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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20338036
Internal Report (National Research Council of Canada. Division of Building Research), 1965-01-01

NATIONAL RESEARCH COUNCIL
CANADA
DIVISION OF BUILDING RESEARCH

SLOPE STABILITY STUDIES, 1963

by

K. Van Dalen

Internal Report No. 306
of the
Division of Building Research

OTTAWA
January 1965

PREFACE

The interpretation of shear strength parameters from laboratory tests on the sensitive Leda clays of Eastern Canada is controversial. It is necessary, therefore, to evaluate the laboratory results by field observations. Several specific stability analyses have been carried out for this purpose.

During the summer of 1963, Professor K. Van Dalen of Carleton University, who was with DBR/NRC as a guest worker, was engaged in a preliminary study of slopes over a broad area of the Ottawa region. The first stage of this work was to identify the largest slopes from aerial photographs of the region. Approximate cross-sections were drawn using stereo pairs and some of these were checked by stadia surveying.

Effective stress stability analyses of these selected slopes were made using tabulated stability coefficients. A more refined analysis by the method of slices was made on some of the slopes. This report was prepared as a basis for further study of the problem by more refined field observations and computer analyses.

Ottawa
January 1965

R. F. Legget
Director

SLOPE STABILITY STUDIES, 1963

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The mobilized shearing resistance of a natural soil may be assessed by analysing the stability of natural slopes. For such a study of the Leda clay, the steepest slopes existing within a limited area near Ottawa were selected from aerial photographs. Profiles were drawn using stereo-photos and some of these were checked on the ground by engineering levelling. Assuming that the steepest slope is at limiting equilibrium, values of c' and ϕ' (cohesion and friction angle in terms of effective stresses) can be determined by stability analyses.

The stability analysis of a slope, assuming the factor of safety, $F = 1.0$ and an appropriate value of ϕ', would give the value of c' which is being mobilized in order to maintain equilibrium. If the slope is on the point of failure the soil has no reserve of cohesion left to be mobilized; F is in fact equal to 1.0, and the value of c' found in the stability analysis is the maximum of which the soil is capable. This value of c' is the cohesive strength of the soil.

If it were possible to find a slope whose F was 1.0, it would be a simple matter to find the cohesive strength of the soil. It is not easy to determine which, if any, of the many slopes within a region have an F of 1.0. The approach used was to measure as many slopes as seemed at all significant within an area. A crude stability analysis was performed on each slope, assuming $F = 1.0$ and determining c'. In most of the slopes F will be greater than 1.0 and thus c', the cohesion mobilized, will be less than the cohesive strength of the soil. The slope within any small region which gives the highest value of c' will be (assuming that the soil properties do not change) the slope with an actual factor of safety closest to 1.0. If slides have occurred immediately adjacent to this slope, one may infer that not only is this slope the one having an F nearest to 1.0 within the region, but further that this factor of safety is approximately equal to 1.0. Thus, the value of c' found from this slope is not only the value of mobilized cohesion nearest to the cohesive strength of the soil, it is in fact approximately equal to the cohesive strength. In this manner, a good estimate (erring on the conservative side if the slope is still standing) of the cohesive strength of the soil in the region may be made.

SCOPE OF WORK

Three areas within the Ottawa district were selected for investigation. These areas were Green Creek - Mud Creek, Breckenridge, and Clarence Creek. The locations of the Green Creek - Mud Creek and Breckenridge areas are shown in Figure 1, and the locations of slope profiles which were studied in detail are shown in Figures 2 and 3. The Clarence Creek region (not shown) is about 30 miles east of Green Creek. The Green Creek - Mud Creek region appeared to be a youthful region; although steep banks were present, there had not been any major slides. The Green Creek landslide is of course the notable exception, but this slide did not occur in the banks of the creek where the steep slopes exist. The Breckenridge area appeared to be a somewhat more-advanced landslide area. Numerous scars of ancient slides were visible - these still remain, however, as steep banks which give rise to moderately large earth flows as evidenced by the recent Breckenridge slide. The third area, surrounding Clarence Creek, appeared to be a well-developed slide area. The area was completely covered by scars of ancient landslides. It was given only a cursory inspection, but few banks of any magnitude were observed and there has been no evidence of any recent movement of the land.

The areas have been adequately documented by moderately low level (6,000 to 9,000 feet) aerial photographs. It was decided, therefore, to use photogrammetric methods to measure the profiles of significant slopes. Measurements were performed using a "Santoni" stereo plotter. The instrument is convenient to use although it was found that a period of time was required to train the operator's eyes to fuse the measuring marks. The machine is particularly suited to the scanning of a stereo pair because of its ease of horizontal movement in X and Y directions. Elevations could be measured to an average accuracy of about $\pm$ 4 feet from photos taken from 6,000 ft. In a number of instances, however, larger errors were present. This may have been due to tip or tilt of the photographs for which no correction was made. The accuracy of the photogrammetric measurements could therefore have been improved, but it was thought that allowance for tip and tilt was not justified in view of other possible errors.

The cohesion required to give each of the measured slopes an F of 1.0 was conveniently and quickly estimated using stability coefficients given by Bishop and Morgenstern (1). Some rearrangement was necessary as the stability coefficients are set up to facilitate finding F when c' is known. The c' required for all slopes investigated with the use of air photos is summarized in Table I. Within each area, two or three slopes giving the highest value of c' were selected for a more careful analysis. If the slope was originally measured by photogrammetric means it was checked where possible by a stadia survey. This more-accurate profile was then analysed by Bishop's method of slices to determine the location of the most critical circle, and the cohesion necessary to give stability was computed.

DETAILED SUMMARY OF WORK DONE TO DATE

(1) Number of Slopes Measured

Thirty-two slopes were measured. Of these, 13 were in the Green Creek area, 16 in the Breckenridge area and 3 in the Clarence Creek area. Slopes 1 to 9 were within an area covered by $2\frac{1}{2}$-ft contour maps, as were slopes 31 and 32. The remainder were initially measured from air photos. Certain slopes were selected as meriting further attention and these slopes, (Nos. 11, 21, and 27), were checked by stadia. Small earth flows had occurred at the scene of slopes 11 and 21 since the air photographs had been taken, confirming that these slopes were nearing an F of 1.0. Slope No. 12 was the natural slope existing prior to the Breckenridge slide in May 1963. It could not be checked by stadia, but was drawn as an average of three sets of determinations from the air photos. It is believed to be a good approximation to the slope existing prior to the slide.

