REPORT ON

GEOTECHNICAL INVESTIGATION FOR HARTENBOS EXTENSION 4 TOWNSHIP, CAPE PROVINCE

for

LIEBENBERG AND STANDER

REPORT NO. : 84/153/1 NOVEMBER 1984

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1. INTRODUCTION AND TERMS OF REFERENCE

At the request of Mr G. Gerber of Liebenberg and Stander we have carried out a geotechnical investigation for the proposed development of the township of Hartenbos Extension 4. The objectives of this investigation may be summarised as follows :

i) To determine the nature, distribution and engineering properties of near-surface soils as they affect the construction of roads and services.

ii) To evaluate excavation procedures associated with installation of services and road cuttings.

iii) To comment on and give recommendations with regard to the stability of both natural and cut slopes.

iv) To evaluate both on-site and locally available materials for use as construction materials.

v) To give foundation recommendations for a proposed reservoir and to evaluate in general terms founding conditions for both school and residential structures.

The requirements for the investigation were discussed at a series of meetings and a site inspection attended by Mr G. Gerber of Liebenberg and Stander and our Mr K. Schwartz. In addition it was indicated to us that the civil works would be carried out in accordance with the SABS Standardised Specification for Civil Engineering Construction (SABS 1200) and that all recommendations should therefore take the requirements of the relevant SABS 1200 specifications into consideration.

At the request of Mr G. Gerber a preliminary report dealing with the various investigation objectives given in points i) to v) above was prepared immediately after the completion of the field investigation. This preliminary report was sent to Liebenberg and Stander on 19 November 1984.

2. INFORMATION SUPPLIED

The following information was supplied to us by Liebenberg and Stander in order to facilitate the investigation :

i) A site plan to the scale of 1:2000 showing the proposed township layout and contours.

ii) A site plan to the scale of 1:2500 showing proposed test pit positions and existing roads, tracks and services.

iii) A set of aerial photographs prepared by Photosurveys (Cape) (Pty) Ltd giving stereographic cover of the area of investigation

3. SITE LOCATION AND DESCRIPTION

The site for the proposed development is located in the municipality of Hartenbos, Cape. The area straddles the existing N2 National Road, with the major portion of the proposed township being located to the west of this road. The Hartenbos to Oudtshoorn road bounds the site to the north. The Phase 1 area of development lies adjacent to the N2 and forms about 60% of the total township area, while Phase 2 lies to the west of Phase 1.

Topographically the area is one of rugged relief. Deep gullies with steep side slopes disect a land surface which comprises hillcrests and associated relatively gently sloping side slopes. The proposed township layout is largely confined to the latter hillcrests and side slopes. The Phase 1 area lies at a lower elevation (15m - 100m AMSL) compared to the Phase 2 area which is located at an elevation of between 100m and 135m AMSL.

Existing developments in the area of investigation comprise a small coloured residential settlement and water reservoirs located in the Phase 1 area of the township and a number of houses to the east of the N2 Freeway. Existing cemetaries are located on Stands 2406 and 2165.

4. NATURE OF THE INVESTIGATION

The investigation was divided into a number of separate exercises and these are described in the following sections :

4.1 Airphoto Interpretation

Conventional airphoto interpretation techniques were used to examine and identify photo features and define mappable units both in terms of geology and landform.

4.2 Field Investigation

4.2.1 Walkover Survey

A walkover survey of the area was conducted in order to check significant physical features. At the same time natural and artificial exposures of the soil profile occurring in the area of interest were visually profiled by an engineering geologist. Copies of the recorded soil profiles (designated EP 1 to EP 8) are included in Appendix A. Profile locations are shown on drawing nos. 84/153/1 and 84/153/2 which cover the Phase 1 and Phase 2 areas of development respectively.

4.2.2 Test Pits

Sixty six test pits were excavated between 29 and 31 October 1984 using a Liebherr 922 tracked backhoe supplied by Transand (Pty) Ltd. Test pits were taken either to refusal of the machine or to its depth limit and were then visually profiled by either a geotechnical engineer or an engineering geologist. During profiling, disturbed soil samples were taken from selected horizons for possible laboratory testing. Test pit positions (designated TP 1 to TP 66) are shown on drawing nos. 84/153/1 and 84/153/2. Copies of the recorded soil profiles are presented in Appendix A.

