BRITISH STANDARD

BS 8006 : 1995

Code of practice for

Strengthened/reinforced soils and other fills

BSI STANDARDS

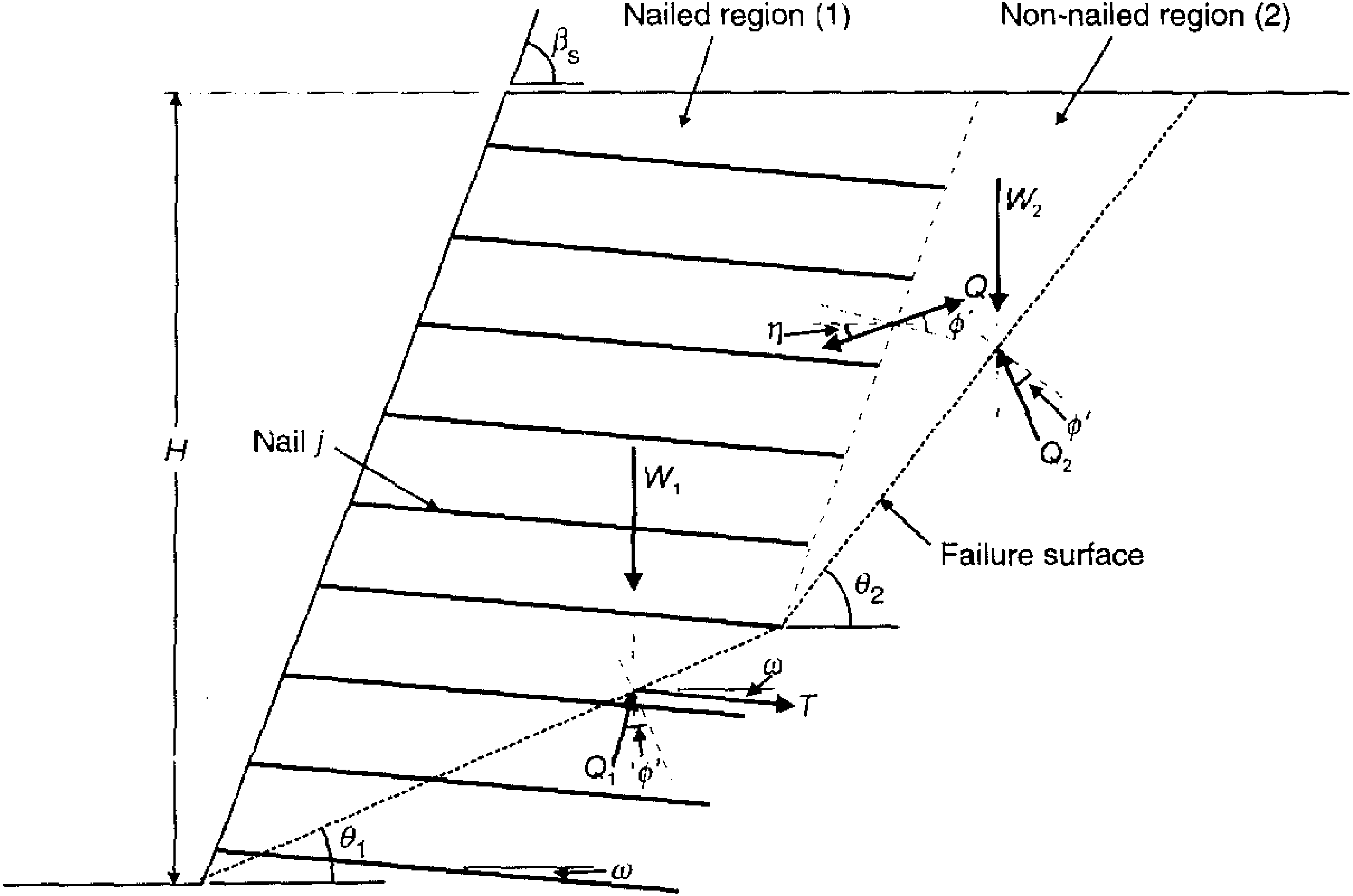


Figure 56. Use of two-part wedge analysis for soil nailing

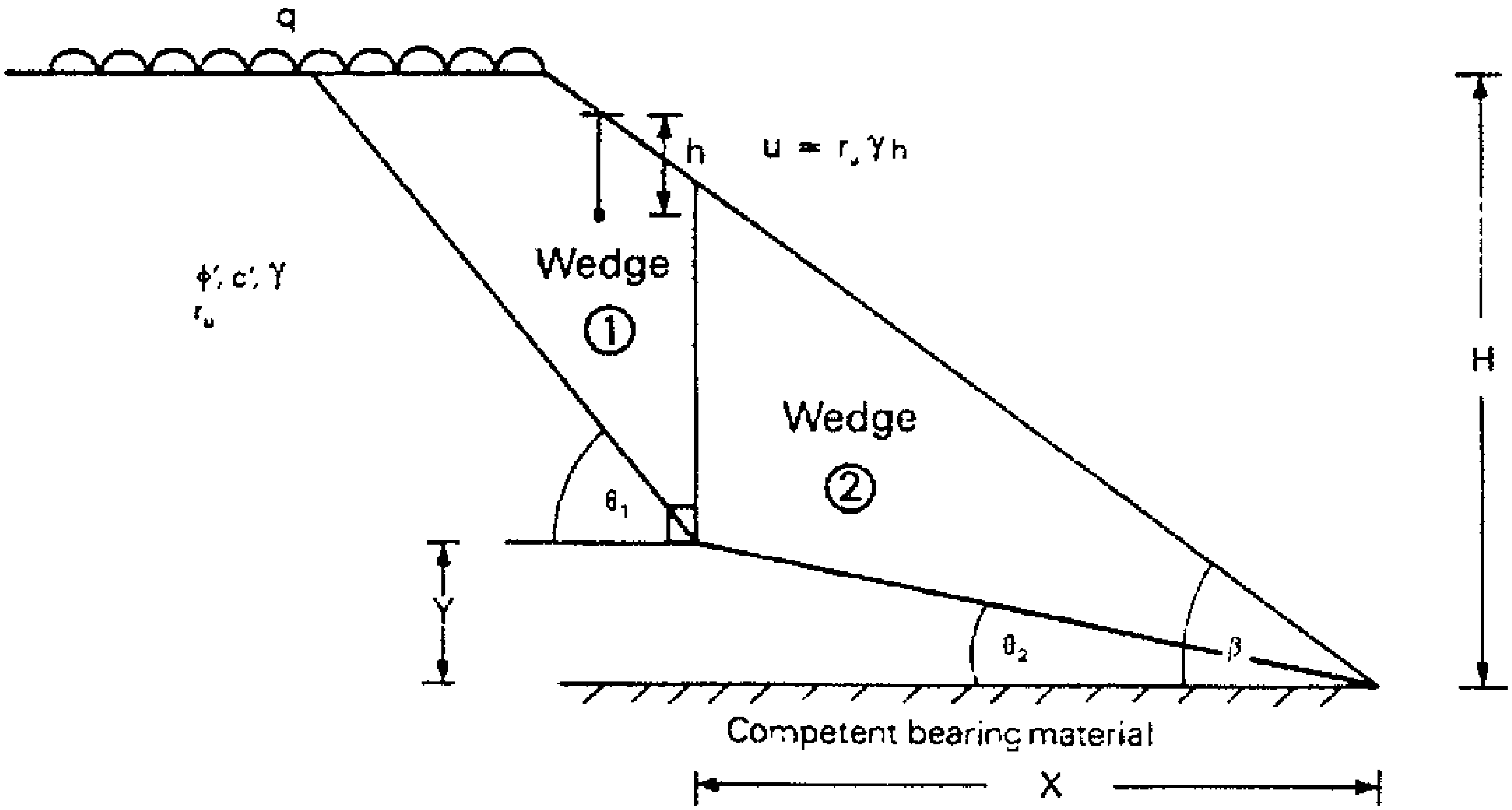
THE DEPARTMENT OF TRANSPORT
THE SCOTTISH OFFICE INDUSTRY DEPARTMENT
THE WELSH OFFICE
Y SWYDDFA GYMREIG
THE DEPARTMENT OF THE ENVIRONMENT FOR NORTHERN IRELAND

HA 68/94

Design Methods for the Reinforcement of Highway Slopes by Reinforced Soil and Soil Nailing Techniques

Summary: This Advice Note gives guidance on design methods for the strengthening of highway earthwork slopes.

83279


q
h
u = r_u γ h
φ', c', γ
r_u
Wedge
①
Wedge
②
H
θ_1
Y
θ_2
β
Competent bearing material
X

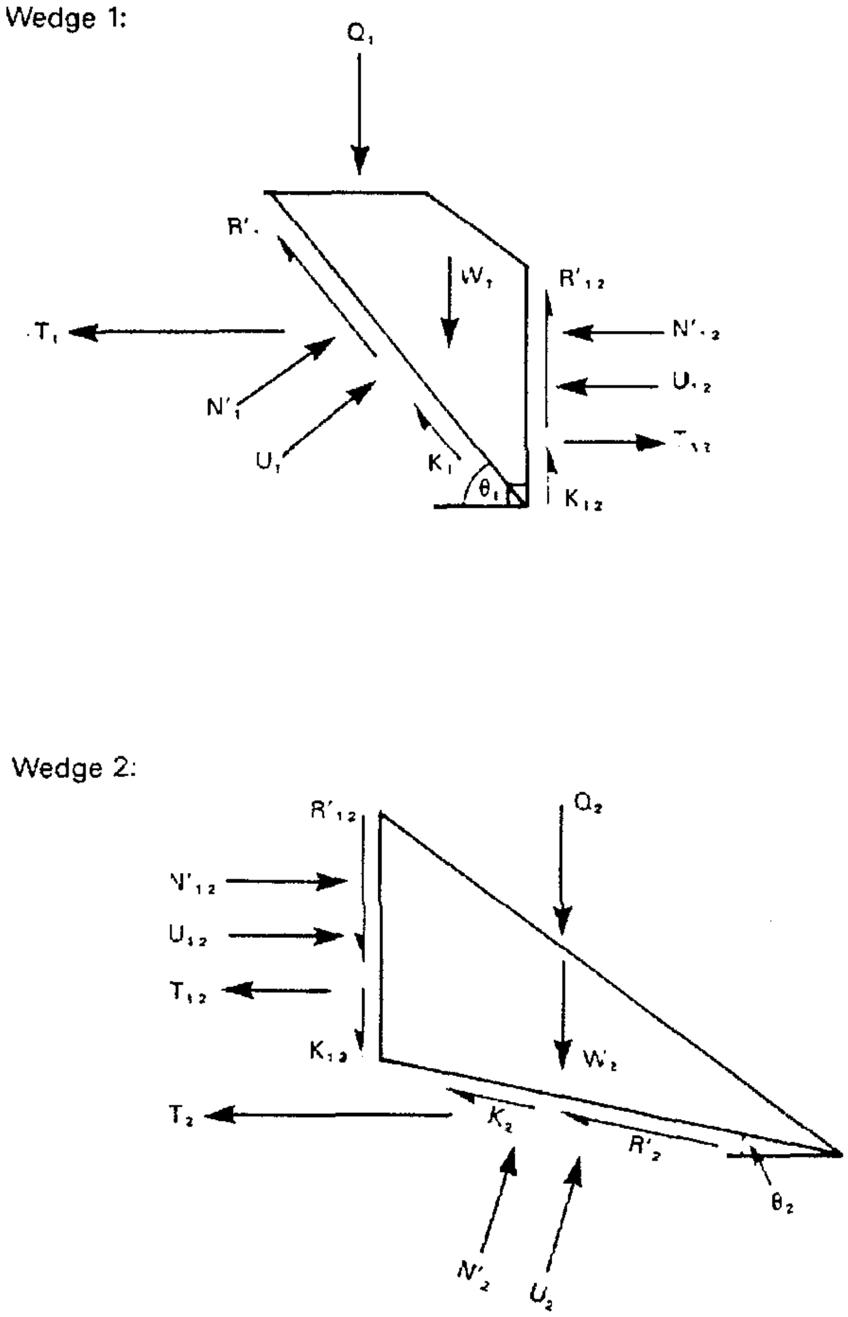
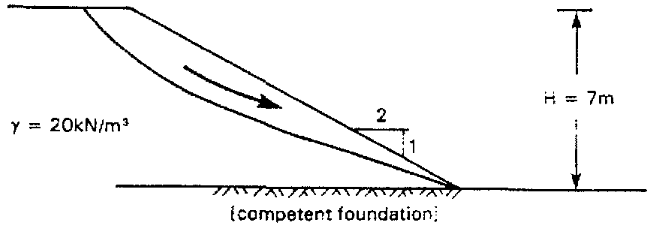