(2) Use of Stability Coefficients

The slopes were analysed initially using the stability coefficients of Bishop and Morgenstern. From Figures 7, 8, 9, 10, 11 and 12 of Bishop and Morgenstern's paper (1), another set of curves was prepared which can be used to give values of c'. These curves require a value to be chosen for ϕ', r_u and γ. With these selected, one enters the appropriate graph with β (the slope) and reads the corresponding value of $c'/\gamma H$. Cross multiplication gives c'. Values of c' for all slopes investigated are listed in Appendix A.

(3) Choice of Values used for γ, ϕ' and r_u

The stability coefficients give a rapid method of estimating c'. A choice of values of γ, ϕ' and r_u must be made for use with the stability coefficients.

(i) Choice of γ. - A study of records of values of bulk density was made. The records from the Green Creek landslide, HMCS Gloucester, Cumberland and the Sewer Plant were used and γ was plotted against depth. The best value of γ was chosen to be 100 pcf.

(ii) Choice of r_u. - No clear evidence was available to indicate the correct value of pore-pressure ratio to be used. It was thought not unreasonable to assume the ground water table (G. W. T.) to reach the surface during times of spring run-off. No seepage was considered and, hence, the pore pressure ratio becomes $r_u = \gamma_w h_w / \gamma h$. If G. W. T. at the surface is considered to hold, then $h_w = h$, γ is 100, and r_u becomes 0.624.

(4) Variation of Parameters

The choice of the values for the parameters was comparatively arbitrary with only slight support from actual observations. Hence, it is useful to determine the sensitivity of the values of c' to changes in γ, ϕ', and r_u. Accordingly, these quantities were varied over what was judged to be the limit of their probable values. Table II indicates the assumed correct value and the range of other values considered.

Because a change in γ results in a change in r_u, $[r_u = \gamma_w h_w / \gamma h]$, the values of r_u for various bulk density and ground water conditions are given in Table III.

The parameters were varied to give seven possible values of c' for each slope. These values may be found in Appendix A. The values of c' for each slope using the most probable combination of values of γ, ϕ' and r_u have been summarized in Table I. Slope No. 9 is shown in Figure 4 and the effect of variations of γ, ϕ' and r_u on the value of c' for this slope is shown graphically in Figure 5.

(5) Selection of Slopes for More Intensive Study

Within each area several slopes were selected for further study on the basis of their values of c' determined using stability coefficients and the most likely values of γ (100), ϕ' (15.0°) and r_u (.624). The slopes selected were Nos. 1, 2, 6, 9 and 11 in the Green Creek area, and Nos. 12, 13, 21 and 27 in the Breckenridge area. These slopes had the highest values of c' within the region and were thus assumed to be the nearest to mobilization of the full cohesive strength of soil. Of the slopes which were selected, Nos. 11, 12, 13, 21 and 27 were measured from air photos, and the others were measured from $2\frac{1}{2}$-ft contour maps that were considered to be sufficiently accurate. Slopes 11, 21 and 27 were remeasured by stadia. Slopes 11 and 21 showed evidence of further movement since the air photos were made. Slopes 12 and 13 no longer exist since the landslide at Breckenridge but were checked by air photo measurements. There were insufficient slopes measured in the Clarence Creek area to select any significant ones.

(6) Stability Analysis of Selected Slopes Using Method of Slices

The slopes which were selected for more intensive study departed considerably from the straight line slope assumed in Bishop's stability coefficient method. Thus, in order to determine more precisely the value of c' required to give stability to these slopes, it is necessary to conduct an analysis using Bishop's method of slices. Only one of the slopes (No. 9, Figure 4) was analysed completely using this method. The value of c' for this slope, as determined by the method of slices, was 610 psf. This compares with the value of 549 psf found using stability coefficients.

A second slope (No. 12), was begun, but only 5 circles were drawn and computed. The value of c' found from these few circles was 808 psf. This value compared with the c' = 760 psf found by use of stability coefficients. More circles should be drawn to confirm the 808 psf value that was obtained.

For slope No. 9 the contours of centres of circles giving equal values of c' were plotted. These contours agree in general with the shape of contours for similar quantities reported by Bishop and Morgenstern (1).

REFERENCE

(1) Bishop, A. W. and N. Morgenstern. Stability coefficients for earth slopes. Géotechnique, Vol. X, No. 4, December 1960, p. 129.

TABLE I

SUMMARY OF c' VALUES FOUND BY USE OF STABILITY COEFFICIENTS. $\gamma = 100.0$, $\phi' = 15.0$, $r_u = .624$

Area	Slope No.	β°	H, ft	c', psf	Remarks
	1	21	61	515	
Green	2	20-1/2	65	540	
	3	25-1/2	47	446	
Creek	4	17-1/2	68	502	
	5	18-1/2	62	478	
&	6	24	56	512	
	7	17	33	239	
Mud	8	17	65	471	
	9	24	60	549	
Creek	10	12-1/2	45	232	
	11	23	60	537	Minor slide discovered when surveyed in field.
	12	27	77	760)	Breckenridge
	13	25	85	796)	Slide
	14	14-1/2	46	285	
	15	20-1/2	55	457	
	16	17-1/2	51	378	
	17	34	36	392	
Brecken-	18	16	44	301	
	19	29	40	407	
ridge	20	17	38	275	
	21	20-1/2	79	657	Near recent slide
Area	22	27	140	1375)	Rock
	23	27-1/2	133	1312)	
	24	19	73	576	
	25	14-1/2	69	427	
	26	12	54	261	
	27	18-1/2	93	716	Near old slide
	28	12	51	246	
Clarence Creek	29	14-1/2	61	377	
	30	13-1/2	31		
Green	31	17-1/2	66	490	Adjacent to Green
Creek	32	16	65	445	Creek landslide

