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RAIN-INDUCED LANDSLIDE SUSCEPTIBILITY: A GUIDEBOOK FOR COMMUNITIES & NON-EXPERTS

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Disclaimer

When life, limb and property are at stake, the findings obtained with the use of the landslide assessment procedure presented in this guidebook should be reviewed and validated by a practicing and experienced geotechnical engineer or engineering geologist. While the authors of this book endeavored to ensure that this assessment procedure has sound scientific and empirical basis, they make no representations or warranties of any kind, expressed or implied, about the completeness, accuracy, reliability, suitability or availability of the assessment procedure with respect to its application. Any reliance you place on the procedure, without the guidance, supervision, or review of a practicing and experienced geotechnical engineer or engineering geologist, is therefore strictly at your own risk.

In no event will the authors be liable for any loss or damage arising from the use of the information presented in this guidebook.

Acknowledgments

This report which includes the guidebook was prepared as part of the project, Reducing Disaster Caused by Rain-Induced Landslide: Training for Communities and Non-Experts. This project was funded through the initiative of Senator Loren Legarda who worked out to include Five Million Pesos in the 2018 General Appropriations Act for this endeavor to start.

The project team was composed of the following: Eduardo T. Bagtang, KASC President and Project Leader; Dr. Daniel C. Peckley Jr., DOST Balik Scientist; Engr. Fides Lovella A. Baddongon; Dr. Lope T. Buen; Engr. Rhonjhon Garming; Engr. Solomon Lao-aten and Francis James G. Balageo III. Engr. Baddongon and Dr. Peckley prepared the illustrations in this guidebook.

The Presidents of the thirteen (13) State University and Colleges: Dr. Gregorio T. Turqueza of Abra State Institute of Sciences and Technology, Dr. Nelia Z. Cauilan of Apayao State College, Dr. Arnulfo M. Mascariñas of Bicol University, Dr. Rosein A. Ancheta, Jr. of Cebu Technological University, Dr. Edito B. Sumile of Davao Oriental State College of Science and Technology, Dr. Dominador O. Aguirre of Eastern Visatas State University, Dr. Rogelio T. Artajo of Guimaras State College, Dr. Eva Marie C. Dugyon of Ifugao State University, Dr. Raul F. Muyong of Iloilo Science and Technology University, Dr. Rexton F. Chakas of Mt. Province State Polytechnic College, Dr. Samuel O. Benigno of Quirino State University, Dr. Pablo S. Crespo, Jr. of University of Antique, and Dr. Milabel Enriquez-Ho of Western Mindanao State University; their cooperation and commitment to this project is invaluable and highly appreciated.

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SENADO NG PILIPINAS

Hon. Loren Legarda
SENADOR

MESSAGE
Rain-Induced Landslide Susceptibility:

A Guidebook for Communities and Non-Experts

My sincerest appreciation and congratulations to the Kalinga State University for this guidebook on disaster risk reduction and management (DRRM), which also chronicles the trainings you conducted for our communities to address their susceptibility to landslides due to heavy rainfall.

The Philippines is blessed with natural wonders and bountiful resources, but it is also a country that is highly vulnerable to disasters and extreme weather events. In particular, heavy rains, which are also intensified and made more frequent by climate change, cause landslides that also threaten the very lives and livelihoods of our people in our communities.

This publication is a powerful tool to raise awareness and inform action for our leaders and citizens to prepare and take necessary measures in the event of rain induced landslides. May this guidebook serve well to secure the safety and welfare of our people, especially those who are at risk and living in disaster-prone communities.

As an advocate of DRRM myself, I made sure that appropriate funding was allocated for this project during the national budget deliberations in the Senate. I commend your initiative to undertake this project, and I hope that many more academic institutions follow suit in leading our citizens and communities towards a more secure and resilient future.

Thank you very much, and my best wishes for the continued success of the Kalinga State University!

LOREN LEGARDA
Senator

EXECUTIVE SUMMARY

The Philippines is one of the most visited country in the world when it comes to the average number of typhoons coming to this archipelago annually. This is due to the geographical location of the Philippines which is located just at the doorstep of the Pacific Ocean where most typhoons precipitate. Aside from the typhoons that would bring heavy rainfall and strong winds, the country is also visited by the yearly onslaught of the Southwest Monsoon or more commonly known as “Hanging Habagat” which brings heavy rainfall not only to the Philippines but also to other neighboring countries. This results to a mean annual rainfall of the Philippines which varies from 965 to 4,064 millimeters annually. Thus, resulting in the Philippines being a disaster prone country especially when it comes to landslides.

This is the main reason that Kalinga State University (KSU) came up with this project to inform, educate and train communities all over the country as well as to prevent loss of lives and properties through appropriate information dissemination and training most especially communities whose geographic location and economic situation make them very vulnerable to landslides. The fundamental resource that was used in this project was the guidebook developed by a team of researchers and geotechnical engineers of KSU led by Dr. Daniel C. Peckley, Jr., a DOST Balik Scientist. The guidebook that features an assessment procedure enabling non-experts to determine if a certain site is prone to rain-induced and shallow-depth landslides. The proposal to train communities all over the country on the assessment tool was then submitted to the Office of Senator Loren B. Legarda to seek support and funding which she worked out for inclusion in the 2018 GAA the amount of Five Million Pesos only (Php 5, 000,000.00) to make the project possible. To be able to train communities all over the country, KSU invited State Universities and Colleges (SUCs) all over the country especially those SUCs which are located in the landslide prone areas for collaboration on the training of communities. A total of Thirteen (13) SUCs partnered with KSU through the forging of a Memorandum of Agreement and an amount of Two Hundred Pesos only (Php 250,000.00) was then transferred to each of the SUCs for them to be able to train communities in their localities. One Thousand Six Hundred Eighty (1, 680) beneficiaries were trained on the assessment tool.

Read me first

This guidebook offers a simplified susceptibility assessment of rain-induced, shallow-depth landslides. The assessment procedure takes off from the idea that the strength of the material or structure ***S*** should always be greater than the applied load or force ***L*** (***S>L***). This concept could be expressed as a factor commonly referred in engineering as <u>Factor of Safety</u> ***Fs* = *S/L*,** which should always be greater than ***1***. **Figure 1** below illustrates the concept:

$$Fs = \frac{\text{Bridge capacity or strength = 30T}}{\text{Weight of truck/load = 25T}} = \underline{1.2}$$

***Fs* is greater than 1, the 25T truck can cross the bridge safely.**

(a)

$$Fs = \frac{\text{Bridge capacity or strength = 30T}}{\text{Weight of truck/load = 36T}} = \underline{0.8}$$

***Fs* is less than 1, the bridge would likely collapse.**

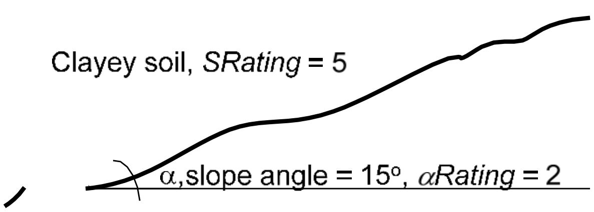
(b)

Figure 1. Factor of Safety ***Fs*** for a 30T-capacity bridge

In this landslide susceptibility assessment procedure, the *S/L* ratio is referred to as the Factor of Stability ***Fs*** and its basic definition is

$$\boldsymbol{Fs_{basic} = SRating/\alpha Rating}$$

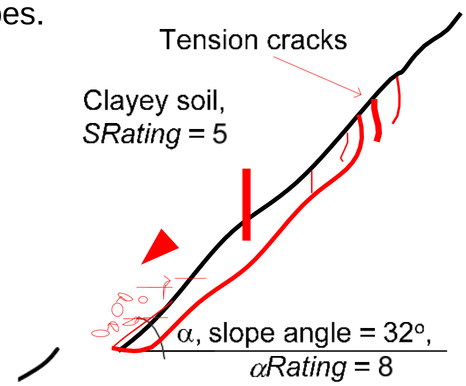
where *SRating* is the strength rating or score of the slope material, while α*Rating* is the rating for the slope angle α. The main force driving landslides is gravity and is directly related to the slope angle α; the higher the slope angle α, the higher the α*Rating*. **Figure 2** illustrates ***Fs***$_{basic}$ for slopes.



$$Fs_{basic} = \frac{\underline{SRating = 5}}{\alpha\text{Rating} = 2} = \underline{2.5}$$

Fs$_{basic}$ **is greater than 1, the slope is stable.**

(a)



$$Fs_{basic} = \frac{\underline{SRating = 5}}{\alpha\text{Rating} = 8} = \underline{0.6}$$

Fs_{basic} **is less than 1, the slope is unstable, susceptible to landslide.**

(b)

Figure 2. Basic Factor of Stability, Fs_{basic}, for slopes

When other factors affecting landslide susceptibility are considered, ***Fs*** can be expressed as

$$Fs = \frac{vFactor*fFactor*(SRating - sRed - dRed)}{\alpha Rating * lFactor}$$

Here, the ***vFactor*** takes into account the vegetation cover of the slope. The ***fFactor*** takes into account the frequency of slope failure, presence of cracks and previous failure history.

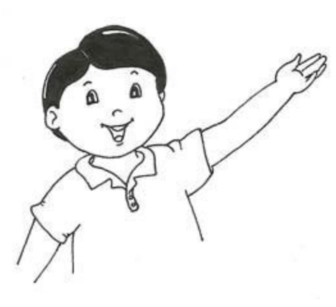
sRed represents the reduction of the shear strength of the slope material due to saturation as indicated by the presence of spring or the elevation of groundwater table due to rainfall infiltration. The ***dRed*** factor represents another reduction of shear strength of the material due to saturation due to poor drainage system. The ***lFactor*** is a factor that takes into account the existing land use. The numerical values of these factors are presented in **Chapter 6**, from page 39 onward.

When rainfall data are available or when rainfall is being measured, the ***sRed*** and ***dRed*** factors can be replaced by a single factor called ***Rain***. Here, ***Fs*** becomes

$$Fs = \frac{vFactor*fFactor*(SRating - Rain)}{\alpha Rating * lFactor}.$$

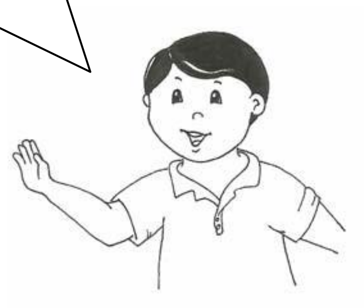
The assessment procedure is based on geotechnical inspections and surveys of 243 landslide and imminent landslide sites in the provinces of Kalinga, Mt. Province and Benguet. The table below summarizes the results of these surveys.

Factor of Stability ***Fs***	No. of sites surveyed	No. of sites that failed	%age failure
Fs $\geq$ 1.2: Stable	5	0	0
1.0 $\leq$ ***Fs*** < 1.2: Marginally stable	7	0	0
0.7 $\leq$ ***Fs*** < 1.0: Susceptible	38	27	71%
Fs < 0.7: Highly susceptible	193	184	95%
Total	243	211	87%



Meet ***Geo***, the geotechnical engineer. His job is to share useful further details and information.

This is basically a manual and visual procedure. It does not involve the use of test equipment (e.g. SPT) that can penetrate 30m or more into the ground. Thus, it should be noted that the procedure may only be applicable to shallow landslides, the depth of which is less than 3m. While the possibility of a deep-seated landslide may be detected through this procedure, it should not be used to perform a definitive evaluation of such a landslide. To learn more about how this assessment procedure was developed, see **Annex B**.



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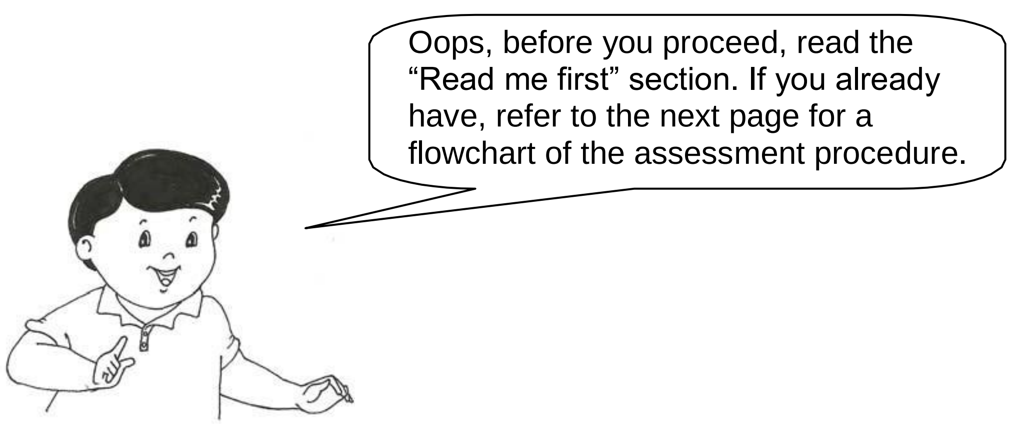


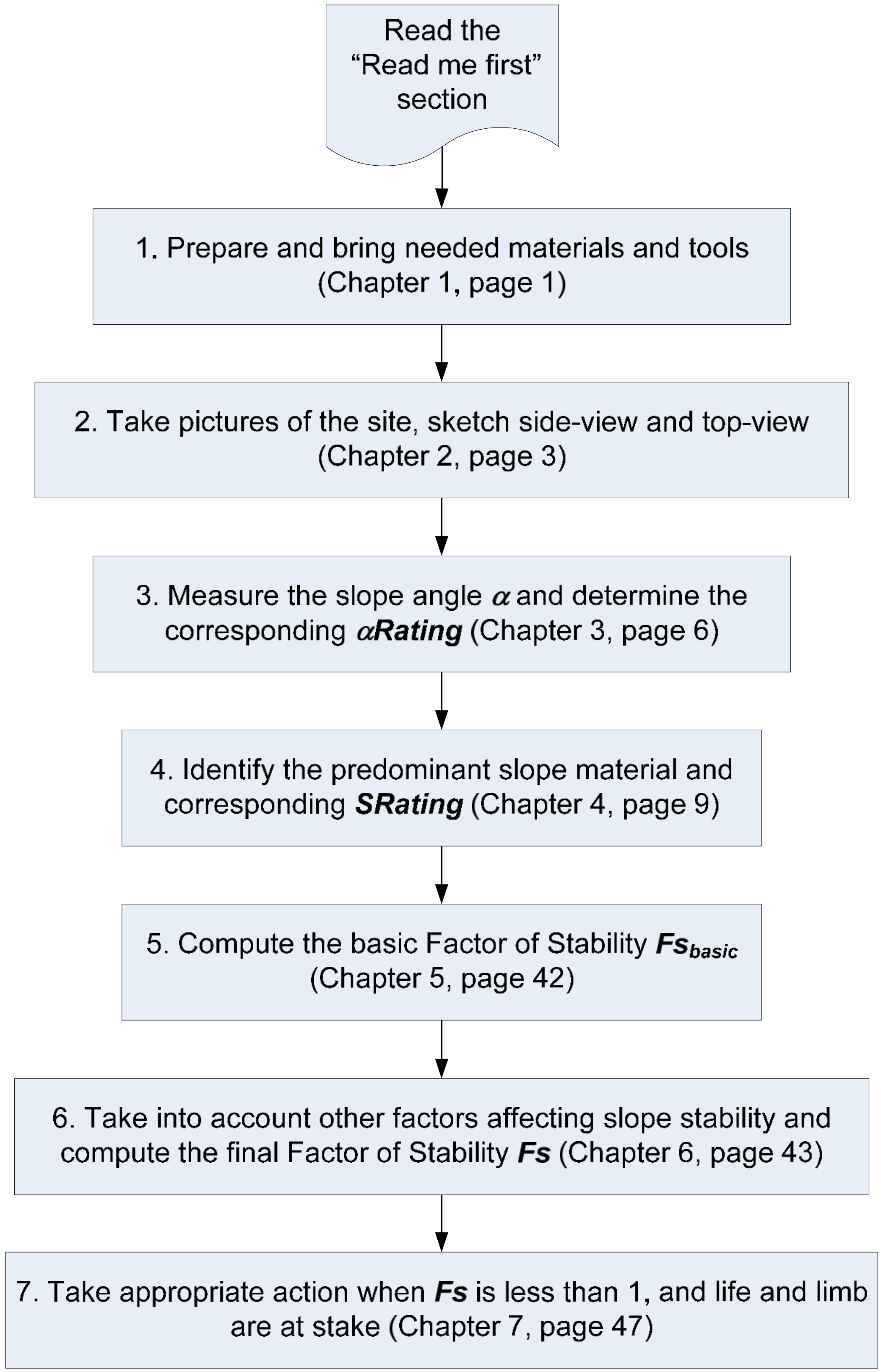
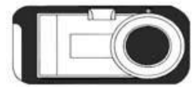
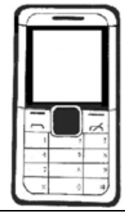
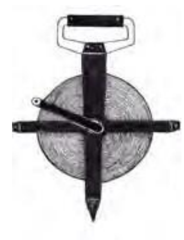
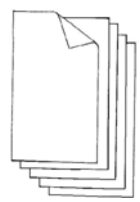
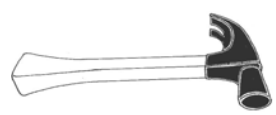
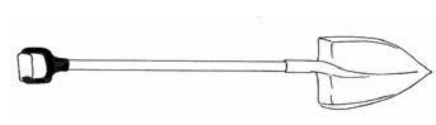
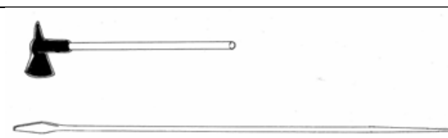
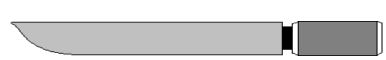


Figure 3. Assessment flowchart

1.0 Bring these with me

1.1 Camera (cellular phone with digicam	 
1.2 Measuring tape (preferably 5m or longer in length)	
1.3 Bond paper (at least 5 pages)	
1.4 Pen or pencil	
1.5 Hammer	
1.6 Four (4)-inch common wire nails	
1.7 Shovel	
1.8 Digging implement, e.g. *crow bar*, pick	
1.9 Bolo for clearing	

Also bring the following, when available and when you are familiar with their use:

1.1 Tiltmeter, anglemeter, protractor or any device to measure slope angle	
1.2 GPS receiver device	
1.3 Swedish weight sounding test[1] equipment (optional but recommended for sandy, silty and clayey soils)	(See Figure 1-1 and Photo 1-1)

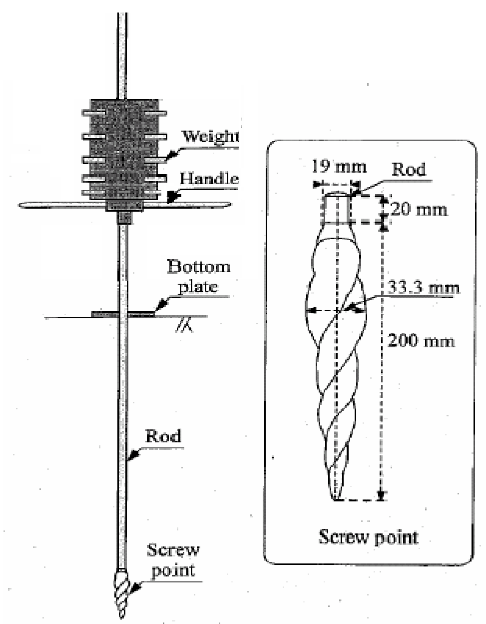


Figure 1-1. Swedish weight sounding test (SWST) equipment

Photo 1-1. Swedish weight sounding on a mountain slope

[1] A manual of the SWST is included here as **Annex C**.

2.0 Take pictures of the site, sketch a plan and cross-section

Sketch a plan and a cross-section/s of the site to be investigated. Indicate the position of existing roads, houses, vegetation and other notable features of the site. Examples of site sketches are shown in **Figures 2-1** and **2-2**.

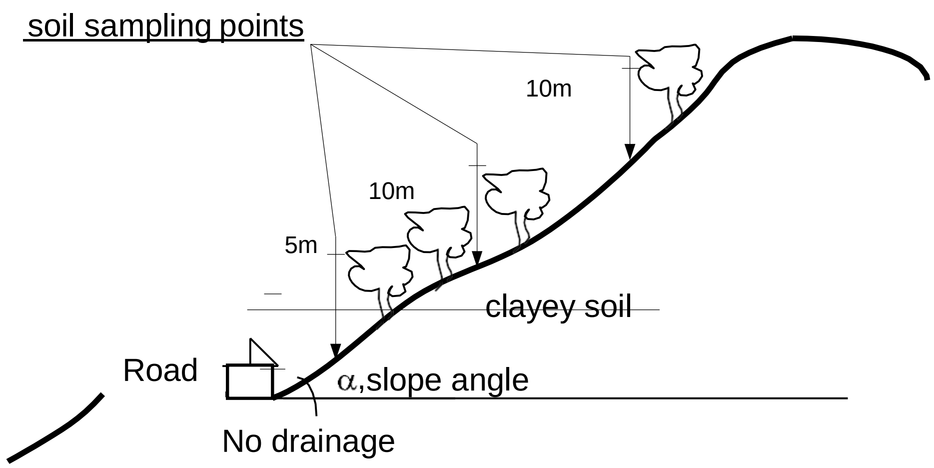


Figure 2-1. Site cross-section or side-view

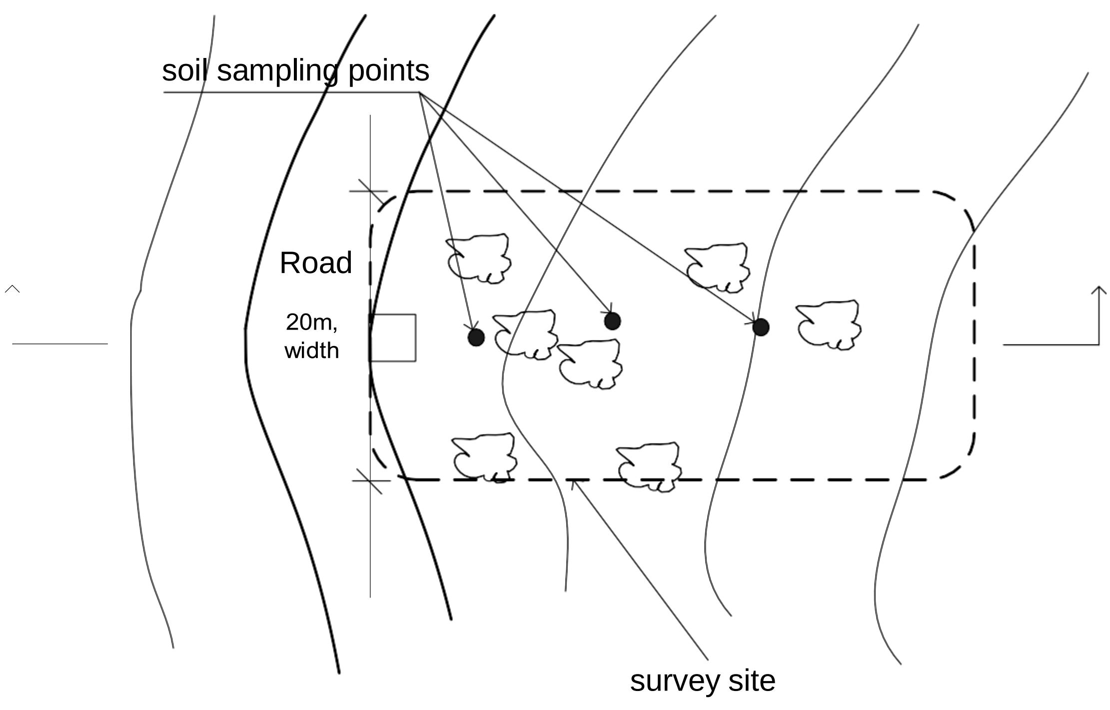


Figure 2-2. Site plan or top view

Please take note when delineating the survey site:

1) It is assumed that the site or slope being considered has one slope angle α and a predominant slope material, e.g. clayey soil, highly fractured hard rock.