4.2.3 Local Quarries

Soil samples were taken for possible laboratory testing at two nearby quarries owned by Commerical Quarries (Pty) Ltd. Quarry 1 is located approximately 2 km from Hartenbos Extension 4 on the Oudtshoorn road while Quarry 2 lies 0,5 km to the south of the Phase 1 area of development.

4.3 Laboratory Testing

The following tests were carried out on selected soil samples recovered during the field stage of investigation :

i) Atterberg Limits and particle size distribution analyses to determine basic engineering properties and effect classification.

ii) Particle size distribution analyses on granular non-plastic materials to effect classification.

iii) Moisture/Density and California Bearing Ratio (CBR) tests to evaluate compaction characteristics and post-compaction strength.

Copies of the recorded test results are presented in Appendix B.

5. DISCUSSION ON TERRAIN CLASSIFICATION

The area of investigation has been mapped using the landscape approach in which terrain classes are recognised on their external features and interrelationships. The method adopted specifically is the land system/land facet classification which makes use of airphoto interpretation coupled with direct field checking. The basic unit of this classification is the "land facet", which is an area of ground with a simple surface form, a specific succession of soil profile horizons (each with reasonably uniform properties) and a characteristic groundwater regime. A recurrent pattern of genetically linked land facets is known as a "land system", which is generally dominated by one major geomorphic process.

In the present area of investigation two land facets within a single land system are considered to occur :

i) Hillcrests and related shallow side slopes (Land Facet 1).

ii) Steeper side slopes leading into drainage channels or gullies (Land Facet 2).

The occurrence and distribution of these land facets as interpreted from the remote (airphoto) and direct (test pits) methods of investigation outlined in Section 4, is shown on drawing nos. 84/153/1 and 84/153/2 (Site Plan and Soil Engineering Map).

In order to define the character of the land system and interrelation between its constituent land facets, a facet index has been prepared and is presented in Table 5.1. In general terms the major portion of the proposed township falls into Land Facet 1, with limited development planned in the steeper side slope areas of Land Facet 2, which generally occurs around the perimeter of both the Phase 1 and Phase 2 areas.

6. SITE GEOLOGY

6.1 General

Available geological maps show the area of investigation to be underlain by horizontally disposed sediments of the Cretaceous Period. These sediments comprise conglomerates interbedded with lenticular siltstones and sandstones. The area has a climatic N-value of 3,0 (Weinert, 1974) so that chemical decomposition of the rock can be expected to form the dominant mode of weathering. Transported soils of colluvial origin occur from surface masking the underlying residual soils and rocks. Site geology is illustrated on the Soil Engineering Map (see drawing nos. 84/153/1 and 84/153/2). In view of the nature of the investigation (in particular the spacing of test

TABLE 5.1

FACET INDEX FOR THE LAND SYSTEM - HARTENBOS EXT. 4

LAND FACET	FORM	SOILS AND ROCKS	ASSOCIATED HYDROLOGY	LAND COVER
1	Hillcrests and related shallow side slopes - slope : 0° - 11° width : 70m - 800m	Fine colluvium not exceeding 1,0m in thickness. Comprises gravelly silty sand overlying shattered clayey silts. These transported soils are underlain directly by residual siltstones, sandstones and conglomerates of the Cretaceous Period.	Above groundwater influence.	Short bush grass on crests and grass and bushes on side slopes.
2	Steeper side slopes leading into deep disecting drainage channels (gullies) or coastal plain - slope : 10° - 60° width : 90m - 350m	Coarse colluvium in excess of 1,0m in thickness. Comprises silty sandy gravels generally, but in coastal plain little or no gravel. These transported soils are underlain by residual siltstones, sandstones and conglomerates of the Cretaceous Period.	Generally above groundwater influence except in gully floors where moderate depth to the water table is anticipated.	Short bush grass and scattered bushes. Generally less vegetation in gully floors.

pits) as well as the lenticular nature of the sediments, it should be borne in mind that the indicated lithological boundaries on the Soil Engineering Map must be considered to be approximate. Both the transported soils and residual soils and rocks are discussed in the following sections, while detailed descriptions of the various horizons may be found in the recorded soil profiles (see Appendix A).

