APPENDIX A

AHP process for weighting four parameters

Step 1: Pair-wise ranking of parameters (judgment matrix).

	Slope	Geology	Landuse	Stream Proximity
Slope	**1**	2	5/2	7/2
Geology	1/2	**1**	2	4
Landuse	2/5	1/2	**1**	2
Stream Proximity	2/7	1/4	1/2	**1**

Step 2: Synthesis of judgment matrix – matrix A

	Slope	Geology	Landuse	Stream Proximity	**Total**
Slope	**1.00**	2.00	2.50	3.50	**9.00**
Geology	0.50	**1.00**	2.00	4.00	**7.50**
Landuse	0.40	0.50	**1.00**	2.00	**3.90**
Stream Proximity	0.29	0.25	0.50	**1.00**	**2.04**
Total	**2.19**	**3.75**	**6.00**	**10.50**	**22.44**

Step 3: Calculation of priorities using approximation method (normalized matrix, each cell is divided by respective column total to obtain the values in the cells.

	Slope	Geology	Landuse	Stream Prox.	**Total**	**Average W**
Slope	0.46	0.53	0.42	0.33	**1.74**	**0.44**
Geology	0.23	0.27	0.33	0.38	**1.21**	**0.30**
Landuse	0.18	0.13	0.17	0.19	**0.67**	**0.17**
Stream Proximity	0.13	0.07	0.08	0.10	**0.38**	**0.09**
Total	**1.00**	**1.00**	**1.00**	**1.00**	**4.00**	**1.00**

Step 4: Consistency measurement (Consistency matrix) A*W

Each column value in step 2 (Matrix A) is multiplied by its respective row W

	Slope	Geology	Landuse	Stream Prox.	**Total**	**Total/W**
Slope	0.44	0.60	0.42	0.33	1.79	**4.11**
Geology	0.22	0.30	0.34	0.38	1.23	**4.08**
Landuse	0.17	0.15	0.17	0.19	0.68	**4.05**
Stream Proximity	0.12	0.08	0.08	0.09	0.38	**4.02**
			Average Lamda max (λ_{max})			**4.07**

Consistency Index (CI) = (λ_{max} - n)/n-1

Where, n = number of criteria under consideration, here 4 parameters

CI = (4.07 – 4)/ (4-1)

= 0.0233

Consistency Ratio (CR) = CI / CI_r

Where, CI is consistency index and CI_r random value of CI for r criteria, here 4 parameters.

CR = 0.0233/ 0.90

= 0.03

CR is acceptable since it is less than 0.09 for a 4x4 matrix.

Average consistency index for different order matrices and acceptable limit of CR

	Size of matrix (n)									
	1	2	3	4	5	6	7	8	9	10
Random CI Value	0.00	0.00	0.52	0.90	1.11	1.25	1.35	1.40	1.45	1.5
Acceptable			<0.05	<0.09	←			<0.10		→

Source: Saaty (1980)

APPENDIX B

Geotechnical Lab Result

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GEOTECHNICAL ENGINEERING LABORATORY

DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED UNDRAINED CONDITIONS

ASTM D 3080-90

Client:	Mr. Dorji Gyeltshen P.	*Job No:*	344/49
Project:	Landslide Hazard and Risk Assessment of Doi Suthep Area	*Date:*	19 ธ.ค. 49
Location:	Doi Suthep, Chiang Mai	*Sample No.*	1, S2(Shale) 770823
Soil Description:	ดินเหนียวปนซิลท์ สีน้ำตาลเข้ม	*Depth (m.)*	-
Remark:		*Tested By:*	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

WORK INSTRUCTIONS

Test procedure was carried out according to ASTM D3080-90, which can be described briefly as follows :

1) The test condition is the consolidated undrained test, using square box, (CU Test)
2) Samples were prepared from an undisturbed soil collected using a 6" tube
3) Three samples were used with the applied normal stress of 4.0, 10.0, 16.0 t/sq.m. coresponding to the overburden pressure of height 2, 5 and 8 m.
4) Each sample was consolidated in a shear box by load steps, consolidation was monitored till completion before starting a new load step
5) After completion of consolidated under full normal stress, the samples were then allowed to be under water for 12 hours to ensure a saturated condition
6) Under full normal stress, the samples were tested under undrained condition, using the shear rate of 1.2 mm./minute (as recommended by J.E. Bowles, Engineering Properties of Soil and Their Measurement)
7) The maximum shearing stress were obtained from all tests , the Mohr-Coulomb failure line was drawn and the value of Cohesion and Friction angle were determined

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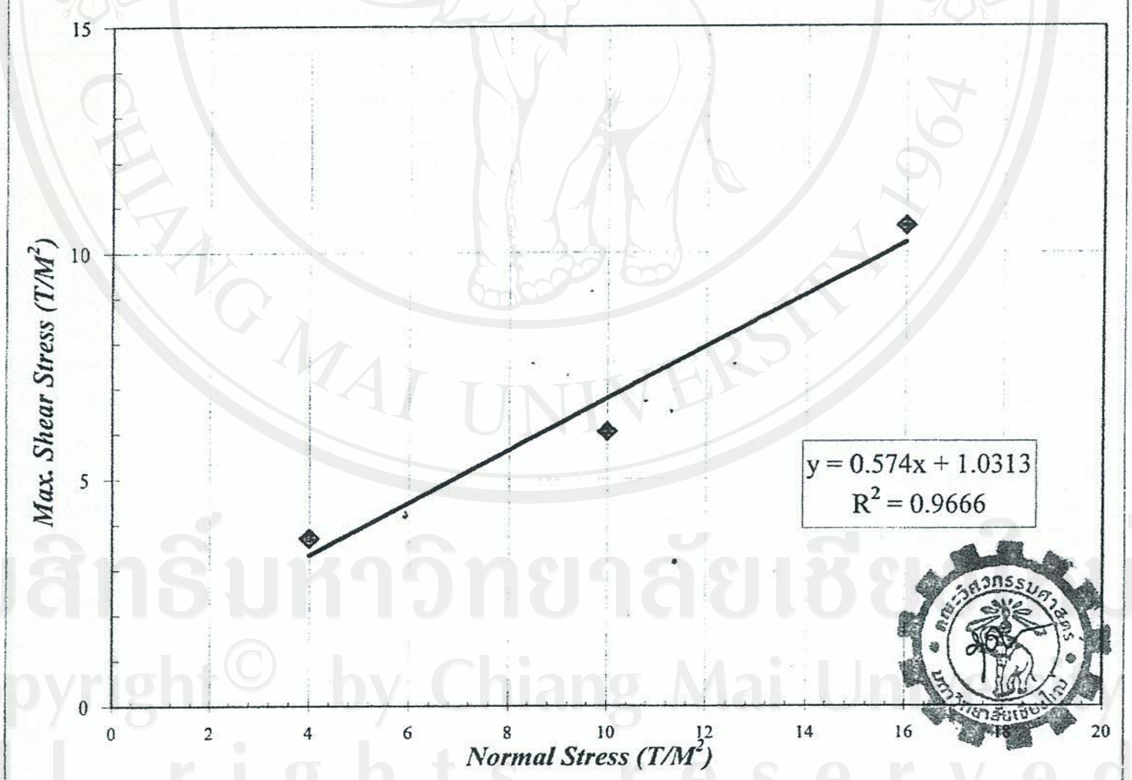
Project:	Landslide Hazard and Risk Assessment of Doi Suthep Area	***Date:***	19 ธ.ค. 49
Location:	Doi Suthep, Chiang Mai	***Sample No.***	1, S2(Shale) 770823
Soil Description:	ดินเหนียวปนซิลท์ สีน้ำตาลเข้ม	***Depth (m.)***	-
		Tested By:	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

	Test1	Test 2	Test3	Test 4	
Normal Stress (T/M2)	4.0	10.0	16.0	-	-
Max. Shear Stress (T/M2)	3.7	6.0	10.6	-	-



Remarks:

***Cohesion, C** (T/M²)* **1.09**

***Friction Angle, ϕ** (degree)* **29**

Direct_shear044_49_sp1.XLS/sample2

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ASTM D 3080-90

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Project:	Landslide Hazard and Risk Assessment of Doi Suthep Area	***Date:***	19 ธ.ค. 49
Location:	Doi Suthep, Chiang Mai	***Sample No.***	1, S2(Shale) 770823
Soil Description:	ดินเหนียวปนซิลท์ สีน้ำตาลเข้ม	***Depth (m.)***	-
Remark:		***Tested By:***	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

Load - Deformation Data

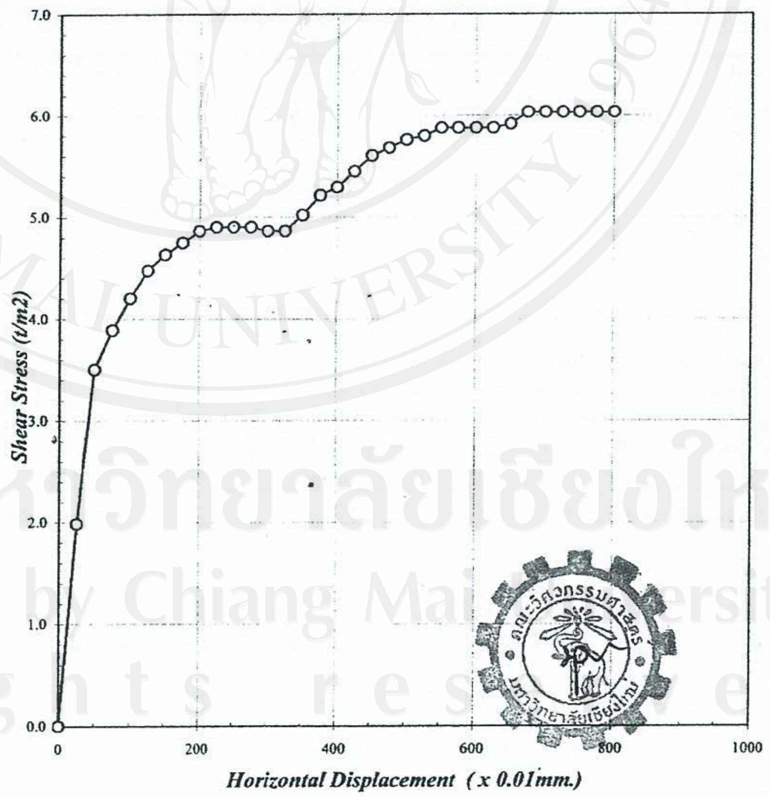
Horiz. Disp. (0.01mm.)	Hori. Load Rd. (Div.)	Verti. Disp. (Div.)	Shear Stress (T/M^2)
0	0	0	0.0
25	51	20	2.0
50	90	40	3.5
75	100	48	3.9
100	108	59	4.2
125	115	67	4.5
150	119	78	4.6
175	122	90	4.7
200	125	104	4.9
225	126	117	4.9
250	126	128	4.9
275	126	140	4.9
300	125	150	4.9
325	125	164	4.9
350	129	178	5.0
375	134	192	5.2
400	136	205	5.3
425	140	217	5.4
450	144	230	5.6
475	146	248	5.7
500	148	255	5.8
525	149	265	5.8
550	151	274	5.9
575	151	282	5.9
600	151	290	5.9
625	151	300	5.9
650	152	310	5.9
675	155	318	6.0
700	155	328	6.0
725	155	337	6.0
750	155	344	6.0
775	155	355	6.0
800	155	362	6.0

Sample Data

Water Content Determination			
Cont + Wet Soil (gm)	132.30	Plan Dimension (cm.)	6.00
Cont + Dry Soil (gm)	106.10	Initial Height (cm.)	1.90
Cont (gm)	17.87	Wt Samp+Cont (gm)	224.21
Water Content (%)	29.70	Wt. Cont (gm)	112.90
		Initial Area (cm^2)	36.00
		Initial Volume (cm^3)	68.40
		Wet Density (t/m^2)	1.627
		Dry Density (t/m^2)	1.255

Diect Shear Apparatus

Load Ring No.	14595
Ring Constant	0.1401 (Kg./Div.)
Shearing Rate	1.20 (mm./min)
Lever Arm Ratio	1:10
Hanging Weight	3.6 (kg)
Normal Stress	10.00 (t/m^3)



Result Summary:

Normal Stress	10.0	T/M^2
Maximum Shear Stress	6.0	T/M^2

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ASTM D 3080-90

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Project:	Landslide Hazard and Risk Assessment of Doi Suthep Area	***Date:***	19 ธ.ค. 49
Location:	Doi Suthep, Chiang Mai	***Sample No.***	1, S2(Shale) 770823
Soil Description:	ดินเหนียวปนซิลท์ สีน้ำตาลเข้ม	***Depth (m.)***	-
Remark:		***Tested By:***	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

Load - Deformation Data

Horiz. Disp. (0.01mm.)	Hori. Load Rd. (Div.)	Verti. Disp. (Div.)	Shear Stress (T/M^2)
0	0	0	0.0
25	10	2	0.4
50	30	27	1.2
75	49	54	1.9
100	60	80	2.3
125	67	107	2.6
150	72	117	2.8
175	74	222	2.9
200	76	140	3.0
225	79	151	3.1
250	82	160	3.2
275	84	174	3.3
300	87	186	3.4
325	88	197	3.4
350	90	207	3.5
375	91	214	3.5
400	93	215	3.6
425	94	232	3.7
450	95	237	3.7
475	95	252	3.7
500	95	244	3.7
525	95	246	3.7
550	95	251	3.7
575	95	254	3.7
600	95	254	3.7
625	94	254	3.7
650	92	256	3.6
675	90	257	3.5
700	88	259	3.4

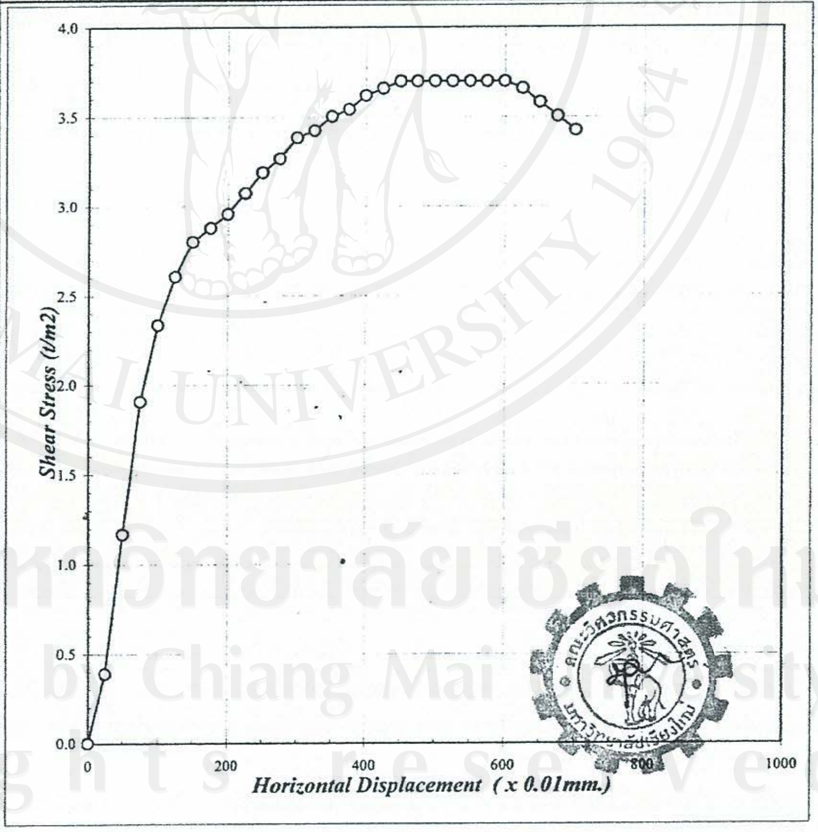
Sample Data

Water Content Determination	
Cont + Wet Soil (gm)	148.01
Cont + Dry Soil (gm)	119.96
Cont (gm)	16.76
Water Content (%)	27.18

Plan Dimension (cm.)	6.00
Initial Height (cm.)	1.90
Wt Samp+Cont (gm)	219.01
Wt. Cont (gm)	112.90
Initial Area (cm^2)	36.00
Initial Volume (cm^3)	68.40
Wet Density (t/m^2)	1.551
Dry Density (t/m^2)	1.220

Diect Shear Apparatus

Load Ring No.	14595
Ring Constant	0.1401 (Kg./Div.)
Shearing Rate	1.20 (mm./min)
Lever Arm Ratio	1:10
Hanging Weight	1.44 (kg)
Normal Stress	4.00 (t/m^3)



Result Summary:

Normal Stress	4.0	T/M^2
Maximum Shear Stress	3.7	T/M^2

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Location:	Doi Suthep, Chiang Mai	***Sample No.***	1, S2(Shale) 770823
Soil Description:	ดินเหนียวปนซิลท์ สีน้ำตาลเข้ม	***Depth (m.)***	-
Remark:		***Tested By:***	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

Load - Deformation Data

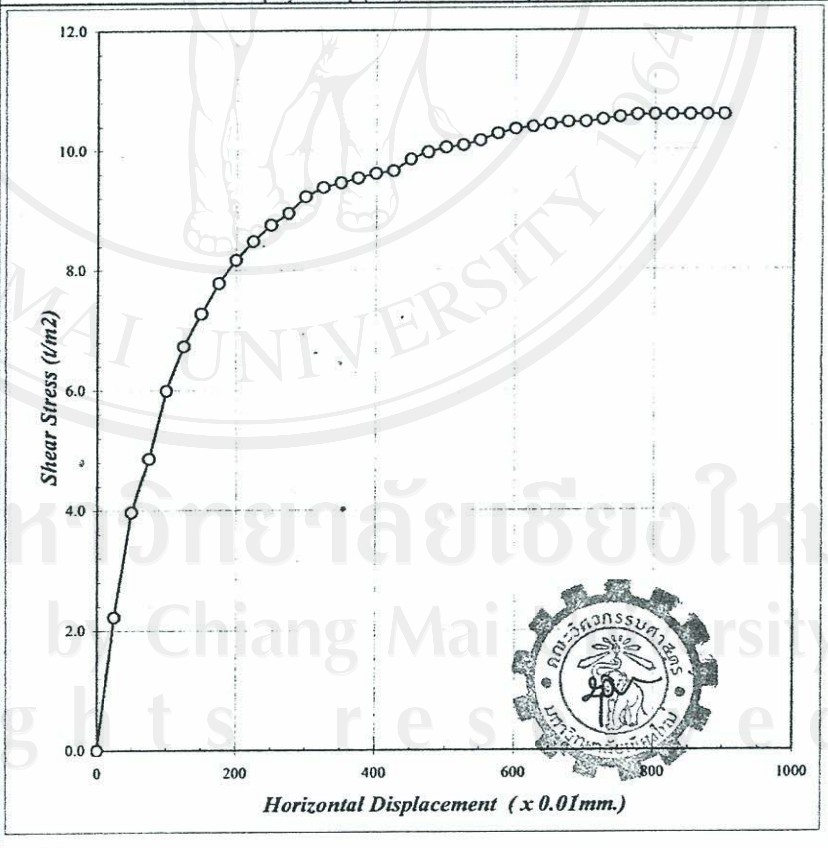
Horiz. Disp. (0.01mm.)	Hori. Load Rd. (Div.)	Verti. Disp. (Div.)	Shear Stress (T/M²)
0	0	0	0.0
25	57	3	2.2
50	102	11	4.0
75	125	29	4.9
100	154	42	6.0
125	173	60	6.7
150	187	77	7.3
175	200	92	7.8
200	210	108	8.2
225	218	120	8.5
250	225	132	8.8
275	230	146	9.0
300	237	159	9.2
325	241	175	9.4
350	243	188	9.5
375	245	200	9.5
400	247	220	9.6
425	248	225	9.7
450	253	236	9.8
475	256	245	10.0
500	258	252	10.0
525	259	261	10.1
550	261	268	10.2
575	264	273	10.3
600	266	277	10.4
625	267	283	10.4
650	268	289	10.4
675	269	290	10.5
700	269	302	10.5
725	270	306	10.5
750	271	312	10.5
775	272	318	10.6
800	272	321	10.6
825	272	325	10.6
850	272	328	10.6
875	272	332	10.6
900	272	333	10.6

Sample Data

Water Content Determination			
Cont + Wet Soil (gm)	149.94	Plan Dimension (cm.)	6.00
Cont + Dry Soil (gm)	118.77	Initial Height (cm.)	1.90
Cont (gm)	13.12	Wt Samp+Cont (gm)	223.88
Water Content (%)	29.50	Wt. Cont (gm)	112.90
		Initial Area (cm²)	36.00
		Initial Volume (cm³)	68.40
		Wet Density (t/m²)	1.623
		Dry Density (t/m²)	1.253