TABLE II

VALUES OF PARAMETERS γ, ϕ' AND r_u

Quantity	Assumed Correct Value	Range of Values
γ	100 pcf	90 to 110 pcf
ϕ'	15.0°	10.0° to 20.0°
r_u	$\frac{\gamma_w h_w}{\gamma h}$ where $h_w = h$	$h_w = 0.8h$ to $1.0h$

TABLE III

POSSIBLE VALUES OF r_u

r_u	Assumed Condition
.624	γ = 100 pcf, $h_w = h$ i.e. G.W.T. at surface
.568	γ = 110 " $h_w = h$
.694	γ = 90 " $h_w = h$
.561	γ = 100 " $h_w = .9h$
.498	γ = 100 " $h_w = .8h$

APPENDIX A

VALUES OF c' FOR VARIOUS SLOPES DETERMINED BY STABILITY COEFFICIENTS

Slope No.	β	H, ft	γ, pcf	u	r_u	ø'	c', psf
1	21°	61'	100	$\gamma_w h$	.624	15°	515
			90	$\gamma_w h$	.694	15°	532
			110	$\gamma_w h$	.568	15°	516
			100	$.9\gamma_w h$	.561	15°	462
			100	$.8\gamma_w h$	.498	15°	409
			100	$\gamma_w h$	.624	10°	647
			100	$\gamma_w h$	.624	20°	426
2	20-1/2°	65'	100	$\gamma_w h$	.624	15°	540
			90	$\gamma_w h$	.694	15°	539
			110	$\gamma_w h$	.568	15°	539
			100	$.9\gamma_w h$	.561	15°	481
			100	$.8\gamma_w h$	.498	15°	427
			100	$\gamma_w h$	.624	10°	683
			100	$\gamma_w h$	.624	20°	444
3	25-1/2°	47'	100	$\gamma_w h$	.624	15°	446
			90	$\gamma_w h$	.694	15°	451
			110	$\gamma_w h$	.568	15°	450
			100	$.9\gamma_w h$	.561	15°	403
			100	$.8\gamma_w h$	.498	15°	362

Slope No.	β	H, ft	γ, pcf	u	r_u	ø'	c', psf
3			100	$\gamma_w h$	.624	10°	544
			100	$\gamma_w h$	.624	20°	384
4	17-1/2°	68'	100	$\gamma_w h$	.624	15°	502
			90	$\gamma_w h$	.694	15°	526
			110	$\gamma_w h$	.568	15°	491
			100	$.9\gamma_w h$	.561	15°	435
			100	$.8\gamma_w h$	.498	15°	377
			100	$\gamma_w h$	.624	10°	650
			100	$\gamma_w h$	.624	20°	388
5	18-1/2°	62'	100	$\gamma_w h$	.624	15°	478
			90	$\gamma_w h$	.694	15°	499
			110	$\gamma_w h$	.568	15°	470
			100	$.9\gamma_w h$	.561	15°	418
			100	$.8\gamma_w h$	.498	15°	365
			100	$\gamma_w h$	.624	10°	614
			100	$\gamma_w h$	.624	20°	378
6	24°	56'	100	$\gamma_w h$	.624	15°	512
			90	$\gamma_w h$	.694	15°	522
			110	$\gamma_w h$	.568	15°	518
			100	$.9\gamma_w h$	.561	15°	462
			100	$.8\gamma_w h$	.498	15°	443
			100	$\gamma_w h$	.624	10°	630
			100	$\gamma_w h$	.624	20°	437

Slope No.	β	H, ft	γ, pcf	u	r_u	ø'	c', psf
7	17°	33'	100	$\gamma_w h$	.624	15°	239
			90	$\gamma_w h$	.694	15°	249
			110	$\gamma_w h$	.568	15°	232
			100	$.9\gamma_w h$	.561	15°	205
			100	$.8\gamma_w h$	.498	15°	176
			100	$\gamma_w h$	.624	10°	310
			100	$\gamma_w h$	.624	20°	181
8	17°	63'	100	$\gamma_w h$	.624	15°	471
			90	$\gamma_w h$	.694	15°	490
			110	$\gamma_w h$	.568	15°	457
			100	$.9\gamma_w h$	.561	15°	403
			100	$.8\gamma_w h$	.498	15°	347
			100	$\gamma_w h$	.624	10°	611
			100	$\gamma_w h$	.624	20°	358
9	24°	60'	100	$\gamma_w h$	.624	15°	549
			90	$\gamma_w h$	.694	15°	560
			110	$\gamma_w h$	.568	15°	556
			100	$.9\gamma_w h$	.561	15°	496
			100	$.8\gamma_w h$	.498	15°	476
			100	$\gamma_w h$	.624	10°	676
			100	$\gamma_w h$	.624	20°	469
10	12-1/2°	45'	100	$\gamma_w h$	.624	15°	232
			90	$\gamma_w h$	.694	15°	256

Slope No.	β	H, ft	γ, pcf	u	r_u	ϕ'	c', psf
10			110	$\gamma_w h$	.568	15°	206
			100	$.9\gamma_w h$	.561	15°	177
			100	$.8\gamma_w h$	.498	15°	138
			100	$\gamma_w h$	.624	10°	332
			100	$\gamma_w h$	.624	20°	138
11	23°	60'	100	$\gamma_w h$	.624	15°	537
			90	$\gamma_w h$	.694	15°	550
			110	$\gamma_w h$	.568	15°	542
			100	$.9\gamma_w h$	.561	15°	488
			100	$.8\gamma_w h$	.498	15°	433
			100	$\gamma_w h$	.624	10°	666
			100	$\gamma_w h$	.624	20°	453
12(a)	27°	77'	100	$\gamma_w h$	.624	15°	758
			90	$\gamma_w h$	.694	15°	758
			110	$\gamma_w h$	.568	15°	762
			100	$.9\gamma_w h$	.561	15°	683
			100	$.8\gamma_w h$	.498	15°	618
			100	$\gamma_w h$	.624	10°	911
			100	$\gamma_w h$	.624	20°	655
12(b)	31°	52'	100	$\gamma_w h$	.624	15°	545
			90	$\gamma_w h$	.694	15°	540
			110	$\gamma_w h$	.568	15°	550

