Appendix A

The experiment of measuring the normal forces in the model tests

And the experimental results

Materials and devices

Materials

- Straws filled with sand 210 mm. with ∅ 4.5 and 6 mm. (mixed ratio 3:2)
- Plywood board (d=12 mm.)
- Sand paper #400
- Wire
- Small wheel ∅ 30 mm.
- Rubber (d=1 mm.)

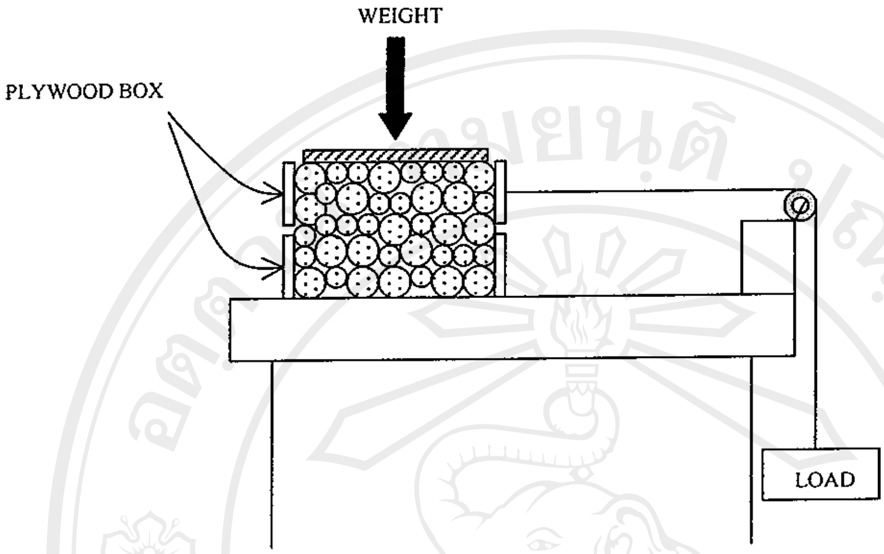
Devices

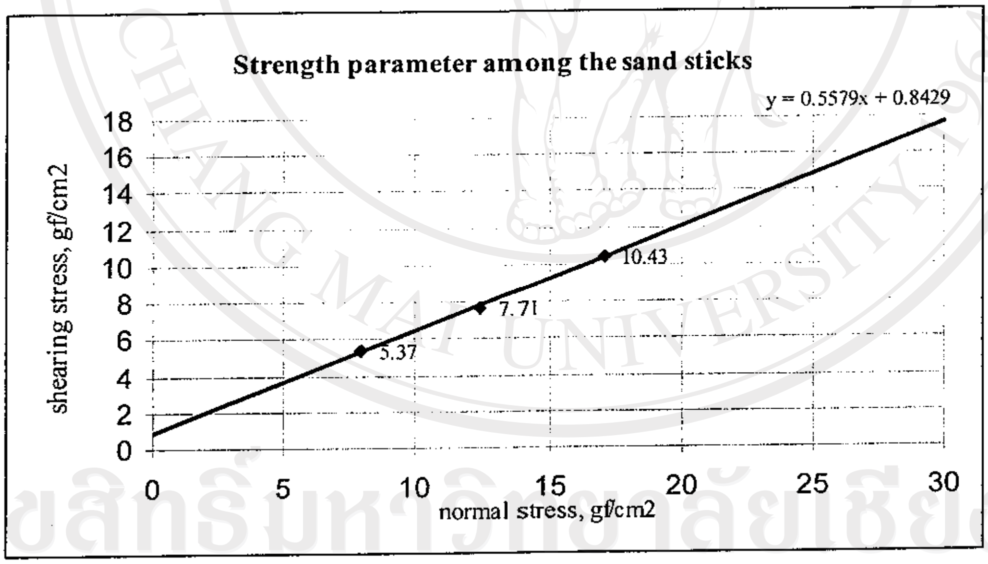
- Computer	NEC PC-9801 RX
- Scanner	KYOWA USB21A
- Data Logger	KYOWA UCAM-20PC
- Vernier	
- Weight items	
- Sensors	KYOWA miniature load cell LM-5KA
	Lot no. EN3610 Class J 5 units
	Lot no. EQ0570 Class L 15 units

Properties of the straws filled with sand

The straw filled with sand are made by put the sand into the straw which has diameter 4.5mm. and 6mm., then compact with the glue. And mix with the portion of 60% (∅=4.5mm.) to 40% (∅=6mm.)

- Shear strength parameter of the straws filled with sand



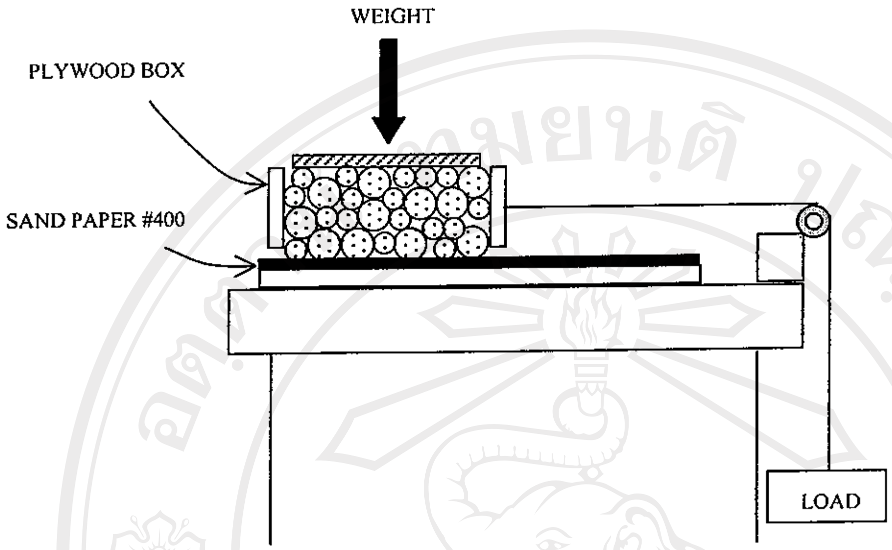


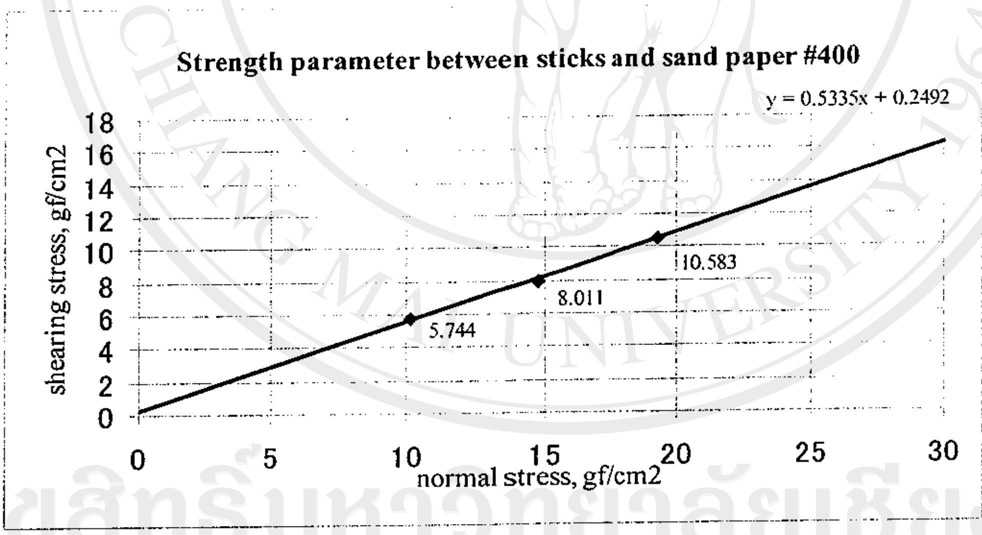
From the graph,

$\varnothing = 29.2^{\circ}$, $C = 0.843$ gf/cm^2 = 0.008 t/m^2 = 0.083 kN/m^2

Fig. A.1 How to determine the shear strength parameter of the straw filled with sand

- Shear strength parameter between the sand paper #400 and the straw filled with sand



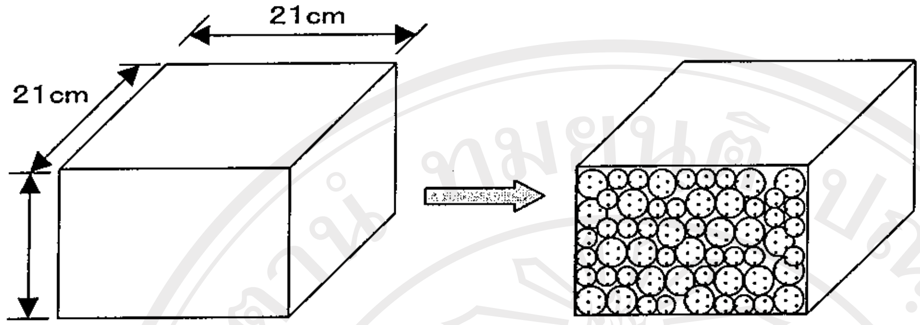


From the graph,

$\varnothing = 28.1^{\circ}$, $C = 0.249\ gf/cm^2 = 0.002\ t/m^2 = 0.024\ kN/m^2$

Fig. A.2 How to determine the friction angle between the straw filled with sand and sand paper #400

- Density of straws filled with sand



$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$\text{Density } (\gamma) = 1.147 \text{ gf/cm}^3$$
$$= 1.147 \text{ t/m}^3 = 11.24 \text{ kN/m}^3$$

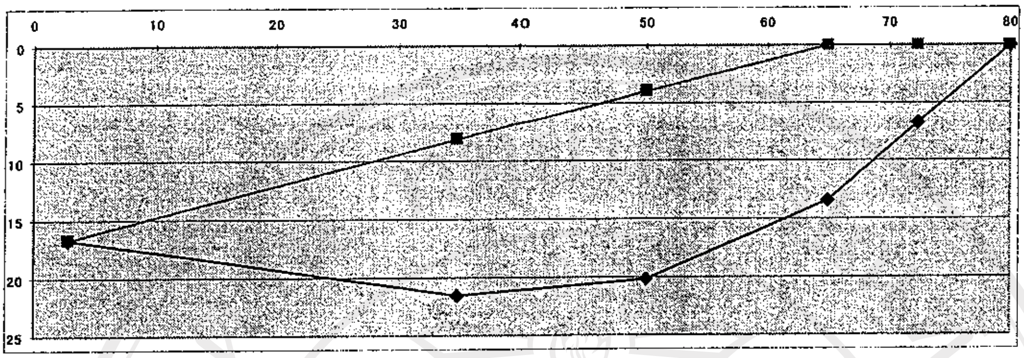
Fig. A.3 How to determine the density of the straw filled with sand

Slope model and cross-section

There are 3 slope models varied in the slope inclination angles; 15.0, 17.5 and 20.0 degrees in the experiment. The shape of slope models are the optimized shape which the composition of the slope model is done by 4 straight line-shaped slip surface (slope was divided in 4 slices which slice 1 is on the left). Each slope model is divided into 3 parts. One is the model base made of rigid plywood boards, 210 mm. width and 800±50 mm. length. Another is the slip surface made of the plywood boards (thickness 12 mm.) covered with sand paper #400. There are 4 load cell sensors (Kyowa : LM-5KA) which were set under the plywood boards for each slice. The other is the sliding mass made of straws filled with sand diameter 4.5 and 6.0 mm. formed to be a slope homogeneously on the plywood board.

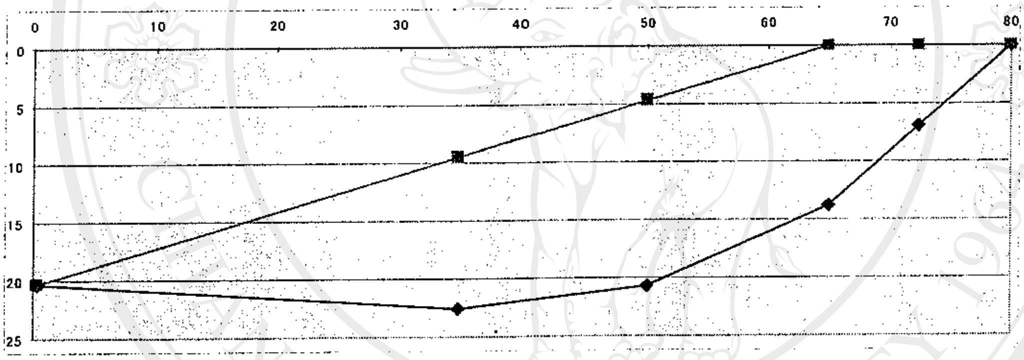
Model 1 Slope inclination angle = 15.0 degrees

Load = 588 N/m Anchoring force = 294 N/m FS=1.5517



Model 2 Slope inclination angle = 17.5 degrees

Load = 588 N/m Anchoring force = 235.2 N/m FS=1.4326



Model 3 Slope inclination angle = 20.0 degrees

Load = 588 N/m Anchoring force = 196 N/m FS=1.3231

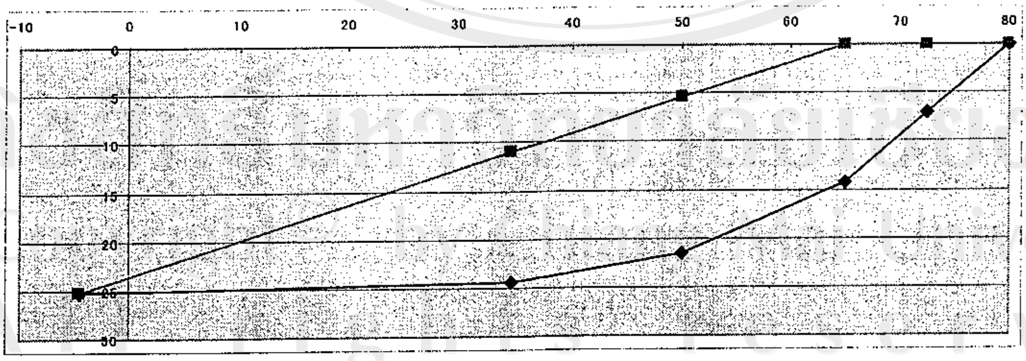


Fig. A.4 The optimized shape of the slope models and model conditions

Table A.1 The co-ordinate of the slope models (unit: cm.)

Model 1			Model 2			Model 3		
X	Y	Z	X	Y	Z	X	Y	Z
2.887	16.643	16.643	0.335	20.388	20.388	-4.528	25.306	25.306
35.000	21.491	8.038	35.000	22.603	9.459	35.000	24.312	10.919
50.000	20.227	4.019	50.000	20.679	4.729	50.000	21.478	5.460
65.000	13.485	0.000	65.000	13.818	0.000	65.000	14.214	0.000
72.500	6.742	0.000	72.500	6.909	0.000	72.500	7.107	0.000
80.000	0.000	0.000	80.000	0.000	0.000	80.000	0.000	0.000

Remark: X: distance in horizontal, cm.

Y: depth of slip surface, cm.

Z: depth of ground surface, cm.

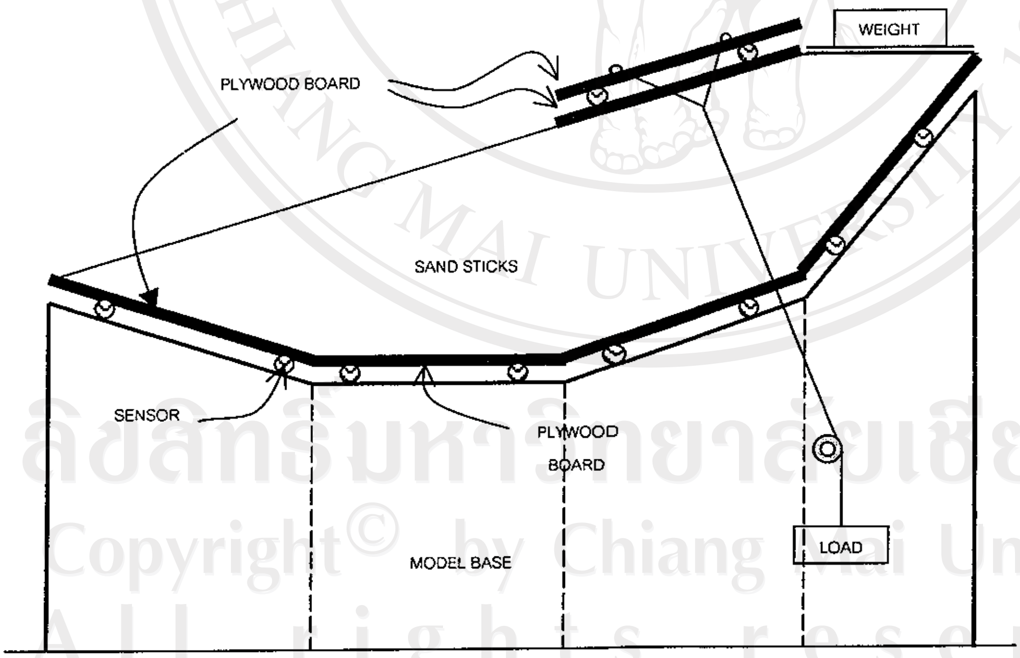


Fig. A.5 Cross-section and the detailed composition of the slope model

Sensor calibration

Before do the experiment, calibrate the sensors by put known weights on the sensor according fig. A.6. Then, measure the force acting on the sensors by Scanner and Data logger. The sensors calibration values were shown in table A.2.

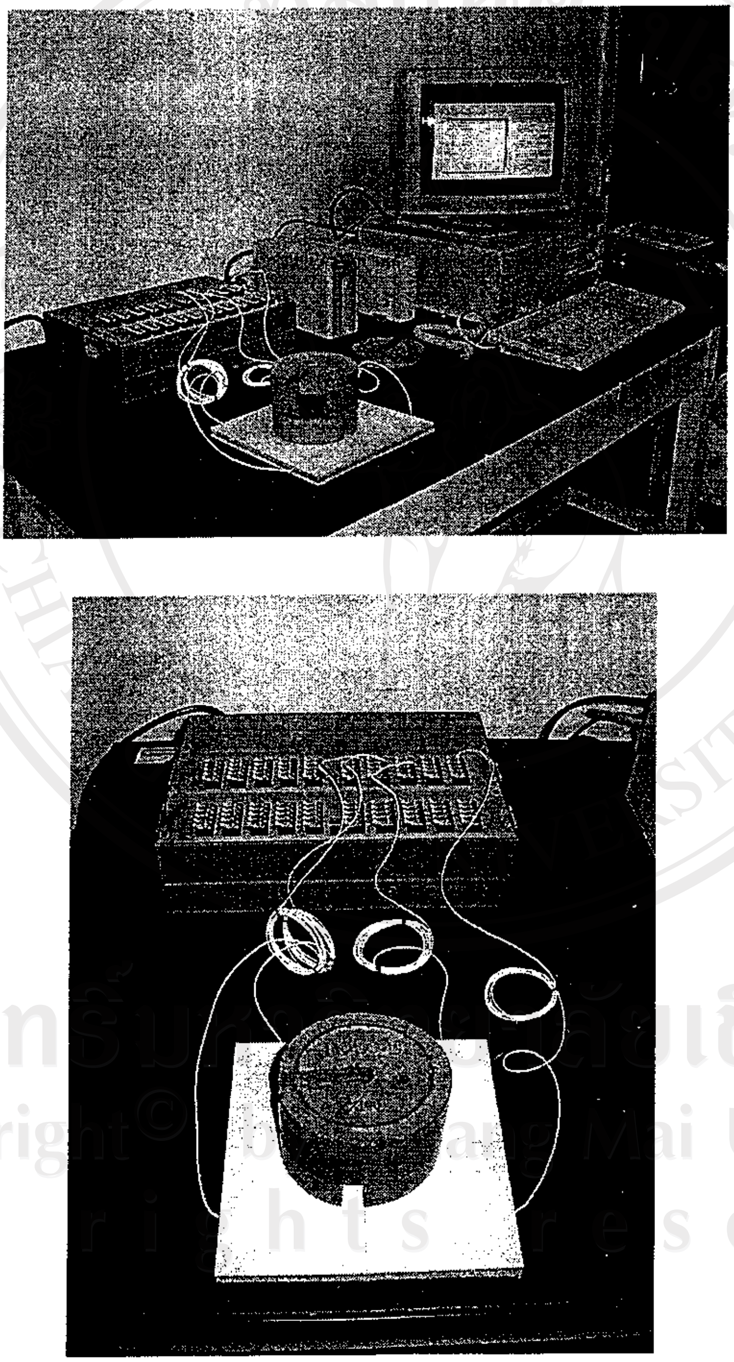


Fig. A.6 Sensors calibration

Table A.2 Sensors correction values (channel 000-019)

LOAD	Channel 000-003		Channel 004-007		Channel 008-011		Channel 012-015		Channel 016-019	
(gf)	(gf)	correction	(gf)	correction	(gf)	correction	(gf)	correction	(gf)	correction
0										
100	100.40	0.99602	101.91	0.98126	98.95	1.011	101.48	0.98542	101.48	0.98542
200	200.79	0.99607	198.84	1.0058	200.42	0.99790	200.42	0.99790	200.42	0.99790
300	303.83	0.98739	295.67	1.0146	299.36	1.0021	296.84	1.0107	296.83	1.0107
400	404.23	0.98954	403.27	0.99189	398.31	1.0042	395.77	1.0107	395.77	1.0107
500	504.63	0.99082	506.21	0.98773	494.72	1.0107	497.26	1.0055	499.78	1.0004
600	602.37	0.99607	600.82	0.99864	598.73	1.0021	593.66	1.0107	596.20	1.0064
700	705.43	0.99230	699.87	1.0002	695.14	1.0070	695.14	1.0070	702.75	0.99609
800	805.80	0.99280	799.86	1.0002	796.62	1.0042	794.08	1.0075	796.61	1.0043
900	906.20	0.99316	901.34	0.99851	895.56	1.0050	893.03	1.0078	895.56	1.0050
1000	1003.96	0.996056	998.02	1.0020	991.97	1.0081	991.97	1.0081	999.58	1.0004
1500	1508.59	0.994306	1498.66	1.00089	1489.23	1.00723	1484.14	1.01067	1501.91	0.998728
2000	2015.84	0.992142	1986.27	1.00691	1981.41	1.00938	1986.47	1.00681	2004.22	0.997894
2500	2504.62	0.998155	2488.87	1.00447	2481.18	1.00759	2483.72	1.00655	2506.56	0.997383
3000	3019.80	0.993443	2982.40	1.00590	2983.52	1.00552	2970.83	1.00982	3016.49	0.994533
3500	3524.44	0.993066	3477.65	1.00643	3475.69	1.00699	3468.09	1.00920	3503.59	0.998975
4000	4039.62	0.990192	3985.21	1.00371	3972.93	1.00681	3970.41	1.00745	4008.46	0.997889
4500	4525.75	0.994310	4501.10	0.999756	4465.13	1.00781	4465.12	1.00781	4520.93	0.995370
5000	5030.37	0.993963	4984.97	1.00302	4959.84	1.00810	4957.30	1.00861	5015.66	0.996878
6000	6052.83	0.991272	5995.98	1.00067	5961.95	1.00638	5961.95	1.00638	6010.15	0.998311
7000	7059.43	0.991581	6984.26	1.00225	6953.92	1.00663	6951.38	1.00699	7027.49	0.996088
8000	8068.67	0.991489	7990.80	1.00115	7953.50	1.00585	7945.89	1.00681	8021.99	0.997259
9000	9080.55	0.991129	8995.33	1.00052	8950.54	1.00553	8942.93	1.00638	9034.26	0.996208
10000	10087.16	0.9913593	9997.99	1.00020	9942.50	1.00578	9945.04	1.00553	10038.91	0.9961241

From table A.2, the correction value of each sensor is 1.00 by approximation.

