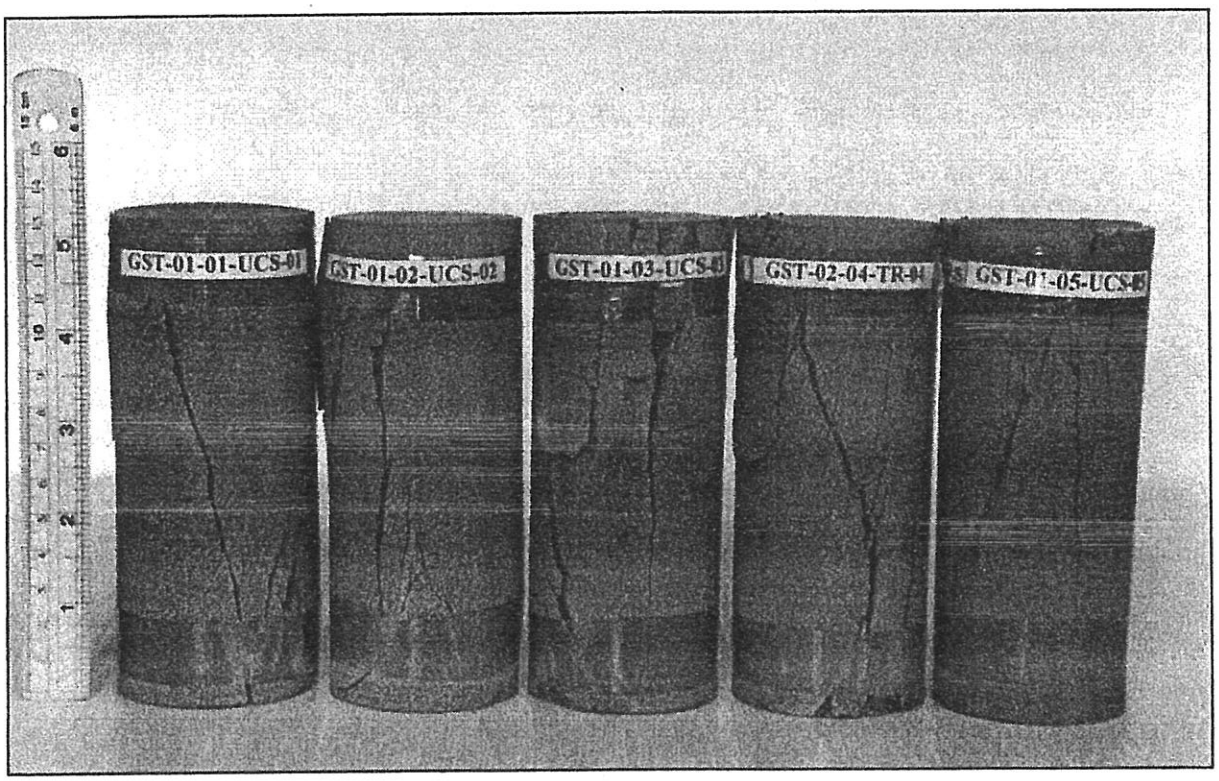
คู่มือปฏิบัติการ

434370 กลศาสตร์หิน

ROCK MECHANICS LABORATORY



ดร.ปรัชญา เทพณรงค์

อาจารย์ประจำโปรแกรมวิศวกรรมธรณี

สาขาวิชาเทคโนโลยีธรณี

สำนักวิชาวิศวกรรมศาสตร์

มหาวิทยาลัยเทคโนโลยีสุรนารี

มกราคม 2551

ASTM INTERNATIONAL
Standards Worldwide

ISRM

คู่มือปฏิบัติการ

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มกราคม 2551

คำนำ

หนังสือคู่มือปฏิบัติการกลศาสตร์หินฉบับนี้ ได้ถูกจัดทำขึ้นเพื่อใช้เป็นเอกสารประกอบการทำปฏิบัติการกลศาสตร์หินซึ่งเป็นส่วนหนึ่งในรายวิชา 434370 กลศาสตร์หิน (Rock Mechanics) โดยผลทดสอบที่ได้จากห้องปฏิบัติการจะถูกนำมาใช้ประโยชน์หลายด้าน อาทิ นำมาประกอบในการประเมินเสถียรภาพของมวลหินภายใต้กิจกรรมต่าง ๆ ทางด้านวิศวกรรม ใช้ในการออกแบบเบื้องต้นของโครงสร้างทางด้านวิศวกรรม ใช้เป็นดัชนีเพื่อการจำแนกหินนั้น ๆ หรือเพื่อเปรียบเทียบกับคุณสมบัติของหินที่ได้มาจากพื้นที่ต่าง ๆ กัน เป็นต้น

หนังสือคู่มือฉบับนี้ได้รวบรวมวิธีการทดสอบแบบมาตรฐานที่ใช้ในระดับสากลจากสององค์การ คือ American Standards for Testing and Materials (ASTM) และ International Society for Rock Mechanics (ISRM) ซึ่งการทดสอบในระบบ ASTM และ ISRM จะเป็นที่นิยมกันอย่างแพร่หลายทั่วโลก ซึ่งรวมไปถึงประเทศไทยด้วย จึงหวังว่าหนังสือคู่มือปฏิบัติการฉบับนี้จะเป็นประโยชน์ต่อนักศึกษา วิศวกร และผู้สนใจทุกคน หากมีข้อผิดพลาดใด กรุณาแจ้งให้ผู้แต่งและเรียบเรียงทราบโดยตรง เพื่อจะได้ดำเนินการแก้ไขปรับปรุงในการจัดพิมพ์ครั้งต่อไป

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อาจารย์ประจำโปรแกรมวิศวกรรมธรณี

สำนักวิชาวิศวกรรมศาสตร์

มหาวิทยาลัยเทคโนโลยีสุรนารี

(ฉบับแก้ไข มกราคม 2552)

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ปฏิบัติการที่ 1

การเลือกเก็บและจัดเตรียมตัวอย่างหิน

วัตถุประสงค์

1) เพื่อเลือกตัวอย่างหินจากภาคสนามสำหรับนำมาทดสอบในแต่ละวิธีตามมาตรฐาน

2) เพื่อจัดเตรียมตัวอย่างหินให้ได้รูปร่างและขนาดตามมาตรฐาน

มาตรฐาน

ASTM D 4543 – 07 และ ISRM Suggested Methods

เครื่องมือการเตรียมตัวอย่างหิน

1) เครื่องเจาะ (Drilling Machine) และหัวเจาะ (Drill Bit) ขนาดต่างๆ

2) เครื่องตัด (Cutting Machine)

3) เครื่องขัด (Grinding Machine)

4) แว่นตา Safety และ อุปกรณ์ครอบหูเพื่อลดเสียง (Earplug)

เครื่องมือการวัดขนาดตัวอย่างหิน

1) เวอร์เนีย อ่านละเอียดอย่างน้อย 0.01 นิ้ว

2) พื้นเรียบ (Flat Surface) และ กล่องรูปตัววี (V-block) 90 องศา
มีความราบและเรียบ (Flat & Smooth) ไม่น้อยกว่า 0.005 in. (13 μm)

3) มาตรวัดการเคลื่อนตัว (Dial Gages) ความละเอียดอย่างน้อย 0.001 นิ้ว (25 μm)

วิธีการเตรียมตัวอย่างหิน

1) เลือกเก็บตัวอย่างหินจากภาคสนามโดยให้หินมีความเป็นเนื้อเดียวกัน (homogeneous) มากที่สุดเท่าที่เป็นไปได้ และเป็นตัวแทนที่ดีสำหรับหินที่ต้องการนำมาทดสอบ ขนาดหินที่เก็บ (Rock Sample) ควรมีขนาดใกล้เคียงกับช่องว่างในเครื่องเจาะ หากหินมีขนาดใหญ่เกินไปอาจต้องทำการย่อยหินให้เล็กลง และควรระวังไม่ให้หินเกิดการแตกร้าวจากการย่อย

2) เลือกขนาดของหัวเจาะให้เหมาะสมกับขนาดตามที่ต้องการแล้วทำการติดตั้งกับเครื่องเจาะพร้อมต่อระบบน้ำเพื่อใช้ในการไหลเวียนเอาเศษตะกอนหินใต้หัวเจาะขึ้นมา

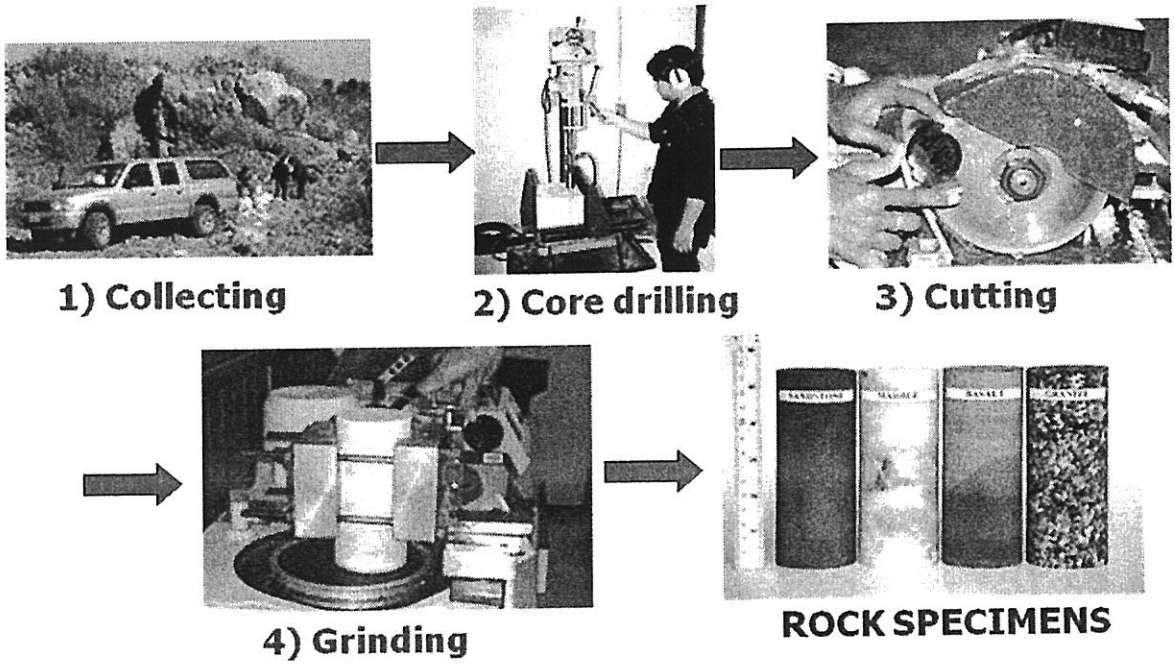
3) เริ่มทำการเจาะโดยใช้ความเร็วรอบที่ต่ำก่อน หมุนคันโยกเพื่อดันหัวเจาะให้สัมผัสหินตัวอย่างช้า ๆ จนกระทั่งฟันของหัวเจาะจมลงในเนื้อหินทั้งหมดจึงค่อยเพิ่มความเร็วรอบขึ้น ทำการเจาะจนกระทั่งเจาะทะลุหินตัวอย่าง

4) นำหินแท่งตัวอย่าง (Core Specimen) ที่เจาะได้ไปตัดปลายทั้งสองด้านให้ได้ขนาดตามต้องการ

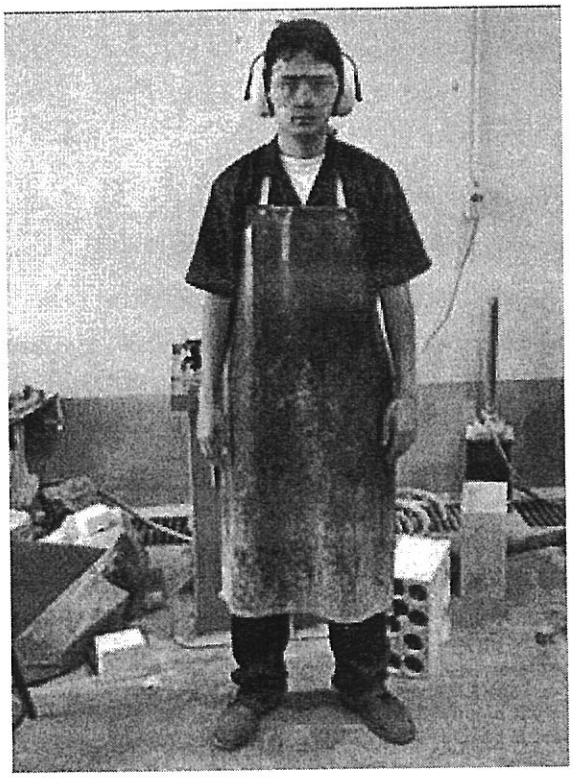
5) นำไปแท่งหินที่ได้ขนาดไปทำการขัด หรือฝนผิวหน้าของแท่งตัวอย่างให้เรียบและตั้งฉากตามมารตฐานกำหนด

6) ทำการบันทึกหมายเลขหินตัวอย่างตามระบบดังในรูปที่ 1-9

7) วัดขนาดของแท่งหินตัวอย่างพร้อมชั่งน้ำหนักเพื่อหาความหนาแน่น วิธีการตามตามเอกสารอ้างท้ายเล่ม



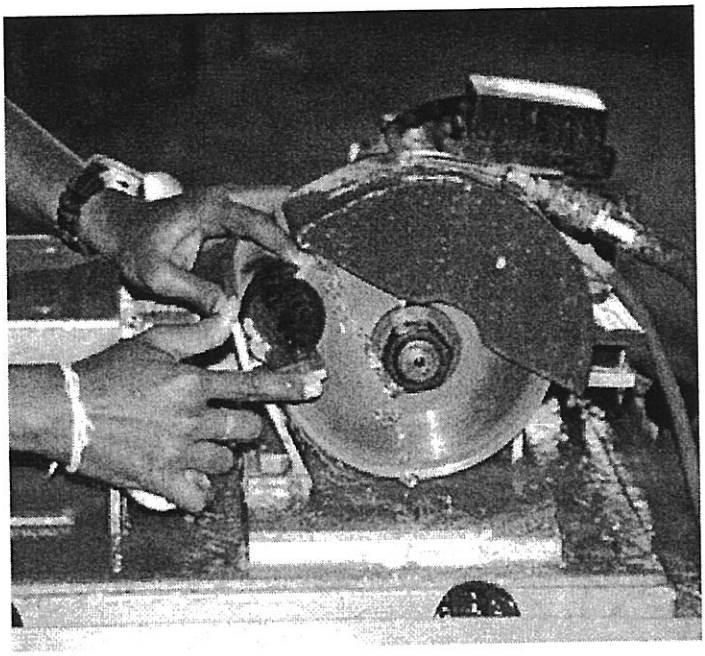
รูปที่ 1-1 ขั้นตอนต่าง ๆ ในกระบวนการเลือกเก็บและเตรียมตัวอย่างหิน



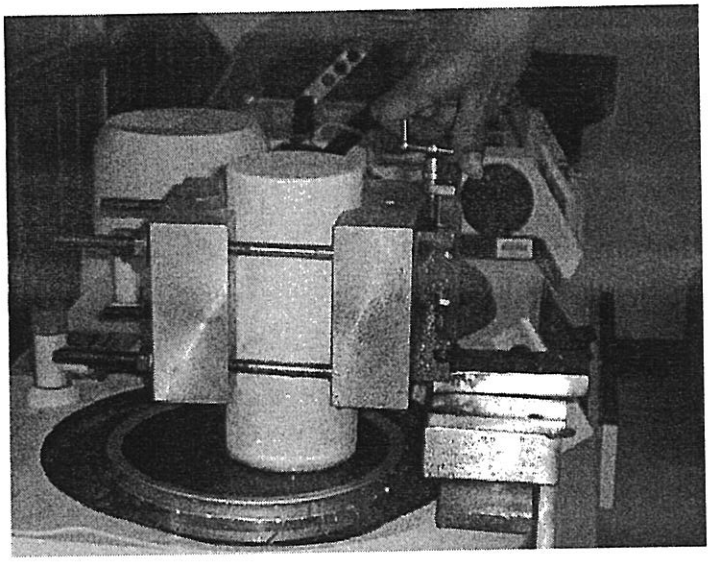
รูปที่ 1-2 ชุดแต่งกายรัดกุมเพื่อความปลอดภัยพร้อมอุปกรณ์ป้องกันอันตราย

รูปที่ 1-3 เครื่องเครื่องเจาะ (Drilling Machine)

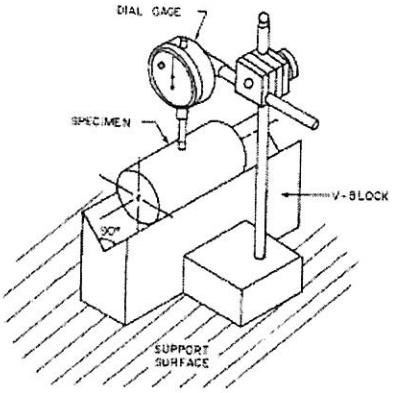
รูปที่ 1-4 หัวเจาะ (Drill Bit) ขนาดต่างๆ



