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High-Precision Strength Evaluation of Rock Materials and Stability Analysis for Rockfill Dams

PWRI

Hiroki SAKAMOTO

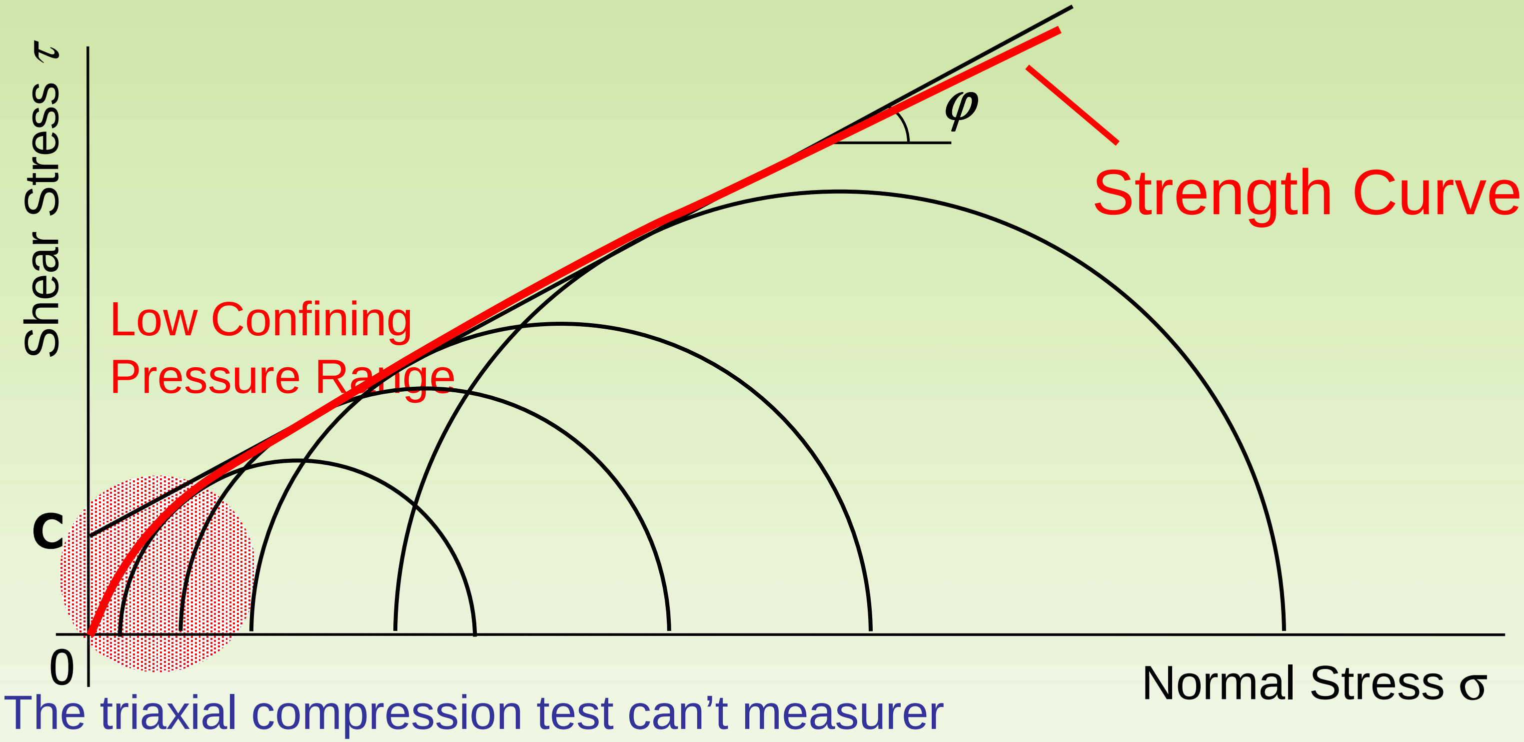
Research Engineer

Public Works Research Institute, JAPAN

Contents

Introduction

- The seismic performance evaluation method of rockfill dams in japan :
  "Modified seismic coefficient method"
- Shear strength of rock materials :
  Evaluation of shear strength is defined by curvature approximation.



