CHAPTER 3

Methodology

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3.1 Field investigation and soil sampling

3.1.1 Landslide site

The landslide is located on highway 1095 at kilometer 53 in Mae Taeng district. The slide occurred on 28th August, 2011 after rainfall on 26th-27th August, 2011. The accumulated precipitation of that period was approximately 40 mm. with the one day maximum of 30 mm on 27th August 2011. The rain gauge station is 3 km northeast of the study area. (Fig. 3.1). Landslide classification systems based on a combination of material and movement mechanism proposed by Varnes (1978) is adapted in this study. Most of the landslides in the study area are translational and debris slide. The debris slide covered highway 1095. The distance from crown to toe was measured at 210 m. The uppermost part of the sliding mass was approximately 25.2 m wide and a maximum depth of 1.5 m. The elevation of the area ranges between 870 m to 950 m MSL and a slope angle of 25° to 32°. Soil samples were collected for laboratory testing (see Figure 3.2). Nine soil samples of at least 2.5 kg were obtained by hand augering from 0 to 150 cm depths at 50 cm intervals. Three undisturbed soil samples were collected using the thin-walled tube at a depth of 150 cm. at different slope position (Top -A, middle -B and bottom-C). Soil samples were tested in the laboratory for index properties identification, clay mineral studies, and strength parameter studies. All index parameters such as liquid limits, and plastic limits were determined in the laboratory along with the grain size distribution.

3.1.2 Non-landslide site

The non-landslide is located at kilometer 50, about 3 kilometres south of the landslide site. This site has a slope angle of 26° to 34° and the elevation ranges between 750-900 m MSL. Soil samples were collected for laboratory testing (Figure 3.2).



Nine soil samples of at least 2.5 kg were obtained by hand augering from 0 to 150 cm depths at 50 cm intervals. Three undisturbed soil samples were collected using the thinwalled tube at depth 150 cm at different slope position (Top -A, middle -B and bottom -C). Soil samples were tested in the laboratory. Figure 3.3 shows a 3D digital elevation model of the landslide and non-landslide areas.

3.2 Geotechnical soil properties

3.2.1 Permeability test

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by Chiang Mai University Permeability is a parameter that characterizes the ability of a soil to allow water, to pass through, and is generally measured as the rate of water flow through the soil in a given period of time. Permeability is one of the most important soil properties of interest to geotechnical.

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Fig. 3.2. Photographs of study areas A) Landslides occurred at kilometer 53 and location of collected soil samples. B) Non-landslide area at kilometer 50.



Figure 3.3 3D digital elevation model of landslide and non-landslide areas with soil sampling locations.

Apparatus:

Hand auger, six PVC pipe (diameter 5 cm and height 2 m), watch, water supply, and scale

Test Procedure:

(1) Drill the borehole in a direction perpendicular to the stratification or plane of compaction, which may or may not be perpendicular to the ground surface. Drill a hole with a diameter at least 5 cm and 1.5 m depth in the soil at the landslide and non-landslide areas and the soil samples were collected every at 0.5 m depth interval for laboratory testing.

(2) Insert PVC pipe into the borehole with and fill water to the top (Fig 3.4).

(3) Start measuring the water surface using a watch and a scale to measure the distance between the water level and the top of the PVC pipe every fifteen minutes, for at least 60 minutes.



Figure 3.4 Drilling the borehole by hand auger and performing in situ permeability test.

3.2.2 Grain size analysis (sieve and hydrometer analysis)

Grain size analysis is performed to determine the percentage of different grain sizes contained within a soil mass (ASTM D422 - Standard Test Method for Particle-Size

Analysis of Soils). The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles (ASTM E100 - Specification for ASTM Hydrometers)

Apparatus:

Sieve shaker, balance, set of sieves, cleaning brush, 152H hydrometer, thermometer, watch.

3.2.2.1 Sieve analysis

2/04/2 (1) Record the weight of each sieve to be used in the analysis.

(2) Take a sample of at least 500 g, dry in an oven at 105 $^{\circ}$ to constant weight.

