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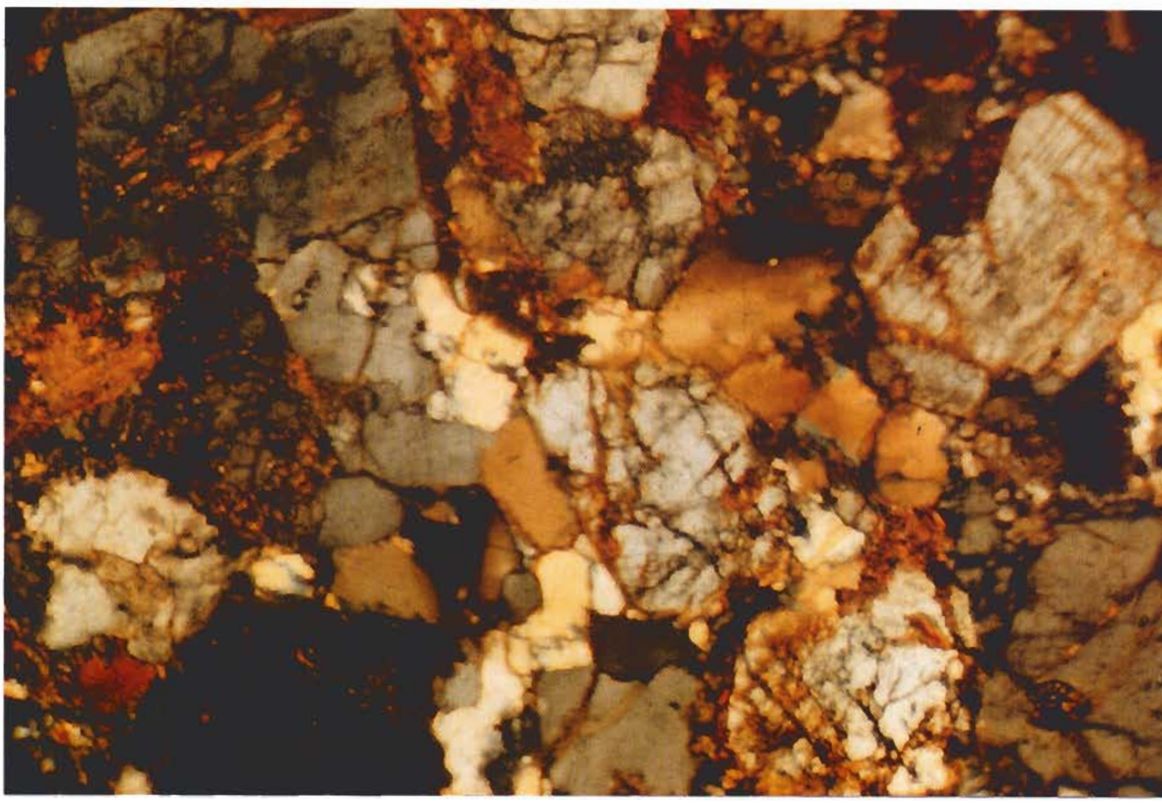

GEOGUIDE 3

TROPICAL WEATHERED IN-SITU MATERIALS

- LABORATORY TESTING

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PREFACE

This geotechnical application guide is one of a series of documents prepared by J R Cook and Professor A McGown of the Department of Civil Engineering, University of Strathclyde, United Kingdom and the Institut Kerja Raya Malaysia (IKRAM). The object of these GEOGUIDES is to provide JKR engineers with a rational and practical methodology for the investigation and geotechnical characterisation of tropically weathered soil and rock masses.

GEOGUIDE 3 outlines methodologies appropriate to the laboratory investigation of soil and rock materials whose character has been influenced by tropical weathering.

Other geotechnical application guides available are as follows:

GEOGUIDE 1	*Tropical Weathered In-Situ Materials - Their Occurrence and General Nature*
GEOGUIDE 2	*Tropical Weathered In-Situ Materials - Site Investigation*
GEOGUIDE 4	*Tropical Weathered In-Situ Materials - Geotechnical Character of Profiles.*
GEOGUIDE 5	*Tropical Weathered In-Situ Materials - Engineering Application of Characterisation.*

1.0 INTRODUCTION

It is widely recognised that there are several tropically weathered in-situ materials whose behaviour is noticeably different from normal sedimentary soils, from which the standard principles of soil mechanics were derived, Terzaghi (1958), Gidigasu (1988) and Moore and Styles (1988). Their behaviour may not be based, as in traditional soils, on stress history but on factors such as mineral bonding and soil suction, Vaughan et al (1988) and Geol Soc (1990).

Vaughan et al (1988) summarised the problems with respect to residual soils by noting that historically two general models have been developed for soil behaviour:-

i) For sedimentary clays, in which sedimentation took place in a very wet state, density is a function of stress history alone; strength and stiffness then become a function of stress history. Hence the classic subdivision into normally and over-consolidated states.

ii) For granular soils it is recognised that they may have been deposited with a wide range of densities so that stress history will have a relatively minor influence. Since density varies with grading and mineralogy as well as packing, the concept of relative density has been introduced in which the in-situ density is related to notional maximum and minimum densities.

The first model was considered irrelevant to tropical soils as stress history does not control the density. The second model, concerned with relative density, was also considered irrelevant as the in-situ density varies widely and cannot be related to behaviour, principally because of the influence of chemical bonding.

Major differences in undertaking and interpreting geotechnical laboratory tests in tropically weathered soild as opposed to sedimentary soils thus derive from the following:-

i) The materials are chemically altered and sometimes bonded rather than produced by a physical sedimentation processes.
ii) The materials are in many cases non saturated and exhibit negative porewater pressures, (soil suction).
iii) There is difficulty in obtaining high quality undisturbed samples in these materials which may have a sensitive fabric.
iv) There is difficulty in obtaining truly representative geotechnical parameters from these heterogeneous materials and masses.

In addition, a TWIMs testing programme may have to encompass a range of weathering products which include soil, rock and soil-rock materials, Fig 1.1. Such a programme would have to incorporate both soil mechanics and rock mechanics testing procedures in an integrated and overlapping schedule of testing. Materials falling within the hard soil to weak rock category are likely to cause particular difficulty with respect to sample disturbance and choice of testing procedure.

2.0 GENERAL PRINCIPLES

2.1 The Nature of the Materials to be Tested

As indicated in GEOGUIDE 1, TWIM profiles are likely to be highly variable and a testing programme needs to consider the use of both soil mechanics and rock mechanics testing procedures. The general nature of the materials to be tested should be a significant consideration in the selection of test methods. In line with the principles of classification outlined in GEOGUIDE 2 the materials may be considered in terms of being soils, rocks or soil-rock mixtures. General classification should be an early indication of the general range of test methods that will be appropriate.

2.2 Modelling Project Behaviour Conditions

The relationship between the in-situ geotechnical character of a soil-rock material or mass and the impact of the project on that material or mass is important in any investigation. This is even more the case for TWIMs, where established empirical correlations may not be appropriate and where materials may be particularly sensitive to varying degrees of project-induced disturbance. Unless the influences of the project are taken into account and related to sampling and laboratory testing, there is little hope of modelling likely engineering performance at the investigation stage, Fig.2.1.

In general terms the laboratory investigations for TWIMs should form part of an overall approach in which information recovered from the desk study, surface and sub-surface investigations in the field are closely integrated with the selection and interpretation of laboratory tests. The use of material description information in the selection of laboratory testing procedures is also strongly recommended. The observed nature of the fabric of a material can be of particular use in making decisions on the relevance, or otherwise, of particular laboratory tests.

2.3 Sample Condition and Test Selection

An impartial assessment of likely sample condition in relation to in-situ material condition is essential. This assessment should not be influenced either by optimistic estimations of a lack of disturbance or by the requirements of any analytical programmes to be used for design. A project requirement for a particular undisturbed parameter value does not necessarily mean that it can or should be supplied by direct sampling and testing methods. It may be necessary and appropriate to deduce values using indirect procedures.

Disturbance needs to be assessed both with respect to sampling in the field, transport of the sample and transfer of the recovered sample to the test apparatus in the laboratory, Idel et al (1969) and Clayton (1986). Test procedures require to be selected on the basis of project requirements, general material types, sample quality and the capability of the test laboratory Tables 2.1 and 2.2.

3.0 INDEX TESTING

3.1 Introduction

Index testing assumes a greater importance for TWIMs than for conventional materials and they may have to interpreted in a different manner. Many authors have highlighted the sensitivity of TWIMs laboratory Index test procedures to presentation/methodology etc., particularly the effects of drying temperatures, eg; Terzaghi (1958), Newill (1961) and Wesley (1973). Even partial drying at moderate temperatures may change the structure and physical behaviour of some TWIMs. Some of these changes are mineralogical and are irreversible when the material is re-mixed with water. These are reflected in changes in the Index properties derived from plasticity, shrinkage, particle size and particle density. It follows that engineering behaviour tests such as compaction, compressibility and shear strength can also be affected.

Conventional Index test data although satisfactory for some purposes, including mineralogical classification, should be used with extreme caution when correlating with engineering behaviour, and particularly non-intrinsic behaviour, as discussed in GEOGUIDE 2. The fabric of TWIMs varies considerably and may strongly influence their engineering properties.

In addition to the more commonly used Index tests there are a number of procedures and parameters which may have special significance in the investigation of TWIMs, Vaughan et al (1988) and Head (1992). These include:

i) Moisture content variation with drying temperature
ii) Void ratio and relative void ratio
iii) Variability of Atterberg limits with mixing

iv) Particle density variations
v) Collapse and swelling potential

Bulk density, void ratio and slake Index test data can be employed to perform the crucial function of facilitating correlations, Fig. 3.1.

3.2 Moisture Content

The conventional definition of moisture content is based on the loss of weight when a soil/rock material is dried to a constant mass at a temperature of between 105 and 110°C, BS1377 (1990). This loss in weight due to drying is associated with the loss of the "free water", Table 3.1. For some TWIMs, in addition to the "free" water that is available to influence engineering behaviour there may be additional water contained within the clay mineral structure that is released at these drying temperatures. The releasibility of this additional water varies with mineral types and some cases results in highly significant differences in moisture content between conventional testing temperatures and engineering working temperatures.

Comparative testing of drying temperatures on duplicate samples is a vital step in the initial stages of a TWIM laboratory investigation, Fig 3.2. If drying tests are conducted at temperatures lower then 100°C then care should be taken to ensure that a constant mass has been achieved. In some cases this may take a matter of days rather then the conventional 24 hours, Fig 3.3.

3.3 Liquid and Plastic Limit Tests

Despite certain precautions required with the procedures and interpretation of the liquid and plastic limit tests, they are an important tool in the characterisation process for TWIMs. Drying of material prior to testing should be avoided and where possible the materials should be kept as close as possible to their natural state. The methods of sample preparation and the test procedure should be clearly reported on every occasion.

Liquid and plastic limits are intrinsic properties with tests carried out on fully remoulded soil. In some materials a lengthy period of the working is required to achieve this. As the amount of manipulation to which a soil is subjected determines the extent to which the soil fabric is broken down the sensitivity to mixing requires verification usually by using a range of mixing times prior to testing, eg 5,10, 30 and 45 minutes.

The Liquid Limit test, as currently described in BS 1377 (1990), utilises the cone penetrometer. The procedure of removing soil particles >425 μm and recalculating the Plasticity Index on the basis of the removed mass can present difficulties in TWIMs. The use of a large scale cone penetration liquid limit test, as suggested by Vaughan et al, (1988) may be more appropriate, provided adequate correlations have been established, Table 3.2.

