310D6223
GEOTEKNIK TAMBANG

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Subjects

1. Rock slope design methods
2. Identification of modes of slope instability
3. Stabilization of rock slopes
4. Movement monitoring
5. Mining applications

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References

Menteri Energi dan Sumber Daya Mineral Republik Indonesia. (2018). Keputusan Menteri Energi dan Sumber Daya Mineral Republik Indonesia Nomor 1827 K/30/MEM/2018 tentang Pedoman Pelaksanaan Kaidah Teknik Pertambangan yang Baik.

Wyllie, D.C. & Mah, C.W. *Rock Slope Engineering 4th Edition*. 2005. Taylor & Francis Group.

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Rock Slope Design Methods

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Rock Slope Design Methods

1) Summary of design methods
2) Limit equilibrium analysis (deterministic)
3) Sensitivity analysis
4) Probabilistic design methods
5) Load and resistance factor design

1) Summary of Design Methods

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Summary of Design Methods

- **Shear force** takes place along either a discrete sliding surface, or within a zone, behind the face.
- If the shear force (displacing force) <u>is greater than</u> the shear strength of the rock (resisting force) on this surface, then <u>the slope will be unstable</u>.

Terms of slope stability

- Factor of safety (FS),

  the quantification of stability.

- Strain,

  failure defined by onset of strains great enough to prevent safe operation of the slope, or that the rate of movement exceeds the rate of mining in an open pit. It is most widely used in the mining field where displacement is tolerated and the slope contains a variety of geological conditions.

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Terms of slope stability

- Probability of failure (PF),

  stability quantified by probability distribution of difference between resisting and displacing forces, which are each expressed as probability distributions.

Terms of slope stability

- Load and Resistance Factor Design (LRFD), stability defined by the factored resistance being greater than or equal to the sum of the factored loads. It has been developed for structural design, and is now being extended to geotechnical systems such as foundations and retaining structures.

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Geoteknik tambang paling kurang terdiri atas:

a. **penyelidikan geoteknik** yang meliputi jumlah, kedalaman, dan lokasi pengeboran inti, deskripsi litologi, preparasi sampel geoteknik, pengukuran dan analisis struktur geologi, kegempaan, pengaruh peledakan, serta hasil penyelidikan hidrologi dan hidrogeologi;

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b. **pengujian sampel geoteknik** yang meliputi pengujian laboratorium dan hasil dari uji sifat fisik dan mekanis sampel;

c. **pengolahan data hasil penyelidikan geoteknik dan pengujian sampel geoteknik** yang menggambarkan model dengan parameter yang ditetapkan dari hasil butir a dan b di atas.

Keputusan Menteri Energi dan Sumber Daya Mineral Republik Indonesia Nomor 1827 K/30/MEM/2018 tentang Pedoman Pelaksanaan Kaidah Teknik Pertambangan yang Baik

Jenis Lereng	Keparahan Longsor (*Consequences of Failure/ CoF*)	Kriteria dapat diterima (*Acceptance Criteria*)		
		Faktor Keamanan (FK) Statis (Min)	Faktor Keamanan (FK) Dinamis (min)	Probabilitas Longsor (*Probability of Failure*) (maks) PoF (FK≤1)
Lereng tunggal	Rendah s.d. Tinggi	1,1	Tidak ada	25-50%
Inter-ramp	Rendah	1,15-1,2	1,0	25%
	Menengah	1,2-1,3	1,0	20%
	Tinggi	1,2-1,3	1,1	10%
Lereng Keseluruhan	Rendah	1,2-1,3	1,0	15-20%
	Menengah	1,3	1,05	10%
	Tinggi	1,3-1,5	1,1	5%

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Kestabilan Lereng

Kriteria keparahan longsor (*consequences of failure*) dapat dilihat di Lampiran II Pedoman Pengelolaan Teknis Pertambangan dalam Keputusan Menteri Energi dan Sumber Daya Mineral Republik Indonesia Nomor 1827 K/30/MEM/2018 tentang Pedoman Pelaksanaan Kaidah Teknik Pertambangan yang Baik.

Conditions that would require the use of FS at the high end of the ranges:

- a limited drilling program;
- absence of rock outcrops, and there is no history of local stability conditions;
- inability to obtain undisturbed samples for strength testing, or difficulty in extrapolating laboratory test results to in situ conditions;

Conditions that would require the use of FS at the high end of the ranges: *(cont.)*

- absence of information on ground water conditions, and significant seasonal fluctuations in ground water levels;
- uncertainty in failure mechanisms of the slope and the reliability of the analysis method.