2) If the slope angle varies, but the variation is within a range of angles defined in **Table 3-1**, and if the predominant material is practically uniform around the area, then this area can already be identified as one site.

3) If the slope angle varies and the variation is not within a range of angles defined in **Table 3-1**, or if the slope material is not uniform around the area of interest, then subdivide the area into sub-areas with widths of around 10m or even longer. Determine the ***Fs*** for each sub-area. **Figure 2-3** illustrates how this is done.

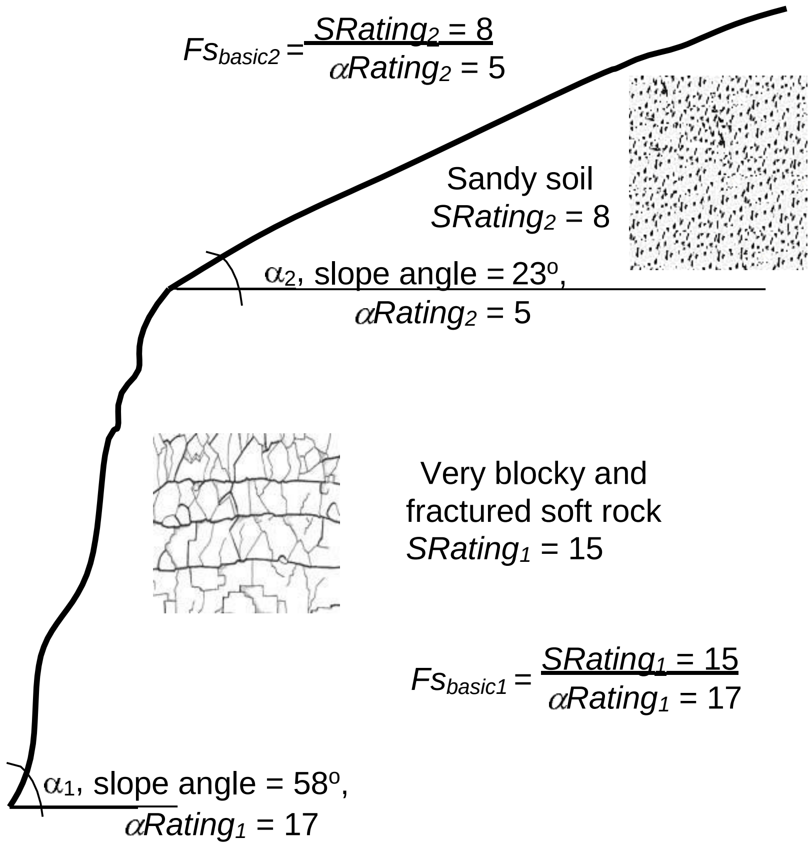
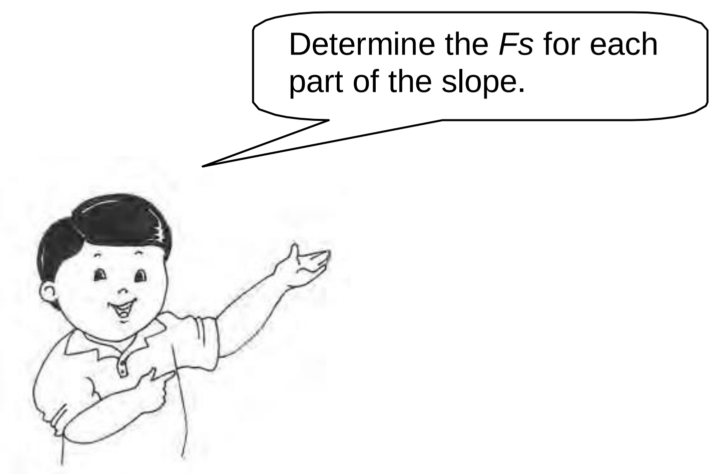


Figure 2-3. Slope with varying slope angle and different slope material



3.0 Measure the slope angle α

In this assessment, slope angles are grouped as shown in Table 3-1:

Table 3-1. Ranges of slope angle *α* and corresponding *αRating*

Slope angle *α*	***αRating***
α greater than 75° (α ≥ 75°)	100
α greater than 60° but less than or equal to 75° (60°≤ α < 75°)	32
α greater than 45° but less than or equal to 60° (45° ≤ α < 60°)	17
α greater than 30° but less than or equal to 45° (30° ≤ α ≤ 45°)	10
α greater than 15° but less than or equal to 30° (15° ≤ α ≤ 30°)	5
α less than or equal to 15° (α < 15°)	2

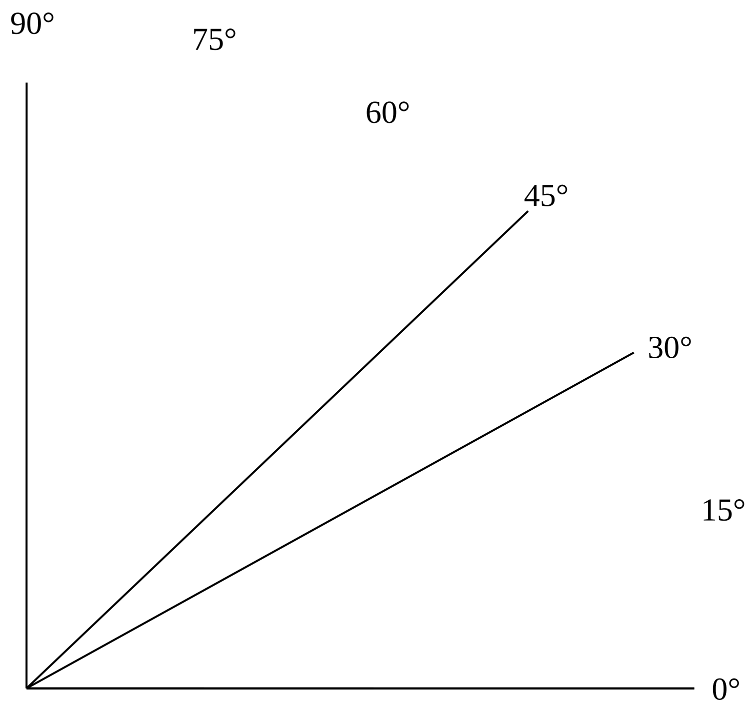
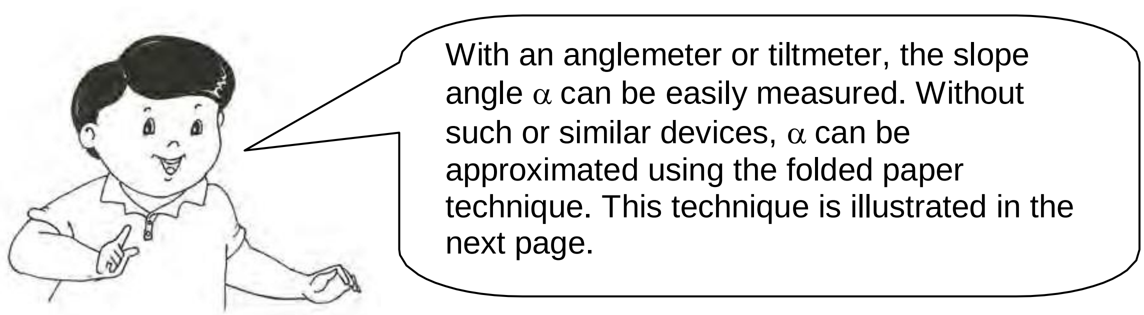
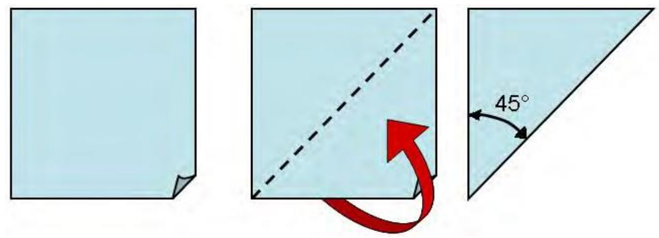


Figure 3-1. Slope angles at 15° increments

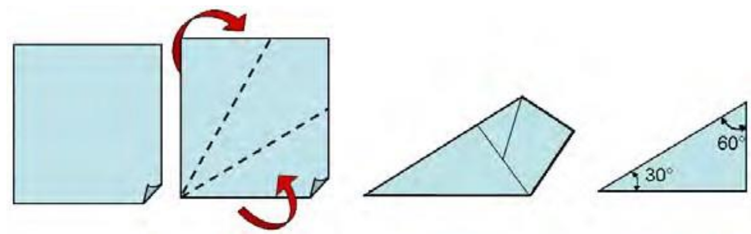


Folded Paper Technique

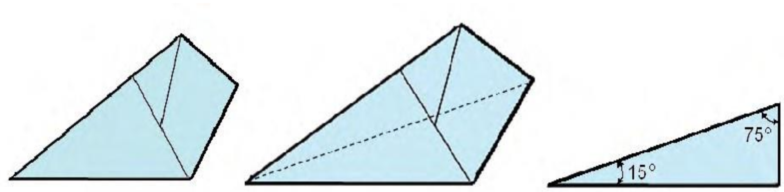
a. To form a 45° angle, fold a square-shaped piece of paper into half, diagonally, forming a triangle of equal size.



b. To form a 30° and 60° angle, fold the square paper into three equal parts, diagonally. The corner with the smallest angle is the 30° while the next larger corner is the 60°.



c. To form the 15° and 75° angle, from position b) fold the smaller angle (30°) one more time, into half. The smallest angle produced is the 15° while the next larger angle is the 75°.



d. To estimate the slope angle using this technique, find a spot outside the area being investigated where a side-view of the slope can be spotted and the slope angle α can be visually compared with any of the above paper-fold angles. See **Figure 3-2**.

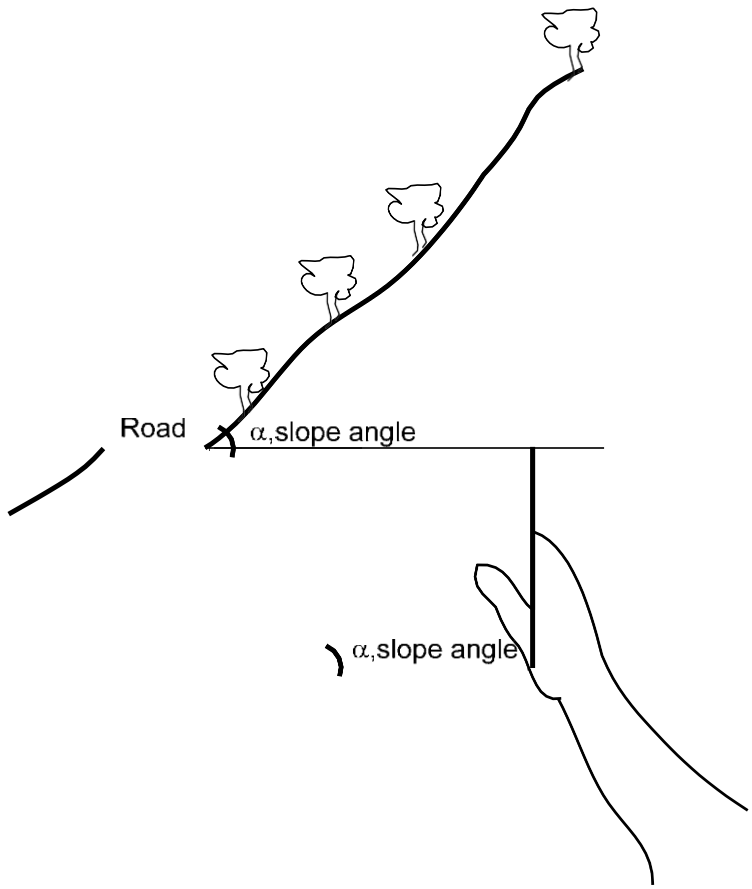
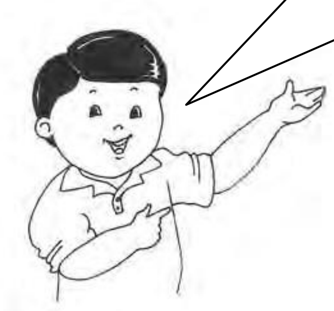


Figure 3-2. Comparing a folded-paper angle (45^o) with the slope angle α



In case you are wondering where the values of α*Rating* came from, these were calculated from *tan*α. They were "normalized" such that the highest α*Rating* is 100 and would correspond to a slope angle close to 90^o or vertical.

The important thing to note is that the higher the slope angle, the higher the α*Rating*. Still interested to know more? Please read **Annex B**.

4.0 Identify the predominant slope material

The first step in identifying the predominant slope material is to determine whether the predominant material is any of the following:

1) Hard rock
2) Soft rock
3) Soil

The slope material is hard rock if it is as hard as or harder than concrete. Four-inch common wire nails cannot penetrate an intact sample of the rock.

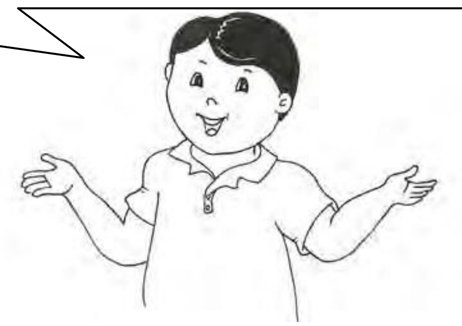
It is soft rock if it is softer than concrete; hammering 4-inch common wire nails into an intact sample is possible. A fist-sized sample cannot be crushed or deformed with hand pressure.

When a fist-sized sample, especially when moist, can be crushed or deformed by hand pressure, the material is soil.

The shear strength of hard rocks against landslides and rock falls depends much on the cracks and discontinuities present in them. For soft rocks, it depends both on their hardness and on cracks and discontinuities. For soils, it depends on the sizes of the soil particles, how dense these particles are, and if a significant amount cementation of exists among these particles.

In this assessment procedure, hard rocks are grouped into 4 classifications; soft rocks, 2 classifications; and soils, 4 classifications, as shown in **Table 4-1**.

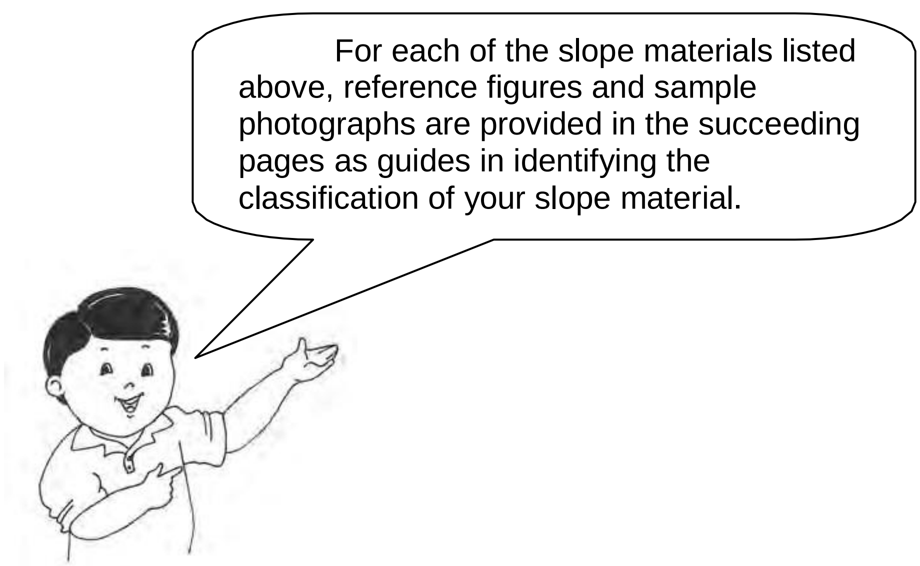
The origin and mineral composition of the slope material is not so important in this procedure, although these information, when available or when they can be identified, are useful in confirming the classification of the slope material and in performing a more detailed assessment, if warranted.



The predominant slope material can belong to any of the following:

Table 4-1. Slope material and *SRating*

Material ID	Slope material	*SRating*	Reference figures and photographs
HR1	Massive and intact hard rock	100	Figure HR1-1, Photos HR1-1 to HR1-4
HR2	Blocky, well-interlocked hard rock, rock mass consisting mostly of cubical blocks	45	Figure HR2-1, Photos HR2-1 to HR2-4
HR3	Very blocky and fractured hard rock (disturbed with multi-faceted angular blocks formed by 4 or more discontinuity sets)	25	Figure HR3-1, Photos HR3-1 to HR3-4
HR4	Disintegrated, unstable rocks and boulders, protruding rock fragments	13	Figure HR4-1, Photos HR4-1 to HR4-4
SR1	Massive and intact soft rock	30	Figure SR1-1, Photos SR1-1 to SR1-4
SR2	Very blocky and fractured soft rock	15	Figure SR2-1, Photos SR2-1 to SR2-4
HS1	Stiff, cemented and dense gravelly, sandy, silty and clayey soils	25	Figure HS1-1, Photos HS1-1 to HS1-4
SS1	Gravelly soil	10	Figure SS1-1, Photos SS1-1 to SS1-4
SS2	Sandy soil	8	Figure SS2-1, Photos SS2-1 to SS2-4
SS3	Clayey/silty soil	5	Figure SS3-1, Photos SS3-1 to SS3-4



If the predominant slope material cannot be identified or ascertained because the slope is covered with vegetation, do the following:

a) Select and clear at least three (3) slope material sampling points, each having an area of around 1square meter (m^2). See **Figures 2-1**, **2-2** and **2-3**.

b) If after clearing, the predominant slope material is **rock**, use the reference figures and photographs listed above to classify the rock material. Refer to the notes in **Chapter 2**, particularly those that mention what to do in cases when significantly different materials are encountered.

c) If **soil**, dig at the sampling points to a depth of at least around 0.5m. Use the reference figures and photographs listed above to classify the soil material. Refer to the notes in **Chapter 2**, particularly those that mention what to do in cases when significantly different materials are encountered.

HR1: Massive and intact hard rock
- (See **Figure HR1-1** and **Photos HR1-1** to **HR1-4**)

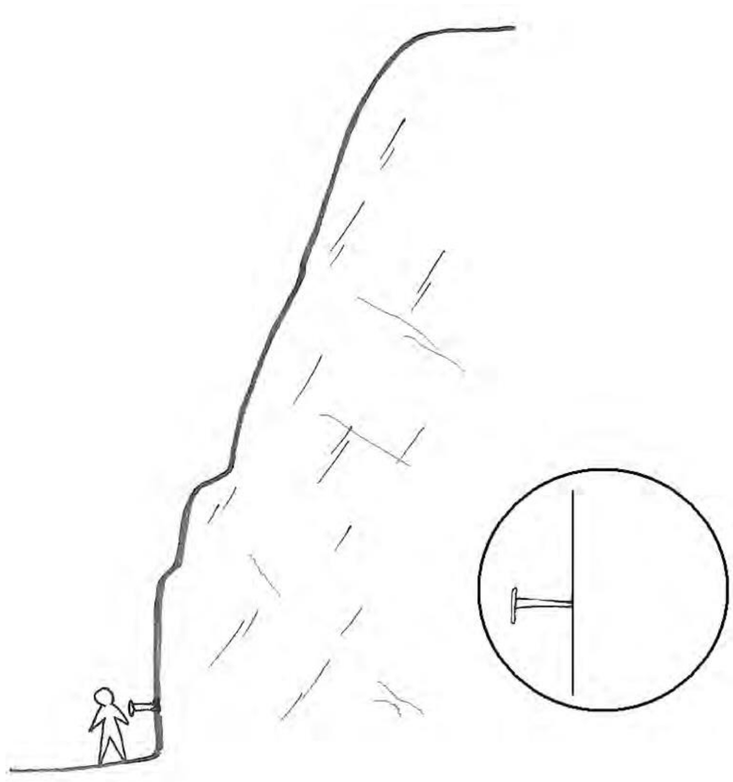


Figure HR1-1. Massive and intact hard rock

a) **hard rock** – cannot be penetrated by 4” common wire nail with a hammer; as hard or harder than concrete ($\geq$ 21MPa or 3ksi)

b) **massive and intact** - few widely spaced cracks or discontinuities, equal or greater than 2m apart, no predominant discontinuity

Examples:

1) volcanic or igneous rocks, such as basalt, andesite, granodiorite
2) metamorphic rocks: marble, schist, slate
3) sedimentary rocks: conglomerate, sandstone, limestone

Strength rating, *SRating* = 100

Photo HR1-1. massive conglomerate (sedimentary) rock

Photo HR1-2. massive andesitic (volcanic) rock

Photo HR1-3. massive limestone (sedimentary)

Photo HR1-4. massive sandstone (sedimentary), cannot be penetrated by 4” common wire nails

HR2: Blocky, well-interlocked hard rock, rock mass consisting mostly of cubical blocks

- (See **Figure HR2-1** and **Photos HR2-1** to **HR2-4**)

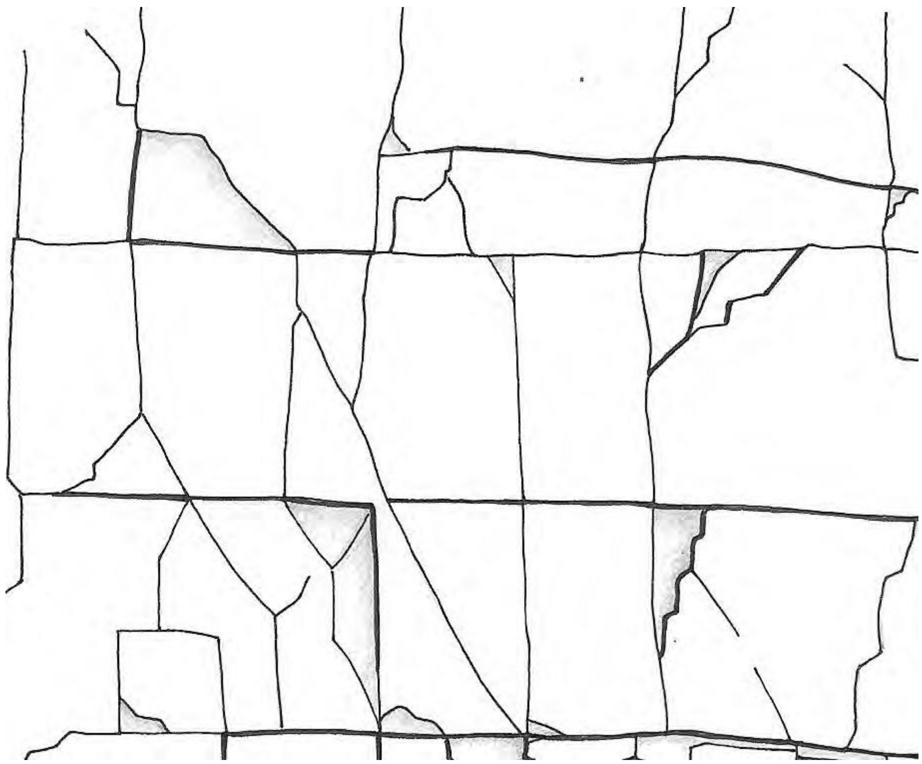


Figure HR2-1. Blocky, well-interlocked hard rock

a) **hard rock** – cannot be penetrated by 4" common wire nail with a hammer; as hard or harder than concrete ($\geq$ 21MPa or 3ksi)

b) **size of blocks** mostly between 60cm (2ft) to 2m (around 6ft)

Examples:

1) volcanic or igneous rocks, such as basalt, andesite, granodiorite
2) metamorphic rocks: marble, slate
3) sedimentary rocks: conglomerate, sandstone

Strength rating, *SRating* = 45

Given an *SRating* = 45, the maximum slope angle α for this material to be stable would be 75^{o}, according to **Table 3-1**. Fs_{basic} = 1.4.

