ENERCON SERVICES, INC.	CALCULATION COVER SHEET	CALC. NO. : TXUT-001-FSAR-2.5-CALC-009			
		REV.	0		
		PAGE NO.	1	of	58
Title:	**Settlement and Bearing Capacity**	Client: TXU Power			
		Project: Comanche Peak COL			

Item	Cover Sheet Items	Yes	No
1	Does this calculation contain any assumptions that require confirmation? (If **YES**, Identify the assumptions)_____		X
2	Does this calculation serve as an "Alternate Calculation"? (If **YES**, Identify the design verified calculation.) **Design Verified Calculation No.**_____		X
3	Does this calculation Supersede an existing Calculation? (If **YES**, identify the superseded calculation.) **Superseded Calculation No.**_____		X

Scope of Revision:

NA – Initial Issue

Revision Impact on Results:

NA – Initial Issue

Preliminary Calculation	☐	Final Calculation	X
Safety-Related	X	Non-Safety Related	☐

(Print Name and Sign)

Originator(s): Thomas Graf	Thomas Graf	Date: 07-25-08
Shanzhi Shu		Date: 07-25-08
Design Verifier: Sam Bryant	Samuel M Bryant	Date: 08-04-08
Approver: Farhad Boniadi	F Boniadi	Date: 08-04-08
Approver: Mike Laggart, Project Manager	Michael Laggart	Date: 8/22/08

CALCULATION REVISION STATUS

REVISION	DATE	DESCRIPTION
0	08-04-08	Initial Issuance of Calculation Package

PAGE REVISION STATUS

PAGE NO.	REVISION	PAGE NO.	REVISION
1-58	0		

APPENDIX REVISION STATUS

APPENDIX NO.	PAGE NO.	REVISION NO.	APPENDIX NO.	PAGE NO.	REVISION NO.
A	1-65	0			
B	1-30	0			
C	1-13	0			

Calculation Design Verification Plan:

1. Review background, methodology, and procedure.
2. Check calculations.

(Print Name and Sign)	
Approver: Farhad Boniadi FBoniadi	**Date: 08-04-08**
Approver: Mike Laggart, Project Manager Michael Laggart	**Date:** 8/22/08

Calculation Design Verification Summary:

1. Reviewed background, methodology, and procedure.
2. Checked calculations.

Based On The Above Summary, The Calculation Is Determined To Be Acceptable.

(Print Name and Sign)	
Design Verifier: Sam Bryant Samuel M Bryant	**Date:08-04-08**
Others:	**Date:**

Item	Checklist Items	Yes	No	N/A
1	**Design Inputs** - Were the design inputs correctly selected, referenced (latest revision), consistent with the design basis and incorporated in the calculation?	X		
2	**Assumptions** – Were the assumptions reasonable and adequately described, justified and/or verified, and documented?	X		
3	**Quality Assurance** – Were the appropriate QA classification and requirements assigned to the calculation?	X		
4	**Codes, Standard and Regulatory Requirements** – Were the applicable codes, standards and regulatory requirements, including issue and addenda, properly identified and their requirements satisfied?			X
5	**Construction and Operating Experience** – Have applicable construction and operating experience been considered?			X
6	**Interfaces** – Have the design interface requirements been satisfied, including interactions with other calculations?	X		
7	**Methods** – Was the calculation methodology appropriate and properly applied to satisfy the calculation objective?	X		
8	**Design Outputs** – Was the conclusion of the calculation clearly stated, did it correspond directly with the objectives and are the results reasonable compared to the inputs?	X		
9	**Radiation Exposure** – Has the calculation properly considered radiation exposure to the public and plant personnel?			X
10	**Acceptance Criteria** – Are the acceptance criteria incorporated in the calculation sufficient to allow verification that the design requirements have been satisfactorily accomplished?			X
11	**Computer Software** – Is a computer program or software used, and if so, are the requirements of CSP 3.02 met?		X	

COMMENTS:

(***Print Name and Sign***)	
Design Verifier: Sam Bryant Samuel M Bryant	**Date:08-04-08**
Others:	**Date:**

COMANCHE PEAK COMBINED OPERATING LICENSE APPLICATION
Calculation Package TXUT-001-FSAR-2.5-CALC-009
SETTLEMENT AND BEARING CAPACITY

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APPENDICES

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1.0 PURPOSE AND SCOPE

This calculation package summarizes foundation bearing capacity estimates and foundation settlement estimates for the proposed primary seismic category I and II structures of Units 3 and 4 at the Comanche Peak Nuclear Power Plant (CPNPP), for the Combined Operating License Application (COLA). This report summarizes selected laboratory test data and design values and presents recommendations based on the specific plant information available at the time of this report.

2.0 SUMMARY OF RESULTS AND CONCLUSIONS

This document provides discussions and results of settlement and bearing capacity analyses performed for the main seismic category I and II structures within the CPNPP Units 3 and 4. Calculations are provided in the appendices. The following is a brief summary of the results and conclusions:

2.1 Settlement

Results of available and newly obtained geotechnical field and laboratory tests are summarized and used to develop a “Best Estimate (BE)” as well as a “Lower Bound (LB)” modulus model for settlement analysis. Based on the available information regarding structure details, loading, and layout, settlements were estimated using two methods of analysis and the BE and LB models. For all seismic category I and II structure foundations founded in Layer C limestone, the estimated total settlements are generally less than ½ inch with the differential settlements of up to about ¼ inch. The structures are expected to experience settlements that are within the project acceptable criterion.

2.2 Bearing Capacity

Bearing capacity for seismic category I and II structures is evaluated using three different failure modes and a conservative set of properties. Results indicate that the ultimate bearing capacity for foundations bearing in Layer C limestone is at least about 146 ksf. The estimated ultimate bearing capacity suggests minimum factors of safety against bearing capacity failure is about 10 for static loading and 2 for seismic loading condition.

3.0 REFERENCES

3.1 Project References

3.1.1 Enercon Services, Inc. (2007), Email correspondence from Robert Schoenewe of Enercon to Frank Syms, dated 06-05-07.

3.1.2 Fugro West, Inc. (2007), Field Packer Test Results, Project Report No. TXUT-001-PR-003, Rev.0.

3.1.3 Fugro West, Inc. (2007), Seismic Refraction Survey, Project Report No. TXUT-001-PR-002, Rev.0.

3.1.4 Fugro West, Inc. (2008), Laboratory Test Data Report, Project Report No. TXUT-001-PR-010, Rev. 0.

3.1.5 William Lettis and Associates, Inc. (2007), Data Report No. TXUT-1908-09 (Borehole Geophysical Logging), Rev. 0.

3.1.6 William Lettis and Associates, Inc. (2007), Data Report No. TXUT-1908-07 (Pressuremeter Testing), Rev. 0.

3.1.7 Stokoe, Ken H. (2007), Estimates of the Nonlinear G/G_{max} Curves for Site Response Analysis for Comanche Peak, email correspondence dated November 12, 2007.

3.1.8 TXU Power (2001), Final Safety Analysis Report (FSAR) for Comanche Peak Steam Electric Station (CPSES) Units 1 and 2.

3.1.9 Washington Group International (2007), Responses to RFI-TXU-COL-CP-0052, 0053, 0054, and 0055, dated 07-09-07.

3.1.10 Washington Group International (2007), Calculation No. LUM-C-002, Bearing Pressure Computations, Rev. A, dated 08-23-07.

3.1.11 Washington Group International (2007), Draft Memorandum titled "Request For Input Data For Seismic Analysis Of Comanche Peak Units 3 and 4," dated 10-30-07.

3.1.12 Washington Group International (2008), Grading and Drainage Plan, Drawings Nos. CVL-12-11-100-001 through CVL-12-11-107-001, Revision D.

3.1.13 Washington Group International & Mitsubishi Heavy Industries (2008), Response to RFI-TXU-COL-CP-0218, dated 03-26-08.

3.1.14 William Lettis and Associates, Inc. (2008), Boring Log Data Report, Project Report No. TXUT-001-PR-005 Rev. 0.

3.1.15 William Lettis and Associates, Inc. (2007), Geologic Test Pits Report, Project Report No. TXUT-001-PR-006 Rev. 0.

3.1.16 William Lettis and Associates, Inc. (2007), Dynamic Profile, Project Report No. TXUT-001-PR-007 Rev. 0.

3.1.17 William Lettis and Associates, Inc. (2007), Shallow Velocity Profile Development Slope Method, Calculation Package No. TXUT-001-FSAR-2.5-CALC-003, Rev. 0.

3.1.18 William Lettis and Associates, Inc. (2007), Engineering Stratigraphy, Calculation Package No. TXUT-001-FSAR-2.5-CALC-004, Rev. 0.

3.2 General References

3.2.1 ASTM D 5878 (2005), Standard Guides for Using Rock-Mass Classification Systems for Engineering Purpose.

3.2.2 Hoek, E. (2007), Practical Rock Engineering, notes from Rock Engineering Course, on-line webpage document at www.rocscience.com.

3.2.3 Hoek, E. and Brown, E.T. (1997), Practical Estimates of Rock Mass Strength, International Journal of Rock Mechanics & Mining Science & Geomechanics Abstracts 34(8), pages 1165-1186.

3.2.4 Hoek E., and Diederichs, M.S. (2006), Empirical Estimation of Rock Mass Modulus, International Journal of Rock Mechanics & Mining Science 43, pages 203-215.

3.2.5 Hoek, E., Marinos, P. and Benissi, M. (1998), Applicability of the Geological Strength Index (GSI) Classification for very Weak and Sheared Rock Masses. The case of the Athens Schist Formation, Bull. Eng. Geol. Environ. 57(2), pages 151-160.

3.2.6 Marinos, P and Hoek, E. (2001), GSI – A Geologically Friendly Tool for Rock Mass Strength Estimation. Proc. GeoEng 2000 Conference, Melbourne, pages 1422-1442.

3.2.7 Marinos, V., Marinos, P. and Hoek, E. (2005), The Geological Strength Index: Applications and Limitations, Bull. Eng. Geol. Environ. 64, pages 55-65.

3.2.8 Naval Facilities Engineering Command (NAVFAC) (1986), Soil Mechanics, Design Manual 7.01.

3.2.9 Perloff, W.H., Baron, W. (1976), Soil Mechanics Principles and Applications, The Ronald Press Company, N.Y.

3.2.10 Poulos, H.G., and Davis, E.H. (1974), Elastic Solutions for Soil and Rock Mechanics, Wiley and Sons, New York.

3.2.11 Taylor, D.W. (1948), Fundamentals of Soil Mechanics, John Wiley and Sons, Inc., New York.

3.2.12 U. S. Army Corps of Engineers (1994), EM 1110-1-2908, Engineering and Design - Rock Foundations.

4.0 ASSUMPTIONS

The following is a list of assumptions that were made as part of preparation of this calculation package:

- All foundations for seismic category I and II structures are assumed to be of mat type foundation founded directly on competent Layer C limestone or on fill concrete placed over the Layer C Limestone.

- For settlement analysis, all loading conditions were assumed to be flexible uniform loading. A Poisson's ratio of 0.30 was assumed for all rock layers.

5.0 DESIGN INPUT

The following paragraphs provide a summary of the data and information with respect to the plant structures, site grading, and subsurface material properties used in preparing this report.

5.1 General Plant information

The power block area of each new unit consists of nine primary seismic category I and II structures; Reactor Building (R/B), Auxiliary Building (A/B), Turbine Building (T/B), East Power Source Building (EPS/B), West Power Source Building (WPS/B), Power Source Fuel Storage Vault (PSFSV), Ultimate Heat Sinks (UHS), Essential Service Water Pipe Tunnel (ESWPT), and Duct Banks. The preliminary general plant arrangement showing the layout and plan dimensions of the structures in the power block area, foundation loadings, and basement embedment depths have been provided for the proposed Units 3 and 4 by Washington Group International (WGI) in References 3.1.9 through 3.1.13.

The following table provides a summary of the pertinent data for the primary seismic category I and II structures within each unit:

Table 5.1-1 Main Seismic Category I & II Structures' Details

Structure	Category	Foundation Size (ft)		Foundation Bottom Elev. (ft)	Static Pressure (ksf)	Seismic Pressure (ksf)
		E-W	N-S			
R/B	I	213	309	783	11.32	55.00
T/B	II	186	315	795	5.86	7.35
A/B	II	133	239	785	6.77	10.99
EPS/B	I	115	69	785	4.31	7.41
WPS/B	I	115	69	785	4.31	7.41
PSFSV	I	85	78	782	5.38	13.00
UHS	I	131	131	787	3.61	7.40
ESWPT	I	25 (Tunnel Width)		791	--	--
Duct Banks	I	3-6 (Duct Width)		818-819	--	--

Based on the center coordinates and dimensions provided in above mentioned references, a relative schematic layout of the main structures within a unit except the ESWPT and duct banks is shown on Figure 3. The above structures' details, loadings and the layout shown on Figure 3 are used as a basis for all calculations and results provided in this report. The acceptable settlement criterion for the structures is a mean of 2 inches total and differential settlement (Ref. 3.1.9).

5.2 Site Grading

Based on the site grading plans developed by WGI (Ref. 3.1.12), the final finish grade for the main plant area will be at elevation 822 feet. The present existing grades vary between El. 830 and 855 feet within the Unit 3 main plant area and between El. 842 and 868 feet within the Unit 4 main plan area. Therefore, approximate cuts range from 8 to 33 feet and 20 to 46 feet for Units 3 and 4 main plant areas, respectively.

5.3 Layer B Shale Removal and Fill Concrete

Table 5.1-1 indicates that foundation bottom elevations for seismic category I and II structures range between elevations 782 and 795 feet (except duct banks). That range falls within the Layer B material (see Table 5.4.2-1 below). Due to the undesirable potential shrink/swell properties, Layer B shale material below the foundations will be removed to the top of the Layer C limestone rock at about elevation 782 feet. Overexcavations below the foundations will be backfilled with concrete to the foundation bottoms.

5.4 Site Conditions and Background Data

5.4.1 Site Exploration

Field exploration and sample collection for the CPNPP Units 3 and 4 project area were performed between November 2006 and April 2007. The field exploration phase included 161 boreholes, ranging from 40 to 550 feet deep, and 3 test pits up to 20 feet deep that were excavated, logged and sampled (Figure 1, Exploration Locations). Logging was performed by William Lettis Associates, Inc. (WLA). Laboratory testing associated with the field work was performed between March 2007 and November 2007 primarily at the Fugro Laboratory in Houston, Texas. Other tests conducted during the field exploration program included the following:

- Downhole pressuremeter testing in 7 boreholes during January, 2007 (Ref. 3.1.6).
- Downhole packer testing in 6 boreholes in February 2007 (Ref. 3.1.2).
- Downhole Suspension P-S logging in 15 boreholes between December 2006 and April 2007 (Ref. 3.1.5).
- Seismic refraction surveys were performed in March 2007 (Ref. 3.1.3).

Evaluations presented herein utilize the results of soil and rock properties described and summarized in the Field Data reports for the various phases of field testing and exploration, including the following Project Reports: Geologic Test Pits (Ref. 3.1.15), Field Packer Test Results (Ref. 3.1.2), Borehole Geophysical Logging (Ref. 3.1.5), and Pressuremeter Test Results (Ref. 3.1.6). This package uses geologic and geotechnical information presented on geologic cross sections prepared by WLA. The referenced data reports contain the results of engineering geologic and geotechnical site and laboratory investigation for the proposed CPNPP Units 3 and 4 site locations.

5.4.2 Subsurface Conditions

Subsurface materials within the project site consist of three main geologic formations in descending order: Glen Rose Formation, Twin Mountain Formation, and Mineral Wells Formation. The Glen Rose Formation consists primarily of limestone with interbedded layers of claystone and shale, and is generally overlain by a layer of fill or residual soils, which varies in thickness from a few feet to a few tens of feet. Boring log and geophysical data further refined the subsurface into twelve major stratigraphic layers labeled A through I. Figure 2 shows a typical geologic cross section for the main site of Units 3 and 4. A summary of the refined stratigraphic layers for the site is provided in Table 5.4.2-1. More detailed information and data regarding the project subsurface materials and stratigraphic layers are provided in References 3.1.16 and 3.1.18.

Residual soil material types ranged from sand and gravel with varying amounts of fines, to silt and sandy lean clay. Some areas of the site (northeast of Unit 4 and east to southeast of Unit 3) contain areas of randomly placed, uncompacted fill. These fill materials are located in areas of previous topographic lows and range in thickness from 5 to about 70 feet deep.

Table 5.4.2-1 Stratigraphic Layer Depth Profile

Formation	Stratigraphic Layers	Primary Lithology	Top of Layer Ave. Elevation (ft)	Average Thickness (ft)
Glen Rose	A	Limestone	834	35
	B1	Shale	798	8
	B2	Shale with Limestone interbeds	790	8
	C	Limestone	782	65
	D	Shale	717	4
	E1	Limestone	714	23
	E2	Limestone	690	35
	E3	Limestone	656	33
Twin Mountain	F	Limestone with Shale and Sand interbeds	622	30
	G	Sandstone	593	80
	H	Shale	513	63
	I	Sandstone	451	67
Mineral Wells	MW	Shale with Sandstone and Limestone interbeds	388	--

5.4.3 Groundwater Conditions

Information gleaned from the FSAR for Units 1 and 2 (Ref. 3.1.8) suggest that static water levels observed within the borings and monitoring wells completed within the Glen Rose Formation ranged between El. 749 and 830 feet. However, the FSAR concluded that the Glen Rose Formation is an essentially impermeable formation and that the piezometric levels measured in

the Glen Rose Formation are associated with perched water in the upper zone of the Glen Rose Formation in the immediate area of each piezometer. The single piezometer completed in the Twin Mountain Formation indicated a piezometric water level at El. 670 feet. The Units 1 and 2 FSAR concludes that the groundwater at the site is not expected to rise above El. 775 feet (Probable Maximum Flood level). Historical groundwater levels around the plant site from a few observation wells in Somervell County suggest that the groundwater levels range between about elevation 600 and 760 feet.

During the field investigation for Units 3 and 4, a number of monitoring wells were installed within the Glen Rose Formations to depths of about 15 to 95 feet below the existing ground surface. Preliminary results from the monitoring suggest piezometric levels ranging between about El. 775 to 858 feet, although some wells were reported to be dry. In general, the subsurface soils and much of the rocks especially the Glen Rose Formation are considered relatively impermeable. All observed piezometric levels at the site are considered to be localized perched water in the upper zone of the Glen Rose Formation and are possibly attributed to surface run-off and not a true indication of the site groundwater level. The results of the Packer tests performed during the site investigation also suggest that the Glen Rose Formation is fairly tight with little potential for "significant" seepage and groundwater.

According to the USGS, the Conservation Pool Elevation of the Squaw Creek Reservoir is 775 feet. Based on the information collected by the USGS gauging station located on Squaw Creek Reservoir during the period of October 1, 2000 to June 4, 2007, the maximum reservoir elevation was recorded at 777.97 feet on June 9, 2004, and the minimum reservoir elevation was recorded at 772.96 feet on April 28 and 29, 2005 (Ref. 3.1.1).

Two areas of uncontrolled fill are present within and in the vicinity of Units 3 and 4 areas and are known to have hydraulic connectivity with Squaw Creek Reservoir. Those fill areas are located east to southeast of Unit 3 and northeast of Unit 4. The bottom of fill in the area between Units 3 and 4 is expected to be above the level of anticipated excavation (~ El. 782 ft) as well as the Squaw Creek Reservoir pool elevation (~ El. 775 ft). The fill area to the east and southeast of Unit 3, which is generally located outside of the limits of the main plant area becomes deeper in a northeasterly direction and extends to levels below the Squaw Creek Reservoir Pool Elevation of 775 feet.

Based on the above information, the groundwater level at the site may conservatively be assumed at an elevation of about 780 feet.

5.5 Geotechnical Laboratory Test Data

5.5.1 Material Index Properties

Laboratory testing was performed to assess engineering properties appropriate for the level of analysis and is discussed herein. Generally, as shown on Figure 2, subsurface conditions consist of fairly shallow thicknesses of soil underlain by alternating layers of limestone, shale, and sandstone. Unit weight and other index properties are described in the Laboratory Data Report (Ref. 3.1.4). Results of the Laboratory Index test results are presented on Figures 4 through 10, and summarized in Table 5.5.1-1:

Table 5.5.1-1 Summary of Index Laboratory Test Result Ranges

Parameter	Material			
	Soil	Shale	Limestone	Sandstone
Total Unit Weight, pcf	_	118-169	136-165	124-147
Total Dry Unit Weight, pcf	_	99-147	119-160	105-134
Water Content, %	_	5-22	1-19	8-19
Carbonate Content, %	_	3-72	74-100	0-7
Organic Content, %	2-3	_	_	_
Specific Gravity	_	2.74-2.78	2.69-2.72	2.65
Slake Durability, %	--	0-83	91-98	_
Liquid Limit Plasticity Index	25-60 9-43	27-71 14-48	–	–

The results of the unit weight tests, the number of tests performed, mean, and the assigned typical values are also summarized in Table 5.5.1-2 with respect to the assigned stratigraphic layers. The representative values of unit weight were selected based on the laboratory test results, material lithology, and engineering judgment, and are considered to be reasonably representative values for design.

Table 5.5.1-2 Rock Material Unit Weights

Layers	Primary Lithology	No. of Tests	Total Unit Weight, pcf		Assigned Typical Total Unit Weight, pcf
			Range	Average	
A	Limestone	40	119-165	149	145
B1	Shale	46	118-163	140	135
B2	Shale with Limestone interbeds				135
C	Limestone	62	135-163	155	155
D	Shale	7	131-169	147	135
E1	Limestone	24	134-161	151	155
E2	Limestone				155
E3	Limestone				150
F	Limestone with Shale and Sand interbeds	4	124-133	130	130
G	Sandstone	8	124-141	134	135
H	Shale	6	138-149	144	140
I	Sandstone	2	154-155	155	145
MW	Shale with Sandstone and Limestone interbeds	--	--	--	150

5.5.2 Strength Properties

Rock strength was assessed using point load tests (both axial and diametral), unconfined compression tests, and triaxial tests (consolidated undrained tests without pore pressure measurements). Compressive strength data are plotted versus elevation on Figure 11. Figures 12 and 13 present a cumulative probability distribution of unconfined compressive strength of limestone and shale that also includes the available data from Units 1 and 2. The combined data set for limestone seems to indicate a normal distribution, whereas the shale data set seems to correlate better with a log normal distribution. Table 5.5.2-1 summarizes strength test results ranges for shale and limestone samples.

Table 5.5.2-1 Summary of Strength Test Results

Strength Type	Material		
	Shale	Limestone	Sandstone
Unconfined Compressive Strength, tsf	13-104	73-812	10
Consolidated-Undrained Compressive Strength (w/o pp), tsf	10-82	126-587	124
Unconsolidated-Undrained Compression Strength, tsf	4-41	204-566	50
Point Load Strength (axial), tsf Point Load Strength (diametral), tsf	--	10-742 14-523	7-136 35

The results of the strength tests, the number of tests performed, mean and the selected representative values are also summarized in Table 5.5.2-2 with respect to the assigned stratigraphic layers. The assigned values of unconfined compression were selected based on the laboratory test results, material lithology, and engineering judgment. These are considered to be reasonably representative values.

Table 5.5.2-2 Unconfined Compressive Strength

Layers	Primary Lithology	Unconfined Compression, tsf			Point Load Test (axial), tsf			Assigned Representative UC Strength, tsf
		No.	Range	Average	No.	Range	Average	
A	Limestone	11	92 - 513	281	11	133 - 645	324	200
B1	Shale	7	13 - 790	291	1	455	-	50
B2	Shale with Limestone interbeds							
C	Limestone	39	73 - 812	290	22	10 - 742	264	250
D	Shale	-	-	-	-	-	-	50
E1	Limestone	6	104 - 311	251	6	73 - 605	260	250
E2	Limestone							
E3	Limestone							
F	Limestone with Shale and Sand interbeds	-	-	-	-	-	-	100
G	Sandstone	1	10	-	1	7	-	200
H	Shale	-	-	-	1	136	-	200
I	Sandstone	-	-	-	-	-	-	200
MW	Shale with Sandstone and Limestone interbeds	-	-	-	-	-	-	300

5.6 Geotechnical In-situ Field Test Data

5.6.1 In situ Shear & Compression Wave Velocity Data

In situ shear (S) and compression (P) wave velocity measurements were performed by Suspension P-S logging method in 15 boreholes by GeoVision Geophysical Services. Details of the field work and results are discussed in GeoVision Report (Ref. 3.1.5). The results were further analyzed and reduced by WLA, and integrated velocity profiles were developed for the project site, which are presented in the Project Calculation Package No. TXUT-001-FSAR-2.5-CALC-003 (Ref. 3.1.17). Figure 14 provides a composite summary of the measured S- and P-wave velocities for all 15 boreholes as well as the respective mean values for the integrated site model.

5.6.2 In Situ Pressuremeter Tests

In situ pressuremeter testing was conducted in seven boreholes by Hughes Insitu Engineering. Details of the field work and results are discussed in Hughes Report (Ref. 3.1.6). Figure 15 provides a summary of the pressuremeter tests results.

5.6.3 In Situ Packer Tests

In situ packer tests were performed in six boreholes by Fugro. Details of the field work and results are discussed in the Project Report TXU-001-PR-003 (Ref. 3.1.2). Figure 16 provides a summary of the packer tests results.

5.6.4 In Situ Rock Quality Designation

In situ Rock Quality Designation (RQD) of the rock core samples was measured by WLA field geologists during the field exploration activities. The results of the measured RQD values are shown on the individual logs within the Boring Log Data Report prepared by WLA (Ref. 3.1.14). Figure 17 provides a summary of the measured RQD values for all borings.

6.0 GEOTECHNICAL DESIGN PROPERTIES

6.1 Characterization of Rock Deformation Properties

A variety of laboratory and field test methods were used to describe the deformation characteristics for rock materials. Deformation characteristics of the subsurface rock materials were developed using two approaches as presented below:

- Best Estimate for Rock Mass Modulus: Subsurface rock deformation characteristics were estimated using in situ shear (S) wave velocities measured during the downhole suspension logging. Because the downhole velocity measurements reflect the local influence of rock discontinuities and material variations, the resulting calculated modulus value are considered more indicative of the rock mass conditions. However, due to the low strain nature of the shear wave velocity, the calculated modulus is an upper bound case when used for settlement calculations. The low strain modulus values were reduced to reflect the relative higher strain levels anticipated for the fully loaded foundations. The modulus model developed based on this procedure is considered to represent the Best Estimate (BE) model for use in settlement analysis.

- Lower Bound for Rock Mass Modulus: Subsurface rock deformation characteristics also were estimated using the results of stress-strain measurements in the laboratory on intact core samples, and in situ tests in boreholes using a pressuremeter. Because the individual core samples and pressuremeter tests do not consider the discontinuities or material variations, the Rock Mass Rating (RMR) System (Ref. 3.2.2), and Geological Strength Index (GSI) System (Refs. 3.2.6 & 3.2.4) were used to incorporate the effects of discontinuities and material variations and assess the overall rock mass deformation characteristics. The modulus model developed based on this procedure is expected to produce a conservative Lower Bound (LB) modulus model for use in settlement analysis.

The following sections provide details and procedures used to develop the above two rock deformation models.

6.1.1 Best Estimate for Rock Mass Modulus

Measured values of shear and compression wave velocities provide an indirect measurement of the low-strain in situ rock modulus. In situ rock modulus is estimated from the shear wave velocities using the following relationships:

$$G_{\max} = \frac{\gamma}{g} \cdot V_s^{\,2}$$

where:

G_{max} = Low Strain Shear Modulus (psf)
V_s = Shear Wave Velocity (fps)
γ = Total Unit Weight (pcf)
g = Gravitational Acceleration Constant (32.2 ft/s^2).

Poisson's ratio (ν) is determined as follows:

$$\nu = \frac{V_p^{\ 2} - 2V_s^{\ 2}}{2 \cdot \left(V_p^{\ 2} - V_s^{\ 2}\right)}$$

where:

ν = Poisson's ratio
V_p = Compression Wave Velocity (fps).

From the above information, the Modulus of Elasticity or Young's Modulus (E) is determined from:

$$E_{max} = 2G \cdot (1 + \nu)$$

$$E = E_{max}(RF)$$

where:

E_{max} = Low Strain Modulus of Elasticity or Young's Modulus
E = Strain Adjusted Modulus of Elasticity or Young's Modulus
RF = Reduction Factor for Modulus Strain Adjustment

Results of the integrated mean velocity profiles along with the Poisson's ratio values are discussed and presented in the Project Calculation Package No. TXUT-001-FSAR-2.5-CALC-003 (Ref. 3.1.17). The low strain modulus (E_{max}) values were empirically reduced in order to develop a modulus model that is more compatible with the level of anticipated settlement. Reduction curves used for this adjustment are shown on Figure 18 (Ref. 3.1.7). An iterative process was used between strain, calculated modulus and settlement in order to select the appropriate reduction factor for each layer. The following relation between the axial and shear strain was used for utilizing Figure 18:

$$\gamma_{max} = (1 + \nu)\varepsilon$$

where:

γ_{max} = Maximum Shear Strain
ε = Axial Strain
ν = Poisson's ratio

A summary of the velocity data, Poisson's ratio values, and the calculated Young's Modulus values versus depth and stratigraphic layers are summarized in the following Table 6.1.1-1:

Table 6.1.1-1 Summary of Rock Velocities, Poisson's Ratio, and Young's Modulus

Layers	Mean V_s, fps	Mean V_p, fps	Poisson's Ratio	Total Unit Weight, pcf	Shear Modulus (G_{max}), tsf	Young's Modulus (E_{max}), tsf	Strain Reduction Factor (RF)	Strain Adjusted E_{max} (E), tsf
A	3,548	8,788	0.40	145	28,343	79,361	0.98	77,774
B1	2,609	6,736	0.41	135	14,269	40,239	0.55	22,131
B2	2,716	7,640	0.43	135	15,463	44,226	0.55	24,324
C	5,685	11,324	0.33	155	77,787	206,913	0.98	202,775
D	3,019	8,312	0.42	135	19,106	54,2612	0.55	29,844
E1	4,943	10,486	0.36	155	58,807	159,954	0.98	156,755
E2	6,880	13,164	0.31	155	113,926	298,486	0.98	292,516
E3	4,042	9,255	0.38	150	38,054	105,029	0.98	102,928
F	3,061	7,927	0.41	130	18,914	53,338	0.68	36,270
G	3,290	7,593	0.38	135	22,690	62,625	0.88	55,110
H	3,429	8,188	0.39	140	25,561	71,060	0.83	58,979
I	3,092	7,686	0.40	145	21,526	60,273	0.92	55,451
MW	5,546	10,627	0.32	150	71,642	189,134	1.00	189,134

A summary plot of the mean low strain Young's modulus (E_{max}) and the strain adjusted Young's modulus (E) values versus stratigraphic layer and the elevation is presented on Figure 19.

6.1.2 Lower Bound for Rock Mass Modulus

6.1.2.1 Rock Mass Quality

As part of the exploration conducted by WLA and Fugro for the Units 3 and 4 COLA, rock coring and logging were performed onsite, with observations of rock quality that included discontinuities and jointing information recorded on the boring logs. Rock mass quality information was recorded in photographs and noted on the core logs. Rock Quality Designation (RQD) values are plotted versus elevation on Figure 17 along with a line representing the average. RQD values ranged from 0 to 100 percent, with a statistical average value of 96 percent. RQD is one of the input parameters used to determine the Rock Mass Rating (RMR). Average RQD values selected for stratigraphic layers ranged from 80 to 99 percent depending on the layer.

6.1.2.2 Rock Mass Classification using RMR and GSI

Bieniawski published details for the Rock Mass Rating (RMR) System which is also referenced as the Geomechanics Classification System (Ref. 3.2.1). The RMR method is meant to account

for large scale discontinuities that would not be represented by laboratory testing of rock samples. It is a geomechanics classification that can be applied to estimate the in situ modulus of deformation and behavior of a rock mass based on empirical data and experience.

The GSI system (Refs. 3.2.3 and 3.2.5) provides a system for estimating the rock mass strength of different geological conditions as an alternative to the RMR Classification. The GSI is in part specific to the rock type. The strength of a jointed rock mass depends on the properties of the intact rock pieces, discontinuities, spacing and orientation, and filling.

For the CPNPP site, both the RMR and the GSI systems were used to estimate the rock mass modulus.

The RMR was evaluated for each stratigraphic layer, in accordance with the U.S. Army Corps of Engineers Rock Foundations Manual (Ref. 3.2.12), and most recently updated by Hoek (Ref. 3.2.2).

The following six (6) parameters are used to classify a rock mass using the RMR system:

- Uniaxial Compressive Strength of the intact rock
- Rock Quality Designation (RQD)
- Spacing of discontinuities
- Condition of discontinuities surfaces
- Groundwater conditions
- Orientation of discontinuities relative to the engineered structure

The rock is described, based on observations and tests, and points are assigned for the condition of the rock. All rock description category points are tallied and the resulting number is the RMR, ranging potentially from 0 to 100. Parameters are used to provide an overall rating, as indicated on Figure 20 Rock Mass Rating System and Project Parameters.

Figure 20 presents the ratings for each stratigraphic layer, along with the resulting RMR, which ranges from 63 (clayshale) to 89 (sandstone). An average RMR value of 70 for the rock mass as a whole was selected as representative for the bearing strata (Layer C) and deeper.

The GSI is a system of rock-mass characterization based on visually assessing the geological character of the rock material and for the prediction of rock mass strength and deformability. The lithology, structure and condition of discontinuity surfaces in the rock mass are estimated from visual examinations of the rock mass exposed in outcrops, in surface excavations and borehole cores (Ref. 3.2.7). The GSI combines rock mass blockiness discontinuity conditions. The system for estimating the GSI from the geological observations is presented in Figure 21; GSI Chart.

The GSI classification was originally introduced because Bieniawski's RMR classification was difficult to apply to very poor quality rock masses. For better quality rock masses, the value of

GSI can also be estimated directly from the RMR classification. The GSI can be estimated directly from the 1989 version of Bieniawski's Rock Mass Rating (RMR_{89}), where RMR has the groundwater rating set to 15 and the adjustment for joint orientation set to zero. In this case the GSI can be calculated from:

$$GSI = RMR_{89} - 5$$

Within the CPNPP site, GSI values were developed for each stratigraphic layer that was interpreted by WLA based on the RMR classification and the relationship between RMR and GSI, as described above. GSI Values ranged from 58 to 84. An average GSI value of 68 was selected as representative of material within and below the foundation bearing zone.

Selected RMR or GSI values are entered into a set of empirically developed equations to estimate the rock mass strength and deformability properties by means of the Hoek-Brown criterion (Refs. 3.2.3 and 3.2.5). The indices are used in conjunction with appropriate values for the unconfined compressive strength of the intact rock (σ_{ci}) and the petrographic constant (m_i) to calculate the mechanical properties of a rock mass (compressive strength of the rock mass - σ_{cm}) and its deformation modulus, E.

6.1.2.3 Rock Mass Modulus Estimates

Laboratory test results from individual rock samples and the RMR and GSI values were used to estimate the deformation modulus of the rock mass by using empirical equations summarized by Hoek and Diederichs (Ref. 3.2.4). For the CPNPP Project four (4) empirical approaches were selected to define the Rock Mass Modulus range. The following table summarizes these approaches:

Table 6.1.2.3-1 Rock Mass Modulus Empirical Relationships

Empirical Relation	Reference
$E_{rm} = \frac{E_i}{100}\left(0.0028RMR^2 + 0.9e^{\frac{RMR}{22.82}}\right)$	Nicholson and Bieniawski, 1990
$E_{rm} = \frac{1}{2}E_i\left(1-\cos\left(\pi\frac{RMR}{100}\right)\right)$	Mitri et al., 1994
$E_{rm} = E_i\left(s^a\right)^{0.4}$ $s = e^{\frac{(GSI-100)}{9}}$ $\quad a = \frac{1}{2}+\frac{1}{6}\left(e^{-\frac{GSI}{15}} - e^{-\frac{20}{3}}\right)$	Sonmez et al., 2004
$E_{rm} = E_i\left(0.02 + \frac{1-(D/2)}{1+e^{\left(\frac{(60+15D-GSI)}{11}\right)}}\right)$	Hoek & Diederichs, 2006
Where: E_{rm} = Rock Mass Modulus E_i = Intact Modulus = MR (σ_{ci}) σ_{ci} = Uniaxial Compression Strength MR = Modulus Ratio	

Uniaxial compression strength values were taken from Table 5.5.2-2. The modulus ratio values were selected based on the guideline recommendations by Hoek and Diederichs (Ref. 3.2.4), and are shown in Table 6.1.2.3-2:

Table 6.1.2.3-2 Summary of Rock Modulus Ratio Values

Layers	Primary Lithology	Modulus Ratio (MR)
A	Limestone	350
B1	Shale	250
B2	Shale with Limestone interbeds	250
C	Limestone	400
D	Shale	250
E1	Limestone	400
E2	Limestone	400
E3	Limestone	400
F	Limestone with Shale and Sand interbeds	350
G	Sandstone	300
H	Shale	250
I	Sandstone	300
MW	Shale with Sandstone and Limestone interbeds	400

The estimated range of the Rock Mass Modulus (E_{rm}) values for each of the stratigraphic layers, based on the above four correlations and their average value, are presented on Figure 22. Modulus values from the field pressuremeter tests and the laboratory unconfined compression tests are also shown on Figure 22 for comparison. The average estimated rock mass modulus compares well with the lower bound of the intact modulus values from the laboratory or field measurements and is considered to be a reasonable representation of deformation characteristics of the site rock mass profile.

Estimated rock mass properties, including the RMR and GSI ratings, cohesion, friction angle, and Young's modulus for the individual stratigraphic layers, are summarized in Table 6.1.2.3-3.

Table 6.1.2.3-3 Summary of Rock Mass Properties

Layers	Total Unit Weight, pcf	RMR	GSI	Rock Mass Cohesion, tsf	Rock Mass Friction Angle, degrees	Rock Mass Young's Modulus (E_{rm}), tsf
A	145	76	71	3.1 – 4.2	35 - 45	45,754
B1	135	63	58	3.1 – 4.2	35 - 45	5,825
B2	135	63	58	3.1 – 4.2	35 - 45	5,825
C	155	79	74	3.1 – 4.2	35 - 45	69,606
D	135	63	58	3.1 – 4.2	35 - 45	5,825
E1	155	79	74	3.1 – 4.2	35 - 45	69,606
E2	155	79	74	3.1 – 4.2	35 - 45	69,606
E3	150	79	74	3.1 – 4.2	35 - 45	69,606
F	130	75	70	3.1 – 4.2	35 - 45	22,377
G	135	84	79	> 4.2	> 45	45,933
H	140	83	78	> 4.2	> 45	37,587
I	145	83	78	> 4.2	> 45	45,105
MW	150	89	84	> 4.2	> 45	100,149

7.0 ANALYTICAL METHODOLOGY

7.1 Settlement

Rebound deformation due to foundation excavations and settlement from foundation loading are anticipated to be elastic in nature. Rebound and settlements were estimated by elastic theory. The following two methods were used to compute the estimated settlement for the major structures within the CPNPP Units 3 and 4 area:

7.1.1 Non-layered Method

The non-layered method considers the subsurface rock layers supporting the foundations as a homogeneous elastic half-space medium with a uniformly loaded rectangular area. The formulas by Schleicher (1926) are used to calculate the settlement of any location beneath a loaded rectangle foundation (Equation 5-2, Ref. 3.2.9).

$$\delta_d(x,y) = C_s q B \left(\frac{1-\nu^2}{E} \right)$$

The parameter C_s is a geometric factor that accounts for the shape of the rectangle and the position of the point for which the settlement is being calculated. The formula for calculating C_s is as follows (Equation 5-3, Ref. 3.2.9):

$$C_s = \frac{1}{2\pi}(C_1 + C_2 + C_3 + C_4)$$

$$C_1 = B_1 \ln \frac{\sqrt{A_1^2 + B_1^2} + A_1}{\sqrt{A_2^2 + B_1^2} - A_2}$$

$$C_2 = B_2 \ln \frac{\sqrt{A_1^2 + B_2^2} + A_1}{\sqrt{A_2^2 + B_2^2} - A_2}$$

$$C_3 = A_1 \ln \frac{\sqrt{A_1^2 + B_1^2} + B_1}{\sqrt{A_1^2 + B_2^2} - B_2}$$

$$C_4 = A_2 \ln \frac{\sqrt{A_2^2 + B_1^2} + B_1}{\sqrt{A_2^2 + B_2^2} - B_2}$$

$$A_1 = 1 - \frac{2x}{B}$$

$$A_2 = 1 + \frac{2x}{B}$$

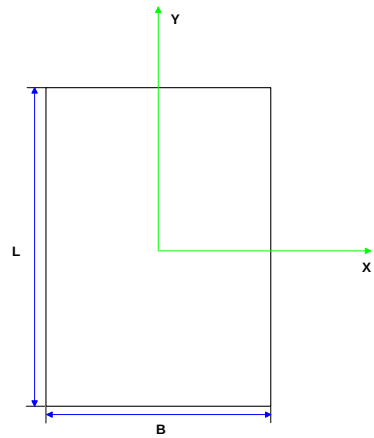
$$B_1 = \frac{L}{B} - \frac{2y}{B}$$

$$B_2 = \frac{L}{B} + \frac{2y}{B}$$

where:

$\delta_d(x, y)$	=	Settlement of the point with coordinates of (x, y)
q	=	Uniform load intensity
C_s	=	Geometric factor
B	=	Width of the loaded area
L	=	Length of the loaded area
ν	=	Poisson's ratio
E	=	Average Elastic or Young's modulus
A_1, A_2	=	Factors to be calculated based on the above formulas and then inserted into the formulas for C_1 through C_4
B_1, B_2	=	Factors to be calculated based on the above formulas and then inserted into the formulas for C_1 through C_4
$C_1 - C_4$	=	Factors to be calculated based on the above formulas and then inserted into the main formula for C_s

x, y = x and y coordinates of the point (see figure below)



The average elastic modulus for the half-space was calculated using a weighted average modulus approach, as indicated by the following relationships (Equation 5.1, Ref. 3.2.12):

$$E_{avg} = \frac{\sum_{i=1}^{n}\left(E_i \Big/ \sum_{j=1}^{i} h_j\right)}{\sum_{i=1}^{n}\left(1 \Big/ \sum_{j=1}^{i} h_j\right)}$$

Where:

E_{avg} = Weighted average modulus

E_i = Elastic modulus of each layer

h_j = Thickness of each layer

n = Number of layers

7.1.2 Layered Method

The layered method is similar to the non-layered method, but considers the subsurface rock materials supporting the foundations to be a layered system. The stress increase with depth caused by a rectangular uniform surface load is computed using a stress distribution theory. Superposition of rectangular areas covering the loaded surfaces is used for the cases where the stress calculation point is not located directly under the corner of a given loaded area or when there is more than one loaded area. The strain of each layer is calculated by dividing the stress increment by the layer modulus and then the strain multiplied by the layer thickness to provide the layer compression or settlement. The computed settlement values of all layers are summed to provide the total settlement values shown below:

$$\delta = \sum_{i=1}^{n} \delta_i = \sum_{i=1}^{n} \varepsilon_i h_i = \sum_{i=1}^{n} \frac{\Delta\sigma_i}{E_i^e} h_i$$

Where:

δ	=	Total Settlement
δ_i	=	Settlement of each layer
ε_i	=	Strain in each layer
h_i	=	Thickness of each layer
$\Delta\sigma_i$	=	Stress increment in each layer due to loading
E_i^e	=	Equivalent elastic modulus of each layer

In the above formula for the equivalent elastic modulus (E_i^e), values of Young's modulus (E_i), plane strain modulus ($E_i^{'}$), or constrained modulus (M_i), as defined below, may be used, depending on the boundary conditions or location of the settlement point.

$$E_i^{'} = \frac{E_i}{1-\nu^2}$$

$$M_i = E_i\left[\frac{1-\nu_i}{(1+\nu_i)(1-2\nu_i)}\right]$$

where:

E_i	=	Young's modulus of each layer
$E_i^{'}$	=	Plane strain modulus of each layer
M_i	=	Constrained modulus of each layer
ν_i	=	Poisson's ratio of each layer

For the cases where the foundation dimensions are relatively large, the lateral deformation at points below the center of the foundation is considered fully constrained and use of the constrained modulus is more appropriate. On the other hand, in the cases of small foundations and areas near corners or edges of large foundations, the lateral deformations will not be constrained and the Young's modulus is more appropriate for settlement computations. For the settlement calculations provided in this report, the plane strain modulus, which considers the strain to be constrained in only one direction, was adopted. The plane strain modulus, which is lower than the constrained modulus and slightly higher than the Young's modulus, was judged to be a reasonable selection and appropriate for representing all points below loaded areas for both large and small size foundations.

There are several elastic solutions that can be used to calculate stress distribution, such as Boussinesq, Mindlin, and Westergaard. There is no definitive proof that either of these solutions is more accurate than the other for the soil or rock applications (Ref. 3.2.11). Among the available solutions, the Boussinesq solution has been most widely used for geotechnical applications. It has also been found that settlements obtained through use of the Boussinesq equation are, in the great majority of cases, larger than the observed settlements. We conservatively selected the Boussinesq solution for computing the stresses distribution under the loaded areas for the settlement calculations presented in this report. The Boussinesq

equation for calculating vertical stress increment under a corner of a rectangular uniformly distributed flexible loaded area is expressed as follows (Ref. 3.2.10):

$$\sigma_z = \frac{q}{4\pi}\left[\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+m^2n^2+1}\frac{m^2+n^2+2}{m^2+n^2+1}+\sin^{-1}\left(\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+m^2n^2+1}\right)\right]$$

$$m = \frac{L}{Z}$$

$$n = \frac{B}{Z}$$

where:

σ_z	=	Stress increment at a depth z
q	=	Uniform load intensity as surface
B	=	Width of the loaded area
L	=	Length of the loaded area
Z	=	Distance below the loaded area
m,n	=	Ratio of loaded area width or length to depth

The vertical stress induced at other locations than the corner or by more than one foundation can be obtained by superposition approach.

7.1.3 Rock Mass Elastic Deformation Model

As described previously, two models were developed to independently represent the best estimate and a lower bound model for the rock mass elastic deformation modulus. The first model, described in Section 6.1.1, was developed based on the in situ shear wave velocity data, and is generally considered to best represent the actual deformation behavior of the subsurface rock mass. The second model, described in section 6.1.2, was developed based on the laboratory test results for the core samples and the available empirical correlations. This model is considered conservative and may be viewed as the lower bound model. A summary of the BE and LB modulus models used for the settlement calculations are shown on Figure 23.

7.1.4 Depth of Influence

In general, the stresses induced within the subsurface rock materials by foundation load decrease with depth. For settlement estimates, the depth of influence, or critical depth, is defined as follows:

- The minimum depth below the foundation at which the imposed vertical component of the stress diminishes to about 20 percent of the maximum stress applied by the foundation (Ref. 3.2.12).

- The minimum depth below the foundation where the applied stress due to foundation load decreases to 10 percent of the effective overburden pressure for fine-grained compressible materials or 20 percent for coarse-grained materials (Ref. 3.2.8).

7.2 Rebound Deformation

Rebound deformation due to general site elevation cuts or foundation excavations (i.e. foundation unloading) will be predominantly elastic in nature because of the relatively low imposed stress levels and nature of the subsurface rock materials. Rebound is based on the same methodology for settlement computation, with the exception that a negative load or stress release is applied instead of a positive load. The amount of the stress release is estimated based on the total weight of the soils or rocks planned to be excavated.

7.3 Liquefaction and Seismic Settlement

Soil liquefaction results from the earthquake-induced temporary buildup of excess pore water pressure in saturated granular materials, which can lead to a condition of near-zero effective stress and the temporary loss of strength. Ground shaking must be significant in intensity and of a long-enough duration to induce build-up of excess pore pressure. A reduction in soil strength due to liquefaction would lead to a reduction in resisting soil pressures, strain increase in buried structures, and potential loss of bearing capacity, settlement, and lateral spreading.

Soil materials considered to be susceptible to liquefaction include loose, saturated sands and non-plastic silts. Liquefaction commonly occurs in Holocene and late-Pleistocene age underconsolidated to consolidated saturated soils. The susceptibility of soils to liquefaction is a function of the distribution of grain sizes (gradation), soil density, cementation, total fines content, and plasticity characteristics of the fines. The resistance to liquefaction increases with increasing (a) grain size distribution, (b) soil density, (c) cementation, (d) fines content, and (e) plasticity characteristics of the fines.

Proposed grades for the foundation bottom of seismic category I structures at CPNPP Units 3 and 4 will be in limestone. The sides of the foundation excavation will be rock as well. Therefore, the power block structures will not be subject to liquefaction induced damage.

Groundwater is generally below the residual soil and existing non-structural fill within the power block area. Any residual soils and nonstructural fill will be removed and replaced with compacted fill where they are beneath structures. Additionally, the potential for ground shaking strong enough to induce liquefaction is low. Therefore, the potential for liquefaction at this site is considered very low.

7.4 Bearing Capacity

Major structures for Units 3 and 4 will be founded on mat foundations bearing on fairly intact Glen Rose Formation bedrock, or on concrete fill placed after shale materials are removed. Ultimate bearing capacity of the Glen Rose rock mass was estimated for three potential failure mechanisms of general shear failure, local shear failure, and compressive failure as presented in the Rock Foundations Manual by the U.S. Army Corps of Engineers (EM 1110-1-2908, Ref. 3.2.12).