Procedure of the experiment

The experiment methods of this study have done in 2 cases.

(a) Slope without anchoring case

How to measure the normal forces acting on the slip surface have done following the steps;

1. Put the plywood boards attached with sensors on the rigid base model. Then, set all sensors to be zero according fig. A.7.

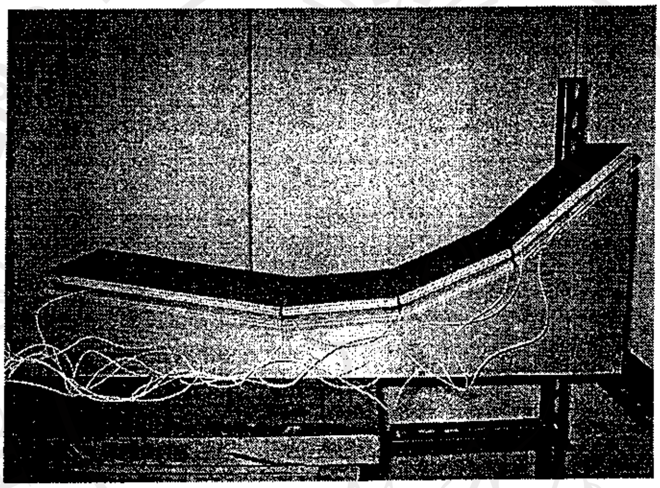


Fig. A.7 All sensors were installed under the plywood boards

2. Pile up the straws filled with sand homogeneously on the model to form to be a slope according fig. A.8. Measure the force acting on the sensors. These measured forces are that from the weight of straws filled with sand. Then, set all sensors to be zero again.

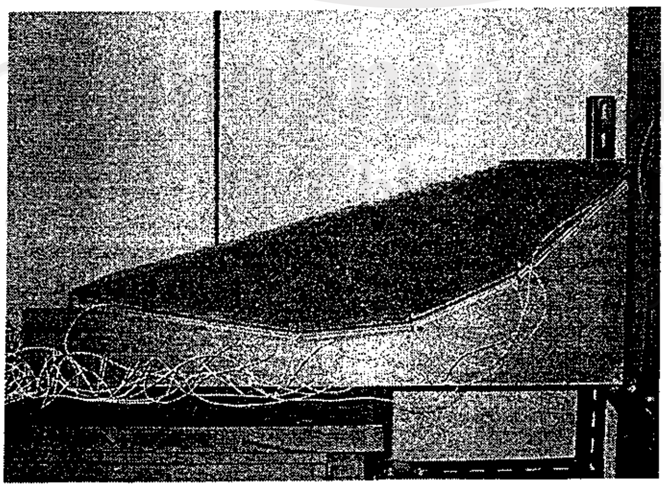


Fig. A.8 The straws filled with sand were homogeneously piled up to be a slope

3. Load the certainly weights on the top of the upper side slice (slice 4) according fig. A.9 and measure the force acting on the sensors after loading immediately (about 10-20 seconds). These measured forces are that from the loading weights. The normal forces acting on the base plane can be obtained from the measured force of straws filled with sand and loading weights.

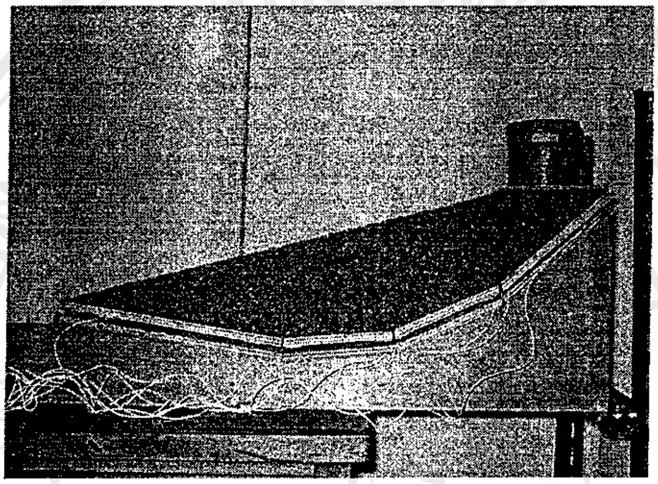


Fig. A.9 The weights were loaded on the upper side slice

4. Increase the load and do as step 3 and 4 until the slope collapse or failure according fig. A.10. While changed the load, should take out the precious load and put the new load instead. Should not gain the load.

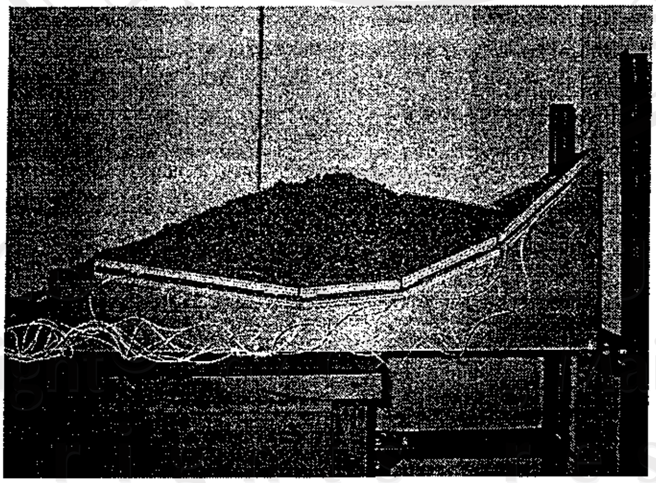


Fig. A.10 Slope failure is occurred

(b) Slope with anchoring case

In the case of anchoring slope, the experiment steps are similar to case (a), except in step 2. After piled up the straws filled with sand to form to be a slope, place the anchoring forces attached with 4 sensors perpendicularly over the position of slice 3 according fig. 8. These 4 sensors attached to the anchoring board are to verify the anchoring forces in the experiment. Then, measure the forces acting on all sensors and follow the same step as case (a).

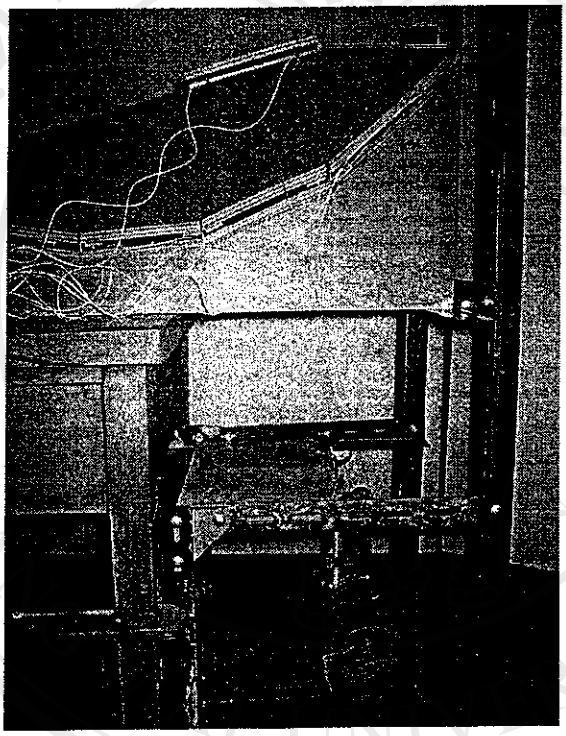


Fig. A.11 The anchoring forces were installed in the case (b) model

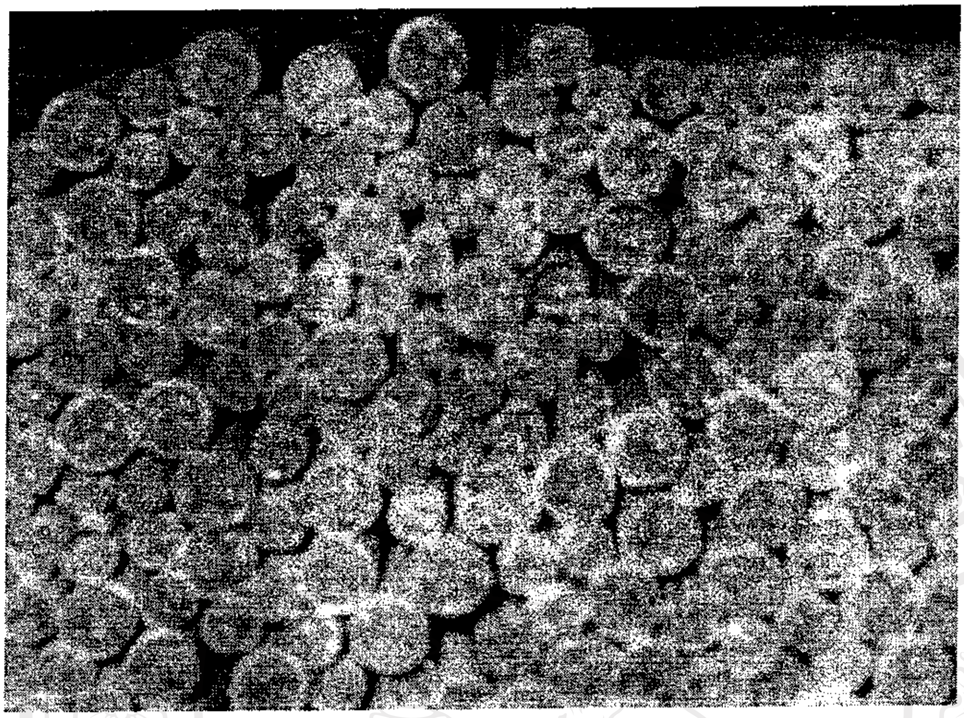


Fig. A.12 Cross-section of the straws filled with sand

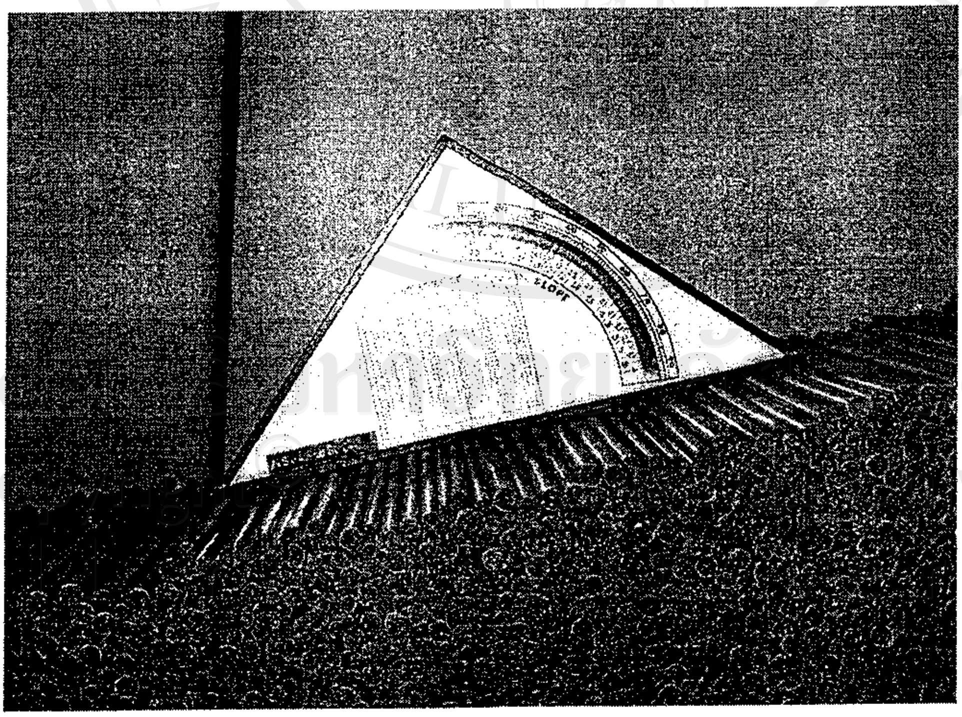


Fig. A.13 Checking the slope angle by handy angle measurement

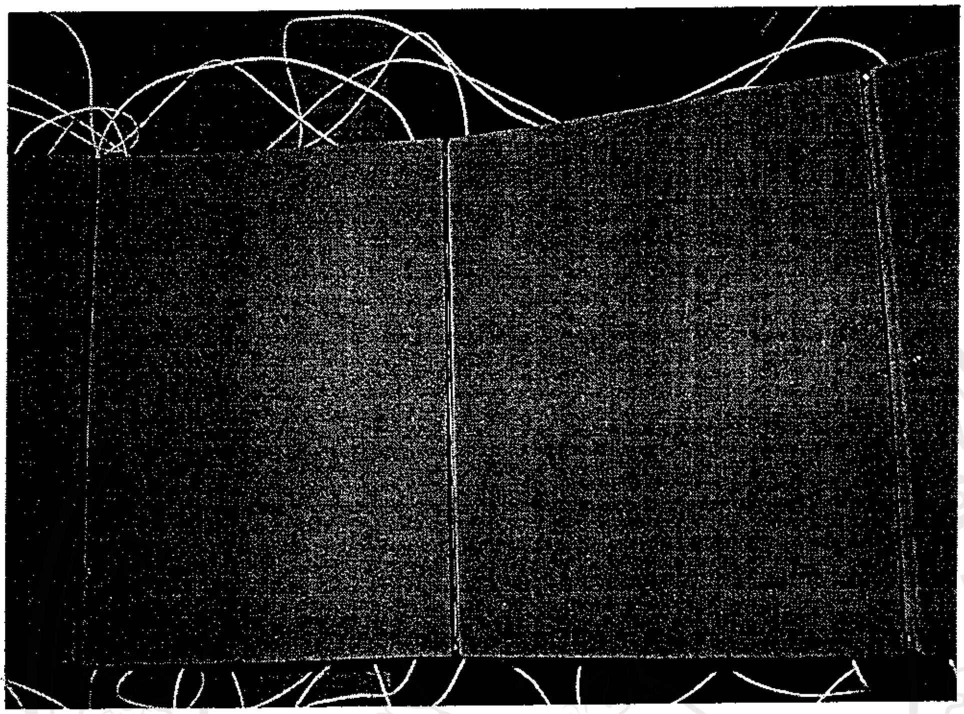


Fig. A.14 The plywood boards covered with the sand paper #400 are separated in each slice

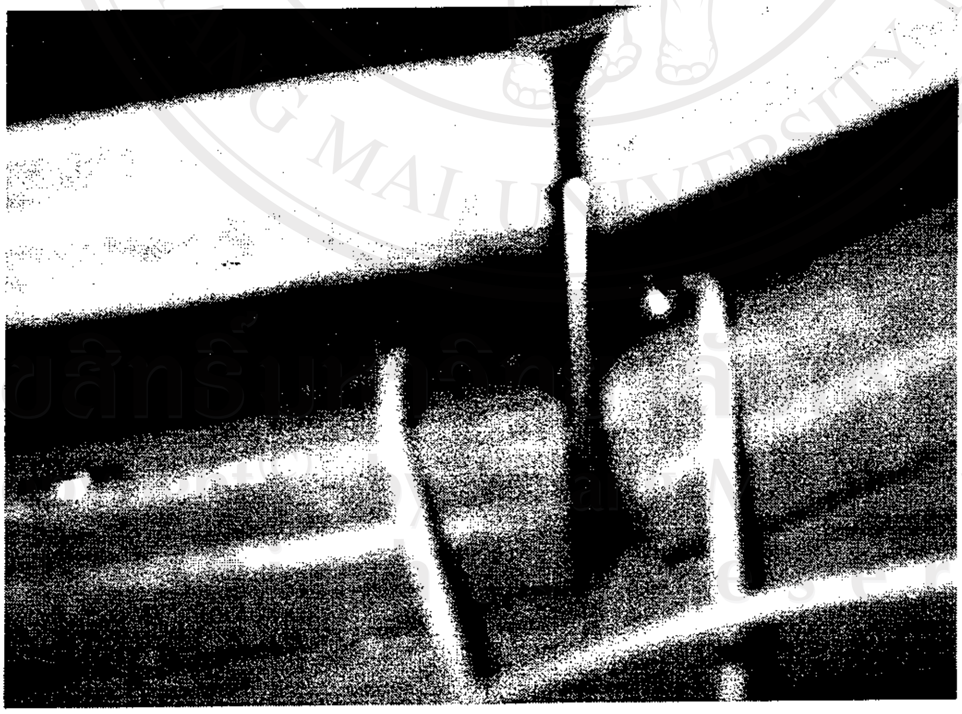
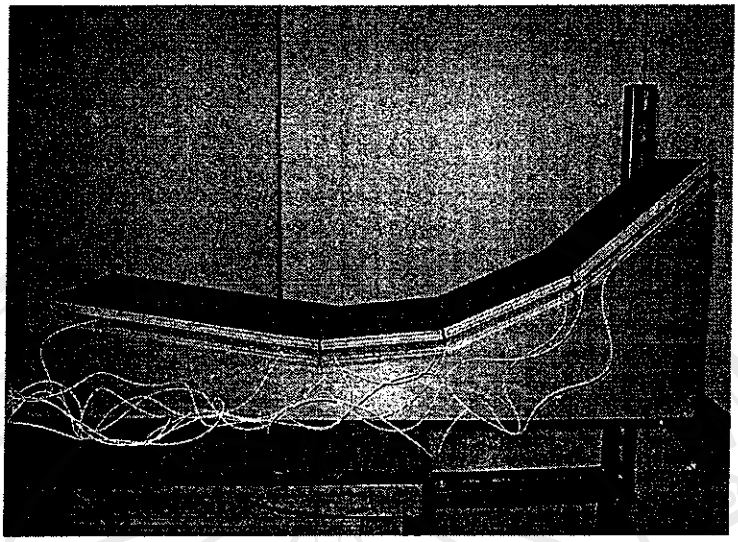
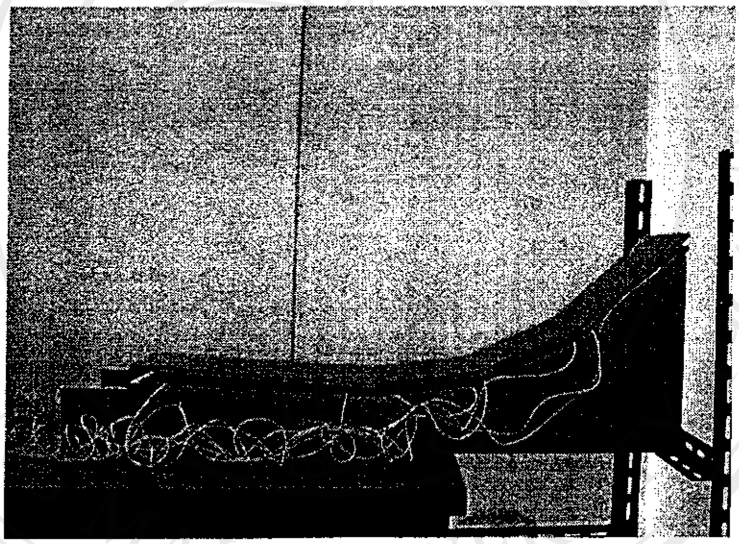


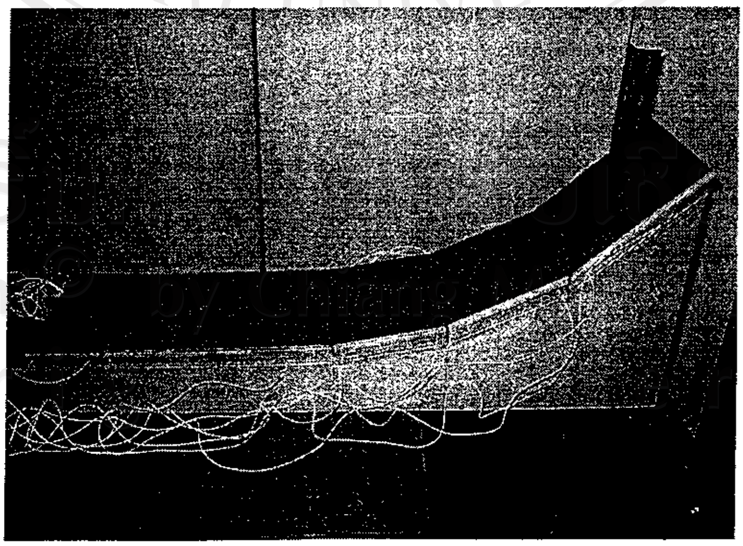
Fig. A.15 The sensors are attached under each slice to measure the normal forces