Diect Shear Apparatus

Load Ring No.	14595
Ring Constant	0.1401 (Kg./Div.)
Shearing Rate	1.20 (mm./min)
Lever Arm Ratio	1:10
Hanging Weight	5.76 (kg)
Normal Stress	16.00 (t/m³)



Result Summary:

Normal Stress	**16.0**	T/M²
Maximum Shear Stress	**10.6**	T/M²

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Location:	Doi Suthep, Chiang Mai	*Sample No.*	2
Soil Description:	ดินปนหินผุ สีน้ำตาลอ่อน	*Depth (m.)*	-
Remark:		*Tested By:*	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

WORK INSTRUCTIONS

Test procedure was carried out according to ASTM D3080-90, which can be described briefly as follows :

1) The test condition is the consolidated undrained test, using square box, (CU Test)
2) Samples were prepared from an undisturbed soil collected using a 6" tube
3) Three samples were used with the applied normal stress of 4.0, 10.0, 16.0 t/sq.m. coresponding to the overburden pressure of height 2, 5 and 8 m.
4) Each sample was consolidated in a shear box by load steps, consolidation was monitored till completion before starting a new load step
5) After completion of consolidated under full normal stress, the samples were then allowed to be under water for 12 hours to ensure a saturated condition
6) Under full normal stress, the samples were tested under undrained condition, using the shear rate of 1.2 mm./minute (as recommended by J.E. Bowles, Engineering Properties of Soil and Their Measurement)
7) The maximum shearing stress were obtained from all tests , the Mohr-Coulomb failure line was drawn and the value of Cohesion and Friction angle were determined

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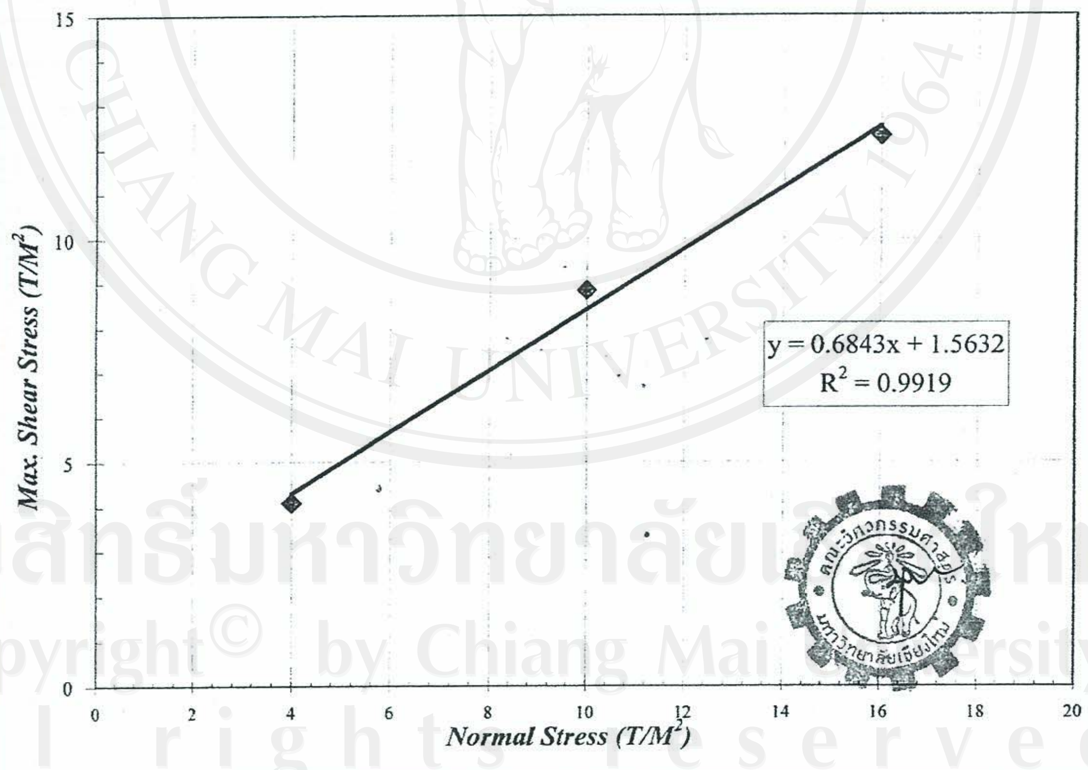
ASTM D 3080-90

Client:	Mr. Dorji Gyeltshen P.	***Job No:***	344/49
Project:	Landslide Hazard and Risk Assessment of Doi Suthep Area	***Date:***	19 ธ.ค. 49
Location:	Doi Suthep, Chiang Mai	***Sample No.***	2
Soil Description:	**ดินปนหินผุ สีน้ำตาลอ่อน**	***Depth (m.)***	-
		Tested By:	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

	Test1	Test 2	Test3	Test 4	
Normal Stress (T/M2)	4.0	10.0	16.0	-	-
Max. Shear Stress (T/M2)	4.1	8.8	12.3	-	-



Remarks:

Cohesion, C *(T/M²)* ***1.56***

Friction Angle, φ *(degree)* ***34***

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Location:	Doi Suthep, Chiang Mai	***Sample No.***	2
Soil Description:	ดินปนหินผุ สีน้ำตาลอ่อน	***Depth (m.)***	-
Remark:		***Tested By:***	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

Load - Deformation Data

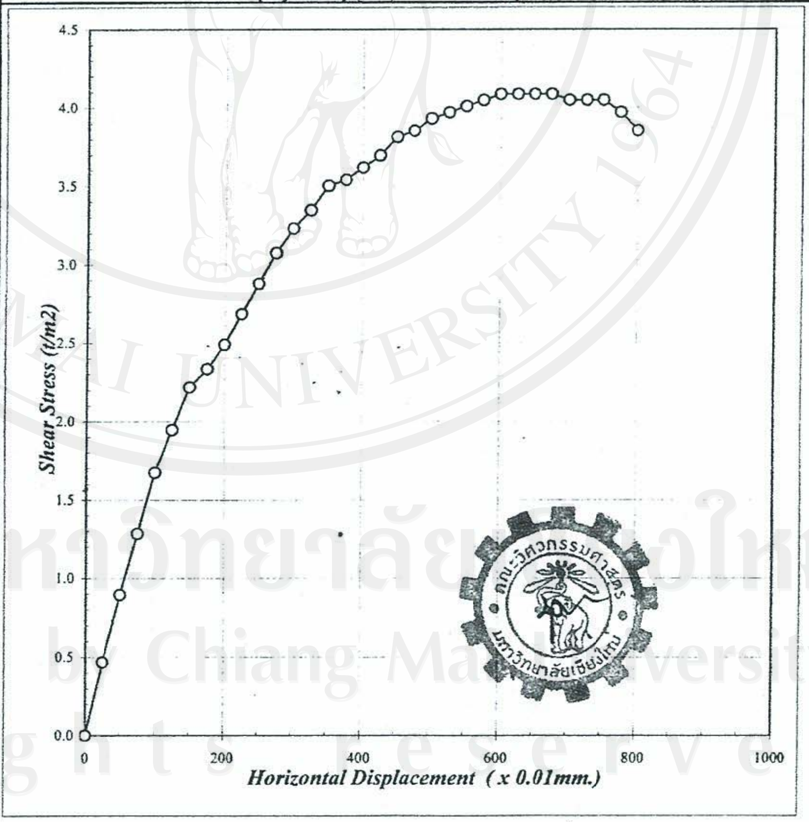
Horiz. Disp. (0.01mm.)	Hori. Load Rd. (Div.)	Verti. Disp. (Div.)	Shear Stress (T/M^2)
0	0	0	0.0
25	12	14	0.5
50	23	34	0.9
75	33	55	1.3
100	43	74	1.7
125	50	89	1.9
150	57	101	2.2
175	60	110	2.3
200	64	117	2.5
225	69	126	2.7
250	74	131	2.9
275	79	136	3.1
300	83	138	3.2
325	86	141	3.3
350	90	143	3.5
375	91	147	3.5
400	93	148	3.6
425	95	148	3.7
450	98	148	3.8
475	99	148	3.9
500	101	147	3.9
525	102	145	4.0
550	103	143	4.0
575	104	134	4.0
600	105	129	4.1
625	105	119	4.1
650	105	117	4.1
675	105	116	4.1
700	104	111	4.0
725	104	106	4.0
750	104	99	4.0
775	102	89	4.0
800	99	86	3.9

Sample Data

Water Content Determination			
Cont + Wet Soil (gm)	162.05	Plan Dimension (cm.)	6.00
Cont + Dry Soil (gm)	141.60	Initial Height (cm.)	1.90
Cont (gm)	17.33	Wt Samp+Cont (gm)	231.40
Water Content (%)	16.46	Wt. Cont (gm)	112.90
		Initial Area (cm^2)	36.00
		Initial Volume (cm^3)	68.40
		Wet Density (t/m^2)	1.732
		Dry Density (t/m^2)	1.488

Diect Shear Apparatus

Load Ring No.	14595
Ring Constant	0.1401 (Kg./Div.)
Shearing Rate	1.20 (mm./min)
Lever Arm Ratio	1:10
Hanging Weight	1.44 (kg)
Normal Stress	4.00 (t/m^3)



Result Summary:

Normal Stress	4.0	T/M^2
Maximum Shear Stress	4.1	T/M^2

ภาควิชาวิศวกรรมโยธา คณะวิศวกรรมศาสตร์ มหาวิทยาลัยเชียงใหม่

239 ถ.ห้วยแก้ว ต.สุเทพ อ.เมือง จ.เชียงใหม่ โทร. 053-944157-66 โทรสาร 053-892376

GEOTECHNICAL ENGINEERING LABORATORY

DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED UNDRAINED CONDITIONS

ASTM D 3080-90

Client:	Mr. Dorji Gyeltshen P.	***Job No:***	344/49
Project:	Landslide Hazard and Risk Assessment of Doi Suthep Area	***Date:***	19 ธ.ค. 49
Location:	Doi Suthep, Chiang Mai	***Sample No.***	2
Soil Description:	**ดินปนหินผุ สีน้ำตาลอ่อน**	***Depth (m.)***	-
Remark:		***Tested By:***	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

Load - Deformation Data

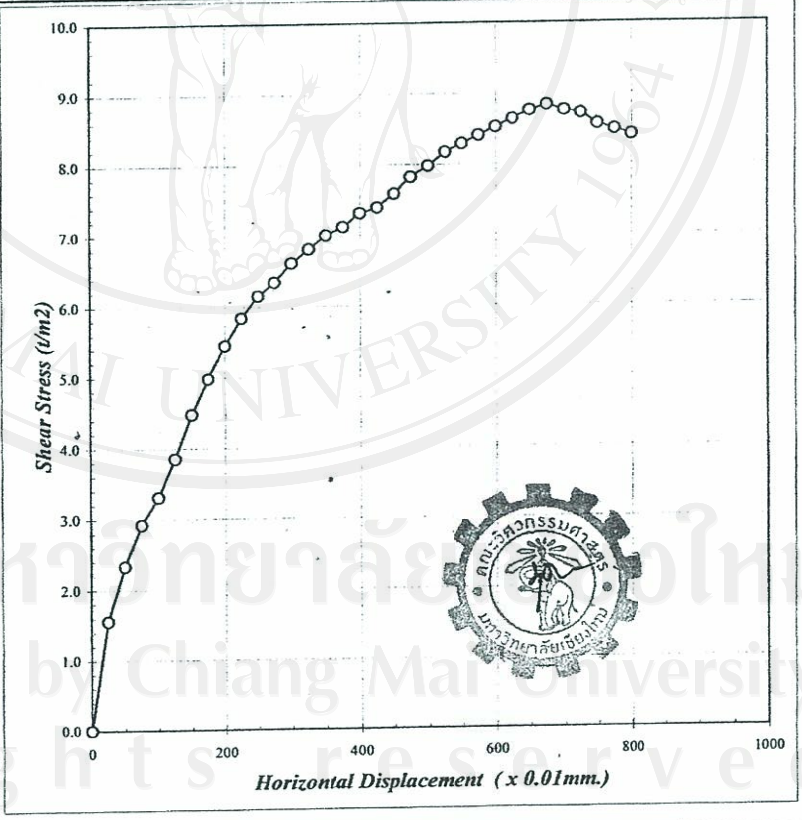
Horiz. Disp. (0.01mm.)	Hori. Load Rd. (Div.)	Verti. Disp. (Div.)	Shear Stress (T/M²)
0	0	0	0.0
25	40	33	1.6
50	60	41	2.3
75	75	50	2.9
100	85	53	3.3
125	99	61	3.9
150	115	71	4.5
175	128	78	5.0
200	140	83	5.4
225	150	87	5.8
250	158	87	6.1
275	163	87	6.3
300	170	87	6.6
325	175	86	6.8
350	180	85	7.0
375	183	82	7.1
400	188	82	7.3
425	190	82	7.4
450	195	82	7.6
475	201	87	7.8
500	205	90	8.0
525	210	100	8.2
550	213	105	8.3
575	216	115	8.4
600	219	122	8.5
625	222	130	8.6
650	225	137	8.8
675	227	142	8.8
700	225	147	8.8
725	224	152	8.7
750	220	155	8.6
775	218	162	8.5
800	216	165	8.4

Sample Data

Water Content Determination			
Cont + Wet Soil (gm)	102.15	Plan Dimension (cm.)	6.00
Cont + Dry Soil (gm)	91.40	Initial Height (cm.)	1.90
Cont (gm)	18.21	Wt Samp+Cont (gm)	230.53
Water Content (%)	14.69	Wt. Cont (gm)	112.90
		Initial Area (cm²)	36.00
		Initial Volume (cm³)	68.40
		Wet Density (t/m²)	1.720
		Dry Density (t/m²)	1.499

Diect Shear Apparatus

Load Ring No.	14595
Ring Constant	0.1401 (Kg./Div.)
Shearing Rate	1.20 (mm./min)
Lever Arm Ratio	1:10
Hanging Weight	3.60 (kg)
Normal Stress	10.00 (t/m³)



Result Summary:

Normal Stress	10.0	T/M²
Maximum Shear Stress	8.8	T/M²

26/12/2006

Direct_shear044_49_sp2.XLS/sample3

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DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED UNDRAINED CONDITIONS

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Client:	Mr. Dorji Gyeltshen P.	***Job No:***	344/49
Project:	Landslide Hazard and Risk Assessment of Doi Suthep Area	***Date:***	19 ธ.ค. 49
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Soil Description:	**ดินปนหินผุ สีน้ำตาลอ่อน**	***Depth (m.)***	-
Remark:		***Tested By:***	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

Load - Deformation Data

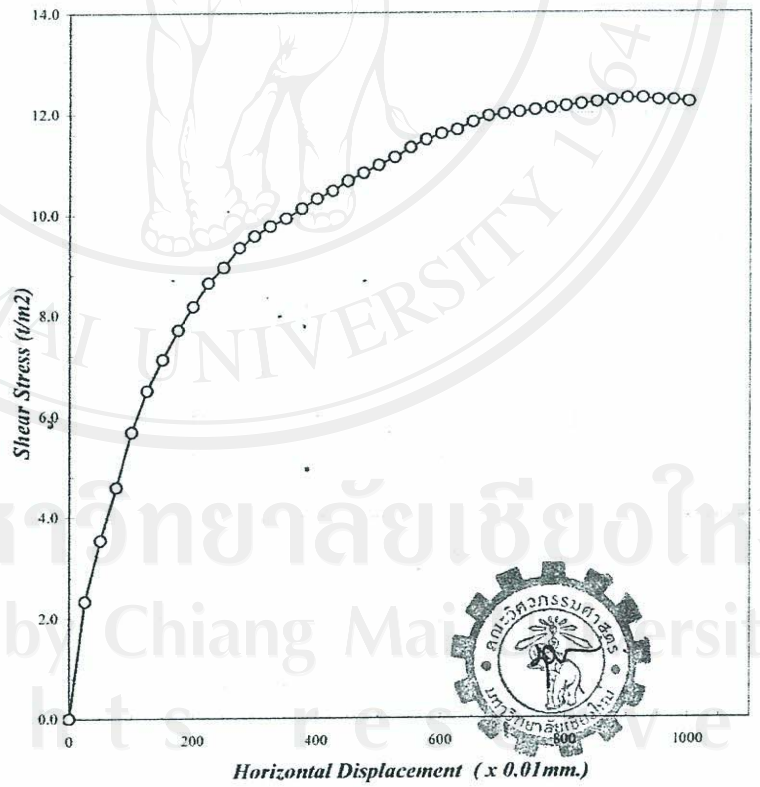
Horiz. Disp. (0.01mm.)	Hori. Load Rd. (Div.)	Verti. Disp. (Div.)	Shear Stress (T/M^2)
0	0	0	0.0
25	60	14	2.3
50	91	33	3.5
75	118	53	4.6
100	146	79	5.7
125	167	93	6.5
150	183	111	7.1
175	198	127	7.7
200	210	141	8.2
225	222	153	8.6
250	230	164	9.0
275	240	173	9.3
300	246	179	9.6
325	251	181	9.8
350	255	186	9.9
375	260	189	10.1
400	265	193	10.3
425	269	201	10.5
450	274	211	10.7
475	278	219	10.8
500	282	229	11.0
525	286	239	11.1
550	291	251	11.3
575	295	261	11.5
600	298	273	11.6
625	300	281	11.7
650	304	289	11.8
675	307	298	11.9
700	308	301	12.0
725	309	307	12.0
750	310	313	12.1
775	311	320	12.1
800	312	325	12.1
825	313	330	12.2
850	314	336	12.2
875	315	342	12.3
900	316	349	12.3
925	316	358	12.3
950	315	369	12.3
975	315	371	12.3
1000	314	376	12.2

Sample Data

Water Content Determination			
Cont + Wet Soil (gm)	217.44	Plan Dimension (cm.)	6.00
Cont + Dry Soil (gm)	190.22	Initial Height (cm.)	1.90
Cont (gm)	23.96	Wt Samp+Cont (gm)	231.53
Water Content (%)	16.37	Wt. Cont (gm)	112.90
		Initial Area (cm^2)	36.00
		Initial Volume (cm^3)	68.40
		Wet Density (t/m^2)	1.734
		Dry Density (t/m^2)	1.490

Diect Shear Apparatus

Load Ring No.	14595
Ring Constant	0.1401 (Kg./Div.)
Shearing Rate	1.20 (mm./min)
Lever Arm Ratio	1:10
Hanging Weight	5.76 (kg)
Normal Stress	16.00 (t/m^3)



Result Summary:

Normal Stress	**16.0**	**T/M^2**
Maximum Shear Stress	**12.3**	**T/M^2**

28/12/2006

CURRICULUM VITAE

Name	Dorji Gyeltshen P
Sex	Male
Date of Birth	November 7, 1976
Nationality	Bhutanese
Educational background	Bachelor Degree in Civil Engineering (2001) Hindustan College of Engineering, Padur, 603103 Madras University, Tamil Nadu, India
	Master of Science in Environmental Science (2007) Chiang Mai University Chiang Mai, Thailand
Scholarships	Royal Government of Bhutan Scholarship; 1997-2001
	Thailand International Development Cooperation Agency (TICA), Thailand, 2005-2007
Work experiences	
January 2002 – present	Assistant Engineer, Department of Roads Ministry of Works & Human Settlement, Thimphu, Bhutan.

3.3 Field Investigations

Once the hazard map was generated, the field investigation was carried out to check whether or not the hazard map generated fits with the field reality. The field checks include the verification of the location of the existing landslides and collection of geotechnical and hydrological data for slope stability analysis, one each in weathered gneiss and weathered shale. Mapping and detailed study are restricted to along roads and highways because firstly, these are the areas likely to have maximum landslide due to cutting of the slopes to built roads and, secondly, limited time in hand to hike the rest of the area. A special attention was paid to the places with high hazard.

3.3.1 Landslide Mapping

Landslides encountered during the field investigation are geo-referenced using Global Positioning System (GPS) and mapped in the hazard map. Slope (both natural and modified due to road cut) and landslide dimensions are measured in the field. Types of landuse were also field checked. Detailed descriptions of the prevailing conditions of existing landslides area is as shown in Table 3.4. The figure 3.8 shows the geo-referenced landslides mapped on the hazard map. Figure 3.9 through figure 3.17 shows the pictures of each landslide.