7.4.1 General Shear Failure

The U.S. Army Corps of Engineers EM 110-1-2908 (Ref. 3.2.12) recommends the traditional Buisman-Terzaghi (Terzaghi, 1943) bearing capacity expression to calculate ultimate bearing capacity for general shear failure mode as shown below.

$$q_{ult} = cC_c N_c + 0.5\gamma B C_\gamma N_\gamma + \gamma D N_q$$

$$N_c = 2N_\phi^{1/2}\left(N_\phi + 1\right)$$

$$N_\gamma = N_\phi^{1/2}\left(N_\phi^2 - 1\right)$$

$$N_q = N_\phi^2$$

$$N_\phi = \tan^2\left(45 + \frac{\phi}{2}\right)$$

Where:

q_{ult} = Ultimate bearing capacity
γ = Effective unit weight (i.e. submerged unit weight if below groundwater table) of rock mass
B = Width of foundation
D = Depth of foundation embedment
c = The cohesion intercept for rock mass
ϕ = Angle of internal friction angle for rock mass
C_c = Foundation shape correction factor for N_c (see Table 7.4.1-1 below)
C_γ = Foundation shape correction factor for N_γ (see Table 7.4.1-1 below)
N_c, N_γ, N_q = Bearing capacity factors

Table 7.4.1-1 Foundation Shape Correction Factors

Foundation Shape	C_c (N_c Correction)	C_γ (N_γ Correction)
Circular	1.2	0.70
Square	1.25	0.85
Rectangular		
L/B = 2	1.12	0.90
L/B = 5	1.05	0.95
L/B = 10	1.00	1.00

7.4.2 Local Shear Failure

Local shear failure represents a special case where a failure surface starts to develop but does not propagate to the surface. For this mode of failure, depth of embedment contributes little to the total bearing capacity. The expression for the ultimate bearing capacity applicable to localized shear failure is as follows:

$$q_{ult} = cC_c N_c + 0.5\gamma B C_\gamma N_\gamma$$

The parameters are the same as those defined in Section 7.4.1.

7.4.3 Compressive Failure

Compressive failure is a case characterized by a foundation that is supported on poorly constrained columns of rock, and the failure mode will be similar to unconfined compression failure. The ultimate bearing capacity may be estimated as shown below:

$$q_{ult} = 2c\tan(45 + \frac{\phi}{2})$$

The parameters are the same as those defined in Section 7.4.1. Using unconfined compression strength parameters (q_{ult}=$2c$) by assuming ϕ=0, the ultimate bearing capacity is approximated by the unconfined compressive strength of rock mass.

7.4.4 Bearing Capacity Parameter Selection

For selecting the design parameters, the U.S. Army Corps of Engineers (Ref. 3.2.12) recommends that because rock masses generally provide generous margins of safety against bearing capacity failure, the initial strength parameter values selected for assessing bearing capacity should be based on lower bound estimates. In general, as a conservative estimation of the bearing capacity using the above procedures, the angle of internal friction (ϕ) is assumed to be zero, and the cohesion is taken as one-half of the lower bound of the unconfined compression strength value.

8.0 CALCULATIONS

8.1 Settlement

Settlement and deformation analyses were conducted by both the non-layered and layered methods described above for the two best estimate and lower bound deformation modulus models that were described in Sections 6.1.1 and 6.1.2. A summary of the settlement results for the center points of the main buildings are shown in Tables 8.1-1 and 2:

Table 8.1-1: Settlement Estimates Based on Best Estimate Modulus Model

Structure	Foundation Static Load (ksf)	Settlement Estimate for Center, inches	
		Non-Layered Method	Layered Method
R/B	11.32	0.12	0.20
T/B	5.86	0.07	0.11
A/B	6.77	0.09	0.14
EPS/B	4.31	0.07	0.10
WPS/B	4.31	0.08	0.12
PSFSV	5.38	0.06	0.08-0.09
UHS	3.61	0.05	0.05-0.06

Table 8.1-2: Settlement Estimates Based on Lower Bound Modulus Model

Structure	Foundation Static Load (ksf)	Settlement Estimate for Center, inches	
		Non-Layered Method	Layered Method
R/B	11.32	0.30	0.37
T/B	5.86	0.19	0.20
A/B	6.77	0.23	0.26
EPS/B	4.31	0.18	0.18
WPS/B	4.31	0.20	0.21
PSFSV	5.38	0.16-0.17	0.14-0.16
UHS	3.61	0.12-0.14	0.10-0.12

Settlement calculations and results for additional corner points of the structures are provided in Appendix A. The differential settlement is anticipated to be about ½ the total settlement values. Due to lack of available loading or dimensions, no settlement calculations were performed for the ESWPT or the duct banks. However, the loads for these structures are expected to be very minimal and, consequently, the resulting settlements likely are insignificant.

Based on the results of the settlement estimates, the proposed structures are not anticipated to experience any settlements in excess of ½ inch, which is well within the acceptable settlement criterion of a mean of 2 inches total and differential settlement, as reported by WGI (Ref. 3.1.9).

8.2 Depth of Influence or Critical Depth

For the settlement calculations using the layered system, a depth of about 1000 feet below the elevation 822 feet was used in the settlement model. The depths of influence, or critical depths as defined by the criteria of 10-20 percent of the effective overburden pressure (Section 7.1.4) for the structures, are shown on the stress distribution plots in Appendix A. The minimum

depths of influence for all structures are generally less than the actual depth used in the settlement calculations.

8.3 Rebound Deformation

Rebound deformation estimates were carried out by both the non-layered and layered methods described above for the best estimate deformation modulus model described in Section 6.1.1. A summary of the rebound estimates for the center points of the main buildings are shown in Table 8.3-1:

Table 8.3-1: Rebound Estimates Based on Best Estimate Modulus Model

Structure	Excavation Depth, ft	Rebound Estimate for Center, inches	
		Non-Layered Method	Layered Method
R/B	40-50	0.07	0.12
T/B	40-50	0.06	0.10
A/B	40-50	0.07	0.10
EPS/B	40-50	0.06	0.08
WPS/B	40-50	0.06	0.10
PSFSV	40-50	0.05	0.06-0.08
UHS	40-50	0.05	0.07

Rebound calculations and results for additional corner points of the structure areas are provided in Appendix B. The rebound values were estimated based on the removal of about 40 feet of soil and rock material to the top of Layer C limestone rock. Based on the results of the rebound estimates, the potential for any significant heave or rebound of the foundation rock due to foundation excavation during the construction is very low.

8.4 Bearing Capacity

Bearing capacity estimates for the three failure modes and the minimum factors of safety are summarized in Table 8.4-1. The lowest estimated bearing capacity of about 146 ksf for all seismic category I and II foundations is for the compressive failure mode. The calculations are presented in Appendix C.

Table 8.4-1: Summary of Ultimate Bearing Capacities

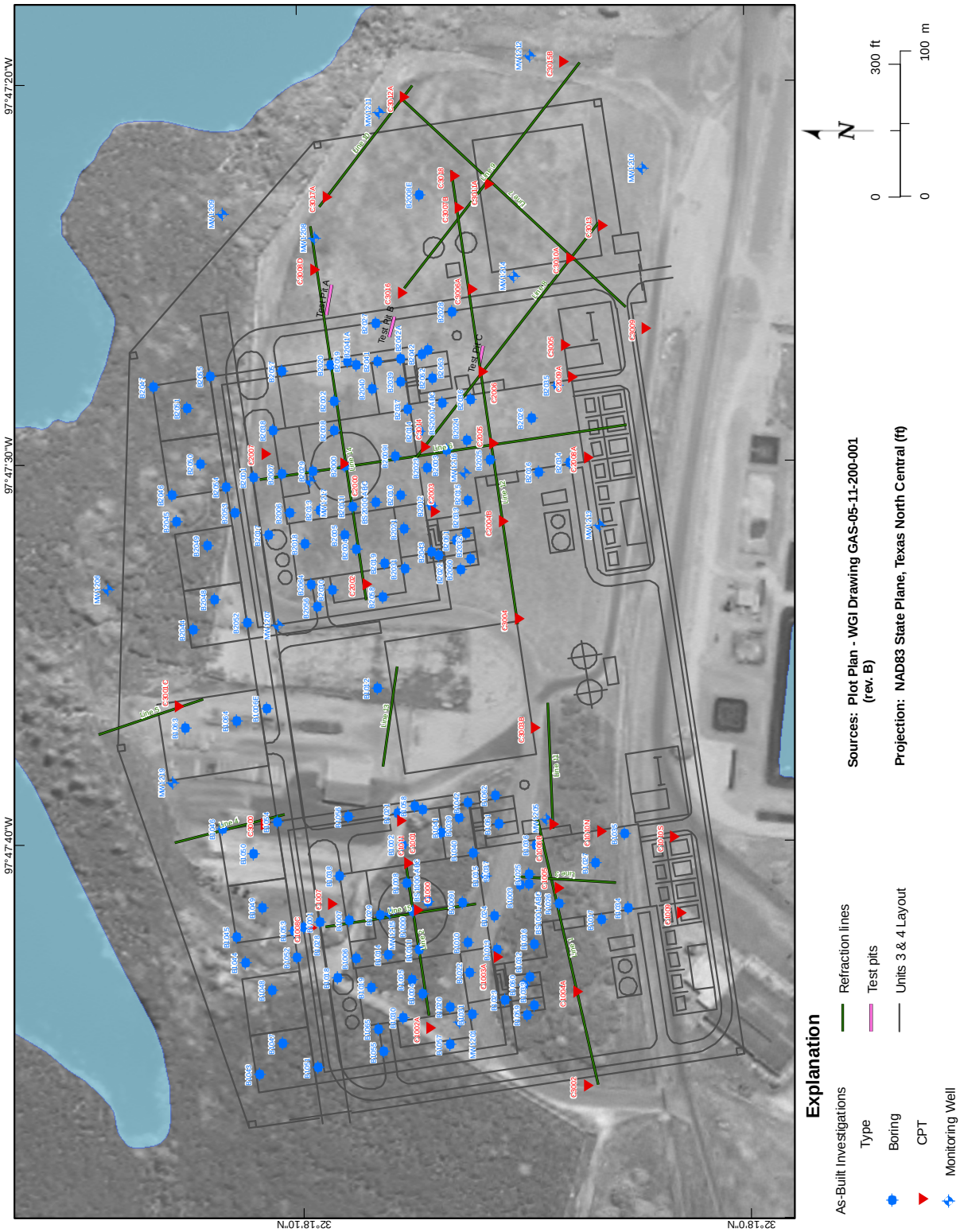
Structure	Foundation Load (ksf)		Ultimate Bearing Capacity (ksf)			Available FOS	
	Static Load	Seismic Load	General Shear	Local Shear	Compression	Static	Seismic
R/B	11.32	55.0	354	348	146	12.9	2.6
T/B	5.86	7.35	342	339	146	24.9	11.1
A/B	6.77	10.99	338	335	146	21.6	8.2
EPS/B	4.31	7.41	343	340	146	33.9	12.5
WPS/B	4.31	7.41	343	340	146	33.9	12.5
PSFSV	5.38	13.0	365	362	146	27.1	7.9
UHS	3.61	7.4	369	365	146	40.4	13.3

Based on the above results, the compression failure mode governs and results in an ultimate bearing capacity of about 146 ksf. From the available factors of safety shown above, the Glen Rose Limestone of Layer C appears to provide adequate bearing capacity for support of the proposed structures.

9.0 SOFTWARE

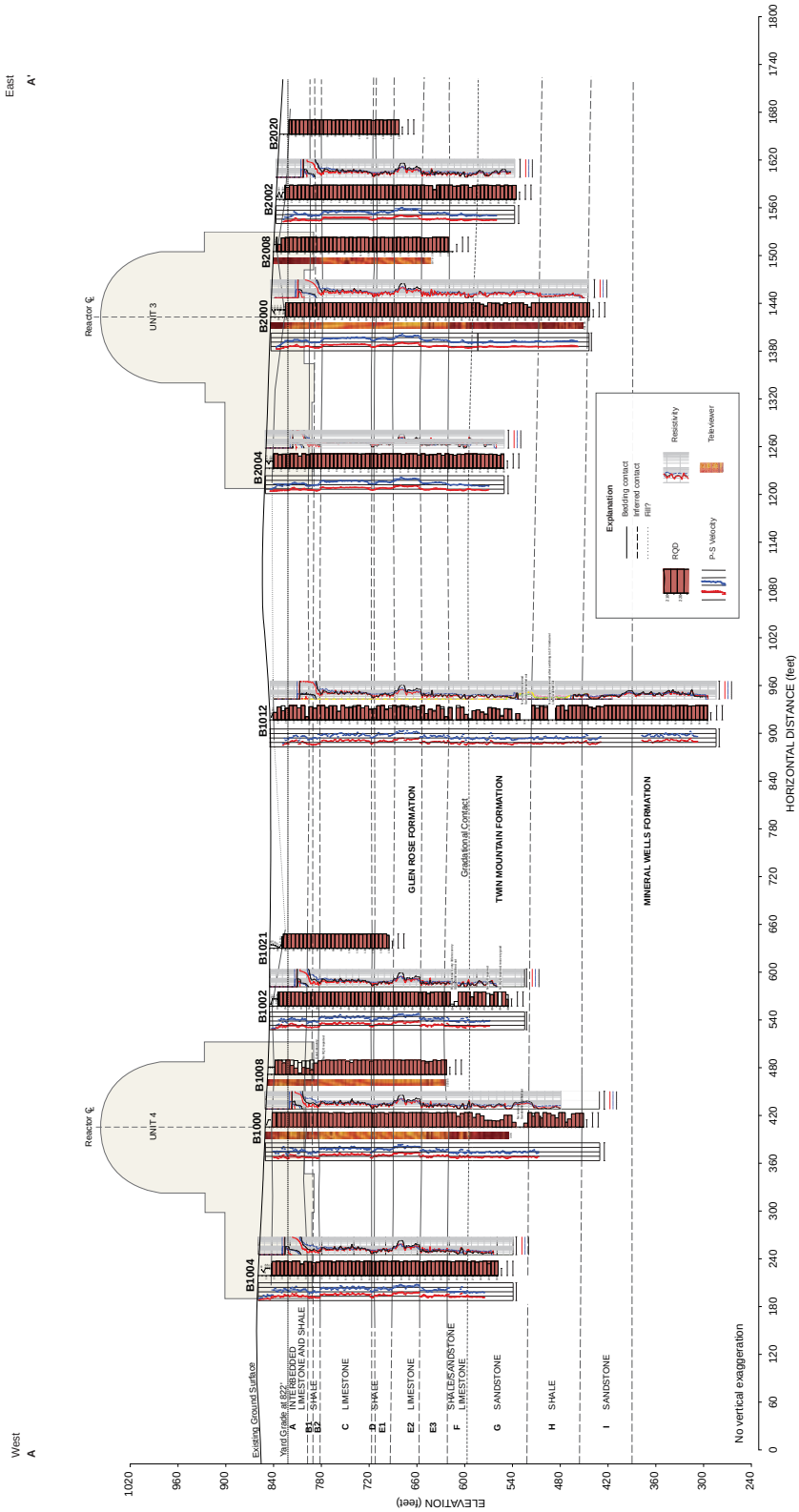
Microsoft Excel and Mathcad are the only sofware programs used for all calculations provided in this report. In general, all calculations were performed with Microsoft Excel, and the same calculations were repeated using the Mathcad program. The duplicate calculation results obtained through using the Mathcad were used to serve as a hand-check for the results obtained by the Excel for the same problem and the input data. The software versions utilized for this calculation package are as follows:

- Microsoft Office Excel – 2003 SP2
- Mathcad – 2007 Version 14.0



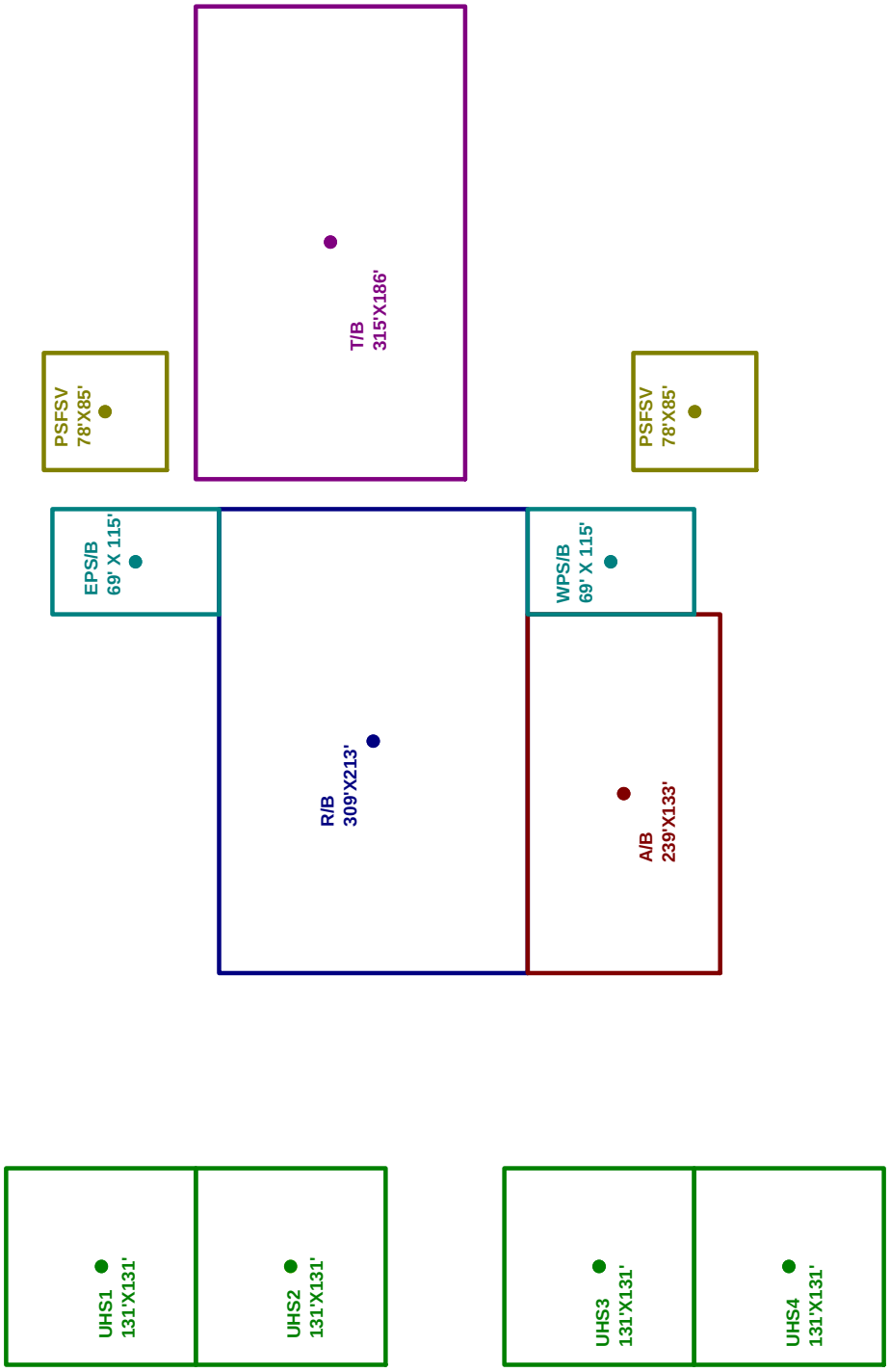
As-Built Exploration Locations

FIGURE 1



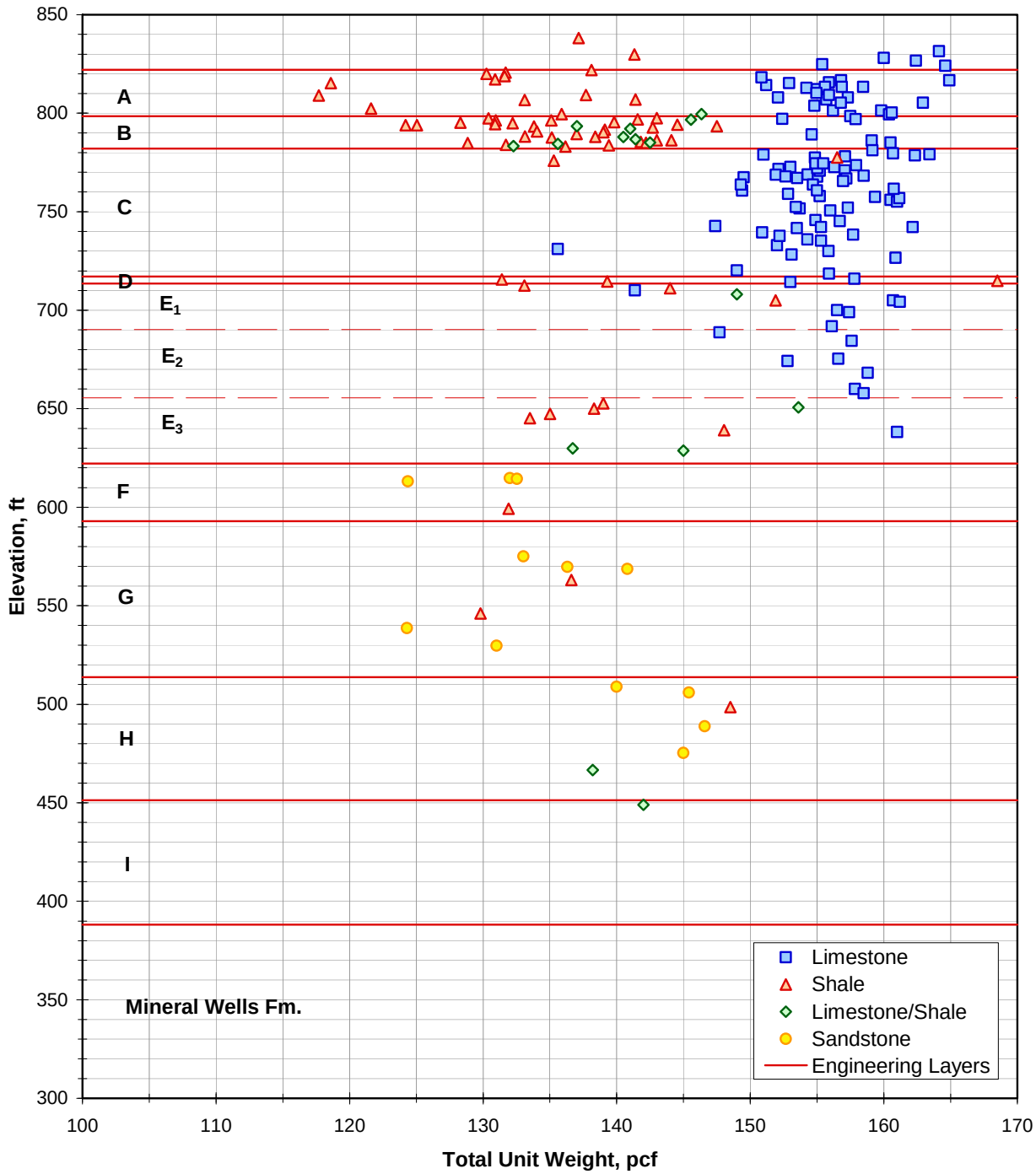
Engineering Cross Section

FIGURE 2



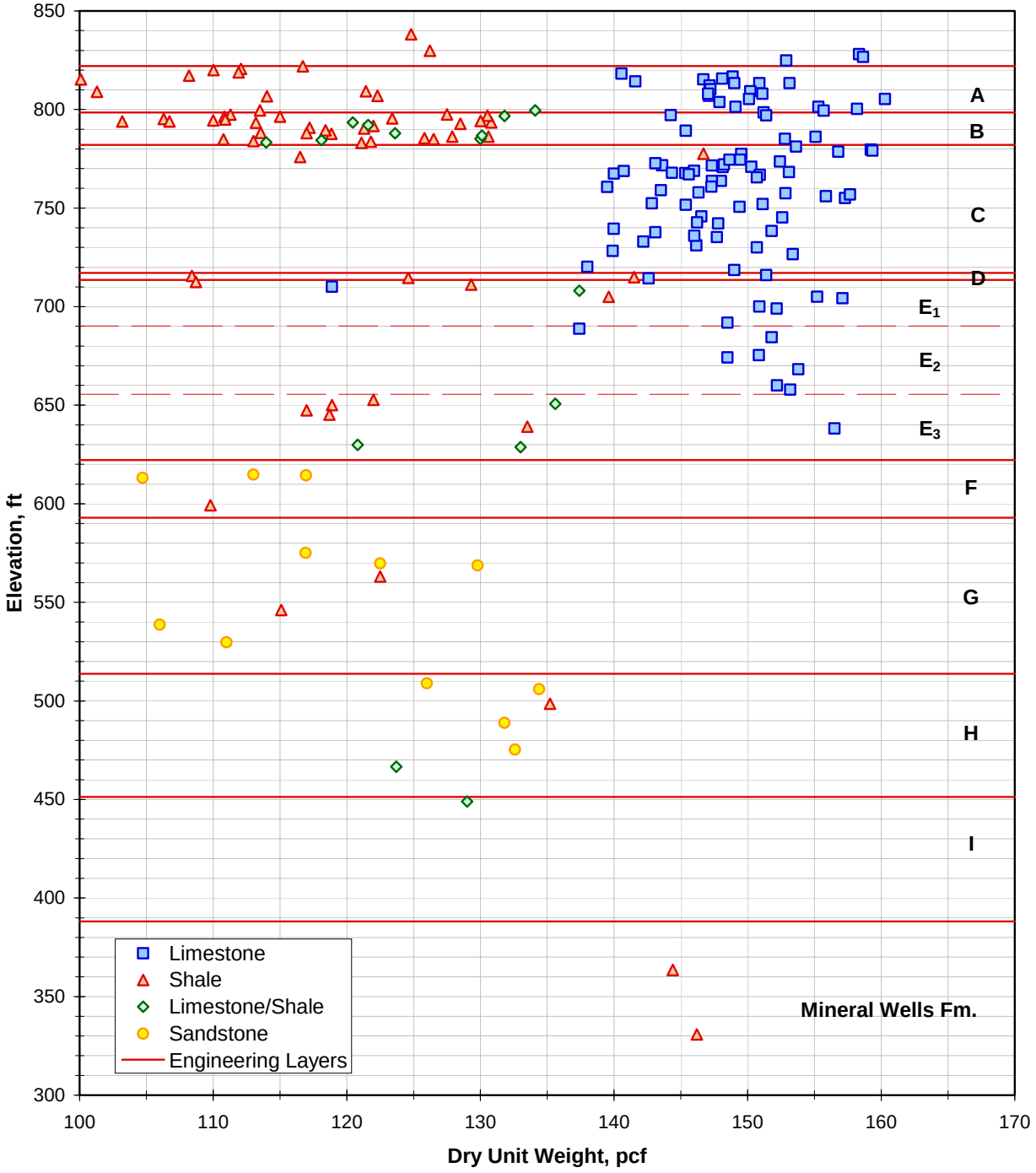
Unit Area Structure Layout

FIGURE 3



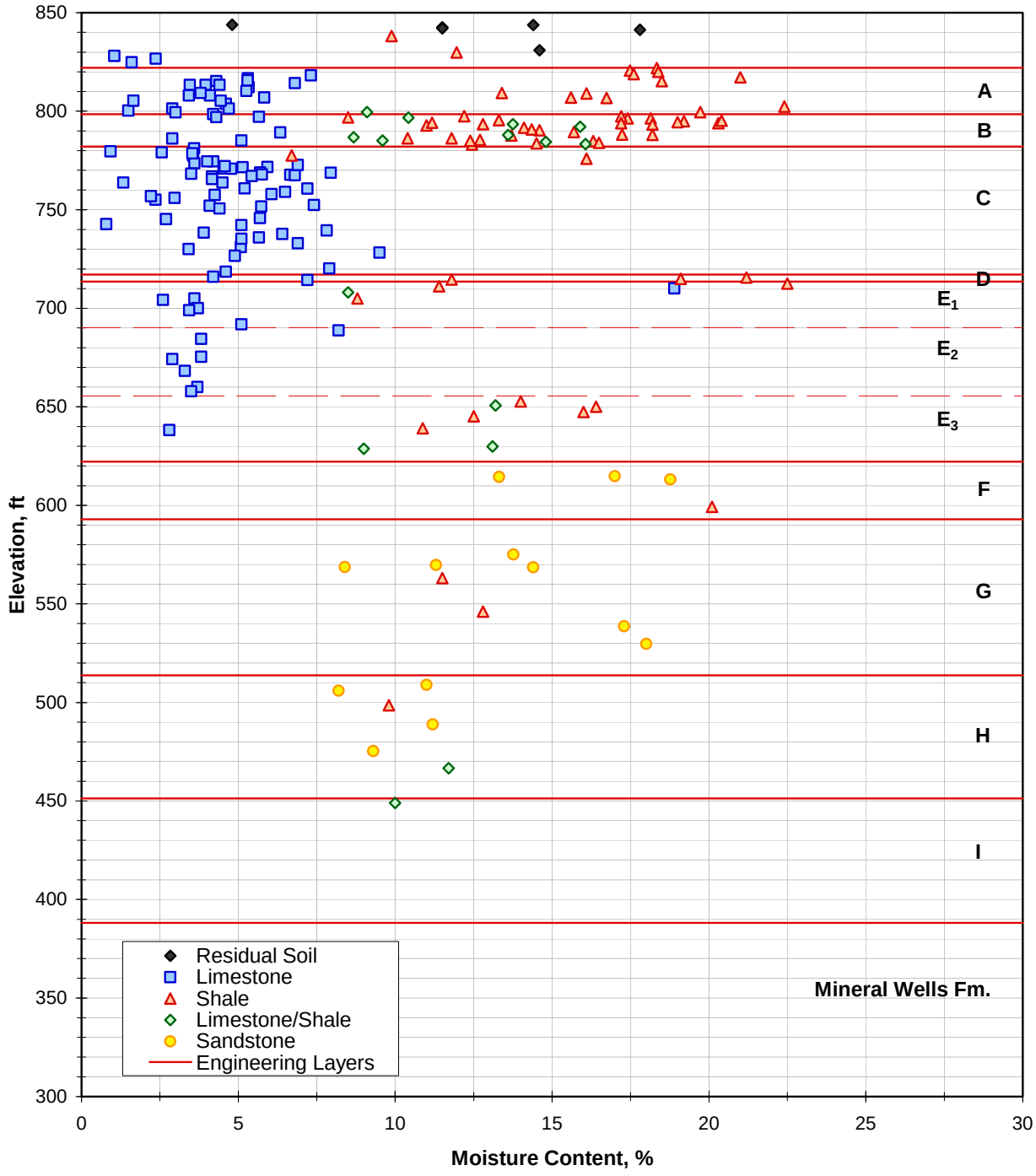
Total Unit Weight vs. Elevation

FIGURE 4



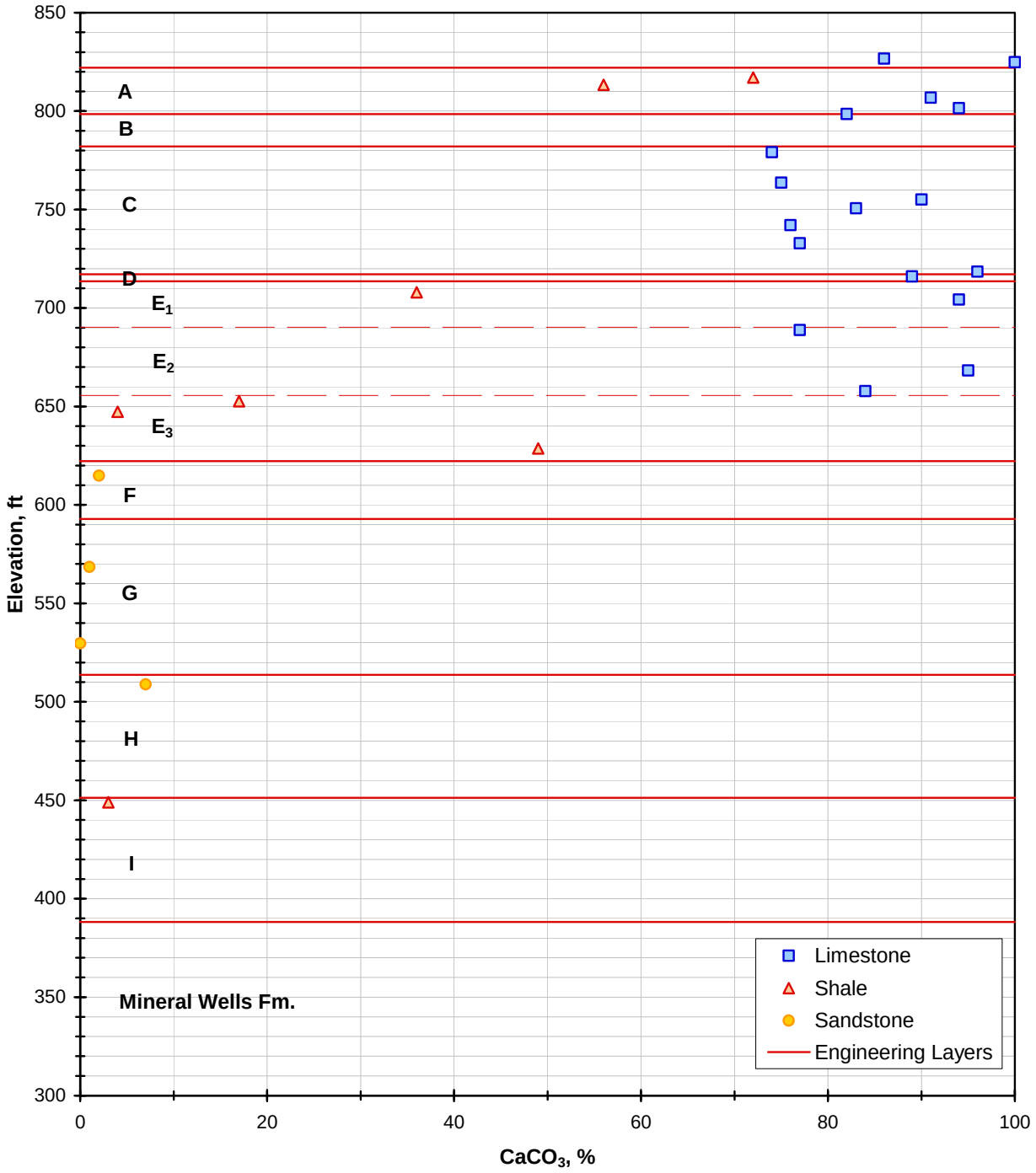
Dry Unit Weight vs. Elevation

FIGURE 5



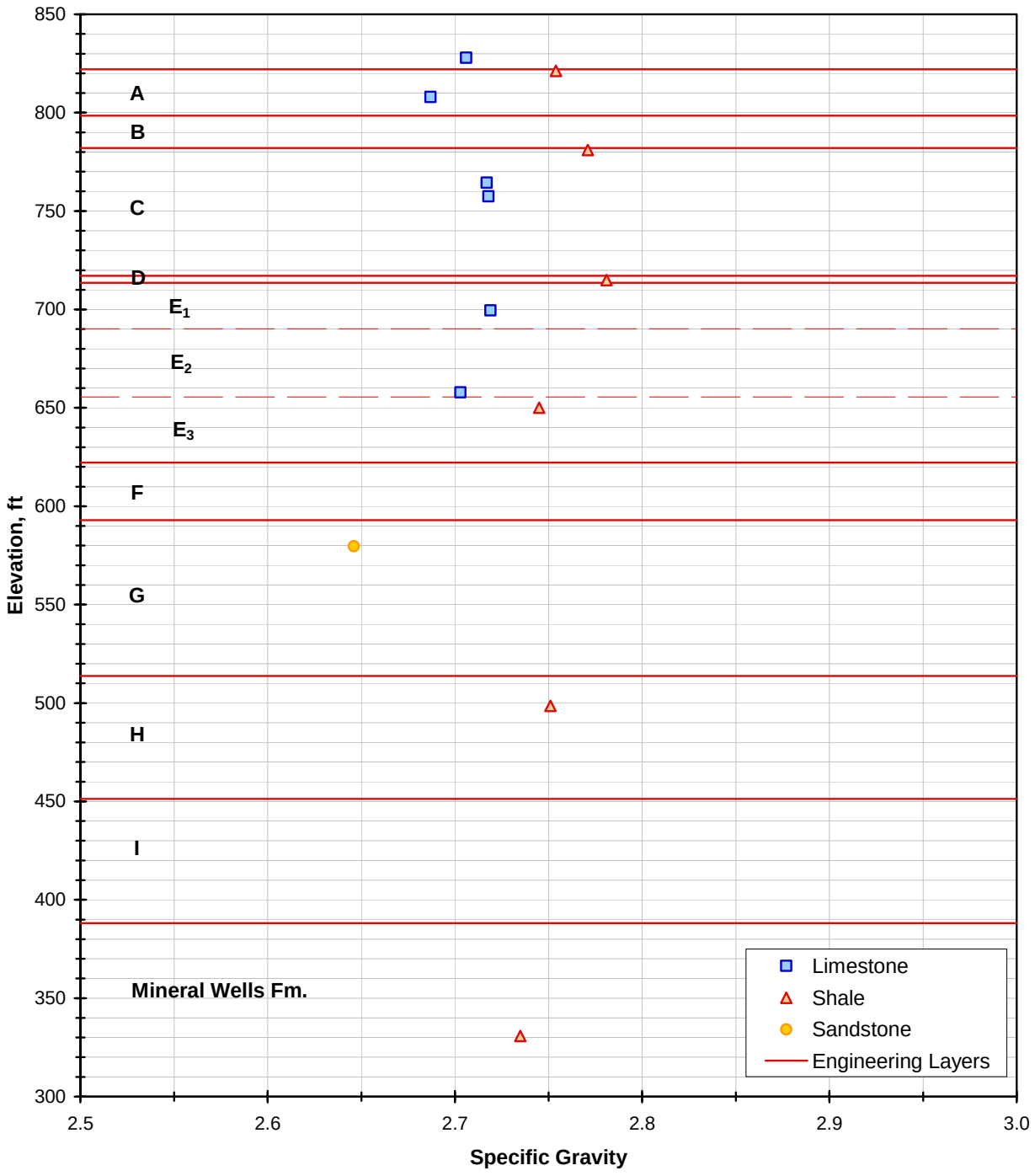
Moisture Content vs. Elevation

FIGURE 6



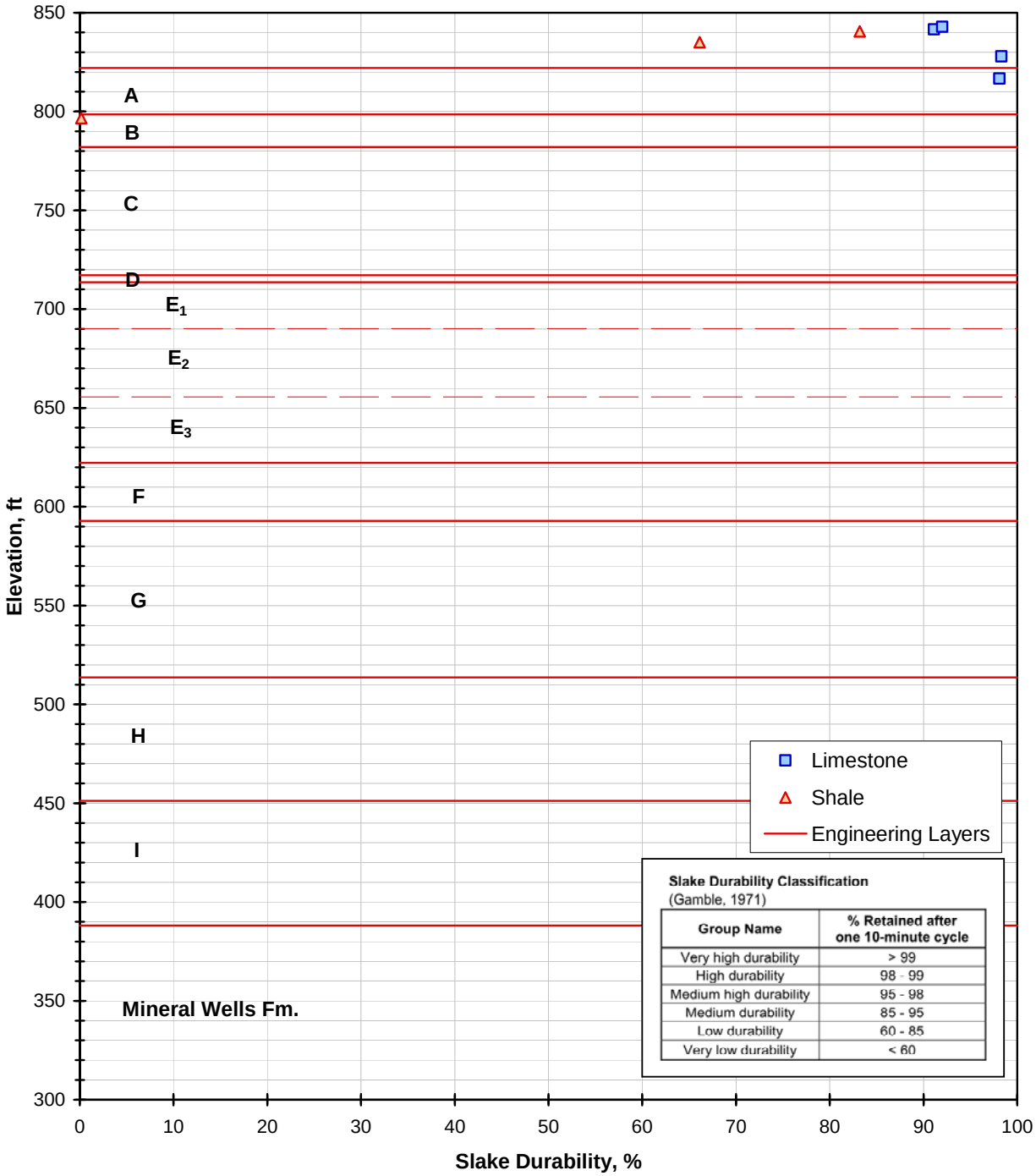
Calcium Carbonate vs. Elevation

FIGURE 7



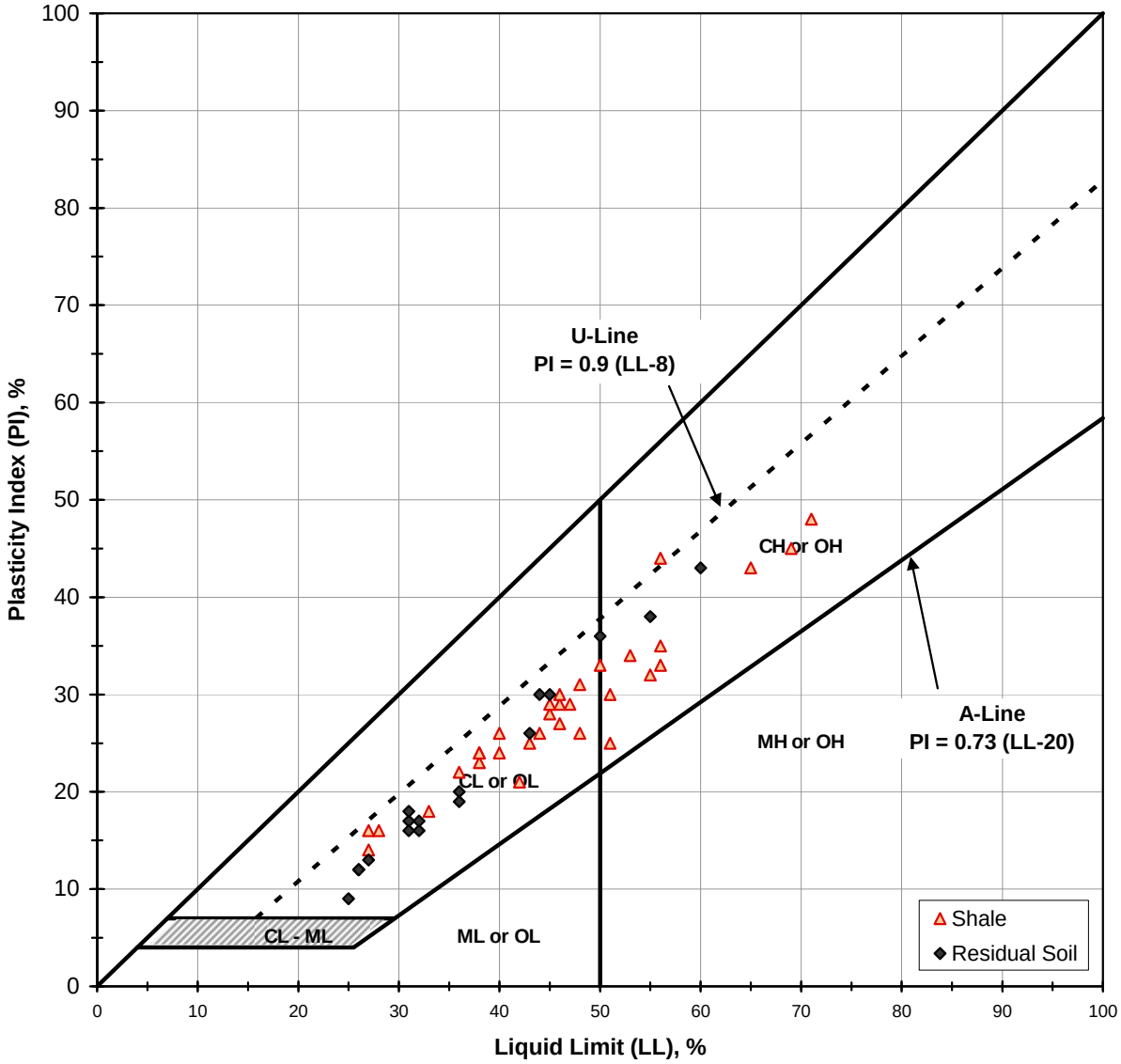
Specific Gravity vs. Elevation

FIGURE 8



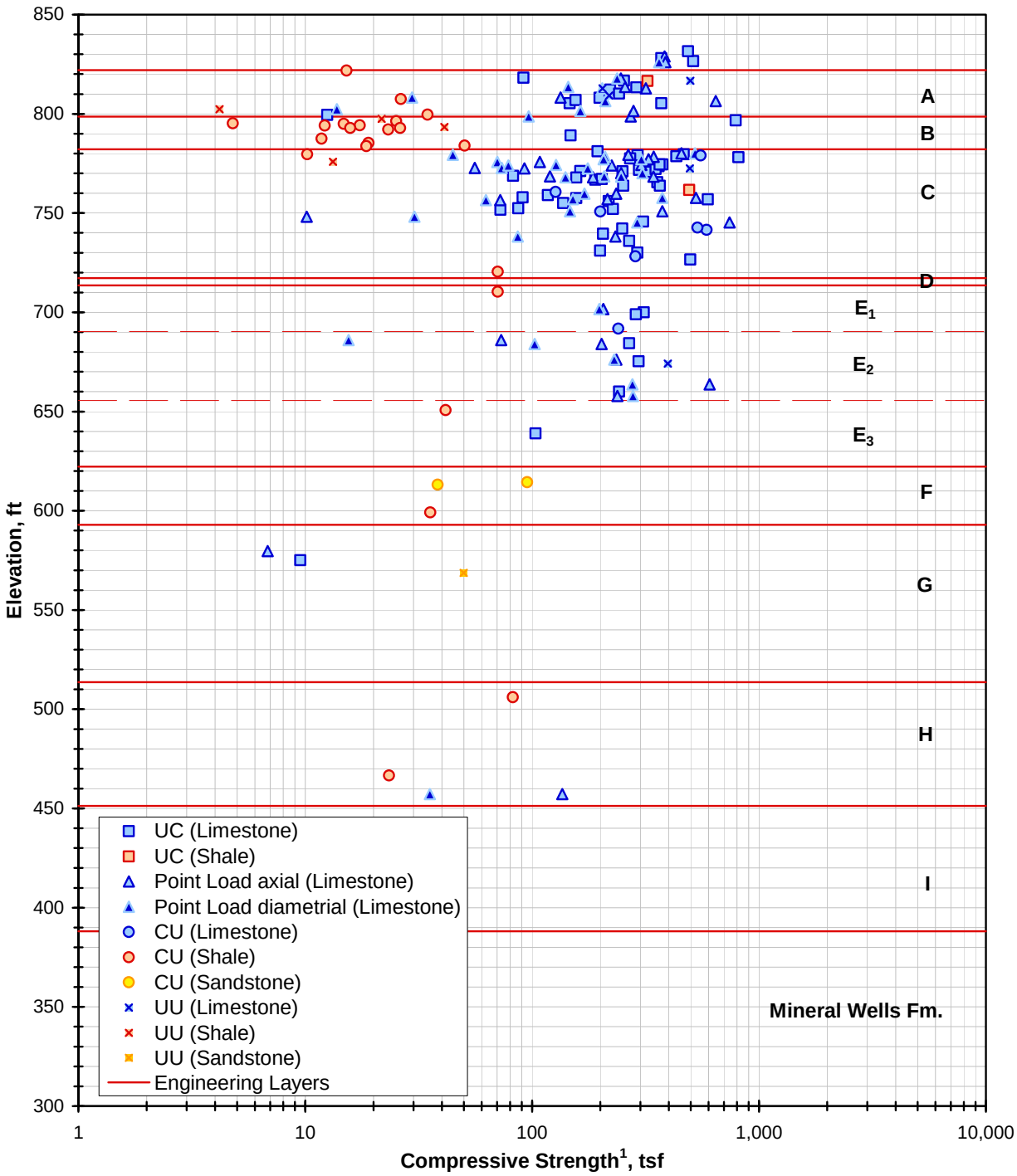
Slake Durability vs. Elevation

FIGURE 9



Plasticity Data

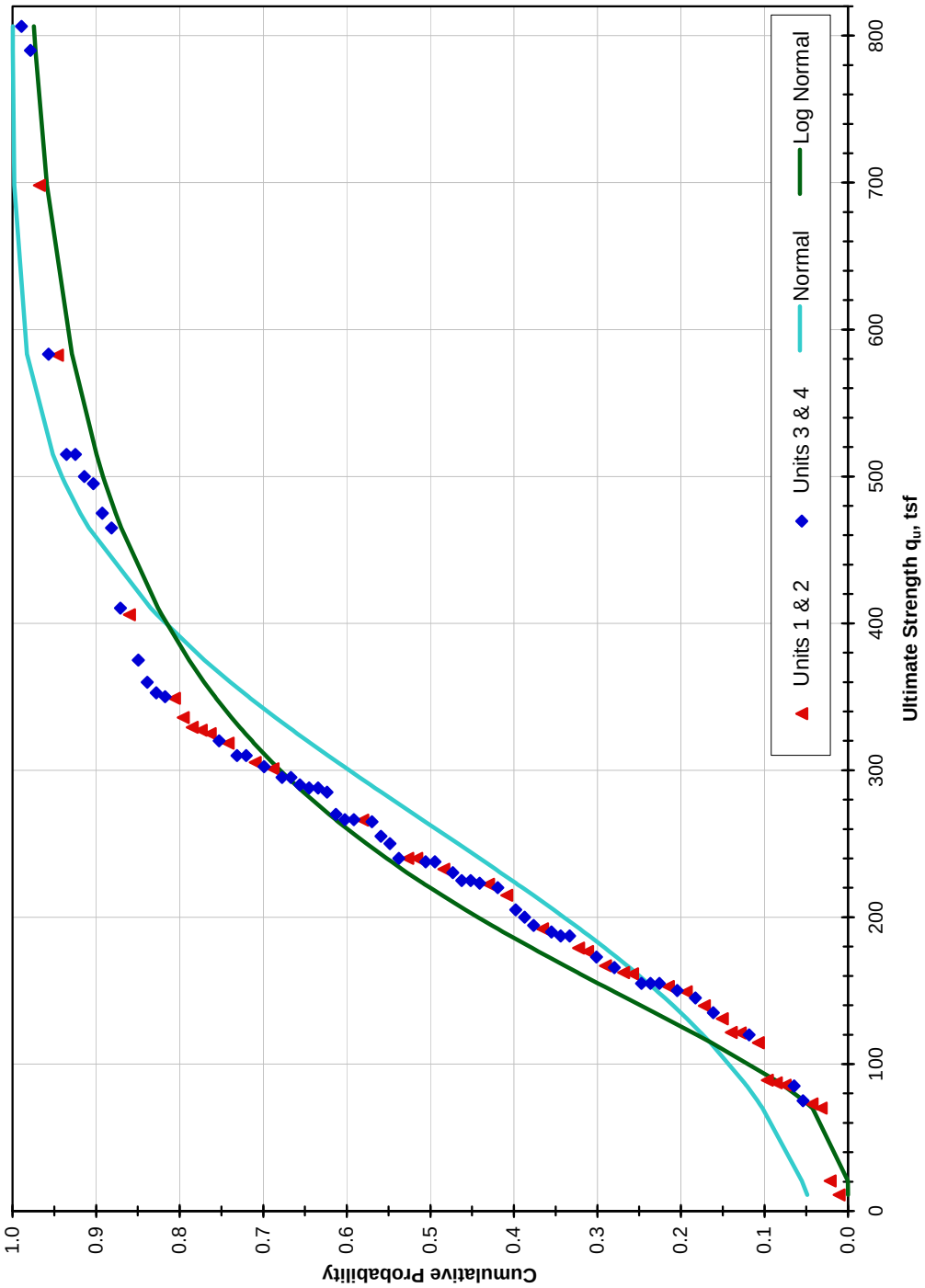
FIGURE 10



Notes:
1- Uniaxial stress for UC and PLI tests and deviator stress for CU and UU tests

