UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Stability of Slope Areas II and IV Below the Sherwood Uranium Mine, Spokane Indian Reservation, Northeastern Washington

by

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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INTRODUCTION

The open-pit Sherwood Uranium Mine is within the Spokane Indian Reservation, in Stevens County, northeastern Washington. It is approximately 35 mi northwest of the city of Spokane (fig. 1). The mine overlooks the Spokane River Arm of Franklin D. Roosevelt Lake from a ridge some 600 ft above the lake. Spoil piles as high as 90 ft extend for over a mile along the ridge in northwesterly and southeasterly directions from the mine workings. Some of the spoil rests directly on top of steep slopes that descend toward the lake, loading the slopes and adding to the shearing stresses.

In 1983, a slope stability study was undertaken in response to concerns that mine spoil containing radionuclides and toxic metals could enter Franklin D. Roosevelt Lake by the process of slope failure, resulting in contamination of waters used for drinking, irrigation, and recreation. In addition, there is concern that a massive landslide might block the flow of the Spokane River resulting in flooding and additional slope failures that could endanger lives and damage valuable property. The results of the initial study were published in U.S. Geological Survey Open-File Report 84-627 (OFR-84-627; Chleborad and Schuster, 1984). In that report, marginally stable slopes were identified and additional detailed analyses were recommended prior to any potentially destabilizing changes in slope conditions, such as additional spoil-pile loading.

This report supplements OFR 84-627. Its purpose is to report the results of additional stability analyses for areas II and IV (pl. 1), and to make recommendations that respond to the findings of the study. Additional analyses were needed to assess the effects of possible changes in slope conditions due to projected additional spoil-pile loading in slope area II and to potential retrogressive failures in slope area IV. Factors of safety were calculated using conventional limit-equilibrium analysis for the drained (zero pore pressure) slope condition (Huang, 1983). Detailed information on the geology, slope conditions, and methods of analysis used for slope areas II and IV is presented in OFR 84-627.

SLOPE AREA II

Summary of Slope Conditions and Previous Results

Slope area II (pl. 1) is located below spoil piles on the west side of the mine area. The slope descends steeply from the mine to a relatively large terrace area and the Spokane River Arm of Franklin D. Roosevelt Lake, approximately 500 ft below. Natural slope angles as high as 30° were measured in the field for slope area II. The slope consists of as much as 120 ft of surficial lacustrine and alluvial sediments overlying crystalline bedrock (fig. 2). The surficial material below elevation 1650 consists of sand, silt, gravel, and silty clay interbedded with varved clay; the terrace at the bottom of the slope is composed of coarse material (mostly pebble gravel and sand) to