Table 3.4 Description of existing landslides

Sl No	GPS Coordinate	Approx. Dimension (m)			Slope (deg)		Landuse type	Rock type	Remarks
		Height	Width	Depth	General	Modified			
1	0485361 2089342	20	15	1 to 2	45	75	Sparsely vegetated	Gneiss	
2	0483547 2089405	30	80	< 2	60	80	Bamboo forest	Gneiss	3 separate slides
3	0481748 2090947	20	30	2 to 3	50	60	Bamboo forest	Gneiss	
4	0481575 2088311	45	15	1 to 2	60	-	Bamboo forest	Gneiss	Natural landslide
5	0477401 2086061	20	60	1 to 2	70	90	Bamboo mixed	Lime-stone	Rock fall
6	0477077 2082343	38	60	5 to 6	35	40	Bamboo mixed	Shale	
7	0477037 2084682	15	10	< 2	40	50	Bamboo mixed	Gneiss	
8	0491800 2078604	15	8	1 to 2	33	50	Forest	Gneiss	
9	0485295 2086369	40	30	2-3	45	-	Bushy	Gneiss	Old landslide

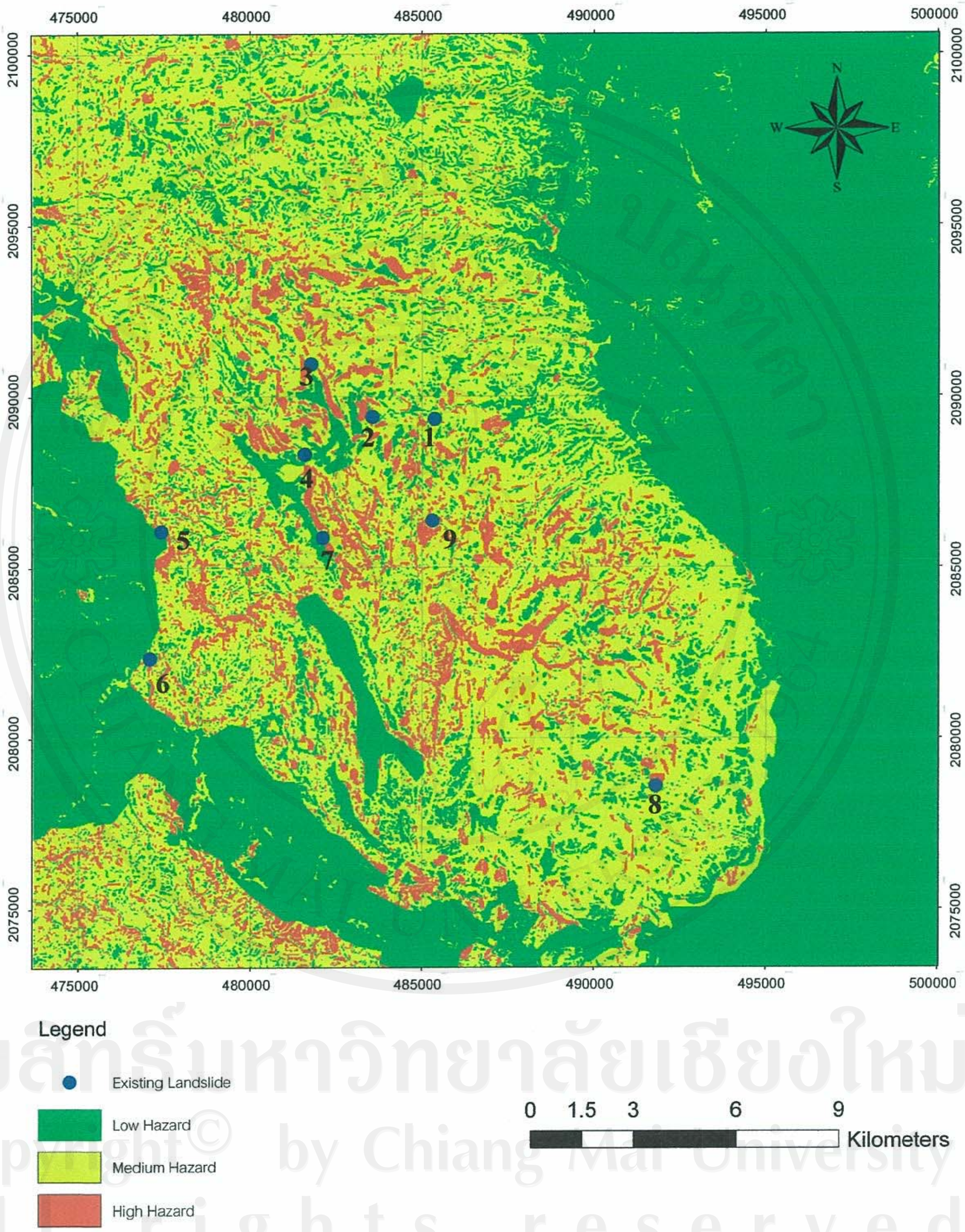


Figure 3.8 Existing landslide mapping

Figure 3.9 Picture of existing landslide (Landslide 1) in weathered gneiss on highway 1096 (Mae Rim-Samoeng highway)

Figure 3.10 Picture of existing landslide (Landslide 2) in weathered gneiss on highway 1096 (Mae Rim-Samoeng highway) near Ban Pong Yaeng Nok.

Figure 3.11 Picture of existing landslide (Landslide 3) in weathered gneiss on road leading to Ban Sam Lang

Figure 3.12 Picture of existing landslide (Landslide 4), a natural landslide in weathered gneiss near Ban Pong Yaeng Nok below highway 1096.

Figure 3.13 Picture of existing landslide (Landslide 5), a rock fall in limestone on highway 1096 (Mae Rim-Samoeng highway).

Figure 3.14 Picture of existing landslide (Landslide 6) in weathered shale on highway 1096 (Mae Rim-Samoeng highway)

Figure 3.15 Picture of existing landslide (Landslide 7), a natural landslide in weathered gneiss above Ban Dong Nok.

Figure 3.16 Picture of existing landslide (Landslide 8) in weathered gneiss before reaching Doi Suthep Temple.

Figure 3.17 Picture of existing landslide (Landslide 9) in weathered gneiss above Ban Mae Sa. The slide occurred in August 2004.

3.3.2 Slope Stability Analysis

Most of the landslides encountered are fresh which occurred during the last monsoon (2006) and are confined to weathered gneiss and shale. To understand the failure mechanism of landslide, slope stability analysis was carried out in weathered gneiss and weathered shale. The slope stability analysis is divided into two parts. The first part focuses on the back analysis of already failed slopes. This analysis is carried out to estimate the water level at which the slope would have failed using Janbu's generalized method of slice. The second part deals with the stability analysis of natural slope to understand and analyze the relation between hydrological conditions and the development of slope movements. The slope stability simulation and modeling was carried out in the natural slope of weathered gneiss and weathered shale using combined hydrological and stability model (CHASM) software, Version 4.1 (build 413), which is based on Bishop's simplified method of slice.

The input parameters required for both methods of stability analysis were obtained through field and laboratory tests and from the literatures. One undisturbed soil samples each from weathered gneiss and weathered shale (Landslide No. 2 and No. 6 respectively in Figure 3.8) was collected as shown in Figure 3.18. Geotechnical parameters such as friction angle (φ), cohesion (c), field density (γ) and hydrological parameters such as permeability were determined. Direct shear test of soils under consolidated undrained conditions was carried out to determine soil strength parameters, φ and c. The natural water content was also determined. The wet density of soil samples was obtained through field density test while dry and saturated densities of the soil samples were obtained in the laboratory. The permeability of the two soils was also measured at the sites. Rainfall data obtained from Thai Meteorological Department website was used.

Figure 3.18 Sampling site: A – Gneiss and B – Shale, for slope stability analysis

3.3.2.1 Back-analysis of Failed Slopes

The analysis of failed slopes is aimed at determining the effect of water or the height of phreatic surface above the slip surface during the time of the slope failure. Geotechnical parameters required by the Janbu's method of slices were determined through field and laboratory tests. The dimensions of the failed slopes were measured in the field. The profiles of the failed slopes are shown in Figure 3.19.

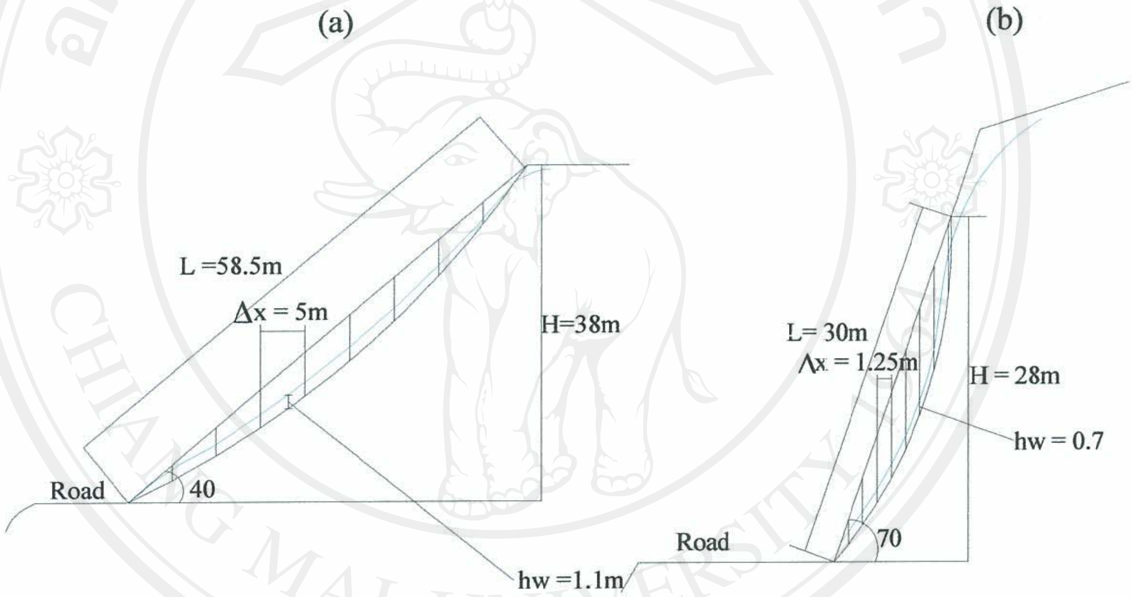


Figure 3.19 Profile of the failed slopes: a) in weathered shale b) in weathered gneiss

Janbu's method for analyzing non-circular failure in slopes is one of the most versatile methods and it is simple enough to permit the solution of problems by hand. When the properties of the soil or waste rock mass vary and the slip surface is not circular as a result to some structural feature such as soil / rock interface, the Janbu's method can be used (Hoek and Bray, 1977). In this method the sliding mass is divided into a number of slices. Unlike other methods, the slices into which the sliding mass is divided need not be of constant width. The factor of safety is given by the formula:

$$FS = f_o \frac{\sum \{c + (p-u)\tan\phi\}\Delta x / n_\alpha}{\sum p.\tan\alpha}$$

Where:

f_o = correction factor

n_α = geometrical functions

c = cohesive strength (kN/m^2)

φ = angle of friction (degree)

p = average weight per unit width of slice (kN)

u = average water pressure on base of slice (kN/m^2)

L = chord length of failure surface (m)

d = depth of failure surface (m)

α = angle of the centre of the base of each slice with respect to the horizontal datum/plane (degree)

Δx = slice width (m)

The inclination α of the center of the base of each slice with respect to the horizontal and the width Δx of the slice are measured. The values of α, Δx, c and φ for each slice are tabulated in Table 3.5 and Table 3.6. The weight of the slice ΔW and the average weight of the slice per unit area of base p are also calculated. Water pressure on the base of each slice is calculated assuming certain value of h_w, which is the height of phreatic surface above base of the slip surface. Thus sum of resisting and driving forces is calculated. Figure 3.20 illustrates a) the section through sliding mass showing slice boundaries and geometrical parameters, b) slice parameters used in the stability analysis and c) calculation of average water pressure u on base of slice.

Table 3.5 Back analysis calculation table for weathered gneiss

FS (assumed)	1.0
FS (calculated)	1.0

Slice	α	Δx m	hm m	hw m	γsoil kN/m³	c kN/m²	φ deg	p kN/m²	u kN/m²	ΔW	ΔW tan α	X	nα	X/nα
1	83	1.0	2.5	0.7	15.23	15.3	34	38.075	6.86	38.08	309.4	36.3	0.10	379.79
2	75	1.0	7.5	0.7	15.23	15.3	34	114.23	6.86	114.2	425.9	87.7	0.23	375.02
3	74	1.0	7.5	0.7	15.23	15.3	34	114.23	6.86	114.2	398.0	87.7	0.25	346.90
4	72	1.0	7.0	0.7	15.23	15.3	34	106.61	6.86	106.6	327.8	82.6	0.29	283.13
5	70	1.0	5.5	0.7	15.23	15.3	34	83.765	6.86	83.77	230.0	67.2	0.33	202.64
6	68	1.0	4.0	0.7	15.23	15.3	34	60.92	6.86	60.92	150.7	51.8	0.37	139.10
7	60	1.0	2.0	0.7	15.23	15.3	34	30.46	6.86	30.46	52.7	31.2	0.54	57.92
8	55	1.0	0.5	0.5	15.23	15.3	34	7.615	4.90	7.615	10.9	17.1	0.64	26.66
											1905.4			1811.19

Table 3.6 Back analysis calculation table for weathered shale

FS (assumed)	1.00
FS (calculated)	1.00

Slice	α	Δx m	hm m	hw m	γsoil kN/m³	c kN/m²	φ	p kN/m²	u kN/m²	ΔW	ΔW tanα	X	nα	X/nα
1	55	5.0	1.5	1.0	12.39	10.7	29	18.59	9.81	92.93	132.7	77.8	0.59	131.9
2	50	5.0	4.0	1.1	12.39	10.7	29	49.56	10.79	247.80	295.2	160.9	0.69	234.4
3	45	5.0	5.5	1.1	12.39	10.7	29	68.15	10.79	340.73	340.6	212.4	0.78	273.2
4	40	5.0	5.5	1.1	12.39	10.7	29	68.15	10.79	340.73	285.8	212.4	0.86	247
5	39	5.0	5.5	1.1	12.39	10.7	29	68.15	10.79	340.73	275.8	212.4	0.88	242.7
6	33	5.0	4.5	1.1	12.39	10.7	29	55.76	10.79	278.78	181.0	178.1	0.96	186.1
7	30	5.0	3.8	1.1	12.39	10.7	29	46.46	10.79	232.31	134.1	152.3	0.99	153.8
8	29	5.0	2.3	1.1	12.39	10.7	29	27.88	10.79	139.39	77.2	100.8	1.00	100.8
9	20	5.0	0.8	0.5	12.39	10.7	29	9.29	4.91	46.46	16.9	65.7	1.06	61.86
											1739.4			1632

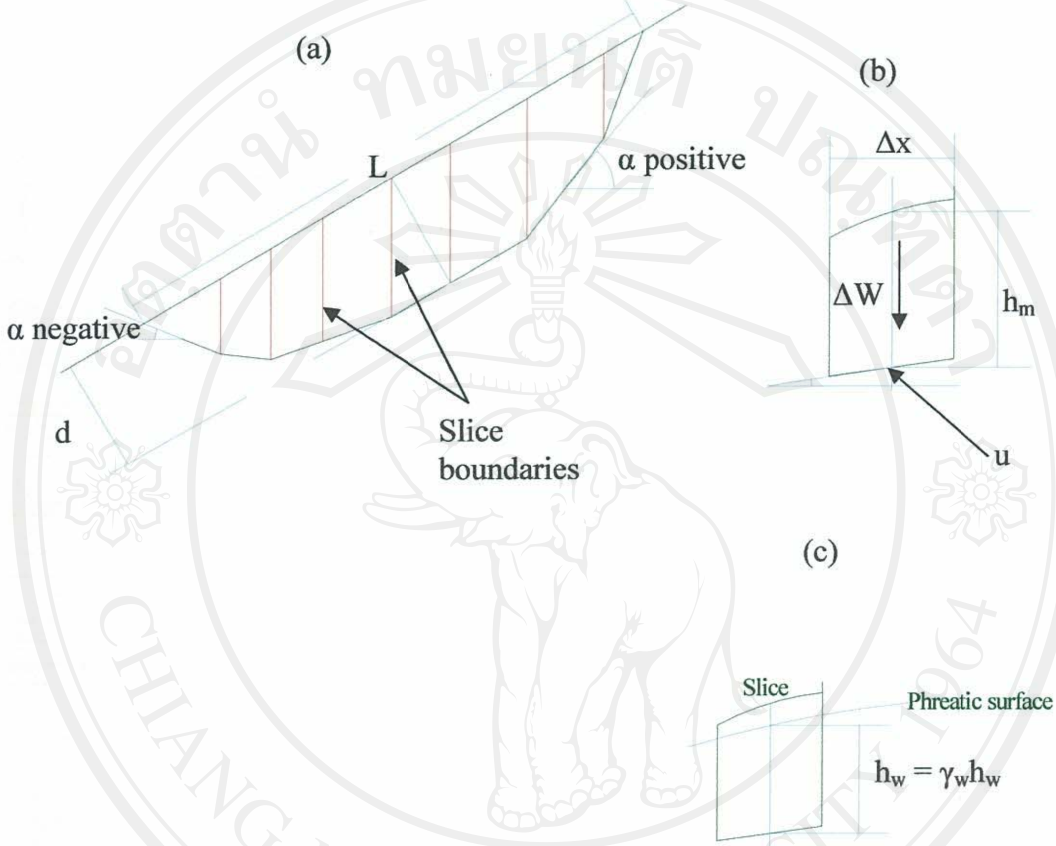


Figure 3.20 Definition of geometrical parameters and method of calculation for Janbu's non-circular failure analysis

After inputting all the parameters in the table, the iteration were performed with different values for h_w each time adjusting the factor of safety closer and closer to 1. The h_w value at the factor of safety equal to 1 is the h_w during the time of the slope failure.

3.3.2.2 Stability Analysis of Natural Slope

Stability analysis of natural slope is carried out using CHASM software. The CHASM is an integrated slope hydrology/slope stability software package that aids the assessment of slope stability conditions. It is designed to help estimate the effect on slope stability of selected storm events, surface covers, slope plan curvatures and other important slope and material properties (Wilkinson *et al.*, 2002).

The dynamics of slope hydrology are computed using a finite difference formulation that accommodates unsaturated and saturated soil conditions. The stability analysis is undertaken using a grid search procedure which is implemented continuously during the simulation period (Wilkinson *et al.*, 2002). The method employed within CHASM 4 is the simplified Bishop's circular stability analysis method with an automated search for the critical slip surface. Figure 3.21 illustrates the definition of geometrical parameters and method of calculation for simplified Bishop's method of slices. The factor of safety is given by:

$$FS = \frac{\sum_{i=0}^{n}\left[c\Delta x_i + (W_i - u_i\Delta x_i)\tan\phi\right]\left[1/M_i(\alpha)\right]}{\sum_{i=0}^{n} W_i \sin\alpha_i}$$

Where $M_i(\alpha) = \cos\alpha_i(1 + \frac{\tan\alpha_i \tan\phi}{FS})$

n = number of slices

FS = factor of safety

c = soil cohesion (kN/m^2)

L = slice length (m)

α = slice angle (degrees)

u = pore water pressure (kN/m^2)

Φ = effective angle of internal friction (degree)

W = total weight of the soil (kN)

Δx = slice width (m) and

θ = slope angle (degree)

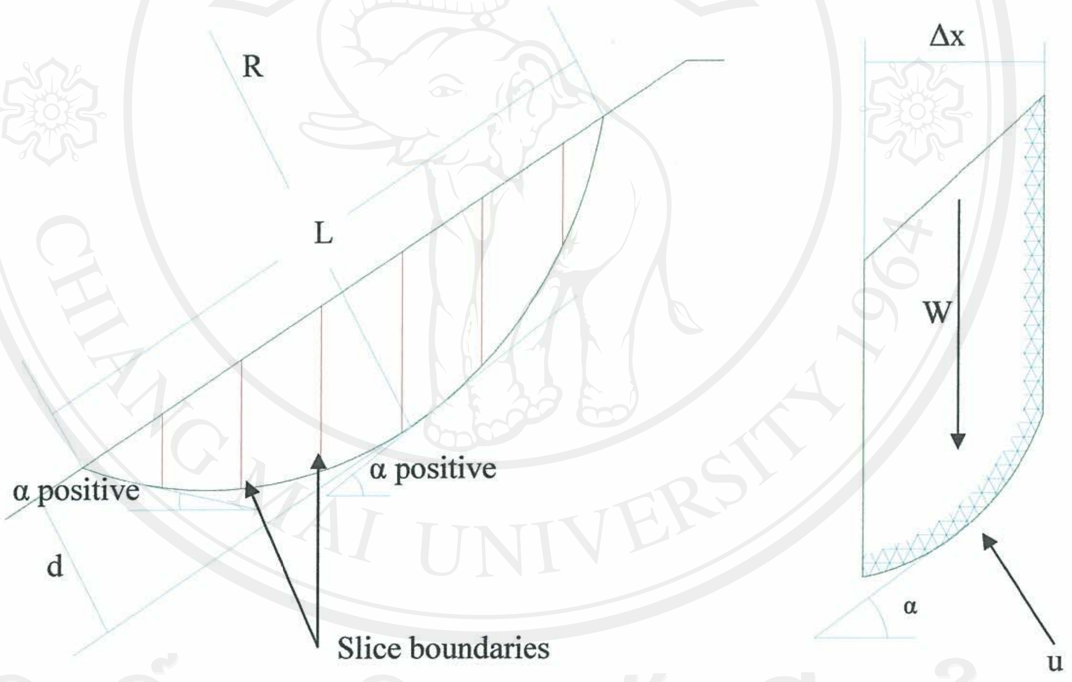


Figure 3.21 Definition of geometrical parameters and method of calculation for Bishop's simplified method of slices

Two natural slopes (Figure 3.22), one near Ban Pong Yaeng Nai and the other near Ban Tong Hua Hin were selected for modeling using CHASM software.

