CHAPTER 15

Presenting Results of Stability Evaluations

Clear and comprehensive presentations of results of slope stability evaluations are important for several reasons:

1. Results need to be checked. Results may be checked and reviewed by several persons, including both engineers in the organization doing the stability analyses and engineers in other organizations that have review and regulatory responsibilities.
2. Results need to be clear to the client or other person for whom the evaluations were made.
3. Responsibility for engineering is sometimes transferred to another engineer within the organization or to an entirely different organization. The person assuming responsibility needs a clear understanding of what has been done and the basis for decisions that have been made.
4. Engineers often need to ''revisit'' their work many years later or resume work after delays cause it to be put aside. Clear documentation of the work that has already been done is important.

The level and form of documentation may vary depending on the progress of the job. In general, some form of written documentation should be prepared and maintained at all stages of the job so that if the job is stopped or delayed prematurely, work can be resumed later and prior work can be understood. The primary emphasis of this chapter is on the presentation of results of a slope stability evaluation once it has been completed. However, many of the components of this final documentation should be prepared as the work progresses.

SITE CHARACTERIZATION AND REPRESENTATION

Any presentation should designate the location of the site and slope being evaluated. As a minimum the presentation should contain sufficient information so that the site can be located and visited by the person reviewing the work. Presentation of the site location may vary from a simple written description of the site location to elaborate site maps, plan sheets, and photographs showing the location in detail. Where such plans and drawings are presented they may also include topographic contours and identification of potentially important features. For example, the site plan may identify nearby reservoirs, rivers, streams, areas of extensive fill work or excavation, structures, and transportation and other infrastructure elements (roads, pipelines, electricity and telecommunication transmission lines, etc.).

An appropriate description of the geologic setting is essential. Geologic details often play a major role in slope stability and thus the geologic information is very important. The extent to which such information is included as a specific part of a stability evaluation as compared to part of the geotechnical engineering for the overall project will vary, of course, and this may or may not be an integral part of the presentation of the slope stability evaluation.

One or more cross sections should be prepared to show the geometry of the slope and immediate foundation area that are being evaluated. Where field investigations have been performed using exploratory borings, test pits, and nonintrusive geophysical methods, soil profile cross sections or an equivalent graphical representation of the subsurface (fence diagrams, three-dimensional solid and surface models, etc.) should be prepared.

A cross-section drawing should be prepared showing all the details that are considered important for the stability analyses, but the cross section may exclude extraneous and minor features if they are known to be unimportant. The cross section should be drawn to scale.

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Trial F =	1.613

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Slice No.	b	h_{shell}	γ_{shell}	h_{core}	γ_{core}	W	α	W sinα	c'	ϕ'	$h_{piez.}$	u	c'b + (W - ub) tanϕ'	m_α	c'b + (W - ub) tanϕ' + m_α
1	20.0	13.1	140	0.0	120	36659	43.2	25110	0	38	0.0	0	28641	1.06	27011
2	35.2	20.8	140	26.6	120	215174	40.2	138831	0	20	23.2	1450	59724	0.91	65660
3	65.0	10.0	140	76.0	120	683527	35.0	391572	0	20	38.3	2392	192187	0.95	202533
4	62.5	29.5	140	84.9	120	894190	28.7	429214	0	20	55.3	3449	247055	0.99	250670
5	89.9	52.5	140	69.1	120	1406585	21.7	519784	0	20	59.9	3741	389600	1.01	384751
6	105.7	82.2	140	34.2	120	1648280	13.1	374514	0	20	34.2	2131	517970	1.03	505280
7	21.2	101.4	140	5.6	120	315386	7.7	42435	0	20	11.5	719	109240	1.02	106965
8	81.8	92.2	140	0.0	120	1055716	3.4	62854	0	38	12.9	805	773349	1.03	752971
9	114.7	54.1	140	0.0	120	867907	-4.8	-72569	0	38	7.2	452	637567	0.96	666912
10	49.8	14.2	140	0.0	120	98993	-11.7	-20099	0	38	0.0	0	77342	0.88	87806
							Σ =	1891646						Σ =	3050560
														F' =	1.613

Note: Trial F adjusted repeatedly until computed value, F', and trial value are the same.

Figure 15.1 Sample spreadsheet for simplified Bishop procedure.

