BuMines OFR 52(3)-84

PE84-178698

A mining research contract report
AUGUST 1983

SURFACE COAL MINE SPOIL STABILITY STUDY EASTERN COAL PROVINCE MANUAL OF PRACTICE

Contract J0395011
Law Engineering Testing Company

Bureau of Mines Open File Report 52(3)-84

BUREAU OF MINES
UNITED STATES DEPARTMENT OF THE INTERIOR

PB84 178698

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. BuMines 52(3)-84	2.	3. Recipient's Accession No.

4. Title and Subtitle
Surface Coal Mine Spoil Stability Study, Eastern Coal Province. Manual of Practice

5. Report Date
August 25, 1983

6.

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10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C) J0395011
(G)

12. Sponsoring Organization Name and Address
Office of Assistant Director--Mining Research
Bureau of Mines
U.S. Department of the Interior
Washington, DC 20241

13. Type of Report & Period Covered
Contract research, 4/20/79--8/25/83

14.

15. Supplementary Notes
Approved for release March 2, 1984.

16. Abstract (Limit: 200 words)

This manual of practice is to be used in combination with volumes I and II of the study on spoil stability in the eastern coal province. The manual applies the predictive matrices developed in the parent study for use in evaluating the stability of typical mine spoil slopes. The values of internal friction and pore pressure coefficient are derived for many varied slope conditions. The results can be used in conventional stability analysis equations to assist mine operators or regulatory personnel in evaluating spoil stability from very limited information.

17. Document Analysis a. Descriptors

Mining research
- Spoil strength
- Spoil stability
- Mining method
- Geologic setting
- Ground water effects
- Natural spoils
- Stability analyses
- Predictive matrices

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group 08I

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release unlimited by NTIS.	Unclassified	41
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI–Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4–77) (Formerly NTIS–35) Department of Commerce

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FOREWARD

This report was prepared by Law Engineering Testing Company, McLean, Virginia under USBM Contract Number J0395011. This contract was administered under the technical direction of the U.S. Bureau of Mines with Lester Adams and David G. Simpson acting as Technical Project Officers. Alan G. Bolton and William R. Mundorf were Contracting Officers for the Bureau of Mines. This report is a summary of the work completed as a part of this contract during the period April 1979 to August 1983. The Manual of Practice was submitted along with Volumes I and II in August, 1983.

This work was completed as part of the study of Surface Coal Mine Spoil Stability of the Eastern Coal Province. Therefore, we extend our grateful appreciation to those mine companies, mine personnel, and other agencies whose time, cooperation, and assistance enabled us to complete this project. It is our sincere hope that the Manual may be of particular value to the participating companies as well as the surface mine industry as some compensation for their cooperation.

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or of the U.S. Government.

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LIST OF ABBREVIATIONS AND SYMBOLS

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Ac.	Acre
b	slice width
C	cohesion intercept, psf
cos	cosine
elev.	elevation
F.S.	Factor of Safety
ft.	foot
h	height of slice
hw	height of water above bottom of slice, ft.
kcf	kips per cubic foot
mi	mile
N	overburden pressure, psf.
OR	Overburden Ratio
pcf	pounds per cubic foot
R_u, r_u	pore pressure coefficient
S	fully mobilized shear strength, psf
sec	secant
sin	sine
SMCRA	Surface Mine Control Reclamation Act
tan	tangent
T_{cl}	thickness of clay in overburden profile
T_l	thickness of limestone in overburden profile

LIST OF ABBREVIATIONS AND SYMBOLS (Cont'd.)

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T_m	thickness of mudstone in overburden profile
T_s	thickness of sand in overburden profile
T_{sh}	thickness of shale in overburden profile
T_{si}	thickness of silt in overburden profile
T_{ss}	thickness of sandstone in overburden profile
T_{sst}	thickness of siltstone in overburden profile
N_a	calculation constant, Janbu Method
W	total weight of slice, lbs
α	slope angle from horizontal at base of slice, degrees
γ_s	total weight of spoil, pcf
γ_η	total weight of natural ground soils, pcf
γ_t	total weight of soil, pcf
γ_w	unit weight of water, 62.4 pcf
ϕ'	effective stress friction angle, degrees
ϕ_r	residual strength friction angle, degrees
u	pore pressure

1.0 PURPOSE OF MANUAL

The purpose of this manual is to provide explanations and instructions for determining the stability of reclaimed spoil slopes based on premining information. This manual has been developed utilizing data obtained during the research investigation titled; Spoil Stability Study - Eastern Coal Province. Illustrated examples are included.

The stability of a proposed reclamation scheme requires information concerning geometry, strength, and groundwater parameters of the spoil pile and the supporting soils. Estimates of these parameters can be made from information readily available to the mine operator or regulatory personnel. The predictive matrices contained in this manual provides a means by which a person unfamiliar with geotechnical engineering can use information such as highwall composition or exploratory borings to obtain estimated strength and groundwater parameters. Most of the information required is normally submitted with the application for a surface mine permit.

The predictive matrix should not take the place of a detailed site investigation. The matrix is based on a limited data base. Detailed investigations are required where failure threatens to cause loss of life or significant property damage. However, the matrix can provide initial evaluations of strength and groundwater and assist the operator in designing a more stable reclamation plan.

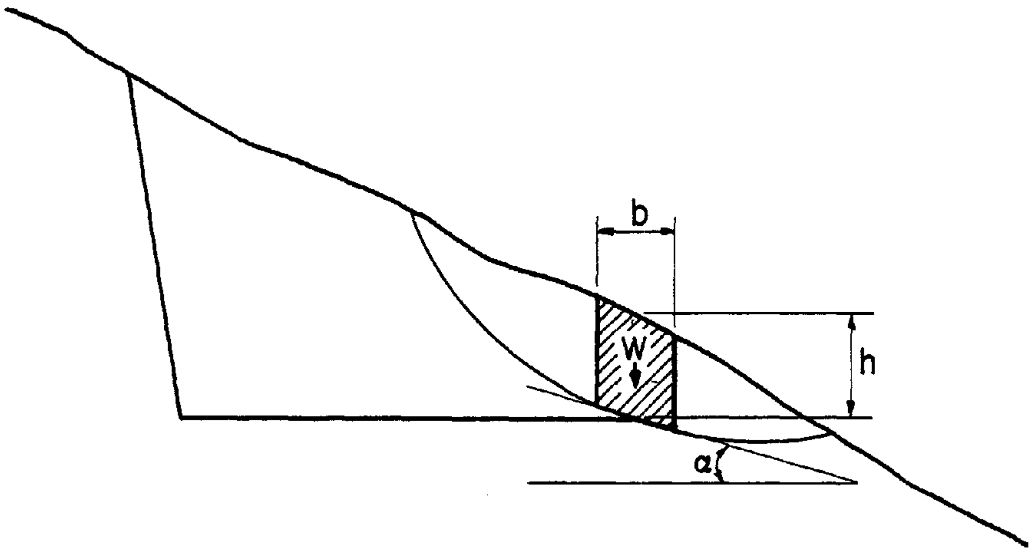
2.0 SPOIL STABILITY ANALYSIS

The stability of reclaimed spoil slopes can be evaluated by standard slope stability equations. Typical stability methods analyze a slope in parts by dividing the slope into many slices (reference Figure 2-1). The failure surface to be analyzed is selected and divided into a number of slices. The forces on each slice are calculated and summed over the entire slope. The forces resisting movement are divided by the forces tending to cause movement. The ratio is defined as the safety factor. A minimum safety factor of 1.3 is required under the current federal regulations. The most common definitions of safety factor are expressed in equations 2-1, 2-2, and 2-3.

The mine operator or regulatory personnel must estimate the value of each parameter used in the equation. Much of this information is based on the geometry of the proposed reclamation plan and is therefore readily available. The soil parameters are often not available but can be estimated from the relationships in this manual.

Fellenius Method

$$F.S. = \frac{\Sigma \tan \emptyset' \; W(\cos\alpha - R_u)}{\Sigma W \sin\alpha} \qquad \text{Eq 2-1}$$



α = THE INCLINATION OF THE SLICE BOTTOM

W = WEIGHT OF THE SLICE

b = WIDTH OF THE SLICE

h = HEIGHT OF THE SLICE

Fig. 2 - 1

DEFINITION OF SLICE GEOMETRY

Bishop Method

Eq 2-2

$$F.S. = \frac{\sum [W(1-R_u)\tan \emptyset']\left[\dfrac{\sec\alpha}{1+ \dfrac{\tan\alpha \tan \emptyset'}{F.S.}}\right]}{\sum W \sin\alpha}$$

Janbu Method

Eq 2-3

$$F.S. = \frac{\sum (W(1-Ru)\tan \emptyset') \dfrac{1}{N_a}}{\sum W \tan\alpha}$$

where $N_a = \cos^2\alpha \ (1 + \tan\alpha \dfrac{\tan \emptyset'}{F.S.})$

Most stability analyses are conducted using computer programs. Computers allow the evaluation of many potential failure surfaces with only a small man-power effort. Programs that utilize equations 2-1 and 2-2 as well as other stability equations, are available to the coal industry (3).

A limited number of stability analyses calculations can be made in a relatively short period of time by hand calculation methods. Programmable calculators and prepared calculation sheets facilitate the calculations. Also, experience in selecting trial failure plane surfaces will mimimize the time required to determine the minimum factor of safety.

3.0 SPOIL PARAMETER ESTIMATION

3.1 Spoil Weight

In a stability analysis, the weight of each slice of soil or rock along the failure surface must be estimated. The slice weight depends on the slice dimensions and the unit weight of the spoil or natural ground. The unit weight of the spoil may be estimated from Table 3.1. This table is not meant to be an accurate assessment of unit weight but rather a reasonable average total unit weight for spoils and soils typically encountered. The stability equations are not very sensitive to the unit weight of the spoil or natural ground, therefore, an approximation based on estimated soil type is appropriate.

TABLE 3-1

UNIT WEIGHT ESTIMATE BASED ON SPOIL TYPE

PREDOMINANT SOIL OR SPOIL TYPE	UNIT WEIGHT (pcf)
Clayey SAND with few cobbles and gravel size particles	107
Fine to medium sandy CLAY with few cobbles and gravel size particles	113
Silty fine to coarse SAND with some gravel and cobbles	116
Fine to coarse SAND with gravel and cobbles	118
Clayey fine to coarse SAND with gravel and cobbles	122
Natural ground (soil)	125

3.2 Spoil Strength

Most spoil stability problems occur several months to years after reclamation is complete, indicating a drained strength failure. Therefore, the spoil strength referred to in this manual is the long-term or drained shear strength.