6.2 Transported Soils

The fine colluvial soils of Land Facet 1 (hillcrest and shallow side slope) do not generally exceed a thickness of 1,0m. They comprise in essence a loose gravelly silty sand at surface and between 0,3m and 0,8m thick underlain by a stiff shattered clayey silt up to 0,5m in thickness. Occasionally the shattered colluvial horizon is absent.

The coarse colluvium of Land Facet 2 (steeper side slopes) exceeds 1,0m in thickness and in places is at least 3,0m thick. The colluvium here comprises a silty sandy gravel in general. However on the extreme eastern and northern sides of the Phase 1 area, there is a noticeable decrease in the proportion of gravel, although the deep colluvial profile is preserved.

6.3 Residual Soils and Rocks

The Cretaceous sediments comprising conglomerates interbedded with lenticular siltstones and sandstones have weathered to form layers of residual soils which are variable in thickness.

In comparison to the coarse grained conglomerates the relatively fine grained siltstones and sandstones have weathered appreciably to form residual siltstone and sandstone soils which occur to depths in excess of approximately 4,0m below surface in some areas. Relatively shallow weathering characterises the conglomerates, with thin residual soils overlying conglomerate bedrock.

In the Phase 1 area of the proposed township the residual siltstone horizons form a significant portion of the horizontally disposed succession (as do the residual sandstones to a lesser extent). In contrast, only limited residual siltstone and sandstone development was encountered in the Phase 2 area. These trends are illustrated in the Soil Engineering Map.

All the residual horizons are characterised by medium to widely spaced bedding (horizontal) with very limited development of jointing, so that the general impression is one of "relative intactness" in the residual materials.

6.4 Water Table

No water table or zones of significant seepage were encountered during the field investigation. It therefore appears that the local water table occurs at depth and below the influence of construction procedures associated with township development. However it can be expected that in natural drainage channels the water table will approach ground level, particularly during the wet season or periods of prolonged rainfall.

7. GEOTECHNICAL EVALUATION AND RECOMMENDATIONS

Geotechnical considerations relevant to the development of Hartenbos Extension 4 township in terms of roads and services are discussed in this section of the report. Founding conditions and recommendations are dealt with in Section 8.

7.1 Excavation Procedures

General excavation procedures for roads and services based on material origin and the SABS 1200 excavation classification are presented in Table 7.1. In terms of the SABS 1200 Earthworks Specification and the in situ soil/rock consistencies as profiled, the following relationships are considered applicable:

i) "soft excavation" - very loose/very soft through to dense/stiff.

ii) "intermediate excavation " - very dense/very stiff through to very soft rock.

iii) "hard rock excavation" - soft rock or better.

In specific areas therefore the relevant test pit soil profiles may be used in conjunction with the above relationships and Table 7.1 to evaluate excavation procedures.

TABLE 7.1

EXCAVATION PROCEDURES BASED ON SABS 1200

MATERIAL ORIGIN	MATERIAL DESCRIPTION	SABS 1200 EXCAVATION CLASSIFICATION		
		SOFT EXCAVATION	INTERMEDIATE EXCAVATION	HARD ROCK EXCAVATION
Transported soil	Land Facet 1 fine colluvium	✓		
	Land Facet 2 coarse colluvium	✓		
Residual soil	Residual siltstone soils	✓	✓	
	Residual sandstone soils	✓	✓	
	Residual conglomerate soils	✓	✓	
Rock	Generally soft rock conglomerate or better (below backhoe refusal depth)			✓

7.2 Slope Stability

7.2.1 Natural Slopes

No evidence of instability in naturally-occurring slopes in the area has been observed, either from the aerial photographs or directly from the field investigation. In the areas where township development is proposed natural slope angles range from less than 5° in hillcrest areas through to 20° on the steeper side slopes leading into gullies. The residual soils and rocks are competent and of relatively high strength while the upper transported soils exhibit moderate strength.

It is our opinion that the natural slopes as they occur at present in the areas where development is proposed, are stable. However water has a significant effect on slope stability and care should be exercised in the planning and construction of the township to ensure that the free-draining nature of these slopes is maintained. Particular care should be exercised where structures are located in areas of relatively steep side slope to ensure that pore water pressure build-up in near-surface soils is kept to a minimum.

