Triaxial strength tests on till samples from the Slope Dynamics Project – Happisburgh, Sidestrand, and Aldbrough

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Internal Report IR/06/065

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INTERNAL REPORT IR/06/065

Triaxial strength tests on till samples from the Slope Dynamics Project – Happisburgh, Sidestrand, and Aldbrough

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Keywords

Report; coastal; landslide; till; strength; triaxial; geotechnical; Holderness; Norfolk; .

Front cover

View westward of Black Ven landslide complex.

Bibliographical reference

HOBBS, P. R. N & FREEBOROUGH, K.A... 2006. Triaxial strength tests on till samples from the Slope Dynamics Project – Happisburgh, Sidestrand, and Aldbrough. *British Geological Survey Internal Report*, IR/06/065. 17pp.

Keyworth, Nottingham British Geological Survey 2006

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Foreword

This report is the published product of part of the Slope Dynamics Project's geotechnical investigation concerned with testing of undisturbed samples collected as part of the field programme.

Acknowledgements

The authors are grateful to colleagues for assistance with sample collection; in particular to Andrew Gibson, Lee Jones, Gareth Jenkins, Catherine Poulton, and Paul Turner.

Contents

Summary

This report describes triaxial strength tests, and the results obtained, as carried out in the laboratories of the British Geological Survey on ‘undisturbed’ hand-prepared U100 samples of geological materials collected at test sites, forming part of the Slope Dynamics Project, at Happisburgh and Sidestrand (North Norfolk) and at Aldbrough (Holderness). The results are placed in the context of data available in the literature. Specimen preparation, test equipment, and test methodology are also briefly described.

1 Introduction

As part of the Slope Dynamics Project four hand-cut undisturbed U100 samples were collected from coastal sites at Happisburgh, Sidestrand, and Aldbrough. These represent three out of twelve coastal study sites being monitored for coastal cliff recession and the contribution of landslide processes. As part of this work, a limited number of geotechnical samples were collected between 1999 and 2003. Of these, four were of ‘undisturbed’ type and intended for triaxial testing at BGS, Keyworth. The samples were taken from glacial deposits exposed in cliff sections. Two of the four samples were considered to be from within a landslide mass, and the other two were considered to be unaffected by landsliding, though adjacent to a landslide. In this context the former could be considered ‘disturbed’ though these were nevertheless collected using an ‘undisturbed’ sampling technique.

The laboratory triaxial test, as specified in BS1377:1990 and described in Head (1992), is used to measure the shear strength parameters of soils and soft rocks, namely cohesion and internal friction angle. This is achieved by subjecting a right cylindrical specimen to several stages of saturation, followed by consolidation, and finally shearing by application of an additional axial stress (‘deviator stress’). The isotropically-consolidated undrained (CIU) version of the triaxial test allows pore pressures within the test specimen to be measured throughout and hence the ‘effective’ strength parameters to be derived from the ‘total’ parameters, notwithstanding the test being carried out in an undrained state. This method allows for a more rapid test than is the case when imposing ‘drained’ conditions on such a large specimen. The multi-stage element of the test indicates that a single specimen has been used and consolidated to three effective stress stages, rather than using the more familiar three individual specimens. The reason for using the multi-stage approach is that fewer samples require less time in the field, and that issues of non-uniformity between samples is removed. The test procedure is designed to reproduce the same result as where individual samples have been used, and is generally suitable for normally and lightly over-consolidated clays (Head, 1992).

2 Test equipment

The apparatus used for the triaxial tests is shown in Figure 1. This is an ‘advanced GDSTTS’ system which has a 100 mm Wykeham Farrance (Bishop & Wesley type) stress-path cell capable of testing specimens up to 100 mm in diameter and 200 mm in height. The system features automated test control and data logging via a PC. Water pressure is applied to the cell and specimen via digital controllers (pumps), which also measure volume change. Axial stress is measured via a built-in load cell. Primary and secondary pressure transducers measure ‘pore’ and ‘back’ pressures (Figure 2). The ‘back’ pressure line is connected to a digital controller in order that water can be introduced (saturation) or removed (consolidation) from the specimen. The triaxial cell differs from the standard Wykeham Farrance design in having two de-airing junction blocks serving both top and bottom specimen ports, rather than just one. The axial ram is hydraulic and operates via a Bellophram™ double rolling seal and Rotolin™ linear bearing housed in the lower half of the cell. This mechanism serves to isolate the pressured cell fluid from the ram.

Figure 1 **GDS advanced triaxial system with 100 mm Bishop & Wesley cell (right) and digital controllers (centre)**

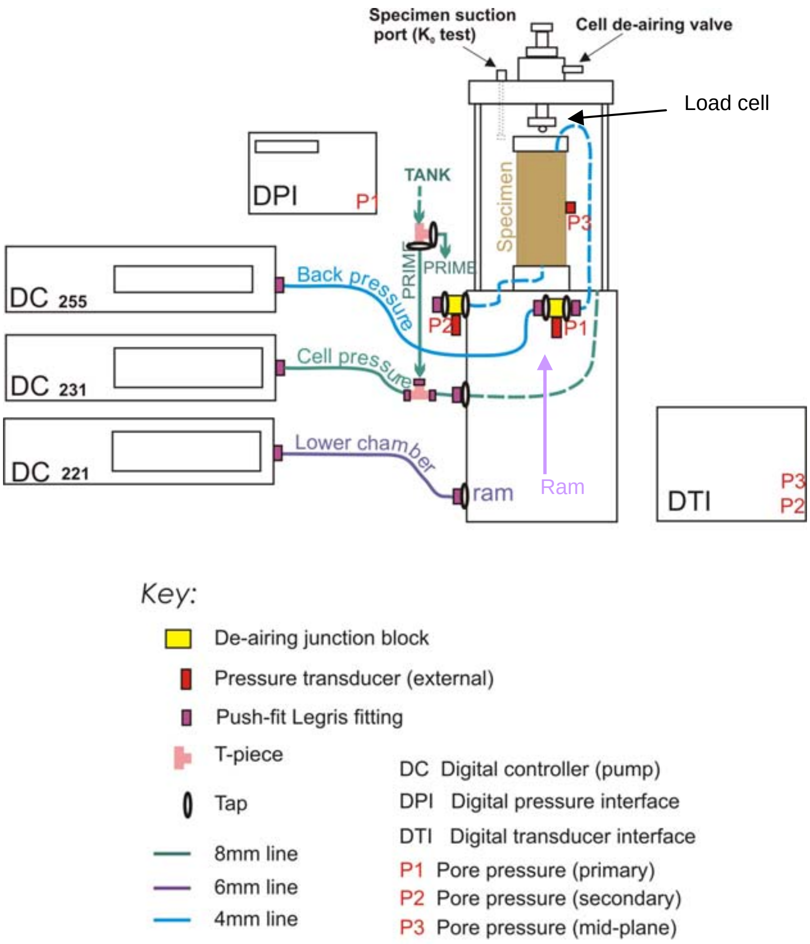

Figure 2 **Schematic of GDS 100 mm triaxial system**

3 Sample preparation

Samples were received from the field in sealed 103 x 250 mm plastic tubes and stored in a special temperature and humidity controlled room. To prepare a triaxial specimen, the sample was removed from its plastic sleeve and trimmed to a length of about 200 mm. The diameter was not trimmed to 100 mm diameter as it was felt that this would induce excessive disturbance. However, any large voids were filled with a paste made up from cuttings from the sample (Figure 3). This specimen 'repair' was used so that the rubber membrane subsequently applied to the specimen would not fail as a result of penetrating voids in the specimen. Such a procedure does not significantly affect the bulk properties or strength. Following this, a moist vertical filter drain was applied to the surface of the specimen, filter papers and saturated filter discs applied to top and bottom, and a 100 mm rubber membrane jacket applied.

Figure 3 Trimming and 'repair' of triaxial specimen

Filter paper drains were used to speed up consolidation. These do not significantly affect the strength parameters of stiff clays. The sample details are shown in Table 1. It was not possible to assign a formation to the two Sidestrand samples as they were taken from within landslide masses.

Location	*Position, depth*	*Samp. No.*	*Date collected*	*Formation*	*Member*	*Lithology*
Happisburgh	Lower cliff 0.25m	HB4	19/04/01	Happisburgh Formation	Happisburgh Till Member	Dark-grey sub-glacial till
Sidestrand	Mudslide, 0.15m	ST4	20/04/01	*unknown*	*unknown*	Medium grey silty clay till
Sidestrand	Debris flow 0.15m	ST5	20/04/01	*unknown*	*unknown*	Light grey till
Aldbrough	below cliff crest, 3.8 m	ALD1	19/08/04	Holderness Formation	Withernsea Member	Grey till

Table 1 Samples for triaxial testing

4 Triaxial test method

Following mounting of the test specimen in the triaxial cell, and filling of the cell with de-ionised / distilled water, a small effective stress was applied (5 kPa) in order to check that a leak-free system had been established. The sample was then subjected to several cycles of saturation via the back-pressure line followed by B-checks, maintaining an effective stress of 5 kPa throughout in order to keep the membrane in contact with the specimen. The total stress was ramped up to 300 kPa during this process in order to increase the degree of saturation. The process was considered complete once the B-value had reached 0.95. At this point the first stage of isotropic consolidation was applied over 24 hours at an effective stress of 50 kPa (Cell pressure= 350 kPa, back pressure = 300 kPa), followed by axial undrained compression loading at a rate of +0.2 mm/min, and unloading at –0.2 mm/min. As this was a multi-stage test the specimen was not compressed to the point of failure, but the loading terminated when a peak stress ratio was reached, followed immediately by unloading to the pre-compression axial force. This enabled the axial stress to be returned to its post-consolidation isotropic value. The stage 2 consolidation at an effective stress of 100 kPa was then run over a 24 hour period, followed by stage 2 loading and unloading. Finally, stage 3 consolidation and stage 3 loading/unloading at 200 kPa effective stress were applied. The stage 3 loading was taken to axial strains beyond the point where shear failure was considered to have occurred.

Stage →	1	2	3
Saturation (back pressure)	0 – 300kPa CP in 3 - 5 stages, (5 kPa effective)	--	--
Isotropic consolidation (drained one end)	50 kPa effective, drainage to 300 kPa BP	100 kPa effective, drainage to 300 kPa BP	200 kPa effective, drainage to 300 kPa BP
Axial compression (undrained loading)	Undrained, with PP 0.2 mm/min	Undrained, with PP 0.2 mm/min	Undrained, with PP 0.2 mm/min
Axial extension (undrained unloading)	Undrained, with PP -0.2 mm/min	Undrained, with PP - 0.2 mm/min	Undrained, with PP -0.2 mm/min

Table 2 CIU multi-stage triaxial test method

5 Triaxial test results

The results of the triaxial tests are summarised in Table 3 and in plots in the Appendix. The abbreviations used are explained in the Glossary. Figures 6a to 6d show the stress-path plots derived from the triaxial tests. Both the ‘total’ and ‘effective’ stress-paths are shown, the difference between them (x-axis) being the pore pressure *increase*, Δu, measured during the compression stage of the test (that is u_0 reduced to zero in each case). In each case the stress-path direction is upward (i.e. increasing stress). The stress-paths for the decompression (axial unloading) stages are not shown. Table 4 shows the MIT parameters s’ and t’ (Head, 1992) used to define the failure envelope and hence the strength parameters c’ and ϕ’.

Sample	w_0 (%)	γ_{d0} (Mg/m^3)	m_{vi} (m^2/MN)	*c’* (*kPa*)	*ϕ'* (*degr.*)	*Shear rate* (*%/min*)
HB4	14.0	1.94	0.4 – 0.5	28.8	24.4	0.1
ST4	22.0	2.06	-	0.4	26.7	0.1
ST5	21.7	1.52	0.7 – 1.5	7.4	17.6	0.1
ALD1	13.0	1.88	0.7 – 1.0	3.8	26.4	0.1

Table 3 Triaxial test results

	Stage 1		Stage 2		Stage 3	
Sample	s' (kPa)	t' (kPa)	s' (kPa)	t' (kPa)	s' (kPa)	t' (kPa)
HB4	56.32	45.82	129.93	84.73	256.98	140.98
ST4	43.4	19.5	65.36	30.16	119.3	53.8
ST5	34.95	17.45	85.44	33.04	202.91	68.21
ALD1	38.77	18.87	92.56	47.16	209.59	95.89

Table 4 Details of effective stress-path parameters at failure
(Mean effective stress, s’, maximum effective shear stress, t’)

Figure 4 Happisburgh HB4 triaxial test specimen (post-test)

Figure 5 Aldbrough ALD1 triaxial test specimen (post-test)

Post-test photos of the Happisburgh and Aldbrough samples are shown in Figures 4 and 5. No photos are available for the Sidestrand specimens.

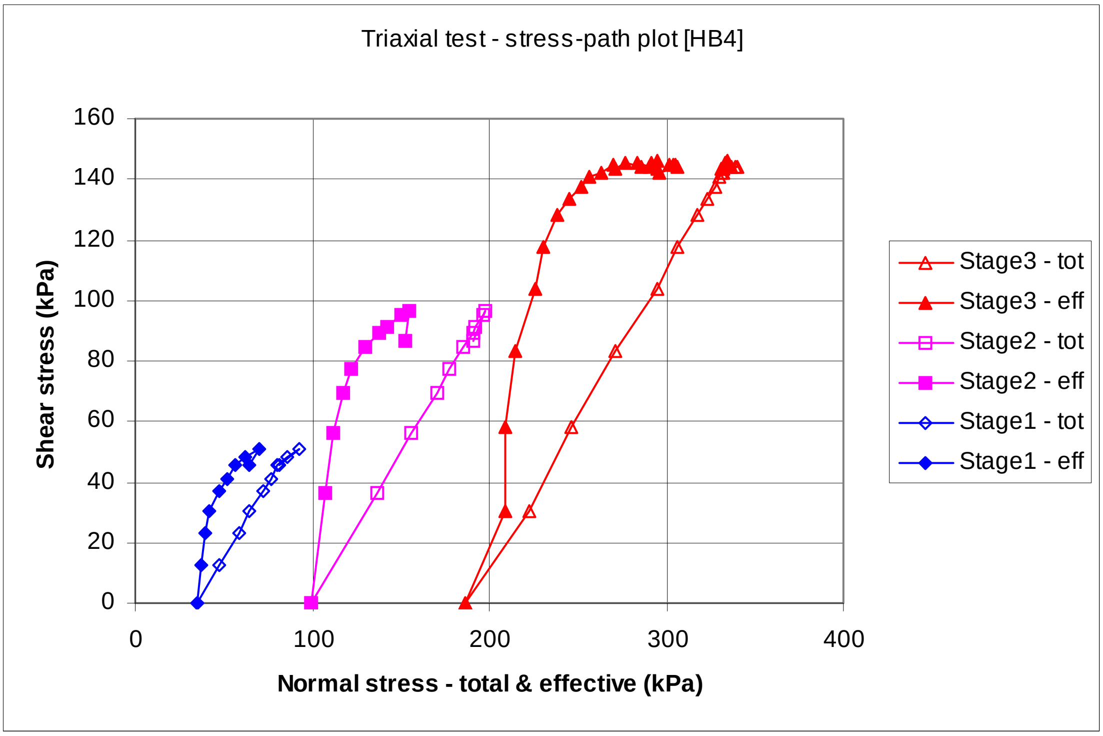

Figure 6a Stress-path plots for total and effective compression states – sample Happisburgh, HB4