It has been determined that an estimate of post reclamation spoil strength can be made from very preliminary information of the overburden to be removed and backfilled along the bench and highwall. An overburden ratio of durable to nondurable or easily-weathered rock can be determined from the overburden profile of the site to be evaluated. Such information is generally available from premining exploratory borings. The overburden ratio (OR) is defined as:

$$OR = \frac{T_{ss} + T_l + T_s}{T_{sst} + T_{sh} + T_m + T_{si} + T_{cl}} \qquad \text{Eq. 3-1}$$

where

T_{ss} = thickness of sandstone in overburden profile
T_l = thickness of limestone in overburden profile
T_s = thickness of sand in overburden profile
T_{sst} = thickness of siltstone in overburden profile
T_{sh} = thickness of shale in overburden profile
T_m = thickness of mudstone in overburden profile
T_{si} = thickness of silt in overburden profile
T_{cl} = thickness of clay in overburden profile

TABLE 3-2. PREDICTIVE MATRICES

PORE WATER PRESSURE (Ru) PREDICTION

1 MINING TYPE		2 DIP		3 DRAINAGE AREA		4 SLOPE		5 SLOPE DIRECTION		6 SUB-TOTAL COLS. 1 to 5	7 SEEPAGE OBSERVED		8 INTERNAL DRAINS				9 SUBTOTAL COLS 7&8
													No Seepage Observed		Seepage Observed		
CATEGORY	Ru	SLOPE (ft/ft x 0.01)	Ru	AREA (ACRES)	Ru	ANGLE (°)	Ru	AZIMUTH (°)	Ru		Total Col. 6	Ru	Total Col. 6	Ru	Total Col. 6	Ru	
Type 1	.024	<0.1	.035	< 1	.015	< 10	.233	150-180 180-210	.037		.5-.40	0	<.16	0	.50-.40	0	
Type 2	.054	0.1-0.5	.027	1-2	.020	10-15	.199	120-150 210-240	.027		.40-.32	.035	.16 -.24	-.035	.40-.32	-.035	
Type 3	.079	0.5-1.0	.021	2-3	.050	15-20	.147	90-120 240-270	.017		.32-.24	.085	.24-.32	-.085	.32-.24	-.085	
		1.0-1.5	.013	3-4	.080	20-25	.093	60-90 270-300	.007		.24-.16	.135	.32-.40	-.135	.24-.16	-.135	
		1.5-2.0	.005	4-5	.106	25-30	.039	0-60 300-360	0		<.16	.185	>.4	-.185	<.16	-.185	
		>2.0	0	>5	.136	>30	0	Total Col. 6								Total Col. 9	

INITIAL PREDICTED Ru = TOTAL COL. (6) = ________ FINAL PREDICTED Ru = TOTAL COLS. (6) ______ + (9) ______ = ________

SPOIL STRENGTH (Ø') PREDICTION

OVERBURDEN RATIO	Ø' (deg)	OVERBURDEN RATIO	Ø' (deg)	OVERBURDEN RATIO	Ø' (deg)	OVERBURDEN RATIO	Ø' (deg)
≤ 0.1	25.6	0.9	39.5	1.7	33.0	2.5	36.4
0.2	26.5	1.0	29.9	1.8	33.4	2.6	36.9
0.3	26.9	1.1	30.4	1.9	33.8	2.7	37.3
0.4	27.3	1.2	30.8	2.0	34.3	2.8	37.7
0.5	27.8	1.3	31.2	2.1	34.7	≥ 2.9	38.0
0.6	28.2	1.4	31.7	2.2	35.1		
0.7	28.6	1.5	32.1	2.3	35.6		
0.8	29.1	1.6	32.5	2.4	36.0		

RESIDUAL STRENGTH ($Ø_r'$) PREDICTION

NATURAL GROUND SLOPE ANGLE (deg)	$Ø_r'$ (deg)	NATURAL GROUND SLOPE ANGLE (deg)	$Ø_r'$ (deg)
12	18.2	22	24.5
14	19.4	24	25.7
16	20.7	26	27.0
18	21.9	28	28.2
20	23.2	30	29.5

The value OR can be used in Table 3-2 to estimate the effective strength friction angle of the spoil. Example calculations of OR and friction angle are given in Figures 3-1 and 4-7.

3.3 Natural Ground Strength

Controlled placement of excess spoil on outslopes and in designated spoil disposal areas is permitted under the provisions of the Permanent Program. Spoil failures encountered in the Eastern Coal Province often involved the virgin soils supporting the spoil.

As a general rule, the soil overburden is normally thin (on the order of 10 feet) at most mine sites within the Eastern Coal Province. Natural soil overburden often contains weak planes inclined in the downslope direction from soil creep or mechanical weathering of the soil. Therefore, it is reasonable to assume that most of the virgin overburden soils exist in a residual strength state.

Based on a rather limited data base, the residual friction angle of the overburden soils is related to the natural or premining ground surface topography. An estimate of residual strength can be made from Table 3-2 and knowledge of the premining outslope angle.

3.4 Pore Pressure Values

The ability of a spoil mass to resist sliding depends on the amount of shear strength available along a potential failure plane. Strength is typically represented by the equation:

$$S = C + N \tan \emptyset' \qquad \text{Eq 3-2}$$

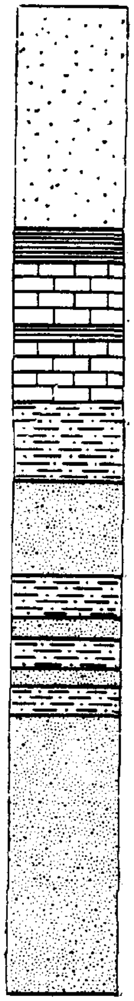
where: N is the effective overburden pressure

C = cohesion intercept
$\emptyset'$ = effective friction angle.

For the purpose of conducting long-term stability analyses, the cohesion intercept is taken as zero and an estimate of $\emptyset'$ is given in Table 3-2. The effective overburden pressure depends on the post reclamation groundwater table or pore water pressure. In order to evaluate the stability of a spoil bank, it is necessary to estimate the pore water pressure along potential failure planes. In stability analyses, pore water pressures are usually estimated from: the phreatic surface, flow nets, or pore water pressure constants. The pore pressure constant, termed R_u value, is defined by the equation:

$$R_u = \frac{\text{pore pressure}}{\text{total overburden pressure}} \qquad \text{Eq 3-3}$$

PRE-MINING
EXPLORATORY
BORING



Durable Rock	Non-Durable Rock
T_{ss} = 27'	T_{sst} = 12'
T_{l} = 8'	T_{sh} = 3'
T_{s} = 15'	T_{m} = 0
	T_{si} = 0
	T_{cl} = 0

$$OR = \frac{27 + 8 + 15}{12 + 3 + 0 + 0 + 0}$$

$$OR = 3.3$$

FROM TABLE 3-2
$\emptyset' = 38°$ (effective friction angle for spoil)

FIGURE 3-1

EXAMPLE DETERMINATION OF SPOIL STRENGTH FROM OVERBURDEN RATIO

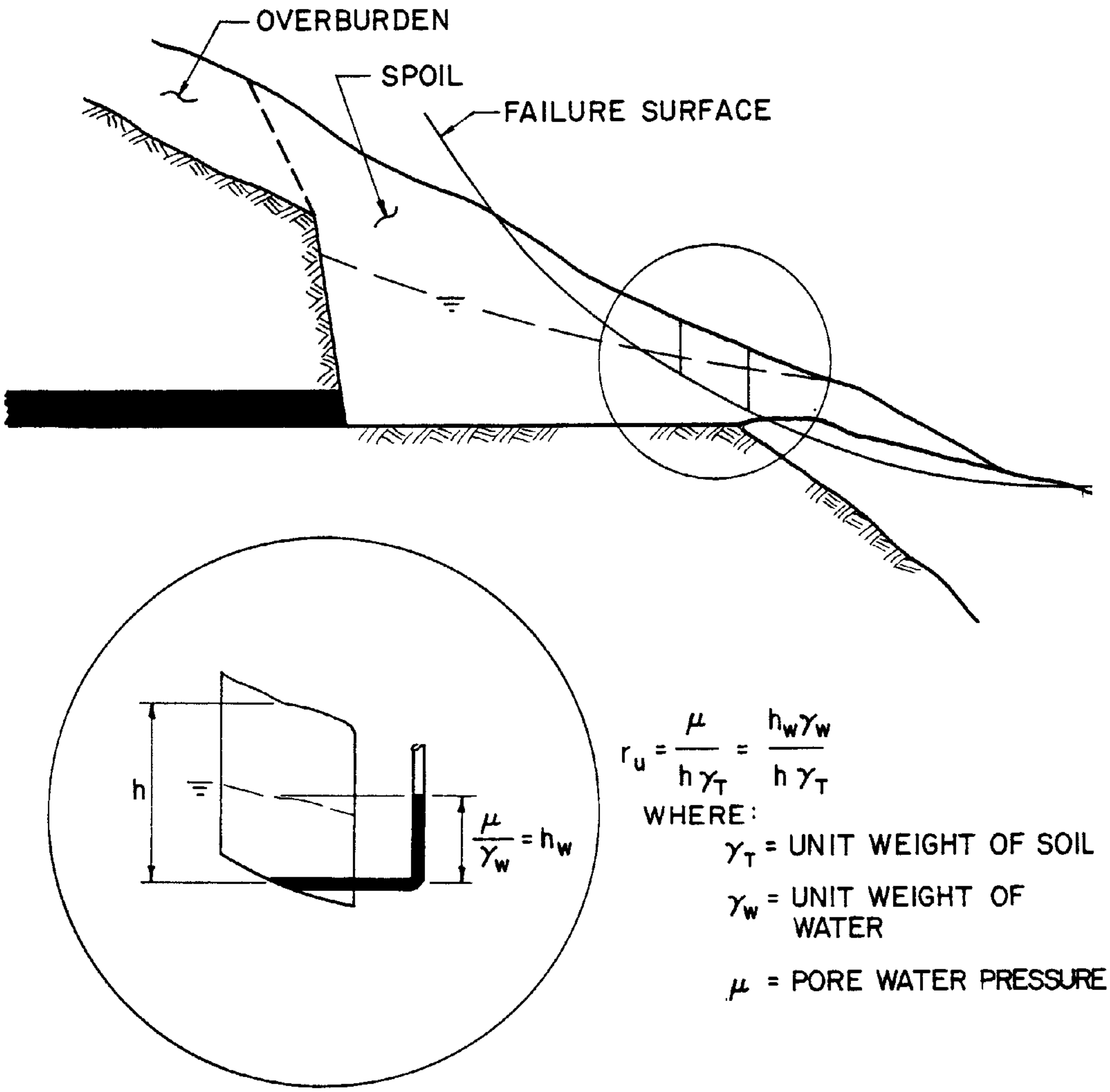


Fig. 3 - 2

DEFINITION OF Ru

The R_u value is used in equations 2-1, 2-2, and 2-3 to calculate the safety factor of a slope with pore water pressure. The value is calculated for each slice analyzed (ref. Figure 3-2) or an average value is selected for the entire slope.

Many factors affect the post reclamation R_u value. The most significant factors have been included in Table 3-2 and are explained in subsequent paragraphs.

3.4.1 Mining Type

Mining type refers to the effect that various degrees of compactive effort have on spoil density and consequently its R_u value. Dense spoil tends to retain water longer than loose spoil due to its low permeability. The added water causes a rise in R_u value. Mining and reclamation sequences have been divided into three categories:

Type I - Dumped & Graded. This includes spoil piles, material shoved on the outslope, or any material placed in lifts greater than 4 feet thick.