Slope No.	β	H, ft	γ, pcf	u	r_u	Ø'	c', psf
12(b)			100	$.9\gamma_w h$	.561	15°	492
			100	$.8\gamma_w h$	.498	15°	448
			100	$\gamma_w h$	.624	10°	643
			100	$\gamma_w h$	.624	20°	477
13	25°	85'	100	$\gamma_w h$	.624	15°	796
			90	$\gamma_w h$	.694	15°	810
			110	$\gamma_w h$	.568	15°	805
			100	$.9\gamma_w h$	.561	15°	722
			100	$.8\gamma_w h$	.498	15°	649
			100	$\gamma_w h$	.624	10°	974
			100	$\gamma_w h$	.624	20°	685
14	14-1/2°	46'	100	$\gamma_w h$	.624	15°	285
			90	$\gamma_w h$	.694	15°	303
			110	$\gamma_w h$	.568	15°	264
			100	$.9\gamma_w h$	.561	15°	232
			100	$.8\gamma_w h$	.498	15°	193
			100	$\gamma_w h$	.624	10°	384
			100	$\gamma_w h$	.624	20°	194
15	20-1/2°	55'	100	$\gamma_w h$	.624	15°	457
			90	$\gamma_w h$	.694	15°	473
			110	$\gamma_w h$	.568	15°	456
			100	$.9\gamma_w h$	.561	15°	407
			100	$.8\gamma_w h$	.498	15°	361

Slope No.	β	H, ft	γ, pcf	u	r_u	ϕ'	c', psf
15			100	$\gamma_w h$	.624	10°	578
			100	$\gamma_w h$	.624	20°	376
16	17-1/2°	51'	100	$\gamma_w h$	.624	15°	378
			90	$\gamma_w h$	.694	15°	394
			110	$\gamma_w h$	.568	15°	368
			100	$.9\gamma_w h$	.561	15°	325
			100	$.8\gamma_w h$	.498	15°	283
			100	$\gamma_w h$	.624	10°	487
			100	$\gamma_w h$	.624	70°	290
17(a)	34°	36'	100	$\gamma_w h$	.624	15°	392
			90	$\gamma_w h$	.694	15°	385
			110	$\gamma_w h$	.568	15°	396
			100	$.9\gamma_w h$	.561	15°	336
			100	$.8\gamma_w h$	.498	15°	326
			100	$\gamma_w h$	.624	10°	457
			100	$\gamma_w h$	.624	20°	347
17(b)	43°	24'	100	$\gamma_w h$	.624	15°	285
			90	$\gamma_w h$	.694	15°	273
			110	$\gamma_w h$	.568	15°	286
			100	$.9\gamma_w h$	.561	15°	258
			100	$.8\gamma_w h$	.498	15°	237
			100	$\gamma_w h$	.624	10°	323
			100	$\gamma_w h$	.624	20°	256

Slope No.	β	H, ft	γ, pcf	u	r_u	∅'	c', psf
18(a)	27°	24'	100	$\gamma_w h$	.624	15°	236
			90	$\gamma_w h$	.694	15°	236
			110	$\gamma_w h$	.568	15°	237
			100	$.9\gamma_w h$	.561	15°	213
			100	$.8\gamma_w h$	.498	15°	193
			100	$\gamma_w h$	.624	10°	284
			100	$\gamma_w h$	.624	20°	204
18(b)	16°	44'	100	$\gamma_w h$	.624	15°	301
			90	$\gamma_w h$	.694	15°	317
			110	$\gamma_w h$	.568	15°	287
			100	$.9\gamma_w h$	.561	15°	253
			100	$.8\gamma_w h$	.498	15°	216
			100	$\gamma_w h$	.624	10°	396
			100	$\gamma_w h$	.624	20°	220
19	29°	40'	100	$\gamma_w h$	.624	15°	407
			90	$\gamma_w h$	.694	15°	406
			110	$\gamma_w h$	.568	15°	410
			100	$.9\gamma_w h$	.561	15°	368
			100	$.8\gamma_w h$	.498	15°	334
			100	$\gamma_w h$	.624	10°	486
			100	$\gamma_w h$	.624	20°	355

Slope No.	β	H, ft	γ, pcf	u	r_u	Ø'	c', psf
20	17°	38'	100	$\gamma_w h$	.624	15°	275
			90	$\gamma_w h$	.694	15°	287
			110	$\gamma_w h$	.568	15°	267
			100	$.9\gamma_w h$	.561	15°	235
			100	$.8\gamma_w h$	.498	15°	203
			100	$\gamma_w h$	.624	10°	357
			100	$\gamma_w h$	.624	20°	209
21	20-1/2°	79'	100	$\gamma_w h$	.624	15°	657
			90	$\gamma_w h$	.694	15°	680
			110	$\gamma_w h$	.568	15°	655
			100	$.9\gamma_w h$	.561	15°	585
			100	$.8\gamma_w h$	.498	15°	519
			100	$\gamma_w h$	.624	10°	830
			100	$\gamma_w h$	.624	20°	540
22(a)	32°	81'	100	$\gamma_w h$	.624	15°	861
			90	$\gamma_w h$	.694	15°	849
			110	$\gamma_w h$	.568	15°	865
			100	$.9\gamma_w h$	.561	15°	778
			100	$.8\gamma_w h$	.498	15°	709
			100	$\gamma_w h$	.624	10°	1011
			100	$\gamma_w h$	.624	20°	756