Model 1, β=15.0°

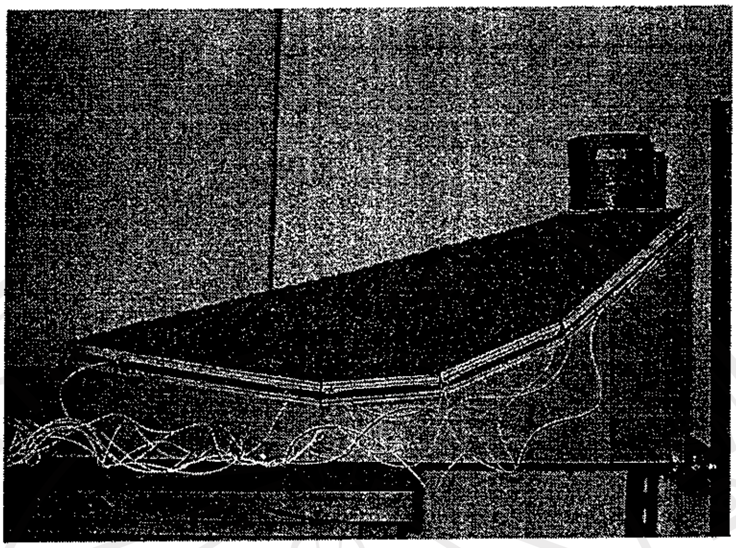


Model 2, β=17.5°

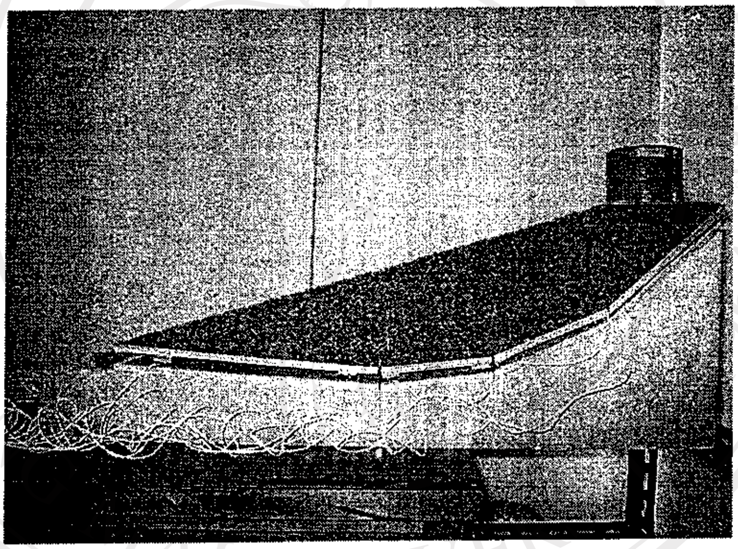


Model 3, β=20.0°

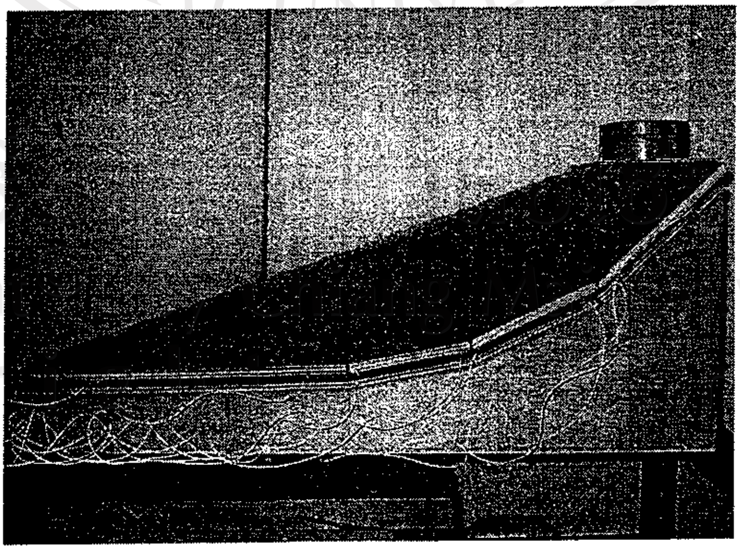
Fig. A.16 The slip plane of all 3 slope models



Model 1, β=15.0°

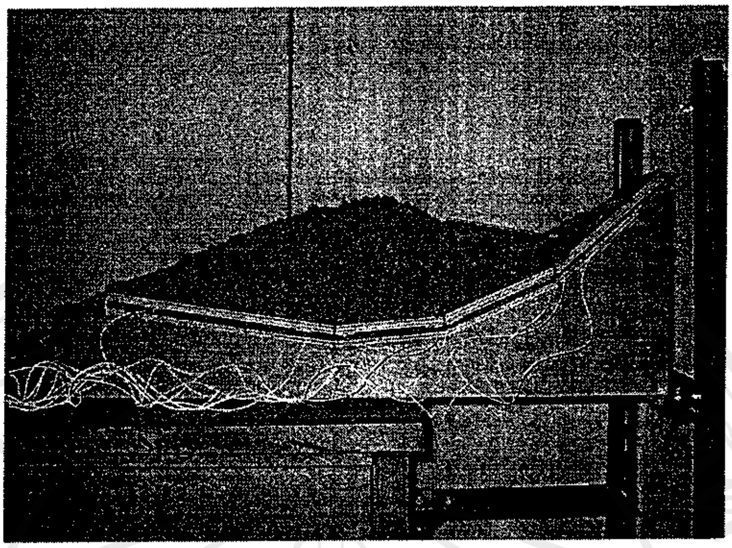


Model 2, β=17.5°

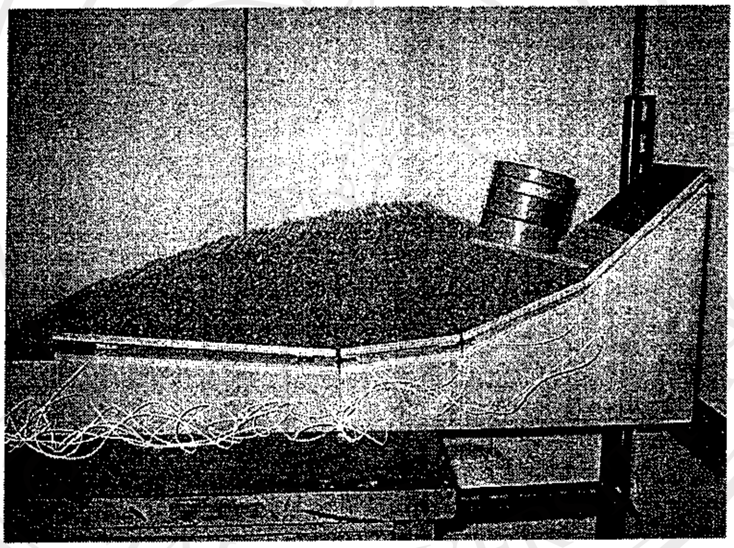


Model 3, β=20.0°

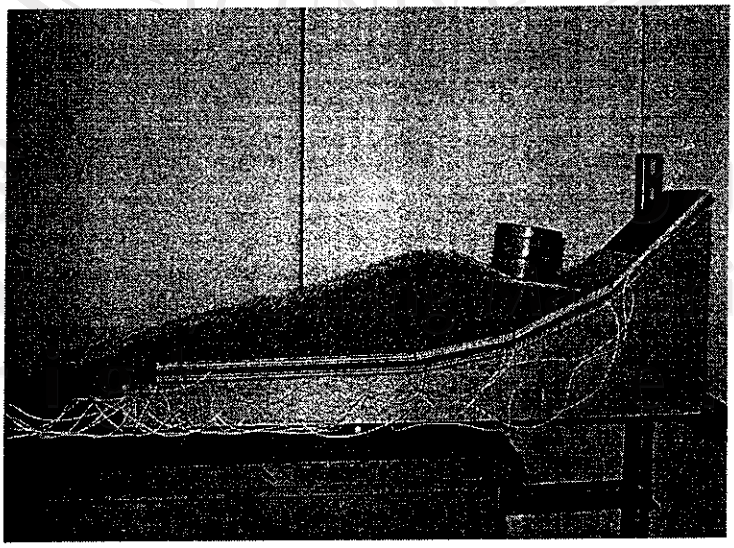
Fig. A.17 The optimized shape of all 3 slope models



Model 1, β=15.0°



Model 2, β=17.5°



Model 3, β=20.0°

Fig. A.18 Failure of the slope models at the maximum load

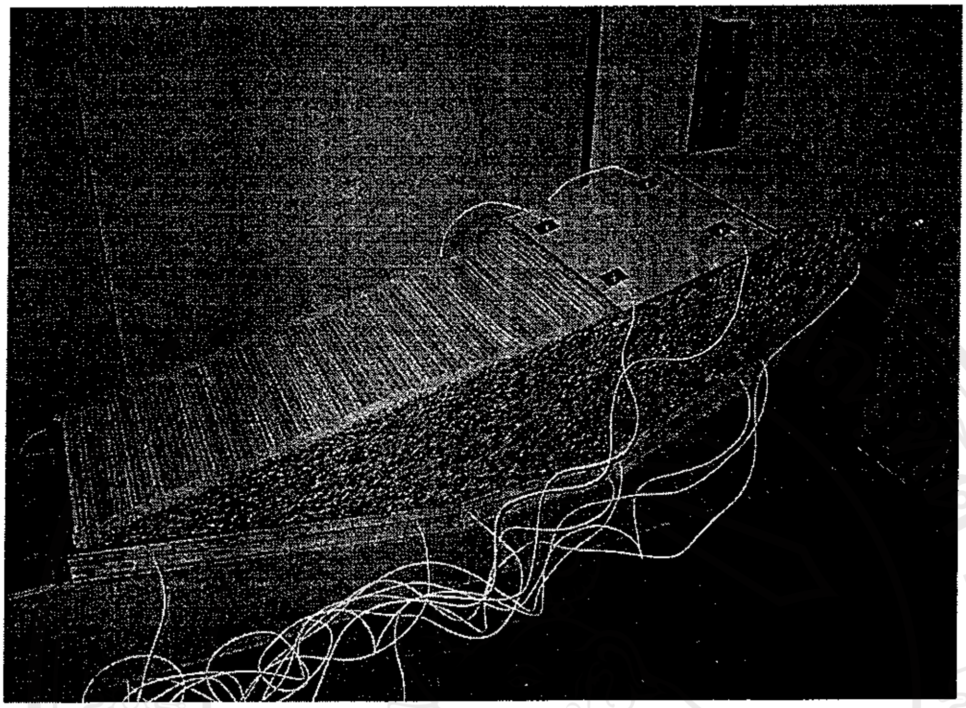


Fig. A.19 Setting 4 sensors to verify the anchoring forces

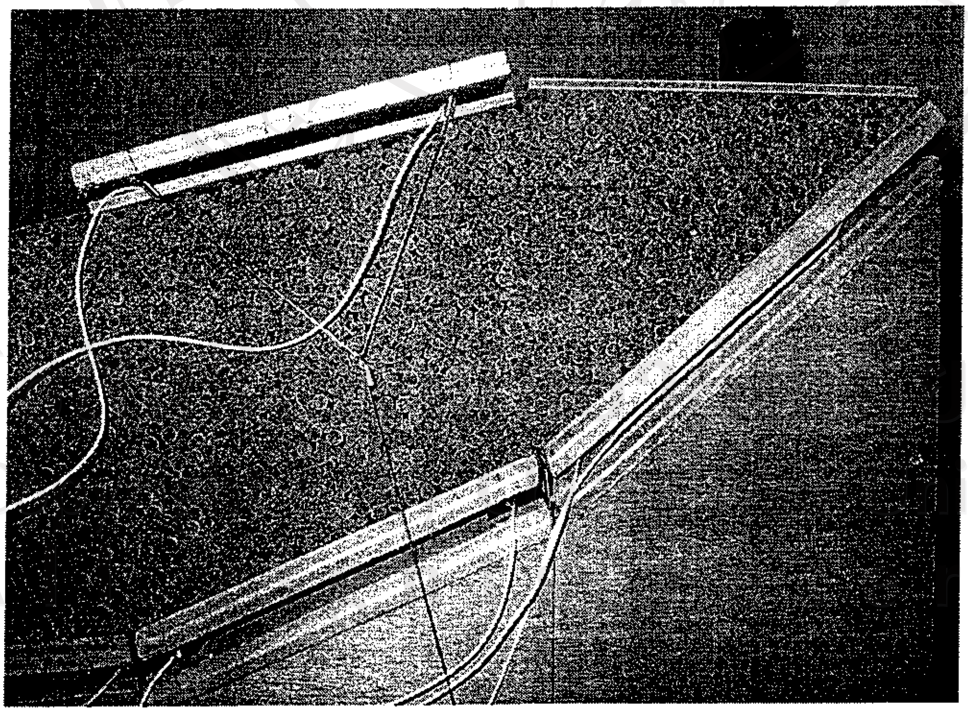


Fig. A.20 Placing the anchoring force perpendicular to the slope

Results of the experiment

The results of the experiment were recorded by Data scanner and Data logger in the term of the normal forces per unit length: gf/cm.

Table A.3 Experimental result of the slope model 1 (β=15.0 degrees)

Case (a) : slope without the anchoring force

Load (N/m)	Normal force (N/m)			
	slice 1	slice 2	slice 3	slice 4
0.000	271.429	243.810	201.048	114.095
23.334	271.333	244.619	201.905	126.905
46.667	272.476	245.333	202.714	141.476
93.333	274.667	246.667	203.000	174.190
186.666	283.238	246.952	207.190	237.429
280.000	285.762	248.524	207.571	294.571
373.333	291.857	247.905	215.238	350.143

Case (b) : slope attached the anchoring force

Load (N/m)	Normal force (N/m)				Anchoring force (N/m)
	slice 1	slice 2	slice 3	slice 4	
0.000	292.857	288.000	347.143	220.810	291.340
46.667	293.952	288.952	350.429	251.524	291.013
93.333	294.667	290.524	354.524	281.333	291.854
186.666	296.952	293.381	363.857	343.095	290.360
280.000	297.667	296.524	367.762	405.429	290.874
373.333	302.333	299.000	373.143	465.619	290.827
466.666	307.476	303.333	384.095	517.952	290.780
588.000	314.095	310.048	393.095	597.190	291.574

Table A.4 Experimental result of the slope model 2 (β=17.5 degrees)

Case (a) : slope without the anchoring force

Load (N/m)	Normal force (N/m)			
	slice 1	slice 2	slice 3	slice 4
0.000	286.857	232.857	206.762	127.429
23.334	287.190	233.714	208.190	141.571
46.667	287.905	234.524	210.286	156.476
93.333	289.524	235.810	214.429	188.810
140.000	291.143	237.714	218.190	219.095
186.666	292.857	238.714	221.952	248.857
280.000	295.762	241.381	225.095	312.381

Case (b) : slope attached the anchoring force

Load (N/m)	Normal force (N/m)				Anchoring force (N/m)
	slice 1	slice 2	slice 3	slice 4	
0.000	293.238	263.190	340.048	193.333	232.307
46.667	293.667	264.667	344.619	224.333	231.840
93.333	294.762	267.333	352.429	254.381	232.493
186.666	296.810	269.952	354.190	313.333	231.466
280.000	298.952	272.667	366.333	369.952	230.907
373.333	300.667	275.667	371.524	427.143	230.347
466.666	303.381	280.714	379.381	484.810	230.533

Table A.5 Experimental result of the slope model 3 (β=20.0 degrees)

Case (a) : slope without the anchoring force

Load (N/m)	Normal force (N/m)			
	slice 1	slice 2	slice 3	slice 4
0.000	322.714	224.333	197.905	107.667
23.334	323.333	225.048	198.762	122.905
46.667	324.905	224.667	200.429	139.000
70.000	325.429	226.095	200.905	153.476
93.333	326.000	226.619	200.714	168.143
140.000	328.571	229.000	200.571	200.762
186.666	330.571	228.619	200.238	228.476

Case (b) : slope attached the anchoring force

Load (N/m)	Normal force (N/m)				Anchoring force (N/m)
	slice 1	slice 2	slice 3	slice 4	
0.000	324.524	256.000	295.143	171.524	201.905
46.667	324.905	257.905	297.190	202.333	202.143
93.333	325.952	258.810	300.048	232.143	201.810
140.000	326.619	260.286	300.238	261.524	201.762
186.666	327.619	262.333	302.667	287.524	201.714
280.000	329.857	264.476	310.048	347.714	202.381
373.333	332.048	267.905	305.857	409.476	202.571

Appendix B

Data of landslides in Northern Thailand

Highway Research and Development Bureau, Ministry of Transport

Boring Log

Location	Route no.1093, section Km.29+000-Patang Village		
Station	35+390.50	Boring No.	BH-1
Offset	L.T. 2.00 m. from CL.	Boring stated	5/12/2000
Surface elevation	101.150 m.	Boring completed	6/12/2000

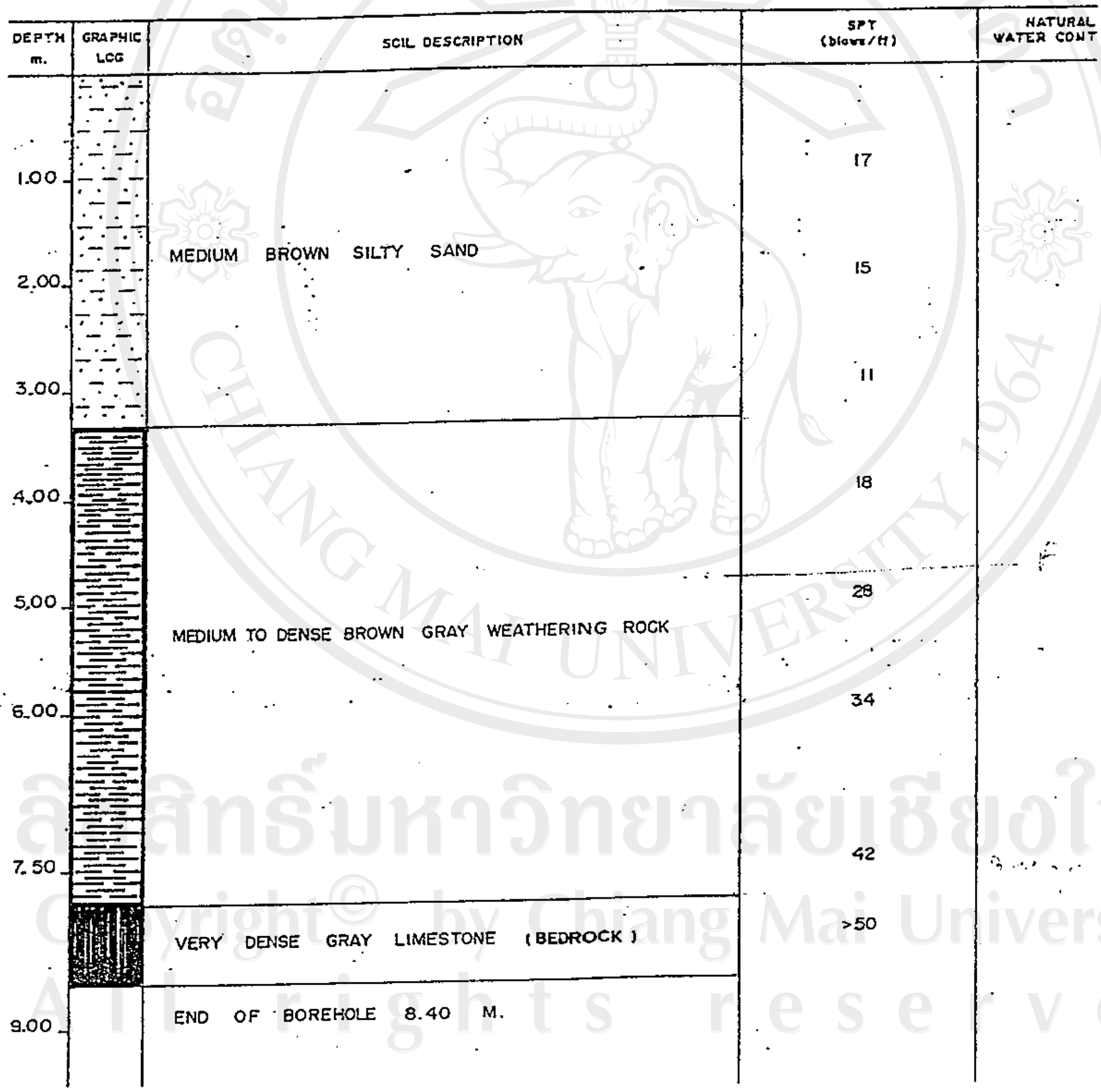


Fig. B.1 Soil profile of Boring log no. BH1 at Km. 35+400, Public highway no. 1093

Highway Research and Development Bureau, Ministry of Transport

Boring Log

Location	Route no.1093, section Km.29+000-Patang Village		
Station	35+391.00	Boring No.	BH-2
Offset	R.T. 2.50 m. from CL.	Boring stated	7/12/2000
Surface elevation	101.115 m.	Boring completed	7/12/2000

DEPTH m.	GRAPHIC LOG	SOIL DESCRIPTION	SPT (blows/ft)	NATURAL WATER CONTEN
1.00		MEDIUM BROWN SILTY SAND	19	
2.00		DENSE BROWN GRAY WEATHERING ROCK	44	
		VERY DENSE BROWN GRAY LIMESTONE (BEDROCK)	> 50	
3.00		END OF BOREHOLE 2.85 M.		
4.00				
5.00				
6.00				

Fig. B.2 Soil profile of Boring log no. BH2 at Km. 35+400, Public highway no. 1093

Highway Research and Development Bureau, Ministry of Transport

Boring Log

Location	Route no.1093, section Km.29+000-Patang Village		
Station	35+392.50	Boring No.	BH-3
Offset	L.T. 7.80 m. from CL.	Boring stated	11/12/2000
Surface elevation	101.145 m.	Boring completed	12/12/2000

DEPTH m.	GRAPHIC LOG	SOIL DESCRIPTION	SPT (blows/ft)	NATURAL WATER CONTE
1.00		LOOSE BROWN GRAY SILTY SAND	5	
2.00		STIFF TO VERY STIFF YELLOWISH BROWN SILTY CLAY	14	
3.00			16	
4.00		MEDIUM YELLOWISH BROWN SILTY SAND	23	
5.00			19	
6.00			17	
7.50		DENSE TO VERY DENSE BROWN GRAY SILTY SAND	34	
9.00			65	
10.50		VERY DENSE GRAY WEATHERING ROCK	53	
12.00		VERY DENSE GRAY LIMESTONE (BEDROCK)	> 50	
13.50		END OF BOREHOLE 12.25 M.		

