M South Africa Cabinette II

SOIL SURVEY INTERPRETATIONS FOR EARTH DAMS

D.M. SCOTNEY[1], P.J. McPHEE[2] and W.B. RUSSELL[1]

[1] Department Agricultural Technical Services, Natal Region

[2] Division of Agricultural Engineering

1975

SOIL SURVEY INTERPRETATIONS FOR EARTH DAMS

D.M. SCOTNEY, P.J. McPHEE and W.B. RUSSELL
Department Agricultural Technical Services, Natal Region

ABSTRACT

Soil survey interpretations are urgently needed in South Africa. A study of selected diagnostic materials, defined in terms of the National system of classification, provides data for an assessment of soil suitability for earth dams. The interpretation is based on soil limitation ratings for embankments, basin areas and spillways. It is intended for use by those concerned with the design and construction of small earth dams.

INTRODUCTION

Despite the recent upsurge in pedological interest in South Africa and the completion of many soil maps, very little, if any, progress has been made in making interpretations. (Scotney, 1971). There is thus a great need for interpretations of many kinds, including those of a non-agricultural nature. Interpretations for engineering purposes are likely to be in great demand within the next decade.

Natal comprises 7,5 percent of the Republic, yet it yields as much is 25 percent of the total run-off. At present, there are over 12 000 farm dams in Natal and East Griqualand which comprise only 6 percent of the total number in the country. Over 90 percent of these are less than 5 metres in height and most of them (85%) are less than 2 hectare in surface area (Dept. Statistics, 1962, 1974). Over the 1964-1974 period about 100 dams per year have been surveyed and completed under the Soil Conservation Act, although many more would have been built without financial aid from the State.

Many dams have failed at considerable cost to the farmer. Poor assessment of soil properties, including erosion hazard, or even a total disregard of soil materials available at the site are among the main reasons for this. A survey of existing dams in Natal showed that over 20 percent were leaking and almost 60 percent had severe erosion in the spillway and return-to-stream areas (Dept. A.T.S., 1969).

Such failures, the high potential for many more water-storage projects in Natal and the need to refine design criteria motivated this study. A wide selection of soil materials were included and are defined in strict accordance with the National system of soil classification (Mac Vicar, et al, 1974). The paper is intended to be of use to engineers, conservation technicians, contractors, farmers and others concerned with the design and construction of small earth dams. It is no more than a first approximation, presented in the hope that it might stimulate others to improve the interpretation.

1. STUDY OF SELECTED SOIL MATERIALS

Interpretations are based on defined criteria. For this reason, and with few available data and limited recorded experience, a study of selected soil materials was undertaken. The results permit interpretive ratings to be allocated to a wide range of materials.

1.1 Selection of samples

Samples were selected to represent a wide range of defined diagnostic horizons and variations within them. Materials totally unsuited to dam building such as organic O-horizons or hard plinthite were automatically excluded from the study. Available soil- and bioclimatic maps enabled sampling sites to be selected. Precise location of the sites was made in the field and 20 kilogram samples of soil were collected from freshly exposed profiles. Where possible, sites were chosen near existing dams.

One hundred samples representing three topsoil- and thirteen subsoil horizons were finally selected for laboratory analysis. The total number of soil forms and soil series included in the study are shown in Appendix 1.

1.2 Experimental procedure

All soil samples were sundried and passed through a 4,75 mm screen prior to analysis.

Mechanical analysis: Samples of approximately 500 g were sieved through a standard set of screens. The hydrometer analysis was carried out using 50 g of material passing through a 0,425 mm screen. This fraction was first treated with hydrogen peroxide and then dispersed with a 4 percent solution of sodium hydroxide (Van der Bank, 1964). Standard procedures were followed throughout the excercise (A.S.T.M., 1958)

Atterberg limits and Proctor Compaction tests: Liquid and plastic limits, plastic index and linear shrinkage values were determined for all samples. These tests were applied to the 'fines' fraction passed through a 0,425 mm screen. These analyses, together with those for determining dry density and optimum moisture contents (OMC) were also carried out in accordance with standard procedures (A.S.T.M., 1958).

Dispersal coefficient: Duplicate samples were prepared for the hydrometer analysis, one of which was not dispersed. Two-hourly readings were then taken and the dispersal coefficients, as defined by Puri (1949) were calculated in the following manner:

$$D.C. = \frac{\%\ \text{clay in non-dispersed sample}}{\%\ \text{clay in dispersed sample}} \times 100$$

Type of clay: Samples of clay were orientated from aqueous suspensions onto glass slides. These represented Mg-clay, Mg/Glycerol clay, and K-clay heated to 110^{o} and 500^{o}C. Type of clay was then determined by standard X-ray diffraction analyses using a Phillips PW 1051 instrument with a cobalt Kα source. These determinations did not include all samples, since much information was already available from studies by de Villiers (1962), Beater (1970), Cass (1975) and Ludorf and Scotney (1975).

1.3 Results

Quantitative data for specially selected samples are assembled in Table 1. They clearly reflect a number of important features to be considered in the selection of materials for dam building.

The relationship between particle size distribution and dry density is of interest. Typical grading curves of five different materials are shown in Appendix 2. It will be seen from these that the melanic material (sample 1) has a poor grading and over 53% clay. The density value is only 1 305 kg/m^3. In general, melanic and vertic materials of over 35% clay have low density values.

Non-expansive materials (samples 2, 3, and 4) with successively lower contents of clay have improved grading characteristics and higher density values. This relationship is confirmed by the significant negative correlation between clay content and dry density shown in Appendix 3 (see 3b). Soft plinthic materials appear to be particularly well graded with highest density values being achieved in the 15 to 35 percent clay range. A sample in Appendix 2 represents regic sand and, although the density is high (1 639 kg/m^3), the poor grading, high permeability and unstable nature render the material unsuitable for embankments.

Atterberg limits measure the plasticity of clay materials and indicate stability and bearing capacity of fine textured soils (S.E.W.R.P.C., 1969). They relate to the 'activity' of materials and are normally shown in diagrammatic form (Williams, 1957). The ratings of shrink-swell potential reflected in Table 1 were established on this basis and show that linear shrinkage values are highest for melanic, vertic, prismacutanic and pedocutanic materials. Montmorillinite and illite are clearly the dominant clay mineral in these soils. Potentially expansive soil series tend to be those with a clay content above the 35 percent limit.

Many dams fail because of tunneling. Two mechanisms are generally recognised (Dept. L.T.D., 1974). The first or chemical process, progresses through the wall from the upstream side and is caused by dispersion of clay materials. The second is a mechanical process in which seepage water loosens and transports coarse particles from the downstream side. Coarse,silty and poorly compacted materials are probably most susceptable to this form of tunneling (often referred to as piping).

The chemical process is particularly important in many eutrophic and calcareous materials. Ritchie (1963) drew attention to the marked correlation between dispersal coefficient and soils prone to this form of tunneling. Values presented in Table 1 suggest that soils with a high hazard for tunneling are mostly found among the gleycutanic, prismacutanic, pedocutanic,G- and E-horizon materials. Low dispersal coefficient values are associated with red apedal, yellow-brown apedal and soft plinthic materials. Some anomalies were,however,found among calcareous materials and emphasise the need for further research in this field.