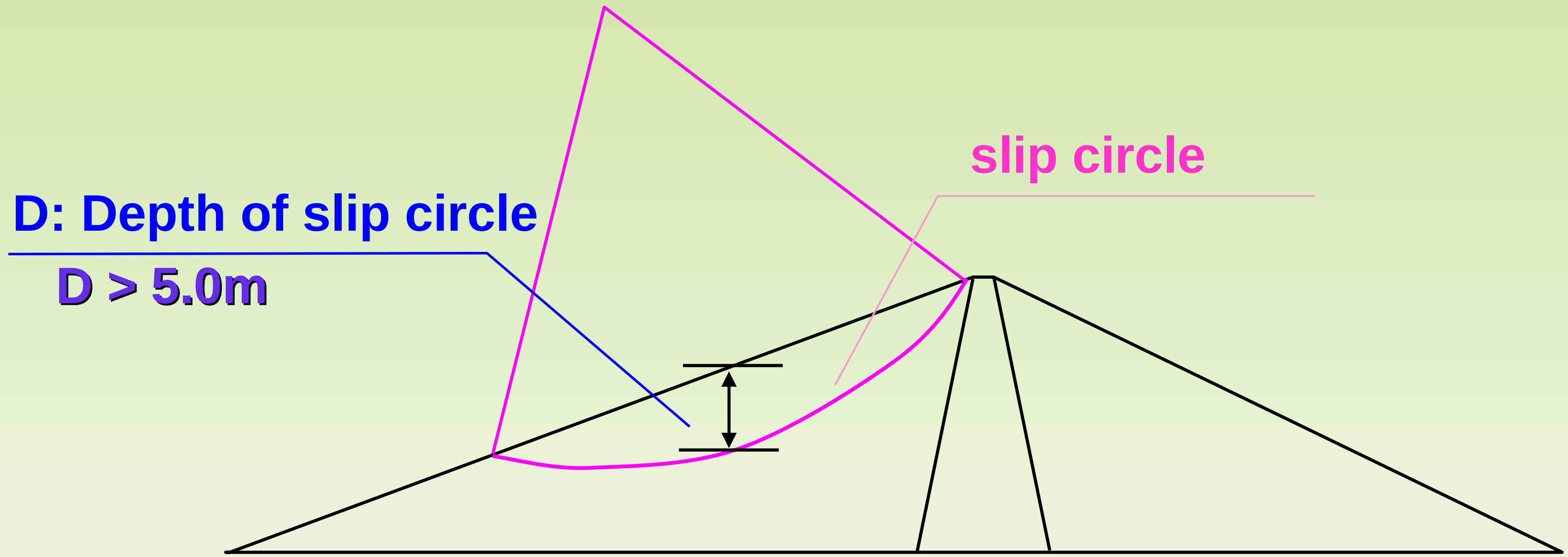
Introduction

"Modified seismic coefficient method"

The shallow slip circle is disregarded

The minimum depth of slip circle is 5m

1. Test's precision
2. The effect of shallow slip failure



Test data by new equipment

Stability analysis at shallow slip circle

Purposes

- **Investigation of shear strength under low confining pressure condition;**
  - Large-scale triaxial compression tests
  - Large-scale box shear tests

- **Evaluation of shallow slip stability using above test results, in which the circle depth is less than 5m**

Laboratory tests

Materials

Material A
Dacite rock

(currently used in the construction of a rockfill dam)

Material B
Sandstone

(aggregate of crushed sandstone)

