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# APPENDICES

# Appendix I

Table 21. Comparison of some engineering rock weathering classification (modified from Saunders & Fookes, 1970).

| Ruxton and Berry (1957) | | | Chandler (1969) | |
|---|---|---|---|---|
| Zone | Character | Percentage of solid rock | Zone | Description |
| I | Residual debris; structureless sandy clay or clayey sand, 1 to 25 m thick; up to 30% clay, dominantly quartz and kaolin, redish-brown when very clayey, light-brown or orange when less clayey. | usually zero | fully weathered IVa | matrix only; distinguishable from solifluction or drift by absence of pebbles; plastic slightly silty clay; may be fissured |
| IIa | Residual debris with core stones which are subordinate, rounded and free, equal amounts of gruss and debris; less than 5% clay but plenty of clay-forming minerals-sericite and kaolin; light colour; less than 10% core stones; deposit up to 60 m thick. | less than 10 | IVb | matrix with occasional claystone pellets less than 1/8 inch diameter but more usually coarse sand size; little or no trace of zone I structure; permeability less than underlying layers |
| IIb | As IIa but 10% to 50% core stones. | | | |
| III | Core stones with residual debris; core stones dominant, rectangular and locked together; most comminuted material is gruss; deposit 7 to 17 m thick. | 50 to 90 | partly weathered III | matrix with frequent lithorelicts up to 1 inch; as weathering progresses, lithorelicts become less angular; water content of matrix greater than that of lithorelicts |
| IV | Partially weathered rock; minor residual debris along major structural planes but more than 50% may be iron stained indicating significant chemical decomposition and breakdown of biotite; 3 to 30 m thick. | greater than 90 | II | angular blocks of marl; first indications of chemical weathering; matrix starting to encroach along joints leading to spheroidal weathering |
| Bedrock | Fresh unweathered granite; medium grained, light grey; two sets of vertical joints spaced 0.5 to 12 m. | c.100 | unweathered I | mudstone (often fissured); water content varies due to different lithology |

Table 21. cont.

Little (1969)

| Grade | Degree of decomposition | Field recognition | Engineering properties |
|---|---|---|---|
| VI | soil | surface layer contains humus and plant roots;<br>no recognisable rock texture;<br>unstable on slopes when vegetable cover destroyed | unsuitable for important foundations; unstable on slopes when cover is destroyed |
| V | completly weathered | rock complotly decomposed by weathering in place but texture still recognisable; in types of granite origin feldspars completely decomposed to clay minerals; cores cannot be recovered by ordinary rotary drilling methods; can be excavated by hand | can be excavated by hand or ripping without use of explosives; unstable for foundations of concrete dams or large structures; may be suitable for foundations of earth dams and for fill; unstable in high cuttings at steep angles; requires erosion protection |
| IV | highly weathered | rock so weathered by weathering that fairly large pieces can be broken and crumbled in the hands; sometimes recovered as core by careful rotary drilling; stained by limonite | similar to grade V; unlikely to be suitable for foundations of concrete dams; erratic presence of boulders makes it an unreliable foundation stratum for large structures |
| III | moderately weathered | considerably weathered; possessing some strength large pieces (e.g. NX drill cores); cannot be broken by hand; often limonite stained; difficult to excavate without use of explosives | excavated with difficulty use of explosives; mostly crushes under bulldozer trucks; suitable for foundation of small concrete structures and rockfill dams; may be suitable for semi-pervious fill; stability in cutting depends on structural features, especially joint attitudes |
| II | slightly weathered | distinctly weathered with slight limonite staining; some decomposed feldspar in granites, strength approaching that of fresh rock; explosives required for excavation | requires explosives for excavation; suitable for concrete dam foundations; high permeability through open joints, often more permeable than the zones above or below; quesionable as concrete aggregate |
| I | fresh rock | fresh rock may have some limonite stained joints immediately beneath weathered rock | staining indicates water percolation along joints; individual pieces may be loosened by blasting or stress relief and support may be required in tunnels and shafts |

Table 21. cont.