Several interesting correlations shown in Appendix 3 were established. These indicate the important role of clay content and were all significant at the 1 percent level. The coefficient of linear extensibility (COLE) presented in Appendix 3 is defined as $\frac{Lm - Ld}{Ld}$ where Lm and Ld refer to the length of the moist and dry samples respectively as provided by the linear shrinkage test. The correlations do not account for the type of clay present in the samples which clearly give rise to the 'scatter' of the points. Sample 25 shown on the liquid limit diagram (see 3a) has a high value as a result of the montmorillinite content whereas sample 31 reflects a low liquid limit and is dominated by kaolinite. Both samples have a total clay content of approximately 60 percent.

Positive correlations are also reflected between clay content and optimum moisture content (see 3c). In this case the effect of type of clay is not so apparent. Type of clay has, however a marked influence on the values of COLE (see 3d).

Sample 25 with a predominance of montmorillinite has a COLE value of $\pm$ 0,35 while that of the kaolinite dominated sample 22 is much lower i.e. 0,13. Both samples have a similar content of clay ($\pm$ 60%).

/ INSERT TABLE 1 /

2. INTERPRETATIONS FOR SMALL EARTH DAMS

The interpretations are based on the experimental results and field experience and apply to embankments not exceeding 5 metres in height. They concern the embankment itself, the basin or impoundment area and the spillway, including the return-to-stream area. Assessments related to the embankment apply to disturbed soil materials.

2.1 Assumptions and criteria

In making interpretations it is necessary to make known the underlying assumptions and to define criteria (Scotney, 1971). In doing this many of the principles and procedures adopted in the United States have been followed (U.S.D.A., 1967; S.E.W.R.P.C., 1969).

Assumptions: It is assumed that a thorough investigation of the proposed site has been made and that it is suitable for a storage dam. Experience has shown that dams on boulder-strewn sites and weathered dolerite are likely to leak and are difficult to construct. It is also assumed that the dam will be designed according to acceptable procedures and its safety assured. It is important that users of the interpretation are completely familiar with the National system of soil classification and will appreciate that soil phases, not dealt with in this paper, may markedly influence the assessment.For embankments it is further assumed that there is sufficient soil depth for use as borrow and that all topsoil material with an organic carbon content exceeding 1,5 percent is excluded from the wall proper. This limit precludes the use of many topsoil materials but allows consideration to be given to some grey orthic horizons. These would be associated with mesotrophic members of forms such as Avalon, Clovelly, Estcourt and Longlands. The low organic carbon content of such soils was noted by Scotney (1970).

Criteria: Many criteria could be selected for interpretations concerning embankments. In this study, however, those features and qualities of disturbed soil material which ensure that the embankment is impervious when compacted and stable when subjected to hydrostatic pressure from impounded water are emphasised. These include permeability when compacted, texture and particle size distribution, compaction characteristics, shrink-swell potential, resistance to tunneling(and piping) erosion hazard and workability (low cost handling). Shear strength is not included as a criterion because of the high degree of stability associated with dams of less then 5 metres in height.

Many of these criteria are inferred qualities for which no direct measurement can be made. Loxton (1962) suggested that permeability could be assessed from other properties, but this is difficult with disturbed materials compacted during construction. Texture is a principle feature affecting permeability. Materials with a balanced mixture of particles have slight limitations for dam building while clayey materials (over 55% clay) and those of a high shrink-swell potential have moderate to very severe limitations. Shrink-swell potential is extremely important in dams that are periodically dry.

Grade of sand is not emphasised in this study primarily because medium and fine grades predominate in Natal. In general, however, ratings would be downgraded for coarser grades of sand.

The hazard of tunneling and other erosion is of vital concern since many dams are ruined by erosion, including wave action. In this case, ratings are made on a subjective basis although dispersal coefficient values permit a reasonable assessment of the hazard of tunneling by the chemical process. Coarse textured materials are liable to mechanical tunneling and should be downgraded accordingly.