Fig. B.3 Soil profile of Boring log no. BH3 at Km. 35+400, Public highway no. 1093

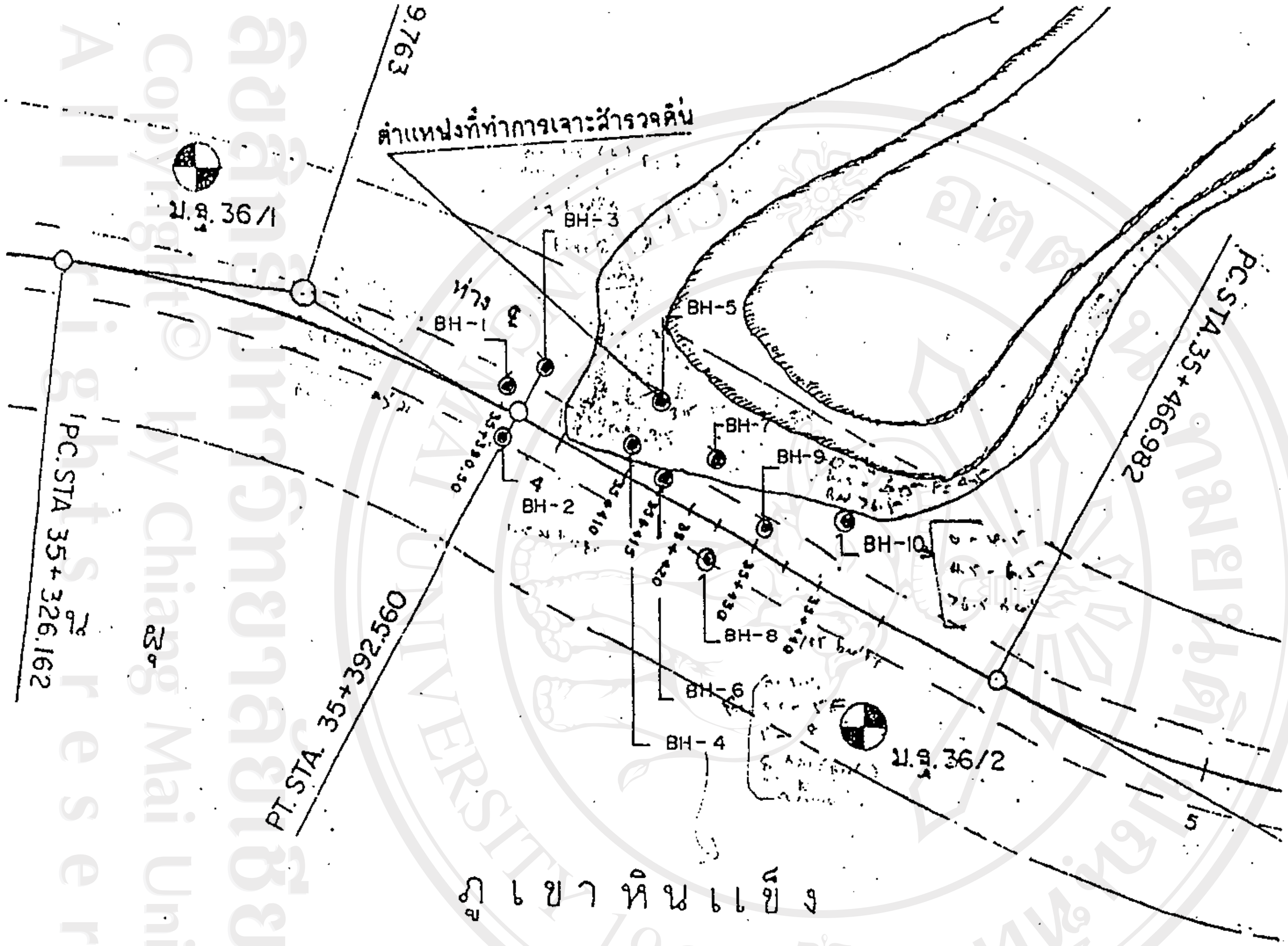


Fig. B.4 Bore holes and profile of Public highway no.1093 at Km. 35+380 – 35+ 450