Photo HR2-1. blocky granodioritic (volcanic) rock

Photo HR2-2. blocky sandstone (sedimentary) with conglomerate

Photo HR2-3. Blocky sandstone (sedimentary)

Photo HR2-4. blocky sandstone and conglomerate (sedimentary)

HR3: Very blocky and fractured hard rock (disturbed with multi-faceted angular blocks formed by 4 or more discontinuity sets)

- (See **Figure HR3-1** and **Photos HR3-1** to **HR3-4**)

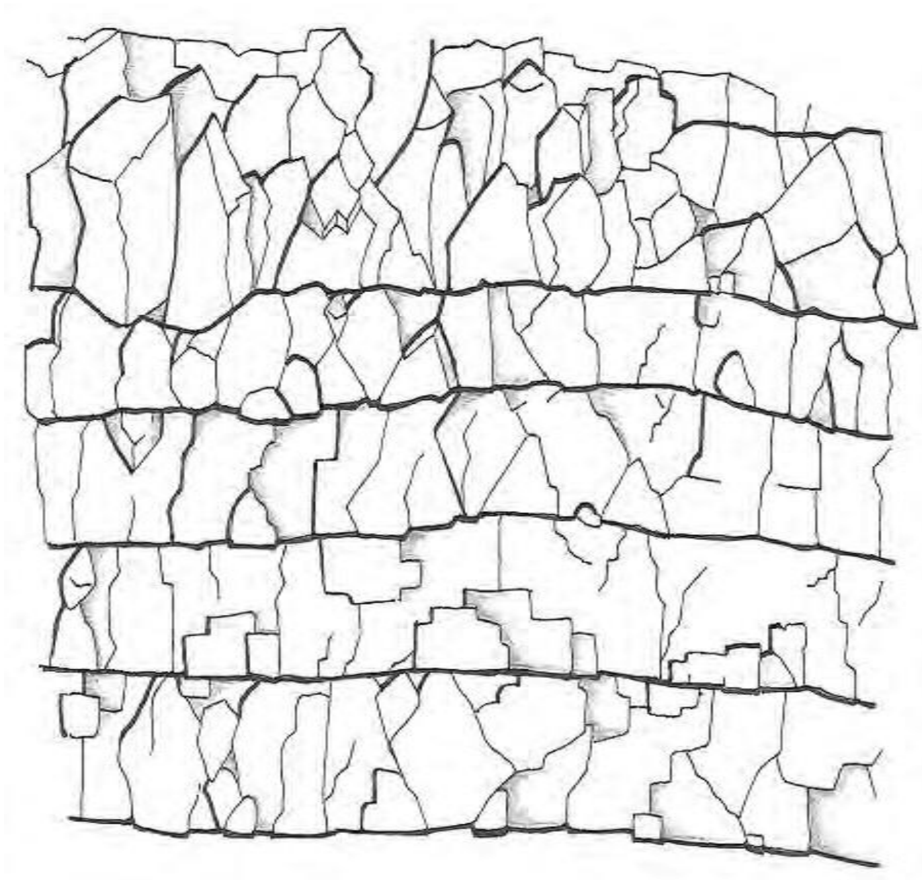


Figure HR3-1. Very blocky, fractured and disturbed hard rock

a) **hard rock** – cannot be penetrated by 4" common wire nail with a hammer; as hard or harder than concrete ($\geq$ 21MPa or 3ksi)

b) **size of blocks** mostly between 10cm (4inches) to 60cm (around 2ft)

Examples:

1) volcanic or igneous rocks, such as basalt, andesite, granodiorite
2) metamorphic rocks: marble, slate
3) sedimentary rocks: conglomerate, sandstone

Strength rating, *SRating* = 25

Given an *SRating* = 25, the maximum slope angle α for this material to be stable would be 60 ^{o}, according to **Table 3-1**. Fs_{basic} = 1.5.

Photo HR3-1. Very blocky and highly fractured granodioritic (volcanic) rock

Photo HR3-2. Highly fractured sedimentary rocks

Photo HR3-3. highly fractured hard rock

Photo HR3-4. highly fractured sandstone and conglomerate (sedimentary)

HR4: Disintegrated, unstable rocks and boulders, protruding rock fragments
- (See **Figure HR4-1** and **Photos HR4-1** to **HR4-4**)

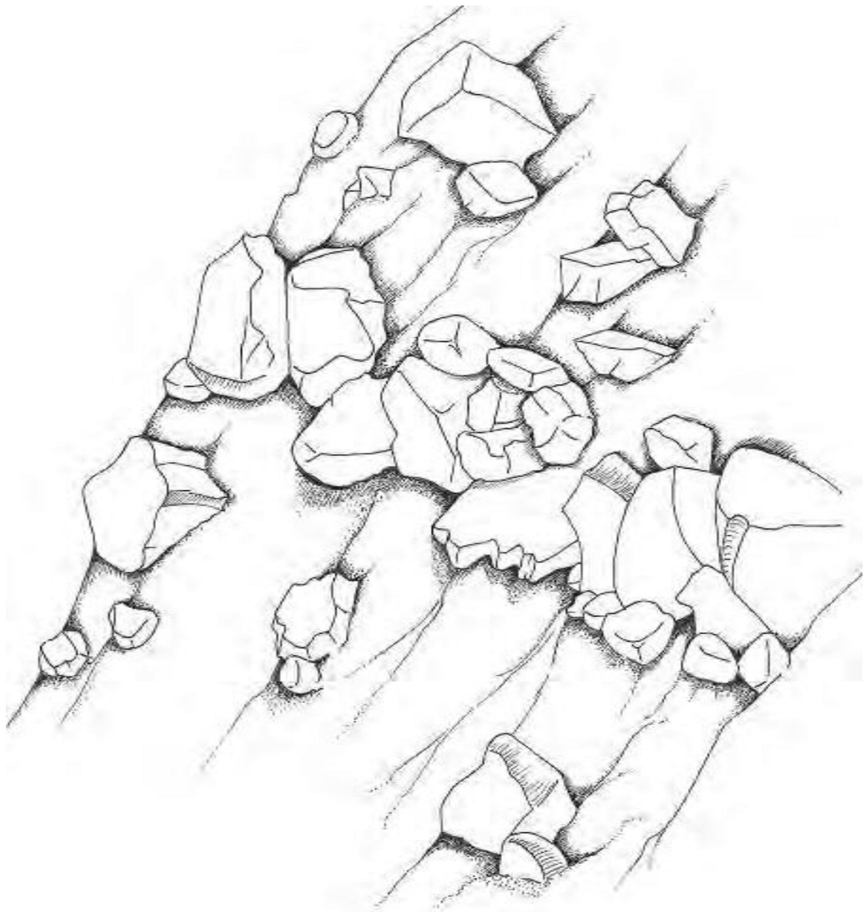


Figure HR4-1. Disintegrated, unstable and protruding rocks
- **a)** may include **soft rock fragments**
- b) **size of blocks** varies

Examples:
1) volcanic or igneous rocks, such as basalt, andesite, granodiorite
2) metamorphic rocks: marble, slate
3) sedimentary rocks: conglomerate, sandstone, limestone

Strength rating, *SRating* = 13

Given an *SRating* = 13, the maximum slope angle α for this material to be stable would be 45°, according to **Table 3-1**. Fs_{basic} = 1.3. Note that the effects of other factors are not considered in Fs_{basic}.

Photo HR4-1. Disintegrated and protruding boulders and fragments

Photo HR4-2. Disintegrated volcanic rocks

Photo HR4-3. Protruding boulders

Photo HR4-4. Another slope with protruding boulders and rock fragments

SR1: Massive and intact soft rock
- (See **Figure SR1-1** and **Photos SR1-1** to **SR1-4**)

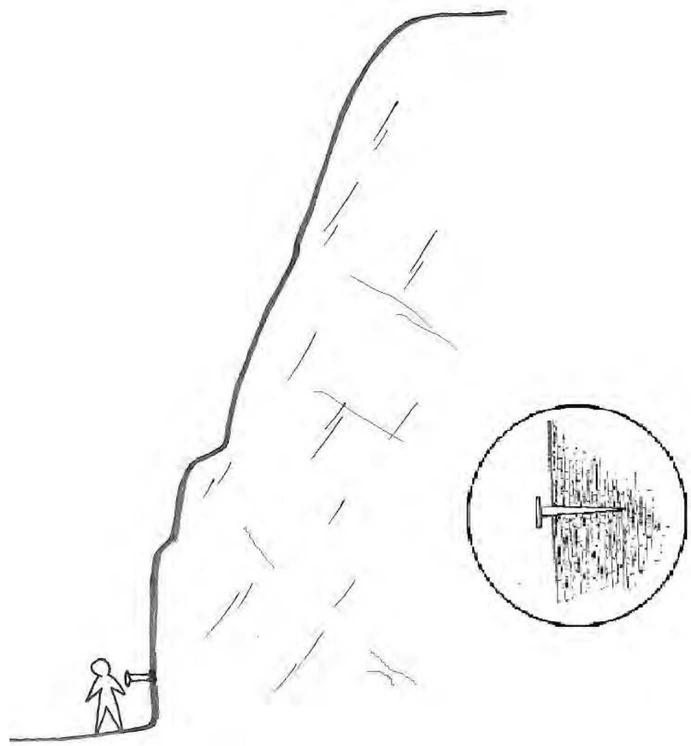


Figure SR1-1. Massive and intact soft rock

a) **soft rock** – can be penetrated by a 4” common wire nail with hammer; weaker than concrete (< 21MPa or 3ksi) but a fist-sized sample will not crumble or deform with hand pressure
b) **massive and intact** - few widely spaced cracks or discontinuities, equal or greater than 2m apart, no predominant discontinuity

Examples:

1) weathered volcanic or igneous rocks
2) weathered metamorphic rocks: slate
3) sedimentary rocks: conglomerate, sandstone, limestone

Strength rating, *SRating* = 30

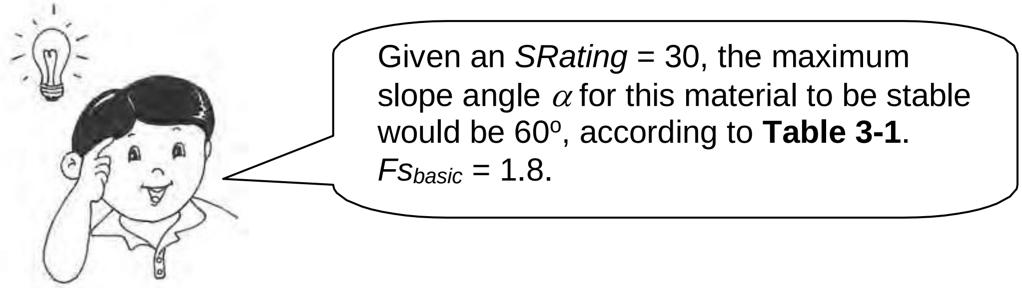


Photo SR1-1. Massive soft conglomerate (sedimentary)

Photo SR1-2. Massive soft rock with a spring (left side)

Photo SR1-3. Massive soft rock,

Photo SR1-4. Massive soft rock, can be penetrated by common wire nails (softer than concrete)

SR2: Very blocky and fractured soft rock
- (See **Figure SR2-1** and **Photos SR2-1** to **SR2-4**)

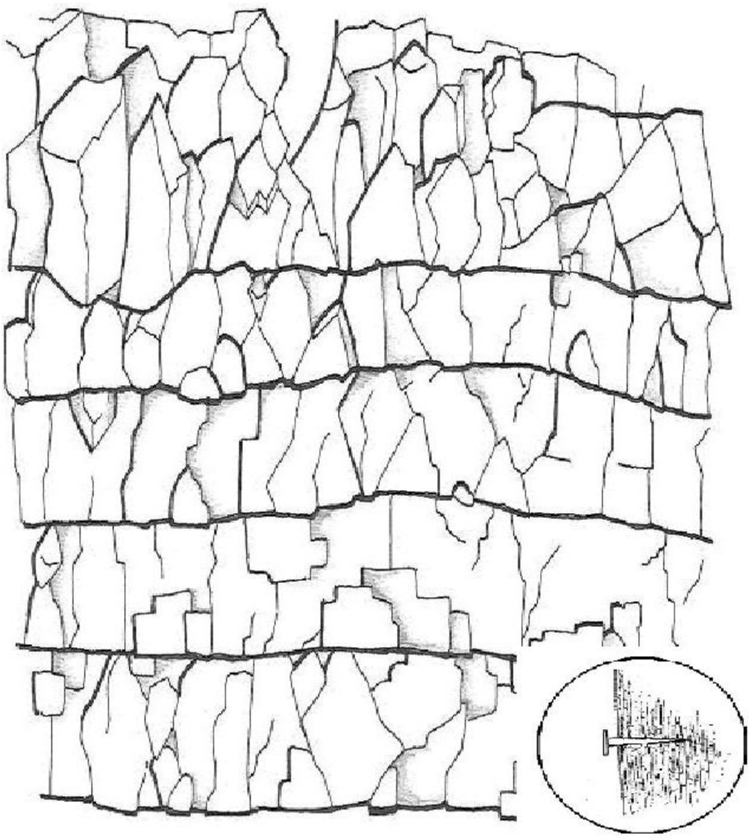


Figure SR2-1. Very blocky and fractured soft rock

a) **soft rock** – can be penetrated by a 4” common wire nail with hammer; weaker than concrete (< 21MPa or 3ksi) but will not crumble or deform with hand pressure

b) **size of blocks** mostly between 10cm (4inches) to 60cm (around 2ft)

Examples:

1) weathered volcanic or igneous rocks
2) weathered metamorphic rocks: slate
3) sedimentary rocks: conglomerate, sandstone, limestone

Strength rating, *SRating* = 15

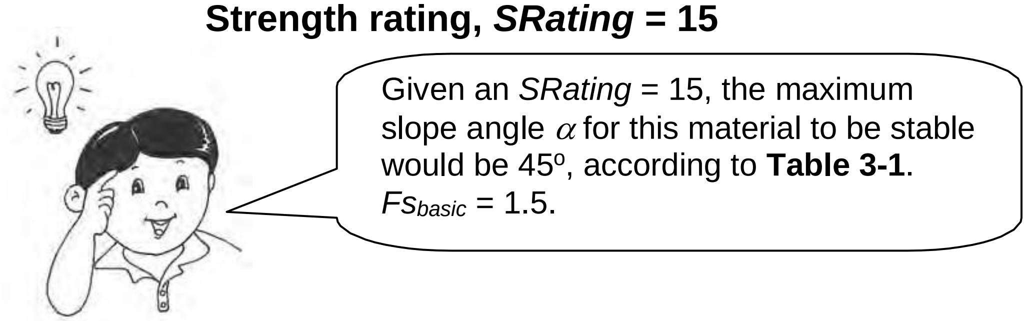


Photo SR2-1. Fractured soft sedimentary rock

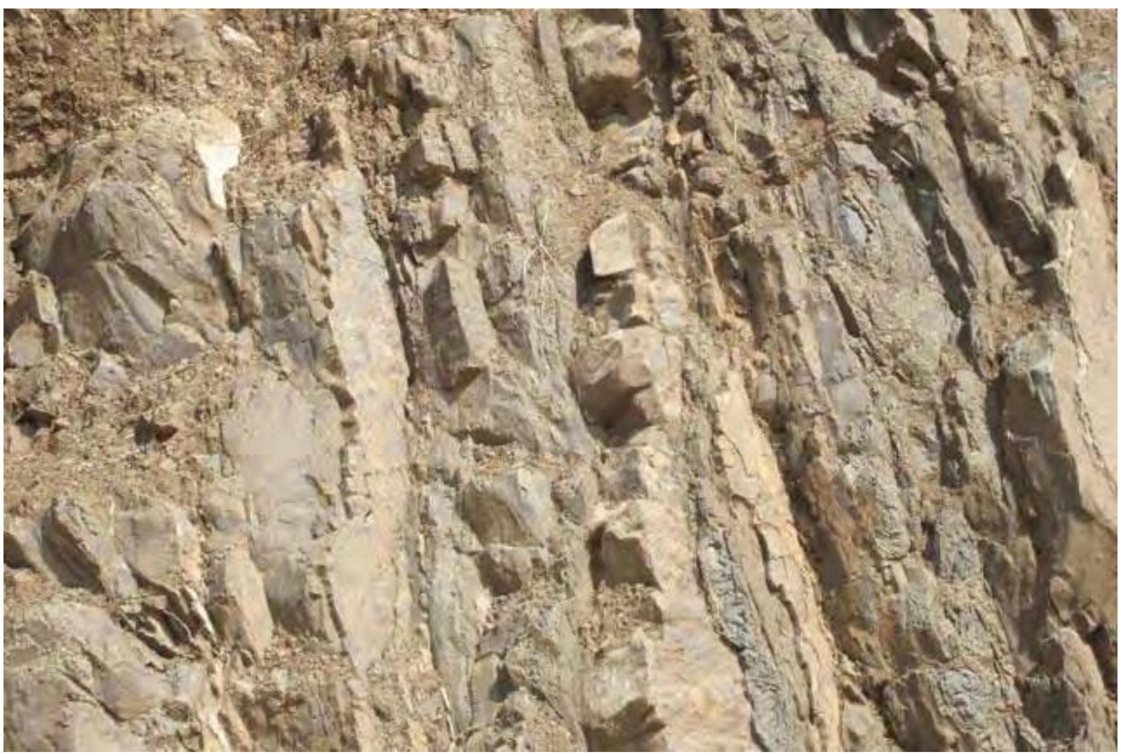


Photo SR2-2. Fractured soft sandstone interbedded with siltstones/mudstones

Photo SR2-3. Fractured soft sandstones with conglomerate

Photo SR2-4. Fractured soft rock, can be penetrated by common wire nails (softer than concrete)

HS1: Stiff, cemented and dense gravelly, sandy, silty and clayey soils
- (See **Figure HS1-1** and **Photos HS1-1** to **HS1-4**)

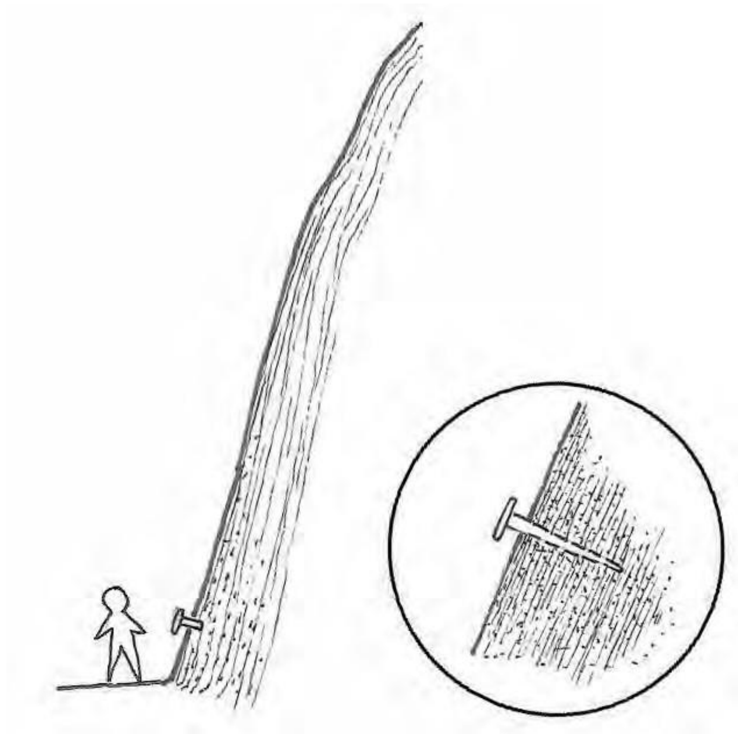


Figure HS1-1: Stiff, cemented and dense gravelly, sandy, silty and clayey soils

Stiff soil

- can be penetrated by a 4” common wire nail with hammer; weaker than concrete (< 21MPa or 3ksi)
- a fist-sized sample will crumble or deform with hand pressure but <u>will not crumble or deform with finger pressure</u>
- thumb will not indent soil but readily indented with thumbnail
- more reliable evaluation can include the conduct of Swedish Weight Sounding Test (SWST): SWST number ***NSW*** ≥ 80.

Strength rating, *SRating* = 25

Given an *SRating* = 25, the maximum slope angle α for this material to be stable would be 60º, according to **Table 3-1**. Fs_{basic} = 1.5.

Unless a definitive test (e.g. SWST) was conducted to establish that the slope material belongs to this classification, <u>use of this classification is discouraged</u>.