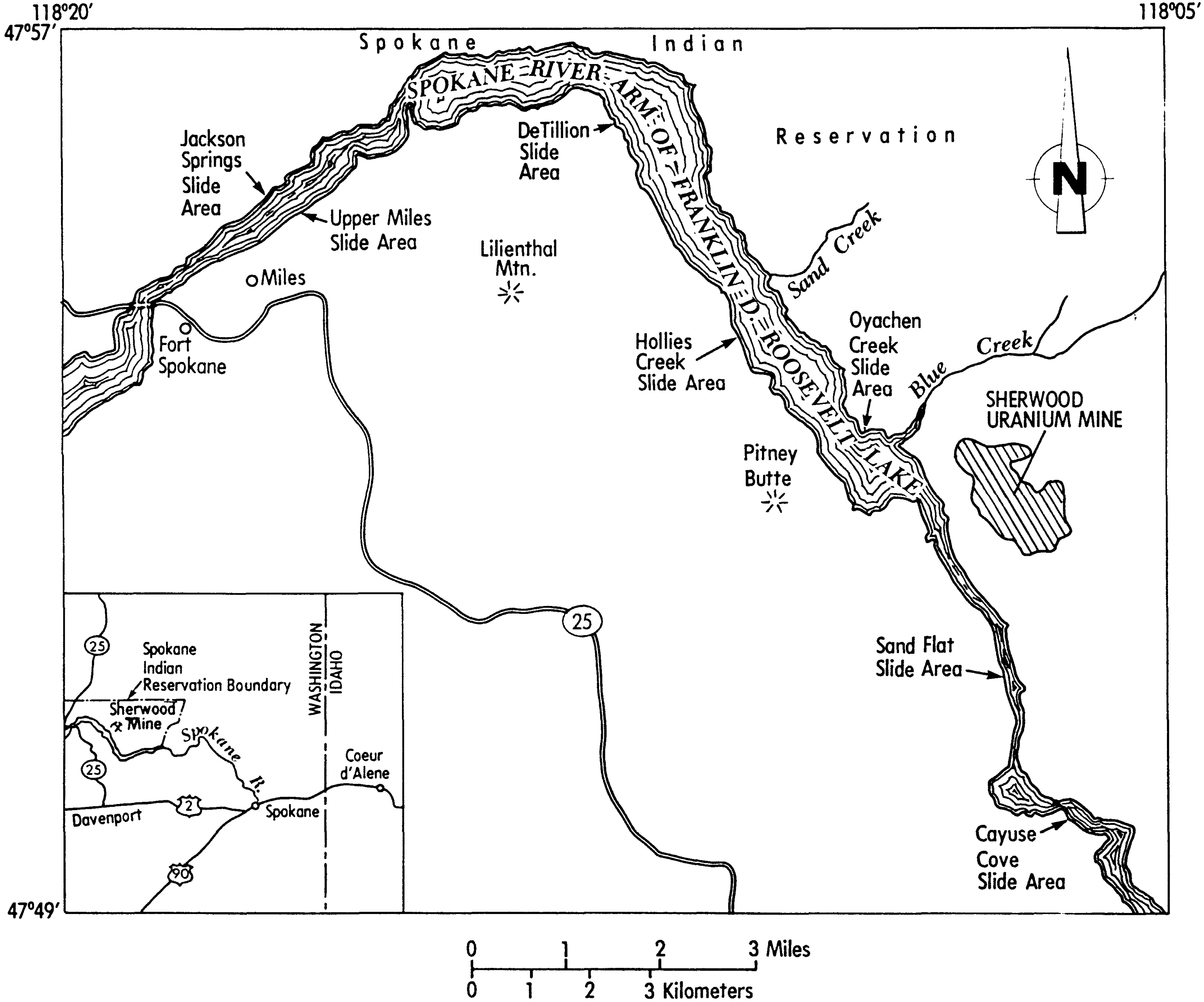

Figure 1.--Index map showing the location of the Sherwood Uranium Mine and landslide areas along the banks of the Spokane River Arm of Franklin D. Roosevelt Lake. Landslide area locations taken from U. S. Bureau of Reclamation Annual Inspection Report, 1982.