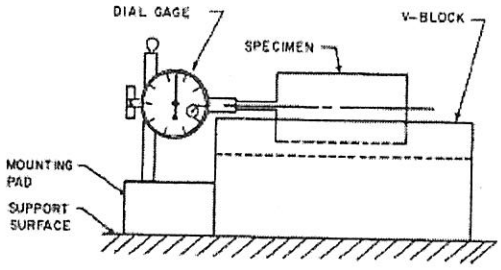
รูปที่ 1-5 เครื่องตัด (Cutting Machine)



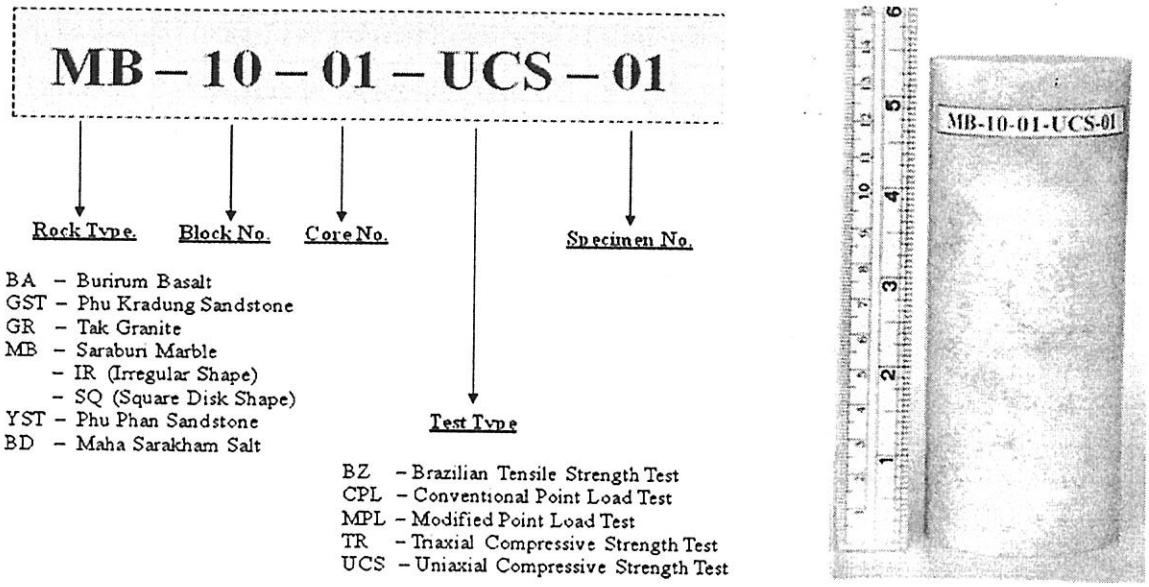
รูปที่ 1-6 เครื่องขัด (Grinding Machine)



รูปที่ 1-7 วิธีการตรวจวัดค่า Straightness / Side Smoothness ตามมาตรฐาน ASTM D 4543 – 07



รูปที่ 1-8 วิธีการตรวจวัดค่า End Flatness / Parallelism / Perpendicularity ตามมาตรฐาน ASTM D 4543 – 07



รูปที่ 1-9 รูปแบบการบันทึกหมายเลขหินตัวอย่าง

ตารางบันทึกขนาดแท่งหินตัวอย่าง

ชนิดหิน..

สำหรับการทดสอบ...

เตรียมตัวอย่างวันที่...

หมายเลขหินตัวอย่าง	เส้นผ่านศูนย์กลาง D (mm)				ความยาว L (mm)				L/D	น้ำหนัก (g)	ความหนาแน่น (g/cc)
	วัดครั้งที่ 1	วัดครั้งที่ 2	วัดครั้งที่ 3	เฉลี่ย	วัดครั้งที่ 1	วัดครั้งที่ 2	วัดครั้งที่ 3	เฉลี่ย			

ปฏิบัติการที่ 2

การทดสอบความเค้นกดสูงสุดในแกนเดียว

วัตถุประสงค์การทดสอบ

1) เพื่อหาค่าความเค้นกดสูงสุดในแกนเดียว (Uniaxial Compressive Strength) ของหินตัวอย่าง

2) เพื่อหาค่าสัมประสิทธิ์ความยืดหยุ่น (Elastic Modulus) ของหินตัวอย่าง

3) เพื่อหาค่าอัตราส่วนของปัวซ์ซอง (Poisson's Ratio) ของหินตัวอย่าง

มาตรฐานการทดสอบ

ASTM D 7012 – 07[1] และ ISRM Suggested Methods

เครื่องมือการทดสอบ

1) เครื่องทดสอบแรงกด (Loading Machine)

2) มาตรวัดการเคลื่อนตัว (Dial Gages) ความละเอียดอย่างน้อย 0.002 mm

หรือมาตรวัดความเครียดพร้อมเครื่องอ่าน (Strain Gages with Readout Unit) ความละเอียดอย่างน้อย 25 με

ตัวอย่างหิน

เป็นแท่งหินทรงกระบอก (Core Specimen) มีขนาดเส้นผ่านศูนย์กลางไม่น้อยกว่า 47 มิลลิเมตร (ASTM) หรือไม่น้อยกว่า 54 มิลลิเมตร (ISRM) อัตราส่วนระหว่างความยาวต่อเส้นผ่านศูนย์กลาง (L/D) อยู่ระหว่าง 2.0 – 2.5 (ASTM) หรือ 2.5 – 3.0 (ISRM) โดยตัวอย่างหินจัดเตรียมตามมาตรฐาน ASTM D 4543 – 07 อย่างน้อยจำนวน 5 ตัวอย่าง (ISRM)

วิธีการทดสอบ

1) เตรียมเครื่องทดสอบแรงกดโดยตรวจสอบแผ่นสำหรับปรับการเอียงตัวด้านบน (Spherical Seat) ให้สามารถหมุนได้อย่างอิสระก่อนการทดสอบทุกครั้ง (รูปที่ 2-1)

2) ติดตั้งตัวอย่างหินพร้อมมาตรวัดการเคลื่อนตัว (Dial Gages) หรือมาตรวัดความเครียด (Strain Gages) ในแนวแกนและแนวตั้งฉากกับแกนของแรงกด พร้อมตั้งให้อ่านที่ศูนย์ (รูปที่ 2-2) และปิดฝาตะแกรงป้องการเศษหินกระเด็น

3) ให้แรงกดในแนวแกนด้วยอัตราเร็วคงที่ประมาณ 0.5 – 1.0 MPa/second หรือให้หินวิบัติ (แตก) ภายใน 5 – 10 นาที (ตามข้อแนะนำของ ISRM)

4) บันทึกค่าแรงกดที่เพิ่มขึ้น และค่าการเคลื่อนตัวจนกระทั่งหินวิบัติ

5) วาดรูปแนวการวิบัติหรือบันทึกภาพตัวอย่างหินเพื่อใช้จำแนกการวิบัติ (Mode of Failure)

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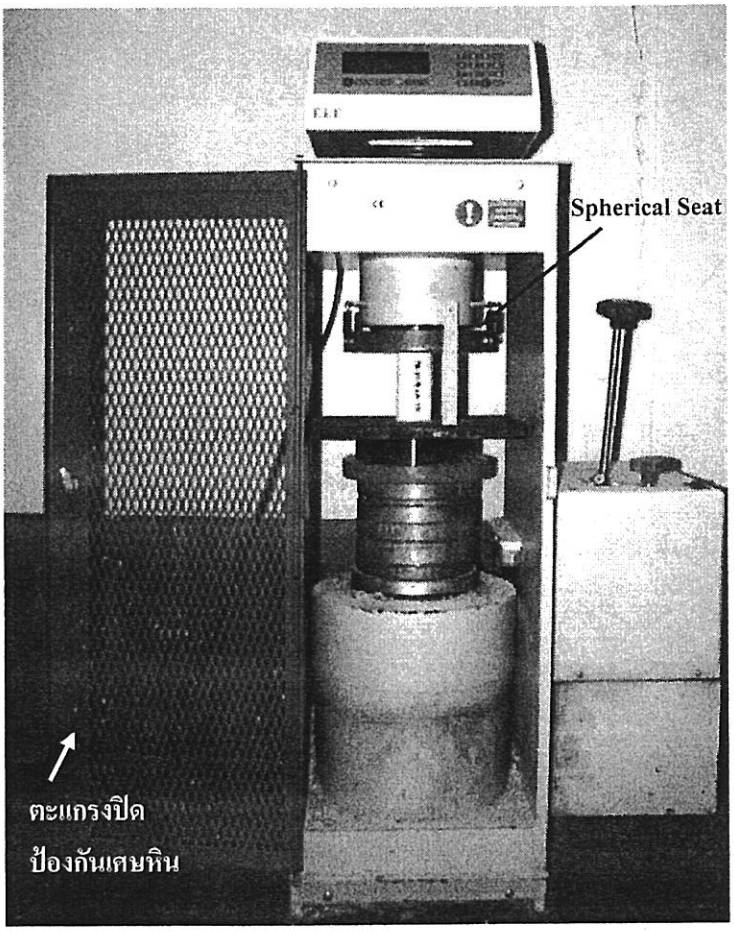
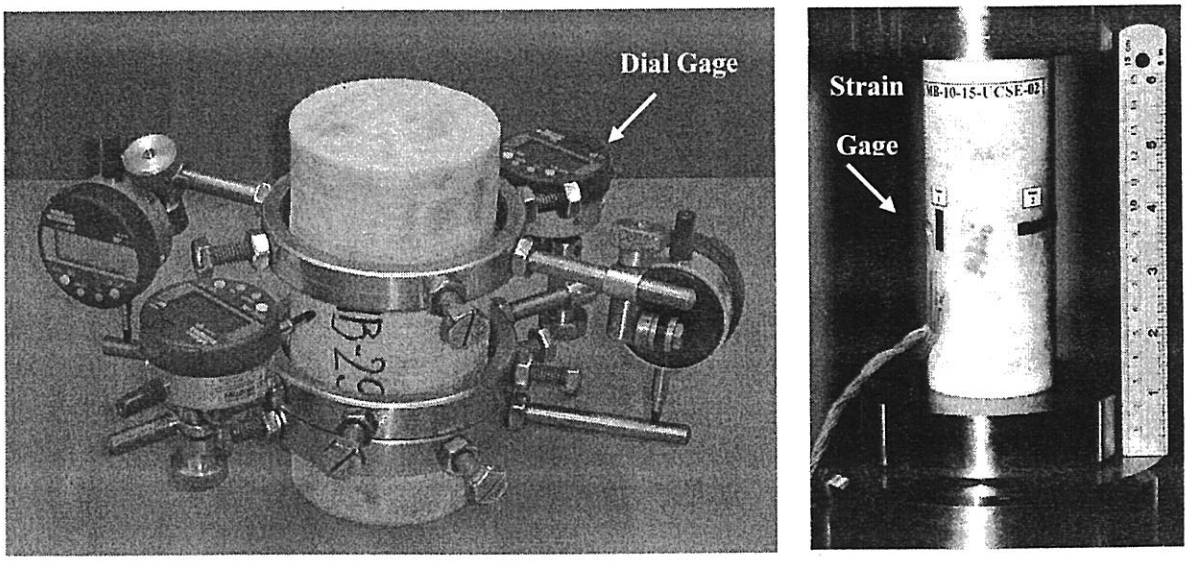
[1] แทนมาตรฐานเดิม ASTM D 2938 – 95 (Unconfined Compressive Strength of Intact Rock Core Specimens) และ D 3148 – 96 (Elastic Moduli of Intact Rock Core Specimens in Uniaxial Compression)



รูปที่ 2-1 เครื่องทดสอบแรงกด ELE ARD 2000 กำลังกดสูงสุด 200 ตัน



(a) (b)

รูปที่ 2-2 การติดตั้ง (a) มาตรวัดการเคลื่อนตัว (Dial Gages) และ (b) มาตรวัดความเครียด (Strain Gages) ในแนวแกนและแนวตั้งฉากกับแกนของแรงกด

การคำนวณ

1) ความเค้นกดสูงสุดในแกนเดียว (Uniaxial Compressive Strength)

$$\sigma_C = P/A$$

โดย P = แรงกดสูงที่สุดวัดที่จุดวิบัติ

A = พื้นที่หน้าตัดเดิมของหินตัวอย่าง ($\pi D^2/4$)

2) ค่าสัมประสิทธิ์ความยืดหยุ่น, E (Elastic Modulus)

2.1) ค่าสัมประสิทธิ์ความยืดหยุ่นแบบตัด, E_s (Secant Elastic Modulus) คำนวณได้จากความชันของกราฟความเค้นในแนวแกน-ความเครียดในแนวแกน โดยการลากเส้นตรงจากจุดศูนย์ไปจนถึงจุด 50% ของค่าความเค้นสูงสุด ดังแสดงในรูปที่ 2-3 (a)

2.2) ค่าสัมประสิทธิ์ความยืดหยุ่นแบบสัมผัส, E_t (Tangent Elastic Modulus) คำนวณได้จากความชันของกราฟความเค้นในแนวแกน-ความเครียดในแนวแกน โดยการลากเส้นสัมผัสกับเส้นความเค้น-ความเครียดที่จุด 50% ของค่าความเค้นสูงสุด ดังแสดงในรูปที่ 2-3 (b)

โดย $\varepsilon_a = \Delta L/L$

ε_a = ความเค้นในแนวแกน

ΔL = ความยาวหินตัวอย่างที่เปลี่ยนแปลง

L = ความยาวเดิมของหินตัวอย่าง

3) ค่าอัตราส่วนของปัวซ์ซอง, ν (Poisson's Ratio)

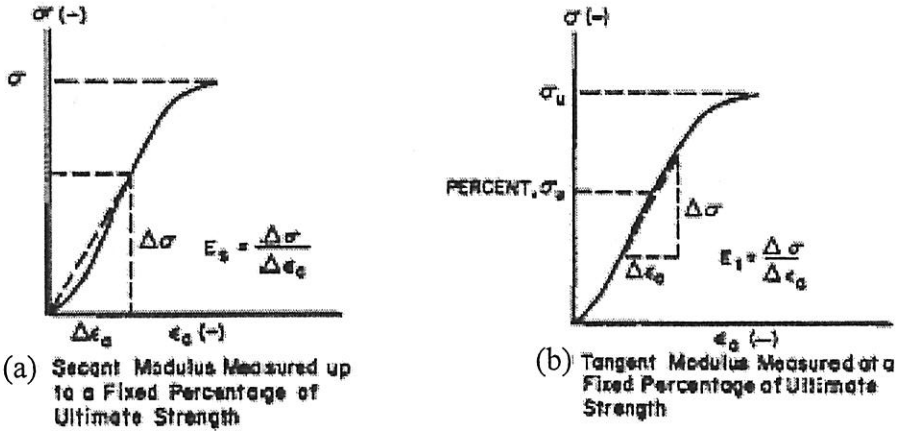
$$\nu = -\varepsilon_a / \varepsilon_l$$

โดย $\varepsilon_l = \Delta D/D$

ΔD = เส้นผ่านศูนย์กลางหินตัวอย่างที่เปลี่ยนแปลง

D = เส้นผ่านศูนย์กลางเดิมของหินตัวอย่าง

ε_a และ ε_l ได้จากการวัดที่จุด 50% ของค่าความเค้นสูงสุด



รูปที่ 2-3 การคำนวณค่าสัมประสิทธิ์ความยืดหยุ่นแบบตัด (E_s) และแบบสัมผัส (E_t)

ผลการทดสอบ

หมายเลขตัวอย่างหิน...ชนิดหิน...

เตรียมตัวอย่างวันที่...ทดสอบวันที่...

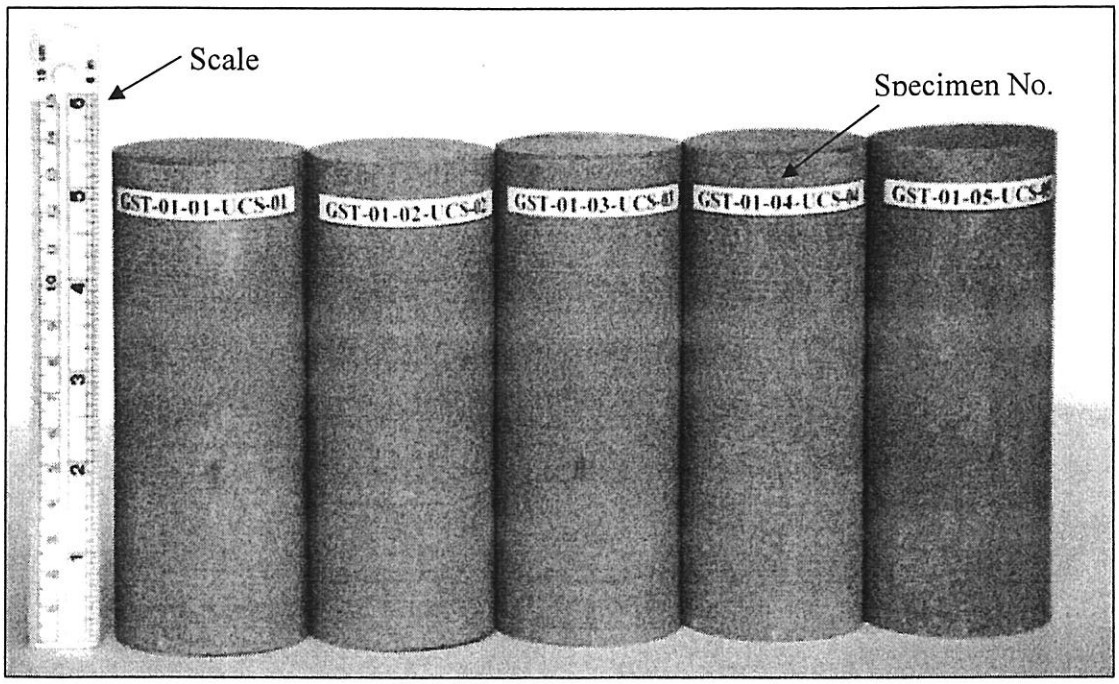
เส้นผ่านศูนย์กลางเฉลี่ย (D)............(mm) ความยาวเฉลี่ย (L)................(mm) L/D ratio.......................................