Correlations that utilise the location of a soil on a conventional A-line chart to indicate other geotechnical parameters may be misleading for TWIMs, particularly for materials where the fabric of the engineering state may be very different from that for the intrinsic state.

3.4 Shrinkage Limit Tests.

Some TWIMs exhibit considerable volume change in response to wetting or drying and the shrinkage limit test may provide an indication of an intrinsic capacity for shrinking or swelling.

The shrinkage limit test, BS1377 (1990) was initially intended for undisturbed samples although remoulded material can be used, Head (1992). Linear shrinkage BS1377 (1990) is a simpler test on remoulded materials, which gives a linear rather than volumetric shrinkage. The established relationship between linear shrinkage and the Plasticity Index for sedimentary soils may not hold true for TWIMs, Fig. 3.4.

It is important to differentiate between materials that shrink irreversibly and those that expand again on re-wetting.

3.5 Particle Size Distribution (PSD)

The complex relationship in tropical wathered materials between particle size, fabric and the nature of the particles mitigates against the widespread use of the PSD unless the correlation between laboratory PSD and in-situ or project working PSD size is understood. Materials which may have the in-situ appearance of a sand can give a laboratory PSD of a silt or clay as a result of the breakdown of relict parent material clasts. In many cases this test may be used more as an indicator of mineralogy or of general trends rather than an absolute definition of particle size or in-situ character, Fig. 3.5.

Drying of soil should be avoided. Detailed procedures for particle size tests should be assessed in the light of both the nature of the material involved and the objective of the proposed test. If sedimentation testing is being carried out then it is necessary for a proper dispersion of the fine particles. Alkaline sodium hexametaphosphate has been found to be suitable for a wide range of soils, including TWIMs. In some cases a stronger concentration of solution may be required for TWIMs. Occasionally an alternative dispersant such as trisodium phosphate may be more effective. Comparative trials may be required at an early stage. In all cases the nature and concentration of dispersants should be reported.

3.6 Density

The term 'Particle Density' (Ps) is replacing the previously used term 'Specific Gravity' (Gs) in current British practice, BS 1377 (1990). Particle density has the same numerical value as specific gravity although it has the units Mg/m^3 rather than being dimensionless.

TWIM profiles may have highly variable particle densities, Table 3.3, and hence it should be measured whenever it is required in the calculation of other properties rather than using assumed values. The test should be conducted at its natural moisture content and due regard should be taken of the moisture availability problems discussed above, BS 1377 (1990).

In addition to being a requirement for geotechnical analysis, the in-situ bulk density (P) and the related dry density (P_d) can prove to be useful index tests, particularly as they may be used to correlate between soil and rock materials. Bulk density may be recommended using a variety of test procedures as summarised in Table 3.4.

3.7 Volume Change

The potential for volume change in unsaturated TWIMs is enhanced both by the occurrence of neoformed swelling clays and a sensitive material fabric which can lead to collapse on flooding. Although indications for such behaviour may be given by other Index tests or by fabric examination, it is recommended that direct testing methods are employed where such behaviour is suspected.
Swelling tests fall into three general procedures; radially confined swelling pressure tests, radially confined swell-amount tests and free swell tests. The first two procedures utilise the standard oedometer equipment and hence necessitate a sample capable of being extruded or cut into the required shape.

The swelling pressure test measures the load required to give zero swell on flooding, while the swell-amount test measures the amount of swell either under minimal load or project working load, BS 1377 (1990). Similar procedures to the above are presented in ISRM (1981). ASTM : D4829 (1990) suggests the use of a swell index (EI) based on the change in sample height based on a 50% saturation. It is recommended that the majority of testing programmes aimed at reproducing project conditions should select the swell-amount test as being the most appropriate. This test forms part of the double oedometer procedure, Jennings and Knight (1957) when it is used in conjunction with standard consolidation procedures involving identical non-flooded samples for comparison purposes.

Testing should normally be undertaken on undisturbed samples where possible as remoulding can allow water access to clay minerals that in the natural state may be locked into other non-swelling mineral assemblages. The exception to this would be the case where the swelling properties of an unsaturated fill was being considered.

The free swell test (ISRM 1981) requires a cylindrical or rectangular prism sample competent enough to withstand unconfined soaking and involves the monitoring the swell on the axial faces by means of attached gauges.

The collapse test BS 1377, (1990), also utilises standard oedometer equipment and entails the flooding of the sample under a constant load, Fig 3.6. The flooding load may either be related to anticipated project conditions or may be a standard value as suggested by Jennings and Knight (1975). They proposed a standard load of 200 kPa as part of their Collapse Potential Index (CPI), Table 3.5.

3.8 Point Load Index

The point load index test is a simple and inexpensive procedure that can be used to gauge the unconfined compressive strength of competent materials. It is of particular use in-situations where good, representative, core samples are available, Broch and Franklin (1972). Points of caution with respect to its use in TWIM environments in particular are:

(i) Surface crushing of samples invalidates the test procedure.
(ii) Index values are sensitive to changes in moisture condition.
(iii) The test requires several identical samples for adequate indexing, (10 minimum).
(iv) Correlations with compressive strength may have to be derived for different material types.

3.9 Slake Durability

The Slake Durability Index Test, (ISRM, 1981), in addition to being a useful performance indicator can have a significant role in indexing materials in the rock to very stiff soil range and may be linked to the field slake test over a range of materials, Fig 3.7. The procedure requires competent lumps of material for testing and fragile samples require careful handling in transportation between the field and laboratory. The combination of slake index with plasticity has been suggested as a useful means of presenting results for argillaceous materials, ISRM (1981).

3.10 Calculated Indices

A number of material indexes may be calculated which can play a significant role in characterising TWIM profiles, eg void ratio, porosity, activity, liquidity index, Fig. 3.8. However, empirical relationships and classifications established for temperate materials cannot be used.

The use of soil activity as an aid to interpretation in conjunction with plasticity has been advocated by Vargas (1988). Vaughan et al (1988) recommended the use of Relative Void Ratio as suitable index test in tropical soil-rock profiles..

4.0 Undisturbed Behaviour Testing

4.1 Introduction

The measurement of undisturbed behaviour in the laboratory requires undisturbed samples of high quality. However, there can be considerable difficulty obtaining high quality representative samples, particularly in the more weathered horizons. Combined with the procedural problems imposed by the frequently under-saturated nature of the materials, sampling problems mean that so-called undisturbed soil and weak rock test data often have to be interpreted with caution.

More indurated materials such as duricrusts or less weathered rock materials will suffer less from the effects of material disturbance but test data still require interpretation as discontinuities rather than the material play an important role in mass behaviour.

Whatever test procedure is involved the orientation, nature and condition of fabric should be carefully considered and noted prior to testing.

4.2 Triaxial Compression

Triaxial compression test procedures play a large role in geotechnical testing programmes but have largely been derived for use on traditional sedimentary soils in temperate climates, Table 4.1. Their application to partially saturated and fabric-influenced materials in climatic environments that impose rapid changes in moisture condition can cause difficulties both in establishing relevant test procedures and in the modelling of site conditions. The standard procedure of imposing saturation on under-saturated materials, Head (1986) appears difficult to justify on the grounds of modelling site conditions

A soil that is partly saturated consists of a three phase system; gas (including air and water vapour); water and solid particles. Analysis of partial saturation is complex. The determination of the effective stresses in partly saturated soils requires measurement of pore air pressures as well as pore water pressure. The following extended Mohr-Coulomb equation has been proposed for the solution of partial saturation problems, Fredlund (1987):

$$\tau = c' + (\sigma_n - u_a)\tan\phi' + (u_a - u_w)\tan\phi^b$$

Where u_a= pore air pressure; u_w= pore water pressure

Brand (1985) comments on the drawbacks of standard triaxial procedures in the derivation of parameters for rain-induced slope failures. These failures may take place under conditions of almost constant total applied stesses but with a decrease in suction. This is in contrast to standard triaxial testing, Fig. 4.1.

Despite the above, undisturbed triaxial testing of suitable samples can be of practical use in the TWIM environment although the resultant parameters must be interpreted in the light of field data and may in some cases serve only as a back-up to empirically established figures. The following comments apply to the general use of triaxial testing of TWIMs:

i) Multistage triaxial testing is not recommended for TWIMs especially in those with an unstable fabric liable to collapse, brittle soils and those that show strain-softening characteristics.
ii) Quick undrained tests are not suitable for unsaturated materials.
iii) Special procedures likely to be required for high void ratio or bonded materials, eg low confining pressure, slow loading rate, Geol. Soc. (1990)
iv) Significant numbers of slope failures in tropical environments are shallow in nature and analysis of these would require parameters derived at appropriate (low) confining pressures.

4.3 Direct Shear

The direct shearbox procedure is a straightforward test that is relatively simple to perform. It has an easier, and potentially less disturbing, sample preparation procedure than for the triaxial test. An added advantage can be gained in fabric-sensitive materials by reverting to the use of a circular shear box which eliminates problems of sample disturbance at box corners.

Research work on the Gerik-Jeli Highway has indicated the advantages to be gained by a circular shear box in conjunction with hand-cut circular tube samples, Fig 4.2 and 4.3, McGown and Cook

(1994). Results from this project have been obtained on materials strongly influenced by fabric, mainly in the Grade V and VI materials but occasionally in grade IV materials. The test, however, suffers from several disadvantages, the main one being that drainage conditions cannot be controlled. Porewater cannot be measured and therefore only total normal stress can be determined. The total stresses are equal to the effective stress if full drainage is allowed. This requires a suitable strain rate to be adopted. An additional problem is that the shear stress on the predetermined failure plane is not uniform, failure occurring progressively from the edges towards the centre of the specimen. The major advantage of the test is its simplicity and the ease of specimen preparation. Double shear box tests involving both saturated and natural moisture conditions on duplicate samples can be used to investigate the influence of moisture content on in-situ performance.

The direct shear apparatus may be adapted for testing weak rock materials and, more usefully, can be used to test discontinuity shear strength, provided the problems of representative sampling can be overcome, ISRM (1981).

4.4 Unconfined Compression

Unconfined compression testing may be used for testing the strength of the more robust tropically weathered materials; from hard soils to strong rocks. Good intact core samples recovered using high quality drilling techniques are particularly adaptable to this technique. Care must be taken in preserving the in-situ moisture condition of the samples and forming the parallel axial faces.

4.5 Consolidation

It is now reasonably accepted that the standard oedometer test is of direct application only for intact clays in the full analysis of amounts and rate of settlement, Head (1994). The use of this test for fabric-influenced TWIMs is not recommended, although adaptions of the test procedure are suggested as Index tests for swell, and collapse.

In general the use is recommended of the more adaptable Rowe Cell, which can accommodate larger samples, Rowe and Barden (1966). There is now substantial evidence that larger, good quality, undisturbed samples provide a better model of in-situ behaviour, Rowe (1972), Smith (1978) and Moetriono (1991). In addition, Rowe Cells provide much greater versatility in terms of drainage conditions.

Careful testing, particularly in the larger cells, can be used to identify the presence of inter-particle bonding in tropical weathered soils, Vaughan et al (1988). The presence of a yield stress gives the consolidation curve the appearance of an over-consolidated sedimentary clay, Fig 4.4.

4.6 Dispersion and Erosion

The principal tests involved in the determination of material erodability are as follows:-

i) Pinhole Test.
ii) Crumb Test.
iii) Dispersion.