SOIL PROPERTY EVALUATION

The basis for the soil properties used in a stability evaluation should be described and appropriate laboratory test data should be presented. If properties are estimated based on experience, or using correlations with other soil properties or from data from similar sites, this should be explained. Results of laboratory tests should be summarized to include index properties, water content, and unit weights. For compacted soils, suitable summaries of compaction moisture–density data are useful. A summary of shear strength properties is particularly important and should include both the original data and the shear strength envelopes used for analyses (Mohr–Coulomb diagrams, modified Mohr–Coulomb diagrams, τ_{ff} vs. σ'_{fc} diagrams).

The principal laboratory data that are used in slope stability analyses are the unit weights and shear strength envelopes. If many more extensive laboratory data are available, the information can be presented separately from the stability analyses in other sections, chapters, or separate reports. Only the summary of shear strength and unit weight information need be presented with the stability evaluation in such cases.

PORE WATER PRESSURES

For effective stress analyses the basis for pore water pressures should be described. If pore water pressures are based on measurements of groundwater levels in bore holes or with piezometers, the measured data should be described and summarized in appropriate figures or tables. If seepage analyses are performed to compute the pore water pressures, the method of analysis, including computer software, that was used should be described. Also, for such analyses the soil properties and boundary conditions as well as any assumptions used in the analyses should be described. Soil properties should include the hydraulic conductivities. Appropriate flow nets or contours of pore water pressure, total head, or pressure head should be presented to summarize the results of the analyses.

SPECIAL FEATURES

Slopes sometimes have special features of their makeup and construction that should be included in the presentation of results. For example, for reinforced slopes the type of reinforcement (nails, geogrid, geotextile, tieback anchors, piles, etc.) is important and should be indicated. In the case of reinforcement, the basis for determining the forces in the reinforcement should be described, including what factors of safety were applied to the reinforcement forces. Important details of any nonsoil materials such as geosynthetics and the interfaces between soil and nonsoil materials or between nonsoil and nonsoil materials (e.g., geomem-

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Table 15.1 Sample Description of Contents of Spreadsheet Presented in Figure 15.1

Column no.	Description
1	Slice number
2	Horizontal width of slice
3	Height of portion of slice in the *shell* material; measured at midpoint of slice, h_{shell}
4	Total unit weight of shell material, γ_{shell}
5	Height of portion of slice in the *core* material; measured at midpoint of slice, h_{core}
6	Total unit weight of *core* material, γ_{core}
7	Weight of slice, $W = b(\gamma_{shell}h_{shell} + \gamma_{core}h_{core})$
8	Inclination of the bottom of the slice, α, in degrees measured from the horizontal [positive when the bottom of the slice is inclined in the same direction as the slope face (e.g., near the crest of the slope); negative when the base of the slice is inclined in the direction opposite that of the slope face (e.g., near the toe of the slope)]
9	Product of slice weight and sine of the angle, α
10	Cohesion value for soil at bottom of slice
11	Friction angle for soil at bottom of slice
12	Height of pieizometric line (h_{piez}) above the center of the base of the slice
13	Pore water pressure at the center of the bottom of the slice, $u = \gamma_{water}h_{piez}$
14	Intermediate term used to compute numerator in equation for factor of safety: $c'b + (W - ub)\tan\phi'$
15	Value of the quantity m_α for trial factor of safety; trial factor of safety is shown above column 15 ($m_\alpha = \cos\alpha + \sin\alpha\tan\phi'/F$)
16	Column 14 divided by column 15, representing terms in the numerator of the expression for factor of safety; column 16 summed for all slices and divided by the summation of column 9 to compute a new factor of safety, F'

branes and geotextiles) should also be included in the report.

For compacted clay fills, the compaction procedures and construction quality control are important in determining the shear strength values. In some cases the construction sequence will determine the geometries that must be considered and may dictate consideration of special stages in construction that need attention, due either to the shear strengths that will exist at that time or the geometric configuration of the slope. Important details of construction should be addressed in the report.

Operational details can also be important and need to be included in a report. For example, the operating procedures for a dam or reservoir will control the amount of drawdown and thus have a direct bearing on stability. Temporary construction or stockpiling of materials or other heavy items near the crest of a slope will influence its stability and should be duly noted and accounted for in the stability evaluation. Also, for seismic areas the characteristics of the design earthquake should be described.