Type II - Truck Haul & Graded. This is typical of contour haulback, hollow fill, valley fill, and some area mining methods. Generally, trucks place spoil in piles which are graded over with dozers in lifts 2 to 4 feet thick.

Type III - Thin Lift and Graded. Typically done by dozers pushing thin lifts ahead of the blade and tracking the entire surface area before placing of next lift.

3.4.2 Dip

The dip of the overburden materials has an effect on R_u. The effect on R_u value is slight since the Pennsylvania sediments of the Eastern Coal Province are relatively flat-lying. Therefore, a normal amount of groundwater mounding within a ridgeline and hillside may be enough to overcome the flat dip of the underlying rock. The actual dip in the direction of the outslope is obtained by multiplying the local dip by the cosine of the angle difference between outslope direction and dip direction. The dip shown in Figure 4-1 was calculated with the given information: (1) local dip = 18 feet/mile SE, (2) outslope direction = 156°. Therefore;

$$\text{Actual dip} = \frac{18 \text{ ft}}{5280 \text{ ft/mi}} \times \cos(156°-135°) = 0.0032 \text{ ft/ft}$$

$$= 0.32 \times 10^{-2} \text{ ft/ft}$$

3.4.3 Drainage Area

It would be expected that the R_u value would increase as the drainage area that contributes flow over a particular spoil area increases. The drainage area can be reduced or increased by the presence of ditches. The drainage area is determined for 150 foot sections along the reclaimed highwall or fill bench. The area contributing to overland flow into the 150 foot section is measured horizontally and is based on post reclamation contours. Figure 4-1 is an illustration of the drainage area contributing to overland flow across a 150-foot section of a contour strip mine.

3.4.4 Slope

As a general rule, shallow failures are associated with steep slopes. As a consequence, the phreatic surface is located closer to the failure plane for steep slopes, resulting in lower R_u values. The value of R_u is selected from Table 3-2 based on the appropriate category of outslope angle.

3.4.5 Slope Direction

Surface mine sites that have high R_u values are often associated with southerly facing slopes. Southern facing slopes usually are subjected to more sunlight and as a result thaw before northern facing slopes and are more likely to be saturated during winter. This may also be due to exposure of slopes facing the predominant storm tracks. The contributing value of R_u is selected from Table 3-2 based on the direction of the reclaimed slope's outslope angle.

3.4.6 Other Factors

All of the factors previously considered need to be evaluated in terms of the observed site conditions or planned construction. The presence of springs on an undeveloped site indicates a constant source of groundwater. The effect of a spring on the value of R_u is summarized in Table 3-2. High R_u values are less affected by springs than low R_u values. An adjustment for the pressure of springs, seeps, aquifers, or other indications of high groundwater is included in Table 3-2. This adjustment is based on limited field data.

There is even less information available concerning internal drains. The adjustment presented in Table 3-2 is based on the premise that internal drains are primarily placed in areas of known seepage. Their function would be to minimize the infiltration of groundwater into the spoil fill. They are usually located near the groundwater source and extended to a collector system beyond the spoil fill. A reduced R_u valued based on the installation of internal drains in areas of no observed seepage is highly speculative and is not substantiated by observations at any of the study sites. Therefore, caution should be used in this case.

Figure 4-3 illustrates the use of Table 3-2 on a real mine site. Figure 3-3 is a blank calculation sheet and is provided for analysis of other problems or planned surface mine development. A mine operator or regulatory personnel can use the values given in Table 3-2 in combination with hand calculations or computer programs to analyze various reclamation schemes. The procedures outlined in this manual are not intended to accurately model all types of spoil material or reclamation schemes for final design but rather provide a more rational approach to selecting stability parameters from information that is readily available.

3.5 Recommended Procedures for Use of the Matrices and Stability Analyses

(1) Obtain topographic maps with sufficient detail so as to be able to identify general drainage paths.

(2) The proposed post reclamation grading scheme should be imposed on the topographic plans.

(3) Typical outslope angles, drainage areas (contributing to flow across 150 feet of outslope), natural ground slope angle, and slope directions should be determined from the topographic maps.

(4) The overburden ratio should be determined from field examination of neighboring highwalls and/or premining borings.

(5) The method of mining and reclamation should be determined.

(6) A field visit to the site should be conducted so as to document actual or potential springs or other wet areas, unstable areas, or areas subject to high concentrations of overland flow.

(7) Several cross-sections should be selected for analyses. The cross-sections selected normally should include those that are in areas most likely to have the lowest stability. These would include areas with steep slopes, springs, large drainage areas, etc.

(8) Along each cross-section several failure planes should be selected and analyzed until a minimum factor of safety can be achieved.

(9) It is necessary to divide each cross-section into vertical slices. Some guidelines for selecting slice boundaries include initiating a new slice boundary at each change in surface angle, at each 10 degree change in the bottom slope angle, and at each change in material type.

(10) Provided that the resulting factor of safety is to low, the operator may incorporate changes such as a reduction in slope angle, etc. until a safistfactory solution is included. Conversely, if the resulting factor of safety is too high, the operator may want to make changes so as to save reclamation costs. These changes should then be checked for stability.

FIGURE 3–3 TYPICAL CALCULATION SHEET

SITE NO. ______________________________

OVERBURDEN RATIO ________	Ø' ______	SPOIL SLOPE ________	Ru_1 ______	(2) Spring, seeps, aquifers, mine drainage, etc?	(3) Internal drains?
NATURAL GROUND SLOPE ______	$Ø_r$' ______	DIP ________	Ru_2 ______		
SPOIL TYPE ________		DRAINAGE AREA ________	Ru_3 ______		
________	γ_s ______	MINING TYPE ________	Ru_4 ______		
NATURAL GROUND DENSITY	γ_n ______	SLOPE DIRECTION ________	Ru_5 ______	________	________

INITIAL Ru = (1) ______ ______ ______

FINAL Ru = (1) ______ + (2) ______ + (3) ______ = ______

FELLENIUS METHOD

Slice	(1) Width	(2) Height	(3) Slope(a)	(4) Ø'	γ	(5)=(1)x(2)xγ W	(6)=(5)cos(3) Wcos(a)	(7)=Rux(5) U	(8)=(6)-(7) N	(9)=(8)Tan(4) NtanØ'	(10)=(5)Sin(3) Wsin(a)
1											
2											
3											
4											
5											
6											
7											
										Σ	Σ

F.S. = $\frac{(9)}{(10)}$ ______ = ______

JANBU METHOD 1st Assumed F.S. ________ 2nd Assumed F.S. ________

Slice	(11) = (5)tan(3) Wtan(a)	(12) = (5)-(7) W-U	(13) = (12)tan Ø' (W-U)tan Ø'	(14) Na	(15) = (13)÷(14) (13)÷Na	(16) Na	(17) = (13)÷(16) (13)÷Na
1							
2							
3							
4							
5							
6							
7							
	Σ				Σ		Σ

Na = $\cos^2(a)(1+(\tan(a) \times \tan(Ø')\div F.S.))$

F.S. = $\frac{(15)}{(11)}$ ______ = ______ F.S. = $\frac{(17)}{(11)}$ ______ = ______

3.6 Selection of Method of Analysis

Two methods are outlined in Figure 3-3 and in the examples presented in Section 4.0. The Fellenius Method (ordinary method of slices) and the Janbu Method are illustrated. The variables obtained from the matrices are not limited in application to these two methods but may be applied to others as well. The Fellenius Method requires only one set of calculations to determine the factor of safety while the Janbu Method usually requires two tests to predict the factor of safety.

The Janbu Method requires an estimate of the actual factor of safety to perform the analysis. A practical method has been observed to limit the number of iterations necessary to converge on the actual factor of safety to usually two iterations. This method is two part. The first part of this method is a rule-of-thumb observed by the authors. The actual factor of safety is approximately equal to the calculated value plus or minus 20 - 50% of the difference between the calculated and assumed values. Notice the trend in the examples below.

	Assumed F.S.	Calculated F.S.
Example 1:		
1st Trial	1.50	1.40
2nd Trial	1.36*	1.36 (actual F.S.)
Example 2		
1st Trial	1.25	1.38
2nd Trial	1.43*	1.43 (Actual F.S.)

* Based on authors' rule of thumb.

Note that when the calculated factor of safety is lower than the assumed factor of safety, the actual factor of safety is usually lower than the first calculated factor of safety. The inverse applies to the case when the first calculated factor of safety is higher than the assumed factor of safety. Unless the calculated factor of safety is equal to the first assumed factor of safety, a second trial is required.

Having performed two sets of calculations and not determined the actual factor of safety (determination of the actual factor of safety is when the calculated value equals the assumed value), the problem can be solved by a graphical approach. Figure 3-4 represents a graphical approach and is self-explanatory.

Having determined the factor of safety for one estimated failure plane does not imply that it represents the minimum factor of safety. Often several trial failure surfaces are required. The analyst should make every effort to try several failure planes along each cross-section.