The first two tests rely largely on the qualitative observation of behaviour allied to empirical correlation with known behaviour. The weakly bonded and fabric-influenced nature of tropically weathered materials makes it very difficult to prepare samples for the Pinhole Test. The dispersion test depends on the comparison of treated and untreated hydrometer PSD results again allied to correlation with known behaviour . There is little available data of the effectiveness of these tests for undisturbed TWIMs. More applicable data may be recovered from the close observation of field exposures.

4.7 Soil Suction

Many soil-rock profiles in Malaysia, particularly on slopes, are known to be in an un-saturated condition. As a result, their in-situ geotechnical performance is likely to be influenced by variations in soil suction, (negative pore water pressures), in response to rainfall infiltration.

Although in-situ soil suction may be measured with suitably sophisticated equipment it is not a routine procedure. An alternative approach is to measure suction indirectly in the laboratory by means of the filter paper method, Chandler and Gutierrez (1986) and Chandler et al (1992). This method involves placing Whatman's No. 42 filter paper in contact with the soil for a period of 7 days and measuring the amount of moisture taken up by the paper (Wfp). Matrix suctions may be arrived by the following empirical relationships, Chandler et al (1992).

$$\text{Suction (kPa)} = 10^{(4.84-0.0622Wfp)} \quad ; \text{for } Wfp < 47\%$$

$$\text{Suction (kPa)} = 10^{(6.05-2.48\log Wfp)} \quad ; \text{for } Wfp > 47\%$$

Research work on the EWH has involved the use of undisturbed hand trimmed tubes samples extruded in the laboratory with filter paper sandwiched and sealed between two cut sections. Typical results are presented in Fig 4.5. The direct effects of suction may be examined by the use of the double direct shear test procedure identified in Section 4.3.

4.8 Permeability

Permeability of undisturbed samples can be derived from data obtained from consolidation tests; either triaxial, standard oedometer or Rowe cell. It may also be obtained from specific procedures using the permeameter equipment. Laboratory derived material permeabilities for TWIMs should be viewed with extreme caution in terms of extrapolation to mass in-situ permeabilities.

5.0 DISTURBED BEHAVIOUR TESTS

5.1 Introduction

The amount of disturbance imposed on a fabric-influenced material may vary considerably depending on the project or sampling conditions. A fundamental aspect of the characterisation of materials for civil engineering construction is in recognising, and establishing various levels of behaviour based not only on scale but upon the influencing elements. The recognition of these levels of behaviour allows an important distinction to be made between inherent in-situ characteristics and those that become apparent during various aspects of construction. This facilitates a more relevant correlation between in-situ character, laboratory testing and likely project performance, Table 5.1, Nik Ramlan Hassan et al (1994).

As an aid to understanding the variations and significance of disturbance, it is frequently useful to establish a base level of totally remoulded behaviour in order to investigate the intrinsic properties of materials, Vaughan (1992) and Burland (1990). Both the preparation of samples for disturbed testing and the subsequent data interpretation, assume great importance in fabric-influenced materials. The following sections outline testing methods in relation to the potential use of TWIMs in construction.

5.2 Testing of TWIMs as Fill Material.

It has been demonstrated that the sample condition and preparation, and the compaction methodology have a significant effect on the shape of the density - moisture curve, Wesley (1973). The following points are therefore particularly relevant to the testing of the density-moisture relationship for the use TWIMs as fill materials:

i) Drying of samples should be avoided as much as possible.
ii) Fresh samples should be used for each moisture point.
iii) The susceptibility of measured moisture content to drying temperature must be appreciated and the amount of 'engineering' moisture that will be available for site working must be assessed.
(iv) The relationship between the laboratory compactive effort and that which will be imparted on site must be understood.

It is recommended that the Californian Bearing Ratio (CBR) test in tropical environments incorporates a soaking procedure. The CBR test is frequently closely related to compaction testing for the pavement supporting elements of a road-fill. As such it is important to form CBR samples at conditions of density and moisture appropriate to those likely to occur on site.

The Moisture Condition Value (MCV) test, Parsons (1976) is now an accepted procedure in British practice. Its use outside the UK is strictly limited and little or no information is available as to its usefulness in fabric-influenced tropical soils, Lee (1994). The test relies heavily on the establishment of empirical relationships in reasonably homogenous materials, therefore, its use in TWIMs is not recommended until extensive correlation testing has been undertaken.

The triaxial strength procedures testing for remoulded TWIMs are more straightforward than undisturbed materials in that problems of sample representability and a probable lack of saturation are lessened.

In some cases the testing of remoulded slurry materials in quick undrained conditions and in the oedometer can yield valuable information with respect to base-line intrinsic properties in terms of Fig. 5.1., Vaughan (1993) and Imam (1993).

5.3 Testing of TWIMs as Aggregate and Pavement Materials

The more robust products of tropical weathering such as true lateritic gravels (ferricrete) can be safely used as pavement materials, Gidigasu (1972) and Charman (1988). At the other end of the spectrum the initial stages of tropical weathering can have severely deleterious effects on the engineering performance of hard-rock aggregates, Wilde (1976). Methods of testing of aggregates are fully dealt with by Smith and Collis (1993) and Table 5.2 summarises the principal physical testing method derived from this publication.

6.0 CHEMICAL, MINERAL AND FABRIC ANALYSIS

6.1 Introduction

The problems raised by the inadequacy of many existing investigation procedures to deal effectively with sampling fabric influenced materials such as TWIMs has been well reported, eg; Rowe (1972), Hobbs et al (1988), and Mori (1989). Characterising the mineralogy and fabric of TWIMs requires a number of specialist techniques, Wilson (1987).

Care is required in the preparation of suitable samples and also in the correlation of results to site conditions, bearing in mind the very small sizes of samples involved.

6.2 Testing Procedures

Standard chemical tests. There are a number of standard chemical tests that are routinely undertaken for civil engineering works, Table 6.1, Head (1992).

Chemical data have always been a key part of the classification of clay minerals and hence can be of importance in understanding the character of TWIMs. Chemical data from whole-material samples may also be used directly in the classification of TWIMS; sesquioxide ratios have, for example, frequently been reported as a defining parameter, Gidigasu (1972). Major element chemical tests may also be used as an aid in the interpretation of XRD results.

Principal non-destructive specialist methods of whole-material chemical analysis include Atomic Absorbtion, Flame Emission and X-Ray Fluorescence. Elements normally analyzed, by convention as % of oxides, are: SiO_2, Al_2O_3, Fe_2O_3, FeO, CaO, MgO, K_2O, N_2O, TiO_2, MnO, H_2O, P_2O, CO_2.

Binocular Optical Microscopy. This may be effectively utilised in the examination and classification of soil or rock fabric and mineralogy. Some care is required in the preparation of suitable samples and in the correlation of results to site conditions, bearing in mind the sizes of samples involved. Instruments may be fitted with camera attachments such that photographs of fabric and mineralogy may taken for later examination or illustration.

Thin Section Microscopy. This is the traditional geological method of examination of the mineralogy and fabric of thin sub-samples of hand specimens under both plane and polarized light. Thin sections may be used for the examination of fabric and texture and as a means of establishing mineral composition by point-count techniques, Irfan and Dearman (1978).

Thin sectioning has limitations in the more weathered or more friable TWIMs. Specialist impregnation techniques may be employed to strengthen materials prior to slide manufacture, Fitzpatrick (1984). Identification of fine clay minerals is very difficult and the use of thin sections alone for the mineralogical examination of mudstones and shales is not recommended. As with the binocular microscope the use of camera attachments can be very useful. It may be necessary to undertake a series of test photographs using different shutter speeds and apertures before a procedure relevant to the particular microscope and material types is arrived at.

Scanning electron microscopy (SEM) is being increasingly used as a means of examining micro-fabric and mineralogy, Collins and McGown (1983). The use of stereoscopic photographic pairs of photographs increases the effectiveness of interpretation. The cost of equipment and the care required in sample preparation are drawbacks to this procedure. The very small size of sample examined needs to borne in mind when using this method and it is necessary to have a clear idea of the nature of the material and the information required when operating the SEM.

The electron microprobe, which is essentially an X-ray fluorescence spectrometer attached to the SEM equipment, allows a chemical analysis to be made of identified spots during the microscope examination.

X-ray diffraction (XRD) has been widely used in the identification of tropical soil mineralogy. There are established standard approaches to sample preparation and interpretation, Wilson (1987), Brindley and Brown (1980). Variations in test procedure, for example by using glycolation or high temperature drying, are essential in the identification of some clay minerals commonly found in the tropical environment.

The XRD procedure produces a trace with peaks generally indicative of the presence of minerals. It is not a truly quantitative procedure and requires a correlation with other mineralogical or chemical evidence before definitive mineral percentages can be arrived at.

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TABLES

Table 2.1 Sample Quality Assessment

CHARACTERISTICS	SAMPLE CLASS
General Material Boundaries	1 2 3 4 5
Classification (PSD, Att.Limits) and Remoulded Earthwork (MDD, CBR)	1 2 3 4
Moisture content Mineralogy	1 2 3
Density, Void Ratio	1 2
Undisturbed Strength, Deformation and Consolidation	1

Adapted from Idel et (1969) and BS5930 (1981)

Table 2.2 Suggested Sample Classes for Typical TWIMs Samples

SAMPLE PROCEDURE	SAMPLE CLASS A	B	C	COMMENT
Wash Returns	5	5	5	Material boundaries only
SPT Tube	N	3	3	Split for fabric/structure examination
Open thin wall sampler	N	1	2-3	Much more disturbance it driven rather than pushed
Single tube core	4	5	5	Not recommended
Double tube core	2	4	4	Effectiveness increases with core size and liner
Triple tube core	1	2	3	Should be a minimum used in sensitive soils
Mazier/Pitcher	1	1	2-3	May be expensive
Bulk (Pit)	4	4	4	Opportunity for large samples for procedure correlations
Block (Pit)	1	1	1	
Tube (Pit)	3	3	3	Small tubes required for moisture content and mineralogy analysis in some materials

Notes:

A: Pedogenic material
B: Non fabric-sensitive soil
C: Fabric-sensitive soil

1,2,3 etc = Sample Classes
N = Not Applicable

Table 3.1 Categories of Water

CATEGORY	DESCRIPTION	AVAILABILITY
Structural Water	Water held within the structure of component minerals	Generally not removable below 110°C except for clays such as halloysite, allophane and gypsum.
Strongly Adsorbed Water	Held on particle surface by strong electrical attraction.	Not removed by drying at 110°C.
Weakly Adsorbed Water	Held on particle surface by weak electrical attraction.	Can be removed by drying at 110°C but not by air drying
Capillary Water ("Free" Water)	Held by surface tension	Removed by air drying.
Gravitational Water ("Free Water)	Moveable water held in the material voids	Removable by drainage.