TABLE 1

PHYSICAL PROPERTIES OF SELECTED DIAGNOSTIC SOIL MATERIALS

DIAGNOSTIC SOIL MATERIALS				SOIL PROPERTIES													
HORIZON		FORM	SERIES	ATTERBERG LIMITS				SHRINK-SWELL POTENTIAL	DISPERSAL COEFF. %	PROCTOR VALUES		PARTICLE SIZE ANALYSIS				TEXTURAL CLASS	TYPE OF CLAY[1]
TOPSOILS	SAMPLE No.			LL. %	PL. %	PI. %	LS. %			DD. kg/m^3	OMC. %	CLAY %	SILT %	SAND %	SAND GRADE		
MELANIC	1	BONHEIM	Bonheim	51,1	22,0	29,1	15,3	high	83,3	1 550	20,5	41,6	11,4	47	f	sandy clay	I, (V, K, M)
	2	MILKWOOD	Milkwood	74,4	31,0	43,4	19,3	very high	20,0	1 305	31,5	53,8	17,2	29	f	clay	I, (V, M)
VERTIC	3	RENSBURG	Phoenix	78,5	23,5	55,0	19,7	very high	81,3	1 370	28,0	63,6	12,4	24	f	clay	M, (I, K)
	4	RENSBURG	Rensburg	61,5	18,8	42,7	18,7	very high	24,5	1 455	24,0	53,0	14,0	33	f	clay	M(I, K, ML)
ORTHIC	5	KROONSTAD	Mkambati	NP	NP	NP	NP	low	57,1	1 879	9,1	9,1	4,9	86	m	loamy sand	K, (I, MU, ML)
	6	KROONSTAD	Velddrif	NP	NP	NP	NP	low	5,0	1 877	9,9	10,2	3,8	86	m	loamy sand	"
	7	ESTCOURT	Enkeldoorn	19,4	14,0	5,4	1,1	low	56,2	1 877	10,3	19,4	6,6	74	f	sandy loam	"
	8	AVALON	Avalon	27,6	14,1	13,5	4,3	low	31,1	1 715	14,5	27,2	9,8	63	f	sandy clay loam	"
	9	GLENROSA	Trevanian	30,4	16,4	14,0	6,7	low	0	1 714	17,0	29,6	14,4	52	m	sandy clay loam	"
	10	KROONSTAD	Bluebank	37,5	23,0	14,5	6,7	low	58,1	1 433	20,6	45,0	23,0	32	f	clay	"
SUBSOILS																	
E-HORIZON	11	CARTREF	Cartref	NP	NP	NP	NP	low	46,7	1 867	9,4	10,3	4,7	85	m	loamy sand	K, (I, G)
	12	CARTREF	Arrochar	25,0	14,6	10,4	4,3	low	48,8	1 855	12,0	27,1	11,9	61	f	sandy clay loam	"
	13	ESTCOURT	Estcourt	19,5	11,8	7,7	2,0	low	24,4	1 815	12,5	23,3	16,7	55	f	sandy clay loam	"
G-HORIZON	14	WILLOWBROOK	Chinyika	42,4	16,0	26,4	12,7	high	58,1	1 650	19,0	37,3	13,0	49,7	f	clay loam	I, (K, M)
	15	KATSPRUIT	Katspruit	49,7	25,4	24,3	10,3	high	5,3	1 470	23,3	48,6	19,0	32,4	f	clay	I, K
	16	RENSBURG	Rensburg	70,0	18,5	51,5	17,7	very high	18,9	1 545	23,0	55,4	10,6	34	f	clay	M, (I, ML)
RED APEDAL B	17	HUTTON	Clansthal	NP	NP	NP	NP	low	3,5	1 840	12,0	9,9	3,1	87	m	loamy sand	K, (ML)
	18	HUTTON	Hutton	NP	NP	NP	NP	low	12,3	1 842	12,4	21,2	6,8	72	f	sandy clay loam	K, (G)
	19	HUTTON	Msinga	NP	NP	NP	NP	low	100	1 867	11,5	15,6	1,4	83	m	sandy loam	K(I, ML)
	20	HUTTON	Farningham	38,7	16,4	22,3	10,3	high	11,9	1 650	19,0	37,4	14,1	48,5	f	clay loam	K(G)
	21	HUTTON	Doveton	32,6	15,9	16,7	8,3	low	4,2	1 720	17,8	40,6	6,9	52,5	f	sandy clay	K(I)
	22	HUTTON	Balmoral	53,8	32,7	21,1	11,3	low	22,5	1 400	28,9	59,5	6,5	34	f	clay	K(G)
	23	HUTTON	Vimy	54,9	27,6	27,3	13,3	low	0	1 390	33,0	62,5	11,5	26	f	clay	K(I)
RED STRUCTURED B	24	SHORTLANDS	Argent	61,7	28,6	33,1	13,7	very high	13,9	1 368	31,9	39,9	8,1	52	f	sandy clay	K(M, I)
	25	SHORTLANDS	Tugela	90,0	25,5	64,5	26,0	very high	92,6	1 420	27,0	60,2	7,8	32	f	clay	I(M, K, MU)
YELLOW BROWN APEDAL B	26	AVALON	Leksand	NP	NP	NP	NP	low	13,2	1 668	16,3	9,2	0,8	90	m	sand	K, (I, MU)
	27	AVALON	Avalon	27,8	15,1	12,7	6,3	medium	7,8	1 820	13,5	24,0	2,0	74	f	sandy clay loam	"
	28	AVALON	Bergville	40,3	23,0	17,3	10,0	low	0	1 580	22,0	37,0	12,0	51	f	clay loam	"
	29	AVALON	Ruston	24,3	15,9	8,4	5,0	low	2,3	1 850	13,0	22,8	7,2	70	f	sandy clay loam	K(I, G, MU)
	30	CLOVELLY	Clovelly	36,5	22,0	14,5	8,7	low	5,9	1 475	24,5	50,3	13,7	36	f	clay	K(G, CH)
	31	CLOVELLY	Balgowan	44,1	24,7	19,4	11,3	low	27,0	1 463	24,8	58,2	12,8	29	f	clay	K(G, CH)
SOFT PLINTHIC B	32	AVALON	Leksand	NP	NP	NP	NP	low	66,7	1 653	15,1	3,1	0	96,9	m	sand	K, (I, MU)
	33	AVALON	Ruston	23,5	15,8	7,7	4,3	low	10,4	1 975	11,0	17,2	6,0	76,8	f	sandy loam	K(I)
	34	AVALON	Avalon	36,5	20,9	15,6	8,0	low	5,9	1 665	18,0	31,0	4,0	64,7	f	sandy clay loam	K(I, MU)
	35	AVALON	Bergville	34,7	18,1	16,6	5,3	low	0	1 655	19,5	21,6	8,4	70	f	sandy clay loam	K(I, MU)
GLEYCUTANIC B	36	KROONSTAD	Mkambati	NP	NP	NP	NP	low	55,6	2 073	8,7	17,4	6,4	76,2	m	sandy loam	I, K, (ML)
	37	KROONSTAD	Bluebank	43,1	17,2	25,9	15,3	low	83,3	1 638	20,3	57,3	10,0	32,7	f	clay	I, K, (ML)
PRISMACUTANIC B	38	ESTCOURT	Enkeldoorn	58,9	20,9	38,0	15,9	very high	85,5	1 630	20,5	47,3	6,0	46,7	f	clay	I, (K, ML, MU)
	39	STERKSPRUIT	Sterkspruit	76,2	26,2	50,0	18,0	very high	38,5	1 457	26,1	60,4	7,0	32,6	f	clay	I, (K, ML, MU)
PEDOCUTANIC B	40	BONHEIM	Stanger	53,9	19,2	34,7	13,0	very high	10,4	1 619	21,7	37,7	4,3	58	f	sandy clay	M, (K, G)
	41	BONHEIM	Glengazi	70,4	30,2	40,2	18,0	very high	31,3	1 400	29,0	69,8	12,7	17,5	f	clay	M, (I, K)
	42	BONHEIM	Bonheim	68,6	24,6	44,0	15,3	very high	45,2	1 576	22,2	52,2	9,8	38	f	clay	M(I)
LITHOCUTANIC B	43	GLENROSA	Trevanian	48,7	20,9	27,8	12,0	high	14,8	1 565	22,0	42,5	13,5	44	f	clay	K(I)
NEOCUTANIC B	44	OAKLEAF	Josini	38,9	16,7	22,2	9,3	high	83,3	1 697	18,3	29,2	13,8	57	f	sandy clay loam	K(I)
	45	OAKLEAF	Makulek	35,9	17,2	18,7	11,7	low	10,2	1 640	20,9	48,2	15,8	36	f	clay	K(I)
REGIC SAND	46	FERNWOOD	Fernwood	NP	NP	NP	NP	low	100	1 639	7,8	2,6	1,4	94,6	f	sand	K(I)
STRATIFIED ALLUVIUM	47	DUNDEE	Dundee	29,5	17,8	11,7	5,5	low	67,6	1 680	16,0	23,8	12,4	63,8	f	sandy clay loam	Variable

[1] CH- chlorite; G-gibbsite; I-illite; K-kaolin; M-montmorillinite; MU-muscovite; ML-mixed layer minerals; V- vermiculite   Parenthesis denotes accessory amounts

Workability is included as a criterion since it is related to cost. It is a subjective assessment that favours friable materials. Very firm or plastic materials that are difficult and expensive to handle are downgraded. Consistence, as defined by Loxton (1962), provides a guide to the degree of workabi lity.

Criteria for basin areas are those affecting the rate of seepage. Assessment applies to soils in situ with emphasis given to the least permeable horizons, depth to bedrock or permeable materials such as gravel or stonelines, degree of fissuring in underlying strata, texture, organic matter and streambed slope. E-horizons associated with concretionary layers frequently cause seepage unless effectively cut off by the wall. Organic deposits are totally unsuitable as foundation materials and are important where there is a danger of them polluting the impounded water. Slope of the streambed influences the ratio of surface area to size of embankment and thus determines the economic feasability of the dam.

