**

---

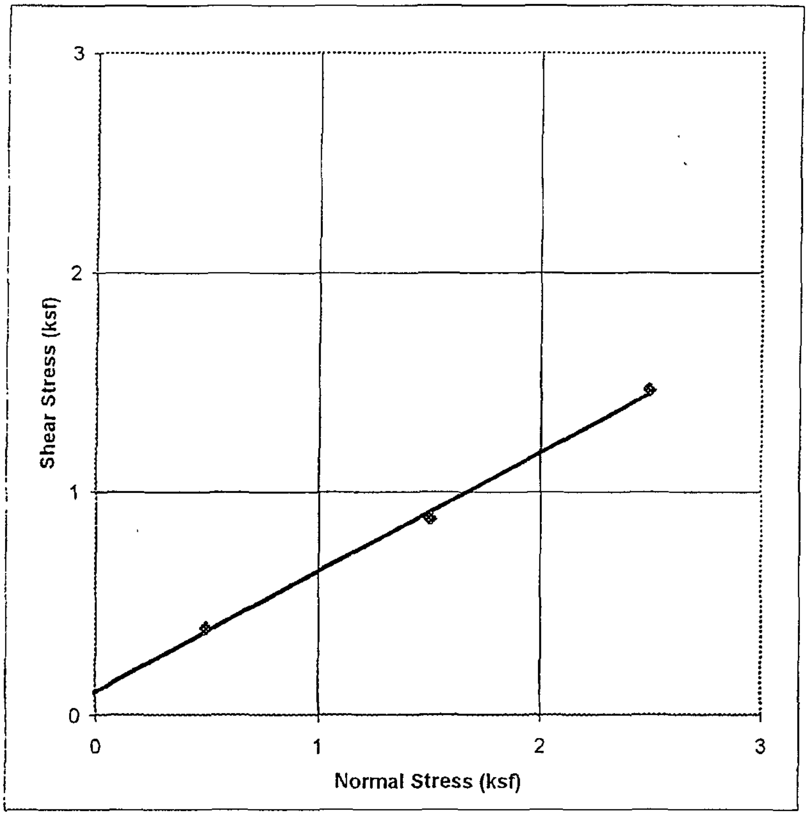
## DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED DRAINED CONDITIONS(ASTM D3080)

---

| | | | |
|---|---|---|---|
| *Initial thickness of specimen (in):* | 1.00 | | |
| Initial diameter of specimen (in): | 2.42 | | |
| Shearing device used: | Geomatic Direct Shear Apparatus, Model 8914 | | |
| Rate of displacement (in/min). | 0 017 | | |
| Direct shear point: | 1 | 2 | 3 |
| Dry mass of specimen (g): | 125.0 | 123.5 | 120.9 |
| Initial Moisture Content (g/g): | 3 8% | 3.7% | 3 5% |
| Initial Wet Density (lb/$ft^3$): | 107.8 | 106.4 | 104.0 |
| Initial Dry Density (lb/$ft^3$): | 103.8 | 102 6 | 100.5 |
| Final Moisture Content (g/g). | 19.3% | 18.7% | 18.4% |
| Final Wet Density (lb/$ft^3$): | 125.2 | 123.3 | 124.2 |
| Final Dry Density (lb/$ft^3$): | 105.0 | 103.9 | 104.9 |
| Normal Stress (kips/$ft^2$): | 0.50 | 1.50 | 2.50 |
| Maximum Shearing Stress (kips/$ft^2$): | 0 4 | 0.9 | 1.5 |
| Vertical Deformation @ Max Shear (in): | 0.004 | 0.003 | 0.001 |
| Horizontal Deformation @ Max Shear (in): | 0 052 | 0 148 | 0.084 |

| | |
|---|---|
| **Internal Friction Angle ϕ** | **28.4°** |
| **Cohesion (kips/$ft^4$)** | **0.0980** |

Notes:



AMEC Earth Environmental Inc
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Albuquerque, NM 87113
Tel (505) 821-1801
Fax (505) 821-7371
www.amec.com

**amec**

**PROJECT:** Maljamar Pipeline Release Project
**LOCATION:** Maljamar, NM
**MATERIAL:** Silty Sand
**SAMPLE SOURCE:** B-3 at 50 5 ft
**SAMPLE PREPARATION:** In Situ, Inundated

**PROJECT NO:** 6-519-004192
**LAB NO:** 6-1371-13
**DATE SAMPLED:** 09/21/06

**Reviewed By:**

---

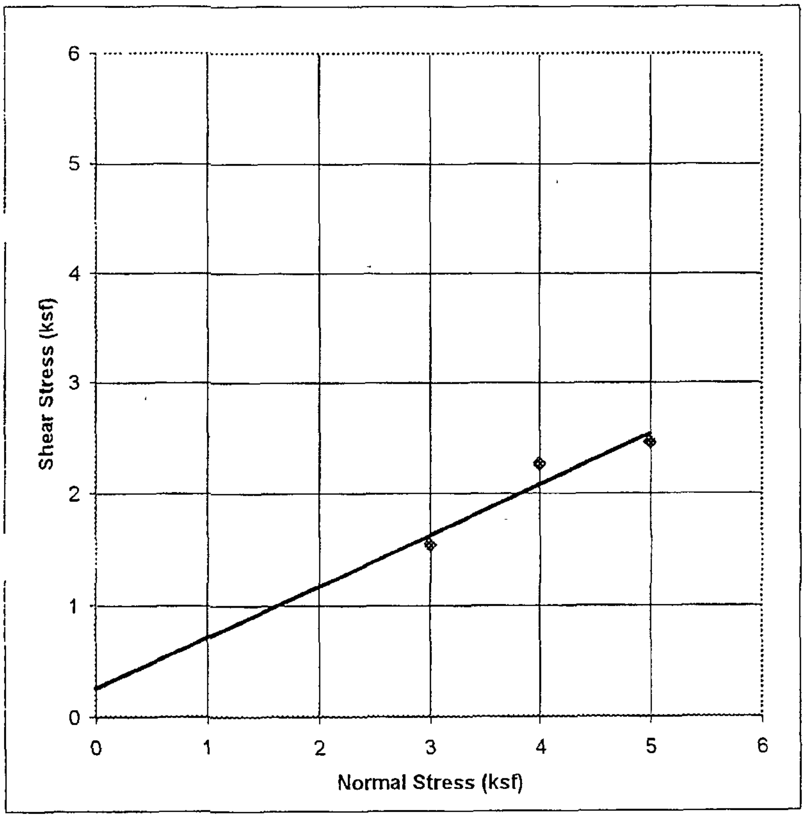
## DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED DRAINED CONDITIONS(ASTM D3080)

---

| | | | |
|---|---|---|---|
| Initial thickness of specimen (in): | 1.00 | | |
| Initial diameter of specimen (in): | 2.42 | | |
| Shearing device used: | Geomatic Direct Shear Apparatus, Model 8914 | | |
| Rate of displacement (in/min): | 0.017 | | |
| Direct shear point | 1 | 2 | 3 |
| Dry mass of specimen (g): | 123.1 | 129.8 | 121.4 |
| Initial Moisture Content (g/g). | 3.4% | 3.7% | 3 8% |
| Initial Wet Density (lb/ft$^3$): | 105.7 | 111.8 | 104.7 |
| Initial Dry Density (lb/ft$^3$): | 102.2 | 107.8 | 100.9 |
| Final Moisture Content (g/g): | 18.7% | 15.9% | 18.7% |
| Final Wet Density (lb/ft$^3$): | 126.4 | 129 8 | 127.8 |
| Final Dry Density (lb/ft$^3$): | 106.4 | 112.0 | 107.7 |
| Normal Stress (kips/ft$^2$): | 3.00 | 4.00 | 5.00 |
| Maximum Shearing Stress (kips/ft$^2$): | 1 5 | 2.3 | 2.4 |
| Vertical Deformation @ Max Shear (in): | 0.000 | 0.000 | -0.001 |
| Horizontal Deformation @ Max Shear (in). | 0 104 | 0.134 | 0.130 |

**Internal Friction Angle ϕ** **24.5°**
**Cohesion (kips/ft$^4$)** **0.2560**

Notes.



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October 9, 2006

URS-Austin
9400 Amberglen Blvd.
Austin, TX 78729

AMEC Job No.: 6-519-004192
Lab #6-1315

Attn: Shannon Hoover

Project: Maljamar Pipeline Release Project

Re: Results of Lab Testing (B-5) Performed by AMEC.

Robert Romero
Manager of Technical Services

Copies: Addressee (2)

amec

**Client:** URS - Austin
9400 Amberglen Blvd.
Austin, TX 78729-

**Attention:** Shannon Hoover

**Project Name:** Maljamar Pipeline Release Project

Albuqurque, NM

**Project Manager:** Robert Romero

**Report Date:** September 30, 2006

**Project #:** 6-519-004192
**Work Order #:** 6
**Sampled By:** Client
**Date Sampled:**

**Sieve Analaysis (ASTM C117/C136)**
**Plasticity Index (ASTM D4318)**
**Soil Classification (ASTM D2487)**

**SOILS / AGGREGATES**

| Sample Location | Soil Class. | L.L. P.I. | #200 | #100 | #50 | #40 | #30 | #16 | #10 | #8 | #4 | 1/4" | 3/8" | 1/2" | 3/4' | 1" | 1 1/4" | 1 1/2" | 2" | 2 1/2" | 3" | 6" | 12" | Lab Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B-5 @ 10 - 11.5' | | | 18 | 58 | 92 | 99 | 99 | 100 | | | | | | | | | | | | | | | | 6-1315-01 |
| B-5 @ 15 - 16.5' | | | 13 | 53 | 96 | 99 | 100 | | | | | | | | | | | | | | | | | 6-1315-02 |
| B-5 @ 30 - 31 5' | | | 14 | 48 | 80 | 82 | 83 | 84 | 85 | 86 | 88 | | 96 | 100 | | | | | | | | | | 6-1315-03 |
| B-5 @ 45 - 46.5' | | | 11 | 21 | 68 | 85 | 94 | 98 | 99 | 99 | 99 | | 100 | | | | | | | | | | | 6-1315-05 |
| B-5 @ 50 - 51.5' | | | 15 | 25 | 61 | 81 | 88 | 94 | 96 | 97 | 100 | | | | | | | | | | | | | 6-1315-06 |

Reviewed By:

**Distribution:** Client: ☑ File: ☑ Supplier: ☑ Other: Addressee (1)
Email: ☐
Don Lopez / URS - Albuquerque (1)

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Albuquerque, NM 87113
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Fax 5058217371

www.amec com

| | |
|---|---|
| PROJECT: | Maljamar Pipeline Release Project |
| LOCATION: | Maljamar, NM |
| MATERIAL: | Silty Sand |
| SAMPLE SOURCE: | B-5 at 20.5 ft |
| SAMPLE PREPARATION: | In Situ, Inundated |

| | |
|---|---|
| PROJECT NO: | 6-519-004192 |
| LAB NO: | 6-1315-07 |
| DATE SAMPLED: | 09/21/06 |

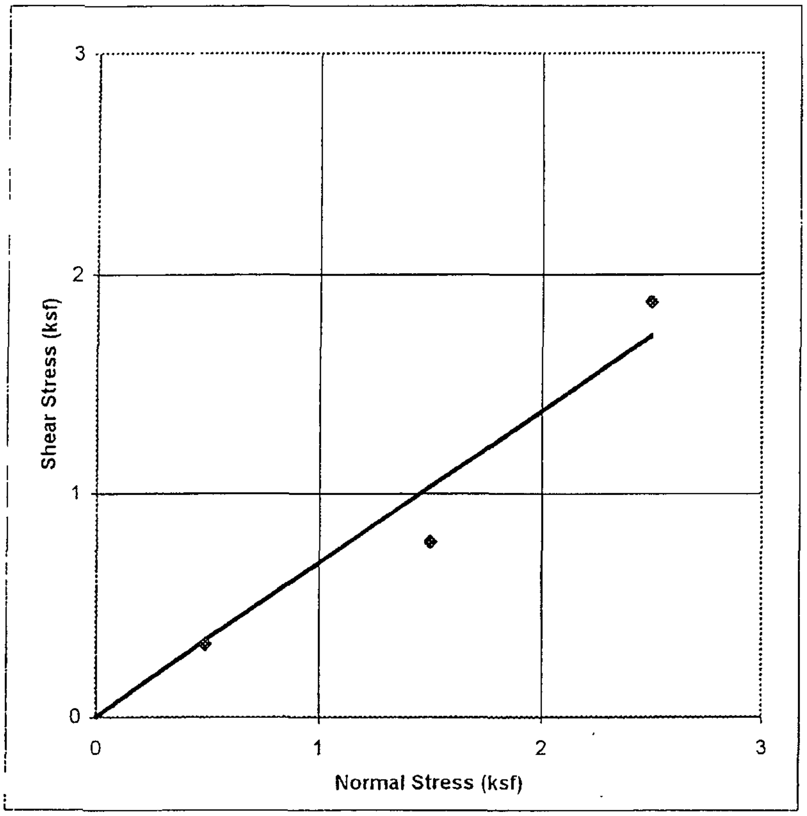
**Reviewed By:**

## DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED DRAINED CONDITIONS(ASTM D3080)

| | | | |
|---|---|---|---|
| Initial thickness of specimen (in). | 1.00 | | |
| Initial diameter of specimen (in): | 2.42 | | |
| Shearing device used: | Geomatic Direct Shear Apparatus, Model 8914 | | |
| Rate of displacement (in/min): | 0.017 | | |
| Direct shear point: | 1 | 2 | 3 |
| Dry mass of specimen (g): | 128.0 | 131.6 | 137.3 |
| Initial Moisture Content (g/g): | 3.6% | 3.7% | 2.8% |
| Initial Wet Density (lb/ft$^3$) | 110.1 | 113.3 | 117.3 |
| Initial Dry Density (lb/ft$^3$): | 106.3 | 109.3 | 114.1 |
| Final Moisture Content (g/g): | 18.6% | 15.3% | 14.2% |
| Final Wet Density (lb/ft$^3$): | 127.0 | 128.7 | 134.4 |
| Final Dry Density (lb/ft$^3$): | 107.1 | 111.6 | 117.7 |
| Normal Stress (kips/ft$^2$): | 0.50 | 1.50 | 2.50 |
| Maximum Shearing Stress (kips/ft$^2$): | 0.3 | 0.8 | 1.9 |
| Vertical Deformation @ Max Shear (in): | 0.003 | -0.002 | 0.005 |
| Horizontal Deformation @ Max Shear (in). | 0.064 | 0.144 | 0.136 |

| | |
|---|---|
| **Internal Friction Angle ϕ** | **34.5°** |
| **Cohesion (kips/ft$^2$)** | **0.0000** |

Notes:



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8519 Jefferson NE
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Fax (505) 821-7371
www amec com

|  |  |  |  |
|---|---|---|---|
| **PROJECT:** | Maljamar Pipeline Release Project | | |
| **LOCATION:** | Maljamar, NM | **PROJECT NO:** | 6-519-004192 |
| **MATERIAL:** | Silty Sand | **LAB NO:** | 6-1315-08 |
| **SAMPLE SOURCE:** | B-5 at 40.5 ft | **DATE SAMPLED:** | 09/21/06 |
| **SAMPLE PREPARATION:** | In Situ, Inundated | | |

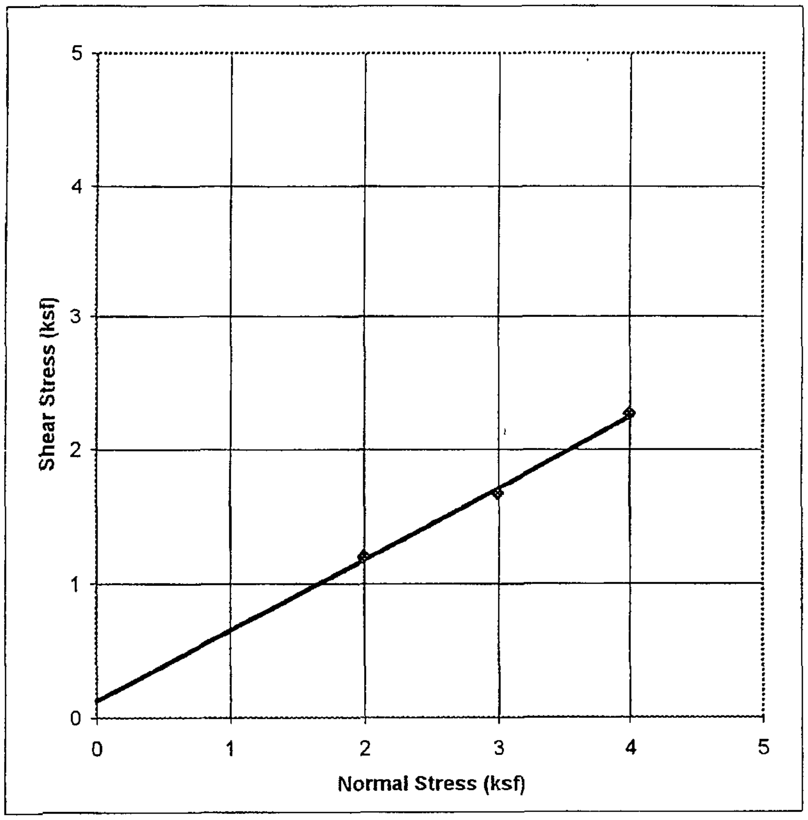
**Reviewed By:**

## DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED DRAINED CONDITIONS(ASTM D3080)

|  |  |  |  |
|---|---|---|---|
| Initial thickness of specimen (in): | 1.00 | | |
| Initial diameter of specimen (in): | 2 42 | | |
| Shearing device used: | Geomatic Direct Shear Apparatus, Model 8914 | | |
| Rate of displacement (in/min): | 0.017 | | |
| Direct shear point: | 1 | 2 | 3 |
| Dry mass of specimen (g): | 121.1 | 122.4 | 115.4 |
| Initial Moisture Content (g/g): | 3.6% | 3.1% | 3.4% |
| Initial Wet Density (lb/ft$^3$): | 104.2 | 104.8 | 99.1 |
| Initial Dry Density (lb/ft$^3$): | 100 6 | 101 7 | 95.9 |
| Final Moisture Content (g/g): | 17.2% | 17.3% | 17.2% |
| Final Wet Density (lb/ft$^3$). | 125.6 | 123.3 | 118.7 |
| Final Dry Density (lb/ft$^3$): | 107.2 | 105.1 | 101.3 |
| Normal Stress (kips/ft$^2$): | 2.00 | 3.00 | 4.00 |
| Maximum Shearing Stress (kips/ft$^2$): | 1.2 | 1.7 | 2.3 |
| Vertical Deformation @ Max Shear (in): | -0.001 | 0.000 | -0.006 |
| Horizontal Deformation @ Max Shear (in): | 0.130 | 0.122 | 0.180 |

|  |  |
|---|---|
| **Internal Friction Angle $\phi$** | **27.8°** |
| **Cohesion (kips/ft$^2$)** | **0.1240** |

Notes:



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www amec com

October 4, 2006

URS-Austin
9400 Amberglen Blvd.
Austin, TX 78729

AMEC Job No.: 6-519-004192
Lab #6-1305

Attn: Shannon Hoover

Project: Maljamar Pipeline Release Project

Re: Results of Lab Testing (B-6) Performed by AMEC.