Figure 2.3 Forces acting on wedges

Example 5: Type 3 Embankment (Slip Repair)



A slip has occurred in a stiff clay embankment *and the geometry of the slip is well approximated* by the following two-part wedge (see Diagram 5):

X = 11m
Y = 3·8m
θ_1 = 35°

1. By trial and error, it is quickly found that values of ϕ', c' which would provide a factor of safety of unity on the above geometry are (assuming r_u = 0):

   ϕ' = 20°
   c' = 1·5kN/m²

2. $\Rightarrow \phi'_{des} = \tan^{-1}\left(\frac{\tan 20°}{1\cdot1}\right) = 18\cdot3°$

   c'_{des} = 0 (conservative)

3. Repair of the slope is to be carried out by excavation, followed by replacement of the slipped material reinforced with layers of geotextile (α = 0·8)

4. T_{max} = 77kN/m
   X = 8·7
   Y = 0
   θ = 42
   L_e = 14·0 (λ_s = 0·8)

5. P_c = 21kN/m, say
f_c = 1·1
f_s = 1·1 } say
f_m = 1·1

=> P_{des} = 15·8kN/m

=> N = 77/15·8 = 4·9, say 5.

=> z_1 = $\frac{1}{2} H/\sqrt{N}$

= 1·57m

=> L_{e1} = $\dfrac{P_{des}}{2\,\alpha\,\sigma'_v \tan \phi'_{des}}$

= $\dfrac{15 \cdot 8}{2 \times 0 \cdot 8 \times (20 \times 1 \cdot 57) \times \tan 18 \cdot 3}$

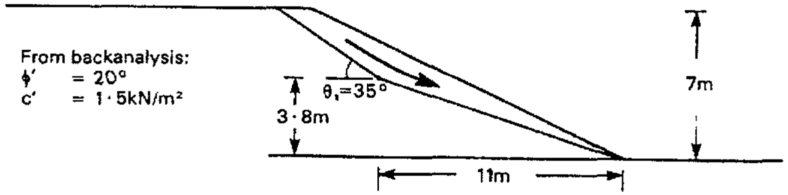
= 1·0m

6. Layer depths:

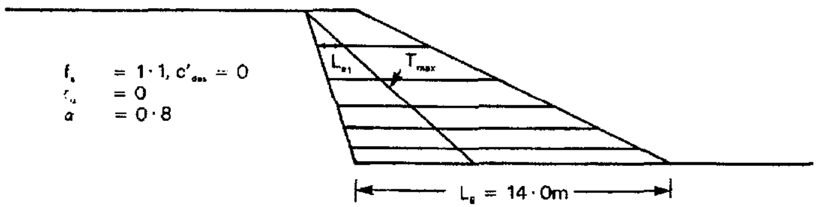
1	1·6
2	3·1
3	4·4
4	5·4
5	6·3
6	7·0

Note: The repair could also have been attempted by using a soil nailing/reinforced soil hybrid design.

Diagram 5: (Slip repair)

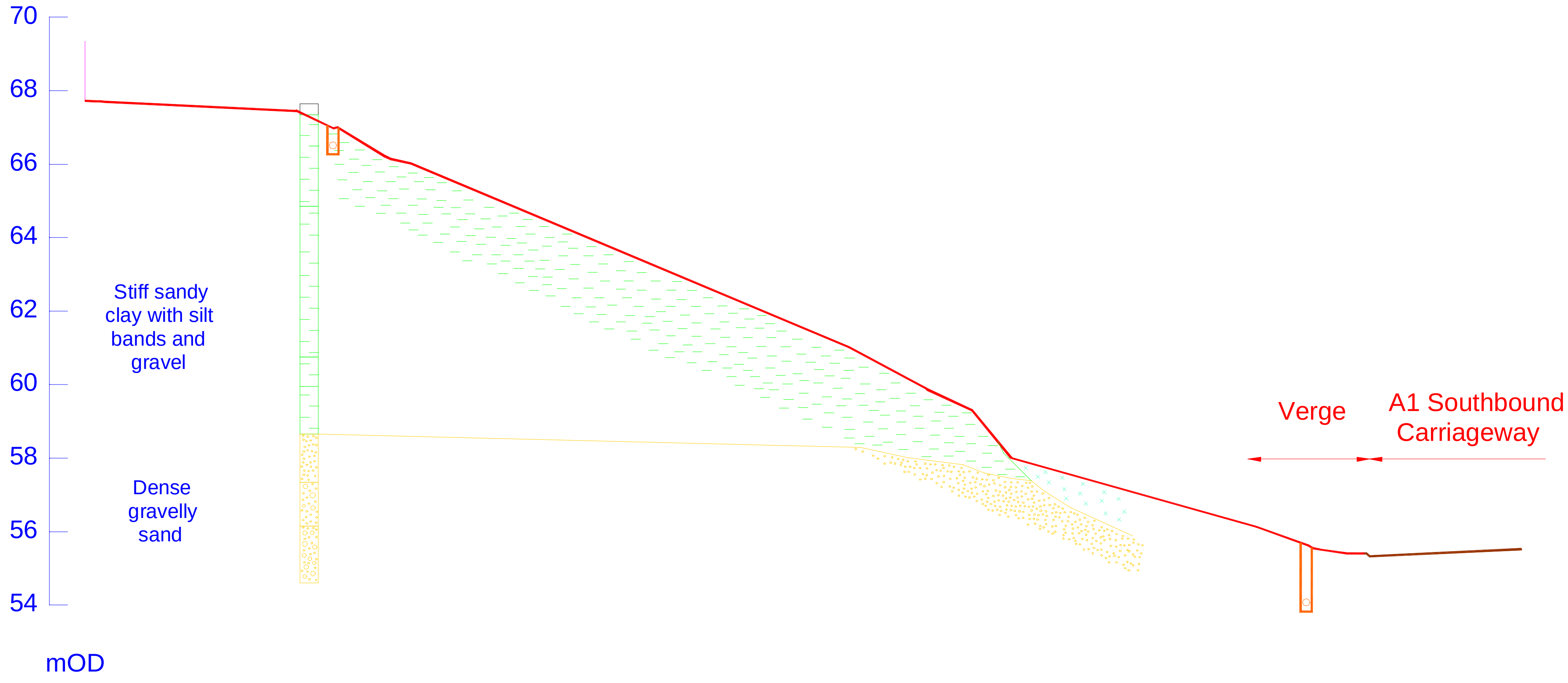


Preliminary reinforcement layout with geotextile:



C02/023	Mar 2002	Figure 2

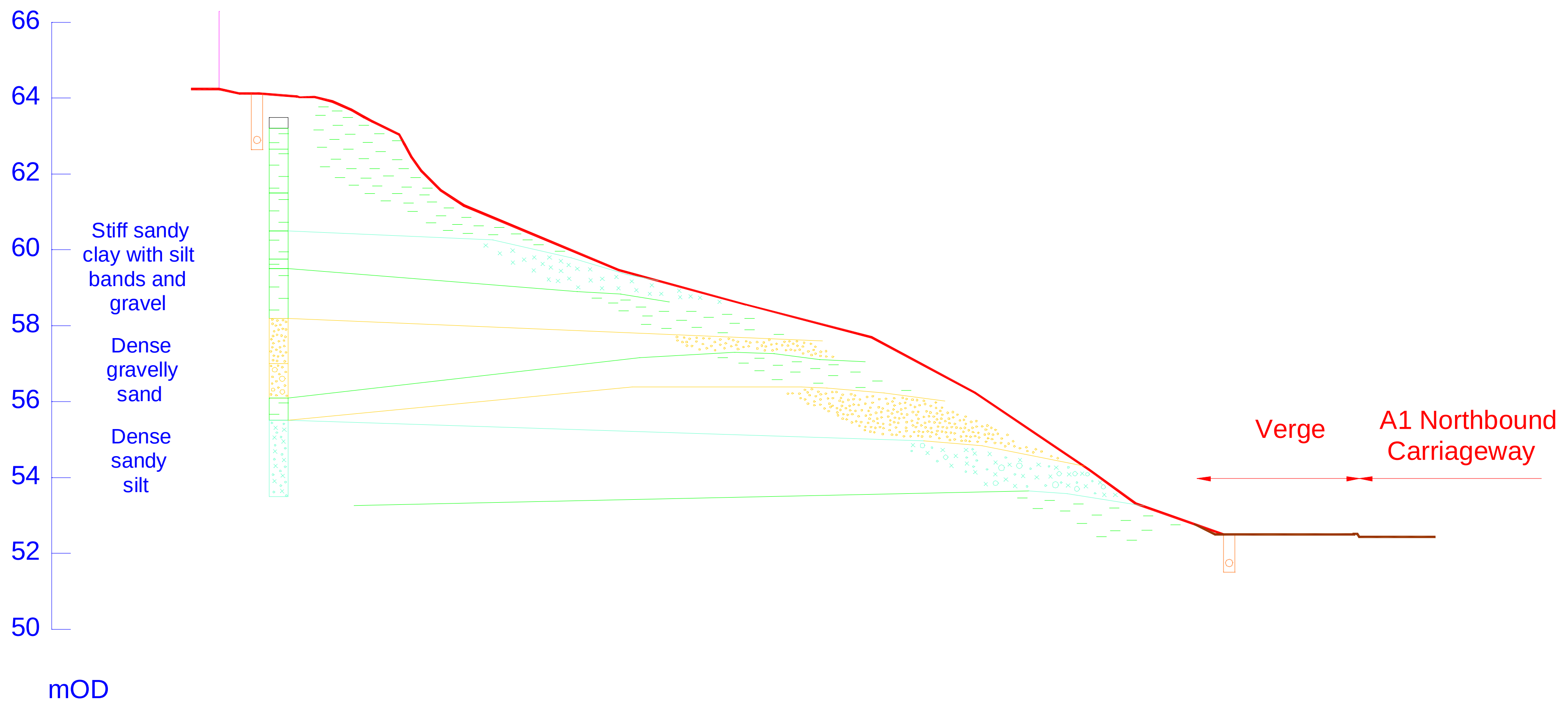
A1 Morpeth Bypass - Slope Failure Remediation