Spillway criteria are primarily concerned with erosion hazard. The spillway proper and return-to-stream area are considered together in this discussion but in practice should be treated separately. Ideally, they should consist of hard rock or comprise natural, well-grassed and stable sites. Such conditions are rare and have not been considered in making the interpretations.

Spillway design is normally based on permissible limits for depth and speed of flow as influenced by texture (Pazzi, 1963). It is necessary,however, to consider other factors such as shrink-swell potential, depth to bedrock and the ability of the soil to support a permanent sward of grass. Such features serve as the main criteria for the interpretations.

A summary of the main criteria used,together with some threshold values established by experimentation,are given in Table 2.

/INSERT TABLE 2/

2.2 Interpretive ratings of selected soil materials

The interpretive ratings are given in terms of soil limitations since few limitations cannot be overcome if costs can be met. Interpretations of this nature are useful. For instance, soil limitations indicated for the basin area are important if treatment to prevent loss by seepage is contemplated. In this way, attention is drawn to likely problems and allows evasive action to be taken in the design or construction phases.

A simple 5-point scale is used to indicate the degree of soil limitation. Broad definitions for each class are given in Table 3 and are similar to those used in the United States (S.E.W.R.P.C., 1969).

Table 2 Criteria and degree of limitation ratings for selected interpretations

Criteria	Degree of limitation		
	Very slight to slight	Moderate	Severe to very severe
1. EMBANKMENTS			
1.1 Permeability when compacted	V. slow, slow	Mod.-slow, mod.	Rapid, v. rapid
1.2 Textural class[1]	SaLm, SaClLm	SaCl, ClLm, Lm, Cl	Sa, LmSa, SiCl
(% clay)	(15-35)	(35-55)	(<15, >55)
1.3 Compaction characteristic	Good	Fair	Poor
(Dry density - kg/m^3)	>1600	1400 - 1600	<1400
1.4 Shrink-swell potential	V. low, low	Moderate	High, v. high
(Linear expansion -%)	<10	10-15	>15
1.5 Resistance to tunneling	Good	Fair	Poor
(Dispersal coeff. -%)	<5	5-20	> 20
1.6 Erosion hazard	V. low, low	Moderate	High, v. high
1.7 Workability	V. good, good	Fair	Poor, v. poor
(Moist consistence)	V. friable, friable	Slightly firm	Firm, v. firm
2. BASIN AREA			
2.1 Permeability	V. slow, slow	Mod.-slow, mod.	Rapid, v. rapid
2.2 Depth to bedrock, gravel etc. (cm)	> 120	50-120	<50
2.3 Organic matter (carbon %)	< 2	2-10	>10
2.4 Slope of streambed (%)	< 2	2-6	>6
3. SPILLWAY[1]			
3.1 Erosion hazard (grassed)	V. low, low	Moderate	High, v. high
3.2 Textural class[2]	Cl, SiCl, SaCl	ClLm, Lm, SaClLm	Sa, LmSa, SaLm
3.3 Shrink-swell potential	V. low, low	Moderate	High, v. high
3.4 Depth to bedrock (cm)	> 120	50-120	< 50
3.5 Slope (%)	< 3	3-8	> 8

[1] Includes return-to-stream

[2] Expansive clays have severe to very severe rating

Table 3 : Definition of limitation categories for interpretation

Degree of limitation	Definition
Very slight	Few or no limitation for use
Slight	Slight limitations easily overcome at low cost
Moderate	Moderate limitation that can normally be overcome with planning, careful design and average management
Severe	Limitations difficult to overcome without careful planning, special design, above average management and high cost
Very severe	Limitations and associated problems very difficult to overcome, costs are generally prohibitive and major modification or reclamation may be required.

Interpretations are generally made on a soil series basis but in this case the limitation ratings are applied to selected diagnostic materials. This should not detract from the series concept and has been done for the sake of convenience. The ratings are presented in Table 4. A list of typical soil series likely to be encountered in the field is also given.

Soil materials unsuitable for dam construction have not been assessed and include organic, humic and other topsoil materials with an organic carbon content exceeding 1,5 percent. All materials with a clay content of less than 6 percent ferrohumic hard plinthite and rock were also excluded.

The ratings provide a very general guide to the suitability of soils for dams and suggest where major problems are likely to be encountered. There is however, much need for refinement based on research. For instance, there is a general relationship between degree of leaching and shrink-swell potential, but a better understanding of the interplay between calcareousness, clay percentage and erosion hazard would improve the interpretation.

/INSERT TABLE 4/

3. PRACTICAL CONSIDERATIONS AND CONCLUSIONS

The interpretations can be of considerable practical value. The line of saturation through the wall, which is dependant on several soil factors is of major concern in the design and construction of a dam. Increasing the gradient of this line through greater compaction and reduced permeability means, in effect, that a narrower base width of the wall will be in order. This in turn will reduce the ultimate cost of the structure. The advantages of selecting materials to meet such needs are thus obvious.

The usefulness of the interpretations is dependant of the users ability to recognize and identify defined soil series. With this information he is able to assess and choose the best site, design a safe and economical structure and select materials for specific purposes. In this way, 'active' soils,sands or other problematic materials could be handled correctly. Furthermore, leaks through the wall, seepage from the basin area and erosion of the spillway and return-to-stream areas would be reduced to a minimum. By recognizing profiles exhibiting abrupt transition, the designer is forewarned of many problems.