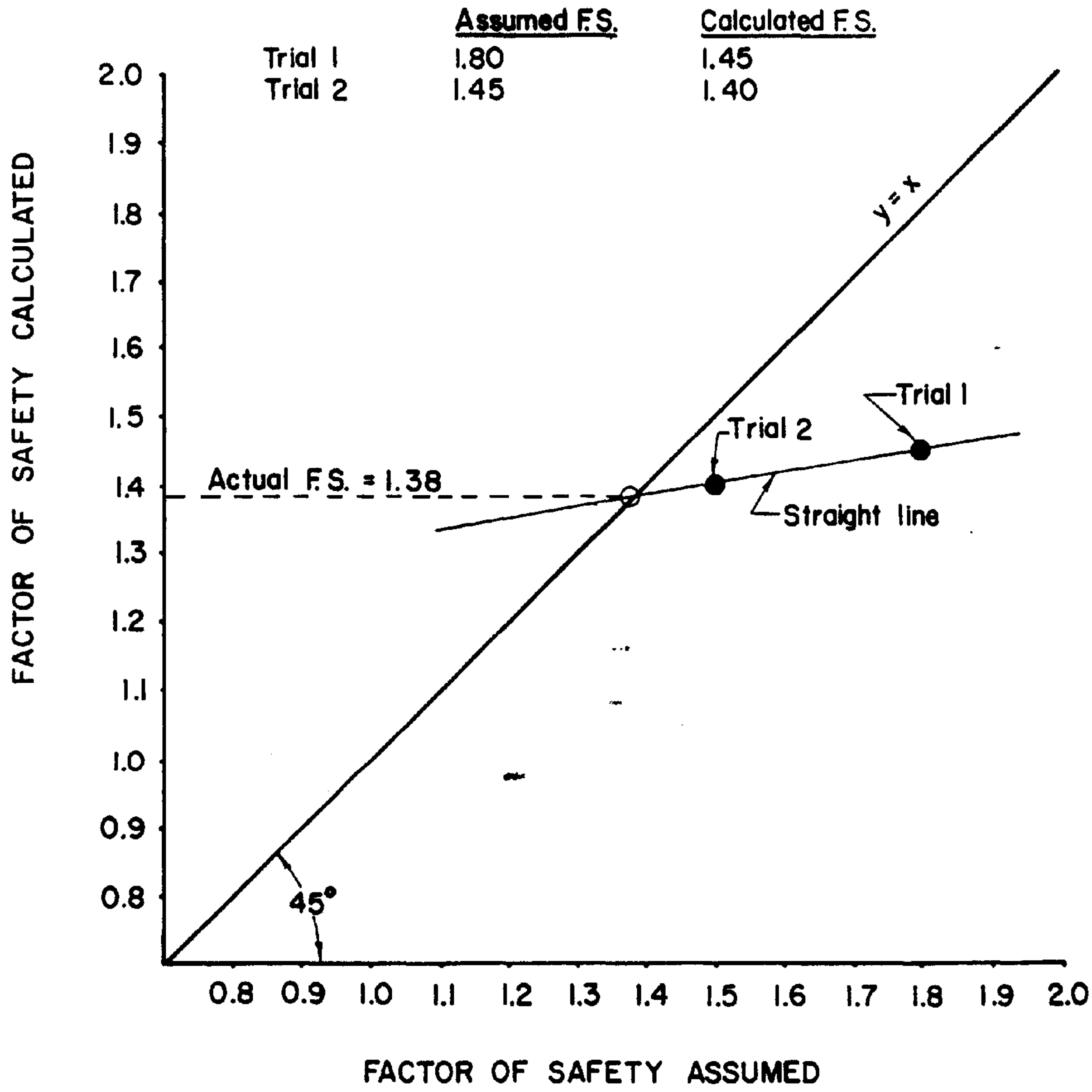


Fig. 3-4 GRAPHIC METHOD FOR PREDICTING ACTUAL FACTOR OF SAFETY

Determination of the term N_a in Eq 1-3 (Janbu Method) can be obtained from a graph containing predetermined values of tan (Ø')/F.S. Figure 3-5 illustrates a graphical solution of N_a.

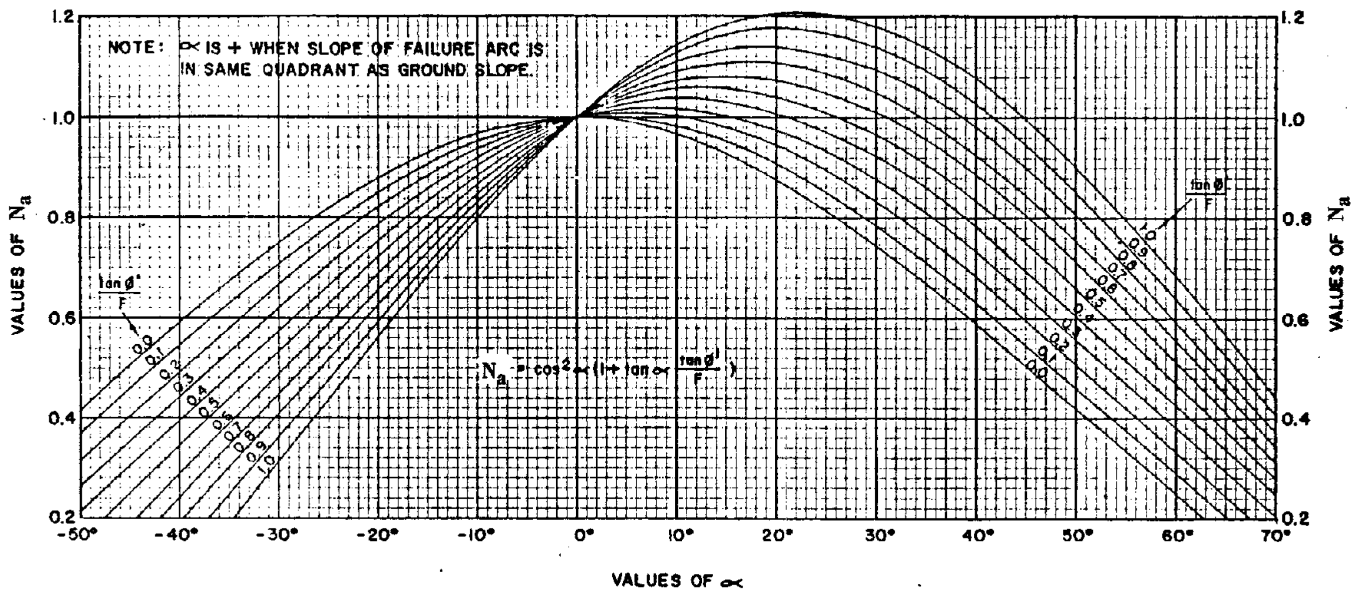


Figure 3-5

GRAPHICAL SOLUTION OF N_a - JANBU METHOD

4.0 EXAMPLES

4.1 Example 1

Example 1 is to be mined using a modified contour method of mining. Coal outcrops near elevation 1175 msl. The first cut material will be placed on the outslope below this elevation. The topogrpahy flattens above elevation 1220. Successive cuts will be made until the entire area is mined out. The material from each cut will be placed in the area of the preceeding cut. Final grading will result in a fairly uniformly graded outslope approximately 3(H):1(V) below elevation 1220. Topsoil will be stockpiled as shown in Fig. 4-1.

A premining site inspection did not reveal the presence of active slides nor high groundwater conditions. USGS landslide intensity maps indicate that old slides were nearby and that the area to be mined and reclaimed is susceptible to movement by sliding when saturated or overloaded. An exploratory boring was conducted nearby. Since the operator planned to place spoil on the outslope, the thickness of the soil overburden was determined by portable augers. About 4.5 feet of clayey silt was situated above a decomposed rock layer.

Three drainage areas were identified. In the example, Area 2 had the largest drainage area. Therefore, it is prudent to analyze a cross-section at this point. Note that the drainage basins were identified along 150-foot sections with the flow determined at the top of the outslope, elevation 1160. Another analysis would be appropriate along a cross-section for an area below drainage Area 1 because the outslope angle steepens somewhat.

A cross-section was prepared, Figure 3-4. The estimated thickness of the clay overburden was included. A failure plane located predominantly in the natural ground was selected. Vertical lines to define slice boundaries were added to the cross-sections. Vertical lines are normally inserted at points where the slope of the ground surface or failure plane change and where subsurface stratification changes occur. The right side of slices 1 and 5 are typical of lines extending from points of stratification changes.

The width and height of each slice was measured by scaling. The slope angle of each slice can be determined in two ways: 1) by drawing a line tangent to the failure plane at the midpoint of each slice and using a protractor to measure the angle from horizontal, 2) by using 2 triangles. In this procedure, one edge is lined up along the points where the vertical slices intersect the failure plane. The analyst then slides the triangle parallel to a point on a grid where the grid blocks can easily be counted. The inverse tangent of the vertical change divided horizontal change yields the angle from horizontal. With practice, method 2 is usually much faster.

The following were calculated for input into the matrices and stability calculations:

(1)	Overburden ratio (see Fig 3-1).	3.3
(2)	Natural Ground Slope (from cross-section).	15°
(3)	Spoil Slope Angle (from cross-section)	16.50
(4)	Slope Direction (from mine plan)	156°
(5)	Dip (dip is 18'/mile on a heading of 135°.	

$$\frac{18 \text{ ft}}{5280 \text{ ft/mi}} \times \cos(156° - 135°) \ldots\ldots\ldots\ldots \underline{0.0032 \text{ ft/ft}}$$

(6)	Mining Type (Section 3.4).	III
(7)	Drainage Area (by planimeter).	4.50 ac
(8)	Springs, seeps, etc (site inspections before and during mining).	None
(9)	Internal Drain System.	None
(10)	Estimated Spoil Composition (estimate from mine operators experience and pre-mining boring logs), silt sand with gravel (see Table 3-1)	116 pcf

The results of the slope stability analyses for the proposed reclamation scheme are presented in Figure 4-3. These results indicate that the proposed plan has a factor of safety less than 1.0. This is certain to cause landslide problems. It is also less than the SMCRA minimum F.S. of 1.3. Therefore, a revised reclamation scheme is indicated in order to meet minimum standards.

Several alternatives are available including avoidance, reduction in spoil thickness, removal of natural ground soils, benching into decomposed rock, surface drainage improvements and keyway cuts, and others. In this example, two changes were incorporated into the revised reclamation plan. These include lined diversion ditches above the slide area to intercept overland flow, and the use of keyway cuts to improve the strength along the anticipated failure plane. The proposed cross-section for the revised reclamation plan is shown in Figure 4-4. Calculations for this plan are presented in Figure 4-5. The results for the revised reclamation plan indicate an acceptable factor of safety of 1.39.

Recommendations for spoil stability enhancement are contained in Section 7.0 of Volume I of this report. Corrective methods and costs are also outlined in this section. A useful outline of corrective procedures is contained in the Office of Surface Mining Manual, Abandoned Mined Lands Reclamation Control Technology Handbook, Chapters 7 and 8, Contract No. J5101111.