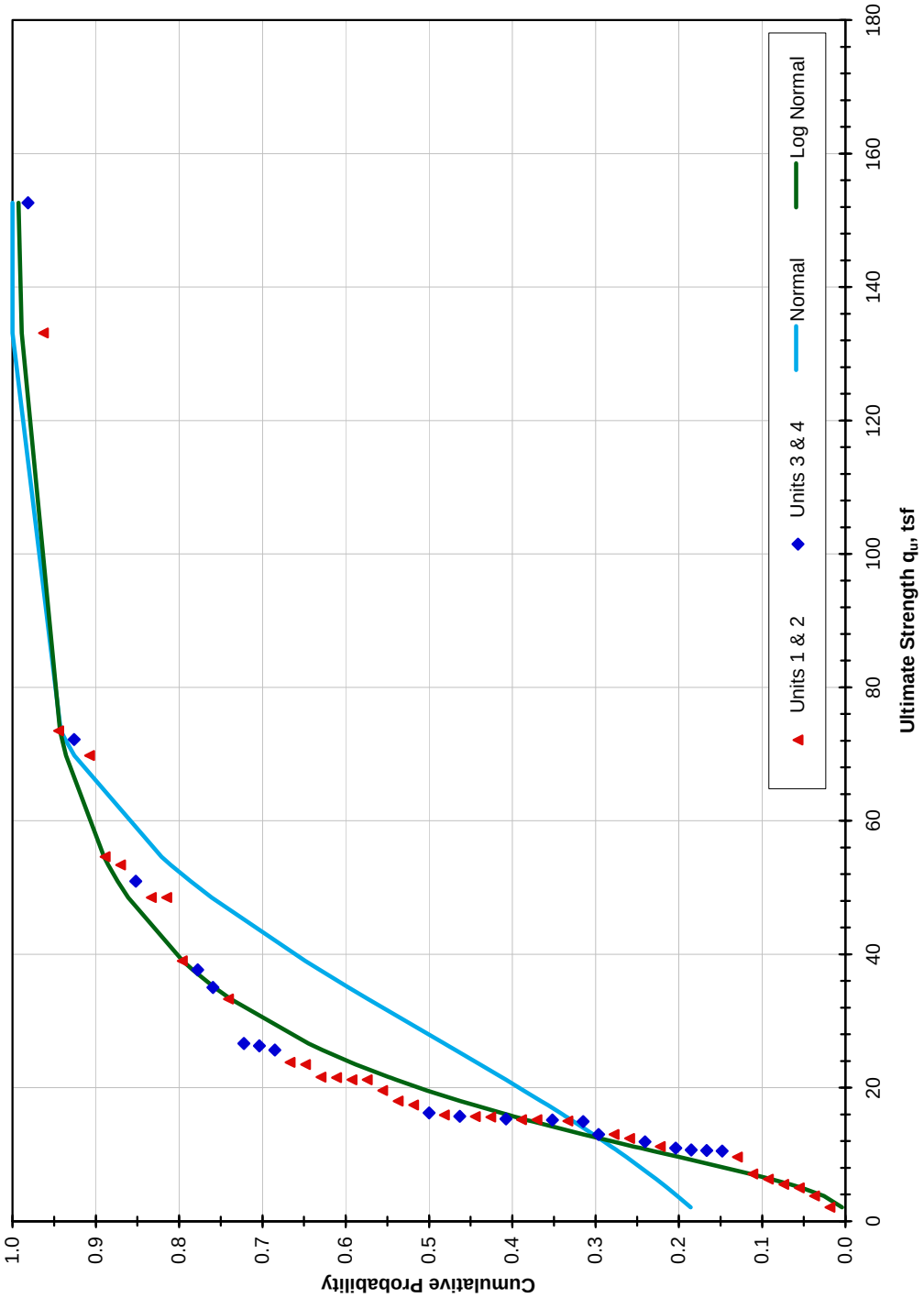
Compressive Strength vs. Elevation

FIGURE 11



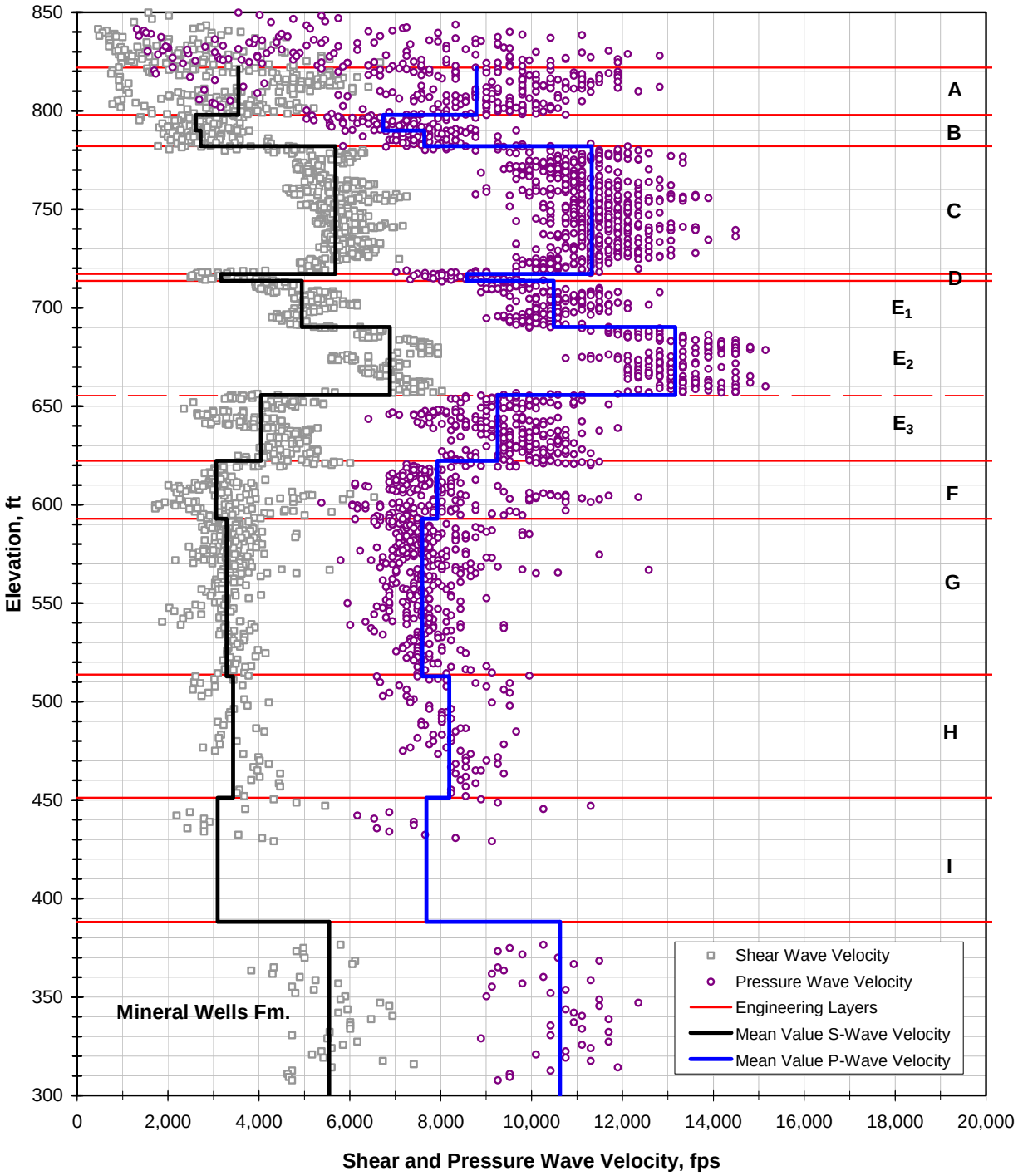
Cumulative Probability of Unconfined Compressive Strength Data
Limestone Samples

FIGURE 12



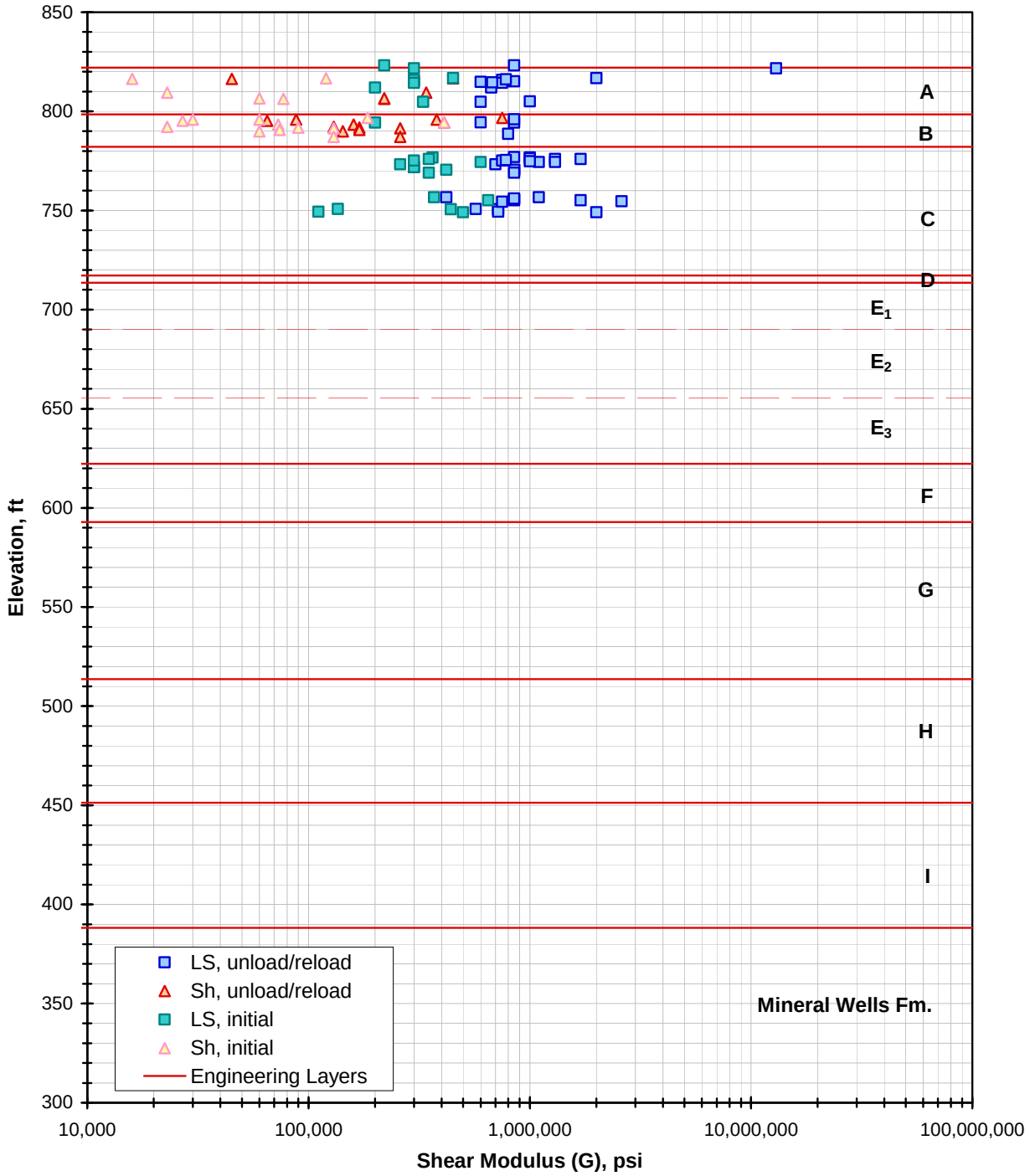
Cumulative Probability of Unconfined Compressive Strength Data
Shale Samples

FIGURE 13



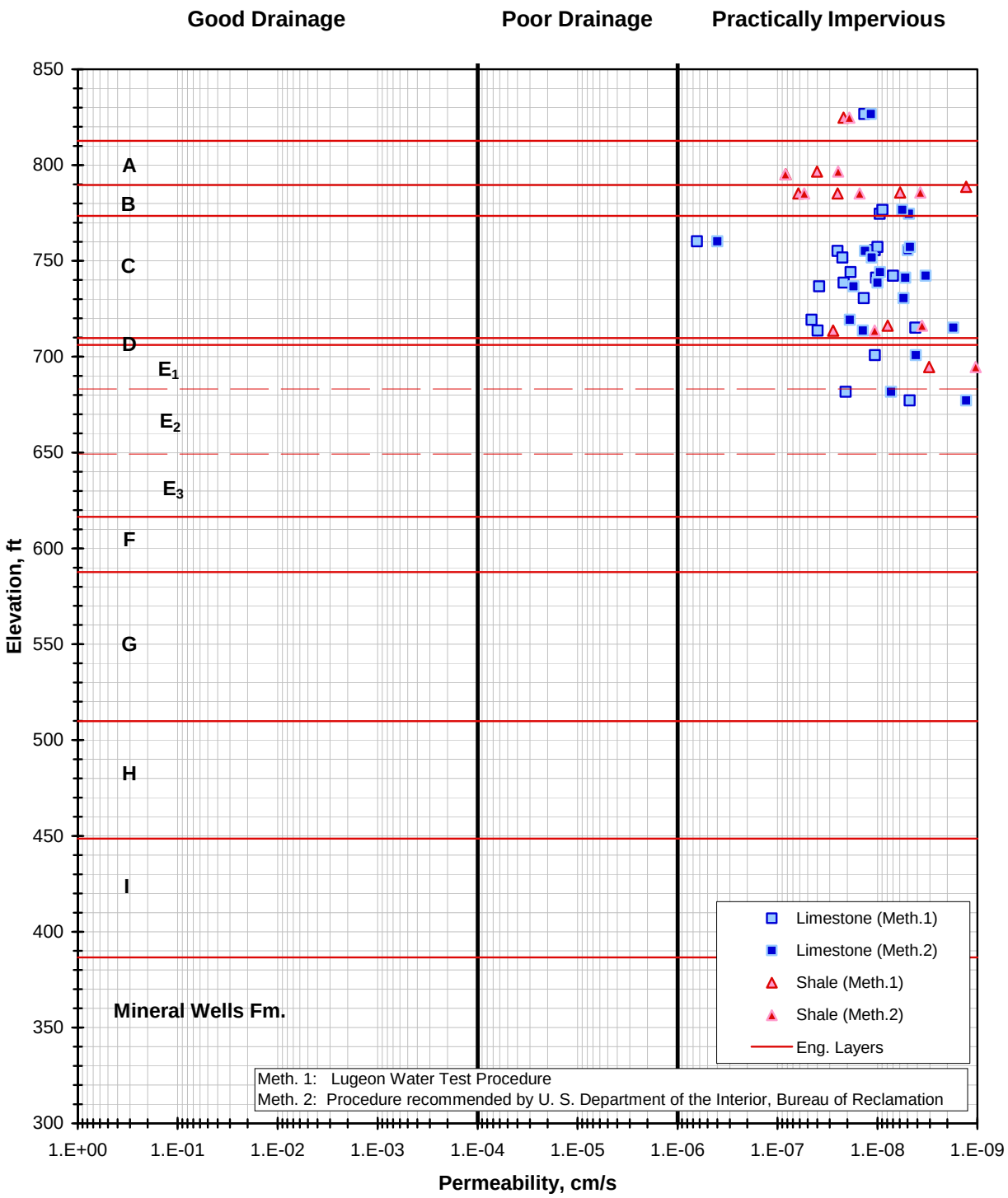
In Situ S- and P-Wave Velocity vs. Elevation

FIGURE 14



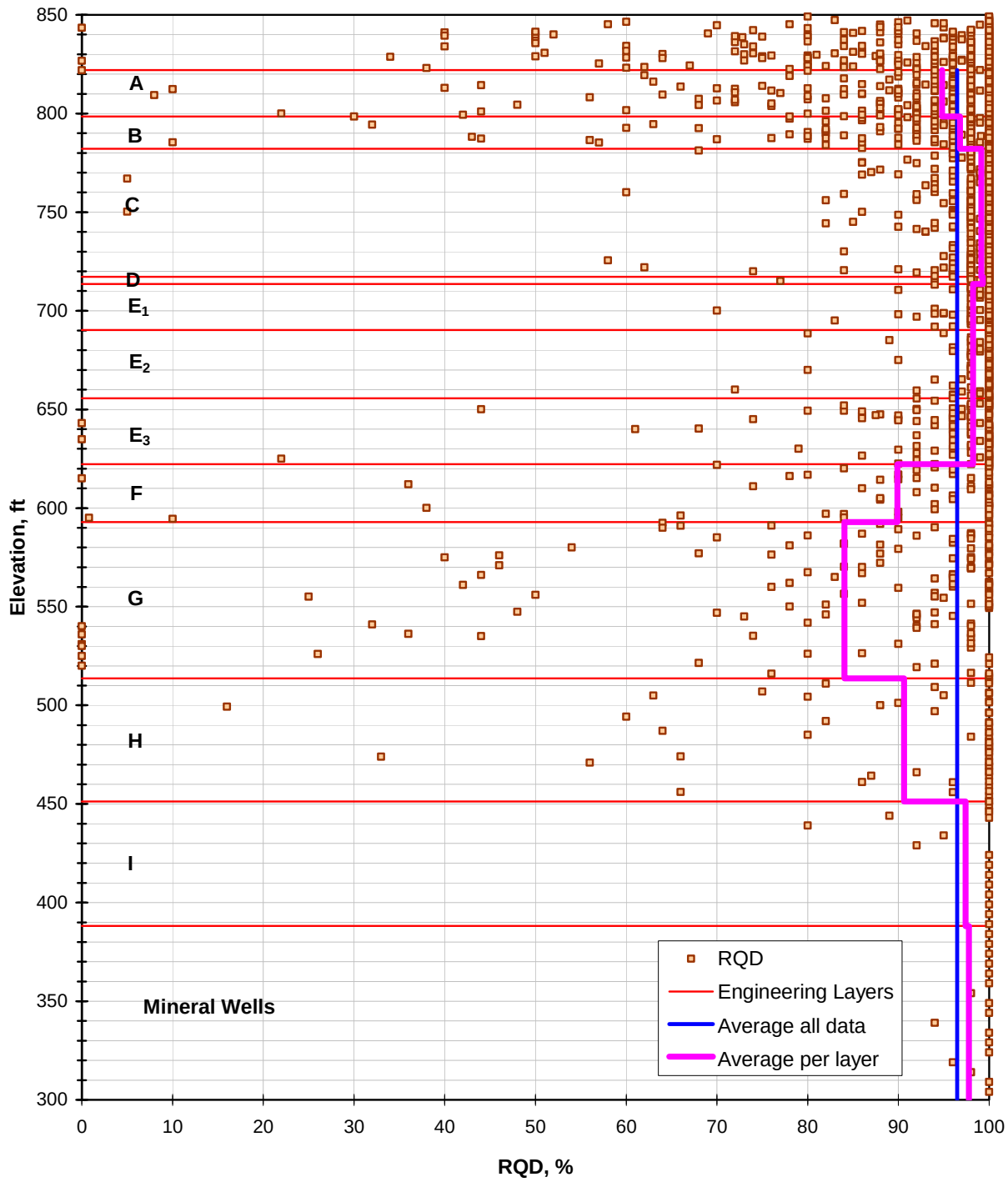
Shear Modulus vs. Elevation
Pressuremeter Tests

FIGURE 15



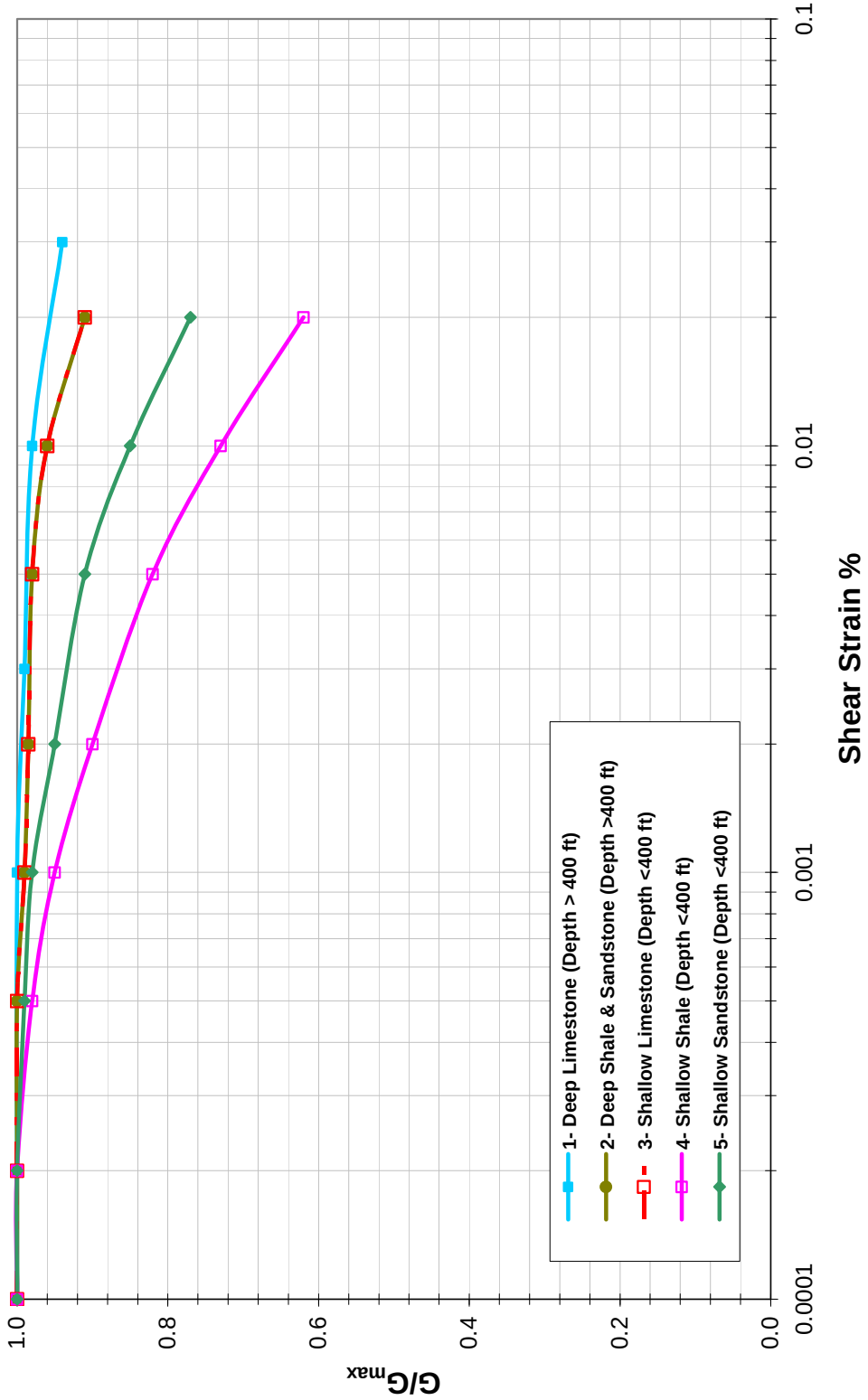
In Situ Packer Test Permeability vs. Elevation

FIGURE 16



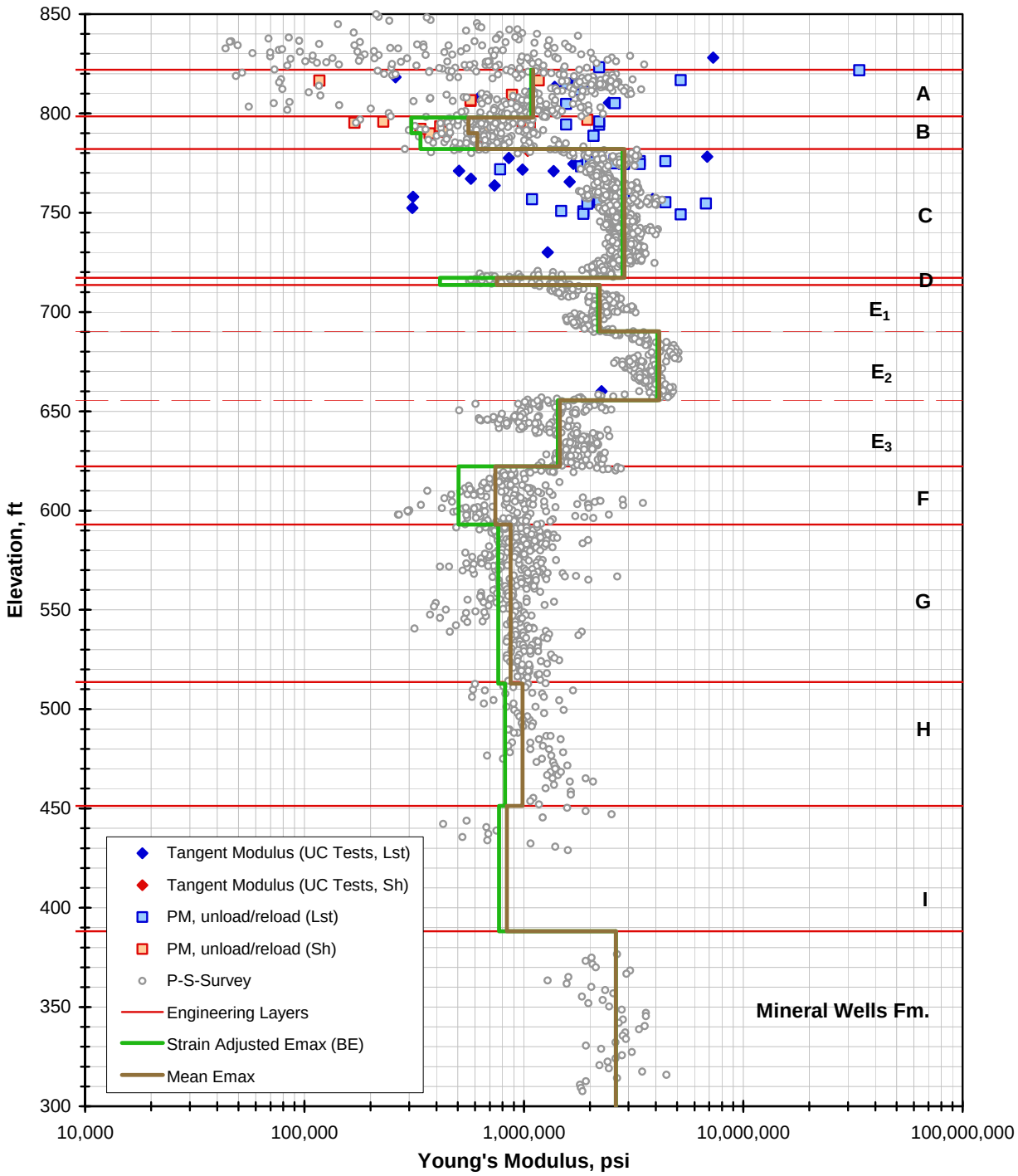
Rock Quality Designation vs. Elevation

FIGURE 17



G/G_{max} vs. Strain for Rock Materials

FIGURE 18



Young's Modulus vs. Elevation

FIGURE 19

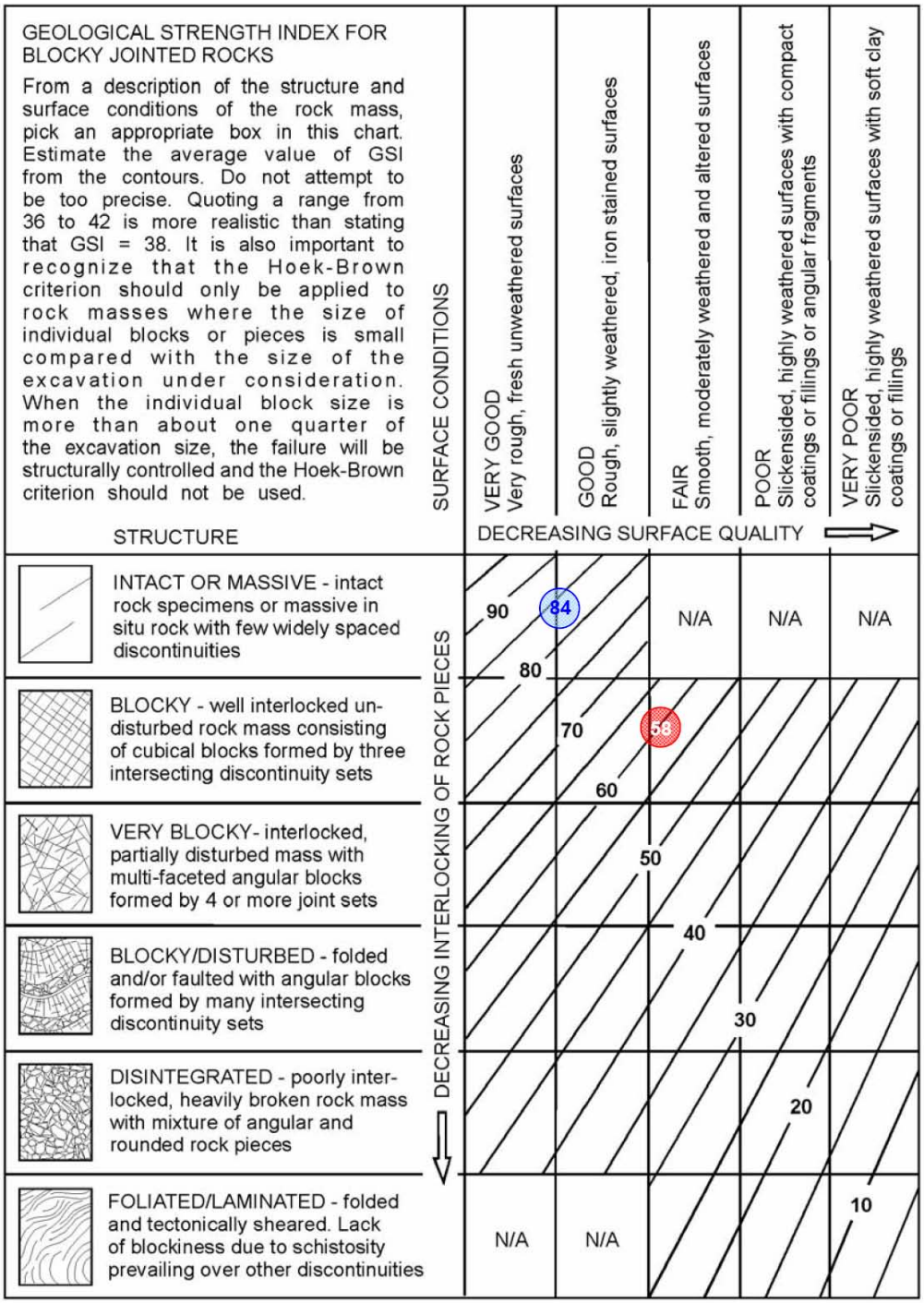
Rock Mass Rating System & Project Parameters

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS			ROCK MASS RATING SYSTEM (after Bieniawski 1989)							PROJECT PARAMETERS									
Parameter			Range of values							A	B	C	D	E	F	G	H	I	MW
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test												
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa	1 - 5 MPa	<1MPa	19	5	24	5	24	10	19	19	19	29
	Rating		15	12	7	4	2	1	0	2	1	2	1	2	2	2	2	2	4
2	Drill core Quality *RQD*		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%			85	80	95	80	95	95	90	95	99	99
	Rating		20	17	13	8	3			17	17	20	17	20	20	17	20	20	20
3	Spacing of discontinuities		> 2 m	0.6 - 2 m	200 - 600 mm	60 - 200 mm	< 60 mm			0.6 - 2 m	200 - 600 mm	0.6 - 2 m	200 - 600 mm	0.6 - 2 m	0.6 - 2 m	> 2 m	> 2 m	> 2 m	> 2 m
	Rating		20	15	10	8	5			15	10	15	10	15	15	20	20	20	20
4	Discontinuity length (persistence)		< 1 m	1 - 3 m	3 - 10 m	10 - 20 m	> 20 m			< 1 m	1 - 3 m	< 1 m	1 - 3 m	< 1 m	1 - 3 m	< 1 m	< 1 m	< 1 m	< 1 m
	Rating		6	4	2	1	0			6	4	6	4	6	4	6	6	6	6
	Separation (aperture)		None	< 0.1 mm	0.1 - 1.0 mm	1 - 5 mm	> 5 mm			< 0.1 mm	0.1 - 1 mm	< 0.1 mm	0.1 - 1 mm	< 0.1 mm	< 0.1 mm	none	< 0.1 mm	< 0.1 mm	none
	Rating		6	5	4	1	0			5	4	5	4	5	5	6	5	5	6
	Roughness		Very rough	Rough	Slightly rough	Smooth	Slickensided			rough	slightly rough	rough	slightly rough	rough	rough	very rough	rough	rough	very rough
	Rating		6	5	3	1	0			5	3	5	3	5	5	6	5	5	6
	Infilling (gouge)		None	Hard filling < 5 mm	Hard filling > 5 mm	Soft filling < 5 mm	Soft filling > 5 mm			None	Hard filling < 5 mm	None	Hard filling < 5 mm	None	Hard filling < 5 mm	None	Hard filling < 5 mm	None	None
	Rating		6	4	2	2	0			6	4	6	4	6	4	6	4	6	6
	Weathering		Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed			Slightly weathered	Slightly weathered	Slightly weathered	Slightly weathered	Slightly weathered	Slightly weathered	Unweathered	Unweathered	Unweathered	Unweathered
	Rating		6	5	3	1	0			5	5	5	5	5	5	6	6	6	6
	Condition of discontinuities (see following guidelines)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous			Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Very rough surfaces Not continuous No separation Unweathered wall rock	Very rough surfaces Not continuous No separation Unweathered wall rock
	Rating		30	25	20	10	0			27	20	27	20	27	23	30	26	28	30
5	Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125			None	None	None	None	None	None	None	None	None	None
		(Joint water press)/ (Major principal σ)	0	< 0.1	0.1 - 0.2	0.2 - 0.5	> 0.5			0	0	0	0	0	0	0	0	0	0
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing			Completely dry	Completely dry	Completely dry	Completely dry	Completely dry	Completely dry	Completely dry	Completely dry	Completely dry	Completely dry
	Rating		15	10	7	4	0			15	15	15	15	15	15	15	15	15	15
B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS			**RATING ADJUSTMENT GUIDELINES**																
			Strike perpendicular to tunnel axis		Strike parallel to tunnel axis														
			Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 -90°		Dip 20 -45°												
			Very favourable	Favourable	Very unfavourable		Fair												
			Drive against dip - Dip 45 - 90°	Drive against dip - Dip 20-45°	Dip 0-20 -Irrespective of strike°														
			Fair	Unfavourable	Fair														
Strike and dip orientations			Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable			Very favourable	Very favourable	Very favourable	Very favourable	Very favourable	Very favourable	Very favourable	Very favourable	Very favourable	Very favourable
Ratings		Tunnels & mines	0	-2	-5	-10	-12												
		Foundations	0	-2	-7	-15	-25			0	0	0	0	0	0	0	0	0	0
		Slopes	0	-5	-25	-50													

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS														
Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21	76	63	79	63	79	75	84	83	85	89
Class number	I	II	III	IV	V	II	II	II	II	II	II	I	I	I	I
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock	good	good	good	good	good	good	very good	very good	very good	very good

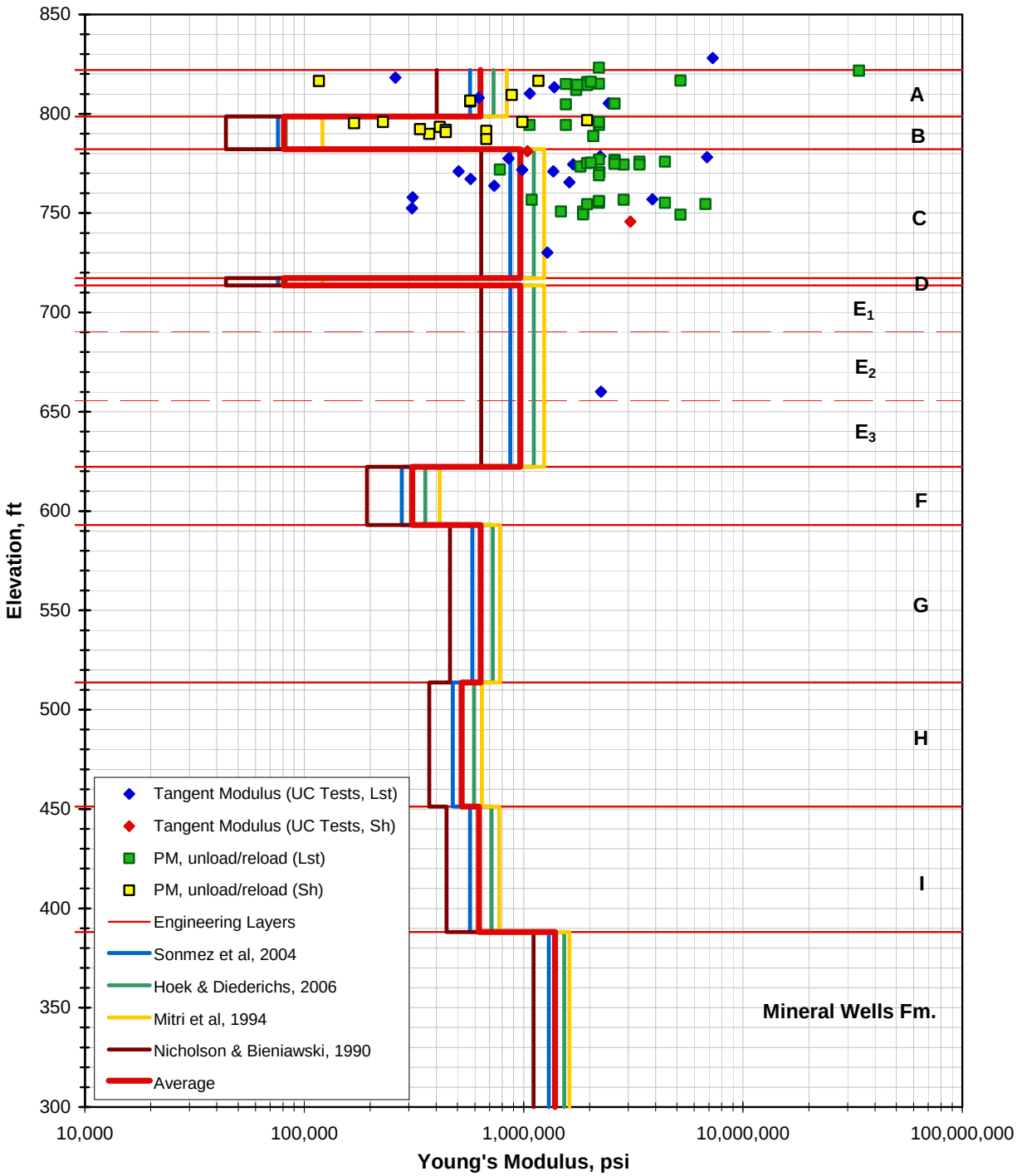
D. MEANING OF ROCK CLASSES (Typical Engineering Properties)							
Class number	I	II	III	IV	V	II	I
Average stand-up time	20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span	1 year for 10 m span	20 yrs for 15 m span
Cohesion of rock mass (kPa)	> 400	300 - 400	200 - 300	100 - 200	< 100	300 - 400 kPa (6.3 - 8.4 ksf)	> 400 kPa (>8.4 ksf)
Friction angle of rock mass (deg)	> 45	35 - 45	25 - 35	15 - 25	< 15	35 - 45	> 45

FIGURE 20



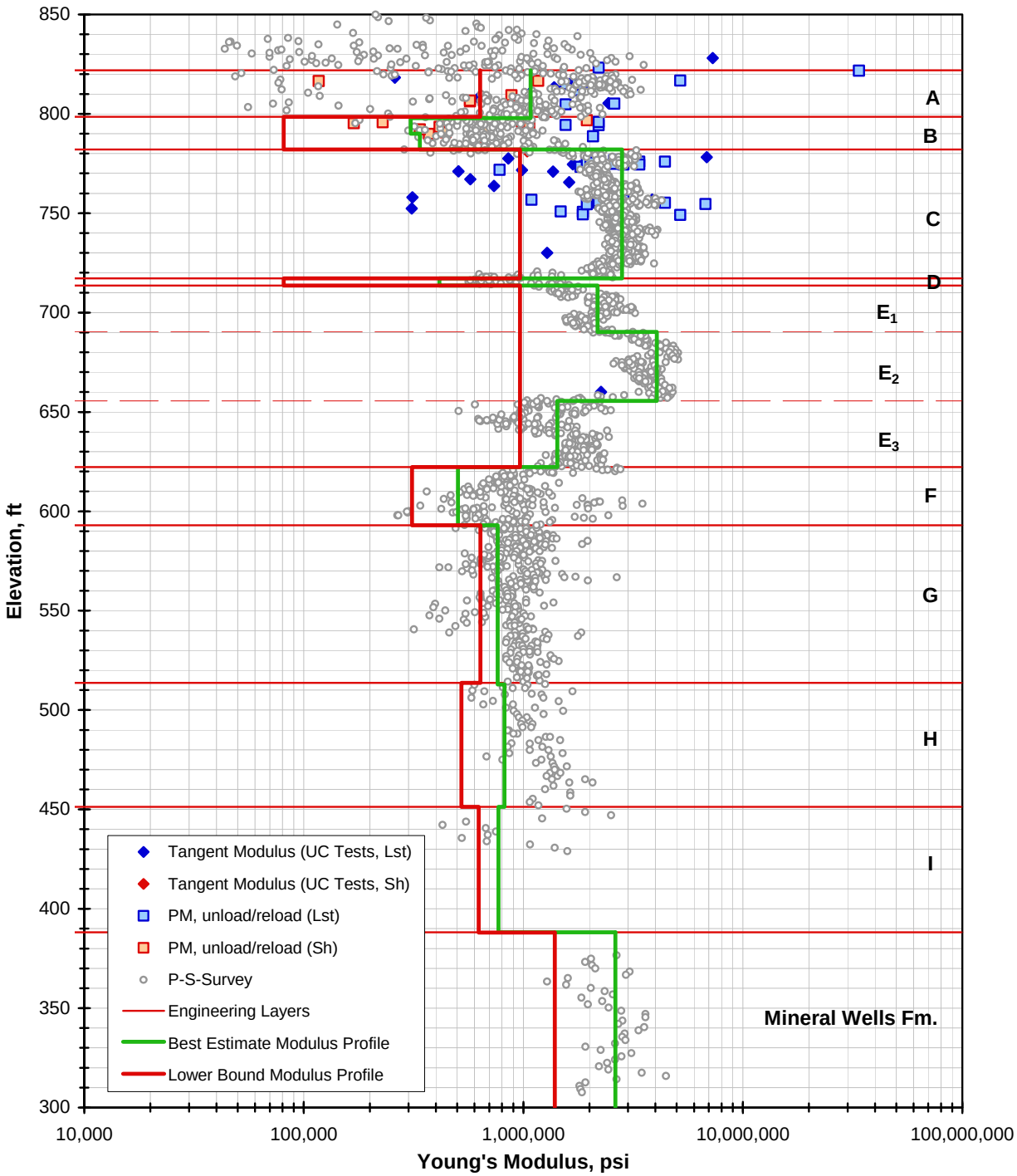
GSI Chart
(after Marinos and Hoek 2000)

FIGURE 21



Estimated Range of
Rock Mass Modulus (E_{rm}) vs. Elevation

FIGURE 22



Best Estimate & Lower Bound Modulus Models vs. Elevation

FIGURE 23

APPENDIX A

Settlement Calculations

Layered Method Using Best Estimated Rock Modulus (BERM) Model (Excel)
Pages 2 through 9
Layered Method Using Lower Bound Rock Modulus (LBRM) Model (Excel)
Pages 10 through 17
Non-Layered Method Using Best Estimated Rock Modulus (BERM) Model (Excel)
Pages 18 through 27
Non-Layered Method Using Lower Bound Rock Modulus (LBRM) Model (Excel)
Pages 28 through 37
Layered Method Using Best Estimated Rock Modulus (BERM) Model (Mathcad)
Pages 38 through 45
Layered Method Using Lower Bound Rock Modulus (LBRM) Model (Mathcad)
Pages 46 through 53
Non-Layered Method Using Best Estimated Rock Modulus (BERM) Model (Mathcad)
Pages 54 through 59
Non-Layered Method Using Lower Bound Rock Modulus (LBRM) Model (Mathcad)
Pages 60 through 65

SETTLEMENT ANALYSIS FOR ELASTIC MATERIALS-Layered Method, Berm Model

METHODOLOGY

This worksheet has been developed to calculate elastic settlement induced by foundation pressure. The soils supporting foundations are considered as layered elastic medium and the stress increment at each layer center due to a rectanglar uniformly loaded area at or below ground surface is computed by classic Boussinesq solution. The settlement for each layer is calculated using the vertical stress increment and elastic modulus of the layer, and total settlement is obtained by summing all layer settlements in the influenced zone.