Photo HS1-1. Cemented/stiff sand deposit

Photo HS1-2. Hammer indentions into the cemented sand deposit

Photo HS1-3. Stiff sandy and gravelly deposit

Photo HS1-4. Stiff and cemented gravelly deposit (note spring at the left side of the slope)

SS1: Gravelly soil

- (See **Figure SS1-1** and **Photos SS1-1** to **SS1-4**)

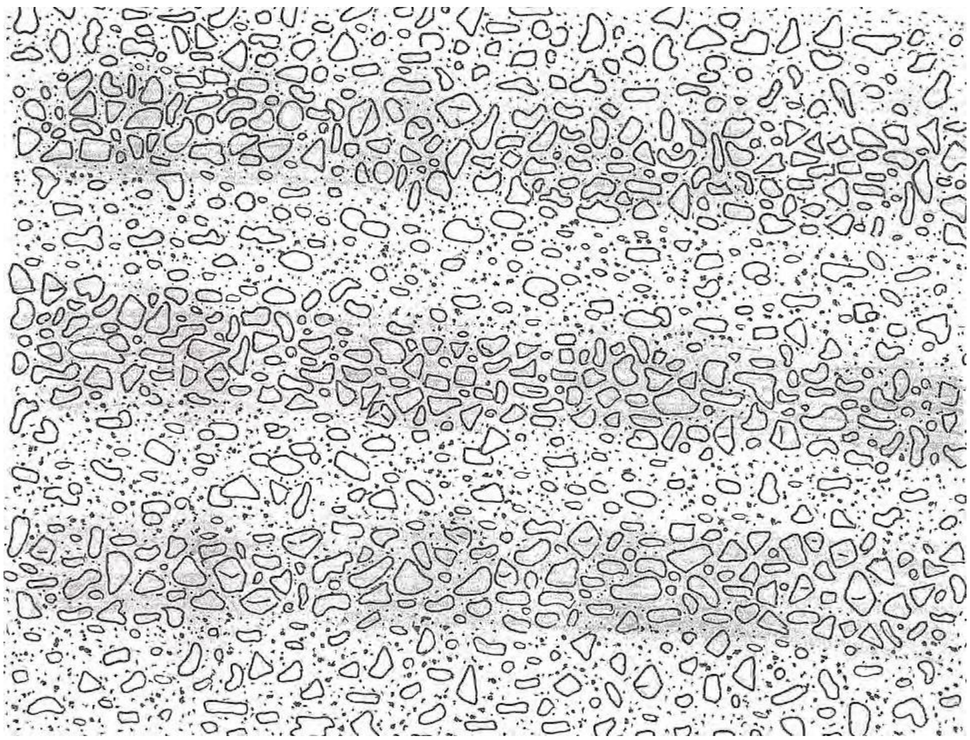


Figure SS1-1. Gravelly soil

Gravelly soil

- **size of most particles** between 5mm (around 1/4inch) to 75mm (3inches)
- fist-sized sample or smaller, containing 5 or more particles, will crumble with finger pressure

Strength rating, *SRating* = 10

Given an *SRating* = 10, the maximum slope angle α for this material to be marginally stable would be 45^{o}, according to **Table 3-1**. Fs_{basic} = 1.

Note that the SWST is not applicable for gravelly soils.

Photo SS1-1. Gravelly soil deposit

Photo SS1-2. Predominantly gravel deposit

Photo SS1-3. A gravelly deposit with springs

Photo SS1-4. An eroded gravelly soil deposit

SS2: Sandy soil
- (See **Figure SS2-1** and **Photos SS2-1** to **SS2-4**)

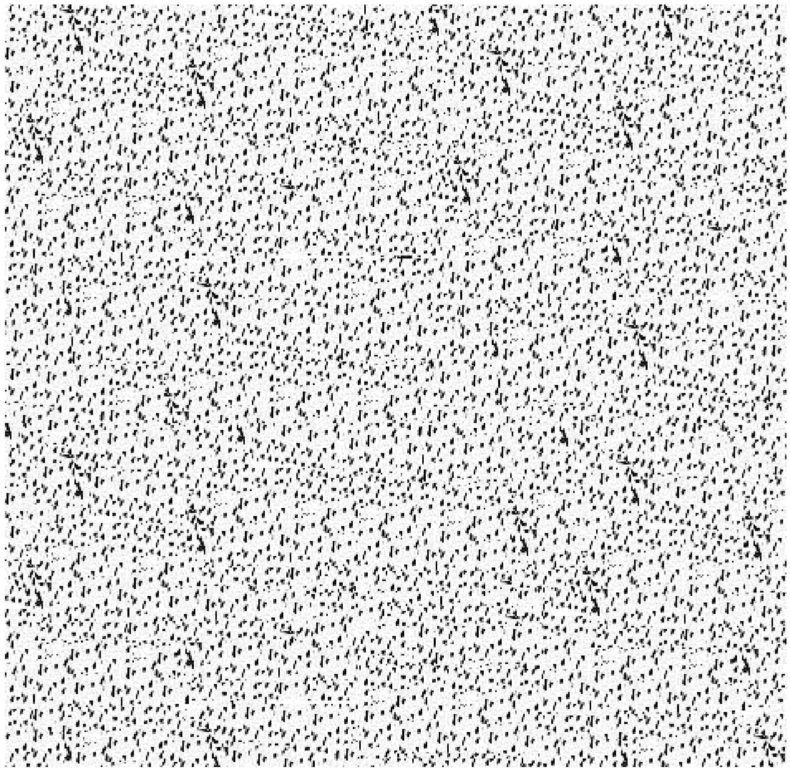


Figure SS2-1. Sandy soil

Sandy soil

- **size of most particles** finer than 5mm (around 1/4inch) and grains can be distinctly felt with fingers
- sample will crumble with finger pressure

Strength rating, *SRating* = 8

Given an *SRating* = 8, the maximum slope angle α for this material to be stable would be 30º, according to **Table 3-1**. Fs_{basic} = 1.6.

The SWST is applicable for sandy soils.

Photo SS2-1. Predominantly sand deposit

Photo SS2-2. Sand deposit

Photo SS2-3. Landslide with sandy material

Photo SS2-4. Slope (left) with predominantly sand deposit

SS3: Clayey/silty soil
- (See **Figure SS2-1** and **Photos SS2-1** to **SS2-4**)

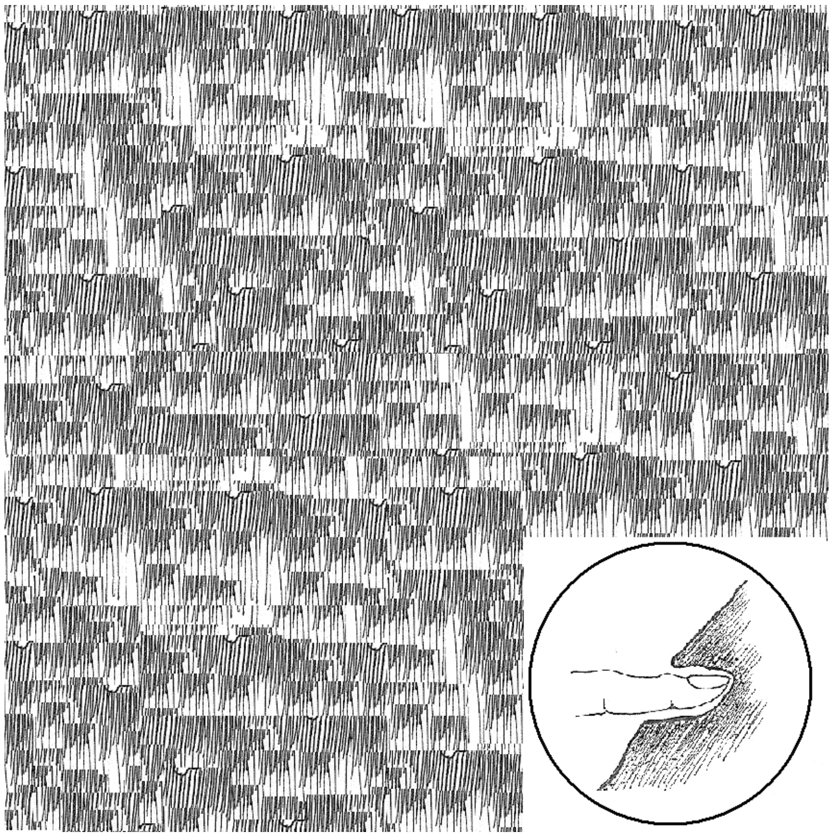


Figure SS1-1. Clayey/silty soil

Clayey, silty soil
- particles cannot be felt with fingers, especially when wet, soaplike
- can be indented with thumb and will crumble with finger pressure

Strength rating, *SRating* = 5

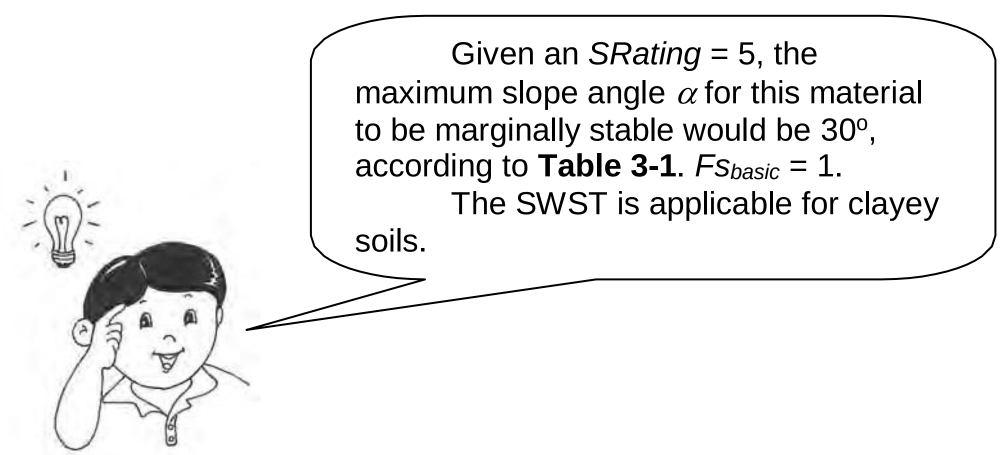



Photo SS3-1. Clayey slope with pine trees


Photo SS3-2. Excavation into a clayey slope

Photo SS2-3. Silty soil (brownish) and clayey (dark gray) material

Photo SS2-4. Thumb indentation into a clayey material

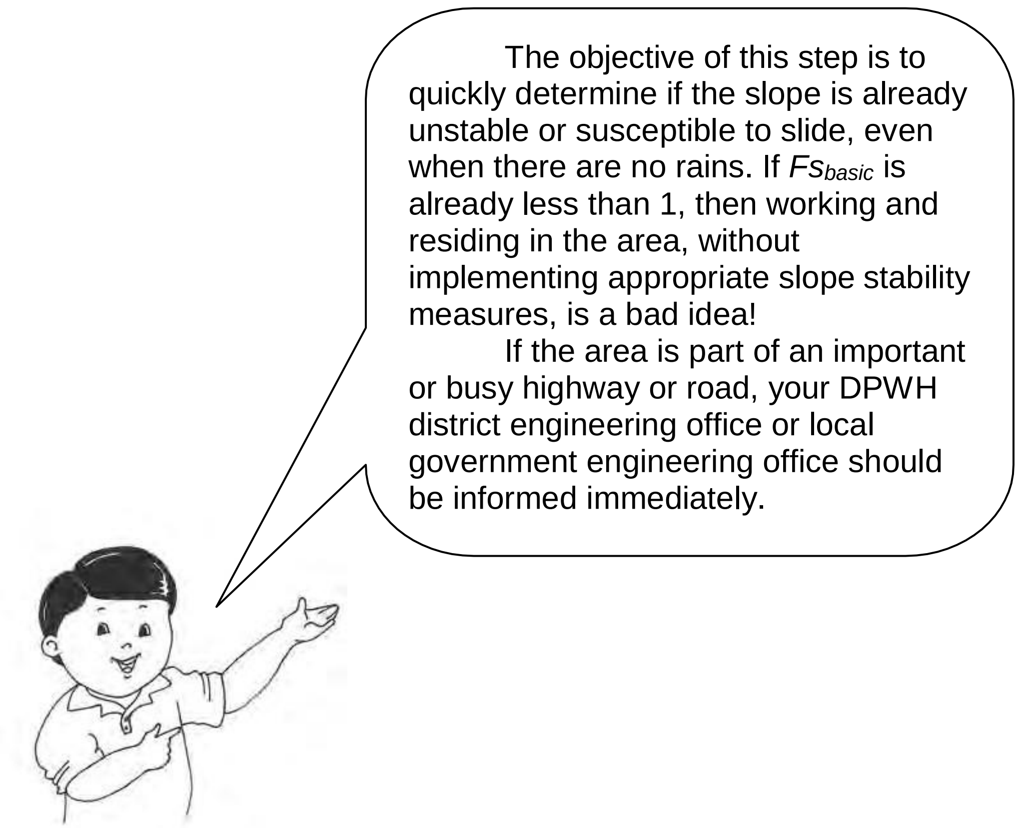
5.0 Compute the basic FS

The basic *Fs* (Fs_{basic}) is the ratio of *SRating* and α*Rating*:

$$Fs_{basic} = SRating/\ \alpha Rating.$$

For example, if the slope angle that was measured is around 23° then α*Rating* = 5. If the predominant slope material is sandy soil, then *SRating* = 8. In this case,

$$Fs_{basic} = 8/5 = 1.6.$$



6.0 Take into account other factors that may affect the stability of slope

6.1 FS considering other factors affecting slope stability

Table 6-1 lists the other factors that may affect the stability of the slope.

Table 6-1. Other factors affecting slope stability

Factor	Shorthand name
Vegetation cover	***vFactor***
Occurrence or frequency of failure	***fFactor***
Presence of springs	***sRed***
Condition of drainage canal/system	***dRed***
Amount of rainfall in 24 hours	***Rain***
Land use	***lFactor***

Considering these factors, ***Fs*** becomes

$$Fs = \frac{\overbrace{vFactor*fFactor*(SRating - sRed - dRed)}^{\text{numerator}}}{\underbrace{\alpha Rating * lFactor}_{\text{denominator}}}$$

When rainfall data are available or when rainfall is being measured, the ***sRed*** and ***dRed*** factors can be replaced by a single factor called ***Rain***. Here, ***Fs*** becomes

$$Fs = \frac{\overbrace{vFactor*fFactor*(SRating - Rain)}^{\text{numerator}}}{\underbrace{\alpha Rating * lFactor}_{\text{denominator}}}$$

Take note, the formula for ***Fs*** is always strength/load or ***S/L***. In the above formula, all factors affecting strength are in the numerator. For example, vegetation can strengthen the slope, thus ***vFactor*** is in the numerator. Rain or poor drainage system results in soil saturation and, consequently, in the reduction of soil shear strength, thus the factors ***Rain*** and ***dRed*** are in the numerator, which reduce the value of ***SRating***.

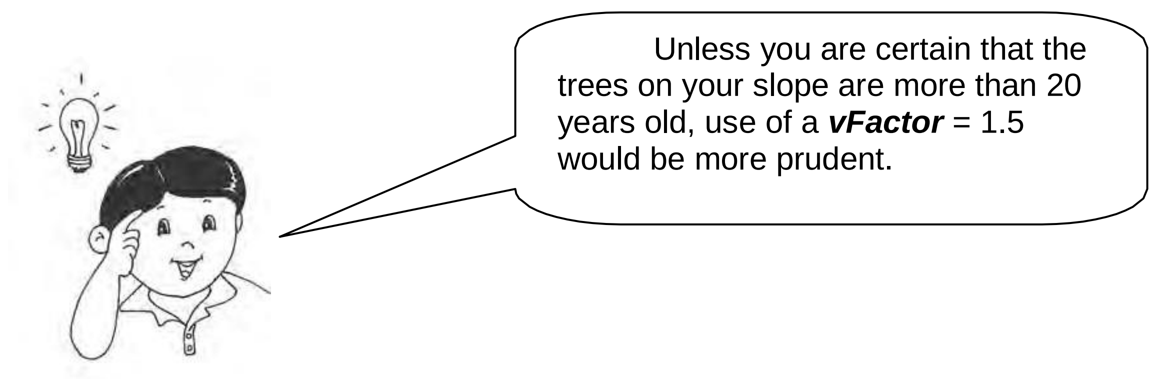
Land use, as in the case when reinforced concrete buildings are built on a slope, results in increased load for the slope. Thus, ***lFactor*** is placed in the denominator.

Following are the numerical values that can be adopted taking into account these factors:

6.2 Vegetation cover

Table 6-2. Types of vegetation and numerical values for *vFactor*

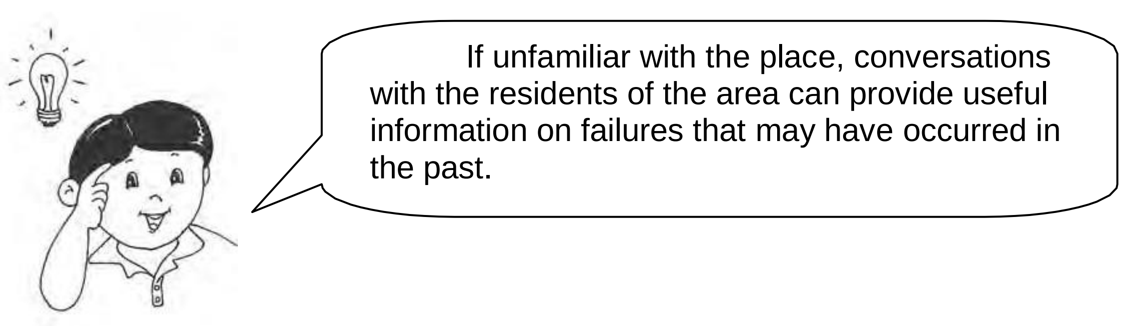
Type	*vFactor*
No vegetation	**1.0**
Predominantly grass or vegetation with shallow roots	**1.1**
Coconut, bamboo or vegetation with moderately deep roots	**1.2**
Dense forests with trees of the same specie having age less than or equal to 20 years	**1.5**
Dense and mixed forests with trees having age less than or equal to 20 years (Tangan, 2010)	**2.0**
Dense forests with pine trees having ages of more than 20 years (Tangan, 2010)	**2.0**
Dense and mixed forests with trees having ages of more than 20 years (Tangan, 2010)	**2.5**



6.3 Frequency of failure, deformation (e.g. rock fall, slides)

Table 6-3. Frequency/occurrence of failure and numerical values for *vFactor*

Frequency/occurrence of failure	*fFactor*
Once a year or more than once a year	**0.5**
Presence of past failure, but occurrence not yearly	**0.7**
Presence of tensile cracks in ground	**0.7**
If with retaining wall, wall is deformed	**0.7**
None	**1.2**



6.4 Presence of spring

Table 6-4. Presence of spring and numerical values for *sRed*

Duration	*sRed*
Yearlong	**2**
Only during rainy season	**1**
No flow/spring	**0**

6.5 Condition of drainage/canal/culvert (within the site/slope)

Table 6-5. Drainage condition and numerical values for *dRed*

Condition	*dRed*
No drainage system	**2**
Totally clogged, filled with debris	**2**
Partially clogged or overflows during heavy rains	**1**
Water leaks into the slope	**1**
Good working condition	**0**

6.6 Amount of rainfall (mm) in 24 hours

Table 6-6. Amount of rainfall (mm) in 24 hours

Amount of rainfall (mm) in 24 hours	*Rain*
50mm or less	**0**
More than 50mm but less than 100mm	**2**
More than 100mm but less than 200mm	**3**
More than 200mm	**4**

Take note that the factors ***sRed*** and ***dRed*** are used in the formula:

$$Fs = \frac{vFactor*fFactor*(SRating - sRed - dRed)}{\alpha Rating * lFactor}$$

while the factor ***Rain*** is used in the formula:

$$Fs = \frac{vFactor*fFactor*(SRating - Rain)}{\alpha Rating * lFactor}$$

The lower value from these two formulae shall be conservatively adopted as the ***Fs*** of the slope. For a more detailed and definitive evaluation of ***Fs***, a geotechnical engineer or an engineering geologist should be consulted.

6.6 Land use (within the site/slope)

Table 6-5. Land use and numerical values for *lFactor*

Land use	*lFactor*
Dense residential area (with closely spaced structures <5m)	**1.4**
Commercial with building/s having 2 storeys or more	**1.4**
Residential area with buildings having 2 storeys spaced at ≥5m	**1.25**
Road/highway with heavy traffic (1 truck or more every 10mins)	**1.4**
Road/highway with light traffic (less than 1 truck every 10mins)	**1.25**
Agricultural area, grasslands and bushlands	**1.0**
Forest	**1.0**
Uninhabited and no vegetation	**1.0**

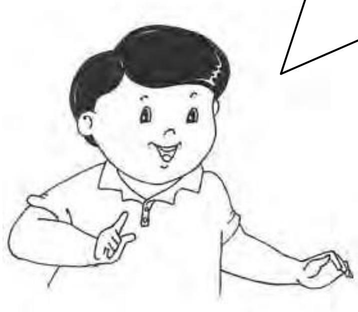
Let's consider an example for the calculation of Fs considering the other factors that can affect slope stability. Consider the same example in Chapter 5 where the ***SRating*** = 8 and the ***αRating*** = 5,

Assume the following:

Covered with grass, thus ***vFactor = 1.1***
No failure observed, ***fFactor = 1.2***
Spring found within the slope, ***sRed = 2***
No drainage canals, ***dRed*** = **2**
Uninhabited, ***lFactor*** = **1.0**

$$Fs = \frac{vFactor*fFactor*(SRating - sRed - dRed)}{\alpha Rating * lFactor}$$

$$Fs = \frac{1.1*1.2*(8-2-2)}{1.0*5} = 1.1$$ **The slope is marginally stable.**



7.0 Take appropriate action when FS is less than 1, and life, limb and property are at stake

In this assessment, the levels of stability or susceptibility are defined as follows:

1) Slopes with ***Fs*** greater than or equal to 1.2 (Fs $\geq$)
   are considered **stable**;
2) Slopes with ***Fs*** between 1 and 1.2 ($1.0 \leq Fs < 1.2$),
   marginally stable;
3) Slopes with ***Fs*** below 1 but greater than or equal to 0.7
   ($0.7 \leq Fs < 1.0$), **susceptible**; and
4) Slopes with ***Fs*** below 0.7 ($Fs < 0.7$), **highly susceptible**.

If the ***Fs*** is less than 1 and if life, limb and property are at stake,

1) Evacuate whenever a strong rain (due to a typhoon or monsoon) is forecasted/expected to fall in the area.

2) Report the situation immediately to concerned authorities with a request for more detailed evaluation to be carried out by a geotechnical engineer or engineering geologist.

3) If the affected area is a private property, the owner should take the initiative to consult a geotechnical engineer or an engineering geologist for appropriate mitigation measures.

Even if the slope has been found to be marginally stable ($1.0 \leq Fs < 1.2$), if a failure would affect several households or a community, a more detailed geotechnical site assessment should be carried out.