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2) Limit Equilibrium Analysis (Deterministic)

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Limit Equilibrium Analysis (Deterministic)

Shear strength equation from Mohr-Coulomb is given by:

$$\tau = c + \sigma' \tan \emptyset$$

where

τ = shear stress,

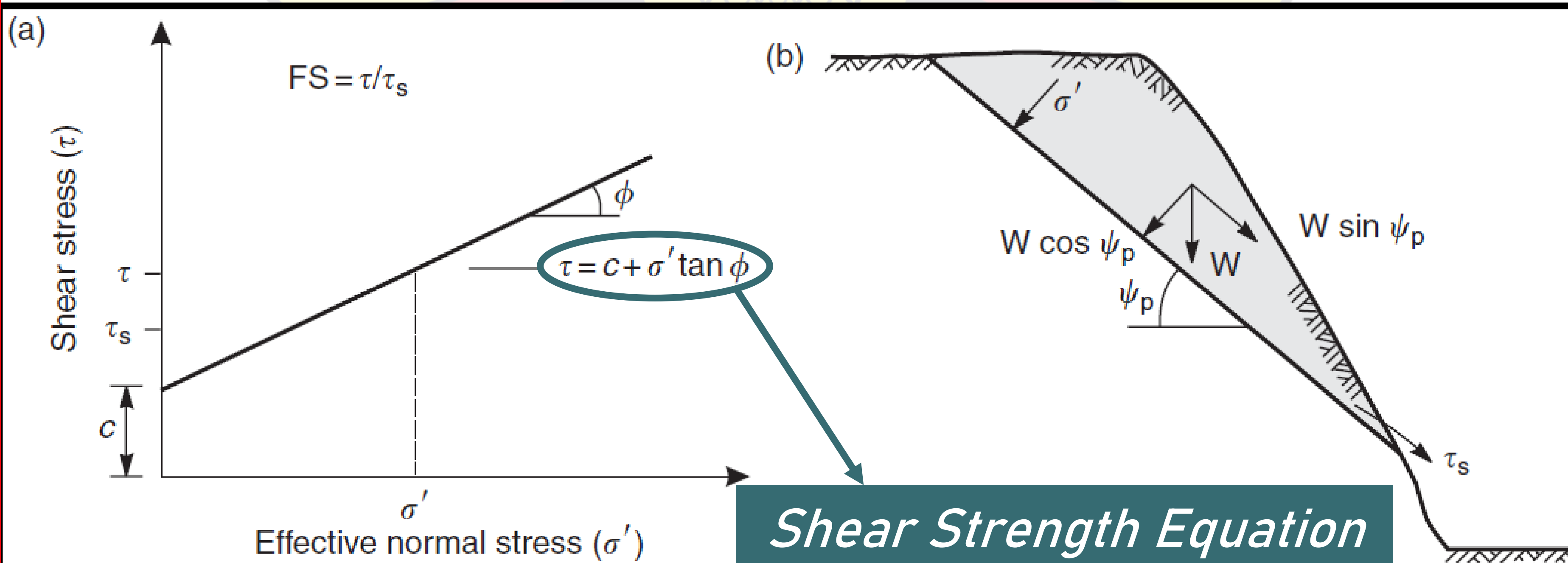
c = cohesion,

σ' = effective normal stress, and

$\emptyset$ = friction angle.

Method of Calculating Factor of Safety of Sliding Block

Wyllie, D.C. & Mah, C.W. Rock Slope Engineering 4th Edition. 2005.



Shear Strength Equation (from Mohr-Coulomb)

Method of Calculating Factor of Safety of Sliding Block

Wyllie, D.C. & Mah, C.W. Rock Slope Engineering 4th Edition. 2005.

Normal stress

$$\sigma = \frac{W \cos \psi_P}{A}$$

Shear stress

$$\tau_S = \frac{W \sin \psi_P}{A}$$

$$\tau_S A = W \sin \psi_P$$

Shear strength

$$\tau = c + \sigma' \tan \phi$$

$$\tau = c + \frac{W \cos \psi_P \tan \phi}{A}$$

Method of Calculating Factor of Safety of Sliding Block

Wyllie, D.C. & Mah, C.W. Rock Slope Engineering 4th Edition. 2005.