CALCULATION PROCEDURE

Presentations of slope stability analyses should clearly identify the procedures used to perform the stability calculations. When computer software is used, the software and references to documentation (manuals) should be specified; software without manuals or documentation should not be used. Inclusion of detailed computer output is usually unnecessary if proper related documentation is presented as described elsewhere in this chapter. If computer output is included, it should be organized in appendixes and clearly labeled.

If spreadsheets are included as part of a presentation of results, a complete description of the content of items (rows, columns) in the spreadsheet should be included. An example for this type of documentation is the spreadsheet for the Simplified Bishop procedure shown in Figure 15.1. Table 15.1 contains a description of the contents of the columns in this spreadsheet, including the equations used for computation of the contents of each column, except where the information is self-explanatory.

ANALYSIS SUMMARY FIGURE

Results of stability calculations for each condition (e.g., end-of-construction, long-term, sudden drawdown) should be presented in separate figures showing, at least, the slope and subsurface geometry. The figure should also show the most critical slip surface that gave the minimum factor of safety. The figure need not include all of the details shown for the cross section described earlier in the section ''Site Characterization and Representation'' but should include sufficient detail that the location of important features relative to the critical slip surface can be readily seen. For example, in an embankment dam, the various zones of pervious and impervious soils should be shown on

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each cross section. For embankments and excavated slopes in natural soils, the locations of various strata should be delineated.

The summary figure for each stability condition should also include information showing what set of shear strength properties were used and, for effective stress analyses, what pore water pressure conditions were used in the analyses. For simple soil and slope conditions the shear strength properties may be shown directly on the figure, at applicable locations in the cross section (Figure 15.2) or in a separate table included on the figure (Figure 15.3). For more complex shear strength conditions, a separate table with references between the table and drawing of the slope may be needed. If a separate table is used, the material properties and the zones to which they apply should be identified clearly. It is usually appropriate in this case to number the materials as well as to use descriptive terms (e.g., 1, silty sand; 2, clay foundation; 3, slope protection; 4, filters) (Figure 15.4 and Table 15.2).

If anisotropic shear strengths or nonlinear Mohr failure envelopes are used in the stability calculations, additional figures should be prepared to show the shear strength. For anisotropic shear strengths the variation in shear strength with the orientation of the failure plane (slip surface) should be shown (Figure 15.5). For nonlinear Mohr failure envelopes the envelope should be shown on a Mohr–Coulomb diagram (Figure 15.6).

For reinforced slopes the reinforcement pattern assumed for the analyses should be shown on an appropriate figure (Figure 15.7). The reinforcement may either be shown on the main figure used to summarize the analysis, or if the reinforcement is relatively com-

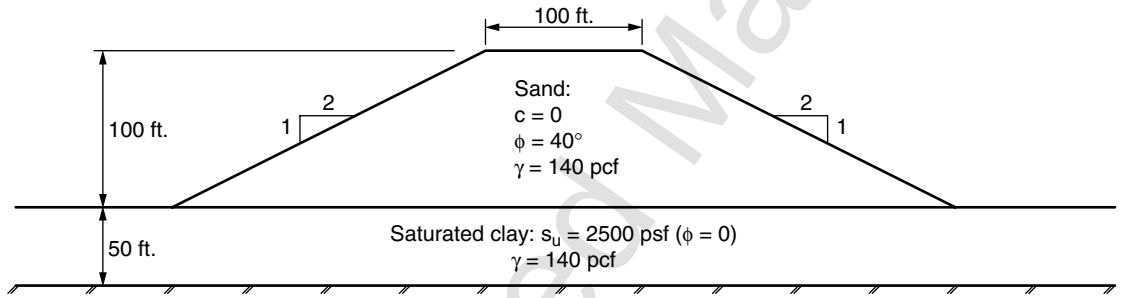


Figure 15.2 Slope with soil properties shown on the cross section.

Mat'l	Description	Unit Wt. (pcf)	c' (psf)	ϕ' (degs)
1	Foundation overburden	134	0	35
2	Core (clay)	130	200	29
3	Transition	135	0	32
4	Shell (gravel)	140	0	37