Annex A: Site assessment score sheet

DOST GIA LANDSLIDES PROJECT

KASC, PHIVOLCS , MGB -CAR, DPWH-KEDO

Tabuk, Kalinga Province

Tool for a Simplified, Site-Specific Evaluation of Rain-Induced Landslide Susceptibility

Instructions: For each step, enter appropriate values in the cell shaded gray based on the description contained in the corresponding table. The worksheet will compute the score corresponding the factor shown in the adjacent cell shaded blue. The overall factor of safety against rainfall induced slope failure will be outputed in the cell shaded green at the bottom of the worksheet.

Value Score

STEP I: Slope Angle

What is the average slope angle (in degrees)?

Value	Description	***αRating***
1	a) $\alpha \geq 75°$ (or with overhang) 82.5°	100
2	b) $60° \leq \alpha < 75°$ 67.5°	32
3	c) $45° \leq \alpha < 60°$ 52.5°	17
4	d) $30° \leq \alpha < 45°$ 37.5°	10
5	e) $15° \leq \alpha < 30°$ 22.5°	5
6	f) $\alpha \leq 15°$ 7.5°	2

STEP 2: Slope material

What is the predominant materal of the slope?

Value	Description	***sRating***
1	**Hard Rock 1**. Massive or intact hard rock. (a) hard rock – cannot be penetrated by 4" common wire nail with a hammer, as hard or harder than concrete (> 21MPa or 3ksi); (b) massive and intact - few widely spaced cracks or discontinuities, equal or greater than 2m apart, no predominant discontinuity.	100
2	**Hard Rock 2**. Blocky, well-interlocked hard rock. (a) hard rock – cannot be penetrated by 4" common wire nail with a hammer, as hard or harder than concrete (> 21MPa or 3ksi); (b) size of blocks mostly between 60cm (2ft) to 2m (around 6ft)	45
3	**Hard Rock 3**. Very blocky, fractured and disturbed hard rock. (a) hard rock – cannot be penetrated by 4" common wire nail with a hammer, as hard or harder than concrete (> 21MPa or 3ksi); (b) size of blocks mostly between 10cm (4inches) to 60cm (around 2ft).	25
4	**Hard Rock 4**. Disintegrated, unstable rocks and boulders, protruding rock fragments. (a) may include soft rock fragments; (b) size of blocks varies.	13
5	**Soft Rock 1**. Massive or intact soft rock. (a) soft rock – can be penetrated by a 4" common wire nail with hammer, weaker than concrete (< 21MPa or 3ksi) but a fist-sized sample will not crumble or deform with hand pressure; (b) massive and intact - few widely spaced cracks or discontinuities, equal or greater than 2m apart, no predominant discontinuity.	30
6	**Soft Rock 2**. Highly fractured soft rock. (a) soft rock – can be penetrated by a 4" common wire nail with hammer, weaker than concrete (< 21MPa or 3ksi) but will not crumble or deform with hand pressure; (b) size of blocks mostly between 10cm (4inches) to 60cm (around 2ft)	15
7	**Hard Soil 1 -** can be penetrated by a 4" common wire nail with hammer; weaker than concrete (< 21MPa or 3ksi); a fist-sized sample will crumble or deform with hand pressure but will not crumble or deform with finger pressure; thumb will not indent soil but readily indented with thumbnail; more reliable evaluation can include the conduct of Swedish Weight Sounding Test (SWST): SWST number NSW ≥ 80.	25
8	**Soft Soil 1**. Gravelly soil - size of most particles between 5mm (around 1/4inch) to 75mm (3inches); fist-sized sample or smaller, containing 5 or more particles, will crumble with finger pressure.	10
9	**Soft Soil 2**. Sandy soil - size of most particles finer than 5mm (around 1/4inch) and grains can be distinctly felt with fingers; sample will crumble with finger pressure.	8
10	**Soft Soil 3**. Silty soil / clayey soil - particles cannot be felt with fingers, especially when wet, soaplike; can be indented with thumb and will crumble with finger pressure.	5

STEP 3: Reduction due to groundwater

Is there a spring at the site?

Value	Description	*sRed*
1	Yearlong	2.0
2	Only during rainy season	1.0
3	No Flow	0.0

STEP 4: Effect of drainage (surface run-off)

What is the condition of the drainage canals at the site?

Value	Description	*dRed*
1	No drainage canals	2.0
2	Totally clogged, filled with debris	2.0
3	Partially clogged or overflows during heavy rains	1.0
4	Water leaks into the slope	1.0
5	Good working condition	0.0

STEP 5: Effect of failure/s in the past or on-going slope movement

Any failure in the past or on-going slope movement?

Value	Description	*fFactor*
1	Once a year or more than once a year	0.50
2	Presence of past failure, but occurrence not yearly	0.70
3	Presence of tensile cracks in ground	0.70
4	If with retaining wall, wall is deformed	0.70
5	None	1.20

STEP 6: Effect of vegetation

What is the predominant vegetation at the site?

Value	Description	*vFactor*
1	No vegetation	1.0
2	Predominantly grass or vegetation with shallow roots	1.1
3	Coconut, bamboo or vegetation with moderately deep roots	1.3
4	Trees with age less than or equal to 20 years	1.5
5	Trees with age more than 20 years	2.5

STEP 7: Effect of land use

What is the present land use?

Value	Description	*lFactor*
1	Dense residential area (with closely spaced structures <5m)	1.40
2	Commercial/residential area with building/s having 2 storeys or more	1.40
3	Residential area with buildings having 1 or 2 storeys spaced at ≥5m	1.25
4	Road/highway with heavy traffic (1 truck or more every 10mins)	1.40
5	Road/highway with light traffic (less than 1 truck every 10mins)	1.25
6	Agricultural area, grasslands and bushlands	1.00
7	Forest	1.00
8	Uninhabited and no vegetation	1.00

Overall Factor of Stability ***Fs***

Formula for calculating ***Fs*** :

$$Fs = \frac{vFactor*fFactor*(SRating - sRed - dRed)}{\alpha\ Rating * lFactor}$$

Landslide susceptibiltiy	***Fs***
Stable	***Fs*** > 1.2
Marginally Stable	1.0 ≤ ***Fs*** < 1.2
Susceptible	0.7 ≤ ***Fs*** <1.0
Highly Susceptible	***Fs*** < 0.7

Acknowledgements: This tool was developed through a grant from the Department of Science and Technology (DOST)-Grant-In-Aid Program through the Philippine Council on Industry and Energy Research and Development (PCIERD).

REMARKS & RECOMMENDATIONS:

Date

Annex B: Article on the rationale for developing the assessment procedure and technical background of the procedure

Note to the reader:

Annex B1, which is entitled "*Business Principles in Geohazard Mitigation and Management*," presents the rationale for undertaking the development of a rain-induced landslide assessment procedure for communities and non-experts. Annex B2, on the other hand, provides a technical background of the assessment procedure. Both are included as annexes of this guidebook to serve as references in enhancing and improving the assessment procedure.

Annex B1 was first published on the *Yellowpad Column* of the *BusinessWorld* newspaper on September 11, 2006.

Annex B1. Business Principles in Geohazard Mitigation and Management

by
Daniel C. Peckley Jr.

When one googles "The most disaster-prone country," the search results give an impression that the Philippines is competing with Bangladesh for the title. Since like Bangladesh the Philippines has limited financial resources, applying sound business principles – which have been developed to maximize the use of available resources – could just be the right approach to mitigate and manage the effects of natural hazards that frequently bring destruction and tragedies to our country.

The Toyota Way on geohazards

With regard to maximizing the use of available resources, perhaps the most well-known business principles are those long advocated and practiced by Toyota, Japan's largest company that is poised to become the world's largest car company. But can these principles be actually applied to disaster mitigation and management?

Let's take at closer look at three of Toyota's management principles, and on how they can be used for disaster mitigation – with particular focus on geohazards such as rain-induced landslides and earthquakes.

Harnessing employee intellect and creativity is the first principle. This is described by Gary Hamel in the February 2006 issue of The Harvard Business Review as follows:

"Unlike its western rivals, Toyota has long believed that first-line employees can be more than cogs in a soulless manufacturing machine; they can be problem solvers, innovators and change agents. While American companies relied on staff experts to come up with process improvements, Toyota gave every employee the skills, tools and permission to solve problems as they arose and to head off new problems before they occurred."

Bias for simple and inexpensive technology is the second principle. Toyota is known for its high-technology innovations, but behind the company's mastery of high technology is its practice to understand the manual process first before building simple technologies to automate it. As pointed out by Dr. Jeffrey Liker in his book the "Toyota Way," Toyota implements simple technologies to minimize investment and expedite implementation. Simple technologies are preferred because they are easy to refine and tune, while large automated systems are costly and more difficult to implement and change.

The third principle is the well-known "Kaizen," which means continuous improvement. This principle can be actually thought of as an integral component of the first two principles.

Empowering barangays

In the context of geohazard mitigation and management, harnessing employee intellect and creativity can mean empowering barangays, such that the "common folk" are able to assess geohazards themselves and take appropriate measures to mitigate the effects of these hazards. While the information dissemination and education campaigns (IECs) and earthquake drills that government agencies have been spearheading are commendable, the destruction and tragedies we experience every year point out that we have to go beyond IECs and drills.

Empowering barangays, however, begs the following questions: Is this possible at all? Is this practical?

The Cordillera rice terraces already attest that the common folk can also be engineers and geologists. To demonstrate that the idea is practical, meanwhile, let us consider present engineering practice in evaluating landslide susceptibility due to rainfall.

In practice, one way to evaluate susceptibility is through scoring methods, an example of which is the ATC-1997 risk evaluation method. In this method, landslide susceptibility criteria, such as slope height and inclination, are listed on a form and for each criterion a slope is given a score based on measured and observed attributes of the slope, very similar to how beauty contests are conducted. To facilitate the scoring process, visual aids of slope attributes, e.g. shape and form of the slope, are provided.

If one takes a closer look at the data and information required to give a slope a sliding susceptibility score following this method, it can be observed that many, if not all, of these data can be obtained by ordinary people. Any construction worker can measure slope height and inclination using a measuring tape, a handy inclinometer and rope. Surface soil thickness can be easily measured by simply digging into the slope or using a simple soil penetrometer. The amount of rainfall can be simply measured using a tin can and a ruler; one does not need a weather station to do this, although, of course, it is always desirable to have more PAGASA weather stations around the country. As for the other information required, one just needs to be a keen observer.

Two weeks or so of skills training may be required, but such training can be provided by the Mines and Geosciences Bureau (MGB) or PHIVOLCS. If we were to think further ahead, this training can actually even start in high school with curriculum changes in high school geometry and geology.

Simple and inexpensive tools

While investing in expensive high-tech gadgets and systems may enhance and sharpen our capabilities in dealing with geohazards, there are a number of inexpensive and simple tools and methods that can be extremely useful for a barangay-based geohazard mitigation and management program.

The Swedish penetrometer (for measuring surface soil thickness and strength) and Schmidt rebound hammer (for rock and concrete hardness) are examples of low-cost, basic tools that the government can subsidize for barangays. The use of Swedish penetrometer, in particular, can become a very practical tool for a barangay-initiated, site-specific investigation because it is easy to use and the whole contraption can be fabricated by local machine shops, even those that are in rural areas.

In Japan, the Swedish penetrometer test is recommended by law for the evaluation of foundation strength for residential construction. Due to the portability of the equipment, this test has been also used by researchers and engineers in reconnaissance and surveys of landslide- and earthquake-disaster-stricken sites.

Kaizen in Geohazards

One simple truth that most engineers and researchers have realized is that there is no such thing as a one-time, one-size-fits-all solution when dealing with geohazards. While much progress has been made over the past decades in terms of scientific knowledge on geohazards, present understanding of their nature, assessment and mitigation is still far from complete. Thereby the need for Kaizen, which in this case would mean the relentless pursuit of practical and cost-effective approaches in dealing with geohazards.

In rain-induced landslides, researchers are still confounded with the complexity and costs involved in accurately predicting and simulating their occurrences despite advances made in digital computing. This is the reason why a number of research activities on landslides are focused on observation and monitoring, and on the development of simple but measurable landslide susceptibility indices. Note that the keyword is susceptibility, not prediction.

Susceptibility indices can be obtained using simple tools, as earlier discussed. While wireless early-warning devices are now being developed, it can be argued that the barangay itself can perhaps observe a slope susceptible to failure better than any high-tech gadget. In the Cherry Hills landslide that occurred in 1999 and in the recent Guinsaugon landslide in Southern Leyte, communities in the vicinity had observed signs of impending failure.

One big advantage of the proposed barangay-based geohazard mitigation and management approach is that an empowered barangay itself can become a rich source of data, information and case histories of which assessment tools and mitigation measures worked and which did not. The ATC-1997 risk assessment methodology, for example, may work for some slopes, but it may not work for others since not all slopes have the same geologic and site characteristics. To a geologist or an engineer, feedback on the performance of present techniques and technologies are very important pieces of information.

Thus, while it may initially seem that empowering barangays means giving up one’s bread and butter, working and learning with them is actually one way to practice Kaizen and remain relevant. Working with them can, in fact, allow the geologist or engineer to devote more time and energy to pursue research on the many unresolved questions about geohazards and on more practical and cost-effective mitigation measures.

Considering the series of tragedies which we have already gone through, we indeed need to invest much more in geohazard mitigation and management. However, to make the most out of these investments and whatever resources we already have, we may have to follow the basic business principle that many of the most-admired companies have practiced: success is best achieved by relying more – not less – on people.

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Annex B2. Development of the rain-induced landslide assessment procedure

The proposed assessment procedure attempts to address certain limitations of existing procedures[1] and to satisfy the seemingly conflicting criteria:

1) It is simple and intuitive, such that it can be used by non-experts. The framework should also be simple enough such that any institutional user, e.g., DPWH and DENR, that wishes to enhance the assessment procedure according to the institution's needs and available expertise may be able to do so.
2) It has solid scientific and empirical basis.
3) It can be used for site-specific assessment, meaning that through this procedure, the susceptibility of a very specific area, say a 20sq. m. of sloping ground, can be evaluated.

1. Geotechnical inspections, surveys and tests

The assessment procedure is based on geotechnical inspections, surveys and tests of 243 landslide and imminent landslide sites in the provinces of Kalinga, Mt. Province and Benguet.

These inspections, surveys and tests involved the following activities:

1) Delineation of survey sites based on slope angle and the predominant slope material. One survey site is assumed to have one slope angle α and a predominant slope material.

2) Recording of site coordinates using a hand-held GPS receiver.

3) Taking of pictures of the site and preparation of sketches which include a site cross-section and plan. In these sketches, notes were taken on the existing vegetation on the slope, observed past failures, presence of springs, condition of drainage system (if any), present land use, and other notable features of the slope.

4) Measurement of the slope angle using an abney level or a laser rangefinder equipped with a tiltmeter.

5) Geotechnical characterization of the slope material. If the slope material is rock, characterization is based on the Hoek-Brown Criterion (Hoek et al., 2002; Marinos et al., 2005; Hoek et al., 2005; Hoek and Marinos, 2007). Rock intact strength is estimated using a Schmidt Rebound Hammer. Hammering 4-inch common wire nails into the rock slope was also introduced to differentiate hard rock from soft rock. Four-inch common wire nails cannot penetrate hard rocks.

   If the material is soil, on-site characterization involved using the ASTM D2488 known as the Standard Practice for Description and Identification of Soils: Visual-Manual Procedure (ASTM, 2004a) as reference. Soil penetration tests were also conducted using the Swedish Weight Sounding Test (SWST), whenever

[1] Refer to Section 6 for a brief review of existing procedures.

applicable and practicable. Laboratory tests included particle size analysis using a set of sieves, using ASTM D2487-00 Practice for Classification of Soils for Engineering Purposes (ASTM, 2004b) as reference.

6) Compilation, evaluation and analyses of data collected.

7) Revisit of survey sites, especially after a heavy rainfall, to confirm and validate the evaluation and analyses carried out.

2. Framework of the assessment procedure

The framework of the assessment procedure was crystallized after a seminar-workshop on rain-induced landslides conducted on June 13-17, 2010 in Sagada, Mt. Province. The seminar-workshop was attended by the KASC Project Team and personnel from PHIVOLCS, MGB-CAR, DOST-PCIERD, DOST-Special Projects unit (SPU) and DOST Balik-Scientist Program (BSP).

The framework takes off from the simple concept that the strength of material *S* should always be greater than the applied load *L*. In other words, $S/L > 1$. In engineering, this ratio is referred to as Factor of Safety, ***Fs***. **Figures 1a** and **1b** in the "Read me first" section of this guidebook illustrate the concept of ***Fs***.

In this study, though, ***Fs*** is referred to as **Factor of Stability**, as a mountain slope that is about to fail but will not affect any person or property can be considered safe, but unstable. For granular and frictional materials, e.g. gravelly, sandy and non-plastic silty soils (US Army Corp of Engineers, 2003),

$$Fs = \tan \phi / \tan \alpha \qquad \text{Eq. 1}$$

where ϕ is the angle of friction of the slope material and α, the slope angle. The expression $\tan \phi$ essentially defines the shear strength of these materials and $\tan \alpha$ is a representation of the load, which is basically due to gravity.

Following is a generalization of the factor of stability for all the slope materials considered in this study:

$$Fs_{basic} = SRating / \alpha Rating \qquad \text{Eq. 2}$$

Here, Fs_{basic} is the basic factor of stability. ***SRating*** is a numerical number or index that ranges from 1 to 100 and characterizes the strength of the slope material, and ***αRating*** is also a number or index that ranges from 1 to 100 and is proportional to the $\tan \alpha$. The ratio of ***SRating*** and ***αRating*** is referred to as <u>basic factor of stability</u> since the only factors considered in Eq. 1 are material strength and the slope angle α; the other factors affecting slope stability are not yet considered. **Figures 2a** and **2b** in the "Read me first" section of this guidebook illustrate the concept of Fs_{basic}.

2.1. Rating system for slope angle α

If slope angles were to be grouped as listed below, the *αRating* is the tangent of the mean of the range of the group, normalized such that the *αRating* for the range $\alpha \geq 75°$ is 100.

Range	Range mean	*αRating*
a) $\alpha \geq 75°$ (or with overhang)	82.5°	***αRating* = 100**
b) $60° \leq \alpha < 75°$	67.5°	***αRating* = 32**
c) $45° \leq \alpha < 60°$	52.5°	***αRating* = 17**
d) $30° \leq \alpha < 45°$	37.5°	***αRating* = 10**
e) $15° \leq \alpha < 30°$	22.5°	***αRating* = 5**
f) $\alpha \leq 15°$	7.5°	***αRating* = 2**

2.2. Basic strength index rating of slope materials

In soil mechanics, the angle of friction ϕ of non-cohesive soils like gravelly, sandy and non-plastic soils is already well established (See for example, Duncan [2004]). For gravelly soils, ϕ can range from 35° to 45° so the basic strength rating ***SRating*** for this material, from $Fs = 1 = \tan\phi / \tan\alpha$, should be around **10**. For sandy soils, ***SRating*** can be around **6**, following the same logic. For non-plastic silty soils, ***SRating*** = **5**.

It is also known that a massive, intact rock mass can have a slope that is vertical or nearly vertical. Such a massive, intact rock shall be assigned ***SRating*** = **100**. Presently, we define this rock to have the following Hoek-Brown parameters (Hoek et al., 2002):

i) Intact rock strength σ_{ci} = 50MPa
ii) Geologic strength index *GSI* = 60
iii) Material index *mi* = 25 (Dioritic rock)
iv) Disturbance index *D* = 0.8
v) Modular ratio *MR* = 325.

For a slope with this material and $\alpha \geq 75°$, the basic factor of stability is

$$Fs_{basic} = SRating/\alpha Rating = 100/100 = 1$$

Note that other factors affecting landslide susceptibility are not yet considered in this *Fs* calculation.

The slope materials initially considered in this research are listed below, together with their corresponding preliminary basic strength ratings. These preliminary ***SRating*** were determined using the following considerations and assumptions:

1) The ***SRating*** presented above for gravelly, sandy and silty soils and massive, intact rock mass, are used as reference;

2) The shear strength of the soils can be characterized using the Mohr-Columb Criterion, and that of rocks, the Hoek-Brown Criterion (Hoek et al., 2002; Marinos et al., 2005; Hoek et al., 2005; Hoek and Marinos, 2007);

3) The maximum depth[2] of landslides is around 3m. The procedure being developed in this study is basically visual and manual. It does not involve the use of drilling or sampling equipment that can penetrate deeper into the ground, thus this assumption. Although such an assumption appears to be restrictive, a wide and extensive application of the procedure is expected.

Note that the Hoek-Brown Criterion allows the conversion of its strength indices and parameters into equivalent Mohr-Columb strength parameters ϕ and c, where ϕ is the angle of friction, as defined above, and c cohesion (Please refer to Hoek et al., 2002 for more details on how this is carried out). With such conversion, which was performed using the software *Roclab* (Rocscience, 2007), and with assumptions and considerations given above, initial ***SRating*** values for the other slope materials considered in this study can be obtained.

Predominant slope material	***SRating***
HR1. Massive or intact hard rock with few widely spaced cracks or discontinuities, no predominant discontinuity intact rock strength, $\sigma_{ci} \geq 20$MPa Schmidt rebound hammer reading, $HR \geq 30$ crack/discontinuity spacing, $s \geq 200$cm Geologic strength index, $55 \leq GSI \leq 100$	***SRating* = 100**
HR2. Blocky, well-interlocked hard rock, rock mass consisting of cubical blocks intact rock strength, $\sigma_{ci} \geq 20$MPa Schmidt rebound hammer reading, $HR \geq 30$ crack/discontinuity spacing, $s \geq 60$cm Geologic strength index, $35 \leq GSI \leq 65$	***SRating* = 45**
HR3. Very blocky, disturbed hard rock with multi-faceted angular blocks formed by 4 or more discontinuity sets intact rock strength, $\sigma_{ci} > 20$MPa Schmidt rebound hammer reading, $HR \geq 30$ crack/discontinuity spacing, $20\text{cm} < s < 60$cm	***SRating = 35***

[2] Although an assumed landslide depth of not greater than 3m may appear restrictive, it is expected that the application of this study's assessment procedure would be extensive. Most of the landslides encountered in this study – more than 95% of the surveyed sites – are not deeper than 3m and yet a number of these shallow landslides caused terrible loss of lives and properties.