(3) The ascending order of sieve numbers (#4 sieve at top and #200 sieve at bottom). Place the pan below #200 sieve.

(4) Place the sieve stack in the mechanical shaker (Fig 3.5) and shake for 10 minutes.

(5) Remove the stack from the shaker and record the weight of each sieve with its retained soil. In addition, weigh and record the weight of the bottom pan with its retained fine soil.

Data analysis : Sieve analysis

(1) Obtain the weight of soil retained on each sieve by subtracting the weight of the empty sieve from the weight of the sieve + retained soil, and record this weight as the weight retained on the data sheet. The sum of these retained weights should be

approximately equals the initial weight of the soil sample. A loss of more than two percent rights reserved is unsatisfactory

(2) Calculate the percent retained on each sieve by dividing the weight retained on each sieve by the original sample weight.

(3) Calculate the percent passing (or percent finer) by starting with 100 percent and subtracting the percent retained on each sieve as a cumulative procedure.

(4) Make a semi-logarithmic plot of grain size vs. percent finer.

(5) Compute C_c and C_u for the soil.



Figure 3.5 The sieve stack in the mechanical shaker.

3.2.2.2 Hydrometer analysis

(1) Take the fine soil from the bottom pan of the sieve set and place it into a beaker. After that add 125 mL of the dispersing agent (sodium hexametaphosphate (40 g/L)) solution. Stir the mixture until the soil is thoroughly wet. Let the soil soak for at least ten minutes. (2) While the soil is soaking, add 125mL of dispersing agent into the control cylinder and fill it with distilled water to the mark. Take the reading at the top of the meniscus formed by the hydrometer stem and the control solution. A reading less than zero is recorded as a negative (-) correction and a reading between zero and sixty is recorded as a positive (+) correction. This reading is called the zero correction. The meniscus correction is the difference between the top of the meniscus and the level of the solution in the control jar (Usually about +1). Shaking the control cylinder in such a way that the contents are mixed thoroughly. Insert the hydrometer and thermometer into the control cylinder and note the zero correction and temperature respectively.

(3) Transfer the soil slurry into a mixer by adding more distilled water, if necessary, until mixing cup is at least half full. Then mix the solution for a period of two minutes.

(4) Immediately transfer the soil slurry into the empty sedimentation cylinder. Add distilled water up to the mark.

(5) Cover the open end of the cylinder with a stopper and secure it with the palm of your hand. Then turn the cylinder upside down and back upright for a period of one minute. (The cylinder should be inverted approximately 30 times during the minute.)

(6) Set the cylinder down and record the time. Remove the stopper from the cylinder. After an elapsed time of one minute and forty seconds, very slowly and carefully insert the hydrometer for the first reading. (Note: It should take about ten seconds to insert or remove the hydrometer to minimize any disturbance, and the release of the hydrometer should be made as close to the reading depth as possible to avoid excessive bobbing).

(7) The reading is taken by observing the top of the meniscus formed by the suspension and the hydrometer stem. The hydrometer is removed slowly and placed back into the control cylinder. Very gently spin it in control cylinder to remove any particles that may have adhered.

(8) Take hydrometer readings after elapsed time of 2 and 5, 8, 15, 30, 60 minutes and 24 hours.

Data analysis : Hydrometer analysis

(1) Apply meniscus correction to the actual hydrometer reading.

(2) From Table 3.1, obtain the effective hydrometer depth L in cm (for meniscus corrected reading).

(3) For known Gs of the soil (if not known, assume 2.65 for this lab purpose), obtain the value of K from Table 3.2.

(4) Calculate the equivalent particle diameter by using the following

Formula:

$$D = K \sqrt{\frac{L}{t}}$$

Where t is time in minutes, and D is given in mm.

Table 3.1. Values of effective depth based on hydrometer and sedimentationcylinder of specific sizes (ASTM E100).