น้ำหนัก...............(g) ความหนาแน่น...............(g/cc)..........อุณหภูมิห้องทดสอบ...............(°C)...............

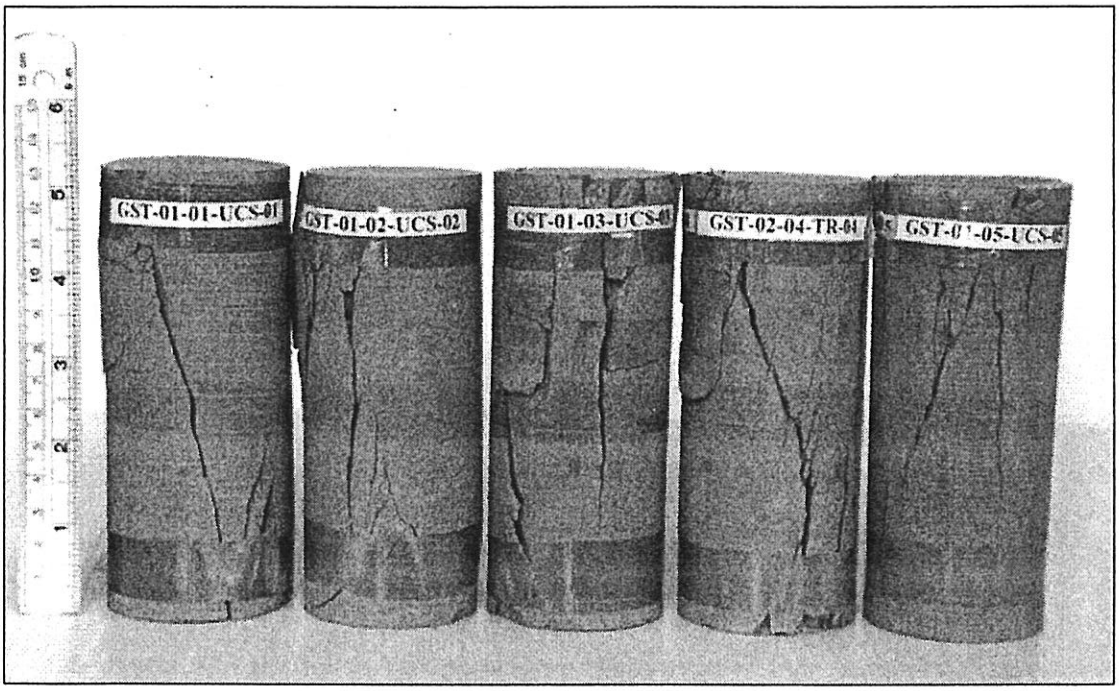
แรงกด	ความเค้น	การยุบตัวในแนวแกน (Axial Deformation)				การขยายตัวในแนวด้านข้าง (Lateral Deformation)			
(kN)	(MPa)	gage 1 (mm)	gage 2 (mm)	ค่าเฉลี่ย (mm)	ความเครียด (mm/mm)	gage 3 (mm)	gage 4 (mm)	ค่าเฉลี่ย (mm)	ความเครียด (mm/mm)

-- ตัวอย่าง--

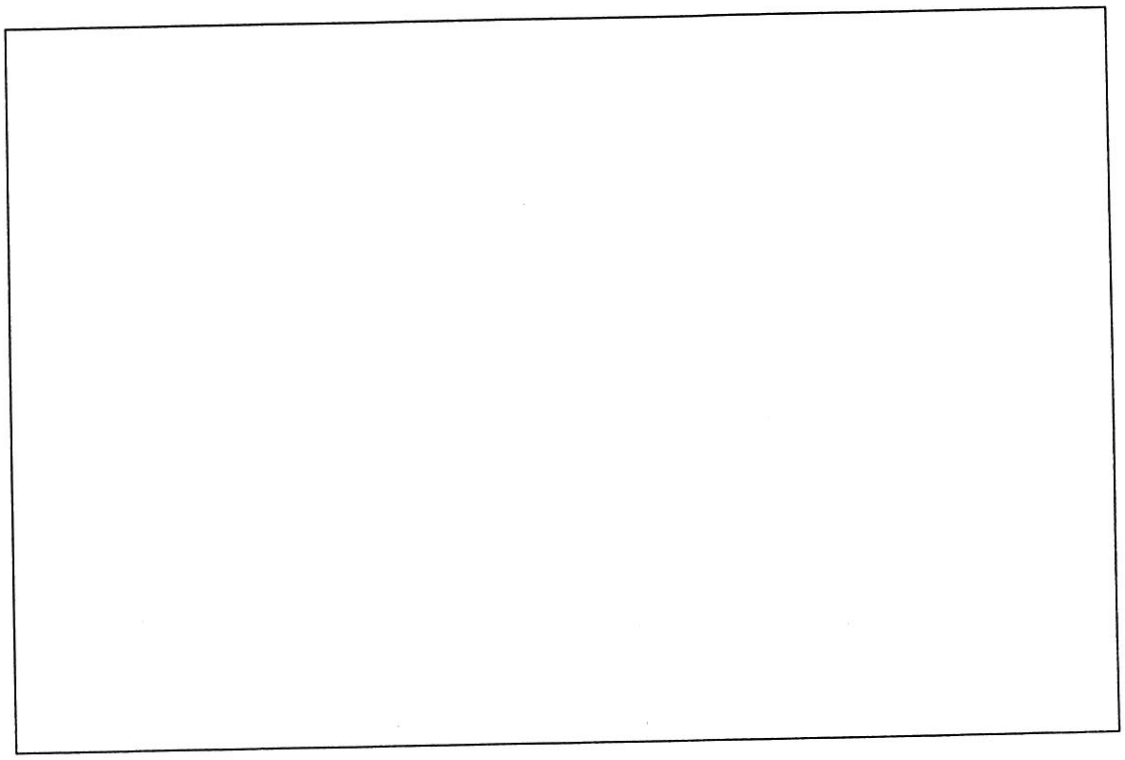
รูปตัวอย่างหินก่อนการทดสอบ



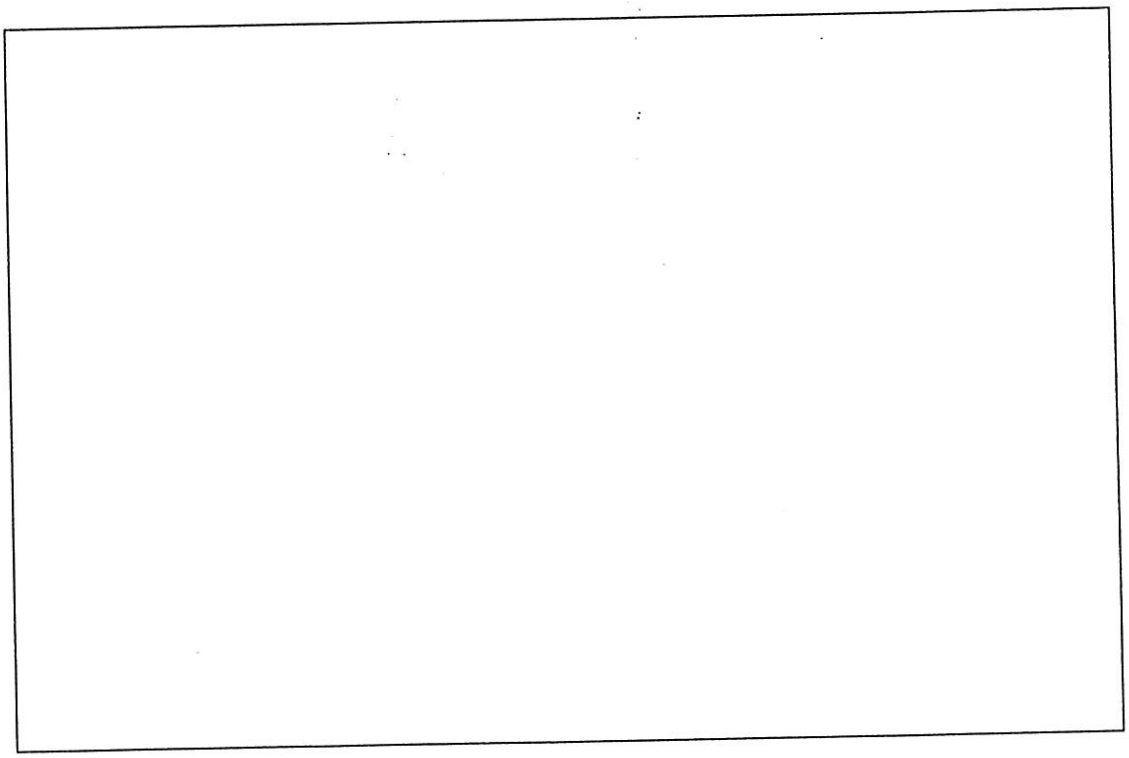
รูปตัวอย่างหินหลังการทดสอบ



รูปตัวอย่างหินก่อนการทดสอบ



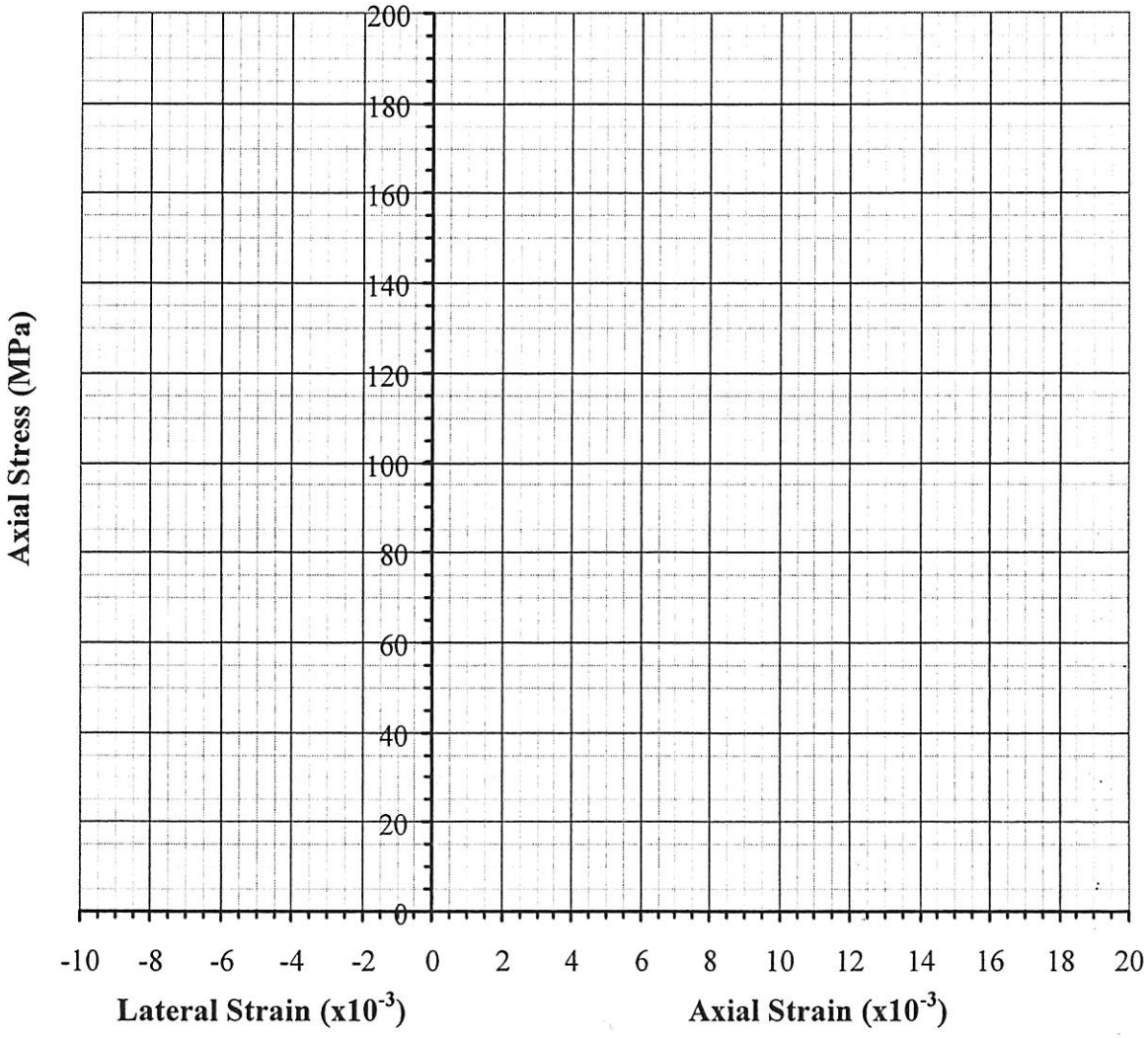
รูปตัวอย่างหินหลังการทดสอบ



กราฟความเค้น-ความเครียด

หมายเลขตัวอย่างหิน.....

Stress - Strain Curves



วิจารณ์ผลการทดสอบ

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.....

สรุปการทดสอบ

1) ค่าความเค้นกดสูงสุดในแกนเดียว, σ_c (Uniaxial Compressive Strength)

หมายเลขตัวอย่าง..... = ... MPa
หมายเลขตัวอย่าง..... = ... MPa
หมายเลขตัวอย่าง..... = ... MPa
หมายเลขตัวอย่าง..... = ... MPa
หมายเลขตัวอย่าง..... = ... MPa
ค่าเฉลี่ย (Average) = ... MPa
ค่าเบี่ยงเบนมาตรฐาน (S.D.) = ... MPa

2) ค่าสัมประสิทธิ์ความยืดหยุ่น, E (Elastic Modulus)

2.1) ค่าสัมประสิทธิ์ความยืดหยุ่นแบบตัด, E_s (Secant Elastic Modulus)

หมายเลขตัวอย่าง..... = ... GPa
หมายเลขตัวอย่าง..... = ... GPa
หมายเลขตัวอย่าง..... = ... GPa
หมายเลขตัวอย่าง..... = ... GPa
หมายเลขตัวอย่าง..... = ... GPa
ค่าเฉลี่ย (Average) = ... GPa
ค่าเบี่ยงเบนมาตรฐาน (S.D.) = ... GPa

2.2) ค่าสัมประสิทธิ์ความยืดหยุ่นแบบสัมผัส, E_t (Tangent Elastic Modulus)

หมายเลขตัวอย่าง..... = ... GPa
หมายเลขตัวอย่าง..... = ... GPa
หมายเลขตัวอย่าง..... = ... GPa
หมายเลขตัวอย่าง..... = ... GPa
หมายเลขตัวอย่าง..... = ... GPa
ค่าเฉลี่ย (Average) = ... GPa
ค่าเบี่ยงเบนมาตรฐาน (S.D.) = ... GPa

3) ค่าอัตราส่วนของปัวซ์ซอง, ν (Poisson's Ratio)

หมายเลขตัวอย่าง..... = ...
หมายเลขตัวอย่าง..... = ...
หมายเลขตัวอย่าง..... = ...
หมายเลขตัวอย่าง..... = ...
หมายเลขตัวอย่าง..... = ...
ค่าเฉลี่ย (Average) = ...
ค่าเบี่ยงเบนมาตรฐาน (S.D.) = ...