Robert Romero
Manager of Technical Services

Copies: Addressee (2)

amec

**Client:** URS - Austin
9400 Amberglen Blvd
Austin, TX 78729-

**Attention:** Shannon Hoover

**Project Name:** Maljamar Pipeline Release Project

Albuqurque, NM

**Project Manager:** Robert Romero

Report Date: September 30, 2006

Project #: 6-519-004192
Work Order #: 2
Sampled By: Client
Date Sampled:

Sieve Analaysis (ASTM C117/C136)
Plasticity Index (ASTM D4318)
Soil Classification (ASTM D2487)

## SOILS / AGGREGATES

| Sample Location | Soil Class. | L.L. | P.I. | #200 | #100 | #50 | #40 | #30 | #16 | #10 | #8 | #4 | 1/4" | 3/8" | 1/2" | 3/4' | 1" | 1 1/4" | 1 1/2" | 2" | 2 1/2" | 3" | 6" | 12" | Lab Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 17 | 53 | 91 | 96 | 97 | 98 | 99 | 99 | 99 | | 99 | 100 | | | | | | | | | | 6-1305-01 |
| | | | | 19 | 59 | 91 | 97 | 98 | 98 | 99 | 99 | 99 | | 100 | | | | | | | | | | | 6-1305-02 |
| | | | | 14 | 45 | 88 | 92 | 92 | 93 | 94 | 94 | 96 | | 99 | 100 | | | | | | | | | | 6-1305-03 |
| | | | | 10 | 26 | 61 | 78 | 85 | 89 | 91 | 91 | 92 | | 95 | 97 | 100 | | | | | | | | | 6-1305-04 |
| | | | | 17 | 46 | 79 | 89 | 94 | 97 | 99 | 99 | 100 | | | | | | | | | | | | | 6-1305-05 |

Reviewed By:

**Distribution:** Client: ☑ File: ☑ Supplier: ☑ Other: Addressee (1)
Email: ☐
Don Lopez / URS - Albuquerque (1)

AMEC Earth Environmental, Inc.
8519 Jefferson NE
Albuquerque, NM 87113
Tel 5058211801
Fax 5058217371
www amec com

**PROJECT:** Maljamar Pipeline Release Project
**LOCATION:** Maljamar, NM
**MATERIAL:** Silty Sand
**SAMPLE SOURCE:** B-6 at 25.5 ft
**SAMPLE PREPARATION:** In Situ, Inundated

**PROJECT NO:** 6-519-004192
**LAB NO:** 6-1305-06
**DATE SAMPLED:** 09/21/06

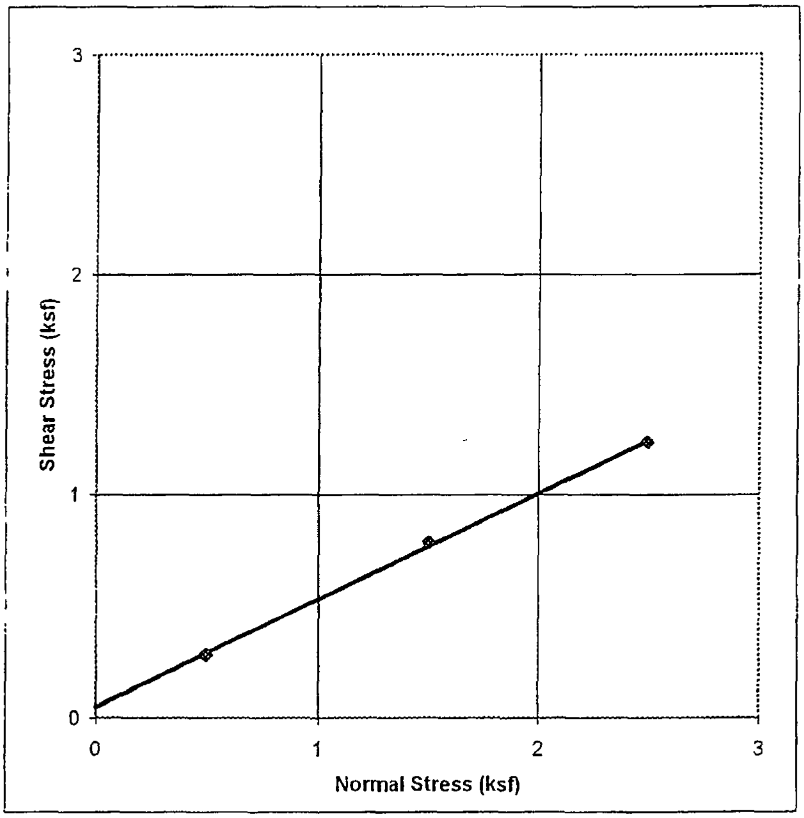
Reviewed By:

## DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED DRAINED CONDITIONS(ASTM D3080)

| | | | |
|---|---|---|---|
| Initial thickness of specimen (in): | 1.00 | | |
| Initial diameter of specimen (in): | 2.42 | | |
| Shearing device used: | Geomatic Direct Shear Apparatus, Model 8914 | | |
| Rate of displacement (in/min): | 0.02 | | |
| Direct shear point: | 1 | 2 | 3 |
| Dry mass of specimen (g): | 119.5 | 114.9 | 105.4 |
| Initial Moisture Content (g/g): | 3.3% | 2.8% | 4.0% |
| Initial Wet Density (lb/ft$^3$): | 102.5 | 98.1 | 91.1 |
| Initial Dry Density (lb/ft$^3$): | 99.2 | 95.5 | 87.6 |
| Final Moisture Content (g/g): | 19.8% | 18.8% | 19.2% |
| Final Wet Density (lb/ft$^3$): | 122.7 | 121.5 | 117.5 |
| Final Dry Density (lb/ft$^3$): | 102.4 | 102.3 | 98.5 |
| Normal Stress (kips/ft$^2$): | 0.50 | 1.50 | 2.50 |
| Maximum Shearing Stress (kips/ft$^2$): | 0.3 | 0.8 | 1.2 |
| Vertical Deformation @ Max Shear (in): | 0.001 | -0.001 | -0.003 |
| Horizontal Deformation @ Max Shear (in): | 0.194 | 0.152 | 0.162 |

**Internal Friction Angle ϕ** **25.6°**
**Cohesion (kips/ft$^4$)** **0.0440**

Notes:



amec

| | |
|---|---|
| **PROJECT:** | Maljamar Pipeline Release Project |
| **LOCATION:** | Maljamar, NM |
| **MATERIAL:** | Silty Sand |
| **SAMPLE SOURCE:** | B-6 at 40.5 ft |
| **SAMPLE PREPARATION:** | In Situ, Inundated |

| | |
|---|---|
| **PROJECT NO:** | 6-519-004192 |
| **LAB NO:** | 6-1305-07 |
| **DATE SAMPLED:** | 09/21/06 |

**Reviewed By:**

---

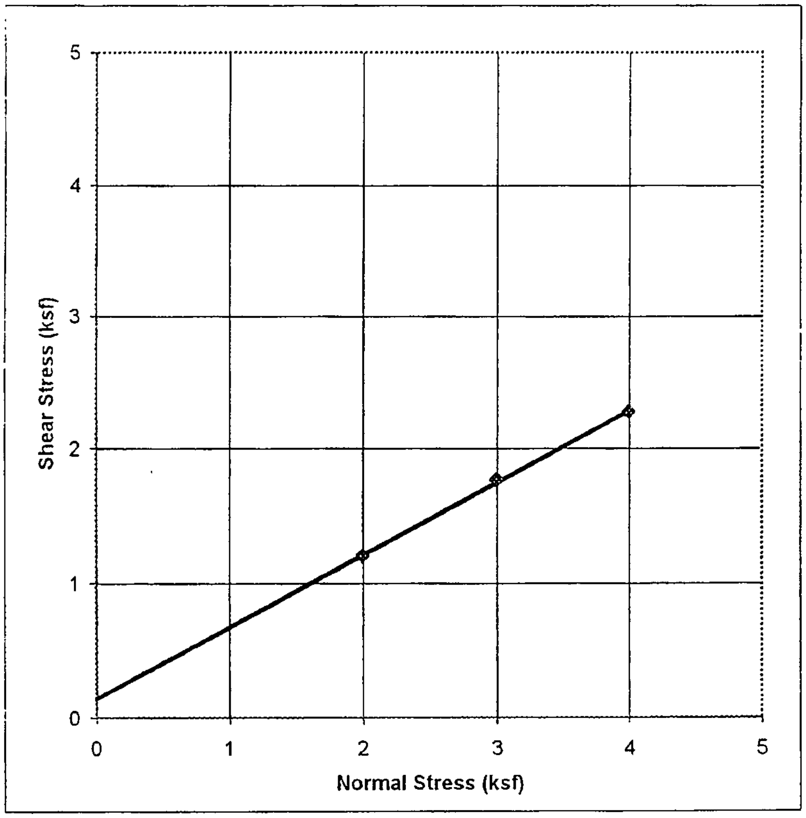
## DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED DRAINED CONDITIONS(ASTM D3080)

---

| | | | |
|---|---|---|---|
| Initial thickness of specimen (in): | 1 00 | | |
| Initial diameter of specimen (in): | 2 42 | | |
| Shearing device used: | Geomatic Direct Shear Apparatus, Model 8914 | | |
| Rate of displacement (in/min): | 0.02 | | |
| Direct shear point: | 1 | 2 | 3 |
| Dry mass of specimen (g). | 119 5 | 109.6 | 125 3 |
| Initial Moisture Content (g/g). | 3.0% | 3.3% | 3 2% |
| Initial Wet Density (lb/ft$^3$): | 102.2 | 94.0 | 107.4 |
| Initial Dry Density (lb/ft$^3$): | 99.3 | 91 1 | 104 1 |
| Final Moisture Content (g/g): | 17.8% | 18.1% | 17.3% |
| Final Wet Density (lb/ft$^3$): | 122.3 | 117 9 | 127.1 |
| Final Dry Density (lb/ft$^3$): | 103.7 | 99 8 | 108.3 |
| Normal Stress (kips/ft$^2$): | 2.00 | 3.00 | 4.00 |
| Maximum Shearing Stress (kips/ft$^2$): | 1.2 | 1.8 | 2.3 |
| Vertical Deformation @ Max Shear (in): | -0.004 | -0.004 | -0.002 |
| Horizontal Deformation @ Max Shear (in): | 0.138 | 0.134 | 0 098 |

| | |
|---|---|
| **Internal Friction Angle ϕ** | **28.1°** |
| **Cohesion (kips/ft$^4$)** | **0.1420** |

Notes:



AMEC Earth Environmental, Inc.
8519 Jefferson NE
Albuquerque, NM 87113
Tel (505) 821-1601
Fax (505) 821-7371
www amec com

October 4, 2006

URS-Austin
9400 Amberglen Blvd.
Austin, TX 78729

AMEC Job No.: 6-519-004192
Lab #6-1308

Attn: Shannon Hoover

Project: Maljamar Pipeline Release Project

Re: Results of Lab Testing (B-7) Performed by AMEC.

Robert Romero
Manager of Technical Services

Copies: Addressee (2)

amec

**Client:** URS - Austin
9400 Amberglen Blvd.
Austin, TX 78729-

**Attention:** Shannon Hoover
**Project Name:** Maljamar Pipeline Release Project

Albuqurque, NM

**Project Manager:** Robert Romero

Report Date: September 30. 2006

Project #: 6-519-004192
Work Order #: 3
Sampled By: Client
Date Sampled:

Sieve Analaysis (ASTM C117/C136)
Plasticity Index (ASTM D4318)
Soil Classification (ASTM D2487)

SOILS / AGGREGATES

| Sample Location | Soil Class. | L.L. | P.I. | #200 | #100 | #50 | #40 | #30 | #16 | #10 | #8 | #4 | 1/4" | 3/8" | 1/2" | 3/4' | 1" | 1 1/4" | 1 1/2" | 2" | 2 1/2" | 3" | 6" | 12" | Lab Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B-7 @ 10-11.5' | | | | 18 | 43 | 78 | 88 | 89 | 90 | 91 | 91 | 93 | | 96 | 99 | 100 | | | | | | | | | 6-1308-01 |
| B-7 @ 20-21.5' | | | | 9.6 | 38 | 91 | 98 | 98 | 98 | 98 | 98 | 99 | | 100 | | | | | | | | | | | 6-1308-02 |
| B-7 @ 30-31.5' | | | | 11 | 36 | 88 | 96 | 96 | 97 | 97 | 97 | 98 | | 100 | | | | | | | | | | | 6-1308-03 |
| B-7 @ 40-41.5' | | | | 5.1 | 16 | 72 | 90 | 95 | 97 | 97 | 97 | 98 | | 98 | 98 | 100 | | | | | | | | | 6-1308-04 |
| B-7 @ 45-46.5' | | | | 11 | 21 | 72 | 93 | 97 | 98 | 99 | 99 | 99 | | 100 | | | | | | | | | | | 6-1308-05 |

Reviewed By:

**Distribution:** Client: ☑ File: ☑ Supplier: ☑ Other: Addressee (1)
Email: ☐
Don Lopez / URS - Albuquerque (1)

AMEC Earth Environmental, Inc.
8519 Jefferson NE
Albuquerque, NM 87113
Tel 5058211801
Fax 5058217371
www.amec com

| | | | |
|---|---|---|---|
| **PROJECT:** | Maljamar Pipeline Release Project | | |
| **LOCATION:** | Maljamar, NM | **PROJECT NO:** | 6-519-004192 |
| **MATERIAL:** | Silty Sand | **LAB NO:** | 6-1308-06 |
| **SAMPLE SOURCE:** | B-7 at 20.5 ft | **DATE SAMPLED:** | 09/21/06 |
| **SAMPLE PREPARATION:** | In Situ, Inundated | | |

**Reviewed By:**

---

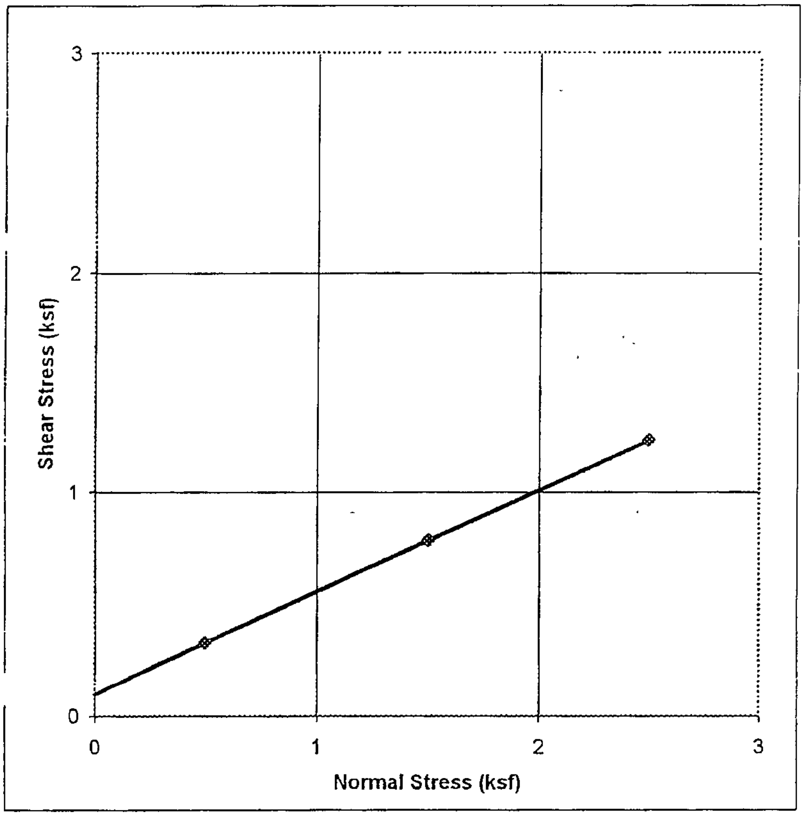
## DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED DRAINED CONDITIONS(ASTM D3080)

---

| | | | |
|---|---|---|---|
| Initial thickness of specimen (in): | 1 00 | | |
| Initial diameter of specimen (in): | 2.42 | | |
| Shearing device used: | Geomatic Direct Shear Apparatus, Model 8914 | | |
| Rate of displacement (in/min). | 0.017 | | |
| Direct shear point. | 1 | 2 | 3 |
| Dry mass of specimen (g): | 125.2 | 125 6 | 125 0 |
| Initial Moisture Content (g/g)· | 2 2% | 2.5% | 2.6% |
| Initial Wet Density (lb/ft$^3$): | 106 4 | 106.9 | 106.5 |
| Initial Dry Density (lb/ft$^3$): | 104.0 | 104.4 | 103.8 |
| Final Moisture Content (g/g)· | 19.1% | 18.3% | 19.2% |
| Final Wet Density (lb/ft$^3$): | 123.9 | 126.8 | 127.2 |
| Final Dry Density (lb/ft$^3$). | 104 1 | 107.2 | 106.6 |
| Normal Stress (kips/ft$^2$): | 0.50 | 1.50 | 2.50 |
| Maximum Shearing Stress (kips/ft$^2$): | 0.3 | 0.8 | 1.2 |
| Vertical Deformation @ Max Shear (in). | 0.004 | -0 001 | -0.003 |
| Horizontal Deformation @ Max Shear (in)· | 0.042 | 0 152 | 0.162 |

**Internal Friction Angle ϕ** **24.5°**
**Cohesion (kips/ft$^2$)** **0.0960**

Notes:



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Albuquerque, NM 87113
Tel (505) 821-1801
Fax (505) 821-7371
www amec com

| | |
|---|---|
| **PROJECT:** | Maljamar Pipeline Release Project |
| **LOCATION:** | Maljamar, NM |
| **MATERIAL:** | Silty Sand |
| **SAMPLE SOURCE:** | B-7 at 40.5 ft |
| **SAMPLE PREPARATION:** | In Situ, Inundated |

| | |
|---|---|
| **PROJECT NO:** | 6-519-004192 |
| **LAB NO:** | 6-1308-07 |
| **DATE SAMPLED:** | 09/21/06 |

Reviewed By:

---

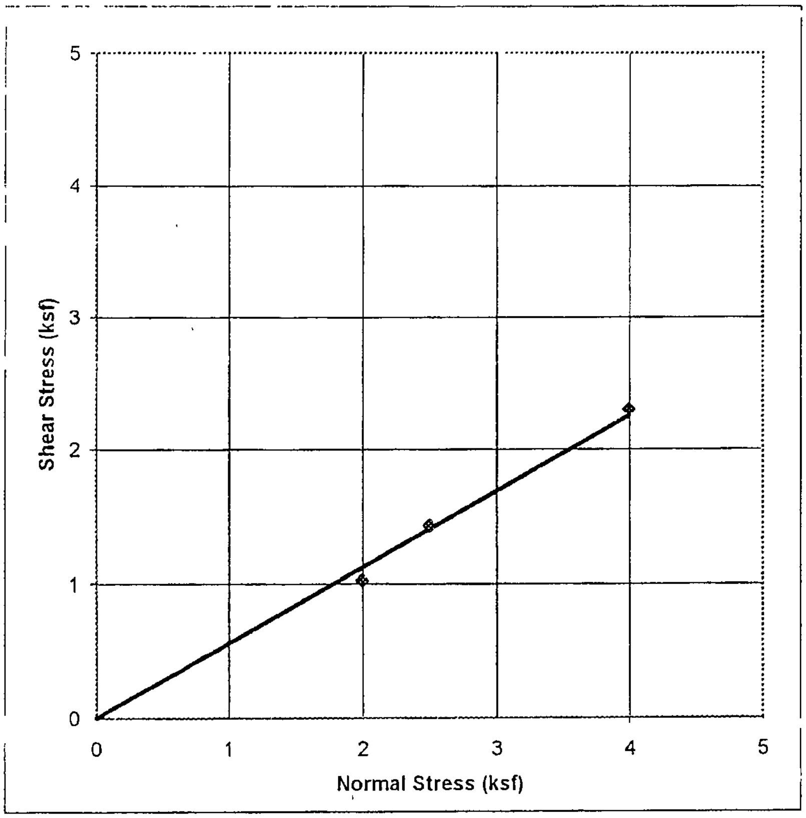
DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED DRAINED CONDITIONS(ASTM D3080)

---

| | | | |
|---|---|---|---|
| Initial thickness of specimen (in): | 1.00 | | |
| Initial diameter of specimen (in). | 2.42 | | |
| Shearing device used: | Geomatic Direct Shear Apparatus, Model 8914 | | |
| Rate of displacement (in/min)· | 0.017 | | |
| Direct shear point: | 1 | 2 | 3 |
| Dry mass of specimen (g) | 121.8 | 120 8 | 121 8 |
| Initial Moisture Content (g/g). | 2 9% | 2.8% | 3.0% |
| Initial Wet Density ($lb/ft^3$): | 104.2 | 103 2 | 104.2 |
| Initial Dry Density ($lb/ft^3$) | 101.2 | 100.3 | 101.2 |
| Final Moisture Content (g/g)· | 19.4% | 20.2% | 19.9% |
| Final Wet Density ($lb/ft^3$). | 122.0 | 123 0 | 125.1 |
| Final Dry Density ($lb/ft^3$)· | 102.2 | 102.4 | 104.3 |
| Normal Stress ($kips/ft^2$): | 2.00 | 2.50 | 4.00 |
| Maximum Shearing Stress ($kips/ft^2$). | 1.0 | 1.4 | 2.3 |
| Vertical Deformation @ Max Shear (in)· | -0.001 | 0.005 | 0.004 |
| Horizontal Deformation @ Max Shear (in) | 0 186 | 0 092 | 0.094 |

| | |
|---|---|
| **Internal Friction Angle ϕ** | **29.4°** |
| **Cohesion ($kips/ft^2$)** | **0.0000** |

Notes:



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Tel (505) 821-1601
Fax (505) 821-7371
www amec com

October 6, 2006

URS-Austin
9400 Amberglen Blvd.
Austin, TX 78729

AMEC Job No.: 6-519-004192
Lab #6-1309

Attn: Shannon Hoover

Project: Maljamar Pipeline Release Project

Re: Results of Lab Testing (B-8) Performed by AMEC.

Robert Romero
Manager of Technical Services

Copies: Addressee (2)

**Client:** URS - Austin
9400 Amberglen Blvd.
Austin, TX 78729-

**Attention:** Shannon Hoover
**Project Name:** Maljamar Pipeline Release Project

Albuquerque, NM

**Project Manager:** Robert Romero

**Report Date:** September 30, 2006

**Project #:** 6-519-004192
**Work Order #:** 4
**Sampled By:** Client
**Date Sampled:**

**Sieve Analaysis (ASTM C117/C136)**
**Plasticity Index (ASTM D4318)**
**Soil Classification (ASTM D2487)**

SOILS / AGGREGATES

| Sample Location | Soil Class. | L.L. | P.I. | #200 | #100 | #50 | #40 | #30 | #16 | #10 | #8 | #4 | 1/4" | 3/8" | 1/2" | 3/4' | 1" | 1 1/4" | 1 1/2" | 2" | 2 1/2" | 3" | 6" | 12" | Lab Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B-8 @ 10-11.5' | | | | 19 | 52 | 89 | 99 | 99 | 99 | 99 | 100 | | | | | | | | | | | | | | 6-1309-01 |
| B-8 @ 20-21.5' | | | | 4.1 | 22 | 89 | 100 | | | | | | | | | | | | | | | | | | 6-1309-02 |
| B-8 @ 30-31.5' | | | | 13 | 31 | 84 | 89 | 89 | 90 | 91 | 91 | 93 | | 98 | 100 | | | | | | | | | | 6-1309-03 |
| B-8 @ 40-41.5' | | | | 8.1 | 25 | 53 | 59 | 60 | 62 | 66 | 67 | 75 | | 85 | 88 | 100 | | | | | | | | | 6-1309-04 |
| B-8 @ 45-46.5' | | | | 14 | 21 | 52 | 70 | 77 | 80 | 81 | 81 | 81 | | 84 | 84 | 85 | 89 | | 100 | | | | | | 6-1309-05 |

Reviewed By:

**Distribution:** Client: ☑ File: ☑ Supplier: ☑ Other: Addressee (1)
Email: ☐
Don Lopez / URS - Albuquerque (1)

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8519 Jefferson NE
Albuquerque, NM 87113
Tel 5058211801
Fax 5058217371

www.amec.com

amec

**PROJECT:** Maljamar Pipeline Release Project
**LOCATION:** Maljamar, NM
**MATERIAL:** Silty Sand
**SAMPLE SOURCE:** B-8 at 20.5 ft
**SAMPLE PREPARATION:** In Situ, Inundated

**PROJECT NO:** 6-519-004192
**LAB NO:** 6-1309-06
**DATE SAMPLED:** 09/21/06

**Reviewed By:**

---

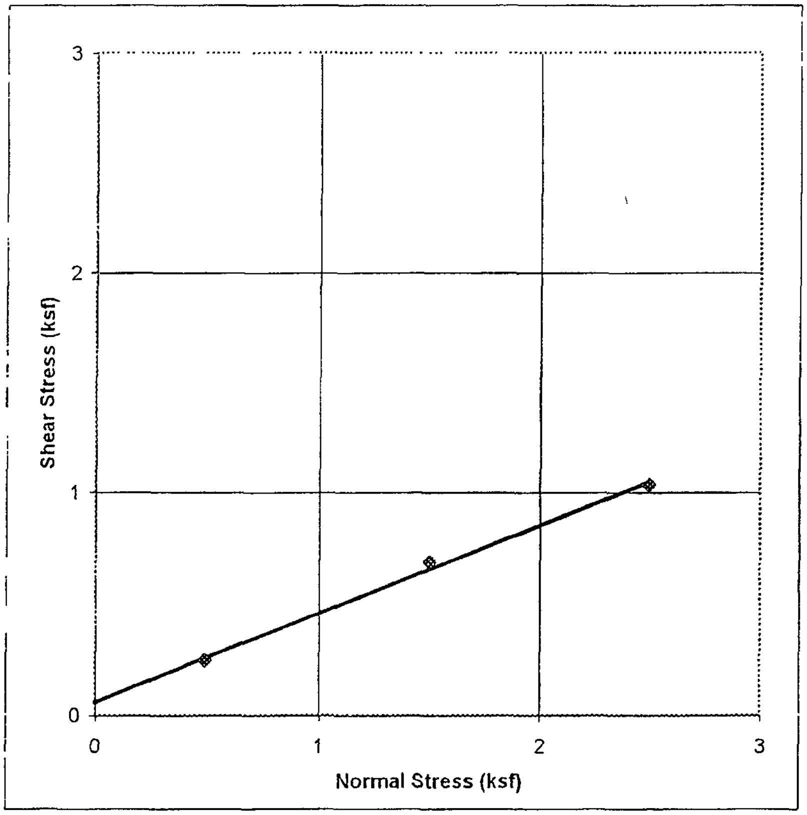
## DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED DRAINED CONDITIONS(ASTM D3080)

---

| | | | |
|---|---|---|---|
| Initial thickness of specimen (in): | 1.00 | | |
| Initial diameter of specimen (in): | 2.42 | | |
| Shearing device used. | Geomatic Direct Shear Apparatus, Model 8914 | | |
| Rate of displacement (in/min). | 0.017 | | |
| Direct shear point· | 1 | 2 | 3 |
| Dry mass of specimen (g)· | 117.6 | 124.3 | 115.2 |
| Initial Moisture Content (g/g): | 3.0% | 2.5% | 2.4% |
| Initial Wet Density (lb/ft$^3$): | 100.6 | 105.8 | 98.0 |
| Initial Dry Density (lb/ft$^3$)· | 97.7 | 103.3 | 95.7 |
| Final Moisture Content (g/g): | 21.1% | 20.2% | 20.7% |
| Final Wet Density (lb/ft$^3$): | 122.7 | 128.5 | 121.7 |
| Final Dry Density (lb/ft$^3$)· | 101.3 | 106.9 | 100.8 |
| Normal Stress (kips/ft$^2$) | 0.50 | 1.50 | 2.50 |
| Maximum Shearing Stress (kips/ft$^2$). | 0.2 | 0.7 | 1.0 |
| Vertical Deformation @ Max Shear (in). | -0.003 | -0.001 | -0.002 |
| Horizontal Deformation @ Max Shear (in)· | 0.096 | 0.084 | 0.084 |

**Internal Friction Angle** $\phi$ **21.6°**
**Cohesion (kips/ft$^2$)** **0.0580**

Notes.