7.2.2 Cut Slopes

Slopes cut for roads and earthworks and up to 5,0m in depth should be excavated to a slope angle of 1(V) : 1,5(H). Long term erosion and ravelling can be expected to occur, particularly in the residual siltstone and sandstone horizons and loose unconsolidated colluvial deposits. In this regard the Soil Engineering Map may be used to identify potential problem areas. Suitable precautions that can be taken to maintain the long-term stability of cut slopes include vegetating (grassing) the slopes and stone pitching.

7.3 Materials Usage

Engineering properties of soils occurring on Hartenbos Extension 4 and obtainable from the local quarries are summarised in Tables 7.2 and 7.3 respectively. Potential uses of these materials in the development of the township are presented in Tables 7.4 and 7.5 together with costs in the case of quarry materials. Particular considerations regarding the various material types and their use as construction materials are discussed in the following sections. The distribution and extent of these materials is shown on the Soil Engineering Map (drawing nos. 84/153/1 and 84/153/2).

TABLE 7.2

SUMMARY OF ENGINEERING PROPERTIES OF ON-SITE MATERIALS

TEST PIT NUMBER	DEPTH (m)	MATERIAL ORIGIN	LL	PI	% PASSING 0,075mm SIEVE	GM	CBR AT % Mod. AASHTO			AASHTO CLASSIFICATION
							98%	95%	93%	
TP 24	0,2 - 0,6	Fine shattered colluvium (Facet 1)	47	25	55	0,84	5	5	3	A - 7 - 6
TP 41	0,4 - 0,8	Fine shattered colluvium (Facet 1)	74	37	50	1,11	2	2	2	A - 7 - 5
TP 45	0,4	Fine shattered colluvium (Facet 1)	68	36	44	1,42	-	-	-	A - 7 - 5
TP 59	0,0 - 1,9	Fine shattered colluvium (Facet 1)	24	12	50	0,71	31	23	18	A - 6
TP 31	0,4 - 1,4	Coarse colluvium (Facet 2)	17	8	55	0,54	54	40	34	A - 4
TP 32	0,0 - 1,5	Coarse colluvium (Facet 2)	-	S/P	5	2,58	148	77	50	A - 1 - a
TP 2	1,7	Residual siltstone	69	36	77	0,33	-	-	-	A - 7 - 5
TP 12	1,8	Residual siltstone	92	69	80	0,40	-	-	-	A - 7 - 6
TP 15	3,0	Residual siltstone	51	20	99	0,01	-	-	-	A - 7 - 5
TP 17	1,2 - 1,8	Residual siltstone	22	8	88	0,13	3	2	2	A - 4

TABLE 7.2 (CONTD)

TEST PIT NUMBER	DEPTH (m)	MATERIAL ORIGIN	LL	PI	% PASSING 0,075mm SIEVE	GM	CBR AT % Mod. AASHTO			AASHTO CLASSIFICATION
							98%	95%	93%	
TP 28	1,0 - 2,0	Residual siltstone	59	20	74	0,40	3	2	1	A - 7 - 5
TP 36	1,0 - 2,0	Residual siltstone	34	12	67	0,38	6	5	5	A - 6
TP 7	1,5	Residual sandstone	-	-	13	1,14	-	-	-	A - 2 - 4
TP 19	1,0 - 2,0	Residual conglomerate	19	9	9	2,51	-	-	-	A - 2 - 4
TP 33	1,2	Residual conglomerate	-	N/P	4	2,53	-	-	-	A - 1 - a
TP 39	0,5 - 1,5	Residual conglomerate	39	12	8	-	140	110	-	A - 2 - 6
TP 43	1,6	Residual conglomerate	22	7	10	2,30	-	-	-	A - 2 - 4
TP 57	0,6 - 1,2	Residual conglomerate	22	8	34	0,95	30	21	16	A - 2 - 4

TABLE 7.3

SUMMARY OF ENGINEERING PROPERTIES OF QUARRY MATERIALS

QUARRY	QUARRY'S MATERIAL DESIGNATION (SAMPEL NO.)	LL	PI	% PASSING 0,075mm SIEVE	GM	CBR AT % Mod. ASHTO COMPACTION			AASHO CLASSIFICATION
						98%	95%	93%	
2 (South of Hartenbos Ext 4	Subbase (SB 2)	26	13	17	2,08	43	22	14	A - 2 - 6
1 (North of Hartenbos Ext 4	Base course (BC 1)	15	3	8	2,48	169	147	132	A - 1 - a
	Subbase (SB 1)	15	3	8	2,44	51	26	11	A - 1 - a
	Crusher dust (CD 1)	-	-	9	2,11	-	-	-	A - 1 - a
	River gravel (RG 1)	-	-	6	2,28	-	-	-	A - 1 - a
	River sand (RS 1)	-	-	1	1,67	-	-	-	A - 1 - b
	Building sand (BS 1)	-	-	13	0,88	-	-	-	A - 2 - 4