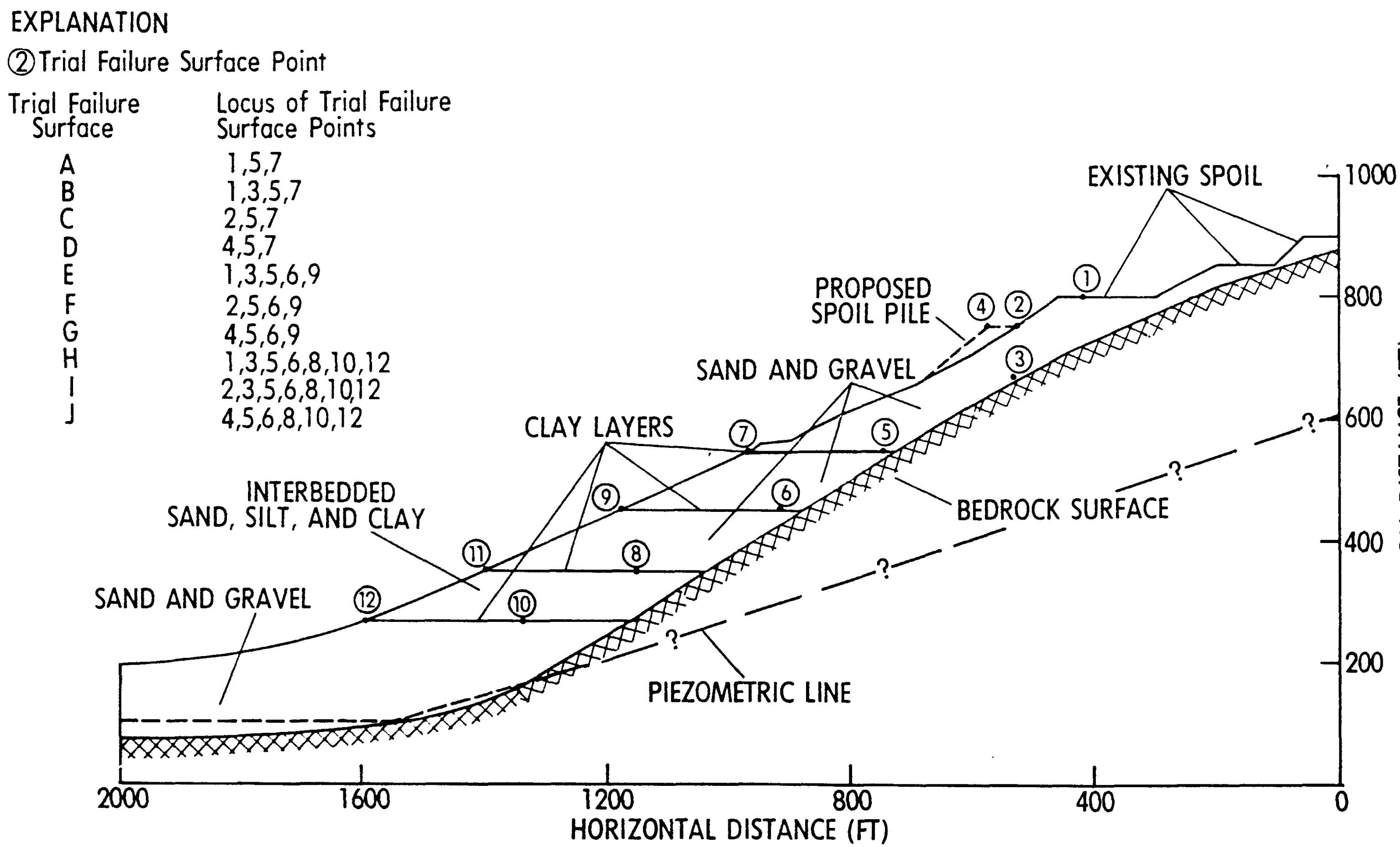

Figure 2.--Idealized cross section D-D' (plate 1, slope area II) showing the location of trial failure surfaces.

a depth of at least 100 ft. Above the 1650-ft elevation, the natural surficial slope material consists entirely of sand and subordinate gravel. The locations of clay layers shown in cross section D-D' (fig. 2) are based on actual clay-bed exposures found in slope area II or are inferred from exposures found in nearby slope areas. Slope area II is bounded by a large area of exposed bedrock to the southeast (slope area I) and to the northwest by the bedrock exposure of slope area III. Spoil piles presently load the top of slope area II, and additional spoil-pile loading is being considered, which would extend downslope to approximately the 1750-ft elevation, as shown in figure 2 (Gary Righittini, Western Nuclear Corp., written commun., 1984). Previous stability analyses for cross section A-A' of slope area II (pl. 1), using the Morgenstern-Price and sliding-wedge methods of analysis under existing slope conditions without additional spoil, yielded factors of safety ranging from 1.62 to 2.01 using peak shear-strength parameters and 1.55 to 1.86 using residual strength values (OFR 84-627). It was recommended in OFR 84-627 that the effects of additional spoil loading in slope area II be analyzed in advance, to determine the advisability of such additional loading.