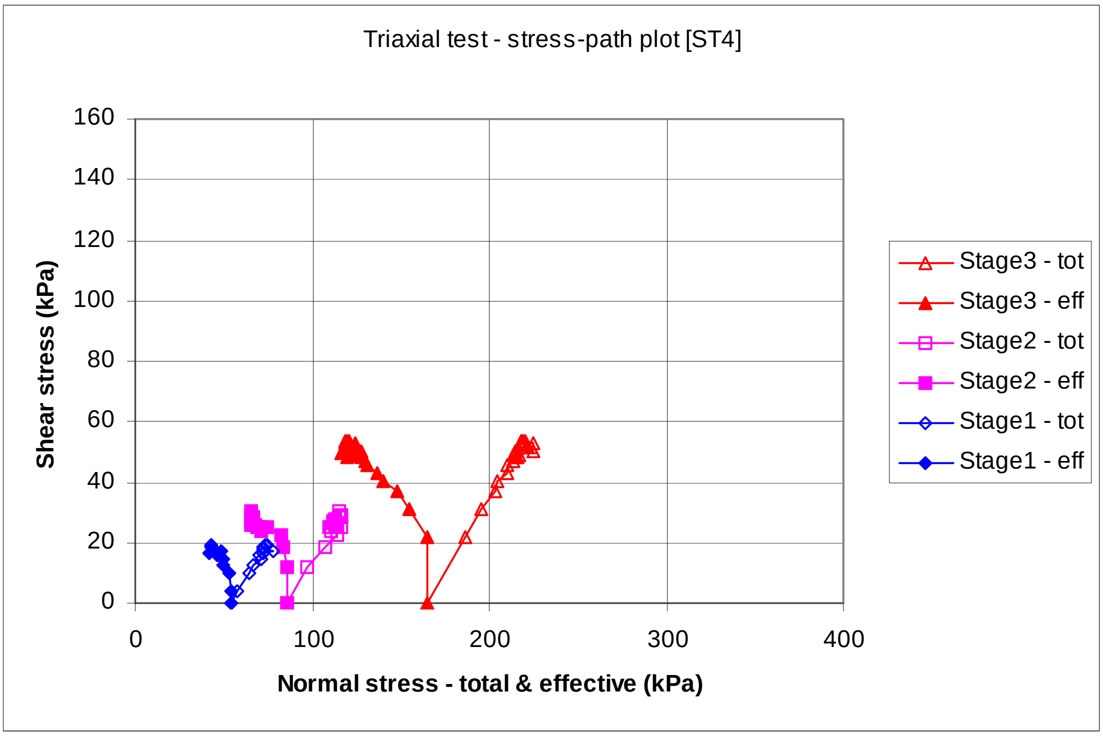

Figure 6b Stress-path plots for total and effective compression states – sample Sidestrand, ST4

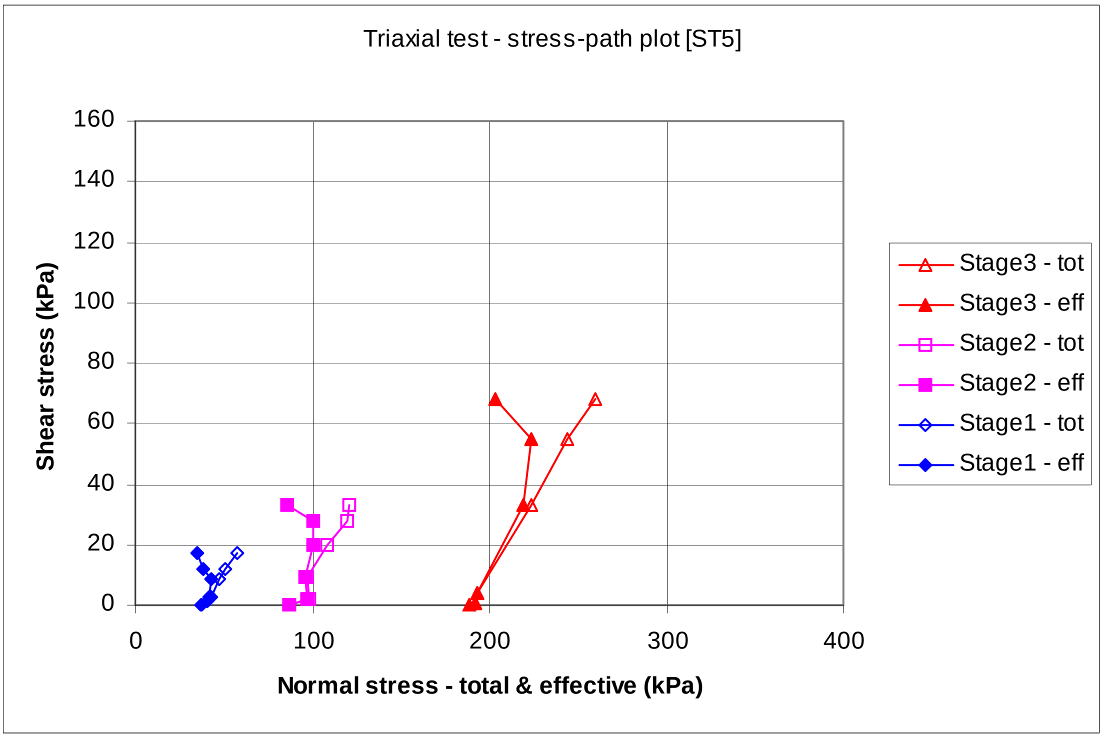

Figure 6c **Stress-path plots for total and effective compression states – sample Sidestrand, ST5**

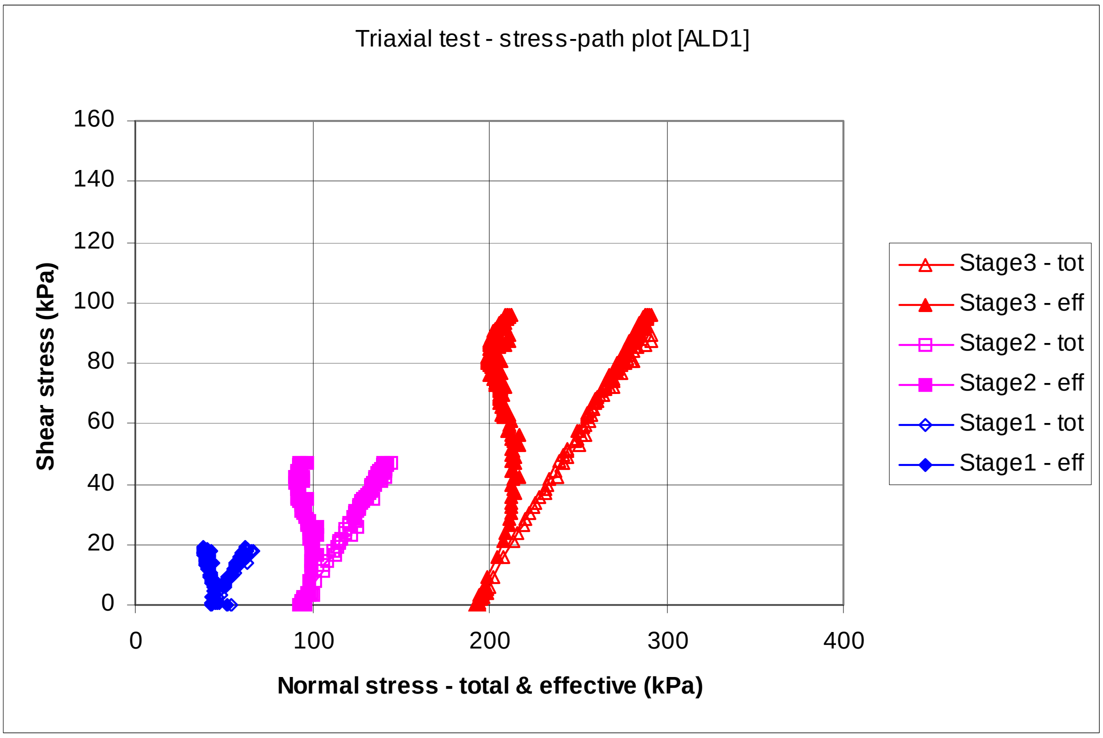

Figure 6d **Stress-path plots for total and effective compression states – sample Aldbrough, ALD1**

Figure 7 **Plot of stresses at compression failure (s' vs. t') for all samples**

The stress-path plots show a range of behaviour from over-consolidated to lightly over-consolidated (normal consolidation is indicated by continued divergence of a pair of 'effective' and 'total' curves whilst over-consolidation is indicated by convergence prior to failure). Specimens ST4 and ST5 show normal consolidation due to remoulding as part of mass movements, and the associated destruction of their former (presumed) over-consolidated fabric. Specimens HB4 and ALD1 appear to be lightly over-consolidated at the stresses applied. None of the specimens appear to show a distinct transition from one state to another at the stresses applied.

With respect to the isotropic consolidation stages of the tests, considerable reduction in volume change was found from stage 1 to stage 2, whereas Stages 2 and 3 were similar in terms of volume change. The values for the isotropic coefficient of volume compressibility, m_{vi}, (Table 2) fall in the 'medium' to 'high' range. Head (1986) gives the following theoretical relationship between isotropic and one-dimensional coefficients:

$$m_{vi} = 1.5m_v$$

The above relationship assumes isotropic behaviour, which is probably incorrect for a till. However, the values thus obtained (Table 2) appear to be reasonable particularly when considering that two of the tills are disturbed.

6 Literature

Few geotechnical data are available in the literature for the tills of north Norfolk. However, Bell (1991) reported that they tend to be matrix dominant with ‘firm’ to ‘stiff’ consistency, ‘low’ to ‘intermediate’ plasticity, and with an undrained shear strength of between 50 and 115 KPa. The tills have low strength sensitivity and are ‘inactive’ to ‘normally active’. Bell (1991) also reported that strength is particularly sensitive to water content. The Cromer Till consists of an upper and lower member in parts separated by laminated silts and clays. The Happisburgh Till Member, represented by sample HB4, unconformably overlies the marine deposits of the How Hill Member (Wroxham Crag Formation) and is the basal member of the Happisburgh Formation (Lee et al., 2004). This unit consists of an over-consolidated grey, massive, matrix-supported ‘diamicton’ that contains occasional sheared inclusions of crushed chalk and Crag material. It was deposited as subglacial deformation till that accreted by processes of subglacial lodgement and pervasive sub-horizontal shearing. The deposits in the mid part of the cliff at Sidestrand, which are probably the source materials for samples ST4 and ST5, consist of the Ostend Clay Member (Happisburgh Formation), the Walcot Till Member (Lowestoft Formation), Bacton Green Till Member (Sheringham Cliffs Formation) (Lee et al., 2004). These consist mainly of uniform fine-grained silts with clay and a relatively minor clast content, a proportion of which is chalk.

A large study of till was made at Cowden on the Holderness coast (2 km north of Aldbrough). This site was set up in 1976 by the Building Research Establishment (BRE) to study a typical lowland, matrix dominant, till and to relate this to tills found in the North Sea as a result of oil and gas field development. The testing programme included a wide variety of in-situ and laboratory investigations (Marsland & Powell, 1985). The two major Late Devensian Till formations on the Holderness coast are the Withernsea Member (formerly ‘Withernsea Till’) and the underlying Skipsea Member (formerly ‘Skipsea Till’), both part of the Holderness Formation; sample ALD1 representing the former. These are believed to be lodgement tills (Lewis, 1999). These tills are matrix dominant and have a clay mineralogy of kaolinite and illite (kaolinite increasing upward), and a clay size content of up to 40 % (Bell & Forster, 1991). The plasticity classification of the tills is ‘low’ to ‘intermediate’; the Withernsea Member being somewhat more plastic than the Skipsea Member. All tills plot well above the Casagrande A-line. There is an overall, but slight, coarsening upward of the clay / silt particle size from the Basement Till to the Skipsea Member. Strength tends to decrease upward; the Skipsea Member being stronger than the Withernsea and the highly weathered near-surface material. Low strength sensitivity to remoulding was noted throughout, as was the case for the Norfolk tills. Bell & Forster (1991) quote values for c’ and ϕ’ of 42 kPa and 26 ^{o} respectively for the Withernsea Till.

7 Conclusions

The triaxial data cover a range of tills, two of which (ST4 & ST5) were from landslide masses. The strength results for the latter therefore strictly refer to ‘remoulded’ strength. This is confirmed by the stress-path trends, and indicates that these tills are behaving as normally-consolidated, having lost any over-consolidated characteristics. However, effective strength does not appear to have been greatly affected, although any strength reduction cannot be assessed as no ‘unslipped’ specimens were available for test. Lodgement tills might be expected to have a high density and strength compared with their remoulded equivalent. Whilst a direct comparison cannot be made here, the results show that the light grey till (sample ST5) from the debris flow at Sidestrand has a significantly lower effective strength, in terms of friction angle, and a lower dry density than the others.

Glossary

BP Back pressure (applied pressure within specimen)
CP Cell pressure (applied pressure to water-jacket surrounding specimen)
c' Effective cohesion
ϕ' Effective friction angle
eff. Effective
m_v Coefficient of volume compressibility (one-dimensional)
m_{vi} Coefficient of volume compressibility (isotropic)
PP Pore pressure (measured pressure within specimen)
s' Mean effective stress (MIT terminology)
t' Maximum effective shear stress (MIT terminology)
tot. Total
w_0 Initial water content
γ_{d0} Initial dry density

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APPENDIX

Triaxial test data sheets

(produced automatically by GDSTTS software)

British Geological Survey

Consolidated Undrained Triaxial Compression Test
BS 1377 : Part 8 : 1990

Specimen Details

		Stage 1	Stage 2	Stage 3
Job Ref.				
Job Location			Happisburgh	
Borehole				
Sample No.		HB4	HB4	HB4
Depth	m	0.25	0.25	0.25
Date		19/04/01	19/04/01	19/04/01
Disturbed / Undisturbed		undis	undis	undis

Description of Specimen

Lower Till (Happisburgh Formation, Happisburgh Till Member)

Initial Specimen Conditions

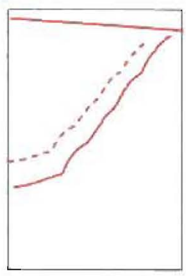
		Stage 1	Stage 2	Stage 3
Height	mm	200.00	196.06	192.48
Diameter	mm	103.00	103.09	103.62
Area	mm^2	8332.29	8346.09	8433.68
Volume	cm^3	1666.46	1636.31	1623.27
Mass	g	3753.00		
Dry Mass	g	3227.28		
Density	Mg/m^3	2.25		
Dry Density	Mg/m^3	1.94		
Moisture Content	%	14.00	14.00	14.00
Degree of Saturation	%			
Specific Gravity	kN/m^3			
(assumed/measured)				

Final Specimen Conditions

		Stage 1	Stage 2	Stage 3
Moisture Content	%			12.61
Density	Mg/m^3			2.28
Dry Density	Mg/m^3			1.94

Sketch of Failure of the Specimen

Load rate = 0.2 mm/min



Date Date:

Checked by. Approved by:

Filename: E:\LABORATORY\GDS\triaxial\TRIAXIAL\data\Happisburgh\[HB4.xls]Report

Date: 26/06/2007

British Geological Survey

Consolidated Undrained Triaxial Compression Test

BS 1377 : Part 8 : 1990

Specimen Details

		Stage 1	Stage 2	Stage 3
Job Ref.		0		
Job Location		Happisburgh		
Borehole		0	0	0
Sample No.		HB4	HB4	HB4
Depth	m	0.25	0.25	0.25
Date		19/04/01	19/04/01	19/04/01

Test Setup

	Stage 1	Stage 2	Stage 3
Date started	27/06/05	27/06/05	27/06/05
Date Finished			
Top Drain Used	y	y	y
Base Drain Used	y	y	y
Side Drains Used	y	y	y
Pressure System Number			
Cell Number			