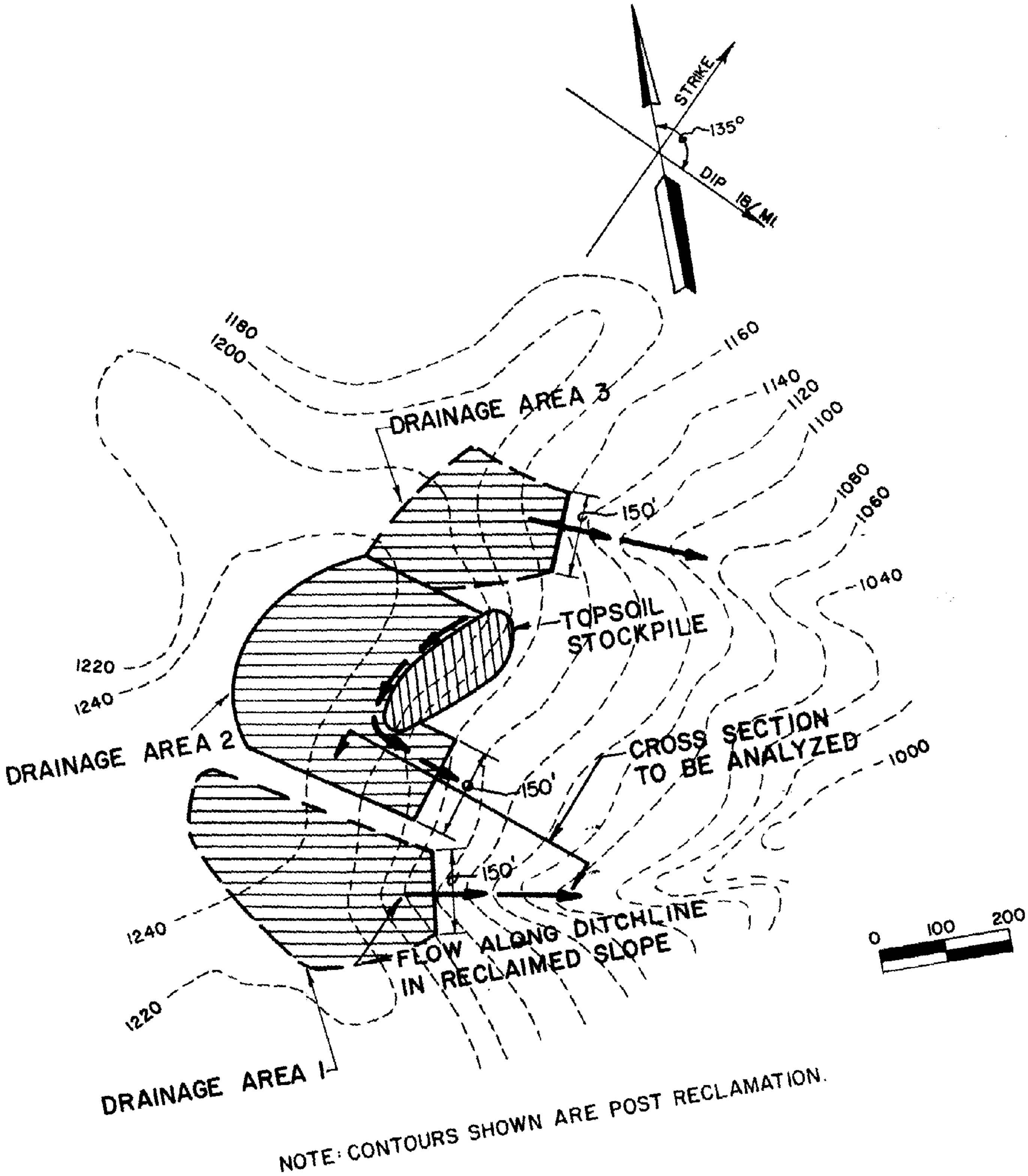


Fig. 4-1

EXAMPLE-1 RECLAMATION SCHEME PLAN VIEW

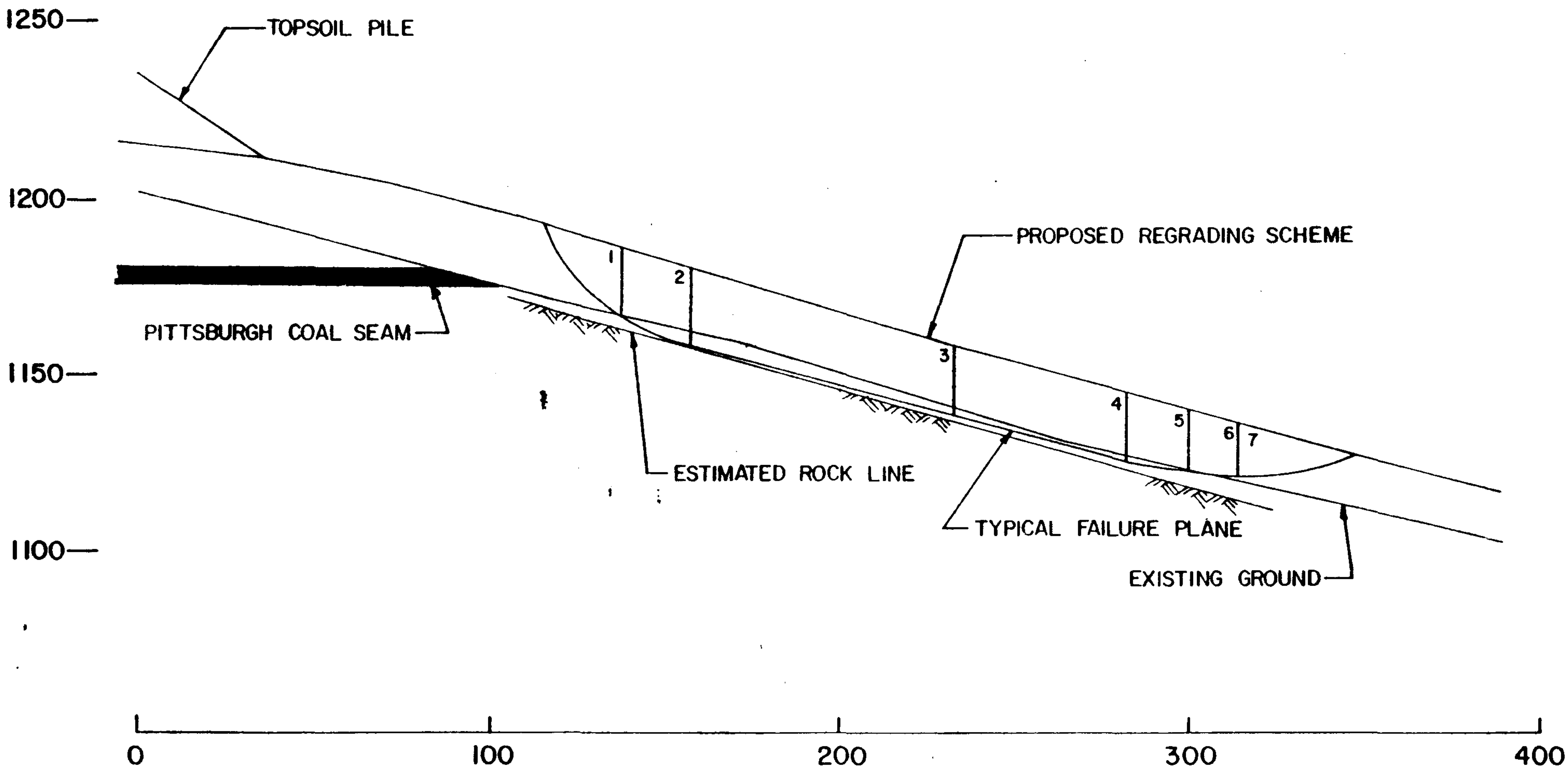


Fig. 4-2
EXAMPLE-I RECLAMATION SCHEME
INITIAL CROSS SECTION

FIGURE 4-3 TYPICAL CALCULATION SHEET

SITE NO. *EXAMPLE-1 INITIAL RECLAMATION SCHEME*

OVERBURDEN RATIO *3.35* $\emptyset'$ *38.0°*
NATURAL GROUND SLOPE *15°* $\emptyset_r'$ *20.1°*
SPOIL TYPE *Silty fine to coarse sand with some gravel & cobbles* γ_s *0.116*
NATURAL GROUND DENSITY γ_n *0.125*

SPOIL SLOPE *16.5°*
DIP *0.0032 ft./ft.*
DRAINAGE AREA *4.50 Ac.*
MINING TYPE *III*
SLOPE DIRECTION *156°*

Ru_1 *0.147*
Ru_2 *0.027*
Ru_3 *0.106*
Ru_4 *0.079*
Ru_5 *0.037*

(2) Spring, seeps, aquifers, mine drainage, etc? *No*

(3) Internal drains? *No*

INITIAL Ru = (1) *0.396* *0* *0*

FINAL Ru = (1) *0.396* + (2) *0* + (3) *0* = *0.396*

FELLENIUS METHOD

Slice	(1) Width	(2) Height	(3) Slope(a)	(4) $\emptyset'$	γ	(5)=(1)x(2)xγ W	(6)=(5)cos(3) Wcos(a)	(7)=Rux(5) U	(8)=(6)-(7) N	(9)=(8)Tan(4) Ntan$\emptyset'$	(10)=(5)Sin(3) Wsin(a)
1	23	13	51	38.0	.116	34.68	21.83	13.73	8.10	6.32	26.95
2	20	22	21	20.1	.125	55.00	51.35	21.78	29.57	10.82	19.71
3	75	21	15.5	20.1	.125	196.88	189.71	77.96	111.75	40.90	52.61
4	50	20	15.5	20.1	.125	125.00	120.45	49.50	70.95	25.97	33.40
5	18	19	9	20.1	.125	42.75	42.22	16.93	25.29	9.26	6.69
6	13	17	6	38.0	.116	25.64	25.50	10.15	15.34	11.99	2.68
7	33	11	-10	38.0	.116	42.11	41.47	16.67	24.79	19.37	-7.31
										Σ 124.63	Σ 134.73

$$F.S. = \frac{(9)}{(10)} \quad \frac{124.63}{134.73} = 0.93$$

JANBU METHOD 1st Assumed F.S. *0.98* 2nd Assumed F.S. *0.94*

Slice	(11) = (5)tan(3) Wtan(a)	(12) = (5)-(7) W-U	(13) = (12)tan $\emptyset'$ (W-U)tan $\emptyset'$	(14) Na	(15) = (13)÷(14) (13)÷Na	(16) Na	(17) = (13)÷(16) (13)÷Na
1	42.83	20.95	16.37	0.786	20.83	0.803	20.39
2	21.11	33.22	12.16	0.997	12.20	1.002	12.14
3	54.60	118.92	43.52	1.025	42.46	1.029	42.29
4	34.67	75.50	27.63	1.025	26.96	1.029	26.85
5	6.77	25.82	9.45	1.033	9.15	1.036	9.12
6	2.69	15.49	12.10	1.073	11.28	1.101	10.99
7	-7.43	25.44	19.88	0.834	23.84	0.828	24.01
	Σ 155.24				Σ 146.72		Σ 145.79