Hydrome	eter 151H	Hydrometer 152H			
Actual Hydrometer Reading	Effective Depth, L (cm)	Actual Hydrometer Reading	Effective Depth, L	Actual Hydrometer Reading	Effective Depth, L (cm)
1.000	16.2	- Contracting	16.2	21	11.0
1.000	16.3	0	16.3	31	11.2
1.001	16.0	1	16.1	32	11.1
1.002	15.8	2	16.0	33	10.9
1.003	15.5	3	15.8	34	10.7
1.004	15.2	4	15.6	35	10.6
1.005	15.0	5	15.5	36	10.4
1.006	14.7	6	15.3	37	10.2
1.007	14.4		15.2	38	10.1
1.008	14.2	8	15.0	39	9.9
1.009	13.9	9	14.8	40	9.7
1.010	13.7	10	14.7	41	9.6
1.011	13.4	11	14.5	42	9.4
1.012	13.1	12	14.3	43	9.2
1.013	12.9	13	14.2	44	9.1
1.014	12.6	14	14.0	45	8.9
1.015	12.3	15	13.8	46	8.8
1.016	12.1	16	13.7	47	8.6
1.017	11.8	17	13.5	48	8.4
1.018	11.5	18	13.3	49	8.3
1.019	11.3	19	13.2	50	8.1
1.020	11.0	20	13.0	51	7.9
1.021	10.7	21	12.9	52	7.8
1.022	10.5	22	12.7	53	7.6
1.023	10.2	23	12.5	54	7.4
1.024	10.0	24	12.4	55	7.3
1.025	9.7	25	12.2	56	7.1
1.026	9.4	26	12.0	57	7 - 1
1.027	9.2	27	11.9	58	6.8
1.028	8.9	28	11.7	59	6.6
1.029	8.6	29	11.5	60	6.5
1.030	8.4	30	11.4		
1.031	8.1			ser	ved
1.032	7.8	2			
1.033	7.6				
1.034	7.3				
1.035	7.0				
1.036	6.8				
1.037	6.5				
1.038	6.2				
1.039	5.9				

Temperature				Specific C	novity of S	oil Dontiala	0		
°C				Specific G			5		
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.01510	0.01505	0.01481	0.01457	0.01435	0.01414	0.01394	0.01374	0.01356
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.01339	0.01321
19	0.01474	0.01449	0.01425	0.01403	0.01382	0.01361	0.01342	0.01323	0.01305
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307	0.01289
				10.1		21-			
21	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273
22	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276	0.01258
23	0.01404	0.01381	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261	0.01243
24	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246	0.01229
25	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215
	1.35	22	(4			1-30%		
26	0.01357	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.01218	0.01201
27	0.01342	0.01319	0.01277	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188
28	0.01327	0.01304	0.01264	0.01264	0.01244	0.01255	0.01208	0.01191	0.01175
29	0.01312	0.01290	0.01269	0.01269	0.01230	0.01212	0.01195	0.01178	0.01162
30	0.01298	0.01276	0.01236	0.01236	0.01217	0.01199	0.01182	0.01165	0.01149

Table 3.2. Values of k to use in equation for computing diameter of particle inhydrometer analysis (ASTM E100).

(5) Determine the temperature correction C_T from Table 3.3.

(6) Determine correction factor "a" from Table 3.4 using G_s.

(7) Calculate corrected hydrometer reading as follows:

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 $R_{c} = R_{ACTUAL} - zero \ correction + C_{T}$ (8) Calculate percent finer as follows:

$$P = \frac{(R_c \times a)}{W_s} \times 100$$

Where W_S is the weight of the soil sample in grams.

(9) Adjust percent fines as follows:

A

$$P_A = \frac{(P \times F_{200})}{100}$$

 $F_{200} = \%$ finer of #200 sieve as a percent

(10) Plot the grain size curve D versus the adjusted percent finer on the semi -logarithmic sheet.