Stress Increment:

The equation of Boussinesq solution to compute the stress increment under the corner of a rectanglar loaded area are shown as below. When the stress calculation point is not located under the corner of a given loaded area, superposition of rectanglar areas covering the loaded surface and stress calculation point are used to calculate the stress.

Boussinesq Solution:

$$\sigma_z = \frac{q}{4\pi}\left[\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+m^2n^2+1}\frac{m^2+n^2+2}{m^2+n^2+1}+\sin^{-1}\left(\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+m^2n^2+1}\right)\right]$$

where q is load intensity, m=L/Z, N=B/Z, and B, L and Z are foundation width, length and stress point depth, respectively. The angle in second term in the parenthesis is less than pi /2 when m2+n2+1>m2n2, otherwise between pi /2 and pi .

Settlement Calculation:

The settlement in a given layer is calculated by an equation shown as below.

$$S_i = \Delta\sigma_{zi} H_i \frac{1-\mu_i^2}{E_i}$$

where H, E and m are layer thickness, modulus and poisson ratio, respectively.

Total Settlement:

$$S = \sum_{i=1}^{n} S_i$$

where n is number of the total layeres influenced by foundation pressures

SUMMARY OF INPUT

Number of Loaded Areas= 9 **Number of Soil Layers=** 25 **Number of Settlement Points=** 22

Poisson's Ratio= 0.30 **Stress distribution code=** 1 **Depth of Grondwater Table=** 50 FT

LOAD UNIT ID	LOAD INTENSITY KSF	EMBEDED DEPTH FT	LOAD UNIT CORNER COORDINATES (FT) X1	Y1	X2	Y2	X3	Y3	X4	Y4
1	11.3	40.0	300.0	333.0	609.0	333.0	609.0	546.0	300.0	546.0
2	6.8	40.0	300.0	200.0	539.0	200.0	539.0	333.0	300.0	333.0
3	5.9	40.0	629.0	376.0	944.0	376.0	944.0	562.0	629.0	562.0
4	4.3	40.0	539.0	546.0	609.0	546.0	609.0	661.0	539.0	661.0
5	4.3	40.0	539.0	218.0	609.0	218.0	609.0	333.0	539.0	333.0
6	3.6	40.0	39.0	431.0	170.0	431.0	170.0	693.0	39.0	693.0
7	3.6	40.0	39.0	87.0	170.0	87.0	170.0	349.0	39.0	349.0
8	5.4	40.0	635.0	582.0	713.0	582.0	713.0	667.0	635.0	667.0
9	5.4	40.0	635.0	175.0	713.0	175.0	713.0	260.0	635.0	260.0

SETTLEMENT POINT COORDINATES

ID	X	Y	ID	X	Y
1	300.0	200.0	2	300.0	333.0
3	300.0	546.0	4	419.5	266.5
5	454.5	439.5	6	539.0	200.0
7	539.0	333.0	8	574.0	275.5
9	574.0	603.5	10	609.0	333.0
11	609.0	546.0	12	674.0	217.5
13	629.0	376.0	14	629.0	562.0
15	674.0	624.5	16	786.5	469.0
17	944.0	376.0	18	944.0	562.0
19	104.5	152.5	20	104.5	283.5
21	104.5	496.5	22	104.5	627.5

LAYER COMPRESSIBILITY

LAYER ID	DEPTH FT	THICKNESS FT	MODULUS KSF	LAYER ID	DEPTH FT	THICKNESS FT	MODULUS KSF
1	3.00	6.00	155548	2	15.00	18.00	155548
3	28.00	8.00	44263	4	36.00	8.00	48648
5	50.00	20.00	405550	6	70.00	20.00	405550
7	92.50	25.00	405550	8	107.00	4.00	59688
9	120.50	23.00	313510	10	149.00	34.00	585033
11	183.00	34.00	205856	12	214.50	29.00	72539
13	239.00	20.00	110220	14	264.00	30.00	110220
15	294.00	30.00	110220	16	324.00	30.00	117959
17	355.00	32.00	117959	18	386.00	30.00	110901
19	417.50	33.00	110901	20	463.00	58.00	378268
21	542.00	100.00	378268	22	642.00	100.00	378268
23	742.00	100.00	378268	24	842.00	100.00	378268
25	942.00	100.00	378268				

CALCULATION RESULTS

Stress Distribution: Bossinesq Solution

Depth (FT)	Stress Increment Contributed by All Loaded Areas at Each Settlement Point, KSF																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50.00	1.69	4.52	2.83	6.77	11.32	1.75	8.43	4.31	4.28	3.91	4.01	5.33	1.69	1.61	5.33	5.86	1.46	1.46	3.60	3.60	3.60	3.60
70.00	1.70	4.52	2.83	6.71	11.23	2.09	8.32	4.25	3.89	4.00	4.65	4.51	3.25	2.80	4.61	5.79	1.46	1.46	3.45	3.46	3.46	3.45
92.50	1.74	4.49	2.85	6.51	10.90	2.33	7.99	4.22	3.47	4.21	5.02	3.24	4.30	3.75	3.56	5.54	1.46	1.46	3.04	3.06	3.06	3.04
107.00	1.78	4.46	2.86	6.32	10.56	2.42	7.71	4.22	3.35	4.34	5.08	2.65	4.62	4.04	3.11	5.30	1.45	1.45	2.72	2.76	2.77	2.72
120.50	1.82	4.42	2.88	6.12	10.16	2.48	7.43	4.21	3.29	4.44	5.06	2.28	4.78	4.17	2.85	5.05	1.43	1.43	2.44	2.51	2.51	2.44
149.00	1.92	4.29	2.90	5.65	9.18	2.57	6.82	4.16	3.25	4.52	4.89	1.89	4.88	4.19	2.57	4.50	1.40	1.40	1.95	2.08	2.09	1.96
183.00	2.02	4.09	2.89	5.09	7.97	2.61	6.13	4.01	3.20	4.45	4.58	1.76	4.76	4.02	2.44	3.91	1.35	1.35	1.56	1.76	1.78	1.57
214.50	2.07	3.86	2.84	4.61	6.95	2.59	5.54	3.83	3.12	4.27	4.26	1.77	4.53	3.79	2.38	3.46	1.30	1.30	1.34	1.60	1.62	1.35
239.00	2.08	3.67	2.78	4.26	6.24	2.56	5.11	3.66	3.03	4.09	4.00	1.79	4.31	3.59	2.32	3.17	1.27	1.25	1.22	1.52	1.54	1.24
264.00	2.07	3.47	2.70	3.95	5.60	2.50	4.70	3.48	2.93	3.88	3.75	1.81	4.07	3.40	2.27	2.92	1.23	1.21	1.14	1.46	1.48	1.16
294.00	2.04	3.24	2.59	3.60	4.94	2.42	4.26	3.26	2.78	3.61	3.47	1.81	3.77	3.16	2.19	2.67	1.19	1.17	1.07	1.40	1.43	1.09
324.00	1.98	3.01	2.47	3.29	4.38	2.32	3.86	3.05	2.64	3.35	3.20	1.80	3.48	2.94	2.10	2.45	1.15	1.12	1.02	1.36	1.39	1.05
355.00	1.91	2.78	2.33	3.01	3.89	2.21	3.50	2.83	2.48	3.09	2.94	1.76	3.20	2.73	2.00	2.26	1.11	1.08	0.99	1.32	1.35	1.02
386.00	1.83	2.57	2.20	2.75	3.48	2.09	3.17	2.63	2.33	2.85	2.71	1.72	2.93	2.53	1.91	2.09	1.07	1.04	0.96	1.28	1.30	1.00
417.50	1.74	2.38	2.07	2.53	3.12	1.98	2.88	2.43	2.18	2.62	2.49	1.66	2.69	2.34	1.81	1.93	1.04	1.00	0.94	1.24	1.26	0.97
463.00	1.62	2.12	1.88	2.24	2.69	1.82	2.51	2.18	1.97	2.32	2.21	1.56	2.37	2.09	1.66	1.74	0.99	0.95	0.91	1.17	1.20	0.94
542.00	1.41	1.75	1.60	1.83	2.12	1.56	2.02	1.80	1.66	1.90	1.82	1.38	1.92	1.73	1.44	1.46	0.90	0.86	0.85	1.06	1.08	0.88
642.00	1.17	1.40	1.30	1.45	1.62	1.28	1.56	1.43	1.34	1.49	1.44	1.17	1.50	1.38	1.19	1.19	0.80	0.77	0.77	0.93	0.94	0.80
742.00	0.98	1.13	1.07	1.16	1.28	1.06	1.24	1.16	1.10	1.19	1.15	0.98	1.20	1.12	0.99	0.99	0.71	0.68	0.69	0.80	0.82	0.71
842.00	0.83	0.93	0.89	0.95	1.03	0.88	1.00	0.95	0.91	0.97	0.94	0.83	0.97	0.92	0.83	0.82	0.62	0.60	0.61	0.70	0.71	0.63
942.00	0.70	0.77	0.75	0.79	0.84	0.74	0.82	0.79	0.76	0.80	0.78	0.70	0.80	0.77	0.71	0.70	0.55	0.53	0.54	0.61	0.61	0.56

Appendix A

SETTLEMENT DISTRIBUTION (INCHES)

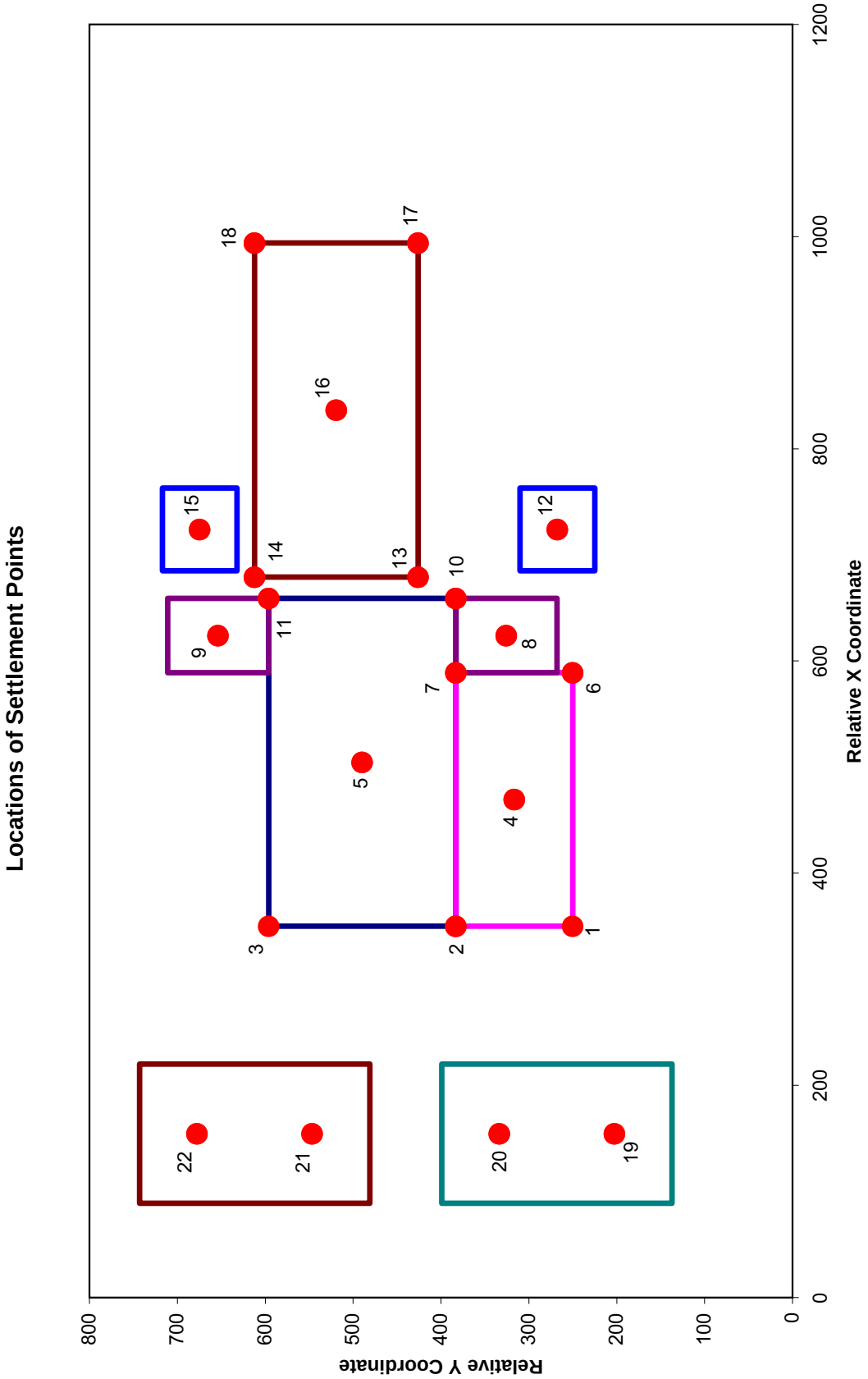
Settle Point / Layer ID	Settlement Contributed by All Loaded Areas for Each Layer at Each Settlement Point																					
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
12	0.01	0.02	0.01	0.02	0.03	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
13	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
14	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
15	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
16	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
17	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
18	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
19	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**0.08**	**0.12**	**0.10**	**0.14**	**0.20**	**0.09**	**0.17**	**0.12**	**0.10**	**0.13**	**0.13**	**0.08**	**0.14**	**0.12**	**0.09**	**0.11**	**0.05**	**0.05**	**0.05**	**0.06**	**0.06**	**0.05**

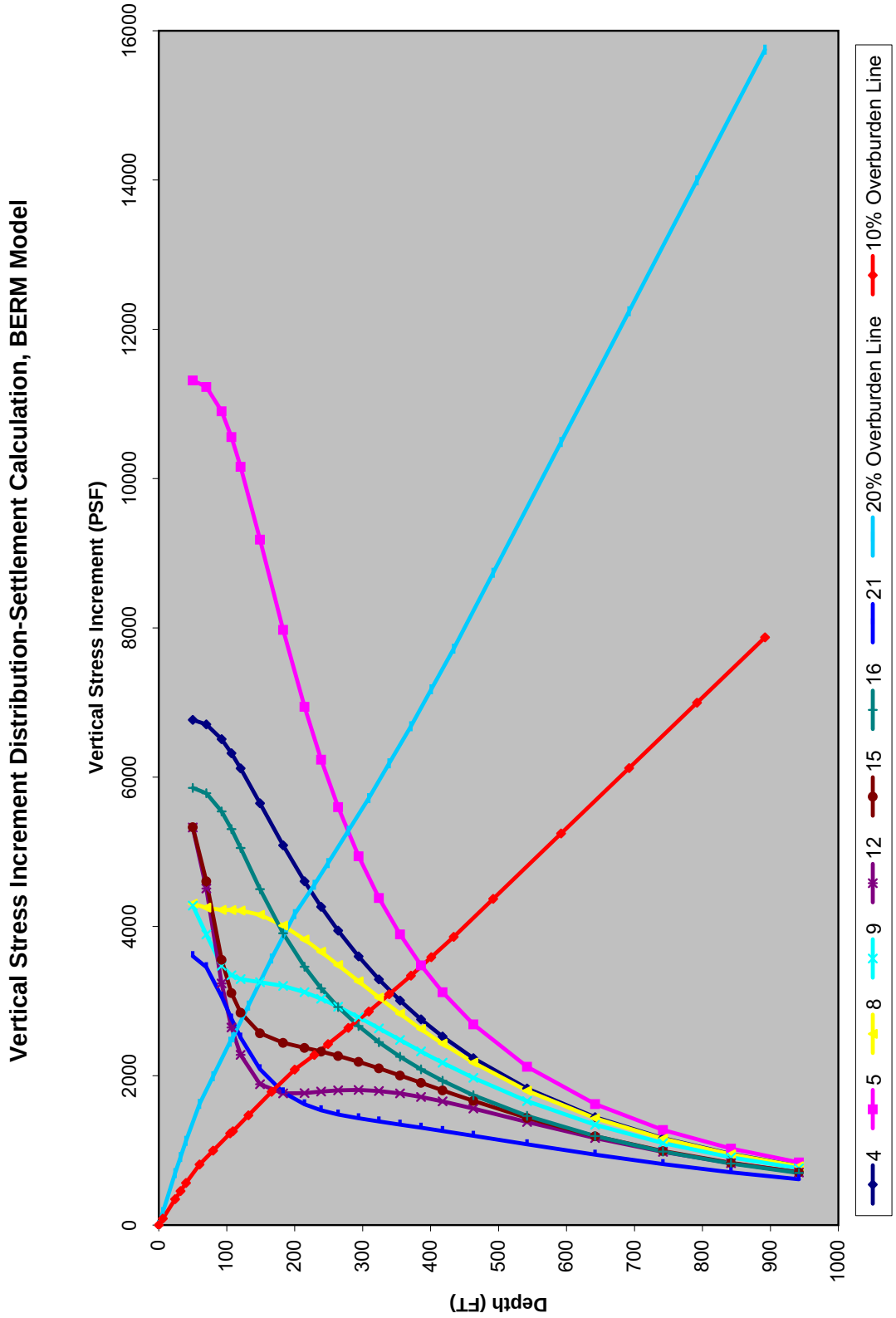
Appendix A

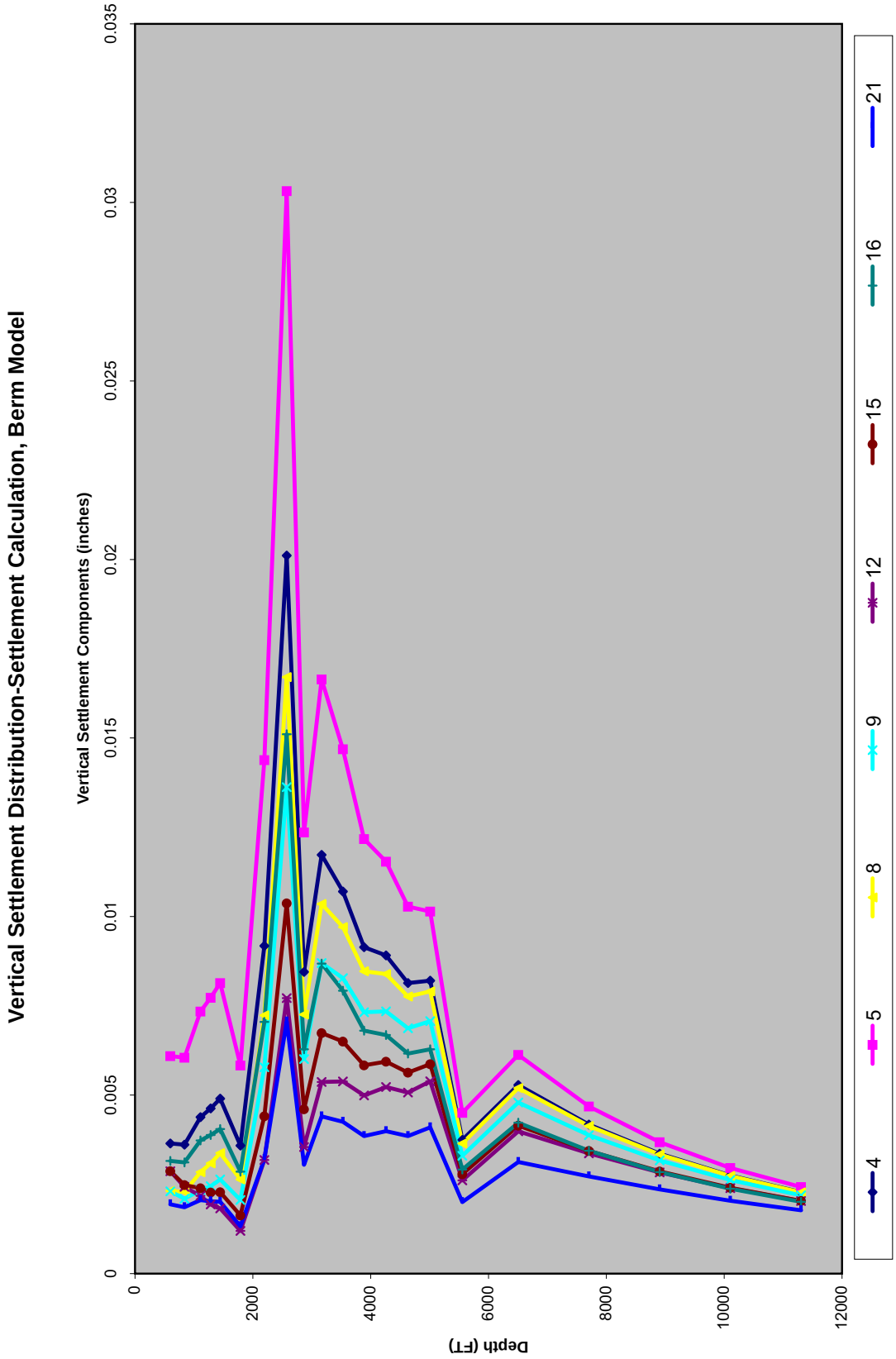
SUMMARY OF SETTLEMENT

Settlement Point	X	Y	Settlement Inches	Settlement Point	X	Y	Settlement Inches
1	300.0	200.0	**0.08**	**2**	300.0	333.0	**0.12**
3	300.0	546.0	**0.10**	**4**	419.5	266.5	**0.14**
5	454.5	439.5	**0.20**	**6**	539.0	200.0	**0.09**
7	539.0	333.0	**0.17**	**8**	574.0	275.5	**0.12**
9	574.0	603.5	**0.10**	**10**	609.0	333.0	**0.13**
11	609.0	546.0	**0.13**	**12**	674.0	217.5	**0.08**
13	629.0	376.0	**0.14**	**14**	629.0	562.0	**0.12**
15	674.0	624.5	**0.09**	**16**	786.5	469.0	**0.11**
17	944.0	376.0	**0.05**	**18**	944.0	562.0	**0.05**
19	104.5	152.5	**0.05**	**20**	104.5	283.5	**0.06**
21	104.5	496.5	**0.06**	**22**	104.5	627.5	**0.05**

Appendix A


Locations of Settlement Points
Relative Y Coordinate
Relative X Coordinate
0
100
200
300
400
500
600
700
800
0
200
400
600
800
1000
1200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22


Vertical Stress Increment Distribution-Settlement Calculation, BERM Model
Vertical Stress Increment (PSF)
0
2000
4000
6000
8000
10000
12000
14000
16000
Depth (FT)
0
100
200
300
400
500
600
700
800
900
1000
4
5
8
9
12
15
16
21
20% Overburden Line
10% Overburden Line


Vertical Settlement Distribution-Settlement Calculation, Berm Model
Vertical Settlement Components (inches)
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
Depth (FT)
0
2000
4000
6000
8000
10000
12000
4
5
8
9
12
15
16
21

SETTLEMENT ANALYSIS FOR ELASTIC MATERIALS-Layered Method,Lbrm Model

METHODOLOGY

This worksheet has been developed to calculate elastic settlement induced by foundation pressure. The soils supporting foundations are considered as layered elastic medium and the stress increment at each layer center due to a rectanglar uniformly loaded area at or below ground surface is computed by classic Boussinesq solution. The settlement for each layer is calculated using the vertical stress increment and elastic modulus of the layer, and total settlement is obtained by summing all layer settlements in the influenced zone.

Stress Increment:

The equation of Boussinesq solution to compute the stress increment under the corner of a rectanglar loaded area are shown as below. When the stress calculation point is not located under the corner of a given loaded area, superposition of rectanglar areas covering the loaded surface and stress calculation point are used to calculate the stress.

Boussinesq Solution:

$$\sigma_z = \frac{q}{4\pi}\left[\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+m^2n^2+1}\frac{m^2+n^2+2}{m^2+n^2+1}+\sin^{-1}\left(\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+m^2n^2+1}\right)\right]$$

where q is load intensity, m=L/Z, N=B/Z, and B, L and Z are foundation width, length and stress point depth, respectively. The angle in second term in the parenthesis is less than pi /2 when m2+n2+1>m2n2, otherwise between pi /2 and pi .

Settlement Calculation:

The settlement in a given layer is calculated by an equation shown as below.

$$S_i = \Delta\sigma_{zi} H_i \frac{1-\mu_i^2}{E_i}$$

where H, E and m are layer thickness, modulus and poisson ratio, respectively.

Total Settlement:

$$S = \sum_{i=1}^{n} S_i$$

where n is number of the total layeres influenced by foundation pressures

SUMMARY OF INPUT

Number of Loaded Areas= 9 **Number of Soil Layers=** 25 **Number of Settlement Points=** 22

Poisson's Ratio= 0.30 **Stress distribution code=** 1 **Depth of Grondwater Table=** 50 FT

LOAD UNIT ID	LOAD INTENSITY KSF	EMBEDED DEPTH FT	LOAD UNIT CORNER COORDINATES (FT) X1	Y1	X2	Y2	X3	Y3	X4	Y4
1	11.3	40.0	300.0	333.0	609.0	333.0	609.0	546.0	300.0	546.0
2	6.8	40.0	300.0	200.0	539.0	200.0	539.0	333.0	300.0	333.0
3	5.9	40.0	629.0	376.0	944.0	376.0	944.0	562.0	629.0	562.0
4	4.3	40.0	539.0	546.0	609.0	546.0	609.0	661.0	539.0	661.0
5	4.3	40.0	539.0	218.0	609.0	218.0	609.0	333.0	539.0	333.0
6	3.6	40.0	39.0	431.0	170.0	431.0	170.0	693.0	39.0	693.0
7	3.6	40.0	39.0	87.0	170.0	87.0	170.0	349.0	39.0	349.0
8	5.4	40.0	635.0	582.0	713.0	582.0	713.0	667.0	635.0	667.0
9	5.4	40.0	635.0	175.0	713.0	175.0	713.0	260.0	635.0	260.0

SETTLEMENT POINT COORDINATES

ID	X	Y	ID	X	Y
1	300.0	200.0	2	300.0	333.0
3	300.0	546.0	4	419.5	266.5
5	454.5	439.5	6	539.0	200.0
7	539.0	333.0	8	574.0	275.5
9	574.0	603.5	10	609.0	333.0
11	609.0	546.0	12	674.0	217.5
13	629.0	376.0	14	629.0	562.0
15	674.0	624.5	16	786.5	469.0
17	944.0	376.0	18	944.0	562.0
19	104.5	152.5	20	104.5	283.5
21	104.5	496.5	22	104.5	627.5

LAYER COMPRESSIBILITY

LAYER ID	DEPTH FT	THICKNESS FT	MODULUS KSF	LAYER ID	DEPTH FT	THICKNESS FT	MODULUS KSF
1	3.00	6.00	91508	2	15.00	18.00	91508
3	28.00	8.00	11650	4	36.00	8.00	11650
5	50.00	20.00	139212	6	70.00	20.00	139212
7	92.50	25.00	139212	8	107.00	4.00	11650
9	120.50	23.00	139212	10	149.00	34.00	139212
11	183.00	34.00	139212	12	214.50	29.00	44754
13	239.00	20.00	91866	14	264.00	30.00	91866
15	294.00	30.00	91866	16	324.00	30.00	75174
17	355.00	32.00	75174	18	386.00	30.00	90209
19	417.50	33.00	90209	20	463.00	58.00	200298
21	542.00	100.00	200298	22	642.00	100.00	200298
23	742.00	100.00	200298	24	842.00	100.00	200298
25	942.00	100.00	200298				

CALCULATION RESULTS

Stress Distribution: Bossinesq Solution

Depth (FT)	Stress Increment Contributed by All Loaded Areas at Each Settlement Point, KSF																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50.00	1.69	4.52	2.83	6.77	11.32	1.75	8.43	4.31	4.28	3.91	4.01	5.33	1.69	1.61	5.33	5.86	1.46	1.46	3.60	3.60	3.60	3.60
70.00	1.70	4.52	2.83	6.71	11.23	2.09	8.32	4.25	3.89	4.00	4.65	4.51	3.25	2.80	4.61	5.79	1.46	1.46	3.45	3.46	3.46	3.45
92.50	1.74	4.49	2.85	6.51	10.90	2.33	7.99	4.22	3.47	4.21	5.02	3.24	4.30	3.75	3.56	5.54	1.46	1.46	3.04	3.06	3.06	3.04
107.00	1.78	4.46	2.86	6.32	10.56	2.42	7.71	4.22	3.35	4.34	5.08	2.65	4.62	4.04	3.11	5.30	1.45	1.45	2.72	2.76	2.77	2.72
120.50	1.82	4.42	2.88	6.12	10.16	2.48	7.43	4.21	3.29	4.44	5.06	2.28	4.78	4.17	2.85	5.05	1.43	1.43	2.44	2.51	2.51	2.44
149.00	1.92	4.29	2.90	5.65	9.18	2.57	6.82	4.16	3.25	4.52	4.89	1.89	4.88	4.19	2.57	4.50	1.40	1.40	1.95	2.08	2.09	1.96
183.00	2.02	4.09	2.89	5.09	7.97	2.61	6.13	4.01	3.20	4.45	4.58	1.76	4.76	4.02	2.44	3.91	1.35	1.35	1.56	1.76	1.78	1.57
214.50	2.07	3.86	2.84	4.61	6.95	2.59	5.54	3.83	3.12	4.27	4.26	1.77	4.53	3.79	2.38	3.46	1.30	1.30	1.34	1.60	1.62	1.35
239.00	2.08	3.67	2.78	4.26	6.24	2.56	5.11	3.66	3.03	4.09	4.00	1.79	4.31	3.59	2.32	3.17	1.27	1.25	1.22	1.52	1.54	1.24
264.00	2.07	3.47	2.70	3.95	5.60	2.50	4.70	3.48	2.93	3.88	3.75	1.81	4.07	3.40	2.27	2.92	1.23	1.21	1.14	1.46	1.48	1.16
294.00	2.04	3.24	2.59	3.60	4.94	2.42	4.26	3.26	2.78	3.61	3.47	1.81	3.77	3.16	2.19	2.67	1.19	1.17	1.07	1.40	1.43	1.09
324.00	1.98	3.01	2.47	3.29	4.38	2.32	3.86	3.05	2.64	3.35	3.20	1.80	3.48	2.94	2.10	2.45	1.15	1.12	1.02	1.36	1.39	1.05
355.00	1.91	2.78	2.33	3.01	3.89	2.21	3.50	2.83	2.48	3.09	2.94	1.76	3.20	2.73	2.00	2.26	1.11	1.08	0.99	1.32	1.35	1.02
386.00	1.83	2.57	2.20	2.75	3.48	2.09	3.17	2.63	2.33	2.85	2.71	1.72	2.93	2.53	1.91	2.09	1.07	1.04	0.96	1.28	1.30	1.00
417.50	1.74	2.38	2.07	2.53	3.12	1.98	2.88	2.43	2.18	2.62	2.49	1.66	2.69	2.34	1.81	1.93	1.04	1.00	0.94	1.24	1.26	0.97
463.00	1.62	2.12	1.88	2.24	2.69	1.82	2.51	2.18	1.97	2.32	2.21	1.56	2.37	2.09	1.66	1.74	0.99	0.95	0.91	1.17	1.20	0.94
542.00	1.41	1.75	1.60	1.83	2.12	1.56	2.02	1.80	1.66	1.90	1.82	1.38	1.92	1.73	1.44	1.46	0.90	0.86	0.85	1.06	1.08	0.88
642.00	1.17	1.40	1.30	1.45	1.62	1.28	1.56	1.43	1.34	1.49	1.44	1.17	1.50	1.38	1.19	1.19	0.80	0.77	0.77	0.93	0.94	0.80
742.00	0.98	1.13	1.07	1.16	1.28	1.06	1.24	1.16	1.10	1.19	1.15	0.98	1.20	1.12	0.99	0.99	0.71	0.68	0.69	0.80	0.82	0.71
842.00	0.83	0.93	0.89	0.95	1.03	0.88	1.00	0.95	0.91	0.97	0.94	0.83	0.97	0.92	0.83	0.82	0.62	0.60	0.61	0.70	0.71	0.63
942.00	0.70	0.77	0.75	0.79	0.84	0.74	0.82	0.79	0.76	0.80	0.78	0.70	0.80	0.77	0.71	0.70	0.55	0.53	0.54	0.61	0.61	0.56

Appendix A

SETTLEMENT DISTRIBUTION (INCHES)

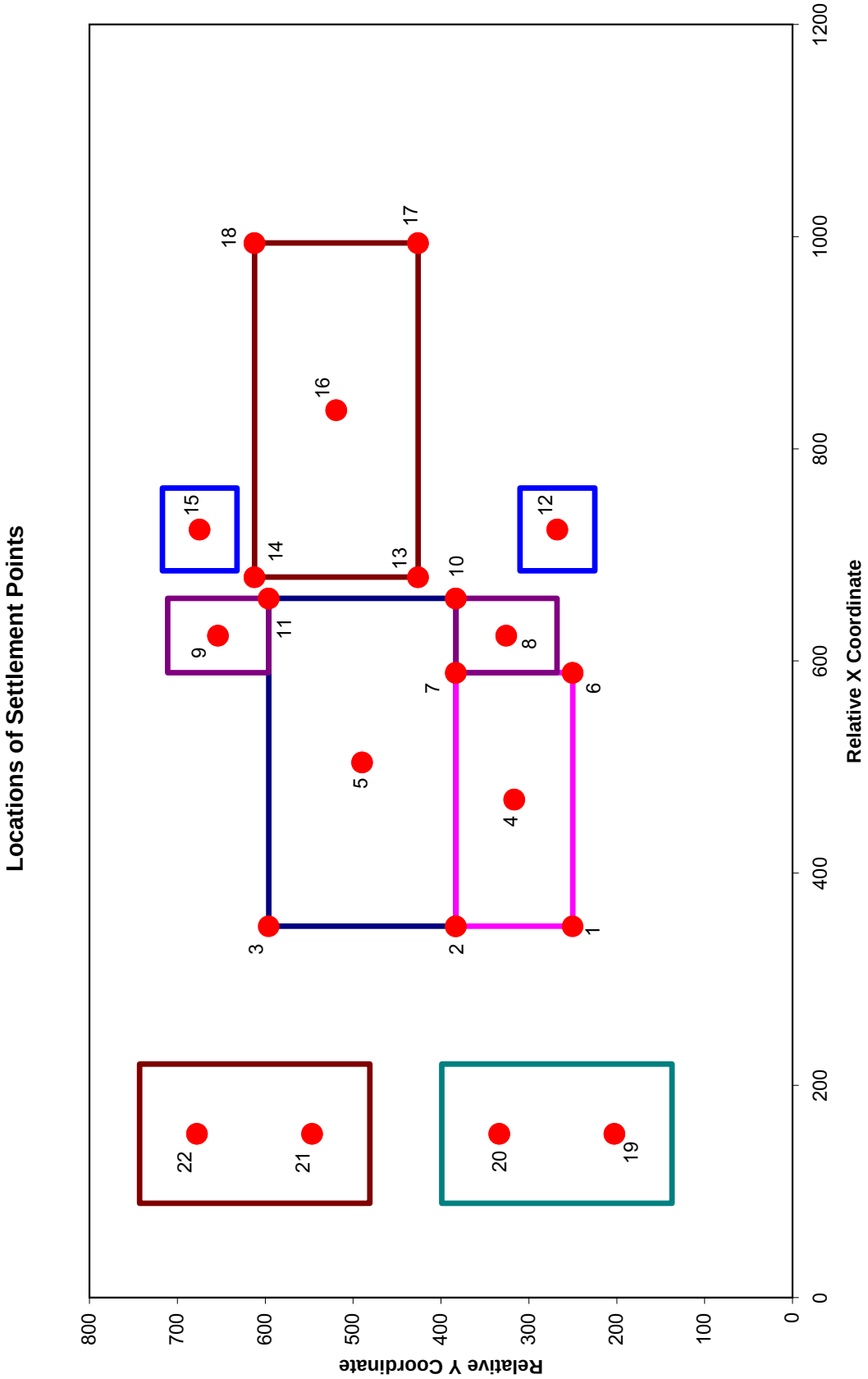
Settle Point Layer ID	Settlement Contributed by All Loaded Areas for Each Layer at Each Settlement Point																					
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.01	0.00	0.01	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01
6	0.00	0.01	0.00	0.01	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01
7	0.00	0.01	0.01	0.01	0.02	0.00	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01
8	0.01	0.02	0.01	0.02	0.04	0.01	0.03	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
9	0.00	0.01	0.01	0.01	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
10	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01
11	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
12	0.01	0.03	0.02	0.03	0.05	0.02	0.04	0.03	0.02	0.03	0.03	0.01	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
13	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
14	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.00
15	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.00
16	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.00
17	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00
18	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
19	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00
20	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
21	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.00
22	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.00
23	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**0.13**	**0.21**	**0.17**	**0.26**	**0.37**	**0.15**	**0.30**	**0.21**	**0.18**	**0.23**	**0.23**	**0.14**	**0.23**	**0.20**	**0.16**	**0.20**	**0.08**	**0.08**	**0.10**	**0.11**	**0.12**	**0.10**

Appendix A

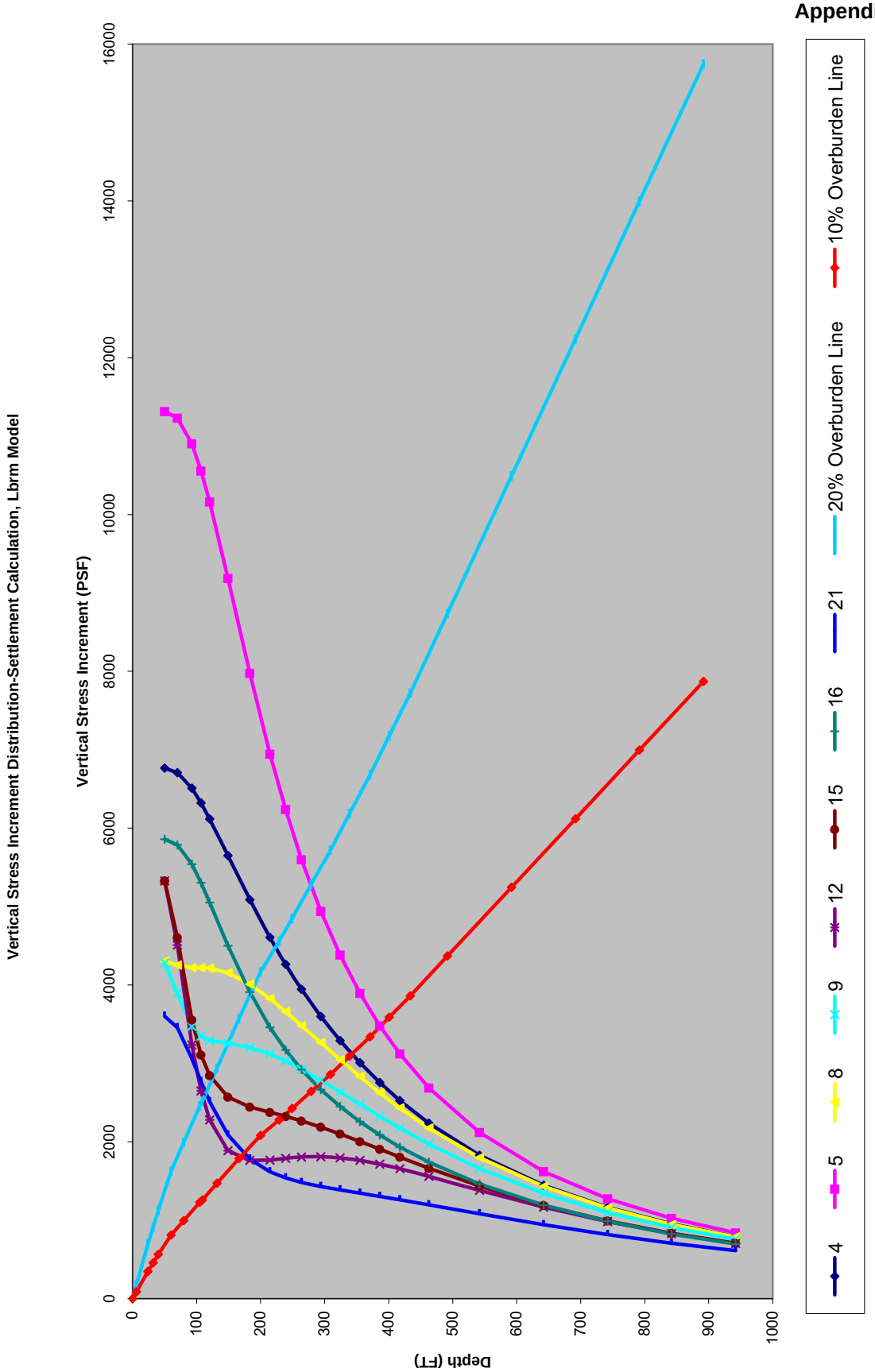
SUMMARY OF SETTLEMENT

Settlement Point	X	Y	Settlement Inches	Settlement Point	X	Y	Settlement Inches
1	300.0	200.0	**0.13**	**2**	300.0	333.0	**0.21**
3	300.0	546.0	**0.17**	**4**	419.5	266.5	**0.26**
5	454.5	439.5	**0.37**	**6**	539.0	200.0	**0.15**
7	539.0	333.0	**0.30**	**8**	574.0	275.5	**0.21**
9	574.0	603.5	**0.18**	**10**	609.0	333.0	**0.23**
11	609.0	546.0	**0.23**	**12**	674.0	217.5	**0.14**
13	629.0	376.0	**0.23**	**14**	629.0	562.0	**0.20**
15	674.0	624.5	**0.16**	**16**	786.5	469.0	**0.20**
17	944.0	376.0	**0.08**	**18**	944.0	562.0	**0.08**
19	104.5	152.5	**0.10**	**20**	104.5	283.5	**0.11**
21	104.5	496.5	**0.12**	**22**	104.5	627.5	**0.10**

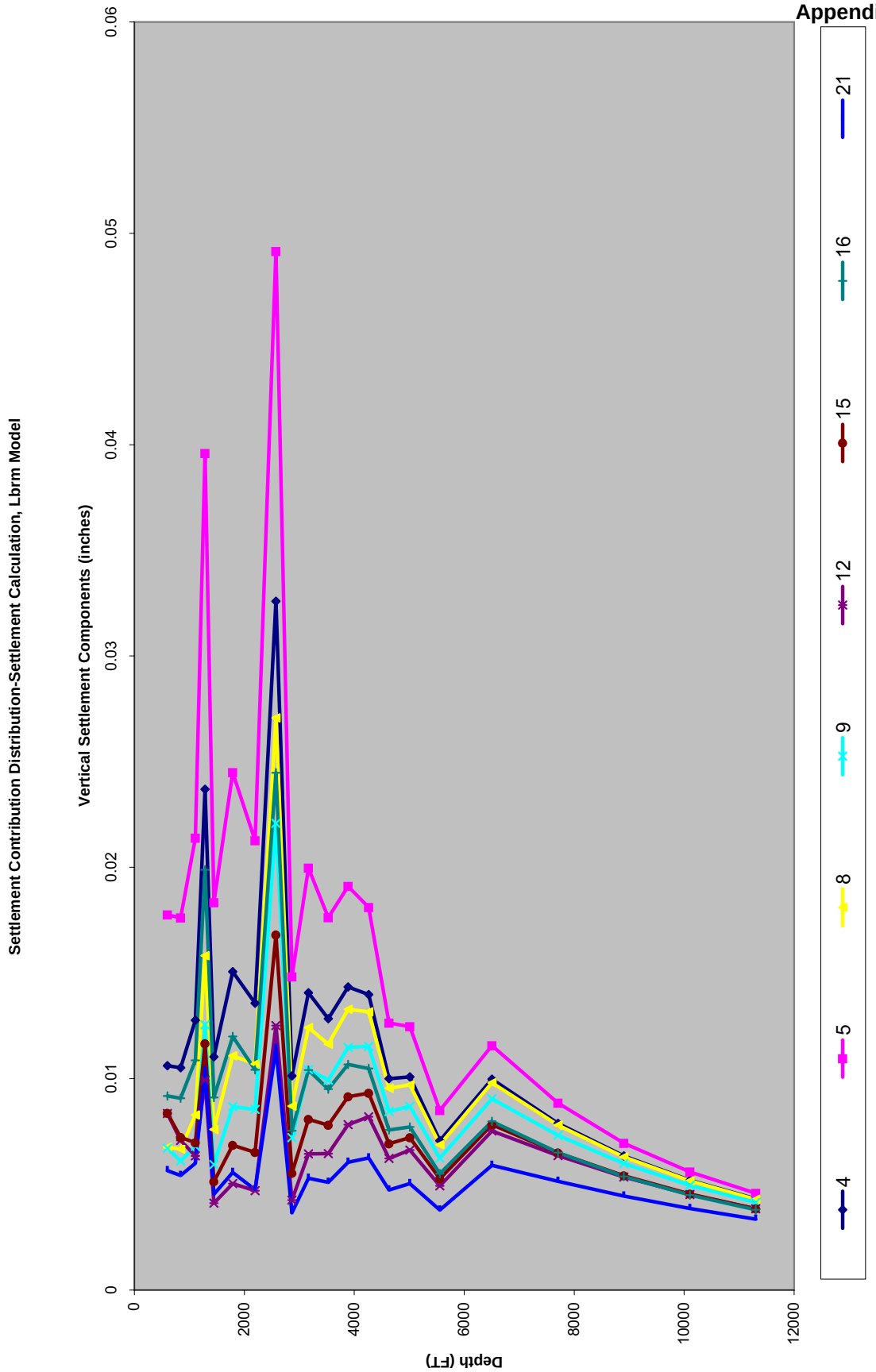
Appendix A


Locations of Settlement Points
Relative X Coordinate
Relative Y Coordinate
0
200
400
600
800
1000
1200
0
100
200
300
400
500
600
700
800
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

Appendix A


Vertical Stress Increment Distribution-Settlement Calculation, Lbrm Model
Vertical Stress Increment (PSF)
0
2000
4000
6000
8000
10000
12000
14000
16000
Depth (FT)
0
100
200
300
400
500
600
700
800
900
1000
4
5
8
9
12
15
16
21
20% Overburden Line
10% Overburden Line

Appendix A


Settlement Contribution Distribution-Settlement Calculation, Lbrm Model
Vertical Settlement Components (inches)
0
0.01
0.02
0.03
0.04
0.05
0.06
0
2000
4000
6000
8000
10000
12000
Depth (FT)
4
5
8
9
12
15
16
21

MODULUS AVERAGING

LAYER ID	LAYER CENTER DEPTH FT	THICKNESS FT	MODULUS PSF	$\sum_{i=1}^{n}\left(E_i \Big/ \sum_{j=1}^{i} h_j\right)$	$\sum_{i=1}^{n}\left(1 \Big/ \sum_{j=1}^{i} h_j\right)$
1.00	3.00	6.00	155,547,652		
2.00	15.00	18.00	155,547,652		
3.00	28.00	8.00	44,262,695		
4.00	36.00	8.00	48,648,130		
5.00	50.00	20.00	405,550,066	20277503	0.050
6.00	70.00	20.00	405,550,066	10138752	0.025
7.00	92.50	25.00	405,550,066	6239232	0.015
8.00	107.00	4.00	59,687,742	865040	0.014
9.00	120.50	23.00	313,510,454	3407722	0.011
10.00	149.00	34.00	585,032,604	4643116	0.008
11.00	183.00	34.00	205,855,826	1286599	0.006
12.00	214.50	29.00	72,539,100	383805	0.005
13.00	239.00	20.00	110,220,264	527370	0.005
14.00	264.00	30.00	110,220,264	461173	0.004
15.00	294.00	30.00	110,220,264	409741	0.004
16.00	324.00	30.00	117,958,712	394511	0.003
17.00	355.00	32.00	117,958,712	356371	0.003
18.00	386.00	30.00	110,901,382	307206	0.003
19.00	417.50	33.00	110,901,382	281476	0.003
20.00	463.00	58.00	378,267,514	836875	0.002
21.00	542.00	100.00	378,267,514	685267	0.002
22.00	642.00	100.00	378,267,514	580165	0.002
23.00	742.00	100.00	378,267,514	503015	0.001
24.00	842.00	100.00	378,267,514	443976	0.001
25.00	942.00	100.00	378,267,514	397340	0.001

$$E_{dw} = \frac{\sum_{i=1}^{n}\left(E_i \Big/ \sum_{j=1}^{i} h_j\right)}{\sum_{i=1}^{n}\left(1 \Big/ \sum_{j=1}^{i} h_j\right)} = \begin{matrix} 2199 & \text{KSI} \\ 316701108 & \text{PSF} \end{matrix}$$

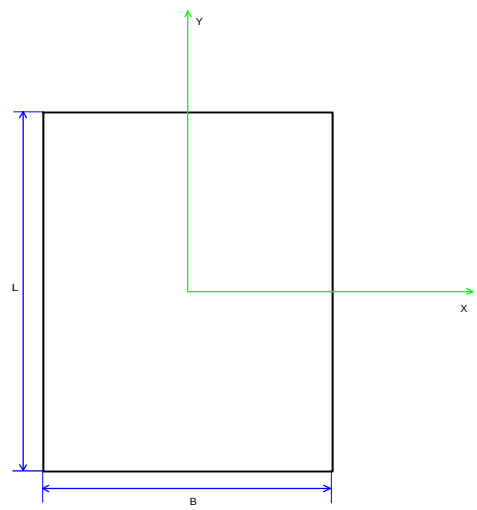
Weighted Modulus Calculation

NON-LAYERED METHOD--BERM MODEL

SETTLEMENT ANALYSIS FOR ELASTIC MATERIALS
Non-Layered Method, Berm Model

Reference: Soil Mechanics Principles and Application, William Perloff and William Baron,1976,Page 199-201