TABLE 4 LIMITATION RATINGS OF SELECTED DIAGNOSTIC SOIL MATERIALS

DIAGNOSTIC SOIL MATERIALS	(% Clay)	DEGREE OF LIMITATION RATINGS: Embankments	Basin areas	Spillways	REPRESENTATIVE SOIL SERIES			REMARKS
1. TOPSOIL HORIZONS								
1.1 Melanic					BONHEIM(yellow)	MILKWOOD	WILLOWBROOK	
a) Non-calcareous	(15-35)	Mod.-severe	Slight-mod.	Mod.-severe	Dumasi	Dansland	Mfuleni	Non-calcareous materials preferable; soils inclined to crack on drying and are difficult to work. Select material for core. Erosion hazard is high. Down grade basin rating if underlying rock fissured.
Calcareous	(")	Severe	"	"	Weenen	Sunday	Sarasdale	
b) Non-calcareous	(> 35)	Severe-v.severe	"	Severe-v.severe	Glengazi	Milkwood	Willowbrook	
Calcareous	(> ")	V. severe	"	V. severe	Bonheim	Graythorne	Chinyika	
1.2 Vertic (dark, self mulching)					ARCADIA	RENSBURG		Severe cracking when dry, highly erodable and difficult to work. Generally unsuitable for embankments. Weathered rock associated with Arcadia form may be highly permeable.
Non-calcareous		V. severe	Slight-mod.	V. severe	Rydalvale	Phoenix		
Calcareous		"	"	"	Arcadia	Rensburg		
1.3 Orthic (grey-brown)					AVALON	CLOVELLY	KROONSTAD	
Organic carbon	(15-35)	V.slight-slight	Mod.	Slight-mod.	Avalon	Southwold	Avoca	Suitable for embankments with clay core.
< 1,5%	(> 35)	Slight	"	Slight	Bergville	Newport	Volksrust	
2. SUBSOIL HORIZONS								
2.1 Red apedal					HUTTON	GRIFFIN	KRANSKOP	
Dystrophic	(6-15m^{1})	Slight-mod.	V. severe	Slight-mod.	Middelburg	Burnside	-	Rapid permeability may cause severe seepage loss in basin area. Compaction characteristics usually poor in clayey soils. These soils should be worked 'slightly dry'. Judicious liming and fertilizer use necessary for grass swards. Rock outcrops to be avoided.
	(15-35)	V.slight-slight	V.severe-severe	Slight	Hutton	Cleveland	Kipipiri	
	(35-55)	Slight	Severe	V.slight-slight	Farningham	Griffin	Kranskop	
	(> 55)	Slight-Mod.	Mod.-severe	"	Balmoral	Farmhill	Umbumbulu	
Mesotrophic	(6-15m^{1})	Slight	Severe-v.severe	Mod.	Clansthal	Erfdeel		Mostly suitable for embankments but seepage losses likely in basin area. Reasonably stable and easily compacted. Frequently associated with rock outcrops.
	(15-35)	V. slight	Severe	Slight-Mod.	Msinga	Umzimkulu		
	(35-55)	V.slight-slight	Mod.-severe	Slight	Doveton	Ixopo		
	(> 55)	Slight	Mod.	"	Vimy	Zwagershoek		
Eutrophic	(6-15m)	Slight-mod.	Severe-v.severe	Mod.-severe	Zwartfontein	Runnymeade		As above but more difficult to work at extremes of moisture.
	(15-35)	Slight	Severe	Mod.	Shorrocks	Welgemoed		
	(35-55)	Slight-mod.	Mod.-severe	Slight-mod.	Makatini	Cradock		
	(> 55)	Mod.	Mod.	"	Marckam	Slagkraal		
Calcareous	(6-15m)	Mod.	Severe	Mod.-severe	Malonga			Prone to cracking and tunneling and generally difficult to work. Erosion hazard high.
	(15-35)	Slight-mod.	Mod.-severe	Mod.	Shigalo			
	(35-55)	Mod.	Mod.	Slight-mod.	Hardap			
	(> 55)	Mod.-severe	Mod.-severe	Mod.	Minhoop			
2.2 Yellow apedal					AVALON	CLOVELLY	GRIFFIN	
Dystrophic	(6-15m)	Slight-mod.	Severe-v.severe	Slight-mod.	Kanhym	Mossdale	Burnside	Volume of material usually limited but can be mixed with underlying red apedal or soft plinthic horizons. Easily worked but requires lime and fertilizer for established swards.
	(15-35)	V.slight-slight	Severe	Slight	Ruston	Oatsdale	Cleveland	
	(35-55)	Slight	Mod.-severe	Slight-v.slight	Normandien	Clovelly	Griffin	
	(> 55)	Slight-mod.	Mod.	"		Balgowan	Farmhill	
Mesotrophic	(6-15m)	Slight-mod.	Severe	Mod.	Leksand	Springfield	Erfdeel	Volume of material usually limited; best mixed with other suitable materials. Easily worked. Underlying shale in basin may be highly fissured.
	(15-35)	Slight	Mod.-severe	Slight-mod.	Avalon	Southwold	Umzimkulu	
	(35-55)	Slight-v.slight	Mod.	Slight	Bergville	Newport	Ixopo	
	(> 55)	Slight	Slight-mod.	"		Clydebank	Zwagershoek	
Eutrophic	(6-15m)	Slight-mod.	Mod.	Mod-severe	Heidelberg	Makuya	Runnymeade	Material not common in Natal; inclined to crack on drying.
	(15-35)	Slight	Mod.-severe	Mod.	Soetmelk	Blinkklip	Welgemoed	
	(35-55)	Slight-mod.	Mod.	Slight-mod.	Bezuidenhout	Summerhill	Cradock	
	(> 55)	Mod.	Slight-mod.	"		Klipputs	Slagkraal	
2.3 Red Structured					SHORTLANDS			
Mesotrophic	(15-35)	V.slight	Severe	Slight-mod.	Bokuil			Rapid permeability on basin area is main limitation; reasonably stable and easy to work.
	(35-55)	V.slight-slight	Mod.-severe	Slight	Argent			
	(> 55)	Slight	Mod.	V.slight-slight	Richmond			
Eutrophic	(15-35)	Slight-mod.	Severe	Mod.	Kinross			As above but with firmer consistence.
	(35-55)	Mod.	Mod.-severe	Slight-mod.	Glendale			
	(> 55)	Mod.-severe	Mod.	Mod.	Shortlands			
Calcareous	(15-35)	Mod.-severe	Mod.-severe	Mod.	Ferry			Moderate to severe cracking on drying; relatively impervious if kept wet; somewhat difficult to work; erosion hazard high and prone to tunneling.
	(35-55)	Severe	"	Mod.-severe	Sunvalley			
	(> 55)	Severe-v.severe	"	Severe	Tugela			
2.4 E-horizon					ESTCOURT	KROONSTAD	LONGLANDS	Generally unsuitable for embankment except on downstream side; depth of horizon limiting; should be mixed with other suitable material; dispersal coefficient and permeability often high. Lateral seepage from basin area important.
	(6-15m)	Mod.	Severe	Severe	Uitvlugt	Mkambati	Longlands	
	(15-35)	Slight-mod.	Mod.-severe	Mod.-severe	Estcourt	Avoca	Albany	
	(> 35)	"	"	Mod.	Buffelsdrif	Volksrust	Winterton	
2.5 G-horizon	(> 35)				KATSPRUIT	RENSBURG	WILLOWBROOK	Impervious material; best selected for core material; mod. to severe cracking on drying, difficult to work; calcareous materials highly erodible and may be subject to tunneling.
Non-calcareous or pH < 7,0		V.slight-slight	V.slight	Slight-mod.	Katspruit	Phoenix	Willowbrook	
Calcareous or pH > 7,0		Slight	"	Mod.-v.severe	Killarney	Rensburg	Chinyika	
2.6 Soft plinthic*								
Clay content refers to series identification.					AVALON	LONGLANDS	WESTLEIGH	Highly suitable materials for dams. Erosion hazard of light textured soils moderately high. Analysis of material necessary.
Mesotrophic	(15-35)	V.slight	Slight	Slight	Avalon	Albany	Devon	
	(> 35)	V.slight-slight	V.slight-slight	V.slight-slight	Bergville	Winterton	Sibasa	
Eutrophic	(15-35)	"	Slight	Slight	Soetmelk			
	(> 35)	Slight	V.slight-slight	Slight	Bezuidenhout			
* excludes concretionary horizons								
2.7 Gleycutanic					KROONSTAD			Impervious material best used in core. Clayey material subject to cracking and is difficult to work. Hazard of erosion and tunneling may be high. Analysis of material necessary.
Clay content refers to series identification	(6-15m)	Slight-mod.	V.slight-slight	Mod.-severe	Mkambati			
	(15-35)	Mod.	V.slight	Mod.	Avoca			
	(> 35)	Mod.-severe	"	Slight-mod.	Volksrust			
2.8 Prismacutanic								Material impervious when wet but subject to cracking and tunneling. Use as core and ensure cover of atleast 50 cm of non-expansive material. Difficult to work and highly erodible. Analysis of material necessary.
Continuous black cutans lacking.					ESTCOURT	STERKSPRUIT		
Clay content refers to series identification	(6-15m)	Mod.-severe	Slight-mod.	V.severe	Balfour	Hartbees		
	(15-35)	Severe	"	"	Estcourt	Sterkspruit		
	(> 35)	Severe-v.severe	"	"	Buffelsdrif	Antioch		
2.9 Pedocutanic								
1) Red B-horizons					BONHEIM	SWARTLAND	VALSRIVIER	
Non-calcareous	(15-35)	V.slight-slight	Severe	Mod.	Kiora	Reveillie	Sunnyside	Rapid permeability in basin area main limitation.
	(35-55)	Slight	Mod.-severe	Slight-mod.	Stanger	Skilderkrans	Waterval	
	(> 55)	Slight-mod.	Mod.	Mod.		Breidbach	Lilydale	
Calcareous	(15-35)	Slight-mod.	Severe-v.severe	Mod.	Bushman	Uitsicht	Zuiderzee	Inclined to crack on drying; somewhat difficult to work. Erosion hazard generally high.
	(35-55)	Mod.	Severe	Slight-mod.	Rasheni	Brookspruit	Craven	
	(> 55)	Mod.-severe	Mod.-severe	Mod.-severe		Prospect	Marienthal	
2) Non-red B-horizons								
Non-calcareous	(15-35)	V.slight	Mod.-severe	Mod.-severe	Dumasi	Rosehill	Horschel	Generally suitable for dam building but clayey material subject to cracking.
	(35-55)	V.slight-slight	"	Mod.	Glengazi	Swartland	Arniston	
	(> 55)	Slight	Mod.	Mod.-severe		Hogsback	Chalumna	
Calcareous	(15-35)	Slight	Severe	Mod.-severe	Weenen	Malakata	Valsrivier	Subject to cracking when dry and difficult to work. Hazard of erosion and tunneling high.
	(35-55)	Slight-mod.	Mod.-severe	Mod.	Bonheim	Nyoka	Lindley	
	(> 55)	Mod.	Mod.	Severe		Omdraai	Sheppardvale	
2.10 Lithocutanic								
Clay content refers to series identification					GLENROSA	MAYO		Rarely suitable for embankments because of shallowness. Sandy material and fissured rock very permeable. Analyses of material necessary.
Non-calcareous	(6-15m)	Mod.	Severe	Severe	Platt	-		
	(15-35)	Slight-mod.	Mod.-severe	Mod.-severe	Trevanian	Mayo		
	(> 35)	Slight	Mod.	Mod.	Saintfaiths	Alison		
Calcareous	(6-15m)	Mod.-severe	Severe-v.severe	Severe-v.severe	Dunvegan			As above but inclined to crack on drying. Erosion hazard generally high.
	(15-35)	Mod.	Severe	Severe	Dothole	Tshipise		
	(> 35)	Slight-mod.	Mod.-severe	Mod.-severe	Ponda	Pafuri		
2.11 Neocutanic					OAKLEAF(red)	OAKLEAF(yellow)		
Non-calcareous	(6-15m)	Slight-mod.	Severe-v.severe	Severe	Rockford	Levubu		Generally suitable for embankments and easily worked. Red soils may be downgraded for rapid permeability.
	(15-35)	Slight	Severe	Mod.-severe	Leeufontein	Josini		
	(> 35)	V.slight-slight	Mod.-severe	Mod.	Highflats	Koedoesvlei		
Calcareous	(6-15m)	Mod.	Severe	Severe-v.severe	Magersfontein	Okavango		As above but with higher erosion hazard.
	(15-35)	Slight-mod.	Mod.-severe	Severe	Letaba	Limpopo		
	(> 35)	Slight	Mod.	Mod.-severe	Makulek	Mutale		