Fookes & Horswill (1969)

| Term | Grade | Abbreviation | Soils (i.e. soft rocks) | Rocks (i.e. hard rocks) |
|---|---|---|---|---|
| true residual soil | VI | Rw (Rs) | the material is completly changed to a soil of new structure and composition in harmony with existing ground surface conditions | the rock is discoloured and is completly changed to a soil with the original fabric completly destroyed |
| completly weathered | V | Cw | the material is altered with no trace of original structure | the rock is discoloured and is externally changed to a soil, but the original fabric is mainly preserved; the properties of the soil depend in part on the nature of the parent rock |
| highly weathered | IV | Hw | the material is mainly altered with occasional small lithorelicts of original soil; little or no trace of original structure | the rock is discoloured; discontinuities may be open and the fabric of the rock near to the discontinuities is altered; alteration penetrates deeply inwards, but lithorelicts are still present |
| moderately weathered | III | Mw | the material is composed of large discoloured lithorelicts of original soil separated by altered material | the rock is discoloured; discontinuities may be open and surface will have greater discolouration with the alteration penetrating inwards; the intact rock is noticeably weaker, as determined in the field, than the fresh rock |
| slightly weathered | II | Sw | the material is composed of angular blocks of fresh soil, which may or may not be discoloured; some altered material starting to penetrate inwards from discontinuities separating blocks | the rock may be slightly discoloured; discontinuities may be open and have slightly discoloured surfaces; the intact rock is not, as determined in the field, weaker than the fresh rock |
| fresh | I | Fr | the parent soil shows no discolouration, loss of strength or any other effects due to weathering | the parent rock shows no discolouration, loss of strength or any other effects due to weathering |

# Appendix II

## Example of Stability Analysis Using Hoek and Bray Stability Charts Method

Considering a cross-section, a, of Subarea 2, the height (H) and angle ($\alpha$) of individual bench slope, two-bench slope and overall slope were measured respectively. The shear strength parameters of slope materials used for the analysis are as follows.

| | Maximum | | Minimum | |
|---|---|---|---|---|
| Materials | $C_r$ ton/m$^3$ | $\phi_r$ degree | $C_r$ ton/m$^3$ | $\phi_r$ degree |
| overburden | | | | |
| Claystone | 10.3 | 22° | 5.7 | 16° |
| Red Beds | 0 | 26° | 0 | 17° |

The overall slope consits of Red Beds above and Overburden Claystone below, thus, the values of shear strength parameters are average from those of the Red Beds rocks and the Overburden Claystone, according to their relative abundance. The average values are used in the calculation.

The steps of analysis using the circular failure charts (Figure 40) to find the factor of safety (F or F.S.) of a slope are described as following.

1) Assume various groundwater conditions which are believed to exist in the slope, in this example, dry, 50-percent saturated, and

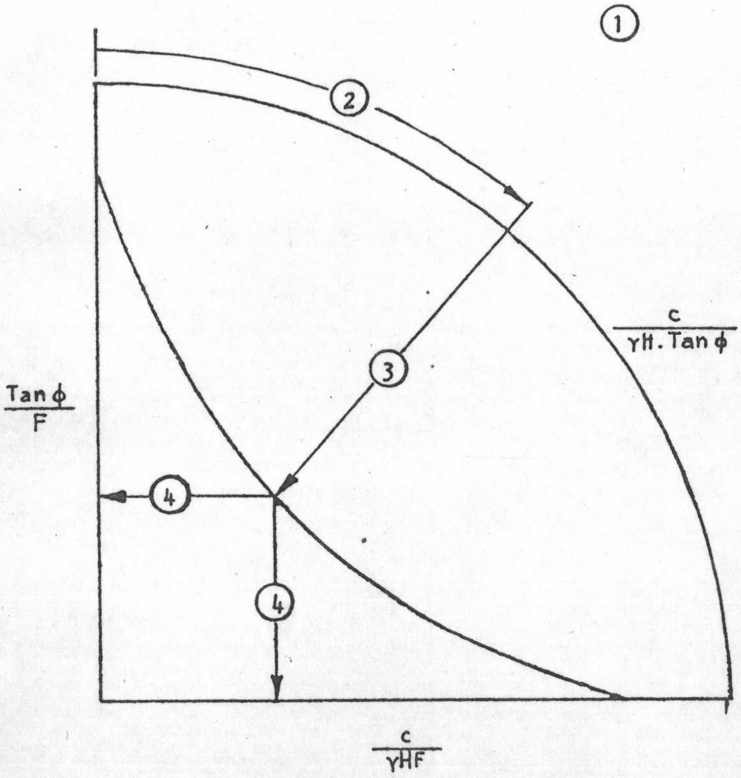


Figure 40. Steps of analysis using the circular failure charts according to the explanation above (after Hoek and Bray, 1974).