METHODOLOGY:



The vertical Settlement of any point of the surface of an elastic half-space uniformly loaded over a rectangular area is expressed as:

$$\delta(x,y) = C(x,y)\frac{qB(1-\mu)}{E}$$

where d(x,y) is vertical settlement at point (x,y) by a rectangular foundation, q is the load intensity, B foundation width, L foundation length, p is poisson's ratio, E is modulus of deformation of the bearing rock. And C(x,y) is a geometric factor which accounts for shape of the rectangle and the the position of the point for which the settlement is being calculated. C can be calculated based on following formulas:

$$C(x,y) = \frac{1}{2\pi}\left(C_1 + C_2 + C_3 + C_4\right)$$

$$C_1 = B_1 \ln\left(\frac{\sqrt{A_1^2 + B_1^2} + A_1}{\sqrt{A_2^2 + B_1^2} - A_2}\right) \qquad C_2 = B_2 \ln\left(\frac{\sqrt{A_1^2 + B_2^2} + A_1}{\sqrt{A_2^2 + B_2^2} - A_2}\right)$$

$$C_3 = A_1 \ln\left(\frac{\sqrt{A_1^2 + B_1^2} + B_1}{\sqrt{A_1^2 + B_2^2} - B_2}\right) \qquad C_4 = A_2 \ln\left(\frac{\sqrt{A_2^2 + B_1^2} + B_1}{\sqrt{A_2^2 + B_2^2} - B_2}\right)$$

$$A_1 = 1 - \frac{2x}{B} \qquad A_2 = 1 + \frac{2x}{B} \qquad B_1 = \frac{L}{B} - \frac{2y}{B} \qquad B_2 = \frac{L}{B} + \frac{2y}{B}$$

INPUT SUMMARY:

NUMBER OF LOADED AREAS= 9 POISSON'S RATIO= 0.30

NUMBER OF SETTLEMENT POINTS= 22 ELASTIC MODULUS= 316701 KSF

LOAD UNIT ID	LOAD INTENSITY PSF	LOAD UNIT CORNER COORDINATES (FT)							
		X1	Y1	X2	Y2	X3	Y3	X4	Y4
1	11320.0	300.0	333.0	609.0	333.0	609.0	546.0	300.0	546.0
2	6770.0	300.0	200.0	539.0	200.0	539.0	333.0	300.0	333.0
3	5860.0	629.0	376.0	944.0	376.0	944.0	562.0	629.0	562.0
4	4310.0	539.0	546.0	609.0	546.0	609.0	661.0	539.0	661.0
5	4310.0	539.0	218.0	609.0	218.0	609.0	333.0	539.0	333.0
6	3610.0	39.0	431.0	170.0	431.0	170.0	693.0	39.0	693.0
7	3610.0	39.0	87.0	170.0	87.0	170.0	349.0	39.0	349.0
8	5380.0	635.0	582.0	713.0	582.0	713.0	667.0	635.0	667.0
9	5380.0	635.0	175.0	713.0	175.0	713.0	260.0	635.0	260.0

SETTLEMENT POINT COORDINATES								
ID	X	Y	ID	X	Y	ID	X	Y
1	300.0	200.0	2	300.0	333.0	3	300.0	546.0
4	419.5	266.5	5	454.5	439.5	6	539.0	200.0
7	539.0	333.0	8	574.0	275.5	9	574.0	603.5
10	609.0	333.0	11	609.0	546.0	12	674.0	217.5
13	629.0	376.0	14	629.0	562.0	15	674.0	624.5
16	786.5	469.0	17	944.0	376.0	18	944.0	562.0
19	104.5	152.5	20	104.5	283.5	21	104.5	496.5
22	104.5	627.5						

OUTPUT SUMMARY:

CALCULATION BASED ON LOADED AREA 1						CALCULATION BASED ON LOADED AREA 2					
Settle ID	General Coordinates		Local Coordinates		Settlement Component	Settle ID	General Coordinates		Local Coordinates		Settlement Component
	X	Y	X'	Y'			X	Y	X'	Y'	
1	300.0	200.0	-239.5	-154.5	0.002	1	300.0	200.0	-66.5	-119.5	0.002
2	300.0	333.0	-106.5	-154.5	0.004	2	300.0	333.0	66.5	-119.5	0.002
3	300.0	546.0	106.5	-154.5	0.004	3	300.0	546.0	279.5	-119.5	0.000
4	419.5	266.5	-173.0	-35.0	0.003	4	419.5	266.5	0.0	0.0	0.003
5	454.5	439.5	0.0	0.0	0.007	5	454.5	439.5	173.0	35.0	0.001
6	539.0	200.0	-239.5	84.5	0.002	6	539.0	200.0	-66.5	119.5	0.002
7	539.0	333.0	-106.5	84.5	0.005	7	539.0	333.0	66.5	119.5	0.002
8	574.0	275.5	-164.0	119.5	0.003	8	574.0	275.5	9.0	154.5	0.001
9	574.0	603.5	164.0	119.5	0.003	9	574.0	603.5	337.0	154.5	0.000
10	609.0	333.0	-106.5	154.5	0.004	10	609.0	333.0	66.5	189.5	0.001
11	609.0	546.0	106.5	154.5	0.004	11	609.0	546.0	279.5	189.5	0.000
12	674.0	217.5	-222.0	219.5	0.002	12	674.0	217.5	-49.0	254.5	0.001
13	629.0	376.0	-63.5	174.5	0.003	13	629.0	376.0	109.5	209.5	0.001
14	629.0	562.0	122.5	174.5	0.003	14	629.0	562.0	295.5	209.5	0.000
15	674.0	624.5	185.0	219.5	0.002	15	674.0	624.5	358.0	254.5	0.000
16	786.5	469.0	29.5	332.0	0.002	16	786.5	469.0	202.5	367.0	0.000
17	944.0	376.0	-63.5	489.5	0.001	17	944.0	376.0	109.5	524.5	0.000
18	944.0	562.0	122.5	489.5	0.001	18	944.0	562.0	295.5	524.5	0.000
19	104.5	152.5	-287.0	-350.0	0.001	19	104.5	152.5	-114.0	-315.0	0.000
20	104.5	283.5	-156.0	-350.0	0.001	20	104.5	283.5	17.0	-315.0	0.000
21	104.5	496.5	57.0	-350.0	0.002	21	104.5	496.5	230.0	-315.0	0.000
22	104.5	627.5	188.0	-350.0	0.001	22	104.5	627.5	361.0	-315.0	0.000

Appendix A

CALCULATION BASED ON LOADED AREA 3						CALCULATION BASED ON LOADED AREA 4					
Settle ID	General Coordinates		Local Coordinates		Settlement Component	Settle ID	General Coordinates		Local Coordinates		Settlement Component
	X	Y	X'	Y'			X	Y	X'	Y'	
1	300.0	200.0	-269.0	-486.5	0.000	1	300.0	200.0	-274.0	-403.5	0.000
2	300.0	333.0	-136.0	-486.5	0.000	2	300.0	333.0	-274.0	-270.5	0.000
3	300.0	546.0	77.0	-486.5	0.001	3	300.0	546.0	-274.0	-57.5	0.000
4	419.5	266.5	-202.5	-367.0	0.001	4	419.5	266.5	-154.5	-337.0	0.000
5	454.5	439.5	-29.5	-332.0	0.001	5	454.5	439.5	-119.5	-164.0	0.000
6	539.0	200.0	-269.0	-247.5	0.001	6	539.0	200.0	-35.0	-403.5	0.000
7	539.0	333.0	-136.0	-247.5	0.001	7	539.0	333.0	-35.0	-270.5	0.000
8	574.0	275.5	-193.5	-212.5	0.001	8	574.0	275.5	0.0	-328.0	0.000
9	574.0	603.5	134.5	-212.5	0.001	9	574.0	603.5	0.0	0.0	0.001
10	609.0	333.0	-136.0	-177.5	0.001	10	609.0	333.0	35.0	-270.5	0.000
11	609.0	546.0	77.0	-177.5	0.002	11	609.0	546.0	35.0	-57.5	0.000
12	674.0	217.5	-251.5	-112.5	0.001	12	674.0	217.5	100.0	-386.0	0.000
13	629.0	376.0	-93.0	-157.5	0.002	13	629.0	376.0	55.0	-227.5	0.000
14	629.0	562.0	93.0	-157.5	0.002	14	629.0	562.0	55.0	-41.5	0.000
15	674.0	624.5	155.5	-112.5	0.001	15	674.0	624.5	100.0	21.0	0.000
16	786.5	469.0	0.0	0.0	0.003	16	786.5	469.0	212.5	-134.5	0.000
17	944.0	376.0	-93.0	157.5	0.002	17	944.0	376.0	370.0	-227.5	0.000
18	944.0	562.0	93.0	157.5	0.002	18	944.0	562.0	370.0	-41.5	0.000
19	104.5	152.5	-316.5	-682.0	0.000	19	104.5	152.5	-469.5	-451.0	0.000
20	104.5	283.5	-185.5	-682.0	0.000	20	104.5	283.5	-469.5	-320.0	0.000
21	104.5	496.5	27.5	-682.0	0.000	21	104.5	496.5	-469.5	-107.0	0.000
22	104.5	627.5	158.5	-682.0	0.000	22	104.5	627.5	-469.5	24.0	0.000

Appendix A

CALCULATION BASED ON LOADED AREA 5						CALCULATION BASED ON LOADED AREA 6					
Settle ID	General Coordinates		Local Coordinates		Settlement Component	Settle ID	General Coordinates		Local Coordinates		Settlement Component
	X	Y	X'	Y'			X	Y	X'	Y'	
1	300.0	200.0	-274.0	-75.5	0.000	1	300.0	200.0	195.5	-362.0	0.000
2	300.0	333.0	-274.0	57.5	0.000	2	300.0	333.0	195.5	-229.0	0.000
3	300.0	546.0	-274.0	270.5	0.000	3	300.0	546.0	195.5	-16.0	0.000
4	419.5	266.5	-154.5	-9.0	0.000	4	419.5	266.5	315.0	-295.5	0.000
5	454.5	439.5	-119.5	164.0	0.000	5	454.5	439.5	350.0	-122.5	0.000
6	539.0	200.0	-35.0	-75.5	0.000	6	539.0	200.0	434.5	-362.0	0.000
7	539.0	333.0	-35.0	57.5	0.000	7	539.0	333.0	434.5	-229.0	0.000
8	574.0	275.5	0.0	0.0	0.001	8	574.0	275.5	469.5	-286.5	0.000
9	574.0	603.5	0.0	328.0	0.000	9	574.0	603.5	469.5	41.5	0.000
10	609.0	333.0	35.0	57.5	0.000	10	609.0	333.0	504.5	-229.0	0.000
11	609.0	546.0	35.0	270.5	0.000	11	609.0	546.0	504.5	-16.0	0.000
12	674.0	217.5	100.0	-58.0	0.000	12	674.0	217.5	569.5	-344.5	0.000
13	629.0	376.0	55.0	100.5	0.000	13	629.0	376.0	524.5	-186.0	0.000
14	629.0	562.0	55.0	286.5	0.000	14	629.0	562.0	524.5	0.0	0.000
15	674.0	624.5	100.0	349.0	0.000	15	674.0	624.5	569.5	62.5	0.000
16	786.5	469.0	212.5	193.5	0.000	16	786.5	469.0	682.0	-93.0	0.000
17	944.0	376.0	370.0	100.5	0.000	17	944.0	376.0	839.5	-186.0	0.000
18	944.0	562.0	370.0	286.5	0.000	18	944.0	562.0	839.5	0.0	0.000
19	104.5	152.5	-469.5	-123.0	0.000	19	104.5	152.5	0.0	-409.5	0.000
20	104.5	283.5	-469.5	8.0	0.000	20	104.5	283.5	0.0	-278.5	0.000
21	104.5	496.5	-469.5	221.0	0.000	21	104.5	496.5	0.0	-65.5	0.002
22	104.5	627.5	-469.5	352.0	0.000	22	104.5	627.5	0.0	65.5	0.002

Appendix A

CALCULATION BASED ON LOADED AREA 7						CALCULATION BASED ON LOADED AREA 8					
Settle ID	General Coordinates		Local Coordinates		Settlement Component	Settle ID	General Coordinates		Local Coordinates		Settlement Component
	X	Y	X'	Y'			X	Y	X'	Y'	
1	300.0	200.0	195.5	-18.0	0.000	1	300.0	200.0	-374.0	-424.5	0.000
2	300.0	333.0	195.5	115.0	0.000	2	300.0	333.0	-374.0	-291.5	0.000
3	300.0	546.0	195.5	328.0	0.000	3	300.0	546.0	-374.0	-78.5	0.000
4	419.5	266.5	315.0	48.5	0.000	4	419.5	266.5	-254.5	-358.0	0.000
5	454.5	439.5	350.0	221.5	0.000	5	454.5	439.5	-219.5	-185.0	0.000
6	539.0	200.0	434.5	-18.0	0.000	6	539.0	200.0	-135.0	-424.5	0.000
7	539.0	333.0	434.5	115.0	0.000	7	539.0	333.0	-135.0	-291.5	0.000
8	574.0	275.5	469.5	57.5	0.000	8	574.0	275.5	-100.0	-349.0	0.000
9	574.0	603.5	469.5	385.5	0.000	9	574.0	603.5	-100.0	-21.0	0.000
10	609.0	333.0	504.5	115.0	0.000	10	609.0	333.0	-65.0	-291.5	0.000
11	609.0	546.0	504.5	328.0	0.000	11	609.0	546.0	-65.0	-78.5	0.000
12	674.0	217.5	569.5	-0.5	0.000	12	674.0	217.5	0.0	-407.0	0.000
13	629.0	376.0	524.5	158.0	0.000	13	629.0	376.0	-45.0	-248.5	0.000
14	629.0	562.0	524.5	344.0	0.000	14	629.0	562.0	-45.0	-62.5	0.000
15	674.0	624.5	569.5	406.5	0.000	15	674.0	624.5	0.0	0.0	0.001
16	786.5	469.0	682.0	251.0	0.000	16	786.5	469.0	112.5	-155.5	0.000
17	944.0	376.0	839.5	158.0	0.000	17	944.0	376.0	270.0	-248.5	0.000
18	944.0	562.0	839.5	344.0	0.000	18	944.0	562.0	270.0	-62.5	0.000
19	104.5	152.5	0.0	-65.5	0.002	19	104.5	152.5	-569.5	-472.0	0.000
20	104.5	283.5	0.0	65.5	0.002	20	104.5	283.5	-569.5	-341.0	0.000
21	104.5	496.5	0.0	278.5	0.000	21	104.5	496.5	-569.5	-128.0	0.000
22	104.5	627.5	0.0	409.5	0.000	22	104.5	627.5	-569.5	3.0	0.000

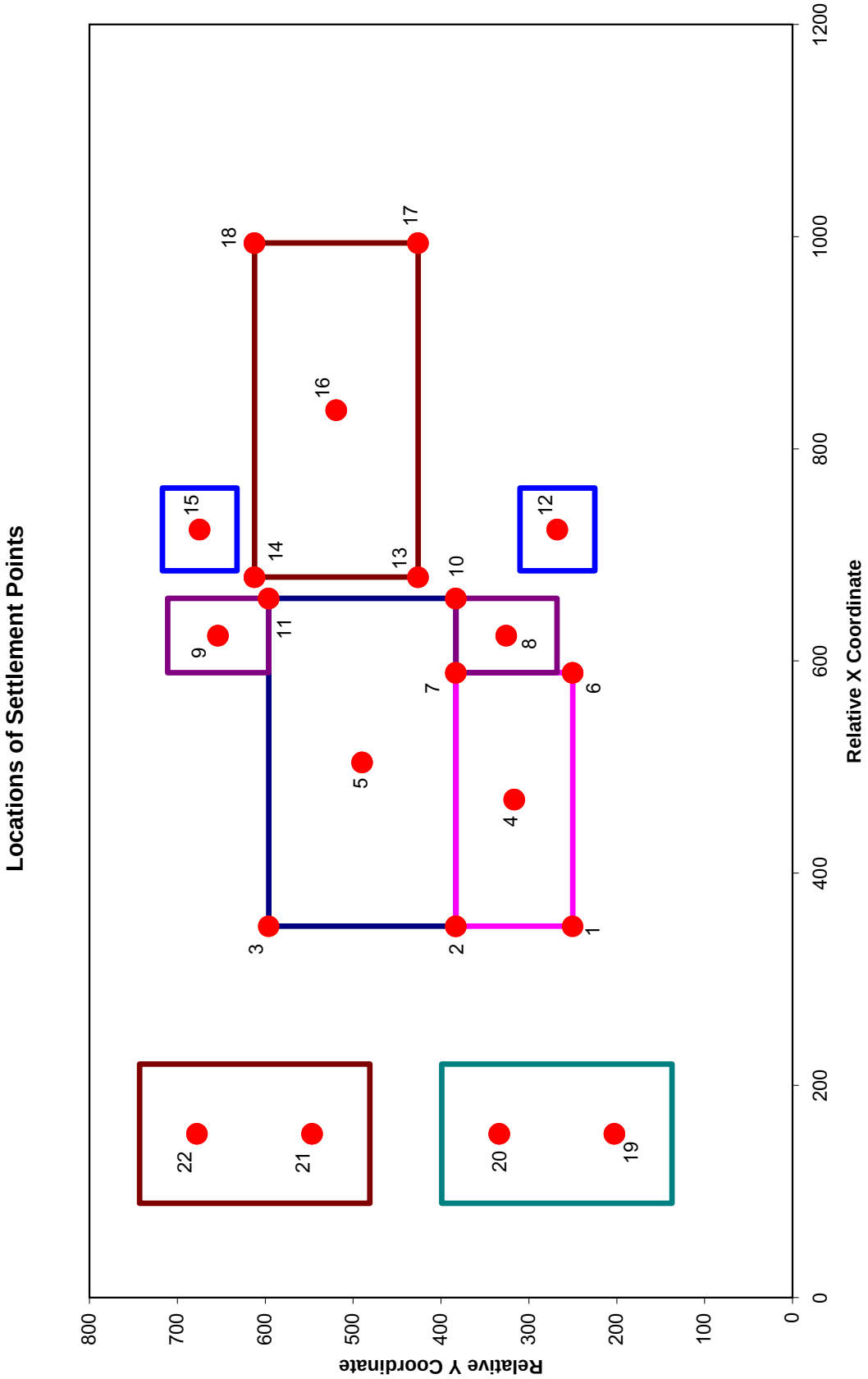
Appendix A

CALCULATION BASED ON LOADED AREA 9					
Settle ID	General Coordinates		Local Coordinates		Settlement Component
	X	Y	X'	Y'	
1	300.0	200.0	-374.0	-17.5	0.000
2	300.0	333.0	-374.0	115.5	0.000
3	300.0	546.0	-374.0	328.5	0.000
4	419.5	266.5	-254.5	49.0	0.000
5	454.5	439.5	-219.5	222.0	0.000
6	539.0	200.0	-135.0	-17.5	0.000
7	539.0	333.0	-135.0	115.5	0.000
8	574.0	275.5	-100.0	58.0	0.000
9	574.0	603.5	-100.0	386.0	0.000
10	609.0	333.0	-65.0	115.5	0.000
11	609.0	546.0	-65.0	328.5	0.000
12	674.0	217.5	0.0	0.0	0.001
13	629.0	376.0	-45.0	158.5	0.000
14	629.0	562.0	-45.0	344.5	0.000
15	674.0	624.5	0.0	407.0	0.000
16	786.5	469.0	112.5	251.5	0.000
17	944.0	376.0	270.0	158.5	0.000
18	944.0	562.0	270.0	344.5	0.000
19	104.5	152.5	-569.5	-65.0	0.000
20	104.5	283.5	-569.5	66.0	0.000
21	104.5	496.5	-569.5	279.0	0.000
22	104.5	627.5	-569.5	410.0	0.000

Appendix A

SUMMARY OF SETTLEMENT							
Settlement Point	X	Y	Settlement Inches	Settlement Point	X	Y	Settlement Inches
1	300.00	200.00	0.06	2	300.00	333.00	0.08
3	300.00	546.00	0.07	4	419.50	266.50	0.09
5	454.50	439.50	0.12	6	539.00	200.00	0.06
7	539.00	333.00	0.10	8	574.00	275.50	0.08
9	574.00	603.50	0.07	10	609.00	333.00	0.08
11	609.00	546.00	0.08	12	674.00	217.50	0.06
13	629.00	376.00	0.08	14	629.00	562.00	0.07
15	674.00	624.50	0.06	16	786.50	469.00	0.07
17	944.00	376.00	0.04	18	944.00	562.00	0.04
19	104.50	152.50	0.05	20	104.50	283.50	0.05
21	104.50	496.50	0.05	22	104.50	627.50	0.05

Appendix A


Locations of Settlement Points
Relative X Coordinate
Relative Y Coordinate
0
200
400
600
800
1000
1200
0
100
200
300
400
500
600
700
800
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

MODULUS AVERAGING

LAYER ID	LAYER CENTER DEPTH FT	THICKNESS FT	MODULUS PSF	$\sum_{i=1}^{n}\left(E_i \Big/ \sum_{j=1}^{i} h_j\right)$	$\sum_{i=1}^{n}\left(1 \Big/ \sum_{j=1}^{i} h_j\right)$
1.00	3.00	6.00	91,508,416		
2.00	15.00	18.00	91,508,416		
3.00	28.00	8.00	11,650,143		
4.00	36.00	8.00	11,650,143		
5.00	50.00	20.00	139,212,424	6960621	0.050
6.00	70.00	20.00	139,212,424	3480311	0.025
7.00	92.50	25.00	139,212,424	2141730	0.015
8.00	107.00	4.00	11,650,143	168843	0.014
9.00	120.50	23.00	139,212,424	1513179	0.011
10.00	149.00	34.00	139,212,424	1104861	0.008
11.00	183.00	34.00	139,212,424	870078	0.006
12.00	214.50	29.00	44,754,165	236795	0.005
13.00	239.00	20.00	91,866,353	439552	0.005
14.00	264.00	30.00	91,866,353	384378	0.004
15.00	294.00	30.00	91,866,353	341511	0.004
16.00	324.00	30.00	75,174,273	251419	0.003
17.00	355.00	32.00	75,174,273	227113	0.003
18.00	386.00	30.00	90,209,128	249887	0.003
19.00	417.50	33.00	90,209,128	228957	0.003
20.00	463.00	58.00	200,298,272	443138	0.002
21.00	542.00	100.00	200,298,272	362859	0.002
22.00	642.00	100.00	200,298,272	307206	0.002
23.00	742.00	100.00	200,298,272	266354	0.001
24.00	842.00	100.00	200,298,272	235092	0.001
25.00	942.00	100.00	200,298,272	210397	0.001

$$E_{dw} = \frac{\sum_{i=1}^{n}\left(E_i \Big/ \sum_{j=1}^{i} h_j\right)}{\sum_{i=1}^{n}\left(1 \Big/ \sum_{j=1}^{i} h_j\right)} = \begin{matrix} 841 & \text{KSI} \\ 121071402 & \text{PSF} \end{matrix}$$

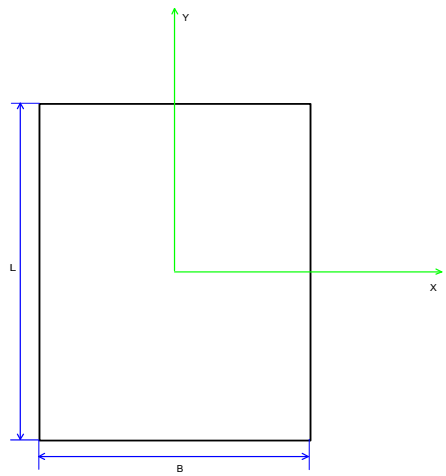
Weighted Modulus Calculation

NON-LAYERED METHOD--LBRM MODEL

SETTLEMENT ANALYSIS FOR ELASTIC MATERIALS
Non-Layered Method, Lbrm Model

Reference: Soil Mechanics Principles and Application, William Perloff and William Baron,1976,Page 199-201

METHODOLOGY:



The vertical Settlement of any point of the surface of an elastic half-space uniformly loaded over a rectangular area is expressed as:

$$\delta(x,y) = C(x,y)\frac{qB(1-\mu)}{E}$$

where d(x,y) is vertical settlement at point (x,y) by a rectangular foundation, q is the load intensity, B foundation width, L foundation length, p is poisson's ratio, E is modulus of deformation of the bearing rock. And C(x,y) is a geometric factor which accounts for shape of the rectangle shown in Figure 1 and the the position of the point for which the settlement is being calculated. C can be calculated based on following formulas:

$$C(x,y) = \frac{1}{2\pi}(C_1 + C_2 + C_3 + C_4)$$

$$C_1 = B_1 \ln\left(\frac{\sqrt{A_1^2 + B_1^2} + A_1}{\sqrt{A_2^2 + B_1^2} - A_2}\right) \qquad C_2 = B_2 \ln\left(\frac{\sqrt{A_1^2 + B_2^2} + A_1}{\sqrt{A_2^2 + B_2^2} - A_2}\right)$$

$$C_3 = A_1 \ln\left(\frac{\sqrt{A_1^2 + B_1^2} + B_1}{\sqrt{A_1^2 + B_2^2} - B_2}\right) \qquad C_4 = A_2 \ln\left(\frac{\sqrt{A_2^2 + B_1^2} + B_1}{\sqrt{A_2^2 + B_2^2} - B_2}\right)$$

$$A_1 = 1 - \frac{2x}{B} \qquad A_2 = 1 + \frac{2x}{B} \qquad B_1 = \frac{L}{B} - \frac{2y}{B} \qquad B_2 = \frac{L}{B} + \frac{2y}{B}$$

INPUT SUMMARY:

NUMBER OF LOADED AREAS= 9 POISSON'S RATIO= 0.30

NUMBER OF SETTLEMENT POINTS= 22 ELASTIC MODULUS= 121071 KSF

LOAD UNIT ID	LOAD INTENSITY PSF	LOAD UNIT CORNER COORDINATES (FT)							
		X1	Y1	X2	Y2	X3	Y3	X4	Y4
1	11320.0	300.0	333.0	609.0	333.0	609.0	546.0	300.0	546.0
2	6770.0	300.0	200.0	539.0	200.0	539.0	333.0	300.0	333.0
3	5860.0	629.0	376.0	944.0	376.0	944.0	562.0	629.0	562.0
4	4310.0	539.0	546.0	609.0	546.0	609.0	661.0	539.0	661.0
5	4310.0	539.0	218.0	609.0	218.0	609.0	333.0	539.0	333.0
6	3610.0	39.0	431.0	170.0	431.0	170.0	693.0	39.0	693.0
7	3610.0	39.0	87.0	170.0	87.0	170.0	349.0	39.0	349.0
8	5380.0	635.0	582.0	713.0	582.0	713.0	667.0	635.0	667.0
9	5380.0	635.0	175.0	713.0	175.0	713.0	260.0	635.0	260.0

SETTLEMENT POINT COORDINATES								
ID	X	Y	ID	X	Y	ID	X	Y
1	300.0	200.0	2	300.0	333.0	3	300.0	546.0
4	419.5	266.5	5	454.5	439.5	6	539.0	200.0
7	539.0	333.0	8	574.0	275.5	9	574.0	603.5
10	609.0	333.0	11	609.0	546.0	12	674.0	217.5
13	629.0	376.0	14	629.0	562.0	15	674.0	624.5
16	786.5	469.0	17	944.0	376.0	18	944.0	562.0
19	104.5	152.5	20	104.5	283.5	21	104.5	496.5
22	104.5	627.5						

OUTPUT SUMMARY:

CALCULATION BASED ON LOADED AREA 1						CALCULATION BASED ON LOADED AREA 2					
Settle ID	General Coordinates		Local Coordinates		Settlement Component	Settle ID	General Coordinates		Local Coordinates		Settlement Component
	X	Y	X'	Y'			X	Y	X'	Y'	
1	300.0	200.0	-239.5	-154.5	0.005	1	300.0	200.0	-66.5	-119.5	0.004
2	300.0	333.0	-106.5	-154.5	0.010	2	300.0	333.0	66.5	-119.5	0.004
3	300.0	546.0	106.5	-154.5	0.010	3	300.0	546.0	279.5	-119.5	0.001
4	419.5	266.5	-173.0	-35.0	0.008	4	419.5	266.5	0.0	0.0	0.008
5	454.5	439.5	0.0	0.0	0.019	5	454.5	439.5	173.0	35.0	0.002
6	539.0	200.0	-239.5	84.5	0.005	6	539.0	200.0	-66.5	119.5	0.004
7	539.0	333.0	-106.5	84.5	0.013	7	539.0	333.0	66.5	119.5	0.004
8	574.0	275.5	-164.0	119.5	0.007	8	574.0	275.5	9.0	154.5	0.003
9	574.0	603.5	164.0	119.5	0.007	9	574.0	603.5	337.0	154.5	0.001
10	609.0	333.0	-106.5	154.5	0.010	10	609.0	333.0	66.5	189.5	0.002
11	609.0	546.0	106.5	154.5	0.010	11	609.0	546.0	279.5	189.5	0.001
12	674.0	217.5	-222.0	219.5	0.005	12	674.0	217.5	-49.0	254.5	0.002
13	629.0	376.0	-63.5	174.5	0.009	13	629.0	376.0	109.5	209.5	0.002
14	629.0	562.0	122.5	174.5	0.007	14	629.0	562.0	295.5	209.5	0.001
15	674.0	624.5	185.0	219.5	0.005	15	674.0	624.5	358.0	254.5	0.001
16	786.5	469.0	29.5	332.0	0.004	16	786.5	469.0	202.5	367.0	0.001
17	944.0	376.0	-63.5	489.5	0.003	17	944.0	376.0	109.5	524.5	0.001
18	944.0	562.0	122.5	489.5	0.003	18	944.0	562.0	295.5	524.5	0.001
19	104.5	152.5	-287.0	-350.0	0.003	19	104.5	152.5	-114.0	-315.0	0.001
20	104.5	283.5	-156.0	-350.0	0.004	20	104.5	283.5	17.0	-315.0	0.001
21	104.5	496.5	57.0	-350.0	0.004	21	104.5	496.5	230.0	-315.0	0.001
22	104.5	627.5	188.0	-350.0	0.004	22	104.5	627.5	361.0	-315.0	0.001

Appendix A

CALCULATION BASED ON LOADED AREA 3						CALCULATION BASED ON LOADED AREA 4					
Settle ID	General Coordinates		Local Coordinates		Settlement Component	Settle ID	General Coordinates		Local Coordinates		Settlement Component
	X	Y	X'	Y'			X	Y	X'	Y'	
1	300.0	200.0	-269.0	-486.5	0.001	1	300.0	200.0	-274.0	-403.5	0.000
2	300.0	333.0	-136.0	-486.5	0.001	2	300.0	333.0	-274.0	-270.5	0.000
3	300.0	546.0	77.0	-486.5	0.001	3	300.0	546.0	-274.0	-57.5	0.000
4	419.5	266.5	-202.5	-367.0	0.002	4	419.5	266.5	-154.5	-337.0	0.000
5	454.5	439.5	-29.5	-332.0	0.002	5	454.5	439.5	-119.5	-164.0	0.000
6	539.0	200.0	-269.0	-247.5	0.002	6	539.0	200.0	-35.0	-403.5	0.000
7	539.0	333.0	-136.0	-247.5	0.002	7	539.0	333.0	-35.0	-270.5	0.000
8	574.0	275.5	-193.5	-212.5	0.002	8	574.0	275.5	0.0	-328.0	0.000
9	574.0	603.5	134.5	-212.5	0.003	9	574.0	603.5	0.0	0.0	0.002
10	609.0	333.0	-136.0	-177.5	0.003	10	609.0	333.0	35.0	-270.5	0.000
11	609.0	546.0	77.0	-177.5	0.004	11	609.0	546.0	35.0	-57.5	0.001
12	674.0	217.5	-251.5	-112.5	0.002	12	674.0	217.5	100.0	-386.0	0.000
13	629.0	376.0	-93.0	-157.5	0.005	13	629.0	376.0	55.0	-227.5	0.000
14	629.0	562.0	93.0	-157.5	0.005	14	629.0	562.0	55.0	-41.5	0.001
15	674.0	624.5	155.5	-112.5	0.003	15	674.0	624.5	100.0	21.0	0.001
16	786.5	469.0	0.0	0.0	0.009	16	786.5	469.0	212.5	-134.5	0.000
17	944.0	376.0	-93.0	157.5	0.005	17	944.0	376.0	370.0	-227.5	0.000
18	944.0	562.0	93.0	157.5	0.005	18	944.0	562.0	370.0	-41.5	0.000
19	104.5	152.5	-316.5	-682.0	0.001	19	104.5	152.5	-469.5	-451.0	0.000
20	104.5	283.5	-185.5	-682.0	0.001	20	104.5	283.5	-469.5	-320.0	0.000
21	104.5	496.5	27.5	-682.0	0.001	21	104.5	496.5	-469.5	-107.0	0.000
22	104.5	627.5	158.5	-682.0	0.001	22	104.5	627.5	-469.5	24.0	0.000

Appendix A

CALCULATION BASED ON LOADED AREA 5						CALCULATION BASED ON LOADED AREA 6					
Settle ID	General Coordinates		Local Coordinates		Settlement Component	Settle ID	General Coordinates		Local Coordinates		Settlement Component
	X	Y	X'	Y'			X	Y	X'	Y'	
1	300.0	200.0	-274.0	-75.5	0.000	1	300.0	200.0	195.5	-362.0	0.001
2	300.0	333.0	-274.0	57.5	0.000	2	300.0	333.0	195.5	-229.0	0.001
3	300.0	546.0	-274.0	270.5	0.000	3	300.0	546.0	195.5	-16.0	0.001
4	419.5	266.5	-154.5	-9.0	0.000	4	419.5	266.5	315.0	-295.5	0.001
5	454.5	439.5	-119.5	164.0	0.000	5	454.5	439.5	350.0	-122.5	0.001
6	539.0	200.0	-35.0	-75.5	0.001	6	539.0	200.0	434.5	-362.0	0.000
7	539.0	333.0	-35.0	57.5	0.001	7	539.0	333.0	434.5	-229.0	0.000
8	574.0	275.5	0.0	0.0	0.002	8	574.0	275.5	469.5	-286.5	0.000
9	574.0	603.5	0.0	328.0	0.000	9	574.0	603.5	469.5	41.5	0.000
10	609.0	333.0	35.0	57.5	0.001	10	609.0	333.0	504.5	-229.0	0.000
11	609.0	546.0	35.0	270.5	0.000	11	609.0	546.0	504.5	-16.0	0.000
12	674.0	217.5	100.0	-58.0	0.001	12	674.0	217.5	569.5	-344.5	0.000
13	629.0	376.0	55.0	100.5	0.001	13	629.0	376.0	524.5	-186.0	0.000
14	629.0	562.0	55.0	286.5	0.000	14	629.0	562.0	524.5	0.0	0.000
15	674.0	624.5	100.0	349.0	0.000	15	674.0	624.5	569.5	62.5	0.000
16	786.5	469.0	212.5	193.5	0.000	16	786.5	469.0	682.0	-93.0	0.000
17	944.0	376.0	370.0	100.5	0.000	17	944.0	376.0	839.5	-186.0	0.000
18	944.0	562.0	370.0	286.5	0.000	18	944.0	562.0	839.5	0.0	0.000
19	104.5	152.5	-469.5	-123.0	0.000	19	104.5	152.5	0.0	-409.5	0.001
20	104.5	283.5	-469.5	8.0	0.000	20	104.5	283.5	0.0	-278.5	0.001
21	104.5	496.5	-469.5	221.0	0.000	21	104.5	496.5	0.0	-65.5	0.004
22	104.5	627.5	-469.5	352.0	0.000	22	104.5	627.5	0.0	65.5	0.004

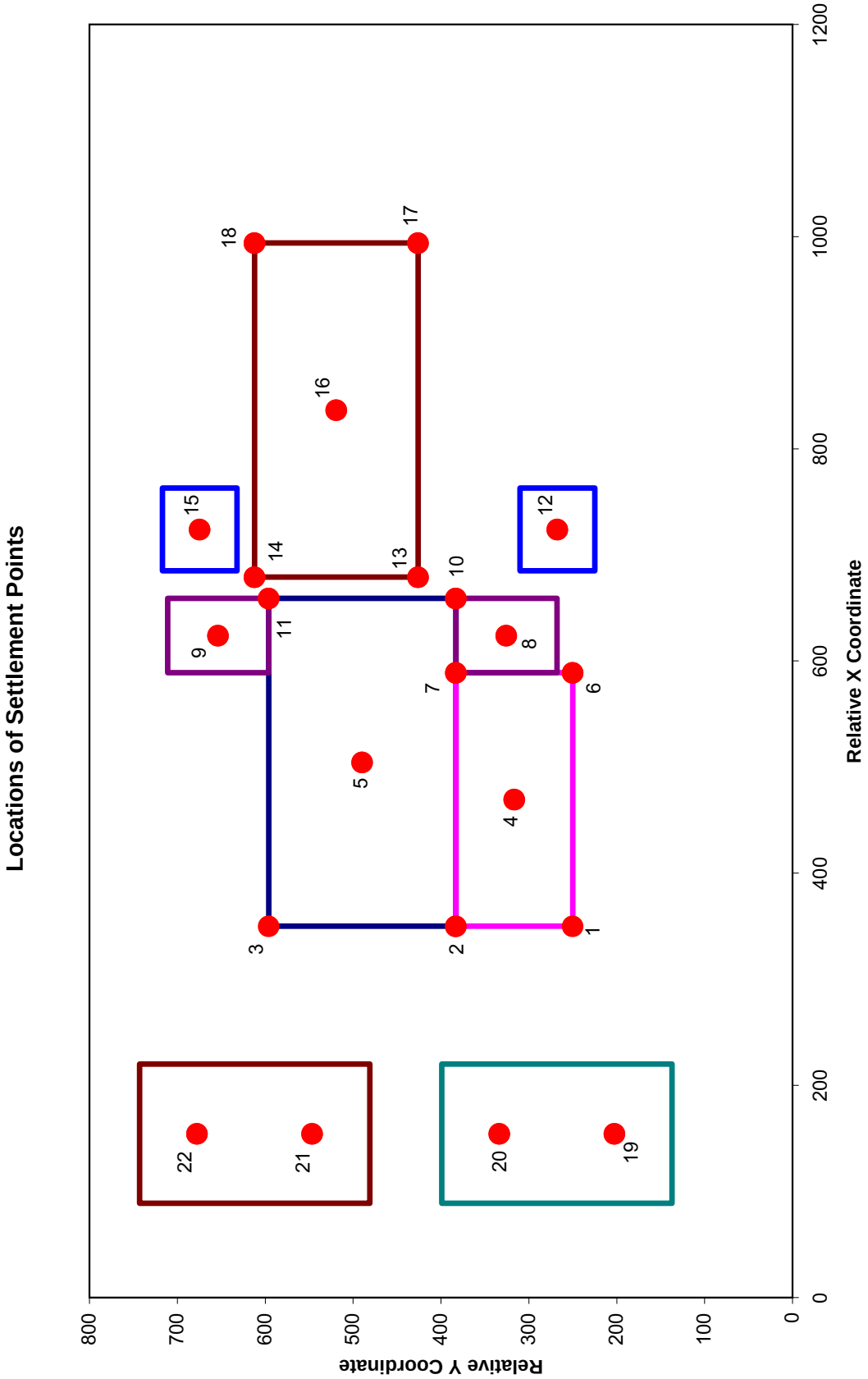
Appendix A

CALCULATION BASED ON LOADED AREA 7						CALCULATION BASED ON LOADED AREA 8					
Settle ID	General Coordinates		Local Coordinates		Settlement Component	Settle ID	General Coordinates		Local Coordinates		Settlement Component
	X	Y	X'	Y'			X	Y	X'	Y'	
1	300.0	200.0	195.5	-18.0	0.001	1	300.0	200.0	-374.0	-424.5	0.000
2	300.0	333.0	195.5	115.0	0.001	2	300.0	333.0	-374.0	-291.5	0.000
3	300.0	546.0	195.5	328.0	0.001	3	300.0	546.0	-374.0	-78.5	0.000
4	419.5	266.5	315.0	48.5	0.001	4	419.5	266.5	-254.5	-358.0	0.000
5	454.5	439.5	350.0	221.5	0.001	5	454.5	439.5	-219.5	-185.0	0.000
6	539.0	200.0	434.5	-18.0	0.001	6	539.0	200.0	-135.0	-424.5	0.000
7	539.0	333.0	434.5	115.0	0.001	7	539.0	333.0	-135.0	-291.5	0.000
8	574.0	275.5	469.5	57.5	0.000	8	574.0	275.5	-100.0	-349.0	0.000
9	574.0	603.5	469.5	385.5	0.000	9	574.0	603.5	-100.0	-21.0	0.001
10	609.0	333.0	504.5	115.0	0.000	10	609.0	333.0	-65.0	-291.5	0.000
11	609.0	546.0	504.5	328.0	0.000	11	609.0	546.0	-65.0	-78.5	0.001
12	674.0	217.5	569.5	-0.5	0.000	12	674.0	217.5	0.0	-407.0	0.000
13	629.0	376.0	524.5	158.0	0.000	13	629.0	376.0	-45.0	-248.5	0.000
14	629.0	562.0	524.5	344.0	0.000	14	629.0	562.0	-45.0	-62.5	0.001
15	674.0	624.5	569.5	406.5	0.000	15	674.0	624.5	0.0	0.0	0.003
16	786.5	469.0	682.0	251.0	0.000	16	786.5	469.0	112.5	-155.5	0.000
17	944.0	376.0	839.5	158.0	0.000	17	944.0	376.0	270.0	-248.5	0.000
18	944.0	562.0	839.5	344.0	0.000	18	944.0	562.0	270.0	-62.5	0.000
19	104.5	152.5	0.0	-65.5	0.004	19	104.5	152.5	-569.5	-472.0	0.000
20	104.5	283.5	0.0	65.5	0.004	20	104.5	283.5	-569.5	-341.0	0.000
21	104.5	496.5	0.0	278.5	0.001	21	104.5	496.5	-569.5	-128.0	0.000
22	104.5	627.5	0.0	409.5	0.001	22	104.5	627.5	-569.5	3.0	0.000

CALCULATION BASED ON LOADED AREA 9					
Settle ID	General Coordinates		Local Coordinates		Settlement Component
	X	Y	X'	Y'	
1	300.0	200.0	-374.0	-17.5	0.000
2	300.0	333.0	-374.0	115.5	0.000
3	300.0	546.0	-374.0	328.5	0.000
4	419.5	266.5	-254.5	49.0	0.000
5	454.5	439.5	-219.5	222.0	0.000
6	539.0	200.0	-135.0	-17.5	0.000
7	539.0	333.0	-135.0	115.5	0.000
8	574.0	275.5	-100.0	58.0	0.001
9	574.0	603.5	-100.0	386.0	0.000
10	609.0	333.0	-65.0	115.5	0.001
11	609.0	546.0	-65.0	328.5	0.000
12	674.0	217.5	0.0	0.0	0.003
13	629.0	376.0	-45.0	158.5	0.000
14	629.0	562.0	-45.0	344.5	0.000
15	674.0	624.5	0.0	407.0	0.000
16	786.5	469.0	112.5	251.5	0.000
17	944.0	376.0	270.0	158.5	0.000
18	944.0	562.0	270.0	344.5	0.000
19	104.5	152.5	-569.5	-65.0	0.000
20	104.5	283.5	-569.5	66.0	0.000
21	104.5	496.5	-569.5	279.0	0.000
22	104.5	627.5	-569.5	410.0	0.000

SUMMARY OF SETTLEMENT							
Settlement Point	X	Y	Settlement Inches	Settlement Point	X	Y	Settlement Inches
1	300.00	200.00	0.15	2	300.00	333.00	0.21
3	300.00	546.00	0.18	4	419.50	266.50	0.23
5	454.50	439.50	0.30	6	539.00	200.00	0.16
7	539.00	333.00	0.26	8	574.00	275.50	0.20
9	574.00	603.50	0.18	10	609.00	333.00	0.22
11	609.00	546.00	0.22	12	674.00	217.50	0.16
13	629.00	376.00	0.21	14	629.00	562.00	0.19
15	674.00	624.50	0.17	16	786.50	469.00	0.19
17	944.00	376.00	0.11	18	944.00	562.00	0.11
19	104.50	152.50	0.12	20	104.50	283.50	0.13
21	104.50	496.50	0.14	22	104.50	627.50	0.12

Appendix A


Locations of Settlement Points
Relative X Coordinate
Relative Y Coordinate
0
200
400
600
800
1000
1200
0
100
200
300
400
500
600
700
800
1
2
3
4
5
6
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22

SETTLEMENT ANALYSIS OF LAYERED SITE-Berm Model, Mathcad Sheet for Cross Check against Excel Sheet

METHODOLOGY

This worksheet has been developed to calculate elastic settlement induced by foundation pressure. The soils supporting foundations are considered as layered elastic medium and the stress increment at each layer center due to a rectanglar uniformly loaded area at or below ground surface is computed by classic Boussinesq solution. The settlement for each layer is calculated using the vertical stress increment and elastic modulus of the layer, and total settlement is obtained by summing all layer settlements in the influenced zone.

Stress Increment: The equation of Boussinesq solution to compute the stress increment under the corner of a rectanglar loaded area are shown as below. When the stress calculation point is not located under the corner of a given loaded area, superposition of rectanglar areas covering the loaded surface and stress calculation point are used to calculate the stress.

Boussinesq Solution:

$$\Delta\sigma_z = \frac{q}{4\pi}\left[\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+m^2n^2+1}\,\frac{m^2+n^2+2}{m^2+n^2+1}+\sin^{-1}\left(\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+m^2n^2+1}\right)\right]$$

where q is load intensity, *m=L/Z, N=B/Z*, and *B, L* and *Z* are foundation width, length and stress point depth, respectively. The angle in second term in the parenthesis is less than π/2 when $m^2+n^2+1>m^2n^2$, otherwise between π/2 and π.

Settlement Calculation:The settlement in a given layer is calculated by an equation shown as below.

$$S_i = \Delta\sigma_{zi} H_i \frac{1-\mu_i^{\,2}}{E_i}$$

where H, E and μ are layer thickness, modulus and poisson ratio, respectively.

Total Settlement: $$S = \sum_1^n S_i$$

where n is number of the total layeres influeenced by foundation pressures

DATA INPUT

Number of Loaded Area: NLA := 9 (Maximum 20)

Number of Stress Points in Z Direction: NSPZ := 25 (Maximum 40)

Number of Settlement Points in Plane: NSPP := 22 (Maximum 40)

Stress Calculation Method: ISCC := 1 (1. Boussinesq)

Loaded Area:	1	2	3	4	5	6	7	8	9
Loaded Intensity (PSF) of Each Loaded Area:	11320	6770	5860	4310	4310	3610	3610	5380	5380
Embedment Depth (FT) of Each Loaded Area:	40	40	40	40	40	40	40	40	40

Coordinates (FT) of Corners of Each Loaded Rectangle:

	X1	Y1	X2	Y2	X3	Y3	X4	Y4
Loaded Area 1	300.0	333.0	609.0	333.0	609.0	546.0	300.0	546.0
Loaded Area 2	300.0	200.0	539.0	200.0	539.0	333.0	300.0	333.0
Loaded Area 3	629.0	376.0	944.0	376.0	944.0	562.0	629.0	562.0
Loaded Area 4	539.0	546.0	609.0	546.0	609.0	661.0	539.0	661.0
Loaded Area 5	539.0	218.0	609.0	218.0	609.0	333.0	539.0	333.0
Loaded Area 6	39.0	431.0	170.0	431.0	170.0	693.0	39.0	693.0
Loaded Area 7	39.0	87.0	170.0	87.0	170.0	349.0	39.0	349.0
Loaded Area 8	635.0	582.0	713.0	582.0	713.0	667.0	635.0	667.0
Loaded Area 9	635.0	175.0	713.0	175.0	713.0	260.0	635.0	260.0

Layer	Depth to Layer Center (FT)	Modulus (PSF)	Poisson Ratio
1	3.00	155,547,652	0.3
2	15.00	155,547,652	0.3
3	28.00	44,262,695	0.3
4	36.00	48,648,130	0.3
5	50.00	405,550,066	0.3
6	70.00	405,550,066	0.3
7	92.50	405,550,066	0.3
8	107.00	59,687,742	0.3
9	120.50	313,510,454	0.3
10	149.00	585,032,604	0.3
11	183.00	205,855,826	0.3
12	214.50	72,539,100	0.3
13	239.00	110,220,264	0.3
14	264.00	110,220,264	0.3
15	294.00	110,220,264	0.3
16	324.00	117,958,712	0.3
17	355.00	117,958,712	0.3
18	386.00	110,901,382	0.3
19	417.50	110,901,382	0.3
20	463.00	378,267,514	0.3
21	542.00	378,267,514	0.3
22	642.00	378,267,514	0.3
23	742.00	378,267,514	0.3
24	842.00	378,267,514	0.3
25	942.00	378,267,514	0.3

Coords of Settlement Points (FT)

X	Y
300	200
300	333
300	546
419.5	266.5
454.5	439.5
539	200
539	333
574	275.5
574	603.5
609	333
609	546
674	217.5
629	376
629	562
674	624.5
786.5	469
944	376
944	562
104.5	152.5
104.5	283.5
104.5	496.5
104.5	627.5

RESULTS:

Stress Increment Matrix (PSF): The column index is layer Identification number, and the row index is settlement point number. The total stress increment contributed by all loaded areas at each layer center of each settlement point.