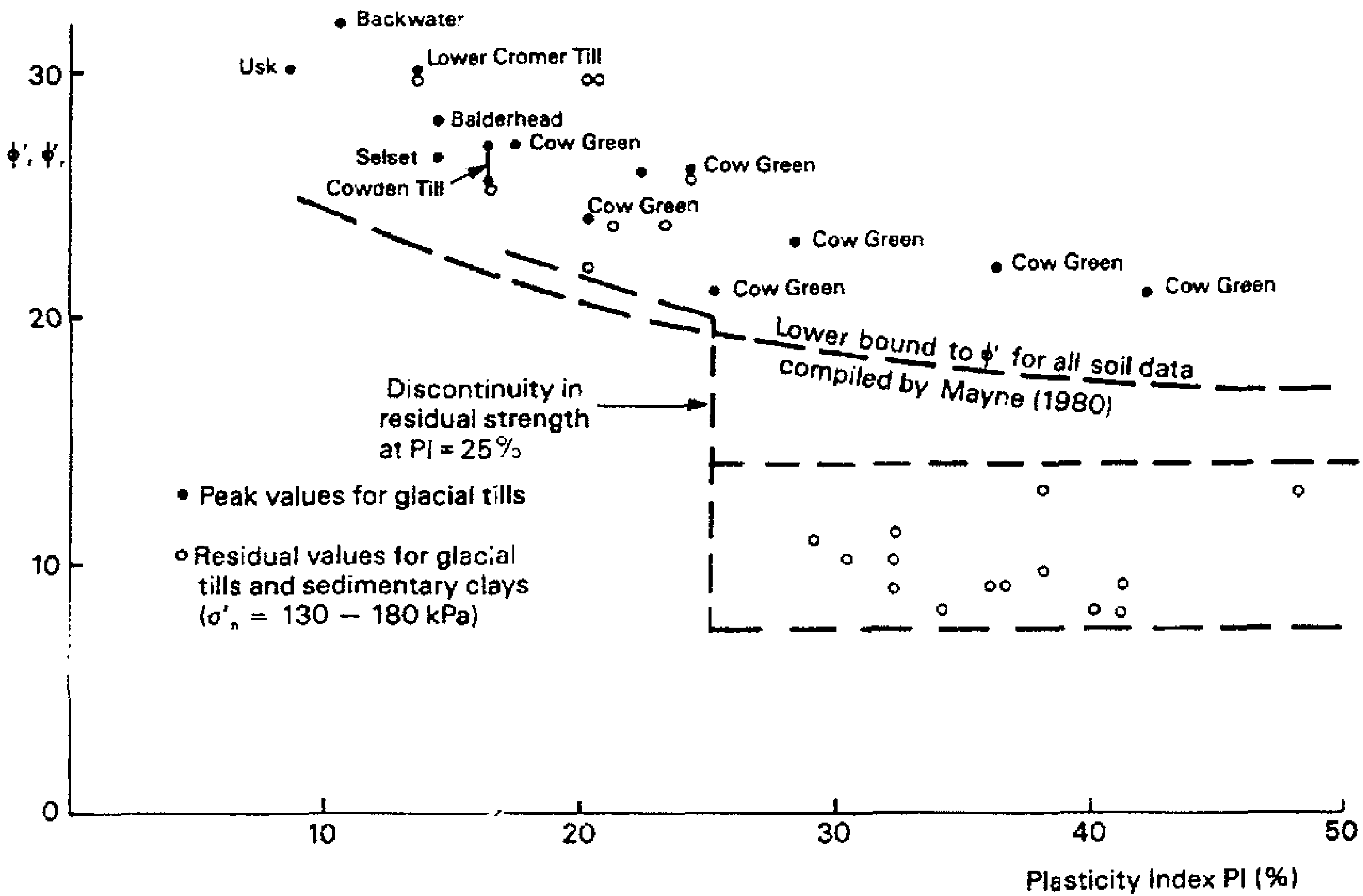
Typical Cross Section - TT6

C02/023	Apr 2002	Figure 2

A1 Morpeth Bypass - Slope Failure Remediation



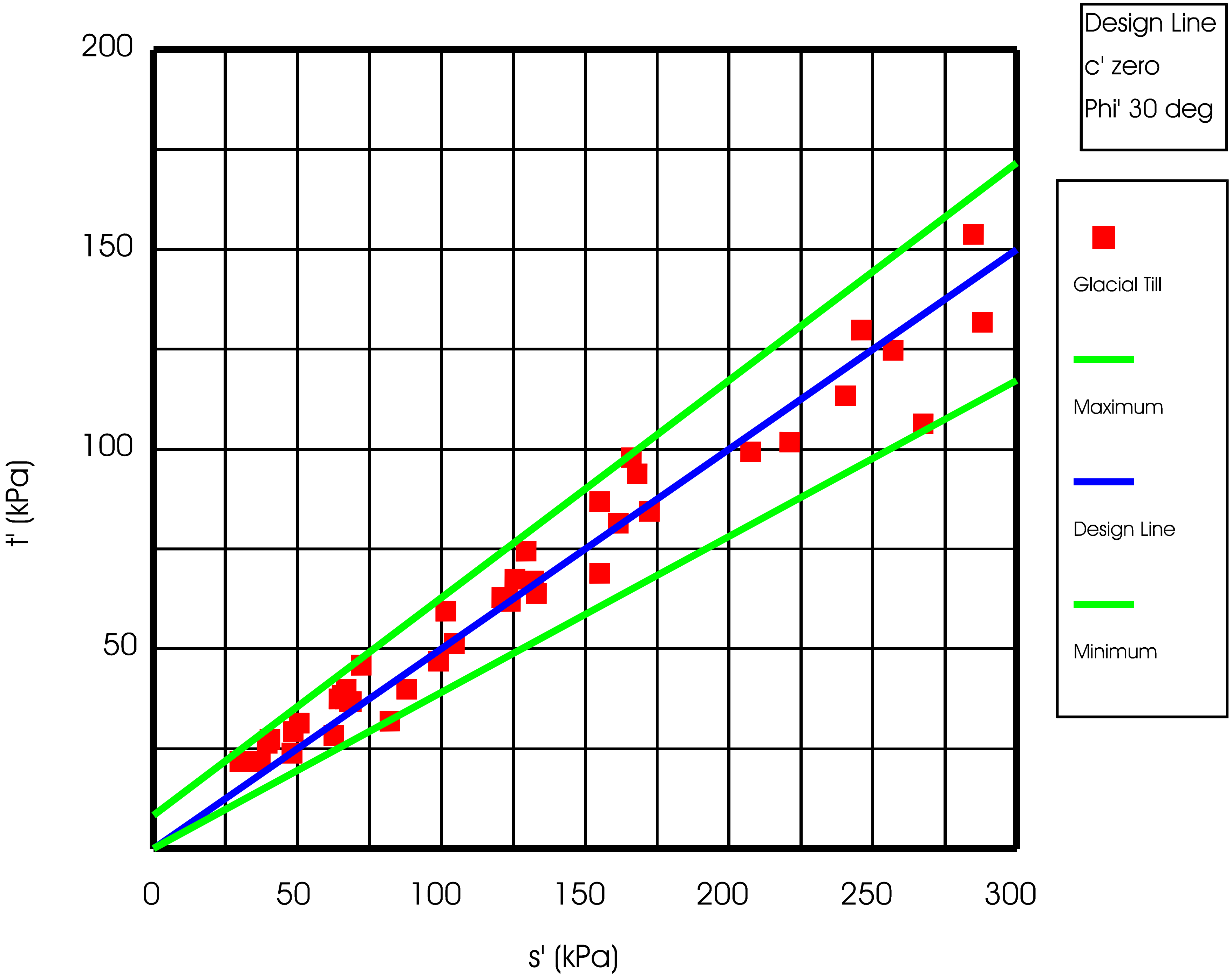
Typical Cross Section - TT3

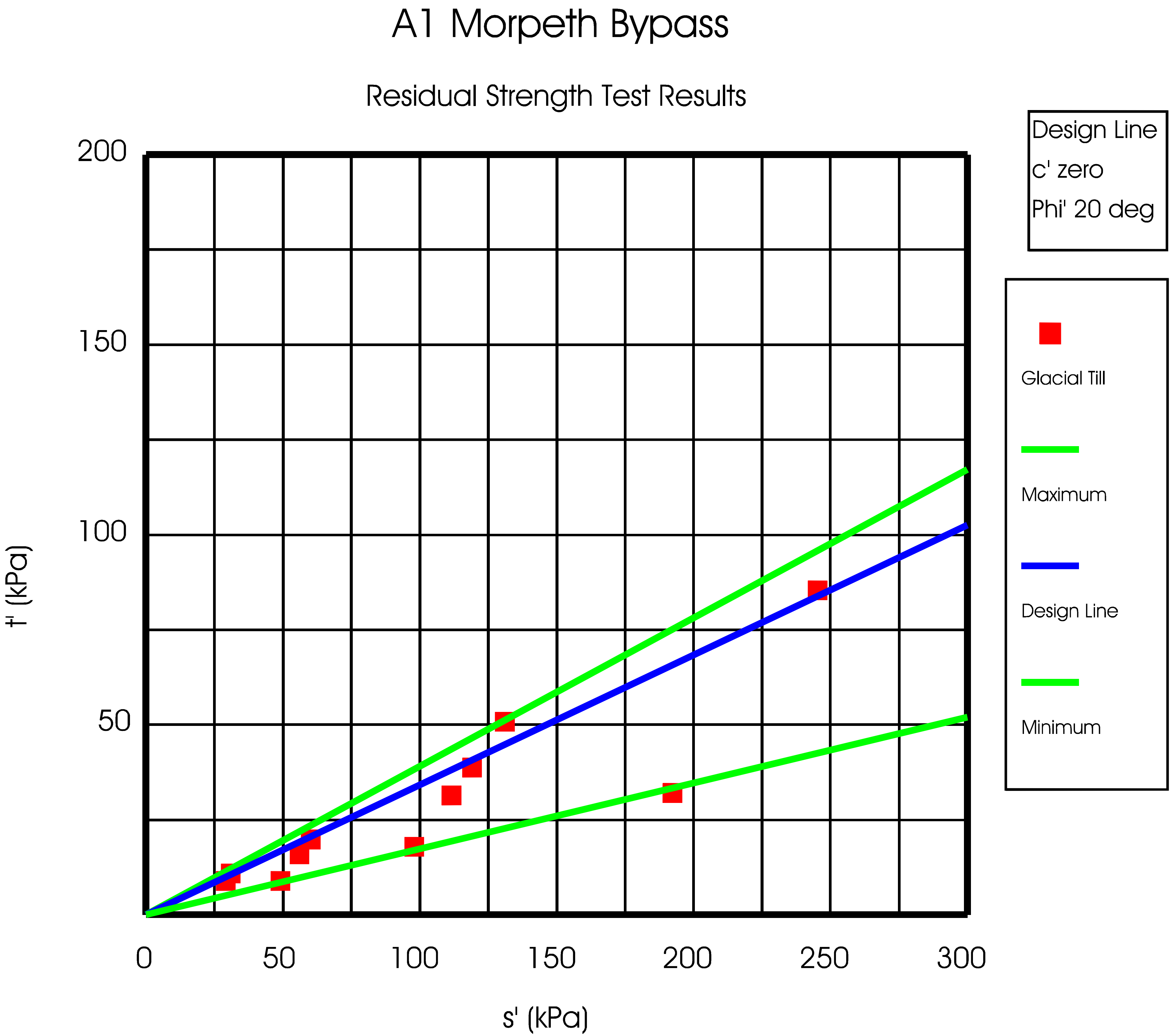


(from Hight, 1983)

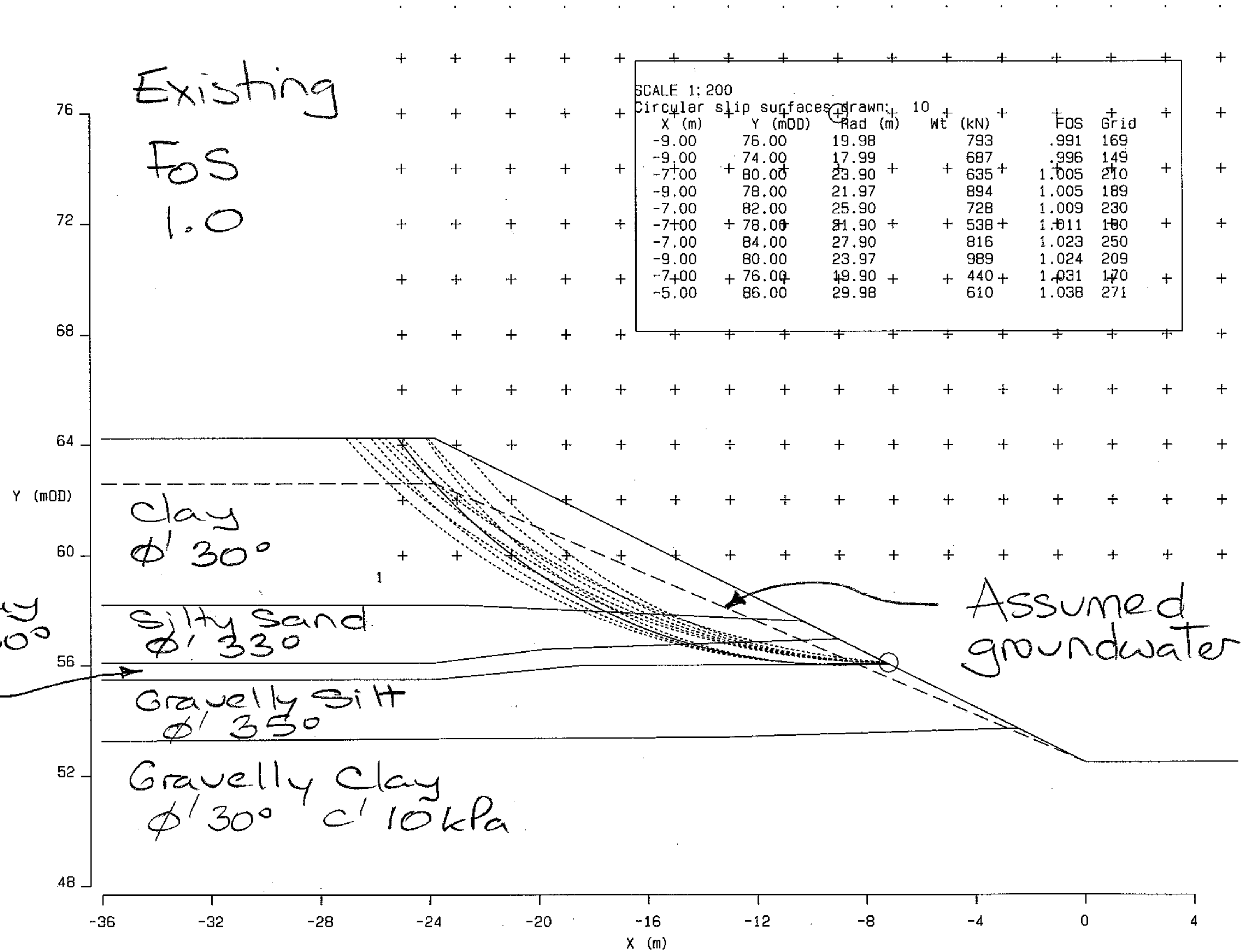
A1 Morpeth Bypass

Effective Stress Test Results




A1 Morpeth Bypass
Residual Strength Test Results
Design Line
c' zero
Phi' 20 deg
200
150
100
50
0
50
100
150
200
250
300
t' (kPa)
s' (kPa)
Glacial Till
Maximum
Design Line
Minimum

Program SLOPE Version 4.14 (c) Oasys Ltd. 1998