15 16 17 18 19 20 21	1.10 -0.90 -0.70 -0.50 -0.30 0.00
16 17 18 19 20 21	-0.90 -0.70 -0.50 -0.30 0.00
17 18 19 20 21	-0.70 -0.50 -0.30 0.00
18 19 20 21	-0.50 -0.30 0.00
19 20 21	-0.30 0.00
20 21	0.00
21	
	0.20
22	0.40
23	0.70
24	1.00
25	1.30
26	1.65
27	2.00
28	2.50
29	3.05
30	3.80

Table 3.3. Temperature correction factors C_T (ASTM E100).

Table 3.4. Correction factors a for unit weight of solids (ASTM E100).



3.2.3 Atterberg limits

This method is performed to determine the plastic and liquid limits of a fine grained soil (ASTM D4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils). The Atterberg limits are based on the moisture content of the soil. The plastic limit is the moisture content that defines where the soil changes from a semi-solid to a plastic (flexible) state. The liquid limit is the moisture content that defines where the soil changes from a plastic to a viscous fluid state. These Atterberg limits are also used to classify a fine-grained soil according to the Unified Soil Classification system or AASHTO system.

3.2.3.1 Liquid limit (LL)

Liquid limit (LL) is defined as the arbitrary limit of water content at which the soil is just about to pass from the plastic state into the liquid state. At this limit, the soil possesses a small value of shear strength, losing its ability to flow as a liquid. In other words, the liquid limit is the minimum moisture content at which the soil tends to flow as a liquid.

Apparatus:

Liquid limit device (Casagrande), flat grooving tool with gage, moisture cans, balance, spatula, wash bottle filled with distilled water, and drying oven.

Test procedure

(1) Take roughly 3/4 of the soil and place it into the porcelain dish. Assume that the soil was previously passed though a No. 40 sieve, air-dried, and then pulverized. Thoroughly mix the soil with a small amount of distilled water until it appears as a smooth uniform paste. Cover the dish with cellophane to prevent moisture from escaping.

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(2) Weigh four of the empty moisture cans, and record the respective weights and can numbers on the data sheet.

(3) Adjust the liquid limit apparatus by checking the height of drop of the cup. The point on the cup that comes in contact with the base should rise to a height of 10 mm. The block

on the end of the grooving tool is 10 mm high and should be used as a gage. Practice using the cup and determine the correct rate to rotate the crank so that the cup drops approximately two times per second.

(4) Place a portion of the previously mixed soil into the cup of the liquid limit apparatus at the point where the cup rests on the base. Squeeze the soil down to eliminate air pockets and spread it into the cup to a depth of about 10 mm at its deepest point. The soil pat should form an approximately horizontal surface.

(5) Use the grooving tool carefully cut a clean straight groove down the center of the cup. The tool should remain perpendicular to the surface of the cup as groove is being made. Use extreme care to prevent sliding the soil relative to the surface of the cup.

(6) Make sure that the base of the apparatus below the cup and the underside of the cup is clean of soil. Turn the crank of the apparatus at a rate of approximately two drops per second and count the number of drops (N), it takes to make the two halves of the soil pat come into contact at the bottom of the groove along a distance of 13 mm (1/2 in.). If the number of drops exceeds 50, then go directly to step eight and do not record the number of drops, otherwise, record the number of drops on the data sheet.

(7) Take a sample, using the spatula, from edge to edge of the soil pat. The sample should include the soil on both sides of where the groove came into contact. Place the soil into a moisture can cover it. Immediately weigh the moisture can containing the soil, record its mass, remove the lid, and place the can into the oven. Leave the moisture can in the oven for at least 16 hours. Place the soil remaining in the cup into the porcelain dish. Clean and dry the cup on the apparatus and the grooving tool.

(8) Remix the entire soil specimen in the porcelain dish. Add a small amount of distilled water to increase the water content so that the number of drops required to close the groove decrease.

(9) Repeat steps sixth, seventh, and eighth for at least two additional trials producing successively lower numbers of drops to close the groove. One of the trials shall be for a closure requiring 25 to 35 drops, one for closure between 20 and 30 drops, and one trial for a closure requiring 15 to 25 drops. Determine the water content from each trial by using the same method used in the first laboratory. Remember to use the same balance for all weighing.