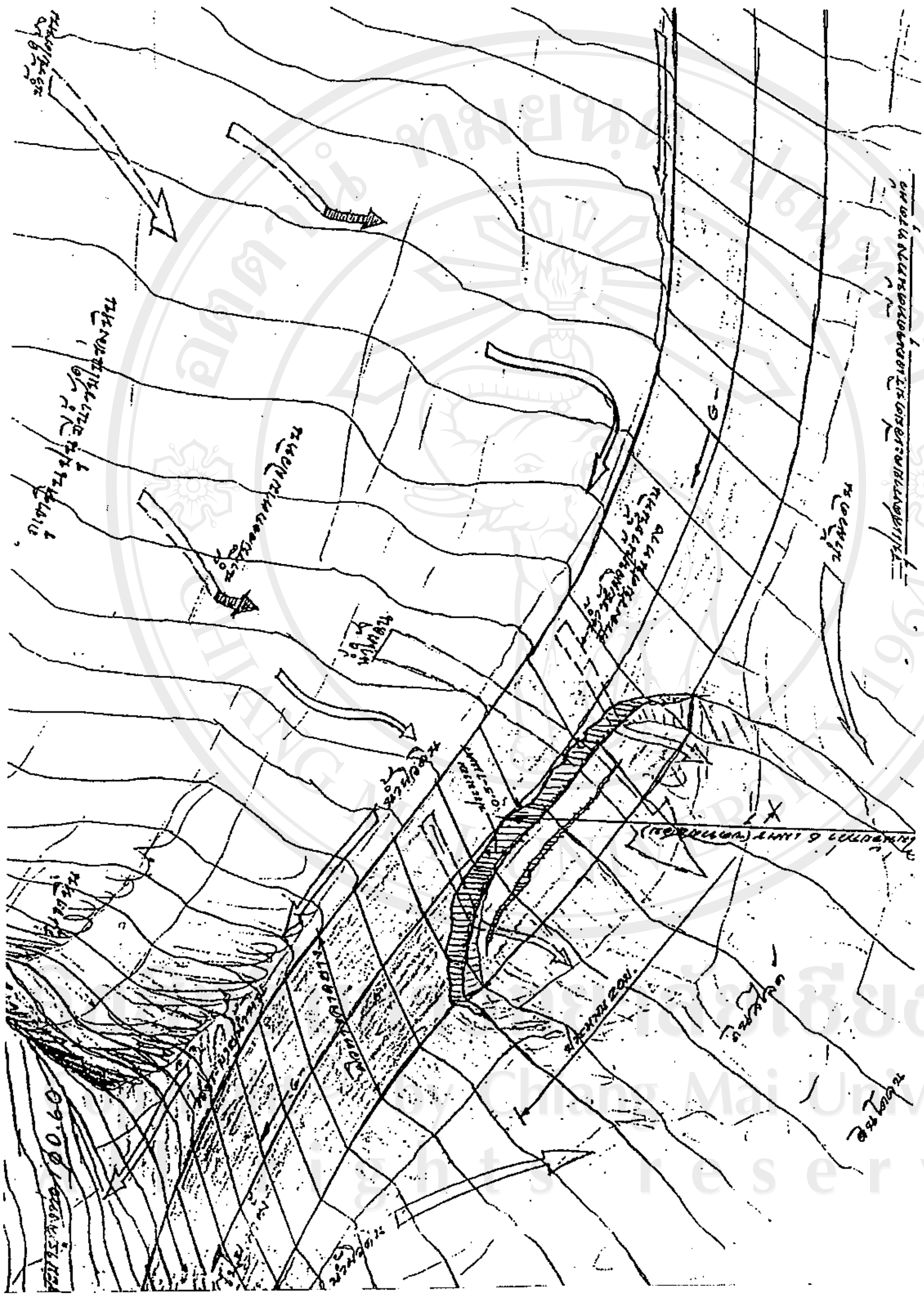


Fig. B.5 Sketch of failure slope at Km. 35+400 of Public highway no.1093

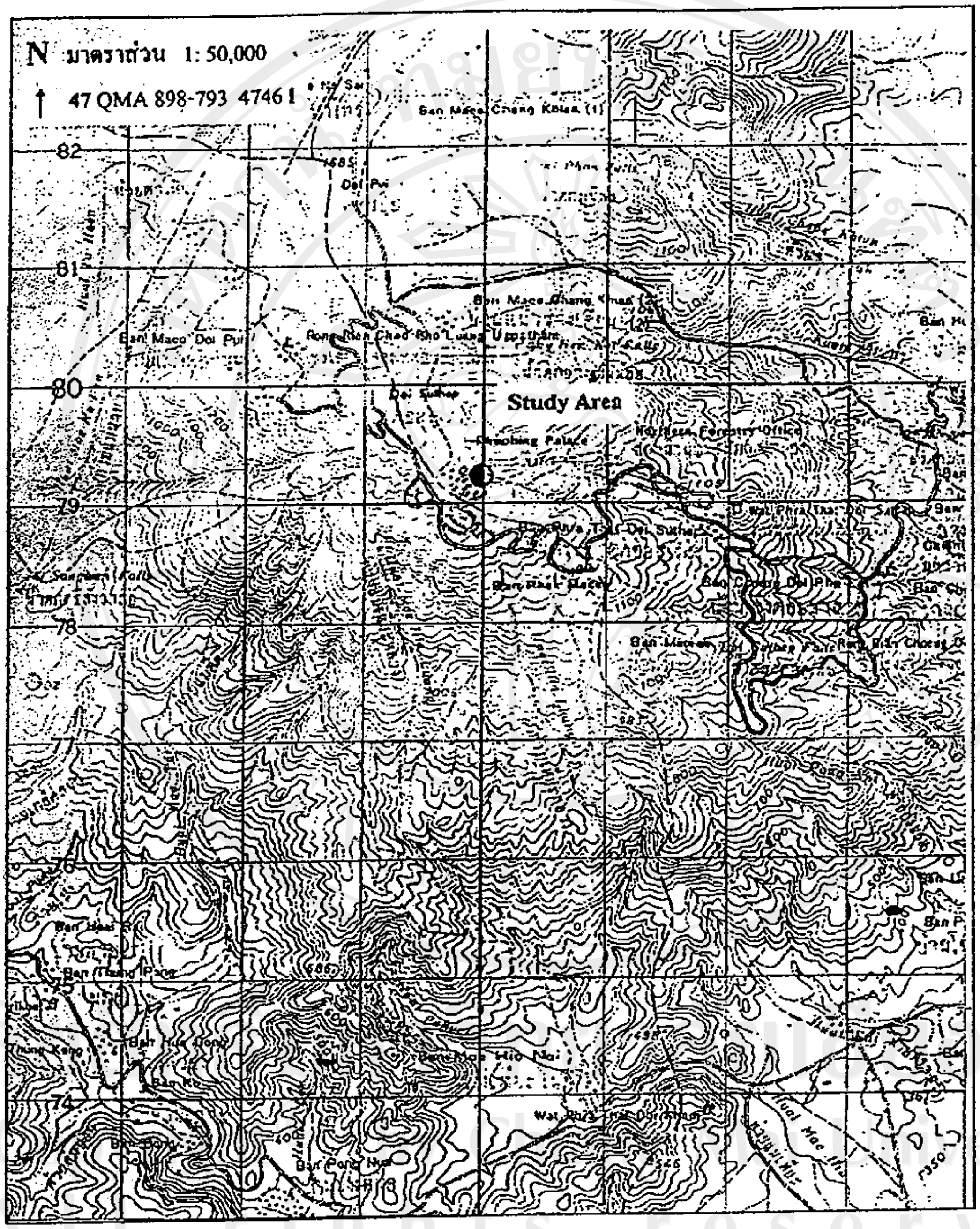


Fig. B.6 Location of the failure mountain slope in Bhuping Palace, Chiang Mai

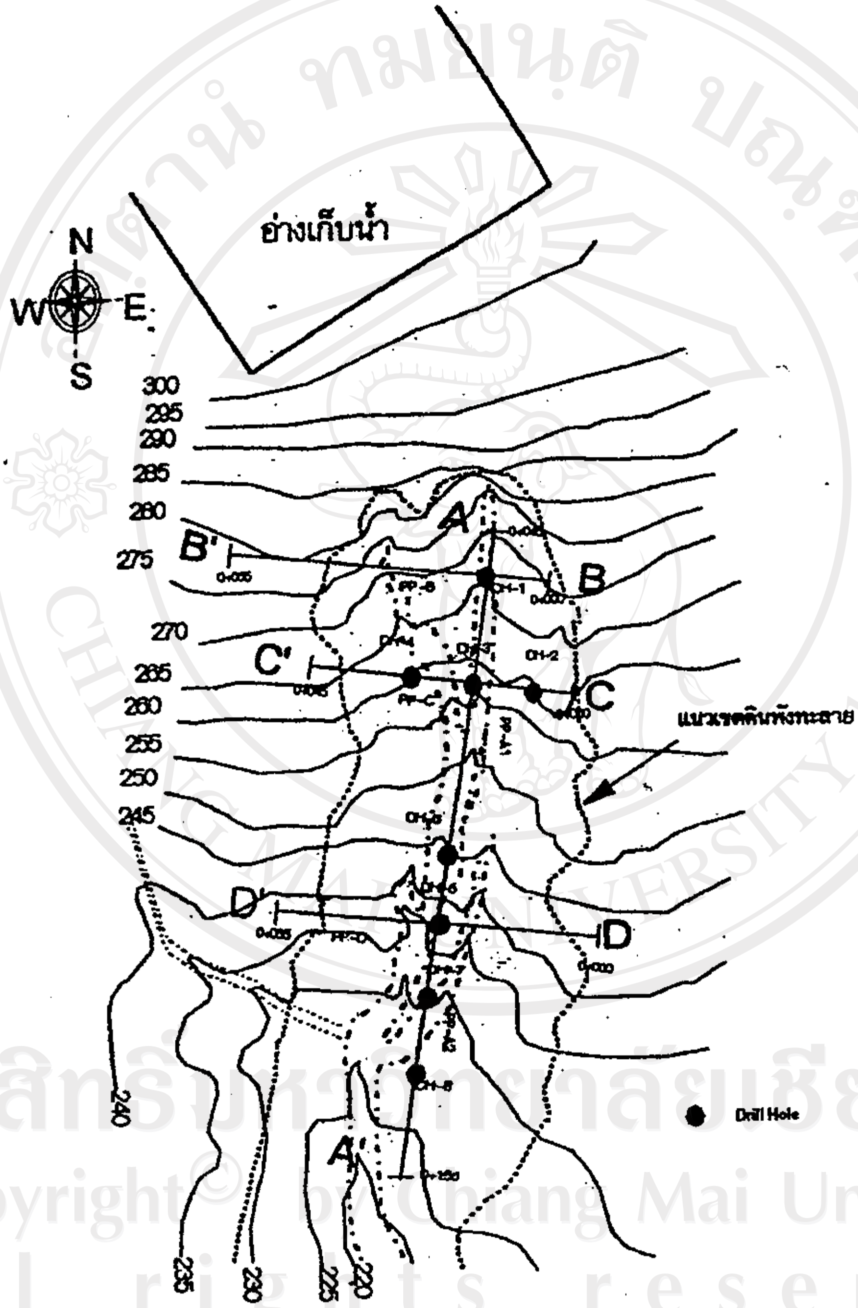


Fig. B.7 Profile plan of the mountain slope in Bhuping Palace, Chiang Mai

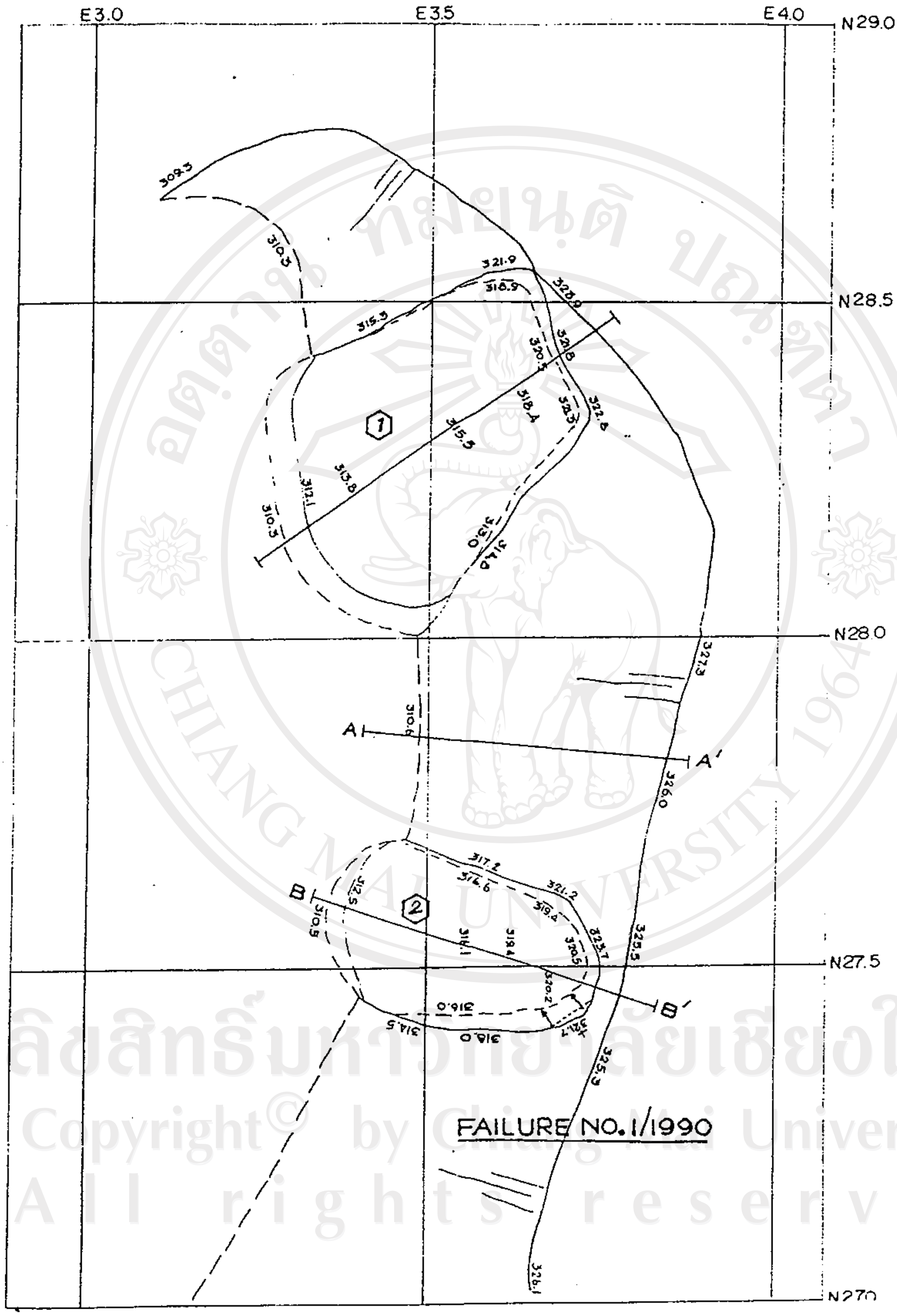


Fig. B.8 Profile plan of the failure slope in Mae Moh Dam, Lampang

Appendix C

Procedures and results of the laboratory tests and field tests

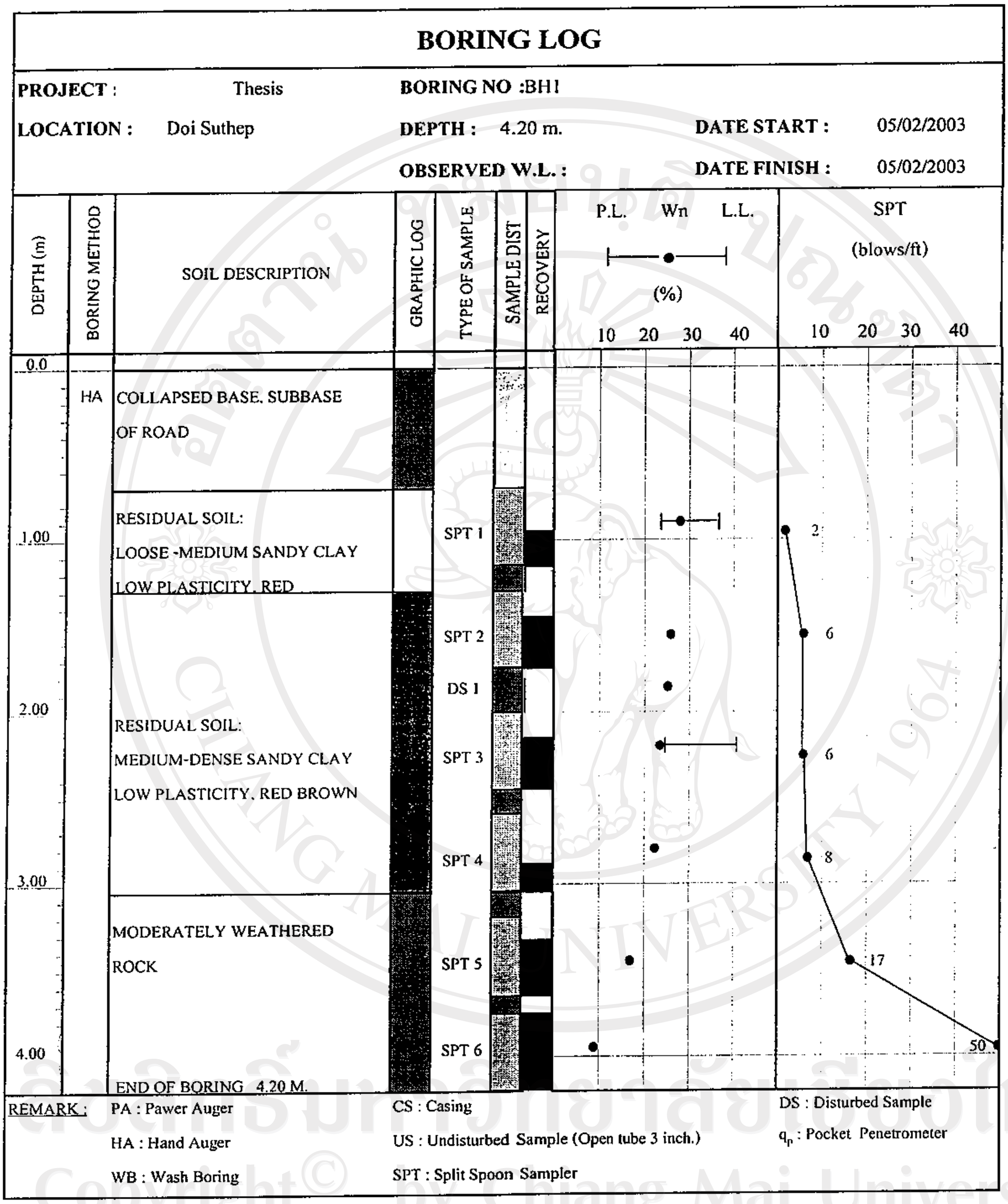


Fig. C.1 Soil profile of boring log no. BH1

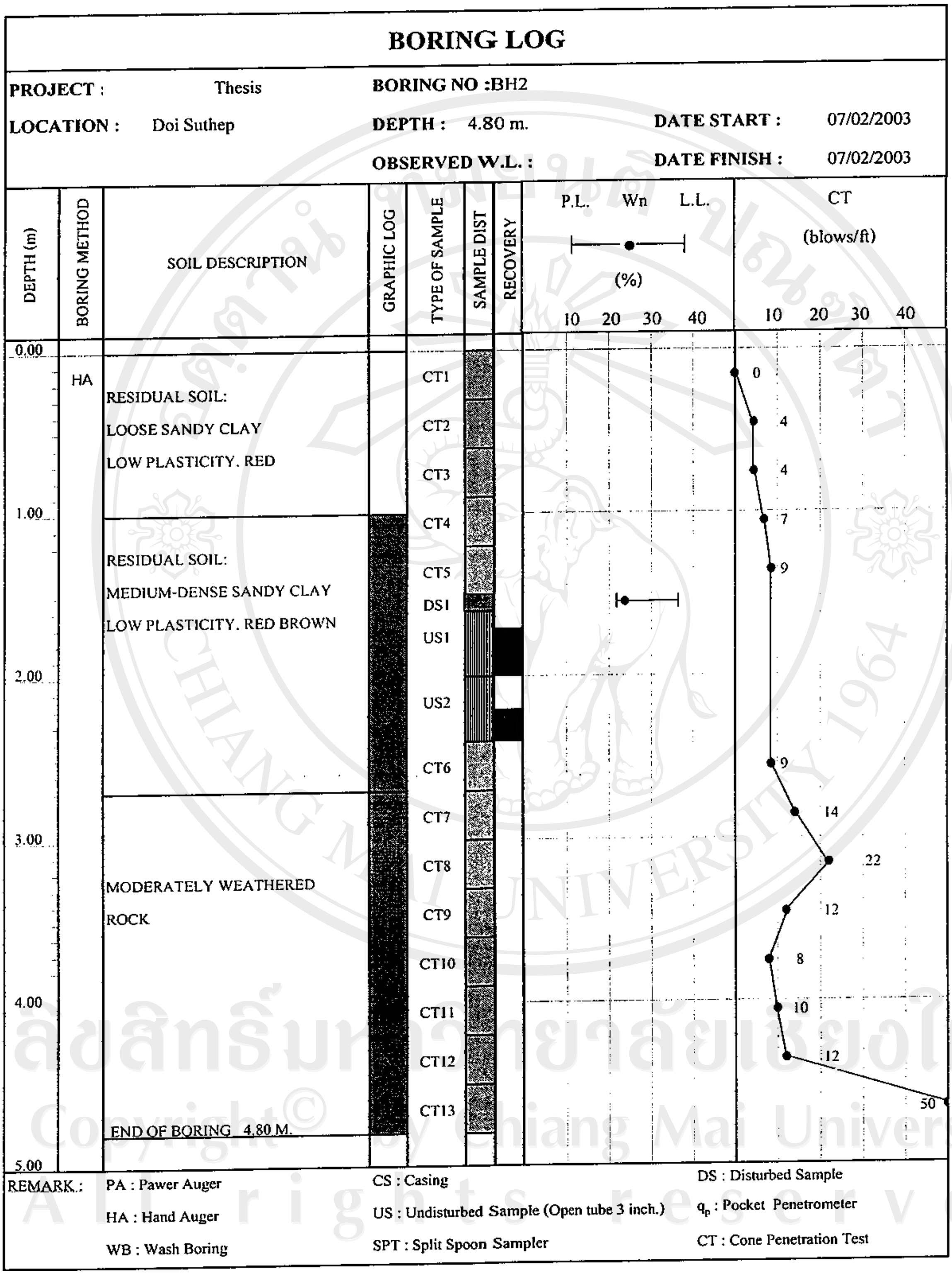


Fig. C.2 Soil profile of boring log no. BH2

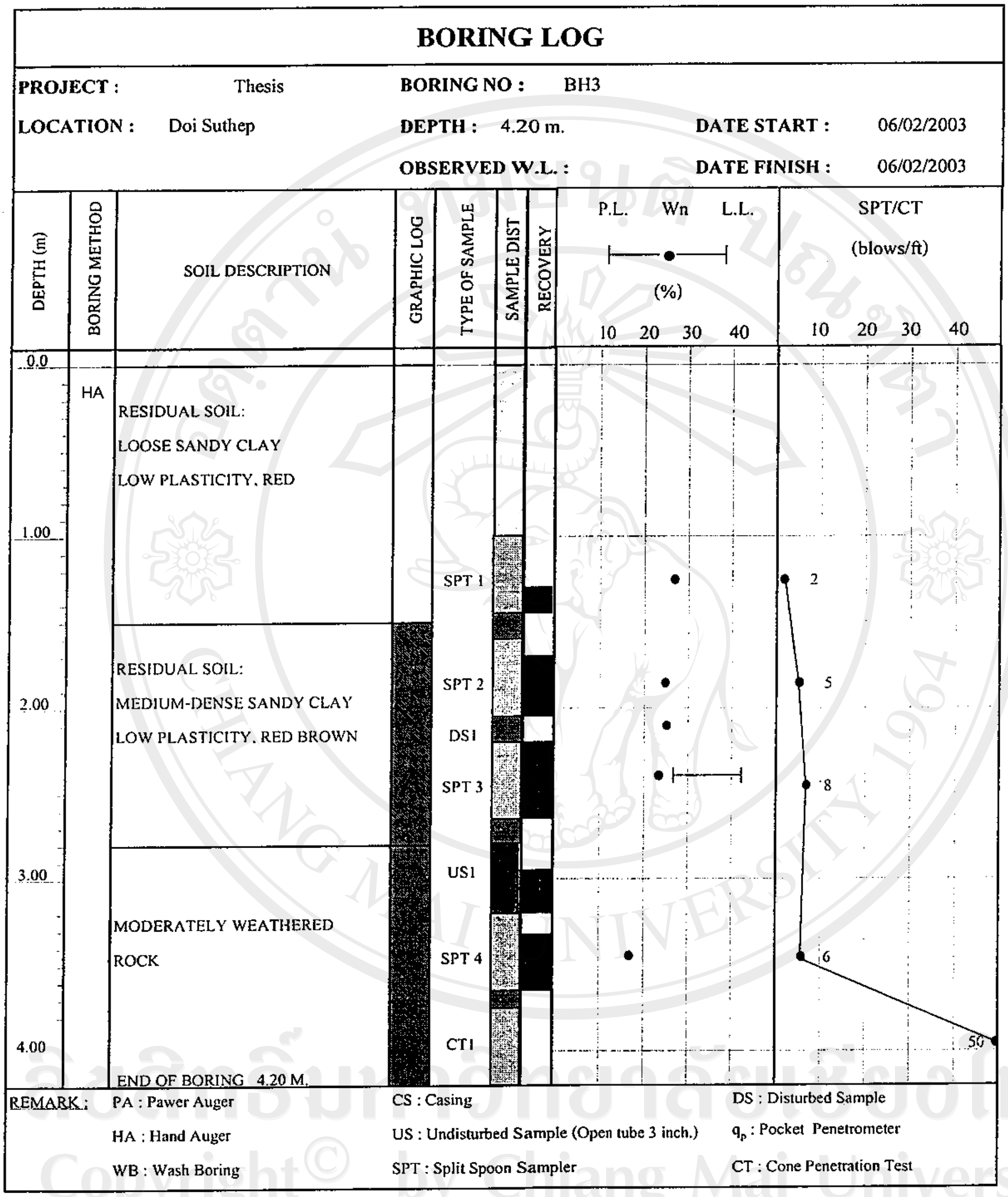
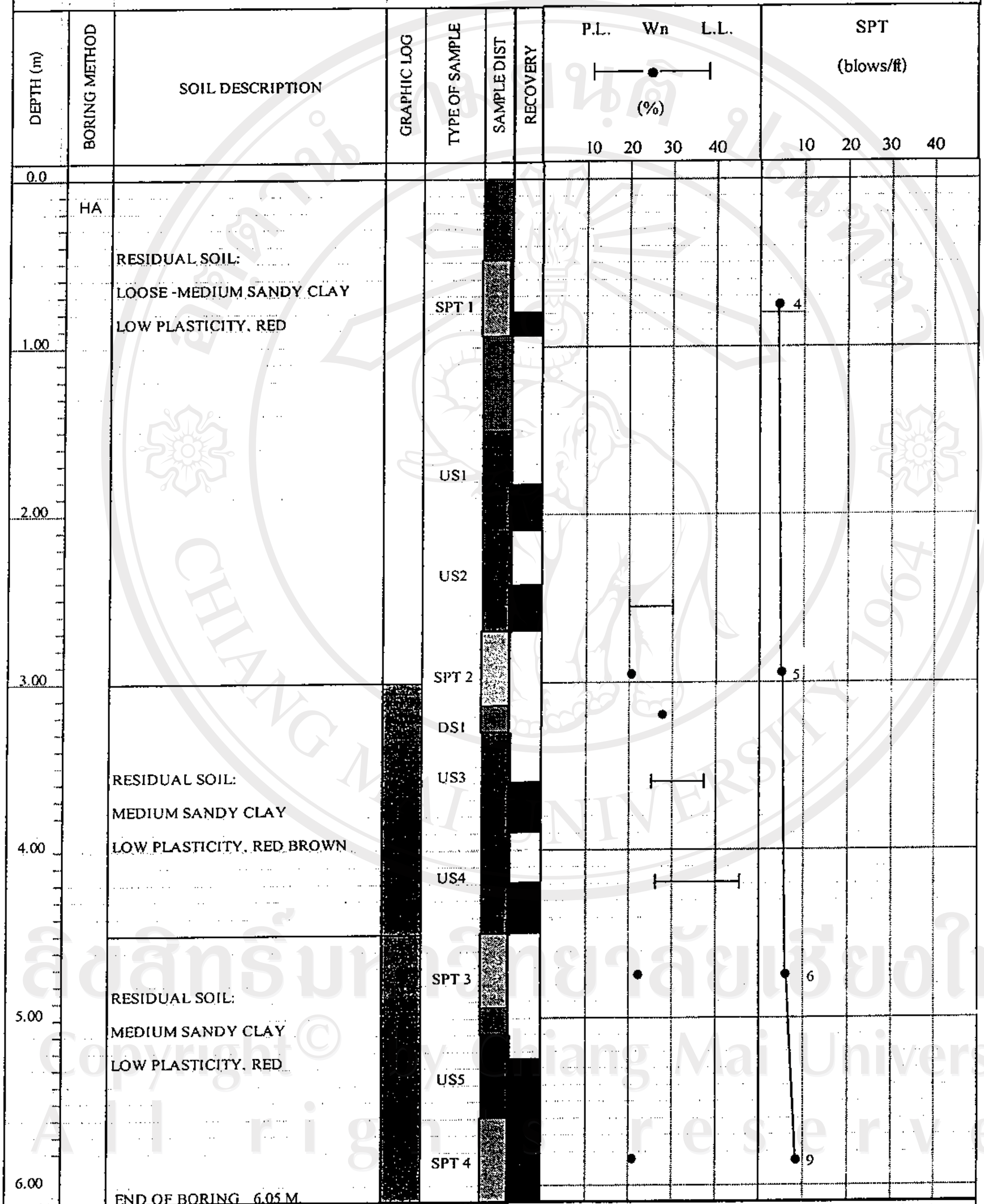


Fig. C.3 Soil profile of boring log no. BH3

BORING LOG

PROJECT : Thesis	**BORING NO :** BH4		
LOCATION : Doi Suthep	**DEPTH :** 6.05 m.	**DATE START :**	12/03/2003
	OBSERVED W.L. :	**DATE FINISH :**	12/03/2003



REMARK :
PA : Pawer Auger
HA : Hand Auger
WB : Wash Boring
CS : Casing
US : Undisturbed Sample (Open tube 3 inch.)
SPT : Split Spoon Sampler
DS : Disturbed Sample
q_u : Pocket Penetrometer

Fig. C.4 Soil profile of boring log no. BH4

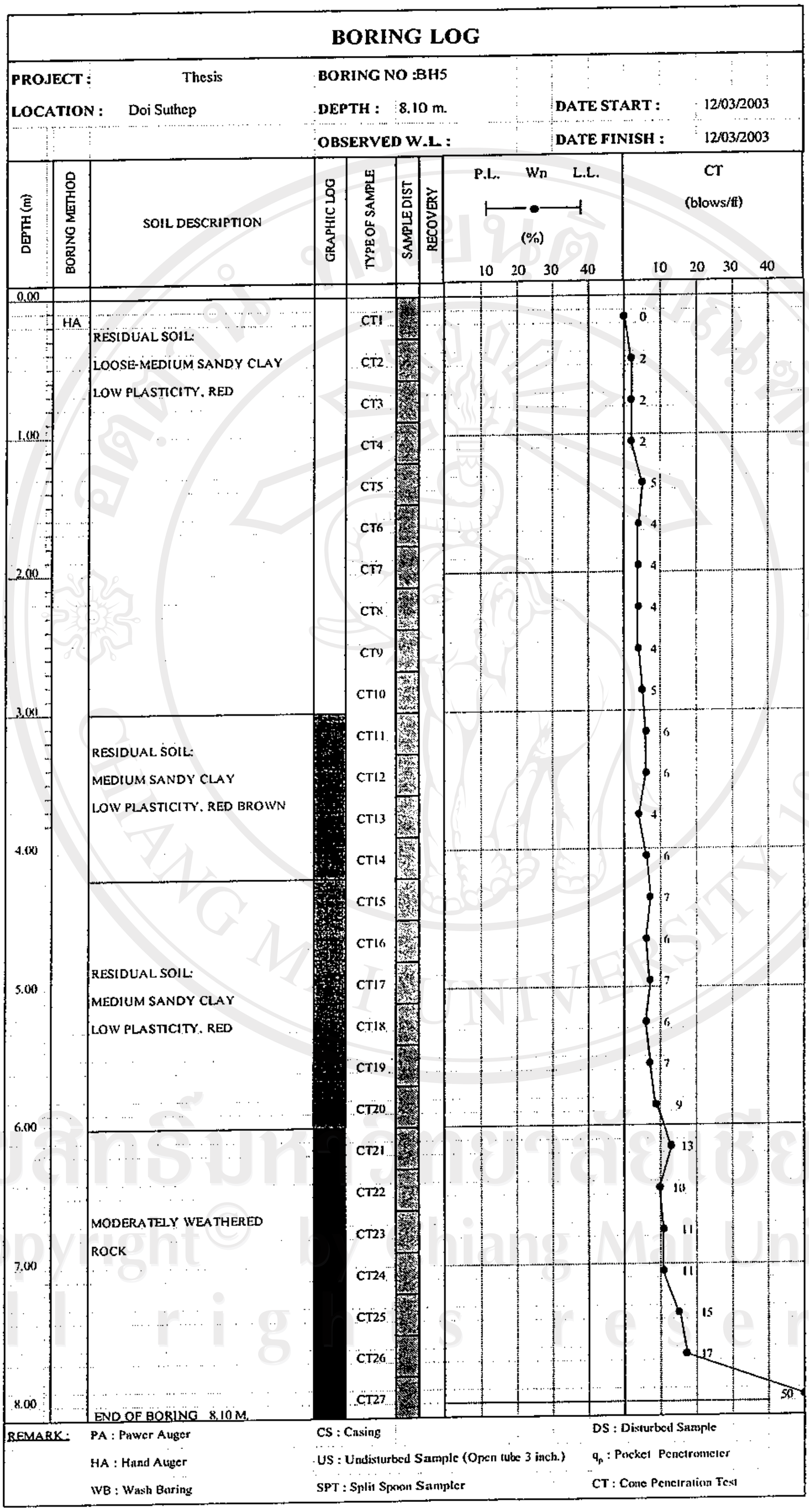


Fig. C.5 Soil profile of boring log no. BH5

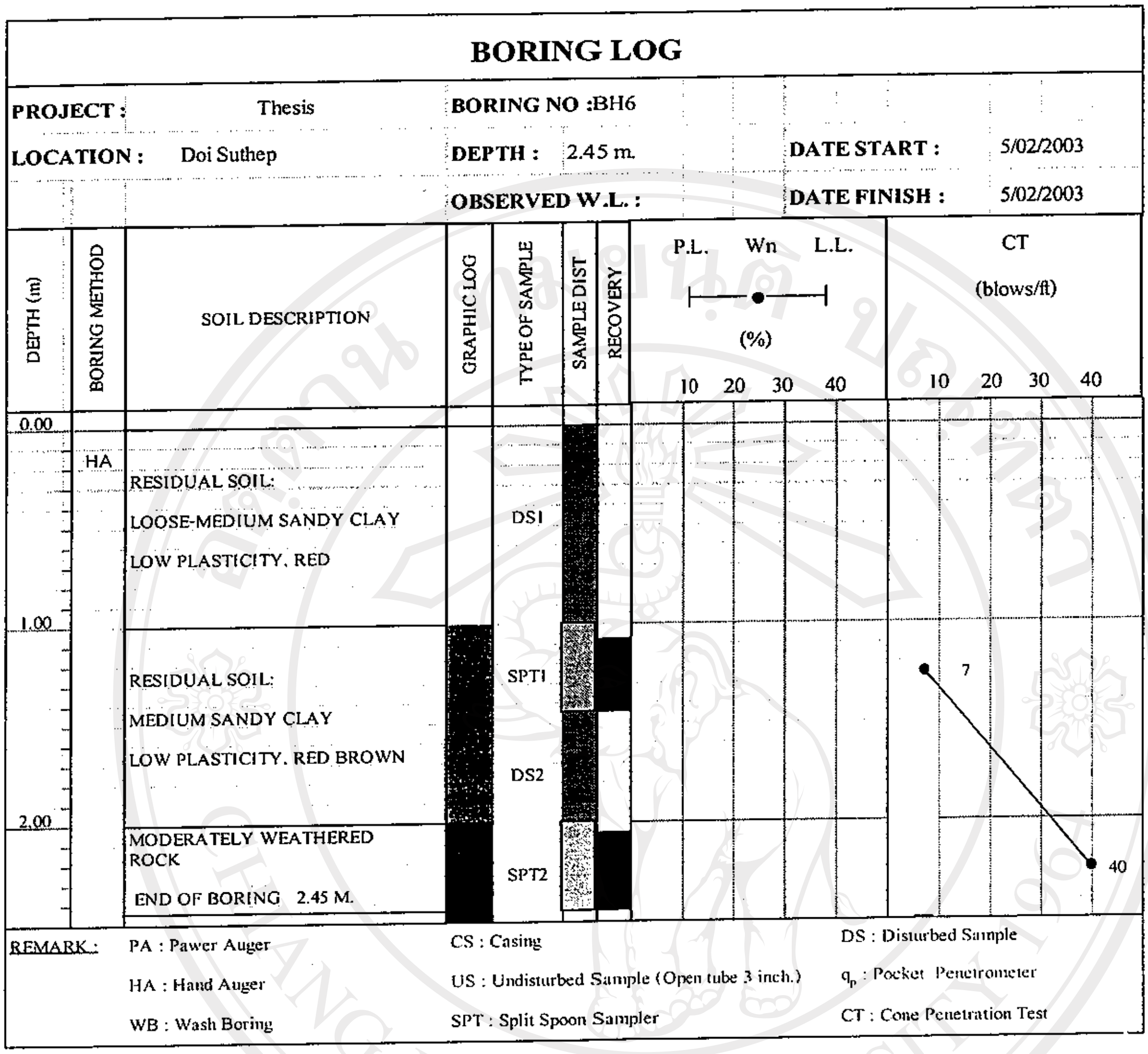


Fig. C.6 Soil profile of boring log no. BH6

Table C.1 Physical and engineering properties of soils of boring log no. BH1

SUMMARY OF TEST RESULTS

PROJECT : Thesis **BORING NO :** BH1

LOCATION : Doi Suthep **DEPTH :** 4.20 m. **DATE START :** 5/02/2003

OBSERVED W.L. : **DATE FINISH :** 5/02/2003

TYPE OF SAMPLE	SAMPLE DEPTH FROM (m)	SAMPLE DEPTH TO (m)	SOIL GROUP (USCS)	GRADATION (%) PASSING NO. 3/8"	NO. 4	NO. 10	NO. 20	NO. 40	NO. 100	NO. 200	W_n (%)	ATTERBERG LIMITS (%) L.L.	P.L.	P.I.	Gs	UNIT WEIGHT WET DENSITY (t/m^3)	DRY DENSITY (t/m^3)	FIELD TESTING SPT (blows/ft)	CT (blows/ft)
SPT 1	0.70	1.15									28.44	37.26	23.22	14.04	2.602			2	
SPT 2	1.30	1.75	CL	99.62	97.67	94.39	85.62	77.46	70.05	66.59	26.15							6	
DS 1	1.75	2.00	CL	99.35	97.91	93.62	83.00	74.51	66.86	63.31	24.92				2.621				
SPT 3	2.00	2.45									22.86	40.62	24.40	16.22	2.617			6	
SPT 4	2.60	3.05	CL	98.51	96.00	89.72	77.08	67.27	58.39	54.59	17.24							8	
SPT 5	3.20	3.65	SC	84.66	79.33	68.94	56.84	49.28	41.98	38.61	21.61							17	
SPT 6	3.75	4.15	SC	69.19	59.76	47.01	35.70	28.84	22.29	19.23	9.76							50	