Slope Stability Analysis



SCALE 1:200
Circular slip surfaces drawn: 10

X (m)	Y (mOD)	Rad (m)	Wt (kN)	FOS	Grid
-9.00	76.00	19.98	793	.991	169
-9.00	74.00	17.99	687	.996	149
-7.00	80.00	23.90	635	1.005	210
-9.00	78.00	21.97	894	1.005	189
-7.00	82.00	25.90	728	1.009	230
-7.00	78.00	21.90	538	1.011	1[illegible]0
-7.00	84.00	27.90	816	1.023	250
-9.00	80.00	23.97	989	1.024	209
-7.00	76.00	19.90	440	1.031	170
-5.00	86.00	29.98	610	1.038	271

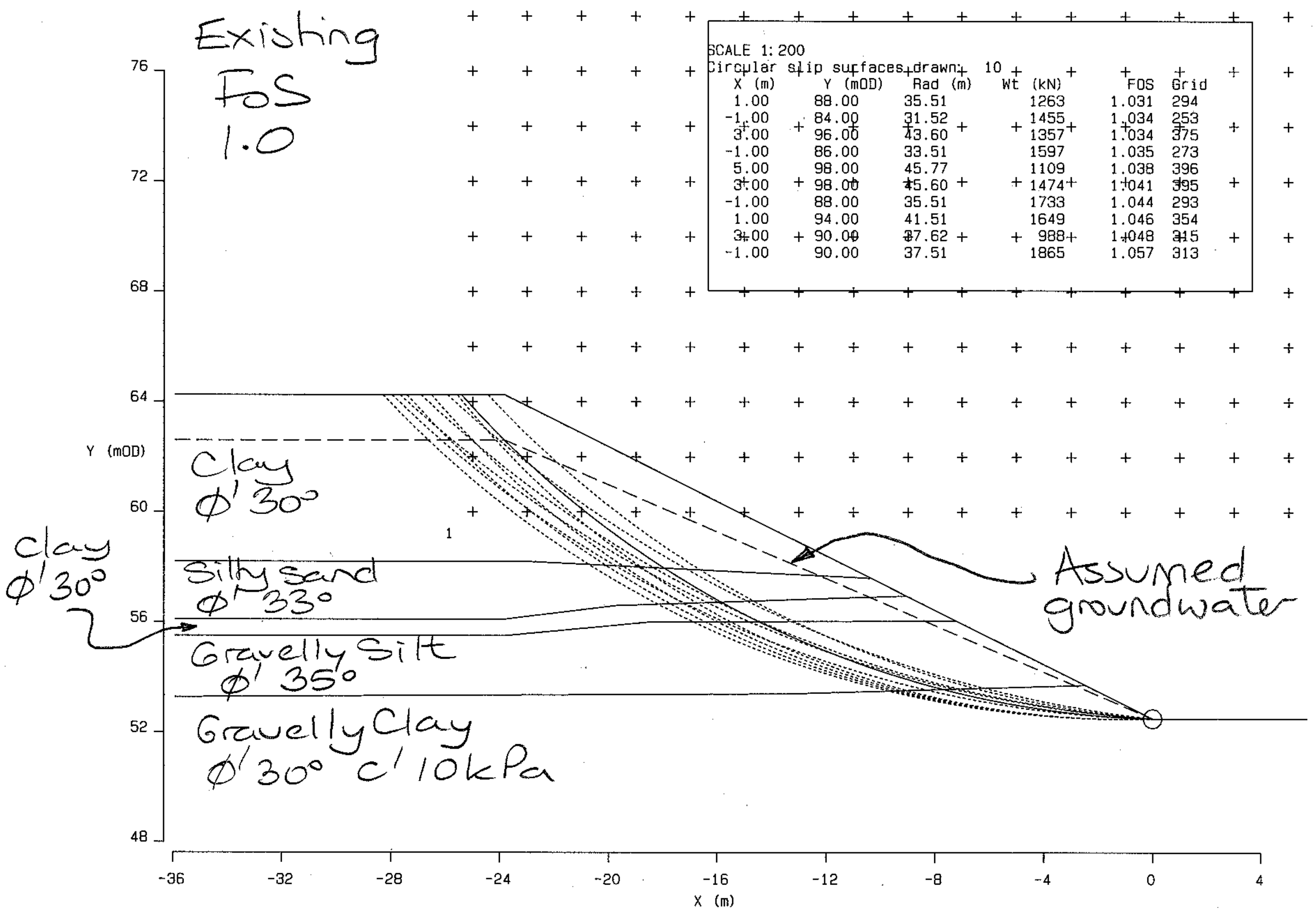
Chris Raison Associates

A1 MORPETH BYPASS - SLOPE FAILURE
SECTION TT3 - BACK ANALYSIS OF FAILURE
Phi' 30 deg - upper slope