Laboratory tests

Materials

Material C
Dacite rock

currently used in the construction of a rockfill dam

Test method

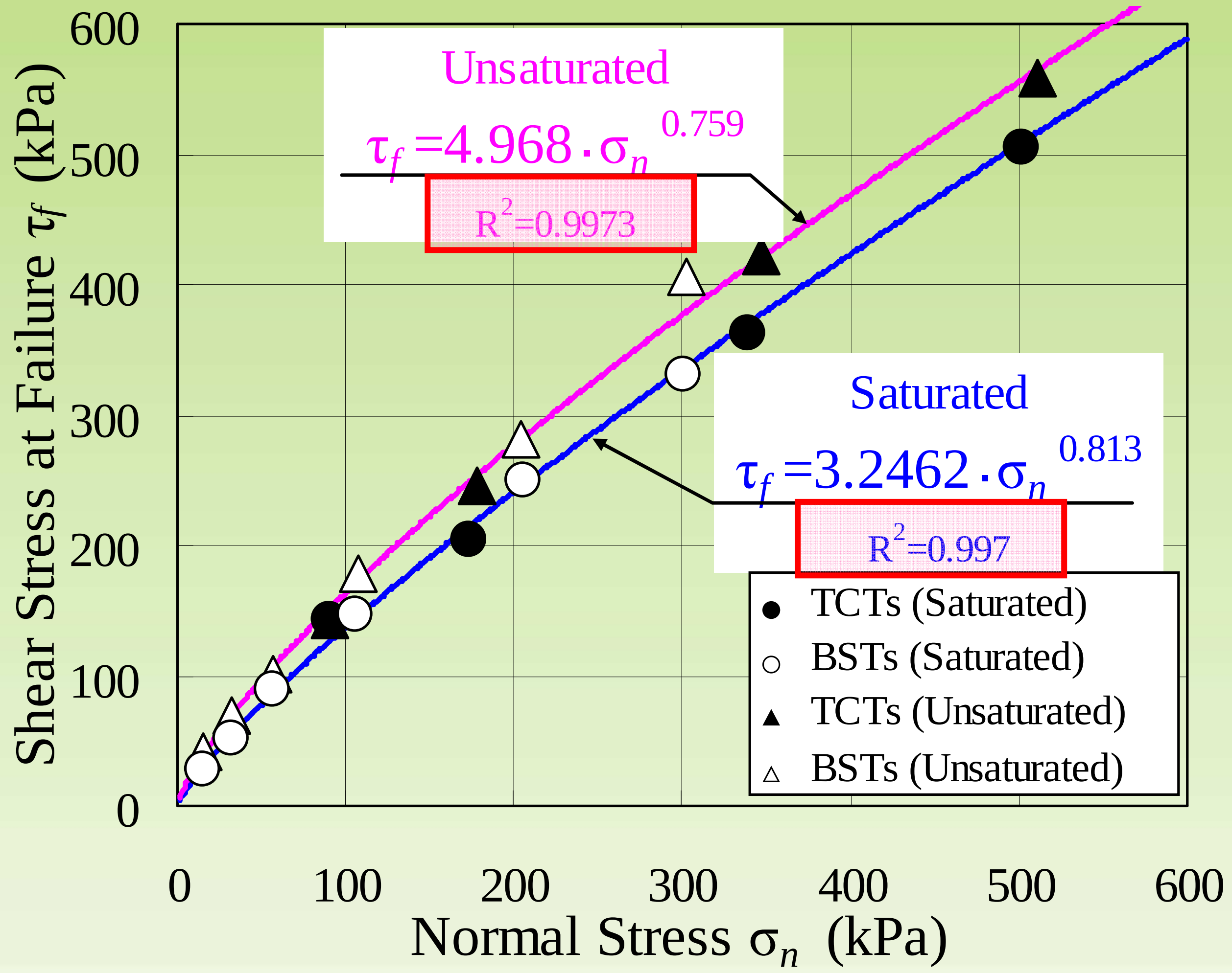
Large-scale Triaxial