Saturation

		Stage 1	Stage 2	Stage 3
Cell Pressure Incr.	kPa	18.70	20.30	19.90
Back Pressure Incr.	kPa	18.10	17.20	17.90
Differential Pressure	kPa	2.90	7.60	7.20
Final Cell Pressure	kPa	23.70	118.90	219.00
Final Pore Pressure	kPa	31.00	117.90	218.50
Final B Value		0.93	0.84	0.88

Consolidation

		Stage 1	Stage 2	Stage 3
Effective Pressure	kPa	1.20	31.80	80.20
Cell Pressure	kPa	399.20	395.30	448.60
Back Pressure	kPa	398.00	363.50	368.40
Excess Pore Pressure	kPa	357.60	345.50	360.70
Pore Pressure at End	kPa	6.30	7.00	6.70
Consolidated Volume	cm^3	1636.31	1623.27	1610.54
Volumetric Strain		0.006030756	0.002654961	0.002615905
Consolidated Height	mm	198.79	195.54	191.97
Consolidated Area	mm^2	8231.79	8301.77	8389.55
Vol. Compressibility	m^2/MN	0.38741	0.31860	0.54498
Consolidation Coef.	$m^2/yr.$			

Filename: E:\LABORATORY\GDStriaxial\TRIAXIALdata\Happisburgh\[HB4.xls]Report
Date: 26/06/2007
Checked by: Date:
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British Geological Survey

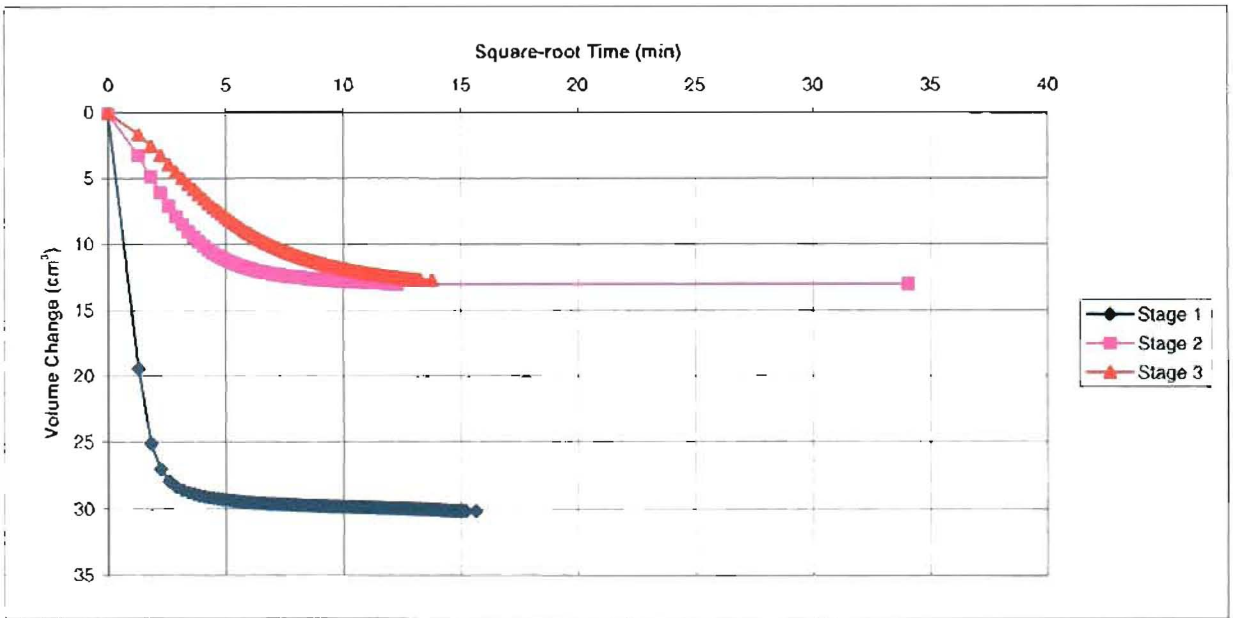
Consolidated Undrained Triaxial Compression Test

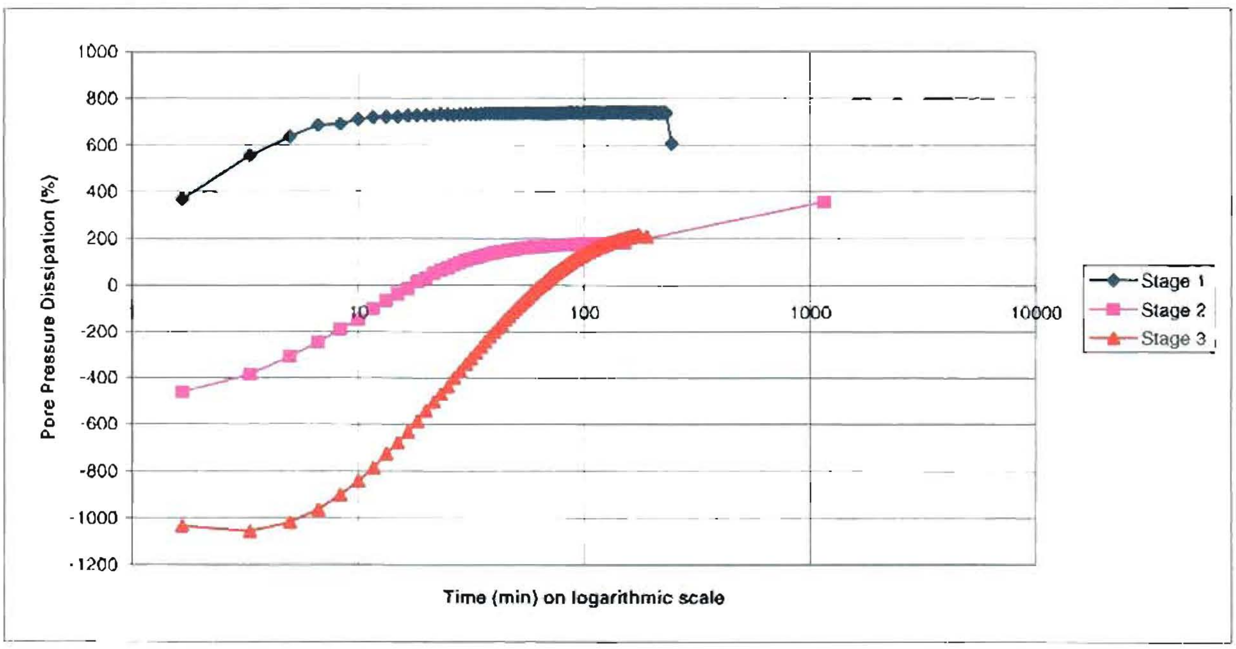
BS 1377 : Part 8 : 1990

Specimen Details

		Stage 1	Stage 2	Stage 3
Job Ref.			0	
Job Location			Happisburgh	
Borehole		0	0	0
Sample No.		HB4	HB4	HB4
Depth	m	0.25	0.25	0.25
Date		19/04/01	19/04/01	19/04/01

Consolidation Stage





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Date: 26/06/2007

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Date:

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Consolidated Undrained Triaxial Compression Test

BS 1377 : Part 8 : 1990

Specimen Details

		Stage 1	Stage 2	Stage 3
Job Ref.		0		
Job Location		Happisburgh		
Borehole		0	0	0
Sample No.		HB4	HB4	HB4
Depth	m	0.25	0.25	0.25
Date		19/04/01	19/04/01	19/04/01

Shearing

		Stage 1	Stage 2	Stage 3
Initial Cell Pressure	kPa	401.5	449.1	547.5
Initial Pore Pressure	kPa	366	349.4	361.4
Rate of Strain	%/hour	5.99994	6.120612501	6.234503027
Max Deviator Stress				
Axial Strain		1.337	1.533	3.121
Axial Stress	kPa	102.12	193.45	291.92
Cor. Deviator stress	kPa	102.12	193.45	291.92
Effective Major Stress	kPa	120.62	251.85	441.12
Effective Minor Stress	kPa	18.50	58.40	149.20
Effective Stress Ratio		6.520	4.313	2.957
s'	kPa	69.56	155.13	295.16
t'	kPa	51.06	96.73	145.96
Shear Resistance Angle	degs	24.45	24.45	24.45
Cohesion c'	kPa	28.78	28.78	28.78
Max Effective Principle Stress Ratio				
Axial Strain		1.004	0.853	1.559
Axial Stress	kPa	91.64	169.47	281.96
Cor. Deviator stress	kPa	91.64	169.47	281.96
Effective Major Stress	kPa	102.14	214.67	397.96
Effective Minor Stress	kPa	10.50	45.20	116.00
Effective Stress Ratio		9.728	4.749	3.431
s'	kPa	56.32	129.93	256.98
t'	kPa	45.82	84.73	140.98

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British Geological Survey

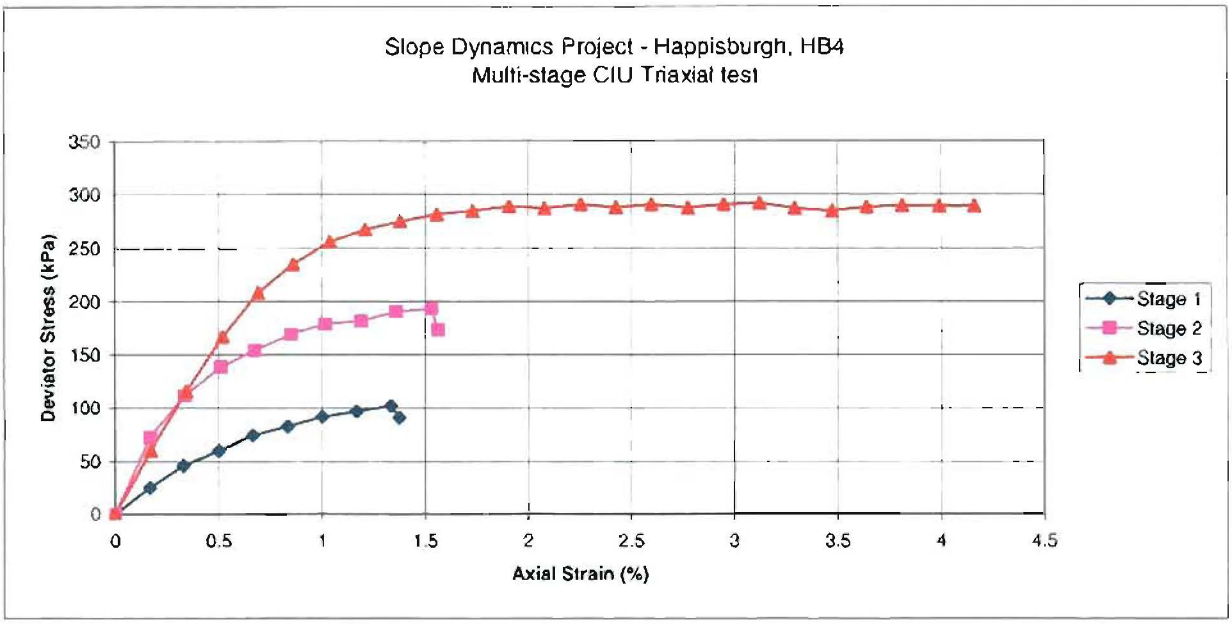
Consolidated Undrained Triaxial Compression Test

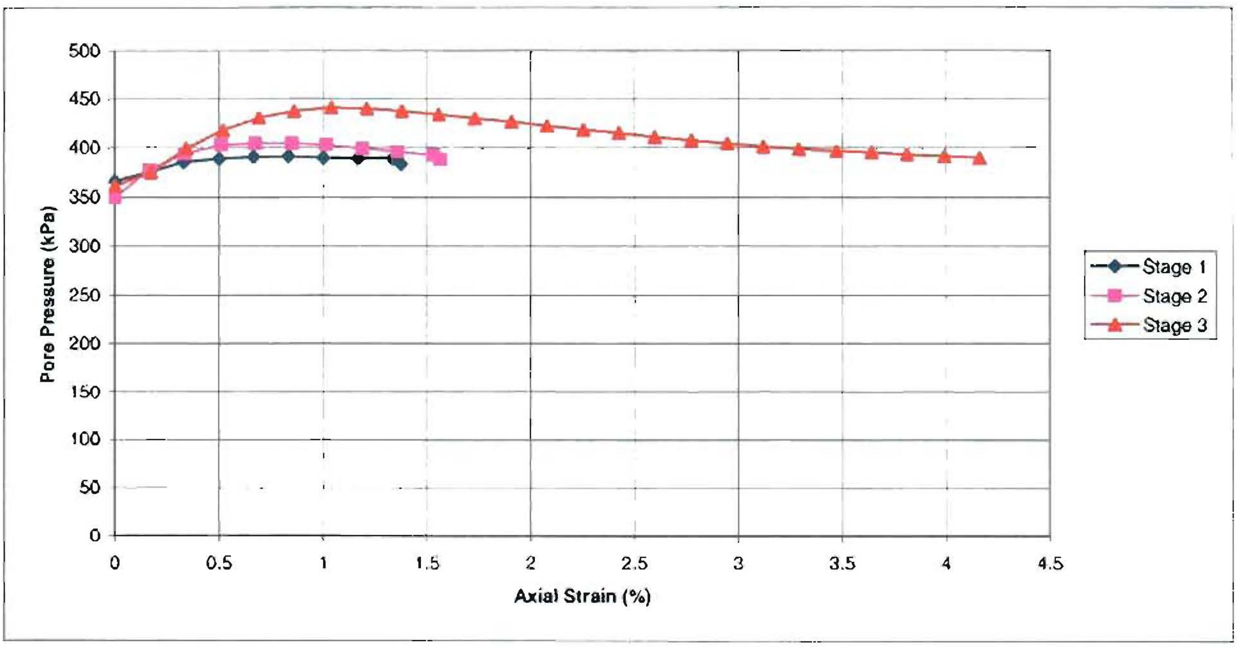
BS 1377 : Part 8 : 1990

Specimen Details

	Stage 1	Stage 2	Stage 3
Job Ref.	0		
Job Location	Happisburgh		
Borehole	0	0	0
Sample No.	HB4	HB4	HB4
Depth m	0.25	0.25	0.25
Date	19/04/01	19/04/01	19/04/01