AMEC Earth Environmental, Inc
8519 Jefferson NE
Albuquerque, NM 87113
Tel (505) 821-1801
Fax (505) 821-7371
www amec com

PROJECT: Maljamar Pipeline Release Project
LOCATION: Maljamar, NM
MATERIAL: Silty Sand
SAMPLE SOURCE: B-8 at 40.5 ft
SAMPLE PREPARATION: In Situ, Inundated

PROJECT NO: 6-519-004192
LAB NO: 6-1309-07
DATE SAMPLED: 09/21/06

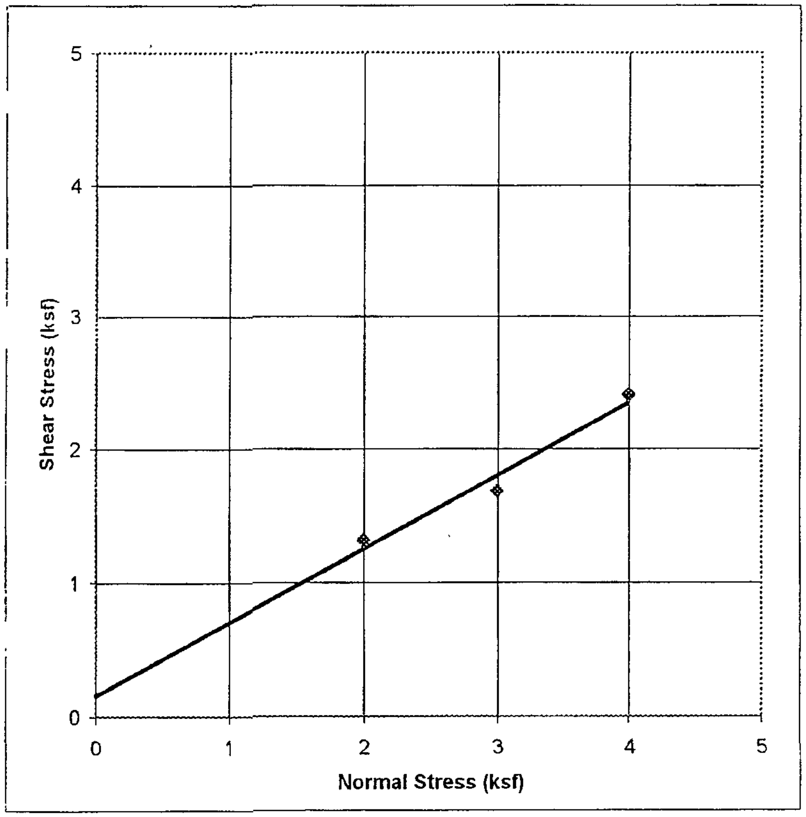
Reviewed By:

## DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED DRAINED CONDITIONS(ASTM D3080)

| | | | |
|---|---|---|---|
| Initial thickness of specimen (in): | 1 00 | | |
| Initial diameter of specimen (in): | 2.42 | | |
| Shearing device used: | Geomatic Direct Shear Apparatus, Model 8914 | | |
| Rate of displacement (in/min): | 0.017 | | |
| Direct shear point: | 1 | 2 | 3 |
| Dry mass of specimen (g): | 116 7 | 115.9 | 114.3 |
| Initial Moisture Content (g/g): | 5.0% | 3.9% | 4.8% |
| Initial Wet Density (lb/ft$^3$): | 101.7 | 100.0 | 99 5 |
| Initial Dry Density (lb/ft$^3$). | 96 9 | 96 2 | 94 9 |
| Final Moisture Content (g/g) | 16.2% | 15.3% | 15.1% |
| Final Wet Density (lb/ft$^3$): | 119.8 | 119.2 | 119 0 |
| Final Dry Density (lb/ft$^3$): | 103.1 | 103 4 | 103.4 |
| Normal Stress (kips/ft$^2$): | 2 00 | 3 00 | 4.00 |
| Maximum Shearing Stress (kips/ft$^2$) | 1 3 | 1.7 | 2.4 |
| Vertical Deformation @ Max Shear (in): | -0 004 | -0 008 | 0 001 |
| Horizontal Deformation @ Max Shear (in): | 0.152 | 0.160 | 0.166 |

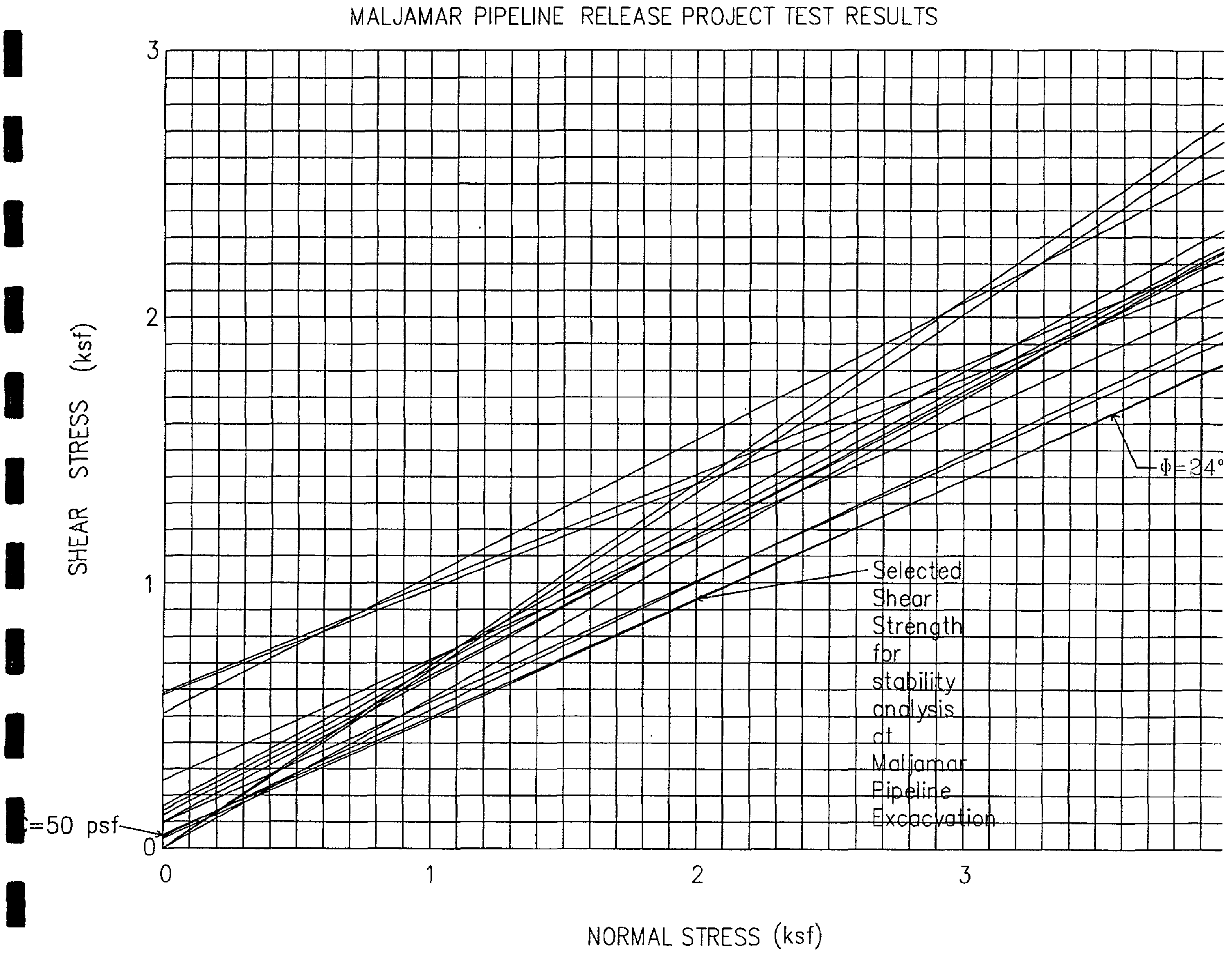
**Internal Friction Angle $\phi$** 28.6°
**Cohesion (kips/ft$^4$)** 0.1580

Notes:



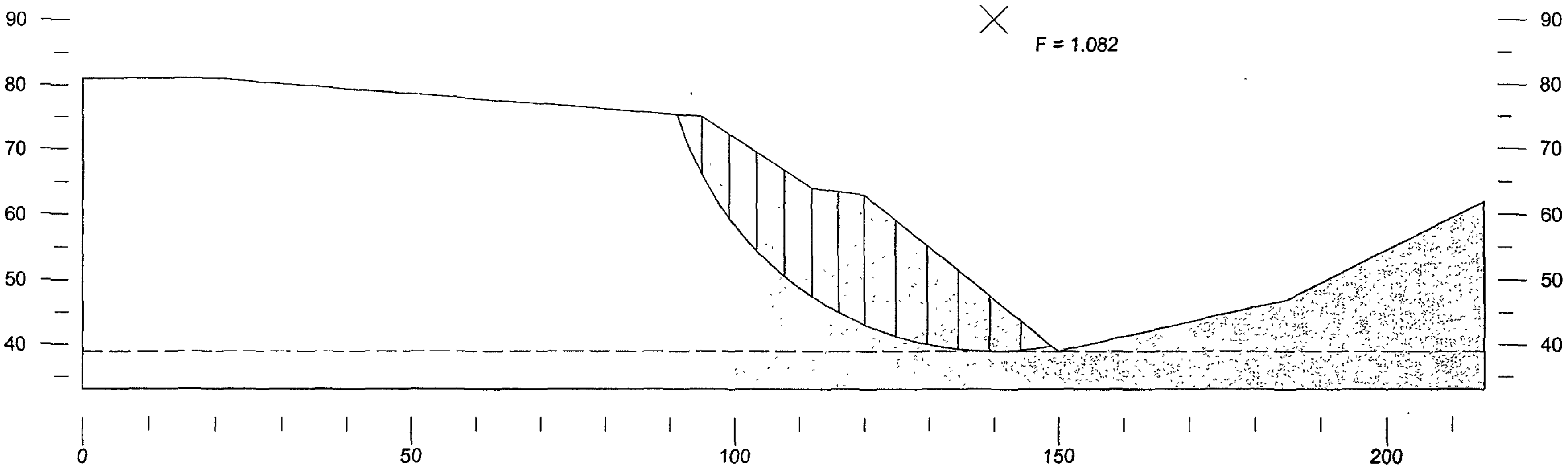
# APPENDIX C

# SLOPE STABILITY ANALYSIS SUPPORTING DOCUMENTATION


MALJAMAR PIPELINE RELEASE PROJECT TEST RESULTS
SHEAR STRESS (ksf)
3
2
1
0
=50 psf
Φ=24°
Selected Shear Strength for stability analysis at Maljamar Pipeline Excacvation
0
1
2
3
NORMAL STRESS (ksf)

| | Gamma pcf | C psf | Phi deg | Piezo Surf. |
|---|---|---|---|---|
| Silty Sand | 120 | 50 | 24 | 1 |

URS Corp - Albuquerque, NM
41008243.00003
Maljamar Pipeline Excavation Project
October 18, 2006
DONALD T. LOPEZ PE
EXISTING STEEP EAST EXCAVATION SLOPE WITH LOWER PHREATIC SURFACE



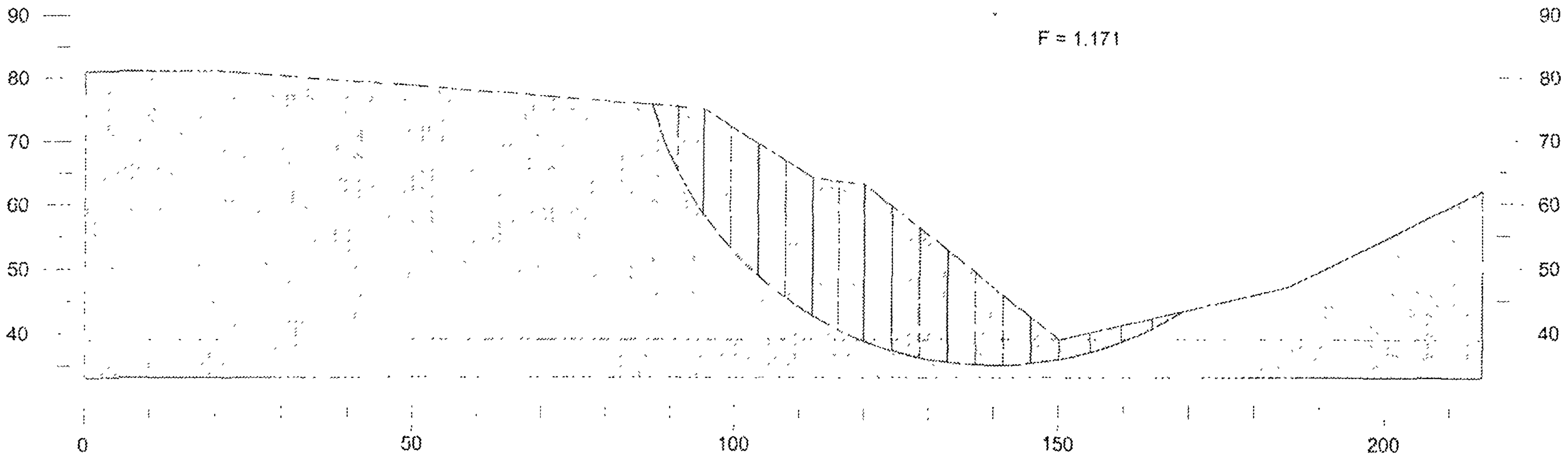
10/18/2006 2:19.09 PM A:\MAL4 GSL URS Corp - Albuquerque, NM F = 1.082

Run no. 1

| | Gamma<br>pcf | C<br>psf | Phi<br>deg | Piezo<br>Surf. |
|---|---|---|---|---|
| Silty Sand | 120 | 50 | 24 | 1 |

URS Corp - Albuquerque, NM
41008243.00003
Maljamar Pipeline Excavation Project
October 18. 2006
DONALD T. LOPEZ PE

EXISTING STEEP EAST EXCAVATION SLOPE WITH LOWER PHRAETIC SURFACE FAILURE SURFACE NOT EXITING AT THE TOE OF SLOPE



12/4/2006 4 44:58 PM C \MALJAMAR\MAL4.GSL URS Corp - Albuquerque, NM F = 1.171

Run no. 2

| | Gamma<br>pcf | C<br>psf | Phi<br>deg | Piezo<br>Surf. |
|---|---|---|---|---|
| Silty Sand | 120 | 50 | 24 | 1 |

URS Corp - Albuquerque, NM
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DECEMBER 4, 2006
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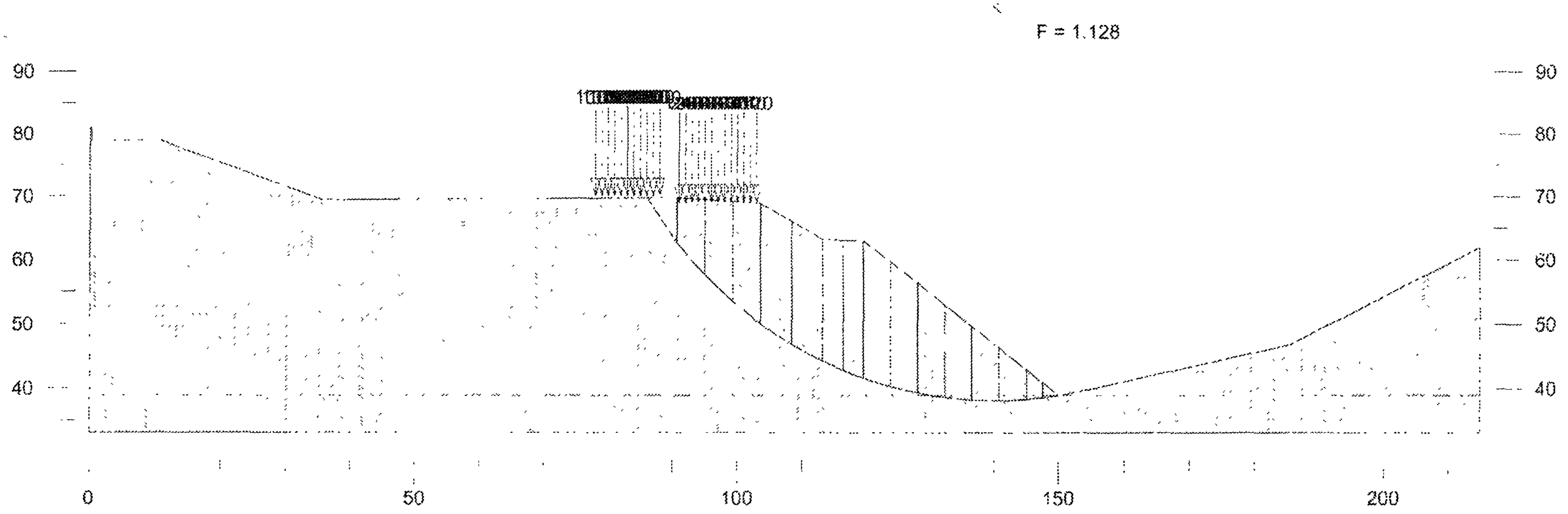
ST LEVEL BENCHES EXCAVATED WITH LOWER PHRAETIC SURFACE WITH SMALL DOZER/EXCAVATOR 10 FEET FROM CENTER OF SOIL AND 1 TO 4 FOOT SOIL PILE AT EDGE



12/4/2006 5:21:04 PM C:\MALJAMAR.MAL4B123.GSL URS Corp - Albuquerque, NM F = 1.128

Run no. 3

|  | Gamma<br>pcf | C<br>psf | Phi<br>deg | Piezo<br>Surf. |
|---|---|---|---|---|
| Silty Sand | 120 | 50 | 24 | 1 |

URS Corp - Albuquerque, NM
41008243 00003
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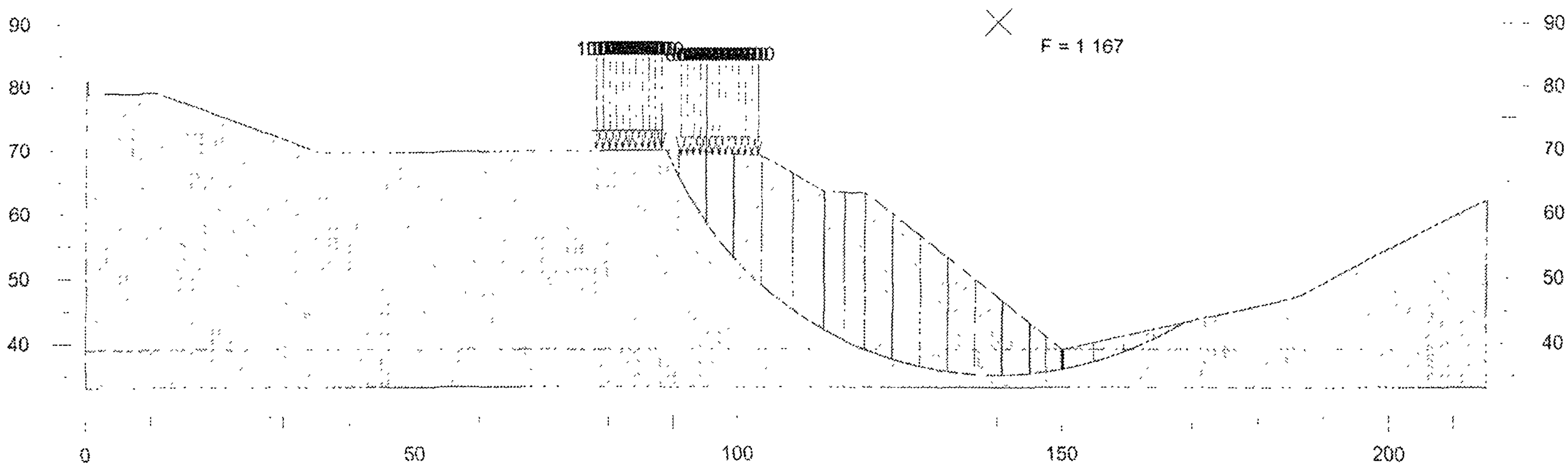
DECEMBER 4, 2006
DONALD T. LOPEZ PE