Compression Tests (TCTs)

(Specimen Size (cm) : ϕ 30 × H60)

Large-scale
Box Shear Tests (BSTs)

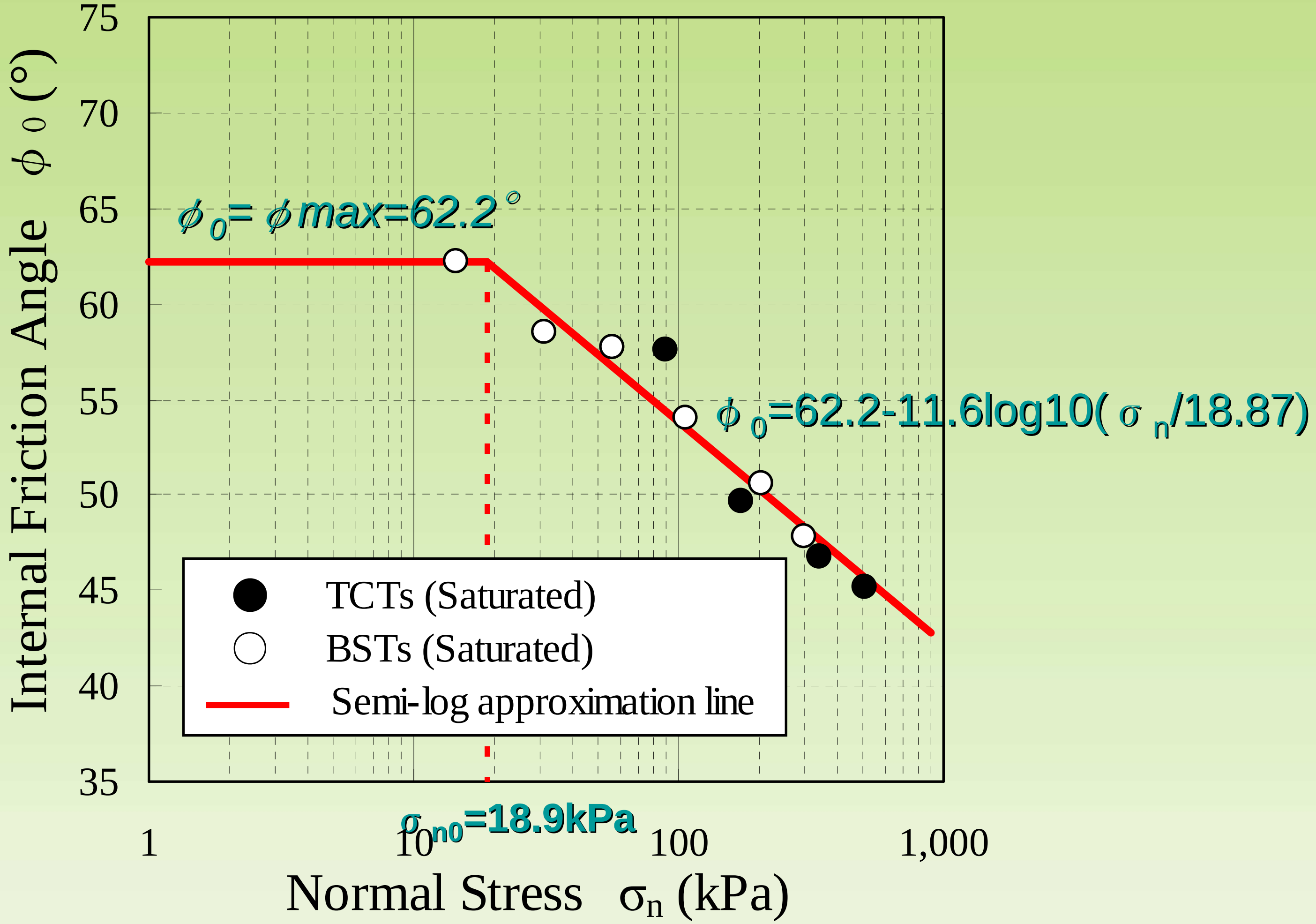
(Specimen Size (cm) : L40 × W40 × H40)