Shearing Stage





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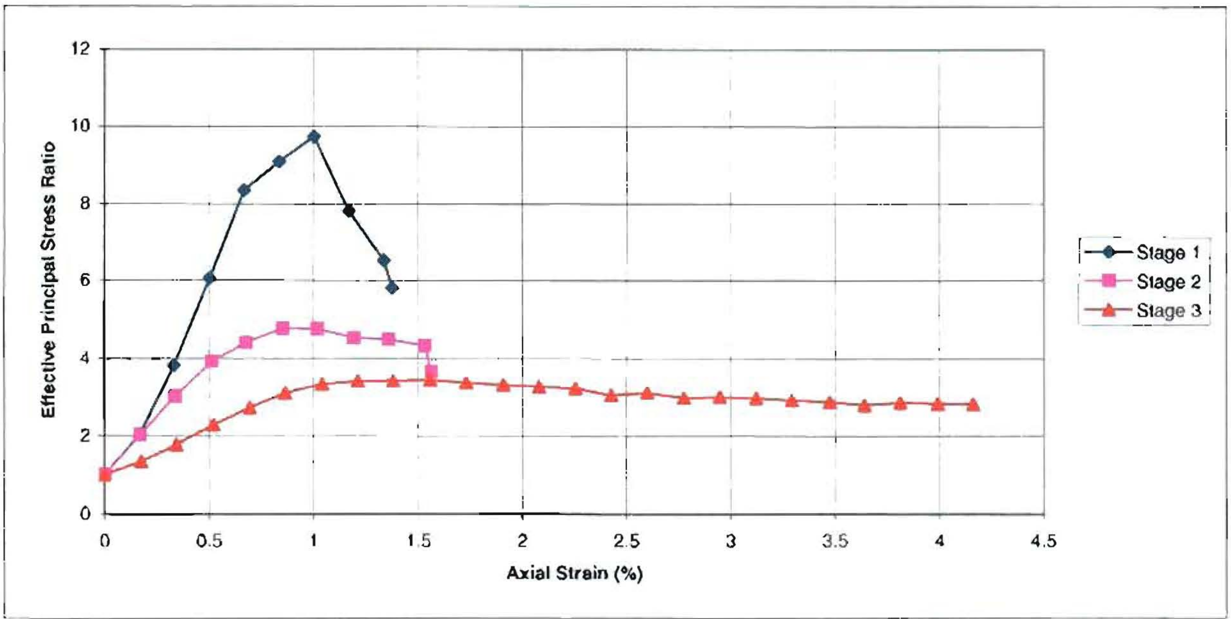
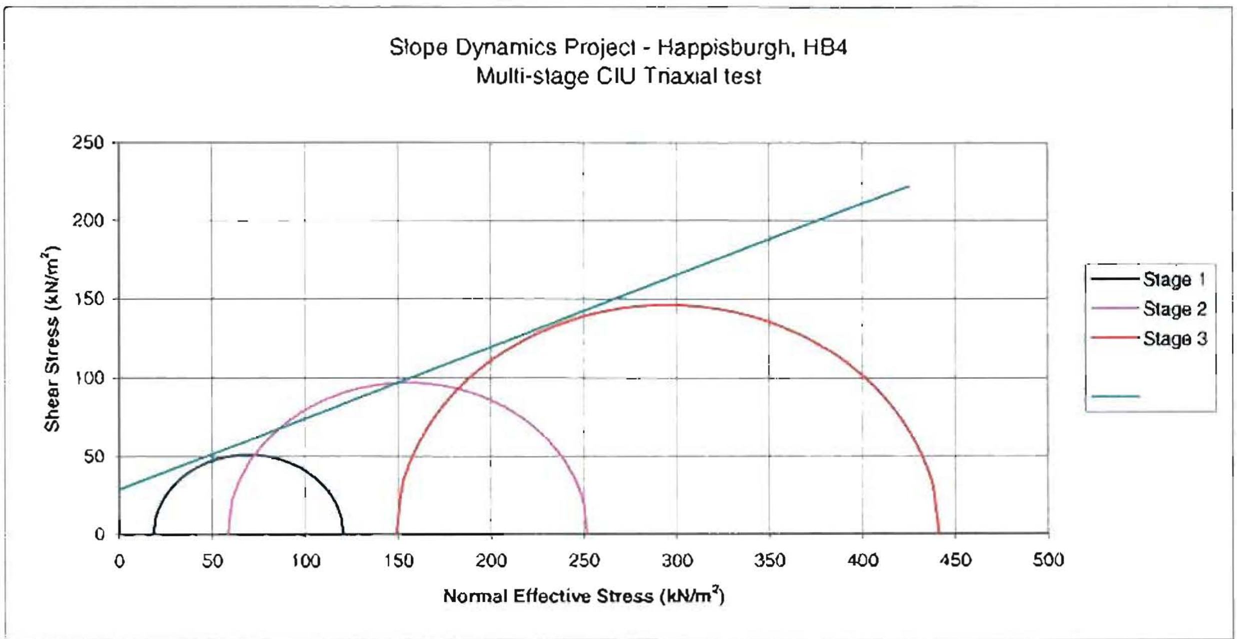
Sample Details

		Stage 1	**Stage 2**	**Stage 3**
Job Ref.		0		
Job Location		Happisburgh		
Borehole		0	0	0
Sample No.		HB4	HB4	HB4
Depth	m	0.25	0.25	0.25
Date		19/04/01	19/04/01	19/04/01

Shearing Stage





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Consolidated Undrained Triaxial Compression Test

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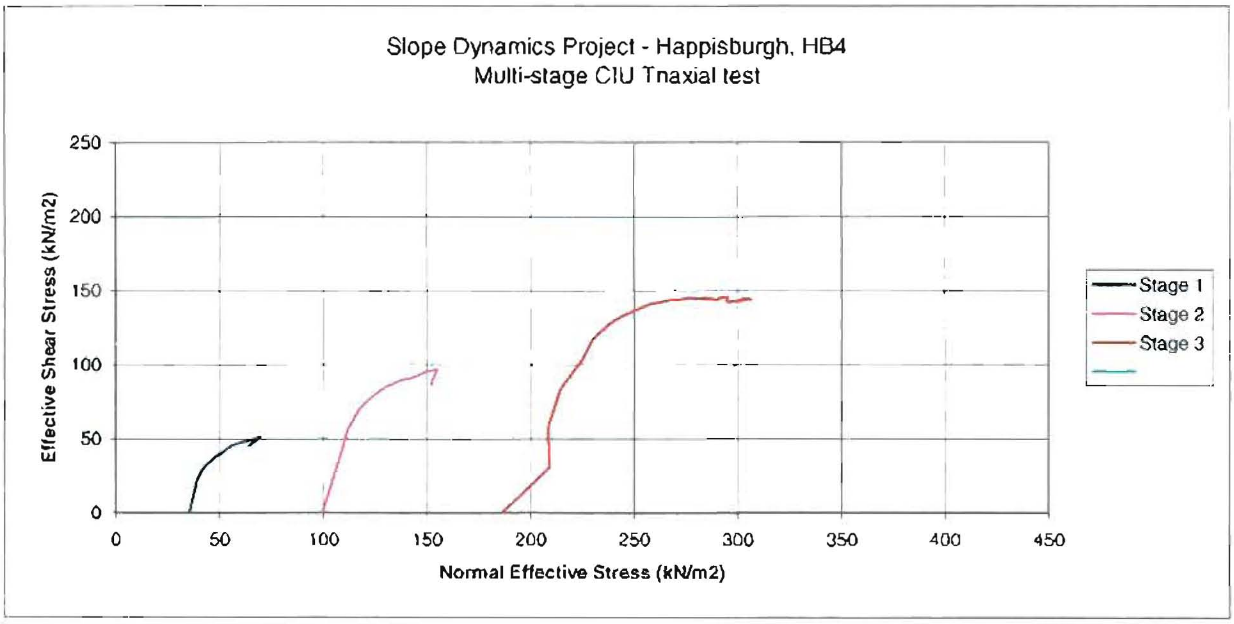
Sample Details

		Stage 1	Stage 2	Stage 3
Job Ref.		0		
Job Location		Happisburgh		
Borehole		0	0	0
Sample No.		HB4	HB4	HB4
Depth	m	0.25	0.25	0.25
Date		19/04/01	19/04/01	19/04/01

Shearing Stage



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Consolidated Undrained Triaxial Compression Test
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Specimen Details

		Stage 1	Stage 2	Stage 3
Job Ref.		Slope Dynamics		
Job Location		Sidestrand mudslide		
Borehole				
Sample No.		ST4	ST4	ST4
Depth	m	0.15	0.15	0.15
Date		20/04/01	20/04/01	20/04/01
Disturbed / Undisturbed		Undist.	Undist.	Undist.

Description of Specimen

mid-greyTILL [mudslide]

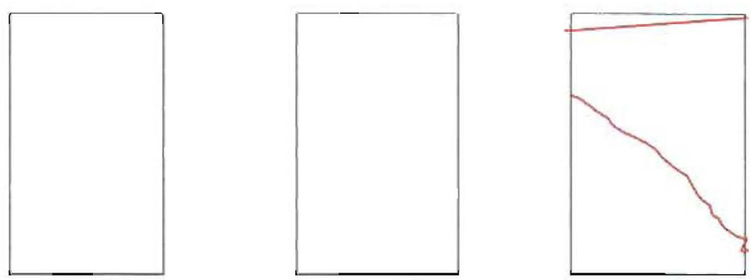
Initial Specimen Conditions

		Stage 1	Stage 2	Stage 3
Height	mm	211.00	203.90	198.68
Diameter	mm	103.00	102.44	103.68
Area	mm^2	8332.29	8241.45	8442.20
Volume	cm^3	1758.11	1680.41	1677.29
Mass	g	3695.60	3695.60	3695.60
Dry Mass	g	3018.16		
Density	Mg/m^3	2.10	2.20	2.20
Dry Density	Mg/m^3	2.06		
Moisture Content	%	21.99	21.99	21.99
Degree of Saturation	%			
Specific Gravity (assumed/measured)	kN/m^3			

Final Specimen Conditions

		Stage 1	Stage 2	Stage 3
Moisture Content	%			18.33
Density	Mg/m^3			2.20
Dry Density	Mg/m^3			1.93

Sketch of Failure of the Specimen



Stage 1 Stage 2 Stage 3

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Specimen Details

		Stage 1	Stage 2	Stage 3
Job Ref.		Slope Dynamics		
Job Location		Sidestrand mudslide		
Borehole		0	0	0
Sample No.		ST4	ST4	ST4
Depth	m	0.15	0.15	0.15
Date		20/04/01	20/04/01	20/04/01

Test Setup

	Stage 1	Stage 2	Stage 3
Date started	14/06/05	14/06/05	14/06/05
Date Finished			
Top Drain Used	y	y	y
Base Drain Used	y	y	y
Side Drains Used	y	y	y
Pressure System Number			
Cell Number			

Saturation

		Stage 1	Stage 2	Stage 3
Cell Pressure Incr.	kPa	19.10	18.70	18.70
Back Pressure Incr.	kPa	17.10	19.00	19.00
Differential Pressure	kPa	8.40	0.40	0.40
Final Cell Pressure	kPa	219.40	319.00	319.00
Final Pore Pressure	kPa	214.50	322.50	322.50
Final B Value		0.91	1.01	1.01

Consolidation

		Stage 1	Stage 2	Stage 3
Effective Pressure	kPa	0.40	54.70	89.90
Cell Pressure	kPa	318.10	401.00	449.00
Back Pressure	kPa	317.70	346.30	359.10
Excess Pore Pressure	kPa	321.90	368.70	398.80
Pore Pressure at End	kPa	4.20	22.40	39.70
Consolidated Volume	cm^3	1680.41	1677.29	1674.04
Volumetric Strain		0.014732273	0.0006185	0.000646677
Consolidated Height	mm	207.89	203.77	198.55
Consolidated Area	mm^2	8086.78	8231.25	8431.29
Vol. Compressibility	m^2/MN			
Consolidation Coef.	m^2/yr.			

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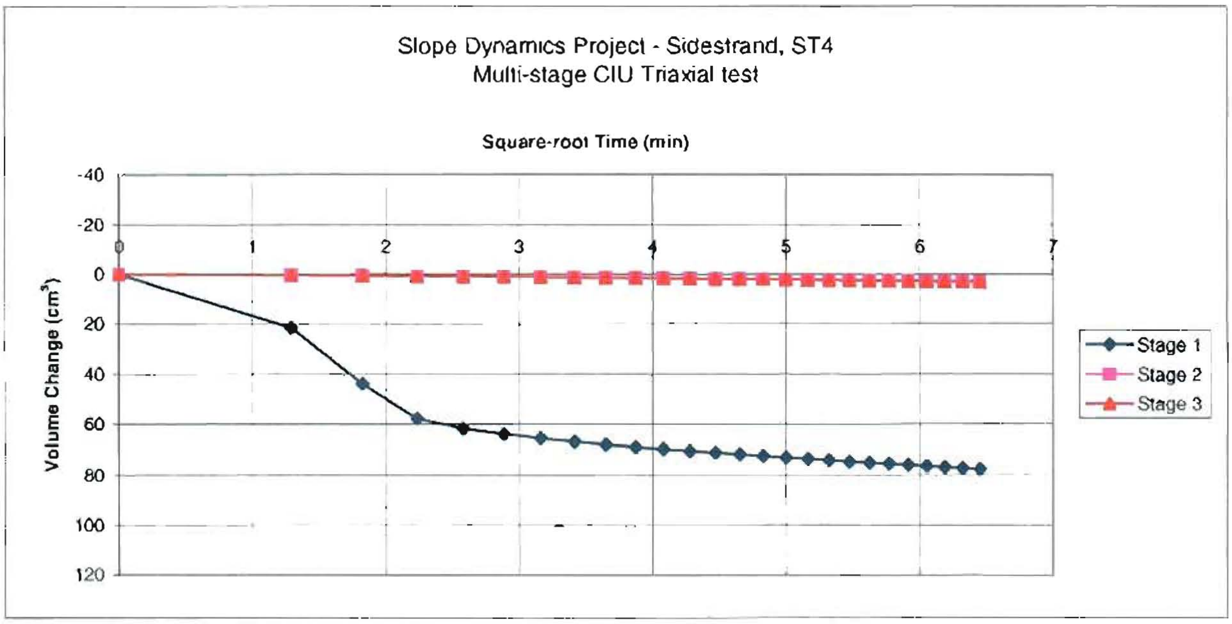
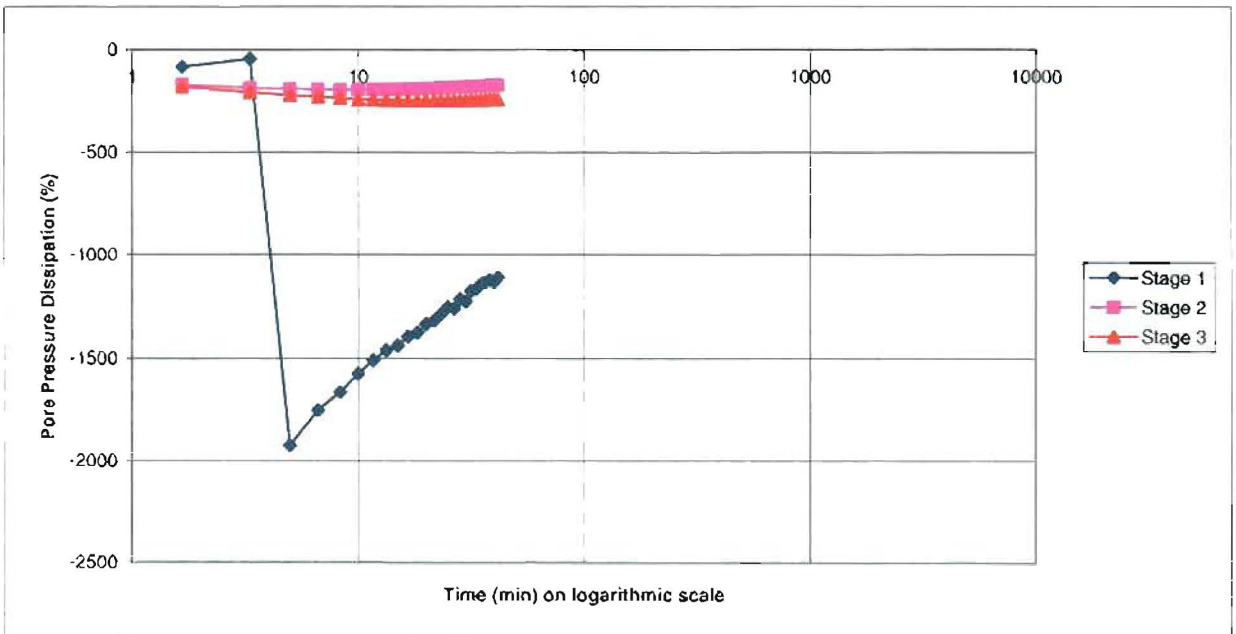
		Stage 1	Stage 2	Stage 3
Specimen Details				
Job Ref.		Slope Dynamics		
Job Location		Sidestrand mudslide		
Borehole		0	0	0
Sample No.		ST4	ST4	ST4
Depth	m	0.15	0.15	0.15
Date		20/04/01	20/04/01	20/04/01