Results of Stability Analyses

Stability analyses were performed using the sliding-wedge method of analysis (OFR 84-627) in order to examine the effects of the proposed additional spoil-pile loading depicted in figure 2. The location of cross section D-D' is shown on plate 1. Material properties used in the analyses are listed in table 1; these properties are the same as those used in previous analyses described in OFR 84-627. The trial failure surfaces shown in figure 2 incorporate all or part of the proposed spoil in each analysis. In all cases, the base or lowermost segment of the trial failure surface is located in a clay layer. Correspondingly, the material properties of the clay were used for those trial failure-surface segments in each analysis. Stability- analysis results for cross section D-D' trial failure surfaces are presented in table 2.

As shown in table 2, some of the calculated factors of safety are below the recommended safe minimum values of 1.5, using peak strengths, or 1.3, using residual strengths (OFR 84-627). Trial failure surfaces A, C, and D, which have factors of safety below the recommended safe minimum values, involve the possible clay layer near elevation 1640; trial failure surface G with a calculated factor of safety of 1.27, using residual strength values, involves the possible clay layer near elevation 1550. As previously stated, these analyses are based on the assumption that the clay layers are continuous across slope area II. However, surface and subsurface field evidence is meager and, therefore, inconclusive. If the weak clay layer assumed present in a given anaylsis is in fact not present, the sliding wedge analysis is inappropriate for the problem and the factors of safety presented here are probably too low.

Recommendations

It is recommended that plans for additional spoil-pile loading in slope area II (fig. 2) be abandoned or postponed until it can be demonstrated by additional drilling and (or) other detailed field studies that clay layers found in nearby outcrops are not continuous across slope area II and that recalculated factors of safety resulting from stability analyses for different slope conditions are not lower than the recommended safe minimums.

Table 1.--Material properties used in stability analyses

Type of material	Unit weight (pcf)		Shear strength, effective stress basis			
	Partially saturated	Saturated	Peak		Residual	
			c' (psf)	∅' (degrees)	c_r' (psf)	$∅_r$' (degrees)
Sand and gravel	115	120	0	37	0	37
Mine spoil	116	121	0	37*	0	37*
Gravel	117	122	0	38	0	37
Silty clay	117	118	597	26	0	14
Varved clay	118	119	448	18	0	10

*Based on field measurement of spoil-pile angles of repose.

Table 2.--Results of stability analyses for slope area II

Trial failure surface	Locus of trial failure surface points (see fig. 2 for location)	Factor of safety	
		Based on peak shear strength	Based on residual shear strength
A	1,5,7	1.51	1.21
B	1,3,5,7	1.56	1.36
C	2,5,7	1.48	1.13
D	4,5,7	1.49	1.00
E	1,3,5,6,9	1.59	1.40
F	2,5,6,9	1.66	1.40
G	4,5,6,9	1.57	1.27
H	1,3,5,6,8,10,12	1.60	1.51
I	2,5,6,8,10,12	1.60	1.48
J	4,5,6,8,10,12	1.60	1.47

SLOPE AREA IV

Summary of Slope Conditions and Previous Results

Slope Area IV (pl. 1) also is located below spoil piles on the west side of the mine area. Slope area IV descends very steeply from the mine to the Spokane River Arm of Franklin D. Roosevelt Lake approximately 600 ft below, with natural slope angles as steep as 37°. Subsurface profiles based on seismic refraction data (OFR 84-627) show surficial deposits as thick as 100 ft, underlain by crystalline bedrock (quartz monzonite and volcanic tuff). Above the 1650-ft elevation, the surficial deposits in slope area IV consist almost entirely of sand and subordinate gravel; below 1650 ft they consist mostly of sand, silt, gravel, and silty clay interbedded with varved clays. Slope area IV is bounded by slopes with large areas of exposed bedrock to the southeast (slope area III) and to the northwest (slope area V).