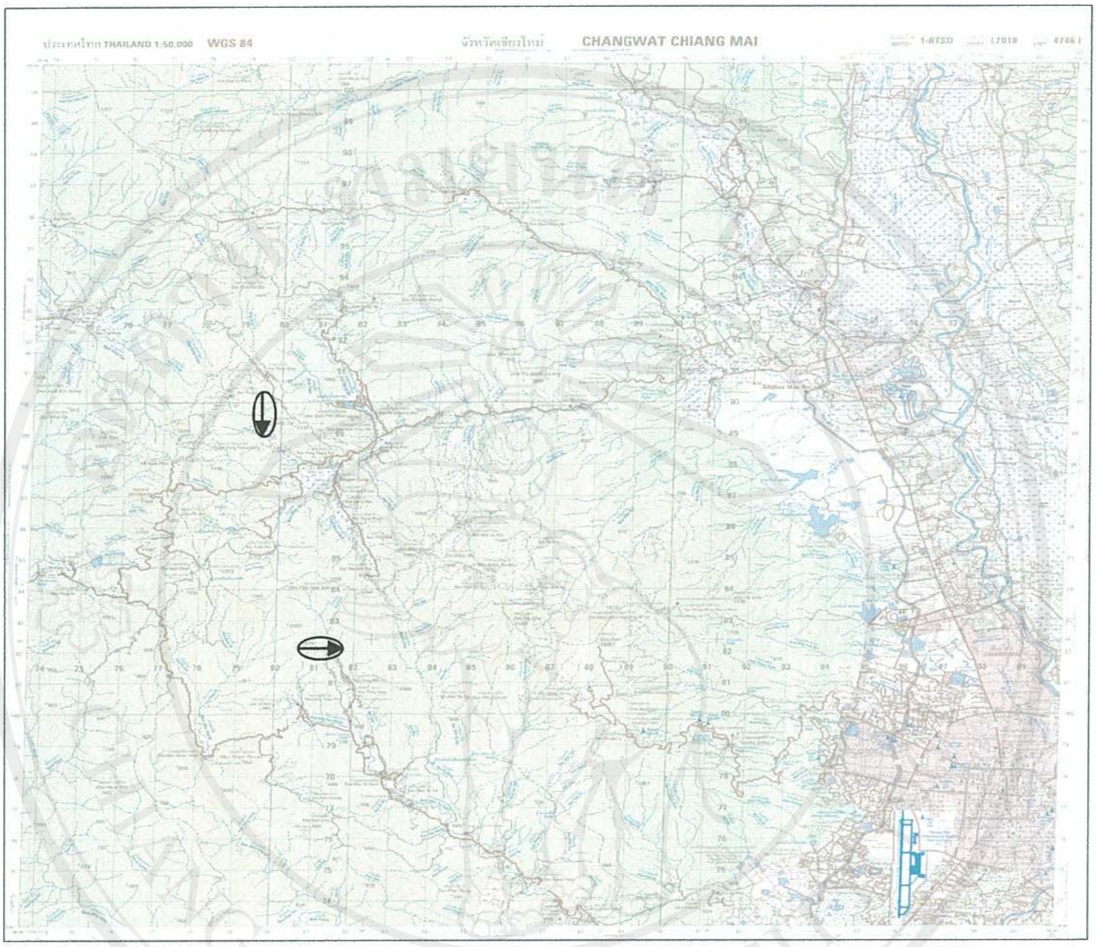


Figure 3.22 Topographic map showing the location and direction of slope under investigation.

The steps outlined in the CHASM 4 HELP has been followed. First the geometry of the slope under investigation, as observed in the field and read from the topographic map was drawn using an automated mesh generator window, which allows drawing a slope profile on the screen, through a simple point and clicking operation (Figure 3.23). From the same window definition of soil layer, water table and choice of slip-circle search grid location (Figure 3.24) for the Bishop's circular stability analysis was achieved.

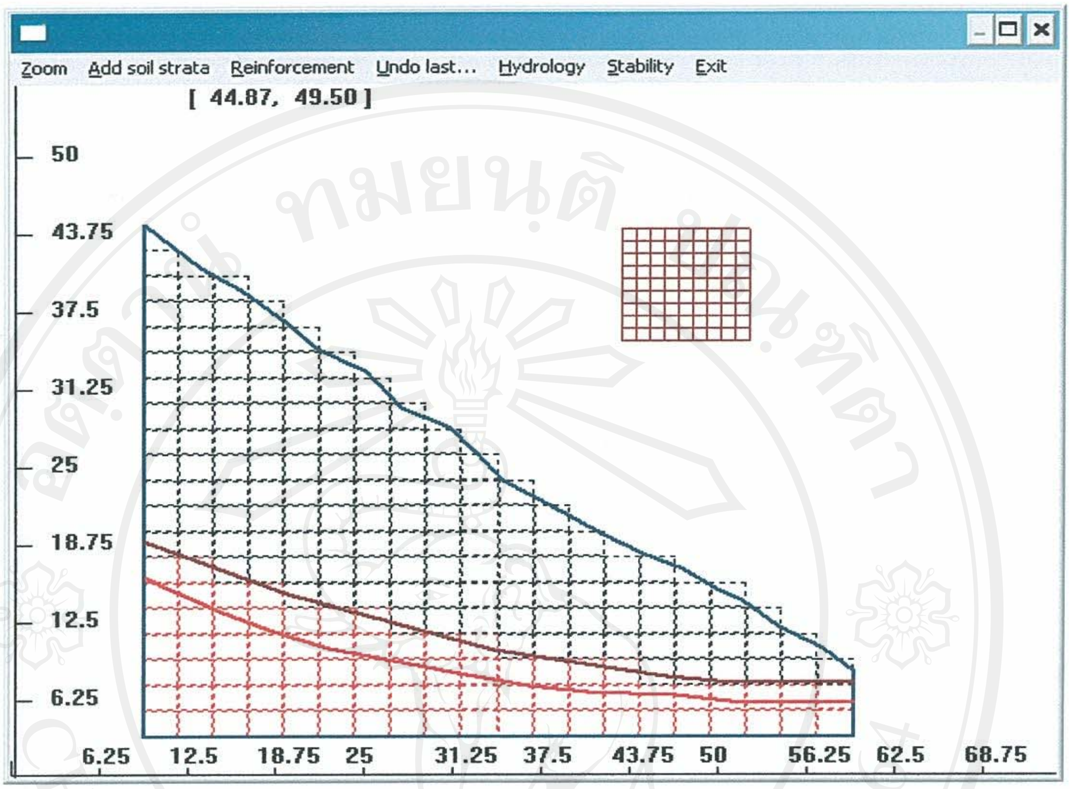


Figure 3.23 On-screen slope geometry and finite difference mesh generation

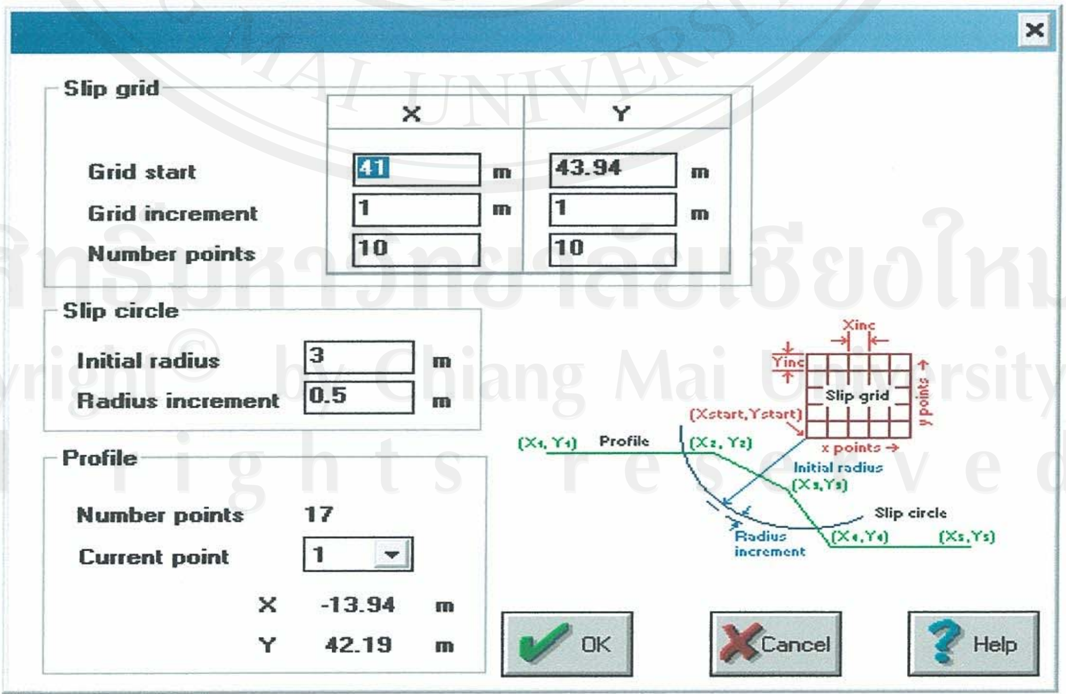


Figure 3.24 Bishop's circular slip search

The second step involved initialization and parameterization of each major component of the model including hydrology, soil and vegetation. In addition to this, other temporal and numerical information such as simulation length and iteration periods were also required. A full list of the model parameters is given in Table 3.7. Initialization and parameterization of the soil, storm and vegetation parameters were done through respective windows. The access to these parameters can also be gained through hydrology summary dialog box (Figure 3.25) which is also used to edit the slope cross- section (including three dimensional slope representations), water table height and the mesh dimension.

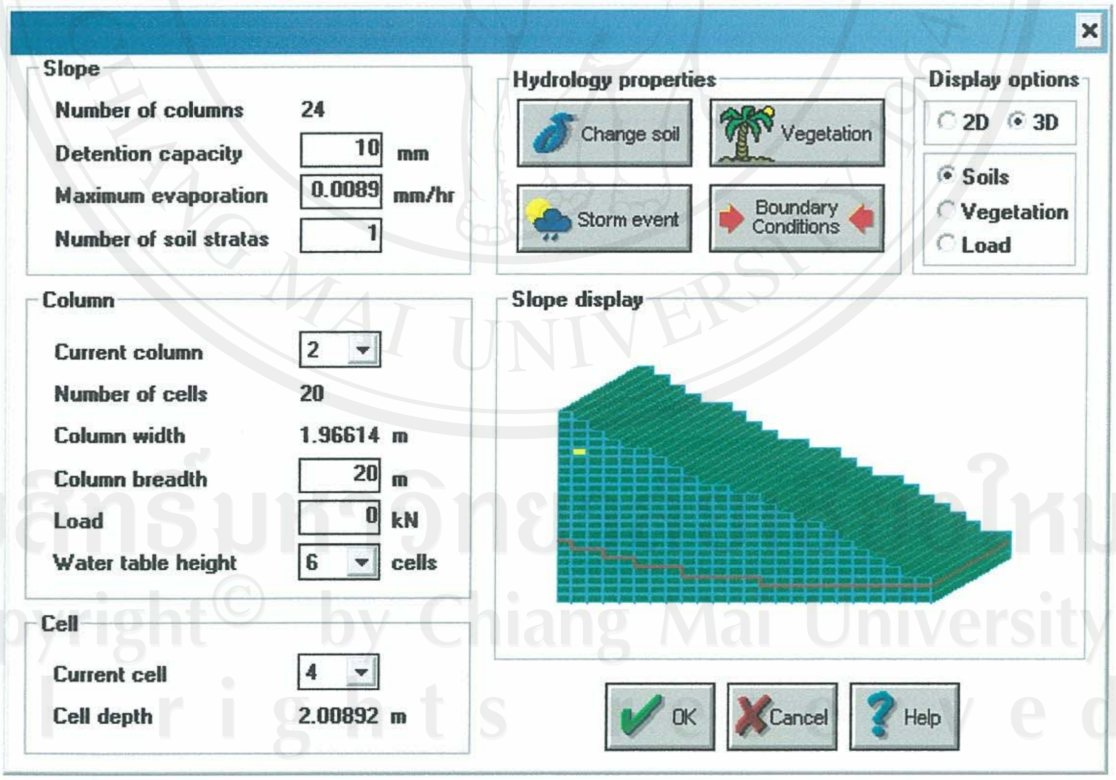


Figure 3.25 Hydrology dialog box (with 3D convergence).

Table 3.7 Input parameters used in back analysis of failed slopes and in natural slopes

Parameter Group	Input Parameter	Unit	Weathered Gneiss	Weathered Shale
Feature geometry	Slope angle	deg	38	31
	Slope length	m	60	60
	Slope height	m	37	32
Soil Properties*	Saturated density (γ_s)	kN/m^3	17.72	15.81
	Wet density (γ_w)	kN/m^3	15.23	12.39
	Dry density (γ_d)	kN/m^3	13.17	9.83
	Cohesion (*C*)	kN/m^2	15.32	10.69
	Friction angle (φ)	deg	34	29
	Specific gravity (G)	gm/cm^3	2.504	2.575
Hydrology	Permeability (k)	m/sec	2.16x10^{-6}	3.57x10^{-6}
	Degree of saturation (S)	%	45.88	47.25
	Depth of water table (d)	m	10-20	5-15
	Water content (w)	%	15.84	28.79
	Max. evaporation	mm	0.0005	0.0005
	Rainfall intensity	mm/hr	5	5
	Detention capacity	mm	10	10
	Initial suction in top cell	m	-2	-2
	Simulation period (continuous)	hr	48	48
Numerical	Mesh resolution(width, depth)	m	2,2	2,2
	Iteration period	sec	60	60

* the same properties is used for back analysis of failed slope

On running the program from the main dialog box the option of resetting the initial moisture condition is offered. After making necessary reset the simulation was carried out. During the simulation period, a result window displays the factor of safety, the X-Y coordinates of the slip grid, the slip circle radius and mass of soil above the critical slip surface. These are displayed in real-time (i.e. as the calculations are made), so that the progress of the simulation can be monitored. Once the simulation has finished, the temporal changes in the factor of safety and the position of the critical failure surface were examined (Figure 3.26). Additionally, the spatial distribution of the soil moisture within the slope was examined at the time of the minimum factor of safety by point and click on the finite difference mesh (Figure 3.27)

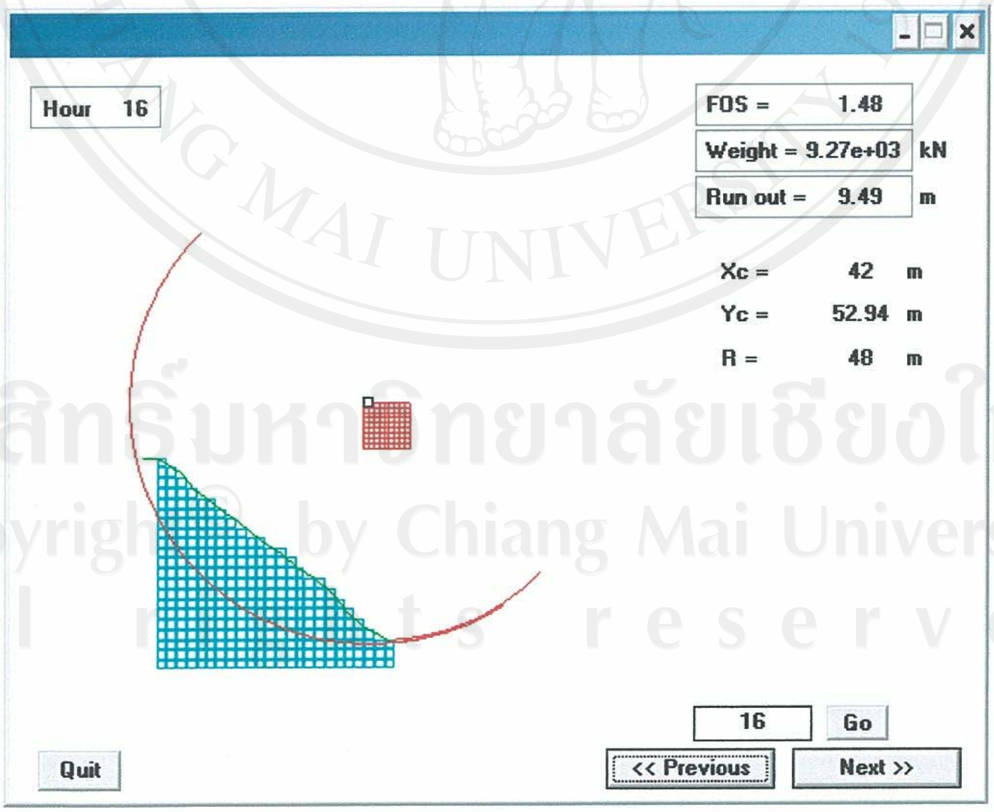


Figure 3.26 CHASM visualization of critical slip surface

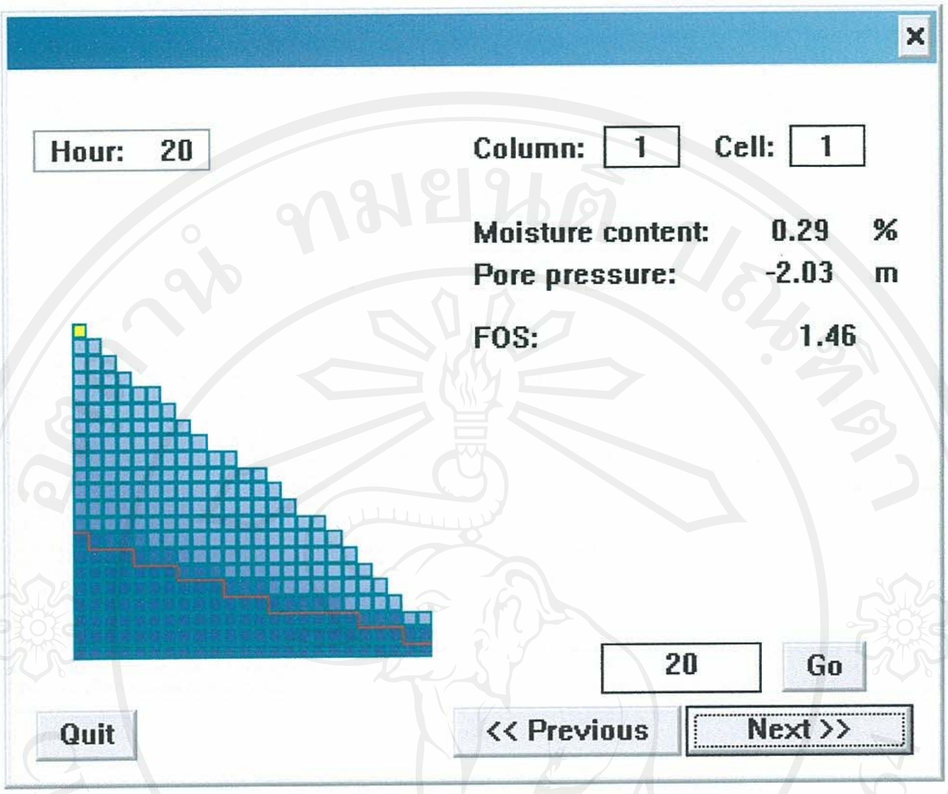


Figure 3.27 CHASM visualization of soil moisture distribution

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Landslide Hazard Map

Landslide hazard map was prepared by integrating the effect of slope, geology, landuse, and stream proximity factors. The zonation map was divided into three zones of landslide hazards, viz., low, medium and high hazard to landslides. The landslide hazard map is shown in Figure 4.1. The percentages of different hazard zones of the area is shown in Table 4.1 and Figure 4.2.