m^{1} = medium grade sand

Knowledge of the particular soil series involved does not always provide adequate information. Until such time as more precise data is generally available the designer will need to submit samples for laboratory analyses. This applies particularly to shrink-swell potential values and dispersal coefficients.

Optimum moisture content values are particularly useful to the farmer. The values obtained for samples of the Msinga (15-35% clay) and Farningham (35-55% clay) series were between 10 and 20 percent and 20 and 30 percent respectively. There is a close correlation between OMC and the moisture content at the plastic limit. The test for plastic limit will thus provide a useful guide for application in the field. A small moist sample is worked between thumb and forefinger until it is just capable of forming a 3 millimeter diameter spindle without disintegrating.

Table 4 reflects that many soils in the basin area have severe limitations, especially those of excessive permeability or with high shrink-swell potentials. The problem of seepage can in many cases be overcome by treatments including physical or chemical puddling. Such treatments are likely to receive far greater attention in the future. Physical puddling of red soils with over 15 percent clay at the time of construction could be effective, while the use of sodium salts and other commercial preparations on eutrophic and calcareous soils have already proved effective.

There is considerable scope for water storage projects in Natal and it is clear that farm dams will play an ever-increasing role in the conservation effort. The poor supply and distribution of stockwatering points has probably caused more erosion and veld deterioration in the Thornveld areas than any other factor. The need for dams is not however, restricted to these dry areas and much remains to be done in the higher rainfall areas where more favourable conditions for storage exist. In these parts there is likely to be a great demand for multi-purpose dams that meet the needs for flood control, irrigation recreation, improved habitats for fish and wildfowl in addition to those of stockwatering and domestic use. A program specifically designed to promote water storage projects at the farm level is thus strongly recommended and should be seen as a priority by the authorities concerned.

Interpretations should compromise between simplicity and the general loss of precision and usefulness. The tendency in this paper is probably towards over-simplification which results from the lack of data. The need for research is considerable, especially for establishing more precise threshold values. Despite its obvious limitations the interpretation has the added advantage that it will encourage non-agriculturalists to use and understand the National system of soil classification. It will also ensure that best use is made of soil maps which indicate the distribution of soil series.

ACKNOWLEDGEMENTS

The authors are indebted to Messrs. R. Jeffrey and D. Dekker for collecting most of the diagnostic soil materials and to Messrs. D.K. Meyer, H.G. Drögemöller, S.K. Armour, A.V. Williamson and H.A. Williamson for the diligent manner in which they undertook the large number of soil analyses. They also record their appreciation to Mr. A.C. Cass for his co-operation and helpfulness in determining the dominant clay minerals.

REFERENCES

AMERICAN SOCIETY FOR TESTING MATERIALS, 1958. Procedures for Testing Soils. Philadelphia.