Table 3.2 Cone Penetration Liquid Limit values

MATERIAL	GRADE	LIQUID LIMIT % STANDARD CONE	LIQUID LIMIT % LARGE CONE	% PASSING 425μ
Shale	V	95	80	93
Shale	VI	90	85	100
C. Granite	III	56	51	44
C. Granite	VI	84		
Phyllite	VI	76	69	75
F. Schist	VI	80	60	80
F. Schist	V-VI	52	45	95
Mica Schist	IV	39	33	50
	V	81	76	100
	VI	76	67	85
F. SST	VI	66	47	65
M. Granite	IV	35	29	33
M. Granite	V	35	30	31
M. Granite	VI	53	41	46
F. Granite	V	59	43	43
F. Granite	VI	72	49	48

Table 3.3 Typical Particle Densities

MINERAL	PARTICLE DENSITY Mg/m^3
Calcite	2.71
Feldspar- orthoclase	2.50 -2.60
Feldspar - plagioclase	2.61-2.75
Gibbsite	2.40
Haematite	4.90-5.30
Halloysite	2.20-2.55
Kaolinite	2.63
Magnetite	5.20
Quartz	2.65

Table 3.4 Methods of Density Measurement

METHOD	REFERENCE	COMMENT
Measured dimensions. Hand trimmed from block or tube.	Part 2: 7.2 BS 1377 (1990)	Material has to be suitable for trimming; eg robust soil or weak rock.
Measured dimensions. Sample within tube.	Part 1: 8.4 BS 1377 (1990)	Used where extrusion may disturb sample; eg loose or weakly bonded soil material.
Water displacement (waxed sample)	Part 2: 7.4 BS 1377 (1990)	Simple test used for irregular shaped water sensitive samples.
Weighed in Water (waxed sample)	Part 2: 7.3 BS 1377 (1990)	As above, generally more accurate.
Weighed in water (non waxed sample)	ISRM (1981), Part 1	Used for irregular lumps of rock-like material not susceptible to swelling or slaking.

Table 3.5 The Collapse Potential Index

COLLAPSE POTENTIAL INDEX (CPI)	PROBLEM SEVERITY
<1	No problem
1 to 5	Moderate trouble
5 to 10	Trouble
10 to 20	Severe trouble
>20	Very severe trouble

$$CPI = (\delta e / 1 + e_0) \times 100\%$$

δe = Change in voids ratio on saturation
e_0 = Initial voids ratio.

Table 4.1 The Use of Triaxial Compression Tests for TWIMs

TEST	COMMENT
<u>Quick-Undrained QU</u>. No drainage during application of either confining pressure or deviator stress. Rapid strain rate	Total stress measurement, not strictly applicable to unsaturated materials. Foundation stability analysis. End of construction earth retaining structure analysis. Fill short term. Cut-slopes during construction.
<u>Consolidated-Quick Undrained C-QU</u>. Drainage during application of confining pressure, none during application of deviator stress. Rapid strain rate	Total stress measurement, not strictly applicable to unsaturated materials. Foundation stability analysis
<u>Consolidated Undrained CU</u>. Drainage during application of confining pressure, none during application of deviator stress. Strain rate function of pore pressure equalisation	Pore pressures usually measured to give effective stresses. Long term earth retaining structure analysis. Fill long term. Natural slopes first time failure. Cut-slopes long term.
<u>Consolidated Drained CD</u>. Full drainage during application of confining pressure and deviator stress. Strain rate function of pore pressure equalisation	Effective stress measurement. Long term earth retaining structure analysis. Embankment during construction. Natural slopes first time failure.

References for testing procedures: BS1377:1990:Part 7; Head, Vol 2 (1994) [undrained]; Head Vol 3 (1986) [drained].

Table 5.1 General Divisions of Geotechnical Behaviour

BEHAVIOUR PATTERN	DESCRIPTION	LABORATORY MODELLING	PROJECT ACTIVITY
Intrinsic Remoulded, de-structured material	Behaviour a function of particle type (mineralogy),shape and size (texture). Dependant on moisture condition.	Completely remoulded index tests	Well compacted fill, haul road performance, erosion.
Meso-Structured Undisturbed material.	Behaviour is a function of intrinsic properties and the material fabric and meso-structure.	Standard "undisturbed" testing, triaxial, shear box, oedometer etc	Possibly lightly compacted fill, erosion, aggregates.
In Situ Mass Macro-structured mass	Behaviour a function of intrinsic and meso, and macro-structural properties of the mass and component materials, allied to the influence of relict mega-discontinuities and material boundaries	Only possible directly by combining relevant material tests with macro-structural data to give a mass character. Indirectly by semi-empirical, terrain correlation or back analysis procedures .	Cut slopes, foundations

NOTES:

Texture:	The morphology, type and size of component particles
Fabric	The spatial arrangement of component particles
Discontinuities	The nature and distribution of surfaces separating elements of fabric, material or soil-rock mass
Structure	The fabric, texture and discontinuity patterns making up the soil-rock material, mass or unit.

The above may be described at number of scale levels:

Micro: <0.5mm	Generally only described with the aid of SEM or petrographic microscope.
Meso: 0.5-5mm	Generally seen with the aid of field microscope or good hand lens.
Macro: 5mm-50m	Patterns visible to the naked in the field
Mega: >50m	Patterns that become apparent by means of maps or remote sensing, although individual elements may be visible at field level.

Table 5.2 Methods of Aggregate Testing

TEST	REFERENCE	COMMENT
Physical Tests		
Aggregate Grading	BS 812 Part 103:1985	>5mm = coarse aggregate.;<5mm = fine aggregate
Aggregate Shape	BS 812 Part 105: 1989	Flakiness, Elongation, Angularity, Roundness
Density	BS 812: 1975	Includes dry, saturated and saturated surface dried
Water Absorption	BS 812: 1975	Frequently a key specification factor.
Aggregate Shrinkage	BRS Digest 35	Can be a key factor in concrete aggregates
Mechanical Tests		
Aggregate Impact value (AIV)	BS 812 Part 112: 1990	Simple portable test. Use soaking test in TWIMs
Aggregate Crushing Value(ACV)	BS 812 Part 110:1990	Related to AIV
10% Fines	BS 812 Part 111:1990	Derivation of the ACV
Point Load Index	ISRM 1981	See section 5
Los Angeles Abrasion (LAA)	ASTM C131	Correlates with AIV/ACV
Polished Stone Value (PSV)	BS 812 Part 114: 1989	
Slake Durability Index	ISRM 1981	See section 5
Sulphate Soundness	ASTM C88	Can be very useful for marginal material definition
Chemical Tests		
Chloride Content	BS 812 Part 117:1988	TWIM aggregates may require fine grinding prior to test.
Sulphate Content	BS 812 Part 118:1988	Total acid-soluble sulphate content.
Organic Content	BS1377	May be of limited value
Alkali reactivity	ASTM C227	Mortar bar test; also gel pat (Jones and Tarleton , 1958)
Adhesion Test	TRL 1962	Use aggregate and bituminous binder.
Petrographic Examination	ASTM C295; Smith and Collis Chap.2	General objectives:
Macroscopic	GEOGUIDE 2	i classification
Thin Section	see section 6	ii correlation of performance
X-ray diffraction	see section 6	iii detection of deleterious constituents eg alkali reactivity.

Table 6.1 Standard Chemical Tests for Civil Engineering Soils and Groundwater

TESTt	REFERENCE IN BS1377:1990	COMMENT
pH	Part 3.9	
Sulphate content		Class. as per BRE Digests 250
Total sulphates in soils	Part 3: 5.2, 5.5	Expressed as total SO_3%.
Water soluble sulphates in soils	Part 3: 5.3, 5.5, 5.6	Expressed as total SO_3%
Sulphates in groundwater	Part 3: 5.4-6	Expressed g/l or ppm
Organic content	Part 3:3	Suitable for most soils; ties in with pH test.
Carbonate content	Part 3:6.3-4	Expressed as a CO_2 %.
Chloride content		Expressed as amount of chloride to 0.01%
water soluble	Part 3: 7.2	
Acid soluble	Part 3: 7.3	
Loss on ignition	Part 3:4	Potentially unreliable in materials containing clay minerals, especially halloysite or allophane.