ปฏิบัติการที่ 3

การทดสอบความเค้นกดสูงสุดในสามแกน

วัตถุประสงค์การทดสอบ

1) เพื่อหาค่าความเค้นกดสูงสุดในสามแกน (Triaxial Compressive Strength) ของหินตัวอย่าง
2) เพื่อหาค่าสัมประสิทธิ์ความยืดหยุ่น (Elastic Modulus) ของหินตัวอย่าง
3) เพื่อหาค่าอัตราส่วนของปัวซ์ซอง (Poisson's Ratio) ของหินตัวอย่าง
4) เพื่อสร้างเกณฑ์การแตกของหิน (Failure Criteria)

มาตรฐานการทดสอบ

ASTM D 7012 – 07[1] และ ISRM Suggested Methods

เครื่องมือการทดสอบ

1) เครื่องทดสอบแรงกด (Loading Machine)
2) อุปกรณ์ Triaxial Cell ให้ความดันล้อมรอบ (Confining Pressure) และปลอกยาง (Flexible Membrane)
3) ปั๊มให้แรงดันและชุดวาล์วรักษาระดับความดันคงที่ (Hydraulic Pump and Control Valve)
4) มาตรวัดความเครียดพร้อมเครื่องอ่าน (Strain Gages with Readout Unit) ความละเอียดอย่างน้อย 25 με

ตัวอย่างหิน

เป็นแท่งหินทรงกระบอก (Core Specimen) มีขนาดเส้นผ่านศูนย์กลางไม่น้อยกว่า 47 มิลลิเมตร (ASTM) หรือไม่น้อยกว่า 54 มิลลิเมตร (ISRM) อัตราส่วนระหว่างความยาวต่อเส้นผ่านศูนย์กลาง (L/D) อยู่ระหว่าง 2.0 – 2.5 (ASTM) หรือ 2.5 – 3.0 (ISRM) โดยตัวอย่างหินจัดเตรียมตามมาตรฐาน ASTM D 4543 – 07 อย่างน้อยจำนวน 5 ตัวอย่าง (ISRM)

วิธีการทดสอบ

1) เตรียมเครื่องทดสอบแรงกดโดยตรวจสอบแผ่นสำหรับปรับการเอียงตัวด้านบน (Spherical Seat) ให้สามารถหมุนได้อย่างอิสระก่อนการทดสอบทุกครั้ง

2) ประกอบชุดอุปกรณ์ Triaxial Cell ซึ่งประกอบด้วย Triaxial Cell, Flexible Membrane (Rubber Sealing Sleeve), Hydraulic Pump และ Control Valve

3) เติมน้ำมันไฮดรอลิกลงใน Triaxial Cell จนเต็มพร้อมไล่ฟองอากาศให้หมด และปรับ Control Valve ไว้ตามระดับความดันที่ต้องการซึ่งวาล์วนี้จะทำหน้าที่รักษาระดับความดันไม่ให้เกินระดับที่กำนดไว้

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[1] แทนมาตรฐานเดิม ASTM D 2664 – 95a (Triaxial Compressive Strength of Undrained Rock Core Specimens Without Pore Pressure Measurements) และ D 5407 – 95 (Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements)

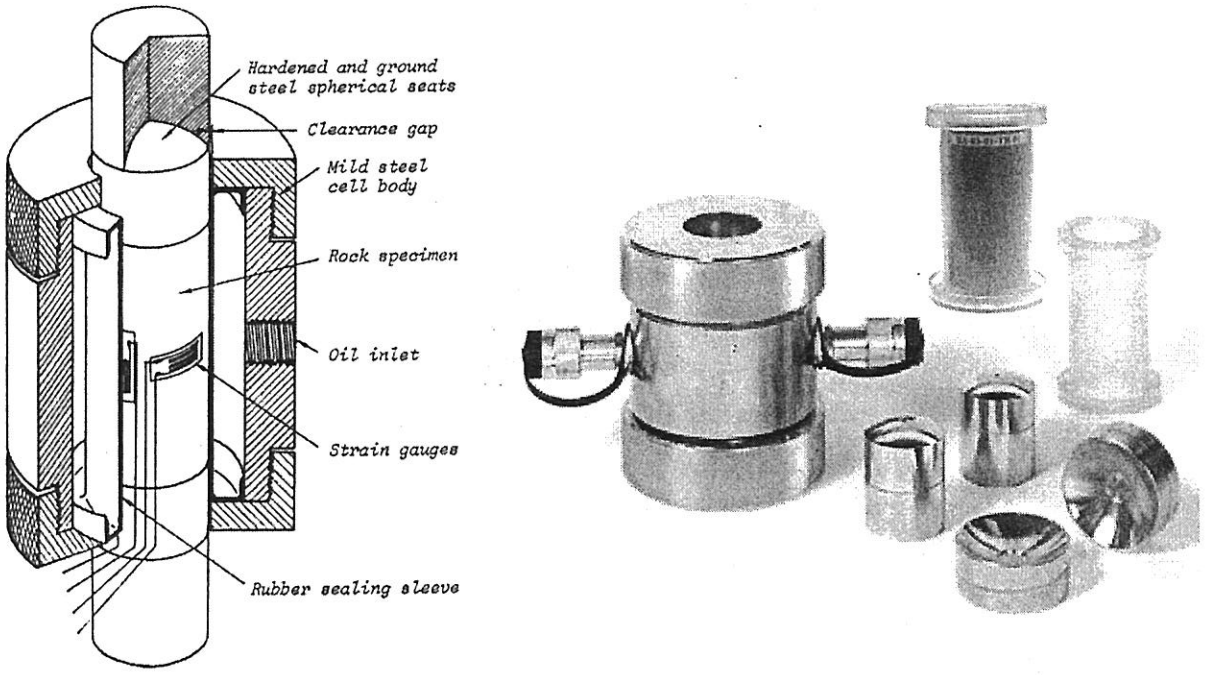
4) ติดตั้งตัวอย่างหินพร้อมมาตรวัดความเครียด (Strain Gages) ในแนวแกนและแนวตั้งฉากกับแกนของแรงกดลงใน Triaxial Cell และใส่ชุด Hardened and Ground Steel Spherical Seat ปิดด้านบนด้านล่าง (รูปที่ 3-1) โดยใส่แรงดันเล็กน้อยเพื่อให้อุปกรณ์ทั้งชุดไม่เคลื่อนตัวหลุดออกจากกัน

5) ติดตั้งชุดอุปกรณ์ Triaxial Cell ทั้งหมดจากขั้นตอนที่ 4 ลงในเครื่องทดสอบแรงกด (รูปที่ 3-2) โดยให้ความดันล้อมรอบ (σ_3) เพิ่มขึ้นพร้อมกันกับแรงกดในแนวแกน (σ_1) จนกระทั่งถึงระดับความดันล้อมรอบคงที่ตามต้องการ จากนั้นเพิ่มแรงกดในแนวแกน (σ_1) ด้วยอัตราเร็วคงที่ประมาณ 0.5 – 1.0 MPa/second จนกระทั่งหินวิบัติ (แตก) หรือ ภายใน 5 – 10 นาที (ตามข้อแนะนำของ ISRM)

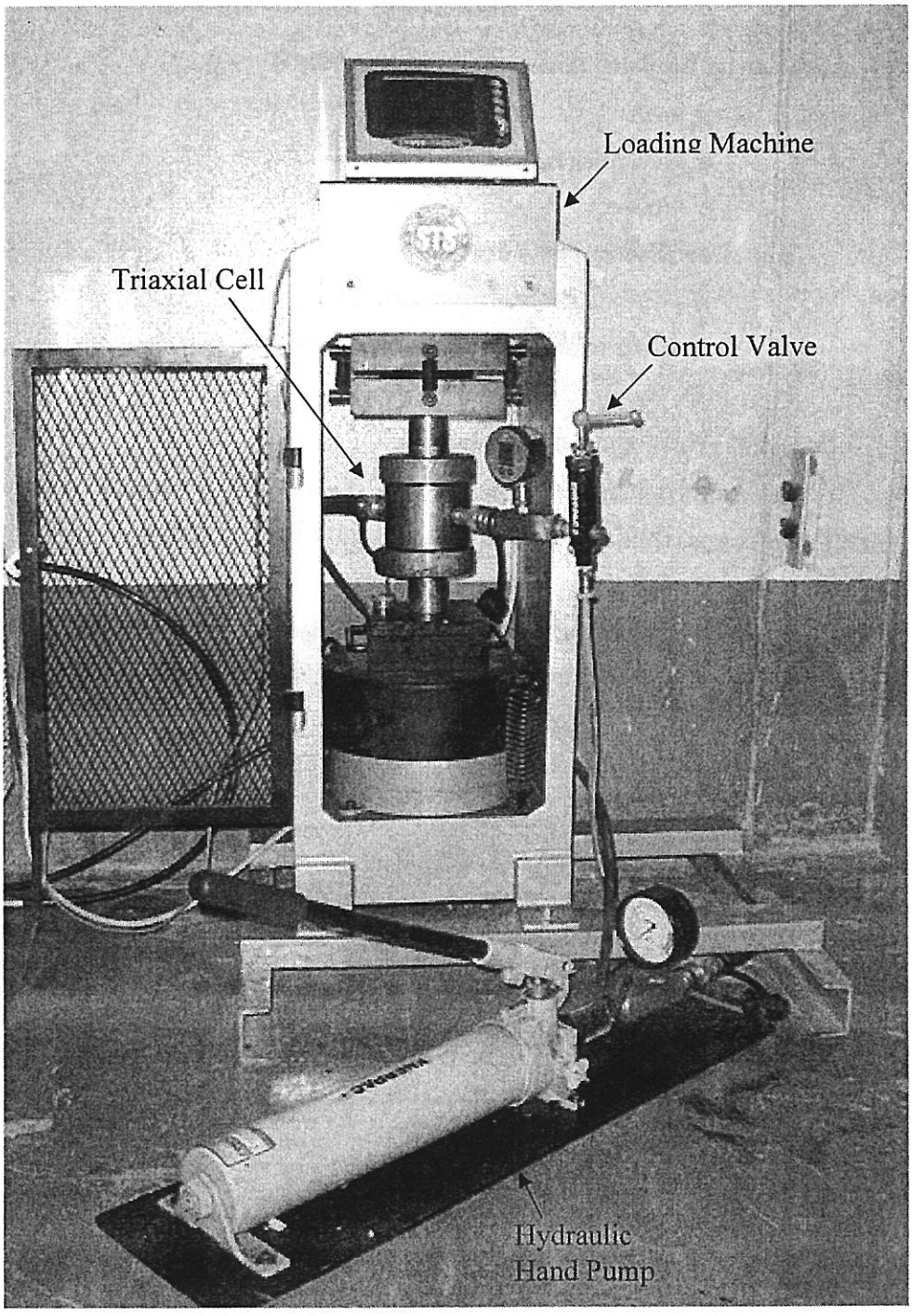
6) บันทึกค่าความดันล้อมรอบที่เพิ่มขึ้น แรงกดที่เพิ่มขึ้น และค่าการเคลื่อนตัวจนกระทั่งหินวิบัติ

7) วาดรูปแนวการวิบัติหรือบันทึกภาพตัวอย่างหินเพื่อใช้จำแนกการวิบัติ (Mode of Failure)

8) ทดสอบตัวอย่างหินโดยเปลี่ยนค่าความดันล้อมรอบตามที่กำหนดไว้



รูปที่ 3-1 Hoek Cell เป็น Triaxial Cell ชนิดหนึ่งที่นิยมใช้ในการทดสอบความเค้นกดสูงสุดในสามแกน (Hoek and Brown, 1980)



รูปที่ 3-2 การติดตั้งชุดอุปกรณ์ Triaxial Cell ทั้งหมดลงในเครื่องทดสอบแรงกด

การคำนวณ

1) ความเค้นกดสูงสุดในสามแกน (Triaxial Compressive Strength)

$\sigma_1 = P/A$

σ_3 = Confining Pressure

$\sigma = (\sigma_1 - \sigma_3)$

โดย P = แรงกดสูงที่สุดวัดที่จุดวิบัติ

A = พื้นที่หน้าตัดเดิมของหินตัวอย่าง ($\pi D^2/4$)

σ = ค่าความเค้นแตกต่าง (Different Failure Stress)

2) ค่าสัมประสิทธิ์ความยืดหยุ่น, E (Elastic Modulus)

2.1) ค่าสัมประสิทธิ์ความยืดหยุ่นแบบตัด, E_s (Secant Elastic Modulus) คำนวณได้จากความชันของกราฟความเค้นแตกต่างในแนวแกน -ความเครียดในแนวแกน โดยการลากเส้นตรงจากจุดศูนย์ไปจนถึงจุด 50% ของค่าความเค้นสูงสุด ดังแสดงในรูปที่ 3-3 (a)

2.2) ค่าสัมประสิทธิ์ความยืดหยุ่นแบบสัมผัส, E_t (Tangent Elastic Modulus) คำนวณได้จากความชันของกราฟความเค้นแตกต่างในแนวแกน-ความเครียดในแนวแกน โดยการลากเส้นสัมผัสกับเส้นความเค้น-ความเครียดที่จุด 50% ของค่าความเค้นสูงสุด ดังแสดงในรูปที่ 3-3 (b)

โดย $\varepsilon_a = \Delta L/L$

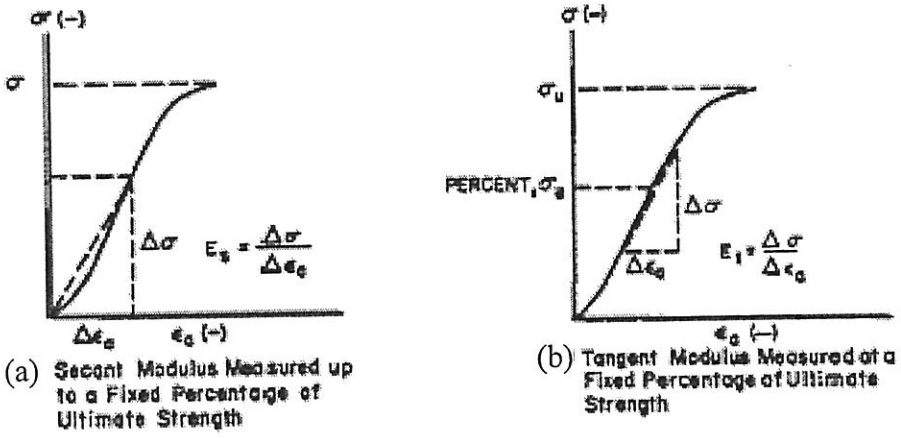
ε_a = ความเค้นในแนวแกน

ΔL = ความยาวหินตัวอย่างที่เปลี่ยนแปลง

L = ความยาวเดิมของหินตัวอย่าง

3) ค่าอัตราส่วนของปัวซ์ซอง, ν (Poisson's Ratio)

ν = - Slope of Axial Curve / Slope of Lateral Curve



(a) Secant Modulus Measured up to a Fixed Percentage of Ultimate Strength

(b) Tangent Modulus Measured at a Fixed Percentage of Ultimate Strength

รูปที่ 3-3 การคำนวณค่าสัมประสิทธิ์ความยืดหยุ่นแบบตัด (E_s) และแบบสัมผัส (E_t)

4) ค่าเกณฑ์การแตกของหิน (Mohr-Coulomb's Failure Criterion)

$$\tau_n = c + \sigma_n \tan \phi_i$$

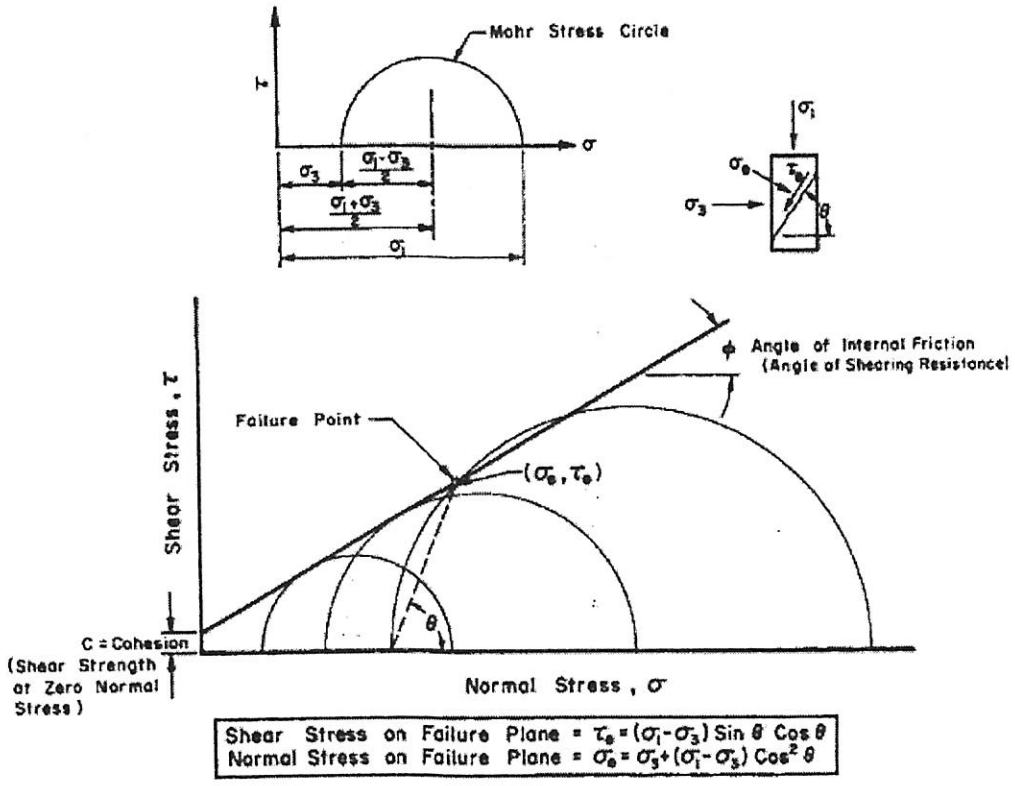
โดย τ_n = ความเค้นเฉือน, ½ $(\sigma_1 - \sigma_3)$

σ_n = ความเค้นตั้งฉาก, ½ $(\sigma_1 + \sigma_3)$

c = ความเค้นยึดติด (cohesion)

ϕ_i = มุมเสียดทานภายใน (Internal Friction Angle)

ค่าความเค้นยึดติด และมุมเสียดทานภายในสามารถหาได้จากการสร้างกราฟความสัมพันธ์ระหว่างความเค้นเฉือน-ความเค้นตั้งฉากในรูปแบบวงกลมของ Mohr (รูปที่ 3-4)



รูปที่ 3-4 การหาค่าความเค้นยึดติด (cohesion) และมุมเสียดทานภายใน (Internal Friction Angle)

ผลการทดสอบ

หมายเลขตัวอย่างหิน..ชนิดหิน..