$Na = \cos^2(a)(1+(\tan(a) \times \tan(\emptyset')\div F.S.))$

$$F.S. = \frac{(15)}{(11)} \quad \frac{146.72}{155.24} = 0.95$$

$$F.S. = \frac{(17)}{(11)} \quad \frac{145.79}{155.24} = 0.94$$

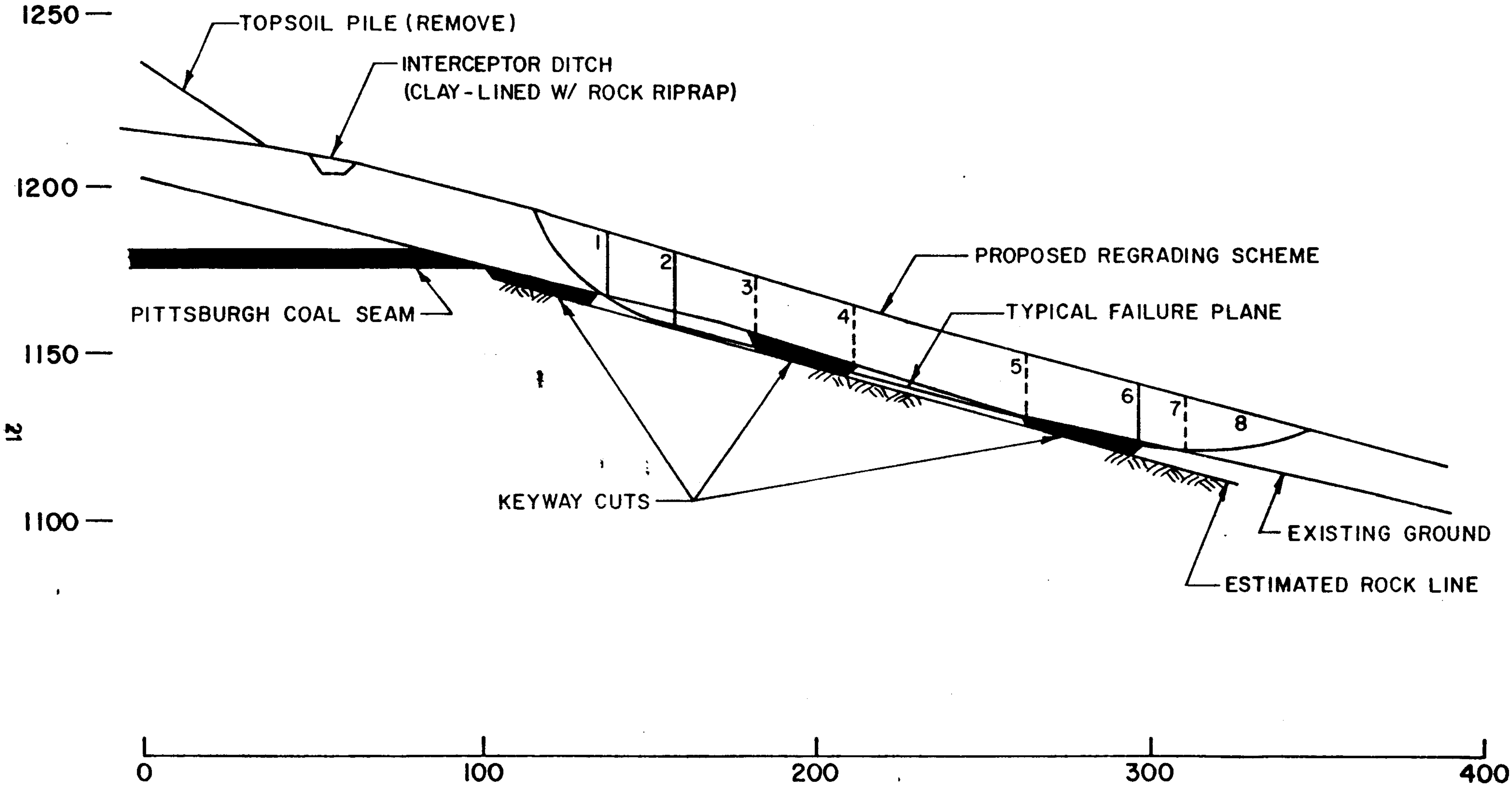


Fig. 4-4
EXAMPLE RECLAMATION SCHEME
REVISED CROSS SECTION

FIGURE 4-5 TYPICAL CALCULATION SHEET

SITE NO. EXAMPLE-1 REVISED RECLAMATION SCHEME WITH KEYWAY CUTS AND INTERCEPTOR DITCH

OVERBURDEN RATIO 3.35 Ø' 38.0°
NATURAL GROUND SLOPE 15° $Ø_r'$ 20.1°
SPOIL TYPE Silty fine to coarse sand with some gravel & cobbles γ_s 0.116
NATURAL GROUND DENSITY γ_n 0.125

SPOIL SLOPE 16.5°
DIP 0.0032 ft./ft.
DRAINAGE AREA 0.50 Ac
MINING TYPE III
SLOPE DIRECTION 156°

Ru_1 0.147
Ru_2 0.027
Ru_3 0.015
Ru_4 0.079
Ru_5 0.037

(2) Spring, seeps, aquifers, mine drainage, etc? No

(3) Internal drains? No

INITIAL Ru = (1) 0.305 0 0

FINAL Ru = (1) 0.305 + (2) 0 + (3) 0 = 0.305

FELLENIUS METHOD

Slice	(1) Width	(2) Height	(3) Slope(a)	(4) Ø'	γ	(5)=(1)x(2)xγ W	(6)=(5)cos(3) Wcos(a)	(7)=Rux(5) U	(8)=(6)-(7) N	(9)=(8)Tan(4) NtanØ'	(10)=(5)Sin(3) Wsin(a)
1	23	13	51	38.0	.116	34.68	21.83	10.58	11.25	8.79	26.95
2	20	17	21	20.1	.125	42.50	39.68	12.96	26.71	9.78	15.23
3	24	21	15.5	20.1	.125	63.00	60.71	19.22	41.49	15.18	16.84
4	30	21	15.5	38.0	.116	73.08	70.42	22.29	48.13	37.61	19.53
5	52	20	15.5	20.1	.125	130.00	125.27	39.65	85.62	31.33	34.74
6	34	19	12	38.0	.116	74.94	73.30	22.86	50.44	39.41	15.58
7	13	17	6	20.1	.125	27.63	27.47	8.42	19.05	6.97	2.89
8	36	11	-8	38.0	.116	45.94	45.49	14.01	31.48	24.59	-6.39
										Σ 173.66	Σ 125.37

$$F.S. = \frac{(9)}{(10)} = \frac{173.66}{125.37} = 1.39$$

JANBU METHOD 1st Assumed F.S. 1.37 2nd Assumed F.S. ____

Slice	(11) = (5)tan(3) Wtan(a)	(12) = (5)-(7) W-U	(13) = (12)tan Ø' (W-U)tan Ø'	(14) Na	(15) = (13)÷(14) (13)÷Na	(16) Na	(17) = (13)÷(16) (13)÷Na
1	42.83	24.10	18.83	0.675	27.90		
2	16.31	29.54	10.81	0.961	11.25		
3	17.47	43.78	16.02	0.997	16.07		
4	20.27	50.79	39.68	1.075	36.91		
5	36.05	90.35	33.06	0.997	33.16		
6	15.93	52.08	40.69	1.073	37.93		
7	2.90	19.21	7.03	1.017	6.91		
8	-6.46	31.93	24.95	0.902	27.65		
	Σ 145.30				Σ 197.78		Σ

Na = $\cos^2(a)(1+(\tan(a) \times \tan(Ø') \div F.S.))$

$$F.S. = \frac{(15)}{(11)} = \frac{197.78}{145.30} = 1.36$$

$$F.S. = \frac{(17)}{(11)} \_\_\_\_ = \_\_\_\_$$

4.2 Example 2

Example 2 is a proposed contour strip mine and will be mined and reclaimed using the contour haulback method. Figure 4-6 is a plan view of the site method. A large drainage basin is outlined on this drawing. Prior to analyses, drainage basins should be outlined throughout the proposed mined area, particularly where overland flows are concentrated. A cross-section through the hillside below Drainage Area 1 was selected for analysis.

Pre-mining inspections did not reveal the presence of landslides along the proposed mining zone. Natural soils were on the order of 2 feet or less. Some seeps were noted just above and below the coal outcrop. The lower two sandstone units are known to be regional aquifers. The presence of the aquifer was detected during exploratory drilling.

A pre-mining exploratory boring was conducted nearby at elevation 1680. The top of the highwall, however, was to be at elevation 1640 near the area of investigation. Therefore, the determination of the Overburden Ratio was based on the stratigraphic section below elevation 1640. A rock toe and drainage system is planned as part of the reclamation scheme. An estimate of the amount of durable rock required to construct the toe and internal drainage system was made. The overburden ratio was adjusted accordingly. Figure 4-7 contains the pre-mining exploratory boring and computations of the Overburden Ratio.

The following were calculated for input into the matrices and stability calculations:

(1) Overburden Ratio (see Fig. 4-7) 2.25

(2) Natural Ground Slope (N/A) . . . . N/A

(3) Spoil Slope Angle (from cross-section) . . . . 26.6°

(4) Slope Direction (from mine plan) . . . . 25°

(5) Dip (Dip is 200'/mile on heading of 155°)

$$\frac{200\text{ ft}}{5280\text{ ft/mi}} \times \cos(25° - 155) = \ldots\ -0.0243\text{ ft/ft.}$$

(6) Mining Type (Section 3.4) II

(7) Drainage Area (by planimeter). . . . . 5.9 AC

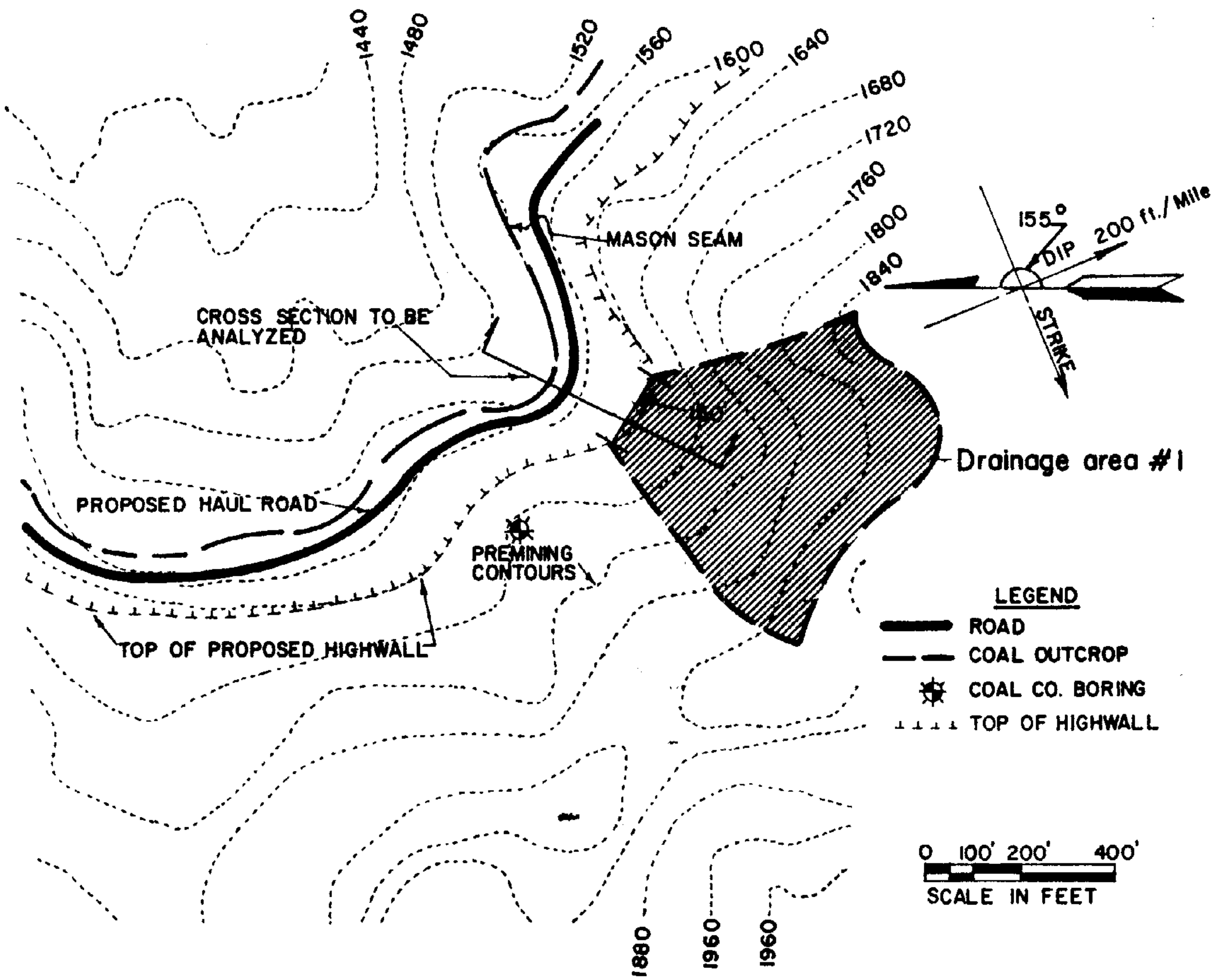
(8) Springs, seeps, etc (site inspections, before and during mining, regional hydrogeologic reports) . . . . Yes

(9) Internal Drain System (5' x 5' on 100' C-C). . . . . . Yes

(10) Estimated Spoil Composition, (estimate from mine operators' experience, pre-mining boring logs, and neighboring spoil fills), clayey sand with gravel and cobbles (Table 3-1) . . . . 122 pcf

Two failure circles were imposed on Figure 4-8. The results of the stability analyses indicate a factor of safety about 1.10 for the shallow failure plane. A revised reclamation scheme is needed to improve the factor of safety.