Test results (Material A)



- Results can be plotted on a **single power approximation curve**.

Test results (Material A)



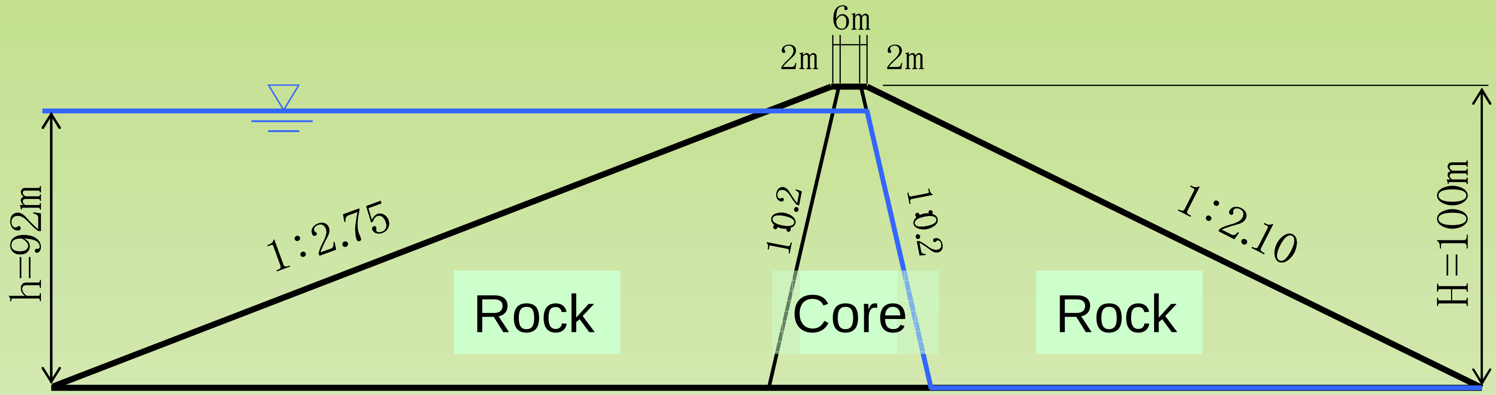
- Internal friction angle ($\phi 0$) has **confining pressure dependency.**

Test results

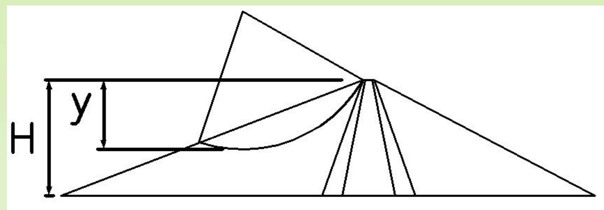
- We confirm that shear strength of rock materials can be approximated by curvature approximation method at low confining pressure range in which box shear test results exist.
- Shear strength of rock materials have confining pressure dependency.