เตรียมตัวอย่างวันที่..ทดสอบวันที่..

เส้นผ่านศูนย์กลางเฉลี่ย (D)..........(mm) ความยาวเฉลี่ย (L)..............(mm) L/D ratio..............................

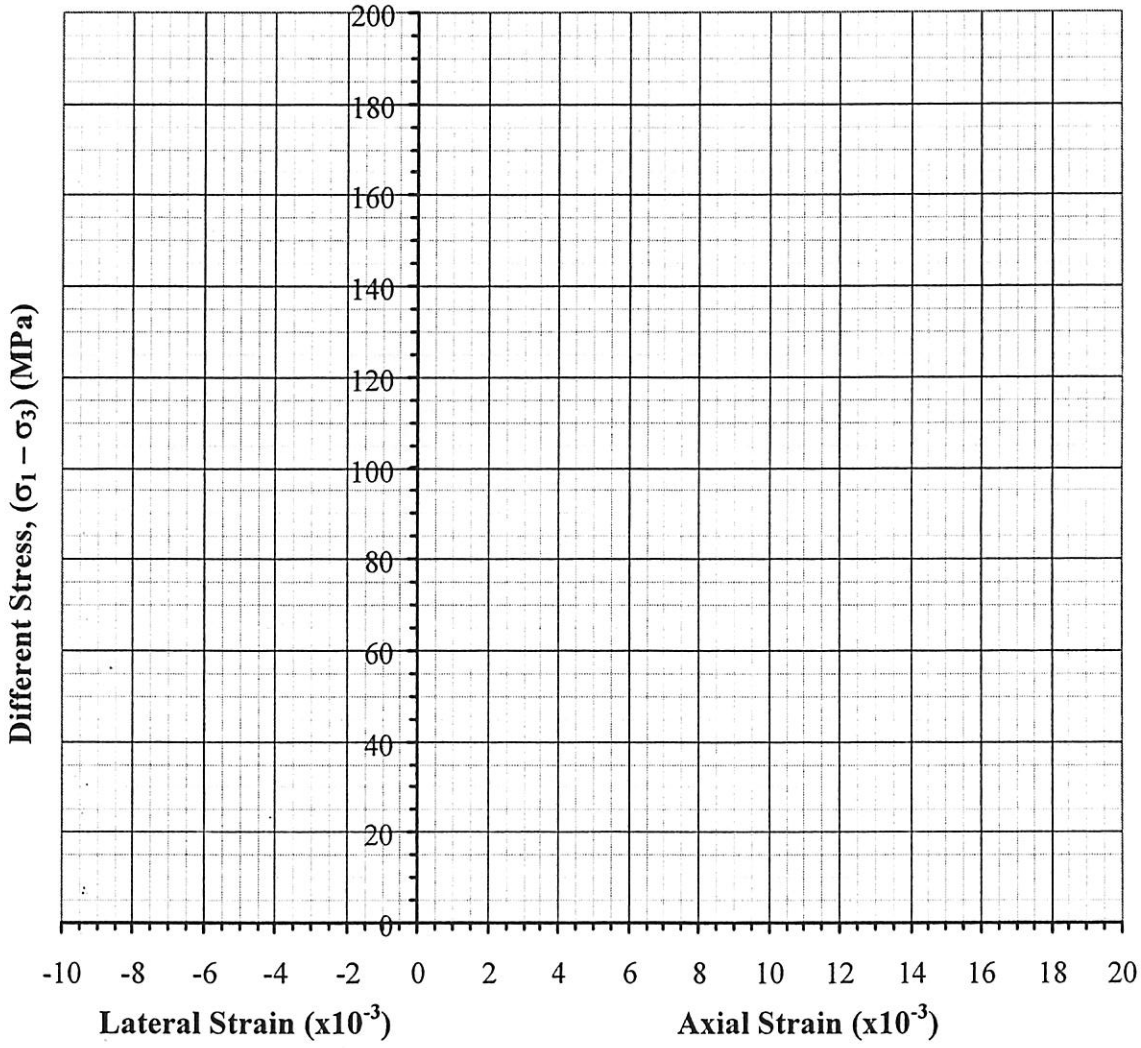
น้ำหนัก..............(g) ความหนาแน่น..............(g/cc)........อุณหภูมิห้องทดสอบ..............(°C)..............

แรงกด	ความเค้น	ความดันล้อมรอบ	การยุบตัวในแนวแกน (Axial Deformation)				การขยายตัวในแนวด้านข้าง (Lateral Deformation)			
P (kN)	σ_1 (MPa)	σ_3 (MPa)	gage 1 (mm)	gage 2 (mm)	ค่าเฉลี่ย (mm)	ความเครียด (mm/mm)	gage 3 (mm)	gage 4 (mm)	ค่าเฉลี่ย (mm)	ความเครียด (mm/mm)

กราฟความเค้น-ความเครียด

หมายเลขตัวอย่างหิน.....

Stress - Strain Curves



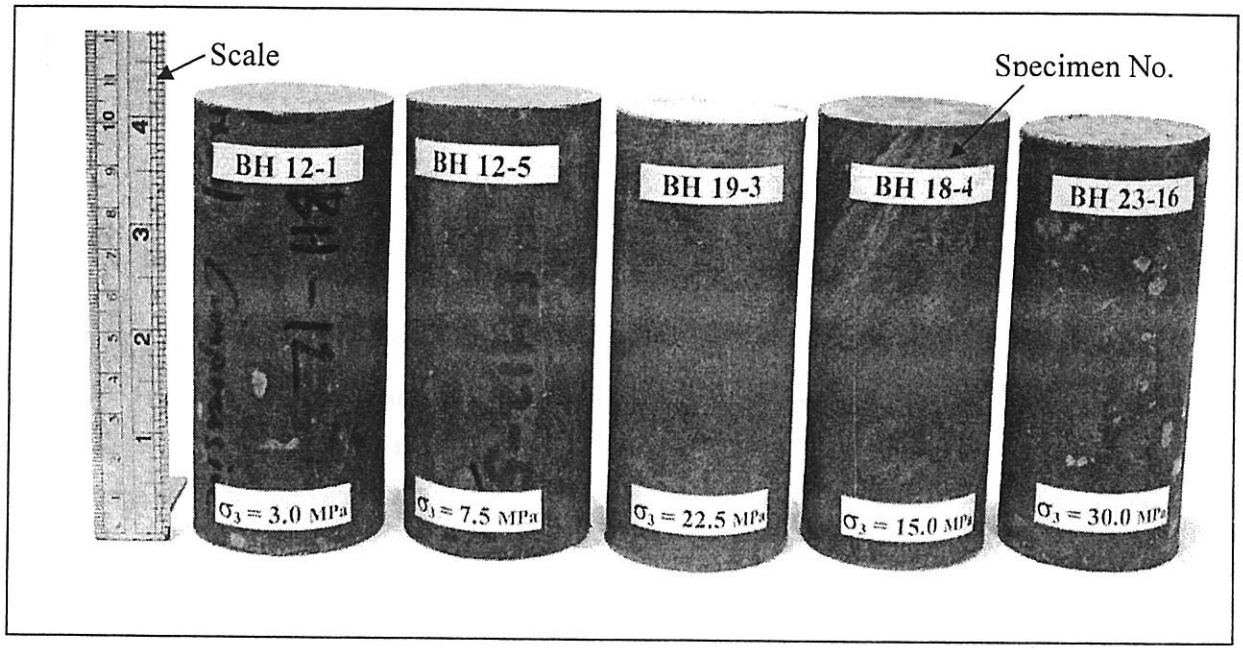
ผลการทดสอบ

หมายเลขหินตัวอย่าง	เส้นผ่านศูนย์กลางเฉลี่ย D (mm)	ความยาวเฉลี่ย L (mm)	L/D	ความหนาแน่น (g/cc)	แรงกดสูงสุด P (kN)	ความดันล้อมรอบ σ_3 (MPa)	ความเค้น σ_1 (MPa)

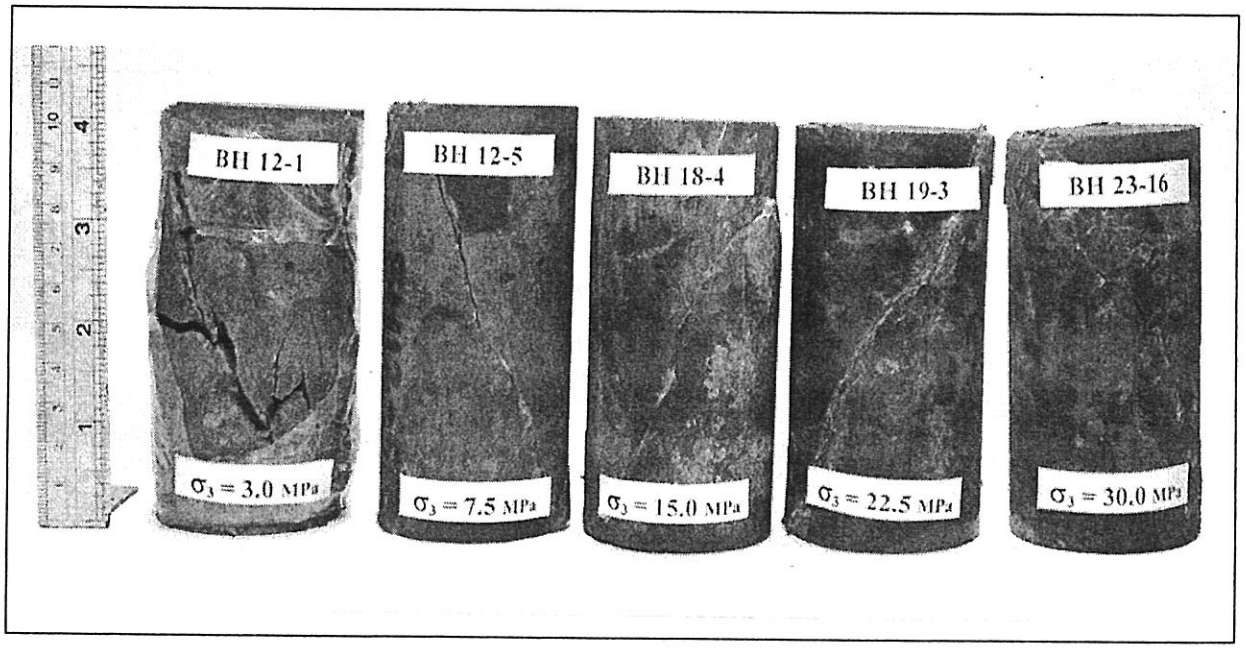
กราฟความสัมพันธ์ระหว่างความเค้นเฉือน-ความเค้นตั้งฉาก ในรูปแบบวงกลมของ Mohr

-- ตัวอย่าง--

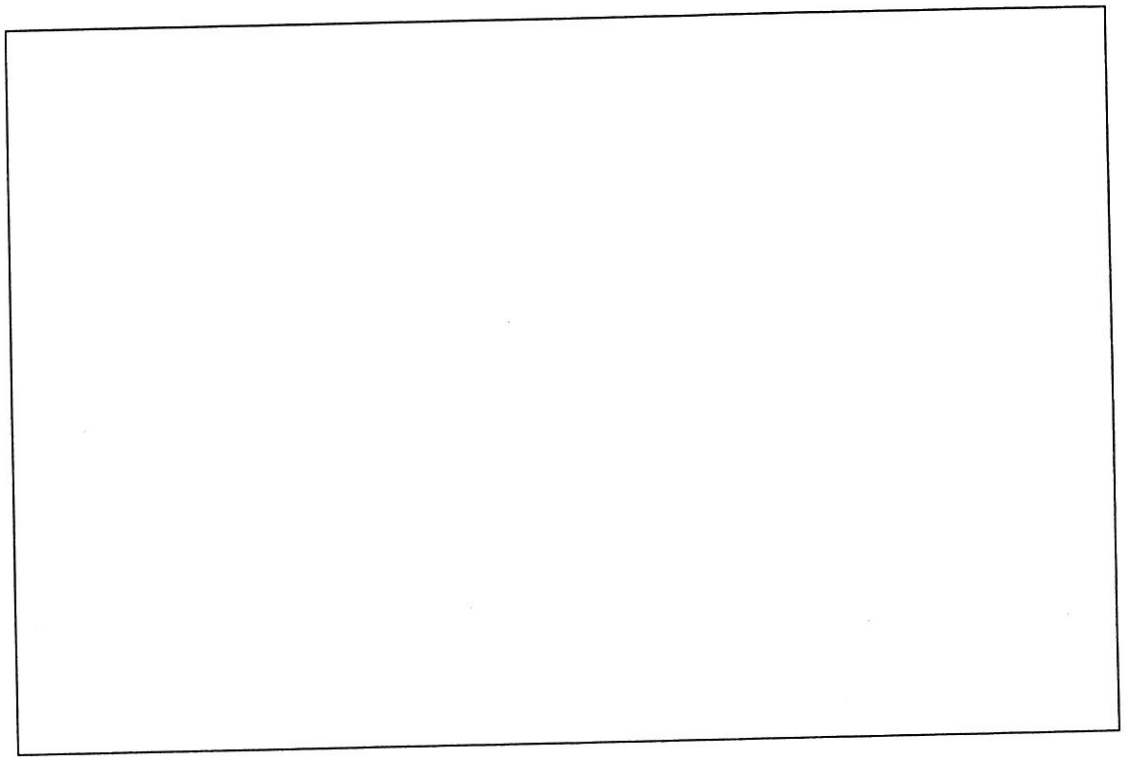
รูปตัวอย่างหินก่อนการทดสอบ



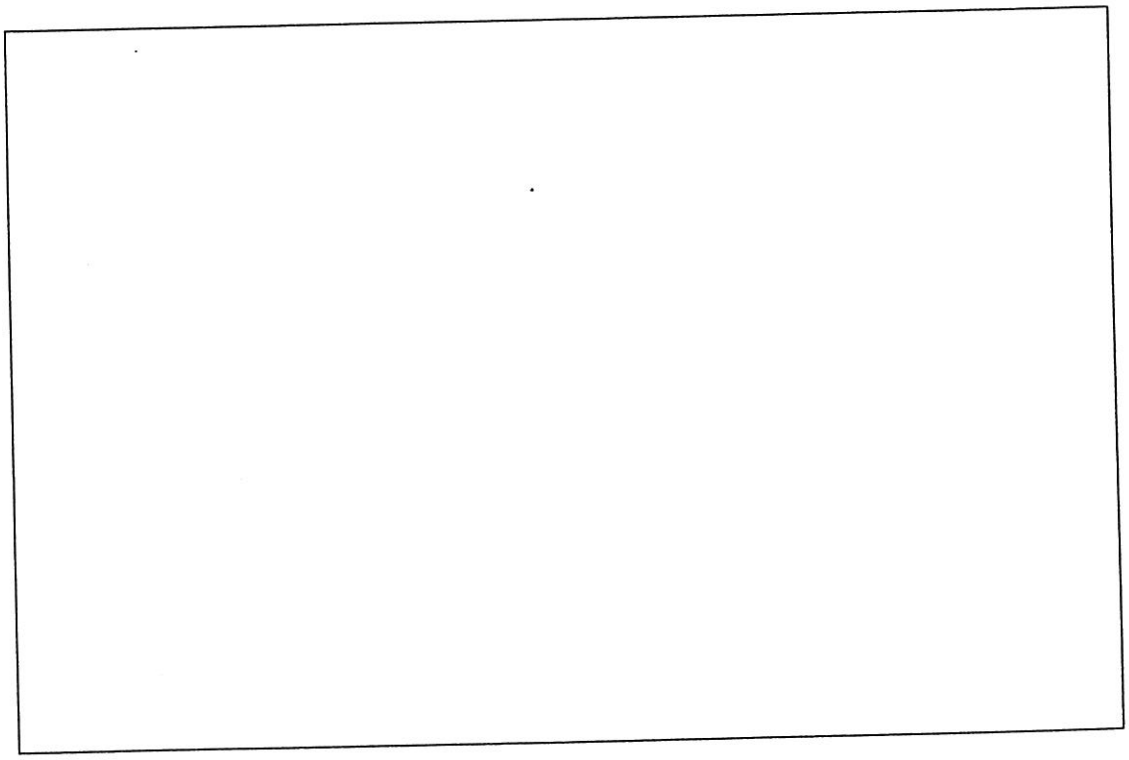
รูปตัวอย่างหินหลังการทดสอบ



รูปตัวอย่างหินก่อนการทดสอบ



รูปตัวอย่างหินหลังการทดสอบ



วิจารณ์ผลการทดสอบ

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สรุปการทดสอบ

1) ค่าความเค้นกดสูงสุดในสามแกน, (Triaxial Compressive Strength)

หมายเลขตัวอย่าง..... σ_1 = ... MPa, และσ_3 = ... MPa

หมายเลขตัวอย่าง..... σ_1 = ... MPa, และσ_3 = ... MPa

หมายเลขตัวอย่าง..... σ_1 = ... MPa, และσ_3 = ... MPa

หมายเลขตัวอย่าง..... σ_1 = ... MPa, และσ_3 = ... MPa

หมายเลขตัวอย่าง..... σ_1 = ... MPa, และσ_3 = ... MPa

2) ค่าสัมประสิทธิ์ความยืดหยุ่น, E (Elastic Modulus)

2.1) ค่าสัมประสิทธิ์ความยืดหยุ่นแบบตัด, E_s (Secant Elastic Modulus)

หมายเลขตัวอย่าง..... = ... GPa

หมายเลขตัวอย่าง..... = ... GPa

หมายเลขตัวอย่าง..... = ... GPa

หมายเลขตัวอย่าง..... = ... GPa

หมายเลขตัวอย่าง..... = ... GPa

ค่าเฉลี่ย (Average) = ... GPa

ค่าเบี่ยงเบนมาตรฐาน (S.D.) = ... GPa

2.2) ค่าสัมประสิทธิ์ความยืดหยุ่นแบบสัมผัส, E_t (Tangent Elastic Modulus)

หมายเลขตัวอย่าง..... = ... GPa

หมายเลขตัวอย่าง..... = ... GPa

หมายเลขตัวอย่าง..... = ... GPa

หมายเลขตัวอย่าง..... = ... GPa

หมายเลขตัวอย่าง..... = ... GPa

ค่าเฉลี่ย (Average) = ... GPa

ค่าเบี่ยงเบนมาตรฐาน (S.D.) = ... GPa

3) ค่าอัตราส่วนของปัวซ์ซอง, ν (Poisson's Ratio)

หมายเลขตัวอย่าง..... = ...