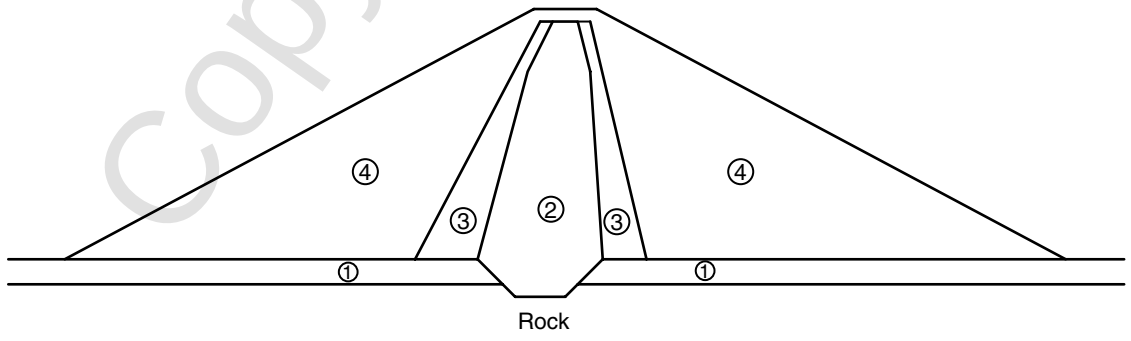
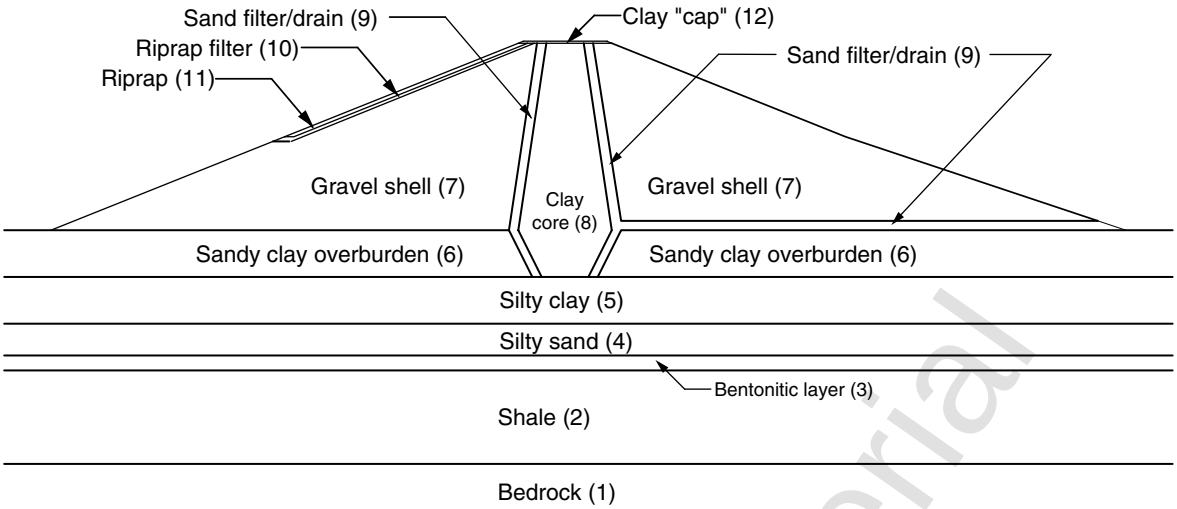


Figure 15.3 Presentation of slope with soil properties in a table.

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Note: Numbers in parentheses correspond to material numbers shown in accompanying Table 15.2 of soil properties.

Figure 15.4 Slope with material property identification numbers and accompanying Table 15.2 with soil properties.

Table 15.2 Soil Properties for Slope Shown in Figure 15.4

Mat'l	Description	Unit weight (pcf)	Cohesion, c' (psf)	Friction angle, ϕ' (deg)
1	Bedrock	150	10,000	0
2	Shale (foundation)	133	100	21
3	Bentonitic layer (foundation)	127	0	12
4	Silty sand (foundation)	124	0	29
5	Silty clay (foundation)	131	100	26
6	Sandy clay overburden	125	0	32
7	Gravel shell	142	0	38
8	Clay core	135	250	24
9	Sand filter/drain	125	0	35
10	Riprap filter	125	0	33
11	Riprap	130	0	36
12	Clay cap on crest	125	1000	0

plex, a separate figure may be used. The figure should clearly show the spacing of the reinforcement and its length. Appropriate information should also be given for the force in the reinforcement. This may consist of information ranging from a simple note on the drawing to indicate that all reinforcement was assumed to carry a certain, constant force, to a table showing the specific forces in each layer of reinforcement. If the force varies along the length of the reinforcement, appropriate information on the variation should be shown either graphically (Figure 15.8) or in tabular form. Caution should be exercised in using computer software that automatically assigns forces to reinforcement based on other information (e.g., manufacturers names or product numbers); the values of the forces that are assigned and eventually used to compute stability should be given clearly.