Stressinc =

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	0	0	0	1693	1703	1739	1777	1821	1919	2018	2070	2082	2072	2036	1980	1909	1828	1742	1616	1406	1174	983	828	703
2	0	0	0	0	4522	4516	4490	4457	4416	4291	4086	3860	3671	3473	3236	3008	2784	2574	2378	2123	1754	1396	1129	928	773
3	0	0	0	0	2830	2834	2849	2863	2877	2898	2889	2842	2780	2701	2589	2466	2333	2200	2067	1884	1600	1304	1072	891	748
4	0	0	0	0	6767	6707	6510	6321	6118	5650	5088	4606	4264	3945	3600	3292	3008	2755	2525	2236	1830	1446	1164	952	791
5	0	0	0	0	.1316	.1229	.0904	.0557	.0160	9184	7975	6945	6237	5600	4941	4383	3895	3480	3121	2689	2122	1622	1275	1026	841
6	0	0	0	0	1749	2095	2331	2420	2481	2567	2607	2594	2557	2501	2416	2317	2207	2094	1978	1816	1557	1281	1059	883	743
7	0	0	0	0	8425	8318	7994	7712	7427	6819	6128	5536	5109	4704	4261	3863	3496	3171	2879	2515	2016	1561	1237	1001	824
8	0	0	0	0	4305	4253	4223	4221	4214	4156	4012	3826	3661	3483	3265	3048	2832	2627	2432	2176	1800	1432	1156	948	788
9	0	0	0	0	4279	3892	3472	3347	3294	3254	3205	3121	3032	2926	2784	2636	2480	2326	2176	1972	1661	1343	1098	908	760
10	0	0	0	0	3912	4004	4213	4344	4438	4525	4452	4270	4085	3876	3613	3352	3092	2849	2619	2322	1895	1488	1191	969	802
11	0	0	0	0	4007	4648	5016	5078	5062	4894	4581	4257	4003	3752	3465	3198	2942	2708	2491	2213	1815	1435	1155	945	785
12	0	0	0	0	5326	4510	3236	2648	2280	1887	1764	1768	1789	1806	1811	1796	1764	1716	1657	1560	1381	1166	982	829	705
13	0	0	0	0	1690	3248	4305	4622	4782	4879	4759	4529	4308	4066	3769	3480	3196	2932	2687	2372	1924	1504	1199	974	805
14	0	0	0	0	1614	2799	3748	4040	4170	4193	4018	3787	3594	3396	3164	2942	2726	2525	2336	2090	1732	1382	1120	921	768
15	0	0	0	0	5331	4607	3556	3110	2847	2570	2443	2375	2324	2266	2188	2100	2005	1906	1806	1664	1436	1191	992	833	706
16	0	0	0	0	5857	5786	5542	5305	5053	4501	3908	3460	3171	2921	2666	2449	2256	2086	1933	1740	1464	1193	985	824	697
17	0	0	0	0	1465	1463	1455	1446	1435	1402	1352	1303	1265	1228	1187	1148	1110	1073	1037	987	902	800	706	623	549
18	0	0	0	0	1465	1463	1455	1446	1434	1400	1348	1295	1253	1212	1165	1121	1079	1039	1001	949	865	767	679	601	531
19	0	0	0	0	3603	3451	3038	2722	2441	1952	1561	1335	1220	1138	1071	1025	990	963	938	905	846	766	686	610	542
20	0	0	0	0	3603	3456	3060	2764	2506	2079	1763	1597	1516	1457	1405	1361	1320	1279	1236	1173	1061	925	803	696	605
21	0	0	0	0	3603	3456	3062	2767	2511	2088	1779	1617	1539	1482	1431	1388	1346	1304	1261	1197	1082	943	817	707	614
22	0	0	0	0	3603	3451	3038	2723	2442	1956	1569	1348	1236	1158	1095	1052	1021	995	972	940	880	797	712	632	559

Settlements Matrix (Inches): The row index of the matrix is settlement point number, and the column index is layer identification number. The Settlement in this matrix is total settlement contributed by each loaded area at each layer of each settlement point.

SettleComp =

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	0	0	0	0.001	0.001	0.001	0.001	0.001	0.001	0.004	0.009	0.004	0.006	0.006	0.005	0.006	0.005	0.006	0.003	0.004	0.003	0.003	0.002	0.002
2	0	0	0	0	0.002	0.002	0.003	0.003	0.004	0.003	0.007	0.017	0.007	0.01	0.01	0.008	0.008	0.008	0.008	0.004	0.005	0.004	0.003	0.003	0.002
3	0	0	0	0	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.012	0.006	0.008	0.008	0.007	0.007	0.006	0.007	0.003	0.005	0.004	0.003	0.003	0.002
4	0	0	0	0	0.004	0.004	0.004	0.005	0.005	0.004	0.009	0.02	0.008	0.012	0.011	0.009	0.009	0.008	0.008	0.004	0.005	0.004	0.003	0.003	0.002
5	0	0	0	0	0.006	0.006	0.007	0.008	0.008	0.006	0.014	0.03	0.012	0.017	0.015	0.012	0.012	0.01	0.01	0.005	0.006	0.005	0.004	0.003	0.002
6	0	0	0	0	0.001	0.001	0.002	0.002	0.002	0.002	0.005	0.011	0.005	0.007	0.007	0.006	0.007	0.006	0.006	0.003	0.004	0.004	0.003	0.003	0.002
7	0	0	0	0	0.005	0.004	0.005	0.006	0.006	0.004	0.011	0.024	0.01	0.014	0.013	0.011	0.01	0.009	0.009	0.004	0.006	0.005	0.004	0.003	0.002
8	0	0	0	0	0.002	0.002	0.003	0.003	0.003	0.003	0.007	0.017	0.007	0.01	0.01	0.008	0.008	0.008	0.008	0.004	0.005	0.004	0.003	0.003	0.002
9	0	0	0	0	0.002	0.002	0.002	0.002	0.003	0.002	0.006	0.014	0.006	0.009	0.008	0.007	0.007	0.007	0.007	0.003	0.005	0.004	0.003	0.003	0.002
10	0	0	0	0	0.002	0.002	0.003	0.003	0.004	0.003	0.008	0.019	0.008	0.012	0.011	0.009	0.009	0.008	0.009	0.004	0.005	0.004	0.003	0.003	0.002
11	0	0	0	0	0.002	0.003	0.003	0.004	0.004	0.003	0.008	0.019	0.008	0.011	0.01	0.009	0.009	0.008	0.008	0.004	0.005	0.004	0.003	0.003	0.002
12	0	0	0	0	0.003	0.002	0.002	0.002	0.002	0.001	0.003	0.008	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.004	0.003	0.003	0.002	0.002
13	0	0	0	0	0.001	0.002	0.003	0.003	0.004	0.003	0.009	0.02	0.009	0.012	0.011	0.01	0.009	0.009	0.009	0.004	0.006	0.004	0.003	0.003	0.002
14	0	0	0	0	0.001	0.002	0.003	0.003	0.003	0.003	0.007	0.017	0.007	0.01	0.009	0.008	0.008	0.007	0.008	0.003	0.005	0.004	0.003	0.003	0.002
15	0	0	0	0	0.003	0.002	0.002	0.002	0.002	0.002	0.004	0.01	0.005	0.007	0.007	0.006	0.006	0.006	0.006	0.003	0.004	0.003	0.003	0.002	0.002
16	0	0	0	0	0.003	0.003	0.004	0.004	0.004	0.003	0.007	0.015	0.006	0.009	0.008	0.007	0.007	0.006	0.006	0.003	0.004	0.003	0.003	0.002	0.002
17	0	0	0	0	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.006	0.003	0.004	0.004	0.003	0.003	0.003	0.003	0.002	0.003	0.002	0.002	0.002	0.002
18	0	0	0	0	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.006	0.002	0.004	0.003	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.002
19	0	0	0	0	0.002	0.002	0.002	0.002	0.002	0.001	0.003	0.006	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.002
20	0	0	0	0	0.002	0.002	0.002	0.002	0.002	0.001	0.003	0.007	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.002	0.003	0.003	0.002	0.002	0.002
21	0	0	0	0	0.002	0.002	0.002	0.002	0.002	0.001	0.003	0.007	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.002	0.003	0.003	0.002	0.002	0.002
22	0	0	0	0	0.002	0.002	0.002	0.002	0.002	0.001	0.003	0.006	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.002	0.002	0.002	0.002

$\mathbf{Settle} := \mathbf{TotalSettle}(\mathbf{NSPP}, \mathbf{NSPZ}, \mathbf{SettleComp})$

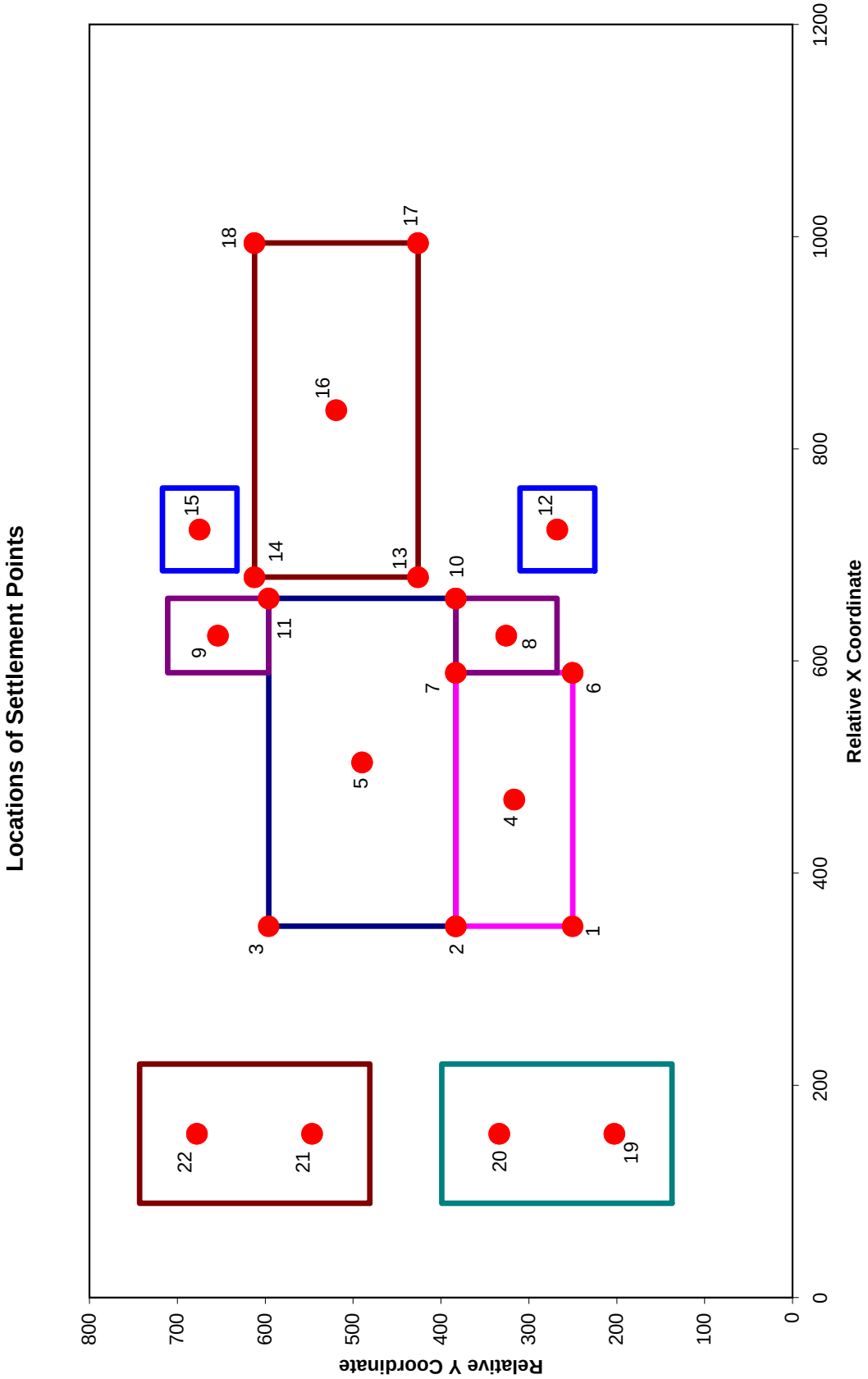
Total Settlement Matrix (Inches)

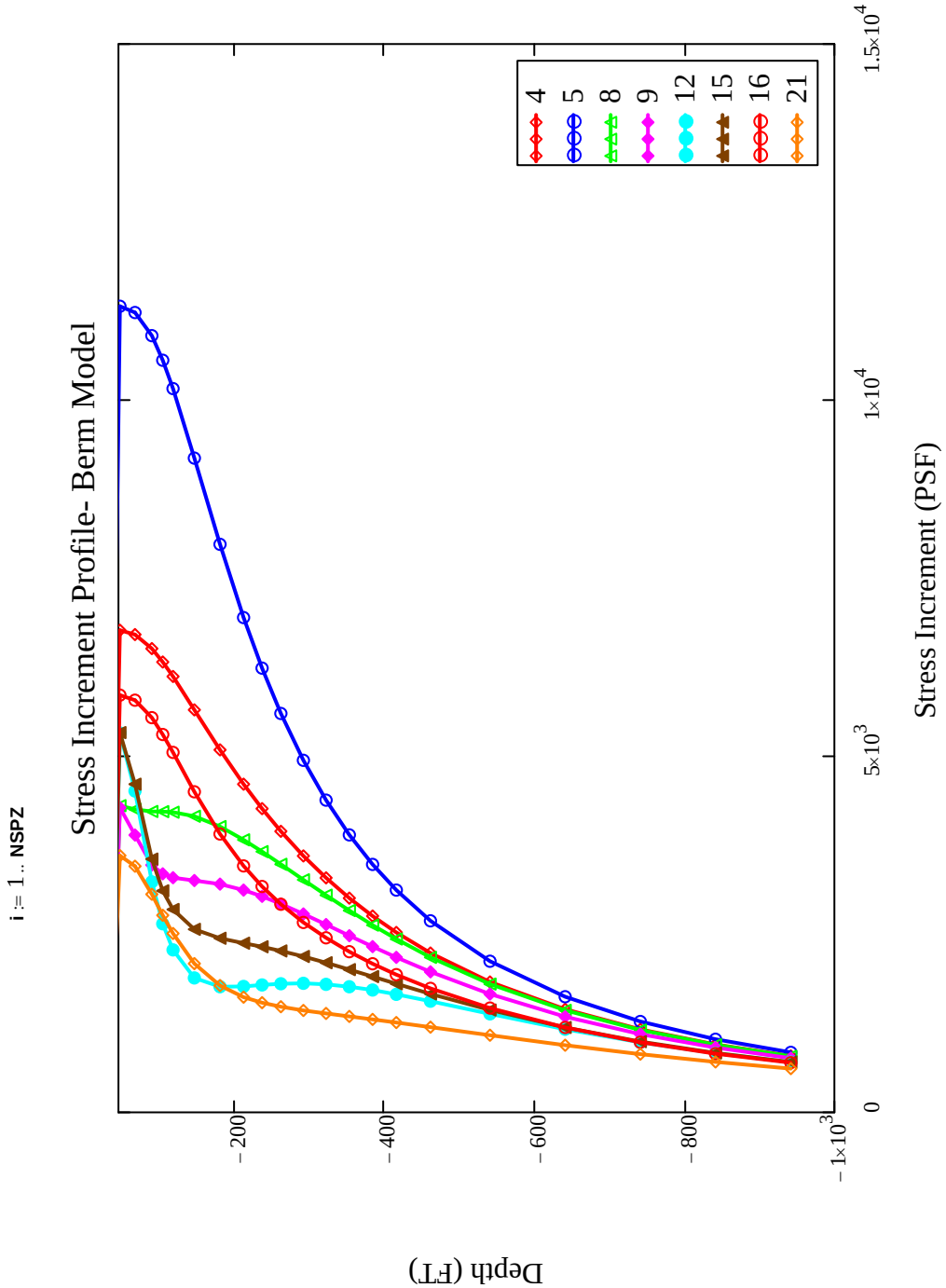
(Column index is the settlement point number)

$\mathbf{Settle}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	0.08	0.12	0.1	0.14	0.2	0.09	0.17	0.12	0.1	0.13	0.13	0.08	0.14	0.12	0.09	0.11	0.05	0.05	0.05	0.06	0.06	0.05

Appendix A


Locations of Settlement Points
Relative X Coordinate
Relative Y Coordinate
0
200
400
600
800
1000
1200
0
100
200
300
400
500
600
700
800
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22


i := 1 .. NSPZ
Stress Increment Profile- Berm Model
Depth (FT)
Stress Increment (PSF)
−200
−400
−600
−800
−1×10^3
0
5×10^3
1×10^4
1.5×10^4
4
5
8
9
12
15
16
21

SETTLEMENT ANALYSIS OF LAYERED SITE-Lbrm Model, Mathcad Sheet for Cross Check against Excel Sheet

METHODOLOGY

This worksheet has been developed to calculate elastic settlement induced by foundation pressure. The soils supporting foundations are considered as layered elastic medium and the stress increment at each layer center due to a rectanglar uniformly loaded area at or below ground surface is computed by classic Boussinesq solution. The settlement for each layer is calculated using the vertical stress increment and elastic modulus of the layer, and total settlement is obtained by summing all layer settlements in the influenced zone.

Stress Increment: The equation of Boussinesq solution to compute the stress increment under the corner of a rectanglar loaded area are shown as below. When the stress calculation point is not located under the corner of a given loaded area, superposition of rectanglar areas covering the loaded surface and stress calculation point are used to calculate the stress.

Boussinesq Solution:

$$\Delta\sigma_z = \frac{q}{4\pi}\left[\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+m^2n^2+1}\frac{m^2+n^2+2}{m^2+n^2+1}+\sin^{-1}\left(\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+m^2n^2+1}\right)\right]$$

where q is load intensity, *m=L/Z, N=B/Z*, and *B, L* and *Z* are foundation width, length and stress point depth, respectively. The angle in second term in the parenthesis is less than π/2 when $m^2+n^2+1>m^2n^2$, otherwise between π/2 and π.

Settlement Calculation:The settlement in a given layer is calculated by an equation shown as below.

$$S_i = \Delta\sigma_{zi} H_i \frac{1-\mu_i^{\,2}}{E_i}$$

where H, E and μ are layer thickness, modulus and poisson ratio, respectively.

Total Settlement: $$S = \sum_1^n S_i$$

where n is number of the total layeres influeenced by foundation pressures

DATA INPUT

Number of Loaded Area: NLA := 9 (Maximum 20)

Number of Stress Points in Z Direction: NSPZ := 25 (Maximum 40)

Number of Settlement Points in Plane: NSPP := 22 (Maximum 40)

Stress Calculation Method: ISCC := 1 (1. Boussinesq)

Loaded Area:	1	2	3	4	5	6	7	8	9
Loaded Intensity (PSF) of Each Loaded Area:	11320	6770	5860	4310	4310	3610	3610	5380	5380
Embedment Depth (FT) of Each Loaded Area:	40	40	40	40	40	40	40	40	40

Coordinates (FT) of Corners of Each Loaded Rectangle:

	X1	Y1	X2	Y2	X3	Y3	X4	Y4
Loaded Area 1	300.0	333.0	609.0	333.0	609.0	546.0	300.0	546.0
Loaded Area 2	300.0	200.0	539.0	200.0	539.0	333.0	300.0	333.0
Loaded Area 3	629.0	376.0	944.0	376.0	944.0	562.0	629.0	562.0
Loaded Area 4	539.0	546.0	609.0	546.0	609.0	661.0	539.0	661.0
Loaded Area 5	539.0	218.0	609.0	218.0	609.0	333.0	539.0	333.0
Loaded Area 6	39.0	431.0	170.0	431.0	170.0	693.0	39.0	693.0
Loaded Area 7	39.0	87.0	170.0	87.0	170.0	349.0	39.0	349.0
Loaded Area 8	635.0	582.0	713.0	582.0	713.0	667.0	635.0	667.0
Loaded Area 9	635.0	175.0	713.0	175.0	713.0	260.0	635.0	260.0

Appendix A

Layer	Depth to Layer Center (FT)	Modulus (PSF)	Poisson Ratio
1	3.00	91,508,416	0.3
2	15.00	91,508,416	0.3
3	28.00	11,650,143	0.3
4	36.00	11,650,143	0.3
5	50.00	139,212,424	0.3
6	70.00	139,212,424	0.3
7	92.50	139,212,424	0.3
8	107.00	11,650,143	0.3
9	120.50	139,212,424	0.3
10	149.00	139,212,424	0.3
11	183.00	139,212,424	0.3
12	214.50	44,754,165	0.3
13	239.00	91,866,353	0.3
14	264.00	91,866,353	0.3
15	294.00	91,866,353	0.3
16	324.00	75,174,273	0.3
17	355.00	75,174,273	0.3
18	386.00	90,209,128	0.3
19	417.50	90,209,128	0.3
20	463.00	200,298,272	0.3
21	542.00	200,298,272	0.3
22	642.00	200,298,272	0.3
23	742.00	200,298,272	0.3
24	842.00	200,298,272	0.3
25	942.00	200,298,272	0.3

Coords of Settlement Points (FT)

X	Y
300	200
300	333
300	546
419.5	266.5
454.5	439.5
539	200
539	333
574	275.5
574	603.5
609	333
609	546
674	217.5
629	376
629	562
674	624.5
786.5	469
944	376
944	562
104.5	152.5
104.5	283.5
104.5	496.5
104.5	627.5

RESULTS:

Stress Increment Matrix (PSF): The column index is layer identification number, and the row index is settlement point number. The total stress increment contributed by all loaded areas at each layer center of each settlement point.

Stressinc =

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	0	0	0	1693	1703	1739	1777	1821	1919	2018	2070	2082	2072	2036	1980	1909	1828	1742	1616	1406	1174	983	828	703
2	0	0	0	0	4522	4516	4490	4457	4416	4291	4086	3860	3671	3473	3236	3008	2784	2574	2378	2123	1754	1396	1129	928	773
3	0	0	0	0	2830	2834	2849	2863	2877	2898	2889	2842	2780	2701	2589	2466	2333	2200	2067	1884	1600	1304	1072	891	748
4	0	0	0	0	6767	6707	6510	6321	6118	5650	5088	4606	4264	3945	3600	3292	3008	2755	2525	2236	1830	1446	1164	952	791
5	0	0	0	0	11316	11229	10904	10557	10160	9184	7975	6945	6237	5600	4941	4383	3895	3480	3121	2689	2122	1622	1275	1026	841
6	0	0	0	0	1749	2095	2331	2420	2481	2567	2607	2594	2557	2501	2416	2317	2207	2094	1978	1816	1557	1281	1059	883	743
7	0	0	0	0	8425	8318	7994	7712	7427	6819	6128	5536	5109	4704	4261	3863	3496	3171	2879	2515	2016	1561	1237	1001	824
8	0	0	0	0	4305	4253	4223	4221	4214	4156	4012	3826	3661	3483	3265	3048	2832	2627	2432	2176	1800	1432	1156	948	788
9	0	0	0	0	4279	3892	3472	3347	3294	3254	3205	3121	3032	2926	2784	2636	2480	2326	2176	1972	1661	1343	1098	908	760
10	0	0	0	0	3912	4004	4213	4344	4438	4525	4452	4270	4085	3876	3613	3352	3092	2849	2619	2322	1895	1488	1191	969	802
11	0	0	0	0	4007	4648	5016	5078	5062	4894	4581	4257	4003	3752	3465	3198	2942	2708	2491	2213	1815	1435	1155	945	785
12	0	0	0	0	5326	4510	3236	2648	2280	1887	1764	1768	1789	1806	1811	1796	1764	1716	1657	1560	1381	1166	982	829	705
13	0	0	0	0	1690	3248	4305	4622	4782	4879	4759	4529	4308	4066	3769	3480	3196	2932	2687	2372	1924	1504	1199	974	805
14	0	0	0	0	1614	2799	3748	4040	4170	4193	4018	3787	3594	3396	3164	2942	2726	2525	2336	2090	1732	1382	1120	921	768
15	0	0	0	0	5331	4607	3556	3110	2847	2570	2443	2375	2324	2266	2188	2100	2005	1906	1806	1664	1436	1191	992	833	706
16	0	0	0	0	5857	5786	5542	5305	5053	4501	3908	3460	3171	2921	2666	2449	2256	2086	1933	1740	1464	1193	985	824	697
17	0	0	0	0	1465	1463	1455	1446	1435	1402	1352	1303	1265	1228	1187	1148	1110	1073	1037	987	902	800	706	623	549
18	0	0	0	0	1465	1463	1455	1446	1434	1400	1348	1295	1253	1212	1165	1121	1079	1039	1001	949	865	767	679	601	531
19	0	0	0	0	3603	3451	3038	2722	2441	1952	1561	1335	1220	1138	1071	1025	990	963	938	905	846	766	686	610	542
20	0	0	0	0	3603	3456	3060	2764	2506	2079	1763	1597	1516	1457	1405	1361	1320	1279	1236	1173	1061	925	803	696	605
21	0	0	0	0	3603	3456	3062	2767	2511	2088	1779	1617	1539	1482	1431	1388	1346	1304	1261	1197	1082	943	817	707	614
22	0	0	0	0	3603	3451	3038	2723	2442	1956	1569	1348	1236	1158	1095	1052	1021	995	972	940	880	797	712	632	559

Settlements Matrix (Inches): The row index of the matrix is settlement point number, and the column index is layer number. The Settlement in this matrix is total settlement contributed by each loaded area at each layer of each settlement point.

SettleComp =

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	0	0	0	0.003	0.003	0.003	0.007	0.003	0.005	0.005	0.015	0.005	0.007	0.007	0.009	0.009	0.007	0.007	0.005	0.008	0.006	0.005	0.005	0.004
2	0	0	0	0	0.007	0.007	0.009	0.017	0.008	0.011	0.011	0.027	0.009	0.012	0.012	0.013	0.013	0.009	0.009	0.007	0.01	0.008	0.006	0.005	0.004
3	0	0	0	0	0.004	0.004	0.006	0.011	0.005	0.008	0.008	0.02	0.007	0.01	0.009	0.011	0.011	0.008	0.008	0.006	0.009	0.007	0.006	0.005	0.004
4	0	0	0	0	0.011	0.011	0.013	0.024	0.011	0.015	0.014	0.033	0.01	0.014	0.013	0.014	0.014	0.01	0.01	0.007	0.01	0.008	0.006	0.005	0.004
5	0	0	0	0	0.018	0.018	0.021	0.04	0.018	0.024	0.021	0.049	0.015	0.02	0.018	0.019	0.018	0.013	0.012	0.009	0.012	0.009	0.007	0.006	0.005
6	0	0	0	0	0.003	0.003	0.005	0.009	0.004	0.007	0.007	0.018	0.006	0.009	0.009	0.01	0.01	0.008	0.008	0.006	0.008	0.007	0.006	0.005	0.004
7	0	0	0	0	0.013	0.013	0.016	0.029	0.013	0.018	0.016	0.039	0.012	0.017	0.015	0.017	0.016	0.012	0.011	0.008	0.011	0.009	0.007	0.005	0.004
8	0	0	0	0	0.007	0.007	0.008	0.016	0.008	0.011	0.011	0.027	0.009	0.012	0.012	0.013	0.013	0.01	0.01	0.007	0.01	0.008	0.006	0.005	0.004
9	0	0	0	0	0.007	0.006	0.007	0.013	0.006	0.009	0.009	0.022	0.007	0.01	0.01	0.011	0.012	0.008	0.009	0.006	0.009	0.007	0.006	0.005	0.004
10	0	0	0	0	0.006	0.006	0.008	0.016	0.008	0.012	0.012	0.03	0.01	0.014	0.013	0.015	0.014	0.01	0.01	0.007	0.01	0.008	0.006	0.005	0.004
11	0	0	0	0	0.006	0.007	0.01	0.019	0.009	0.013	0.012	0.03	0.01	0.013	0.012	0.014	0.014	0.01	0.01	0.007	0.01	0.008	0.006	0.005	0.004
12	0	0	0	0	0.008	0.007	0.006	0.01	0.004	0.005	0.005	0.013	0.004	0.006	0.006	0.008	0.008	0.006	0.007	0.005	0.008	0.006	0.005	0.005	0.004
13	0	0	0	0	0.003	0.005	0.008	0.017	0.009	0.013	0.013	0.032	0.01	0.014	0.013	0.015	0.015	0.011	0.011	0.007	0.01	0.008	0.007	0.005	0.004
14	0	0	0	0	0.003	0.004	0.007	0.015	0.008	0.011	0.011	0.027	0.009	0.012	0.011	0.013	0.013	0.009	0.009	0.007	0.009	0.008	0.006	0.005	0.004
15	0	0	0	0	0.008	0.007	0.007	0.012	0.005	0.007	0.007	0.017	0.006	0.008	0.008	0.009	0.009	0.007	0.007	0.005	0.008	0.006	0.005	0.005	0.004
16	0	0	0	0	0.009	0.009	0.011	0.02	0.009	0.012	0.01	0.024	0.008	0.01	0.01	0.011	0.01	0.008	0.008	0.006	0.008	0.007	0.005	0.004	0.004
17	0	0	0	0	0.002	0.002	0.003	0.005	0.003	0.004	0.004	0.009	0.003	0.004	0.004	0.005	0.005	0.004	0.004	0.003	0.005	0.004	0.004	0.003	0.003
18	0	0	0	0	0.002	0.002	0.003	0.005	0.003	0.004	0.004	0.009	0.003	0.004	0.004	0.005	0.005	0.004	0.004	0.003	0.005	0.004	0.004	0.003	0.003
19	0	0	0	0	0.006	0.005	0.006	0.01	0.004	0.005	0.004	0.009	0.003	0.004	0.004	0.004	0.005	0.003	0.004	0.003	0.005	0.004	0.004	0.003	0.003
20	0	0	0	0	0.006	0.005	0.006	0.01	0.005	0.006	0.005	0.011	0.004	0.005	0.005	0.006	0.006	0.005	0.005	0.004	0.006	0.005	0.004	0.004	0.003
21	0	0	0	0	0.006	0.005	0.006	0.01	0.005	0.006	0.005	0.011	0.004	0.005	0.005	0.006	0.006	0.005	0.005	0.004	0.006	0.005	0.004	0.004	0.003
22	0	0	0	0	0.006	0.005	0.006	0.01	0.004	0.005	0.004	0.01	0.003	0.004	0.004	0.005	0.005	0.004	0.004	0.003	0.005	0.004	0.004	0.003	0.003

$Settle := TotalSettle(NSPP, NSPZ, SettleComp)$

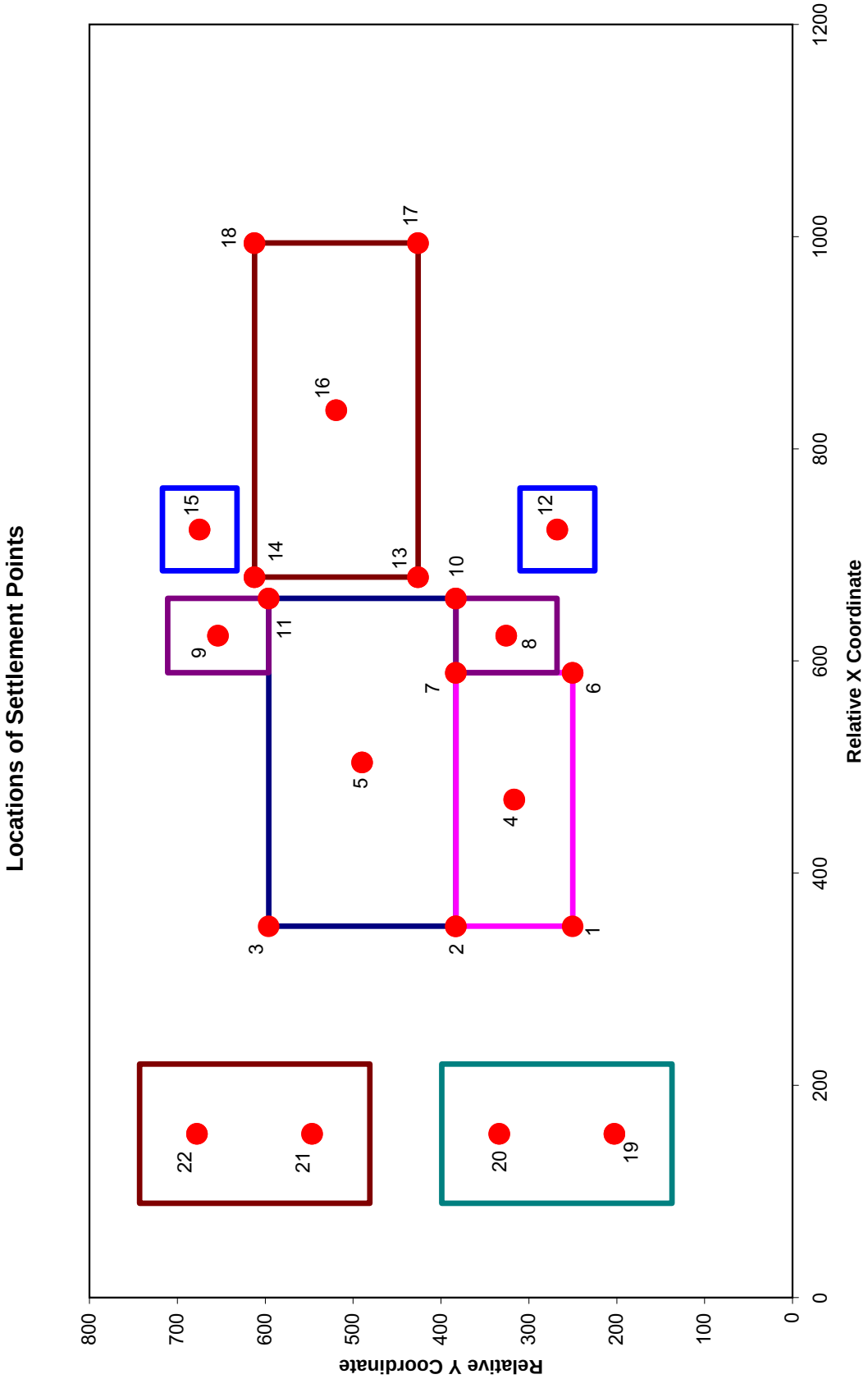
Total Settlement Matrix (Inches)

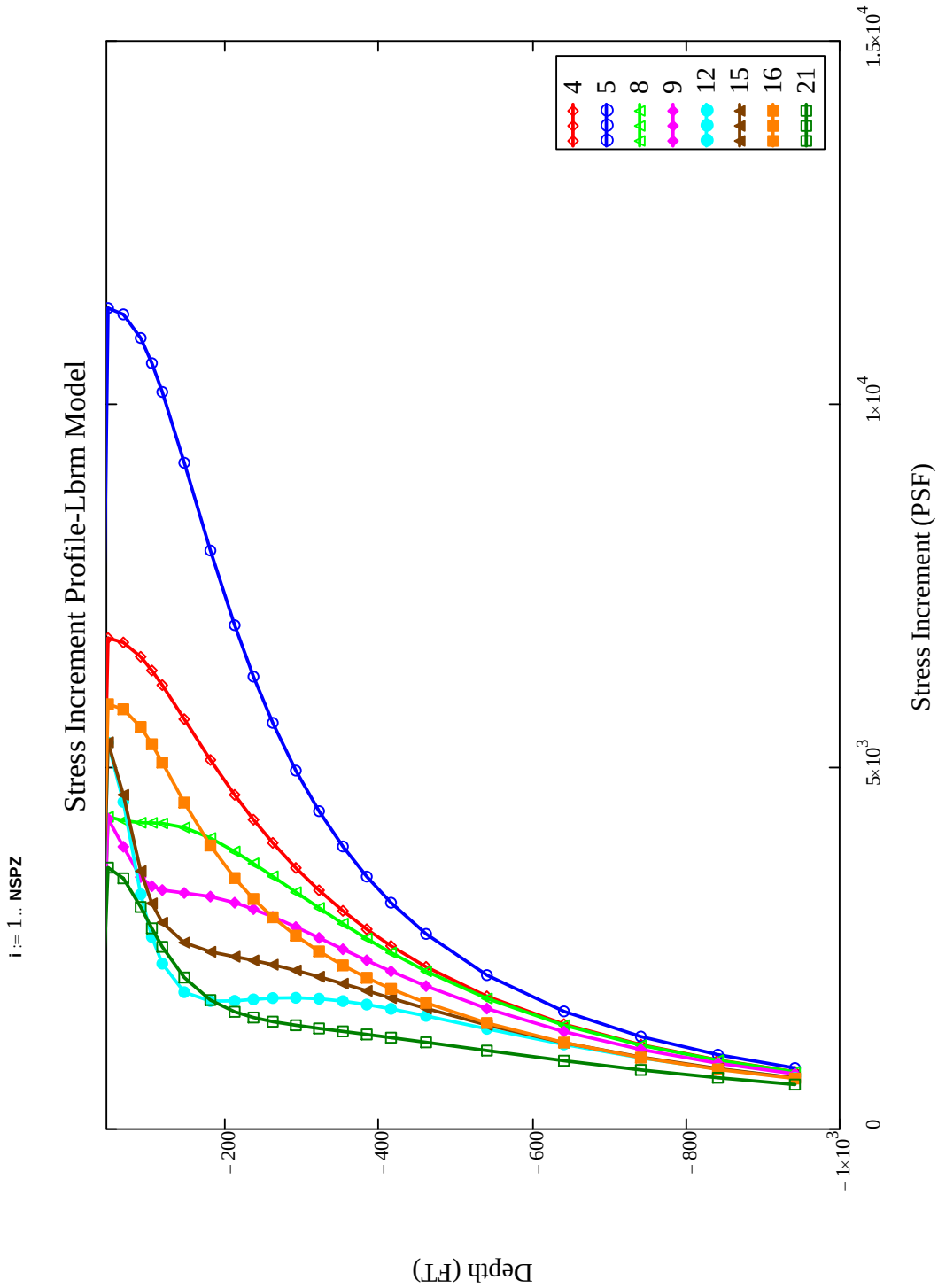
(Column index is the settlement point number)

$Settle^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	0.13	0.21	0.17	0.26	0.37	0.15	0.3	0.21	0.18	0.23	0.23	0.14	0.23	0.2	0.16	0.2	0.08	0.08	0.1	0.11	0.12	0.1

Appendix A


Locations of Settlement Points
Relative X Coordinate
Relative Y Coordinate
0
200
400
600
800
1000
1200
0
100
200
300
400
500
600
700
800
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22


Stress Increment Profile-Lbrm Model
i := 1.. NSPZ
Depth (FT)
Stress Increment (PSF)
0
5×10^3
1×10^4
1.5×10^4
−200
−400
−600
−800
−1×10^3
4
5
8
9
12
15
16
21

MODULUS AVERAGING

LAYER ID	LAYER CENTER DEPTH FT	THICKNESS FT	MODULUS PSF	$\sum_{i=1}^{n}\left(E_i \Big/ \sum_{j=1}^{i} h_j\right)$	$\sum_{i=1}^{n}\left(1 \Big/ \sum_{j=1}^{i} h_j\right)$
1.00	3.00	6.00	155,547,652		
2.00	15.00	18.00	155,547,652		
3.00	28.00	8.00	44,262,695		
4.00	36.00	8.00	48,648,130		
5.00	50.00	20.00	405,550,066	20277503	0.050
6.00	70.00	20.00	405,550,066	10138752	0.025
7.00	92.50	25.00	405,550,066	6239232	0.015
8.00	107.00	4.00	59,687,742	865040	0.014
9.00	120.50	23.00	313,510,454	3407722	0.011
10.00	149.00	34.00	585,032,604	4643116	0.008
11.00	183.00	34.00	205,855,826	1286599	0.006
12.00	214.50	29.00	72,539,100	383805	0.005
13.00	239.00	20.00	110,220,264	527370	0.005
14.00	264.00	30.00	110,220,264	461173	0.004
15.00	294.00	30.00	110,220,264	409741	0.004
16.00	324.00	30.00	117,958,712	394511	0.003
17.00	355.00	32.00	117,958,712	356371	0.003
18.00	386.00	30.00	110,901,382	307206	0.003
19.00	417.50	33.00	110,901,382	281476	0.003
20.00	463.00	58.00	378,267,514	836875	0.002
21.00	542.00	100.00	378,267,514	685267	0.002
22.00	642.00	100.00	378,267,514	580165	0.002
23.00	742.00	100.00	378,267,514	503015	0.001
24.00	842.00	100.00	378,267,514	443976	0.001
25.00	942.00	100.00	378,267,514	397340	0.001

$$E_{dw} = \frac{\sum_{i=1}^{n}\left(E_i \Big/ \sum_{j=1}^{i} h_j\right)}{\sum_{i=1}^{n}\left(1 \Big/ \sum_{j=1}^{i} h_j\right)} = \begin{matrix} 2199 & \text{KSI} \\ 316701108 & \text{PSF} \end{matrix}$$

Weighted Modulus Calculation

NON-LAYERED METHOD--BERM MODEL

WORKSHEET OF FOUNDATION SETTLEMENT ESTIMATION
Nonlayered Method, Berm Model, Mathcad Sheet for Cross Check against Excel Sheet

Reference: Soil Mechanics Principles and Application (1976), William Perloff and William Baron, Page 199-201.

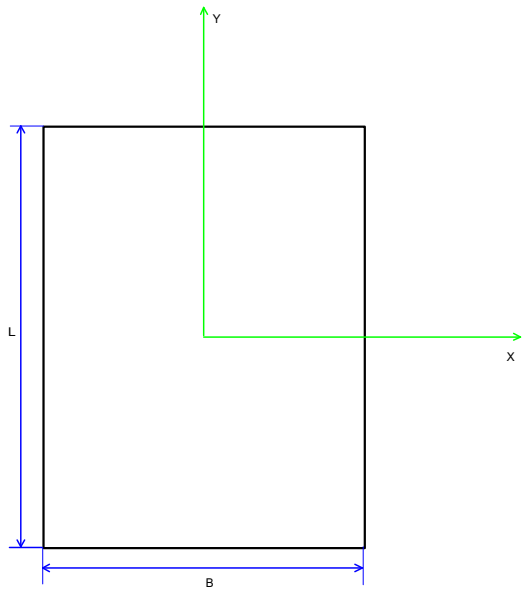


Figure 1. Notation for Rectanglular Loaded Area Shown in Plan View

The vertical Settlement of any point of the surface of an elastic half-space uniformly loaded over a rectangular area is expresses as

$$\delta(x, y, q, B, L) = C(x, y, B, L) \cdot \left[q \cdot B \cdot \frac{(1 - \mu)}{E_d} \right]$$

δ(x,y,q,B,L) = Vertical deformation at point (x,y) induced by a rectangular foundation.

q = unit load (psf)

B = foundation width (ft)

L = foundation length (ft)

μ= poisson's ratio

E_d = modulus of deformation of the rock foundation

C is a geometric factor which accounts for the shape of the rectangle shown in Figure B-1 and the position of the point for which the settlement is being calculated. C can be calculated based on following formulas:

$$\mathbf{A1}(\mathbf{x},\mathbf{B}) := 1 - 2\cdot\frac{\mathbf{x}}{\mathbf{B}} \qquad \mathbf{A2}(\mathbf{x},\mathbf{B}) := 1 + 2\cdot\frac{\mathbf{x}}{\mathbf{B}}$$

$$\mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L}) := \frac{\mathbf{L}}{\mathrm{B}} - 2\cdot\frac{\mathbf{y}}{\mathbf{B}} \qquad \mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L}) := \frac{\mathbf{L}}{\mathrm{B}} + 2\cdot\frac{\mathbf{y}}{\mathbf{B}}$$

$$\mathbf{C1}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) := \mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L})\cdot\ln\left[\frac{\left[\sqrt{(\mathbf{A1}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} + \mathbf{A1}(\mathbf{x},\mathbf{B})\right]}{\left[\sqrt{(\mathbf{A2}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} - \mathbf{A2}(\mathbf{x},\mathbf{B})\right]}\right]$$

$$\mathbf{C2}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) := \mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L})\cdot\ln\left[\frac{\left[\sqrt{(\mathbf{A1}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} + \mathbf{A1}(\mathbf{x},\mathbf{B})\right]}{\left[\sqrt{(\mathbf{A2}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} - \mathbf{A2}(\mathbf{x},\mathbf{B})\right]}\right]$$

$$\mathbf{C3}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) := \mathbf{A1}(\mathbf{x},\mathbf{B})\cdot\ln\left[\frac{\left[\sqrt{(\mathbf{A1}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} + \mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L})\right]}{\left[\sqrt{(\mathbf{A1}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} - \mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L})\right]}\right]$$

$$\mathbf{C4}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) := \mathbf{A2}(\mathbf{x},\mathbf{B})\cdot\ln\left[\frac{\left[\sqrt{(\mathbf{A2}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} + \mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L})\right]}{\left[\sqrt{(\mathbf{A2}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} - \mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L})\right]}\right]$$

$$\mathbf{C}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) := 0.159\cdot(\mathbf{C1}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) + \mathbf{C2}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) + \mathbf{C3}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) + \mathbf{C4}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}))$$

DATA INPUT

Number of Loaded Area: $\mathbf{NLA} := 9$

Number of Settlement Points in Plane: $\mathbf{NSPP} := 22$

Elastic Modulus: $\mathbf{E} := 316701108$ **PSF**

Poisson's Ratio: $\mu := \mathbf{0.3}$

Loaded Intensity (PSF) of Each Loaded Area:

11320	6770	5860	4310	4310	3610	3610	5380	5380

Loaded Area Coordinates (FT) of Rectangle Corners of Each Loaded Area:

	X1	Y1	X2	Y2	X3	Y3	X4	Y4
1	300.0	333.0	609.0	333.0	609.0	546.0	300.0	546.0
2	300.0	200.0	539.0	200.0	539.0	333.0	300.0	333.0
3	629.0	376.0	944.0	376.0	944.0	562.0	629.0	562.0
4	539.0	546.0	609.0	546.0	609.0	661.0	539.0	661.0
5	539.0	218.0	609.0	218.0	609.0	333.0	539.0	333.0
6	39.0	431.0	170.0	431.0	170.0	693.0	39.0	693.0
7	39.0	87.0	170.0	87.0	170.0	349.0	39.0	349.0
8	635.0	582.0	713.0	582.0	713.0	667.0	635.0	667.0
9	635.0	175.0	713.0	175.0	713.0	260.0	635.0	260.0

Coordinates of Settlement Points (FT)

X	Y
300	200
300	333
300	546
419.5	266.5
454.5	439.5
539	200
539	333
574	275.5
574	603.5
609	333
609	546
674	217.5
629	376
629	562
674	624.5
786.5	469
944	376
944	562
104.5	152.5
104.5	283.5
104.5	496.5
104.5	627.5

$$\mathbf{X} := \left| \begin{array}{l} \textbf{for } \mathbf{i} \in 1 .. \mathbf{NSPP} \\ \quad \mathbf{X_i} \leftarrow \mathbf{CSP_{i,1}} \\ \mathbf{X} \end{array} \right.$$

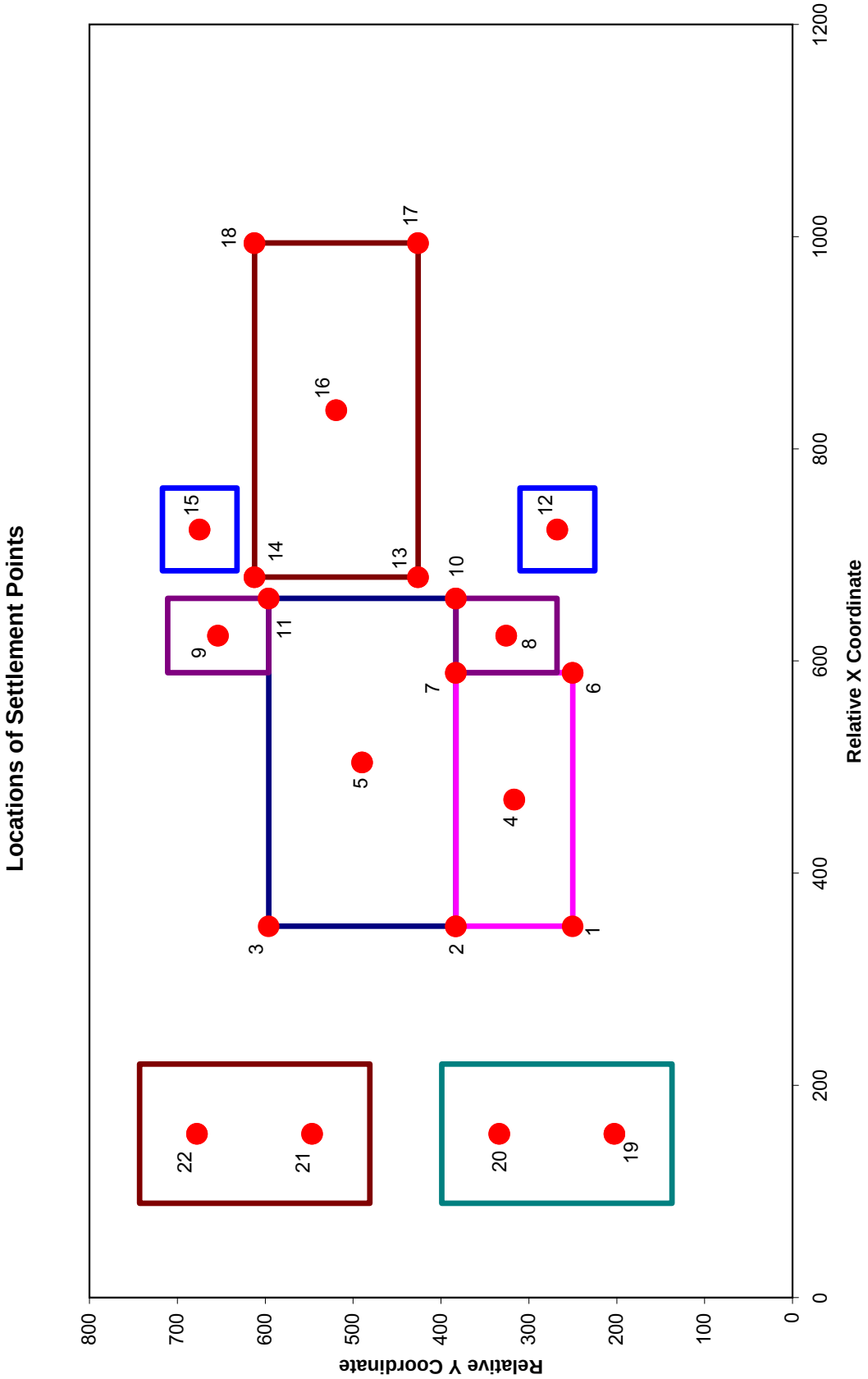
$$\mathbf{Y} := \left| \begin{array}{l} \textbf{for } \mathbf{i} \in 1 .. \mathbf{NSPP} \\ \quad \mathbf{Y_i} \leftarrow \mathbf{CSP_{i,2}} \\ \mathbf{Y} \end{array} \right.$$

Settlement Matrix (inches): Row index is settlement point number

ST =

	1
1	0.06
2	0.08
3	0.07
4	0.09
5	0.12
6	0.06
7	0.1
8	0.08
9	0.07
10	0.08
11	0.08
12	0.06
13	0.08
14	0.08
15	0.06
16	0.07
17	0.04
18	0.04
19	0.05
20	0.05
21	0.05
22	0.05

Appendix A


Locations of Settlement Points
Relative Y Coordinate
Relative X Coordinate
0
100
200
300
400
500
600
700
800
0
200
400
600
800
1000
1200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

MODULUS AVERAGING

LAYER ID	LAYER CENTER DEPTH FT	THICKNESS FT	MODULUS PSF	$\sum_{i=1}^{n}\left(E_i \Big/ \sum_{j=1}^{i} h_j\right)$	$\sum_{i=1}^{n}\left(1 \Big/ \sum_{j=1}^{i} h_j\right)$
1.00	3.00	6.00	91,508,416		
2.00	15.00	18.00	91,508,416		
3.00	28.00	8.00	11,650,143		
4.00	36.00	8.00	11,650,143		
5.00	50.00	20.00	139,212,424	6960621	0.050
6.00	70.00	20.00	139,212,424	3480311	0.025
7.00	92.50	25.00	139,212,424	2141730	0.015
8.00	107.00	4.00	11,650,143	168843	0.014
9.00	120.50	23.00	139,212,424	1513179	0.011
10.00	149.00	34.00	139,212,424	1104861	0.008
11.00	183.00	34.00	139,212,424	870078	0.006
12.00	214.50	29.00	44,754,165	236795	0.005
13.00	239.00	20.00	91,866,353	439552	0.005
14.00	264.00	30.00	91,866,353	384378	0.004
15.00	294.00	30.00	91,866,353	341511	0.004
16.00	324.00	30.00	75,174,273	251419	0.003
17.00	355.00	32.00	75,174,273	227113	0.003
18.00	386.00	30.00	90,209,128	249887	0.003
19.00	417.50	33.00	90,209,128	228957	0.003
20.00	463.00	58.00	200,298,272	443138	0.002
21.00	542.00	100.00	200,298,272	362859	0.002
22.00	642.00	100.00	200,298,272	307206	0.002
23.00	742.00	100.00	200,298,272	266354	0.001
24.00	842.00	100.00	200,298,272	235092	0.001
25.00	942.00	100.00	200,298,272	210397	0.001

$$E_{dw} = \frac{\sum_{i=1}^{n}\left(E_i \Big/ \sum_{j=1}^{i} h_j\right)}{\sum_{i=1}^{n}\left(1 \Big/ \sum_{j=1}^{i} h_j\right)} = \begin{matrix} 841 & \text{KSI} \\ 121071402 & \text{PSF} \end{matrix}$$

Weighted Modulus Calculation

NON-LAYERED METHOD--LBRM MODEL

WORKSHEET OF FOUNDATION SETTLEMENT ESTIMATION
Non-layered Method, Lbrm Model, Mathcad Sheet for Cross Check Against Excel Sheet

Reference: Soil Mechanics Principles and Application (1976), William Perloff and William Baron, Page 199-201.