Factor of Safety (FS)

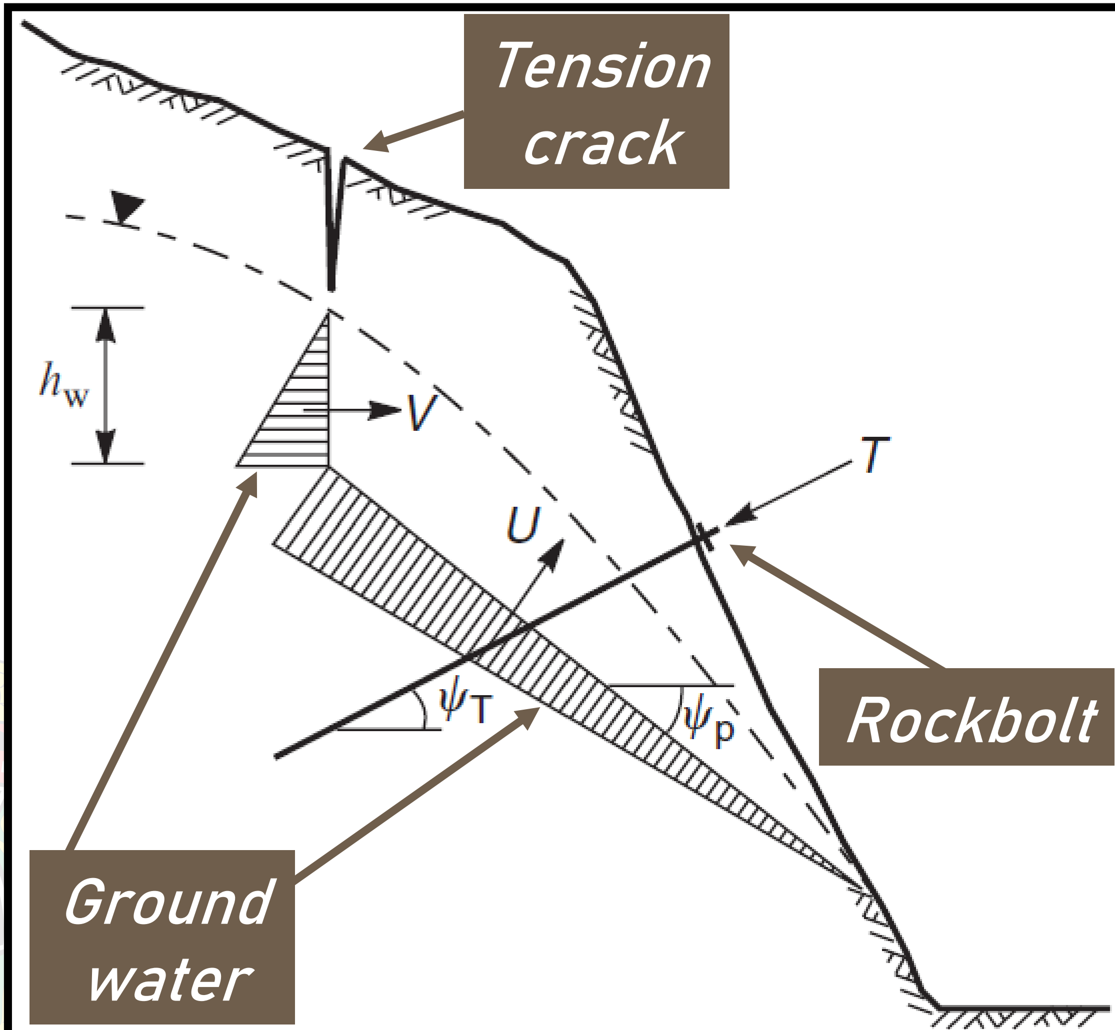
$$FS = \frac{resisting\ forces}{driving\ forces}$$

$$FS = \frac{cA + W\cos\psi_p\tan\emptyset}{W\sin\psi_p}$$

What if the sliding surface is clean and contains no infilling?

The Effect of Ground Water and Bolt Forces

Wyllie, D.C. & Mah, C.W. Rock Slope Engineering 4th Edition. 2005.



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The Effect of Ground Water

- The water pressures that are generated in the tension crack and on the sliding surface can be approximated by triangular force diagrams.