หมายเลขตัวอย่าง..... = ...

หมายเลขตัวอย่าง..... = ...

หมายเลขตัวอย่าง..... = ...

หมายเลขตัวอย่าง..... = ...

ค่าเฉลี่ย (Average) = ...

ค่าเบี่ยงเบนมาตรฐาน (S.D.) = ...

4) ค่าเกณฑ์การแตกของหิน (Mohr-Coulomb's Failure Criterion)

ความเค้นยึดติด (cohesion), c = ...

มุมเสียดทานภายใน (Internal Friction Angle), ϕ_i = ...

ปฏิบัติการที่ 4

การทดสอบความเค้นดึงแบบบราซิล

วัตถุประสงค์การทดสอบ

เพื่อหาค่าความเค้นดึงแบบบราซิลหรือค่าความเค้นดึงแบบแยก (Brazilian or Splitting Tensile Strength) ของหินตัวอย่าง

มาตรฐานการทดสอบ

ASTM D 3967 – 05 และ ISRM Suggested Methods

เครื่องมือการทดสอบ

1) เครื่องทดสอบแรงกด (Loading Machine)

2) Flat Bearing Blocks หรือ Curved Bearing Blocks

3) เวอร์เนีย อ่านละเอียดอย่างน้อย 0.01 นิ้ว

ตัวอย่างหิน

เป็นแผ่นหินทรงกระบอก (Circular Disk Specimen) มีขนาดเส้นผ่านศูนย์กลางไม่น้อยกว่า 50 มิลลิเมตร (ASTM) หรือไม่น้อยกว่า 54 มิลลิเมตร (ISRM) อัตราส่วนระหว่างความหนาต่อเส้นผ่านศูนย์กลาง (t/D) อยู่ระหว่าง 0.2 – 0.75 (ASTM) หรือ 0.5 (ISRM) โดยตัวอย่างหินจัดเตรียมตามมาตรฐาน ASTM D 3967 – 05 อย่างน้อยจำนวน 10 ตัวอย่าง

วิธีการทดสอบ

1) เมื่อหินที่จัดเตรียมเสร็จแล้วให้ใช้ปากกาเขียนตามแนวเส้นผ่านศูนย์กลางทั้งสองด้านเพื่อเป็นแนวอ้างอิง (รูปที่ 4-1)

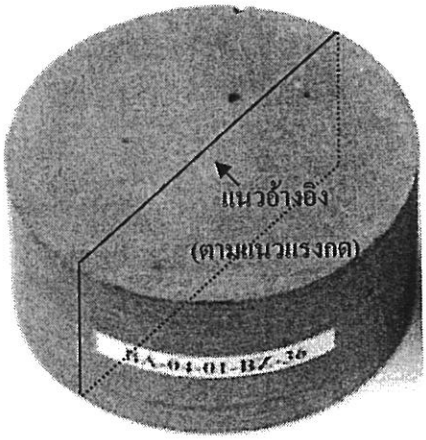
2) ติดตั้งตัวอย่างหินใน Flat Bearing Blocks หรือ Curved Bearing Blocks (รูปที่ 4-2) โดยให้ตัวอย่างหินอยู่ในแนวเส้นผ่านศูนย์กลางและให้แนวอ้างอิงอยู่กลางแนวกด

3) ใช้เวอร์เนียวัดเส้นผ่านศูนย์กลางความละเอียดอย่างน้อย 0.01 นิ้ว อย่างน้อย 3 ค่า (ให้ผ่านตามแนวอ้างอย่างน้อย 1 ค่า) แล้วใช้ค่าเฉลี่ย

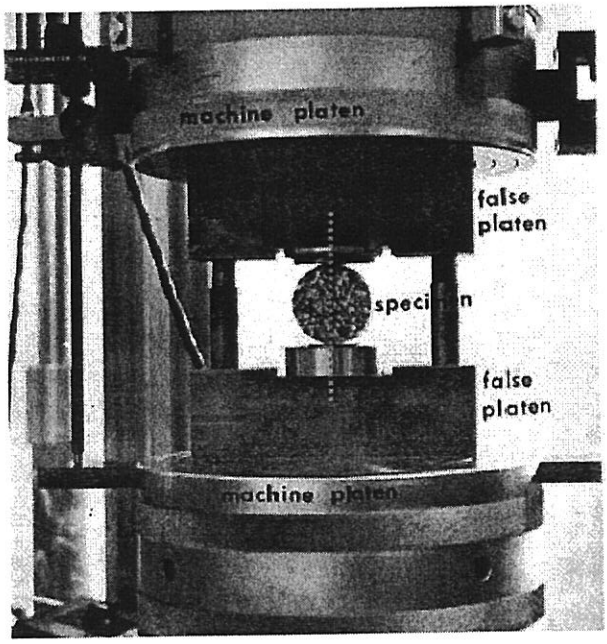
4) ใช้เวอร์เนียวัดความหนาความละเอียดอย่างน้อย 0.01 นิ้ว อย่างน้อย 3 ค่า (ผ่านจุดศูยน์กลางแผ่นหินอย่างน้อย 1 ค่า) แล้วใช้ค่าเฉลี่ย

5) ให้แรงกดในแนวแกนด้วยอัตราเร็วคงที่ประมาณ 0.05 – 0.35 MPa/second หรือให้หินวิบัติ (แตก) ภายใน 1 – 10 นาที (ASTM)

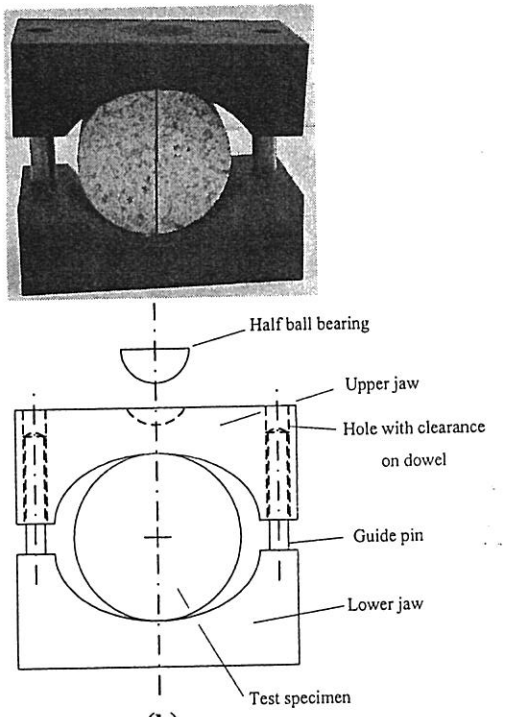
6) บันทึกค่าแรงกดสูงสุดที่หินวิบัติ และวาดรูปแนวการวิบัติหรือบันทึกภาพตัวอย่างหิน



รูปที่ 4-1 สร้างแนวอ้างอิงตามแนวเส้นผ่านศูนย์กลางของตัวอย่างหิน



(a)



(b)

รูปที่ 4-2 หินตัวอย่างติดตั้งใน (a) Flat Bearing Blocks หรือ (b) Curved Bearing Blocks โดยให้อย่างกึ่งกลางแนวการกด

การคำนวณ

ค่าความเค้นดึงแบบบราซิลหรือค่าความเค้นดึงแบบแยก (Brazilian or Splitting Tensile Strength)

$$\sigma_B \text{ หรือ } \sigma_t = 2P/\pi tD$$

โดย σ_B หรือ σ_t = ค่าความเค้นดึงแบบบราซิลหรือค่าความเค้นดึงแบบแยก (MPa หรือ psi)

P = แรงกดสูงที่สุดวัดที่จุดวิบัติ (N หรือ lbf)

t = ความหนาของหินตัวอย่าง (mm หรือ in.)

D = เส้นผ่านศูนย์กลางของหินตัวอย่าง (mm หรือ in.)

ผลการทดสอบ

ชนิดหิน.....

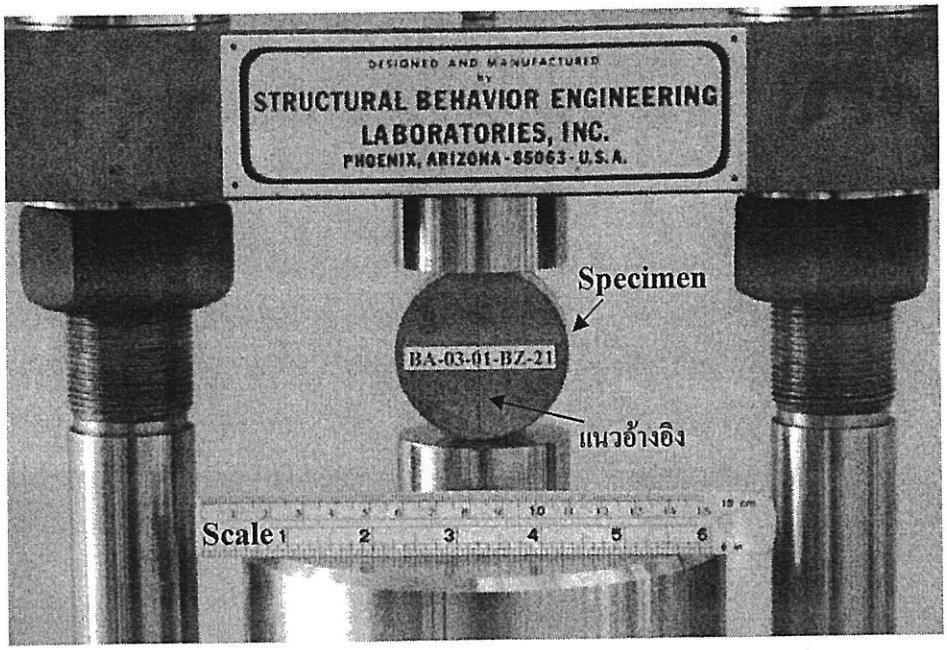
เตรียมตัวอย่างวันที่..... ทดสอบวันที่.....

อุณหภูมิห้องทดสอบ..... (°C).....

หมายเลขหินตัวอย่าง	เส้นผ่านศูนย์กลางเฉลี่ย D (mm)	ความหนาเฉลี่ย t (mm)	t/D	ความหนาแน่น (g/cc)	แรงกดสูงสุด P (N)	ค่าความเค้นดึงแบบบราซิล σ_B (MPa)