BEATER, B.E. 1970. Soil Series of the Natal Sugar Belt. S.A. Sugar Asstn., Durban.

CASS, A.C., 1975. Personal communication.

DEPARTMENT AGRICULTURAL TECHNICAL SERVICES, 1969. Report on soil conservation works. Dept. A.T.S., Natal Region (Unpublished).

DEPARTEMENT LANDBOU-TEGNIESE DIENSTE, 1974. Verslag oor 'n ondersoek in verband met die swigting van klein gronddamme deur die vorming van spoel-tonnels Dept. L.T.D., Pretoria (Verslag C/Bou 687 - Vertroulik).

DEPARTMENT OF STATISTICS, 1962. Agricultural census 1959-1960, No. 34. Govt. Printer, Pretoria.

________________ 1974. Agricultural census 1970-1971, No. 44. Govt. Printer, Pretoria.

DE VILLIERS,J.M. 1962. A study of soil formation in Natal. Ph.D.Thesis, Univ. of Natal, Pietermaritzburg.

LOXTON, R.F., 1962. A simplified soil-survey procedure for farm planning. Dept. A.T.S., Pretoria.

LUDORF, R. and SCOTNEY, D.M. 1975. Soils of the Lions River and Mooi River Valley Soil Conservation Districts. Tech. Comm. No. 94. Dept. A.T.S., Pretoria.

MACVICAR, C.N., DE VILLIERS, J.M. LOXTON, R.F., VERSTER,E. LAMBRECHTS, J.J.N., MERRYWEATHER, F.R., LE ROUX, J. and VON M. HARMSE, H.J. 1974. Soil Classification. A system for South Africa, 1st Edition. Soils and Irrigation Res. Inst., Dept. A.T.S., Pretoria (In Press).

PAZZI, J.J.O., 1963. Die bou van plaas damme. Dept. L.T.D., Pamflet 365, Pretoria.

PURI, A.N. 1949. Soils: Their Physics and Chemistry. 1st Ed. Reinhold Pub. Corp., New York.

RITCHIE, J.A., 1963. Earthwork tunneling and the application of soil testing procedures. J. Soil Con. Service, 19 (3), New South Wales.

SOUTH EASTERN WISCONSIN REGIONAL PLANNING COMMISSION, 1969. Soils development guide. Planning Guide No. 6. South-eastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin.

UNITED STATES DEPARTMENT OF AGRICULTURE, 1967. Guide to interpreting engineering uses of soils. U.S.D.A. Soil Conservation Service, Washington.

VAN DER BANK, W.J., 1964. Mechanical composition of red ferrugenous Natal soils. M.Sc. Thesis, Univ. of Natal, Pietermaritzburg.

WILLIAMS, A.A.B., 1957. Discussion on a paper by J.E.B. Jennings and K. Knight. The prediction of total heave from the double oedometer test. Trans. of S.Afr. Inst. of Civil Eng.

APPENDIX 1 SELECTED DIAGNOSTIC MATERIALS INVESTIGATED

DIAGNOSTIC HORIZON	REPRESENTATIVE SOIL FORMS	NO. OF SAMPLES
1. TOPSOILS		
Melanic	Bonheim, Milkwood, Willowbrook	5
Vertic	Rensburg	2
Orthic(grey)	Avalon, Estcourt, Kroonstad, Glenrosa, Clovelly	10
	Sub Total	17
2. SUBSOILS		
E-horizon	Cartref, Longlands, Kroonstad, Estcourt	8
G-horizon	Katspruit, Willowbrook, Rensburg	8
Red apedal	Hutton, Griffin	17
Red structured	Shortlands	3
Yellow apedal	Clovelly, Griffin, Avalon, Glencoe	18
Soft plinthic	Avalon, Longlands	7
Gleycutanic	Kroonstad	4
Prismacutanic	Estcourt, Sterkspruit	5
Pedocutanic	Bonheim, Swartland	6
Lithocutanic	Glenrosa	1
Neocutanic	Oakleaf	3
Regic sand	Fernwood	1
Alluvium	Dundee	2
	Sub Total	83
	TOTAL	100

SAMPLES PER FORM

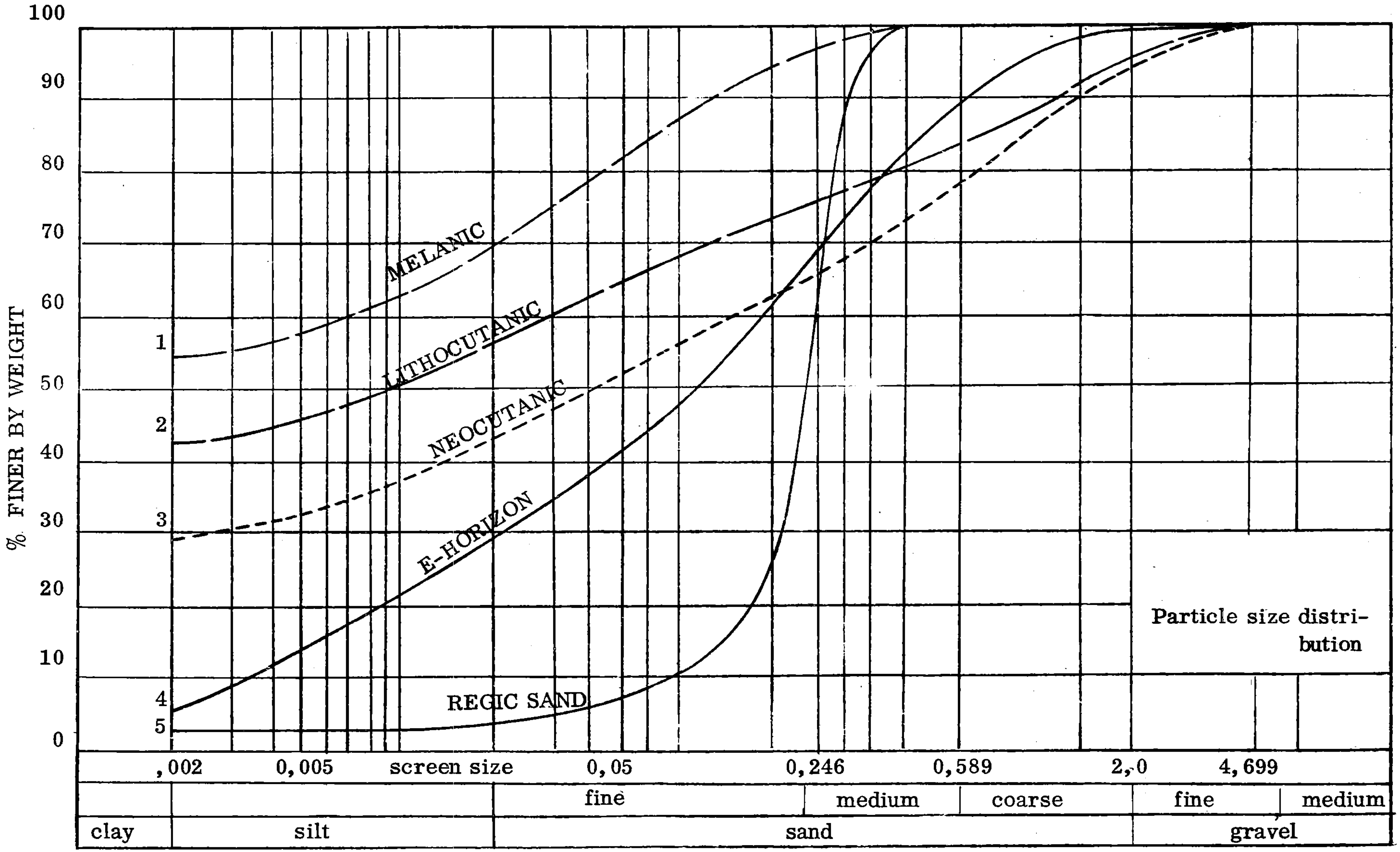
Avalon (15)
Bonheim (7)
Cartref (2)
Clovelly (8)
Dundee (2)
Estcourt (6)
Fernwood (1)
Glencoe (1)
Glenrosa (3)
Griffin (8)
Hutton (12)
Katspruit (6)
Kroonstad (10)
Longlands (3)
Milkwood (1)
Oakleaf (3)
Rensburg (3)
Shortlands (3)
Sterkspruit (2)
Swartland (1)
Willowbrook (3)