REMARK : US : Undisturbed Sample (Open tube 3 inch.) DS : Disturbed Sample SPT : Split Spoon Sampler CT : Cone Penetration Test

Table C.2 Physical and engineering properties of soils of boring log no. BH2

SUMMARY OF TEST RESULTS

PROJECT : Thesis **BORING NO :** BH2

LOCATION : Doi Suthep **DEPTH :** 4.80 m. **DATE START :** 7/02/2003

OBSERVED W.L. : **DATE FINISH :** 7/02/2003

TYPE OF SAMPLE	SAMPLE DEPTH		SOIL GROUP	GRADATION (%) PASSING							W_n	ATTERBERG LIMITS (%)			Gs	UNIT WEIGHT		FIELD TESTING	
	FROM (m)	TO (m)	(USCS)	NO. 3/8"	NO. 4	NO. 10	NO. 20	NO. 40	NO. 100	NO. 200	(%)	L.L.	P.L.	P.I.		WET DENSITY (t/m^3)	DRY DENSITY (t/m^3)	SPT (blows/ft)	CT (blows/ft)
CT1	0.00	0.30													2.617				0
CT2	0.30	0.60													2.617				4
CT3	0.60	0.90													2.617				4
CT4	0.90	1.20	CL	100.00	98.87	96.69	87.89	78.08	68.08	63.82	23.29	36.67	22.09	14.58					7
CT5	1.20	1.50	CL	100.00	98.87	96.69	87.89	78.08	68.08	63.82	23.29	36.67	22.09	14.58					9
DS1	1.50	1.60	CL	100.00	98.87	96.69	87.89	78.08	68.08	63.82	23.29	36.67	22.09	14.58	2.621				
US1	1.60	2.00									21.04				2.621	1.966	1.701		
US2	2.00	2.40									19.88				2.617	1.982	1.653		
CT6	2.40	2.70																	9
CT7	2.70	3.00																	14
CT8	3.00	3.30																	22
CT9	3.30	3.60																	12
CT10	3.60	3.90																	8
CT11	3.90	4.20																	10
CT12	4.20	4.50																	12
CT13	4.50	4.80																	50

REMARK : US : Undisturbed Sample (Open tube 3 inch.) DS : Disturbed Sample SPT : Split Spoon Sampler CT : Cone Penetration Test

Table C.3 Physical and engineering properties of soils of boring log no. BH3

SUMMARY OF TEST RESULTS

PROJECT : Thesis **BORING NO :** BH3

LOCATION : Doi Suthep **DEPTH :** 4.20 m. **DATE START :** 6/02/2003

OBSERVED W.L. : **DATE FINISH :** 6/02/2003

TYPE OF SAMPLE	SAMPLE DEPTH		SOIL GROUP (USCS)	GRADATION (%) PASSING							W_n	ATTERBERG LIMITS (%)			Gs	UNIT WEIGHT		FIELD TESTING	
	FROM (m)	TO (m)		NO. 3/8"	NO. 4	NO. 10	NO. 20	NO. 40	NO. 100	NO. 200	(%)	L.L.	P.L.	P.I.		WET DENSITY (t/m^3)	DRY DENSITY (t/m^3)	SPT (blows/ft)	CT (blows/ft)
SPT 1	1.00	1.45									27.13							2	
SPT 2	1.60	2.05	CL	100.00	99.53	97.54	85.47	74.46	64.73	60.59	24.14							5	
DS 1	2.05	2.20	CL	97.50	96.04	93.24	81.71	71.20	61.92	57.89	24.89								
SPT 3	2.20	2.65									22.74	41.79	26.30	15.49				8	
US1	2.80	3.20																	
SPT4	3.20	3.65	SC	99.74	96.66	81.60	64.07	54.54	46.31	42.27	17.87							6	
CT1	3.75	4.20																	50

REMARK : US : Undisturbed Sample (Open tube 3 inch.) DS : Disturbed Sample SPT : Split Spoon Sampler CT : Cone Penetration Test

Table C.4 Physical and engineering properties of soils of boring log no. BH4

SUMMARY OF TEST RESULTS

PROJECT : Thesis — **BORING NO :** BH4

LOCATION : Doi Suthep — **DEPTH :** 6.05 m. — **DATE START :** 12/03/2003

OBSERVED W.L. : — **DATE FINISH :** 12/03/2003

TYPE OF SAMPLE	SAMPLE DEPTH FROM (m)	SAMPLE DEPTH TO (m)	SOIL GROUP (USCS)	GRADATION (%) PASSING NO. 3/8"	NO. 4	NO. 10	NO. 20	NO. 40	NO. 100	NO. 200	W_n (%)	ATTERBERG LIMITS (%) L.L.	P.L.	P.I.	Gs	UNIT WEIGHT WET DENSITY (t/m^3)	DRY DENSITY (t/m^3)	FIELD TESTING SPT (blows/ft)	CT (blows/ft)
SPT 1	0.50	0.95																4	
US1	1.50	2.10									22.80					1.903	1.550		
US2	2.10	2.70	CL	95.76	94.22	90.55	81.61	73.61	66.24	62.03	21.92	30.76	20.48	10.28		1.924	1.578		
SPT2	2.70	3.15									20.94							5	
DS1	3.15	3.30									28.34								
US3	3.30	3.90	CL	99.61	99.05	97.16	88.05	79.15	70.94	67.45	24.87	37.57	25.50	12.07		1.943	1.556		
US4	3.90	4.50	CL	100.00	99.45	98.27	90.08	82.07	74.24		22.83	45.36	26.86	18.50		1.975	1.608		
SPT3	4.50	4.95									22.49							6	
US5	5.10	5.60																	
SPT4	5.60	6.05									21.19							9	

REMARK : US : Undisturbed Sample (Open tube 3 inch.) DS : Disturbed Sample SPT : Split Spoon Sampler CT : Cone Penetration Test

Table C.5 Physical and engineering properties of soils of boring log no. BH5

SUMMARY OF TEST RESULTS

PROJECT : Thesis **BORING NO :** BH5 (1)

LOCATION : Doi Suthep **DEPTH :** 8.10 m. **DATE START :** 12/03/2003

OBSERVED W.L. : **DATE FINISH :** 12/03/2003

TYPE OF SAMPLE	SAMPLE DEPTH		SOIL GROUP (USCS)	GRADATION (%) PASSING							W_n	ATTERBERG LIMITS (%)			Gs	UNIT WEIGHT		FIELD TESTING	
	FROM (m)	TO (m)		NO. 3/8"	NO. 4	NO. 10	NO. 20	NO. 40	NO. 100	NO. 200	(%)	L.L.	P.L.	P.I.		WET DENSITY (t/m^3)	DRY DENSITY (t/m^3)	SPT (blows/ft)	CT (blows/ft)
CT1	0.00	0.30																	0
CT2	0.30	0.60																	2
CT3	0.60	0.90																	2
CT4	0.90	1.20																	2
CT5	1.20	1.50																	5
CT6	1.50	1.80																	4
CT7	1.80	2.10																	4
CT8	2.10	2.40																	4
CT9	2.40	2.70																	4
CT10	2.70	3.00																	5
CT11	3.00	3.30																	6
CT12	3.30	3.60																	6
CT13	3.60	3.90																	4
CT14	3.90	4.20																	6
CT15	4.20	4.50																	7

REMARK : US : Undisturbed Sample (Open tube 3 inch.) DS : Disturbed Sample SPT : Split Spoon Sampler CT : Cone Penetration Test

Table C.5 (2) Physical and Engineering properties of soils of boring log no. BH5

SUMMARY OF TEST RESULTS

PROJECT : Thesis **BORING NO :** BH5 (2)

LOCATION : Doi Suthep **DEPTH :** 8.10 m. **DATE START :** 12/03/2003

OBSERVED W.L. : **DATE FINISH :** 12/03/2003

TYPE OF SAMPLE	SAMPLE DEPTH FROM (m)	TO (m)	SOIL GROUP (USCS)	GRADATION (%) PASSING NO. 3/8"	NO. 4	NO. 10	NO. 20	NO. 40	NO. 100	NO. 200	W_n (%)	ATTERBERG LIMITS (%) L.L.	P.L.	P.I.	Gs	UNIT WEIGHT WET DENSITY (t/m³)	DRY DENSITY (t/m³)	FIELD TESTING SPT (blows/ft)	CT (blows/ft)
CT16	4.50	4.80																	6
CT17	4.80	5.10																	7
CT18	5.10	5.40																	6
CT19	5.40	5.70																	7
CT20	5.70	6.00																	9
CT21	6.00	6.30																	13
CT22	6.30	6.60																	10
CT23	6.60	6.90																	11
CT24	6.90	7.20																	11
CT25	7.20	7.50																	15
CT26	7.50	7.80																	17
CT27	7.80	8.10																	50

REMARK : US : Undisturbed Sample (Open tube 3 inch.) DS : Disturbed Sample SPT : Split Spoon Sampler CT : Cone Penetration Test

Table C.6 Physical and engineering properties of soils of boring log no. BH6

SUMMARY OF TEST RESULTS

PROJECT : Thesis **BORING NO :** BH6

LOCATION : Doi Suthep **DEPTH :** 4.20 m. **DATE START :** 5/02/2003

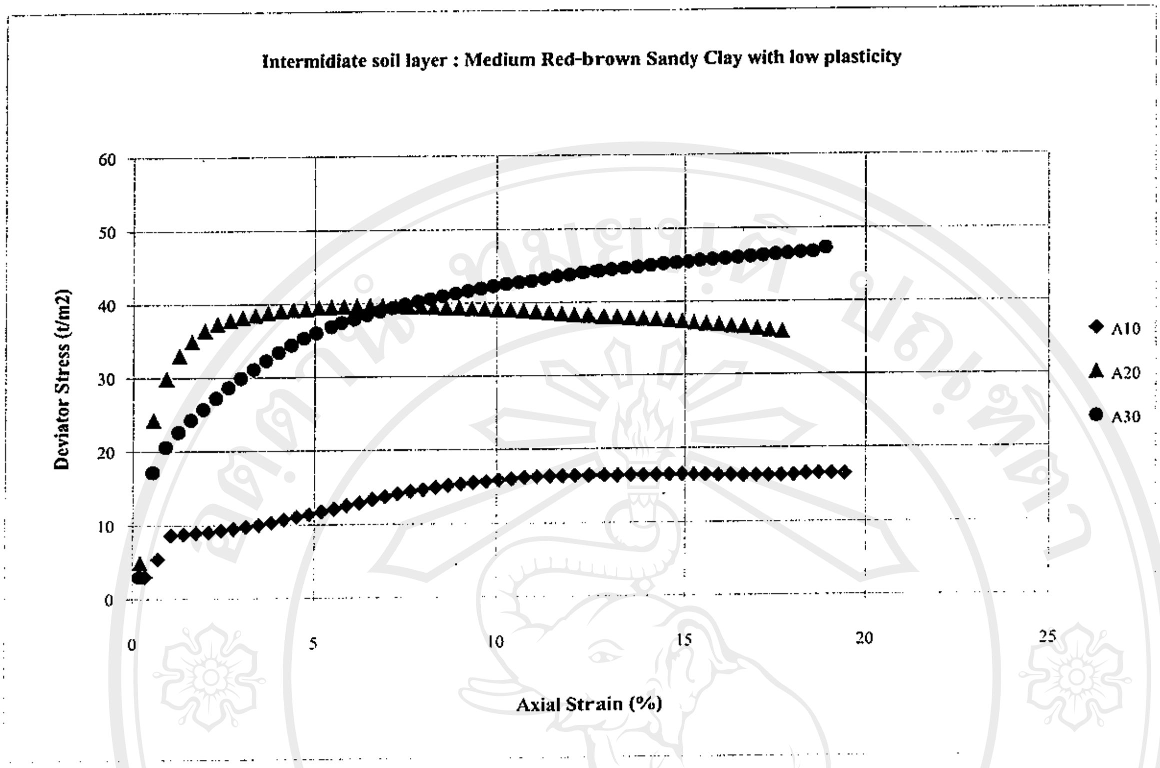
OBSERVED W.L. : **DATE FINISH :** 5/02/2003

TYPE OF SAMPLE	SAMPLE DEPTH		SOIL GROUP	GRADATION (%) PASSING							W_n	ATTERBERG LIMITS (%)			Gs	UNIT WEIGHT		FIELD TESTING	
	FROM (m)	TO (m)	(USCS)	NO. 3/8"	NO. 4	NO. 10	NO. 20	NO. 40	NO. 100	NO. 200	(%)	L.L.	P.L.	P.I.		WET DENSITY (t/m^3)	DRY DENSITY (t/m^3)	SPT (blows/ft)	CT (blows/ft)
SPT 1	1.00	1.45	SC	96.94	93.67	85.09	72.21	62.94	54.11	49.67								7	
DS1	1.45	2.00																	
SPT2	2.00	2.45																40	

REMARK : US : Undisturbed Sample (Open tube 3 inch.) DS : Disturbed Sample SPT : Split Spoon Sampler CT : Cone Penetration Test

Table C.7 The maximum deviator stress and the percentage of strain at the maximum deviator stress

Bore hole	Sample No.	Consolidated pressure (t/m^2)	At the maximum deviator stress				
			ε (%)	$\Delta\sigma$ (t/m^2)	Δu (t/m^2)	σ_1' (t/m^2)	σ_3' (t/m^2)
BH 2	A10	7.028	18.73	16.586	0.000	24.614	8.029
	A20	14.056	6.51	39.652	0.712	54.709	15.057
	A30	21.084	18.92	47.213	0.711	70.008	22.795
BH 4	B05	3.514	10.15	15.699	0.000	20.924	5.225
	B10	7.028	17.20	20.085	0.000	28.824	8.739
	B20	14.056	19.97	27.660	0.000	44.138	16.478
BH 4	C05	3.514	9.85	12.696	0.000	18.632	5.936
	C10	7.028	7.68	20.868	-1.421	31.028	10.160
	C20	14.056	12.06	26.272	0.000	43.460	17.188
	C30	21.084	19.52	39.953	0.000	64.170	24.216



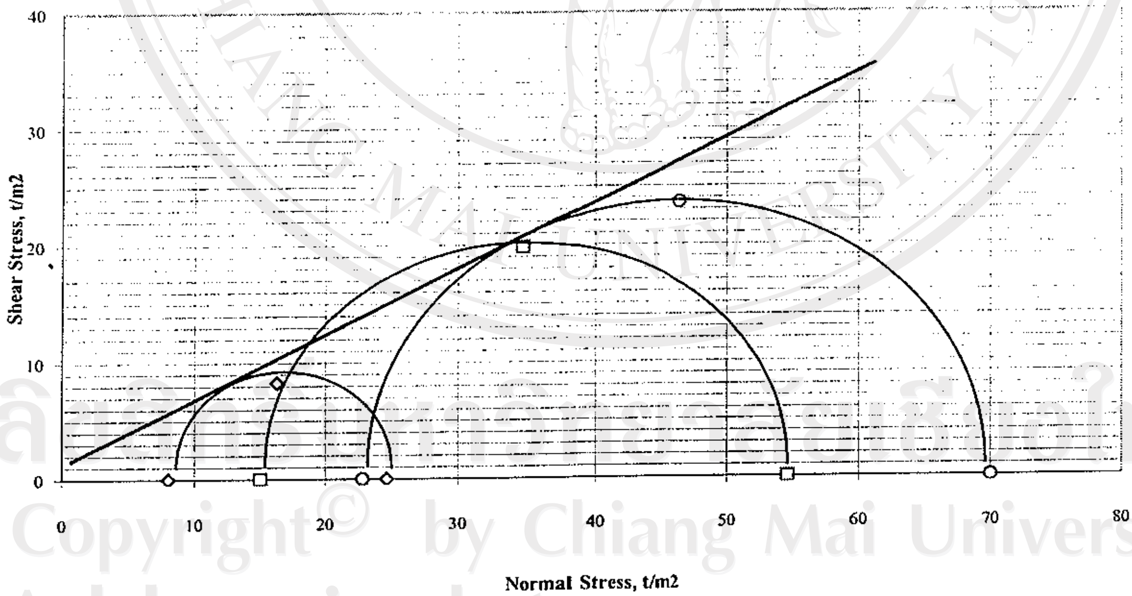
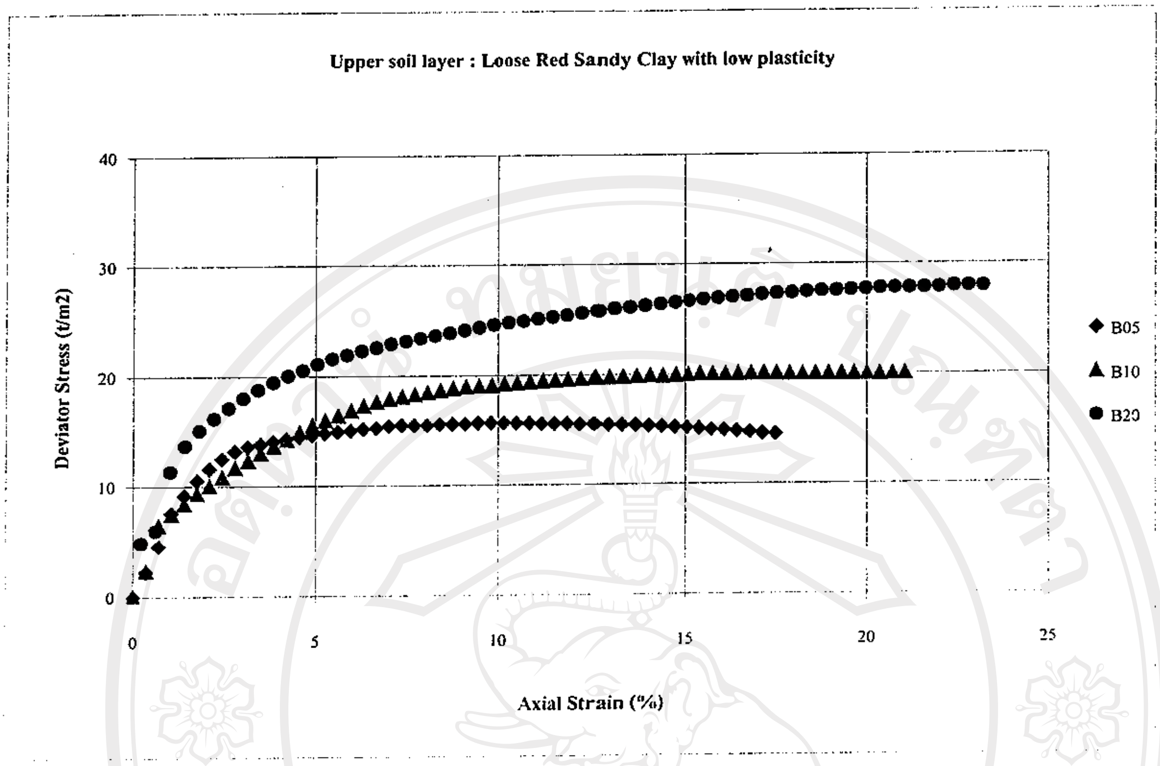


Fig. C.7 Deviator stress vs. strain relationship, and effective principle stress Mohr's circle of sample A