Liquid limit analysis:

(1) Calculate the water content of each of the liquid limit moisture cans after they have been in the oven for at least 16 hours.

(2) Plot the number of drops, N, (on the log scale) versus the water content (w). Draw the best-fit straight line through the plotted points and determine the liquid limit (LL) as the water content at 25 drops.

3.2.3.2 Plastic limit (PL)

The plastic limit (PL) is the water content where soil starts to exhibit plastic behavior. A thread of soil is at its plastic limit when it is rolled to a diameter of 3 mm or begins to crumble. To improve consistency, a 3 mm diameter rod is often used to gauge the thickness of the thread when conducting the test. (AKA Soil Snake Test).

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Apparatus:

Glass plate, moisture cans, distilled water, and dry oven.

Test procedure

(1) Weigh the remaining empty moisture cans, and record the respective weights and can numbers on the data sheet.

(2) Take the remaining 1/4 of the original soil sample and add distilled water until the soil is at a consistency where it can be rolled without sticking to the hands.

(3) Form the soil into an ellipsoidal mass. Roll the mass between the palm or the fingers and the glass plate. The thread shall be deformed so that its diameter reaches 3.2 mm, taking no more than two minutes.

(4) When the diameter of the thread reaches the correct diameter, break the thread into several pieces. Knead and reform the pieces into ellipsoidal masses and re-roll them. Continue this alternate rolling, gathering together, kneading and re-rolling until the thread crumbles under the pressure required for rolling and can no longer be rolled into a 3.2 mm diameter thread.

(5) Gather the portions of the crumbled thread together and place the soil into a moisture can, then cover it. If the can does not contain at least 6 grams of soil, add soil to the can

from the next trial (See Step 6). Immediately weigh the moisture can containing the soil, record its mass, remove the lid, and place the can into the oven. Leave the moisture can in the oven for at least 16 hours.

(6) Repeat steps third, fourth, and fifth at least two more times. Determine the water content from each trial by using the same method used in the first laboratory. Remember to use the same balance for all weighing.

Plastic limit analysis

(1) Calculate the water content of each of the plastic limit moisture cans after they have been in the oven for at least 16 hours.

(2) Compute the average of the water contents to determine the plastic limit, PL.

(3) Calculate the plasticity index, PI=LL-PL. Report the liquid limit, plastic limit, and plasticity index to the nearest whole number, omitting the percent designation.

3.2.4 Shear strength (Direct shear test)

The shear strength is one of the most important engineering properties of a soil, because it is required whenever a structure is dependent on the soil's shearing resistance. This is the oldest and simplest form of shear test. The test equipment consist of a metal shear box in which the sample is placed as shown in figure 3.6. In this laboratory, a direct shear device will be used to determine the shear strength of a cohesionless soil (i.e. angle of internal friction (f)). From the plot of the shear stress versus the horizontal displacement, the maximum shear stress is obtained for a specific vertical confining stresses, a plot of the maxi mum shear stresses versus the vertical (normal) confining stresses for each of the tests is produced.



Figure 3.6 Diagram of direct shear arrangement (Mecsi, 2009).

Apparatus:

Direct shear device, load and deformation dial gauges, and balance.

Test Procedure:

(1) Weigh the initial mass of soil in the pan.

(2) Measure the diameter and height of the shear box. Compute 15% of the diameter in millimeters.

(3) Carefully assemble the shear box and place it in the direct shear device. Then place a porous stone and a filter paper in the shear box.

(4) Place the sand into the shear box and level off the top. Place a filter paper, a porous stone, and a top plate (with ball) on top of the sand

(5) Remove the large alignment screws from the shear box! Open the gap between the shear box halves to approximately 0.025 in. using the gap screws, and then back out the gap screws.

(6) Weigh the pan of soil again and compute the mass of soil used.

(7) Complete the assembly of the direct shear device and initialize the three gauges

(Horizontal displacement gage, vertical displacement gage and shear load gage) to zero.