A summary of results of stability calculations for more than one stability condition on a single figure is not desirable. Similarly, summary on one figure of re-

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α - deg	s_u - psf
-90	3500
-75	3400
-60	3000
-45	2400
-30	2000
-15	1850
0	1800
15	1900
30	2100
45	2400
60	2800
75	3300
90	3500



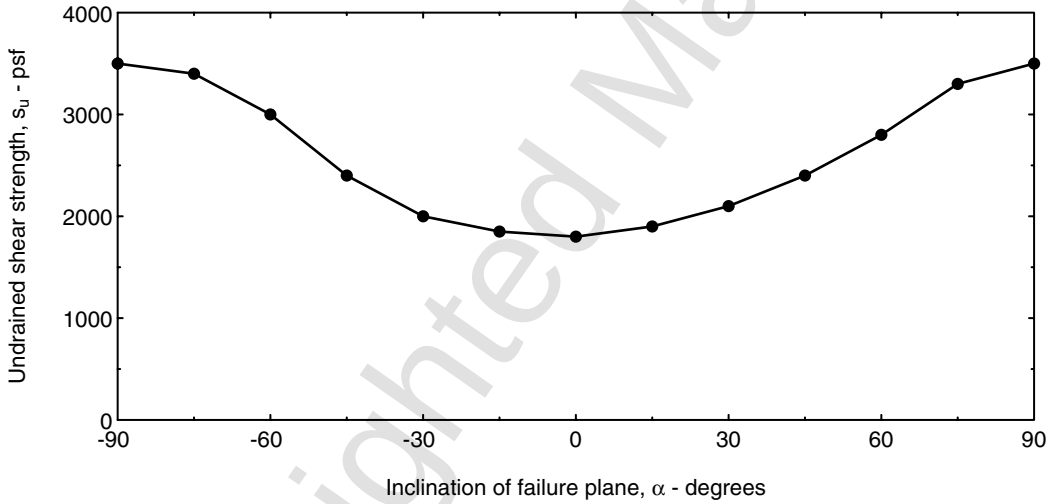


Figure 15.5 Presentation of the variation of undrained shear strength with failure plane orientation for a soil that is anisotropic.

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sults of parametric studies in which more than one variable was changed (see the next section) should be avoided.

When analyses are performed using slope stability charts, the summary figure should include the critical slip surface if it can be determined from the chart. The summary figure or accompanying text should designate what charts were used and other relevant information, including appropriate summary calculations. Several examples of summary calculations with slope stability charts are presented in the Appendix.

PARAMETRIC STUDIES

Parametric studies are useful to examine the effect of various assumptions about important quantities, especially when there is significant uncertainty about the values. Parametric studies may be performed by varying the shear strengths, pore water pressures, surface or seismic loads, and slope and subsurface geometry and computing the factor of safety for each set of assumed value. When parametric studies are performed, only one quantity at a time should be varied. For ex-

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σ' - psf	τ - psf
0	500
5000	2000
10000	3000
15000	3600
20000	4000

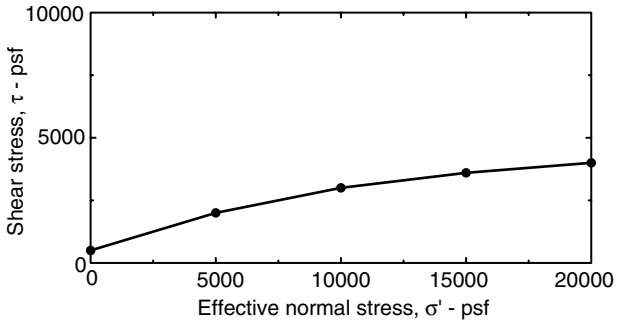


Figure 15.6 Presentation of nonlinear Mohr failure envelope.

ample, the shear strength of a particular stratum might be varied, or different reservoir levels and seepage patterns might be assumed.

When several quantities are varied in parametric studies, separate figures should be presented for each quantity that is varied. For example, a figure might be prepared to show how the factor of safety varies with the shear strength of a particular stratum (Figure 15.9). The figure might show the cross section and, on the same figure, a diagram or table showing how the factor of safety varies with the shear strength. If the critical slip surfaces vary significantly as the value of a quantity is varied, selected individual critical slip surfaces or surfaces representing the extremes might be illustrated. However, there is no need to show critical slip surfaces for each value of each quantity that is varied if there is little effect on the location of the critical slip surface.