Slope No.	β	H, ft	γ, pcf	u	r_u	Ø'	c', psf
22(b)	27°	140'	100	$\gamma_w h$	.624	15°	1375
			90	$\gamma_w h$	.694	15°	1375
			110	$\gamma_w h$	.568	15°	1380
			100	$.9\gamma_w h$	.561	15°	1240
			100	$.8\gamma_w h$	.498	15°	1125
			100	$\gamma_w h$	.624	10°	1655
			100	$\gamma_w h$	.624	20°	1189
23	27-1/2°	133'	100	$\gamma_w h$	.624	15°	1312
			90	$\gamma_w h$	.694	15°	1326
			110	$\gamma_w h$	.568	15°	1312
			100	$.9\gamma_w h$	.561	15°	1191
			100	$.8\gamma_w h$	.498	15°	1075
			100	$\gamma_w h$	.624	10°	1580
			100	$\gamma_w h$	.624	20°	1140
24	19°	73'	100	$\gamma_w h$	.624	15°	576
			90	$\gamma_w h$	.694	15°	600
			110	$\gamma_w h$	.568	15°	572
			100	$.9\gamma_w h$	.561	15°	509
			100	$.8\gamma_w h$	.498	15°	446
			100	$\gamma_w h$	.624	10°	702
			100	$\gamma_w h$	.624	20°	462

Slope No.	β	H, ft	γ, pcf	u	r_u	Ø'	c', psf
25	14-1/2°	69'	100	$\gamma_w h$	.624	15°	427
			90	$\gamma_w h$	.694	15°	455
			110	$\gamma_w h$	.568	15°	396
			100	$.9\gamma_w h$	.561	15°	348
			100	$.8\gamma_w h$	.498	15°	290
			100	$\gamma_w h$	.624	10°	576
			100	$\gamma_w h$	.624	20°	291
26	12°	54'	100	$\gamma_w h$	.624	15°	261
			90	$\gamma_w h$	.694	15°	294
			110	$\gamma_w h$	.568	15°	222
			100	$.9\gamma_w h$	.561	15°	195
			100	$.8\gamma_w h$	.498	15°	148
			100	$\gamma_w h$	.624	10°	383
			100	$\gamma_w h$	.624	20°	147
27	18-1/2°	93'	100	$\gamma_w h$	.624	15°	716
			90	$\gamma_w h$	.694	15°	749
			110	$\gamma_w h$	.568	15°	706
			100	$.9\gamma_w h$	.561	15°	628
			100	$.8\gamma_w h$	.498	15°	548
			100	$\gamma_w h$	.624	10°	921
			100	$\gamma_w h$	.624	20°	568

Slope No.	β	H, ft	γ, pcf	u	r_u	Ø'	c', psf
28	12°	51'	100	$\gamma_w h$	.624	15°	246
			90	$\gamma_w h$	.694	15°	277
			110	$\gamma_w h$	.368	15°	209
			100	$.9\gamma_w h$	.561	15°	184
			100	$.8\gamma_w h$	.498	15°	140
			100	$\gamma_w h$	.624	10°	362
			100	$\gamma_w h$	.624	20°	138
29	14-1/2°	61'	100	$\gamma_w h$	.624	15°	377
			90	$\gamma_w h$	.694	15°	402
			110	$\gamma_w h$	.568	15°	350
			100	$.9\gamma_w h$	.561	15°	308
			100	$.8\gamma_w h$	.498	15°	256
			100	$\gamma_w h$	.624	10°	510
			100	$\gamma_w h$	.624	20°	257
30	13-1/2°	31'	100	$\gamma_w h$	.624	15°	
			90	$\gamma_w h$	.694	15°	
			110	$\gamma_w h$	.568	15°	
			100	$.9\gamma_w h$	.561	15°	
			100	$.8\gamma_w h$	.498	15°	
			100	$\gamma_w h$	.624	10°	
			100	$\gamma_w h$	.624	20°	

Slope No.	β	H, ft	γ, pcf	u	r_u	Ø'	c', psf
31	17-1/2°	66'	100	$\gamma_w h$	.624	15°	490
			90	$\gamma_w h$	.694	15°	510
			110	$\gamma_w h$	.568	15°	476
			100	$.9\gamma_w h$	.561	15°	421
			100	$.8\gamma_w h$	.498	15°	367
			100	$\gamma_w h$	.624	10°	630
			100	$\gamma_w h$	.624	20°	376
32	16°	65'	100	$\gamma_w h$	.624	15°	445
			90	$\gamma_w h$	.694	15°	468
			110	$\gamma_w h$	.568	15°	424
			100	$.9\gamma_w h$	.561	15°	374
			100	$.8\gamma_w h$	.498	15°	319
			100	$\gamma_w h$	.624	10°	585
			100	$\gamma_w h$	.624	20°	325