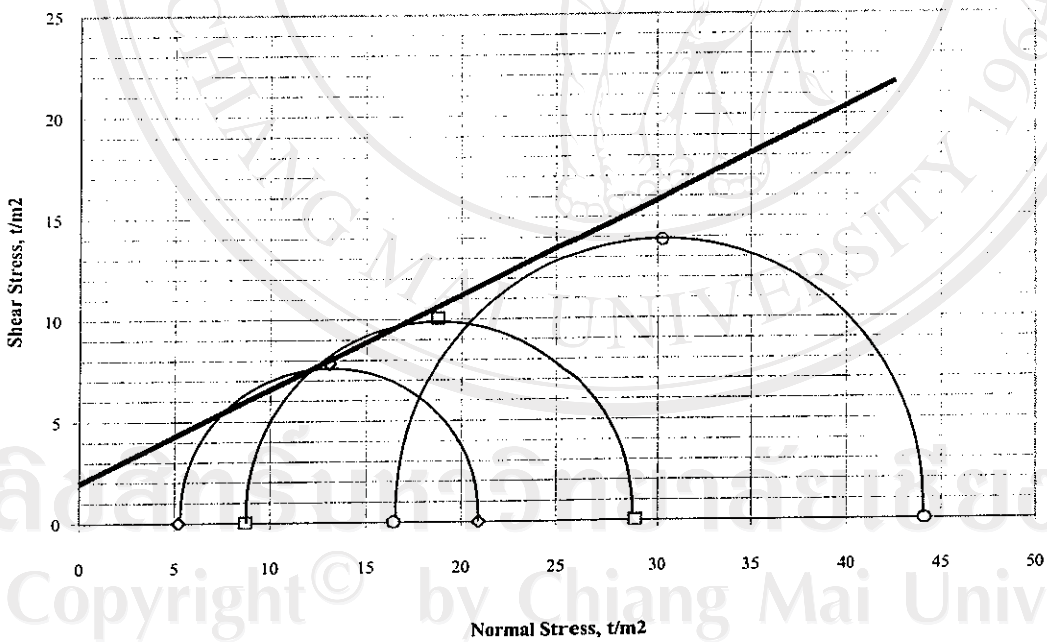
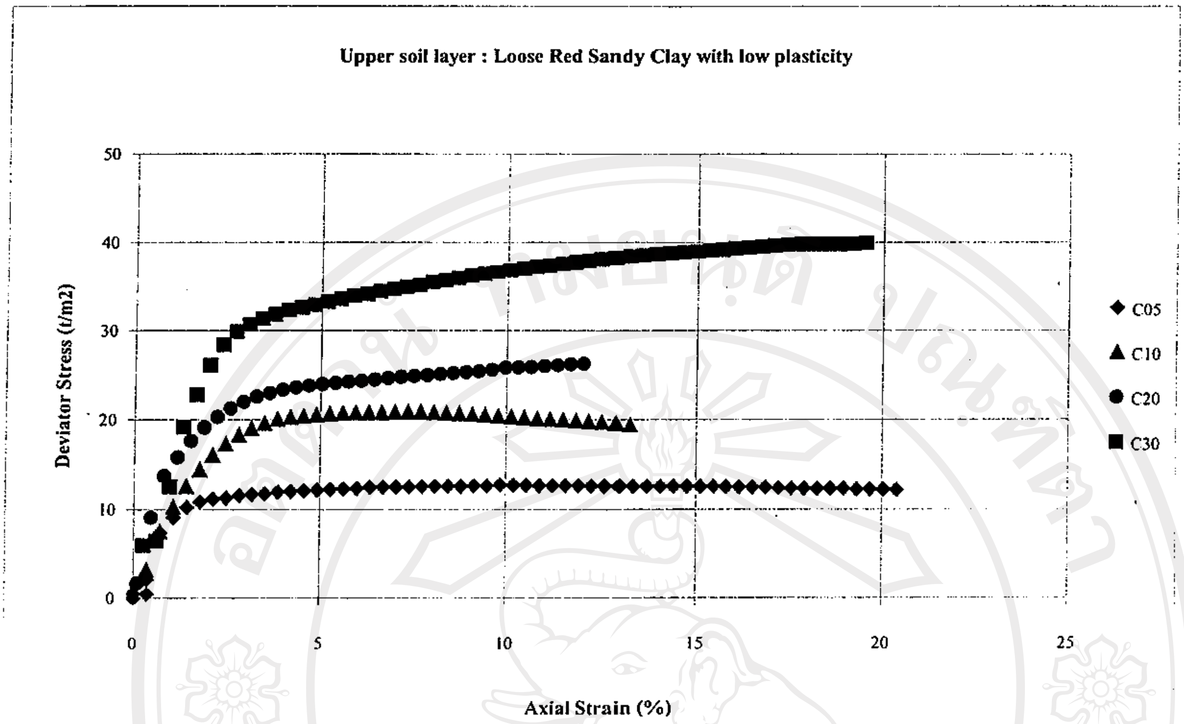


Fig. C.8 Deviator stress vs. strain relationship, and effective principle stress Mohr's circle of sample B



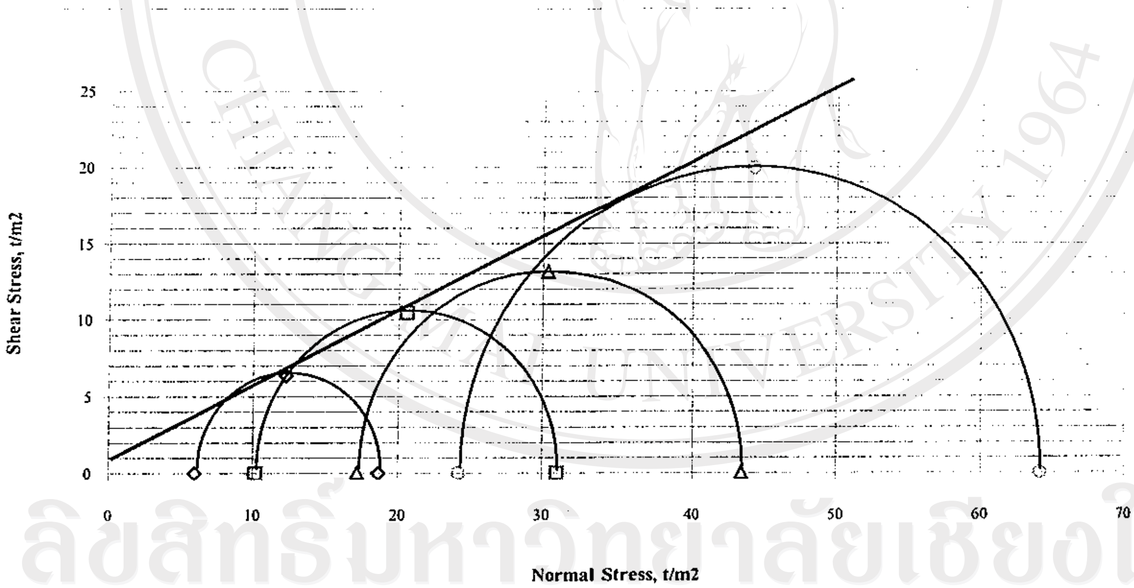


Fig. C.9 Deviator stress vs. strain relationship, and effective principle stress Mohr's circle of sample C

Laboratory procedures in soil mechanics

1. Tests for physical properties of soil

   The procedures in all tests are reasonably standard, ASTM standard, as following;

   a. Natural water content

   b. Atterberg's limit ASTM D423-66, D424-59, D427-61

   c. Grain size analysis ASTM D421, D422-63

   d. Specific gravity ASTM D854-58

2. Triaxial test – Consolidated undrained with pore pressure measurements

   2.1 Sample preparation and device setting

2.1.1 Carefully cut soil samples from a sample extruder in 10 cm. length for each test samples. Then trim the soil samples by using a miter box to be a cylinder shape which L/d ratio equals 2. Use vernier to measure the measure the height and three diameters at the top, at mid-height, and at the base of the specimen. Campute the average diameter of the specimen and weigh it. Take the remained soil to find water content of specimen.

2.1.2 Verify a proving ring by weight checking with a calibration chart of product company and calibrate a transducer by a standard pressure test machine. Then, check a condition of a cell base and all connectors. Water used in the test should be boiled-deaired water.

2.1.3 Place the porous stones with wet filter paper at the base and top of the specimen, and place a top cap on a porous stone. To help saving a time of saturation, cut 4-8 strips of filter paper that are about 5 mm. wide and long enough to fit under the porous stones. 2layers of condoms (acted as cell membrane) will be placed cover the specimen and tight it with 2 O-rings at the top and the base. Coat the outer rim of platen, cell cover and piston with a grease to protect a water leakage.

2.2 Sample saturation

Using a lead chamber fluid alternately apply the cell pressure and back pressure continuous with rate 5 psi/min until the desired pressure (25 psi) to make a saturated sample. To hold the sample standing, and not to expand inside the cell or self-destruct, cell pressure should be larger than back pressure about 1-2 psi. Then, set a dial gauge to measure a sample deformation and attach a transducer to the cell so that the pore pressure can be measured.

2.3 Sample saturation checking

Observing a response of water pressure in soil sample by close off a back pressure line and apply the increment of cell pressure ($\Delta\sigma_3$ about 5-15 psi). Then, read water pressure from a transducer. If water pressure increases more than 95 percents, assume the sample is saturated and continue. If it is less, the sample is still not saturated. The sample should be leaved in saturated condition for 12-24 hours more and checked saturation again.

2.4 Sample consolidation

After saturation is complete, close the back pressure line and apply cell pressure until the desired consolidated pressure according to table 4.2. Open a drainage valve (valve A) to release the water until it stops. Consolidation stage usually spends time at least 24 hours. If water pressure is larger than saturated stage's, the consolidation is not finished. So the sample should continue a consolidation.

2.5 Axial stress increment

Make a final check of deformation gauge, load gauge, and cell pressure gauge and that the load piston is still in contact with the sample. Re-zero all gauges and set the compression machine to the strain rate 0.12 mm/min. Start the test and make the load and deformation dial reading (every 25 divisions of dial gauge) until 15-20 percents strain of deformation occurs.

Fig. C.10 Slope failure on the right way of public highway no. 1004 at Km. 13+855.00

Fig. C.11 The sliding mass is still on the failure slope

Fig C.12 Disturbed soil sampling by hand auger

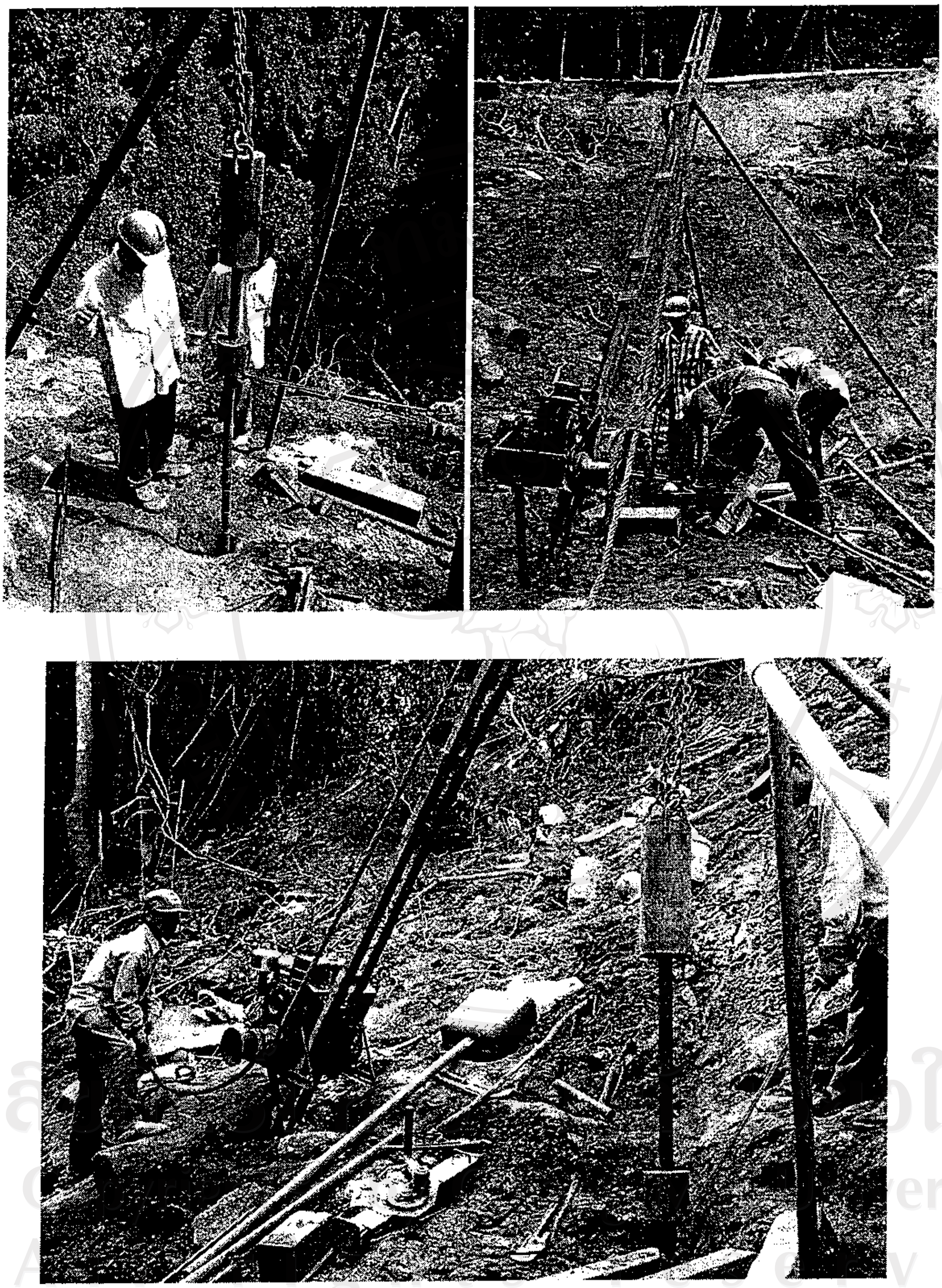


Fig. C.13 SPT and CPT in the field along the centerline of the slope

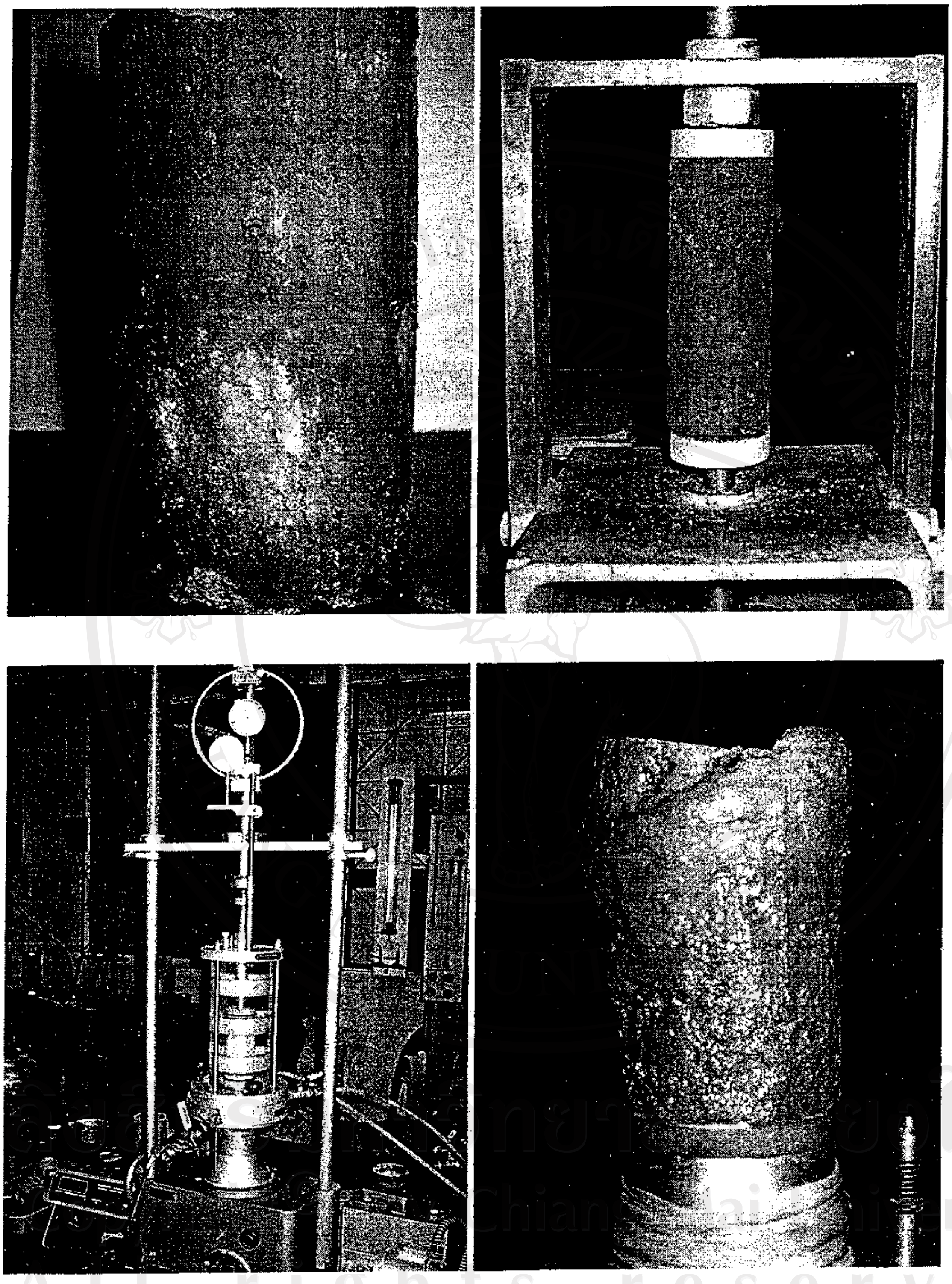


Fig. C.14 Undisturbed samples for triaxial test to obtain the shear strength parameter of soil

Table C.8 Values or value ranges for Poisson's ratio, μ

Type of soil	μ
Clay, saturated	0.4-0.5
Clay, unsaturated	0.1-0.3
Sandy clay	0.2-0.3
Silt	0.3-0.35
Sand, gravelly sand	0.1-1.00
Commonly used	0.3-3.4
Rock (depend on type of rock)	0.1-0.4
Loess	0.1-0.3
Ice	0.36
Concrete	0.15
Steel	0.33

Source: Bowles, 1997

Table C.9 Value ranges for Modulus of elasticity, E for selected soils

Type of soil	E, MPa
Clay	
Very soft	2-15
Soft	5-25
Medium	15-50
Hard	50-100
Sandy	25-250
Glacial till	
Loose	10-150
Dense	150-720
Very dense	500-1440
Loess	15-60
Sand	
Silty	5-20
Loose	10-25
Dense	50-81
Sand and gravel	
Loose	50-150
Dense	100-200
Shale	150-5000
Silt	2-20

Source: Bowles, 1997

Appendix D

Results of the analysis by various slope stability analysis methods

Table D.1 Fellenius method – Model 1 ($\beta = 15.0^{o}$) - The results of the normal forces and the percentage of difference

(a) Case a : Slope without the anchoring force

Load (N/m)	Normal force (N/m)				Percentage of difference (%)				
	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	244.977	254.258	232.982	86.273	-9.75	4.29	15.88	-24.38	13.57
23.334	244.977	254.258	232.982	103.980	-9.71	3.94	15.39	-18.06	11.78
46.667	244.977	254.258	232.982	121.686	-10.09	3.64	14.93	-13.99	10.66
93.333	244.977	254.258	232.982	157.098	-10.81	3.08	14.77	-9.81	9.62
186.666	244.977	254.258	232.982	227.924	-13.51	2.96	12.45	-4.00	8.23
280.000	244.977	254.258	232.982	298.748	-14.27	2.31	12.24	1.42	7.56
373.333	244.977	254.258	232.982	369.573	-16.06	2.56	8.24	5.55	8.10
							Average		9.93

(b) Case b : Slope attached the anchoring force

Load (N/m)	Normal force (N/m)				Percentage of difference (%)				
	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	244.977	254.258	529.121	86.273	-16.35	-11.72	52.42	-60.93	35.35
46.667	244.977	254.258	529.121	121.686	-16.66	-12.01	50.99	-51.62	32.82
93.333	244.977	254.258	529.121	157.098	-16.86	-12.48	49.25	-44.16	30.69
186.666	244.977	254.258	529.121	227.924	-17.50	-13.34	45.42	-33.57	27.46
280.000	244.977	254.258	529.121	298.748	-17.70	-14.25	43.88	-26.31	25.54
373.333	244.977	254.258	529.121	369.573	-18.97	-14.96	41.80	-20.63	24.09
466.666	244.977	254.258	529.121	440.399	-20.33	-16.18	37.76	-14.97	22.31
588.000	244.977	254.258	529.121	532.472	-22.01	-17.99	34.60	-10.84	21.36
							Average		27.45

Table D.2 Fellenius method – Model 2 ($\beta = 17.5^{o}$) - The results of the normal forces and the percentage of difference

(a) Case a : Slope without the anchoring force

Load (N/m)	Normal force (N/m)				Percentage of difference (%)				
	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	260.776	248.247	232.875	87.428	-9.09	6.61	12.63	-31.39	14.93
23.334	260.776	248.247	232.875	104.940	-9.20	6.22	11.86	-25.87	13.29
46.667	260.776	248.247	232.875	122.452	-9.42	5.85	10.74	-21.74	11.94
93.333	260.776	248.247	232.875	157.474	-9.93	5.27	8.60	-16.60	10.10
140.000	260.776	248.247	232.875	192.498	-10.43	4.43	6.73	-12.14	8.43
186.666	260.776	248.247	232.875	227.521	-10.95	3.99	4.92	-8.57	7.11
280.000	260.776	248.247	232.875	297.568	-11.83	2.84	3.46	-4.74	5.72
							Average		10.22

(b) Case b : Slope attached the anchoring force

Load (N/m)	Normal force (N/m)				Percentage of difference (%)				
	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	260.776	248.247	471.045	87.428	-11.07	-5.68	38.52	-54.78	27.51
46.667	260.776	248.247	471.045	122.452	-11.20	-6.20	36.69	-45.42	24.88
93.333	260.776	248.247	471.045	157.474	-11.53	-7.14	33.66	-38.10	22.61
186.666	260.776	248.247	471.045	227.521	-12.14	-8.04	32.99	-27.39	20.14
280.000	260.776	248.247	471.045	297.568	-12.77	-8.96	28.58	-19.57	17.47
373.333	260.776	248.247	471.045	367.614	-13.27	-9.95	26.79	-13.94	15.98
466.666	260.776	248.247	471.045	437.661	-14.04	-11.57	24.16	-9.73	14.87
							Average		20.49

Table D.3 Fellenius method – Model 3 ($\beta = 20.0^{o}$) - The results of the normal forces and the percentage of difference

(a) Case a : Slope without the anchoring force

Load	Normal force (N/m)				Percentage of difference (%)				
(N/m)	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	303.514	248.610	234.069	88.756	-5.95	10.82	18.27	-17.56	13.15
23.334	303.514	248.610	234.069	106.040	-6.13	10.47	17.76	-13.72	12.02
46.667	303.514	248.610	234.069	123.322	-6.58	10.66	16.78	-11.28	11.33
70.000	303.514	248.610	234.069	140.604	-6.73	9.96	16.51	-8.39	10.40
93.333	303.514	248.610	234.069	157.886	-6.90	9.70	16.62	-6.10	9.83
140.000	303.514	248.610	234.069	192.452	-7.63	8.56	16.70	-4.14	9.26
186.666	303.514	248.610	234.069	227.016	-8.18	8.74	16.90	-0.64	8.62
							Average		10.66