Table 4.1 Percentages of different hazard zones of the study area.

Hazard Categories	Area (%)
Low landslide hazard	49.38
Medium landslide hazard	43.43
High landslide hazard	7.19

As more importance is given to the slope component, most of the high hazard areas occupy steep terrain in the mountains surrounded by moderate hazard areas with gentler terrain and low hazard in the low lands.

4.2 Landslide Risk Map

Hazard maps that are not accompanied by a risk analysis are not meaningful for effective decision making. Landslide risk map (Figure 4.3) was prepared by

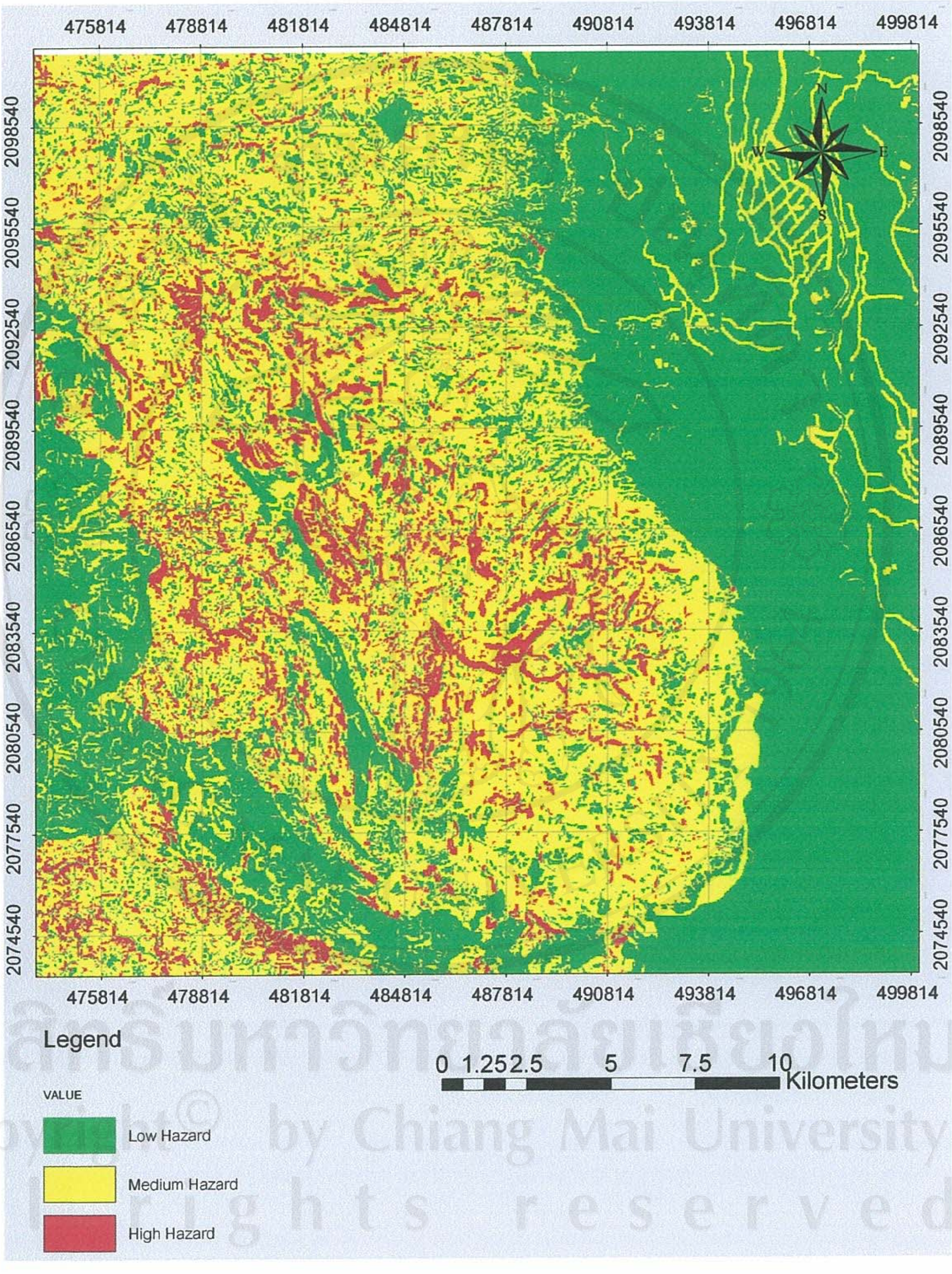


Figure 4.1 Landslide hazard map of the study area

integrating the distance to the villages and other inhabited places with the hazard map. The landslide risk map was divided into three zones of landslide risk, viz. low, medium and high. The percentages of different risk zones in the study area are given in Table 4.2 and also shown in Figure 4.2.

Table 4.2 Percentages of different risk zones of the study area.

Risk Categories	**Area (%)**
Low landslide risk	77.63
Medium landslide risk	20.08
High landslide risk	2.29

The areas of higher risk are those with high hazard places close to the villages and other inhabited places.

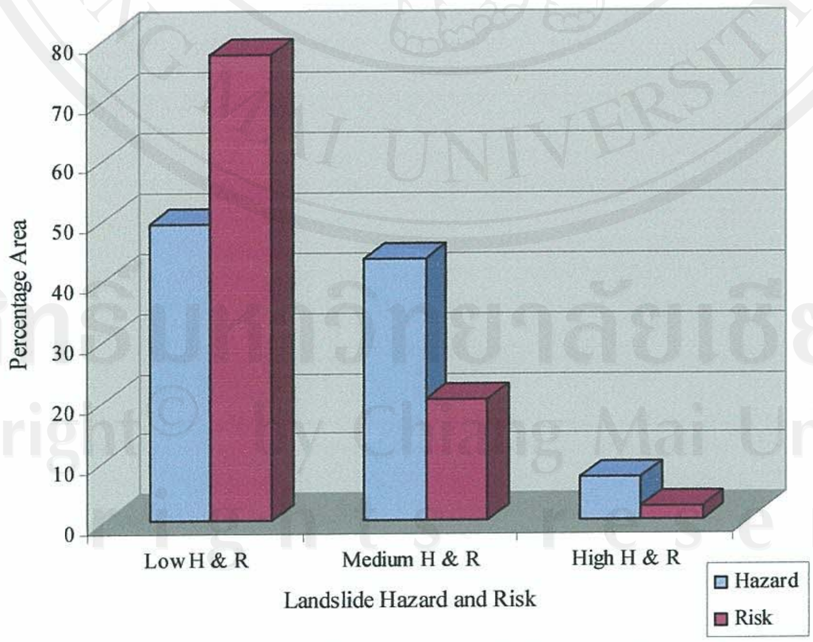


Figure 4.2 Histogram depicting the size of the area in each zone of landslide hazard and risk map

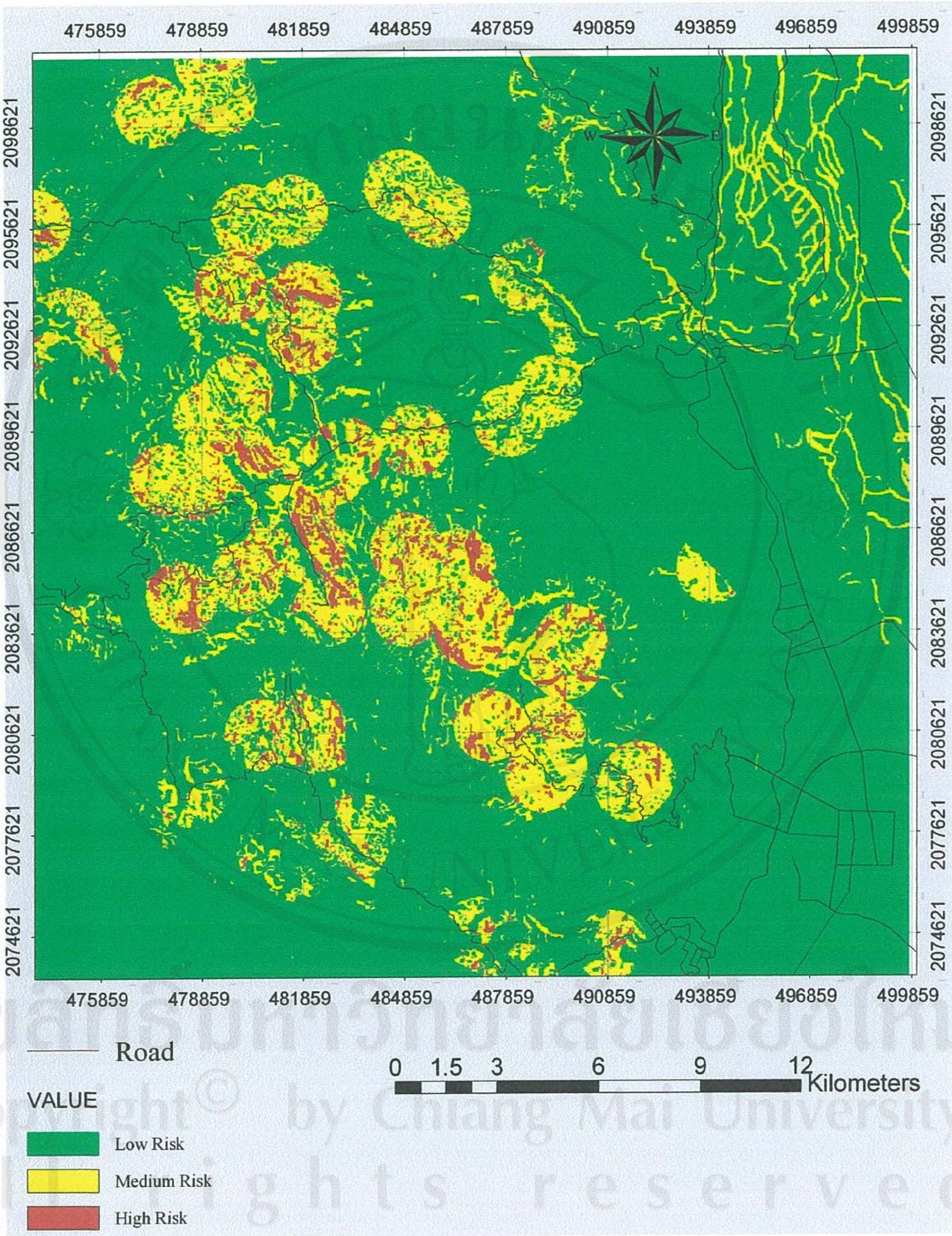


Figure 4.3 Landslide risk map of the study area.

4.3 Role of Factors in Landsliding

Landslide occurrence and behavior are governed by numerous spatial factors that can be, for the purpose of regional susceptibility assessment, cut down to several important ones. These factors can be relatively easily acquired from geological maps, topographic maps, digital elevation models, and satellite images. Using these data, good landslide susceptibility models can be developed.

4.3.1 Slope

As is the case with any landslide occurrence, a slope is one of the major factors leading to a slope failure under its own weight. The slope map, generated from the digital elevation model with the output cell size of 30m x 30m, shows that the general slope angle of the study area ranges from 0° to 60° with an average slope of 13.9° and standard deviation of 10.8°. Percentages of areas in different classes of slope angle are shown in Table 4.3. However, at different places, the natural slopes have been modified by human activities especially road and highway construction making the slopes steeper and more vulnerable to landslides. Almost all of landslides encountered during field investigation have occurred at angles of more than 45°. Studies have shown that the landslide probability increases with slope angle. As the slope angle increase, then the shear stress in the soil or other unconsolidated material generally increases. Gentle slopes are expected to have a low frequency of landslides because of the generally lower shear stress associated with low gradients. Steep natural slopes resulting from outcropping bedrock, however, may not be susceptible to landslides.

Table 4.3 Percentages of areas in different classes of slope angle

Slope Angle	Area (%)
Less than 15°	**41.01**
Between 15° - 30°	**50.62**
More than 30°	**8.37**

4.3.2 Geology

Geology of the area is seen to play a vital role in the occurrence of landslides in the study area. About 48.14% of the study area is made up of granitic and gneissic rocks where most of the landslides were encountered. Table 4.4 shows the geologic components of the study area. It was seen during the field investigation that at some places, these rocks are subjected to different degrees of weathering enhancing the probability of landsliding. These weathered materials, in the presence of certain triggering factor, can easily give way to landsliding.

Table 4.4 Percentages of areas in different classes of rock types

Geology	Area (%)
Unconsolidated Sediment	**31.87**
Carbonate Rock	**10.01**
Clastic Rock	**9.98**
Granite and Gneiss	**48.14**

4.3.3 Landuse

In the case of the relationship between landslide occurrence and the land cover, landslide occurrences were higher in bushes and grass areas, and lower in broadleaf areas. The sloping land in the vicinity of the landslide areas has been used for cultivation of various crops by villagers for a considerable period of time. The destabilized slopes are mostly abandoned land after farming on slopes or deforested land for commercial purposes as can be made out from the type of vegetation. Such slopes have been covered with inappropriate types of vegetation such as banana, bamboo, etc. Farmers usually practice farming on slopes without proper understanding of slope degradation and potential for slope destabilization. Although there is no immediate threat due to farming activities, continuation of such practices by many farmers may result in serious consequences in future. Further, as the population increases, more people are likely to get involved in such practices. Table 4.5 shows the different percentages of landuse pattern in the study area.

Table 4.5 Percentages of areas in different classes of landuse pattern

Landuse	**Area (%)**
Forest	**70.82**
Urban Land	**15.84**
Agricultural Land	**12.82**
Water Body	**0.52**

4.3.4 Stream Proximity

Inclusion of stream proximity was to assess the influence of drainage lines on landslide occurrence. For this purpose, the proximity to a drainage line was identified by buffering. In the case of the relationship between landslide occurrence and distance from drainage, as the distance from the drainage line increases, the landslide frequency generally decreases. This can be attributed to the fact that terrain modification caused by gully erosion and undercutting may influence the initiation of landslides.

Hence, some of the major drainage segments were digitized to include the effect of this causative factor and converted into raster format and buffered. The medium hazard zone in the plain area especially the river banks can be attributed to the threat posed by river under-cutting or bank erosion. However, during the field investigation no landslide triggered by under cutting or works of the streams had been sited.

4.4 Back-Analysis of Failed Slope

The back-analysis of the failed slope is aimed to ascertain the height of phreatic surface above the slip surface (h_w), which triggered the landslide. The back-analysis of the failed slope indicated that both the slopes in weathered gneiss and weathered shale failed under the influence of water at varying depth. The factor of safety for both slopes under dry condition was rather high but decreased as the water level increased.

Table 4.6 Phreatic surface height (h_w) when slopes failed and FS under dry condition

Material	Phreatic surface height (m)	FS under dry condition
Gneiss	0.7	1.407
Shale	1.1	1.434

The factor of safety during dry condition was found to be 1.407 and 1.434 for weathered gneiss and weathered shale slopes respectively indicating that the slopes are unlikely to fail. However, when subjected to heavy rainfall, the result shows that the weathered gneiss slope failed when the water level reached to about 0.7 m above slip surface while the weathered shale slope failed when the water level rose to about 1.1 m above the slip surface.

4.5 Stability Analysis of Natural Slope

The slope stability analysis of natural slopes, one each in weathered gneiss and shale, was carried out to assess the stability status and simulate the behavior of the slope in response to rainfall using CHASM software. Two intensities of rainfall, viz, 5 mm/hr (120 mm/day) and 10 mm/hr (240 mm/day) are used for the simulation. The results of the stability analysis of the two slopes, using 5 mm/h intensity (120 mm/day), are as shown in Table 4.7 and Table 4.8. The result include factor of safety, coordinates of the centre of the slip circle, the radius, weight of slip and mean runout distance. It can be seen that the factor of safety decreases as the simulation time progresses. Figure 4.4 shows the declination of the factor of safety with simulation time. The displays of the results are real-time as the calculations are made.

Under the existing set of conditions, the results show that the slope in the weathered gneiss is fairly stable with initial factor of safety 1.41. After the slope is subjected to 158 hours (6.6 days) of rainfall with the intensity of 5 mm/h (120 mm/day), the factor of safety reduces to 1.00. Similarly, the factor of safety for the weathered shale slope reduces from initial 1.34 to 1.00 after experiencing 151 hours (6.3 days) of rainfall with the intensity of 5 mm/h (120 mm/day). These indicate that the two slopes are rather stable but weaken very rapidly under the influence of prolonged rainfall with high intensity. The relationship of rainfall and slope instability is very much evident from the reduction of the factor of safety in relation to the simulation time. Thus if either the duration or the intensity of rainfall is increased the factor of safety will decrease provided that other factors remain constant.

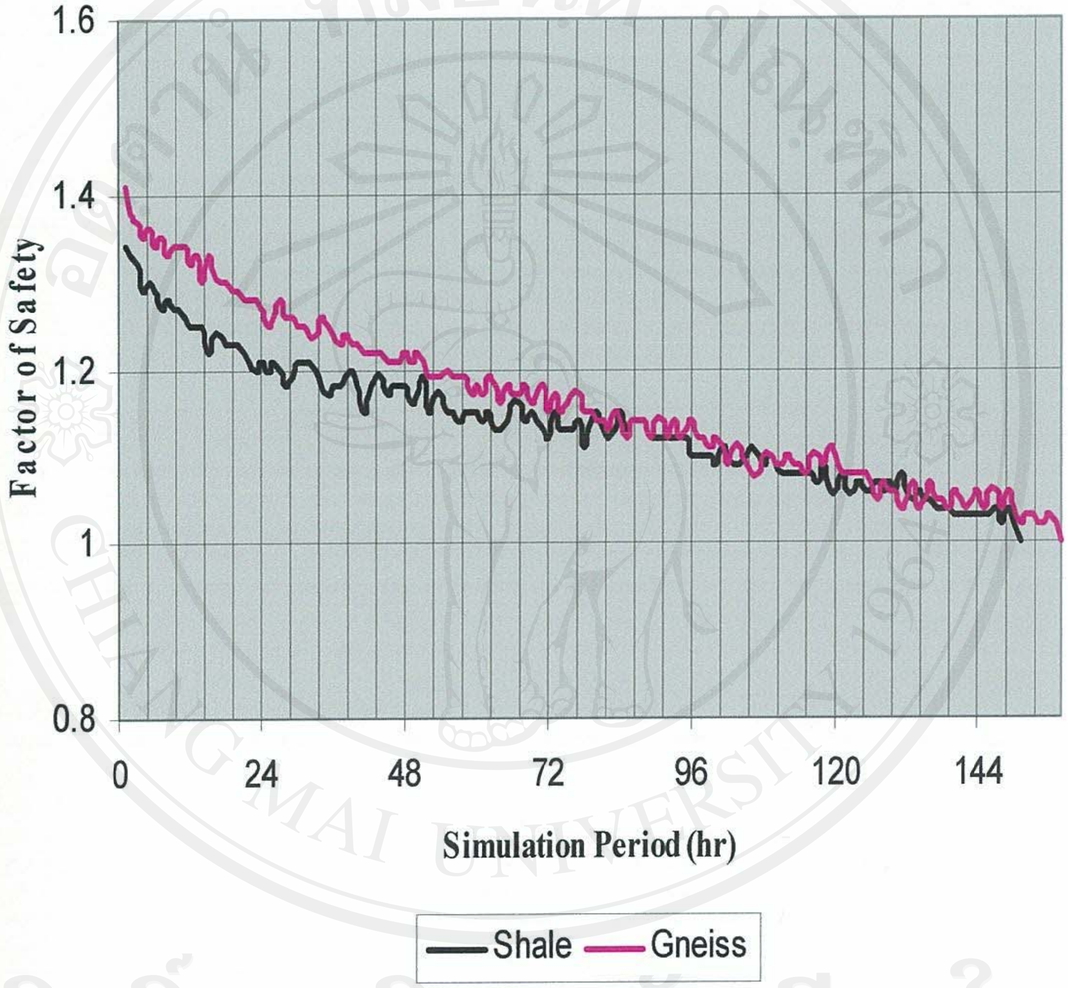


Figure 4.4 Dynamic factor of safety plot for the slopes in weathered gneiss and weathered shale with rainfall intensity of 5 mm/hr (120 mm/day)