Geologic strength index, $25 \leq GSI \leq 65$

HR4. Highly fractured and seamy hard rock **_SRating = 25_**
folded with angular blocks
persistence of bedding planes and schistosity
intact rock strength, $\sigma_{ci} \geq 20$MPa
Schmidt rebound hammer reading, $HR \geq 30$
discontinuity spacing, $s \leq$ 20cm
Geologic strength index, $15 \leq GSI \leq 35$

HR5. Disintegrated, unstable rocks and boulders, **_SRating = 15_**
protruding rock fragments
intact rock strength, $\sigma_{ci} > 20$MPa
discontinuity spacing, $s \leq 20$cm
Geologic strength index, $5 \leq GSI \leq 25$

SR1. Massive or intact ***soft*** rock with few widely **_SRating_ = 30**
spaced cracks or discontinuities,
no predominant discontinuity
intact rock strength, $\sigma_{ci} < 20$MPa
Schmidt rebound hammer reading, $HR < 30$
crack/discontinuity spacing, $s \geq 200$cm
Geologic strength index, $55 \leq GSI \leq 100$

SR2. Highly fractured ***soft*** rock **_SRating = 15_**
intact rock strength, $\sigma_{ci} < 20$MPa
Schmidt rebound hammer reading, $HR < 30$
discontinuity spacing, $s \leq 20$cm
Geologic strength index, $5 \leq GSI \leq 35$

HS1. Stiff and dense gravelly, sandy, **_SRating = 20_**
silty and clayey soils
depth ≥ 0.5m
$15 \leq$ *SPT-N* value ≤ 50,
SWST Nsw value ≥ 80
cohesion , $c' \geq 30$kPa
angle of internal friction, $35° \leq \phi' \leq 50°$

SS1. Gravel/silty or sandy or clayey gravel deposit **_SRating = 10_**
depth > 0.5m
SPT-N value ≤ 20,
angle of internal friction, $30° \leq \phi' \leq 50°$

SS2. Sand/silty sand deposit **_SRating = 6_**
depth > 0.5m
SPT-N value ≤ 10,

SWST Nsw value ≤ 80
undrained shear strength, *Su* ≤ 80kPa
angle of internal friction, 15° ≤ *ϕ'* ≤ 35°

SS3. Soft clay/silt **SRating = 5**
depth > 0.5m
SPT-N value ≤ 5,
SWST Nsw value ≤ 60
undrained shear strength, *Su* ≤ 70 kPa
cohesion, 5kPa ≤ *c'* ≤ 20kPa
angle of internal friction, 5° ≤ *ϕ'*≤ 25°

2.3. Overall Fs considering other factors

The *Fs*, considering other factors that may affect the landslide susceptibility, shall be given as follows:

Fs = (vFactor*fFactor*[SRating - sRed – dRed]) / lFactor* αRating Eq. 3

where

vFactor is a factor that takes into account slope vegetation cover, if any;
fFactor is a factor that takes into account the frequency of slope failure, presence of cracks and previous failure history;
sRed represents a reduction of the shear strength of the slope material due to saturation, as evidenced by the presence of spring/elevation of groundwater table due to infiltration;
dRed represents another reduction of shear strength of the material due to saturation because of poor drainage system; and
lFactor is a factor that takes into account the land use.

Initially, the numerical values set for these factors were the following:

2.3.1 Presence of spring

Yearlong	***spRed* = 2.5**
Only during rainy season	***spRed* = 1.2**
No flow	***spRed* = 0**

2.3.2 Condition of drainage/canal/culvert (within the site)

No drainage system	***dRed* = 2.5**
Totally clogged, filled with debris	***dRed* = 2.5**
Partially clogged or overflows during heavy rains	***dRed* = 1.2**
Water leaks into the slope	***dRed* = 1.2**
Good working condition	***dRed* = 0**

2.3.3 Frequency of failure, deformation (e.g. rock fall, slides)

Once a year or more than once a year *fFactor* **= 0.5**
Presence of past failure, but occurrence not yearly ***fFactor* = 0.8**
Presence of tensile cracks in ground ***fFactor* = 0.8**
If with retaining wall, wall is deformed ***fFactor* = 0.8**
None ***fFactor* = 1.2**

2.3.4 Vegetation cover

No vegetation ***vFactor* = 1.0**
Predominantly grass or vegetation with shallow roots ***vFactor* = 1.1**
Coconut, bamboo or vegetation with moderately deep roots ***vFactor* = 1.3**
Trees with age less than or equal to 20 years ***vFactor* = 1.5**
Trees with age more than 20 years ***vFactor* = 2.5**

2.3.5 Land Use

Dense residential area (with closely spaced structures <5m) ***lFactor* = 1.4**
Commercial/residential area with building/s having 2 storeys or more ***lFactor* = 1.4**
Residential area with buildings having 1 or 2 storeys spaced at ≥5m ***lFactor* = 1.25**
Road/highway with heavy traffic (1 truck or more every 10mins) ***lFactor* = 1.4**
Road/highway with light traffic (less than 1 truck every 10mins) ***lFactor* = 1.25**
Agricultural area, grasslands and bushlands ***lFactor* = 1.0**
Forest ***lFactor* = 1.0**
Uninhabited and no vegetation ***lFactor* = 1.0**

Unlike in other landslide susceptibility rating systems developed previously, the introduction of factors that modifies the value of *SRating* is intuitive and would conform to recent observations on the effects of these factors. For example, it is generally known that root systems of trees reinforce soils on slopes, thus this factor should be multiplied to *SRating* and given a numerical value greater than 1 if the slope is covered with trees.

For the thick clayey slopes in Sagada, *SRating* = 5. According to this rating system, *Fs* = 1 (marginally stable), when the slope is between 15° and 30°. As these slopes are covered with thick pine forests, the net *SRating* would be 2*5 = 10. This indicates that these slopes can still be stable at slope angles between 30° and 45°, as we have observed in the environmental scanning carried out in the Sagada workshop.

It is also generally known that the effect of saturation on soils is a reduction in their shear strength. At 100% saturation, this effect can result in a reduction of shear strength by as much as 20%, compared to the shear strength at 30% saturation. In the case of a sandy soil mass, having *SRating* = 6, when the soil mass becomes saturated due to poor drainage and groundwater rises as observed by strong spring flow from the soil mass, the *SRating* becomes

$$Net\ SRating = 6 - 2.5 - 2.5 = 1.$$

Note that a slope with a net *SRating* = 1 is no longer stable even with slopes of less than 15°. This was observed in the Himay-angan Landslide in Southern Leyte in February 2007 (Uchimura et al., 2007) and in the Paracelis Landslide in 2005 (Peckley et al., 2007).

The assessment procedure also attempts to numerically evaluate the effects of environmental factors such as lost forest cover, poor drainage and others. It is hoped that such numerical evaluation would facilitate appropriate actions that can be undertaken by communities and concerned authorities.

3. Levels of stability and susceptibility

In this study, the following definitions were adopted:

1) slopes having $Fs \geq 1.2$ shall be considered stable;
2) slopes having $1.0 \leq Fs < 1.2$, marginally stable;
3) slopes having $0.7 \leq Fs < 1.0$, susceptible; and
4) slopes having $Fs < 0.7$, highly susceptible.

4. Slight changes in the rating system

One feature of the assessment procedure presented above is that it alleviates the need to perform many and lengthy iterations in determining the appropriate numerical values of the factors required in evaluating *Fs*. A quick trial-and-error can be conducted to establish reasonable numerical values of these factors, given the following attributes of the procedure:

a) The numerical values of *SRating* are bounded by the *SRatings* of massive and intact rock, and non-cohesive soils. As pointed out earlier, a massive and intact rock can support a slope that is vertical, thus an *SRating* of 100 can already be set for this particular material. On the other hand, the *SRatings* for non-cohesive soils were directly drawn from established values of the angle friction ϕ of these materials.

b) The determination of *SRatings* for the other rock slope material classifications are based on the Hoek-Brown Criterion, which has quite a strong empirical foundation on rock mechanics and is presently being used fairly extensively in geotechnical engineering.

c) The introduction of the other factors affecting slope stability into the procedure is intuitive. The numerical values of these factors can be directly drawn from documented observations of recent landslides, as illustrated above.

From April 2009 to March 2010, the project team conducted several series of surveys to validate the proposed rain-induced landslide susceptibility evaluation procedure. Special attention was given to sites that failed after the first series of surveys. The survey results indicated that slight modifications in the proposed procedure have to be introduced. The changes are as follows:

4.1 On the rating system of the predominant slope material

Predominant slope material	***SRating***
HR1. Massive or intact hard rock with few widely spaced cracks or discontinuities, no predominant discontinuity intact rock strength, $\sigma_{ci} \geq 20$MPa Schmidt rebound hammer reading, $HR \geq 30$ crack/discontinuity spacing, $s \geq 200$cm geologic strength index, $55 \leq GSI \leq 100$	***SRating* = 100**
HR2. Blocky, well-interlocked hard rock, rock mass consisting of cubical blocks intact rock strength, $\sigma_{ci} \geq 20$MPa Schmidt rebound hammer reading, $HR \geq 30$ crack/discontinuity spacing, $s \geq 60$cm geologic strength index, $35 \leq GSI \leq 65$	***SRating* = 45**
HR3. Very blocky, highly fractured hard rock* with multi-faceted angular blocks formed by 4 or more discontinuity sets intact rock strength, $\sigma_{ci} > 20$MPa Schmidt rebound hammer reading, $HR \geq 30$ crack/discontinuity spacing, 10cm < s < 60cm geologic strength index, $15 \leq GSI \leq 65$	***SRating* = 25** (from 35)

* The previous classifications of HR3 and HR4 were combined as the distinction between the two was unclear and confusing.

HR4. Disintegrated, unstable rocks and boulders, protruding rock fragments and boulders intact rock strength, $\sigma_{ci} > 20$MPa discontinuity spacing, $s \leq 10$cm geologic strength index, $5 \leq GSI \leq 25$	***SRating* = 13**

SR1. Massive or intact ***soft*** rock with few widely spaced cracks or discontinuities, — ***SRating* = 30**
no predominant discontinuity
intact rock strength, $\sigma_{ci} < 20\text{MPa}$
Schmidt rebound hammer reading, $HR < 30$
crack/discontinuity spacing, $s \geq 200\text{cm}$
geologic strength index, $55 \leq GSI \leq 100$

SR2. Highly fractured ***soft*** rock — ***SRating* = 15**
intact rock strength, $\sigma_{ci} < 20\text{MPa}$
Schmidt rebound hammer reading, $HR < 30$
crack/discontinuity spacing, $s \leq 20\text{cm}$
geologic strength index, $5 \leq GSI \leq 35$

HS1. Stiff and dense gravelly, sandy, silty and clayey soils — ***SRating* = 25** (from 20)
$depth \geq 0.5\text{m}$
$15 \leq SPT\text{-}N$ value ≤ 50,
$SWST\ Nsw$ value ≥ 80
cohesion, $c' \geq 30\text{kPa}$
angle of internal friction, $35° \leq \phi' \leq 50°$

SS1. Gravel/silty or sandy or clayey gravel deposit — ***SRating* = 10**
$depth > 0.5\text{m}$
$SPT\text{-}N$ value ≤ 20,
angle of internal friction, $30° \leq \phi' \leq 50°$

SS2. Sand/silty sand deposit — ***SRating* = 8** (from 6)
$depth > 0.5\text{m}$
$SPT\text{-}N\ value \leq 10$,
$SWST\ Nsw\ value \leq 80$
undrained shear strength, $Su \leq 80\text{kPa}$
angle of internal friction, $15° \leq \phi' \leq 35°$

SS3. Soft clay/silt — ***SRating* = 5**
$depth > 0.5\text{m}$
$SPT\text{-}N\ value \leq 5$,
$SWST\ Nsw\ value \leq 60$
undrained shear strength, $Su \leq 70$ kPa
cohesion, $5\text{kPa} \leq c' \leq 20\text{kPa}$
angle of internal friction, $5° \leq \phi' \leq 25°$

4.2 On the presence of spring

Yearlong	***spRed* = 2.0** from (2.5)
Only during rainy season	***spRed* = 1.0** from (1.2)

No flow ***spRed* = 0**

4.3 On the condition of drainage/canal/culvert (within the site)

No drainage system ***dRed* = 2.0** from (2.5)
Totally clogged, filled with debris ***dRed* = 2.0** from (2.5)
Partially clogged or overflows during heavy rains ***dRed* = 1.0** from (1.2) Water leaks into the slope ***dRed* = 1.0** from (1.2)
Good working condition ***dRed* = 0**

4.4 On the occurrence of failure, deformation (e.g. rock fall, slides)

Once a year or more than once a year ***fFactor* = 0.5** from (0.7)
Presence of past failure, but occurrence not yearly ***fFactor* = 0.7** from (0.8)
Presence of tensile cracks in ground ***fFactor* = 0.7** from (0.8)
If with retaining wall, wall is deformed ***fFactor* = 0.7** from (0.8)
None ***fFactor* = 1.2** from (1.25)

5. Validation

As of April 2010, the total number of sites surveyed was 243. When the *Fs* of these sites are grouped as presented in **Section 3**, the results, as shown in **Table 1,** can be obtained.

As seen in **Table 1**, none of the sites with *Fs* above 1.0 failed and almost 68% of the sites with *Fs* below 1 failed. For those with *Fs* below 0.7, the percentage of failure was quite high at 95%.

When the same sites are evaluated using the procedure developed by the Japan Road Association (JRA) Methodology (ATC, 1997), the results shown in **Table 2** can be obtained. The results that can be obtained using the procedure proposed by the Japanese Ministry of Construction (JMOC) Methodology (ATC, 1997) are shown in **Table 3**.

From these tables, it can be inferred that the results of the assessment procedure developed in this study and the JRA procedure are consistent with the indicated levels or categorization of landslide susceptibility. Such consistency cannot be observed with the evaluation carried out using JMOC procedure.

Although the JRA procedure also appears simple and can be modified for non-expert use, it can be noted that it does not include a clear and numerical basis why slope failure is "likely", "probable" or "unlikely". In the procedure developed in this study, slope failure susceptibility is based on the calculated *Fs*, which has a clear meaning, i.e., an *Fs* below 1 means the strength of slope material cannot sustain or support the gravitational force which is attributed to the slope gradient. Moreover, the empirical data on which the JRA procedure was developed were taken from case studies on landslides due to earthquake. Refer to sub-section 3.6.2 for more information on the JRA Procedure.

While the assessment procedure developed in this study took off from established engineering principles, and the landslide data gathered would validate its application, continuous improvement of the procedure and more data gathering are suggested. As can be inferred from **Table 1**, it can be said that there may have been “too much” focus on gathering data for sites that are very susceptible to landslides, i.e., those having an *Fs* below 0.7. It would be more desirable to gather more data that fit into the other levels of susceptibility.

6. Existing assessment procedures

This section presents a brief review of existing procedures for evaluating rain-induced landslide susceptibility that are being used in the Philippines and abroad.

6.1 DENR-MGB Procedure

At present, the DENR Mines and Geosciences Bureau (MGB) is conducting regional rain-induced landslide susceptibility mapping, based on 1:50,000 topographic maps of NAMRIA. In this endeavor, the susceptibility of slopes to fail depends on the following parameters: slope gradient (angle), fracturing, weathering and ground stability. Susceptibility is classified as low, moderate and high. **Table 4** provides an overview of the DENR-MGB Procedure.

While appropriate for mapping with scale from 1:50,000 to 1:10,000, significant enhancement of the DENR-MGB procedure would be required for site-specific susceptibility assessment, where a definitive or numerical value of Factor of Stability (or Safety) would be required. It should also be noted that a slope angle of 35^{o} or higher does not necessarily mean high susceptibility.

6.2 Other existing procedures

In the 1990s, when disasters due to rain-induced landslides started to gain more attention globally, the Asian Technical Committee on Geotechnology for Natural Hazards of the International Society of Soil Mechanics and Foundation Engineering and the Japanese Geotechnical Society (JGS) compiled procedures developed in Japan, Hong Kong and elsewhere for the evaluation and prediction of slope failure by heavy rain (ATC, 1997; Orense, 2003).

The procedures for the evaluation of landsliding potential were classified into three grades: Grade 1: Geomorphological Methods, Grade II: Overall Score Evaluation Methods, and Grade 3: Geotechnical Methods. **Table 5** presents a summary of these landslide susceptibility assessment procedures. Examples of these methodologies are the so-called JRA Methodology by the Japanese Road Association, shown in **Tables 6a** and **6b**, and the JMOC Methodology by the Japanese Ministry of Construction, shown in **Tables 7a** and **7b**.

Developed in 1988, the JRA Methodology is a simple procedure for predicting slope instability of cut-slopes along roads. Here, instability of a slope is evaluated in two steps, the first of which involves getting the slope’s total score based on the 12 parameters shown in **Table 6a**. The second step involves categorization of instability depending on whether the slope has a retaining wall or not, as shown in **Table 6b**. Although this procedure is based on case studies of landslides caused by the 1978 Izu-Oshima Earthquake (JRA, 1988 as cited by Orense, 2003), the project team included this methodology as an procedure for evaluating the data gathered, for three reasons: (1) it incorporated the parameter on spring water flow, a very important parameter for rain-induced landslides; (2) the methodology appears to be earthquake-intensity neutral, i.e., earthquake intensity is not among the parameters considered in the evaluation of instability; and (3) many of the sites surveyed in this study were road cut-slopes.

The JMOC is a simple and straightforward method in evaluating landslide risk, based on the eight parameters shown in **Table 7a**. Risk ranking is presented in **Table 7b**.

While these Grade II evaluation methods are less mathematically rigorous and their use can be simple and straightforward, it can be noted that these methods are evidently not built upon established knowledge, professional practice and advances in soil mechanics and rock mechanics.

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Table 1. Summary of evaluation using the procedure developed in this study

Factor of Stability ***Fs***	No. of sites surveyed	No. of sites that failed	%age failure
Fs $\geq$ 1.2: Stable	2	0	0
1.0 $\leq$ ***Fs*** < 1.2: Marginally stable	8	0	0
0.7 $\leq$ ***Fs*** < 1.0: Susceptible	40	27	68%
Fs < 0.7: Highly susceptible	193	184	95%
Total	243	211	87%

Table 2. Summary of evaluation using the JRA procedure (1988 as cited by ATC, 1997)

Susceptibility	No. of sites surveyed	No. of sites that failed	%age failure
A: Slope failure likely	235	207	88%
B: Slope failure probably	8	4	50%
C: Slope failure not likely	0	0	0
Total	243	211	87%

Table 3. Summary of evaluation using the JMOC procedure (1997 as cited by ATC, 1997)

Risk ranking	No. of sites surveyed	No. of sites that failed	%age failure
Very high	32	207	72%
High	180	161	89%
Moderate	31	27	87%
Total	243	211	87%

Table 4. MGB landslide susceptibility assessment procedure

Parameters	Low	Moderate	High
Slope gradient	Low to moderate (<18°)	Moderate to steep (18°-35°)	Steep to very steep (>35°)
Fracturing	Normally lacks fracturing, tight jointing, fresh massive bedrock	Moderately fractured; moderately tight bedding/jointing	Highly fractured, jointed (esp. when joints dip towards the slope face
Weathering	Slight to moderate	Moderate	Highly to completely weathered
Ground stability	Stable with no identified landslide scars, either old, recent or active	Areas with indicative and/or old landslides, presence of small tension cracks	-Presence of active and/or recent landslides - Presence of numerous and large tension cracks - Areas with drainages that are prone to debris damming - Areas with numerous old landslides/escarpments - Slope stability evident (e.g. presence of tension cracks, tilted posts, etc. -- Nearness to fault

Table 5. Classification of slope failure potential evaluation procedures (modified from ATC [1997])

Grade	Description	Required information
Grade I	Geomorphological Methods – appropriate for regional landsliding potential evaluation	Topographical maps, geological maps, aerial Maps
Grade II	Overall Score Evaluating Methods – simple, more detailed than geomorphological methods, appropriate for rapid landsliding potential evaluation of specific sites	Topographical maps, geological maps, vegetation, land use maps
Grade III	Geotechnical Methods – most detailed, more time-consuming, most expensive among the three; site-specific evaluation	Topographical maps, geological maps, vegetation, soil boring data, rainfall data

Table 6a. Japan Road Association (JRA) Procedure: parameters (ATC, 1997)

Item	Category	Weight
(1) Height of Slope, H (m)	$50m \leq H$	10
	$30m \leq H < 50m$	8
	$10m \leq H < 30m$	7
	$H < 10m$	3
(2) Angle of slope, α	$1{:}0.6 \leq \alpha$	7
	$1{:}1.0 \leq \alpha < 1{:}0.6$	4
	$\alpha < 1{:}1.0$	1
(3) Overhang	Formed in no-walled slope	7
	Formed in walled slope	4
	Not formed	0
(4) Geology	Many unstable stones	10
	Many stones on the surface of slope	7
	Very weathered rock	6
	Gravelly soil	5
	Weathered rock	4
	Cracked rock	4
	Sand	4
	Clay	1
	Intact rock	0
(5) Thickness of weathered soil	More than 0.5m	3
	Less than 0.5m	0
(6) Water flow	Flow	2
	No flow	0
(7) Frequency of rock falls	More than once per year	5
	Less than once per year	3
	None	0

Item	Category	Rank
(8) Deformation of slope	Deformed	I
	Not deformed	III
(9) Deformation of retaining wall	Deformed	I
	Not deformed	III
(10) Rockfall which induce traffic problems	Occurred	I
	Not occurred	III
(11) Cut or fill on slope	Many cuts or fills	I
	Few cuts or fills	II
	None	III
(12) Stability of retaining walls	Unstable	I
	Walls stable	II
	Very stable	III

Table 6b. JRA Procedure instability categorization (ATC, 1997)

(a) Without retaining wall (Stage 1)

Weight based on (8) to (11)	Summation of Weight from (1) to (7)		
	< 13	14 to 23	> 24
Class I ≥ 1	(A)	(A)	(A)
One class II, other class III	(B)	(A)	(A)
All class III	(C)	(B)	(A)

(A): slope failure likely

(B): slope failure probable

(C): slope failure not likely

(b) With retaining wall (Stage 2)

Rank in (12)	Summation of Weight from (1) to (7)		
	(A)	(B)	(C)
I	A	A	A
II	A	B	C
III	B	C	C

A: slope failure likely

B: slope failure probable

C: slope failure not likely

Table 7a. Japan Ministry of Construction (JMOC) Procedure: parameters (ATC, 1997)

Factors		Score: Natural slopes	Score: Artificially modified slopes	Remarks
1. Slope height	≥10m	7	7	
	<10m	3	3	
2. Slope inclination	≥45°	1	1	
	<45°	0	0	
3. Overhangs	present	3	3	
	absent	0	0	
4. Surface soil thickness	≥0.5m	1	1	
	<0.5m	0	0	
5. Springs	present	1	1	
	absent	0	0	
6. Failures around the area	present	3	3	
	absent	0	0	
7. Technical standard of protection measures	satisfied		0	
	unsatisfied		3	
8. Abnormality in protection measures	much		3	
	none		0	

Table 7a. Japan Ministry of Construction (JMOC) Procedure: risk ranking (ATC, 1997)

Rank	Score: Natural slopes	Score: Artificial slopes	Risk ranking
A	>9	>15	Very high
B	6-8	9-14	High
C	≤5	≤8	Moderate

Annex C: Swedish weight sounding test manual

UNESCO NATIONAL COMMISION
OF THE PHILIPPINES

SWEDISH WEIGHT SOUNDING TEST
Manual

Fides Lovella A. Baddongon, KASC
Daniel C. Peckley Jr., DOST Balik Scientist

Introduction

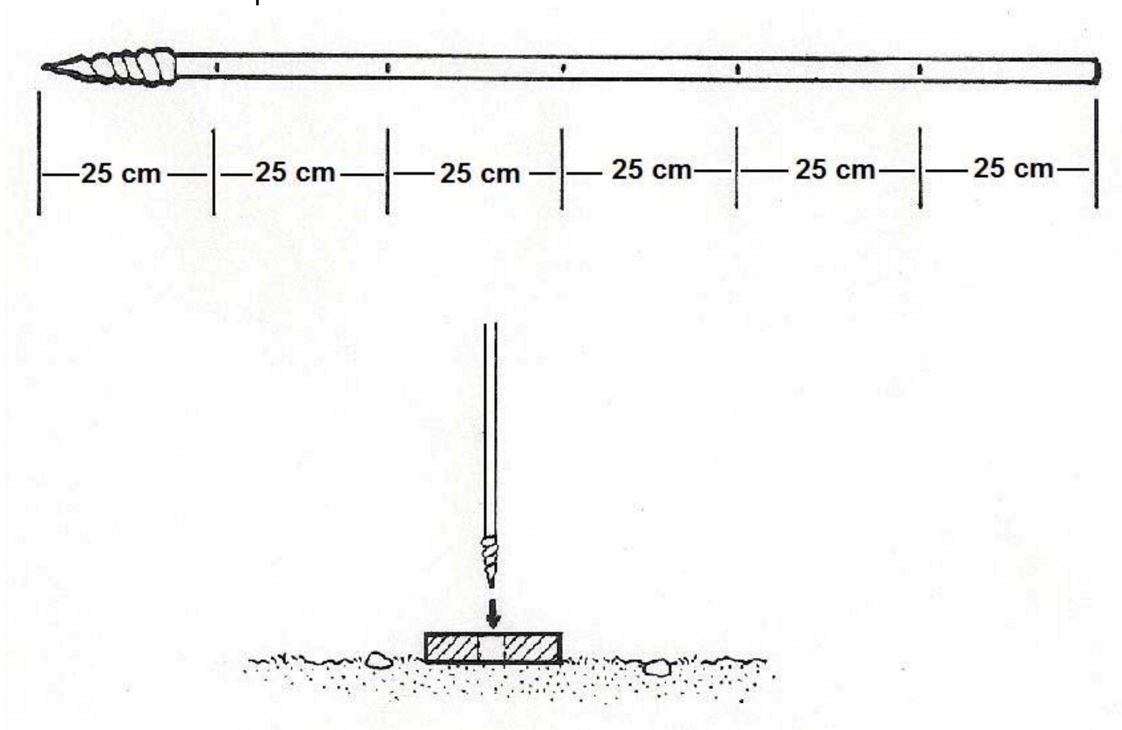
The Swedish Weight Sounding Test (SWST) was developed and standardized by the Geotechnical Commission of the Swedish State Railways and was used since 1914 as part of the investigation of soil strata in Sweden. Because SWST is simple and yields quick and reliable results, it has gained worldwide acceptance as test for shallow subsurface soil layers.