Consolidation Stage





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Consolidated Undrained Triaxial Compression Test

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Specimen Details

		Stage 1	Stage 2	Stage 3
Job Ref.		Slope Dynamics		
Job Location		Sidestrand mudslide		
Borehole		0	0	0
Sample No.		ST4	ST4	ST4
Depth	m	0.15	0.15	0.15
Date		20/04/01	20/04/01	20/04/01

Shearing

		Stage 1	Stage 2	Stage 3
Initial Cell Pressure	kPa	400.3	450.4	549.9
Initial Pore Pressure	kPa	345.5	364.4	385
Rate of Strain	%/hour	5.687146919	5.885251443	6.039821548
Max Deviator Stress				
Axial Strain		1.759	2.450	3.688
Axial Stress	kPa	39.00	60.32	107.61
Cor. Deviator stress	kPa	39.00	60.32	107.61
Effective Major Stress	kPa	62.90	95.52	173.11
Effective Minor Stress	kPa	23.90	35.20	65.50
Effective Stress Ratio		2.632	2.714	2.643
s'	kPa	43.40	65.36	119.30
t'	kPa	19.50	30.16	53.80
Shear Resistance Angle	degs	26.70	26.70	26.70
Cohesion c'	kPa	0.36	0.36	0.36
Max Effective Principle Stress Ratio				
Axial Strain		1.759	2.450	3.688
Axial Stress	kPa	39.00	60.32	107.61
Cor. Deviator stress	kPa	39.00	60.32	107.61
Effective Major Stress	kPa	62.90	95.52	173.11
Effective Minor Stress	kPa	23.90	35.20	65.50
Effective Stress Ratio		2.632	2.714	2.643
s'	kPa	43.40	65.36	119.30
t'	kPa	19.50	30.16	53.80

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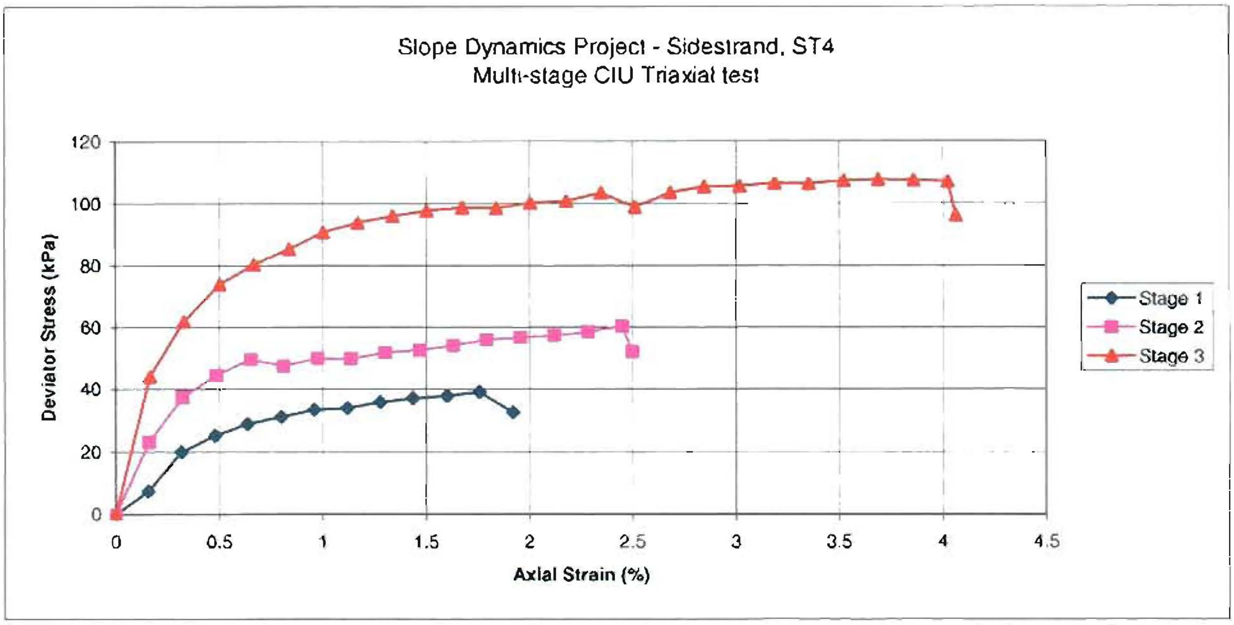
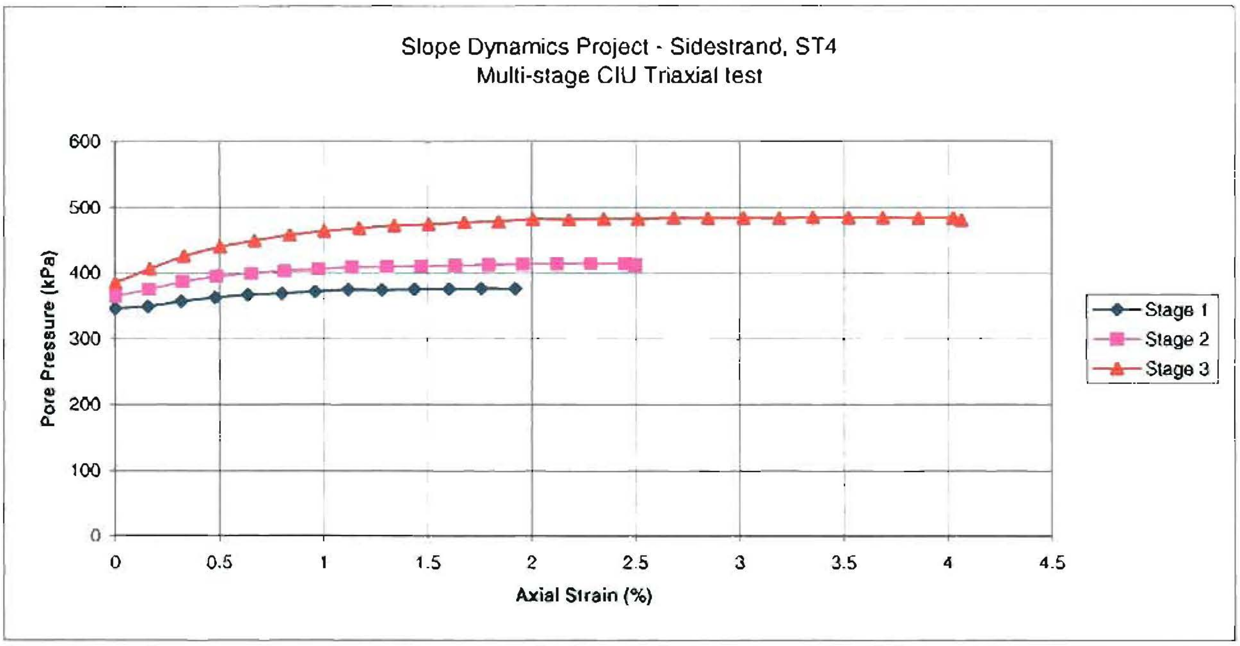
Specimen Details

		Stage 1	Stage 2	Stage 3
Job Ref.		Slope Dynamics		
Job Location		Sidestrand mudslide		
Borehole		0	0	0
Sample No.		ST4	ST4	ST4
Depth	m	0.15	0.15	0.15
Date		20/04/01	20/04/01	20/04/01

Shearing Stage





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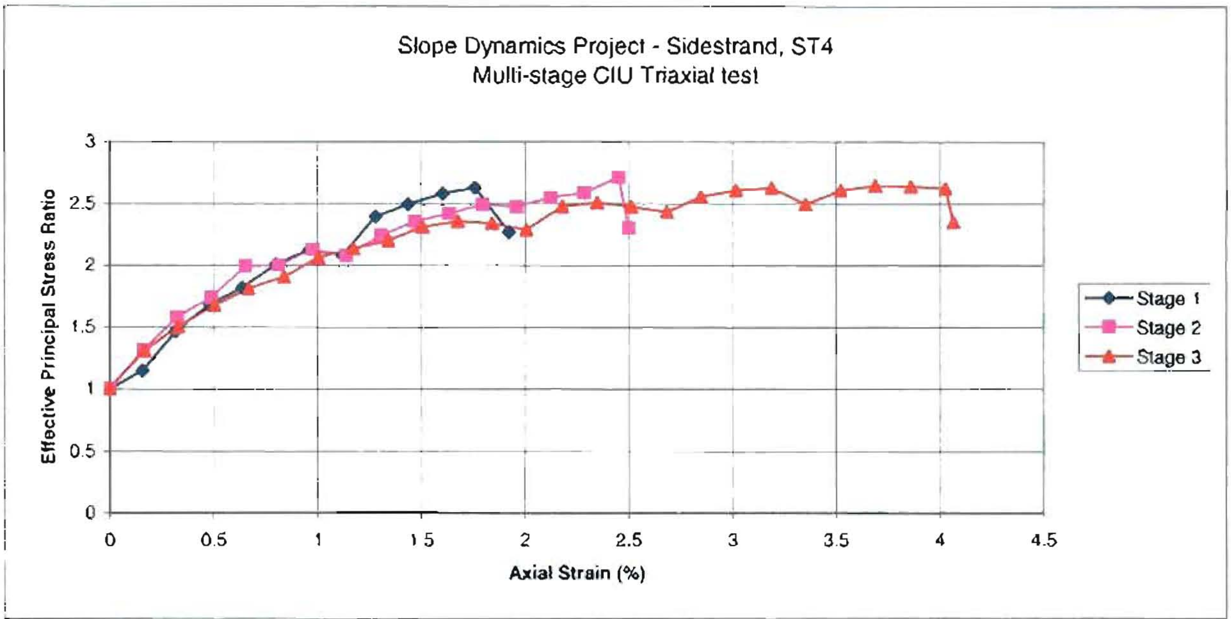
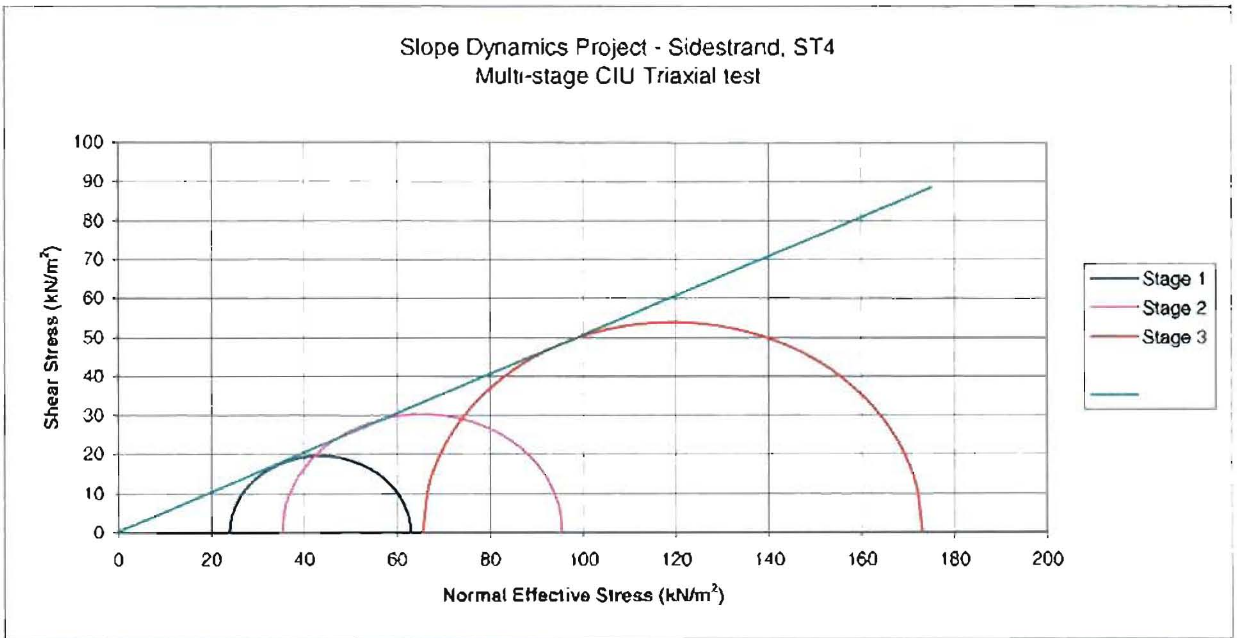
Sample Details

		Stage 1	Stage 2	Stage 3
Job Ref.		Slope Dynamics		
Job Location		Sidestrand mudslide		
Borehole		0	0	0
Sample No.		ST4	ST4	ST4
Depth	m	0.15	0.15	0.15
Date		20/04/01	20/04/01	20/04/01

Shearing Stage





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Consolidated Undrained Triaxial Compression Test

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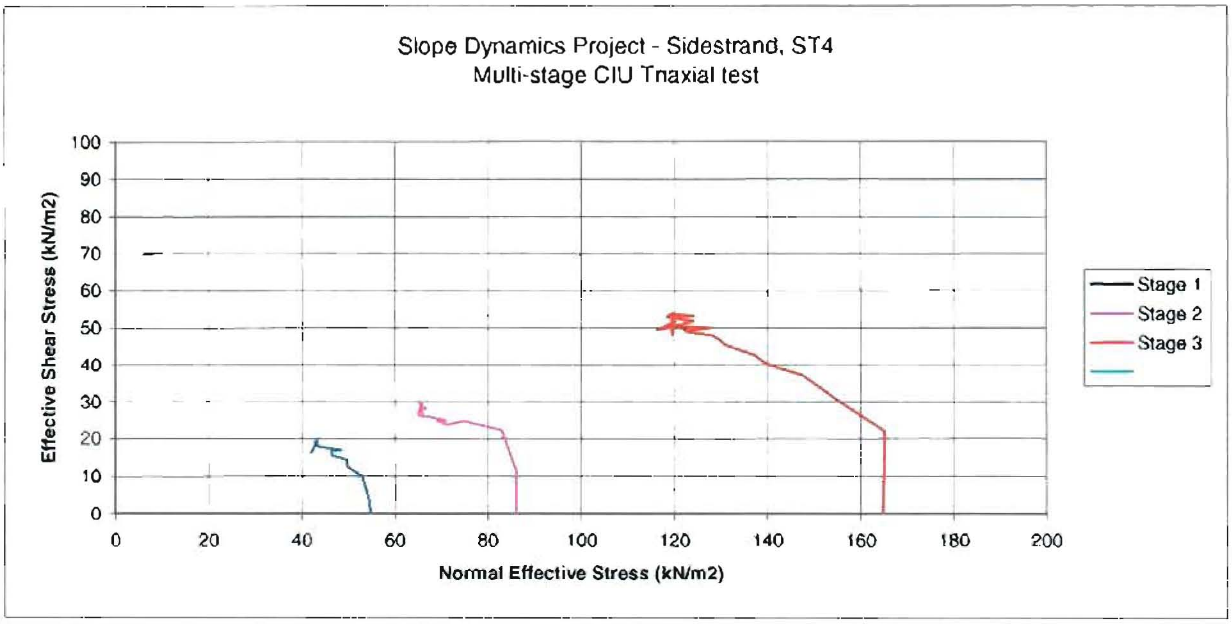
Sample Details

		Stage 1	Stage 2	Stage 3
Job Ref.		Slope Dynamics		
Job Location		Sidestrand mudslide		
Borehole		0	0	0
Sample No.		ST4	ST4	ST4
Depth	m	0.15	0.15	0.15
Date		20/04/01	20/04/01	20/04/01