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The Effect of Ground Water

- Based on this assumption, the water forces acting in the tension crack (V) and on the sliding plane (U), are as follows:

$$V = \frac{1}{2}\gamma_w {h_w}^2$$

$$U = \frac{1}{2}\gamma_w h_w A$$

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The Effect of Ground Water

Try to formulate the **factor of safety** of the slope under water pressures condition that are generated in the tension crack and on the sliding surface.

The Effect of Ground Water and Bolt Forces

- If the tension in the anchor is *T* and it is installed at an angle Ψ_T below the horizontal, then the normal force (N_T) and shear force (S_T) acting on the sliding plane due to the anchor tension are respectively:

$N_T = T \sin(\Psi_T + \Psi_p)$ and

$S_T = T \cos(\Psi_T + \Psi_p)$

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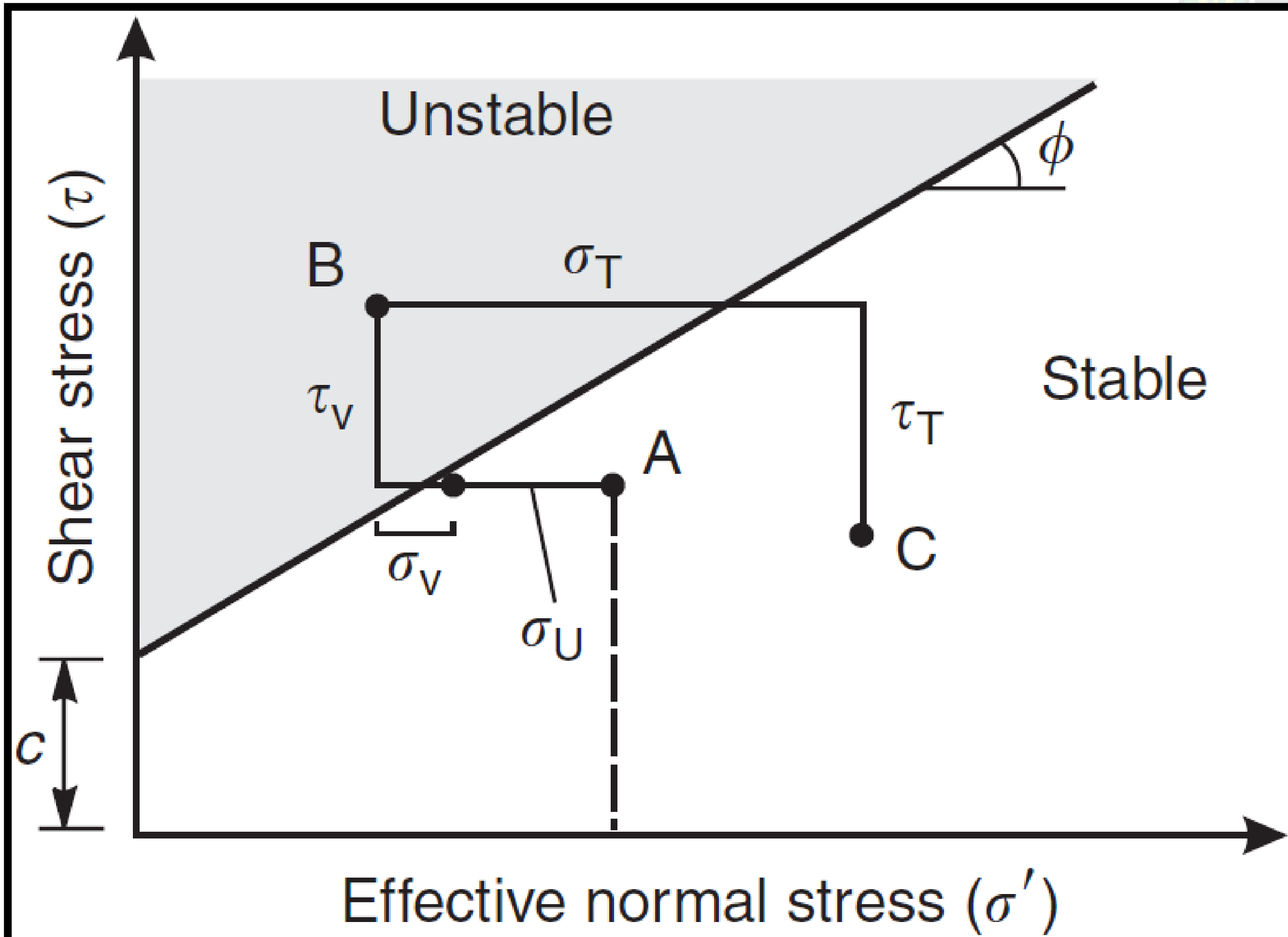
The Effect of Ground Water and Bolt Forces

Try to formulate the **factor of safety** of the slope under water pressures condition that are generated in the tension crack and on the sliding surface, also when the bolt is installed.