TABLE 7.4

SUMMARY OF POTENTIAL USES OF ON-SITE MATERIAL

LAND FACET	MATERIAL TYPE	EXPECTED THICKNESS RANGE (m)	POTENTIAL USES					COMMENTS
			BASE	SUBBASE	SELECTED LAYERS	GENERAL FILL	SPOIL	
1	Fine colluvium. Gravelly silty sand.	0,2 - 1,0			✓	✓		Relatively thin and difficult to select.
1	Fine colluvium. Shattered clayey silt.	0,1 - 1,0					✓	Unsuitable for use.
2	Coarse colluvium. Silty sandy gravel.	1,0 - 3,0	✓	✓				Light crushing may be required to break up coarse fraction if used as base.
1 & 2	Residual siltstone.	0,5 - 4,0+					✓	Unsuitable for use.
1 & 2	Residual sandstone.	0,5 - 4,0+			✓	✓		Of limited extent and difficult to select.
1 & 2	Residual conglomerate.	1,0 - 3,0+	✓	✓				Light crushing may be required to break up coarse fraction.

TABLE 7.5

SUMMARY OF POTENTIAL USES OF QUARRY MATERIALS AND CURRENT COSTS

QUARRY NUMBER	QUARRY'S MATERIAL DESIGNATION	POTENTIAL USES						QUARRY PRICE Cu. METRE (R)
		BASE	SUBBASE	SELECTED LAYER	CONCRETE SAND	BUILDING SAND	PIPE BEDDING	
2 (South of Hartenbos Ext 4)	Subbase			✓				3,30
1 (North of Hartenbos Ext 4)	Base course	✓	✓					10,07
	Subbase			X				3,30
	Crusher dust				X			10,29
	River gravel	X	X					7,92
	River sand				✓	✓		9,13
	Building sand					X		6,63

KEY : ✓ Complies with SABS specification

X Does not comply with SABS specification but may be suitable if standards are revised

7.3.1 Colluvium

The upper gravelly colluvial soils of Land Facet 1 are considered suitable for use in road construction (see Table 7.4). This material could be stockpiled for future use, but may be difficult to select due to its relatively thin vertical extent.

The shattered clayey silts of Land Facet 1 which generally underlie the gravelly horizon are potentially expansive and considered to be unsuitable for use in road construction. However if mixed with the overlying gravelly colluvium, they will form a suitable general fill. More details are given in Section 7.3.6.

Transported colluvial gravels of Land Facet 2 exhibit low plasticity and good compaction characteristics although light crushing may be required to break up coarser gravel fractions.

7.3.2 Residual Siltstone Soils

The upper residual siltstone soils are potentially expansive and are considered to be unsuitable for use in road construction. Further details in this regard are discussed in Section 7.3.6. The quality of the residual siltstone soils could be improved with the addition of granular soils.

7.3.3 Residual Sandstone Soils

Residual sandstone soils are of limited extent (see Soil Engineering Map). However these soils are considered to form a suitable subgrade and may be used in selected layers and as a general fill.

7.3.4 Residual Conglomerate Soils

Good compaction qualities and good subgrade conditions characterise the residual conglomerate soils. As set out in Table 7.4 these materials are suitable for use as subbase and base possibly with some light crushing in the case of the latter.

7.3.5 Quarry Materials

Suitable construction materials are available from the No. 1 and No. 2 quarries of Commercial Quarries (Pty) Ltd (see Tables 7.3 and 7.5). Although these materials are being used locally and available information (Weinert, 1980) indicates that no potential problems are anticipated, it is recommended that further testing be carried out on any quarry materials that will be used in order to assess suitability, particularly as regards deleterious impurities and variability. No pipe bedding material falling within the SABS specification was located in the area. However in view of the nature of the development certain of the local quarry materials may prove suitable if less stringent criteria are adopted.