-- ตัวอย่าง--

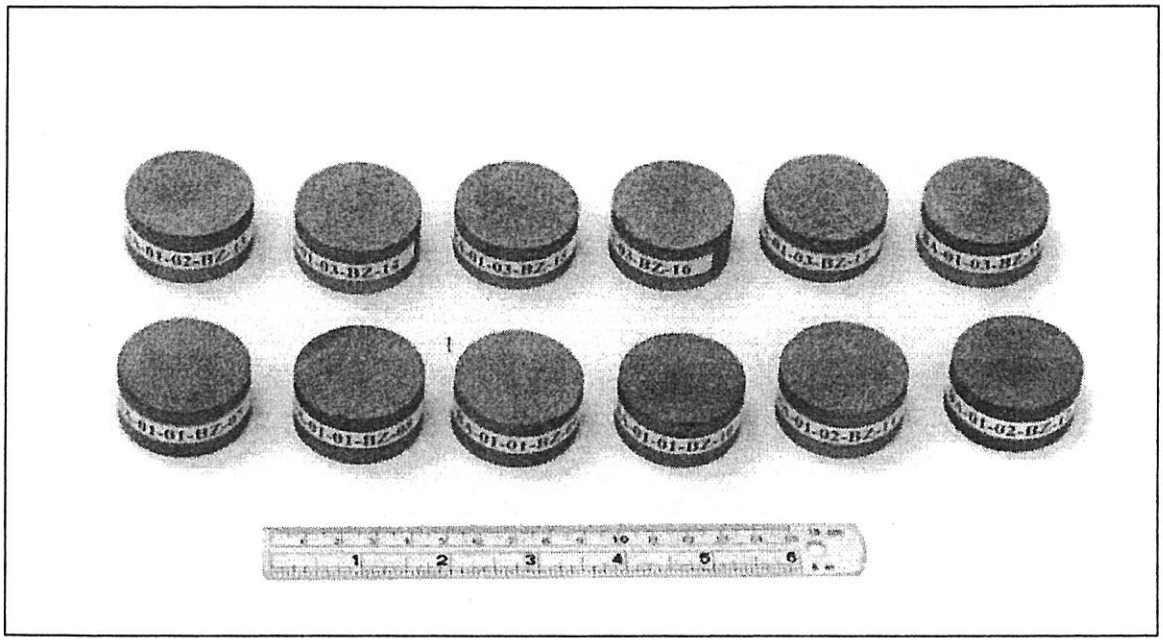
รูปตัวอย่างหินก่อนการทดสอบ



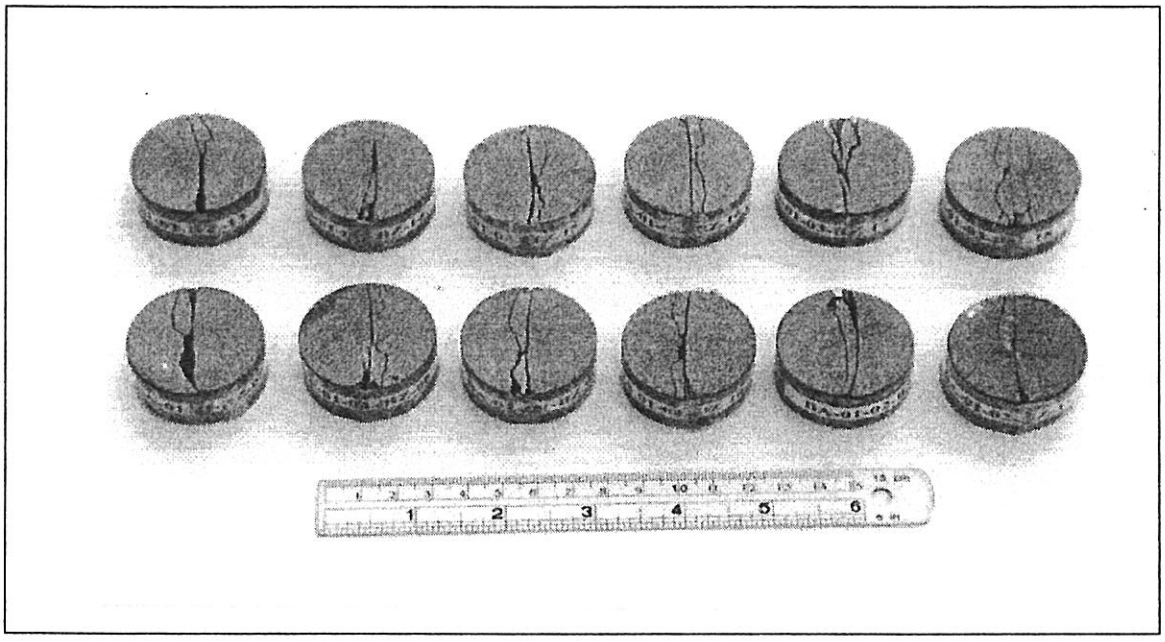
รูปตัวอย่างหินหลังการทดสอบ

-- ตัวอย่าง--

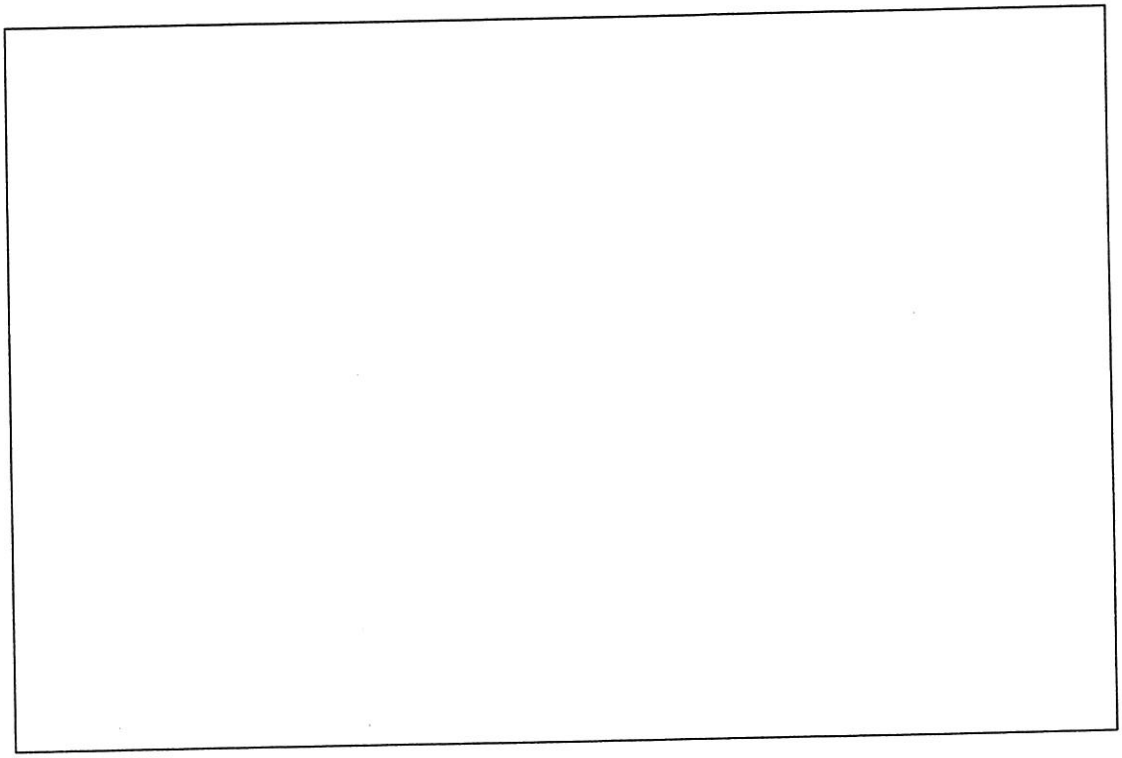
รูปตัวอย่างหินก่อนการทดสอบ



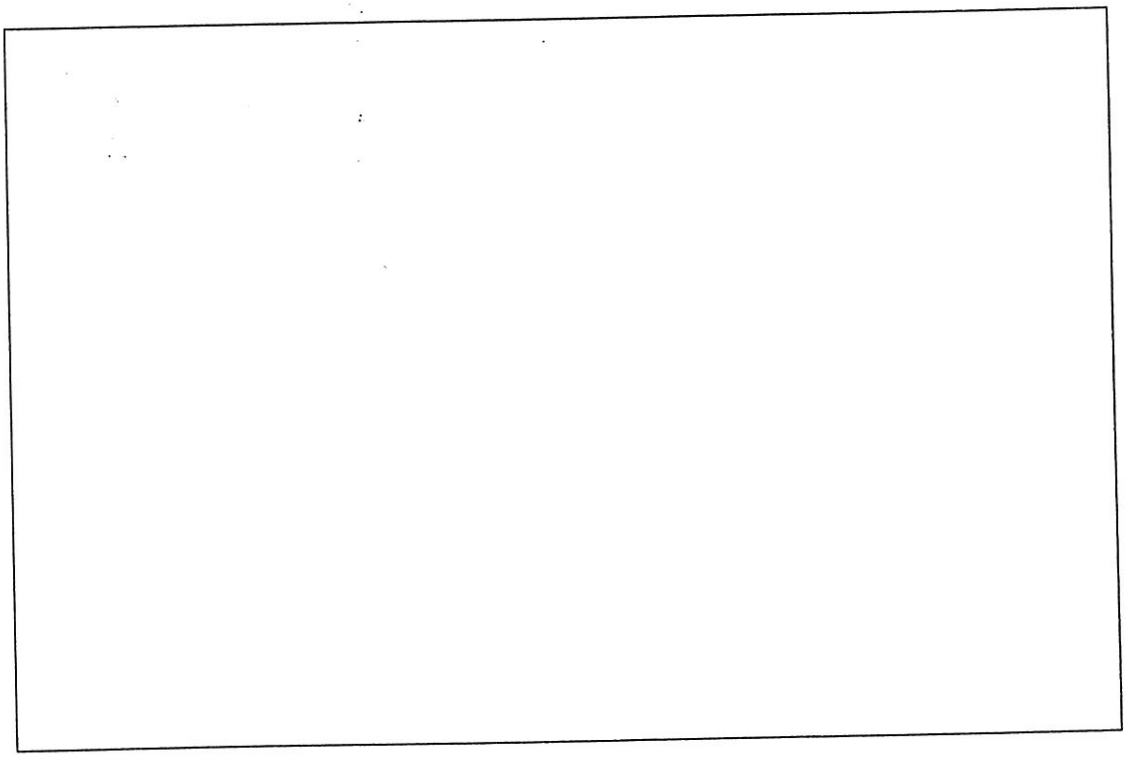
รูปตัวอย่างหินหลังการทดสอบ



รูปตัวอย่างหินก่อนการทดสอบ



รูปตัวอย่างหินหลังการทดสอบ



วิจารณ์ผลการทดสอบ

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สรุปการทดสอบ

ค่าความเค้นดึงแบบบราซิลหรือค่าความเค้นดึงแบบแยก, σ_B (Brazilian or Splitting Tensile Strength)

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

ค่าเฉลี่ย (Average) = ... MPa

ค่าเบี่ยงเบนมาตรฐาน (S.D.) = ... MPa

ปฏิบัติการที่ 5

การทดสอบความเค้นเฉือน

วัตถุประสงค์การทดสอบ

เพื่อหาค่าความเค้นเค้นเฉือนสูงสุด (Shear Strength) ของหินตัวอย่าง

มาตรฐานการทดสอบ

ASTM D 5607 – 02 (Reapproved 2006) และ ISRM Suggested Methods

เครื่องมือการทดสอบ

1) เครื่องทดสอบแรงกด (Direct Shear Machine) รูปที่ 5-1 และ 5-2 ประกอบด้วย

-ชุดให้แรงเฉือน (Shear Force)

-ชุดให้แรงกดตั้งฉากคงที่ (Constant Normal Force)

2) มาตรวัดการเคลื่อนตัว (Dial Gages) ความละเอียดอย่างน้อย 0.05 mm และช่วงชักยาวกว่า 20 mm (ISRM)

3) ปูนซีเมนต์ยิปซัมชนิดแข็งพิเศษ (High Strength Gypsum Cement)

ตัวอย่างหิน

เก็บหินตัวอย่างที่มีระนาบรอยแตก วิธีการเก็บให้รบกวนบริเวณระนาบรอยแตกให้น้อยที่สุด รูปร่างและขนาดให้จัดเตรียมด้วยการตัดแต่งให้ได้ตามแสดงอยู่ในรูปที่ 5-3 และระนาบรอยแตกของหินตัวอย่างควรมีพื้นที่อย่างน้อย 1900 mm^2 (หรือ 3 $in.^3$)

วิธีการทดสอบ

1) นำตัวอย่างติดตั้งลงในเครื่องทดสอบแรงเฉือน (ตามรูปที่ 5-4) โดยใช้ปูนซีเมนต์ยิปซัมชนิดแข็งพิเศษเป็นตัวยึดติด เริ่มต้นจากติดด้านล่างก่อนต้องให้แนวของระนาบรอยแตกขนานกับแนวของแรงเฉือน เมื่อปูนซีเมนต์เริ่มจะแข็งตัวพอ

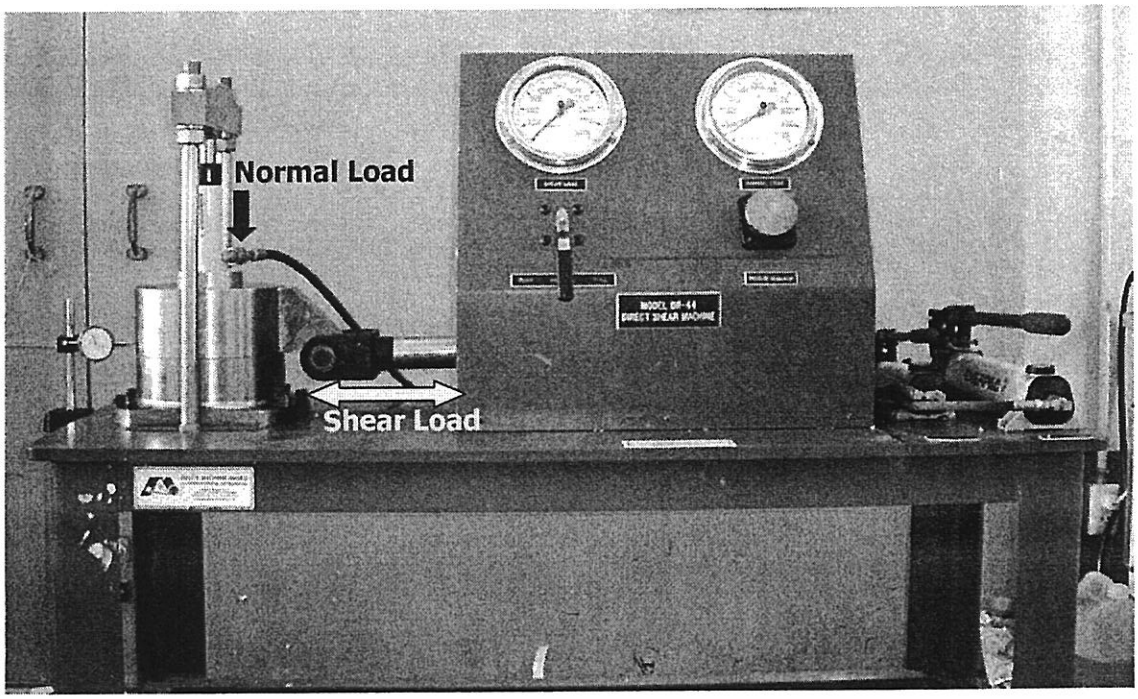
2) นำแบบหล่อส่วนบนติดตั้งพร้อมใช้ปูนซีเมนต์ใส่จนเต็มแล้วฝาปิดด้านบนครอบ รอจนปูนซีเมนต์แห้งจนได้กำลังสูงที่สุด ประกอบชุดให้แรงกดตั้งฉากคงที่ (Constant Normal Force) และชุดให้แรงเฉือน (Shear Force)

3) ติดตั้งมาตรวัดการเคลื่อนตัว (Dial Gages) ในแนวแกนขนานกับแรงเฉือน พร้อมตั้งให้อ่านที่ศูนย์

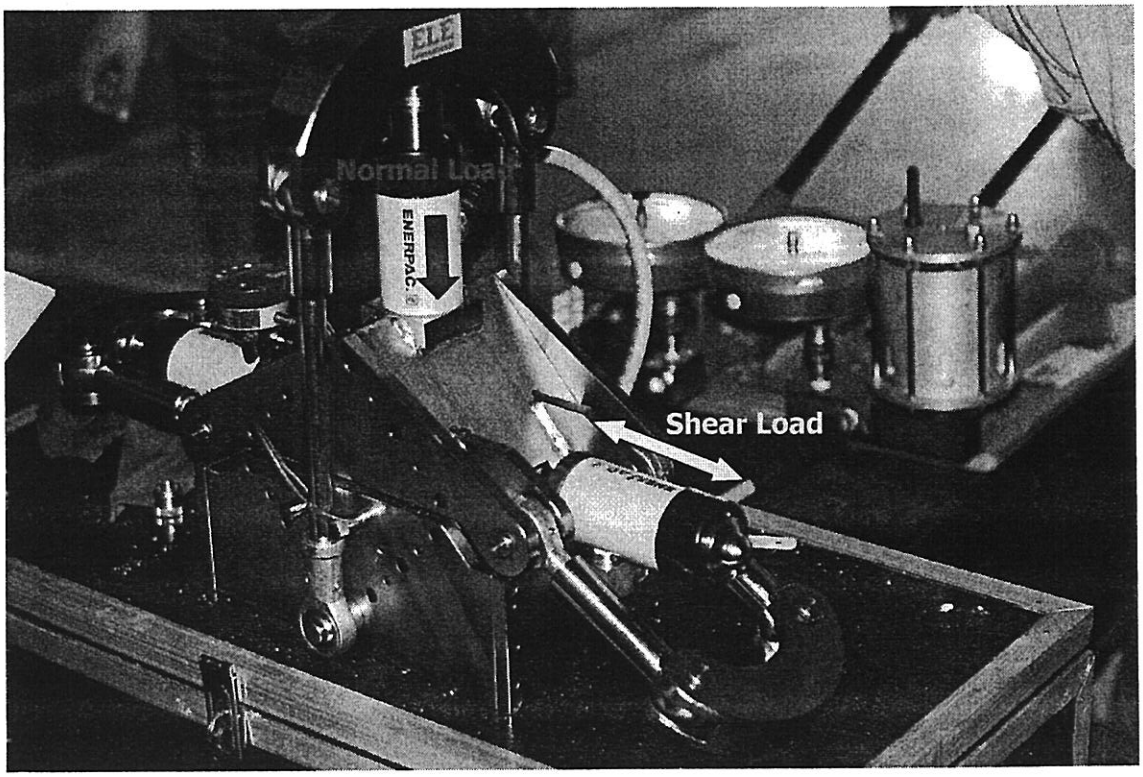
4) ให้แรงกดตั้งฉากคงที่ตามระดับที่ต้องการและรักษาระดับแรงกดให้คงที่ตลอดการทดสอบ

5) ให้แรงเฉือนพร้อมบันทึกค่าแรงเฉือนที่เพิ่มขึ้น และค่าการเคลื่อนตัว (รูปที่ 5-5)

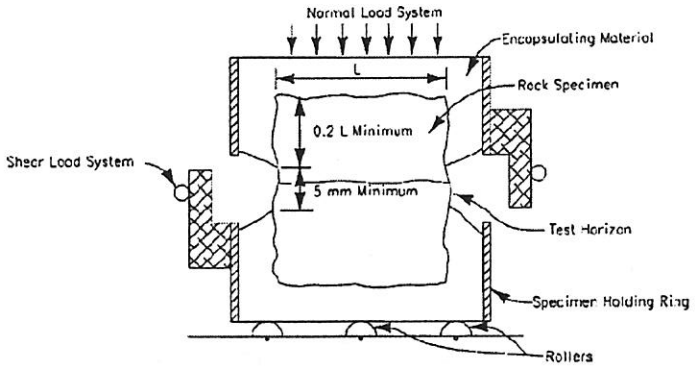
6) บันทึกภาพตัวอย่างหินหลังจากถูกแรงเฉือน



รูปที่ 5-1 เครื่องทดสอบแรงเฉือนสูงสุดแบบใช้ในห้องปฏิบัติการ (Laboratory Direct Shear Tester)

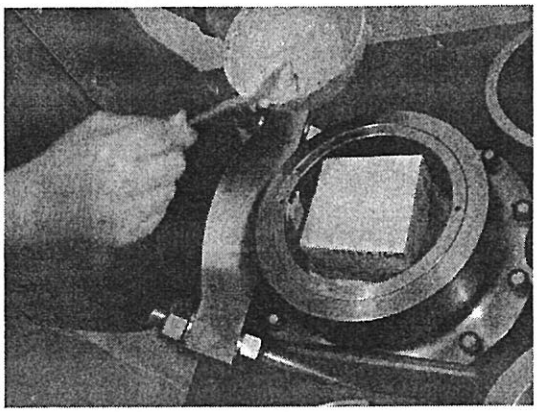


รูปที่ 5-2 เครื่องทดสอบแรงเฉือนสูงสุดแบบเคลื่อนย้ายไปทดสอบในภาคสนามได้ (Portable Direct Shear Tester)