Job No. C02/023
Sheet No. 9
Rev.
Drg. Ref.
Made by CAR Date 11-Apr-02 Data TT3_F1.SLP Checked

PCL5-LASERJET 4-A4
Printed 11-Apr-02

Page 1
Time 19:02



SCALE 1:200

Circular slip surfaces drawn: 10

X (m)	Y (mOD)	Rad (m)	Wt (kN)	FOS	Grid
1.00	88.00	35.51	1263	1.031	294
-1.00	84.00	31.52	1455	1.034	253
3.00	96.00	43.60	1357	1.034	375
-1.00	86.00	33.51	1597	1.035	273
5.00	98.00	45.77	1109	1.038	396
3.00	98.00	45.60	1474	1.041	395
-1.00	88.00	35.51	1733	1.044	293
1.00	94.00	41.51	1649	1.046	354
3.00	90.00	37.62	988	1.048	315
-1.00	90.00	37.51	1865	1.057	313

Program SLOPE Version 4.14 (c) Oasys Ltd. 1998
Slope Stability Analysis

PCL5-LASERJET 4-A4
Printed 11-Apr-02

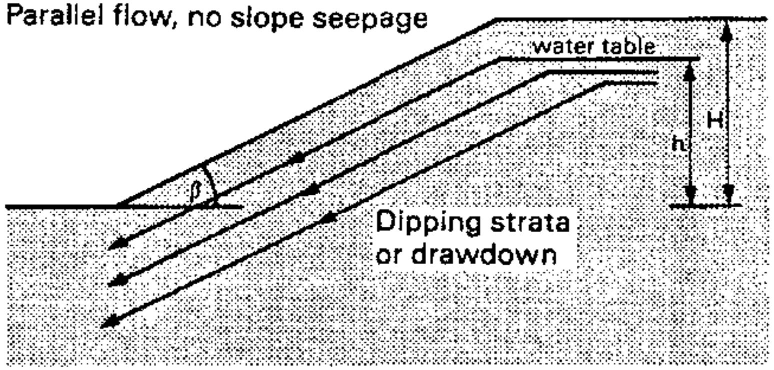
Page 1
Time 19:03

Chris Raison Associates

A1 MORPETH BYPASS - SLOPE FAILURE
SECTION TT3 - BACK ANALYSIS OF FAILURE
Phi' 30 deg - whole slope

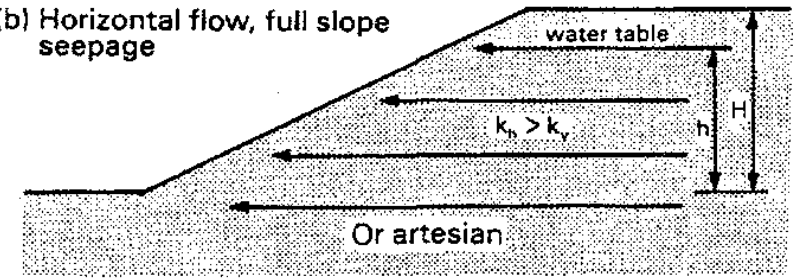
Job No. C02/023
Sheet No. 10
Rev.
Drg. Ref.
Made by CAR Date 11-Apr-02 Data TT3_F2.SLP Checked

(a) Parallel flow, no slope seepage



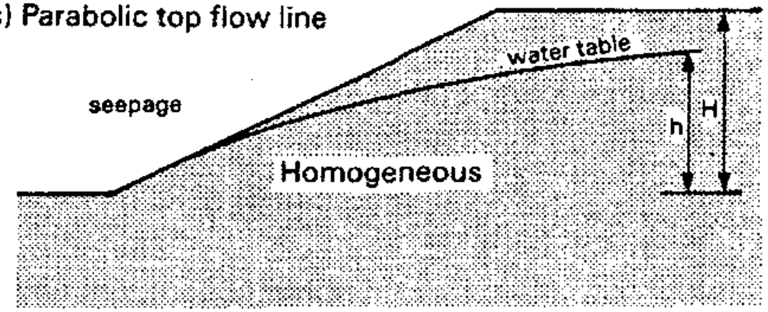
$r_u = \frac{\gamma_w}{\gamma} \cos^2\beta$ for $\frac{h}{H} > 0.8$ or $(H-h) < 3$ m

(b) Horizontal flow, full slope seepage



$r_u = \frac{\gamma_w}{\gamma}$ for $\frac{h}{H} > 0.8$ or $(H-h) < 3$ m

(c) Parabolic top flow line

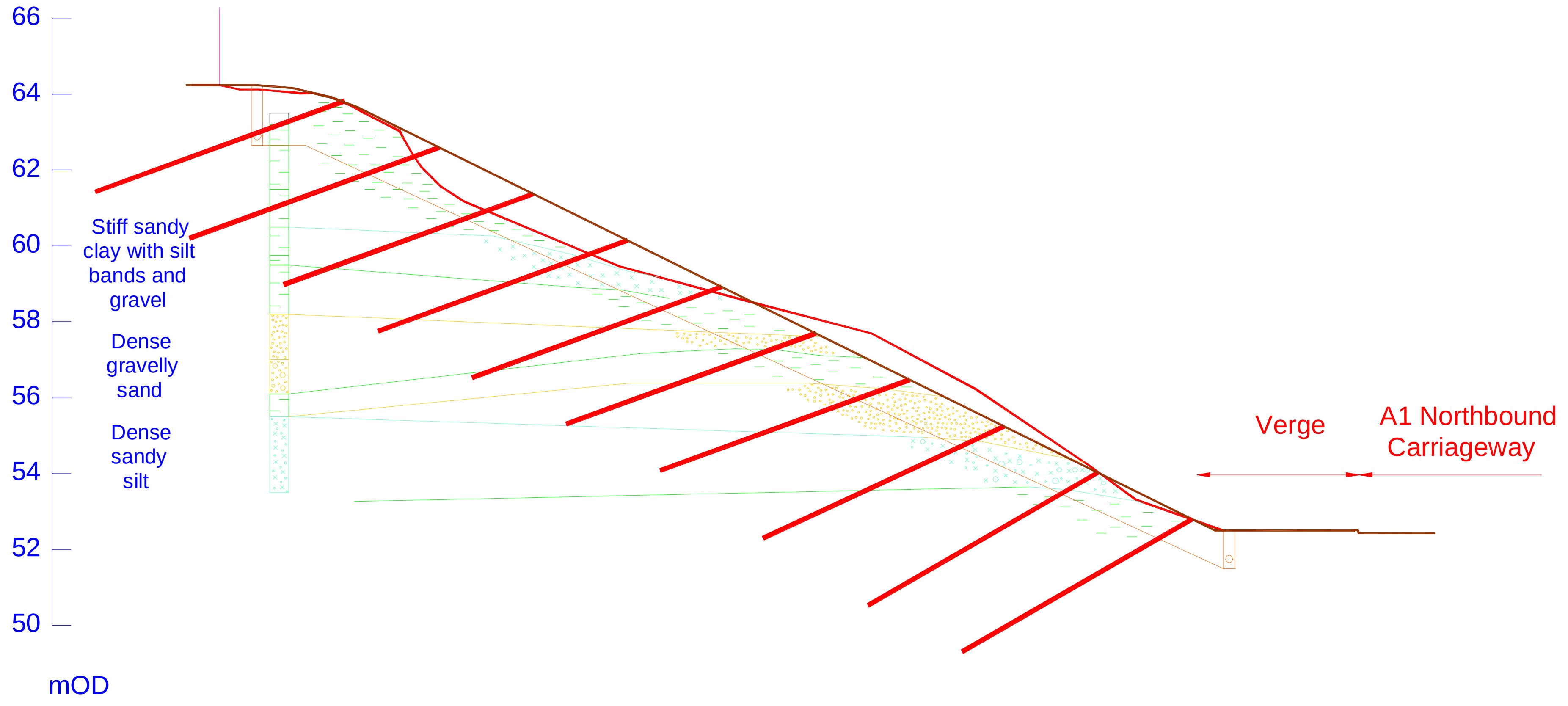


$r_u = \frac{\gamma_w}{\gamma} \cos\beta$ for $\frac{h}{H} > 0.8$ or $(H-h) < 3$ m

Ref: Mitchell (1983)