EXISTING STEEP EAST EXCAVATION SLOPE FIRST LEVEL BENCHES EXCAVATED WITH LOWER PHRAETIC SURFACE WITH SMALL DOZER AND FIVE FOOT SOIL PILE AT EDGE



12/4/2006 5 09 08 PM C \MALJAMAR\MAL4B12.GSL  URS Corp - Albuquerque, NM   F = 1.167

Run No. 4

| | Gamma pcf | C psf | Phi deg | Piezo Surf. |
|---|---|---|---|---|
| Silty Sand | 120 | 50 | 24 | 1 |

URS Corp - Albuquerque, NM
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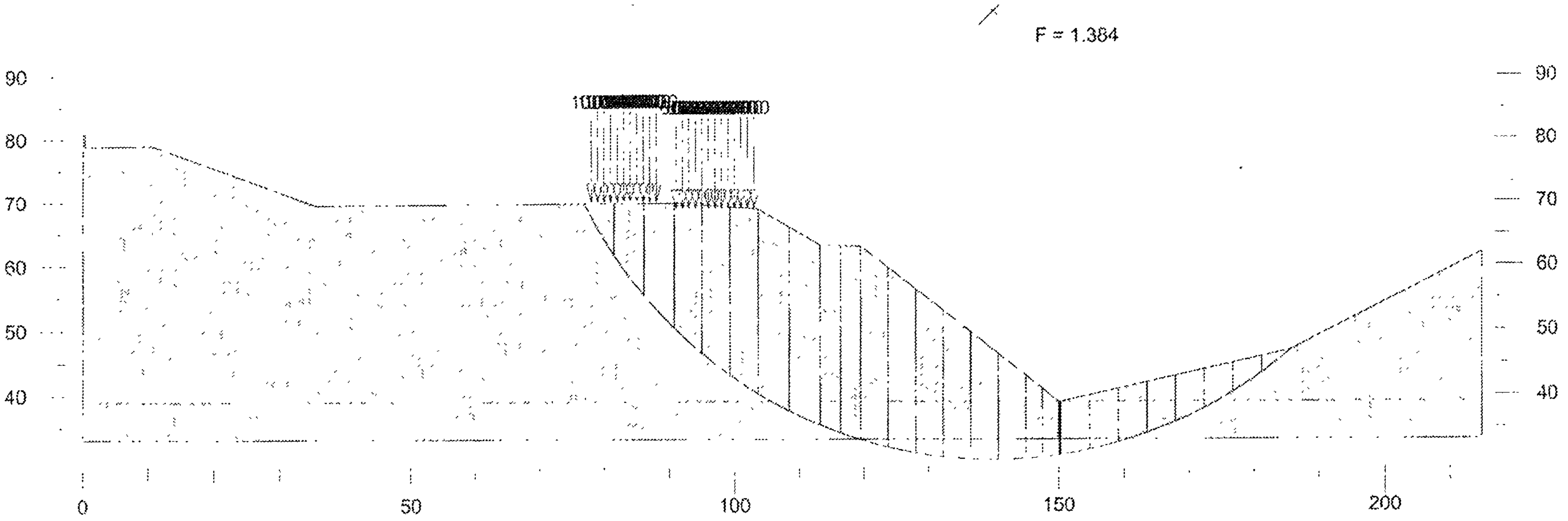
EXISTING STEEP EAST EXCAVATION SLOPE FIRST LEVEL BENCHES EXCAVATED WITH LOWER PHREATIC SURFACE WITH SMALL DOZER AND FIVE FOOT SOIL PILE AT EDGE



12/4/2006 5:10:13 PM C:\MALJAMAR\MAL4B123.GSL URS Corp - Albuquerque, NM F = 1.384

Run no. 5

|  | Gamma | C | Phi | Piezo |
|---|---|---|---|---|
|  | pcf | psf | deg | Surf. |
| Silty Sand | 120 | 50 | 24 | 1 |

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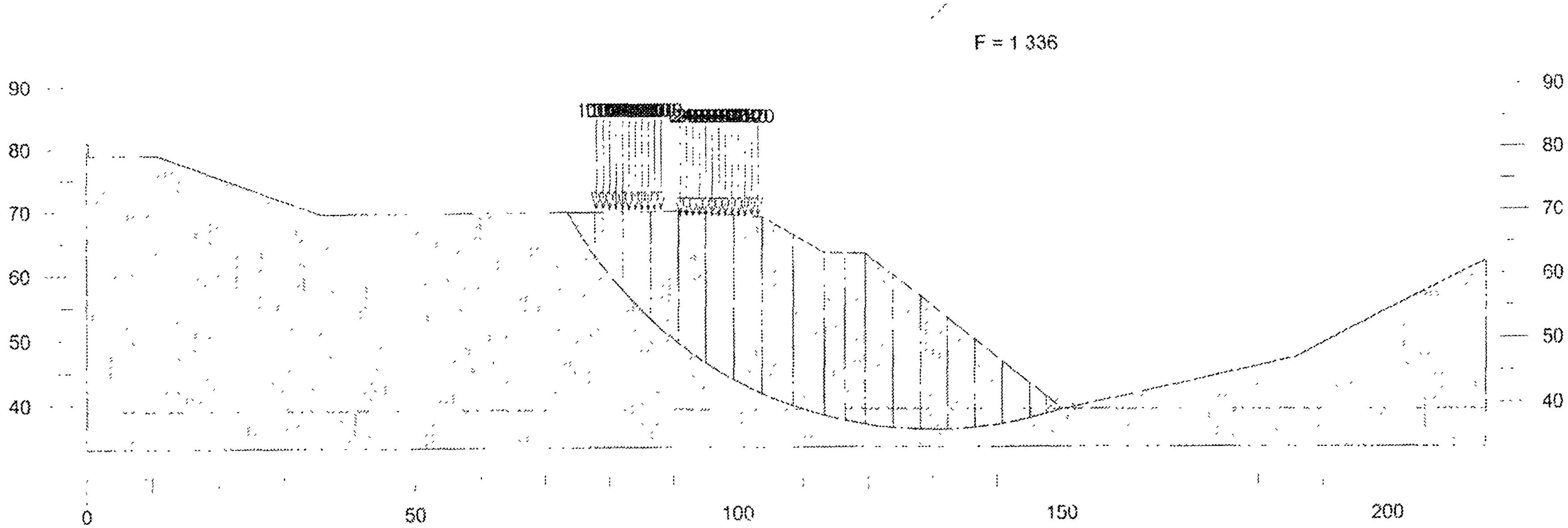
DONALD T LOPEZ PE

ISTING STEEP EAST EXCAVATION SLOPE FIRST LEVEL BENCHES EXCAVATED WITH LOWER PHRAETIC SURFACE WITH SMALL DOZER AND 1 TO 4 FOOT SOIL PILE AT EDGE



12/4/2006 5 18 39 PM C:\MALJAMAR\MAL4B123 GSL URS Corp - Albuquerque NM F - 1 336

Run no. 6

| | Gamma<br>pcf | C<br>psf | Phi<br>deg | Piezo<br>Surf. |
|---|---|---|---|---|
| Silty Sand | 120 | 50 | 24 | 1 |

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October 18,2006
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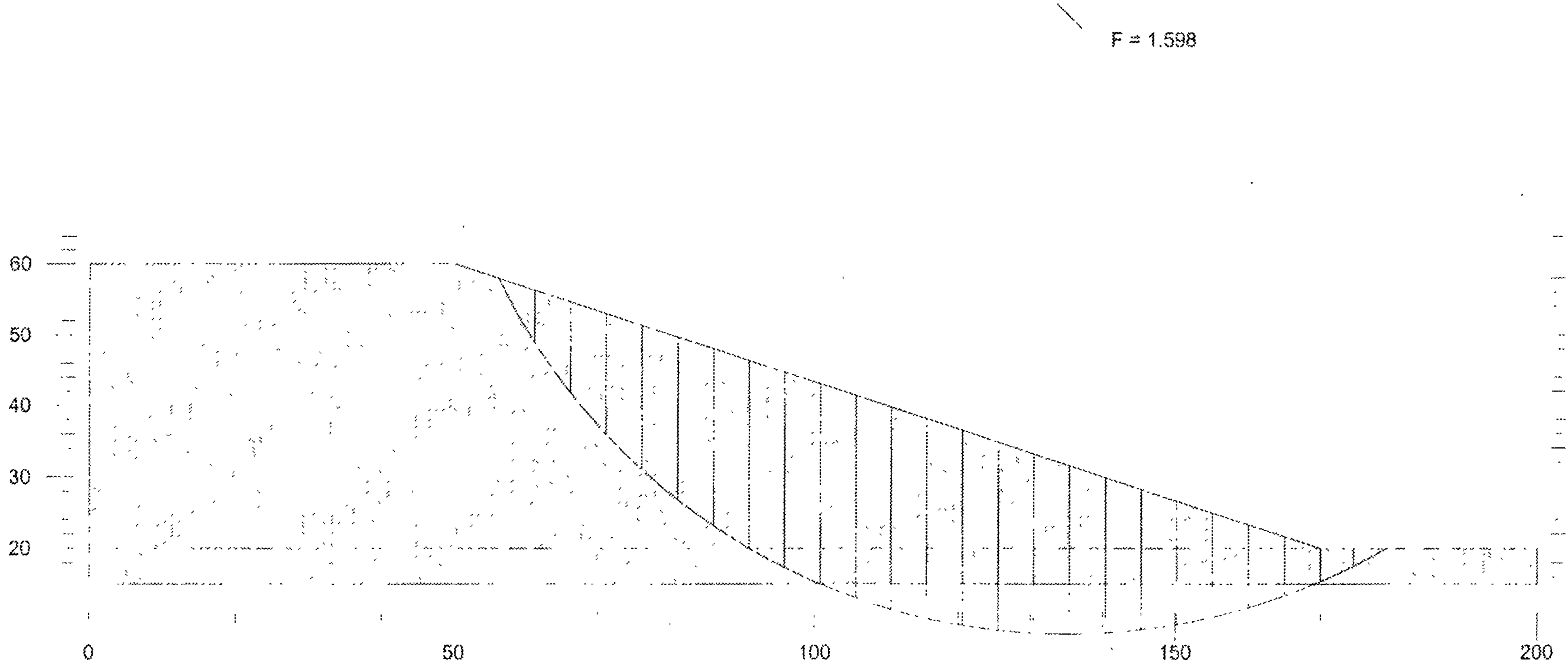
FINAL EAST EXCAVATION SLOPE 1V ON 3H WITH LOWER PHRAETIC SURFACE AT BASE OF EXCAVATION



12/4/2006 12.18.11 PM C:\MALJAMAR\MAL2 GSL URS Corp - Albuquerque, NM F = 1 598

Run no. 7

|  | Gamma<br>pcf | C<br>psf | Phi<br>deg | Piezo<br>Surf. |
|---|---|---|---|---|
| Silty Sand | 120 | 50 | 24 | 1 |

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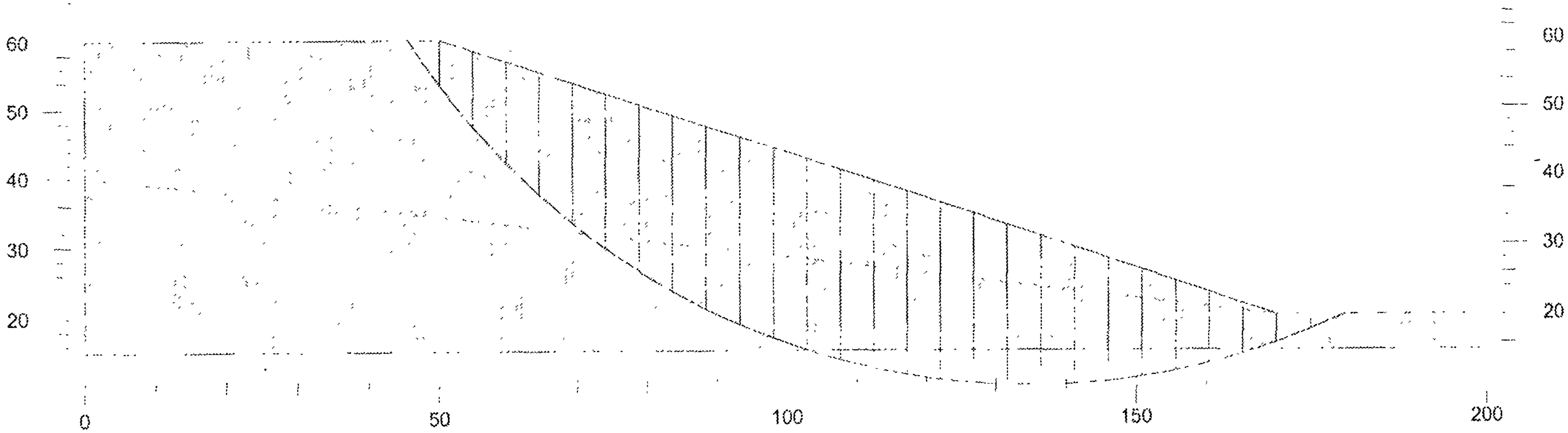
FINAL EAST EXCAVATION SLOPE 1V ON 3H WITH SLOPING PHRAETIC SURFACE TO BASE OF EXCAVATION

F = 1.384



12/1/2006 12:02:24 PM C:\MALJAMAR\MAL2A.GSL URS Corp - Albuquerque, NM F = 1.384

Run no. 8

| | Gamma pcf | C psf | Phi deg | Piezo Surf. | Area above constr. line |
|---|---|---|---|---|---|
| Silty Sand | 120 | 50 | 24 | 1 | 323 |

323 = Total Area

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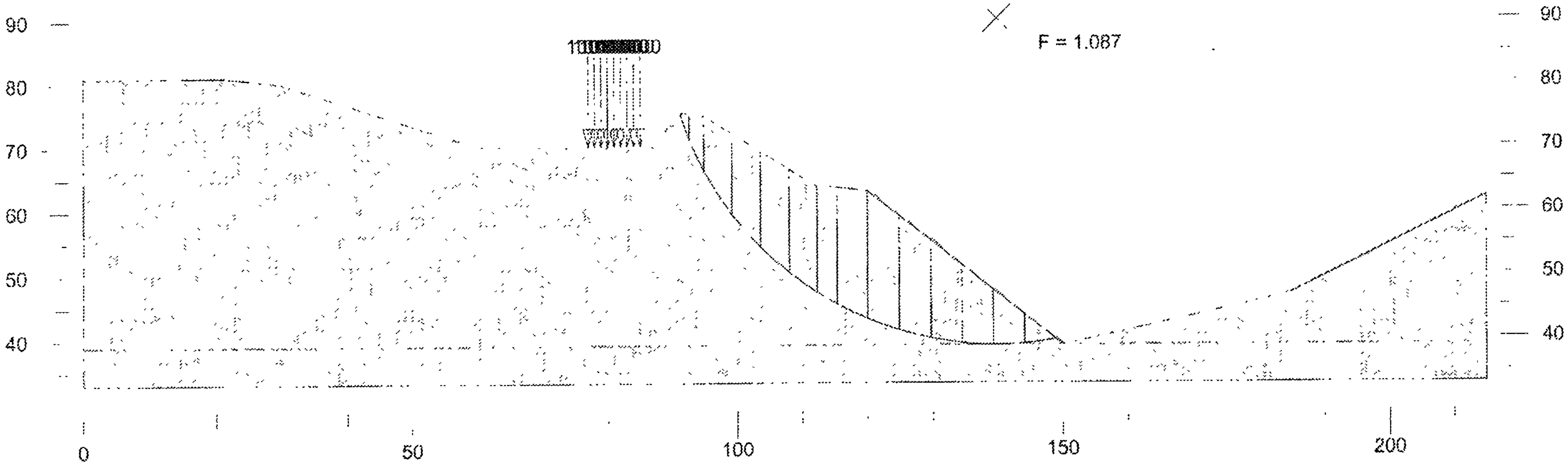
ER PHRAETIC SURFACE AND A DOZER 10 FEET FROM LAST EXCAVATION SOIL PILE I.E. DOZER OR EXCAVATOR CAN NOT BE CLOSER THAT 10 FEET FROM EDGE OF SLOPE



12/13/2006 3:35:02 PM A:\MAL4.GSL URS Corp - Albuquerque, NM F = 1.087

Run no. 9

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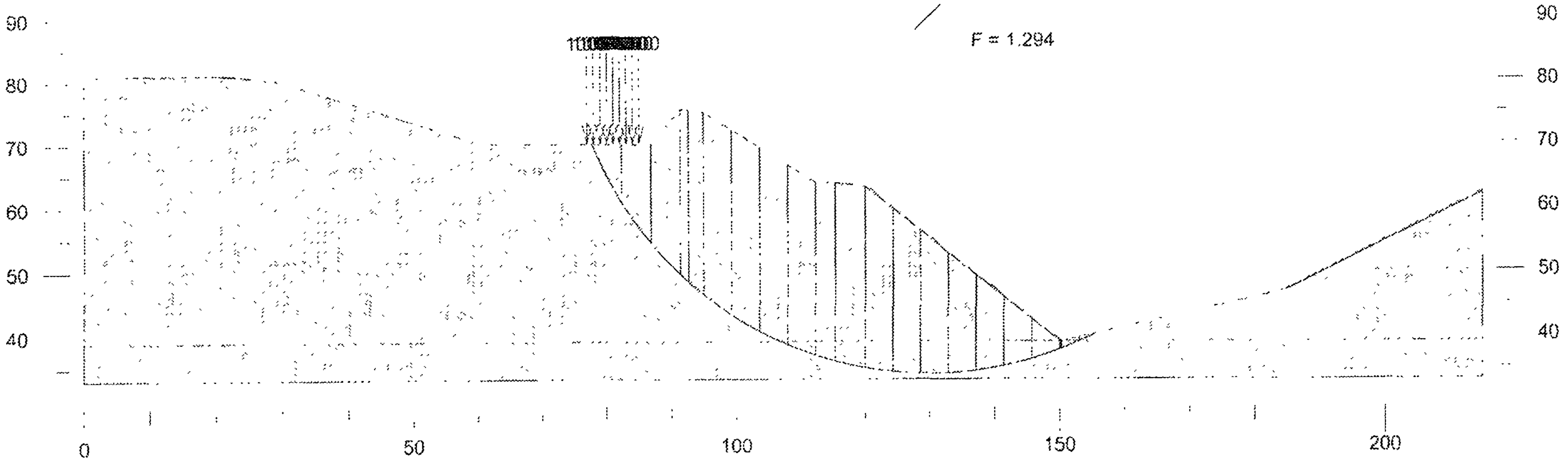
Maljamar Pipeline Excavation Project
December 13, 2006
DONALD T. LOPEZ PE

| | Gamma pcf | C psf | Phi deg | Piezo Surf. | Area above constr. line |
|---|---|---|---|---|---|
| Silty Sand | 120 | 50 | 24 | 1 | 323 |

323 = Total Area

ER PHRAETIC SURFACE AND A DOZER 10 FEET FROM LAST EXCAVATION SOIL PILE I.E. DOZER OR EXCAVATOR CAN NOT BE CLOSER THAT 10 FEET FROM EDGE OF SLOPE



12/13/2006 3:37:07 PM A:\MAL4.GSL URS Corp - Albuquerque NM F = 1.294

Run no. 10

|  | Gamma<br>pcf | C<br>psf | Phi<br>deg | Piezo<br>Surf. | Area above<br>constr line |
|---|---|---|---|---|---|
| Silty Sand | 120 | 50 | 24 | 1 | 323 |

323 = Total Area

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December 13, 2006
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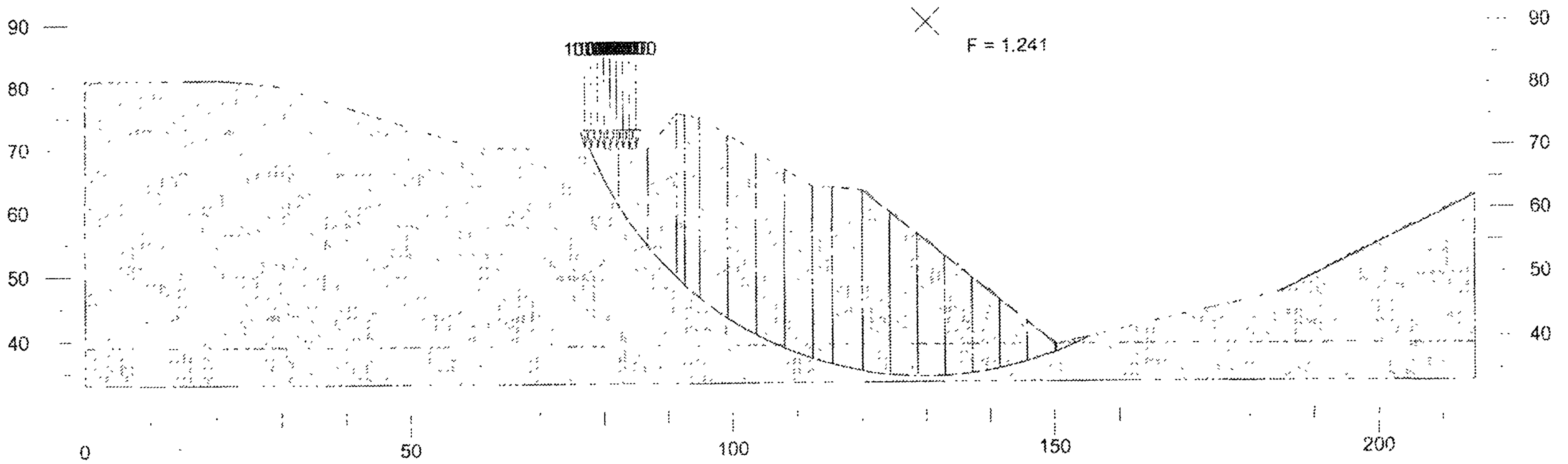
Seismic coefficient = 0.02 (Simulates Equipment Vibration)