(8) Set the vertical load (or pressure) to a predetermined value, and then close bleeder

valve and apply the load to the soil specimen by raising the toggle switch.

(9) Start the motor with selected speed so that the rate of shearing is at a selected constant rate, and take the horizontal displacement gauge, vertical displacement gage and shear load gage readings. Record the readings on the data sheet. (Note: Record the vertical displacement gage readings, if needed).

(10) Continue taking readings until the horizontal shear load peaks and then falls, or the horizontal displacement reaches 15% of the diameter.

Analysis:

(1) Calculate the density of the soil sample from the mass of soil and volume of the shear box.

(2) Convert the dial readings to the appropriate length and load units and enter the values on the data sheet in the correct locations. Compute the sample area A, and the vertical (Normal) stress s_v .

 $S_v =$



(3) Calculate shear stress (t) using

Where F= shear stress (measured with shear load gage)

(4) Plot the horizontal shear stress (t) versus horizontal (lateral) displacement (H).

(6) Plot the value of the maximum shear stress versus the corresponding vertical stress for each test, and determine the angle of internal friction (f)from the slope of the approximated Mohr-Coulomb failure envelope.

(7) Calculate the maximum shear stress for each test.

3.3 X-Ray Diffraction Mineralogical Analysis

X-ray diffraction is a technique that provides detailed information about the atomic structure of crystalline substances. It is a powerful tool in the identification of minerals in rocks and soils. The bulk of the clay fraction of many soils is crystalline, but clay particles are too small for optical crystallographic methods was applied. Therefore, XRD has long been a mainstay in the identification of clay-sized minerals in soils. X-ray diffraction occurs when X-rays are scattered by atoms arranged in an orderly array in crystals. The atoms serve as scattering centers (Moore and Reynolds, 1997), re-emitting X-rays at the same wavelength as the incident radiation in all directions (coherent scattering). The orderly arrangement of atoms results in the scattered X-rays within the crystal being (i) in phase in specific directions dictated by symmetry and atomic spacings and (ii) out of phase in all other directions. The X-rays that are in phase constructively interfere and emerge as intense beams (diffracted beams) from the crystal, while those that are out of phase destructively interfere and hence have minimal emergence. This systematic combination of constructive and destructive interference arising from the periodicity of atoms in crystals is X-ray diffraction. Detailed information about the internal symmetry and arrangement of atoms in crystals can be gained from XRD. However, this chapter will emphasize only those aspects that are most pertinent to the identification of naturally occurring minerals in soils. INTVE

Intuitively, the simple way to comprehend the relatively complex phenomenon of XRD is to envision regularly spaced planes of atoms in mineral structures (Figure 3.7). The distance between a given set of planes is termed *d-spacing*. The d-spacing, although on a scale of Angstroms, can be determined quite accurately using XRD. The principles underlying this determination are elegantly expressed by the Bragg equation: $n\lambda = 2d \sin \theta$



Figure 3.7 Schematic representation of XRD by regularly spaced planes of atoms in a crystal. Theta (θ) is the angle that the beam makes with the atomic planes; 2 θ is the angle that the diffracted beam deviates from the primary beam; d is the distance between equivalent atomic planes in the crystal (d-spacing); and λ is wavelength of the radiation. Note that when DE + EF = $n\lambda$, where *n* is an integer, the diffracted beams from each plane of atoms would be in phase, leading to constructive interference which accounts for XRD. In effect, when that condition is met, an XRD peak is observed. The Bragg equation can be used to calculate d-spacing from the 2 θ angle at which the diffraction peak occurs. (Bragg, 1934).

Apparatus:

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X-ray powder diffractometer (XRD) (Figure 3.8), glass slide, mortar and pestle.

Test procedure:

(1) Samples for X-ray diffraction were prepared from a soil sample passed a #200 sieve and were ground in a mortar to a fine powder.

(2) Place the sample onto a glass slide, assuring a flat upper surface pack into a sample container

(3) Carefully, create a flat upper surface and try to achieve a random distribution of lattice orientations unless creating an oriented smear.