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FIGURES

Figure 1.1 Typical Range of TWIM Strengths

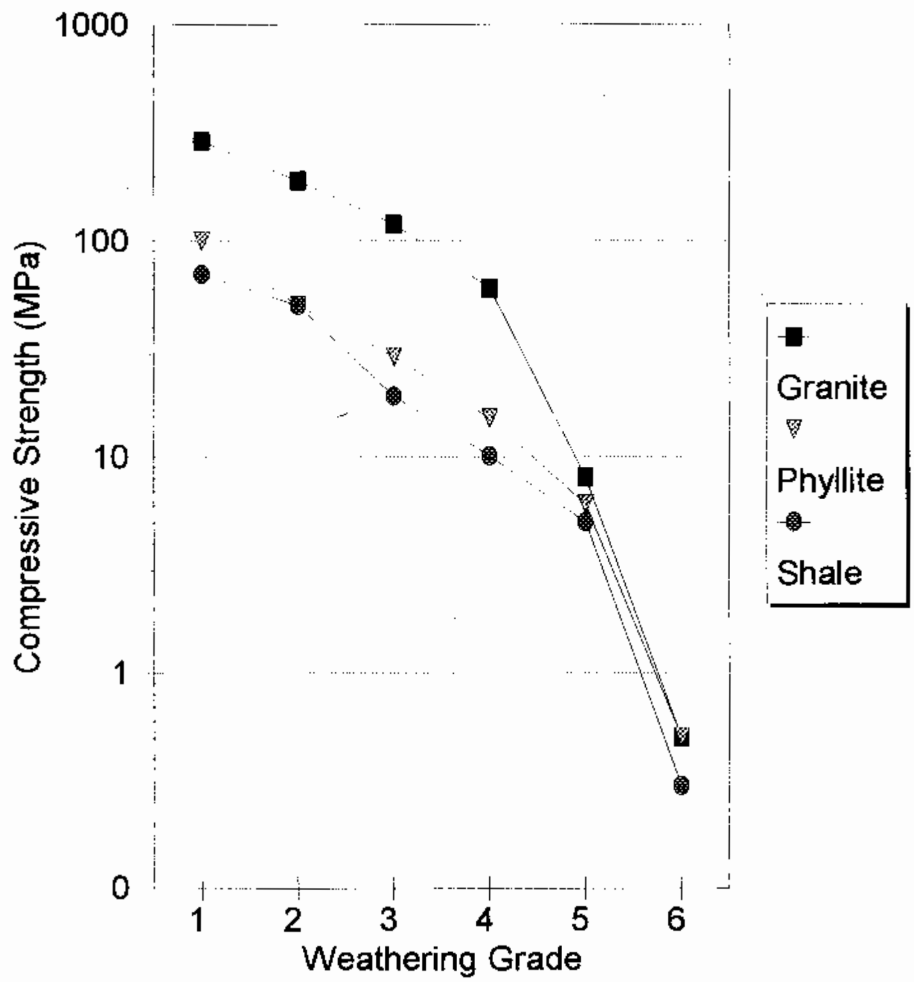


Figure 2.1 Relationship Between Character, Project and Performance

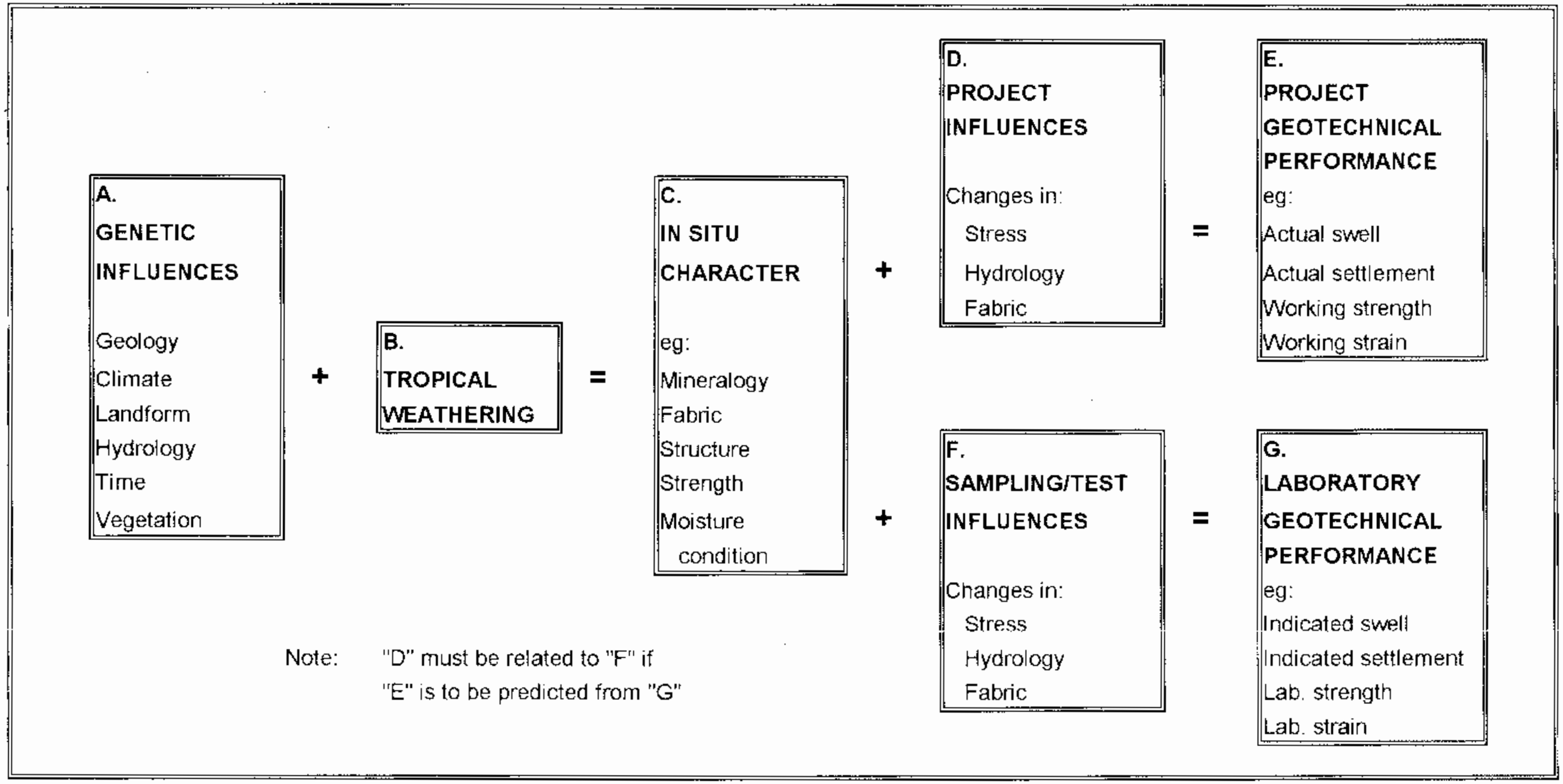


Figure 3.1 Index Correlation Tests on Fine Grained Granite

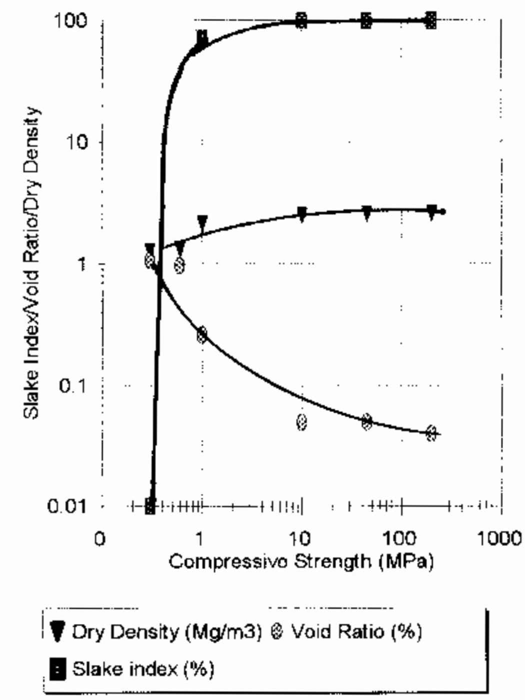


Figure 3.2 The Effects of Drying Temperature on Moisture Content

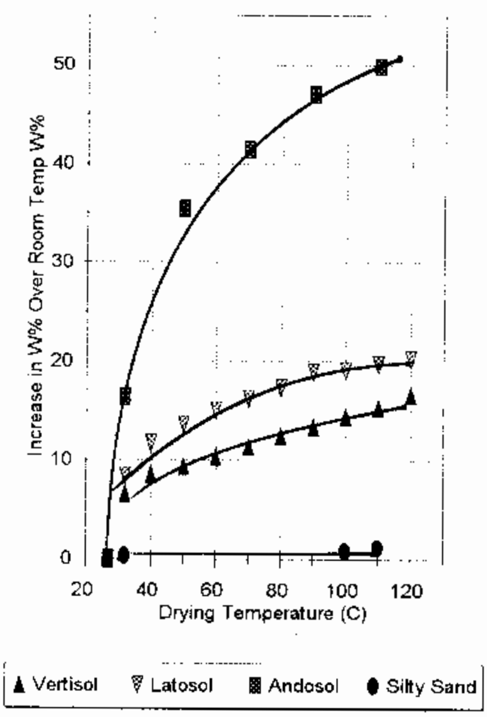


Figure 3.3 Influence of Time Required for Moisture Content Testing

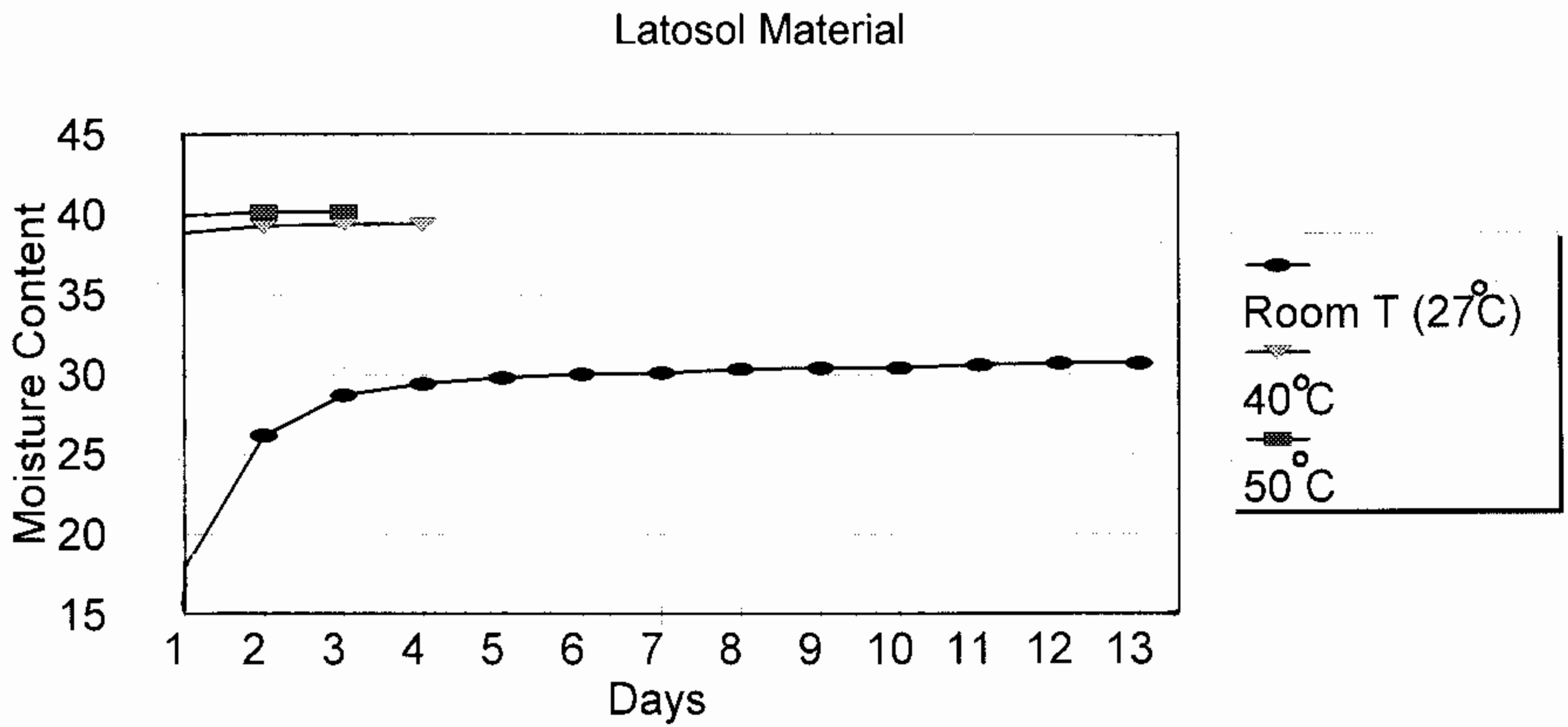


Figure 3.4 Plasticity Index Vs Linear Shrinkage for Grades V-VI TWIMs

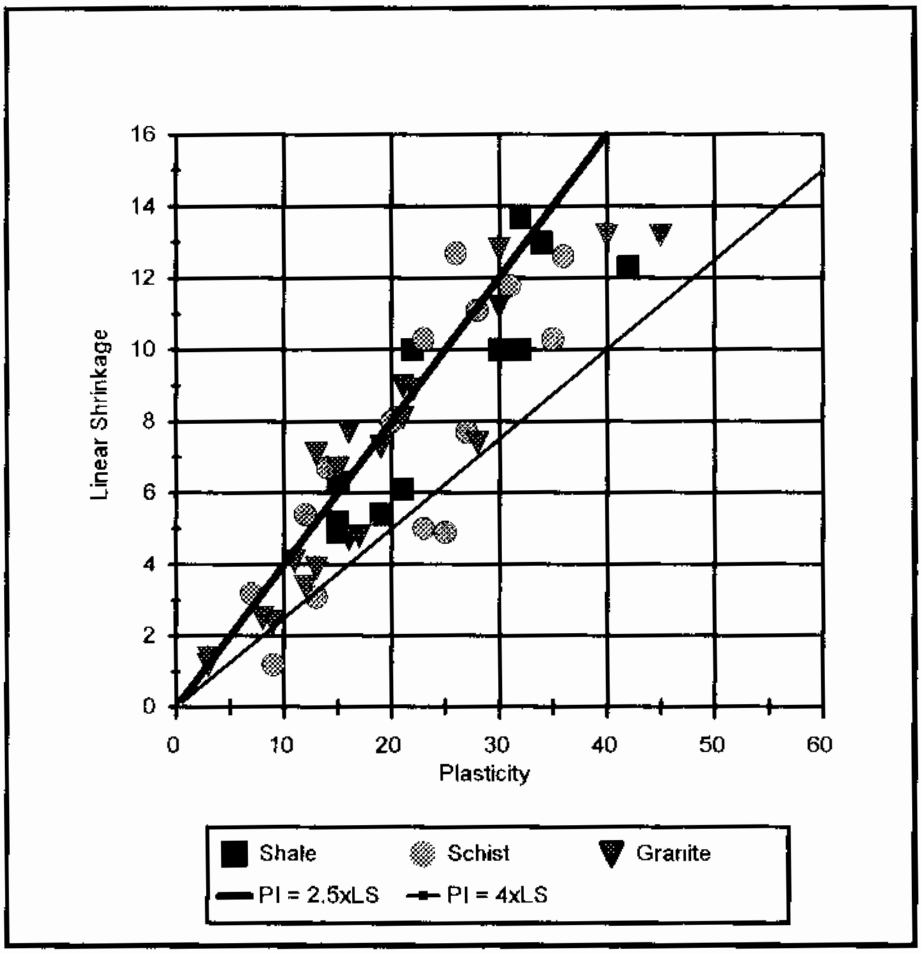
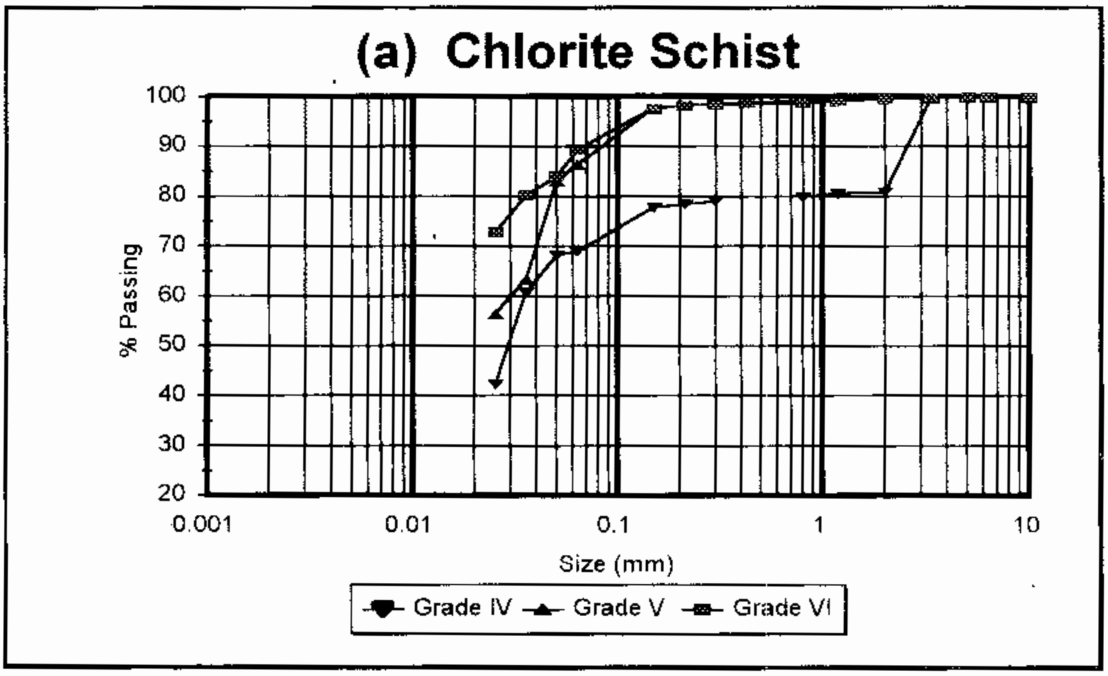