Sliding stability analysis

Analysis method ： Modified seismic coefficient method



Analysis model



y: Elevation gap from dam crest

H: Dam height

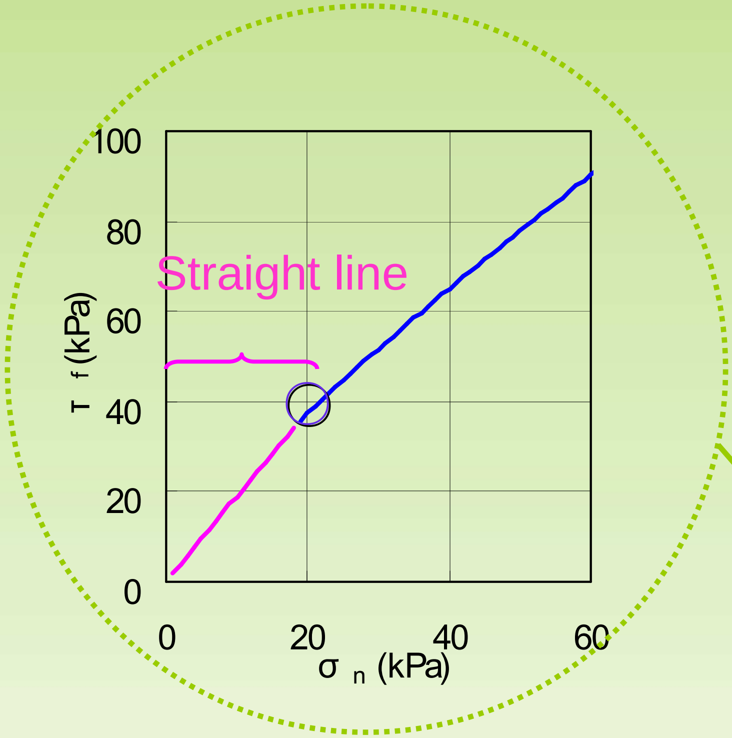
k : Seismic force of dam body

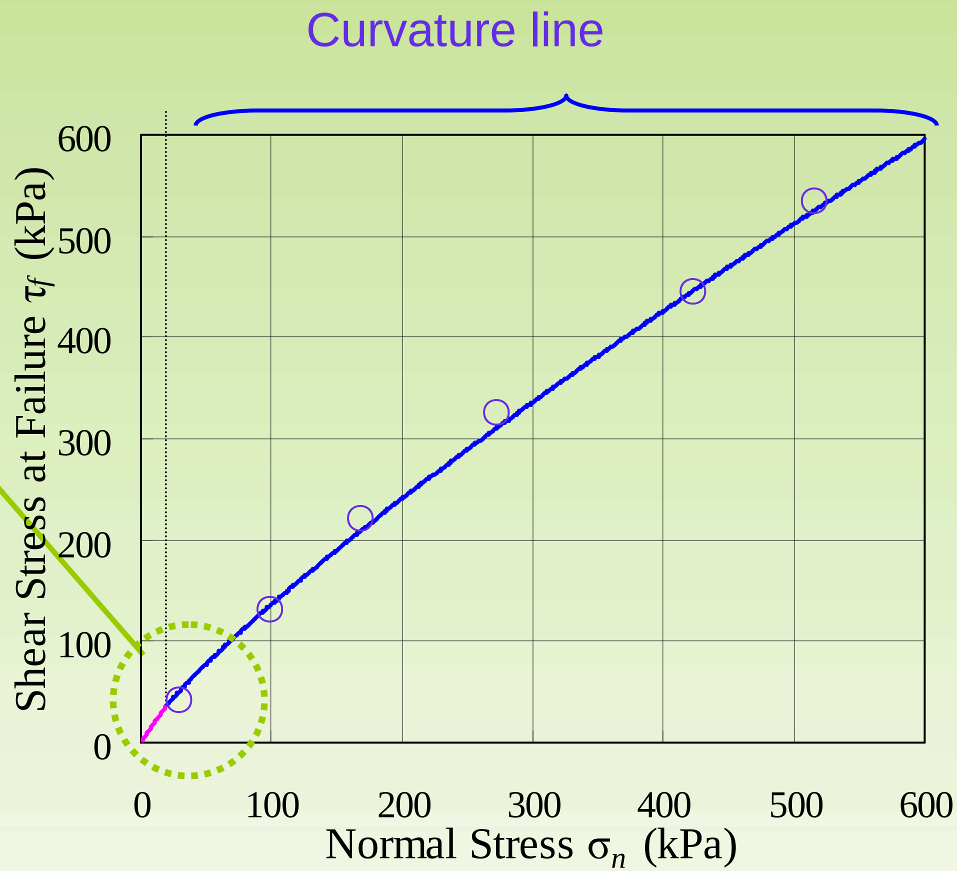
k_F: Design seismic intensity of ground

Seismic force coefficient

Sliding stability analysis

Evaluation method of shear strength : ϕ_0 method





15~20 kPa ≒1m earth covering

Sliding stability analysis

Material property for analysis

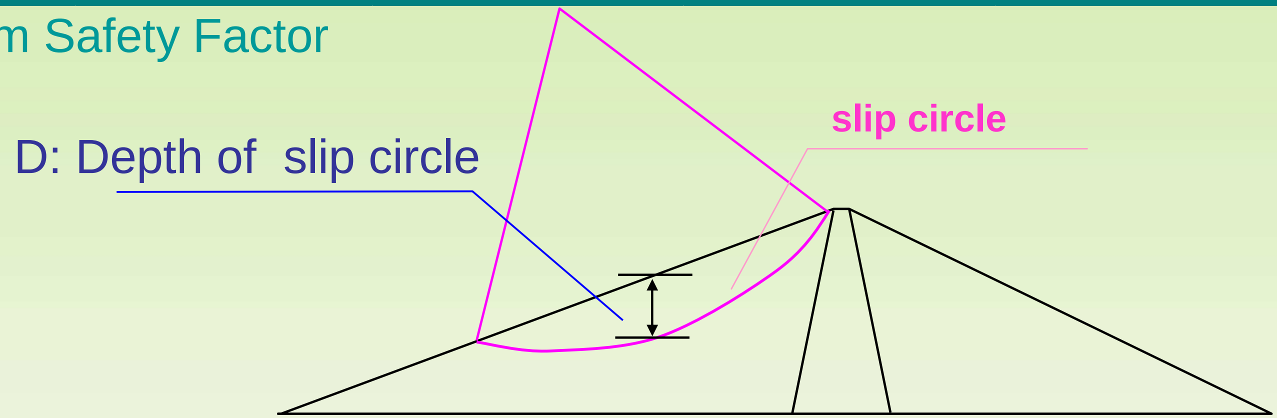
Material		ϕ_0 Method			Mohr-Coulomb's Failure Criterion		Wet Weight (kN/m^3)	Dry Weight (kN/m^3)
		ϕ_{max} (°)	a	σ_{n0} (kN/m^2)	c (kN/m^2)	ϕ (°)		
Rock	A	62.2	11.6	18.87	–	–	20.2	19.1
	B	71.2	10.71	12.32	–	–	23.4	21.9
	C	69.1	12.87	18.37	–	–	22.7	21
Core		–	–	–	0	35	21.9	21.8

Sliding stability analysis

Analysis results

Material		A	B	C
D at SF_{min} (m)	upstream	15.6	27.4	33.5
	donwstream	30.9	30.5	40.1
SF_{min}	upstream	1.156	1.642	1.464
	donwstream	1.393	1.842	1.640

SF_{min}: Minimum Safety Factor



- Shallower slip circle than 5m don’t have minimum safety factor.

Conclusions

- We confirm the distribution of shear strength of rock materials can be approximated by curvature approximation method at low confining pressure range.
- It is made clear that shallower slip circles than 5m don't have minimum safety factor.