C02/023	Apr 2002	Figure 2

A1 Morpeth Bypass - Slope Failure Remediation

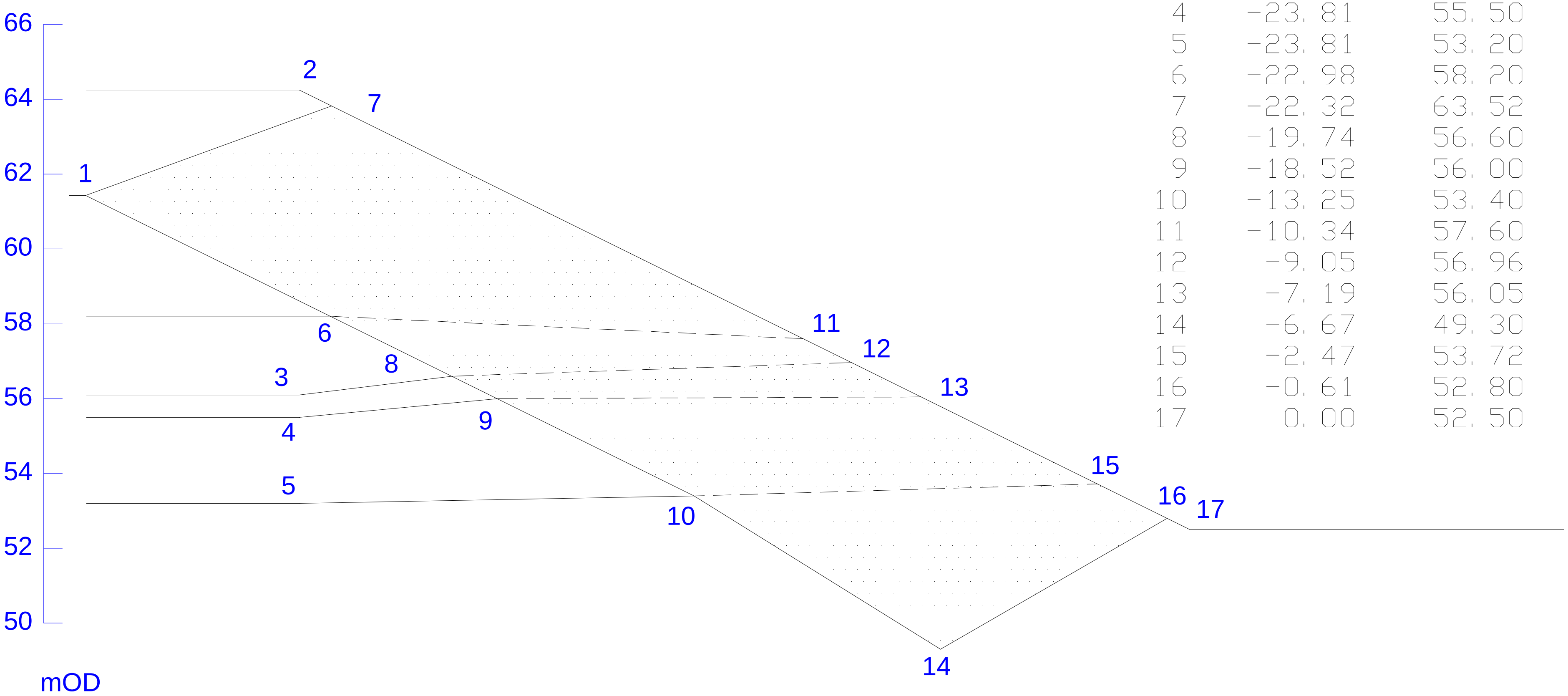


Typical Cross Section - TT3

C02/023	Apr 2002	Figure 3

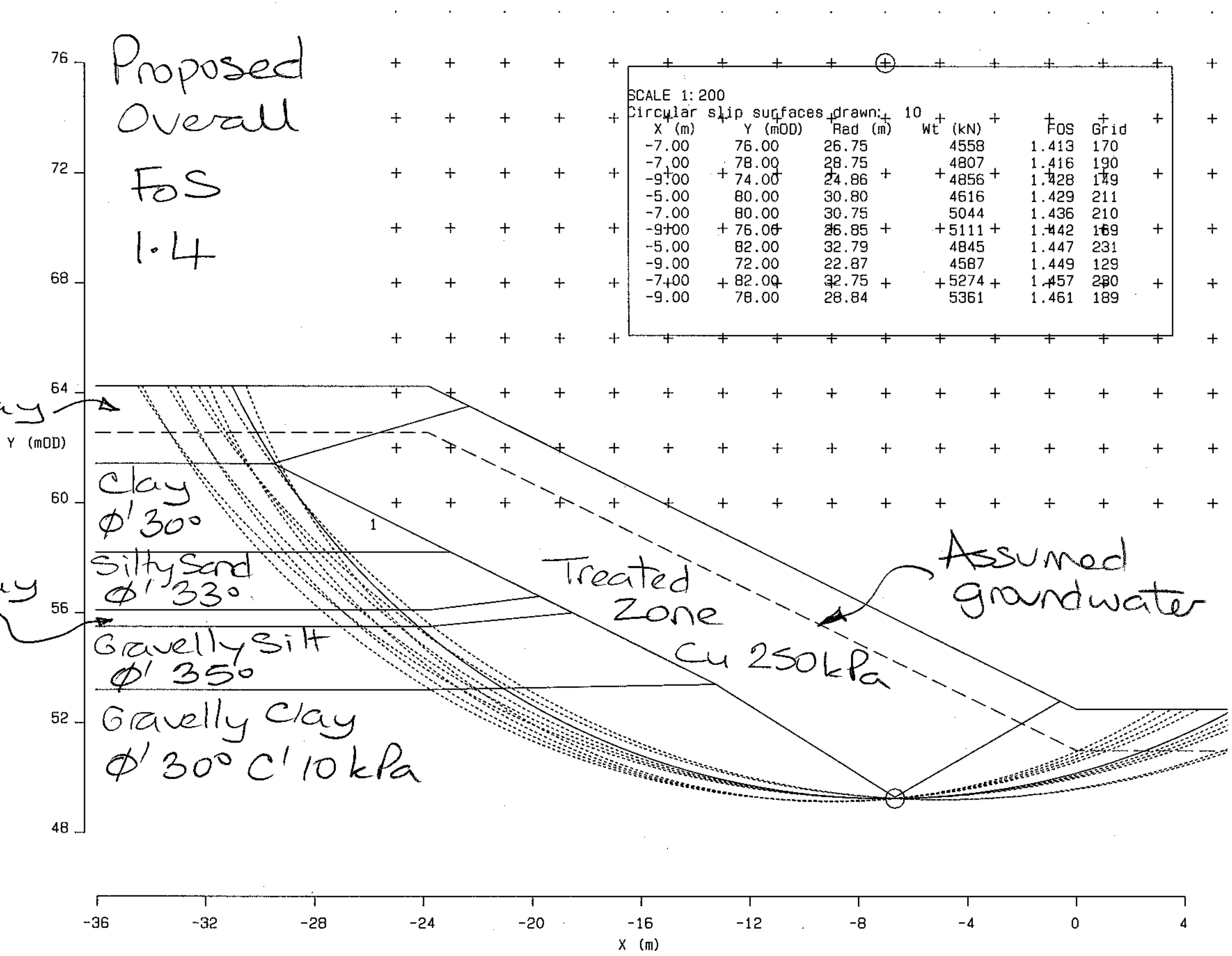
A1 Morpeth Bypass - Slope Failure Remediation

Point	x	y
1	-29.53	61.43
2	-23.81	64.25
3	-23.81	56.10
4	-23.81	55.50
5	-23.81	53.20
6	-22.98	58.20
7	-22.32	63.52
8	-19.74	56.60
9	-18.52	56.00
10	-13.25	53.40
11	-10.34	57.60
12	-9.05	56.96
13	-7.19	56.05
14	-6.67	49.30
15	-2.47	53.72
16	-0.61	52.80
17	0.00	52.50



Typical SLOPE Design Section - TT3

Program SLOPE Version 4.14 (c) Oasys Ltd. 1998
Slope Stability Analysis



SCALE 1:200
Circular slip surfaces drawn: 10

X (m)	Y (mOD)	Rad (m)	Wt (kN)	FOS	Grid
-7.00	76.00	26.75	4558	1.413	170
-7.00	78.00	28.75	4807	1.416	190
-9.00	74.00	24.86	4856	1.428	149
-5.00	80.00	30.80	4616	1.429	211
-7.00	80.00	30.75	5044	1.436	210
-9.00	76.00	26.85	5111	1.442	169
-5.00	82.00	32.79	4845	1.447	231
-9.00	72.00	22.87	4587	1.449	129
-7.00	82.00	32.75	5274	1.457	230
-9.00	78.00	28.84	5361	1.461	189

Chris Raison Associates

A1 MORPETH BYPASS - SLOPE FAILURE
SECTION TT3 - SOIL NAIL TREATMENT
Phi' 30 deg - whole slope

Job No.	Sheet No.	Rev.
C02/023	11	

Drg. Ref.

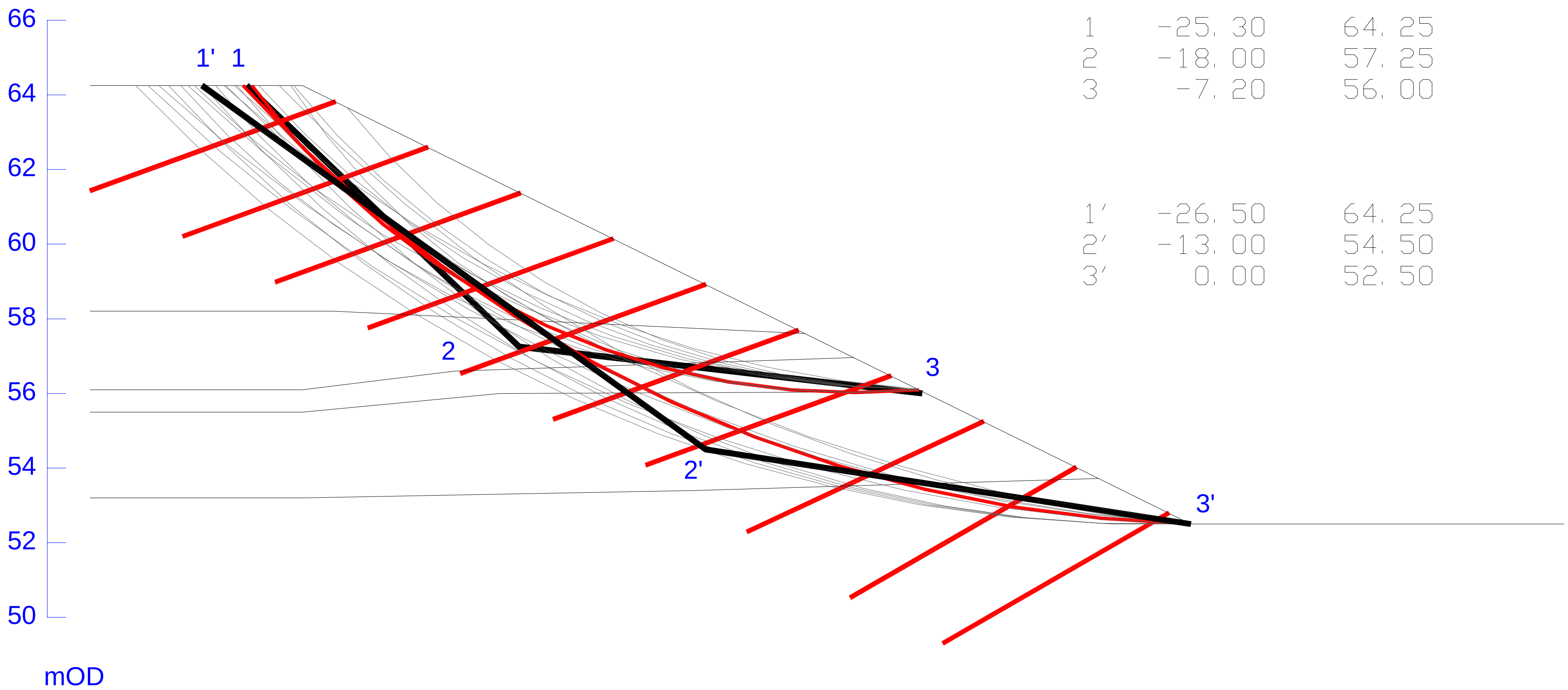
Made by CAR | Date 11-Apr-02 | Data TT3_SN1.SLP | Checked