The Effect of Ground Water and Bolt Forces



3) Sensitivity Analysis

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Sensitivity Analysis

- In reality, each parameter has a range of values, and a method of examining the effect of this variability on the factor of safety is to carry out **sensitivity analyses** using upper and lower bound values for those parameters considered critical to design.

Sensitivity Analysis

- *However, it is difficult to examine the relationship for more than three parameters* between each of the parameters.
- Consequently, the usual design procedure involves a combination of analysis and judgment in assessing the influence on stability of variability in the design parameters, and then selecting an appropriate factor of safety.

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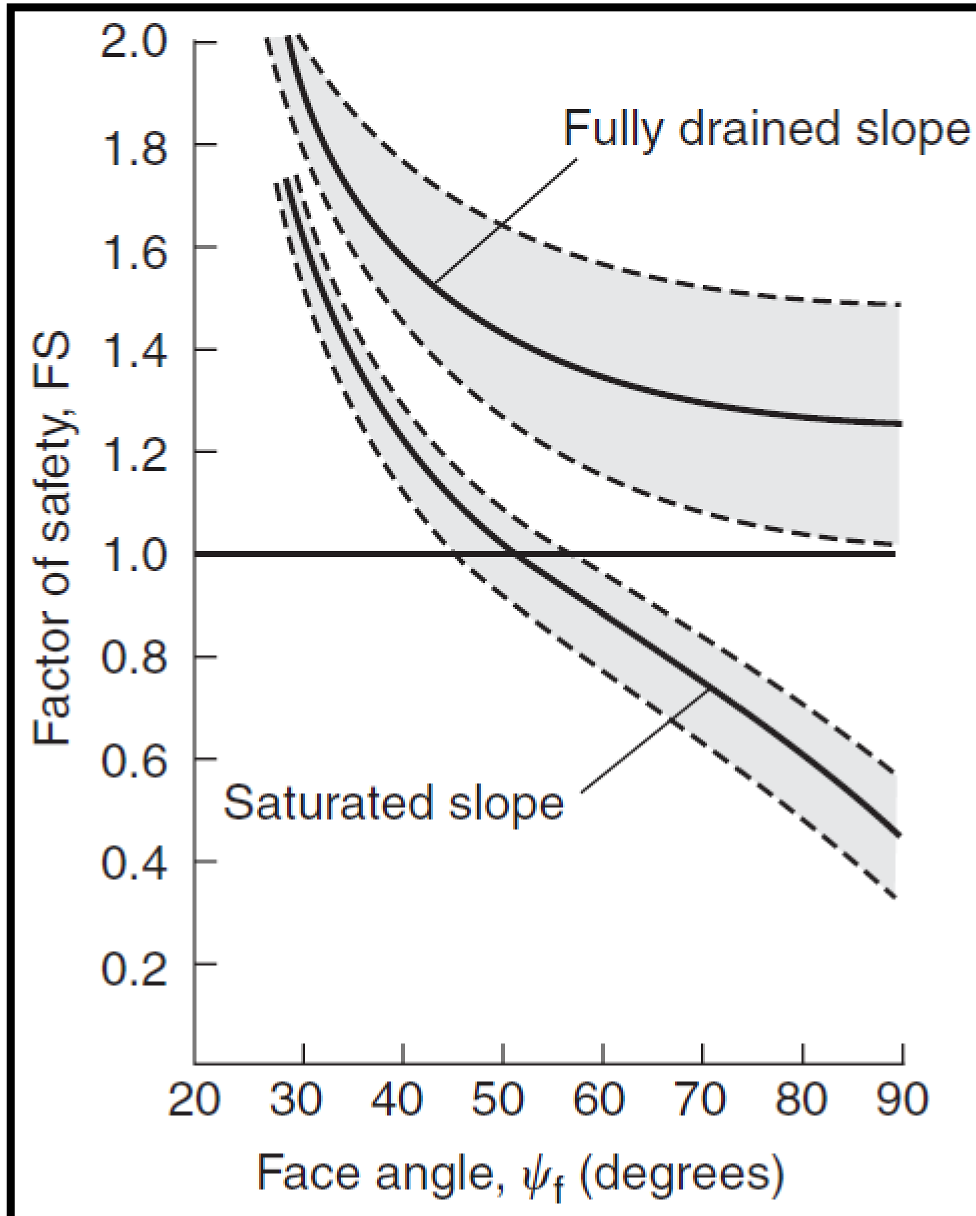
Sensitivity Analysis