Shearing Stage



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Specimen Details

		Stage 1	Stage 2	Stage 3
Job Ref.		Slope Dynamics		
Job Location		Sidestrand		
Borehole				
Sample No.		ST5	ST5	ST5
Depth	m	0.15	0.15	0.15
Date		20/04/2001	20/04/2001	20/04/2001
Disturbed / Undisturbed		undisturbed tube	undisturbed tube	undisturbed tube

Description of Specimen

Light grey till (debris flow)

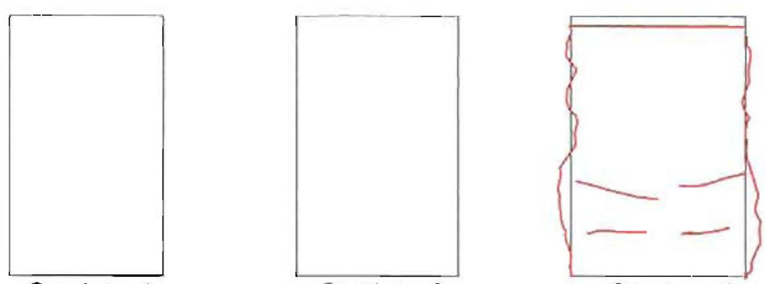
Initial Specimen Conditions

		Stage 1	Stage 2	Stage 3
Height	mm	197.00	190.14	183.74
Diameter	mm	103.00	103.21	103.77
Area	mm^2	8332.29	8366.41	8457.72
Volume	cm^3	1641.46	1590.80	1553.98
Mass	g	3291.00	3291.00	3291.00
Dry Mass	g	2500.27		
Density	Mg/m^3	2.00	2.07	2.12
Dry Density	Mg/m^3	1.52		
Moisture Content	%	24.03		
Degree of Saturation	%			
Specific Gravity (assumed/measured)	kN/m^3			

Final Specimen Conditions

		Stage 1	Stage 2	Stage 3
Moisture Content	%			20.14
Density	Mg/m^3			
Dry Density	Mg/m^3			1.72

Sketch of Failure of the Specimen



Specimen 1 Specimen 2 Specimen 3

Date. Date

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Specimen Details

		Stage 1	Stage 2	Stage 3
Job Ref.		Slope Dynamics		
Job Location		Sidestrand		
Borehole		0	0	0
Sample No.		ST5	ST5	ST5
Depth	m	0.15	0.15	0.15
Date		20/04/2001	20/04/2001	20/04/2001

Test Setup

	Stage 1	Stage 2	Stage 3
Date started	20/06/05	20/06/05	20/06/05
Date Finished			
Top Drain Used	y	y	y
Base Drain Used	y	y	y
Side Drains Used	y	y	y
Pressure System Number			
Cell Number			

Saturation

		Stage 1	Stage 2	Stage 3
Cell Pressure Incr.	kPa	17.60	17.60	17.60
Back Pressure Incr.	kPa	17.60	17.60	17.60
Differential Pressure	kPa	0.10	0.10	0.10
Final Cell Pressure	kPa	18.70	18.70	18.70
Final Pore Pressure	kPa	21.00	21.00	21.00
Final B Value		1.01	1.01	1.01

Consolidation

		Stage 1	Stage 2	Stage 3
Effective Pressure	kPa	0.10	28.50	58.10
Cell Pressure	kPa	19.00	56.60	105.90
Back Pressure	kPa	18.90	28.10	47.80
Excess Pore Pressure	kPa	21.50	25.00	22.00
Pore Pressure at End	kPa	2.60	12.90	12.70
Consolidated Volume	cm^3	1590.80	1553.98	1512.81
Volumetric Strain		0.01028799	0.007714153	0.008832567
Consolidated Height	mm	194.97	188.67	182.11
Consolidated Area	mm^2	8160.84	8237.33	8308.32
Vol. Compressibility	m^2/MN		1.44640	0.68825
Consolidation Coef.	$m^2/yr.$			

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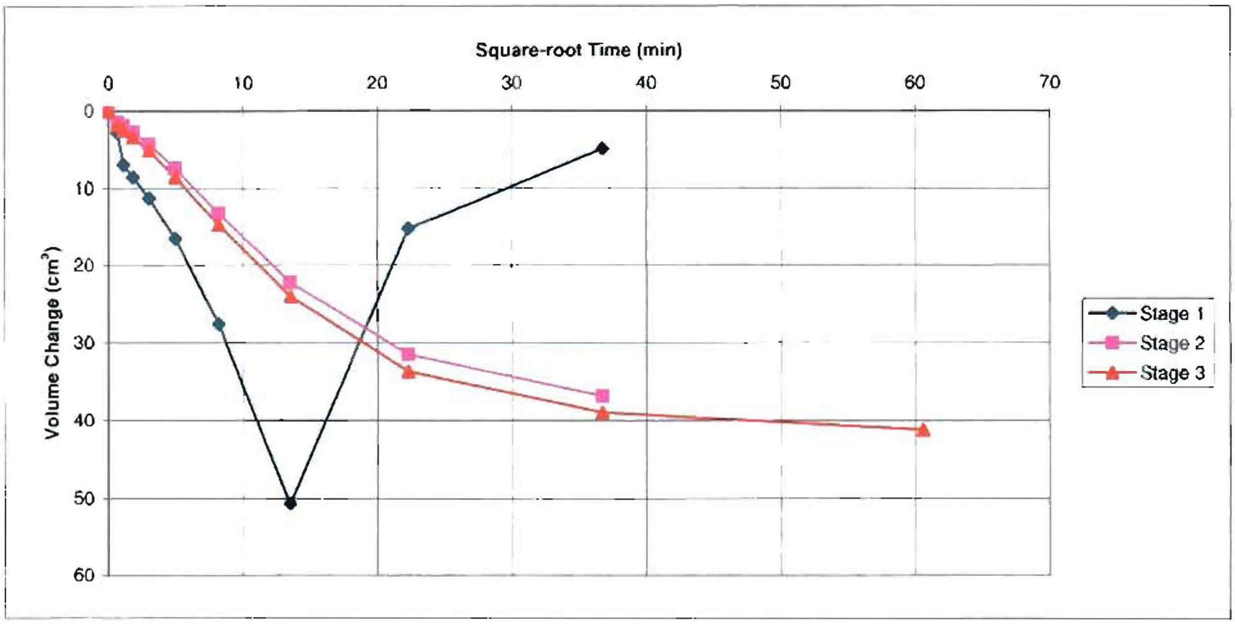
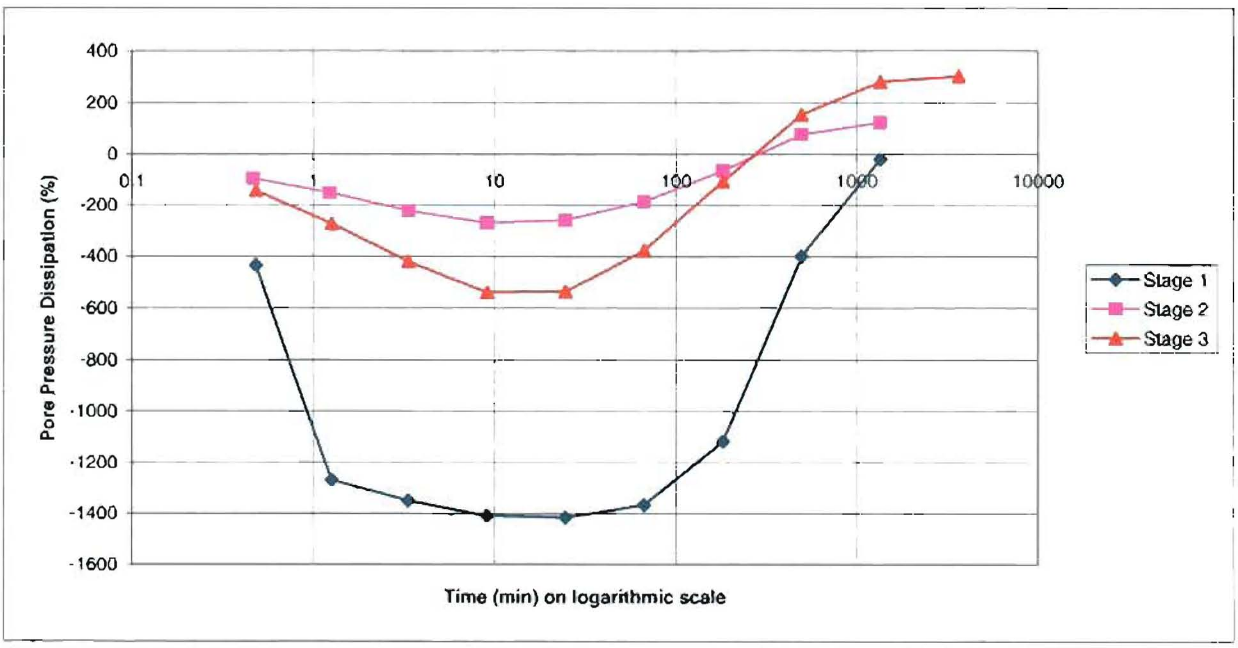
Specimen Details

		Stage 1	Stage 2	Stage 3
Job Ref.		Slope Dynamics		
Job Location		Sidestrand		
Borehole		0	0	0
Sample No.		ST5	ST5	ST5
Depth	m	0.15	0.15	0.15
Date		20/04/2001	20/04/2001	20/04/2001

Consolidation Stage





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		Stage 1	Stage 2	Stage 3
Specimen Details				
Job Ref.		Slope Dynamics		
Job Location		Sidestrand		
Borehole		0	0	0
Sample No.		ST5	ST5	ST5
Depth	m	0.15	0.15	0.15
Date		20/04/2001	20/04/2001	20/04/2001

		Stage 1	Stage 2	Stage 3
Shearing				
Initial Cell Pressure	kPa	59.5	109.5	209.7
Initial Pore Pressure	kPa	22.6	22	20.5
Rate of Strain	%/hour	6.091309645	6.311034028	6.53106277
Max Deviator Stress				
Axial Strain		2.478	2.618	2.711
Axial Stress	kPa	34.89	66.09	136.42
Cor. Deviator stress	kPa	34.89	66.09	136.42
Effective Major Stress	kPa	52.39	118.49	271.12
Effective Minor Stress	kPa	17.50	52.40	134.70
Effective Stress Ratio		2.994	2.261	2.013
s'	kPa	34.95	85.44	202.91
t'	kPa	17.45	33.04	68.21
Shear Resistance Angle	degs	17.56	17.56	17.56
Cohesion c'	kPa	7.40	7.40	7.40
Max Effective Principle Stress Ratio				
Axial Strain		2.478	2.618	2.711
Axial Stress	kPa	34.89	66.09	136.42
Cor. Deviator stress	kPa	34.89	66.09	136.42
Effective Major Stress	kPa	52.39	118.49	271.12
Effective Minor Stress	kPa	17.50	52.40	134.70
Effective Stress Ratio		2.994	2.261	2.013
s'	kPa	34.95	85.44	202.91
t'	kPa	17.45	33.04	68.21

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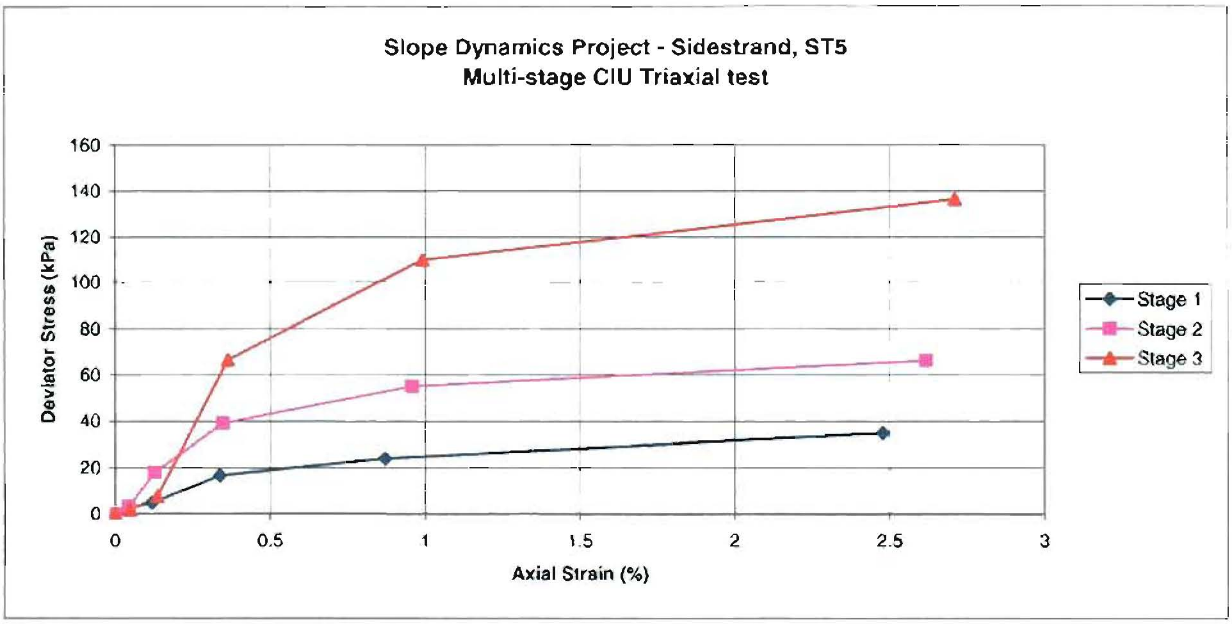
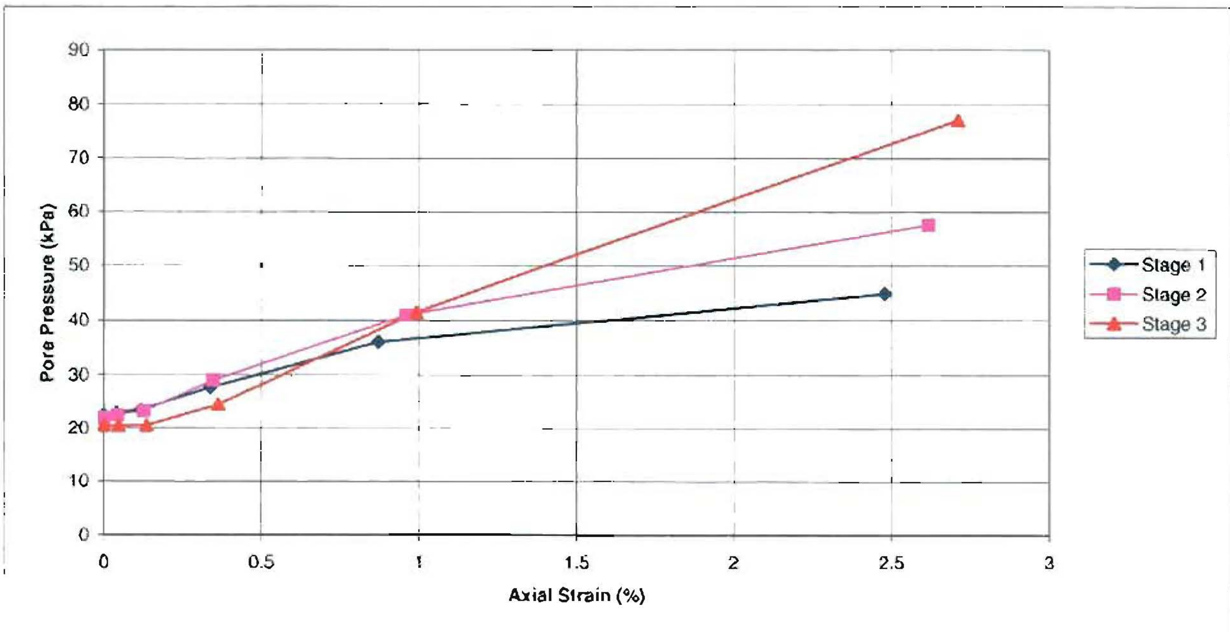
Specimen Details