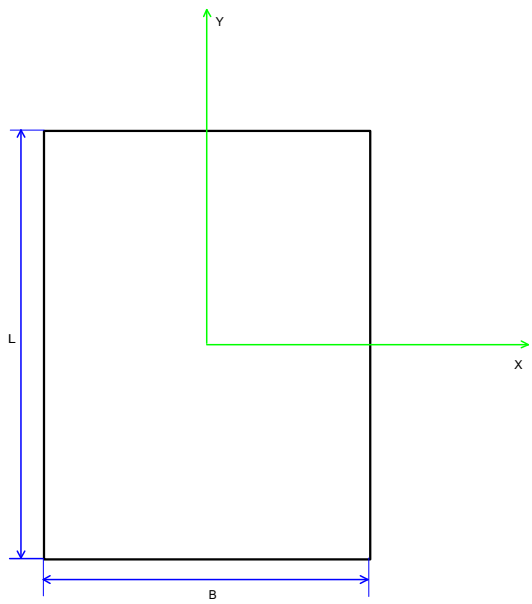


Figure 1. Notation for Rectanglular Loaded Area Shown in Plan View

The vertical Settlement of any point of the surface of an elastic half-space uniformly loaded over a rectangular area is expresses as

$$\delta(x, y, q, B, L) = C(x, y, B, L) \cdot \left[q \cdot B \cdot \frac{(1-\mu)}{E_d} \right]$$

δ(x,y,q,B,L) = Vertical deformation at point (x,y) induced by a rectangular foundation.

q = unit load (psf)

B = foundation width (ft)

L = foundation length (ft)

μ= poisson's ratio

E_d = modulus of deformation of the rock foundation

C is a geometric factor which accounts for the shape of the rectangle shown in Figure B-1 and the position of the point for which the settlement is being calculated. C can be calculated based on following formulas:

$$\mathbf{A1}(\mathbf{x},\mathbf{B}) := 1 - 2\cdot\frac{\mathbf{x}}{\mathbf{B}} \qquad \mathbf{A2}(\mathbf{x},\mathbf{B}) := 1 + 2\cdot\frac{\mathbf{x}}{\mathbf{B}}$$

$$\mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L}) := \frac{\mathbf{L}}{\mathrm{B}} - 2\cdot\frac{\mathbf{y}}{\mathbf{B}} \qquad \mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L}) := \frac{\mathbf{L}}{\mathrm{B}} + 2\cdot\frac{\mathbf{y}}{\mathbf{B}}$$

$$\mathbf{C1}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) := \mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L})\cdot\ln\left[\frac{\left[\sqrt{(\mathbf{A1}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} + \mathbf{A1}(\mathbf{x},\mathbf{B})\right]}{\left[\sqrt{(\mathbf{A2}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} - \mathbf{A2}(\mathbf{x},\mathbf{B})\right]}\right]$$

$$\mathbf{C2}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) := \mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L})\cdot\ln\left[\frac{\left[\sqrt{(\mathbf{A1}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} + \mathbf{A1}(\mathbf{x},\mathbf{B})\right]}{\left[\sqrt{(\mathbf{A2}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} - \mathbf{A2}(\mathbf{x},\mathbf{B})\right]}\right]$$

$$\mathbf{C3}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) := \mathbf{A1}(\mathbf{x},\mathbf{B})\cdot\ln\left[\frac{\left[\sqrt{(\mathbf{A1}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} + \mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L})\right]}{\left[\sqrt{(\mathbf{A1}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} - \mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L})\right]}\right]$$

$$\mathbf{C4}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) := \mathbf{A2}(\mathbf{x},\mathbf{B})\cdot\ln\left[\frac{\left[\sqrt{(\mathbf{A2}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} + \mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L})\right]}{\left[\sqrt{(\mathbf{A2}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} - \mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L})\right]}\right]$$

$$\mathbf{C}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) := 0.159\cdot(\mathbf{C1}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) + \mathbf{C2}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) + \mathbf{C3}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) + \mathbf{C4}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}))$$

DATA INPUT

Number of Loaded Area: $NLA := 9$

Number of Settlement Points in Plane: $NSPP := 22$

Elastic Modulus: $E := 121071402$ PSF

Poisson Ratio: $\mu := 0.3$

Loaded Intensity (PSF) of Each Loaded Area:

11320	6770	5860	4310	4310	3610	3610	5380	5380

Loaded Area Coordinates (FT) of Rectangle Corners of Each Loaded Area:

	X1	Y1	X2	Y2	X3	Y3	X4	Y4
1	300.0	333.0	609.0	333.0	609.0	546.0	300.0	546.0
2	300.0	200.0	539.0	200.0	539.0	333.0	300.0	333.0
3	629.0	376.0	944.0	376.0	944.0	562.0	629.0	562.0
4	539.0	546.0	609.0	546.0	609.0	661.0	539.0	661.0
5	539.0	218.0	609.0	218.0	609.0	333.0	539.0	333.0
6	39.0	431.0	170.0	431.0	170.0	693.0	39.0	693.0
7	39.0	87.0	170.0	87.0	170.0	349.0	39.0	349.0
8	635.0	582.0	713.0	582.0	713.0	667.0	635.0	667.0
9	635.0	175.0	713.0	175.0	713.0	260.0	635.0	260.0

Coordinates of Settlement Points (FT)

X	Y
300	200
300	333
300	546
419.5	266.5
454.5	439.5
539	200
539	333
574	275.5
574	603.5
609	333
609	546
674	217.5
629	376
629	562
674	624.5
786.5	469
944	376
944	562
104.5	152.5
104.5	283.5
104.5	496.5
104.5	627.5

$$X := \left| \begin{array}{l} \text{for } i \in 1..NSPP \\ \quad X_i \leftarrow CSP_{i,1} \\ X \end{array} \right.$$

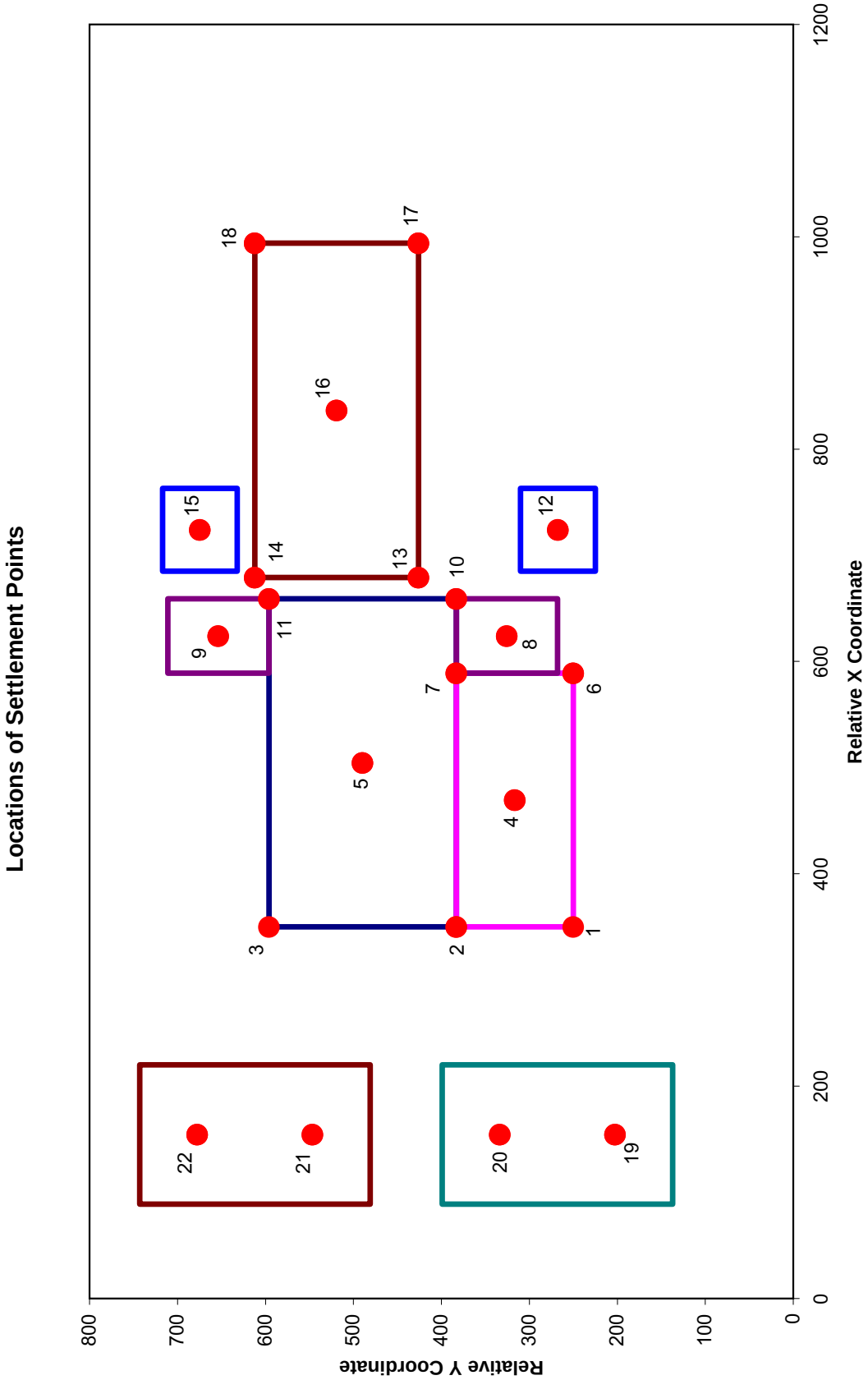
$$Y := \left| \begin{array}{l} \text{for } i \in 1..NSPP \\ \quad Y_i \leftarrow CSP_{i,2} \\ Y \end{array} \right.$$

Settlement Matrix (inches): Row index is settlement point number

ST =

	1
1	0.15
2	0.21
3	0.18
4	0.23
5	0.3
6	0.17
7	0.27
8	0.2
9	0.19
10	0.22
11	0.22
12	0.16
13	0.22
14	0.2
15	0.17
16	0.19
17	0.11
18	0.11
19	0.12
20	0.14
21	0.14
22	0.12

Appendix A


Locations of Settlement Points
Relative Y Coordinate
Relative X Coordinate
0
100
200
300
400
500
600
700
800
0
200
400
600
800
1000
1200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

APPENDIX B

Rebound Calculations

Layered Method Using Best Estimated Rock Modulus (BERM) Model (Excel)
Pages 2 through 7
Non-layered Method Using Best Estimated Rock Modulus (BERM) Model (Excel)
Pages 8 through 17
Layered Method Using Best Estimated Rock Modulus (BERM) Model (Mathcad)
Pages 18 through 24
Non-layered Method Best Estimated Rock Modulus (BERM) Model (Mathcad)
Pages 25 through 30

REBOUND ANALYSIS FOR ELASTIC MATERIALS- Layered Method, BERM Model

METHODOLOGY

This worksheet has been developed to calculate elastic rebound induced by foundation excavation. The soils below foundations are considered as layered elastic medium and the stress decrement at each layer center due to a rectanglar uniformly unloaded area at or below ground surface is computed by classic Boussinesq solution. The rebound for each layer is calculated using the vertical stress decrement and elastic modulus of the layer, and total rebound is obtained by summing all layer rebound in the influenced zone.

Stress Decrement:

The equation of Boussinesq solution to compute the stress decrement under the corner of a rectanglar loaded area are shown as below. When the stress calculation point is not located under the corner of a given unloaded area, superposition of rectanglar areas covering the unloaded surface and stress calculation point are used to calculate the stress.

Boussinesq Solution:

$$\sigma_z = \frac{q}{4\pi}\left[\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+m^2n^2+1}\frac{m^2+n^2+2}{m^2+n^2+1}+\sin^{-1}\left(\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+m^2n^2+1}\right)\right]$$

where q is unload intensity, m=L/Z, N=B/Z, and B, L and Z are foundation width, length and stress point depth, respectively. The angle in second term in the parenthesis is less than π /2 when $m^2+n^2+1>m^2$ otherwise between π /2 and π .

Rebound Calculation:

The rebound in a given layer is calculated by an equation shown as below.

$$S_i = \Delta\sigma_{zi} H_i \frac{1-\mu_i^2}{E_i}$$

where H, E and m are layer thickness, modulus and poisson ratio, respectively.

Total Rebound:

$$S = \sum_{i=1}^{n} S_i$$

where n is number of the total layeres influenced by foundation excavation

SUMMARY OF INPUT

Number of Unloaded Areas= 9 **Number of Soil Layers=** 25 **Number of Rebound Points=** 22

Poisson's Ratio= 0.30 **Stress distribution code=** 1 **Depth of Grondwater Table=** 50 FT

UNLOAD UNIT ID	UNLOAD INTENSITY KSF	EMBEDED DEPTH FT	UNLOAD UNIT CORNER COORDINATES (FT)							
			X1	Y1	X2	Y2	X3	Y3	X4	Y4
1	5.7	40.0	300.0	333.0	609.0	333.0	609.0	546.0	300.0	546.0
2	5.7	40.0	300.0	200.0	539.0	200.0	539.0	333.0	300.0	333.0
3	5.7	40.0	629.0	376.0	944.0	376.0	944.0	562.0	629.0	562.0
4	5.7	40.0	539.0	546.0	609.0	546.0	609.0	661.0	539.0	661.0
5	5.7	40.0	539.0	218.0	609.0	218.0	609.0	333.0	539.0	333.0
6	5.7	40.0	39.0	431.0	170.0	431.0	170.0	693.0	39.0	693.0
7	5.7	40.0	39.0	87.0	170.0	87.0	170.0	349.0	39.0	349.0
8	5.7	40.0	635.0	582.0	713.0	582.0	713.0	667.0	635.0	667.0
9	5.7	40.0	635.0	175.0	713.0	175.0	713.0	260.0	635.0	260.0

REBOUND POINT COORDINATES

ID	X	Y	ID	X	Y
1	300.0	200.0	2	300.0	333.0
3	300.0	546.0	4	419.5	266.5
5	454.5	439.5	6	539.0	200.0
7	539.0	333.0	8	574.0	275.5
9	574.0	603.5	10	609.0	333.0
11	609.0	546.0	12	674.0	217.5
13	629.0	376.0	14	629.0	562.0
15	674.0	624.5	16	786.5	469.0
17	944.0	376.0	18	944.0	562.0
19	104.5	152.5	20	104.5	283.5
21	104.5	496.5	22	104.5	627.5

LAYER COMPRESSIBILITY

LAYER ID	DEPTH FT	THICKNESS FT	MODULUS KSF	LAYER ID	DEPTH FT	THICKNESS FT	MODULUS KSF
1	3.00	6.00	155548	2	15.00	18.00	155548
3	28.00	8.00	44263	4	36.00	8.00	48648
5	50.00	20.00	405550	6	70.00	20.00	405550
7	92.50	25.00	405550	8	107.00	4.00	59688
9	120.50	23.00	313510	10	149.00	34.00	585033
11	183.00	34.00	205856	12	214.50	29.00	72539
13	239.00	20.00	110220	14	264.00	30.00	110220
15	294.00	30.00	110220	16	324.00	30.00	117959
17	355.00	32.00	117959	18	386.00	30.00	110901
19	417.50	33.00	110901	20	463.00	58.00	378268
21	542.00	100.00	378268	22	642.00	100.00	378268
23	742.00	100.00	378268	24	842.00	100.00	378268
25	942.00	100.00	378268				

CALCULATION RESULTS

Stress Distribution: Bossinesq Solution

Depth (FT)	Stress Decrement Contributed by All Unloaded Areas at Each Rebound Points, KSF																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50.00	1.42	2.84	1.42	5.67	5.67	1.49	5.67	5.64	5.62	2.84	2.93	5.61	1.53	1.57	5.62	5.67	1.42	1.42	5.66	5.66	5.66	5.66
70.00	1.43	2.83	1.43	5.57	5.64	1.93	5.59	5.23	4.94	2.91	3.55	4.75	2.36	2.68	4.85	5.60	1.42	1.42	5.42	5.42	5.42	5.42
92.50	1.46	2.83	1.46	5.27	5.51	2.19	5.36	4.58	3.98	3.08	3.89	3.41	2.98	3.43	3.72	5.35	1.41	1.41	4.76	4.79	4.79	4.76
107.00	1.49	2.83	1.50	5.01	5.38	2.26	5.17	4.24	3.54	3.18	3.93	2.77	3.20	3.60	3.21	5.11	1.40	1.40	4.26	4.30	4.30	4.26
120.50	1.53	2.82	1.54	4.76	5.23	2.29	4.97	3.98	3.24	3.25	3.91	2.36	3.32	3.64	2.90	4.85	1.38	1.38	3.81	3.88	3.87	3.80
149.00	1.62	2.80	1.64	4.24	4.86	2.28	4.56	3.56	2.85	3.30	3.73	1.88	3.43	3.52	2.51	4.28	1.35	1.35	3.00	3.14	3.13	3.00
183.00	1.70	2.73	1.74	3.70	4.37	2.21	4.11	3.21	2.57	3.24	3.44	1.66	3.39	3.25	2.27	3.66	1.29	1.29	2.33	2.54	2.53	2.32
214.50	1.73	2.64	1.79	3.30	3.95	2.12	3.73	2.95	2.39	3.10	3.16	1.58	3.25	2.99	2.11	3.18	1.23	1.23	1.92	2.18	2.16	1.90
239.00	1.74	2.55	1.81	3.03	3.64	2.04	3.46	2.77	2.27	2.97	2.96	1.55	3.11	2.79	2.01	2.87	1.19	1.18	1.69	1.97	1.96	1.67
264.00	1.72	2.46	1.81	2.80	3.36	1.96	3.21	2.60	2.16	2.82	2.76	1.52	2.95	2.61	1.92	2.60	1.14	1.13	1.52	1.81	1.79	1.49
294.00	1.69	2.33	1.78	2.56	3.05	1.86	2.93	2.42	2.04	2.63	2.54	1.49	2.75	2.41	1.81	2.33	1.09	1.08	1.36	1.66	1.64	1.33
324.00	1.63	2.20	1.73	2.35	2.78	1.77	2.68	2.25	1.92	2.45	2.34	1.45	2.55	2.22	1.71	2.11	1.04	1.03	1.24	1.54	1.52	1.22
355.00	1.57	2.06	1.67	2.16	2.54	1.68	2.45	2.09	1.81	2.27	2.16	1.41	2.35	2.05	1.61	1.91	1.00	0.97	1.14	1.43	1.41	1.12
386.00	1.50	1.93	1.61	2.00	2.32	1.59	2.25	1.94	1.70	2.10	1.99	1.36	2.17	1.90	1.51	1.75	0.95	0.93	1.07	1.34	1.33	1.05
417.50	1.43	1.81	1.53	1.85	2.13	1.50	2.06	1.80	1.60	1.94	1.84	1.31	1.99	1.76	1.42	1.60	0.91	0.88	1.00	1.26	1.24	0.99
463.00	1.32	1.64	1.42	1.66	1.89	1.38	1.83	1.62	1.46	1.73	1.65	1.22	1.77	1.58	1.30	1.42	0.85	0.82	0.93	1.15	1.14	0.92
542.00	1.15	1.38	1.24	1.39	1.55	1.19	1.50	1.36	1.25	1.43	1.37	1.08	1.46	1.32	1.12	1.18	0.76	0.73	0.82	1.00	0.99	0.82
642.00	0.96	1.12	1.03	1.12	1.23	1.00	1.19	1.10	1.03	1.14	1.10	0.92	1.15	1.06	0.93	0.95	0.66	0.64	0.71	0.84	0.84	0.71
742.00	0.81	0.91	0.86	0.92	0.99	0.84	0.96	0.90	0.85	0.93	0.90	0.78	0.93	0.87	0.78	0.79	0.58	0.56	0.62	0.71	0.71	0.62
842.00	0.69	0.76	0.72	0.76	0.81	0.70	0.79	0.75	0.71	0.77	0.74	0.66	0.77	0.73	0.66	0.66	0.51	0.49	0.54	0.61	0.61	0.55
942.00	0.58	0.64	0.61	0.64	0.67	0.60	0.66	0.63	0.61	0.64	0.62	0.57	0.64	0.61	0.56	0.56	0.45	0.43	0.47	0.53	0.53	0.48

REBOUND DISTRIBUTION (INCHES)

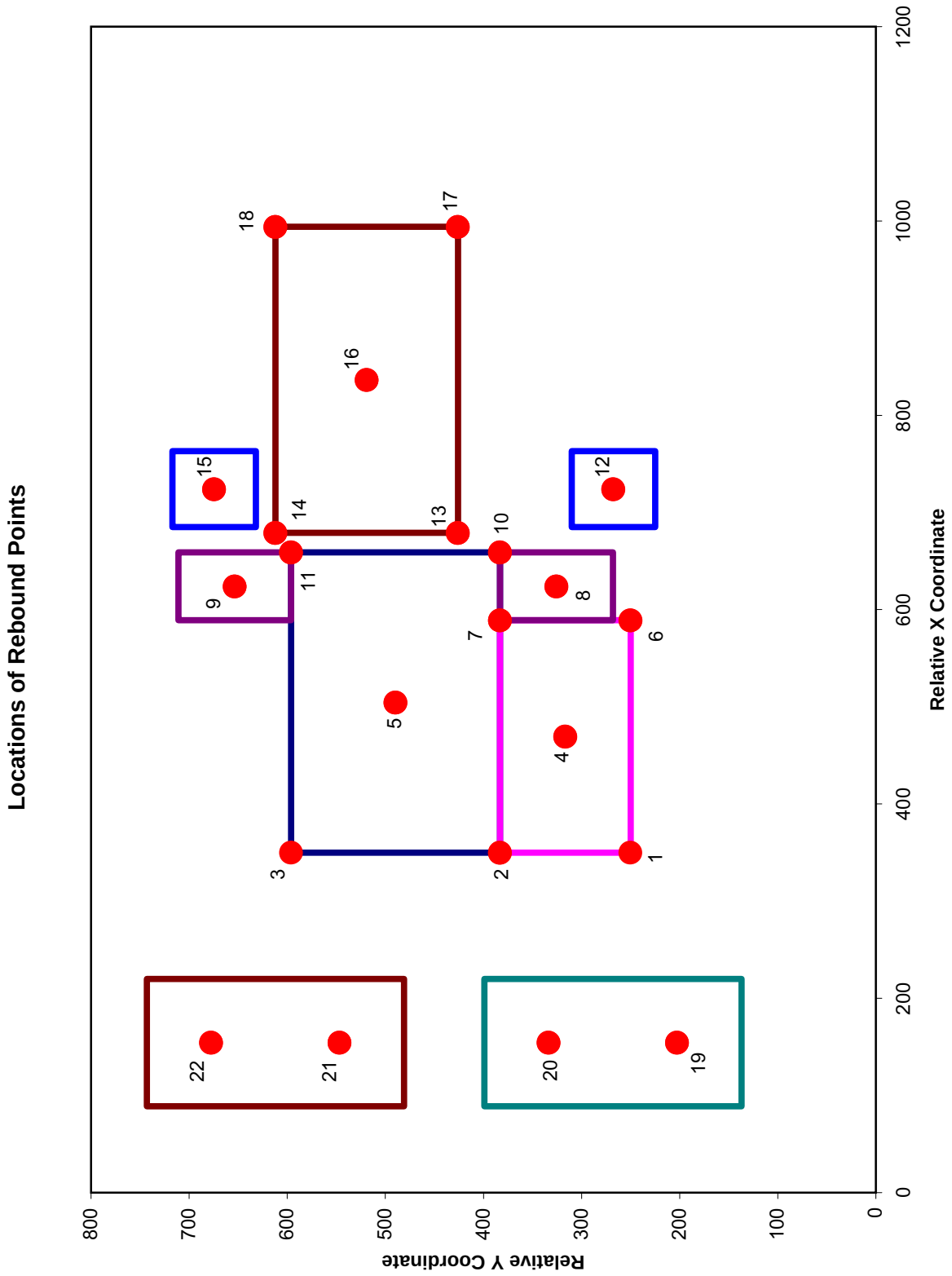
Rebound Point Layer ID	Rebound Contributed by All Unloaded Areas for Each Layer at Each Rebound Point																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
12	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
13	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
14	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.00
15	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
18	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**0.06**	**0.09**	**0.07**	**0.10**	**0.12**	**0.07**	**0.11**	**0.10**	**0.08**	**0.10**	**0.10**	**0.06**	**0.10**	**0.09**	**0.08**	**0.10**	**0.04**	**0.04**	**0.07**	**0.07**	**0.07**	**0.07**

Appendix B

SUMMARY OF REBOUND

Rebound Point	X	Y	Rebound Inches	Rebound Point	X	Y	Rebound Inches
1	300.0	200.0	**0.06**	**2**	300.0	333.0	**0.09**
3	300.0	546.0	**0.07**	**4**	419.5	266.5	**0.10**
5	454.5	439.5	**0.12**	**6**	539.0	200.0	**0.07**
7	539.0	333.0	**0.11**	**8**	574.0	275.5	**0.10**
9	574.0	603.5	**0.08**	**10**	609.0	333.0	**0.10**
11	609.0	546.0	**0.10**	**12**	674.0	217.5	**0.06**
13	629.0	376.0	**0.10**	**14**	629.0	562.0	**0.09**
15	674.0	624.5	**0.08**	**16**	786.5	469.0	**0.10**
17	944.0	376.0	**0.04**	**18**	944.0	562.0	**0.04**
19	104.5	152.5	**0.07**	**20**	104.5	283.5	**0.07**
21	104.5	496.5	**0.07**	**22**	104.5	627.5	**0.07**

Appendix B


Locations of Rebound Points
Relative Y Coordinate
Relative X Coordinate
0
100
200
300
400
500
600
700
800
0
200
400
600
800
1000
1200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

MODULUS AVERAGING

LAYER ID	LAYER CENTER DEPTH FT	THICKNESS FT	MODULUS PSF	$\sum_{i=1}^{n}\left(E_i \Big/ \sum_{j=1}^{i} h_j\right)$	$\sum_{i=1}^{n}\left(1 \Big/ \sum_{j=1}^{i} h_j\right)$
1.00	3.00	6.00	155,547,652		
2.00	15.00	18.00	155,547,652		
3.00	28.00	8.00	44,262,695		
4.00	36.00	8.00	48,648,130		
5.00	50.00	20.00	405,550,066	20277503	0.050
6.00	70.00	20.00	405,550,066	10138752	0.025
7.00	92.50	25.00	405,550,066	6239232	0.015
8.00	107.00	4.00	59,687,742	865040	0.014
9.00	120.50	23.00	313,510,454	3407722	0.011
10.00	149.00	34.00	585,032,604	4643116	0.008
11.00	183.00	34.00	205,855,826	1286599	0.006
12.00	214.50	29.00	72,539,100	383805	0.005
13.00	239.00	20.00	110,220,264	527370	0.005
14.00	264.00	30.00	110,220,264	461173	0.004
15.00	294.00	30.00	110,220,264	409741	0.004
16.00	324.00	30.00	117,958,712	394511	0.003
17.00	355.00	32.00	117,958,712	356371	0.003
18.00	386.00	30.00	110,901,382	307206	0.003
19.00	417.50	33.00	110,901,382	281476	0.003
20.00	463.00	58.00	378,267,514	836875	0.002
21.00	542.00	100.00	378,267,514	685267	0.002
22.00	642.00	100.00	378,267,514	580165	0.002
23.00	742.00	100.00	378,267,514	503015	0.001
24.00	842.00	100.00	378,267,514	443976	0.001
25.00	942.00	100.00	378,267,514	397340	0.001

$$E_{dw} = \frac{\sum_{i=1}^{n}\left(E_i \Big/ \sum_{j=1}^{i} h_j\right)}{\sum_{i=1}^{n}\left(1 \Big/ \sum_{j=1}^{i} h_j\right)} = \begin{matrix} 2199 & \text{KSI} \\ 316701108 & \text{PSF} \end{matrix}$$

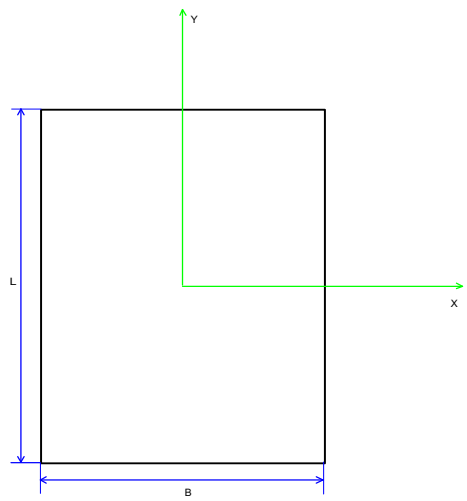
Weighted Modulus Calculation

NON-LAYERED METHOD--BERM MODEL

REBOUND ANALYSIS FOR ELASTIC MATERIALS
NonLayered Method, Berm Model

Reference: Soil Mechanics Principles and Application, William Perloff and William Baron,1976,Page 199-201

METHODOLOGY:



The vertical rebound of any point of the surface of an elastic half-space uniformly unloaded over a rectangular area is expressed as:

$$\delta(x,y) = C(x,y)\frac{qB(1-\mu)}{E}$$

where d(x,y) is vertical rebound at point (x,y) by a rectangular foundation, q is the unload intensity, B foundation width, L foundation length, p is poisson's ratio, E is modulus of deformation of the bearing rock. And C(x,y) is a geometric factor which accounts for shape of the rectangle shown in Figure 1 and the the position of the point for which the rebound is being calculated. C can be calculated based on following formulas:

$$C(x,y) = \frac{1}{2\pi}(C_1 + C_2 + C_3 + C_4)$$

$$C_1 = B_1 \ln\left(\frac{\sqrt{A_1^2 + B_1^2} + A_1}{\sqrt{A_2^2 + B_1^2} - A_2}\right) \qquad C_2 = B_2 \ln\left(\frac{\sqrt{A_1^2 + B_2^2} + A_1}{\sqrt{A_2^2 + B_2^2} - A_2}\right)$$

$$C_3 = A_1 \ln\left(\frac{\sqrt{A_1^2 + B_1^2} + B_1}{\sqrt{A_1^2 + B_2^2} - B_2}\right) \qquad C_4 = A_2 \ln\left(\frac{\sqrt{A_2^2 + B_1^2} + B_1}{\sqrt{A_2^2 + B_2^2} - B_2}\right)$$

$$A_1 = 1 - \frac{2x}{B} \qquad A_2 = 1 + \frac{2x}{B} \qquad B_1 = \frac{L}{B} - \frac{2y}{B} \qquad B_2 = \frac{L}{B} + \frac{2y}{B}$$

INPUT SUMMARY:

NUMBER OF UNLOADED AREAS= 9 POISSON'S RATIO= 0.30

NUMBER OF REBOUND POINTS= 22 ELASTIC MODULUS= 316701 KSF

UNLOAD UNIT ID	UNLOAD INTENSITY PSF	UNLOAD UNIT CORNER COORDINATES (FT)							
		X1	Y1	X2	Y2	X3	Y3	X4	Y4
1	5670.0	300.0	333.0	609.0	333.0	609.0	546.0	300.0	546.0
2	5670.0	300.0	200.0	539.0	200.0	539.0	333.0	300.0	333.0
3	5670.0	629.0	376.0	944.0	376.0	944.0	562.0	629.0	562.0
4	5670.0	539.0	546.0	609.0	546.0	609.0	661.0	539.0	661.0
5	5670.0	539.0	218.0	609.0	218.0	609.0	333.0	539.0	333.0
6	5670.0	39.0	431.0	170.0	431.0	170.0	693.0	39.0	693.0
7	5670.0	39.0	87.0	170.0	87.0	170.0	349.0	39.0	349.0
8	5670.0	635.0	582.0	713.0	582.0	713.0	667.0	635.0	667.0
9	5670.0	635.0	175.0	713.0	175.0	713.0	260.0	635.0	260.0

REBOUND POINT COORDINATES								
ID	X	Y	ID	X	Y	ID	X	Y
1	300.0	200.0	2	300.0	333.0	3	300.0	546.0
4	419.5	266.5	5	454.5	439.5	6	539.0	200.0
7	539.0	333.0	8	574.0	275.5	9	574.0	603.5
10	609.0	333.0	11	609.0	546.0	12	674.0	217.5
13	629.0	376.0	14	629.0	562.0	15	674.0	624.5
16	786.5	469.0	17	944.0	376.0	18	944.0	562.0
19	104.5	152.5	20	104.5	283.5	21	104.5	496.5
22	104.5	627.5						

Appendix B

OUTPUT SUMMARY:

CALCULATION BASED ON UNLOADED AREA 1						CALCULATION BASED ON UNLOADED AREA 2					
Rebound ID	General Coordinates		Local Coordinates		Rebound Component	Rebound ID	General Coordinates		Local Coordinates		Rebound Component
	X	Y	X'	Y'			X	Y	X'	Y'	
1	300.0	200.0	-239.5	-154.5	0.001	1	300.0	200.0	-66.5	-119.5	0.001
2	300.0	333.0	-106.5	-154.5	0.002	2	300.0	333.0	66.5	-119.5	0.001
3	300.0	546.0	106.5	-154.5	0.002	3	300.0	546.0	279.5	-119.5	0.000
4	419.5	266.5	-173.0	-35.0	0.001	4	419.5	266.5	0.0	0.0	0.002
5	454.5	439.5	0.0	0.0	0.004	5	454.5	439.5	173.0	35.0	0.001
6	539.0	200.0	-239.5	84.5	0.001	6	539.0	200.0	-66.5	119.5	0.001
7	539.0	333.0	-106.5	84.5	0.002	7	539.0	333.0	66.5	119.5	0.001
8	574.0	275.5	-164.0	119.5	0.001	8	574.0	275.5	9.0	154.5	0.001
9	574.0	603.5	164.0	119.5	0.001	9	574.0	603.5	337.0	154.5	0.000
10	609.0	333.0	-106.5	154.5	0.002	10	609.0	333.0	66.5	189.5	0.001
11	609.0	546.0	106.5	154.5	0.002	11	609.0	546.0	279.5	189.5	0.000
12	674.0	217.5	-222.0	219.5	0.001	12	674.0	217.5	-49.0	254.5	0.001
13	629.0	376.0	-63.5	174.5	0.002	13	629.0	376.0	109.5	209.5	0.001
14	629.0	562.0	122.5	174.5	0.001	14	629.0	562.0	295.5	209.5	0.000
15	674.0	624.5	185.0	219.5	0.001	15	674.0	624.5	358.0	254.5	0.000
16	786.5	469.0	29.5	332.0	0.001	16	786.5	469.0	202.5	367.0	0.000
17	944.0	376.0	-63.5	489.5	0.001	17	944.0	376.0	109.5	524.5	0.000
18	944.0	562.0	122.5	489.5	0.001	18	944.0	562.0	295.5	524.5	0.000
19	104.5	152.5	-287.0	-350.0	0.001	19	104.5	152.5	-114.0	-315.0	0.000
20	104.5	283.5	-156.0	-350.0	0.001	20	104.5	283.5	17.0	-315.0	0.000
21	104.5	496.5	57.0	-350.0	0.001	21	104.5	496.5	230.0	-315.0	0.000
22	104.5	627.5	188.0	-350.0	0.001	22	104.5	627.5	361.0	-315.0	0.000

Appendix B

CALCULATION BASED ON UNLOADED AREA 3						CALCULATION BASED ON UNLOADED AREA 4					
Rebound ID	General Coordinates		Local Coordinates		Rebound Component	Rebound ID	General Coordinates		Local Coordinates		Rebound Component
	X	Y	X'	Y'			X	Y	X'	Y'	
1	300.0	200.0	-269.0	-486.5	0.000	1	300.0	200.0	-274.0	-403.5	0.000
2	300.0	333.0	-136.0	-486.5	0.000	2	300.0	333.0	-274.0	-270.5	0.000
3	300.0	546.0	77.0	-486.5	0.000	3	300.0	546.0	-274.0	-57.5	0.000
4	419.5	266.5	-202.5	-367.0	0.001	4	419.5	266.5	-154.5	-337.0	0.000
5	454.5	439.5	-29.5	-332.0	0.001	5	454.5	439.5	-119.5	-164.0	0.000
6	539.0	200.0	-269.0	-247.5	0.001	6	539.0	200.0	-35.0	-403.5	0.000
7	539.0	333.0	-136.0	-247.5	0.001	7	539.0	333.0	-35.0	-270.5	0.000
8	574.0	275.5	-193.5	-212.5	0.001	8	574.0	275.5	0.0	-328.0	0.000
9	574.0	603.5	134.5	-212.5	0.001	9	574.0	603.5	0.0	0.0	0.001
10	609.0	333.0	-136.0	-177.5	0.001	10	609.0	333.0	35.0	-270.5	0.000
11	609.0	546.0	77.0	-177.5	0.001	11	609.0	546.0	35.0	-57.5	0.001
12	674.0	217.5	-251.5	-112.5	0.001	12	674.0	217.5	100.0	-386.0	0.000
13	629.0	376.0	-93.0	-157.5	0.002	13	629.0	376.0	55.0	-227.5	0.000
14	629.0	562.0	93.0	-157.5	0.002	14	629.0	562.0	55.0	-41.5	0.000
15	674.0	624.5	155.5	-112.5	0.001	15	674.0	624.5	100.0	21.0	0.000
16	786.5	469.0	0.0	0.0	0.003	16	786.5	469.0	212.5	-134.5	0.000
17	944.0	376.0	-93.0	157.5	0.002	17	944.0	376.0	370.0	-227.5	0.000
18	944.0	562.0	93.0	157.5	0.002	18	944.0	562.0	370.0	-41.5	0.000
19	104.5	152.5	-316.5	-682.0	0.000	19	104.5	152.5	-469.5	-451.0	0.000
20	104.5	283.5	-185.5	-682.0	0.000	20	104.5	283.5	-469.5	-320.0	0.000
21	104.5	496.5	27.5	-682.0	0.000	21	104.5	496.5	-469.5	-107.0	0.000
22	104.5	627.5	158.5	-682.0	0.000	22	104.5	627.5	-469.5	24.0	0.000

Appendix B

CALCULATION BASED ON UNLOADED AREA 5						CALCULATION BASED ON UNLOADED AREA 6					
Rebound ID	General Coordinates		Local Coordinates		Rebound Component	Rebound ID	General Coordinates		Local Coordinates		Rebound Component
	X	Y	X'	Y'			X	Y	X'	Y'	
1	300.0	200.0	-274.0	-75.5	0.000	1	300.0	200.0	195.5	-362.0	0.000
2	300.0	333.0	-274.0	57.5	0.000	2	300.0	333.0	195.5	-229.0	0.000
3	300.0	546.0	-274.0	270.5	0.000	3	300.0	546.0	195.5	-16.0	0.001
4	419.5	266.5	-154.5	-9.0	0.000	4	419.5	266.5	315.0	-295.5	0.000
5	454.5	439.5	-119.5	164.0	0.000	5	454.5	439.5	350.0	-122.5	0.000
6	539.0	200.0	-35.0	-75.5	0.000	6	539.0	200.0	434.5	-362.0	0.000
7	539.0	333.0	-35.0	57.5	0.001	7	539.0	333.0	434.5	-229.0	0.000
8	574.0	275.5	0.0	0.0	0.001	8	574.0	275.5	469.5	-286.5	0.000
9	574.0	603.5	0.0	328.0	0.000	9	574.0	603.5	469.5	41.5	0.000
10	609.0	333.0	35.0	57.5	0.001	10	609.0	333.0	504.5	-229.0	0.000
11	609.0	546.0	35.0	270.5	0.000	11	609.0	546.0	504.5	-16.0	0.000
12	674.0	217.5	100.0	-58.0	0.000	12	674.0	217.5	569.5	-344.5	0.000
13	629.0	376.0	55.0	100.5	0.000	13	629.0	376.0	524.5	-186.0	0.000
14	629.0	562.0	55.0	286.5	0.000	14	629.0	562.0	524.5	0.0	0.000
15	674.0	624.5	100.0	349.0	0.000	15	674.0	624.5	569.5	62.5	0.000
16	786.5	469.0	212.5	193.5	0.000	16	786.5	469.0	682.0	-93.0	0.000
17	944.0	376.0	370.0	100.5	0.000	17	944.0	376.0	839.5	-186.0	0.000
18	944.0	562.0	370.0	286.5	0.000	18	944.0	562.0	839.5	0.0	0.000
19	104.5	152.5	-469.5	-123.0	0.000	19	104.5	152.5	0.0	-409.5	0.000
20	104.5	283.5	-469.5	8.0	0.000	20	104.5	283.5	0.0	-278.5	0.001
21	104.5	496.5	-469.5	221.0	0.000	21	104.5	496.5	0.0	-65.5	0.002
22	104.5	627.5	-469.5	352.0	0.000	22	104.5	627.5	0.0	65.5	0.002

Appendix B

CALCULATION BASED ON UNLOADED AREA 7						CALCULATION BASED ON UNLOADED AREA 8					
Rebound ID	General Coordinates		Local Coordinates		Rebound Component	Rebound ID	General Coordinates		Local Coordinates		Rebound Component
	X	Y	X'	Y'			X	Y	X'	Y'	
1	300.0	200.0	195.5	-18.0	0.001	1	300.0	200.0	-374.0	-424.5	0.000
2	300.0	333.0	195.5	115.0	0.001	2	300.0	333.0	-374.0	-291.5	0.000
3	300.0	546.0	195.5	328.0	0.000	3	300.0	546.0	-374.0	-78.5	0.000
4	419.5	266.5	315.0	48.5	0.000	4	419.5	266.5	-254.5	-358.0	0.000
5	454.5	439.5	350.0	221.5	0.000	5	454.5	439.5	-219.5	-185.0	0.000
6	539.0	200.0	434.5	-18.0	0.000	6	539.0	200.0	-135.0	-424.5	0.000
7	539.0	333.0	434.5	115.0	0.000	7	539.0	333.0	-135.0	-291.5	0.000
8	574.0	275.5	469.5	57.5	0.000	8	574.0	275.5	-100.0	-349.0	0.000
9	574.0	603.5	469.5	385.5	0.000	9	574.0	603.5	-100.0	-21.0	0.000
10	609.0	333.0	504.5	115.0	0.000	10	609.0	333.0	-65.0	-291.5	0.000
11	609.0	546.0	504.5	328.0	0.000	11	609.0	546.0	-65.0	-78.5	0.000
12	674.0	217.5	569.5	-0.5	0.000	12	674.0	217.5	0.0	-407.0	0.000
13	629.0	376.0	524.5	158.0	0.000	13	629.0	376.0	-45.0	-248.5	0.000
14	629.0	562.0	524.5	344.0	0.000	14	629.0	562.0	-45.0	-62.5	0.000
15	674.0	624.5	569.5	406.5	0.000	15	674.0	624.5	0.0	0.0	0.001
16	786.5	469.0	682.0	251.0	0.000	16	786.5	469.0	112.5	-155.5	0.000
17	944.0	376.0	839.5	158.0	0.000	17	944.0	376.0	270.0	-248.5	0.000
18	944.0	562.0	839.5	344.0	0.000	18	944.0	562.0	270.0	-62.5	0.000
19	104.5	152.5	0.0	-65.5	0.002	19	104.5	152.5	-569.5	-472.0	0.000
20	104.5	283.5	0.0	65.5	0.002	20	104.5	283.5	-569.5	-341.0	0.000
21	104.5	496.5	0.0	278.5	0.001	21	104.5	496.5	-569.5	-128.0	0.000
22	104.5	627.5	0.0	409.5	0.000	22	104.5	627.5	-569.5	3.0	0.000

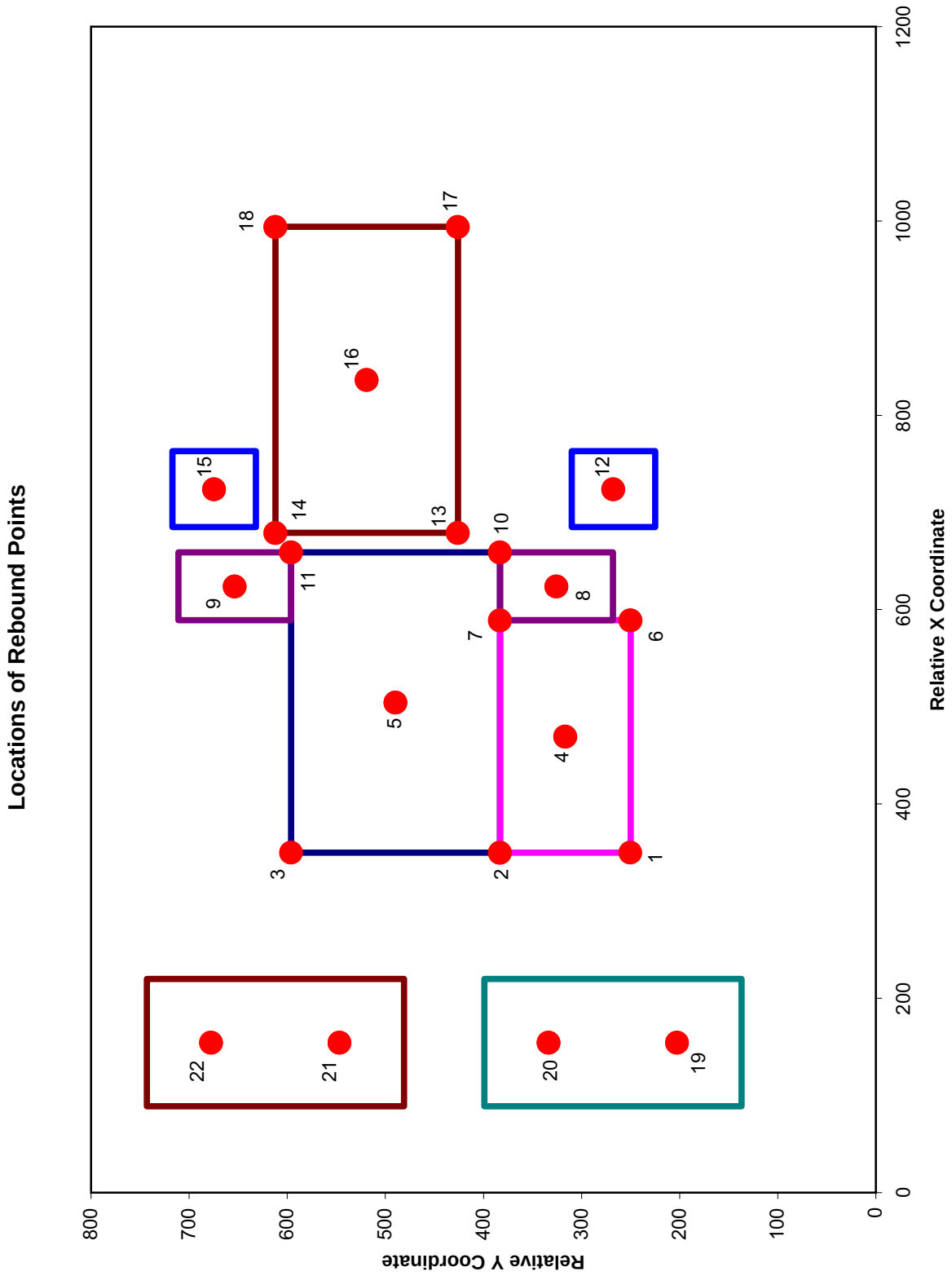
Appendix B

CALCULATION BASED ON UNLOADED AREA 9					
Rebound ID	General Coordinates		Local Coordinates		Rebound Component
	X	Y	X'	Y'	
1	300.0	200.0	-374.0	-17.5	0.000
2	300.0	333.0	-374.0	115.5	0.000
3	300.0	546.0	-374.0	328.5	0.000
4	419.5	266.5	-254.5	49.0	0.000
5	454.5	439.5	-219.5	222.0	0.000
6	539.0	200.0	-135.0	-17.5	0.000
7	539.0	333.0	-135.0	115.5	0.000
8	574.0	275.5	-100.0	58.0	0.000
9	574.0	603.5	-100.0	386.0	0.000
10	609.0	333.0	-65.0	115.5	0.000
11	609.0	546.0	-65.0	328.5	0.000
12	674.0	217.5	0.0	0.0	0.001
13	629.0	376.0	-45.0	158.5	0.000
14	629.0	562.0	-45.0	344.5	0.000
15	674.0	624.5	0.0	407.0	0.000
16	786.5	469.0	112.5	251.5	0.000
17	944.0	376.0	270.0	158.5	0.000
18	944.0	562.0	270.0	344.5	0.000
19	104.5	152.5	-569.5	-65.0	0.000
20	104.5	283.5	-569.5	66.0	0.000
21	104.5	496.5	-569.5	279.0	0.000
22	104.5	627.5	-569.5	410.0	0.000

Appendix B

SUMMARY OF REBOUND							
rebound Point	X	Y	Rebound Inches	rebound Point	X	Y	Rebound Inches
1	300.00	200.00	0.05	2	300.00	333.00	0.06
3	300.00	546.00	0.05	4	419.50	266.50	0.07
5	454.50	439.50	0.07	6	539.00	200.00	0.05
7	539.00	333.00	0.07	8	574.00	275.50	0.06
9	574.00	603.50	0.06	10	609.00	333.00	0.06
11	609.00	546.00	0.06	12	674.00	217.50	0.05
13	629.00	376.00	0.06	14	629.00	562.00	0.06
15	674.00	624.50	0.05	16	786.50	469.00	0.06
17	944.00	376.00	0.04	18	944.00	562.00	0.04
19	104.50	152.50	0.05	20	104.50	283.50	0.05
21	104.50	496.50	0.05	22	104.50	627.50	0.05

Appendix B


Locations of Rebound Points
Relative Y Coordinate
Relative X Coordinate
0
100
200
300
400
500
600
700
800
0
200
400
600
800
1000
1200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

REBOUND ANALYSIS OF LAYERED SITE-Berm Model, Mathcad Sheet for Cross Check against Excel Sheet

METHODOLOGY

This worksheet has been developed to calculate elastic rebound induced by foundation excavation. The soils below foundations are considered as layered elastic medium and the stress decrement at each layer center due to a rectanglar uniformly unloaded area at or below ground surface is computed by Boussinesq solution. The rebound for each layer is calculated using the vertical stress decrement and elastic modulus of the layer, and total rebound is obtained by summing all layer rebounds in the influenced zone.