ER PHRAETIC SURFACE AND A DOZER 10 FEET FROM LAST EXCAVATION SOIL PILE I.E. DOZER OR EXCAVATOR CAN NOT BE CLOSER THAT 10 FEET FROM EDGE OF SLOPE



12/13/2006 3 37 41 PM A \MAL4 GSL URS Corp - Albuquerque, NM F = 1.241

Run no. 4

URS Corp - Albuquerque, NM
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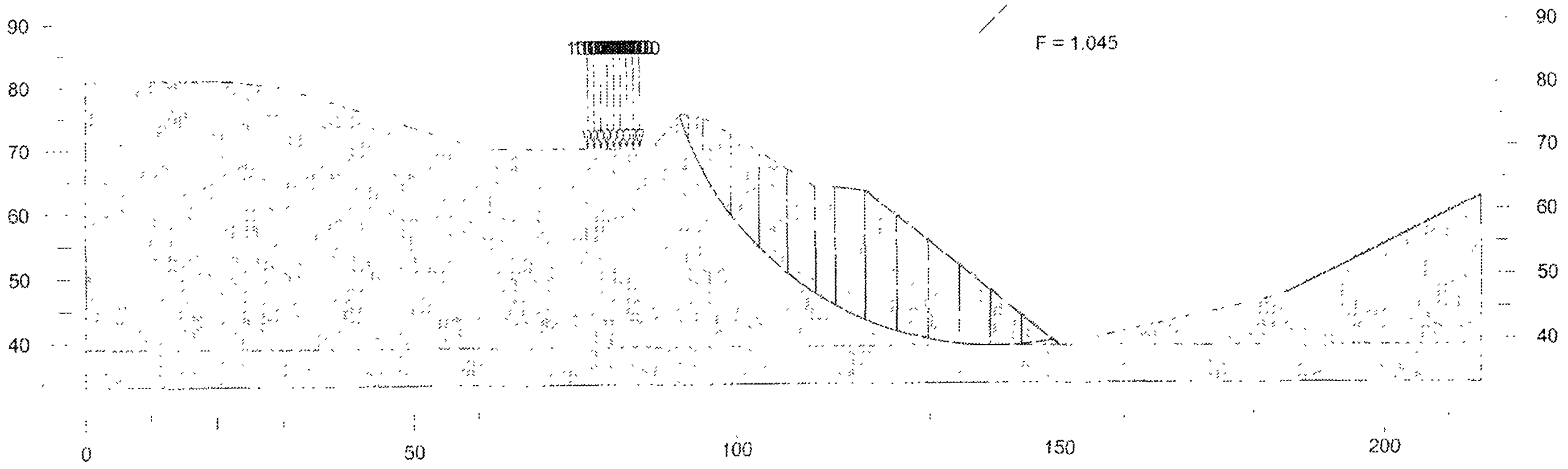
| | Gamma<br>pcf | C<br>psf | Phi<br>deg | Piezo<br>Surf. | Area above<br>constr. line |
|---|---|---|---|---|---|
| Silty Sand | 120 | 50 | 24 | 1 | 323 |

323 = Total Area

Seismic coefficient = 0.02 (Simulates Equipment Vibration)

ER PHRAETIC SURFACE AND A DOZER 10 FEET FROM LAST EXCAVATION SOIL PILE I E. DOZER OR EXCAVATOR CAN NOT BE CLOSER THAT 10 FEET FROM EDGE OF SLOPE



12/13/2006 3 38 08 PM A:\MAL4 GSL URS Corp - Albuquerque, NM F = 1.045

Run No. 12

| | Gamma<br>pcf | C<br>psf | Phi<br>deg | Piezo<br>Surf |
|---|---|---|---|---|
| Silty Sand | 120 | 50 | 24 | 1 |

Seismic coefficient = 0.05

(Simulated Earthquake)

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Maljamar Pipeline Excavation
December 13, 2006
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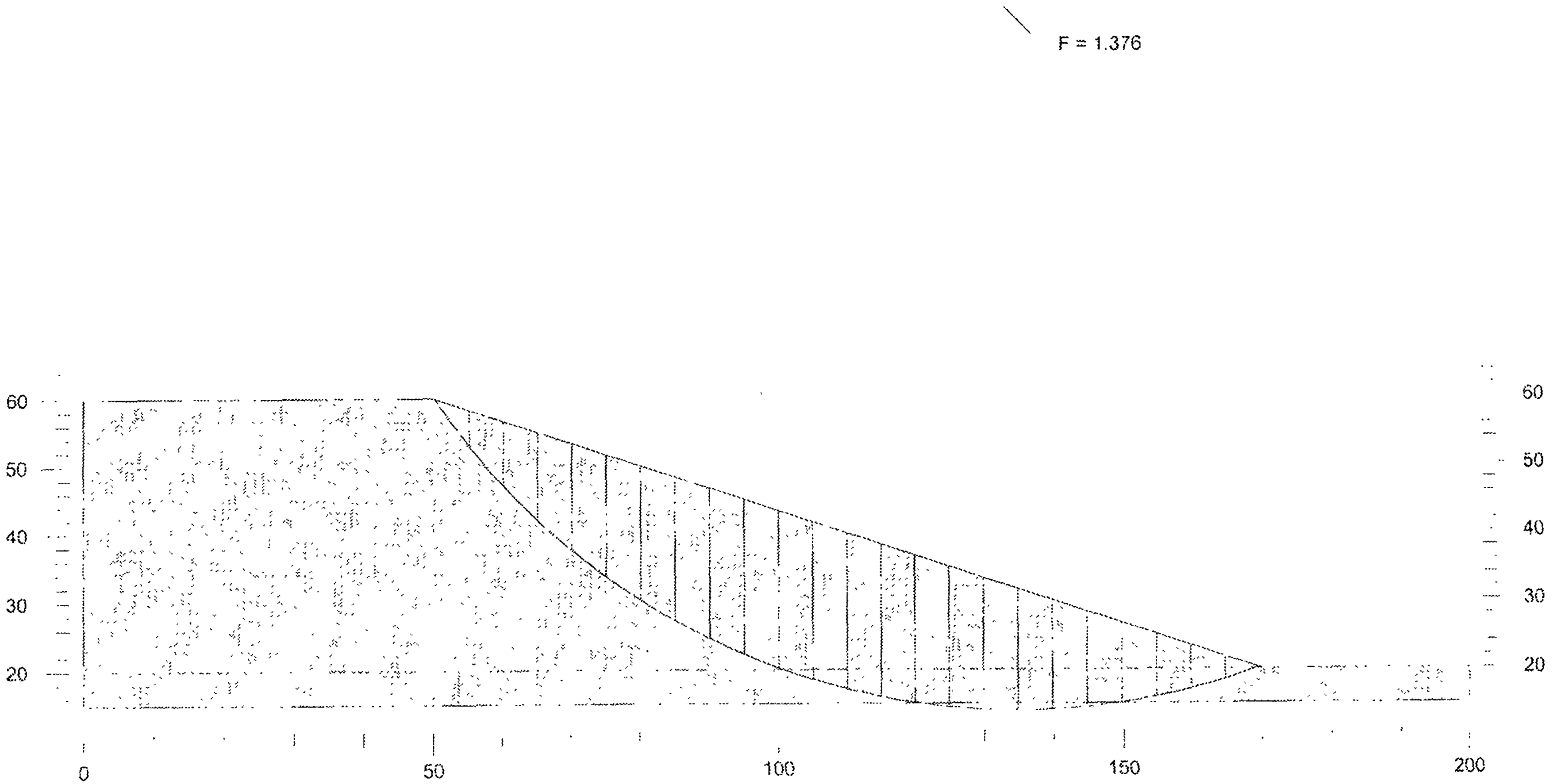
FINAL EAST EXCAVATION SLOPE 1V ON 3H WITH LOWER PHREATIC SURFACE AND APPROPRIATE EARTHQUAKE LOAD



12/13/2006 2 13 56 PM A:\MAL2.GSL URS Corp - Albuquerque NM F = 1.376

Donald T. Lopez PE
Copy.

# GSLOPE

ver. 4.1

Limit Equilibrium Slope Stability Analysis

for Windows

# User's Manual

# TABLE OF CONTENTS

# LEGAL NOTICE

To the best of our knowledge the calculations performed by this software are accurate. However, neither Mitre Software Corporation nor anyone else involved in the development or distribution of this program can assume any liability whatsoever for the accuracy or reliability of the program and its related documentation. Therefore, results from this program are neither guaranteed nor implied to be correct. As such, Mitre Software Corporation cannot be held responsible for incorrect results or damages resulting from the use of this program. Design calculations performed by this program should be checked and verified by a registered professional engineer.

Suitability of any material or infringement of patents is the sole responsibility of the user. The user must satisfy himself through independent investigation that all materials can be used safely.

More critical failure surfaces and other failure mechanisms than those identified by this program may exist. The user must assure himself that all potential failure surfaces and failure mechanisms have been analyzed or otherwise identified.

Engineering judgement is required during the design and analysis of slopes and embankments. The interpretation of factor of safety against collapse that is the end product of calculations produced by this program must always be evaluated for overall reasonableness. A professional geotechnical engineer who is familiar with site conditions, geometry of the structure, soil properties, external loadings and reinforcement materials must be engaged to ensure that final design and factor of safety against collapse are reasonable and that the assumptions made in this program are applicable to the slope or embankment analyzed.

# 1. INTRODUCTION

GSLOPE uses Bishop's Modified Method (Bishop, 1955) and Janbu's Simplified Method (Janbu et al., 1956), two most commonly used methods of limit equilibrium slope stability analysis, to find the factor of safety of slopes in granular and cohesive materials. It is designed to work with slopes with or without geosynthetic reinforcement.

Use of this program is subject to the terms of the software license agreement. In addition, the reader's attention is drawn to the legal notice which precedes this section of the manual.

Technical support for GSLOPE is available from:

Mitre Software Corporation
9636-51 Avenue, Suite 200
Edmonton, AB
Canada T6E 6A5

Phone:(780) 434-4452
Fax: (780) 437-7125
info@mitresoftware.com
www.mitresoftware.com

Note that the telephone area code was changed from 403 to 780 in January 1999.

## 1.1 FEATURES

GSLOPE can model slopes containing multiple soil materials having a wide variety of geometries. Each soil material can have its own pore pressure condition, or all may share the same pore pressure condition. The slope can also be partially submerged. Pore pressure conditions can be specified either in terms of piezometric lines or as Ru values.

Each soil material present in the slope is normally specified in terms of its total unit weight, effective cohesion, and effective friction angle. The soil-reinforcement interaction coefficient of each soil can also be specified. Up to 20 different soil materials can be included in an analysis, along with up to 100 layers of reinforcement. Quick methods are provided for adding layers of reinforcement and adjusting reinforcement layers so that they just daylight.

Surcharge loads can be simulated by defining a material with a high unit weight, but zero strength parameters.

Seismic loading can be input as a horizontal acceleration for pseudo-static analysis.

Screen graphics can show soil layers, piezometric surfaces, external forces, reinforcement, and potential slip surfaces. You can zoom in for a close-up of the slip surface and inspect individual slices if desired.

GSLOPE carries out extensive data checking and error flagging.

GSLOPE has three types of grid search, plus it can analyze a surface of general shape. During searches, every slip surface is drawn on the screen so that the user can see which surface is being analyzed.

Contours of factor of safety can be shown on the screen, and are updated as the analysis progresses. Because analysis proceeds rapidly, there is also a speed control and stop/resume button.

The ground surface profile, the soil profiles, piezometric surfaces, external line loads, and layers of reinforcement can be defined graphically using a mouse. The associated coordinates can also be edited directly.

GSLOPE allows the use of a "construction line" which simplifies production and subsequent modification of a detailed stratigraphic cross-section. Some of the possibilities this opens up are as follows:-

> The stratigraphy of an area to be excavated can be drawn once and then used as a basis for several analyses, each cut with a different excavation line.
>
> To add a berm, outline it with the construction surface, and choose Fill.
>
> To submerge the toe of a slope, insert a material at the ground surface, draw a horizontal construction line at the desired elevation, choose Other Fill, and enter the appropriate material name and properties for water as the first material.

Points on the geometry can be relocated graphically using the mouse, or finely adjusted using the cursor keys. When a fully-specified slip surface is modified in this way, the factor of safety is continuously updated to reflect the current shape of the slip surface.

The .GSL file format used by GSLOPE for Windows is the same as used by the DOS version of GSLOPE.

## 1.2 INSTALLATION

To instal GSLOPE, run setup.exe from the program CD and follow the prompts. The default installation folder is C:\Program Files\Gslope.

To instal the driver for the Sentinel Pro security key, run Sentinel\Setup.exe from the program CD. This may not be necessary if you already have the Sentinel drivers installed for another program. It does not matter whether the key is in position when the driver is installed, nor does it matter whether GSLOPE has been installed at that time.

Since will need to restart your computer anyway in order to activate the driver, it is suggested you shut your machine down, and then connect the security key to the parallel port. The key can be cascaded with other Sentinel keys and/or a printer. Then power up your computer again.

If no key driver is present, the key will not be recognized.

### 1.2.1 Security Key Troubleshooting

If at some point in the future the key is not recognized, reinstall the sentinel driver. In some cases it might be necessary to uninstall the driver, restart the computer, and then reinstall the driver and restart the computer again.

The latest version of the sentinel driver can be found at the Safenet website,

http://www.safenet-inc.com/support

As of June 2005, the latest version of the driver is:

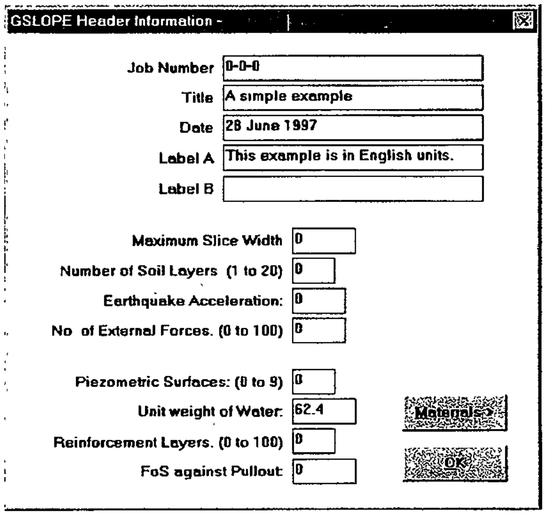
Sentinel Protection Installer 7.1

## 1.3 GETTING STARTED WITH GSLOPE

This section explains how to define a sample analysis in the fastest and simplest way possible. It shows how to draw soil stratigraphy and demonstrates excavation of a cross section using a construction line, minimizing the effort required to define the geometry.

### 1.3.1 Header Data and System of Units

Start GSLOPE, and choose Edit Header. Enter information as shown below:



Job Number: 0-0-0
Title: A simple example
Date: 28 June 1997
Label A: This example is in English units.
Label B:
Maximum Slice Width: 0
Number of Soil Layers (1 to 20): 0
Earthquake Acceleration: 0
No of External Forces. (0 to 100): 0
Piezometric Surfaces: (0 to 9): 0
Unit weight of Water: 62.4
Reinforcement Layers. (0 to 100): 0
FoS against Pullout: 0

The most important item on the Header screen is the Unit Weight of Pore Fluid. It is used to define the system of units used in the analysis as follows:

### UNITS ASSUMED BY GSLOPE BASED ON UNIT WEIGHT OF WATER

| | | | |
|---|---|---|---|
| Unit Weight of Water | 9.81 | 62.4 | 1000 |
| Unit Weights | $kN/m^3$ | $lb/ft^3$ | $kp/m^3$ |
| Dimensions | m | ft | m |
| Cohesion | kPa | $lb/ft^2$ | $kp/m^2$ |
| External Forces | kN/m | lb/ft | kp/m |
| Reinforcement Allowable Tension | kN/m | lb/ft | kp/m |

This example is in English units, so enter the Unit Weight of Water as 62.4 (pounds per cubic foot) and press OK when done. There is no need to enter the number of materials, etc. because these entries can be made automatically by drawing them on the screen.

## 1.3.2 Define the Limits of the Geometry

Prepare to draw stratigraphy by choosing Set Extents. This defines the lateral extents of the geometry in terms of X-coordinates, and supplies an initial value for the base Y-coordinate used to display the geometry. Enter the desired extents as follows:

| | |
|---|---|
| X-coordinate of Left Side | 0 |
| X-coordinate of Right Side | 280 |
| Y-coordinate of Base | 180 |

Click OK when done. An appropriate set of coordinate axes appears. To make drawing easier, choose Set Snaps and set both the X-Coordinate Snap and the Y-Coordinate Snap to 1. This will ensure that all points that you draw will have their coordinates rounded to the nearest integer.

### 1.3.3 Draw the Stratigraphy

To draw the ground surface, select Draw Soil Layers Material 1. Note that the cursor coordinates are now displayed in the upper left corner of the GSLOPE window. The first point on any material is always on the left edge of the geometry, so do not worry about the X-coordinate for this first point. Adjust the cursor to display a Y-coordinate of 256, and press the left mouse button. The first point on Material 1 (= the ground surface in this case) is drawn at X=0, Y=256. Move the cursor to a point beyond the right side of the geometry (make the X-coordinate greater than 280 or simply move the cursor to the right side of the screen) and draw a second point, also at Y=256. A simple cross-section, consisting of a single, flat material appears.

Select Draw Soil Layers Material 2 and draw a second horizontal surface, at Y=250. Then add more horizontal surfaces at the following elevations:

| | |
|---|---|
| Material 3 | Y = 242 |
| Material 4 | Y = 202 |
| Material 5 | Y = 195 |

Select Edit Material Properties and enter the names and properties of the various materials as follows:

| | Material Name | Total Unit Wt. | Cohesion | Friction Angle | Piezo Surface |
|---|---|---|---|---|---|
| 1 | Upper firm clay | 114 | 750 | 21 | 0 |
| 2 | Lower firm clay | 111 | 650 | 22 | 1 |
| 3 | Soft clay 1 | 108 | 250 | 20 | 1 |
| 4 | Clay till | 124 | 700 | 26 | 1 |
| 5 | Hard Bottom | -1 | | | |

Do not worry about the other columns for now. Click Close when done.

### 1.3.4 Assign a Filename

Choose File Save As and assign the name SAM1.GSL.

### 1.3.5 Excavate a Slope

We will now create a slope by excavating part of the stratigraphy. Choose Draw Construction Line and pick a first point anywhere above the ground surface (Y>=256). Choose additional points as follows:

| | | |
|---|---|---|
| Point 2 | X = 107 | Y = 256 |
| Point 3 | X = 185 | Y = 216 |
| Point 4 | X = 280 | Y = 216 |

For point 4, the final X-coordinate, any value over 280 will be corrected to 280 in order to match the limit of the geometry.

If you have drawn the excavation surface correctly, Choose Other Excavate/All Materials and press Construct to create the slope. Choose File Save to write the changes to SAM1.GSL. Click on the bar at the base of the window to force a screen redraw. This will remove any remnants of the construction line. If the construction line still remains, remove it by choosing Set Preferences and unchecking the box labelled "Construction Surface".

### 1.3.6 Draw a Piezometric Surface

Choose Draw Piezo Surfaces Piezo Surface 1 and draw a single surface with the following coordinates:

| | | | |
|---|---|---|---|
| 0, 247 | 50, 246 | 90, 244 | 120, 239 |
| 151, 230 | 185, 216 | 280, 216 | |

As when drawing materials, if you make a mistake, you can use the right mouse button to back up.

### 1.3.7 Define a Grid of Centers

Choose Draw Grid of Centers and pick opposite corners of the grid at 160, 280 and 180, 300.

### 1.3.8 Define a Range of Tangents

Choose Draw Range of Tangents and pick two elevations as follows:

Y = 206

Y = 200

### 1.3.9 Run an Analysis

Check that under the Slip Surface menu, the Regular Grid Search option is checked. Then choose Analyze Calculate (or press Shift-F9) to display the grid selection screen. The required grid parameters have already been filled in automatically when the grid and tangents were drawn. Click OK, and the analysis proceeds.

Each slip surface is displayed on the screen as the calculation proceeds. A bar at the base of the screen displays information on the current surface in the following order:

| | | | | | | |
|---|---|---|---|---|---|---|
| X-coord of center | Y-coord of center | Radius | No. of Iterations | No. of Slices | Factor of Safety | Malpha Warnings |

M-alpha warnings are issued under certain unusual conditions when the calculated normal forces on the base of a slice can become unrealistic. Further information on M-alpha may be found in the Technical Notes, which are available separately.

Choose Set Preferences to show the display preferences currently selected. Check Contours and click OK. The contours of Factor of Safety for the analysis just carried out appear on the screen. To extend the contoured area, press Shift-F9 to bring up the grid selection screen, and change X-steps and Y-steps from their default value of 2 to values of, say, 5 and 6. Click OK, and watch how the contours appear as the analysis proceeds.

Since the critical center for this run is in the lower left corner of the defined grid, you may wish to try using Draw Grid of Centers to redraw the grid lower down and farther to the left, e.g. from 140, 260 to 190, 320. Press F9 to recalculate with the new grid.

Zoom in on the displayed cross-section by choosing View Zoom Window (or by pressing Ctrl-W) and then defining a window by clicking its opposite corners. Get back to the full-screen view by using View Zoom All or by pressing Ctrl-A.

Print out the full cross-section by choosing File Print Graphics.

## 1.4 FILE ORGANIZATION

Data file organization in GSLOPE is extremely simple; all of the information about any given analysis is contained in one file, e.g. SAM1.GSL. When a file is read using File Load, the information is loaded into RAM and can be modified, calculations can be performed, cross-sections printed out etc. without affecting the file. If you make modifications and save them using File Save, you will overwrite the previous file. If this is not what you intend, use File Save As, and supply a new filename under which the data is to be saved.