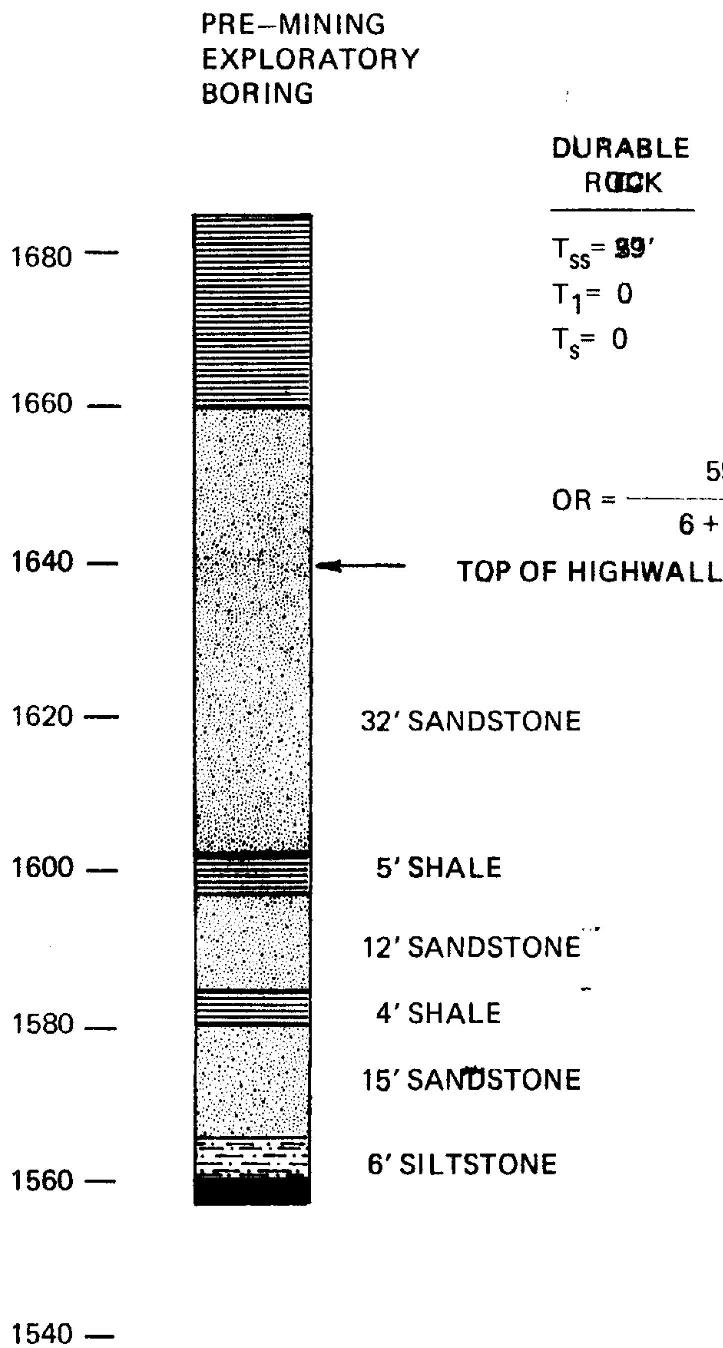
A large drainage area is situated above the section analyzed with overland flow directed towards a concave land form at the point of analysis. Intercepting this flow, and groundwater flow through the overburden soils would probably reduce the post reclamation Ru value for this site. Therefore we assumed that an interceptor ditch would be placed above the highwall and possibly more than one. Ditch relief should be provided in accordance with state or SMCRA regulations. A chimney drain constructed from the bench to the surface of the spoil has been frequently employed for ditch relief and to drain concave sections of contour fills. With the size of the drainage area reduced, the factor of safety is about 1.30. Calculations for the revised reclamation scheme are contained in Figures 4-11 and 4-12.



NOTE: Contours shown are existing contours. Highwall to be reclaimed to approximate original contour, haul road to be constructed as per cross section

Fig. 4-6

EXAMPLE 2 RECLAMATION SCHEME
PLAN VIEW



DURABLE ROCK	NON–DURABLE ROCK
$T_{ss} = 59'$	$T_{sst} = 6'$
$T_1 = 0$	$T_{sh} = 15'$
$T_s = 0$	$T_m = 0$
	$T_{si} = 0$
	$T_{ci} = 0$

$$OR = \frac{59}{6 + 15} = 2.81$$

Assume 20% of durable sandstone is to be used for stone toe and rock drains;

thus,

$OR = 0.80 \times 2.81 = 2.25$

From table 3-2

$\emptyset' = 35.3^{o}$ (effective friction angle for spoil)

FIGURE 4-7

EXAMPLE - 2 DETERMINATION OF SPOIL STRENGTH FROM OVERBURDEN RATIO

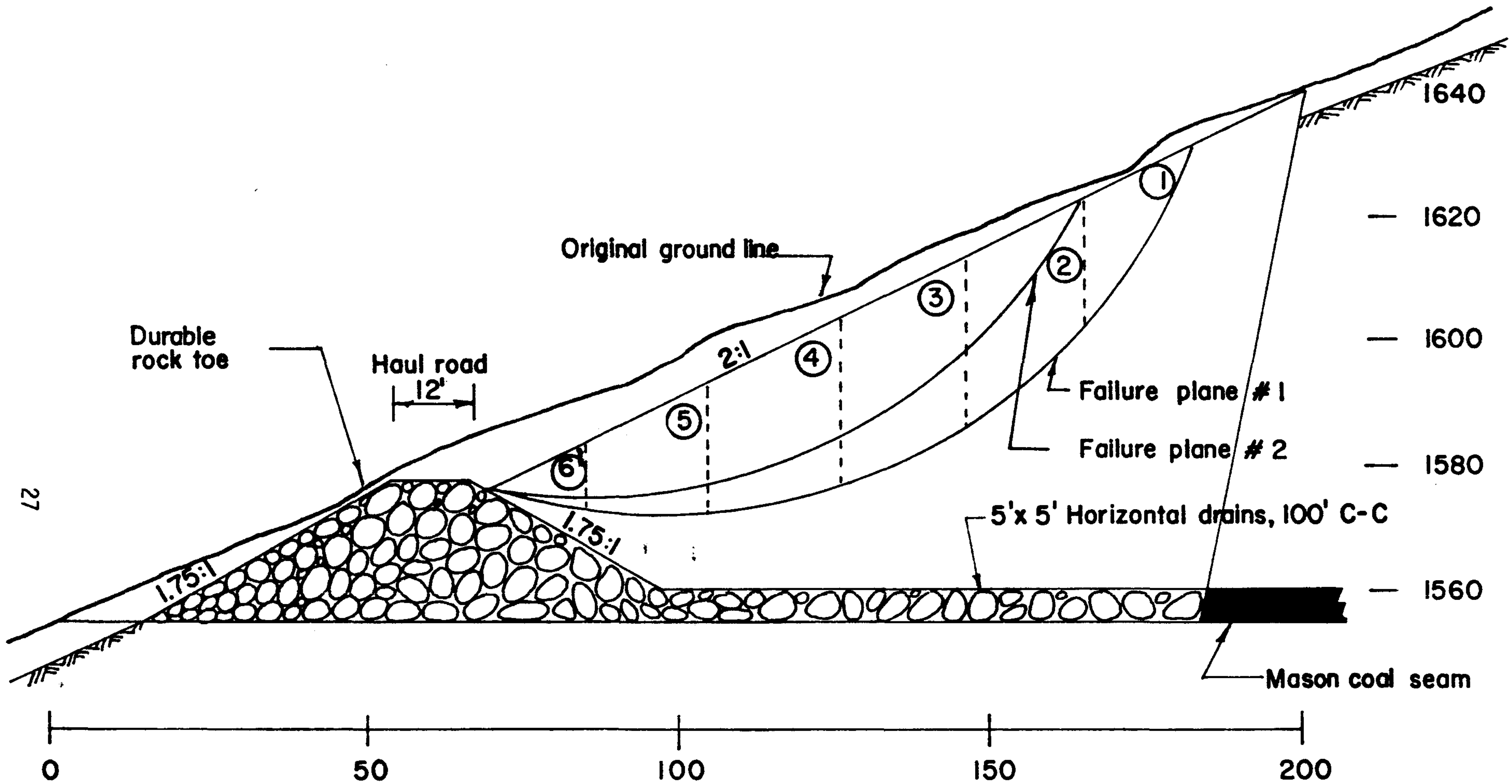


Fig. 4-8

EXAMPLE 2 RECLAMATION SCHEME
TYPICAL CROSS SECTION

FIGURE 4-9 TYPICAL CALCULATION SHEET

SITE NO. EXAMPLE-2 INITIAL RECLAMATION SCHEME, DEEP FAILURE PLANE

OVERBURDEN RATIO 2.25 Ø' 35.3°
NATURAL GROUND SLOPE N/A $Ø_r$' N/A
SPOIL TYPE Clayey fine to coarse sand with gravel and cobbles γ_s 0.122
NATURAL GROUND DENSITY γ_n 0.125

SPOIL SLOPE 26.6°
DIP -0.0243 ft/ft.
DRAINAGE AREA 5.9 Ac.
MINING TYPE II
SLOPE DIRECTION 25°

Ru_1 0.039
Ru_2 0.035
Ru_3 0.136
Ru_4 0.054
Ru_5 0

(2) Spring, seeps, aquifers, mine drainage, etc? YES

(3) Internal drains? YES

INITIAL Ru = (1) 0.264 (2) 0.085 (3) -0.085

FINAL Ru = (1) 0.264 + (2) 0.085 + (3) -0.085 = 0.264

FELLENIUS METHOD

Slice	(1) Width	(2) Height	(3) Slope(a)	(4) Ø'	γ	(5)=(1)x(2)xγ W	(6)=(5)cos(3) Wcos(a)	(7)=Rux(5) U	(8)=(6)-(7) N	(9)=(8)Tan(4) NtanØ'	(10)=(5)Sin(3) Wsin(a)
1	18	14	57	35.3	.122	30.74	16.74	8.12	8.63	6.11	25.78
2	20	25	38.5	35.3	.122	61.00	47.74	16.10	31.64	22.40	37.97
3	20	28	25.5	35.3	.122	68.32	61.66	18.04	43.64	30.89	29.41
4	20	25	11	35.3	.122	61.00	59.88	16.10	43.78	30.99	11.64
5	20	17	0	35.3	.122	41.48	41.48	10.95	30.53	21.62	0
6	15	6	-8	35.3	.122	10.98	10.87	2.90	7.97	5.65	-1.53
7											
										Σ 117.66	Σ 103.27

$$F.S. = \frac{(9)}{(10)} \quad \frac{117.66}{103.27} = 1.14$$

JANBU METHOD 1st Assumed F.S. 1.12 2nd Assumed F.S. 1.10

Slice	(11) = (5)tan(3) Wtan(a)	(12) = (5)-(7) W-U	(13) = (12)tan Ø' (W-U)tan Ø'	(14) Na	(15) = (13)÷(14) (13)÷Na	(16) Na	(17) = (13)÷(16) (13)÷Na
1	47.34	22.62	16.02	0.585	27.37	0.591	27.13
2	48.52	44.90	31.79	0.920	34.53	0.926	34.33
3	32.59	50.28	35.60	1.060	33.58	1.065	33.44
4	11.86	44.90	31.79	1.082	29.38	1.084	29.32
5	0	30.53	21.62	1.000	21.62	1.000	21.62
6	-1.54	8.08	5.72	0.894	6.40	0.891	6.42
7							
	Σ 138.77				Σ 152.88		Σ 152.26