		Stage 1	Stage 2	Stage 3
Job Ref.		Slope Dynamics		
Job Location		Sidestrand		
Borehole		0	0	0
Sample No.		ST5	ST5	ST5
Depth	m	0.15	0.15	0.15
Date		20/04/2001	20/04/2001	20/04/2001

Shearing Stage





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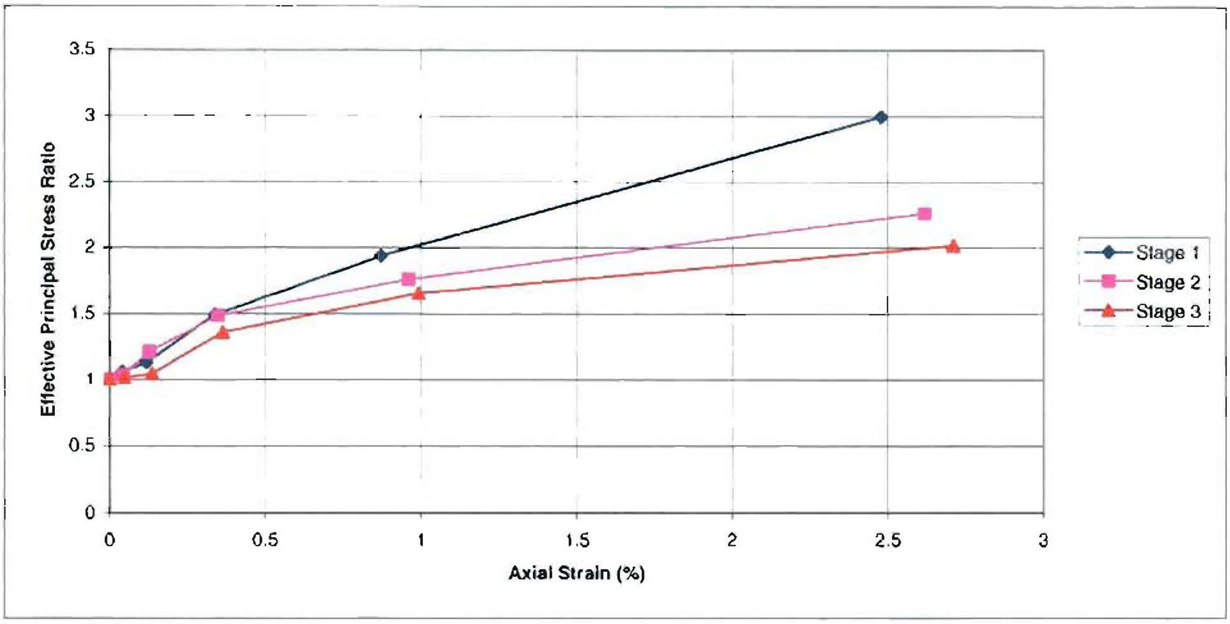
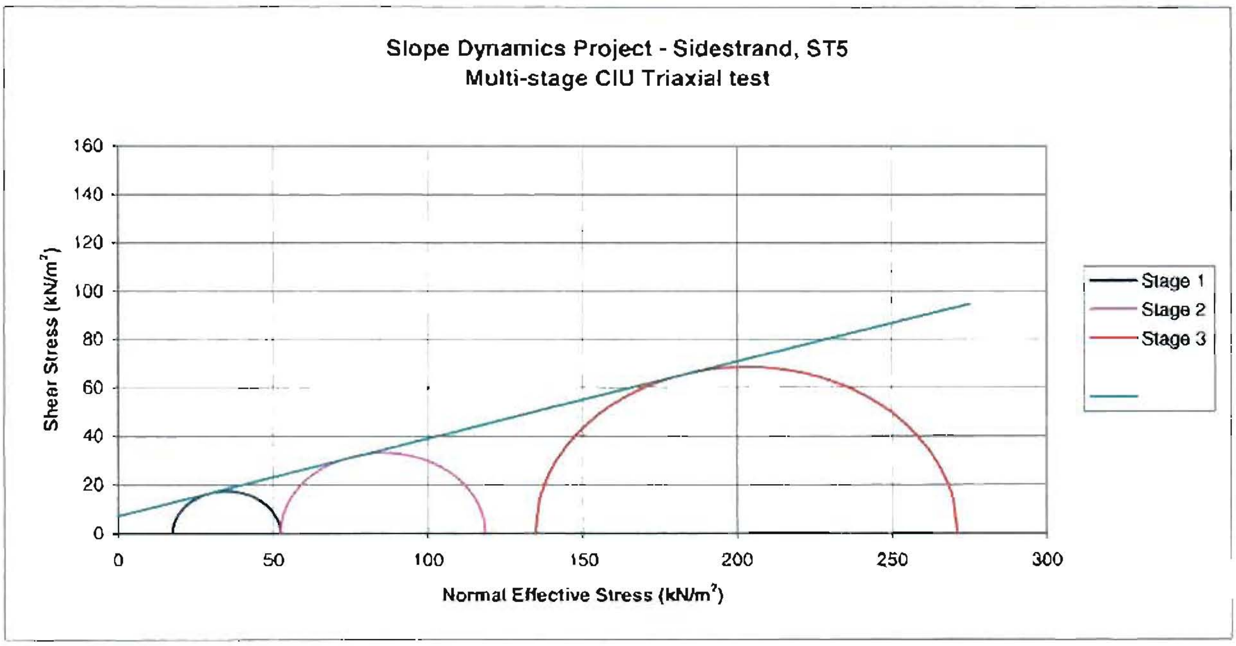
Sample Details

		Stage 1	Stage 2	Stage 3
Job Ref.		Slope Dynamics		
Job Location		Sidestrand		
Borehole		0	0	0
Sample No.		ST5	ST5	ST5
Depth	m	0.15	0.15	0.15
Date		20/04/2001	20/04/2001	20/04/2001

Shearing Stage





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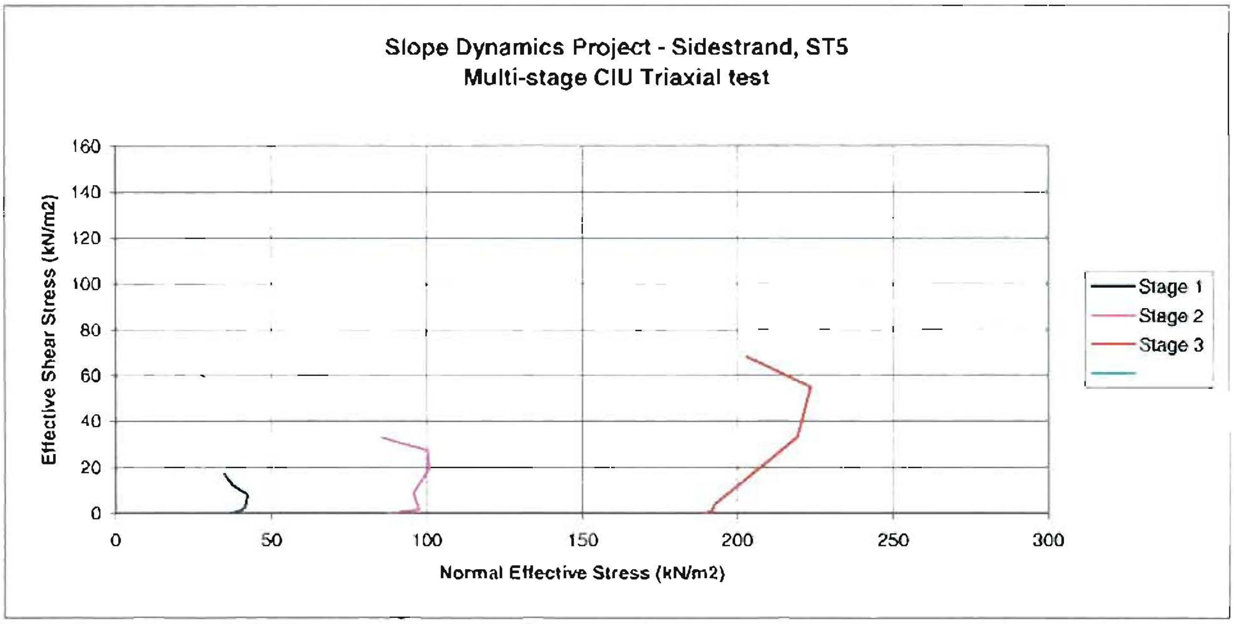
Sample Details

		Stage 1	Stage 2	Stage 3
Job Ref.		Slope Dynamics		
Job Location		Sidestrand		
Borehole		0	0	0
Sample No.		ST5	ST5	ST5
Depth	m	0.15	0.15	0.15
Date		20/04/2001	20/04/2001	20/04/2001

Shearing Stage



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Date:

British Geological Survey

Consolidated Undrained Triaxial Compression Test
BS 1377 : Part 8 : 1990

Specimen Details

		Stage 1	Stage 2	Stage 3
Job Ref.		Aldbrough		
Job Location				
Borehole				
Sample No.		ALD1	ALD1	ALD1
Depth	m	0.15 [3.8 m bgl]	0.15 [3.8 m bgl]	0.15 [3.8 m bgl]
Date		19/08/04	19/08/04	19/08/04
Disturbed / Undisturbed		undis	undis	undis

Description of Specimen

Upper grey Till [Withernsea Till Member, Holderness Formation]

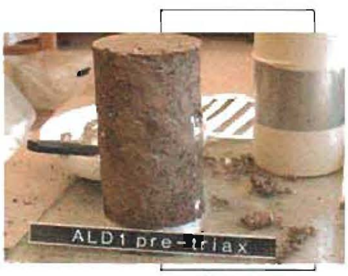
Initial Specimen Conditions

		Stage 1	Stage 2	Stage 3
Height	mm	195.20	189.03	183.64
Diameter	mm	103.50	102.22	102.97
Area	mm^2	8413.38	8207.01	8327.41
Volume	cm^3	1642.29	1551.37	1529.24
Mass	g	3525.70		
Dry Mass	g	3080.75		
Density	Mg/m^3	2.15	2.27	2.31
Dry Density	Mg/m^3	1.88		
Moisture Content	%	12.62		
Degree of Saturation	%			
Specific Gravity (assumed/measured)	kN/m^3			

Final Specimen Conditions

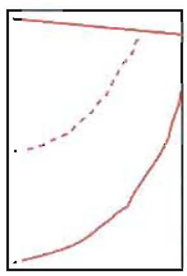
		Stage 1	Stage 2	Stage 3
Moisture Content	%	12.86		
Density	Mg/m^3	0.00	0.00	0.00
Dry Density	Mg/m^3			

Sketch of Failure of the Specimen



Pre-test

Post-test


Failure mode

Date. Date:

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Specimen Details

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Borehole		0	0	0
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Date		19/08/04	19/08/04	19/08/04

Test Setup

Date started	15/05/06	15/05/06	15/05/06
Date Finished			
Top Drain Used	y	y	y
Base Drain Used	y	y	y
Side Drains Used	y	y	y
Pressure System Number			
Cell Number			

Saturation

Cell Pressure Incr.	kPa	2.10	17.60	9.10
Back Pressure Incr.	kPa	0.80	19.50	4.40
Differential Pressure	kPa	5.50	9.50	13.30
Final Cell Pressure	kPa	9.00	38.60	49.00
Final Pore Pressure	kPa	6.00	30.50	42.00
Final B Value		0.50	0.83	0.50

Consolidation

Effective Pressure	kPa	0.90	34.50	67.70
Cell Pressure	kPa	317.40	299.70	348.20
Back Pressure	kPa	316.50	265.20	280.50
Excess Pore Pressure	kPa	255.40	256.00	257.00
Pore Pressure at End	kPa	4.50	5.30	5.80
Consolidated Volume	cm^3	1551.37	1529.24	1497.15
Volumetric Strain		0.018454493	0.004755799	0.006993911
Consolidated Height	mm	191.60	188.13	182.35
Consolidated Area	mm^2	8102.85	8128.95	8210.93
Vol. Compressibility	m^2/MN	0.84396	0.98396	0.71610
Consolidation Coef.	$m^2/yr.$			

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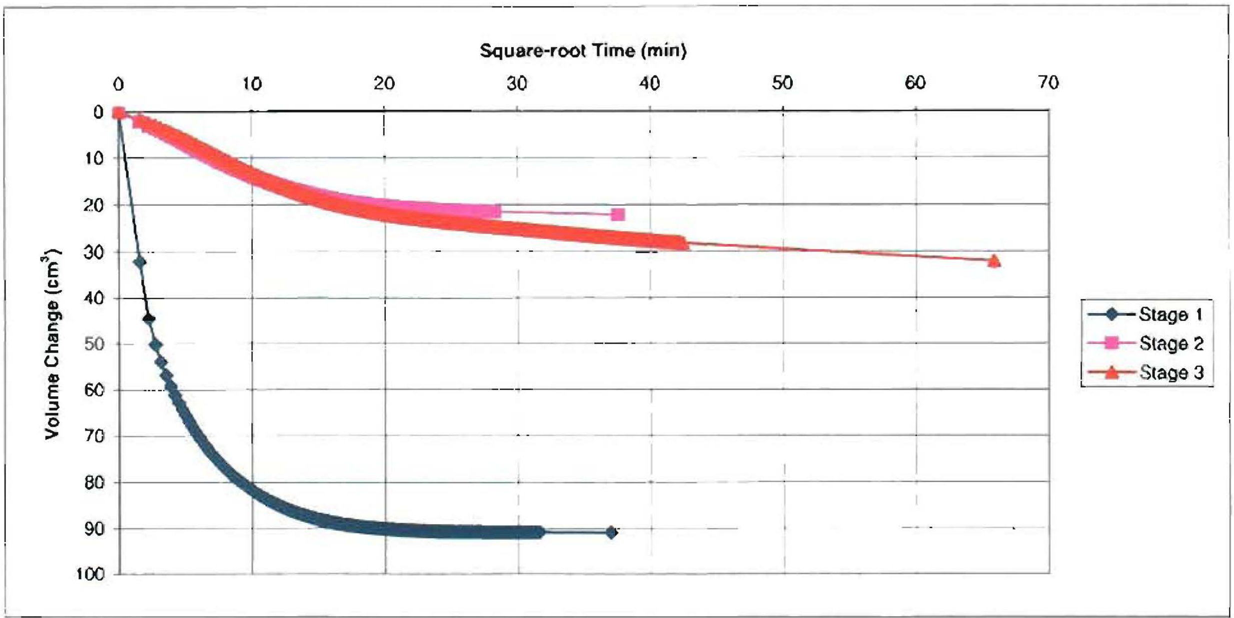
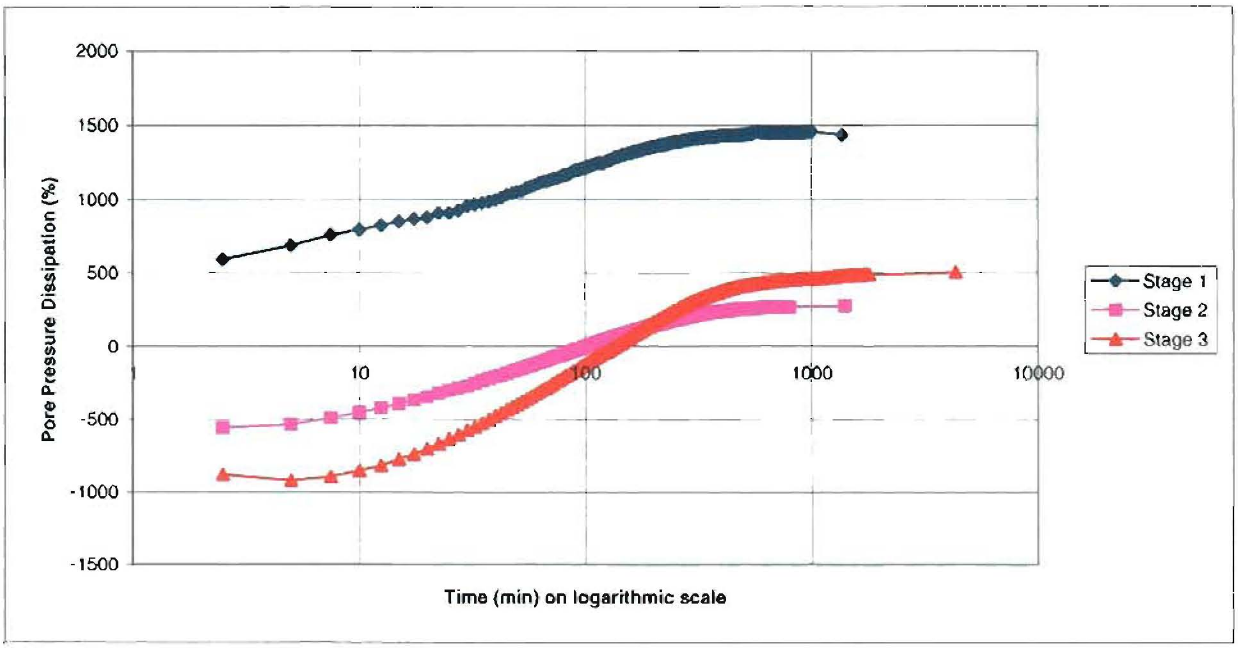
Consolidation Stage