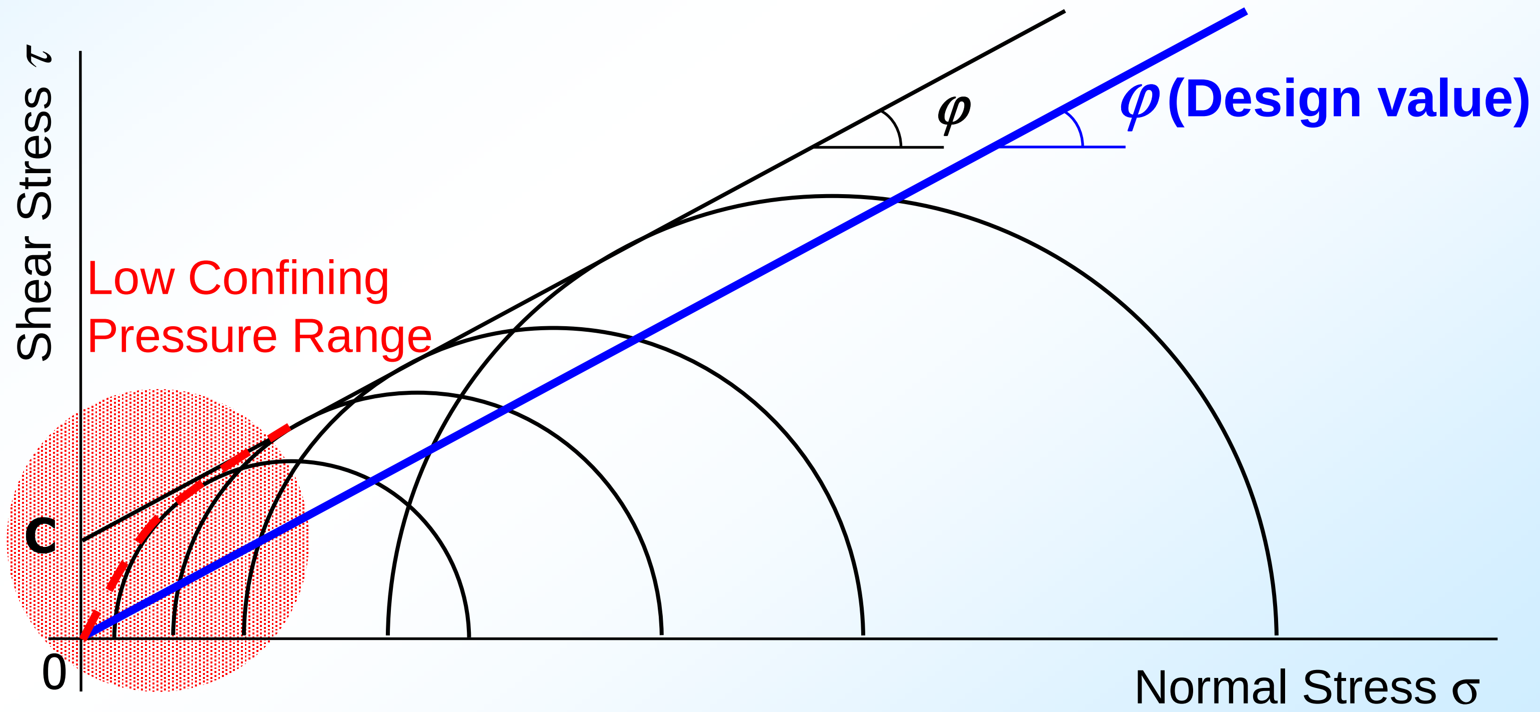
Thank you
for your kind attention!

Reference

Background

The design Shear strength of rock materials :

- Base on Mohr-Coulomb's failure criterion.
- Cohesion is zero, only internal friction angle is used for design value.



Background

The problem of evaluation of shear strength

The triaxial compression test, (which is the most common strength test for rock materials,) can't assure the test precision under very low confining pressure condition. (σ 3< 100kPa)