7.3.6 Problem Areas for Road Construction

The potentially expansive nature of the shattered fine colluvium (Land Facet 1) and residual siltstone soil, indicates that these materials form a poor subgrade. It is anticipated that the relatively thinly developed shattered fine colluvium can easily be removed to spoil (see Section 7.3.1). In areas of road construction where residual siltstone soils occur, it is recommended that these materials be undercut to a depth of 0,6m below finished road level with excavated material being removed to spoil. The relevant areas are delineated on the Soil Engineering Map and it is anticipated that they can be defined more accurately by inspection during construction.

The fine grained nature and low post-compaction strength of the residual siltstone soils indicate that care should be exercised (when undercutting) to create as little disturbance of these soils as possible before the placing of the selected layers.

8. EVALUATION OF GENERAL FOUNDING CONDITIONS AND RECOMMENDATIONS

8.1 Proposed Reservoir

It has been indicated to us by Mr G. Gerber that it is proposed to construct a reservoir at the topographical high point in the Phase 2 area of development (elevation ± 135m AMSL). With reference to the relevant test pit profiles (TP 38 and TP 39) it is recommended that the proposed reservoir be founded at a depth of between 0,5m and 1,0m below natural ground level. Founding should take place on dense residual sandstone/conglomerate using a maximum allowable bearing pressure of 400 kN/m^2, in which case total settlements are not expected to exceed 10mm. Limited occurrence of residual siltstone soils occurs in the immediate vicinity of the site of the proposed reservoir, and from the available literature it appears that these soils although potentially expansive, have a low swelling pressure. Nevertheless water emanating from the reservoir should be carefully controlled to prevent ingress into the subsurface soils since thin interbedded siltstone lenses or bands can be expected to occur across the area.

8.2 Schools

Available information shows that a primary school is planned on Stand 1799 in the Phase 2 area of development. From the Soil Engineering Map it may be seen that the Land Facet 1/Land Facet 2 boundary passes through the site, so that it can be anticipated that both the nature of the colluvium and its thickness change across the area. To the west of the facet boundary shallow fine colluvium overlies residual conglomerate (or limited siltstone rock), while to the east of the facet boundary coarse colluvium (gravelly silty sand) exceeding 1,0m in thickness overlies residual conglomerates.

The fine colluvium is considered to be potentially moderately expansive while the coarse colluvium is highly compressible. The colluvium in general is therefore considered to be unsuitable for use as a founding horizon. Both the residual conglomerates and siltstone rock exhibit low compressibility and will in our opinion form suitable founding horizons.

It is therefore recommended that the proposed structures be founded at depths of between 0,5m and 1,2m on residual siltstones/conglomerates using a maximum allowable bearing pressure of 400 kN/m². In this event total settlements are not expected to exceed 10mm. Suitable compaction of the coarse colluvium should be carried out prior to casting the floor slabs. Cognisance should be taken of the potentially expansive fine colluvium when designing surface beds and in view of its relatively shallow vertical extent, consideration should be given to its removal and replacement with a suitably compacted inert granular fill (such as the coarse colluvium).

8.3 General Founding Conditions for Residential and Other Structures

The following general comments may be made with regard to the location of structures on the in situ soils and rocks underlying the Phase 1 and 2 areas of development :

i) Shattered potentially moderately expansive horizons occur within the fine colluvium of Land Facet 1 and must be taken into account in the design of structural foundations and surface beds.

ii) The coarse colluvium of Land Facet 2 is generally moderately to highly compressible and exceeds a thickness of 1,0m. These soils as they occur in situ are considered unsuitable for use as a founding horizon. However with special treatment such as compaction, founding could take place on these soils.

iii) Residual conglomerate and sandstone soils and rocks in both Land Facets 1 and 2 form competent founding horizons of moderate to low compressibility. These materials occur within 1,0m of ground surface in Land Facet 1 which covers the major portion of the proposed township.

iv) Potentially very highly expansive residual siltstone soils occur in the vicinity of the existing reservoirs and cemetary (Stand 2165) on the Phase 1 area of development (see Soil Engineering Map). The stratigraphically underlying residual siltstone horizon to the north (in the vicinity of TP 27 and TP 17) is considered to be potentially moderately expansive. Foundation design should take this into account when placing structures in areas where residual siltstone soils occur.

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