Table 4.7 Simulation result for weathered gneiss slope with 5 mm/hr (120 mm/day) rainfall intensity

Hours	**FS**	**X (m)**	**Y (m)**	**Radius (m)**	**Weight (kN)**	**Runout (m)**
1	1.41	41.0	52.9	52.0	1.53×10^4	9.5
5	1.36	41.0	52.9	51.5	1.47×10^4	9.5
10	1.34	41.0	52.9	50.5	1.32×10^4	9.5
15	1.33	41.0	52.9	50.5	1.33×10^4	9.5
20	1.29	41.0	52.9	49.0	1.13×10^4	9.5
25	1.25	41.0	52.9	50.0	1.27×10^4	9.5
30	1.25	41.0	52.9	48.5	1.07×10^4	9.5
35	1.25	41.0	52.9	48.5	1.07×10^4	9.5
40	1.23	41.0	52.9	48.5	1.08×10^4	9.5
45	1.21	42.0	52.9	48.0	9.62×10^3	9.5
50	1.22	42.0	52.9	48.0	9.61×10^3	9.5
55	1.20	42.0	52.9	48.0	9.64×10^3	9.5
60	1.18	42.0	52.9	48.0	9.67×10^3	9.5
65	1.18	42.0	52.9	48.0	9.67×10^3	9.5
70	1.17	42.0	52.9	48.0	9.68×10^3	9.5
75	1.16	42.0	52.9	48.0	9.69×10^3	9.5
80	1.14	42.0	52.9	48.0	9.74×10^3	9.5
85	1.12	42.0	52.9	48.0	9.77×10^3	9.5
90	1.14	42.0	51.9	47.0	9.47×10^3	9.5
95	1.13	42.0	51.9	47.0	9.47×10^3	9.5
100	1.12	42.0	51.9	47.0	9.50×10^3	9.5
105	1.09	42.0	51.9	47.0	9.52×10^3	9.5
110	1.09	42.0	49.9	45.0	8.94×10^3	9.5
115	1.08	42.0	51.9	47.0	9.55×10^3	9.5
120	1.10	42.0	51.9	47.0	9.52×10^3	9.5
125	1.08	42.0	49.9	45.0	8.97×10^3	9.5
130	1.06	42.0	49.9	45.0	8.99×10^3	9.5
135	1.05	42.0	49.9	45.0	9.01×10^3	9.5
140	1.06	42.0	49.9	45.0	8.99×10^3	9.5
145	1.04	42.0	49.9	45.0	9.02×10^3	9.5
150	1.04	42.0	47.9	43.0	8.42×10^3	9.5
155	1.02	43.0	43.9	39.0	8.34×10^3	8.7
158	1.00	43.0	43.9	39.0	8.22×10^3	8.7

End of simulation	Runout only applicable if FS < 1
Vegetation: off	Total duration: 168 hours
Reinforcement: off	Storm start: 0 hours
Leakage: off	Storm end: 168 hours

Table 4.8 Simulation result for weathered shale slope with 5 mm/hr (120 mm/day) rainfall intensity

Hours	FS	X (m)	Y (m)	Radius (m)	Weight (kN)	Runout (m)
1	1.34	44.6	53.6	52.5	1.49×10^4	3.6
5	1.30	44.6	53.6	51.5	1.36×10^4	3.6
10	1.27	44.6	53.6	51.0	1.30×10^4	3.6
15	1.22	44.6	53.6	50.5	1.24×10^4	3.6
20	1.23	44.6	53.6	50.5	1.24×10^4	3.6
25	1.20	44.6	53.6	50.0	1.18×10^4	3.6
30	1.21	44.6	53.6	50.5	1.24×10^4	3.6
35	1.17	44.6	53.6	50.5	1.26×10^4	3.6
40	1.18	44.6	53.6	50.0	1.19×10^4	3.6
45	1.17	44.6	53.6	49.5	1.13×10^4	3.6
50	1.17	44.6	53.6	49.5	1.13×10^4	3.6
55	1.15	44.6	53.6	50.0	1.20×10^4	3.6
60	1.15	44.6	53.6	49.5	1.14×10^4	3.6
65	1.14	44.6	53.6	49.5	1.14×10^4	3.6
70	1.14	44.6	53.6	49.0	1.07×10^4	3.6
75	1.13	44.6	53.6	47.0	8.41×10^3	3.6
80	1.15	44.6	53.6	48.5	1.01×10^4	3.6
85	1.13	44.6	53.6	49.0	1.08×10^4	3.6
90	1.12	44.6	53.6	49.0	1.08×10^4	3.6
95	1.12	44.6	53.6	45.0	6.38×10^3	3.4
100	1.09	44.6	53.6	45.0	6.41×10^3	3.4
105	1.10	44.6	53.6	45.0	6.39×10^3	3.4
110	1.09	44.6	53.6	45.0	6.43×10^3	3.4
115	1.08	44.6	53.6	45.0	6.42×10^3	3.4
120	1.06	44.6	53.6	45.0	6.46×10^3	3.4
125	1.06	44.6	53.6	45.0	6.47×10^3	3.4
130	1.06	44.6	53.6	45.0	6.45×10^3	3.4
135	1.05	44.6	53.6	45.0	6.49×10^3	3.4
140	1.03	44.6	53.6	45.0	6.50×10^3	3.4
145	1.03	44.6	53.6	45.0	6.50×10^3	3.4
150	1.02	44.6	53.6	45.0	6.55×10^3	3.4
151	1.00	44.6	53.6	44.5	6.09×10^3	3.4

End of simulation	Runout only applicable if FS < 1
Vegetation: off	Total duration: 168 hours
Reinforcement: off	Storm start: 0 hours
Leakage: off	Storm end: 168 hours

Figure 4.5 shows the dynamic factor of safety plot for the slopes in weathered gneiss and weathered shale with the rainfall intensity of 10 mm/h (240 mm/day). The simulation results obtained are presented in Table 4.9 and Table 4.10 for slope in weathered gneiss and weathered shale respectively. The result also includes the actual mode of failure, i.e. the critical slip surface with coordinates and slip circle radius.

Rainfall intensity of magnitude 240 mm/day could be rare in the study area where average monthly rainfall, in the past, have rarely exceeded 300 mm. However, such an extreme event might occur in the future as was the case in southern Thailand. Rainfall intensity of such extreme magnitude had occurred in Nakhon Si Thammarat province in the southern Thailand in 1988 which led to unprecedented widespread slope failures in the mountainous areas and debris flows and flooding in lower areas downstream (Phien-wej *et al.*, 1993). The unusual rainfall intensity during three days amounted to more than 700 mm while the mean annual rainfall of the area is only a little above 2000 mm. This triggered one of the worst natural disaster in the living history of the region killing 373 people and property damage amounting to 280 million dollars. Should such an extreme event occur in the future, then the natural slopes under investigation would reach to critical state after 91 hours in weathered gneiss and 77 hours in weathered shale. Nutalaya and Sophonsakulrat (1989) found that rainfall intensity of 260 mm/day was a threshold for the occurrence of widespread landslides in southern Thailand.

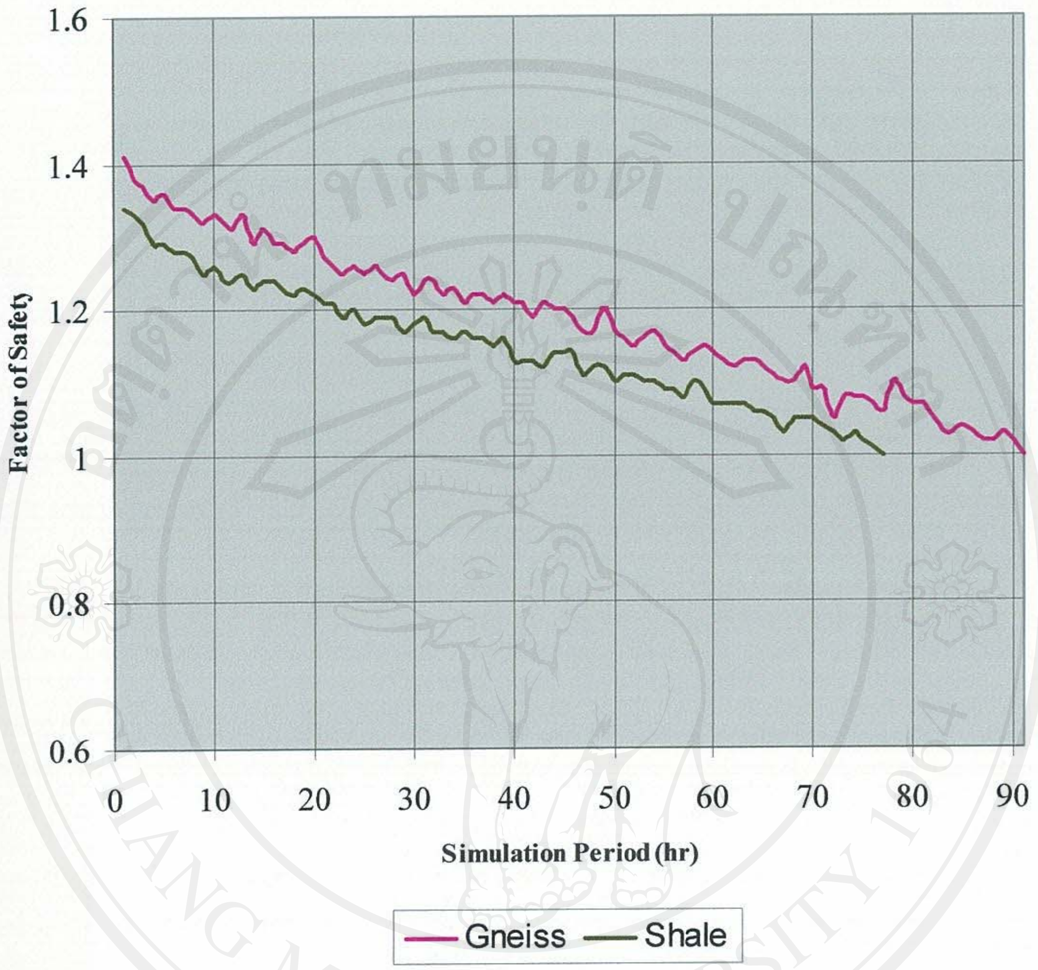


Figure 4.5 Dynamic factor of safety plot for the slopes in weathered gneiss and weathered shale with rainfall intensity of 10 mm/hr (240 mm/day)

One of the important parts of the simulation result is the weight of the slide mass and the runout distance. Very often the damage potential of an unstable slope is related to the weight and the distance the sliding mass travel. In the gneiss slope the weight of the sliding mass ranges from 8,220 kN to 15,300 kN while in the shale slope the weight of the sliding mass ranges from 6,090 kN to 14,900 kN. The average runout distance for gneiss and shale slopes are 9.5 m and 3.6 m respectively, with the

Table 4.9 Simulation result for weathered gneiss slope with 10 mm/hr (240 mm/day) rainfall intensity

Hours	FS	X (m)	Y (m)	Radius (m)	Weight (kN)	Runout (m)
1	1.41	41.0	52.9	52.0	1.53 $\times 10^4$	9.5
3	1.37	41.0	52.9	51.5	1.47 $\times 10^4$	9.5
6	1.34	41.0	52.9	51.5	1.47 $\times 10^4$	9.5
9	1.32	41.0	52.9	51.0	1.40 $\times 10^4$	9.5
12	1.31	41.0	52.9	51.0	1.40 $\times 10^4$	9.5
15	1.31	41.0	52.9	50.5	1.33 $\times 10^4$	9.5
18	1.28	41.0	52.9	50.5	1.33 $\times 10^4$	9.5
21	1.27	41.0	52.9	50.5	1.34 $\times 10^4$	9.5
24	1.26	41.0	52.9	48.5	1.07 $\times 10^4$	9.5
27	1.25	41.0	52.9	48.5	1.07 $\times 10^4$	9.5
30	1.22	41.0	52.9	48.5	1.07 $\times 10^4$	9.5
33	1.22	41.0	52.9	48.5	1.08 $\times 10^4$	9.5
36	1.22	41.0	52.9	48.5	1.08 $\times 10^4$	9.5
39	1.22	41.0	52.9	48.5	1.08 $\times 10^4$	9.5
42	1.19	41.0	51.9	47.5	1.05 $\times 10^4$	9.5
45	1.2	41.0	52.9	48.5	1.08 $\times 10^4$	9.5
48	1.17	42.0	52.9	48.0	9.67 $\times 10^3$	9.5
51	1.16	42.0	52.9	48.0	9.68 $\times 10^3$	9.5
54	1.17	42.0	52.9	48.0	9.68 $\times 10^3$	9.5
57	1.13	42.0	52.9	48.0	9.75 $\times 10^3$	9.5
60	1.14	42.0	52.9	48.0	9.73 $\times 10^3$	9.5
63	1.13	42.0	52.9	48.0	9.75 $\times 10^3$	9.5
66	1.11	42.0	52.9	48.0	9.77 $\times 10^3$	9.5
69	1.12	42.0	51.9	47.0	9.48 $\times 10^3$	9.5
72	1.05	42.0	49.9	45.0	8.99 $\times 10^3$	9.5
75	1.08	42.0	49.9	45.0	8.95 $\times 10^3$	9.5
78	1.10	42.0	51.9	47.0	9.50 $\times 10^3$	9.5
81	1.07	42.0	51.9	47.0	9.53 $\times 10^3$	9.5
84	1.03	42.0	49.9	45.0	9.02 $\times 10^3$	9.5
87	1.02	42.0	49.9	45.0	9.02 $\times 10^3$	9.5
90	1.02	42.0	49.9	45.0	9.03 $\times 10^3$	9.5
91	1.00	42.0	49.9	45.0	9.05 $\times 10^3$	9.5

End of simulation — Runout only applicable if FS < 1 .

Vegetation: off — Total duration: 100 hours

Reinforcement: off — Storm start: 0 hours

Leakage: off — Storm end: 100 hours

Table 4.10 Simulation result for weathered shale slope with 10 mm/hr (240 mm/day) rainfall intensity

Hours	**FS**	**X (m)**	**Y (m)**	**Radius (m)**	**Weight (kN)**	**Runout (m)**
1	1.34	44.6	53.6	52.5	1.49×10^4	3.6
3	1.32	44.6	53.6	52.0	1.42×10^4	3.6
6	1.28	44.6	53.6	51.5	1.36×10^4	3.6
9	1.25	44.6	53.6	50.5	1.23×10^4	3.6
12	1.24	44.6	53.6	50.5	1.23×10^4	3.6
15	1.24	44.6	53.6	50.5	1.24×10^4	3.6
18	1.22	44.6	53.6	50.5	1.24×10^4	3.6
21	1.21	44.6	53.6	50.0	1.18×10^4	3.6
24	1.20	44.6	53.6	50.0	1.18×10^4	3.6
27	1.19	44.6	53.6	50.5	1.25×10^4	3.6
30	1.18	44.6	53.6	49.5	1.12×10^4	3.6
33	1.17	44.6	53.6	49.5	1.12×10^4	3.6
36	1.16	44.6	53.6	49.5	1.13×10^4	3.6
39	1.16	44.6	53.6	49.5	1.13×10^4	3.6
42	1.13	44.6	53.6	49.5	1.14×10^4	3.6
45	1.14	44.6	53.6	49.5	1.13×10^4	3.6
48	1.12	44.6	53.6	49.5	1.14×10^4	3.6
51	1.11	44.6	53.6	49.5	1.14×10^4	3.6
54	1.10	44.6	53.6	49.0	1.08×10^4	3.6
57	1.08	44.6	53.6	48.5	1.02×10^4	3.6
60	1.07	44.6	53.6	46.0	7.41×10^3	3.5
63	1.07	44.6	53.6	45.0	6.40×10^3	3.4
66	1.05	44.6	53.6	45.0	6.44×10^3	3.4
69	1.05	44.6	53.6	45.0	6.45×10^3	3.4
72	1.03	44.6	53.6	45.0	6.49×10^3	3.4
77	1.00	44.6	53.6	45.0	6.52×10^3	3.4

End of simulation — Runout only applicable if FS < 1

Vegetation: off — Total duration: 100 hours

Reinforcement: off — Storm start: 0 hours

Leakage: off — Storm end: 100 hours

maximum runout distance for the slope in gneiss as 25.18 m and for the slope in shale as 17.79 m. The slope in gneiss has a comparatively higher weight and longer runout distance. Thus if at all the conditions become favorable to lower the factor of safety below 1.00, the slope in gneiss will bring comparatively larger damage than the landslide in shale.

In this study, only one soil strata has been considered. Many studies have shown that the deep seated and devastating landslides usually occur where the thickness the soil thickness over bedrock is very high. It was seen during the field investigation that the soil thickness is quite thin in the study area. This is evident from the thickness of the existing landslides and vertical soil profile seen along the road cuts.

Another factor which needs to be studied during the slope stability analysis is the effect of vegetation on the stability of slope. Although the CHASM software is provided with a provision to incorporate the effect of vegetation in slope stability analysis (Ibraim and Anderson, 2002), the same could not be included due to the absence of reliable data. However, it is generally known that inclusion of the vegetation has positive effect. It is a clear fact that vegetation can contribute to slope stability by achieving the following effects: (1) preventing surface erosion through the soil binding properties of roots; (2) reducing the effects of splash erosion through rainfall interception of vegetation canopy; (3) reducing the incidence of shallow slope instability through the anchoring properties of roots; (4) channeling run-off to alter slope hydrology; and (5) providing support to the base of the slope and trapping material moving down the slope (Lammeranne *et al.*, 2005). Inclusion of the vegetation in the simulation would have yielded higher factor of safety than what was obtained under. The software indicates that the increases in factor of safety upon inclusion of vegetation in the stability analysis is because of the reduction in the effective rainfall reaching the ground due to canopy obstruction and increment in cohesion of the soil due to its roots.

It is known that rapid infiltration of rainfall, causing soil saturation and a temporary rise in pore water pressures (reduction of soil suction to zero) is generally believed to be the mechanism by which most landslides are triggered during rainfall. This effect of rainfall can be clearly visualized with the CHASM software. However, slopes composed of either soil and/or rock respond differently as a function of their geological, physical, mechanical and hydraulic characteristics during the rainfall process (Lan *et al.*, 2003). In addition, the slopes with different permeability have distinct hydraulic and mechanical behaviors during the same rainfall process. A study carried out by Lan *et al.* (2005) showed that pore water pressure and slope stability distribution show significantly different features at different depths of the slope profile during the rainfall process.

From the field verification of the landslides, it can be seen that most of the landslides that occur in weathered gneiss are relatively thinner than those in shale. The thickness of the weathered shale slide is about 5 to 6 meters comparing to the thickness of the slide in weathered gneiss which is only about 2 to 3 meters. This confirms to the findings of the study conducted by Lan *et al.* (2003) that slope with higher permeability results in deep seated landslide while lesser permeability slopes results in shallower landslides as permeability of the weathered shale is on the higher side than that of weathered gneiss. The permeability of the weathered shale and weathered gneiss are 3.57×10^{-6} m/s and 2.16×10^{-6} m/s respectively.

CHAPTER 5

CONCLUSIONS

Landslide occurrence and behavior are governed by numerous spatial factors that can be, for the purpose of regional landslide hazard and risk assessment, cut down to several important ones. The factors considered in this study are slope, geology, landuse and stream proximity. These factors can be relatively easily acquired from geological maps, topographic maps and digital elevation model.

The heuristic approach adopted in this study has been proven elsewhere as one of the good methods especially hazard and risk assessment maps are to be made at a regional scale. The main drawback of this approach, however, lies in the subjectivity involved, both in the direct mapping as well as in the assignment of weights to the parameter classes. Nevertheless, the allocation of parameter weighting values can be assisted by the AHP, which permits a quantitative evaluation of each parameter based on the analyst's expertise. It has been shown that the use of the AHP method gives a means to define the factor weights in the linear landslide susceptibility model. Using the weights derived from AHP, a reasonably good landslide hazard and risk models were developed.

GIS has been proven to be an excellent tool in the spatial analysis of the terrain parameters for landslide hazard and risk zonation. Using GIS, good results are obtained in regional reconnaissance maps, when experienced-based conclusions on hazard susceptibility are qualitatively extrapolated over large areas. The maximum benefit of GIS is obtained at larger scales, when the details about the causative factors are determined in relation to the occurrence of landslides. The use of GIS can also be extended to the optimization of the hazard model, which otherwise is very cumbersome or not possible at all. However, the use of GIS cannot replace extensive field work and data collection. Therefore, more multidisciplinary collaboration is needed to establish a more rational dynamic model, as well as more detailed knowledge and understanding of the in situ-conditions of geomorphology, geology, and hydrology for accurate estimation of the spatial and temporal distribution of related parameters and their variance.