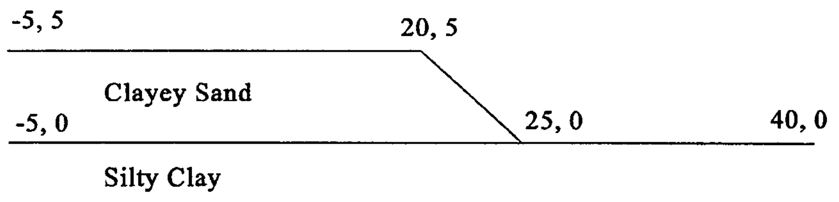
If you are carrying out a lot of analyses, it is simplest to make a separate folder for each project you are working on. Each time you exit GSLOPE, it records the locations of the last few files you worked on, and makes them available directly on the FILE menu next time GSLOPE is run.

## 1.5 A SIMPLE EXAMPLE WITH REINFORCEMENT

### 1.5.1 Defining the Geometry

The geometry could be created by drawing using the mouse cursor, as described in the first example, and this is the usual way for data to be entered. However, in order to demonstrate the procedure, in this example the geometry will be defined by entering coordinates on the various tabular editing screens.

Before entering any data, obtain a drawing or make a sketch showing the cross-section you wish to Analyse, and mark the main coordinates on it. An example cross section is shown below:



The top of each soil material present is defined as a line which runs from the left to the right side of the geometry. The actual width of the geometry used does not affect the calculation. However, graphical output of the cross-section usually fits best on the page when the width of the geometry is about 5 to 10 times the ground surface elevation change across the geometry. In this example, the geometry extends from X=-5 m to X=40 m. All materials and piezometric surfaces must therefore begin at X=-5 and end at X=40.

The first material normally represents the one found immediately below the ground surface profile. In the example, the first material, Clayey Sand, has 4 points as follows:

| Point No. | X-coordinate (m) | Y-coordinate (m) |
|---|---|---|
| 1 | -5 | 5 |
| 2 | 20 | 5 |
| 3 | 25 | 0 |
| 4 | 40 | 0 |

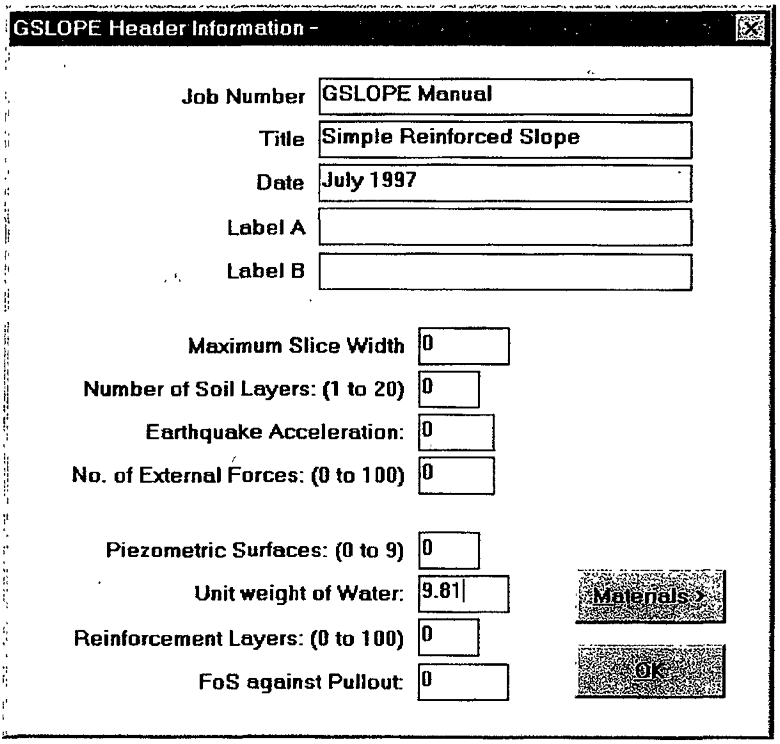
The points are arranged in order of increasing X-coordinate, and each succeeding point on a given material must have a greater X-coordinate. Usually the difference between succeeding points is set at 0.05 units or more. Slopes can fail from left to right or right to left, although the default setting for Segment Choice (see Section 2.8.5) is better suited to slopes failing from left to right as in this example.

In this simple example, the second material represents the foundation soil. The profile representing the top of this material has just two points as follows:

| Point No. | X-coordinate (m) | Y-coordinate (m) |
|---|---|---|
| 1 | -5 | 0 |
| 2 | 40 | 0 |

### 1.5.2 Enter The Header Data

When entering your own data, you can either start fresh or edit an existing data file. To start fresh, choose File New to clear all the data in RAM. (This is not necessary if you have just started the program.) Choose Edit Header, then fill in appropriate header data in the upper five fields as shown below. This header information will appear on plots and printouts, but takes no direct part in the analysis.


GSLOPE Header Information -

Job Number: GSLOPE Manual
Title: Simple Reinforced Slope
Date: July 1997
Label A:
Label B:

Maximum Slice Width: 0
Number of Soil Layers: (1 to 20): 0
Earthquake Acceleration: 0
No. of External Forces: (0 to 100): 0

Piezometric Surfaces: (0 to 9): 0
Unit weight of Water: 9.81
Reinforcement Layers: (0 to 100): 0
FoS against Pullout: 0

Maximum Slice Width

The maximum slice width affects the number of vertical slices into which the slope will be divided for calculation purposes. You can leave this blank, and the program will assume a value of 1.0. You can come back and change the value later if necessary.

Number of Soil Layers
It is helpful to enter the correct number of materials whose geometry you will be entering now, so enter the number 2 in this field. You can still add, delete, and insert materials later.

Earthquake Acceleration
Seismic loading is not considered in this example, so enter zero for the seismic coefficient or leave this field blank.

No. of External Forces
There are no external forces in this example, so enter zero here.

Piezometric Surfaces
The example has only one piezometric surface for all the materials, so enter 1 for the number of piezometric surfaces.

Unit Weight of Water
The value entered in this field defines the system of units to be used in the analysis. This example is in metric units, so enter the value 9.81 as the Unit Weight of Water in kN/m$^3$. This means that all unit weights must be in kN/m$^3$, coordinates must be in meters, cohesions in kPa, and external forces and reinforcement forces in kN per meter width. If the example had used English units, you would have entered 62.4 as the Unit Weight of pore fluid in lb/ft$^3$. In that case all unit weights would have been in lb/ft$^3$, dimensions would have been in feet, cohesion would have been in psf, and reinforcement forces in lb per foot width.

To use kilogram force units (kp), enter the value 1000 as the Unit Weight of Water in kp/m$^3$. All unit weights will then have to be in the same units, coordinates in meters, cohesion in kp/m$^2$, and forces in kp per meter width.

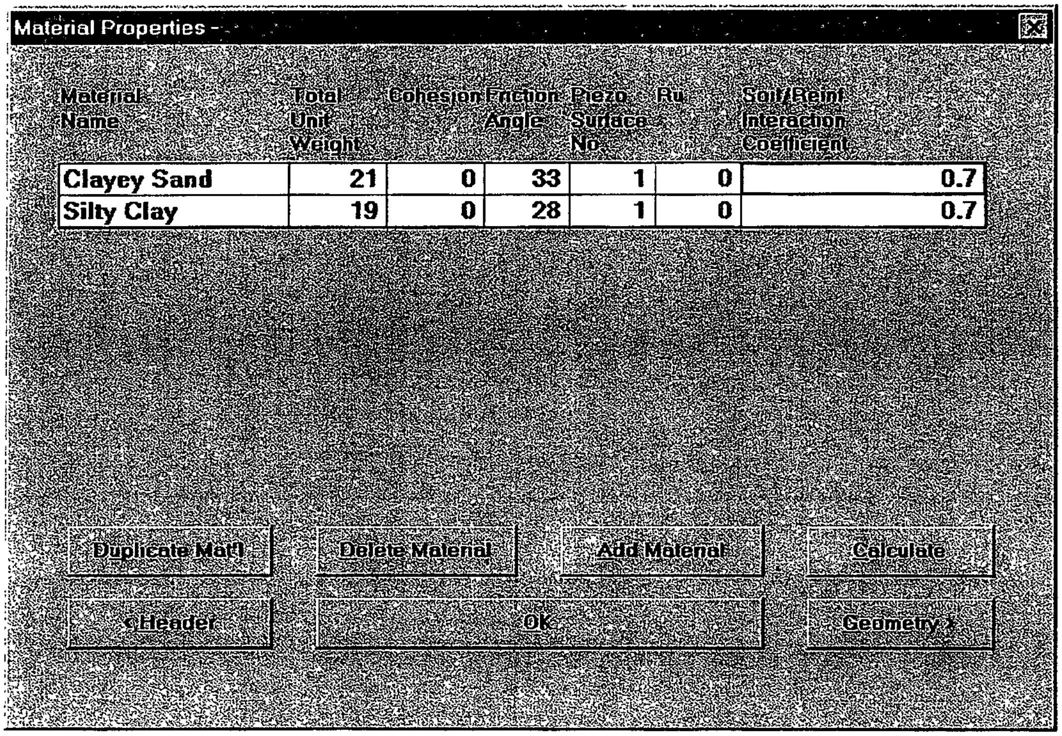
No. of Reinforcement Layers
This is the number of layers of geosynthetic reinforcement in the cross-section. You can leave this value at zero for now, as we will add the reinforcement graphically later.

FoS against Reinf. Pullout
For the Factor of Safety against reinforcement pullout, enter a value of 1.5. Note that this is not applied to the strength of the reinforcement, but rather affects the rate at which tension is assumed to build up with distance from the ends of the reinforcement.

When finished with the Header window, click Materials> to go directly to the Material Properties window.

### 1.5.3 Entering Material Properties

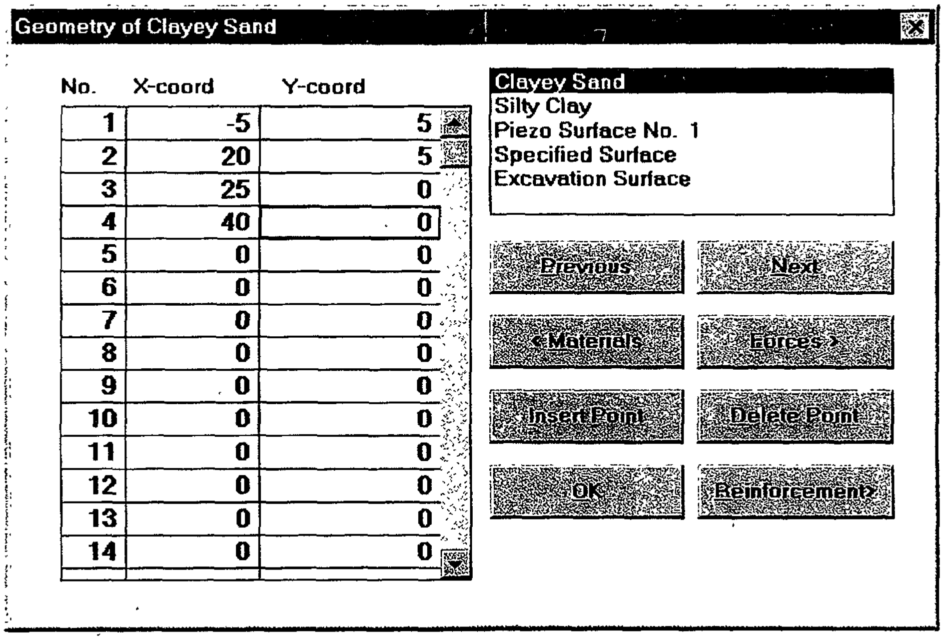
Make entries as shown below. The unit weight values represent the total unit weight of each of the materials under the expected conditions, i.e. the values include the weight of any moisture present in the soil. In this example, both soils are assumed to have the same piezometric conditions, so enter 1 for the applicable piezometric surface of each soil.



| Material Name | Total Unit Weight | Cohesion | Friction Angle | Piezo Surface No. | Ru | Soil/Reinf Interaction Coefficient |
|---|---|---|---|---|---|---|
| Clayey Sand | 21 | 0 | 33 | 1 | 0 | 0.7 |
| Silty Clay | 19 | 0 | 28 | 1 | 0 | 0.7 |

### 1.5.4 The Geometry Window

Click Geometry> to display the Geometry window and then enter the coordinates of the uppermost material, Clayey Sand, as (-5, 5), (20, 5), (25, 0), and (40, 0). Click Next and enter just two coordinates to represent the second material, Silty Clay. The coordinates are (-5, 0) and (40, 0).



| No. | X-coord | Y-coord |
|---|---|---|
| 1 | -5 | 5 |
| 2 | 20 | 5 |
| 3 | 25 | 0 |
| 4 | 40 | 0 |
| 5 | 0 | 0 |
| 6 | 0 | 0 |
| 7 | 0 | 0 |
| 8 | 0 | 0 |
| 9 | 0 | 0 |
| 10 | 0 | 0 |
| 11 | 0 | 0 |
| 12 | 0 | 0 |
| 13 | 0 | 0 |
| 14 | 0 | 0 |

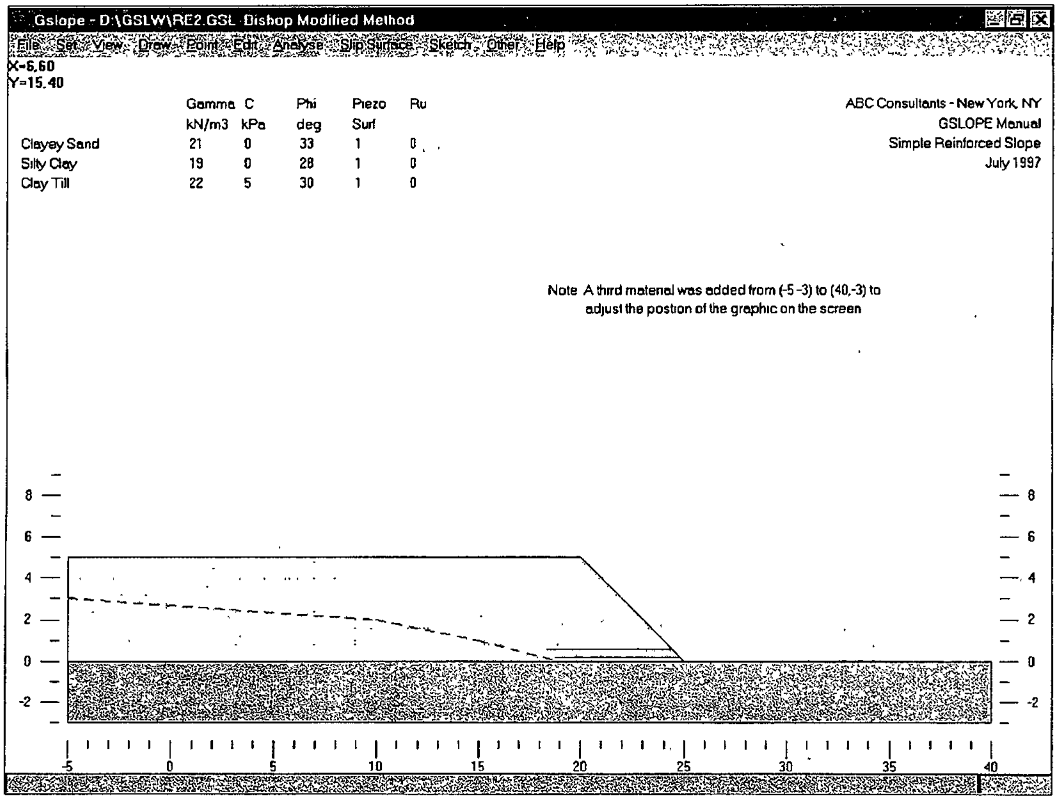
Clayey Sand
Silty Clay
Piezo Surface No. 1
Specified Surface
Excavation Surface

To enter the coordinates of the single piezometric surface, click Next or click on the item labelled "Piezo Surface No. 1" in the list box. Enter the following coordinates:
(-5, 3), (10, 2), (15, 1), (19, 0), (40, 0). Press OK. You can improve your view of the geometry by choosing Set Extents and setting the Y-coordinate of the base to -2. Also check the box labelled "Override default base coordinate".

At this point, it is a good idea to save your work. Because no name has been defined yet for this file, choose File Save As... , then edit the presented file specification so as to save the data in a file called RE1.GSL .

### 1.5.5 Specifying the Reinforcement

Select Draw Reinforcement and draw a single layer of reinforcement 6 m long at elevation 0.2. Do not worry about getting the elevation exactly right, or making the reinforcement end at the slope face, just concentrate on getting the length right. It could for example be drawn at Elevation 0.2, extending from X=20 to X=26.



X=6.60
Y=15.40

|  | Gamma<br>kN/m3 | C<br>kPa | Phi<br>deg | Piezo<br>Surf | Ru |
|---|---|---|---|---|---|
| Clayey Sand | 21 | 0 | 33 | 1 | 0 |
| Silty Clay | 19 | 0 | 28 | 1 | 0 |
| Clay Till | 22 | 5 | 30 | 1 | 0 |

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Note A third matenal was added from (-5 -3) to (40,-3) to adjust the postion of the graphic on the screen

You could now draw more layers of reinforcement, but it is easier and more precise to use the Reinforcement editing screen. Choose Edit Reinforcement to display the Reinforcement editing screen. It shows the left and right extents and the elevation for the one layer of reinforcement you just drew. Depending on the current Snap settings (see Section 2.2.2) you may have to edit the elevation to get Y = 0.2.

Click Add to add a layer of reinforcement. GSLOPE assumes to start that it has the same X1 and X2 coordinates as layer 1, and fills in a Y-coordinate 0.9 m below, or at Y = -0.7. Edit the Y coordinate of the second layer of reinforcement to show a value of 0.6. Now drag the Reinforcement editing window by its title bar so that most of it is off the left side of the screen, with just the command buttons showing. Now you can see the two layers of reinforcement displayed on the cross-section. Click Trim to move the reinforcement layers over to intersect the face of the slope. Press Add four times to add four more layers of reinforcement.

We want to add six more layers with length 5 m. The easiest way to do this is to click Add twice more, click the checkbox labelled "show lengths", and change the lengths of layers 7 and 8 from 6 m to 5 m. Then click Trim once more and click Add four more times to add the final four layers.

As you have seen, if only one layer of reinforcement is present, the Add button defaults to a reinforcement spacing of 3 ft or 0.9 m, depending on the Unit Weight of Water entered in the Header. If two or more layers of reinforcement are present, Add uses the same spacing as the last two layers.

The reinforcement is currently specified with an allowable tension of 1 kN per meter width. For the first layer of reinforcement, change the allowable tension value to 6.7 (kN/m), which might represent HP500 fabric, for example. Copy the value to the other reinforcement layers by clicking Repeat eleven times.

Close the Reinforcement editing window.

### 1.5.6 Specify a Grid Search

Select Draw Grid of Centers and define a grid by clicking on approximately (22, 6) and (27, 11). Use Draw Range of Tangents to define a range of tangents from Y=0 to Y=-2. Press Shift-F9 or select Analyse Calculate to see the coordinates of the chosen grid. Change the X-increment and the Y-increment to 1, and make the number of steps 5 in both X and Y. Click OK to calculate.

You can Press Ctrl-W and define the opposite corners of a window to zoom in for a closer look at the slip surface. You can also select View Preferences and add slice boundaries and contours of factor of safety to the display. Press Ctrl-A to return to the full geometry display.

### 1.5.7 Henry's Option: Circles through a given point

If you wish to limit a particular search to slip surfaces passing through a given point such as the toe of a slope or perhaps the buried end of the lowest layer of reinforcement, you can use Henry's Option. Select Draw Henry's Option Point and click on the toe of the slope at X=25, Y=0. Press Shift-F9 to bring up the grid dialog box, and note that the program has already checked the Henry's Option check box, a logical consequence of drawing the Henry's Option point. Click

Calculate to proceed with the analysis. If you had pressed F9 instead of Shift-F9, the analysis would have proceeded immediately.)

### 1.5.8 Adding a Surcharge

300 Lb/ft$^2$ 1.45 psi

Try adding a 10 kPa surcharge to the existing geometry. Select Edit Material Properties, check that the current cell in the table is on the top line, and click Duplicate Material to add an extra material at the ground surface. For the new uppermost material, change the name "Clayey Sand" to "10 kPa Surcharge", set the unit weight to 100 kN/m$^3$ and the friction and cohesion to zero. To avoid any confusion, set the piezometric surface number to zero also, even though it will not affect the calculation in this case. KN/m$^3$ = 1 Kpcf

100 KN/m$^3$ = 636 Lb/ft$^3$

Click Geometry> to bring up the Geometry window. For the Surcharge material, change the first coordinate from (-5, 5) to (-5, 5.1) and move the focus to the second coordinate, (20, 5). Click Insert Point to insert an extra point, and edit Point No. 2 it to become (19.9, 5.1). You have effectively created a thin heavy layer with zero strength, equivalent to a 10 kPa surcharge. Click OK to close the Geometry window.

### 1.5.9 Submerging the toe

We will now modify the geometry to represent a situation where a one-meter depth of water covers the toe of the slope. First, we insert water as the uppermost material. Click Edit Material Properties and then click Duplicate Material. Change the name of the uppermost material to Water, with unit weight of 9.81 kN/m$^3$, $\varphi = 0$ , and c = 0 kPa. Set the piezometric surface number and Ru value for this material to zero.

You have now inserted Water as the uppermost material, but it has zero thickness at all points across the geometry. To make a free water surface at elevation Y = 1, draw a horizontal Construction Line at Y = 1, i.e. draw it from (-5, 1) to (40, 1). Then choose Other Fill/Material 1 Water only and press Construct to create the free water surface.

The existing piezometric surface No. 1 represents a situation where seepage from the backslope is intercepted by a drain near the back of the reinforcement, and is not likely to be compatible with the existence of a meter of ponded water at the toe. To make the piezometric conditions more realistic, change the coordinates of piezometric surface No. 1 to the following:

| Point No. | Coordinates |
|---|---|
| 1 | (-5, 3.5) |
| 2 | (10, 3) |
| 3 | (15, 2.5) |
| 4 | (24, 1) |
| 5 | (40, 1) |

You can do this by one of the following:

(a) Select Edit Geometry to bring up the Geometry window. Click Next several times to display the coordinates of piezometric surface No. 1. Edit the existing coordinates as shown above.

(b) Select Draw Piezo Surfaces Piezo Surface No. 1. Click each of the coordinates as shown above. You will have to set the snap for the Y-coordinate to 0.5 to be able to specify the first and third coordinates precisely. Alternatively, it may be simpler to get all the coordinates right to the nearest integer, then edit the first and third Y-coordinate values as required.