PCL5-LASERJET_4-A4
Printed 11-Apr-02

Page 1
Time 19:07

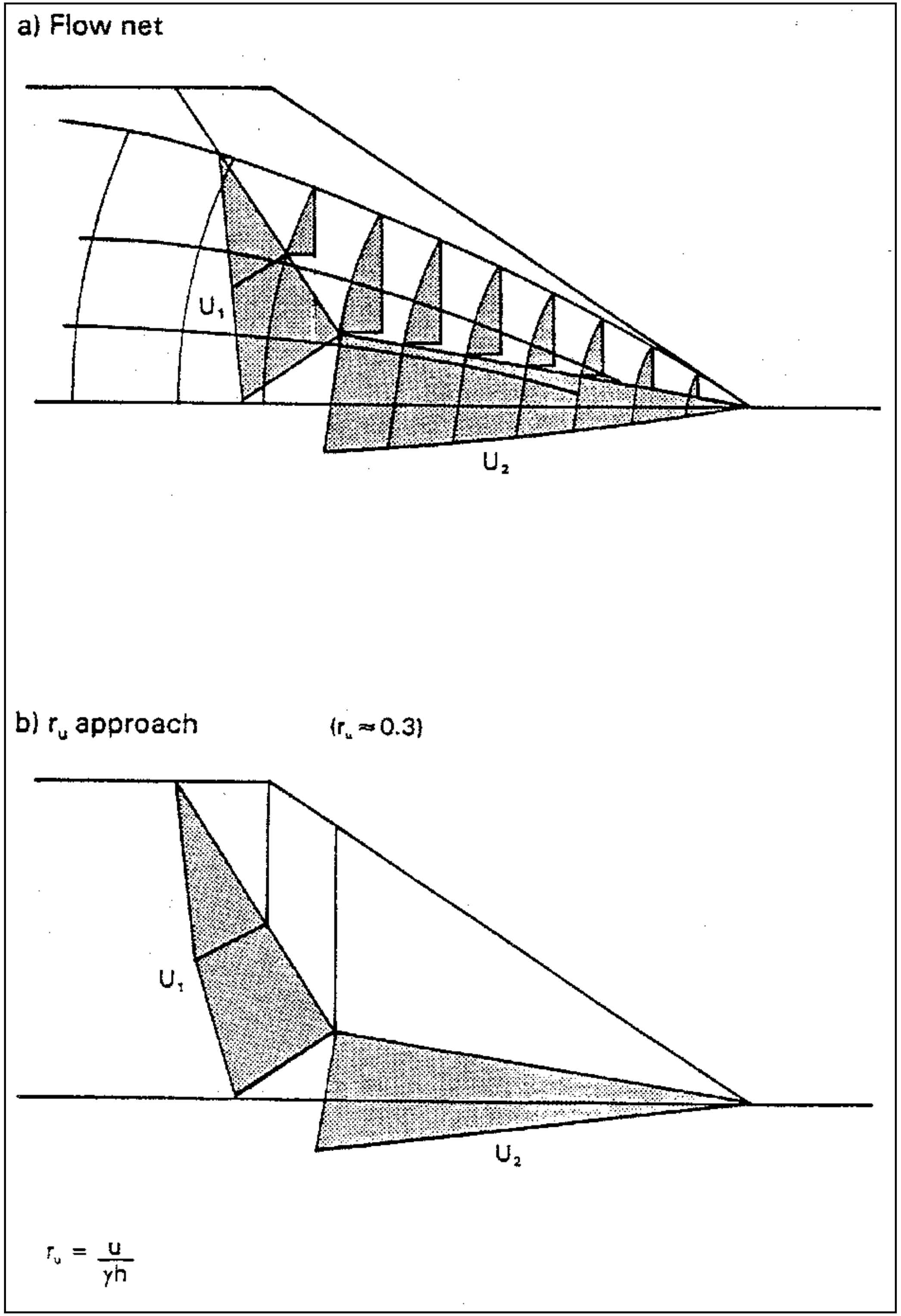
C02/023	Apr 2002	Figure 4

A1 Morpeth Bypass - Slope Failure Remediation



Point	x	y
1	-25.30	64.25
2	-18.00	57.25
3	-7.20	56.00
1'	-26.50	64.25
2'	-13.00	54.50
3'	0.00	52.50

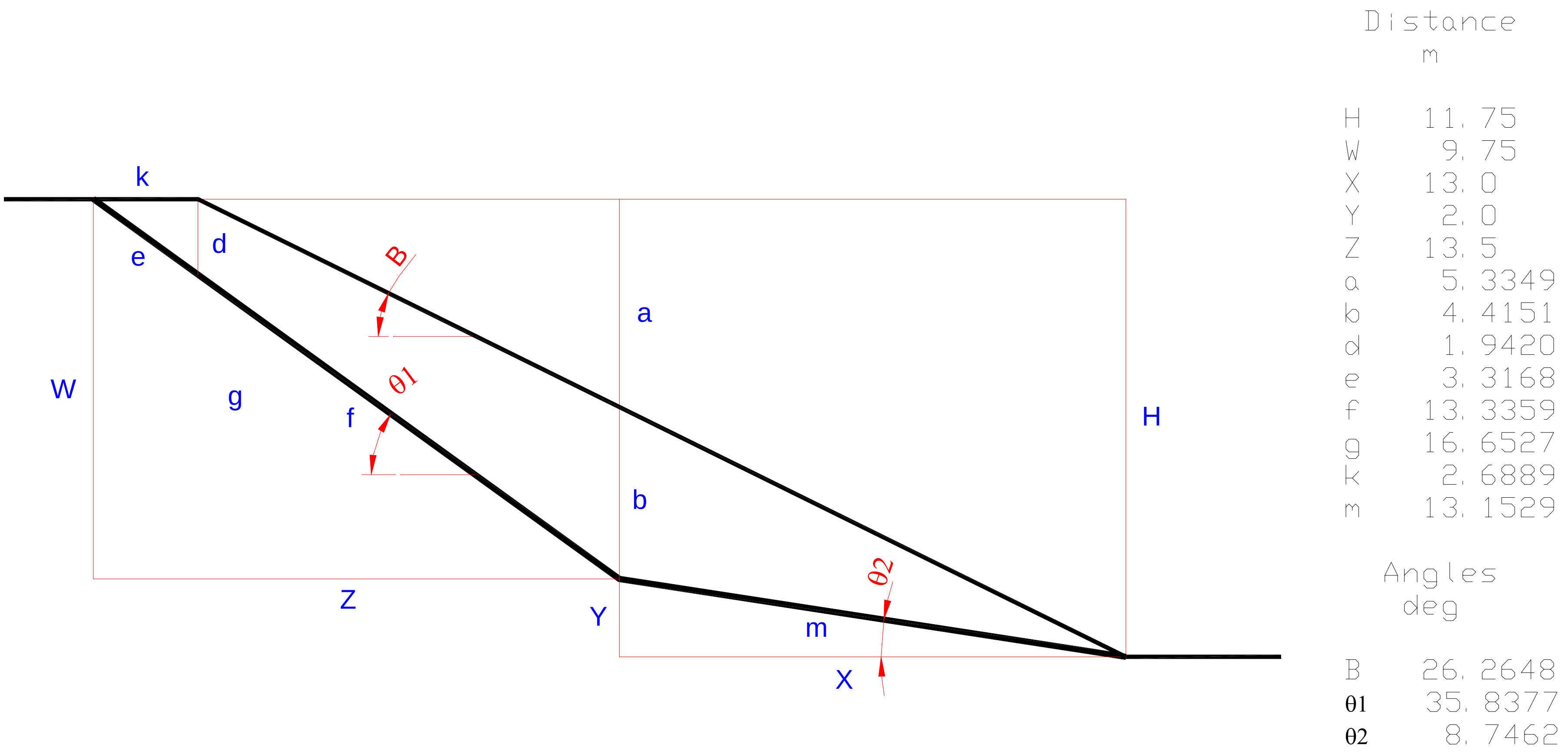
Two Part Wedge Design Section - TT3



a) Flow net
U1
U2
b) ru approach
(ru ≈ 0.3)
U1
U2
ru = u / γh

C02/023	Apr 2002	Figure 5

A1 Morpeth Bypass - Slope Failure Remediation



Two Part Wedge Design - Dimensions - TT3

A1 Morpeth Bypass
Slope Failure Remediation

Appendix A

Two Part Wedge Analysis
Slope Section TT3 - Whole Slope

Slope Geometry

H	11.75	m
W	9.75	m
X	13.00	m
Y	2.00	m
Z	13.50	m
Slope	26.2648	deg
Angle t1	35.8377	deg
Angle t2	8.7462	deg

Soil Properties

Unit wt	20.00	kN/m3
Peak ø'	32.00	deg
Design ø'	22.00	deg
Design c'	0.00	kPa
Cu	100	kPa
Surcharge	5	kPa
Inclination of nails	20	deg

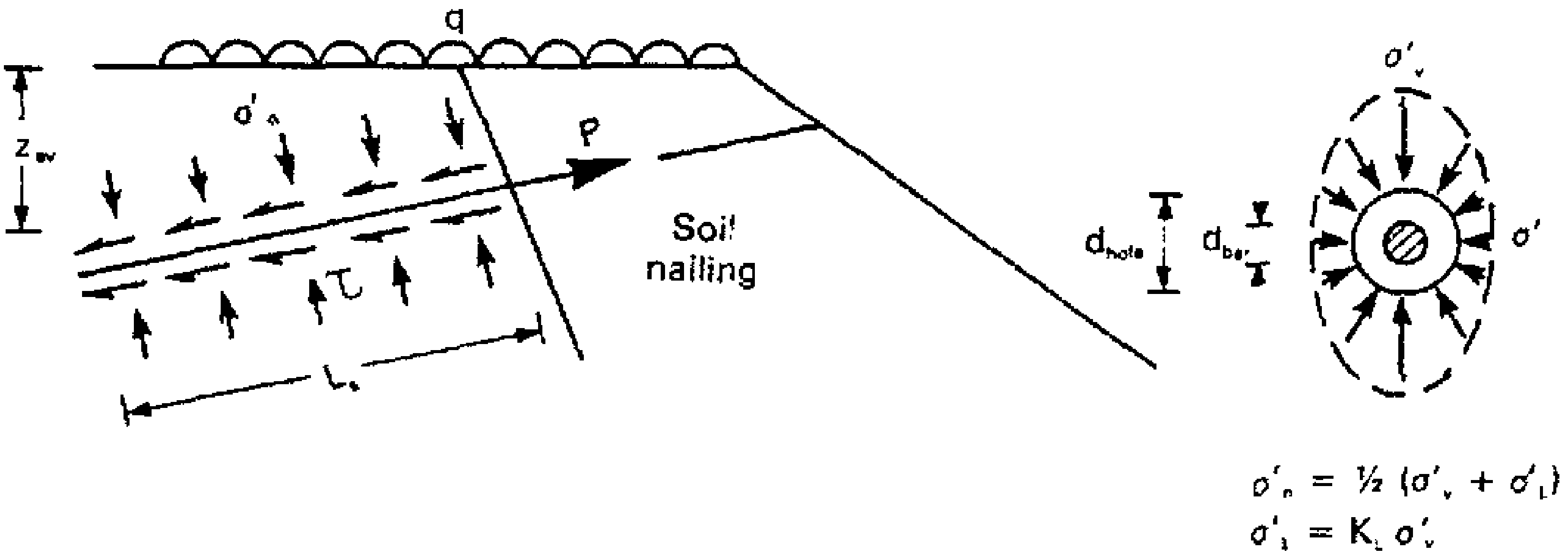
Computed Dimensions

a	5.3349	m
b	4.4151	m
d	1.9420	m
e	3.3168	m
f	13.3359	m
g	16.6527	
k	2.6889	m
m	13.1529	m