DIAGNOSTIC MATERIALS NOT INVESTIGATED

1) Topsoils
- Humic A-horizon
- Organic A-horizon
- Orthic materials with over 1,5% organic carbon

2) Subsoils
- Ferro humic B-horizon
- Hard plinthite/rock
- Saprolite
- Unconsolidated materials

PARTICLE SIZE DISTRIBUTION OF SELECTED MATERIALS



APPENDIX 3

RELATIONSHIPS BETWEEN CLAY PERCENTAGE AND SELECTED ENGINEERING PROPERTIES

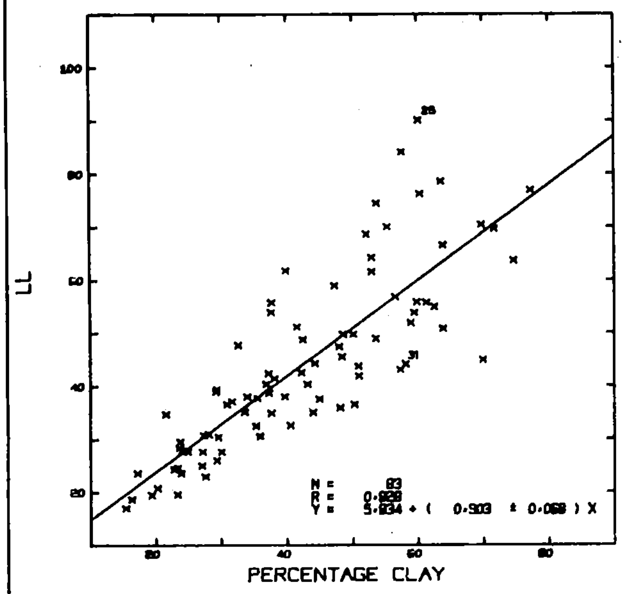


FIGURE 3(a)

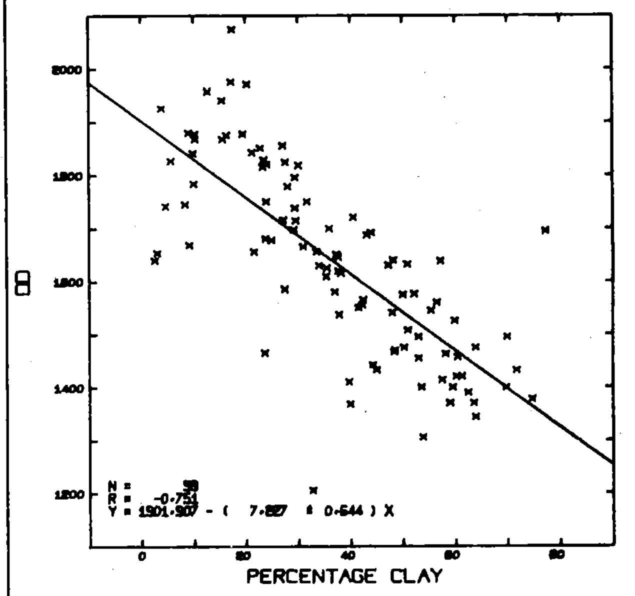


FIGURE 3(b)

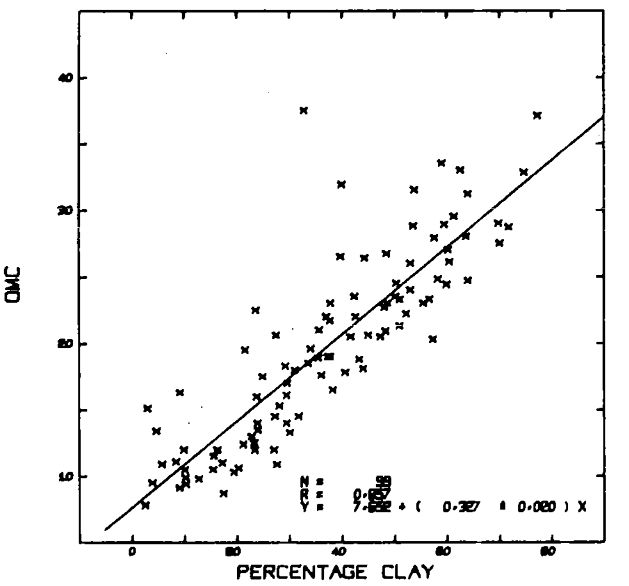


FIGURE 3(c)

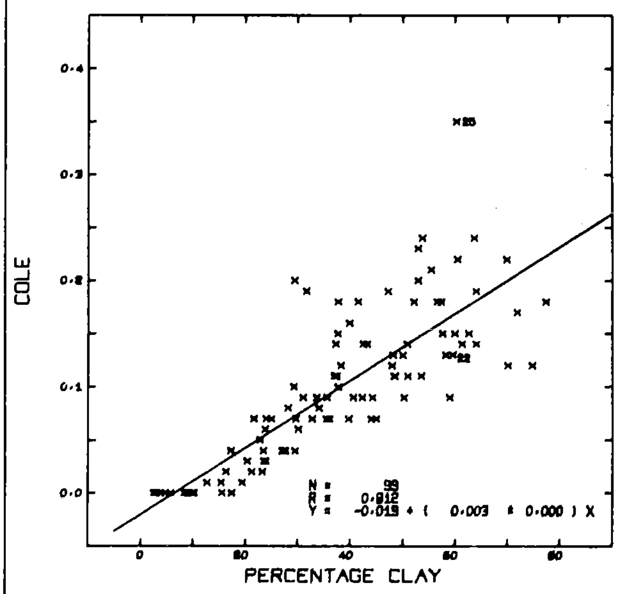


FIGURE 3(d)