The usage of this landslide hazard and risk map should not be an end in itself. These maps should be rather used as a tool to narrow down the selection of a site for any developmental schemes such as roads, building construction, villages, towns, etc. in the initial planning phase. The use of such maps should always be followed by detailed subsoil and geotechnical investigation to acquire thorough information about the site.

The role of water as a triggering agent has been explicitly elucidated using the CHASM software. The effect of water and development of pore water pressure can be dynamically studied with the software. As is the case anywhere, water is one of the main agent triggering landslides in the study area and due consideration should be given to rainfall before anything is planned.

From this study, the assessment of landslide causative factors and hydrological modeling, it can be interpreted that the distribution of landslides is largely governed by a combination of geoenvironmental conditions, such as different landuse patterns, slope, proximity (<50 m) to the streams and geology of an area triggered by rainfall. And it can be concluded that the GIS-based methodology for integration of various topographic, geological, structural, landuse/landcover and other datasets seems to be quite suitable for developing a landslide hazard and risk zonation map.

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APPENDIX A

AHP process for weighting four parameters

Step 1: Pair-wise ranking of parameters (judgment matrix).

	Slope	Geology	Landuse	Stream Proximity
Slope	**1**	2	5/2	7/2
Geology	1/2	**1**	2	4
Landuse	2/5	1/2	**1**	2
Stream Proximity	2/7	1/4	1/2	**1**

Step 2: Synthesis of judgment matrix – matrix A

	Slope	Geology	Landuse	Stream Proximity	**Total**
Slope	**1.00**	2.00	2.50	3.50	**9.00**
Geology	0.50	**1.00**	2.00	4.00	**7.50**
Landuse	0.40	0.50	**1.00**	2.00	**3.90**
Stream Proximity	0.29	0.25	0.50	**1.00**	**2.04**
Total	**2.19**	**3.75**	**6.00**	**10.50**	**22.44**

Step 3: Calculation of priorities using approximation method (normalized matrix, each cell is divided by respective column total to obtain the values in the cells.

	Slope	Geology	Landuse	Stream Prox.	**Total**	**Average W**
Slope	0.46	0.53	0.42	0.33	**1.74**	**0.44**
Geology	0.23	0.27	0.33	0.38	**1.21**	**0.30**
Landuse	0.18	0.13	0.17	0.19	**0.67**	**0.17**
Stream Proximity	0.13	0.07	0.08	0.10	**0.38**	**0.09**
Total	**1.00**	**1.00**	**1.00**	**1.00**	**4.00**	**1.00**

Step 4: Consistency measurement (Consistency matrix) A*W

Each column value in step 2 (Matrix A) is multiplied by its respective row W

	Slope	Geology	Landuse	Stream Prox.	**Total**	**Total/W**
Slope	0.44	0.60	0.42	0.33	1.79	**4.11**
Geology	0.22	0.30	0.34	0.38	1.23	**4.08**
Landuse	0.17	0.15	0.17	0.19	0.68	**4.05**
Stream Proximity	0.12	0.08	0.08	0.09	0.38	**4.02**
			Average Lamda max (λ_{max})			**4.07**

Consistency Index (CI) = (λ_{max} - n)/n-1

Where, n = number of criteria under consideration, here 4 parameters

CI = (4.07 – 4)/ (4-1)

= 0.0233

Consistency Ratio (CR) = CI / CI_r

Where, CI is consistency index and CI_r random value of CI for r criteria, here 4 parameters.

CR = 0.0233/ 0.90

= 0.03

CR is acceptable since it is less than 0.09 for a 4x4 matrix.

Average consistency index for different order matrices and acceptable limit of CR

	Size of matrix (n)									
	1	2	3	4	5	6	7	8	9	10
Random CI Value	0.00	0.00	0.52	0.90	1.11	1.25	1.35	1.40	1.45	1.5
Acceptable			<0.05	<0.09	←		<0.10			→

Source: Saaty (1980)

APPENDIX B

Geotechnical Lab Result

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239 ถ.ห้วยแก้ว ต.สุเทพ อ.เมือง จ.เชียงใหม่ โทร. 053-944157-66 โทรสาร 053-892376

GEOTECHNICAL ENGINEERING LABORATORY

DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED UNDRAINED CONDITIONS

ASTM D 3080-90

Client:	Mr. Dorji Gyeltshen P.	*Job No:*	344/49
Project:	Landslide Hazard and Risk Assessment of Doi Suthep Area	*Date:*	19 ธ.ค. 49
Location:	Doi Suthep, Chiang Mai	*Sample No.*	I, S2(Shale) 770823
Soil Description:	ดินเหนียวปนซิลท์ สีน้ำตาลเข้ม	*Depth (m.)*	-
Remark:		*Tested By:*	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

WORK INSTRUCTIONS

Test procedure was carried out according to ASTM D3080-90, which can be described briefly as follows :

1) The test condition is the consolidated undrained test, using square box, (CU Test)
2) Samples were prepared from an undisturbed soil collected using a 6" tube
3) Three samples were used with the applied normal stress of 4.0, 10.0, 16.0 t/sq.m. coresponding to the overburden pressure of height 2, 5 and 8 m.
4) Each sample was consolidated in a shear box by load steps, consolidation was monitored till completion before starting a new load step
5) After completion of consolidated under full normal stress, the samples were then allowed to be under water for 12 hours to ensure a saturated condition
6) Under full normal stress, the samples were tested under undrained condition, using the shear rate of 1.2 mm./minute (as recommended by J.E. Bowles, Engineering Properties of Soil and Their Measurement)
7) The maximum shearing stress were obtained from all tests , the Mohr-Coulomb failure line was drawn and the value of Cohesion and Friction angle were determined

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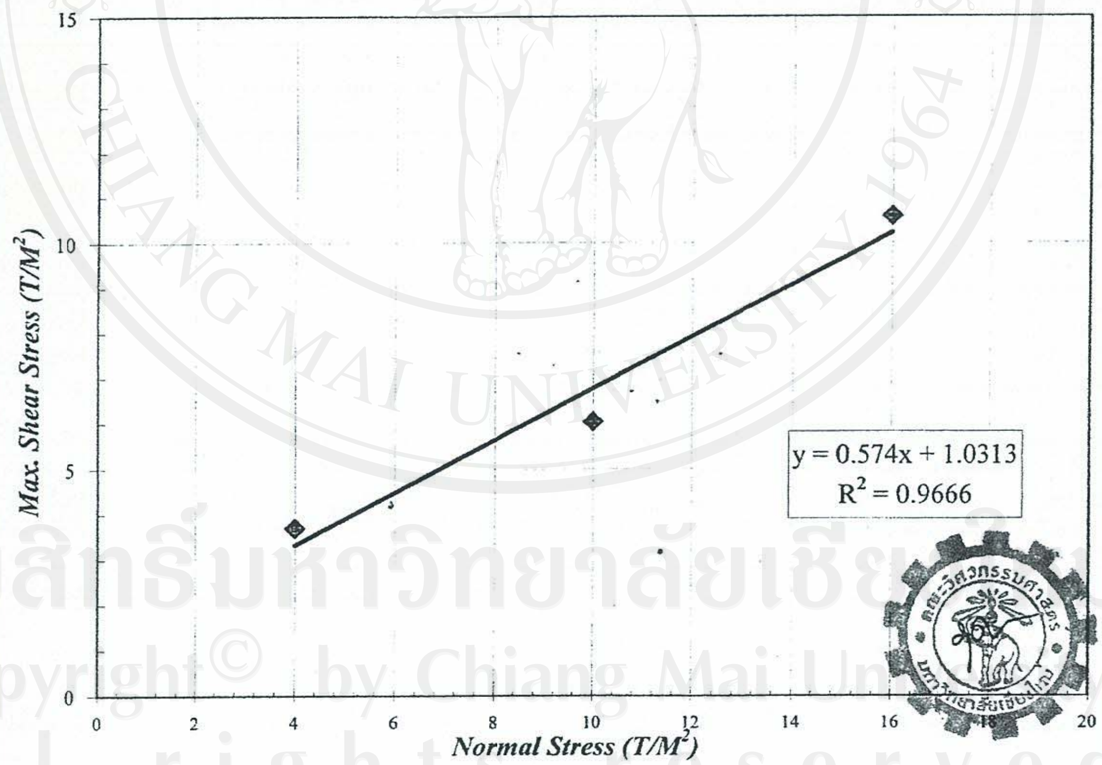
Location:	Doi Suthep, Chiang Mai	*Sample No.*	1, S2(Shale) 770823
Soil Description:	ดินเหนียวปนซิลท์ สีน้ำตาลเข้ม	*Depth (m.)*	-
		Tested By:	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

	Test1	Test 2	Test3	Test 4	
Normal Stress (T/M2)	4.0	10.0	16.0	-	-
Max. Shear Stress (T/M2)	3.7	6.0	10.6	-	-



Remarks:

Cohesion, C (T/M²) 1.09

Friction Angle, ϕ (degree) 29

Direct_shear044_49_sp1.XLS/sample2

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Remark:		***Tested By:***	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

Load - Deformation Data

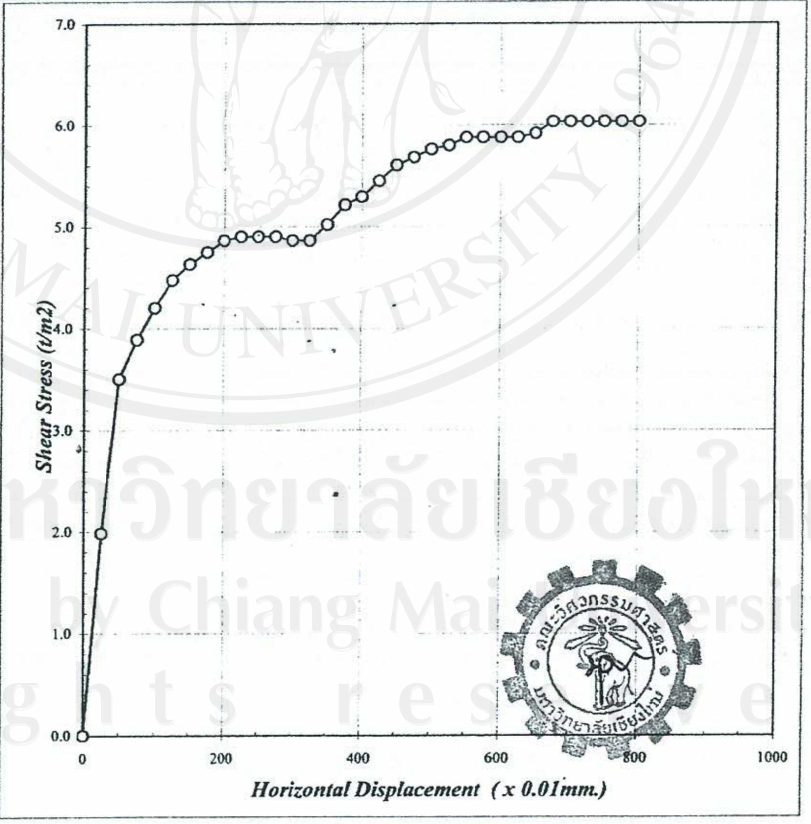
Horiz. Disp. (0.01mm.)	Hori. Load Rd. (Div.)	Verti. Disp. (Div.)	Shear Stress (T/M^2)
0	0	0	0.0
25	51	20	2.0
50	90	40	3.5
75	100	48	3.9
100	108	59	4.2
125	115	67	4.5
150	119	78	4.6
175	122	90	4.7
200	125	104	4.9
225	126	117	4.9
250	126	128	4.9
275	126	140	4.9
300	125	150	4.9
325	125	164	4.9
350	129	178	5.0
375	134	192	5.2
400	136	205	5.3
425	140	217	5.4
450	144	230	5.6
475	146	248	5.7
500	148	255	5.8
525	149	265	5.8
550	151	274	5.9
575	151	282	5.9
600	151	290	5.9
625	151	300	5.9
650	152	310	5.9
675	155	318	6.0
700	155	328	6.0
725	155	337	6.0
750	155	344	6.0
775	155	355	6.0
800	155	362	6.0

Sample Data

Water Content Determination			
Cont + Wet Soil (gm)	132.30	Plan Dimension (cm.)	6.00
Cont + Dry Soil (gm)	106.10	Initial Height (cm.)	1.90
Cont (gm)	17.87	Wt Samp+Cont (gm)	224.21
Water Content (%)	29.70	Wt. Cont (gm)	112.90
		Initial Area (cm^2)	36.00
		Initial Volume (cm^3)	68.40
		Wet Density (t/m^2)	1.627
		Dry Density (t/m^2)	1.255

Diect Shear Apparatus

Load Ring No.	14595
Ring Constant	0.1401 (Kg./Div.)
Shearing Rate	1.20 (mm./min)
Lever Arm Ratio	1:10
Hanging Weight	3.6 (kg)
Normal Stress	10.00 (t/m^3)



Result Summary:

Normal Stress	10.0	T/M^2
Maximum Shear Stress	6.0	T/M^2

26/12/2006

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239 ถ.ห้วยแก้ว ต.สุเทพ อ.เมือง จ.เชียงใหม่ โทร. 053-944157-66 โทรสาร 053-892376

GEOTECHNICAL ENGINEERING LABORATORY

DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED UNDRAINED CONDITIONS

ASTM D 3080-90

Client:	Mr. Dorji Gyeltshen P.	***Job No:***	344/49
Project:	Landslide Hazard and Risk Assessment of Doi Suthep Area	***Date:***	19 ธ.ค. 49
Location:	Doi Suthep, Chiang Mai	***Sample No.***	1, S2(Shale) 770823
Soil Description:	ดินเหนียวปนซิลท์ สีน้ำตาลเข้ม	***Depth (m.)***	-
Remark:		***Tested By:***	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

Load - Deformation Data

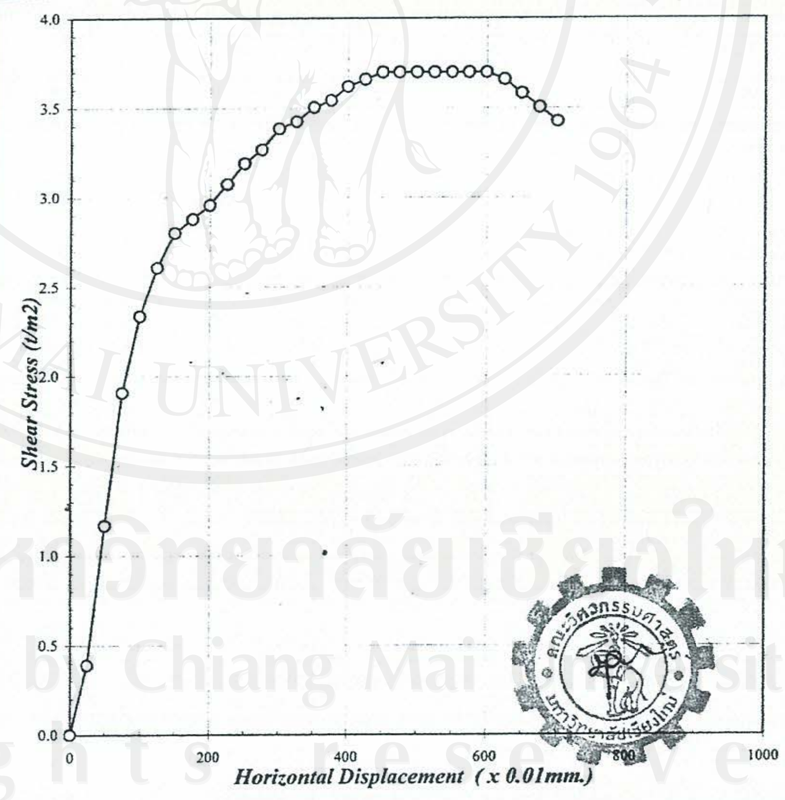
Horiz. Disp. (0.01mm.)	Hori. Load Rd. (Div.)	Verti. Disp. (Div.)	Shear Stress (T/M²)
0	0	0	0.0
25	10	2	0.4
50	30	27	1.2
75	49	54	1.9
100	60	80	2.3
125	67	107	2.6
150	72	117	2.8
175	74	222	2.9
200	76	140	3.0
225	79	151	3.1
250	82	160	3.2
275	84	174	3.3
300	87	186	3.4
325	88	197	3.4
350	90	207	3.5
375	91	214	3.5
400	93	215	3.6
425	94	232	3.7
450	95	237	3.7
475	95	252	3.7
500	95	244	3.7
525	95	246	3.7
550	95	251	3.7
575	95	254	3.7
600	95	254	3.7
625	94	254	3.7
650	92	256	3.6
675	90	257	3.5
700	88	259	3.4

Sample Data

Water Content Determination			
Cont + Wet Soil (gm)	148.01	Plan Dimension (cm.)	6.00
Cont + Dry Soil (gm)	119.96	Initial Height (cm.)	1.90
Cont (gm)	16.76	Wt Samp+Cont (gm)	219.01
Water Content (%)	27.18	Wt. Cont (gm)	112.90
		Initial Area (cm²)	36.00
		Initial Volume (cm³)	68.40
		Wet Density (t/m³)	1.551
		Dry Density (t/m³)	1.220

Diect Shear Apparatus

Load Ring No.	14595
Ring Constant	0.1401 (Kg./Div.)
Shearing Rate	1.20 (mm./min)
Lever Arm Ratio	1:10
Hanging Weight	1.44 (kg)
Normal Stress	4.00 (t/m²)



Result Summary:

Normal Stress	**4.0**	**T/M²**
Maximum Shear Stress	**3.7**	**T/M²**

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GEOTECHNICAL ENGINEERING LABORATORY

DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED UNDRAINED CONDITIONS

ASTM D 3080-90

Client:	Mr. Dorji Gyeltshen P.	***Job No:***	344/49
Project:	Landslide Hazard and Risk Assessment of Doi Suthep Area	***Date:***	19 ธ.ค. 49
Location:	Doi Suthep, Chiang Mai	***Sample No.***	1, S2(Shale) 770823
Soil Description:	ดินเหนียวปนซิลท์ สีน้ำตาลเข้ม	***Depth (m.)***	-
Remark:		***Tested By:***	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

Load - Deformation Data

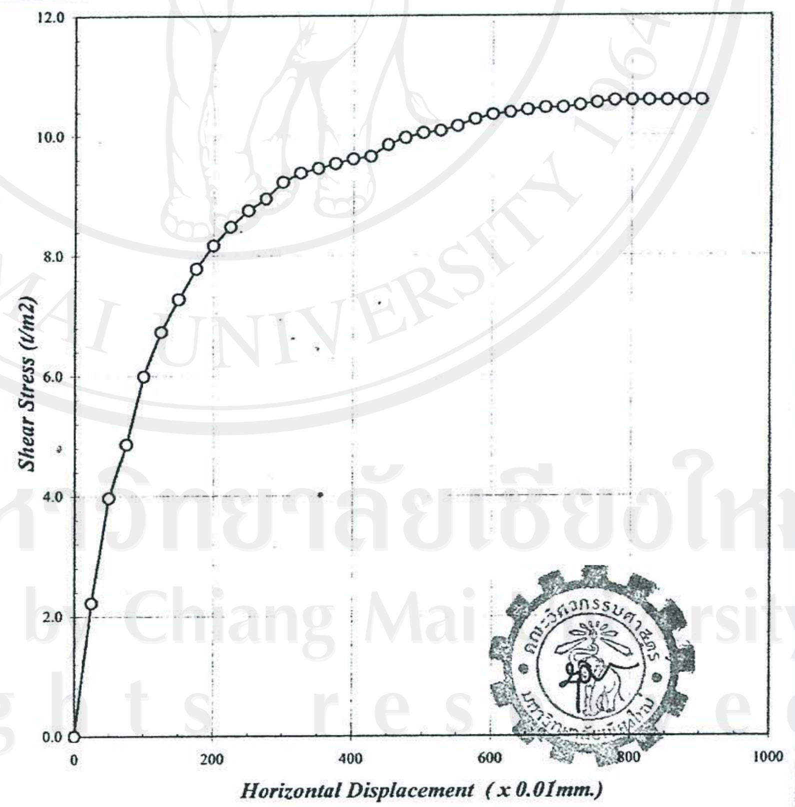
Horiz. Disp. (0.01mm.)	Hori. Load Rd. (Div.)	Verti. Disp. (Div.)	Shear Stress (T/M²)
0	0	0	0.0
25	57	3	2.2
50	102	11	4.0
75	125	29	4.9
100	154	42	6.0
125	173	60	6.7
150	187	77	7.3
175	200	92	7.8
200	210	108	8.2
225	218	120	8.5
250	225	132	8.8
275	230	146	9.0
300	237	159	9.2
325	241	175	9.4
350	243	188	9.5
375	245	200	9.5
400	247	220	9.6
425	248	225	9.7
450	253	236	9.8
475	256	245	10.0
500	258	252	10.0
525	259	261	10.1
550	261	268	10.2
575	264	273	10.3
600	266	277	10.4
625	267	283	10.4
650	268	289	10.4
675	269	290	10.5
700	269	302	10.5
725	270	306	10.5
750	271	312	10.5
775	272	318	10.6
800	272	321	10.6
825	272	325	10.6
850	272	328	10.6
875	272	332	10.6
900	272	333	10.6