100 percent saturated respectively. The charts which are the closest to these conditions are then chosen.

2) Calculate for the value of $\frac{C}{\gamma \text{ H} \tan \phi}$ where;

H = slope height , $\gamma$ = density of slope materials

C = cohesion , $\phi$ = friction angle

3) Choose the slope angle related to the calculated value $\frac{C}{\gamma \text{ H} \tan \phi}$ in the chart.

4) Read out either $\frac{\tan \phi}{F}$ or $\frac{C}{\gamma HF}$ and from this value calculate for the factor of safety, F.

The information of maximum shear strength parameters of the slope section, a, in Subarea 2 and the calculated values obtained from each step of analysis are shown as an example in Table 22 below.

The same steps of calculation are repeated for the minimum values of shear strength parameters.

Table 22. Example of calculation of slope-section, a, of Subarea 2 using circular failure charts number 1, 3 and 5.

| Slope | Geometry | | Material prop. | | | Chart no. | $\frac{C}{\gamma H \tan\emptyset}$ | $\frac{C}{\gamma HF}$ | F | $\frac{\tan\emptyset}{F}$ | F | $F_{ave.}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | H | ψ | γ | C | Ø | | | | | | | |
| Overall | 48.5 | 24.5 | 2.05 | 8.92 | 22.5 | 1 | 0.22 | .048 | 1.87 | .220 | 1.88 | 1.87 |
| | " | " | " | " | " | 3 | " | .065 | 1.38 | .290 | 1.43 | 1.40 |
| | " | " | " | " | " | 5 | " | .069 | 1.30 | .300 | 1.38 | 1.34 |
| Two - bench | 23.0 | 41.0 | 2.05 | 10.3 | 22.0 | 1 | 0.54 | .104 | 2.10 | .195 | 2.07 | 2.08 |
| | " | " | " | " | " | 3 | " | .120 | 1.82 | .225 | 1.79 | 1.80 |
| | " | " | " | " | " | 5 | " | .132 | 1.65 | .240 | 1.68 | 1.66 |
| Individual bench | 11.0 | 53.9 | 2.05 | 10.3 | 22.0 | 1 | 1.13 | .157 | 2.90 | .150 | 2.69 | 2.79 |
| | " | " | " | " | " | 3 | " | .166 | 2.75 | .160 | 2.52 | 2.63 |
| | " | " | " | " | " | 5 | " | .183 | 2.49 | .170 | 2.38 | 2.43 |

Notations: H = slope height (meters)
ψ = slope angle (degree)
C = cohesion (metric ton/$m^2$)
Ø = friction angle (degree)

Chart no. 1 = dry slope
Chart no. 3 = partially sat.
Chart no. 5 = fully sat.

# Appendix III

## Example of Stability Analysis Using Simplified Bishop Method of Slices

Considering a cross-section, a, of Subarea 2 (Figure 41), the center of critical failure surface and critical tension crack are determined by using the chart presented in Figure 42. It provides a start for a more sophisticated circular failure analysis in which the location of the circular failure surface having the lowest factor of safety is found by the iterative methods.

The slope mass is divided into many slices, 13 in this case, each having the same width. The cross-sectional area and height of each slice are determined together with the angle $\alpha$ which is the angle between the radial line and central line of slice at failure surface (See Figure 41).

It should be noted here that, water condition has to be assumed and is used in Bishop's equation as the pore pressure ratio ($r_u$). The parameter is defined by the equation below.