Previous stability analyses using the Morgenstern-Price and sliding-wedge methods of analysis revealed six trial failure surfaces in slope area IV with factors of safety lower than the recommended safe minimums (OFR 84-627). All of those surfaces are located in the lower part of the slope and involve clay beds actually cropping out on the slope or inferred to exist on the basis of clay outcrops found in nearby slopes at similar elevations. It was recommended in OFR 84-627 that slope area IV be routinely examined to identify any potential landslides that might result in retrogressive failures involving spoil material in the upper parts of the slope, and that additional slope stability analyses be performed to examine the effects of such retrogressive failures.

Results of Stability Analyses

Additional stability analyses were performed to check the likelihood of retrogressive slope failure developing on the upper part of slope area IV due to failure of the lower part. The sliding-wedge method of analysis and appropriate shear strength parameters described in OFR 84-627 were used to obtain factors of safety. Material properties used in the analyses are shown in table 1. In order to examine the effects of support lost to the upper part of slope area IV due to a slope failure on the lower part, a wedge failure along trial failure surface 6a, 7a, 12 was assumed, resulting in removal of material in the hachured area shown in figure 3. The resulting surface geometry (6a, 6b, 7a, 12, in fig. 3) was then incorporated into the analyses of trial failure surfaces 5b, 6, 6b; 5a, 6, 6b; and 4a, 6, 6b, all involving the remaining part of the uppermost clay layer between points 6 and 6b. The results of these analyses are shown in table 3. As seen in table 3, of those trial failure surfaces involving the uppermost clay layer, only trial failure surface 5b, 6, 6b has a factor of safety (1.32 based on residual shear-strength parameters) approaching the safe minimum recommended in OFR 84-627 (1.30 based on residual parameters). The stability of the slope above the uppermost clay bed would be governed by the strength properties of sand, gravel and (or) spoil, and slope angles in excess of 35° to 37° would be required for instability as indicated by the infinite slope analyses of OFR 84-627. The existing natural slope above the uppermost clay bed is approximately 20°. The results shown in table 3 indicate that, under existing conditions, removal of support from the upper slope area due to failure(s) in the lower part probably would not result in retrogressive failures involving