Figure 3.5 Particle Size Trends in Response to Weathering



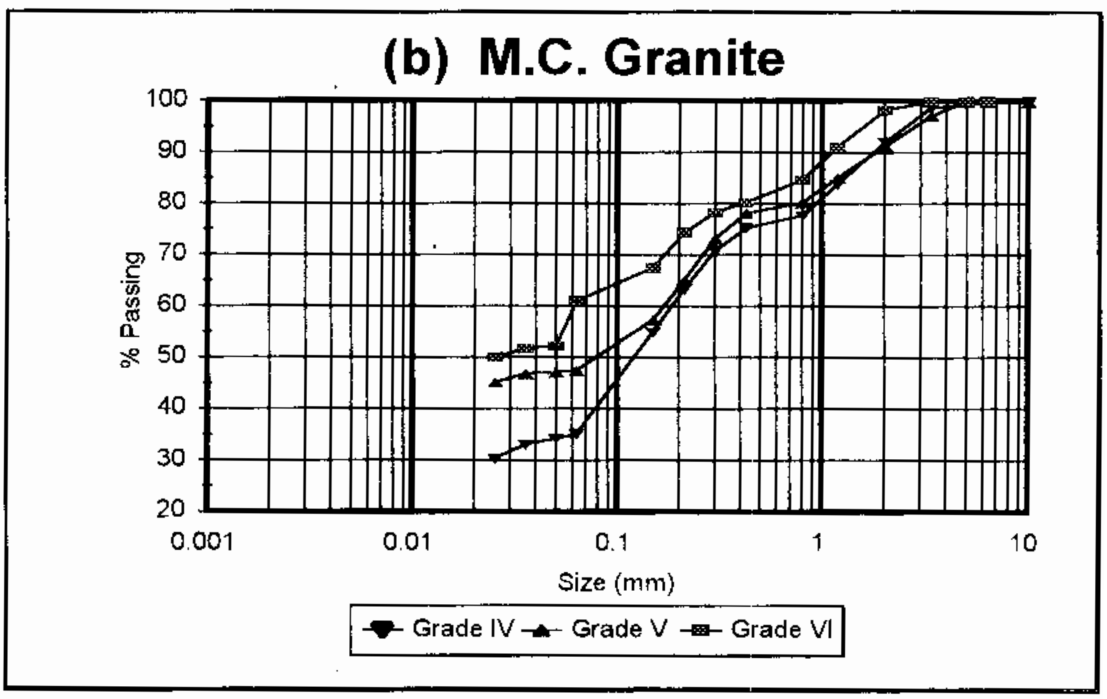


Figure 3.6 Typical Collapse Test Results

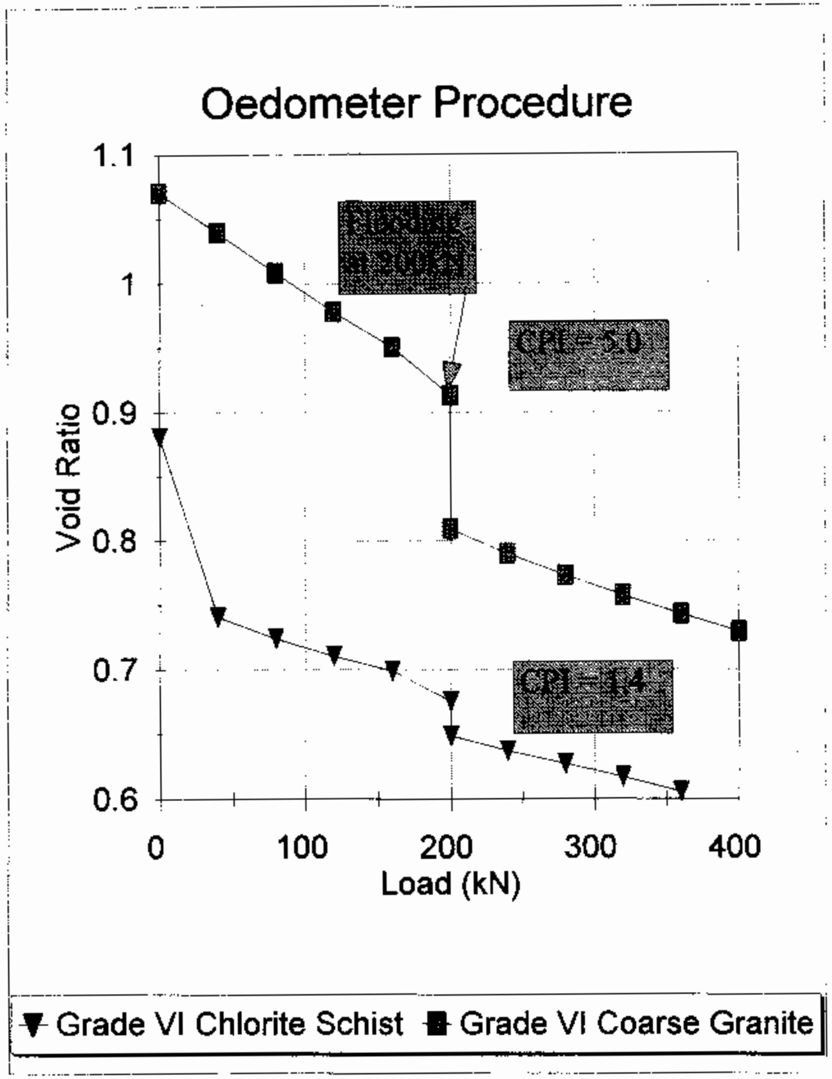


Figure 3.7 Typical Slake Durability Test Results

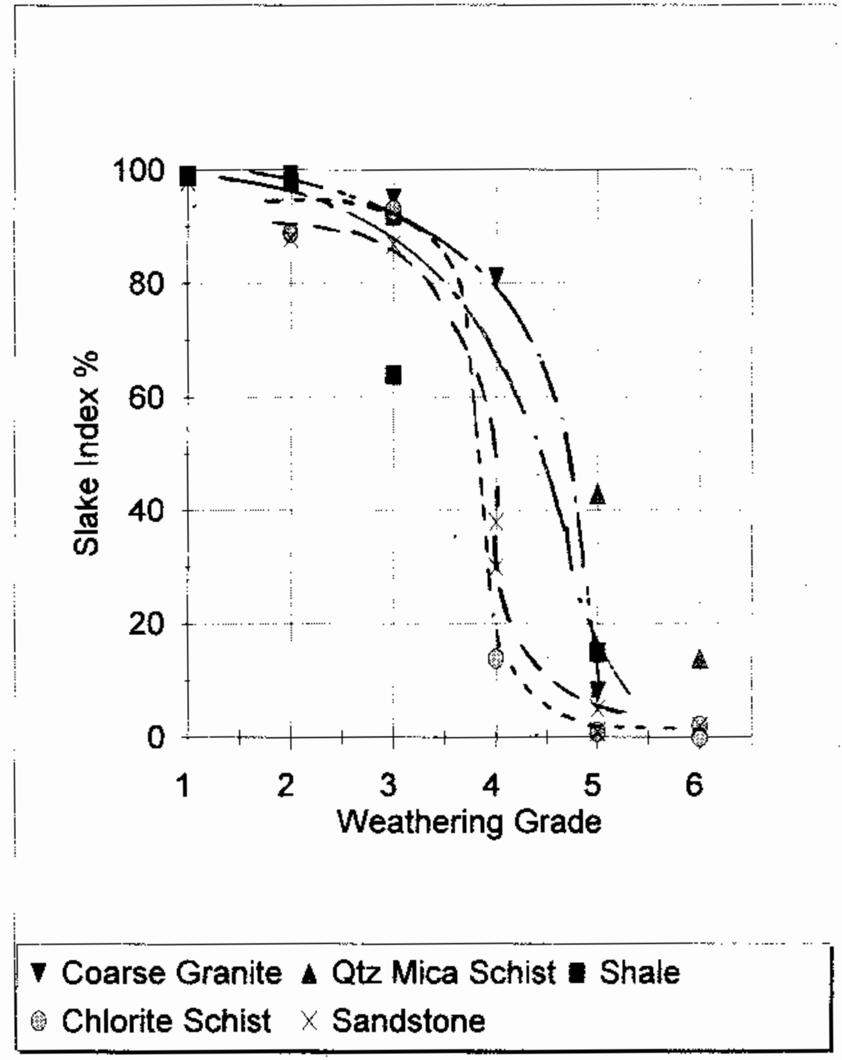


Figure 3.8 Typical Void Ratio Variations with Weathering