Stress Decrement: The equation of Boussinesq solution to compute the stress decrement under the corner of a rectanglar unloaded area are shown as below. When the stress calculation point is not located under the corner of a given loaded area, superposition of rectanglar areas covering the unloaded surface and stress calculation point are used to calculate the stress.

Boussinesq Solution:

$$\Delta\sigma_z = \frac{q}{4\pi}\left[\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+m^2n^2+1}\frac{m^2+n^2+2}{m^2+n^2+1}+\sin^{-1}\left(\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+m^2n^2+1}\right)\right]$$

where q is unload intensity, *m=L/Z, N=B/Z*, and *B, L* and *Z* are foundation width, length and stress point depth, respectively. The angle in second term in the parenthesis is less than π/2 when $m^2+n^2+1>m^2n^2$, otherwise between π/2 and π.

Rebound Calculation:The rebound in a given layer is calculated by an equation shown as below.

$$S_i = \Delta\sigma_{zi} H_i \frac{1-\mu_i^{\,2}}{E_i}$$

where H, E and μ are layer thickness, modulus and poisson ratio, respectively.

Total Rebound: $$S = \sum_1^n S_i$$

where n is number of the total layeres influenced by foundation excavation

DATA INPUT

Number of Unloaded Area: NLA := 9 (Maximum 20)

Number of Stress Points in Z Direction: NSPZ := 25 (Maximum 40)

Number of Rebound Points in Plane: NSPP := 22 (Maximum 40)

Stress Calculation Method: ISCC := 1 (1. Boussinesq)

Unloaded Area:	1	2	3	4	5	6	7	8	9
Unloaded Intensity (PSF) of Each Unloaded Area:	5670	5670	5670	5670	5670	5670	5670	5670	5670
Embedment Depth (FT) of Each Unloaded Area:	40	40	40	40	40	40	40	40	40

Coordinates (FT) of Corners of Each Unloaded Rectangle:

	X1	Y1	X2	Y2	X3	Y3	X4	Y4
Unloaded Area 1	300.0	333.0	609.0	333.0	609.0	546.0	300.0	546.0
Unloaded Area 2	300.0	200.0	539.0	200.0	539.0	333.0	300.0	333.0
Unloaded Area 3	629.0	376.0	944.0	376.0	944.0	562.0	629.0	562.0
Unloaded Area 4	539.0	546.0	609.0	546.0	609.0	661.0	539.0	661.0
Unloaded Area 5	539.0	218.0	609.0	218.0	609.0	333.0	539.0	333.0
Unloaded Area 6	39.0	431.0	170.0	431.0	170.0	693.0	39.0	693.0
Unloaded Area 7	39.0	87.0	170.0	87.0	170.0	349.0	39.0	349.0
Unloaded Area 8	635.0	582.0	713.0	582.0	713.0	667.0	635.0	667.0
Unloaded Area 9	635.0	175.0	713.0	175.0	713.0	260.0	635.0	260.0

Layer	Depth to Layer Center (FT)	Modulus (PSF)	Poisson Ratio
1	3.00	155,547,652	0.3
2	15.00	155,547,652	0.3
3	28.00	44,262,695	0.3
4	36.00	48,648,130	0.3
5	50.00	405,550,066	0.3
6	70.00	405,550,066	0.3
7	92.50	405,550,066	0.3
8	107.00	59,687,742	0.3
9	120.50	313,510,454	0.3
10	149.00	585,032,604	0.3
11	183.00	205,855,826	0.3
12	214.50	72,539,100	0.3
13	239.00	110,220,264	0.3
14	264.00	110,220,264	0.3
15	294.00	110,220,264	0.3
16	324.00	117,958,712	0.3
17	355.00	117,958,712	0.3
18	386.00	110,901,382	0.3
19	417.50	110,901,382	0.3
20	463.00	378,267,514	0.3
21	542.00	378,267,514	0.3
22	642.00	378,267,514	0.3
23	742.00	378,267,514	0.3
24	842.00	378,267,514	0.3
25	942.00	378,267,514	0.3

Coords of Rebound Points (FT)

X	Y
300	200
300	333
300	546
419.5	266.5
454.5	439.5
539	200
539	333
574	275.5
574	603.5
609	333
609	546
674	217.5
629	376
629	562
674	624.5
786.5	469
944	376
944	562
104.5	152.5
104.5	283.5
104.5	496.5
104.5	627.5

RESULTS:

Stress Decrement Matrix (PSF): The column index is the layer number, and the row index is rebound point number. The total stress decrement contributed by all unloaded areas at each layer center of each rebound point.

Stressinc =

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	0	0	0	1418	1427	1460	1494	1533	1617	1697	1734	1738	1723	1685	1633	1569	1500	1428	1323	1152	965	811	686	585
2	0	0	0	0	2835	2835	2834	2830	2824	2796	2731	2640	2554	2455	2329	2198	2064	1933	1806	1635	1378	1117	915	759	637
3	0	0	0	0	1418	1427	1463	1501	1544	1641	1740	1795	1812	1808	1781	1735	1675	1606	1531	1421	1236	1031	861	723	613
4	0	0	0	0	5665	5566	5267	5011	4758	4238	3703	3296	3030	2797	2556	2349	2162	1998	1849	1660	1389	1124	921	764	641
5	0	0	0	0	5669	5636	5515	5385	5234	4856	4373	3945	3640	3356	3052	2784	2539	2324	2130	1887	1547	1226	989	810	673
6	0	0	0	0	1491	1933	2195	2263	2289	2278	2207	2117	2040	1960	1865	1771	1677	1587	1500	1380	1195	996	835	704	599
7	0	0	0	0	5667	5591	5362	5166	4970	4560	4108	3730	3461	3208	2932	2683	2453	2248	2061	1827	1499	1189	962	790	658
8	0	0	0	0	5642	5234	4583	4236	3975	3563	3210	2949	2771	2605	2421	2252	2091	1943	1804	1625	1362	1102	904	750	630
9	0	0	0	0	5621	4940	3977	3537	3243	2850	2574	2394	2275	2164	2040	1923	1809	1700	1596	1457	1245	1026	853	715	605
10	0	0	0	0	2839	2915	3080	3180	3249	3305	3242	3105	2970	2819	2633	2449	2268	2098	1938	1731	1431	1143	928	765	640
11	0	0	0	0	2931	3548	3888	3934	3907	3730	3439	3161	2955	2759	2542	2345	2160	1993	1841	1645	1367	1098	897	743	624
12	0	0	0	0	5613	4754	3407	2773	2364	1883	1658	1579	1547	1522	1491	1455	1411	1361	1306	1224	1081	916	776	661	566
13	0	0	0	0	1532	2356	2979	3198	3325	3435	3392	3254	3112	2950	2749	2549	2352	2167	1995	1773	1456	1155	934	768	641
14	0	0	0	0	1571	2679	3427	3600	3637	3518	3249	2986	2792	2609	2407	2224	2054	1900	1758	1576	1316	1063	872	726	611
15	0	0	0	0	5618	4849	3716	3215	2899	2512	2267	2113	2011	1916	1808	1706	1606	1512	1422	1301	1119	930	780	660	564
16	0	0	0	0	5667	5596	5350	5110	4853	4281	3658	3179	2870	2602	2334	2109	1914	1748	1602	1423	1179	953	786	658	559
17	0	0	0	0	1417	1415	1407	1397	1385	1348	1292	1235	1189	1144	1092	1043	996	951	908	851	761	662	578	507	446
18	0	0	0	0	1417	1415	1407	1398	1385	1348	1291	1231	1183	1135	1079	1026	975	927	883	823	733	637	557	490	432
19	0	0	0	0	5658	5419	4763	4258	3805	3004	2335	1921	1692	1515	1357	1238	1142	1066	1002	926	818	709	618	540	474
20	0	0	0	0	5659	5424	4787	4304	3876	3136	2538	2176	1973	1812	1660	1537	1431	1339	1256	1151	996	839	712	609	525
21	0	0	0	0	5659	5424	4786	4301	3872	3128	2526	2160	1955	1793	1641	1520	1415	1325	1245	1142	993	839	715	613	529
22	0	0	0	0	5658	5419	4762	4255	3801	2995	2321	1903	1671	1493	1334	1216	1122	1049	988	916	815	712	623	547	481

Rebounds Matrix (Inches): The column index of the matrix is the layer number, and the row index is rebound point number. The rebound in this matrix is total rebound contributed by each unloaded area at each layer of each rebound point.

SettleComp =

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	0	0	0	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.008	0.003	0.005	0.005	0.005	0.005	0.004	0.005	0.002	0.003	0.003	0.002	0.002	0.002
2	0	0	0	0	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.012	0.005	0.007	0.007	0.006	0.006	0.006	0.006	0.003	0.004	0.003	0.003	0.002	0.002
3	0	0	0	0	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.008	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.004	0.003	0.002	0.002	0.002
4	0	0	0	0	0.003	0.003	0.004	0.004	0.004	0.003	0.007	0.014	0.006	0.008	0.008	0.007	0.006	0.006	0.006	0.003	0.004	0.003	0.003	0.002	0.002
5	0	0	0	0	0.003	0.003	0.004	0.004	0.004	0.003	0.008	0.017	0.007	0.01	0.009	0.008	0.008	0.007	0.007	0.003	0.004	0.004	0.003	0.002	0.002
6	0	0	0	0	0.001	0.001	0.001	0.002	0.002	0.001	0.004	0.009	0.004	0.006	0.006	0.005	0.005	0.005	0.005	0.002	0.003	0.003	0.002	0.002	0.002
7	0	0	0	0	0.003	0.003	0.004	0.004	0.004	0.003	0.007	0.016	0.007	0.01	0.009	0.007	0.007	0.007	0.007	0.003	0.004	0.003	0.003	0.002	0.002
8	0	0	0	0	0.003	0.003	0.003	0.003	0.003	0.002	0.006	0.013	0.005	0.008	0.007	0.006	0.006	0.006	0.006	0.003	0.004	0.003	0.003	0.002	0.002
9	0	0	0	0	0.003	0.003	0.003	0.003	0.003	0.002	0.005	0.01	0.005	0.006	0.006	0.005	0.005	0.005	0.005	0.002	0.004	0.003	0.002	0.002	0.002
10	0	0	0	0	0.002	0.002	0.002	0.002	0.003	0.002	0.006	0.014	0.006	0.008	0.008	0.007	0.007	0.006	0.006	0.003	0.004	0.003	0.003	0.002	0.002
11	0	0	0	0	0.002	0.002	0.003	0.003	0.003	0.002	0.006	0.014	0.006	0.008	0.008	0.007	0.006	0.006	0.006	0.003	0.004	0.003	0.003	0.002	0.002
12	0	0	0	0	0.003	0.003	0.002	0.002	0.002	0.001	0.003	0.007	0.003	0.005	0.004	0.004	0.004	0.004	0.004	0.002	0.003	0.003	0.002	0.002	0.002
13	0	0	0	0	0.001	0.001	0.002	0.002	0.003	0.002	0.006	0.014	0.006	0.009	0.008	0.007	0.007	0.006	0.006	0.003	0.004	0.003	0.003	0.002	0.002
14	0	0	0	0	0.001	0.001	0.002	0.003	0.003	0.002	0.006	0.013	0.006	0.008	0.007	0.006	0.006	0.006	0.006	0.003	0.004	0.003	0.003	0.002	0.002
15	0	0	0	0	0.003	0.003	0.003	0.002	0.002	0.002	0.004	0.009	0.004	0.006	0.005	0.005	0.005	0.004	0.005	0.002	0.003	0.003	0.002	0.002	0.002
16	0	0	0	0	0.003	0.003	0.004	0.004	0.004	0.003	0.007	0.014	0.006	0.008	0.007	0.006	0.006	0.005	0.005	0.002	0.003	0.003	0.002	0.002	0.002
17	0	0	0	0	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.005	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.001	0.002	0.002	0.002	0.001	0.001
18	0	0	0	0	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.005	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.001	0.002	0.002	0.002	0.001	0.001
19	0	0	0	0	0.003	0.003	0.003	0.003	0.003	0.002	0.004	0.008	0.003	0.005	0.004	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.001
20	0	0	0	0	0.003	0.003	0.003	0.003	0.003	0.002	0.005	0.009	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.002	0.003	0.002	0.002	0.002	0.002
21	0	0	0	0	0.003	0.003	0.003	0.003	0.003	0.002	0.005	0.009	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.002	0.003	0.002	0.002	0.002	0.002
22	0	0	0	0	0.003	0.003	0.003	0.003	0.003	0.002	0.004	0.008	0.003	0.004	0.004	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.001

$Settle := TotalSettle(NSPP, NSPZ, SettleComp)$

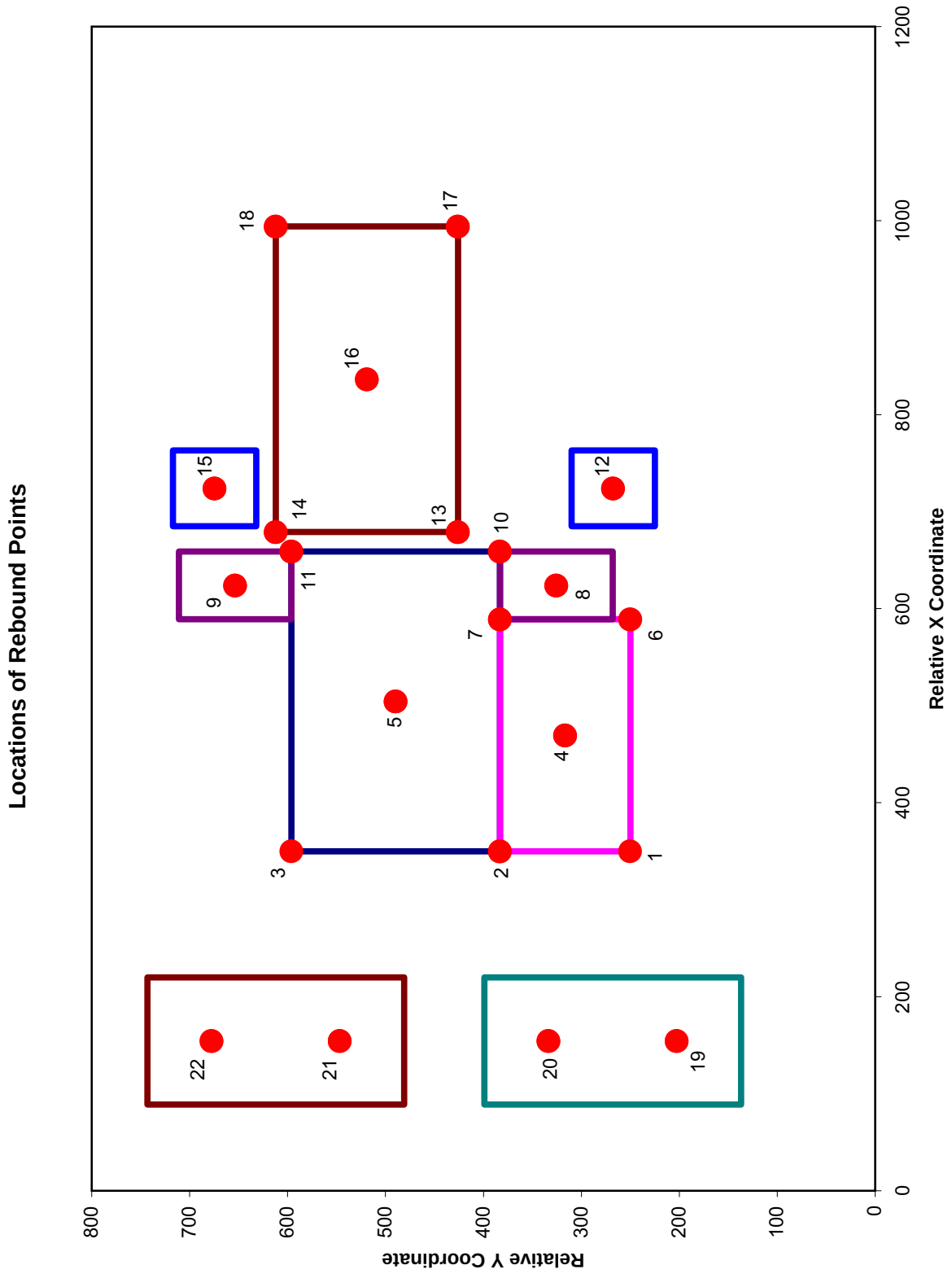
Total Rebound Matrix (Inches)

(Column index is the rebound point number)

$Settle^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	0.06	0.09	0.07	0.1	0.12	0.07	0.11	0.1	0.08	0.1	0.1	0.06	0.1	0.09	0.08	0.1	0.04	0.04	0.07	0.07	0.07	0.07

Appendix B


Locations of Rebound Points
Relative Y Coordinate
Relative X Coordinate
0
100
200
300
400
500
600
700
800
0
200
400
600
800
1000
1200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

Appendix B

MODULUS AVERAGING

LAYER ID	LAYER CENTER DEPTH FT	THICKNESS FT	MODULUS PSF	$\sum_{i=1}^{n}\left(E_i \Big/ \sum_{j=1}^{i} h_j\right)$	$\sum_{i=1}^{n}\left(1 \Big/ \sum_{j=1}^{i} h_j\right)$
1.00	3.00	6.00	155,547,652		
2.00	15.00	18.00	155,547,652		
3.00	28.00	8.00	44,262,695		
4.00	36.00	8.00	48,648,130		
5.00	50.00	20.00	405,550,066	20277503	0.050
6.00	70.00	20.00	405,550,066	10138752	0.025
7.00	92.50	25.00	405,550,066	6239232	0.015
8.00	107.00	4.00	59,687,742	865040	0.014
9.00	120.50	23.00	313,510,454	3407722	0.011
10.00	149.00	34.00	585,032,604	4643116	0.008
11.00	183.00	34.00	205,855,826	1286599	0.006
12.00	214.50	29.00	72,539,100	383805	0.005
13.00	239.00	20.00	110,220,264	527370	0.005
14.00	264.00	30.00	110,220,264	461173	0.004
15.00	294.00	30.00	110,220,264	409741	0.004
16.00	324.00	30.00	117,958,712	394511	0.003
17.00	355.00	32.00	117,958,712	356371	0.003
18.00	386.00	30.00	110,901,382	307206	0.003
19.00	417.50	33.00	110,901,382	281476	0.003
20.00	463.00	58.00	378,267,514	836875	0.002
21.00	542.00	100.00	378,267,514	685267	0.002
22.00	642.00	100.00	378,267,514	580165	0.002
23.00	742.00	100.00	378,267,514	503015	0.001
24.00	842.00	100.00	378,267,514	443976	0.001
25.00	942.00	100.00	378,267,514	397340	0.001

$$E_{dw} = \frac{\sum_{i=1}^{n}\left(E_i \Big/ \sum_{j=1}^{i} h_j\right)}{\sum_{i=1}^{n}\left(1 \Big/ \sum_{j=1}^{i} h_j\right)} = \begin{matrix} 2199 & \text{KSI} \\ 316701108 & \text{PSF} \end{matrix}$$

Weighted Modulus Calculation

NON-LAYERED METHOD--BERM MODEL

WORKSHEET OF REBOUND ESTIMATION
Non-layered Method, Berm Model, Mathcad Sheet for Cross Check against Excel Sheet

Reference: Soil Mechanics Principles and Application (1976), William Perloff and William Baron, Page 199-201.

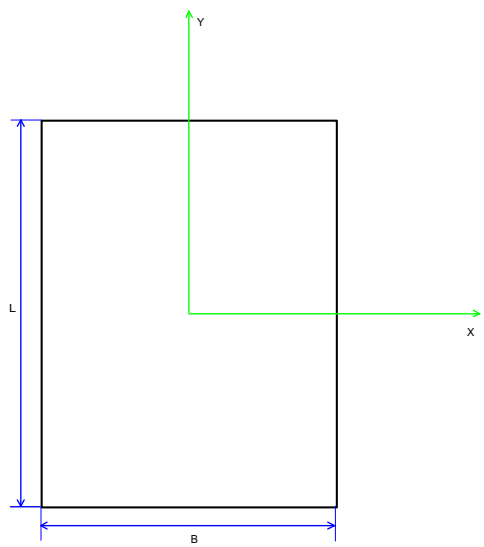


Figure 1. Notation for Rectanglular Loaded Area Shown in Plan View

The vertical rebound of any point of the surface of an elastic half-space uniformly unloaded over a rectangular area is expresses as

$$\delta(x, y, q, B, L) = C(x, y, B, L) \cdot \left[q \cdot B \cdot \frac{(1 - \mu)}{E_d} \right]$$

δ(x,y,q,B,L) = Vertical deformation at point (x,y) induced by a rectangular foundation excavation.

q = unit unload (psf)

B = foundation width (ft)

L = foundation length (ft)

μ= poisson's ratio

E_d = modulus of deformation of the rock foundation

C is a geometric factor which accounts for the shape of the rectangle shown in Figure 1 and the position of the point for which the rebound is being calculated. C can be calculated based on following formulas:

$$\mathbf{A1}(\mathbf{x},\mathbf{B}) := 1 - 2\cdot\frac{\mathbf{x}}{\mathbf{B}} \qquad \mathbf{A2}(\mathbf{x},\mathbf{B}) := 1 + 2\cdot\frac{\mathbf{x}}{\mathbf{B}}$$

$$\mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L}) := \frac{\mathbf{L}}{\mathrm{B}} - 2\cdot\frac{\mathbf{y}}{\mathbf{B}} \qquad \mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L}) := \frac{\mathbf{L}}{\mathrm{B}} + 2\cdot\frac{\mathbf{y}}{\mathbf{B}}$$

$$\mathbf{C1}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) := \mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L})\cdot\ln\left[\frac{\left[\sqrt{(\mathbf{A1}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} + \mathbf{A1}(\mathbf{x},\mathbf{B})\right]}{\left[\sqrt{(\mathbf{A2}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} - \mathbf{A2}(\mathbf{x},\mathbf{B})\right]}\right]$$

$$\mathbf{C2}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) := \mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L})\cdot\ln\left[\frac{\left[\sqrt{(\mathbf{A1}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} + \mathbf{A1}(\mathbf{x},\mathbf{B})\right]}{\left[\sqrt{(\mathbf{A2}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} - \mathbf{A2}(\mathbf{x},\mathbf{B})\right]}\right]$$

$$\mathbf{C3}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) := \mathbf{A1}(\mathbf{x},\mathbf{B})\cdot\ln\left[\frac{\left[\sqrt{(\mathbf{A1}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} + \mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L})\right]}{\left[\sqrt{(\mathbf{A1}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} - \mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L})\right]}\right]$$

$$\mathbf{C4}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) := \mathbf{A2}(\mathbf{x},\mathbf{B})\cdot\ln\left[\frac{\left[\sqrt{(\mathbf{A2}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} + \mathbf{B1}(\mathbf{y},\mathbf{B},\mathbf{L})\right]}{\left[\sqrt{(\mathbf{A2}(\mathbf{x},\mathbf{B}))^2 + (\mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L}))^2} - \mathbf{B2}(\mathbf{y},\mathbf{B},\mathbf{L})\right]}\right]$$

$$\mathbf{C}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) := 0.159\cdot(\mathbf{C1}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) + \mathbf{C2}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) + \mathbf{C3}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}) + \mathbf{C4}(\mathbf{x},\mathbf{y},\mathbf{B},\mathbf{L}))$$

DATA INPUT

Number of Unloaded Area: $\mathbf{NLA} := 9$

Number of Rebound Points in Plane: $\mathbf{NSPP} := 22$

Elastic Modulus: $\mathbf{E} := 316701108$ **PSF**

Poisson Ratio: $\mu := \mathbf{0.3}$

Unloaded Intensity (PSF) of Each Unloaded Area:

5670	5670	5670	5670	5670	5670	5670	5670	5670

Unloaded Area Coordinates (FT) of Rectangle Corners of Each Unloaded Area:

	X1	Y1	X2	Y2	X3	Y3	X4	Y4
1	300.0	333.0	609.0	333.0	609.0	546.0	300.0	546.0
2	300.0	200.0	539.0	200.0	539.0	333.0	300.0	333.0
3	629.0	376.0	944.0	376.0	944.0	562.0	629.0	562.0
4	539.0	546.0	609.0	546.0	609.0	661.0	539.0	661.0
5	539.0	218.0	609.0	218.0	609.0	333.0	539.0	333.0
6	39.0	431.0	170.0	431.0	170.0	693.0	39.0	693.0
7	39.0	87.0	170.0	87.0	170.0	349.0	39.0	349.0
8	635.0	582.0	713.0	582.0	713.0	667.0	635.0	667.0
9	635.0	175.0	713.0	175.0	713.0	260.0	635.0	260.0

Coordinates of Rebound Points (FT)

X	Y
300	200
300	333
300	546
419.5	266.5
454.5	439.5
539	200
539	333
574	275.5
574	603.5
609	333
609	546
674	217.5
629	376
629	562
674	624.5
786.5	469
944	376
944	562
104.5	152.5
104.5	283.5
104.5	496.5
104.5	627.5

$$\mathbf{X} := \left| \begin{array}{l} \textbf{for } \mathbf{i} \in 1 .. \mathbf{NSPP} \\ \quad \mathbf{X_i} \leftarrow \mathbf{CSP_{i,1}} \\ \mathbf{X} \end{array} \right.$$

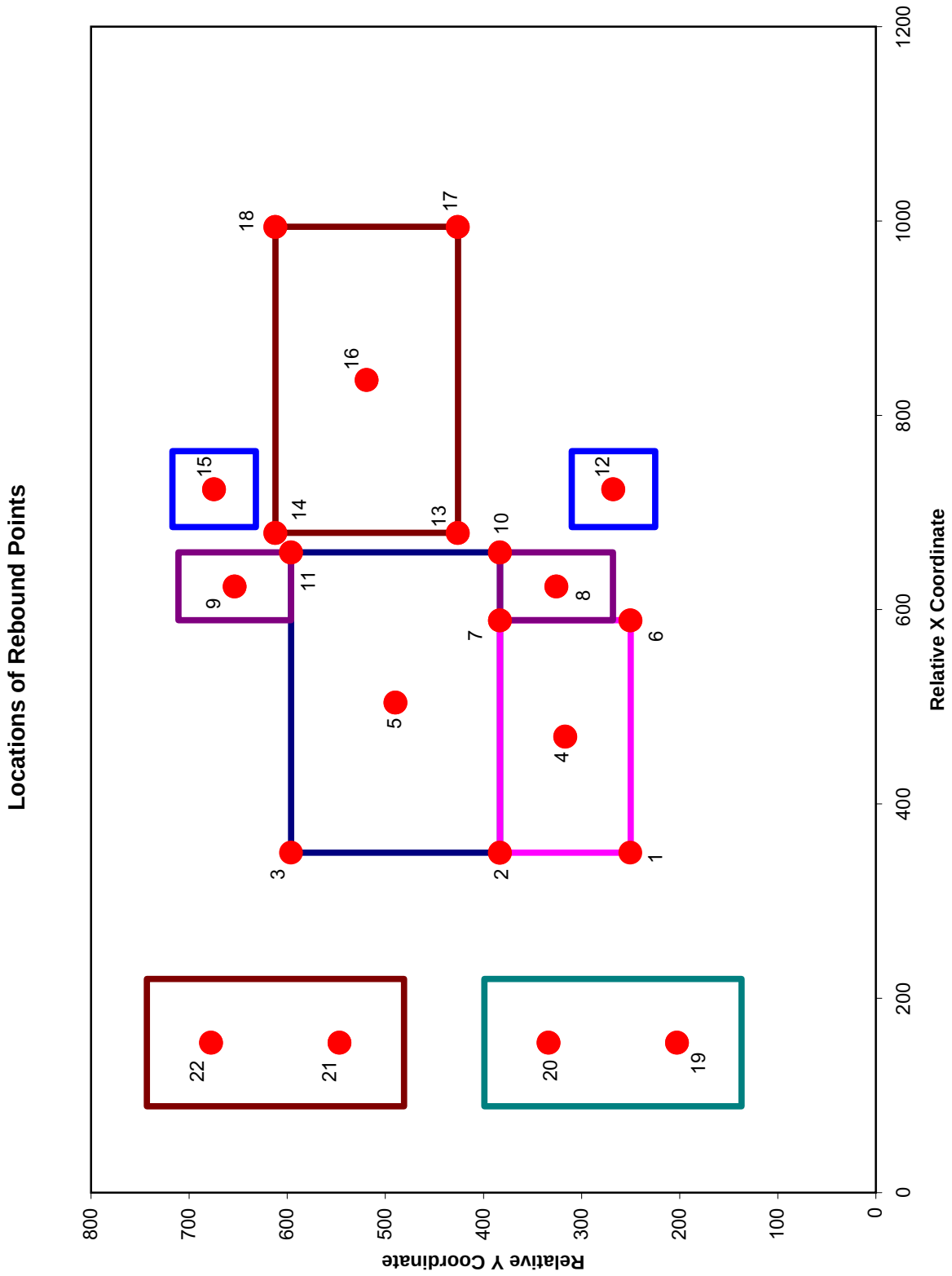
$$\mathbf{Y} := \left| \begin{array}{l} \textbf{for } \mathbf{i} \in 1 .. \mathbf{NSPP} \\ \quad \mathbf{Y_i} \leftarrow \mathbf{CSP_{i,2}} \\ \mathbf{Y} \end{array} \right.$$

Rebound Matrix (inches): Row index is rebound point number

ST =

	1
1	0.05
2	0.06
3	0.05
4	0.07
5	0.07
6	0.05
7	0.07
8	0.07
9	0.06
10	0.06
11	0.06
12	0.05
13	0.06
14	0.06
15	0.06
16	0.06
17	0.04
18	0.04
19	0.05
20	0.06
21	0.06
22	0.05

Appendix B


Locations of Rebound Points
Relative Y Coordinate
Relative X Coordinate
0
100
200
300
400
500
600
700
800
0
200
400
600
800
1000
1200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

APPENDIX C

Bearing Capacity Calculations

BEARING CAPACITY CALCULATION

ASSUMPTION AND BASIS:

1. Reactor Building, R/B.

2. Building will be founded on mat foundation on Unit C.

INPUT PARAMETERS:

FOUNDATION WIDTH:	B= 213 FEET
FOUNDATION LENGTH:	L= 309 FEET
FOUNDATION EMBEDMENT:	D= 40 FEET
ROCK/SOIL EFFECTIVE UNIT WEIGHT:	γ= 150 PCF
ROCK/SOIL COHESION:	c= 73000 PSF
ROCK/SOIL INTERNAL FRICTION ANGLE:	ϕ= 0 DEG
UNCONFINED COMPRESSIVE STRENGTH:	q_u= 146000 PSF

REFERENCE:
Corp of Engineers (1994) EM 1110.1-2908

CALCULATION:

METHOD 1: GENERAL SHEAR FAILURE

$$q_{ult} = cN_c C_c + 0.5\gamma B N_\gamma C_\gamma + \gamma D N_q$$

$$N_\phi = \tan^2(45 + \phi/2)$$

$$N_c = 2N_\phi^{1/2}(N_\phi + 1)$$

$$N_\gamma = N_\phi^{1/2}(N_\phi^2 - 1)$$

$$N_q = N_\phi^2$$

INPUT:	B= 213 FEET	L= 309 FEET	D= 40 FEET
	γ= 150 PCF	c= 73000 PSF	ϕ= 0
RESULT:	N_ϕ= 1	N_c= 1	N_γ= 0
	q_{ult}= 353.9 KSF		

METHOD 2: LOCAL SHEAR FAILURE

$$q_{ult} = cN_c C_c + 0.5\gamma B N_\gamma C_\gamma$$

INPUT:	B= 213 FEET	L= 309 FEET	γ= 150 PCF

c= 73000 PSF ϕ= 0

RESULT: N_c= 1 N_γ= 0 q_{ult}= 347.9 KSF

METHOD 3: COMPRESSIVE FAILURE

$$q_{ult} = 2c\tan(45+\phi/2)$$

INPUT: c= 73000 PSF ϕ= 0

RESULT: q_{ult}= 146 KSF

SUMMARY RESULT:

Case 3 Governs: q_{ult}= 146 KSF

BEARING CAPACITY CALCULATION

ASSUMPTION AND BASIS:

1. Auxiliary Building, A/B.

2. Building will be founded on mat foundation on Unit C.

INPUT PARAMETERS:

FOUNDATION WIDTH:	B= 133 FEET
FOUNDATION LENGTH:	L= 239 FEET
FOUNDATION EMBEDMENT:	D= 40 FEET
ROCK/SOIL EFFECTIVE UNIT WEIGHT:	γ= 88 PCF
ROCK/SOIL COHESION:	c= 73000 PSF
ROCK/SOIL INTERNAL FRICTION ANGLE:	ϕ= 0 DEG
UNCONFINED COMPRESSIVE STRENGTH:	q_u= 146000 PSF

REFERENCE:
Corp of Engineers (1994) EM 1110.1-2908

CALCULATION:

METHOD 1: GENERAL SHEAR FAILURE

$$q_{ult} = cN_c C_c + 0.5\gamma B N_\gamma C_\gamma + \gamma D N_q$$

$$N_\phi = \tan^2(45 + \phi/2)$$

$$N_c = 2N_\phi^{1/2}(N_\phi + 1)$$

$$N_\gamma = N_\phi^{1/2}(N_\phi^2 - 1)$$

$$N_q = N_\phi^2$$

INPUT:	B= 133 FEET	L= 239 FEET	D= 40 FEET
	γ= 88 PCF	c= 73000 PSF	ϕ= 0
RESULT:	N_ϕ= 1	N_c= 1	N_γ= 0
	q_{ult}= 338.3 KSF		

METHOD 2: LOCAL SHEAR FAILURE

$$q_{ult} = cN_c C_c + 0.5\gamma B N_\gamma C_\gamma$$

INPUT:	B= 133 FEET	L= 239 FEET	γ= 88 PCF

c= 73000 PSF ϕ= 0

RESULT: N_c= 1 N_γ= 0 q_{ult}= 334.7 KSF

METHOD 3: COMPRESSIVE FAILURE

$$q_{ult} = 2c\tan(45 + \phi/2)$$

INPUT: c= 73000 PSF ϕ= 0

RESULT: q_{ult}= 146 KSF

SUMMARY RESULT:

Case 3 Governs: q_{ult}= 146 KSF

BEARING CAPACITY CALCULATION

ASSUMPTION AND BASIS:

1. Reactor Building, T/B.

2. Building will be founded on mat foundation on Unit C.

INPUT PARAMETERS:

FOUNDATION WIDTH:	B= 186 FEET
FOUNDATION LENGTH:	L= 315 FEET
FOUNDATION EMBEDMENT:	D= 40 FEET
ROCK/SOIL EFFECTIVE UNIT WEIGHT:	γ= 88 PCF
ROCK/SOIL COHESION:	c= 73000 PSF
ROCK/SOIL INTERNAL FRICTION ANGLE:	ϕ= 0 DEG
UNCONFINED COMPRESSIVE STRENGTH:	q_u= 146000 PSF

REFERENCE:
Corp of Engineers (1994) EM 1110.1-2908

CALCULATION:

METHOD 1: GENERAL SHEAR FAILURE

$$q_{ult} = cN_c C_c + 0.5\gamma B N_\gamma C_\gamma + \gamma D N_q$$

$$N_\phi = \tan^2(45 + \phi/2)$$

$$N_c = 2N_\phi^{1/2}(N_\phi + 1)$$

$$N_\gamma = N_\phi^{1/2}(N_\phi^2 - 1)$$

$$N_q = N_\phi^2$$

INPUT:	B= 186 FEET	L= 315 FEET	D= 40 FEET
	γ= 88 PCF	c= 73000 PSF	ϕ= 0
RESULT:	N_ϕ= 1	N_c= 1	N_γ= 0
	q_{ult}= 342.2 KSF		

METHOD 2: LOCAL SHEAR FAILURE

$$q_{ult} = cN_c C_c + 0.5\gamma B N_\gamma C_\gamma$$

INPUT:	B= 186 FEET	L= 315 FEET	γ= 88 PCF

c= 73000 PSF ϕ= 0

RESULT: N_c= 1 N_γ= 0 q_{ult}= 338.7 KSF

METHOD 3: COMPRESSIVE FAILURE

$$q_{ult} = 2c\tan(45+\phi/2)$$
$$q_{ult} = 2c\tan(45+\phi/2)$$

INPUT: c= 73000 PSF ϕ= 0

RESULT: q_{ult}= 146 KSF

SUMMARY RESULT:

Case 3 Governs: q_{ult}= 146 KSF

BEARING CAPACITY CALCULATION

ASSUMPTION AND BASIS:

1. Power Source Buildings, WPS/EPS.

2. Building will be founded on mat foundation on Unit C.

INPUT PARAMETERS:

FOUNDATION WIDTH:	B= 69 FEET
FOUNDATION LENGTH:	L= 115 FEET
FOUNDATION EMBEDMENT:	D= 40 FEET
ROCK/SOIL EFFECTIVE UNIT WEIGHT:	γ= 88 PCF
ROCK/SOIL COHESION:	c= 73000 PSF
ROCK/SOIL INTERNAL FRICTION ANGLE:	ϕ= 0 DEG
UNCONFINED COMPRESSIVE STRENGTH:	q_u= 146000 PSF

REFERENCE:
Corp of Engineers (1994) EM 1110.1-2908

CALCULATION:

METHOD 1: GENERAL SHEAR FAILURE

$$q_{ult} = cN_c C_c + 0.5\gamma B N_\gamma C_\gamma + \gamma D N_q$$

$$N_\phi = \tan^2(45 + \phi/2)$$

$$N_c = 2N_\phi^{1/2}(N_\phi + 1)$$

$$N_\gamma = N_\phi^{1/2}(N_\phi^2 - 1)$$

$$N_q = N_\phi^2$$

INPUT:	B= 69 FEET	L= 115 FEET	D= 40 FEET
	γ= 88 PCF	c= 73000 PSF	ϕ= 0
RESULT:	N_ϕ= 1	N_c= 1	N_γ= 0
	q_{ult}= 343.2 KSF		

METHOD 2: LOCAL SHEAR FAILURE

$$q_{ult} = cN_c C_c + 0.5\gamma B N_\gamma C_\gamma$$

INPUT:	B= 69 FEET	L= 115 FEET	γ= 88 PCF

c= 73000 PSF ϕ= 0

RESULT: N_c= 1 N_γ= 0 q_{ult}= 339.7 KSF

METHOD 3: COMPRESSIVE FAILURE

$$q_{ult} = 2c\tan(45+\phi/2)$$

INPUT: c= 73000 PSF ϕ= 0

RESULT: q_{ult}= 146 KSF

SUMMARY RESULT:

Case 3 Governs: q_{ult}= 146 KSF

BEARING CAPACITY CALCULATION

ASSUMPTION AND BASIS:

1. Power Source Fuel Tank Vault, PSFTV.

2. Building will be founded on mat foundation on Unit C.

INPUT PARAMETERS:

FOUNDATION WIDTH:	B= 78 FEET
FOUNDATION LENGTH:	L= 85 FEET
FOUNDATION EMBEDMENT:	D= 40 FEET
ROCK/SOIL EFFECTIVE UNIT WEIGHT:	γ= 88 PCF
ROCK/SOIL COHESION:	c= 73000 PSF
ROCK/SOIL INTERNAL FRICTION ANGLE:	ϕ= 0 DEG
UNCONFINED COMPRESSIVE STRENGTH:	q_u= 146000 PSF

REFERENCE:
Corp of Engineers (1994) EM 1110.1-2908

CALCULATION:

METHOD 1: GENERAL SHEAR FAILURE

$$q_{ult} = cN_c C_c + 0.5\gamma B N_\gamma C_\gamma + \gamma D N_q$$

$$N_\phi = \tan^2(45 + \phi/2)$$

$$N_c = 2N_\phi^{1/2}(N_\phi + 1)$$

$$N_\gamma = N_\phi^{1/2}(N_\phi^2 - 1)$$

$$N_q = N_\phi^2$$

INPUT:	B= 78 FEET	L= 85 FEET	D= 40 FEET
	γ= 88 PCF	c= 73000 PSF	ϕ= 0
RESULT:	N_ϕ= 1	N_c= 1	N_γ= 0
	q_{ult}= 365.1 KSF		

METHOD 2: LOCAL SHEAR FAILURE

$$q_{ult} = cN_c C_c + 0.5\gamma B N_\gamma C_\gamma$$

INPUT:	B= 78 FEET	L= 85 FEET	γ= 88 PCF

c= 73000 PSF ϕ= 0

RESULT: N_c= 1 N_γ= 0 q_{ult}= 361.6 KSF

METHOD 3: COMPRESSIVE FAILURE

$$q_{ult} = 2c\tan(45+\phi/2)$$

$$q_{ult} = 2c\tan(45+\phi/2)$$

INPUT: c= 73000 PSF ϕ= 0

RESULT: q_{ult}= 146 KSF

SUMMARY RESULT:

Case 3 Governs: q_{ult}= 146 KSF

BEARING CAPACITY CALCULATION

ASSUMPTION AND BASIS:

1. Ultimate Heat Sink, UHS.

2. Building will be founded on mat foundation on Unit C.

INPUT PARAMETERS:

FOUNDATION WIDTH:	B= 131 FEET
FOUNDATION LENGTH:	L= 131 FEET
FOUNDATION EMBEDMENT:	D= 40 FEET
ROCK/SOIL EFFECTIVE UNIT WEIGHT:	γ= 88 PCF
ROCK/SOIL COHESION:	c= 73000 PSF
ROCK/SOIL INTERNAL FRICTION ANGLE:	ϕ= 0 DEG
UNCONFINED COMPRESSIVE STRENGTH:	q_u= 146000 PSF

REFERENCE:
Corp of Engineers (1994) EM 1110.1-2908

CALCULATION:

METHOD 1: GENERAL SHEAR FAILURE

$$q_{ult} = cN_c C_c + 0.5\gamma B N_\gamma C_\gamma + \gamma D N_q$$

$$N_\phi = \tan^2(45 + \phi/2)$$

$$N_c = 2N_\phi^{1/2}(N_\phi + 1)$$

$$N_\gamma = N_\phi^{1/2}(N_\phi^2 - 1)$$

$$N_q = N_\phi^2$$

INPUT:	B= 131 FEET	L= 131 FEET	D= 40 FEET
	γ= 88 PCF	c= 73000 PSF	ϕ= 0
RESULT:	N_ϕ= 1	N_c= 1	N_γ= 0
	q_{ult}= 368.5 KSF		

METHOD 2: LOCAL SHEAR FAILURE

$$q_{ult} = cN_c C_c + 0.5\gamma B N_\gamma C_\gamma$$

INPUT:	B= 131 FEET	L= 131 FEET	γ= 88 PCF

c= 73000 PSF ϕ= 0

RESULT: N_c= 1 N_γ= 0 q_{ult}= 365 KSF

METHOD 3: COMPRESSIVE FAILURE

$$q_{ult} = 2c\tan(45 + \phi/2)$$

INPUT: c= 73000 PSF ϕ= 0

RESULT: q_{ult}= 146 KSF

SUMMARY RESULT:

Case 3 Governs: q_{ult}= 146 KSF