DETAILED INPUT DATA

If it is known that someone else will perform additional analyses, and a significant amount of input data (coordinate or pore water pressure data) will be needed, it is helpful to provide such data in tabular

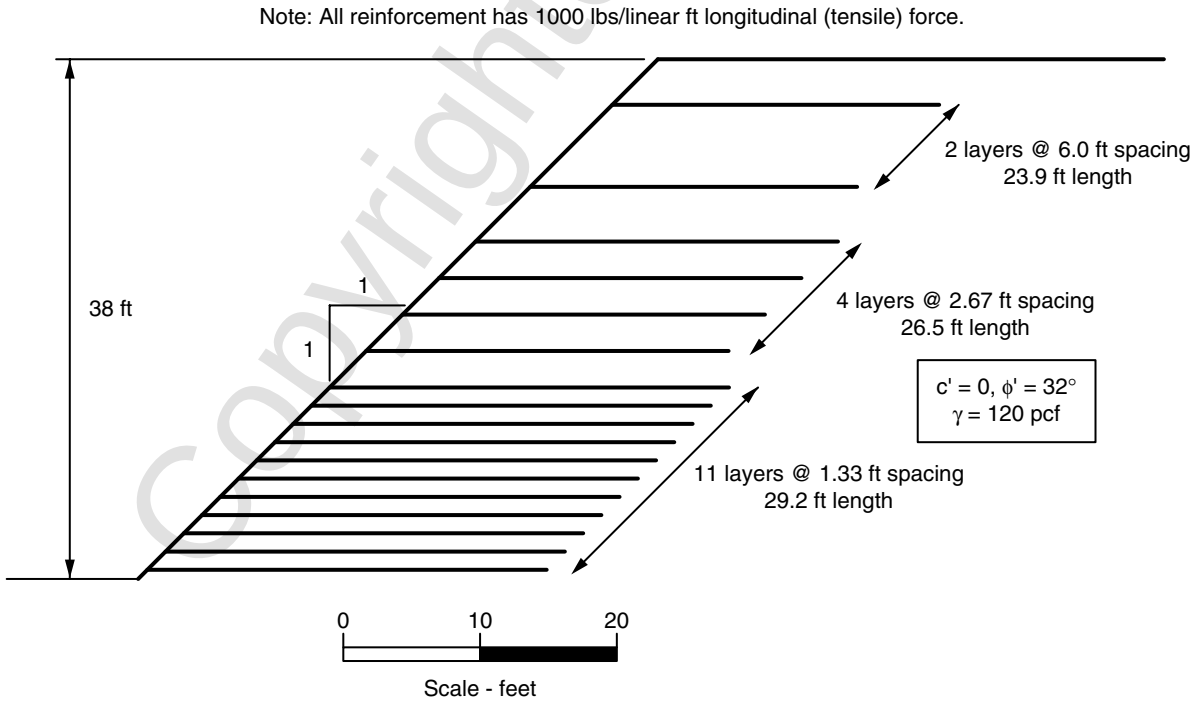


Figure 15.7 Presentation of reinforcement layout.