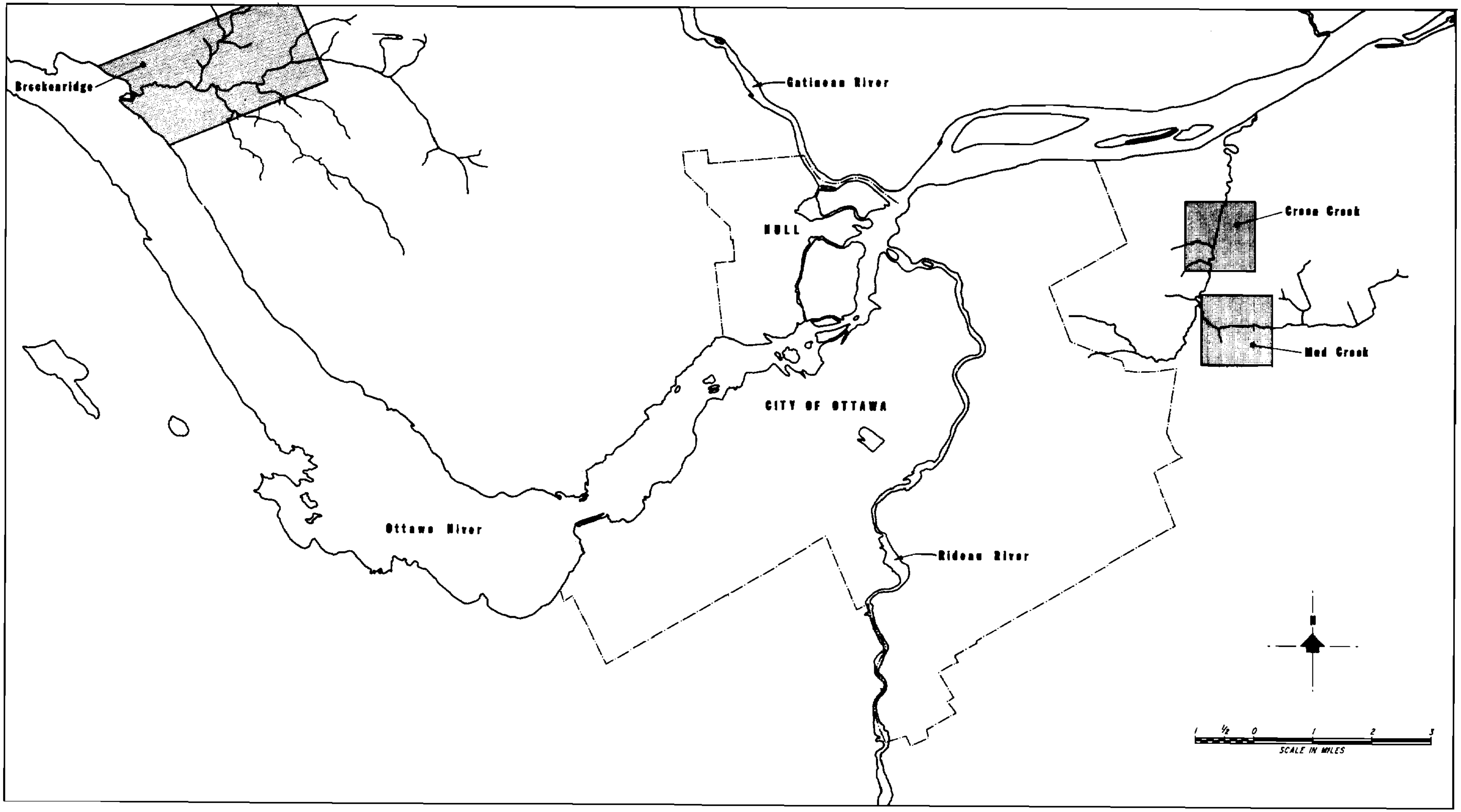
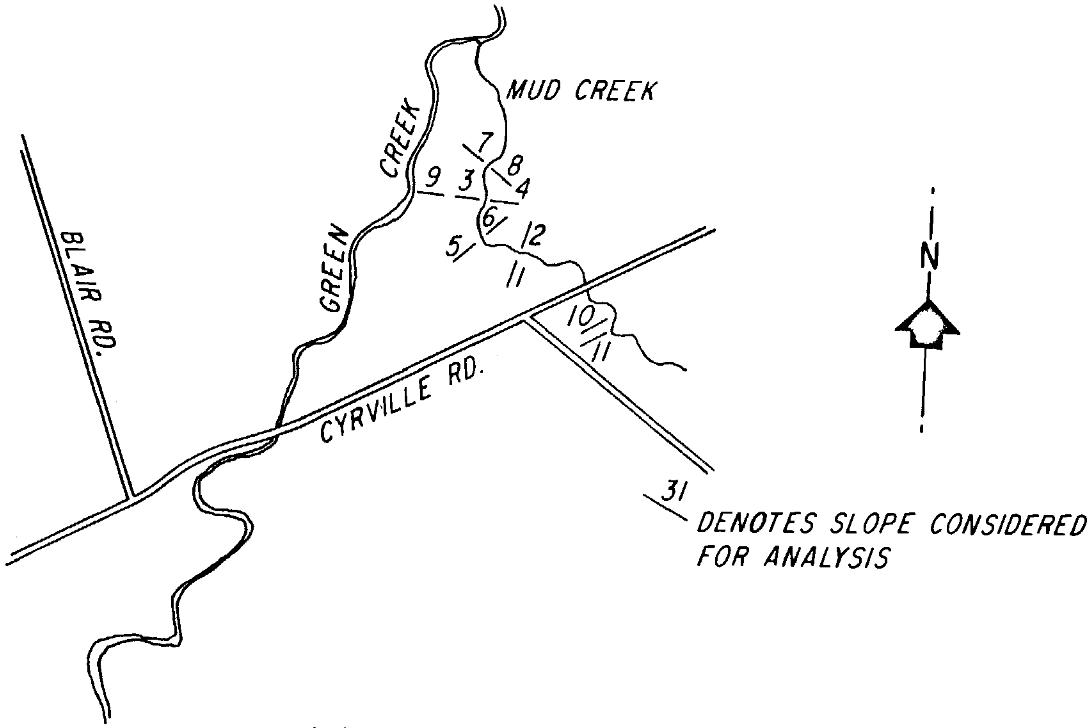
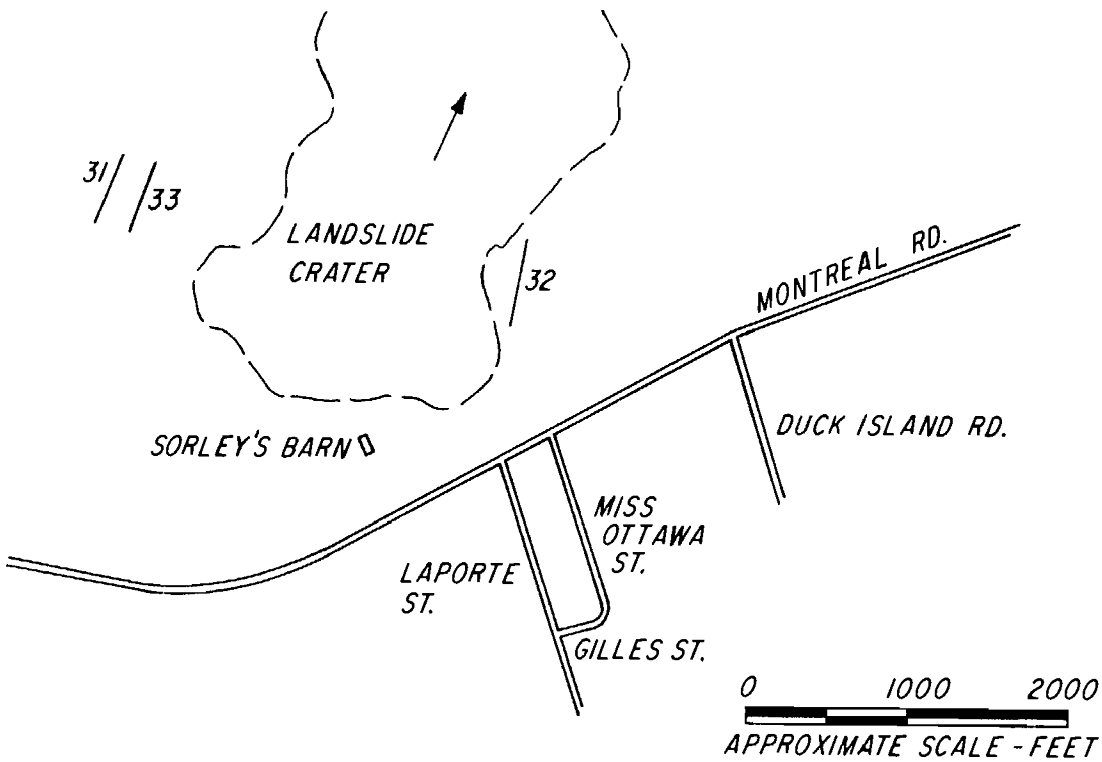