$$r_u = U/\gamma h$$

$$= \gamma_w h_w/\gamma h$$

where; $u$ = hydrostatic pressure = $\gamma_w h_w$

$h_w$ = height of water in the slice

$h$ = height of slice

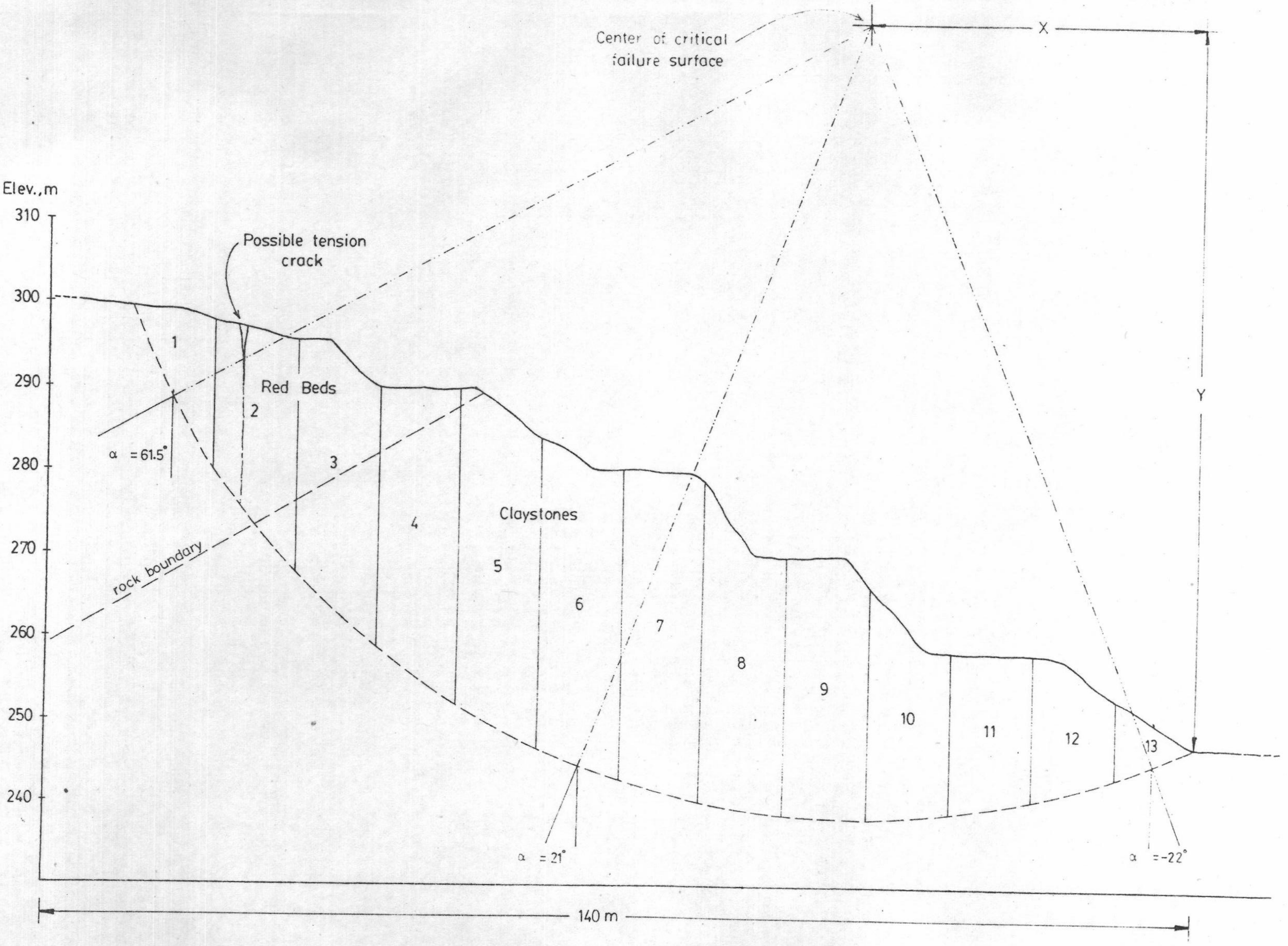
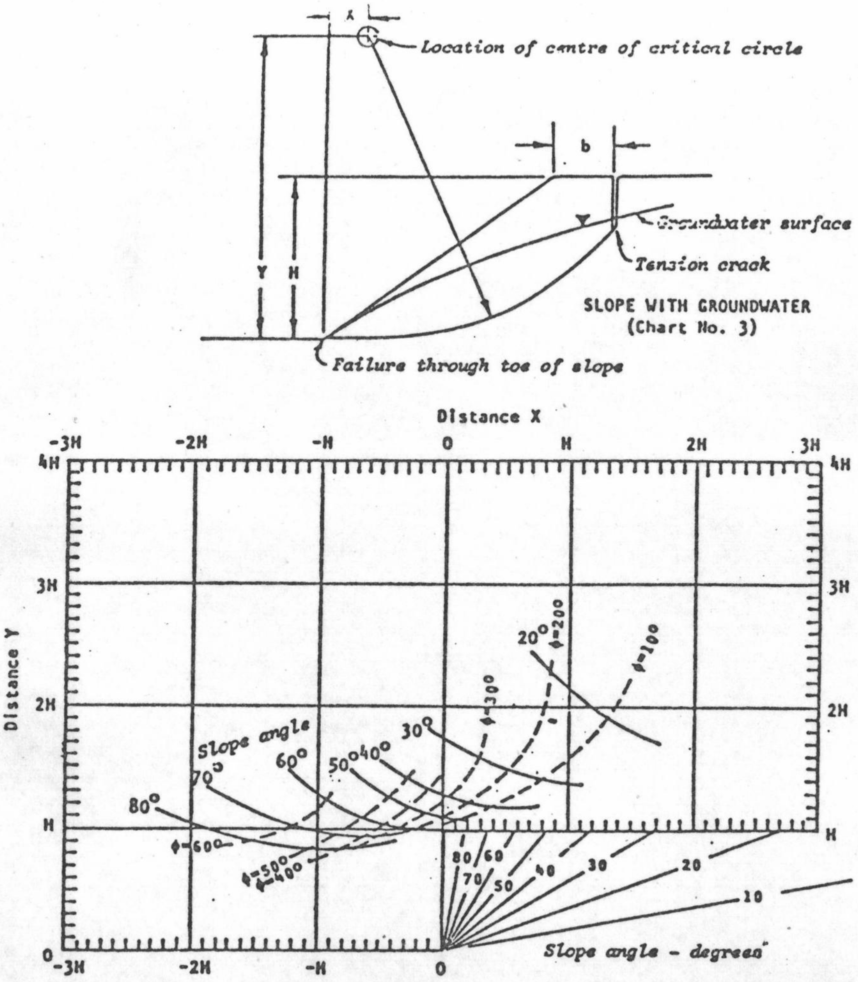
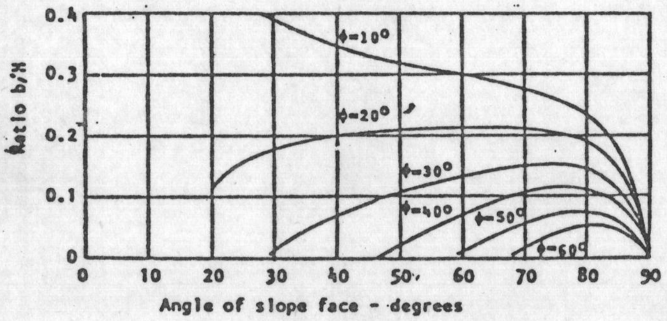