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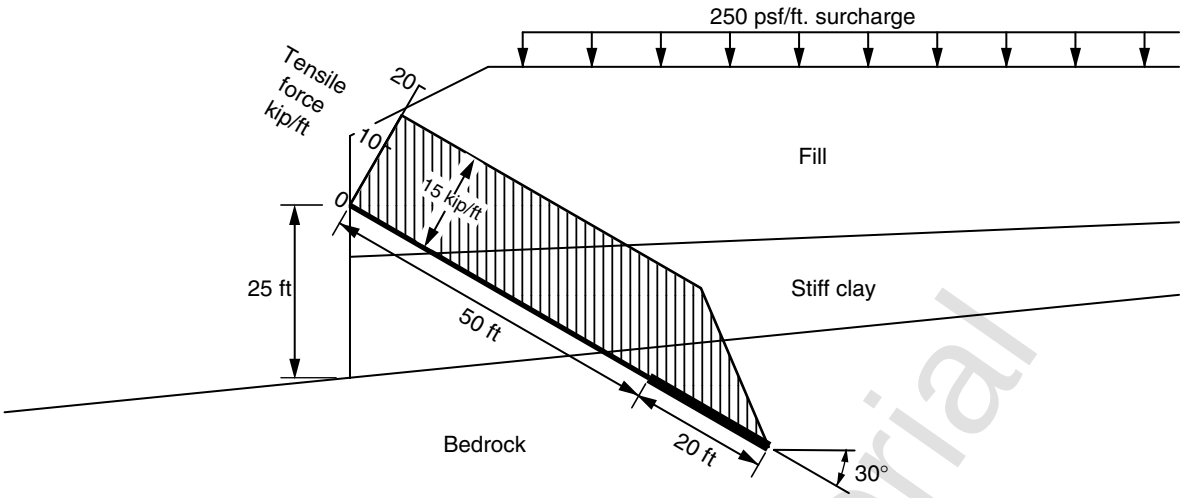
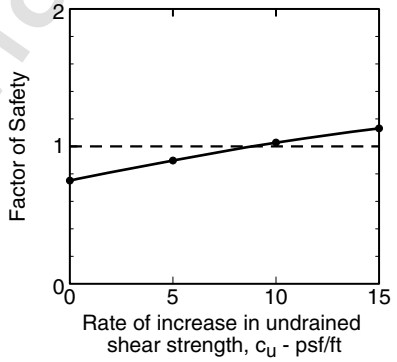


Figure 15.8 Presentation of reinforcement (tie-back anchor) with longitudinal force distribution.

Rate of increase in undrained shear strength, c_z - psf/ft	Factor of Safety
0 (constant strength)	0.75
5	0.90
10	1.03
15	1.13



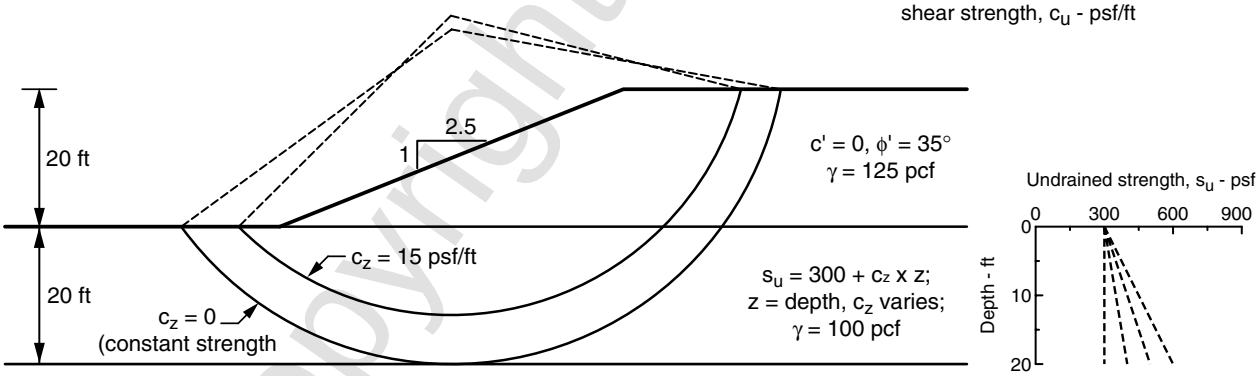


Figure 15.9 Presentation of results for parametric study in which the rate of increase in undrained shear strength (c_z) for the foundation was varied.

form to reduce the amount of effort that will be required later. If such data are included in a presentation they should be neatly organized in appropriate appendixes and clearly labeled and described. Electronic versions of the data on removable storage media may also be provided.

TABLE OF CONTENTS

A sample table of contents for presentation of a stability evaluation is shown in Table 15.3. Details will vary from slope to slope, but most of the items shown should be contained in any presentation of results.

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Table 15.3 Sample Table of Contents for Presentation of Results of Stability Analyses

Introduction
Description of site
  Location
  Geology
Soil properties
  Laboratory testing program (or basis for selection)
  Unit weights
  Shear strengths
    Undrained shear strengths
    Drained shear strengths
Groundwater, seepage, and pore water pressure conditions
Special features
  Slope reinforcing
  Nonsoil materials and interfaces
  Construction procedures
Stability evaluation procedures
  Computer software
  Slope stability charts
  Empirical correlations and experience with slope in area
Summary of results
  End-of-construction stability
  Long-term stability
  Stability for rapid drawdown
  Seismic (earthquake stability)
Discussion and recommendation

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