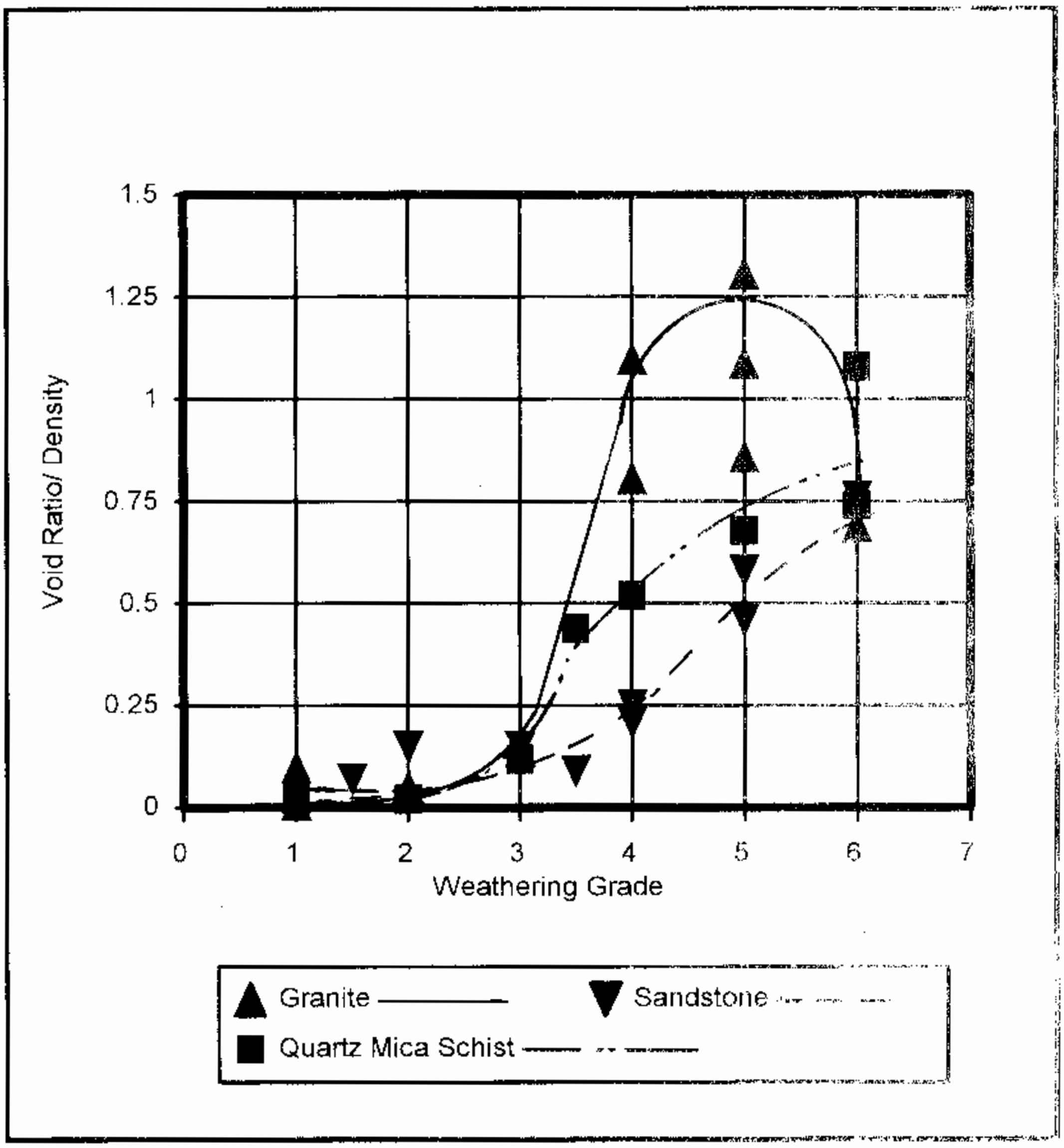
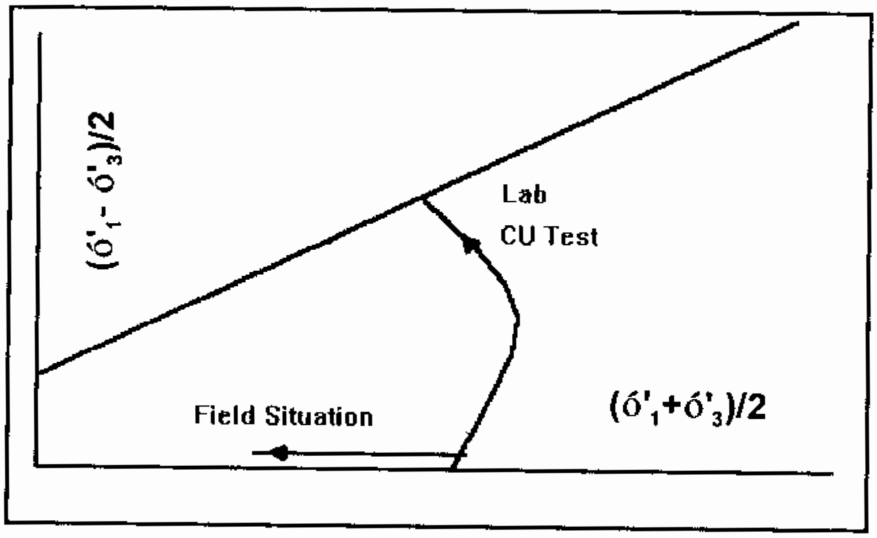


Figure 4.1   Comparison of Laboratory and In Situ Stress Paths



Field situation following rain storm: loss of pore suction

Figure 4.2   Comparison of Square and Round Shear Box Results

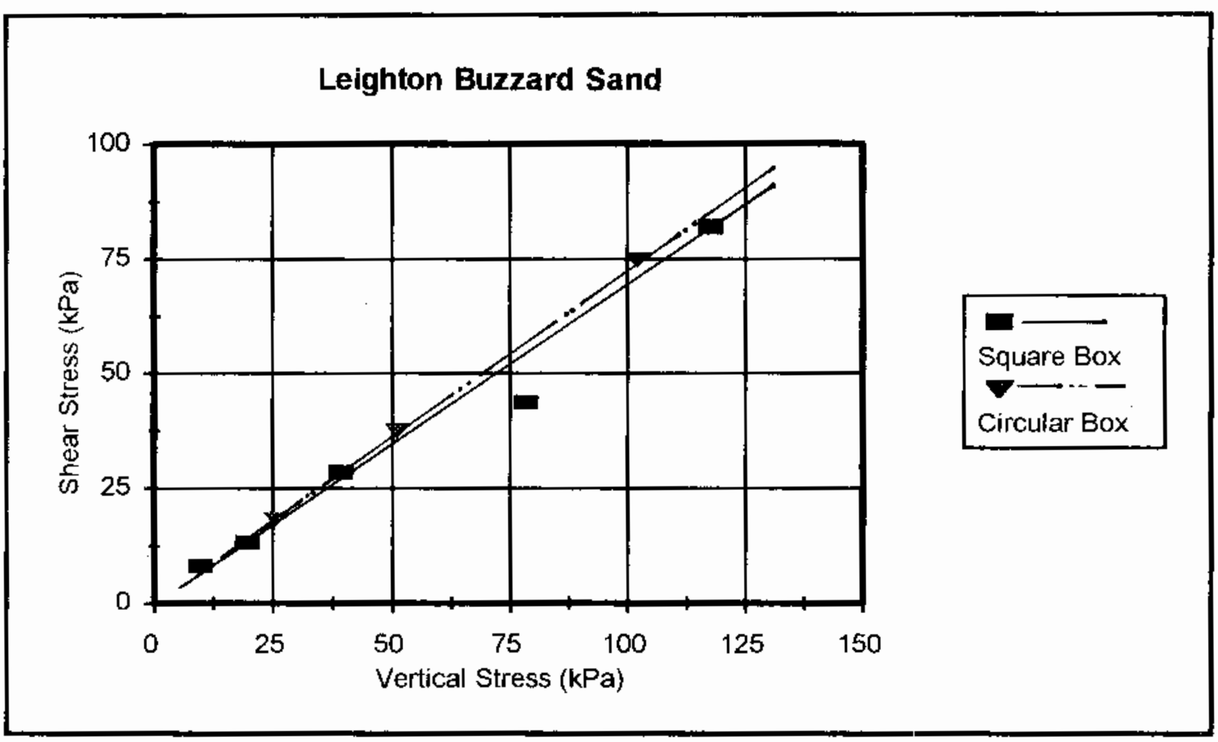
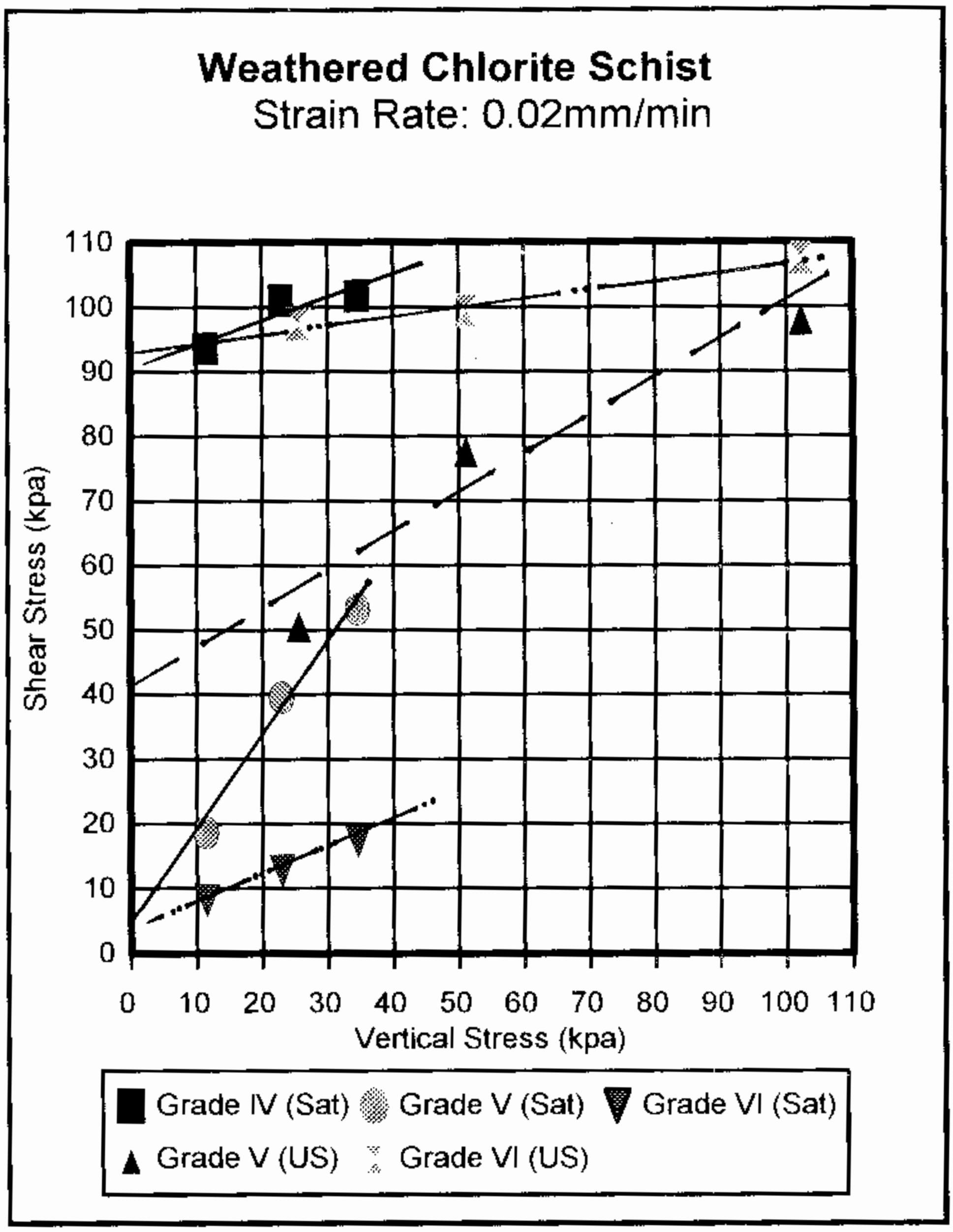