$Na = \cos^2(a)(1+(\tan(a)x\tan(Ø')\div F.S.))$

$$F.S. = \frac{(15)}{(11)} \quad \frac{152.88}{138.77} = 1.10$$

$$F.S. = \frac{(17)}{(11)} \quad \frac{152.26}{138.77} = 1.10$$

FIGURE 4-10 TYPICAL CALCULATION SHEET

SITE NO. EXAMPLE-2 INITIAL RECLAMATION SCHEME, SHALLOW FAILURE PLANE

OVERBURDEN RATIO 2.25 Ø' 35.3°
NATURAL GROUND SLOPE N/A $Ø_r$' N/A
SPOIL TYPE Clayey fine to coarse sand with gravel and cobbles γ_s 0.122
NATURAL GROUND DENSITY γ_n 0.125

SPOIL SLOPE 26.6°
DIP -0.0243 ft./ft.
DRAINAGE AREA 5.9 Ac
MINING TYPE II
SLOPE DIRECTION 25°

Ru_1 0.039
Ru_2 0.035
Ru_3 0.136
Ru_4 0.054
Ru_5 0

(2) Spring, seeps, aquifers, mine drainage, etc? YES

(3) Internal drains? YES

INITIAL Ru = (1) 0.264 (2) 0.085 (3) -0.085

FINAL Ru = (1) 0.264 + (2) 0.085 + (3) -0.085 = 0.264

FELLENIUS METHOD

Slice	(1) Width	(2) Height	(3) Slope(a)	(4) Ø'	γ	(5)=(1)x(2)xγ W	(6)=(5)cos(3) Wcos(a)	(7)=Rux(5) U	(8)=(6)-(7) N	(9)=(8)Tan(4) NtanØ'	(10)=(5)Sin(3) Wsin(a)
1											
2	20	9.5	51.5	35.3	.122	23.18	14.43	6.12	8.31	5.88	18.14
3	20	18	34	35.3	.122	43.92	36.41	11.59	24.82	17.57	24.56
4	20	18	19	35.3	.122	43.92	41.53	11.59	29.93	21.19	14.30
5	20	13.5	6	35.3	.122	32.94	32.76	8.70	24.06	17.04	3.44
6	15	5	-5	35.3	.122	9.15	9.12	2.42	6.70	4.74	-0.80
7											
										Σ 66.42	Σ 59.64

$$F.S. = \frac{(9)}{(10)} \quad \frac{66.42}{59.64} = 1.11$$

JANBU METHOD 1st Assumed F.S. 1.11 2nd Assumed F.S. 1.08

Slice	(11) = (5)tan(3) Wtan(a)	(12) = (5)-(7) W-U	(13) = (12)tan Ø' (W-U)tan Ø'	(14) Na	(15) = (13)÷(14) (13)÷Na	(16) Na	(17) = (13)÷(16) (13)÷Na
1							
2	29.14	17.06	12.08	0.698	17.30	0.707	17.09
3	29.62	32.33	22.89	0.983	23.28	0.991	23.09
4	15.12	32.33	22.89	1.090	20.99	1.096	20.89
5	3.46	24.24	17.16	1.055	16.26	1.057	16.24
6	-0.80	6.73	4.77	0.937	5.09	0.935	5.10
7							
	Σ 76.54				Σ 82.94		Σ 82.14

$Na = \cos^2(a)(1+(\tan(a) \times \tan(Ø')\div F.S.))$

$$F.S. = \frac{(15)}{(11)} \quad \frac{82.94}{76.54} = 1.08$$

$$F.S. = \frac{(17)}{(11)} \quad \frac{82.14}{76.54} = 1.08$$

FIGURE 4-11 TYPICAL CALCULATION SHEET

SITE NO. EXAMPLE-2 REVISED RECLAMATION SCHEME, DEEP FAILURE PLANE

OVERBURDEN RATIO 2.25 Ø' 35.3
NATURAL GROUND SLOPE N/A $Ø_r$' N/A
SPOIL TYPE Clayey fine to coarse sand with gravel and cobbles γ_s 0.122
NATURAL GROUND DENSITY γ_n 0.125

SPOIL SLOPE 26.6°
DIP -0.0243 ft./ft.
DRAINAGE AREA 1.5 Ac
MINING TYPE II
SLOPE DIRECTION 25°

Ru_1 0.039
Ru_2 0.035
Ru_3 0.020
Ru_4 0.054
Ru_5 0

(2) Spring, seeps, aquifers, mine drainage, etc? YES

(3) Internal drains? YES

INITIAL Ru = (1) 0.150 (2) 0.185 (3) -0.185

FINAL Ru = (1) 0.150 + (2) 0.185 + (3) -0.185 = 0.150

FELLENIUS METHOD

Slice	(1) Width	(2) Height	(3) Slope(a)	(4) Ø'	γ	(5)=(1)x(2)xγ W	(6)=(5)cos(3) Wcos(a)	(7)=Rux(5) U	(8)=(6)-(7) N	(9)=(8)Tan(4) NtanØ'	(10)=(5)Sin(3) Wsin(a)
1	18	14	57.	35.3	.122	30.74	16.64	4.61	12.13	8.59	25.78
2	20	25	38.5	35.3	.122	61.00	47.74	9.15	38.59	27.32	37.97
3	20	28	25.5	35.3	.122	68.32	61.66	10.25	51.42	36.41	29.41
4	20	25	11	35.3	.122	61.00	59.88	9.15	50.73	35.92	11.64
5	20	17	0	35.3	.122	41.48	41.48	6.22	35.26	24.96	0
6	15	6	-8	35.3	.122	10.98	10.87	1.65	9.23	6.53	-1.53
7											
										Σ 139.73	Σ 103.27

F.S. = $\frac{(9)}{(10)}$ $\frac{139.73}{103.27}$ = 1.35

JANBU METHOD 1st Assumed F.S. 1.35 2nd Assumed F.S. 1.32

Slice	(11) = (5)tan(3) Wtan(a)	(12) = (5)-(7) W-U	(13) = (12)tan Ø' (W-U)tan Ø'	(14) Na	(15) = (13)÷(14) (13)÷Na	(16) Na	(17) = (13)÷(16) (13)÷Na
1	47.34	26.13	18.50	0.536	34.51	0.542	34.16
2	48.52	51.85	36.71	0.868	42.30	0.874	42.01
3	32.59	58.07	41.12	1.018	40.37	1.023	40.19
4	11.86	51.85	36.71	1.062	34.57	1.064	34.50
5	0	35.26	24.97	1.000	24.97	1.000	24.96
6	-1.54	9.33	6.61	0.908	7.27	0.907	7.29
7							
	Σ 138.77				Σ 183.99		Σ 183.11

Na = $\cos^2(a)(1+(\tan(a) \times \tan(Ø') \div F.S.))$

F.S. = $\frac{(15)}{(11)}$ $\frac{183.99}{138.77}$ = 1.33

F.S. = $\frac{(17)}{(11)}$ $\frac{183.11}{138.77}$ = 1.32

FIGURE 4-12 TYPICAL CALCULATION SHEET

SITE NO. *EXAMPLE-2 REVISED RECLAMATION SCHEME, SHALLOW FAILURE PLANE*

OVERBURDEN RATIO *2.25* Ø' *35.3*
NATURAL GROUND SLOPE *N/A* $Ø_r$' *N/A*
SPOIL TYPE *Clayey fine to coarse sand with gravel and cobbles* γ_s *0.122*
NATURAL GROUND DENSITY γ_n *0.125*

SPOIL SLOPE *26.6°*
DIP *-0.0243 ft./ft.*
DRAINAGE AREA *1.5 Ac*
MINING TYPE *II*
SLOPE DIRECTION *25°*

Ru_1 *0.039*
Ru_2 *0.035*
Ru_3 *0.020*
Ru_4 *0.054*
Ru_5 *0*

(2) Spring, seeps, aquifers, mine drainage, etc? *YES*

(3) Internal drains? *YES*

INITIAL Ru = (1) *0.150* (2) *0.185* (3) *-0.185*

FINAL Ru = (1) *0.150* + (2) *0.185* + (3) *-0.185* = *0.150*

FELLENIUS METHOD

Slice	(1) Width	(2) Height	(3) Slope(a)	(4) Ø'	γ	(5)=(1)x(2)xγ W	(6)=(5)cos(3) Wcos(a)	(7)=Rux(5) U	(8)=(6)-(7) N	(9)=(8)Tan(4) NtanØ'	(10)=(5)Sin(3) Wsin(a)
1											
2	20	9.5	51.5	35.3	.122	23.18	14.43	3.48	10.95	7.76	18.14
3	20	18	34	35.3	.122	43.92	36.41	6.59	29.82	21.12	24.56
4	20	18	19	35.3	.122	43.92	41.53	6.59	34.94	24.74	14.30
5	20	13.5	6	35.3	.122	32.94	32.76	4.94	27.82	19.70	3.44
6	15	5	-5	35.3	.122	9.15	9.12	1.37	7.74	5.48	-0.80
7											
										Σ 78.80	Σ 59.64

F.S. = (9)/(10) = *78.80*/*59.64* = *1.32*

JANBU METHOD 1st Assumed F.S. *1.32* 2nd Assumed F.S. *1.29*

Slice	(11) = (5)tan(3) Wtan(a)	(12) = (5)-(7) W-U	(13) = (12)tan Ø' (W-U)tan Ø'	(14) Na	(15) = (13)÷(14) (13)÷Na	(16) Na	(17) = (13)÷(16) (13)÷Na
1							
2	29.14	19.70	13.95	0.649	21.50	0.655	21.30
3	29.62	37.33	26.43	0.936	28.24	0.942	28.07
4	15.12	37.33	26.43	1.059	24.96	1.063	24.87
5	3.46	28.00	19.83	1.045	18.97	1.046	18.95
6	-0.80	7.78	5.51	0.948	5.82	0.945	5.83
7							
	Σ 76.54				Σ 99.49		Σ 99.02

$Na = \cos^2(a)(1+(\tan(a)x\tan(Ø')\div F.S.))$

F.S. = (15)/(11) = *99.49*/*76.54* = *1.30*

F.S. = (17)/(11) = *99.02*/*76.54* = *1.29*

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