Sample Data

Water Content Determination			
Cont + Wet Soil (gm)	149.94	Plan Dimension (cm.)	6.00
Cont + Dry Soil (gm)	118.77	Initial Height (cm.)	1.90
Cont (gm)	13.12	Wt Samp+Cont (gm)	223.88
Water Content (%)	29.50	Wt. Cont (gm)	112.90
		Initial Area (cm²)	36.00
		Initial Volume (cm³)	68.40
		Wet Density (t/m³)	1.623
		Dry Density (t/m³)	1.253

Diect Shear Apparatus

Load Ring No.	14595
Ring Constant	0.1401 (Kg./Div.)
Shearing Rate	1.20 (mm./min)
Lever Arm Ratio	1:10
Hanging Weight	5.76 (kg)
Normal Stress	16.00 (t/m³)



Result Summary:

Normal Stress	**16.0**	T/M²
Maximum Shear Stress	**10.6**	T/M²

26/12/2006

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DIRECT SHEAR TEST OF SOILS UNDER CONSOLIDATED UNDRAINED CONDITIONS

ASTM D 3080-90

Client:	Mr. Dorji Gyeltshen P.	*Job No:*	344/49
Project:	Landslide Hazard and Risk Assessment of Doi Suthep Area	*Date:*	19 ธ.ค. 49
Location:	Doi Suthep, Chiang Mai	*Sample No.*	2
Soil Description:	ดินปนหินผุ สีน้ำตาลอ่อน	*Depth (m.)*	-
Remark:		*Tested By:*	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

WORK INSTRUCTIONS

Test procedure was carried out according to ASTM D3080-90, which can be described briefly as follows :

1) The test condition is the consolidated undrained test, using square box, (CU Test)
2) Samples were prepared from an undisturbed soil collected using a 6" tube
3) Three samples were used with the applied normal stress of 4.0, 10.0, 16.0 t/sq.m. coresponding to the overburden pressure of height 2, 5 and 8 m.
4) Each sample was consolidated in a shear box by load steps, consolidation was monitored till completion before starting a new load step
5) After completion of consolidated under full normal stress, the samples were then allowed to be under water for 12 hours to ensure a saturated condition
6) Under full normal stress, the samples were tested under undrained condition, using the shear rate of 1.2 mm./minute (as recommended by J.E. Bowles, Engineering Properties of Soil and Their Measurement)
7) The maximum shearing stress were obtained from all tests , the Mohr-Coulomb failure line was drawn and the value of Cohesion and Friction angle were determined

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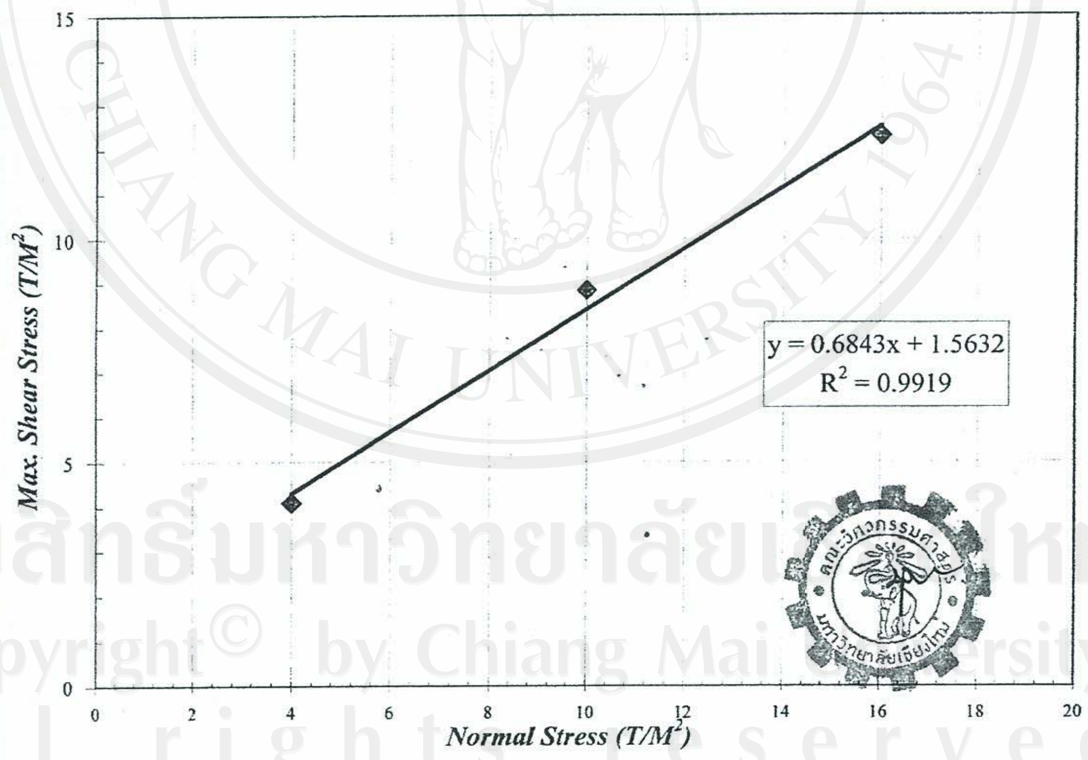
ASTM D 3080-90

Client:	Mr. Dorji Gyeltshen P.	*Job No:*	344/49
Project:	Landslide Hazard and Risk Assessment of Doi Suthep Area	*Date:*	19 ธ.ค. 49
Location:	Doi Suthep, Chiang Mai	*Sample No.*	2
Soil Description:	ดินปนหินผุ สีน้ำตาลอ่อน	*Depth (m.)*	-
		Tested By:	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

	Test1	Test 2	Test3	Test 4	
Normal Stress (T/M2)	4.0	10.0	16.0	-	-
Max. Shear Stress (T/M2)	4.1	8.8	12.3	-	-



Remarks:

Cohesion, C (T/M²)	*1.56*
Friction Angle, φ (degree)	*34*

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Location:	Doi Suthep, Chiang Mai	***Sample No.***	2
Soil Description:	ดินปนหินผุ สีน้ำตาลอ่อน	***Depth (m.)***	-
Remark:		***Tested By:***	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

Load - Deformation Data

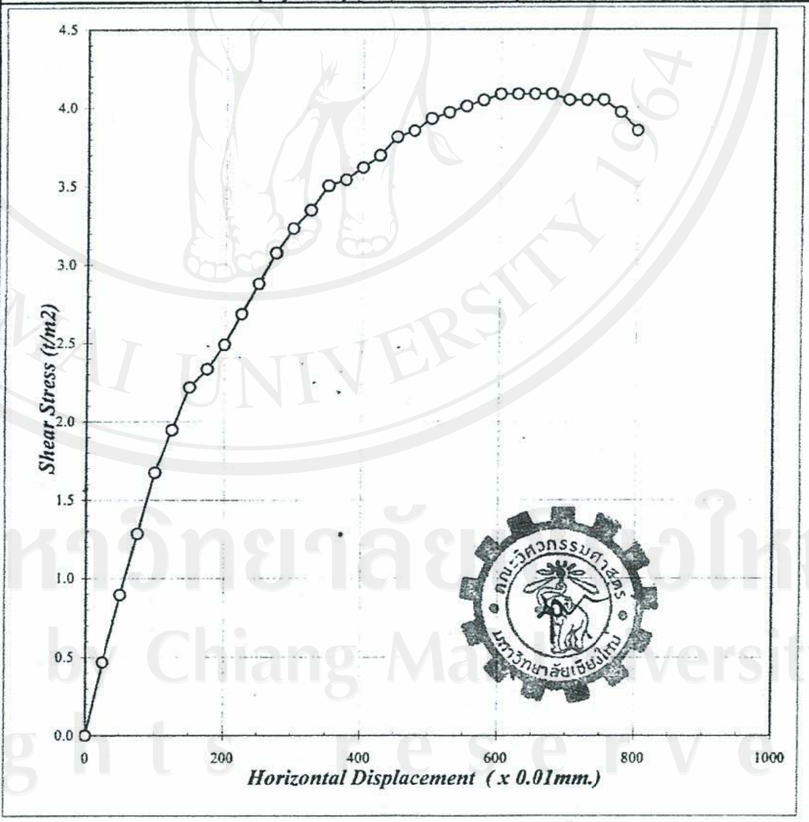
Horiz. Disp. (0.01mm.)	Hori. Load Rd. (Div.)	Verti. Disp. (Div.)	Shear Stress (T/M²)
0	0	0	0.0
25	12	14	0.5
50	23	34	0.9
75	33	55	1.3
100	43	74	1.7
125	50	89	1.9
150	57	101	2.2
175	60	110	2.3
200	64	117	2.5
225	69	126	2.7
250	74	131	2.9
275	79	136	3.1
300	83	138	3.2
325	86	141	3.3
350	90	143	3.5
375	91	147	3.5
400	93	148	3.6
425	95	148	3.7
450	98	148	3.8
475	99	148	3.9
500	101	147	3.9
525	102	145	4.0
550	103	143	4.0
575	104	134	4.0
600	105	129	4.1
625	105	119	4.1
650	105	117	4.1
675	105	116	4.1
700	104	111	4.0
725	104	106	4.0
750	104	99	4.0
775	102	89	4.0
800	99	86	3.9

Sample Data

Water Content Determination			
Cont + Wet Soil (gm)	162.05	Plan Dimension (cm.)	6.00
Cont + Dry Soil (gm)	141.60	Initial Height (cm.)	1.90
Cont (gm)	17.33	Wt Samp+Cont (gm)	231.40
Water Content (%)	16.46	Wt. Cont (gm)	112.90
		Initial Area (cm²)	36.00
		Initial Volume (cm³)	68.40
		Wet Density (t/m³)	1.732
		Dry Density (t/m³)	1.488

Diect Shear Apparatus

Load Ring No.	14595
Ring Constant	0.1401 (Kg./Div.)
Shearing Rate	1.20 (mm./min)
Lever Arm Ratio	1:10
Hanging Weight	1.44 (kg)
Normal Stress	4.00 (t/m²)



Result Summary:

Normal Stress	4.0	T/M²
Maximum Shear Stress	4.1	T/M²

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Location:	Doi Suthep, Chiang Mai	***Sample No.***	2
Soil Description:	ดินปนหินผุ สีน้ำตาลอ่อน	***Depth (m.)***	-
Remark:		***Tested By:***	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

Load - Deformation Data

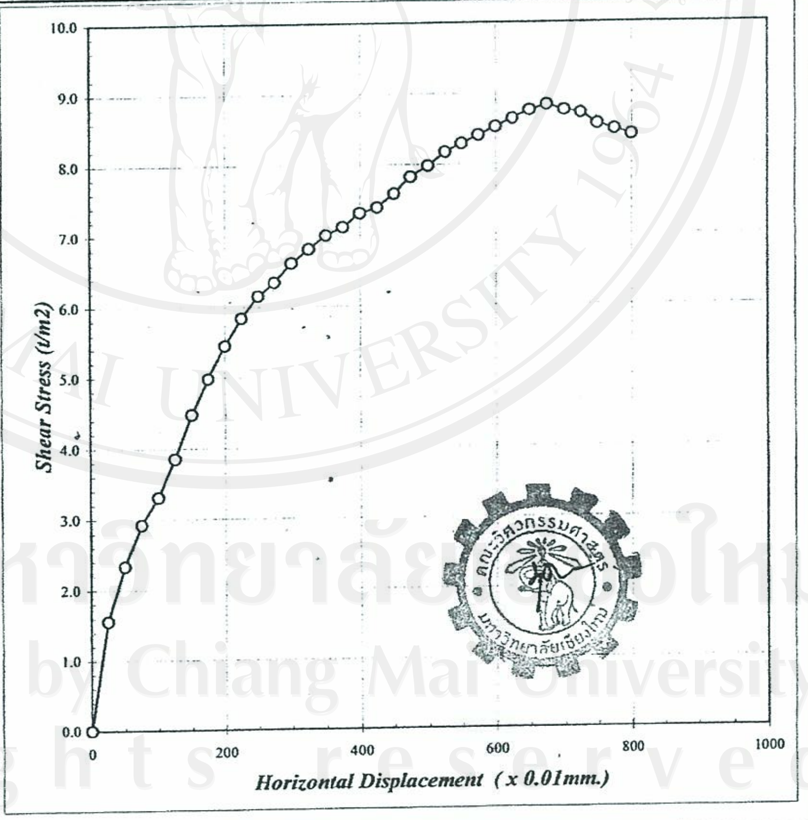
Horiz. Disp. (0.01mm.)	Hori. Load Rd. (Div.)	Verti. Disp. (Div.)	Shear Stress (T/M^2)
0	0	0	0.0
25	40	33	1.6
50	60	41	2.3
75	75	50	2.9
100	85	53	3.3
125	99	61	3.9
150	115	71	4.5
175	128	78	5.0
200	140	83	5.4
225	150	87	5.8
250	158	87	6.1
275	163	87	6.3
300	170	87	6.6
325	175	86	6.8
350	180	85	7.0
375	183	82	7.1
400	188	82	7.3
425	190	82	7.4
450	195	82	7.6
475	201	87	7.8
500	205	90	8.0
525	210	100	8.2
550	213	105	8.3
575	216	115	8.4
600	219	122	8.5
625	222	130	8.6
650	225	137	8.8
675	227	142	8.8
700	225	147	8.8
725	224	152	8.7
750	220	155	8.6
775	218	162	8.5
800	216	165	8.4

Sample Data

Water Content Determination			
Cont + Wet Soil (gm)	102.15	Plan Dimension (cm.)	6.00
Cont + Dry Soil (gm)	91.40	Initial Height (cm.)	1.90
Cont (gm)	18.21	Wt Samp+Cont (gm)	230.53
Water Content (%)	14.69	Wt. Cont (gm)	112.90
		Initial Area (cm^2)	36.00
		Initial Volume (cm^3)	68.40
		Wet Density (t/m^2)	1.720
		Dry Density (t/m^2)	1.499

Diect Shear Apparatus

Load Ring No.	14595
Ring Constant	0.1401 (Kg./Div.)
Shearing Rate	1.20 (mm./min)
Lever Arm Ratio	1:10
Hanging Weight	3.60 (kg)
Normal Stress	10.00 (t/m^3)



Result Summary:

Normal Stress	10.0	T/M^2
Maximum Shear Stress	8.8	T/M^2

26/12/2006

Direct_shear044_49_sp2.XLS/sample3

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Location:	Doi Suthep, Chiang Mai	***Sample No.***	2
Soil Description:	**ดินปนหินผุ สีน้ำตาลอ่อน**	***Depth (m.)***	-
Remark:		***Tested By:***	สายันห์
		Checked By:	รศ.ดร.บุญส่ง

Load - Deformation Data

Horiz. Disp. (0.01mm.)	Hori. Load Rd. (Div.)	Verti. Disp. (Div.)	Shear Stress (T/M²)
0	0	0	0.0
25	60	14	2.3
50	91	33	3.5
75	118	53	4.6
100	146	79	5.7
125	167	93	6.5
150	183	111	7.1
175	198	127	7.7
200	210	141	8.2
225	222	153	8.6
250	230	164	9.0
275	240	173	9.3
300	246	179	9.6
325	251	181	9.8
350	255	186	9.9
375	260	189	10.1
400	265	193	10.3
425	269	201	10.5
450	274	211	10.7
475	278	219	10.8
500	282	229	11.0
525	286	239	11.1
550	291	251	11.3
575	295	261	11.5
600	298	273	11.6
625	300	281	11.7
650	304	289	11.8
675	307	298	11.9
700	308	301	12.0
725	309	307	12.0
750	310	313	12.1
775	311	320	12.1
800	312	325	12.1
825	313	330	12.2
850	314	336	12.2
875	315	342	12.3
900	316	349	12.3
925	316	358	12.3
950	315	369	12.3
975	315	371	12.3
1000	314	376	12.2

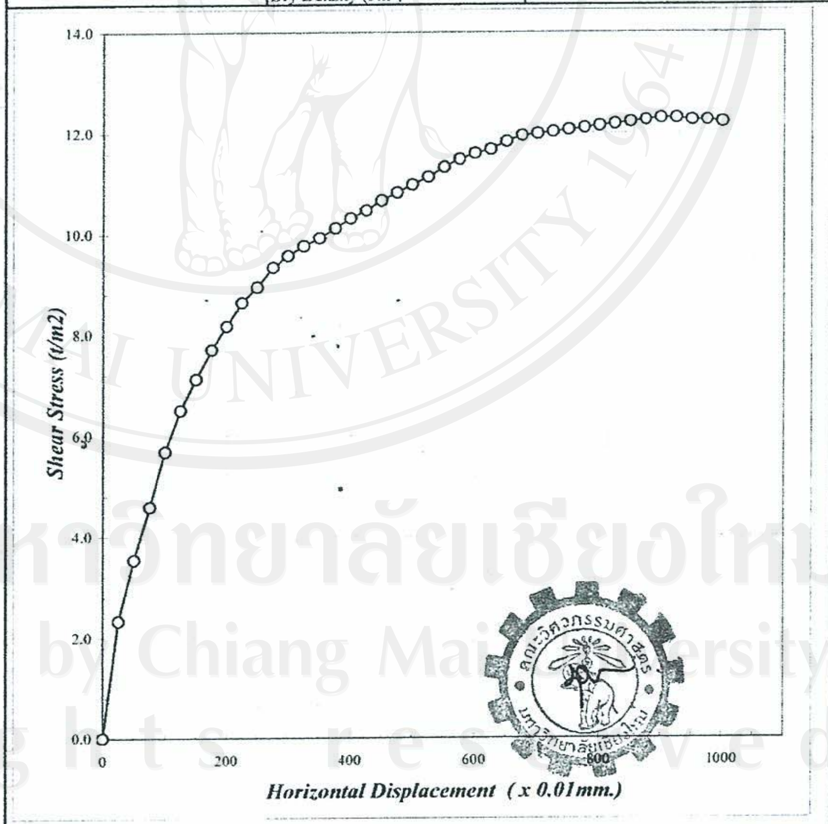
Sample Data

Water Content Determination	
Cont + Wet Soil (gm)	217.44
Cont + Dry Soil (gm)	190.22
Cont (gm)	23.96
Water Content (%)	16.37

Plan Dimension (cm.)	6.00
Initial Height (cm.)	1.90
Wt Samp+Cont (gm)	231.53
Wt. Cont (gm)	112.90
Initial Area (cm²)	36.00
Initial Volume (cm³)	68.40
Wet Density (t/m²)	1.734
Dry Density (t/m²)	1.490

Diect Shear Apparatus

Load Ring No.	14595
Ring Constant	0.1401 (Kg./Div.)
Shearing Rate	1.20 (mm./min)
Lever Arm Ratio	1:10
Hanging Weight	5.76 (kg)
Normal Stress	16.00 (t/m³)



Result Summary:

Normal Stress	**16.0**	**T/M²**
Maximum Shear Stress	**12.3**	**T/M²**

28/12/2006

CURRICULUM VITAE

Name	Dorji Gyeltshen P
Sex	Male
Date of Birth	November 7, 1976
Nationality	Bhutanese
Educational background	Bachelor Degree in Civil Engineering (2001) Hindustan College of Engineering, Padur, 603103 Madras University, Tamil Nadu, India
	Master of Science in Environmental Science (2007) Chiang Mai University Chiang Mai, Thailand
Scholarships	Royal Government of Bhutan Scholarship; 1997-2001
	Thailand International Development Cooperation Agency (TICA), Thailand, 2005-2007

Work experiences

January 2002 – present	Assistant Engineer, Department of Roads Ministry of Works & Human Settlement, Thimphu, Bhutan.