(b) Case b : Slope attached the anchoring force

Load	Normal force (N/m)				Percentage of difference (%)				
(N/m)	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	303.514	248.610	433.031	88.756	-6.47	-2.89	46.72	-48.25	26.08
46.667	303.514	248.610	433.031	123.322	-6.58	-3.60	45.71	-39.05	23.74
93.333	303.514	248.610	433.031	157.886	-6.88	-3.94	44.32	-31.99	21.78
140.000	303.514	248.610	433.031	192.452	-7.07	-4.49	44.23	-26.41	20.55
186.666	303.514	248.610	433.031	227.016	-7.36	-5.23	43.07	-21.04	19.18
280.000	303.514	248.610	433.031	296.147	-7.99	-6.00	39.67	-14.83	17.12
373.333	303.514	248.610	433.031	365.278	-8.59	-7.20	41.58	-10.79	17.04
							Average		20.78

Table D.4 Simplified Janbu method – Model 1 ($\beta = 15.0^{o}$) - The results of the normal forces and the percentage of difference

(a) Case a : Slope without the anchoring force

Load (N/m)	Normal force (N/m)				Percentage of difference (%)				
	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	247.046	253.142	233.647	103.334	-8.98	3.83	16.21	-9.43	9.61
23.334	247.106	253.051	231.895	124.888	-8.93	3.45	14.85	-1.59	7.20
46.667	247.166	252.964	230.165	146.381	-9.29	3.11	13.54	3.47	7.35
93.333	247.297	252.792	226.819	189.204	-9.96	2.48	11.73	8.62	8.20
186.666	247.995	252.006	223.824	274.302	-12.44	2.05	8.03	15.53	9.51
280.000	248.939	250.880	223.316	359.145	-12.89	0.95	7.59	21.92	10.84
373.333	249.913	249.760	222.954	443.837	-14.37	0.75	3.58	26.76	11.37
							Average		9.15

(b) Case b : Slope attached the anchoring force

Load (N/m)	Normal force (N/m)				Percentage of difference (%)				
	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	247.241	252.850	515.588	129.691	-15.58	-12.20	48.52	-41.27	29.39
46.667	247.066	252.731	512.752	169.885	-15.95	-12.54	46.32	-32.46	26.82
93.333	246.951	252.664	511.124	207.974	-16.19	-13.03	44.17	-26.08	24.87
186.666	246.855	252.572	509.322	282.037	-16.87	-13.91	39.98	-17.80	22.14
280.000	247.209	252.321	503.807	365.438	-16.95	-14.91	36.99	-9.86	19.68
373.333	247.643	252.042	496.577	452.22	-18.09	-15.71	33.08	-2.88	17.44
466.666	247.956	251.798	489.258	537.915	-19.36	-16.99	27.38	3.85	16.90
588.000	248.462	251.298	481.430	649.415	-20.90	-18.95	22.47	8.75	17.77
							Average		21.88

Table D.5 Simplified Janbu method – Model 2 ($\beta = 17.5^{\circ}$) - The results of the normal forces and the percentage of difference

(a) Case a : Slope without the anchoring force

Load	Normal force (N/m)				Percentage of difference (%)				
(N/m)	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	261.619	246.710	231.965	106.057	-8.80	5.95	12.19	-16.77	10.93
23.334	261.655	246.569	230.146	127.665	-8.89	5.50	10.55	-9.82	8.69
46.667	261.691	246.431	228.345	149.224	-9.11	5.08	8.59	-4.63	6.85
93.333	261.770	246.152	224.922	192.150	-9.59	4.39	4.89	1.77	5.16
140.000	261.991	245.281	224.504	234.846	-10.01	3.18	2.89	7.19	5.82
186.666	262.200	244.370	224.178	277.471	-10.47	2.37	1.00	11.50	6.33
280.000	262.624	242.560	223.665	362.494	-11.20	0.49	-0.64	16.04	7.09
							Average		7.27

(b) Case b : Slope attached the anchoring force

Load	Normal force (N/m)				Percentage of difference (%)				
(N/m)	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	261.504	246.603	456.782	127.150	-10.82	-6.30	34.33	-34.23	21.42
46.667	261.483	246.446	454.898	165.857	-10.96	-6.88	32.00	-26.07	18.98
93.333	261.469	246.351	453.843	202.957	-11.29	-7.85	28.78	-20.22	17.03
186.666	261.552	246.063	449.929	281.795	-11.88	-8.85	27.03	-10.07	14.46
280.000	261.742	245.596	442.185	368.966	-12.45	-9.93	20.71	-0.27	10.84
373.333	261.893	245.181	434.487	455.359	-12.90	-11.06	16.95	6.61	11.88
466.666	262.089	244.593	428.029	541.139	-13.61	-12.87	12.82	11.62	12.73
							Average		15.33

Table D.6 Simplified Janbu method – Model 3 ($\beta = 20.0^{\circ}$) - The results of the normal forces and the percentage of difference

(a) Case a : Slope without the anchoring force

Load (N/m)	Normal force (N/m)				Percentage of difference (%)				
	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	303.169	246.670	231.553	109.362	-6.06	9.96	17.00	1.57	8.65
23.334	303.151	246.452	229.579	131.042	-6.24	9.51	15.50	6.62	9.47
46.667	303.118	246.040	228.402	152.631	-6.71	9.51	13.96	9.81	10.00
70.000	303.067	245.373	228.160	174.164	-6.87	8.53	13.57	13.48	10.61
93.333	303.021	244.655	227.958	195.684	-7.05	7.96	13.57	16.38	11.24
140.000	302.930	243.225	227.593	238.606	-7.80	6.21	13.47	18.85	11.58
186.666	302.840	241.801	227.274	281.402	-8.39	5.77	13.50	23.16	12.71
							Average		10.61

(b) Case b : Slope attached the anchoring force

Load (N/m)	Normal force (N/m)				Percentage of difference (%)				
	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	303.262	246.805	418.193	125.753	-6.55	-3.59	41.69	-26.68	19.63
46.667	303.256	246.594	416.871	163.354	-6.66	-4.39	40.27	-19.26	17.65
93.333	303.246	246.435	415.815	200.455	-6.97	-4.78	38.58	-13.65	16.00
140.000	303.214	246.144	412.650	241.967	-7.17	-5.43	37.44	-7.48	14.38
186.666	303.171	245.774	408.370	285.832	-7.46	-6.31	34.92	-0.59	12.32
280.000	303.103	245.119	399.707	372.916	-8.11	-7.32	28.92	7.25	12.90
373.333	302.979	243.609	394.793	458.789	-8.75	-9.07	29.08	12.04	14.74
							Average		15.37

Table D.7 Spencer method – Model 1 ($\beta = 15.0^{\circ}$) - The results of the normal forces and the percentage of difference

(a) Case a : Slope without the anchoring force

Load	Normal force (N/m)				Percentage of difference (%)				
(N/m)	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	250.504	256.291	233.499	98.305	-7.71	5.12	16.14	-13.84	10.70
23.334	251.383	257.051	232.812	117.708	-7.35	5.08	15.31	-7.25	8.75
46.667	252.147	257.771	232.391	136.930	-7.46	5.07	14.64	-3.21	7.60
93.333	253.524	259.115	232.104	175.078	-7.70	5.05	14.34	0.51	6.90
186.666	257.083	262.947	232.407	251.936	-9.23	6.48	12.17	6.11	8.50
280.000	261.179	268.019	232.591	329.649	-8.60	7.84	12.05	11.91	10.10
373.333	265.350	273.191	232.672	407.639	-9.08	10.20	8.10	16.42	10.95
								Average	9.07

(b) Case b : Slope attached the anchoring force

Load	Normal force (N/m)				Percentage of difference (%)				
(N/m)	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	243.922	248.656	503.910	147.380	-16.71	-13.66	45.16	-33.25	27.20
46.667	244.653	249.368	503.636	183.121	-16.77	-13.70	43.72	-27.20	25.35
93.333	245.152	249.987	504.037	217.984	-16.80	-13.95	42.17	-22.52	23.86
186.666	246.077	251.332	506.184	286.346	-17.13	-14.33	39.12	-16.54	21.78
280.000	248.254	253.889	508.009	359.800	-16.60	-14.38	38.14	-11.25	20.09
373.333	250.764	256.443	509.455	435.427	-17.06	-14.23	36.53	-6.48	18.58
466.666	252.938	258.680	511.083	510.740	-17.74	-14.72	33.06	-1.39	16.73
588.000	255.892	261.767	513.935	608.548	-18.53	-15.57	30.74	1.90	16.69
								Average	21.29

Table D.8 Spencer method – Model 2 ($\beta = 17.5^{\circ}$) - The results of the normal forces and the percentage of difference

(a) Case a : Slope without the anchoring force

Load	Normal force (N/m)				Percentage of difference (%)				
(N/m)	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	265.295	249.925	232.703	99.917	-7.52	7.33	12.55	-21.59	12.25
23.334	266.116	250.616	232.231	119.083	-7.34	7.23	11.55	-15.88	10.50
46.667	266.858	251.270	232.005	138.112	-7.31	7.14	10.33	-11.74	9.13
93.333	268.226	252.502	232.041	175.920	-7.36	7.08	8.21	-6.83	7.37
140.000	270.235	254.759	232.289	214.363	-7.18	7.17	6.46	-2.16	5.74
186.666	272.137	257.217	232.462	252.857	-7.08	7.75	4.74	1.61	5.29
280.000	275.933	262.284	232.661	330.040	-6.70	8.66	3.36	5.65	6.09
							Average		8.05

(b) Case b : Slope attached the anchoring force

Load	Normal force (N/m)				Percentage of difference (%)				
(N/m)	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	258.542	242.662	444.296	145.102	-11.83	-7.80	30.66	-24.95	18.81
46.667	259.215	243.279	445.228	179.296	-11.73	-8.08	29.19	-20.08	17.27
93.333	259.712	243.820	446.339	213.157	-11.89	-8.80	26.65	-16.21	15.88
186.666	261.332	245.751	448.998	283.027	-11.95	-8.96	26.77	-9.67	14.34
280.000	263.703	248.241	450.806	357.896	-11.79	-8.96	23.06	-3.26	11.77
373.333	265.816	250.399	452.800	432.538	-11.59	-9.17	21.88	1.26	10.97
466.666	268.048	252.568	455.389	507.118	-11.65	-10.03	20.03	4.60	11.58
							Average		14.37

Table D.9 Spencer method – Model 3 ($\beta = 20.0^{\circ}$) - The results of the normal forces and the percentage of difference

(a) Case a : Slope without the anchoring force

Load (N/m)	Normal force (N/m)				Percentage of difference (%)				
	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	307.482	249.841	233.382	101.637	-4.72	11.37	17.93	-5.60	9.90
23.334	308.276	250.420	233.081	120.547	-4.66	11.27	17.27	-1.92	8.78
46.667	309.168	251.139	233.102	139.455	-4.84	11.78	16.30	0.33	8.31
70.000	310.212	252.112	233.262	158.501	-4.68	11.51	16.11	3.27	8.89
93.333	311.172	253.208	233.396	177.546	-4.55	11.73	16.28	5.59	9.54
140.000	313.034	255.508	233.588	215.666	-4.73	11.58	16.46	7.42	10.05
186.666	314.844	257.906	233.720	253.826	-4.76	12.81	16.72	11.10	11.35
								Average	9.55

(b) Case b : Slope attached the anchoring force

Load (N/m)	Normal force (N/m)				Percentage of difference (%)				
	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	300.296	243.461	406.091	142.780	-7.47	-4.90	37.59	-16.76	16.68
46.667	300.932	243.930	407.588	176.033	-7.38	-5.42	37.15	-13.00	15.74
93.333	301.544	244.483	409.189	209.351	-7.49	-5.54	36.37	-9.82	14.80
140.000	302.647	245.499	410.403	244.934	-7.34	-5.68	36.69	-6.34	14.01
186.666	303.900	246.597	411.347	281.962	-7.24	-6.00	35.91	-1.93	12.77
280.000	306.131	248.578	413.244	355.921	-7.19	-6.01	33.28	2.36	12.21
373.333	308.684	250.721	416.965	429.502	-7.04	-6.41	36.33	4.89	13.67
								Average	14.27

Table D.10 Slice Spring method – Model 1 ($\beta = 15.0^{o}$) - The results of the normal forces and the percentage of difference

(a) Case a : Slope without the anchoring force

Load (N/m)	Normal force (N/m)				Percentage of difference (%)				
	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	266.514	236.851	222.545	110.689	-1.81	-2.85	10.69	-2.99	4.59
23.334	267.024	237.357	224.400	128.323	-1.59	-2.97	11.14	1.12	4.20
46.667	267.454	237.792	226.430	145.860	-1.84	-3.07	11.70	3.10	4.93
93.333	268.342	238.403	230.874	180.809	-2.30	-3.35	13.73	3.80	5.80
186.666	269.163	241.872	244.733	248.217	-4.97	-2.06	18.12	4.54	7.42
280.000	271.160	246.191	256.604	317.690	-5.11	-0.94	23.62	7.85	9.38
373.333	273.333	250.879	267.299	387.986	-6.35	1.20	24.19	10.81	10.64
								Average	6.71

(b) Case b : Slope attached the anchoring force

Load (N/m)	Normal force (N/m)				Percentage of difference (%)				
	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
46.667	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
93.333	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
186.666	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
280.000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
373.333	266.212	273.645	439.597	471.373	-11.95	-8.48	17.81	1.24	9.87
466.666	267.772	275.224	448.069	541.569	-12.91	-9.27	16.66	4.56	10.85
588.000	269.612	279.139	458.258	633.278	-14.16	-9.97	16.58	6.04	11.69
								Average	10.80

Table D.11 Slice Spring method – Model 2 ($\beta = 17.5^{\circ}$) - The results of the normal forces and the percentage of difference

(a) Case a : Slope without the anchoring force

Load (N/m)	Normal force (N/m)				Percentage of difference (%)				
	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	283.142	231.175	222.605	109.901	-1.30	-0.72	7.66	-13.76	5.86
23.334	281.045	232.601	223.146	129.825	-2.14	-0.48	7.18	-8.30	4.52
46.667	279.857	234.377	227.920	145.016	-2.80	-0.06	8.39	-7.32	4.64
93.333	280.493	235.025	233.170	179.229	-3.12	-0.33	8.74	-5.07	4.32
140.000	281.362	237.038	239.304	213.496	-3.36	-0.28	9.68	-2.56	3.97
186.666	282.150	239.145	245.474	247.756	-3.66	0.18	10.60	-0.44	3.72
280.000	283.647	243.548	257.817	316.311	-4.10	0.90	14.54	1.26	5.20
							Average		4.60

(b) Case b : Slope attached the anchoring force

Load (N/m)	Normal force (N/m)				Percentage of difference (%)				
	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
46.667	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
93.333	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
186.666	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
280.000	276.982	265.156	386.405	390.916	-7.35	-2.75	5.48	5.67	5.31
373.333	278.474	266.601	395.433	460.296	-7.38	-3.29	6.44	7.76	6.22
466.666	279.808	269.298	403.974	529.957	-7.77	-4.07	6.48	9.31	6.91
							Average		6.16

Table D.12 Slice Spring method – Model 3 ($\beta = 20.0^{\circ}$) - The results of the normal forces and the percentage of difference

(a) Case a : Slope without the anchoring force

Load	Normal force (N/m)				Percentage of difference (%)				
(N/m)	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	320.336	234.508	224.533	111.965	-0.74	4.54	13.45	3.99	5.68
23.334	320.744	234.784	226.913	128.972	-0.80	4.33	14.16	4.94	6.06
46.667	321.124	235.375	229.672	145.892	-1.16	4.77	14.59	4.96	6.37
70.000	321.520	236.360	232.751	162.781	-1.20	4.54	15.85	6.06	6.91
93.333	321.855	237.397	235.860	179.654	-1.27	4.76	17.51	6.85	7.60
140.000	322.470	239.512	242.140	213.360	-1.86	4.59	20.73	6.28	8.36
186.666	323.034	241.695	248.446	247.049	-2.28	5.72	24.08	8.13	10.05
							Average		7.29

(b) Case b : Slope attached the anchoring force

Load	Normal force (N/m)				Percentage of difference (%)				
(N/m)	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
46.667	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
93.333	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
140.000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
186.666	315.807	263.718	347.676	315.540	-3.61	0.53	14.87	9.74	7.19
280.000	317.490	264.574	357.649	383.535	-3.75	0.04	15.35	10.30	7.36
373.333	318.625	269.03	365.959	452.457	-4.04	0.42	19.65	10.50	8.65
							Average		7.73

Table D.13 Rigid bodies-spring method – Model 1 ($\beta = 15.0^{o}$) - The results of the normal forces and the percentage of difference

(a) Case a : Slope without the anchoring force

Load	Normal force (N/m)				Percentage of difference (%)				
(N/m)	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	261.984	231.636	222.531	118.219	-3.48	-4.99	10.69	3.61	5.69
23.334	262.439	232.042	223.435	136.737	-3.28	-5.14	10.66	7.75	6.71
46.667	262.861	232.403	224.340	155.294	-3.53	-5.27	10.67	9.77	7.31
93.333	263.705	233.141	226.165	192.379	-3.99	-5.48	11.41	10.44	7.83
186.666	266.238	234.180	234.142	265.289	-6.00	-5.17	13.01	11.73	8.98
280.000	269.194	235.053	244.026	338.198	-5.80	-5.42	17.56	14.81	10.90
373.333	272.214	236.001	253.252	411.652	-6.73	-4.80	17.66	17.57	11.69
							Average		8.44

(b) Case b : Slope attached the anchoring force

Load	Normal force (N/m)				Percentage of difference (%)				
(N/m)	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	260.490	258.430	427.218	198.422	-11.05	-10.27	23.07	-10.14	13.63
46.667	260.263	258.189	428.402	232.651	-11.46	-10.65	22.25	-7.50	12.97
93.333	260.133	258.008	429.389	267.021	-11.72	-11.19	21.12	-5.09	12.28
186.666	260.165	258.023	429.898	337.202	-12.39	-12.05	18.15	-1.72	11.08
280.000	261.919	260.658	422.317	418.689	-12.01	-12.10	14.83	3.27	10.55
373.333	263.640	263.849	419.143	498.108	-12.80	-11.76	12.33	6.98	10.96
466.666	264.842	266.242	422.383	572.273	-13.87	-12.23	9.97	10.49	11.64
588.000	266.563	270.277	427.349	668.202	-15.13	-12.83	8.71	11.89	12.14
							Average		11.91

Table D.14 Rigid bodies-spring method – Model 2 ($\beta = 17.5^{o}$) - The results of the normal forces and the percentage of difference

(a) Case a : Slope without the anchoring force

Load	Normal force (N/m)				Percentage of difference (%)				
(N/m)	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	276.082	227.586	220.406	120.223	-3.76	-2.26	6.60	-5.65	4.57
23.334	276.464	228.070	221.330	138.587	-3.73	-2.41	6.31	-2.11	3.64
46.667	276.811	228.493	222.237	157.024	-3.85	-2.57	5.68	0.35	3.11
93.333	277.541	229.386	224.184	193.804	-4.14	-2.72	4.55	2.64	3.51
140.000	279.000	229.310	230.023	229.433	-4.17	-3.54	5.42	4.72	4.46
186.666	280.285	229.673	235.136	265.489	-4.29	-3.79	5.94	6.68	5.18
280.000	282.925	230.202	245.347	337.786	-4.34	-4.63	9.00	8.13	6.53
								Average	4.43

(b) Case b : Slope attached the anchoring force

Load	Normal force (N/m)				Percentage of difference (%)				
(N/m)	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	273.72	247.095	384.037	185.891	-6.66	-6.12	12.94	-3.85	7.39
46.667	273.615	246.838	385.125	219.868	-6.83	-6.74	11.75	-1.99	6.83
93.333	273.511	246.701	385.95	254.017	-7.21	-7.72	9.51	-0.14	6.15
186.666	274.414	248.713	379.583	331.443	-7.55	-7.87	7.17	5.78	7.09
280.000	276.012	252.342	374.964	411.337	-7.67	-7.45	2.36	11.19	7.17
373.333	277.159	254.581	378.445	485	-7.82	-7.65	1.86	13.55	7.72
466.666	278.548	256.668	383.146	558.194	-8.19	-8.57	0.99	15.14	8.22
								Average	7.22

Table D.15 Rigid bodies-spring method – Model 3 ($\beta = 20.0^{\circ}$) - The results of the normal forces and the percentage of difference

(a) Case a : Slope without the anchoring force

Load (N/m)	Normal force (N/m)				Percentage of difference (%)				
	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	317.743	228.334	220.308	122.837	-1.54	1.78	11.32	14.09	7.18
23.334	318.099	228.899	221.141	141.032	-1.62	1.71	11.26	14.75	7.33
46.667	318.613	228.960	223.274	158.813	-1.94	1.91	11.40	14.25	7.37
70.000	319.325	228.288	226.724	176.419	-1.88	0.97	12.85	14.95	7.66
93.333	319.879	228.425	229.291	194.242	-1.88	0.80	14.24	15.52	8.11
140.000	321.065	228.639	234.441	229.949	-2.28	-0.16	16.89	14.54	8.47
186.666	322.211	228.777	239.590	265.708	-2.53	0.07	19.65	16.30	9.64
							Average		7.97

(b) Case b : Slope attached the anchoring force

Load (N/m)	Normal force (N/m)				Percentage of difference (%)				
	slice 1	slice 2	slice 3	slice 4	slice 1	slice 2	slice 3	slice 4	|Average|
0.000	315.217	242.567	356.292	178.286	-2.87	-5.25	20.72	3.94	8.19
46.667	315.138	242.353	357.242	211.908	-3.01	-6.03	20.21	4.73	8.49
93.333	315.217	242.674	356.192	247.421	-3.29	-6.23	18.71	6.58	8.71
140.000	315.889	244.414	349.842	289.205	-3.29	-6.10	16.52	10.58	9.12
186.666	316.680	246.536	345.876	329.998	-3.34	-6.02	14.28	14.77	9.60
280.000	317.787	249.085	347.926	403.885	-3.66	-5.82	12.22	16.15	9.46
373.333	319.527	249.986	355.309	475.737	-3.77	-6.69	16.17	16.18	10.70
							Average		9.18

Biography

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