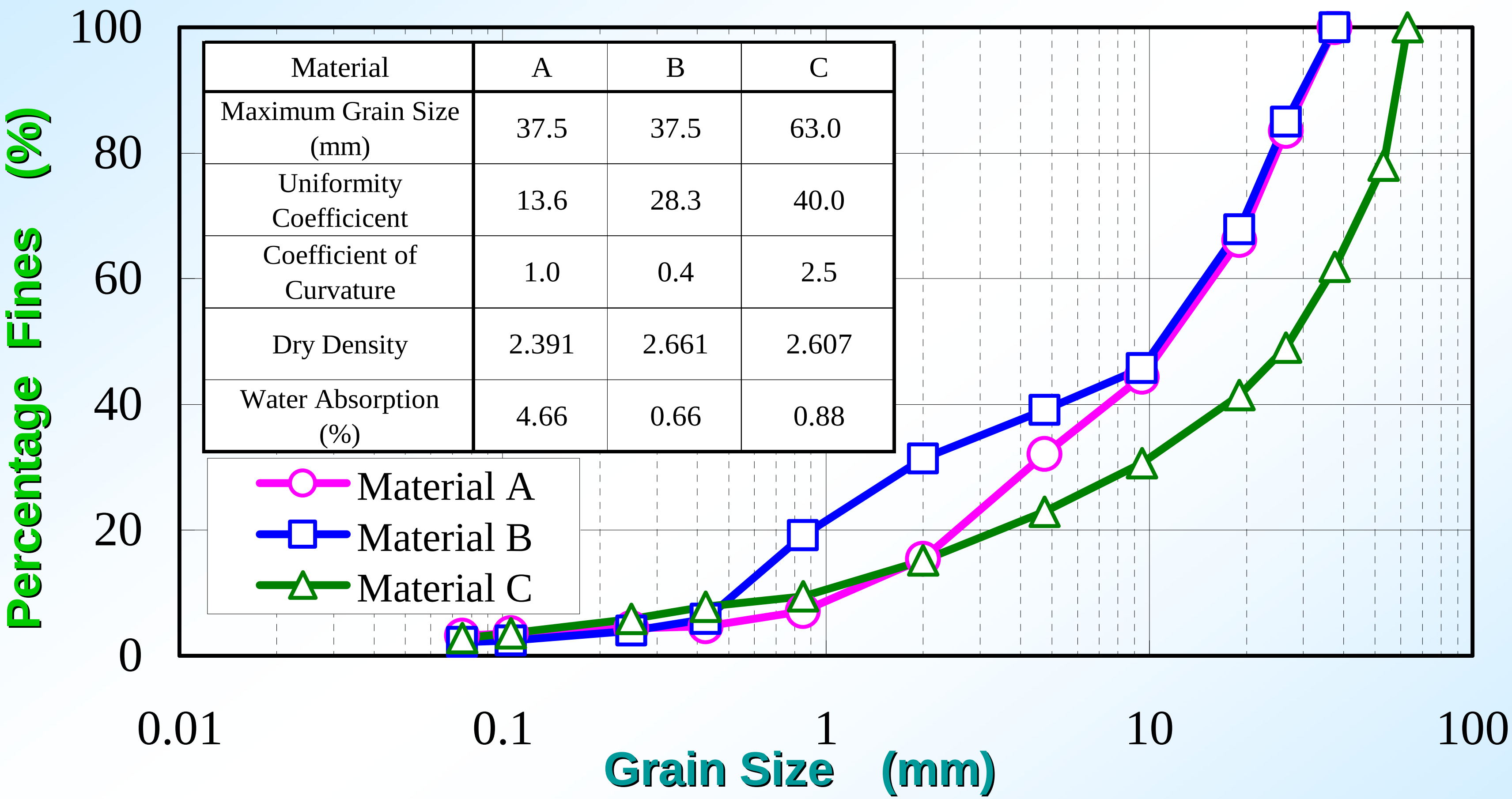
So, we couldn't check these strength distribution under low pressures is actually like this picture.

Develop the method of measurering the shear strength under low confining pressure condition

&

Eevaluate shear strength of rock materials considering the confining pressure dependency

Grain size distribution curves of test materials



Material	A	B	C
Maximum Grain Size (mm)	37.5	37.5	63.0
Uniformity Coefficicent	13.6	28.3	40.0
Coefficient of Curvature	1.0	0.4	2.5
Dry Density	2.391	2.661	2.607
Water Absorption (%)	4.66	0.66	0.88

	0.075	0.250	0.850	2	4.75	19	75
Silt	Fine Sand	Medium Sand	Coarse Sand	Fine Gravel	Medium Gravel	Coarse Gravel	

Large-scale Triaxial Compression Tests (TCTs)

Test Condition

<table>
<tr><td>Test and Specimen Condition</td><td colspan="3">CD condition
Saturated / Unsaturated</td></tr>
<tr><td>Specimen Size (cm)</td><td colspan="3">ϕ 30×H60</td></tr>
<tr><td rowspan="2">Relative Density (%)</td><td colspan="2">A,B</td><td>C</td></tr>
<tr><td colspan="2">90</td><td>85</td></tr>
<tr><td rowspan="2">Confining Pressure (kPa)</td><td>A,B</td><td colspan="2">49,98,196,294
(saturated, unsaturated)</td></tr>
<tr><td>C</td><td colspan="2">49,98,196,294,392,588,785
(saturated)
49,98,196, 392
(unsaturated)</td></tr>
</table>

Large-scale Box Shear Tests (BSTs)

Test Condition

Test and Specimen Condition	Constant Pressure Condition, Saturated / Unsaturated (Removed friction around the shear box)
Specimen Size (cm)	L40×W40×H40
Relative Density (%)	90
Normal Stress (kPa)	15,25,49,98,196,294

Special Safety Inspection of Dams by Site Officers

Should be conducted immediately after
"Earthquakes that generate earthquake motion with maximum acceleration of 25 gal or more observed at the dam foundation or earthquake with Japan Meteorological Agency seismic intensity of 4 or higher"

Primary Inspection (Visual Inspection) :

410 dams

Secondary Inspection (Detailed Visual Inspection & Safety Check Based on Measured Behavior) :

323 dams

Results of Special Safety Inspection

- No severe damage which affects the safety of dams was reported.
- Cracks generated at dam crest and/or spillway, and increase in leakage/seepage through dam bodies and/or their foundation were reported at several dams.
- Dam owners continued careful monitoring of dam behavior, and made detailed investigation and repair of their damage.

Fujinuma-ike
(After Tohoku earthquake)

View from left abutment toward the breached portion