Swedish weight sounding tests are commonly conducted to obtain estimates of the shear strength or SPT-Numbers of soil deposits[1]. In Japan, with the enactment of the Japan Housing Quality Assurance Act in year 2000 this test has been recommended for the evaluation of foundation strength for residential construction[2]. Due to the portability of the equipment, this test has been also used in reconnaissance and surveys of landslides and earthquake-disaster-stricken sites[3].

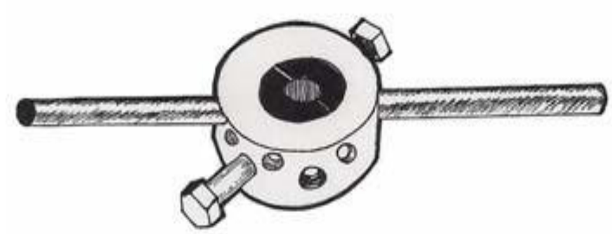
The Swedish Weight Equipment consists of a screw point, sounding rods, rotating handle and 10 individual weights of 10 kg each, making a total of 100 kg.

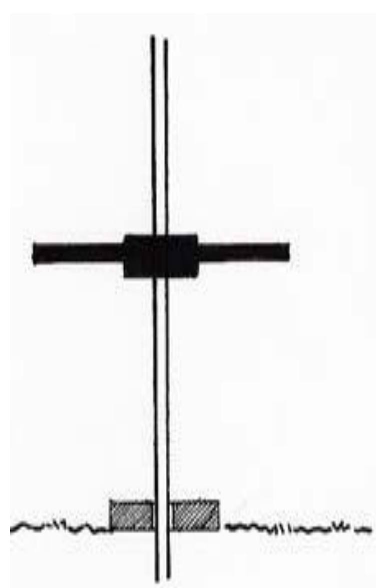
[1] (Tsukamoto et al. 2004, [2] Tsukamoto et al., 2006; Suemasa et al. 2005), [3] (Towhata et al, 2004)

1. Identify and locate the points where penetration shall be carried out. Position the bottom plate on the soil for penetration. Connect the screw point to the series of rods. Mark every 25 cm of the connected rods starting from the tip of the screw point for ease in the determination of depth. Place it in the hole located at the middle of the base plate.

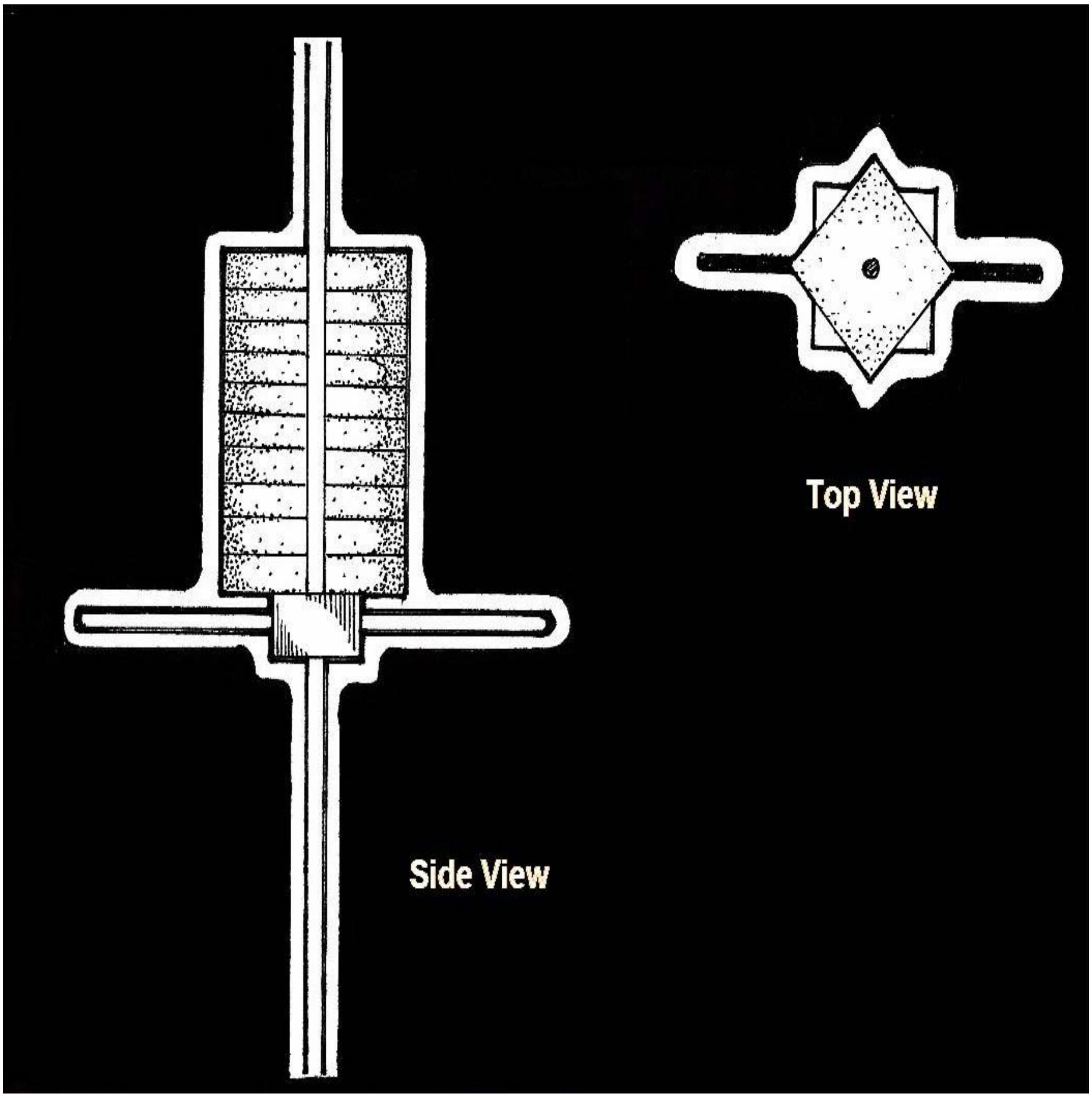


2. Attach the handle into the vertical rod and tighten the ball clamp using a #24 wrench. This handle assembly will also hold the weights that will be applied later.

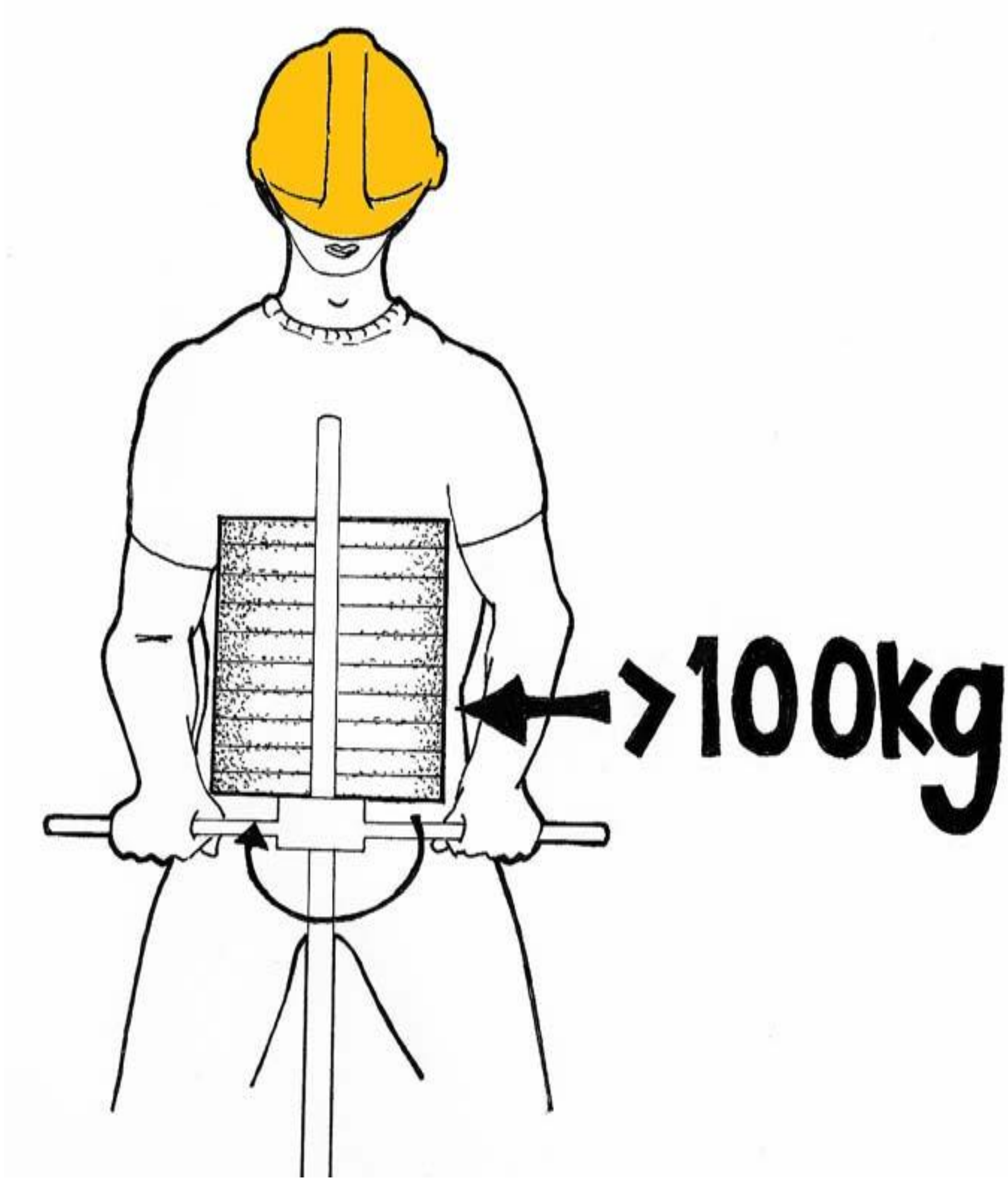




3. The assembly is gradually loaded by placing each of the ten surface weights (WSW) of 10 kg until a total surface weight of 100 kg (0.98KN) is reached. As each load is added, the point starts penetrating the soil. This load is recorded, just as any further loads required to continue penetration.



4. As soon as the rod refuses to penetrate under the load of 100 kg, the handle assembly is rotated by hand at half- turns. The handle should not be rotated if the load applied is less than 100 kg.



5. The number of half turns required for every 25 cm depth penetration of the rod is recorded and is taken to represent the penetration resistance of the soil in each 25 cm depth, (Na). The number of half-rotations for every 25-cm depth is multiplied by four to obtain the equivalent number of rotations for 1-meter penetration, (NSW). Place data in the record sheet provided.

Swedish Weight Sounding Test (Penetrometer)					
Project Name:				Date:	
Location:				Performed by:	
Weight W_{SW}	No. Of half-turns	Total Depth	Penetration Depth	Eq. No. of rotations for 1-m penetration	Eq. SPT-N Value[1]
KN	Na	D (m)	L (cm)	N_{SW}	SPT-N

[1] Equivalent SPT-N

For Sandy Soils

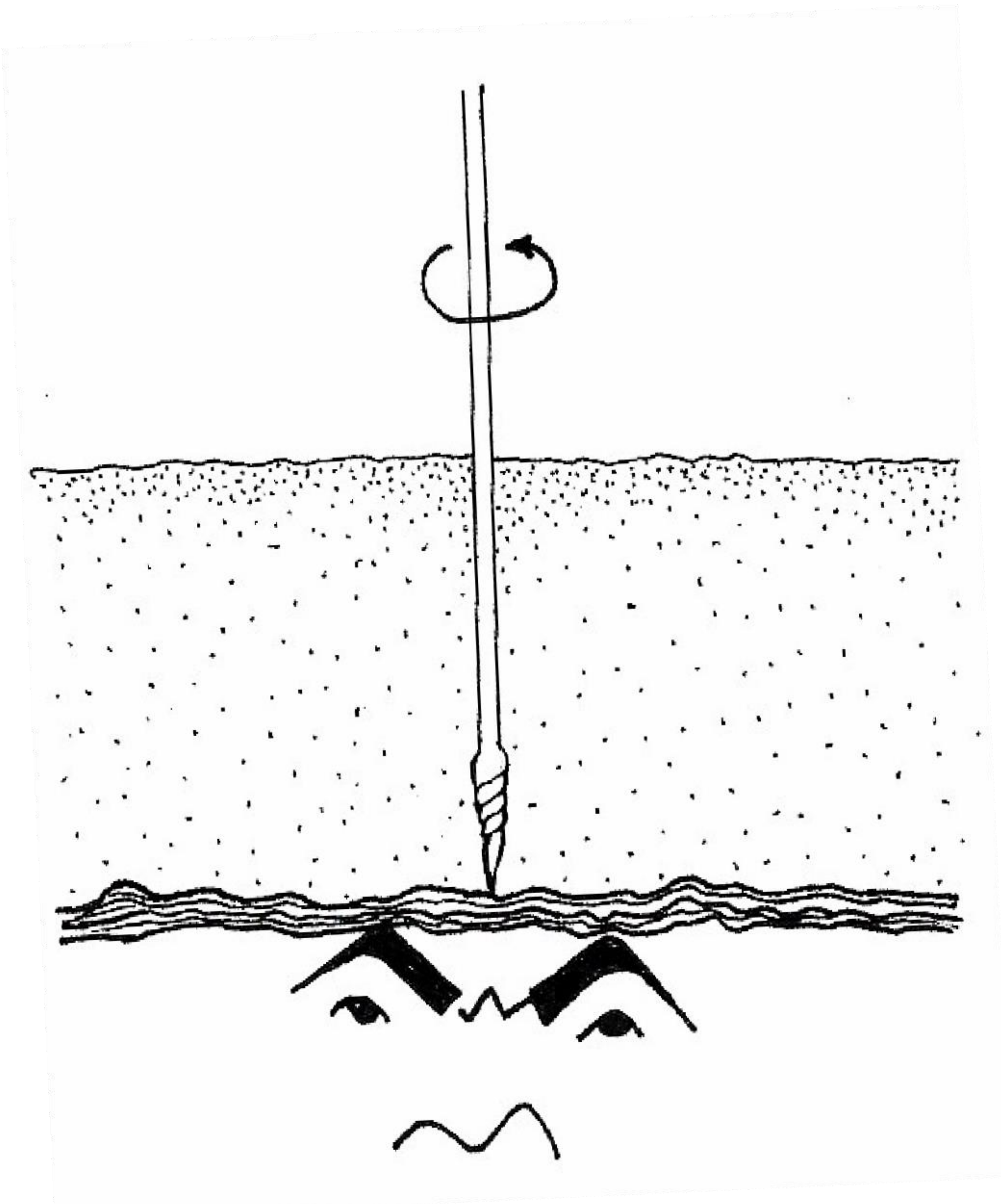
$N = 2 + 0.067N_{SW}$ (Inada, M., 1960)

For Clayey Soils

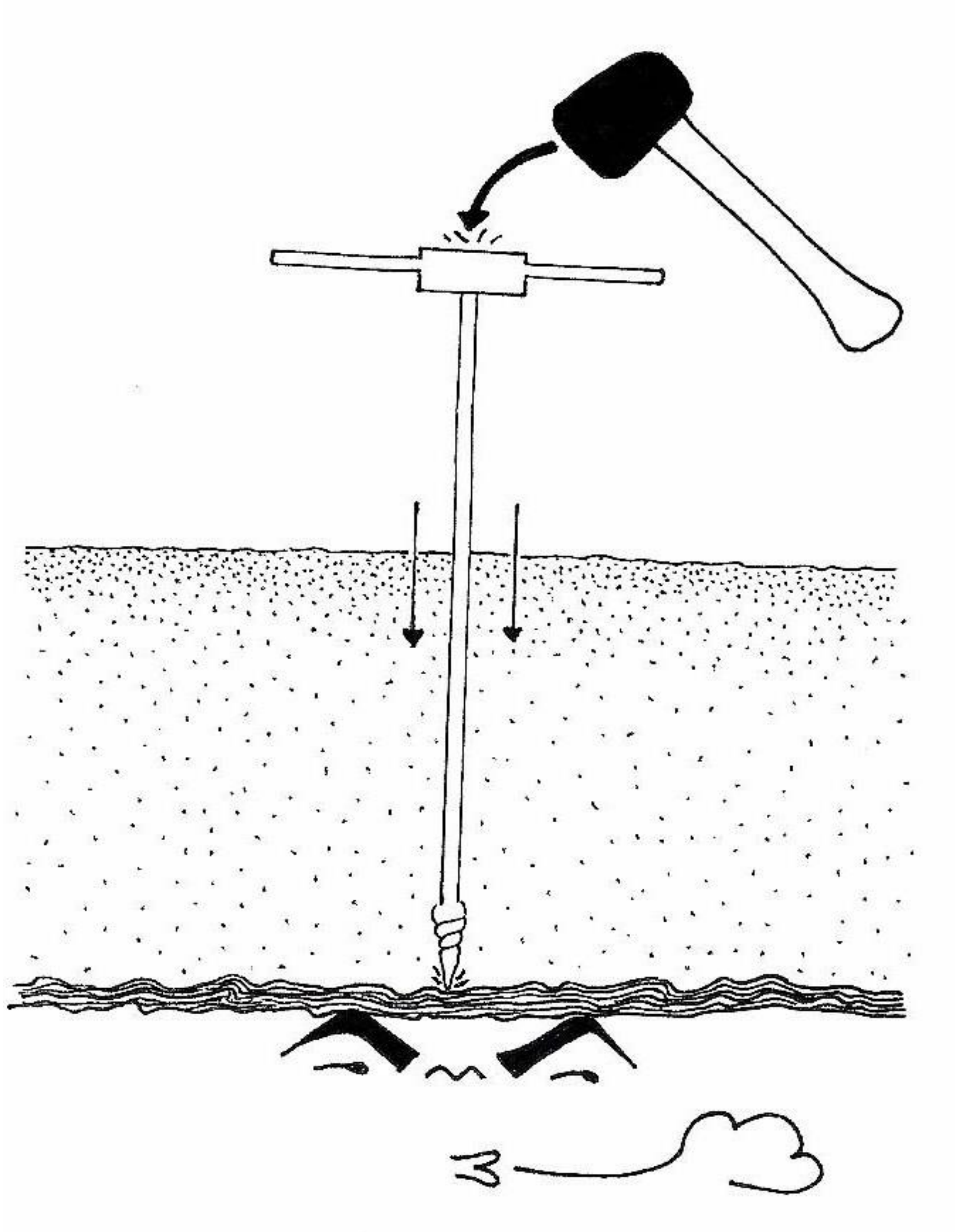
$N = 3 + 0.050\ N_{SW}$ (Inada, M., 1960)

6. Penetration testing should be terminated when a certain penetration resistance or a certain depth is reached. Testing could be terminated if the following situations are experienced:

a. The screw point does not sink any more when rotated;



b. The screw point does not sink even when driven by at least 10 blows of a 3.0 kg sledge hammer.