Computed Forces

W1	739.5	kN
W2	574.0	kN
U1	182.4	kN
U2	116.1	kN
K1	0.0	kN
K2	0.0	kN
Q1	13.4	kN
T1	255.8	kN
Sliding factor	1.0	
T2	-90.5	kN
T total	165.4	kN
Inclination factor	1.17	

Total Force to be provided by soil nails: **193 kN/m run**



b) Soil nail pull-out

Nail Geometry

Grouted Diameter	100	mm in clays
Length	7.0	m
Spacing	2.0	m
Bar diameter	32	mm
Bar Capacity	230	kN

Soil Nail Capacities Based on Peak Effective Stress Parameters

Row	Lf	Average Depth	Face Pull Out Force	Le	Average Depth	Anchor Pull Out Force
	m	m		m	m	kN
1	2.112	0.787	5	4.888	1.984	29
2	2.668	1.064	8	4.332	3.305	41
3	3.225	1.288	13	3.775	4.108	47
4	3.781	1.512	17	3.219	4.332	42
5	4.337	1.736	23	2.663	4.556	37
6	4.893	1.961	29	2.107	4.781	31
7	5.450	2.185	37	1.550	5.005	24
8	3.373	1.456	16	3.627	4.501	54
9	1.662	0.760	4	5.338	4.006	67
10	0.331	0.143	0	6.669	3.388	74

Average Ks 1.20

Total Force provided by soil nails: 223 kN/m run

Soil Nail Capacities Based on Undrained Shear Strength

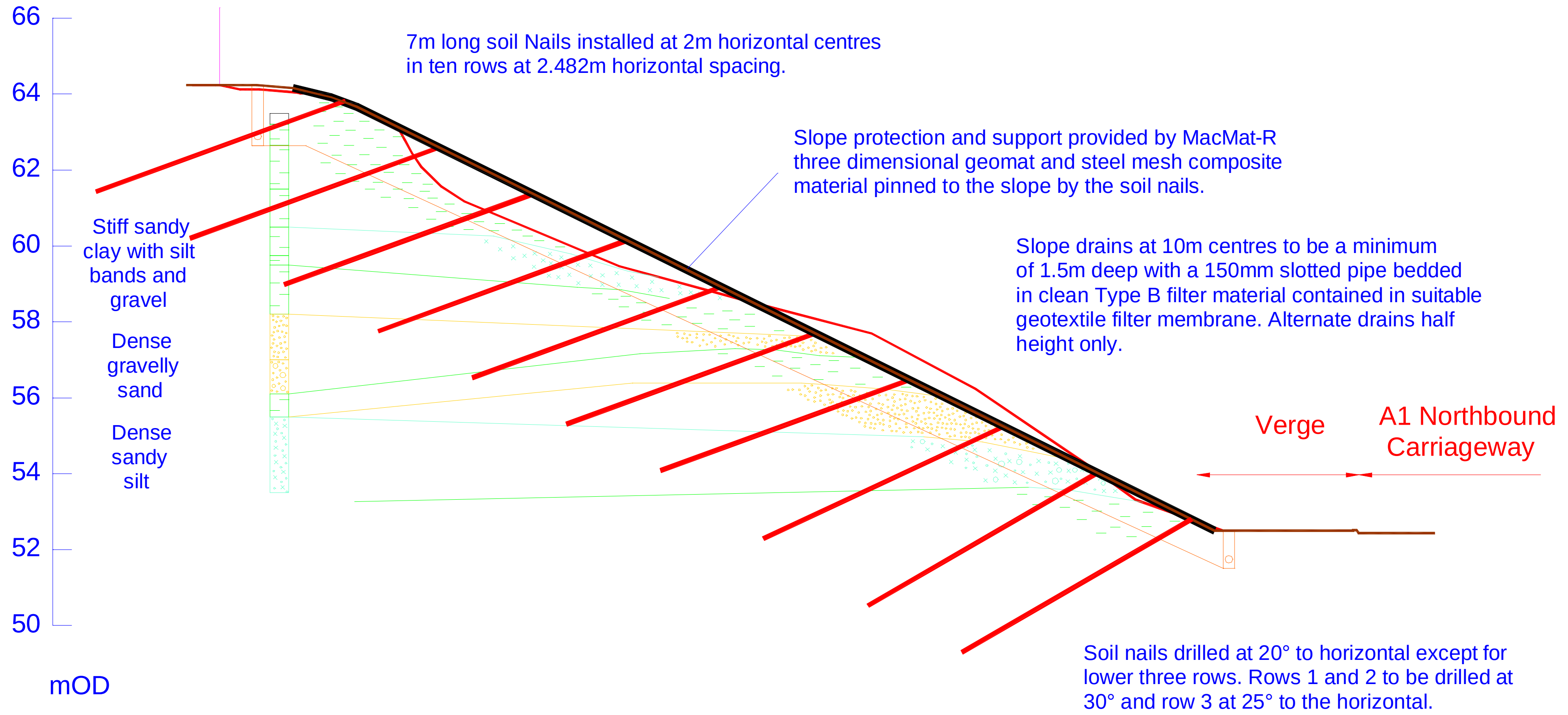
Row	Lf	Shaft Friction	Face Pull Out Force	Le	Shaft Friction	Anchor Pull Out Force
	m	kPa		m	kPa	kN
1	2.112	50	33	4.888	50	77
2	2.668	50	42	4.332	50	68
3	3.225	50	51	3.775	50	59
4	3.781	50	59	3.219	50	51
5	4.337	50	68	2.663	50	42
6	4.893	50	77	2.107	50	33
7	5.45	50	86	1.55	50	24
8	3.373	50	53	3.627	50	57
9	1.662	50	26	5.338	50	84
10	0.331	50	5	6.669	50	105

Design Cu	100	kPa
Adhesion factor	0.5	

Total Force provided by soil nails: 300 kN/m run

C02/023	Apr 2002	Figure 2

A1 Morpeth Bypass - Slope Failure Remediation



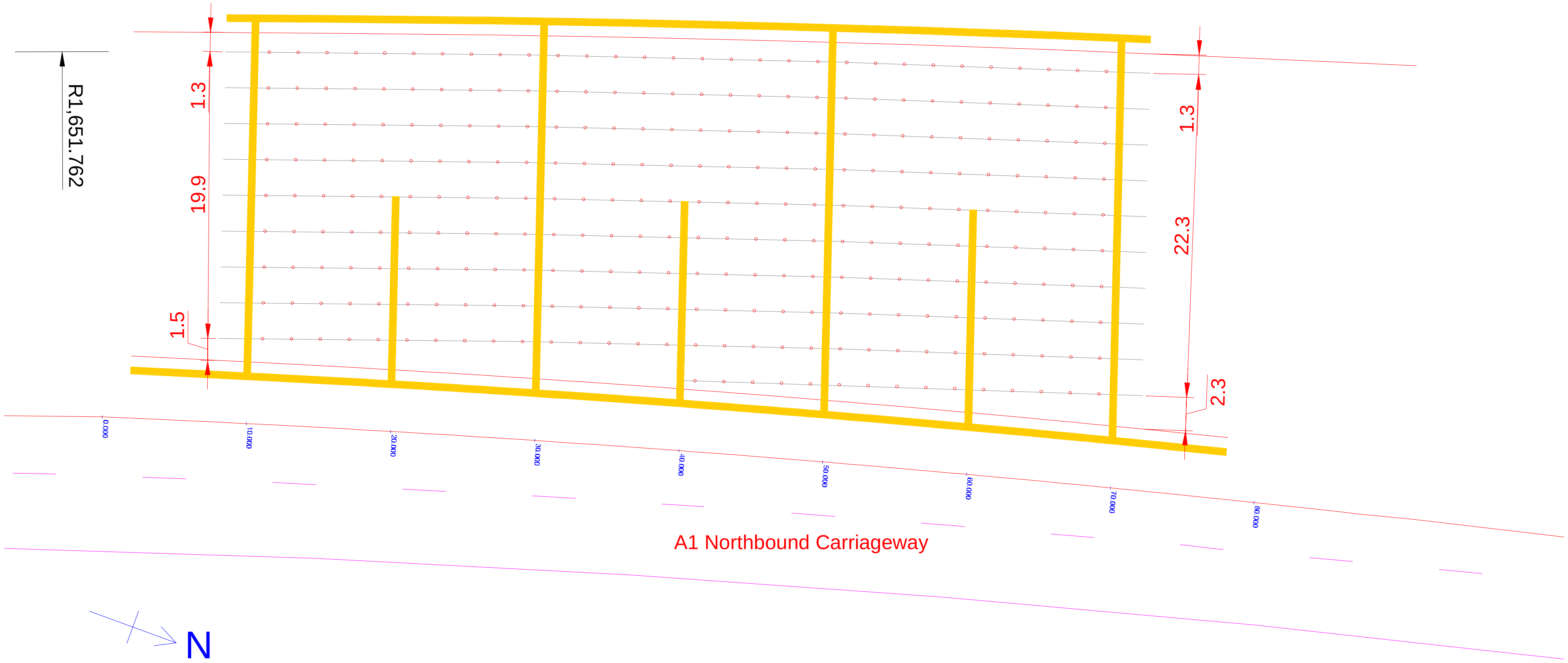
Typical Cross Section - TT3

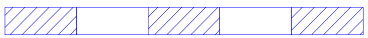
C02/023	Apr 2002	Figure 1

A1 Morpeth Bypass - Slope Failure Remediation

Soil nails installed at 2m horizontal centres on a grid line with a horizontal radius of 1,651.76m. Nine/ten parallel rows at 2.482m horizontal spacing. All nails 7m long.

All slope drains to be a minimum of 1.5m deep with a 150mm slotted pipe bedded in clean Type B filter material contained in suitable geotextile filter membrane. Drains assumed 0.5m wide.





Layout Plan - TT3

Total number of soil nails - 285 number