(4) For unit cell determinations, a small amount of a standard with known peak positions (that do not interfere with the sample) can be added and used to correct peak positions.



Data collection

The intensity of diffracted X-rays is continuously recorded as the sample and detector rotate through their respective angles. A peak intensity occurs when the mineral contains lattice planes with d-spacings appropriate to diffract X-rays at that value of θ . Although each peak consists of two separate reflections (K α_1 and K α_2), at small values of 2 θ the peak locations overlap with K α_2 appearing as a hump on the side of K α_1 . Greater

separation occurs at higher values of θ . Typically these combined peaks are treated as one. The 2λ position of the diffraction peak is typically measured as the center of the peak at 80% peak height. Results are commonly presented as peak positions at 2 θ and X-ray counts (intensity) in the form of a table or an x-y plot (shown above). Intensity (I) is either reported as peak height intensity, that intensity above background, or as integrated intensity, the area under the peak. The relative intensity is recorded as the ratio of the peak intensity to that of the most intense peak (relative intensity = $I/I_1 \times 100$). The dspacing of each peak is then obtained by solution of the Bragg equation for the appropriate value of λ . Once all d-spacings have been determined, automated search/match routines compare the ds of the unknown to those of known materials. Because each mineral has a unique set of d-spacings, matching these d-spacings provides an identification of the unknown sample. A systematic procedure is used by ordering the d-spacings in terms of their intensity beginning with the most intense peak. Files of d-spacings for hundreds of thousands of inorganic compounds are available from the International Centre for Diffraction Data as the Powder Diffraction File (PDF). Many other sites contain dspacings of minerals such as the American Mineralogist Crystal Structure Database. Commonly this information is an integral portion of the software that comes with the instrumentation.

3.4 Slope stability analysis (Combined HydrologyAnd Stability Model)

Stability analysis of natural slope is carried out using CHASM software. The main page interface of the combined hydrologic and slope stability program (CHASM) is presented in Figure 3.9.



Figure 3.9 CHASM main page interface.

(1) The process starts by drawing slope profile of the study area. Next, the soil depths and grid resolution are selected. It is important to select soil depths that are similar to the grid resolution. CHASM recommends a grid resolution of 1-meter by 1-meter (Wilkinson et al. 2002).

(2) The soil properties were input for each soil type. Saturated moisture content and saturated hydraulic conductivity were used for the analysis. Figure 3.10 is an image of CHASM's soil property window.

Hydrological properties Saturated moisture content 25 % Saturated bulk density 17	
Saturated moisture content 25 % Saturated bulk density 17	
	kN/m
Permeability 1.3e-U5 m/s Unsaturated bulk density 16	kN/m
Suction moisture relationship	kPa
Subtoin instate relationship SMC Friction angle 39.5	deg.

Figure 3.10 CHASM soil property interface.

(3) The rainfall data from the 27th August 2011 storm event in units of meters for each hour of the storm were input for the rainfall data. The analysis was run for 48 hours. Rainfall data was entered into CHASM by entering the precipitation for each hour of the simulation in the Rain Fall Data (Figure 3.11).

Time		Rainfall		
Length of simulation Iteration period	48 hrs 60 secs	Precipitation	30 m	m/hr
Storm start time	1 hrs	Effective ppt (grass)	9.85385 m	m/hr
Storm stop time Storm Hour	1 hrs	Effective ppt (tree)	17.07692 m	m/hr

Figure 3.11 CHASM rainfall data interface.

(4) When all the hydrological data was input into CHASM, the model was run by selecting the "Run Simulation" on the main page. During the simulation period, a result window displays the factor of safety, hour, the X-Y coordinates of the slip grid, the slip circle radius and mass of soil above the critical slip surface (Figure 3.12). Next, Figure 3.13 presents the water content and pore pressures for each of the cells.



Figure 3.12 CHASM visualization of critical slip surface of landslide area.



Figure 3.13 CHASM visualization of pore pressure of landslide area.