(c) Use Point/Move followed by use of the mouse or cursor keys, as described in section 2.5. You will still have to set the Y-Coordinate snap to 0.5 to do this precisely.

If you run an analysis with this geometry, you will notice that the slip surface passes vertically through the water. This leads to a horizontal force due to water pressure against the exposed slice boundary. You do not need to make any special allowance for this force, as it is accounted for by the program.

## 1.6 MODIFYING THE GEOMETRY

### 1.6.1 Moving, Deleting, or Inserting a Point

It is possible to change the position of a point on a material surface, piezometric surface or the current specified slip surface by selecting Edit/Geometry and then manually modifying the listed coordinates. Similarly, you can insert or delete a point by inserting and deleting a line in the table of coordinates. However, it is much easier to use Point/Move, Point/Delete, or Point/Insert and carry out these operations graphically. The use of these features is described in section 2.5.

# 2. MAIN MENU OPTIONS

This section provides a reference list of main menu functions.

## 2.1 The FILE menu

### 2.1.1 File New

This option clears the current analysis and resets most program parameters to their default values. Of course any file changes you may wish to retain should be Saved before selecting the New option.

### 2.1.2 File Load

This option is used to read an existing GSLOPE data file from the disk. GSLOPE data files are identified with the filename extension .GSL. This extension is added to any name the user supplies. The DOS version of GSLOPE uses the same file format.

Once a file has been loaded, it can be modified in any way and analysis can proceed without further access to the file on disk. This means that you can revert to the last saved version of the file simply by reloading it.

### 2.1.3 File Save

The Save option writes the current analysis to disk, including all the latest edits. In order to prevent an accidental overwrite of an existing file, confirmation of the writing operation is requested. If you want to save to a new filename, use the Save As option as described below.

Note that the results of an analysis are not normally saved to disk, as they can quickly be re-created by loading and running the data file from which the results were produced.

### 2.1.4 File Save As

This allows you to save your work under a new filename, or to define a name if none exists yet. The .GSL extension is added if you do not specify it. If a file of the same name already exists it will be overwritten.

### 2.1.5 File Graphics to Clipboard

This copies to the Windows Clipboard all the graphical elements currently shown on the screen. The resulting graphic can then be pasted into another application such as a word processor. This operation is typically carried out by selecting "Paste Special" and choosing to paste a Picture.

### 2.1.6 File Export Metafile

This is essentially the same operation as copying the graphics to the Windows Clipboard, except that the information is written to a Windows Graphics Metafile. This is used mainly when the destination application is on a different machine.

### 2.1.7 File Print Input

This brings up a window showing the input data for the current analysis in tabular form. You can inspect the data or print it out. The font used for the printout is as defined under Set Font Printer Tabulations. If you need more control over the appearance of the output, choose Copy and then paste the text into a word processor. A fixed-width font is recommended to give proper alignment of the printout.

### 2.1.8 File Print Graphics

This prints the current geometry. The currently selected display preferences are included. The font used is the one defined under Set Font Printer Graphics. A field is provided for an optional drawing or figure number, which is placed in the bottom-right corner of the printed output. It is not normally visible on the screen, but can be viewed by zooming out (Ctrl-O).

### 2.1.9 File Print Results

This displays the results of the latest calculation in tabular form. The table can be inspected, copied to the clipboard, or printed out. The font used for the printout is the one defined under Set Font Printer Tabulations. It is recommended that a fixed-pitch font such as Courier be used, otherwise the columns in the table will appear uneven.

### 2.1.10 File Exit

This option exits the program. Before finally quitting the program, you are asked to confirm that you have saved any changes to your data file.

## 2.2 The SET Menu

### 2.2.1 Set Extents

If no valid dataset is currently loaded, the values entered in Set Extents are used to define the coordinate axes shown on the screen. It is typically used just before starting to draw a new stratigraphy from scratch.

### 2.2.2 Set Snaps

The snap values are used as a basis for rounding off coordinates created by drawing. The snap values default to 0.1 units in each of X and Y.

### 2.2.3 Set Preferences

This allows you to select which items appear on the screen and on printed graphics. These settings are also subject to automatic adjustments in response to certain menu choices. For example, if you draw a Henry's Option point, it will be assumed that you want it to be visible.

### 2.2.4 Set Contours

This sets the contour interval used when plotting contours of factor of safety, and limits the range of contours to be displayed. The show contours check box in this window is a mirror of the one in the Preferences window.

### 2.2.5 Set Font

This lets you specify the fonts to be used for screen display and printer output. It is recommended that tabular displays and printouts use a fixed-pitch font such as Courier New to avoid irregular columns.

### 2.2.6 Set Method

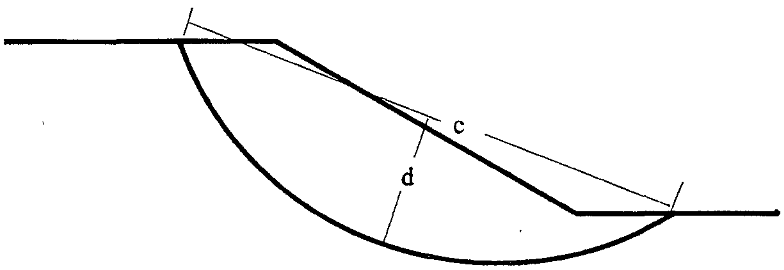
This allows you to specify the method of analysis. The Bishop Modified Method is applied as default. The Janbu Simplified method is similar to the Bishop Modified method in that zero shear stress is assumed between adjacent slices. This means that the vertical stresses at the slice bases are similar in both methods. The difference between the two methods lies in the calculation of overall equilibrium. Bishop's method makes use of moment equilibrium about a center of rotation, while Janbu's method is based on horizontal force equilibrium.

The fo factor reflects a correction proposed by Janbu (1956), based on the ratio of depth to length of the failure surface and whether the materials are mainly frictional or mainly cohesive. GSLOPE calculates the depth to length ratio, d/c, as shown below. The fo factor is then calculated as:

$$1 + 0.15 \text{ x } (d/c)^{½}$$

This is a compromise between the values proposed by Janbu for cohesive and frictional materials, and resembles the approach used by Fredlund et al. (1978). The value of fo is never less than 1.0 and seldom exceeds 1.1.

Note that Janbu's Simplified method (without fo factor) is functionally equivalent to the Wedge method.



### 2.2.7 Set Advanced

This allows you to change the M-alpha limit and the maximum number of slices used for the analysis. M-alpha is discussed in section 3.7.

## 2.3 The VIEW Menu

### 2.3.1 View Zoom

View Zoom Window lets you define a portion of the geometry to be blown up to occupy the full window.

View Zoom Previous reverts to the immediately previous view.

View Zoom In centers the view on a point you pick and doubles the current display scale.

View Zoom Out reduces the current display scale by 20%.

View Zoom All reestablishes the default display, where the full width of the geometry is displayed along with axis labels.

### 2.3.2 View Pan

Pan lets you pick two points. The first click chooses an arbitrary point in the geometry. The second click indicates the location on the screen where the first point is to be displayed.

### 2.3.3 View One Material

This selection limits the display to only the first material, whether it be soil, water, or surcharge. Sometimes this is useful for finding errors in geometry. Clicking on the bar at the base of the screen adds each material in turn.

## 2.4 The DRAW Menu

All of the drawing operations described here can also be accomplished by direct editing of coordinates under the EDIT menu. It is often useful to draw items approximately first, then edit the resulting coordinates afterwards if precise values are required.

### 2.4.1 Draw Soil Layers

When drawing soil layers, you are encouraged to draw the layers in order 1, 2, 3 etc. The first point on every soil layer must have the same X-coordinate, corresponding to the left edge of the geometry. Each point on a given soil surface must have a greater X-coordinate than the previous one. No point on any soil surface may be located above the line defining the top of the previous soil layer.

If you draw the surfaces in consecutive order, the above rules are enforced by the program as each point is drawn. If you make an error, you can undo the previous point by clicking the right mouse button.

### 2.4.2 Draw Piezo Surfaces

Piezometric surfaces must obey the same rules as soil layers, except that they are allowed to cross over each other. They can therefore be drawn in any order.

### 2.4.3 Draw Specified Slip Surface

The specified slip surface does not have to start at the left edge of the geometry, but it must start above the ground surface. X-coordinates must still increase with each successive point. The final point on the specified slip surface must also be above the ground surface. After drawing the last point, press the right mouse button to tell the program that the drawing operation is complete.

Drawing a specified slip surface turns off display of the grid of centers, range of tangents, and the Henry's Option point.

### 2.4.4 Draw Construction Line

The construction line is subject to the same rules as piezometric surfaces, in that it must cross the full width of the geometry but may extend above the various material surfaces, including the ground surface. The construction surface lays the groundwork for a later Construct As, Excavate, or Fill operation (see section 2.9), simplifying the creation of complex geometries with many intersection points.

### 2.4.5 Draw External Forces

Because the analysis is two-dimensional, "External Forces" effectively means "Line Loads". When you draw an external force, the first point chosen is the point of application of the force (the tip of the arrow). The next point defines the direction from which the force originates (the tail of the arrow). The magnitude of the force is input from the keyboard. Force units depend on the system of units in use, see section 1.3.1.

Note that all force magnitudes can be displayed on graphics by checking the appropriate option under Set Preferences. If you want to display the magnitudes of only a few forces, see the first paragraph of section 2.6.1.

### 2.4.6 Draw Reinforcement

This allows you to draw a layer of reinforcement. Layers of reinforcement are assumed to be horizontal, with the elevation fixed by the first point drawn. Reinforced slopes typically have several reinforcement layers at regular intervals. After the first layer has been drawn, it is easier and more precise to define any additional layers using the functions built into the Reinforcement edit window.

### 2.4.7 Draw Grid of Centers

This defines opposite corners of a grid of centers to be used in a search for the lowest factor of safety. Invoking this option also turns off display of the specified surface.

### 2.4.8 Draw Range of Tangents

This lets you pick a range of elevations to use as tangent lines in limiting the range of radii used in a regular grid search for the lowest factor of safety. Use of this option turns off display of the Henry's Option point.

### 2.4.9 Draw Henry's Option Point

This lets you pick a point through which all circular surfaces must pass. The Henry's Option point appears as a diamond. Use of this option turns off display of the current range of tangents.

## 2.5 The POINT Menu

### 2.5.1 Point Move

This provides the easiest way to modify an existing geometry. To move a point on a material surface, first choose Point On a Material or verify that there is a check mark next to the On a Material menu item. Then select Point Move and use the mouse to click on the point you wish to move. When a point is chosen, it is highlighted by a small black square. If no point is close to your click, no highlight appears. If this happens, move the cursor closer to the desired point, and click again.

Once a point has been selected, you can indicate the desired new position by clicking on the desired new position of the point and/or by using the cursor keys to adjust its position. The incremental movement produced by pressing a cursor key is controlled by the snap values for the X and Y directions. These values can be changed by using Set/Snaps. Note that the current coordinates of the selected point, together with the gradients of the lines to the neighboring points are shown in the box which appears in the upper part of the screen. Press ESC or the right mouse button when you have finished adjusting the position.

#### 2.5.1.1 Using Ctrl to Increase the Step Size

Pressing Ctrl-Up, Ctrl-Down, Ctrl-Left and Ctrl-Right cause the selected point to move in increments of five times the values currently set for the snaps in the X and Y directions.

#### 2.5.1.2 Using Shift to Switch to a different Point

You do not need to use the mouse to select every point you move. Once a point has been highlighted for moving, you can shift the focus to other points as follows:

| | |
|---|---|
| Shift-Left | Preceding point on the same material |
| Shift-Right | Following point on the same material |
| Shift-Up | Nearest point on the material above |
| Shift-Down | Nearest point on the material below |

Note that both of these methods (mouse or cursor keys) allow you to move the point anywhere, including locations which are above the top of the overlying material, or below the underlying material. If this happens, you may later receive a message regarding coordinate errors when you attempt to run an analysis or use Edit/Check Data. Minor bounds errors which might be associated with rounding are corrected automatically by the data check which occurs before each analysis. Large bounds errors can be rationalized by selecting Edit/Resolve Crossovers. If any material is found to protrude above an overlying material, the lower material is trimmed to fit.

#### 2.5.1.3 Using Alt when Materials Share a Common Point

Often the point you select has identical coordinates in more than one material surface. If you select such a point directly with the mouse, the actual point selected is the one on the uppermost of the materials which share a common point at that same location. If you then move the point either with cursor keys or a mouse click, all materials sharing that common point will be affected. The rule is that points on later numbered materials normally follow the movement of points on earlier materials. If there were three materials (1, 2 and 3) present at a point, and you wanted to move down materials 2 and 3, leaving material 1 undisturbed, you would first select the triple point with a mouse-click, then press Shift-Down to shift the focus to material 2, then press Down or Ctrl-Down to move materials 2 and 3.

If you want to raise the uppermost material only, you can leave the later numbered materials behind by pressing the Alt key along with the Up key.

Note that once you have started shifting a particular point using the cursor keys, you can "sweep up" points on higher-numbered materials (but not lower-numbered materials). This means that if you want to move both a point on material 1 and a point on material 2 to a different but common point, you should start by using cursor keys to move the point on material 1 to pass over the location of the desired point on material 2. This "sweeping up" works only if the two points at some stage share exactly the same coordinates, so if the second point has some decimal places in its coordinates, it may refuse to pick up. You can remedy this simply by moving the second point slightly with the cursor keys, as this will round its coordinates off in accordance with the current snap settings.

In summary, when moving points:

| | |
|---|---|
| Set Snaps | Controls how quickly points move per keystroke |
| Ctrl-cursor | Makes points move in 5x larger increments |
| Shift-cursor | Shifts the focus from one point or material to another |
| Alt-cursor | Decouples currently selected point, so it moves alone |
| Shift-Delete | Deletes the current point |

### 2.5.2 Point Insert

To insert an additional point, choose Point Insert and click on the upper surface of the material where the point is to be inserted. A new point is created, highlighted by a small black square. The new point is located on the line you selected, except that its coordinates are rounded off if necessary to reflect the X and Y snap values.

If no black square appears, your click was probably not close enough to an existing line, so try clicking again.

If several materials are coincident along the selected line, the new point is inserted only on the uppermost of these materials. When a point is inserted in this way, the new point is treated as if it had just been selected using Point/Move. Use the cursor keys or the mouse to move the point if desired. Then press ESC or the right mouse button when finished.

### 2.5.3 Point Delete

To delete a point, choose Point Delete and click on the point you wish to delete. If several materials share the same point, only the point on the uppermost material is deleted. The remaining points can of course be deleted by repeating the procedure.

If you have more than one point to delete, a better way to delete points is to first select the point using Point Move, and then delete the point using Shift-Delete. You can then continue to delete points by pressing Shift-Delete repeatedly. Remember to press ESC or the right mouse button when finished.

## 2.6 The EDIT Menu

### 2.6.1 Edit Header

The first six fields show header information about the analysis - job number, date, and title of the run. This window also defines the main features of the analysis. Note that in the fifth and sixth fields you can insert a code to show the value of an external force using the format F#xx, where xx is the number of the external force. This is useful if you are varying forces as is sometimes done to estimate the force on a retaining structure, for example. This is an alternative to displaying the values of all forces by checking the option "Force Magnitudes" under Set/Preferences.

Of the remaining items in this window, the most important is the Unit Weight of Water, which is normally either 9.81 or 62.4. This entry determines the system of units used by GSLOPE:

| Unit wt. of water | Units required in analysis |
|---|---|
| 9.81 kN/m3 | Distances in meters<br>Cohesion in kPa<br>Unit weights in kN/$m^3$<br>Allowable reinforcement tension in kN/m |
| 62.4 lb/ft3 | Distances in feet<br>Cohesion in psf<br>Unit weights in pcf<br>Allowable reinforcement tension in lb/ft |
| 1000 kp/m3 | Distances in meters<br>Cohesion in kp/m2<br>Unit weights in kp/m3<br>Allowable reinforcement tension in kp/m |

Max Slice Width can be used to influence the number of slices used in the analysis - the greater the maximum width, the fewer the number of slices. The technique by which slice boundaries are chosen is explained in Section 3.

No. of Soil Layers shows the number of materials present in the geometry. If the slope is partially submerged, water should be the first material defined, with exactly the same unit weight as defined on the header, and zero cohesion and friction. Forces due to water pressure in a body of free water are applied automatically. If free water is not present, it should not be included as a separate material. The presence of artesian water conditions is modeled using piezometric surfaces which may extend above the ground surface, and does not require water as a separate material.

Earthquake Acceleration refers to the seismic acceleration, as a decimal of gravity, (eg 0.05g) to be used in pseudo-static analysis of the slope. Seismic forces are applied horizontally, through the center of gravity of each slice, in a direction which will reduce the factor of safety for the slip surface being considered and taking into account any applied loads.

Piezometric Surfaces defines the number of piezometric surfaces to be considered. This does not need to be the same as the number of materials in the analysis. Each material may have its own piezometric surface, one piezometric surface may be shared by any or all materials, or piezometric surfaces may be omitted from the analysis altogether. Further information on supplying pore pressure information is given in section 3.4.

Unit Wt. of Water is the unit weight to be used in the computation of forces due to fluid-filled tension cracks and forces due to submergence of the slope, and effectively defines the system of units to be used in the analysis. It is also used in conjunction with the conditions of zero cohesion and zero friction to identify submerged conditions which require a hydrostatic horizontal force to be allowed for in the analysis. For this reason it is important to use exactly the same unit weight for pore fluid as for water submerging the toe of a slope.

Reinforcement Layers indicates how many layers of reinforcement are present in the analysis. This is irrespective of whether the reinforcement has any effect on the result.

FoS against Pullout is the factor used in determining the available bond between the soil and the reinforcement, as discussed in Section 3.6. It does not directly affect the maximum force in the reinforcement. It does affect the length required for the maximum force to be developed.

### 2.6.2 Edit Material Properties

This window lists the names of the various materials (free water, surcharge, and soil layers) which form the slope geometry. It also shows for each material the total unit weight, friction angle, cohesion, the number of the piezometric surface that applies to it, its Ru value, and the soil-reinforcement interaction coefficient. Note that Material 1 (at the top of the list) must be the uppermost material in the geometry. If a free water surface is present, water should be the uppermost material specified. If no free water surface is present, water should not be specified as a material.

If the uppermost material is to be treated as a liquid, but its unit weight is not exactly the same as that shown for water in the Main Header (e.g. mine tailings slimes, etc.), you can still have the material treated as a liquid by including the string "liquid" (not case-sensitive) in the name of the material. The cohesion and friction angle of the material must also be zero for the liquid condition to be applied. Note that slip surfaces pass vertically through liquids.

If a material has its unit weight entered as -1, this flags it as a hard layer or "hard bottom" material, below which slip surfaces cannot pass. A "hard bottom" material can also be used to simulate a weak layer, if a thin weak layer is placed just above it.

No part of material 1 may dip below of material 2, no part of material 2 may dip below material 3, and so on. A check for these conditions is made every time a new analysis is carried out.

If the piezometric surface number is zero or blank, the program assumes there is no piezometric surface for this material. It is assumed that the pore pressure due to any piezometric surface cannot be negative.

Ru is the ratio of pore pressure to the total vertical overburden stress at any point. Pore pressure contributions from the appropriate piezometric surface and Ru are added together for the analysis, though it would be unusual to use the two methods in combination for the same material. In the case of a material having zero friction and zero cohesion, the Ru field is used to denote the extent to which cracks are filled with water (see also Section 3.2). The chief use of Ru is in theoretical studies of slope stability. For analysis of real slopes, Ru is often not very useful, mainly because the equivalent piezometric surface varies with the location of the slip plane.

### 2.6.3 Edit Geometry

The Geometry window shows a tabulation of the coordinates of the upper surface profile of each material and piezometric surface, along with the specified surface and the construction surface. Soil surfaces may not cross over each other, but they may be coincident. Surfaces may not double back, ie X-coordinates must always increase. Slopes may fail to either left or right. All surfaces must start at the same X-coordinate and end at the same X-coordinate.

There is no computational penalty if the geometry is made extremely wide; but the automatic scaling used for plotting will give too small a picture of the slope if unduly wide coordinates are chosen. By the same token, if the X-coordinate range used is very small, and the slope comes out as too large on the plots, the X-coordinates can be extended to make the geometry better suit the page. All materials and all piezometric surfaces should be extended to the same minimum and maximum X-coordinates. A good rule is to make the width of the geometry 5 to 10 times the height of the slope.

The program assumes that the geometry continues horizontally beyond the limits of the given range of X-coordinates. This means than overly large circles whose ground surface intersections lie outside the given range of X-coordinates can still be analyzed.

### 2.6.4 Edit External Forces

This shows the point of action of each external force, along with its horizontal (+ve downwards) and vertical (+ve to the right) components. Because the analysis is two-dimensional, external forces are expressed in force per unit width. This corresponds to lb/ft width if the unit weight of water has been entered as 62.4, and kN/m width if the unit weight of water has been entered as 9.81. If the unit weight of water has been entered as 1000, external forces are expressed in kilograms force per meter width, or kp/m.

### 2.6.5 Edit Reinforcement Layers

GSLOPE allows you to enter up to 100 layers of geosynthetic reinforcement by defining the horizontal extents, elevation, and allowable tension (force/unit width) in each reinforcement layer.

It is assumed that all reinforcement layers are horizontal. X1 and X2 are the X-coordinates of the left and right ends of the reinforcement. $T_{allowable}$ reflects the allowable tension in the reinforcement and is normally assigned based on minimum average roll values of tensile strength with reduction factors allowing for creep, installation damage, and the effects of chemical and biological attack over the life of the structure.

In order to facilitate the input of multiple layers of reinforcement, the editor includes an interpolation facility. For example, assume you want to place geosynthetic reinforcement at 1.2 m vertical spacing between 94 m and 100 m elevation. First, fill in full details of the first reinforcement layer, showing its elevation as 100. Then move the cursor down to the sixth line and fill in 94 for the value of Y. A single press of the F8 key will interpolate all the intervening data fields. In this example, any non-zero parameters filled in for the sixth reinforcement will be used as a basis for interpolation. If you leave any of the data fields for the sixth reinforcement as zero or blank, the interpolation function will simply copy the values from the first layer.