FIGURE I KEY PLAN OF AREAS CONSIDERED FOR SLOPE STABILITY STUDIES



(a) Mud Creek Slopes



(b) Green Creek Slopes

FIGURE 2

LOCATIONS OF SLOPES AT GREEN CREEK - MUD CREEK

BR. 3267-2

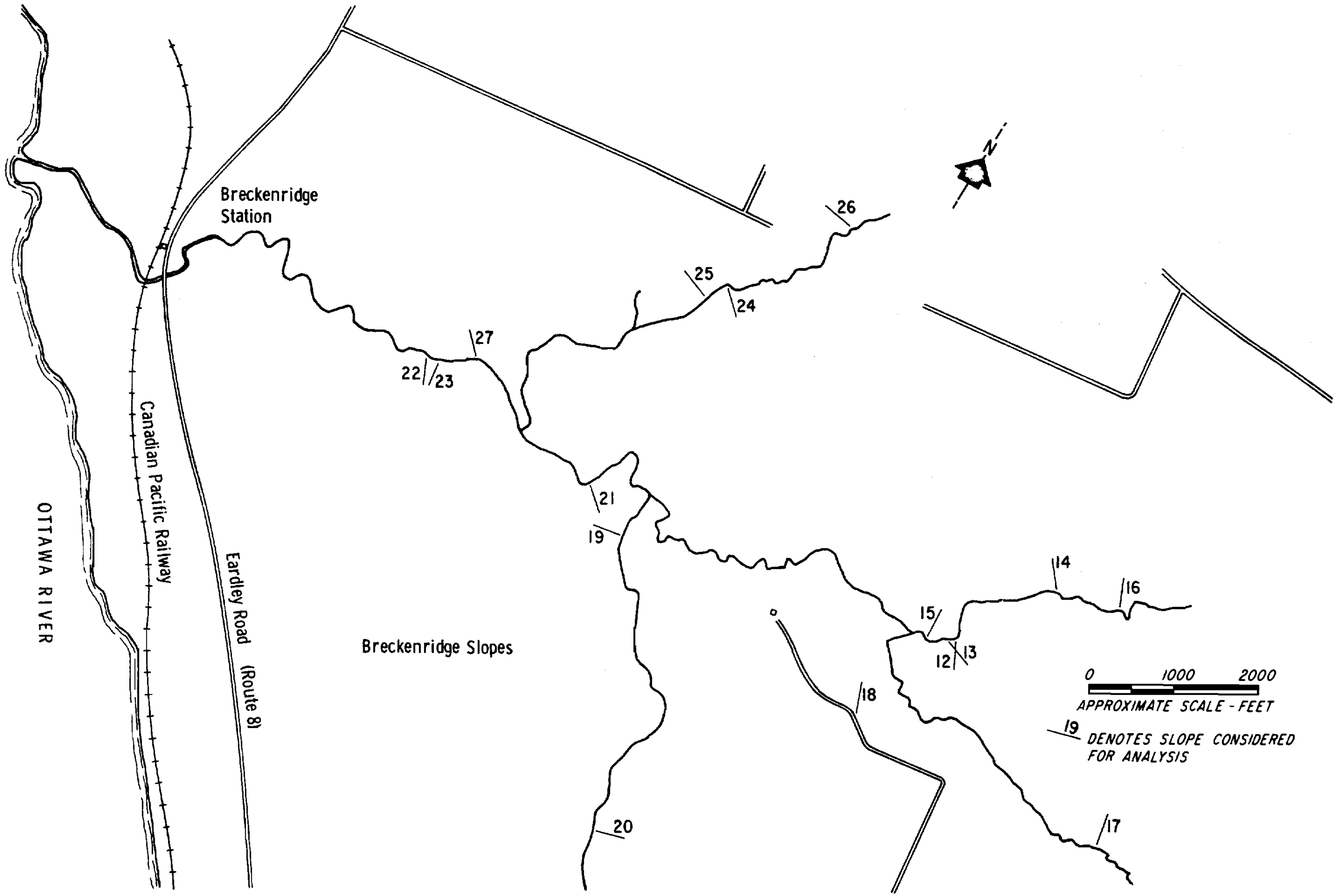


FIGURE 3
LOCATIONS OF SLOPES AT BRECKENRIDGE

BR. 3247-3