Figure 41. Slope-section, a, of Subarea 2.



Location of centre of critical circle for failure through toe



Location of critical tension crack position

Figure 42. Location of critical failure surface and critical tension crack for slopes with groundwater present (after Hoek and Bray, 1974).

$\gamma$ = bulk density of slope material

$\gamma_w$ = density of water

For a fully-saturated condition; $h_w = h$,

then $r_u = \gamma_w/\gamma$

Substitute $\gamma_w$ by 1.0 metric ton/$m^3$ (approximate density of water) and $\gamma$ by 2.05 metric ton/$m^3$ (approximate density of claystone)

then $r_u = 0.49$

In the partially-saturated condition, pore pressure ratio ($r_u$) are assumed to be 20 %, 50 % and 70 % of that in fully-saturated condition.

The steps of calculation to obtain the factor of safety, F, is shown as an example in Table 23. The calculation is for the case of maximum shear strength parameters with a 50 percent - saturated condition ($r_u = 0.24$).

The same calculation is done for the minimum values of shear strength parameters as well as the other water-saturation conditions.

Table 23. Example of simplified Bishop's method of slices.

| Slice no. | b | h | W | α | Wsinα | U | Ub | Cb | (A) (W-Ub)tanØ | (B) (A)+Cb |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 10.5 | 197.31 | 61.5 | 173.40 | 5.17 | 51.7 | 89.2 | 60.31 | 149.51 |
| 2 | 10 | 23.0 | 475.33 | 50.5 | 366.78 | 11.32 | 113.2 | 89.2 | 150.00 | 239.20 |
| 3 | 10 | 30.5 | 627.81 | 42.0 | 420.09 | 15.01 | 150.1 | 89.2 | 197.87 | 287.07 |
| 4 | 10 | 35.0 | 714.94 | 34.0 | 399.79 | 17.22 | 172.2 | 89.2 | 224.81 | 314.01 |
| 5 | 10 | 38.4 | 791.81 | 28.0 | 371.73 | 18.89 | 188.9 | 89.2 | 249.73 | 338.93 |
| 6 | 10 | 37.2 | 755.94 | 21.0 | 270.90 | 18.30 | 183.0 | 89.2 | 237.32 | 326.52 |
| 7 | 10 | 38.7 | 790.52 | 14.5 | 197.93 | 19.04 | 190.4 | 89.2 | 248.58 | 337.78 |
| 8 | 10 | 33.7 | 673.94 | 8.5 | 99.61 | 16.58 | 165.8 | 89.2 | 210.48 | 299.68 |
| 9 | 10 | 30.6 | 627.81 | 3.0 | 32.86 | 15.05 | 150.5 | 89.2 | 197.71 | 286.91 |
| 10 | 10 | 23.2 | 467.65 | -3.5 | -28.55 | 11.41 | 114.1 | 89.2 | 146.44 | 235.64 |
| 11 | 10 | 18.6 | 386.30 | -9.5 | -63.76 | 9.15 | 91.5 | 89.2 | 122.11 | 211.31 |
| 12 | 10 | 14.0 | 290.83 | -16.0 | -80.16 | 6.89 | 68.9 | 89.2 | 91.93 | 181.13 |
| 13 | 10 | 4.6 | 83.27 | -22.0 | -31.19 | 2.26 | 22.6 | 89.2 | 25.13 | 114.33 |

Σ Wsin α = 2129.43

<u>Note</u>. The data and calculated results were from cross-section, a, of Subarea 2 by using the maximum C, Ø value; C = 8.92 metric ton/$m^2$ Ø = 22.5° and a partial saturated condition ($r_u$ = 0.24).

Table 23. cont.

| ($C_1$) Assume $F_1$=1.40 $\frac{\sec\alpha}{1+\frac{\tan\phi\tan\alpha}{F_1}}$ | $x_1$= (B)×($C_1$) | ($C_2$) Assume $F_2$=1.68 $\frac{\sec\alpha}{1+\frac{\tan\phi\tan\alpha}{F_2}}$ | $x_2$= (B)×($C_2$) | ($C_3$) Assume $F_3$=1.70 $\frac{\sec\alpha}{1+\frac{\tan\phi\tan\alpha}{F_3}}$ | $x_3$= (B)×($C_3$) |
|---|---|---|---|---|---|
| 1.36 | 203.33 | 1.44 | 215.29 | 1.45 | 216.78 |
| 1.16 | 277.47 | 1.21 | 289.43 | 1.21 | 289.43 |
| 1.06 | 304.29 | 1.10 | 315.78 | 1.10 | 315.78 |
| 1.00 | 314.01 | 1.08 | 323.43 | 1.03 | 323.43 |
| 0.98 | 332.15 | 1.00 | 338.93 | 1.00 | 338.93 |
| 0.96 | 313.46 | 0.98 | 319.99 | 0.98 | 319.99 |
| 0.96 | 324.27 | 0.97 | 327.65 | 0.97 | 327.65 |
| 0.97 | 290.69 | 0.97 | 290.69 | 0.97 | 290.69 |
| 0.99 | 284.04 | 0.99 | 284.04 | 0.99 | 284.04 |
| 1.02 | 240.35 | 1.02 | 240.35 | 1.02 | 240.35 |
| 1.07 | 226.10 | 1.06 | 223.99 | 1.06 | 223.99 |
| 1.14 | 206.49 | 1.12 | 202.86 | 1.12 | 202.86 |
| 1.22 | 139.48 | 1.20 | 137.20 | 1.20 | 137.20 |

$\Sigma x_1 = 3573.42$

$F_1 = \frac{\Sigma x_1}{\Sigma W \sin\alpha}$

$= 1.68$

$\Sigma x_2 = 3628.84$

$F_2 = \frac{\Sigma x_1}{\Sigma W \sin\alpha}$

$= 1.70$

$\Sigma x_3 = 3628.84$

$F_3 = \frac{\Sigma x_3}{\Sigma W \sin\alpha}$

$= 1.70$

# BIOGRAPHY

Mr. Wisan Tandicul was born in Bangkok, Thailand on November 5, 1957. He graduated from the Department of Geology, Faculty of Science, Khon-Kaen University in 1980 with a B.Sc. degree in Geology.