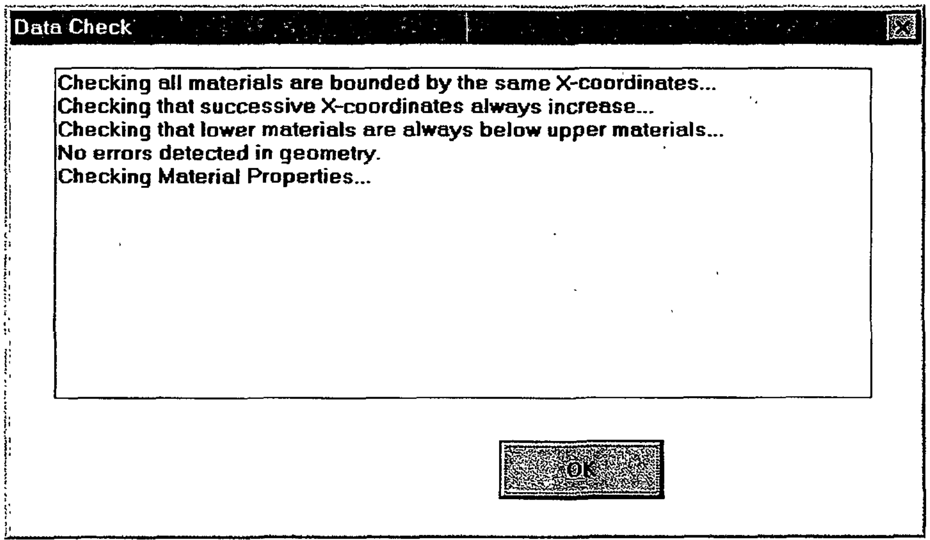
The reinforcement editing window is also equipped with functions like Trim, which adjusts the horizontal position of the reinforcement so that it ends at the slope face, and Add, which adds a layer of reinforcement, extrapolating its parameters from the two preceding layers. In each case, the display is immediately updated with the new information, so you can see exactly what is going on.

The soil/geosynthetic interaction coefficient for each soil is entered on the material properties screen. If the analysis does not include reinforcement, this column is not used, and can simply be left blank.

Further information on how reinforcement is incorporated into the analysis can be found in sections 3.6 and 3.7.

### 2.6.6 Edit Check

This option has three stages; first it checks that all material and piezometric surfaces have the same first and last X-coordinates as Material 1, and that for all surfaces the X-coordinates increase with each succeeding point, so there is no doubling back. If no errors are found in the X-coordinates, the next stage is to check the Y-coordinates for crossovers, as each succeeding material must lie completely beneath the previous one. Any errors detected in the coordinates are listed. If the coordinate check is successful, the material properties are checked to see that they are within a reasonable range, and any very unusual conditions are listed on the screen. The program can be run without this data check, but its use is definitely recommended. If no errors are found in the data file, the screen shows the following note:-



```
Checking all materials are bounded by the same X-coordinates...
Checking that successive X-coordinates always increase...
Checking that lower materials are always below upper materials...
No errors detected in geometry.
Checking Material Properties...
```

If the program detects geometrical errors such as surfaces which cross over or have X-coordinates which decrease, it will refuse to run an analysis until the problem is rectified. If the check routine detects material parameters which are outside the normal ranges, it will display a warning, but will still allow an analysis to proceed. Small geometrical errors likely due to rounding are corrected automatically. When this occurs, the message "No uncorrectable errors detected in geometry" appears.

### 2.6.7 Edit Resolve Crossovers

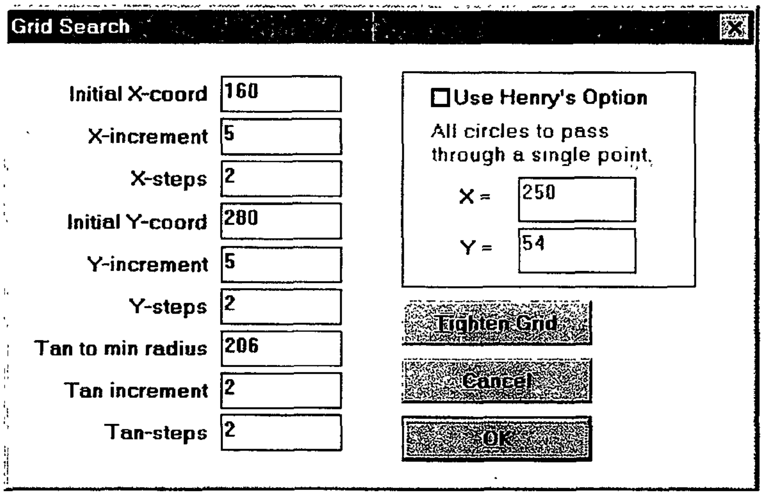
For a valid analysis, a lower material must never rise above the top of an upper material, i.e. material 2 must not have any points which lie above material 1. Minor infractions of this rule frequently occur due to rounding errors caused when points are inserted or deleted. Such minor infractions are corrected by the check routine which runs before each analysis. Major infractions can occur when points are moved up beyond the area occupied by the immediately overlying material.

If you are happy with the way the geometry appears on the screen but are faced with one of these errors when trying to run an analysis or Data Check, you can use Resolve Crossovers to get rid of the infractions automatically. The routine assumes that material 1 has priority over material 2, which in turn has priority over material 3, and so on.

## 2.7 The ANALYSE Menu

### 2.7.1 Analyse Calculate

The Calculate option or pressing Shift-F9 brings up the grid selection screen for circular or composite surfaces:-



Initial X-coord 160
X-increment 5
X-steps 2
Initial Y-coord 280
Y-increment 5
Y-steps 2
Tan to min radius 206
Tan increment 2
Tan-steps 2

☐ Use Henry's Option
All circles to pass through a single point.
X = 250
Y = 54

The example shown here sets up a 3 x 3 grid of centers whose lower left corner is at X=160, Y=280. The first circle to be analyzed will be tangent to Y=206, i.e. it will have a radius of 74. Subsequent circles about the same center will be tangent to 204 and 202.

A click on OK initiates the analysis. If the input file has been edited since the last run, a data check is carried out on the problem geometry only. This is similar to the check done under the EDIT menu, except that no review of material properties is included. If no errors are detected, the analysis proceeds.

Tighten Grid works as follows: first, the size of the grid spacing increments for X, Y, and the tangent locations are halved from their previous values. Then the origin point of the grid is adjusted such that it lies one increment below and to the left of the latest surface of minimum FOS. The tangent is also adjusted to suit this surface. This works best with a 3 x 3 grid, i.e. with Xsteps=2 and Ysteps=2

### 2.7.2 Analyse Recalculate

Recalculate is the same as Calculate, except that it skips the display of the grid selection window, and proceeds straight to the calculation.

## 2.8 The SLIP SURFACE Menu

### 2.8.1 Slip Surface Regular Grid Search

This option is set as the default when GSLOPE is started. The grid of centers as defined in the grid selection window is used exactly as specified. GSLOPE attempts to use every grid point as a center in combination with every tangent in the specified range. Advantages of this approach are:

> It generates a rectangular plot of contours of factor of safety.
> It is not distracted by local minima.
> Because the range of radii is constrained, there is more control over the range of surfaces analyzed. For example, this approach makes it possible to avoid analyzing very shallow surface slides in granular materials that constitute correct answers but are not really of interest.

### 2.8.2 Slip Surface Grid/Radial Search

This is the same as Regular Grid Search, except that the range of radii searched about each center continues beyond the specified range until a minimum factor of safety is found for the current center.

### 2.8.3 Slip Surface Stepwise Search

This starts off with a radial search, using a 3 x 3 grid of centers. If the lowest factor of safety does not correspond to a circle centered at the center of the grid, the grid is displaced by one increment in X, Y or both. The process continues until the minimum factor of safety corresponds to a circle whose center is at the center of the grid.

For simple slopes, this approach tends to find the minimum factor of safety very rapidly, but its disadvantages include the following:

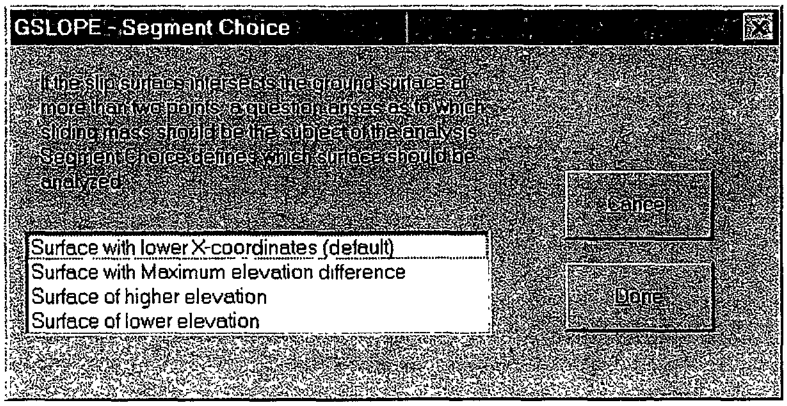
> Be aware that the result may vary depending on the starting point. This is because the method focuses on local gradients in the contours of factor of safety and may completely overlook minima not immediately adjacent to the starting point.
>
> Be especially cautious if using this with reinforced slopes. The reinforcement is of course placed with the express intention of "filling in" low areas in the contours of factor of safety. This leads to "flat" contour plots with many local minima, which this method will probably miss. The Regular Grid Search or the Radial Search method is usually a better choice for such situations.

### 2.8.4 Slip Surface Specified Surface

This selection corresponds to the use of a slip surface of general shape, not based on any particular center. It is activated if you use Draw Specified Surface to draw a potential failure surface of general shape, so it is rarely necessary to select this menu item directly.

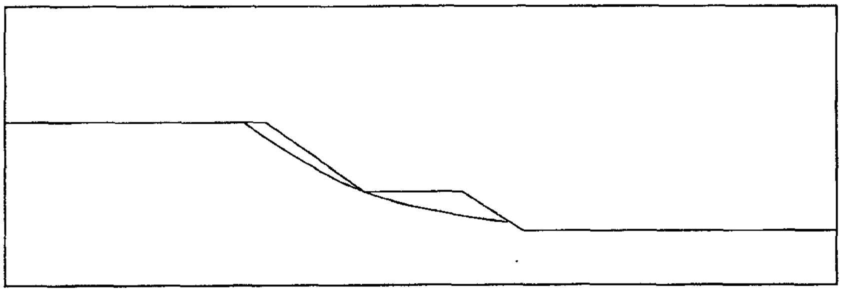
### 2.8.5 Slip Surface Segment Choice

For every circular or composite surface to be analyzed, the program must choose the limits of the potential sliding mass. Normally the intersection points with the first or top material give the limits of the analysis. If the failure surface intersects the ground surface at more than two points, a question arises as to which surface (i.e. which segment of the circle) should be analyzed.



If the slip surface intersects the ground surface at more than two points, a question arises as to which sliding mass should be the subject of the analysis. Segment Choice defines which surface should be analyzed.

The default is to use the leftmost two points as the limits of the analysis. If your slope fails from right to left, you will likely need to use a different segment choice.



## 2.9 The OTHER Menu

### 2.9.1 Other Construct As

This lets you select a material whose coordinates are to be made the same as those of the construction surface. Use this with care, as overlying and underlying materials are also modified to conform to the newly constructed surface.

### 2.9.2 Other Excavate

Like Fill, this option is valid only if a construction surface has been defined. The existing stratigraphy is "excavated" down to the level of the construction surface. It can be used in a wide variety of situations to minimize the amount of work involved in defining a complex geometry, as it avoids any need to calculate intersection points.

The coordinates of new points generated by this operation are rounded off corresponding to the current X and Y snap values.

### 2.9.3 Other Fill

This option is valid only if a construction surface has been defined. The existing stratigraphy is "filled" up to the level of the construction surface, usually using the uppermost material. It is useful for adding berms to a cross-section or for adding free water at the toe of a slope. It avoids any need to calculate intersection points.
The coordinates of new points generated by this operation are rounded off corresponding to the current X and Y snap values.

### 2.9.4 Other Choose Colors

This allows you to compose and save your own custom sets of colors to be used to display stratigraphy. As shipped, GSLOPE uses a set of colors defined in a file called PASTEL.COL. Pastel colors are recommended because saturated colors look rather overpowering on the screen. On color printers, they use up excessive amounts of toner, and they can obscure some features of the plot.

To change the color of a material, click Other Choose Colors to bring up the Color Selection window, then in the column on the right side of the window, click on the color you want to change. Pick the color from the color selection dialog box. Any changes you make will be lost when you exit GSLOPE, unless you save them using the Save Color Scheme button. You can name your own set of colors and leave PASTEL.COL intact. When you exit GSLOPE, the name of your set of colors will then be saved as the default. To reset the default to PASTEL.COL, use Load Color Scheme to load PASTEL.COL and then exit GSLOPE.

## 2.10 The HELP Menu

### 2.10.1 Help About GSLOPE

This brings up a box showing the copyright message and the version number of the program, along with contact information for Mitre Software Corporation. Contact information is also shown in section 1.0 of this manual.

# 3. HOW THE ANALYSIS WORKS

This section gives an overview of the steps involved in calculating the Factor of Safety using Bishop's Modified Method.

## 3.1 Dividing the Sliding Mass Into Slices

The various steps involved in the analysis for the factor of safety are as follows:-

For the postulated slip surface (circular, composite or fully-specified), a calculation is done to find the intersection points of the slip surface with the material surfaces.

Normally the intersection points of the slip surface with the first or top material give the limits of the analysis. If the failure surface intersects the ground surface at more than two points, the segment bounded by the two leftmost points is used for the analysis. If your slope fails from right to left, you may need to choose a different segment, see section 2.8.5.

The slice boundaries are assigned at the X-coordinates of every material intersection point and also at the X-coordinates of every point where the material surfaces are defined. This means that no slice can ever have more than one material at its base, and no slice ever contains a break in slope, either at the ground surface, or at a material interface. If any of the resulting slices have a width greater than the maximum slice width specified, they are subdivided until the maximum slice width is not exceeded. If this procedure results in more than fifty slices, the specified maximum slice width is increased to allow a reduction in the total number of slices. For typical situations, a total of twenty slices is usually considered ample. The maximum number of slices can be adjusted using Set Advanced. If you are seeing a message at the base of the screen saying "Slice width doubled to limit No. of slices", it is best to manually increase the maximum slice width shown in the Main Header. Controlling the slice width rather than the total number of slices leads to more precise consistency from one analysis to the next and thus helps the search routines work better. It also speeds up calculation.

The mid-points of the slice bases are then calculated. The X-coordinates are taken as the average of the left and right X-coordinates for every slice and in the case of the composite slices, the Y-coordinate is the average of the Y-coordinates of the bases of the left and right boundaries.

## 3.2 Tension Cracks

The materials at the base of each slice are then determined by reference to the intersection point of the material surface with the X-coordinate at each slice center. The first slice is checked to see if the material at its base has zero strength, i.e. is a liquid or a tension crack zone. If this is the case, the slice is removed from the computation, and the check proceeds to the next slice until a material with a finite strength is found at the slice base.

The slices removed are substituted for by a hydrostatic force, which is always calculated on the basis of the given unit weight of water from the Header screen. For materials having zero strength, it has been found convenient to use the field labeled Ru value to control the hydrostatic pressure forces for the end slices. A value of 1.0 in this field is taken to mean that hydrostatic pressure exists over the full height of the end slice boundary, and could therefore be used to simulate the effect of a water-filled tension crack. (A half-filled crack would correspond to 0.5). A value of zero in the Ru field for this material would simulate the effect of a dry tension crack, with the material acting as a surcharge.

## 3.3 Partial Submergence

Since it is always appropriate to apply the full hydrostatic force when water is present at the end slice boundary, a special case has been made. That is, if the last slice removed had a base material with the same unit weight as water, and zero strength properties, the full hydrostatic force is applied to the end slice boundary, regardless of the value in the Ru field. If you are not interested in tension cracks, and you have no materials in your stratigraphy having zero strength, you can ignore these effects. Further information on partial submergence can be found in section 2.6.2.

The same slice removal and water force substitution process takes place at the other end of the failure surface also.

## 3.4 Pore Pressure Conditions

Pore pressures are normally defined using piezometric surfaces. Each material can have its own piezometric surface, or a given piezometric surface may apply to more than one material. The pore pressure at the base of any slice is assumed to be equivalent to the head of water represented by the height difference between the mid-point of the base of the slice and the elevation of the corresponding piezometric surface vertically above. If no piezometric surface is defined for a particular material, it is assumed to have zero pore pressure throughout, unless it has a nonzero Ru value.

Pore pressures are not adjusted by the program in response to cut and fill operations. If pore pressure response to construction or rapid drawdown is to be included in the analysis, the corresponding changes to the piezometric surfaces must be supplied by the user.

Artesian conditions can be represented by piezometric surfaces which extend above the ground surface. In case of rapid drawdown, consider that removal of water can give rise to a pore pressure response due to unloading.

## 3.5 Calculation of the Factor of Safety

In Bishop's Modified Method, the factor of safety is defined as the factor by which the soil strength can be divided before the slope reaches a state of limiting equilibrium. The factor of safety is assumed to be the same for all slices. The method also assumes that there are no shear forces on the vertical boundaries between slices. This means that if we assume an initial value of the Factor of Safety, we can make use of a vertical equilibrium equation for each slice which involves only the following:

> weight of the slice, including any surcharge or free water, and the vertical component of any external force applied to the slice
> pore pressure at the slice base
> normal force on the slice base
> shear force on the slice base

The first two items in the list are already known. Because the shear force on the slice base is related to the normal force through the known values of friction, and cohesion, reduced appropriately by the assumed value of the Factor of Safety, the last two items amount to only one unknown. Thus the normal and shear forces on the base of each slice can be calculated, based on the assumed value of the Factor of Safety. Note that the forces due to reinforcement do not enter the calculation yet, because they are assumed to be horizontal.

We can then sum all the moments acting on the entire sliding mass. These include moments due to the following:

> Weight of each slice, including surcharge and free water
> Normal force on the base of each slice
> Shear force on the base of each slice
> Pseudo-static seismic forces
> Hydrostatic forces due to water in tension cracks
> Hydrostatic forces due to free water against a vertical slice face
> Tensile forces in reinforcement layers
> External forces

If the moments on the slide mass do not sum to zero, an adjustment is made to the Factor of Safety until equilibrium is reached. Convergence to three decimal places is usually reached in three or four iterations.

It will be noted from the above that the tensile force in the reinforcement layer enters the equation of overall moment equilibrium on the same basis as the soil weight, along with any surcharges and seismic forces. This means that, in general, no additional factor of safety is being applied to the tension in the reinforcement, beyond the factors for long-term creep, installation damage, and chemical degradation etc. already included in the allowable tension value. At the same time, the calculation assumes that the stabilizing effect of the reinforcement is limited to the tensile force it exerts on the potential sliding mass, and takes no credit for any possible soil strength increase due to confining action occurring in the backfill.

## 3.6 Interaction between Soil and Reinforcement

For each reinforcement layer, the program first finds the location of the point where the slip surface intersects the reinforcement. It then uses the total vertical stress and the pore pressure at that point to arrive at a value for the shear strength of the soil at the intersection point using the relationship:

$$\text{Soil shear strength} = \text{cohesion} + (\text{vertical stress} - \text{pore pressure})\text{Tan}\ \varphi$$

The program then determines the distance from the intersection point to the nearer end of the reinforcement. This represents the available bond length between the reinforcement layer and the soil.

The available pullout force is then calculated as:

$$\frac{2 \text{ x interaction coefficient x soil strength x bond length}}{\text{Factor of Safety against reinforcement pullout}}$$

For the overall moment calculation as described above, the force in the reinforcement layer is taken as the lesser of the 'Max Tension per unit width' specified for the reinforcement and the available pullout force as calculated above.

The force for each reinforcement layer is calculated in turn. All of the reinforcement forces are then incorporated into the stability calculation as if they were horizontal external forces applied to the sliding mass. The program automatically selects which reinforcement layers are active, and in which direction the forces apply. A fresh set of reinforcement calculations is carried out for every slip surface analysed, since the contribution of each layer varies with the location of the slip surface.

The Factor of Safety Against Pullout is entered at the bottom of the Header screen, which is reached via Edit Header. It should be noted that this factor is applied only to the force required for pullout, and does not directly affect the maximum force that can be generated in a reinforcement layer.

## 3.7 The M-alpha Parameter

From vertical equilibrium, the normal force on the base of a slice can be shown (Fredlund, 1978) to be:

$$P = \frac{W - \dfrac{j\,c\,\text{Sin}\,\alpha + j\,u\,\text{Sin}\,\alpha\,\text{Tan}\,\varphi}{F}}{m_\alpha}$$

where:

$W$ = Total weight of slice
$c$ = Cohesion of slice base material
$\varphi$ = Friction angle of slice base material
$P$ = Total normal force on base of slice
$b$ = Slice width
$\alpha$ = The angle the slice base makes with the horizontal. This is taken as positive for a slice that is tending to slide downhill to the right.
$j$ = The length of the base of a slice, so that $j\ \text{Sin}\ \alpha = b$

M-alpha (or $m_\alpha$) is defined as:

$$m_\alpha = \text{Cos}\,\alpha + \frac{\text{Sin}\,\alpha\,\text{Tan}\,\varphi}{F}$$

If the failure surface is very deep, it is possible for the slice base angle to attain a large negative value. This can lead to M-alpha values which approach zero, giving an unrealistically large value for the normal force. If an M-alpha value of less than a limiting value (default limit = 0.3) is encountered in the final iteration of overall moment equilibrium, an M-alpha warning is noted. Values above 0.2 are usually of little significance. The M-alpha warning limiting value can be changed using Set/Advanced...

## 3.8 Contribution of Reinforcement

As described in section 3.5 above, GSLOPE incorporates the moments or forces due to reinforcement into the overall equilibrium equation. Remember that the definition of factor of safety is the factor by which the soil strength must be reduced in order to bring the mass of soil into a state of limit equilibrium along a given slip surface, and that the factor of safety is assumed to be the same for all slices. In applying Bishop's method, for example, GSLOPE assumes an initial value of the Factor of Safety, F and then adjusts it until equilibrium is just achieved with 1/F times the available soil strength mobilized at the base of every slice.

This means that beyond the various safety factors already built into the value of $T_{allowable}$ (see section 3.6), GSLOPE does not apply any further factor of safety to the force in the reinforcement, but assumes that $T_{allowable}$ is actually available to be mobilized. The value of $T_{allowable}$ is thus treated in the same way as other input parameters such as soil unit weights, pore pressure conditions, seismic acceleration, and the values of any surcharges or other external loads which may be present.

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