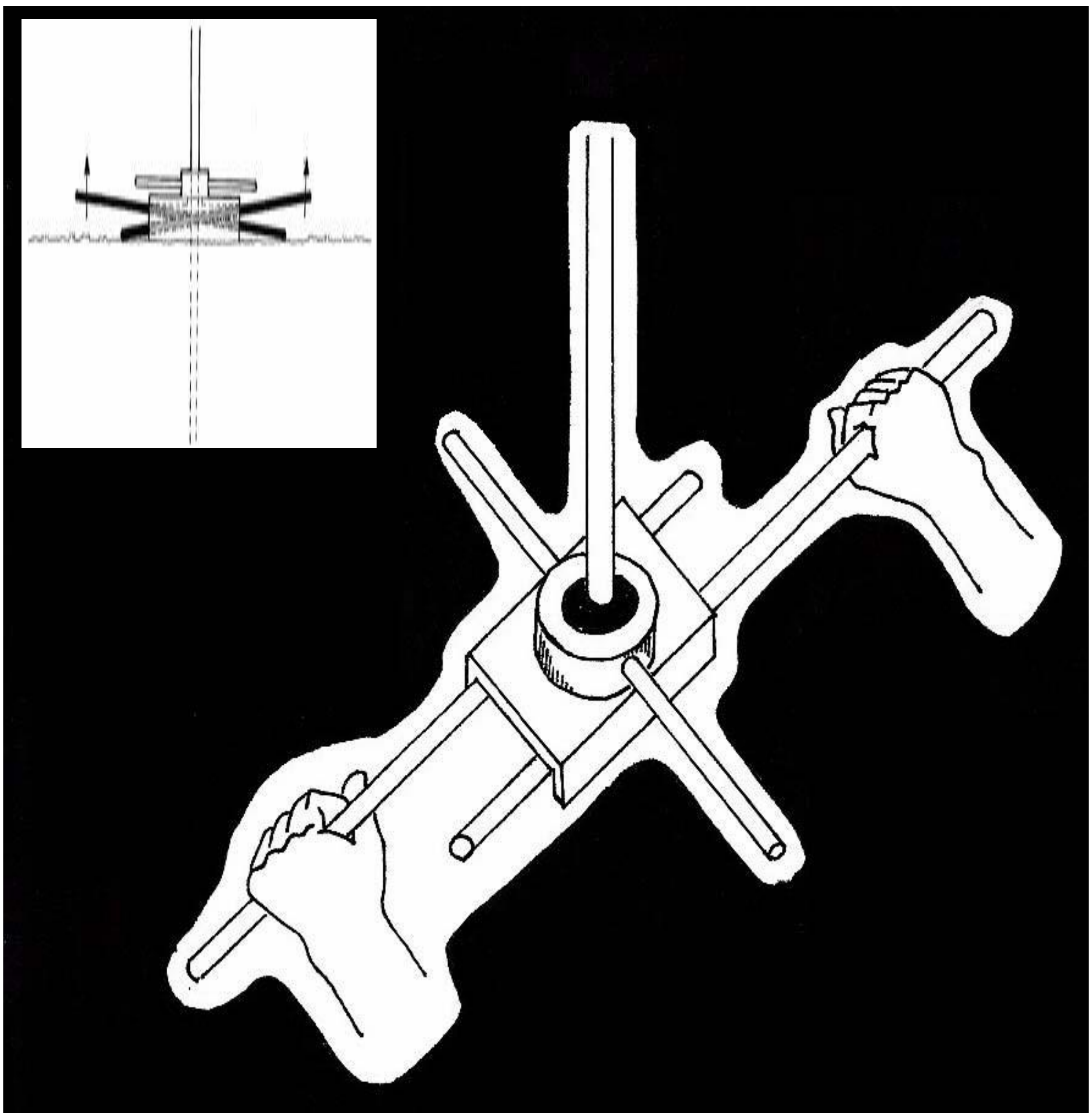


c. Two adjacent 25 cm thick layers are encountered with increasing penetration resistance exceeding 50 half turns per 25 cm, or penetration is less than 1 cm per blow after 5 blows of the sledge hammer.

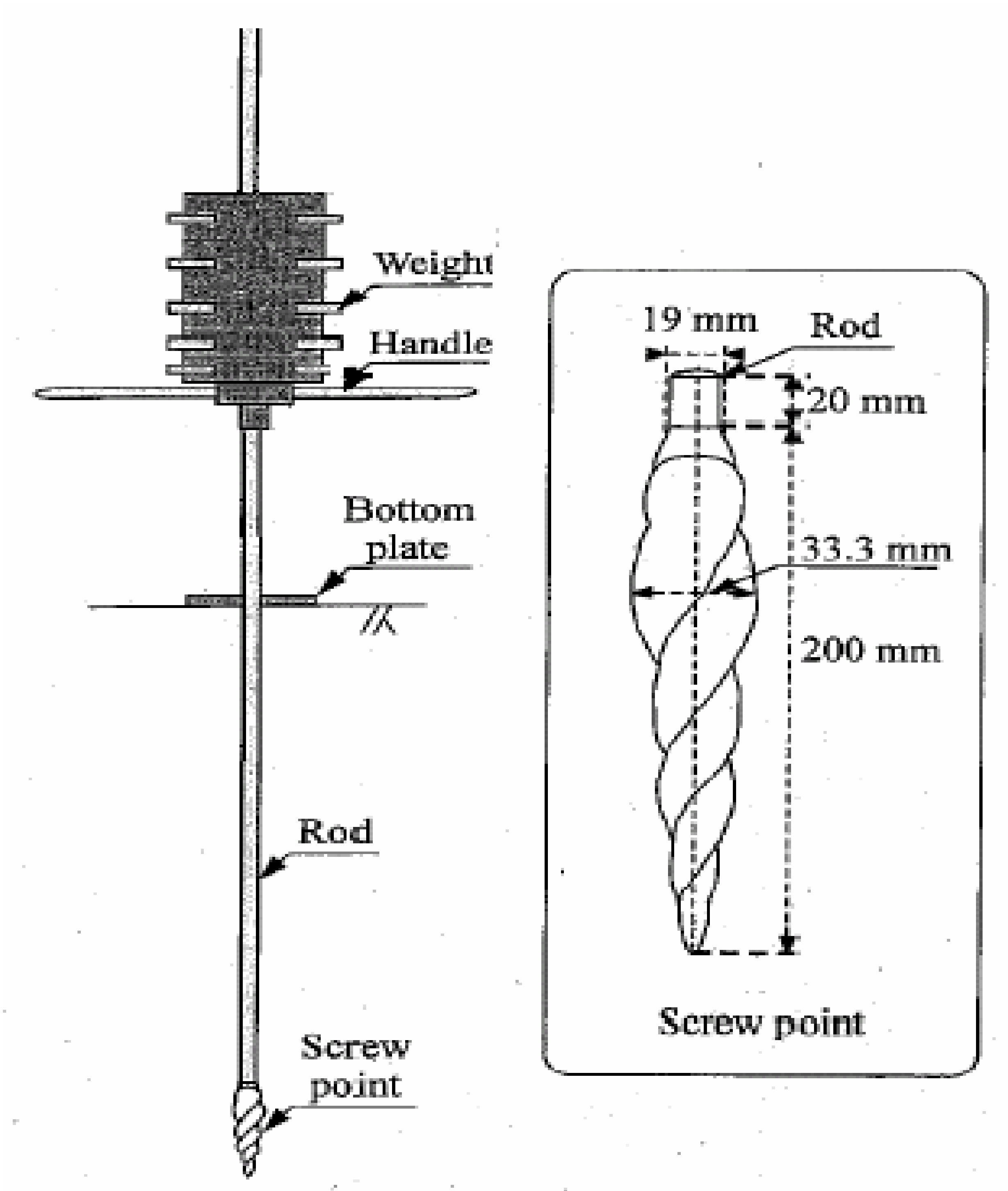
7. Complete all other necessary data in the record sheet including the information needed at the heading of the sheet.

Swedish Weight Sounding Test (SWST)					
Project Name:				Date:	
Location:				Performed by:	
Weight W_{sw}	No. Of half-turns	Total Depth	Penetration Depth	Eq. No. of rotations for 1-m penetration	Eq. SPT-N Value[1]
KN	Na	D (m)	L (cm)	N_{sw}	SPT-N

8. Upon termination of the penetration test, unload the weights then remove the series of penetrated rods by positioning two rods on the opposite sides of the bottom plate. Pull upwards the two ends of these rods to create a lever. If the penetrated rod has been loosened, use the handle assembly to pull it further out. If necessary, the position of the handle assembly could be adjusted and relocated as the rod is slowly removed, depending on the difficulty in pulling the rod out.



The Parts of the Swedish Weight Sounding Equipment



IMPLEMENTATION OF THE REDUCING DISASTER CAUSED BY RAIN-INDUCED LANDSLIDE: TRAINING FOR COMMUNITIES AND NON-EXPERTS BY COOPERATING SUCs THROUGHOUT THE COUNTRY

(2018 – 2019)

Supported by:
Senator Loren Regina B. Legarda

Source of Funds:
General Appropriations Act of 2018

KALINGA STATE UNIVERSITY (KSU)
Led by their President,
DR. EDUARDO T. BAGTANG
and their Project Team composed of
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ENGR. SOLOMON B. LAO-ATEN, and
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Dr. EDUARDO T. BAGTANG,
Project Leader

The Ceremonial Signing of MOAs was held on July 17, 2018 and was attended by the three Presidents of ASC, DOSCST, and UA. (left to right, Dr. Nelia Cauilan, Dr. Edito Sumile, Dr. Pablo Crespo, Jr. & Dr. Eduardo Bagtang)

Trainees from the different SUCs were trained in Tabuk City, Kalinga on July 17-18, 2018.

Engr. Rhonjhon Garming demonstrating the Swedish Sound Weight Test to the participants.

Dr. Lope Buen teaching the participants how to assess a site using the tool.

In 2010, KSU developed a guidebook as part of the output for the DOST Grant-in-Aid (GIA) Project: Development of Non-Expert Tool for Site-Specific Evaluation of Rain-Induced Landslide Susceptibility. With its desire to help communities mitigate landslide disasters, KSU submitted to the Office of Senator Loren Legarda a project proposal to train communities all over the country using the guidebook and by collaborating with 13 State Universities and Colleges (SUCs).

ABRA STATE INSTITUTE OF SCIENCES AND TECHNOLOGY (ASIST)

Led by their President,
DR. GREGORIO T. TURQUEZA
and their Project Team composed of
ELIZIER B. LAZO, and
REYNALD T. ISLAO

Dr. GREGORIO T. TURQUEZA, Project Leader

Clarifications were raised during the discussion on the assessment tool.

The measurement of rainfall using a non-recordable rain gauge was also taught to the trainers of ASIST.

The Swedish Sound Weight Test was demonstrated to the participants.

The 2nd day of training consisted of assessment of landslide sites.

ASIST was invited on a trainer's training at Tabuk City, Kalinga to be capacitated on the landslide guidebook. They were also taught on the significance of the Swedish Sound Weight Test, the application of the assessment tool and the use of the Manual Rain Gauge and its importance to far-flung communities.

APAYAO STATE COLLEGE (ASC)
Led by their President,
DR. NELIA Z. CAUILAN
and their Project Team composed of
DAVID A. RODOLFO,
QUEENIE A. BERBANO,
DR. MARIA CHRISTINA Z. MANICAD,
RODEL TAPURO,
ORENCIO CALON, and
JAIME TAGUIAM

Dr. NELIA Z. CAUILAN,
Project Leader

The Registration of the participants.

ASC facilitators conducted a site inspection together with their participants.

The participants assess a landslide prone are in their community.

ASC initially coordinated with the Provincial Disaster Risk Reduction and Management Office (PDRRMO) in identifying communities susceptible to rain-induced landslides. Field validation was conducted and six community beneficiaries was chosen. A total of two hundred twenty-seven (227) participants were trained. Majority of the participants were barangay officials. A total of twelve (12) sites were evaluated to determine its factor of safety and majority of them were identified to be highly susceptible to rain induced landslide.

BICOL UNIVERSITY (BU)
Led by their President,
DR. ARNULFO M. MASCARIÑAS
and their Project Implementer,
ALWIN JOSEPH M. MACERES

DR. ARNULFO M. MASCARIÑAS, Project Leader

Trainees of BU participated in a training conducted in Tabuk City, Kalinga.

Bicol University invited Dr. Lope Buen to be a resource speaker in their training that was conducted on March 28-29, 2019.

After the lectures, the trainees were actual site susceptibility assessments.

Dr. Buen of KSU assisted and taught the participants in the use of the assessment tool.

BU used the Nationwide Operational Assessment of Hazards (NOAH) of the University of the Philippines in identifying communities that will be beneficiaries of the training. The six communities that were identified to be trained are the following: Jovellar, Camalig, Guinobatan, Ligao City, Malilipot, and Manito. The university also coordinated with the Albay Provincial Safety Office (APSEMO) in identifying and validating of target participants. The university was then provided with a copy of the provincial landslide vulnerability report.

CEBU TECHNOLOGICAL UNIVERSITY (CTU)
Led by their President,
DR. ROSEIN A, ANCHETA, JR.
and their Project Team composed of
DR. ASUNCION B. MONSANTO, and EVALINDA A. PELIMER

DR. ROSEIN A, ANCHETA, JR., Project Leader

An orientation was conducted for CTU faculty and staff on the use of the guidebook in mitigating landslides.

Participants practiced assessing sites in their community using the assessment tool.

CTU facilitators disseminating and discussing the Assessment Tool.

CTU implementers taught the Folded Paper Technique in measuring the slope angle of a site.

CTU chose their partner communities from the List of “Moderate-to-High-Landslide-Susceptible-Area-in-CentralVisayas” from the Mines and Geosciences Bureau. The Municipality of San Fernando was considered by CTU’s College of Engineering due to it being an active partner of the College. Six sitios of Brgy. Ilaya of the same municipality were trained with a total of one hundred forty participants.

DAVAO ORIENTAL STATE COLLEGE OF SCIENCE AND TECHNOLOGY (DOSCST)

Led by their President,
DR. EDITO B. SUMILE.
and their Project Team composed of
DR. JESSIE V. ALZATE,
ENGR. PETER PAUL SILVA,
MR. JOHN REY R. CODILLA, and
MR. REY L. RABUYA

DR. EDITO B. SUMILE,
Project Leader

President Sumile spearheaded a coordination meeting with other LGU officials of communities to be involved.

DOSCST personnel discussing the Landslide Guidebook to one of their chosen community.

The Folded Paper Technique was taught to participants of DOSCST's training.

DOSCST facilitators discussing the Assessment tool to their trainees.

DOSCST conducted a reconnaissance survey to confirm municipalities that were identified as susceptible to shallow rainfall-induced landslides. It is from this that DOSCST selected six communities that will undergo training. The team also coordinated with various government officials for the conduct of field visits and also to serve as guides to the project areas where the training will be conducted. One hundred seventy-eight participants were trained in total. DOSCST saw the need to further train other communities and so the project was presented to the Provincial Government for future expansion and possible funding which resulted to a forging of a Memorandum of Agreement between the two government agencies.

EASTERN VISAYAS STATE UNIVERSITY (EVSU)
Led by their President,
DR. DOMINADOR O. AGUIRRE, JR.
and their Project Team composed of
MR. FAUSTITO A. AURE,
MR. IAN CONAN B. JUANICO
MR. DINDO DUANE S. BISCANTE

DR. DOMINADOR O. AGUIRRE,
Project Leader

Dr. Lope T. Buen, the resource speaker from KSU answering some queries from the participants of EVSU.

Some of the participants were helping other participants in understanding how to use the assessment tool.

There were discussions held during the on-site assessments of landslide prone areas in Tacloban City, Leyte.

One of the sites visited for assessment was a mountain slope near a community wherein a by-pass road is under construction.

EVSU invited communities within Leyte Province that are vulnerable to landslides, as well as non-government organizations who help communities in disaster prone areas. The university involved the Mines and Geosciences Bureau – Eastern Visayas to present the landslide prone areas within their province.

GUIMARAS STATE COLLEGE (GSC)
Led by their President,
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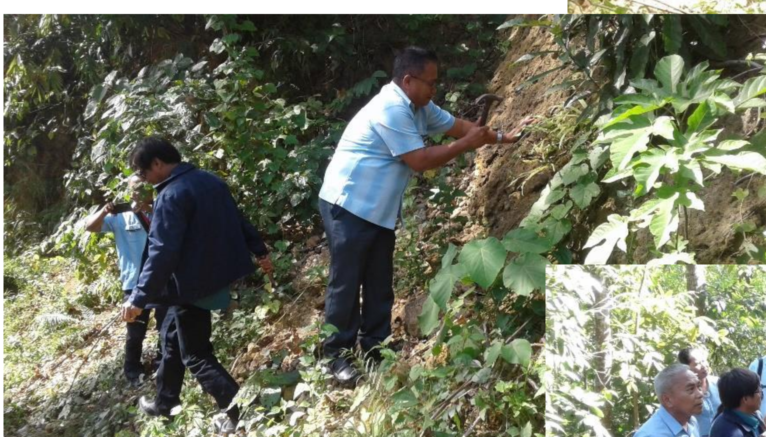
and their Project Team composed of
DR. LUNA V. LAMERA,
DR. LILIAN DIANA B. PARREÑO,
DR. ROGELIO M. BORRO,
DR. AGUSTIN N. ARCEÑA,
MR. AMADOR JAVELLANA JR., and
MS. JUNE RHEO T. RICABLANCA

DR. ROGELIO T. ARTAJO
Project Leader

The trainers' training on the Landslide Project was held at Guimaras State College.

The faculty and staff of GSC as trainees conducting an assessment on a landslide prone area in Guimaras.



A faculty of GSC identifies the slope material using a hammer and a 4 inch wire nail.

President Artajo joined the group in the assessment of landslide susceptibility of various sites.

GSC invited the resource speakers from KSU to build their capacity and knowledge on the guidebook so that they'll be able to conduct trainings by themselves to communities in Guimaras. The assessment tool was introduced to them and was demonstrated during the site visitation. While being taught, the participants also practiced and tried to apply the assessment tool.

IFUGAO STATE UNIVERSITY (IFSU)
Led by their President,
DR. EVA MARIE C. DUGYON
and their Project Team composed of
MARAH JOY A. NANGLEGAN,
FROILYN G. MUTAL,
PHYLICE BREBONERIA, and
MS. KRISSA CLENA G. CABBIGAT

DR. EVA MARIE C. DUGYON
Project Leader

Ms. Nanglegan discusses the Guidebook to their participants.

The participants also tried to use the assessment tool on a slope nearby the training site.

The Assessment Tool as well as the Paper Folded Techniques was taught to the participants of IFSU.

A 4 inch wire nail was used to try to identify the soil material of the slope.

IFSU identified six communities from the municipalities of Hingyon, Banaue & Kiangan to serve as beneficiaries of the trainings. To keep the trainings fun and exciting, the facilitators conducted workshops, role playing, and other activities as well as involving the participants in leading some parts of the training program. The training involved one hundred ninety-three participants which included barangay officials as well as community members. Most of the speakers delivered their parts using the local language for easier understanding. The communities trained expressed their gratitude to the facilitators and communicated their interest for more trainings related to this.

ILOILO SCIENCE AND TECHNOLOGY UNIVERSITY (ISAT-U)
Led by their President,
DR. RAUL F. MUYONG
and their Project Team composed of
ROSANNA R. DUREZA,
TRACY N. TACUBAN, and
MANFRED VON P. MAGAT

DR. RAUL F. MUYONG
Project Leader

A participant trying to assess the slope of a site using the assessment tool.

A 4 inch nail and a hammer were used in identifying the slope material of a site.

The participants practice the Folded Paper Technique during the training.

The participants discussed among themselves on the use of the assessment tool.

ISAT-U sent their trainees to the Trainers' training conducted by KSU in Tabuk City, Kalinga. Afterwards the trainees organized a capacity building for ISAT-U faculty and then those who were capacitated helped in the conduct of trainings in the Province of Iloilo for landslide prone communities. The Mines and Geosciences Bureau of Western Visayas discussed the specific sites in the Province that are prone to landslide.

MT. PROVINCE STATE POLYTECHNIC COLLEGE (MPSPC)
Led by their President,
DR. REXTON F. CHAKAS
and their Project Team composed of
DR. EMILY ANN B. MARRERO,
WILEEN CHIARA T. LASANGEN,
ROSE B. AMOY,
LLOYD F. ILACAD,
CLETO P. DALMACIO, and
DAVID Y. FOMEG-AS

DR. REXTON F. CHAKAS
Project Leader

Dr. Marrero of MPSPC discusses the Landslide Project to their participants.

The Swedish Sound Weight Test being practiced and tested by MPSPC participants.

A site was assessed by MPSPC's participants using the assessment tool.

Another site was assessed using the assessment tool.

MPSPC invited the municipalities of Tadian, Bauko, and Bontoc to participate in the training. Barangay officials of the aforementioned municipalities, personnel from MPSPC & Mt. Province's PDRRMO were the participants of the training. The total number of participants from the two batches of training conducted was one hundred forty-two. The trainees commended the training and urged that similar trainings be conducted to other barangays and municipalities and recommended that students will be involved.

QUIRINO STATE UNIVERSITY (QSU)

Led by their President,
DR. SAMUEL O. BENIGNO
and their Project Team composed of
DR. FREDISMINDA M. DOLOJAN,
PAUL B. PABLO,
ISRAEL M. ERAÑA,
NITO GALANTA, and
BENJAMIN JULIAN

DR. SAMUEL O. BENIGNO
Project Leader

The participants of QSU' s training practice the assessment tool at a landslide site.

QSU' s participants try the paper folding technique in measuring the slope angle.

To identify the slope material, a 4 inch common wire nail was used.

The participants during the lectures.

QSU collaborated with the Provincial Disaster Risk Reduction Management Office and the Mines and Geosciences Bureau to determine the barangays that were affected by rain-induced landslides. Most of participants were community leaders, barangay officials as well as household members. The project team conducted the trainings at the community centers of each barangay beneficiary for the participants' convenience. A total of one hundred sixty four participants were trained.

UNIVERSITY OF ANTIQUE (UA)
Led by their President,
DR. PABLO S. CRESPO, JR.
and their Project Team composed of
YURI G. GONZAGA,
NEE B. LIBRANDO, and
MARK ANTHONY A. ODANGO

DR. PABLO S. CRESPO, JR.
Project Leader

Engr. Librando of UA Hamtic Campus giving his Lecture to their participants.

Engr. Lao-aten of KSU teaches the Folded Paper Technique to participants of UA's training.

UA's training participants inspect a possible landslide prone area.

Another site was inspected using the assessment tool.

The University of Antique participated in the trainers' training conducted by KSU at Tabuk City, Kalinga on July 17-18, 2019. Afterwards they organized and prepared for trainings to be conducted in the Province of Antique. They invited speakers from KSU to teach on the landslide guidebook to the communities selected from their province. The participants inspected and assessed various sites within and nearby the communities.

WESTERN MINDANAO STATE UNIVERSITY (WMSU)
Led by their President,
DR. MILABEL ENRIQUEZO-HO
and their Project Team composed of
ROBERT O. PARCON, and
RYAN V. TANDOY

Dr. MILABEL ENRIQUEZ-HO, Project Leader

Engr. Solomon Lao-aten, resource person from KSU taught the Folded Paper Technique.

The Landslide Guidebook was disseminated to the participants.

The importance of landslide mitigation was explained to the community members.

Engr. Garming, resource person from KSU discussed the assessment tool.

WMSU participated in KSU's trainers' training that was conducted in Tabuk City, Kalinga on July 17-18, 2019. Afterwards they identified communities within the Zamboanga Peninsula who served as trainees. They invited resource speakers from KSU to discuss some parts of the trainings.