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Shearing

		Stage 1	Stage 2	Stage 3
Initial Cell Pressure	kPa	299.5	349.2	449.2
Initial Pore Pressure	kPa	256.5	256	257.1
Rate of Strain	%/hour	6.147479508	6.348145861	6.534505131
Max Deviator Stress				
Axial Strain		1.332	2.337	3.455
Axial Stress	kPa	37.75	94.31	191.77
Cor. Deviator stress	kPa	37.75	94.31	191.77
Effective Major Stress	kPa	57.65	139.71	305.47
Effective Minor Stress	kPa	19.90	45.40	113.70
Effective Stress Ratio		2.897	3.077	2.687
s'	kPa	38.77	92.56	209.59
t'	kPa	18.87	47.16	95.89
Shear Resistance Angle	degs	26.44	26.44	26.44
Cohesion c'	kPa	3.76	3.76	3.76
Max Effective Principle Stress Ratio				
Axial Strain		1.332	2.337	3.455
Axial Stress	kPa	37.75	94.31	191.77
Cor. Deviator stress	kPa	37.75	94.31	191.77
Effective Major Stress	kPa	57.65	139.71	305.47
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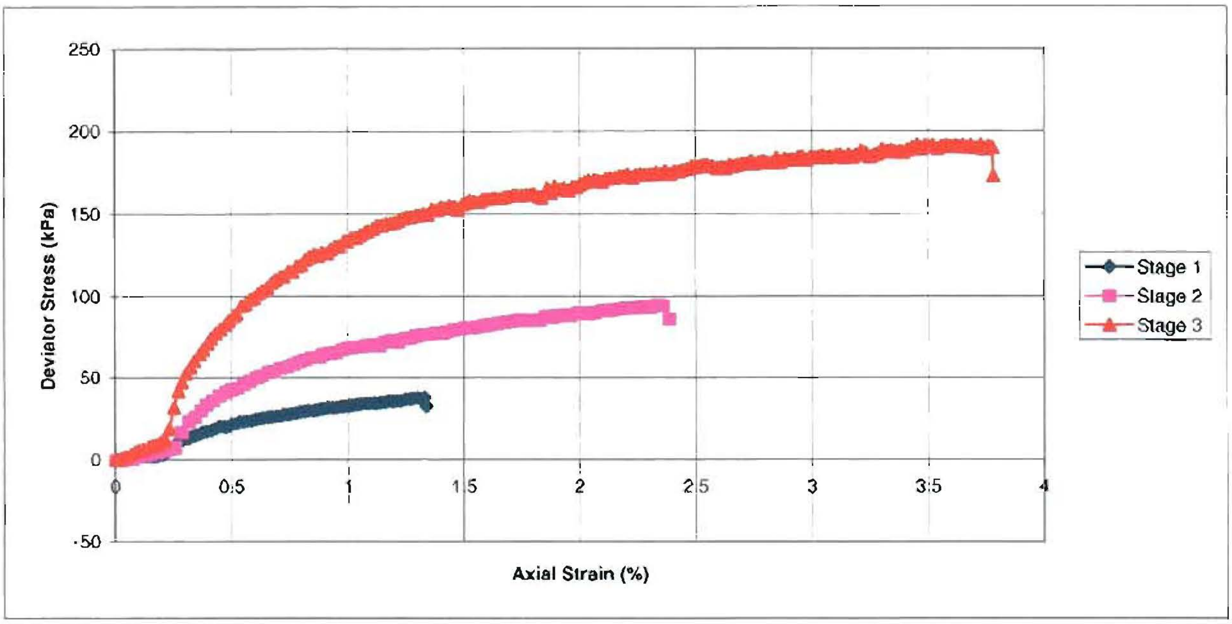
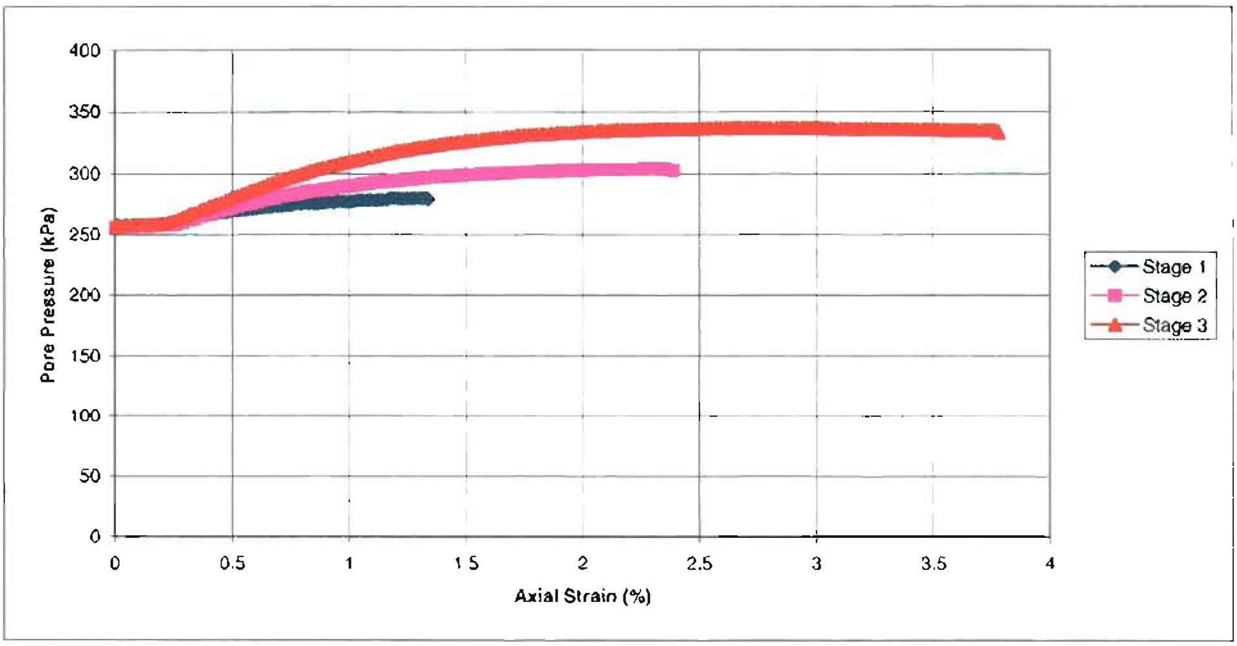
Shearing Stage





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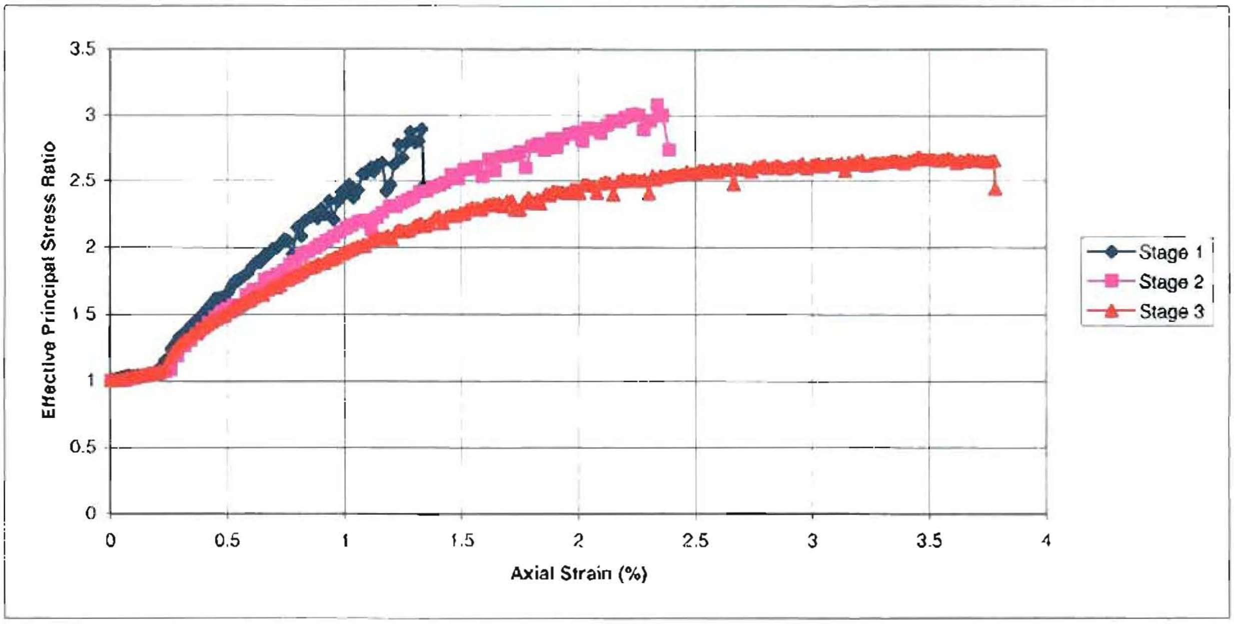

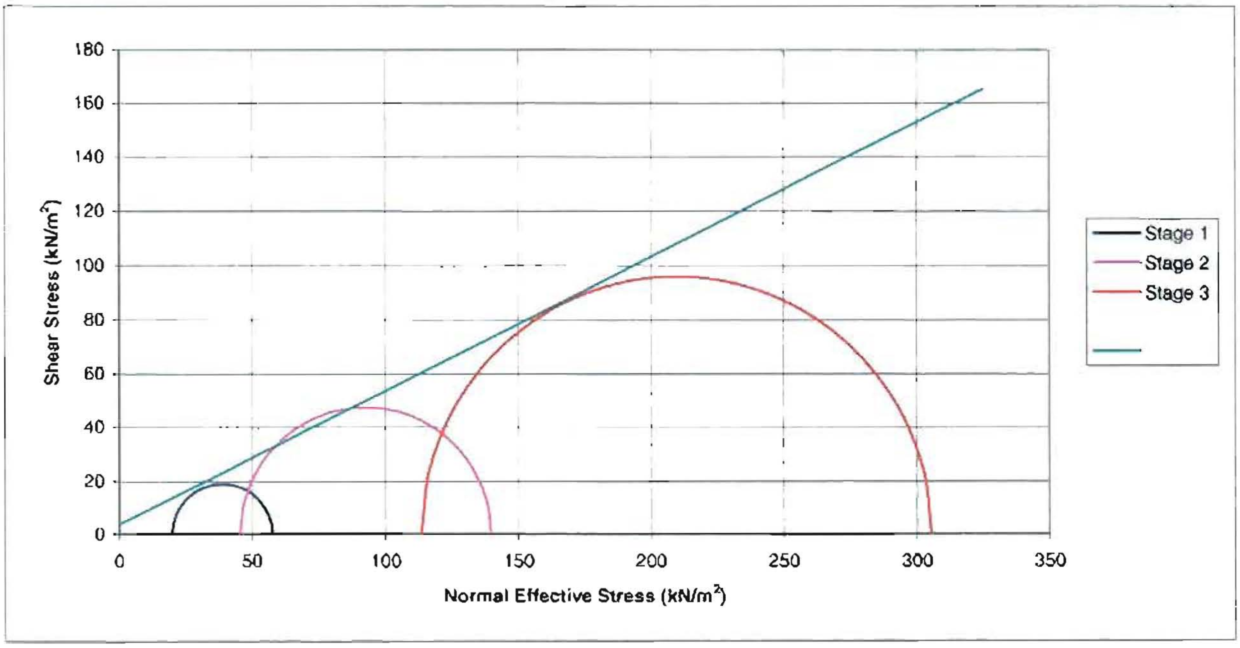

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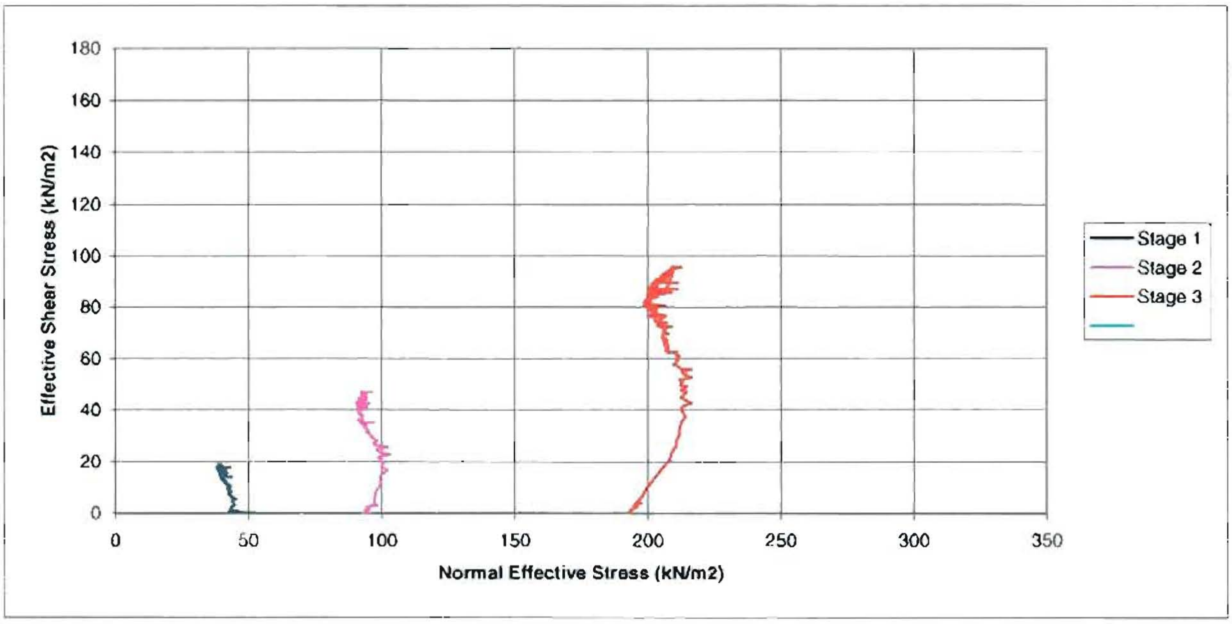

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