- Sensitivity analyses were carried out for both the face angle and the water pressure; fully drained and to fully saturated.



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Sensitivity Analysis

- The value of sensitivity analysis is to assess which parameters have the greatest influence on stability.
- This information can then be used in planning **investigation programs** to collect data that will define this parameter(s) more precisely.

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4) Probabilistic Design Methods

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Probabilistic Design Methods

- **Probabilistic design** is a systematic procedure for examining the effect of the variability of each parameter on slope stability.

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a) Distribution Functions

- In probability analysis, each parameter for which there is some uncertainty is assigned a range of values that is defined by a probability density function.

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a) Distribution Functions

Some types of distribution functions that are appropriate for geotechnical data:

- ✓ normal distribution *(most common)*;
- ✓ beta distribution;
- ✓ negative exponential distribution; and
- ✓ triangular distribution.

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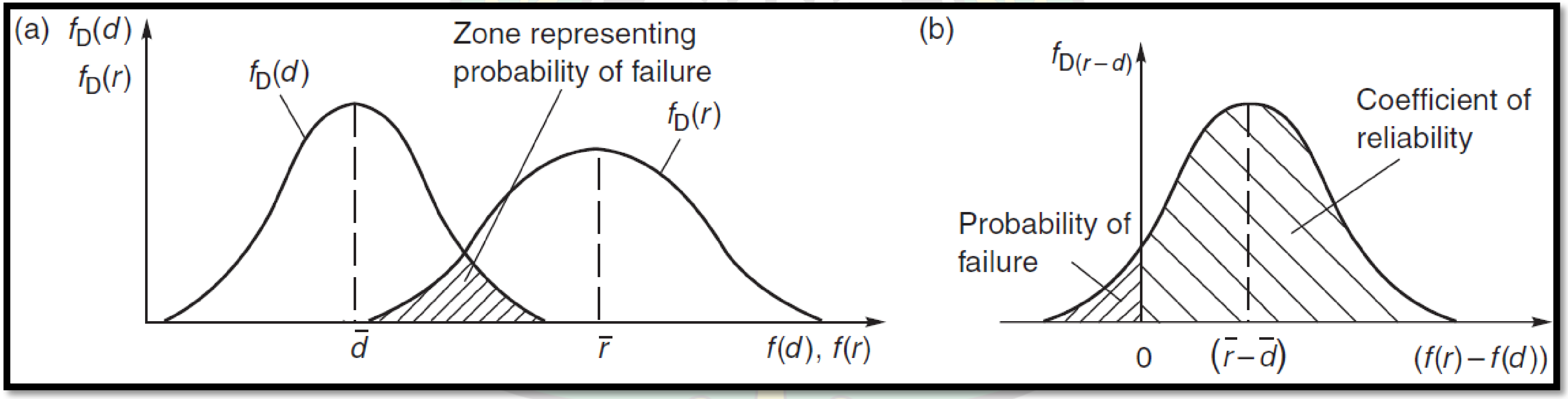
b) Probability of Failure

- The margin of safety method
- Monte Carlo method

i) The Margin of Safety Method

- **The margin of safety** is <u>the difference between the resisting and displacing forces</u>, with the slope being unstable if the margin of safety is negative.



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ii) Monte Carlo Method

- **Monte Carlo** analysis is an alternative method of calculating the probability of failure which is more versatile than the margin of safety method.
- The Monte Carlo technique is an iterative procedure.

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5) Load and Resistance Factor Design

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Load and Resistance Factor Design

- This design method is based on the use of probability theory to develop a rational design basis for structural design that accounts for variability in both loads and resistance.
- The objective is to produce a uniform margin of safety for steel and concrete structures such as bridges, and geotechnical structures such as foundations under different loading conditions.

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THANK YOU

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