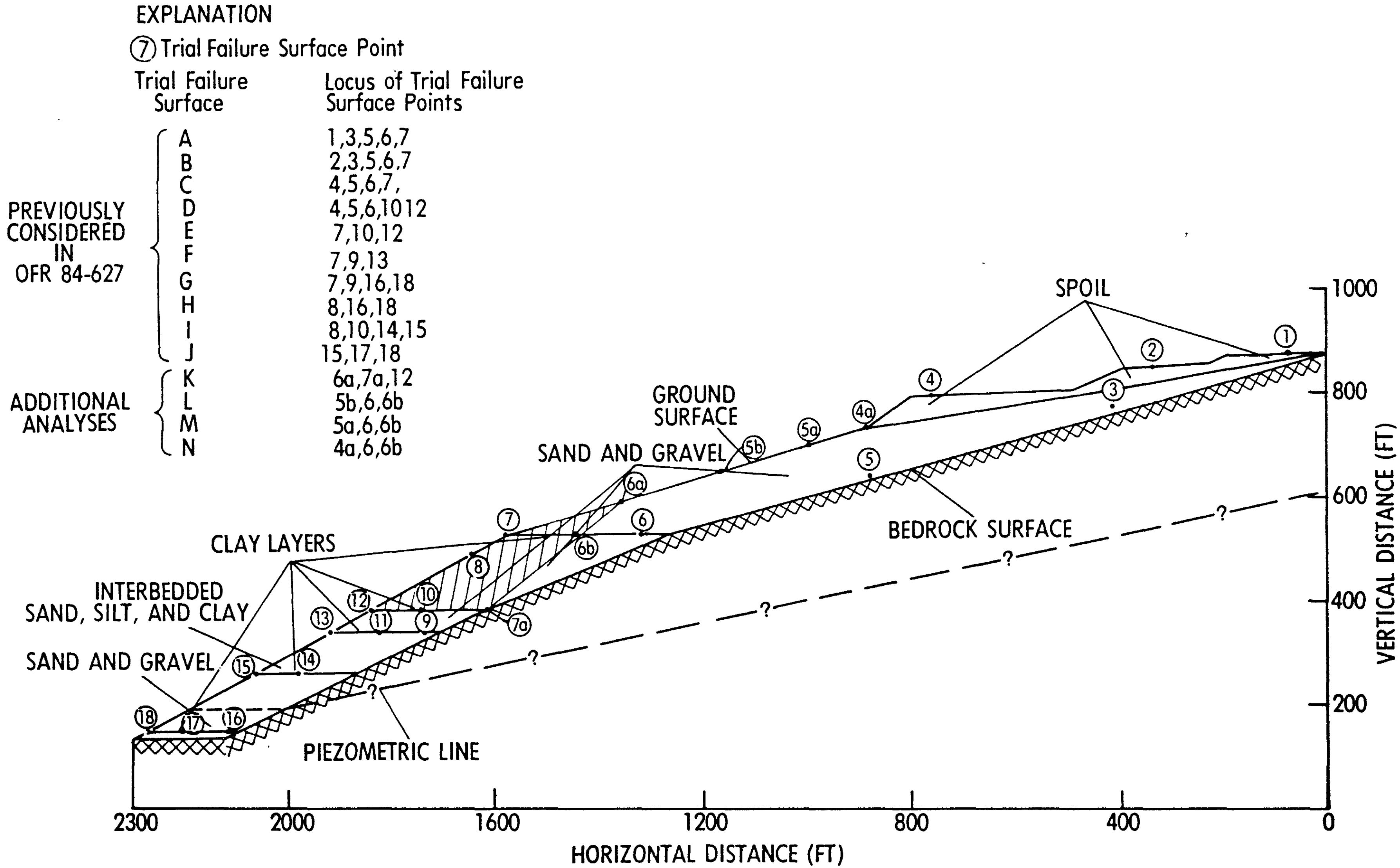

Figure 3.--Idealized cross section B-B' (plate 1, slope area IV) showing the location of trial failure surfaces and hypothetical wedge failure resulting in removal of material in hachured area.

Table 3.--Results of stability analyses for slope area IV

Trial failure surface	Locus of trial failure surface points (see fig. 3 for location)	Factor of safety	
		Based on peak shear strength	Based on residual shear strength
K	6a,7a,12	1.56	1.21
L	5b,6,6b	1.87	1.32
M	5a,6,6b	1.85	1.51
N	4a,6,6b	2.01	1.74

spoil material. Additional spoil-pile loading downslope of the existing piles, and above the trial failure surfaces considered in these analyses, would add to the shearing stresses and could reduce factors of safety below safe minimums. Any future plans for additional spoil-pile loading downslope of existing spoil into marginally stable areas will require detailed analyses. As previously mentioned, the actual location, extent, and orientation of clay beds used in the analyses are largely inferred on the basis of outcrops on adjacent slopes. Additional field work would be needed to verify their existence and to better ascertain their locations and orientations should more detailed analyses be required.

Alternatives in Response to Findings

The following suggested alternatives are presented with the assumption that spoil-pile loading will not be extended downslope of existing spoil in slope area IV into potentially unstable areas.

Alternative A:

No action; no continuation of field studies.

Discussion.--This alternative can be justified by the additional stability analyses which show that retrogressive failures into existing spoil at the top of the slope are unlikely.