Figure 4.3 Typical Direct Shear Results



US = Natural unsaturated condition
Sat = Sample saturated prior to testing

Figure 4.4 Typical e-log p plot for a Latosol

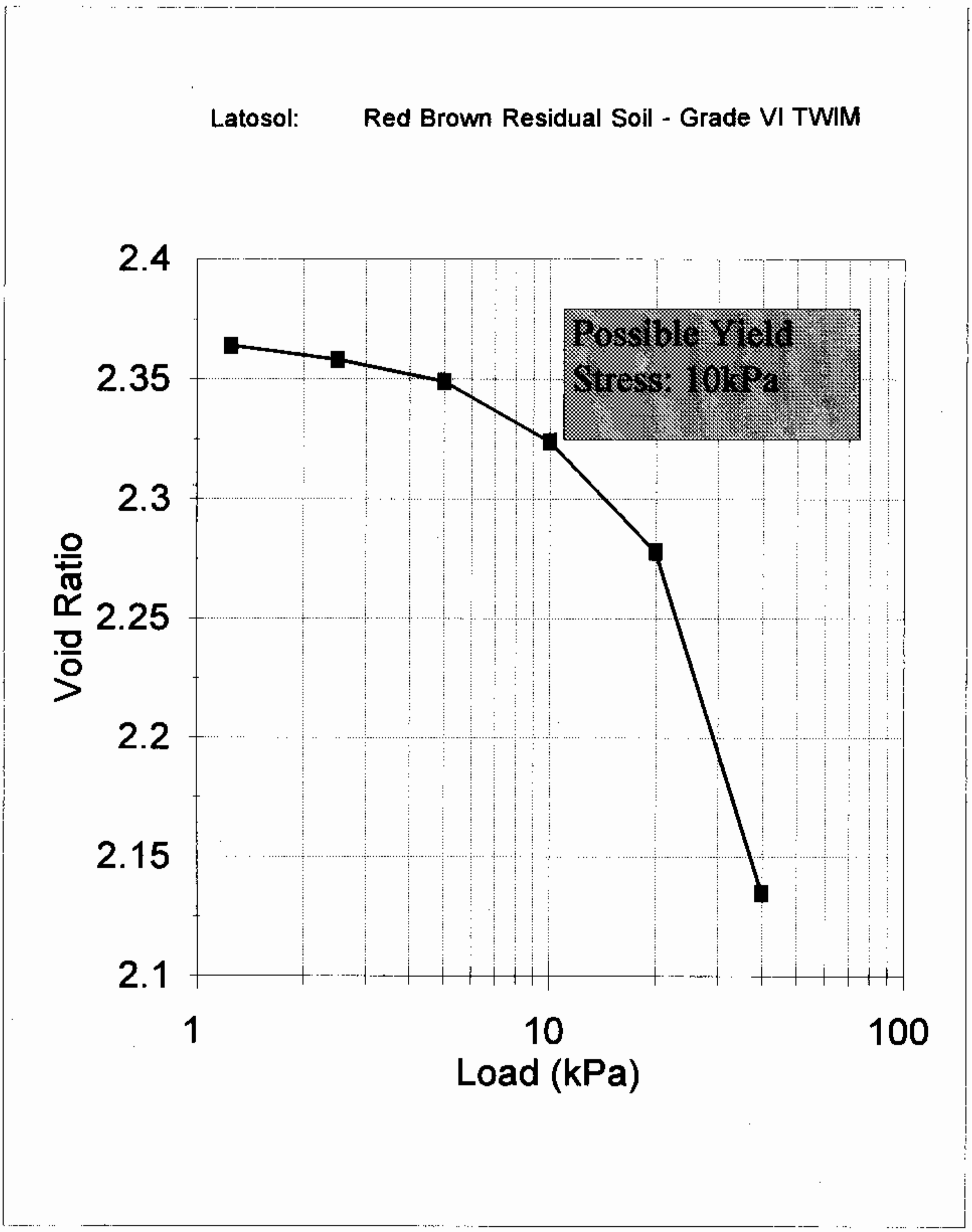


Figure 4.5 Typical Filter Paper Suction Data from Grate IV-VI EWH Materials

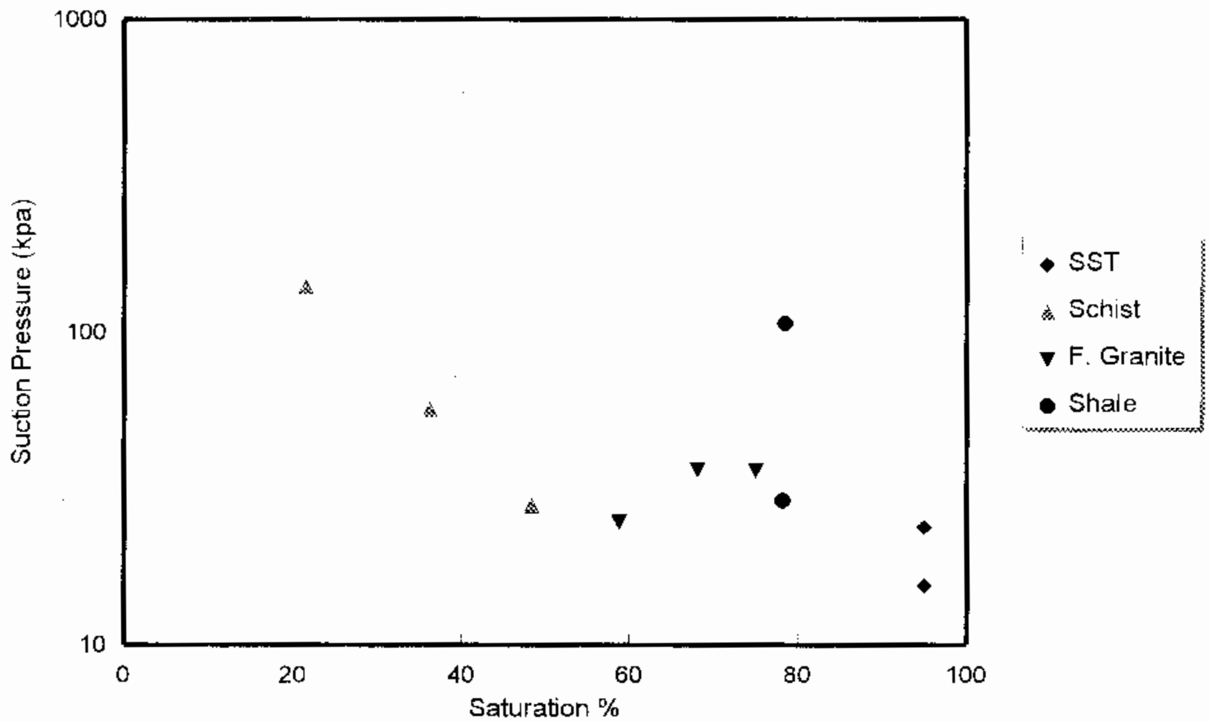
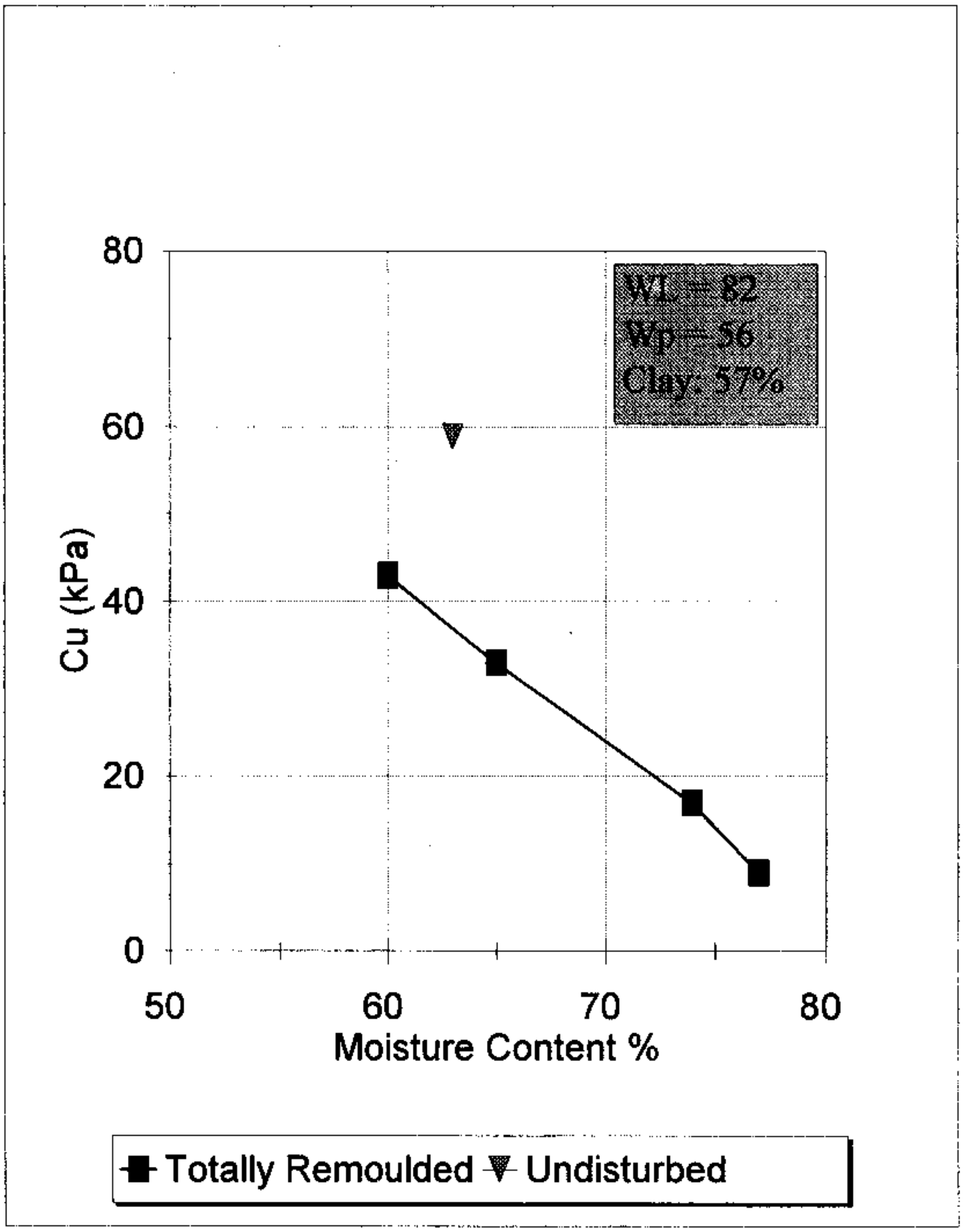


Figure 5.1 Typical Undrained Shear Strength Variation of a Latosol



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