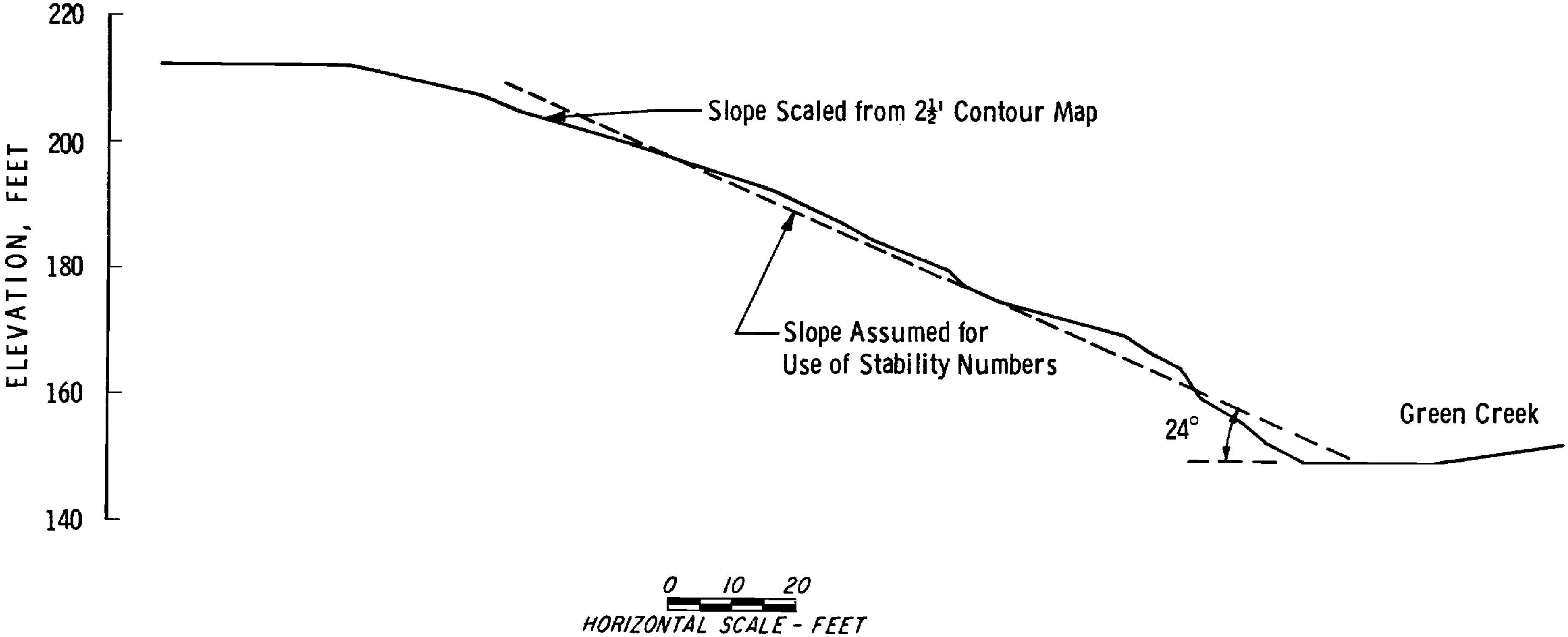


FIGURE 4

CROSS-SECTION OF SLOPE NO. 9 GREEN CREEK
(Air Photo L7-16 Produced by A.E. Simpson Ltd., Montreal, Nov. 1957)

BR. 3267-4

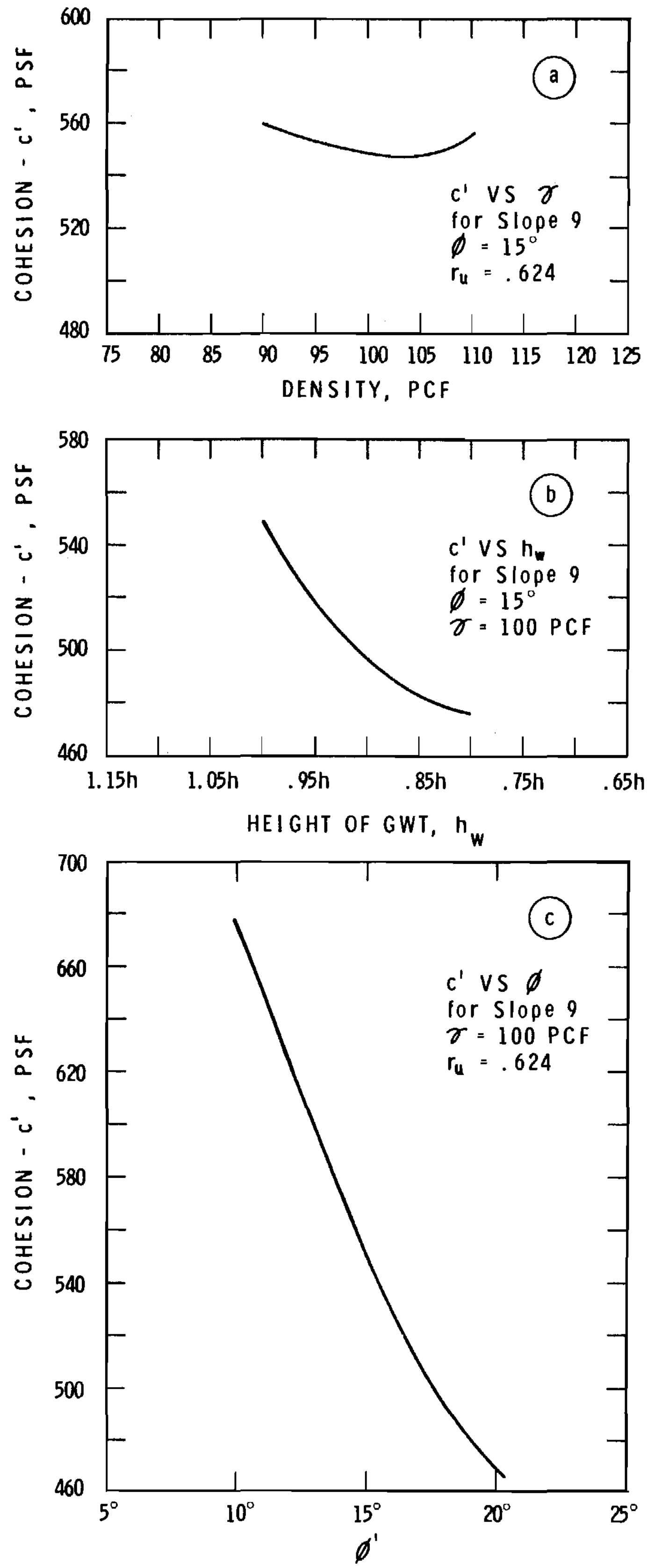


FIGURE 5

THE EFFECT ON c' OF VARIATIONS IN γ, ø AND r_u

SR. 3267-5