Advantage of Alternative A.--No additional cost.

Disadvantage of Alternative A.--Ignores the uncertainties that exist regarding the location, orientation, and extent of clay layers in the slope. Does not provide for the early detection of a slope failure that may result if slope conditions are significantly different than those assumed in the stability analyses.

Alternative B:

Drilling to better determine the location, extent, and orientation of clay layers in the slope.

Discussion.--As many as 10 individual silty clay-varved clay units may exist in slope area IV (OFR 84-627). However, only the clay bed shown at 1500-ft elevation has been located in outcrop in slope area IV (pl. 1). Ten to 15 auger drill holes may be needed, some as deep as 150 ft, to better determine the extent and orientation of the clay beds. The steep terrain would likely limit the number of possible drill-hole locations.

Advantages of Alternative B.--Alternative B could result in a vastly improved knowledge of the location, orientation, and extent of clay layers on which to base slope stability analyses and any decisions concerning additional field work.

Disadvantages of Alternative B.--The major disadvantage is the probable high cost of drilling. Parts of slope area IV are very steep and inaccessible to ordinary truck-mounted drilling equipment. Some of the desired drilling may be very time consuming and costly, if not impossible. Large granitic cobbles and boulders, occasionally present in the coarser grained strata, could necessitate costly moves of the drill and complicate stratigraphic intrepretation. Additionally, there is some question whether or not clay beds can be detected using an augering system unless they are relatively thick. Other drilling techniques that would yield continuous sample, such as Shelby tube sampling, would be more expensive.

Alternative C:

Surface survey to detect slope movement on slope area IV.

Discussion.--A surface survey using an electronic distance-measuring device or an optical survey instrument with an accuracy of plus or minus a few millimeters could be used to monitor small magnitude slope movements that might forewarn of an impending massive slope failure. Stable instrument locations providing a view of the entire slope can be found opposite slope area IV across the Spokane River Arm or possibly on bedrock locations in slope area III. Stable bench marks, needed as a frame of reference against which slope movements can be compared, could be located on the bedrock outcrops in slope areas III and V shown in plate 1. We recommend that survey targets or hubs be positioned on slope area IV at elevations just above the clay layers (pl. 1 and fig. 3) in order to detect movements at the toes of potential landslides where initial horizontal and (or) vertical displacements might be expected due to bulging. Other targets or hubs should be located between clay beds to detect vertical and horizontal movements near the heads and midpoints of the potential sliding masses identified in OFR 84-627 and in this report. The targets or hubs placed on slope area IV must be anchored deeply enough, possibly 6 ft or more, to avoid the effects of movements due to erosion or shallow slips in the very loose surface material. Initially, measurements should be made over short time intervals in order to establish a data base for future comparison. Once a data base has been obtained, the time between measurments can be lengthened to appropriate intervals determined by such landslide-related factors as precipitation, fluctuation in reservoir level, additional spoil-pile loading, evidence of significant slope movement, etc.

Advantages of Alternative C.--The possible early detection of a massive slope failure should allow time for mitigative or preventive action. The system can be easily established and maintained.

Disadvantages of Alternative C.--In relation to Alternative A, the moderate cost of one or two individuals' time to make measurements, reduce and plot data, and maintain the system, could be considered a disadvantage. In addition, there is a possibility that survey targets will be incorrectly placed due to the uncertainty of clay bed locations.

Recommendations

If money were no object, alternative B would be recommended in order to gain additional information on clay-bed locations which could be used to establish a surface survey and which would determine the credibility of the interpretations on which the stability analyses are based. However, in view of the relatively high cost of the drilling alternative and the absence of plans to add spoil downslope of existing spoil piles, the surface survey (Alternative C) appears to be a logical alternative that would, in the opinion of the authors, provide some protection against serious loss due to a massive slope failure with a measure of insurance against the uncertainties involved, at a relatively low cost.

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