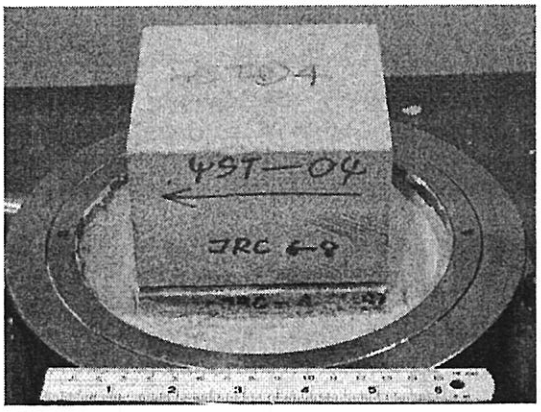


รูปที่ 5-3 ข้อกำหนดขนาดของรูปร่างและการติดตั้งตัวอย่างหินในเครื่องทดสอบ

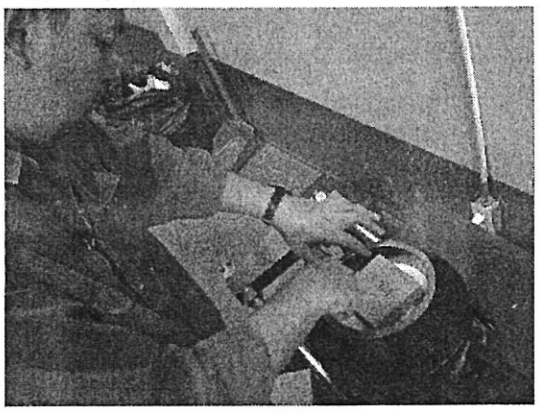
(a)



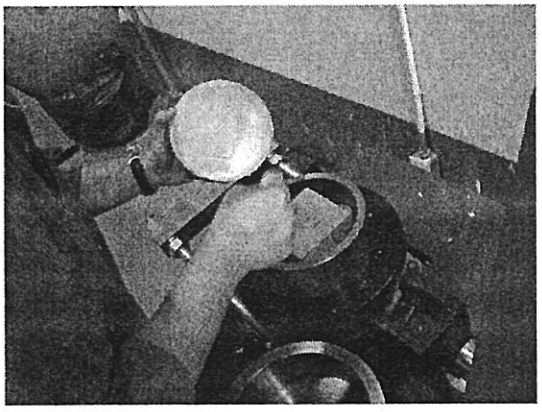
(b)



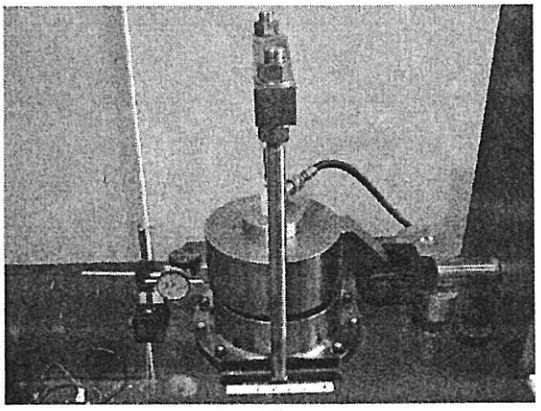
(c)



(d)

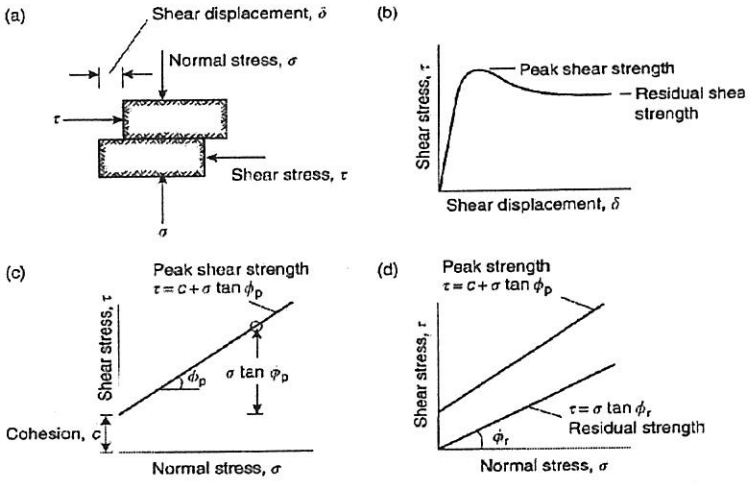


(e)



(f)

รูปที่ 5-4 ขั้นตอนการติดตั้งหินตัวอย่างลงในเครื่องทดสอบแรงเฉือน (a-f)



รูปที่ 5-5 รูปแบบการนำเสนอผลการทดสอบระหว่างความเค้นเฉือนและความเค้นตั้งฉากโดยใช้กฎของ Coulomb

การคำนวณ

1) ความเค้นตั้งฉาก (Normal Stress)

$$\sigma_n = P_n/A$$

โดย P_n = แรงกดตั้งฉากกับระนาบรอยแตกของหินตัวอย่าง (Normal Force)

A = พื้นที่ระนาบรอยแตกของหินตัวอย่าง

2) ความเค้นเฉือน (Shear Stress)

$$\tau = P_s/A$$

โดย P_s = แรงเฉือนที่ขนานกับระนาบรอยแตกของหินตัวอย่าง (Shear Force)

A = พื้นที่ระนาบรอยแตกของหินตัวอย่าง

3) กฎของ Coulomb

$$\tau = c_p + \sigma_n \tan \phi_p$$

และ

$$\tau = \sigma_n \tan \phi_r$$

โดย c_p = แรงยึดติดสุดยอด (Peak Cohesion)

ϕ_p = มุมเสียดทานสำหรับความเค้นเฉือนสุดยอด (Peak Friction Angle)

ϕ_r = มุมเสียดทานสำหรับความเค้นเฉือนคงเหลือ (Residual Friction Angle)

ผลการทดสอบ

ชนิดหิน..

เตรียมตัวอย่างวันที่...ทดสอบวันที่...

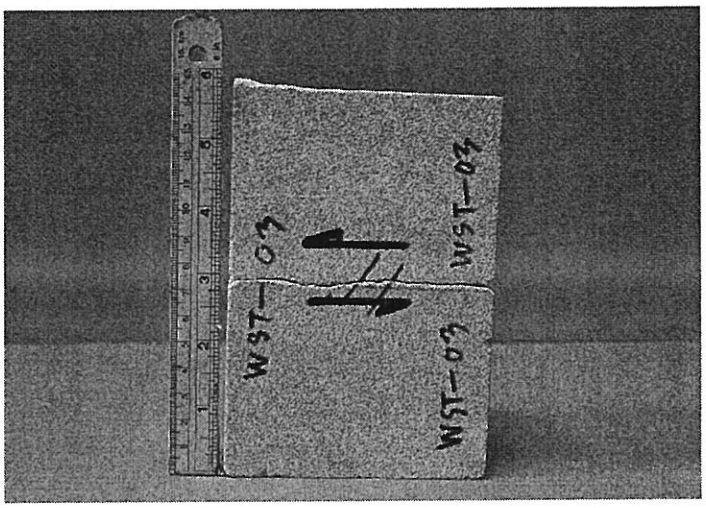
พื้นที่ระนาบรอยแตกที่ตั้งฉากกับแรงกดคงที่ (A)...

น้ำหนัก.................(g) ความหนาแน่น...................(g/cc).........อุณหภูมิห้องทดสอบ.................(°C)...............

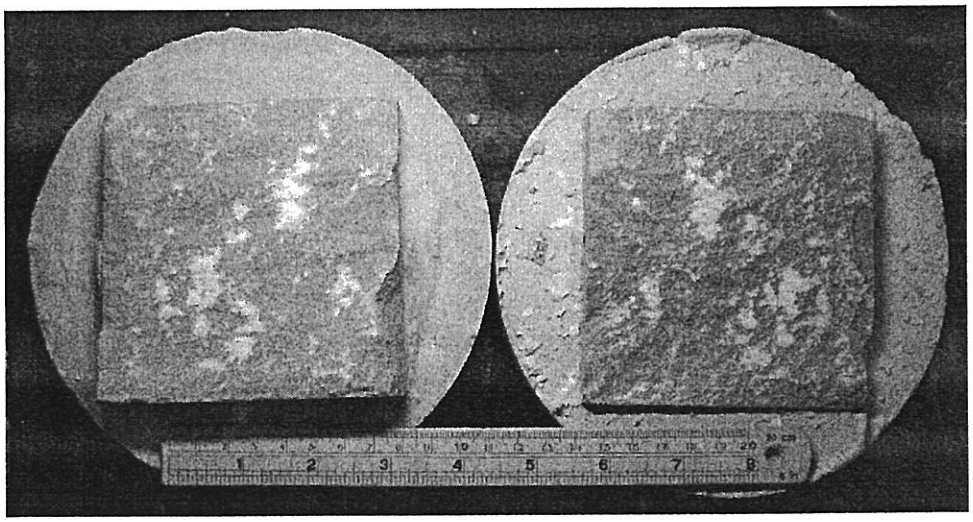
หมายเลขหินตัวอย่าง		หมายเลขหินตัวอย่าง		หมายเลขหินตัวอย่าง		หมายเลขหินตัวอย่าง	
แรงกดตั้งฉากคงที่ = ... (lbs)		แรงกดตั้งฉากคงที่ = ... (lbs)		แรงกดตั้งฉากคงที่ = ... (lbs)		แรงกดตั้งฉากคงที่ = ... (lbs)	
แรงเฉือน (lbs)	การเคลื่อนตัว (mm)	แรงเฉือน (lbs)	การเคลื่อนตัว (mm)	แรงเฉือน (lbs)	การเคลื่อนตัว (mm)	แรงเฉือน (lbs)	การเคลื่อนตัว (mm)

-- ตัวอย่าง--

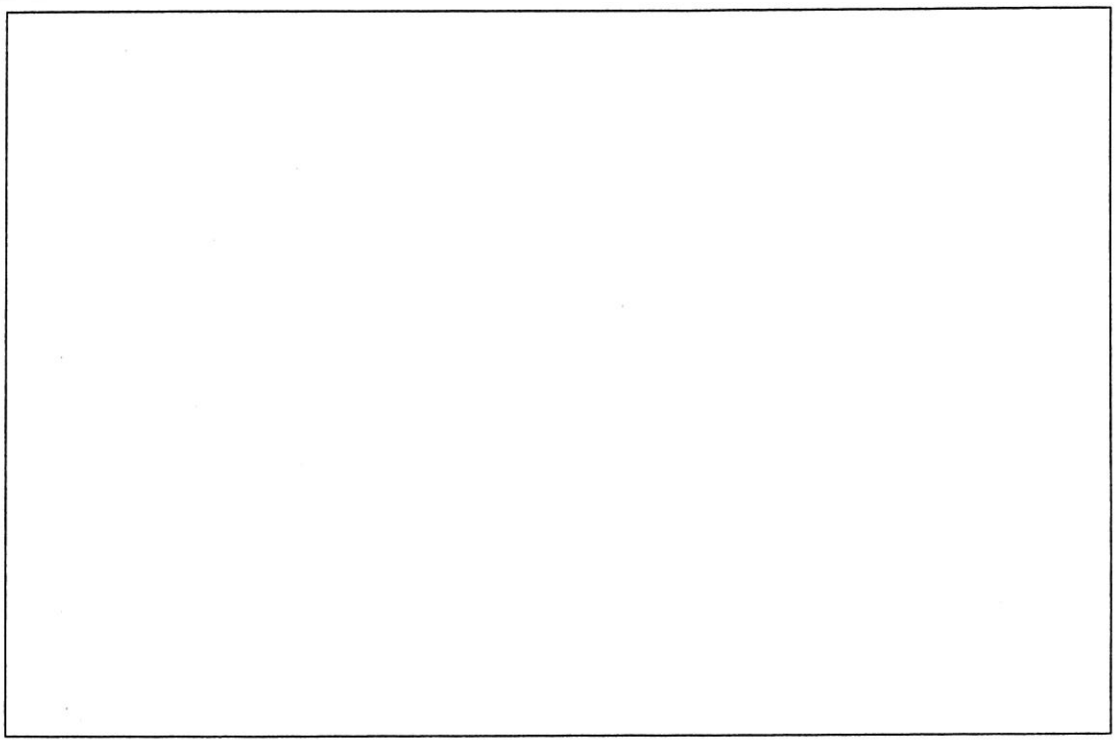
รูปตัวอย่างก่อนการทดสอบ



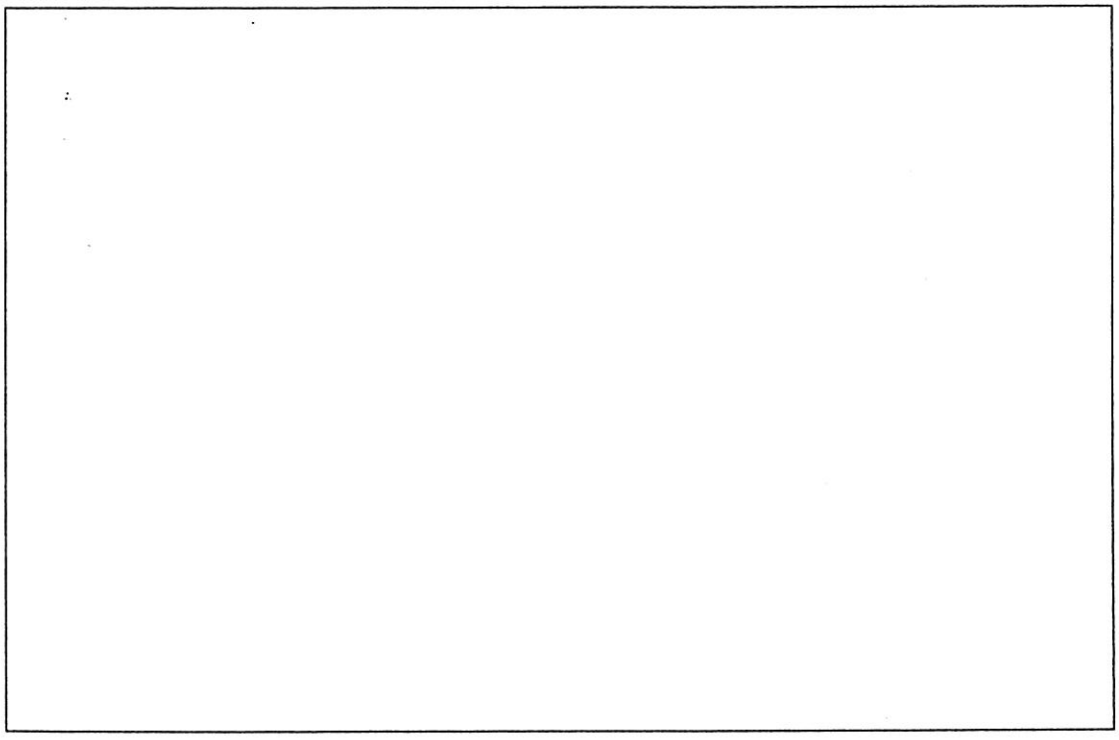
รูปตัวอย่างหินหลังการทดสอบ



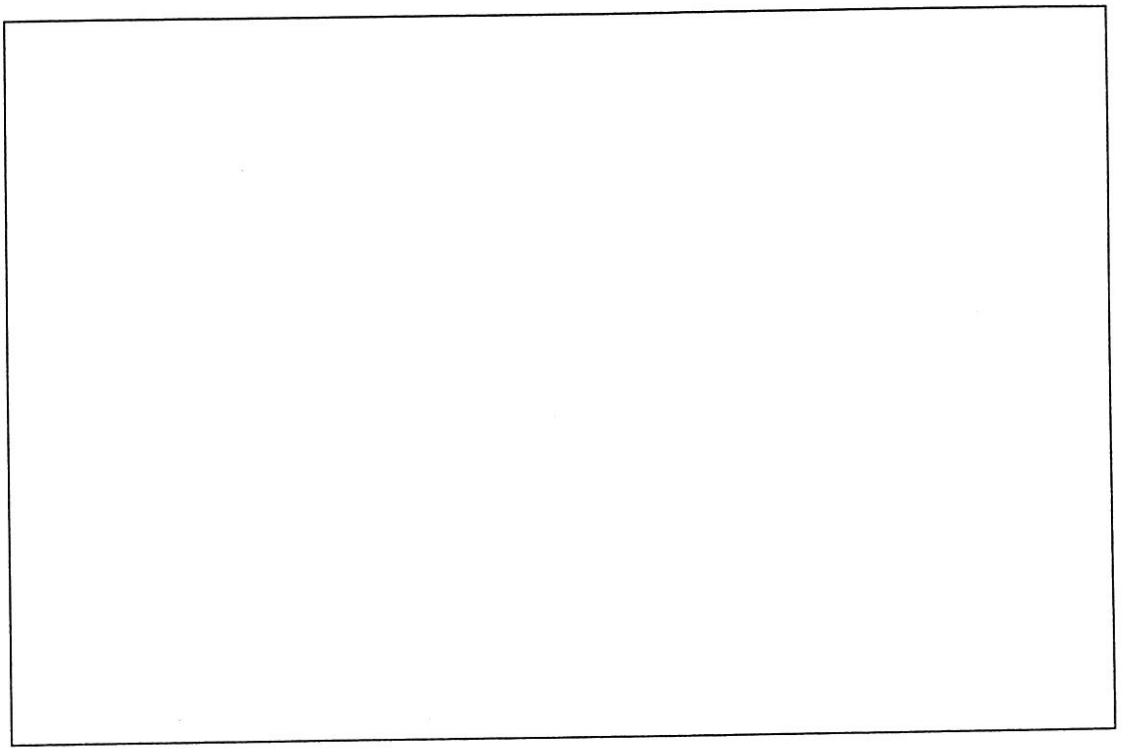
รูปตัวอย่างหินก่อนการทดสอบ



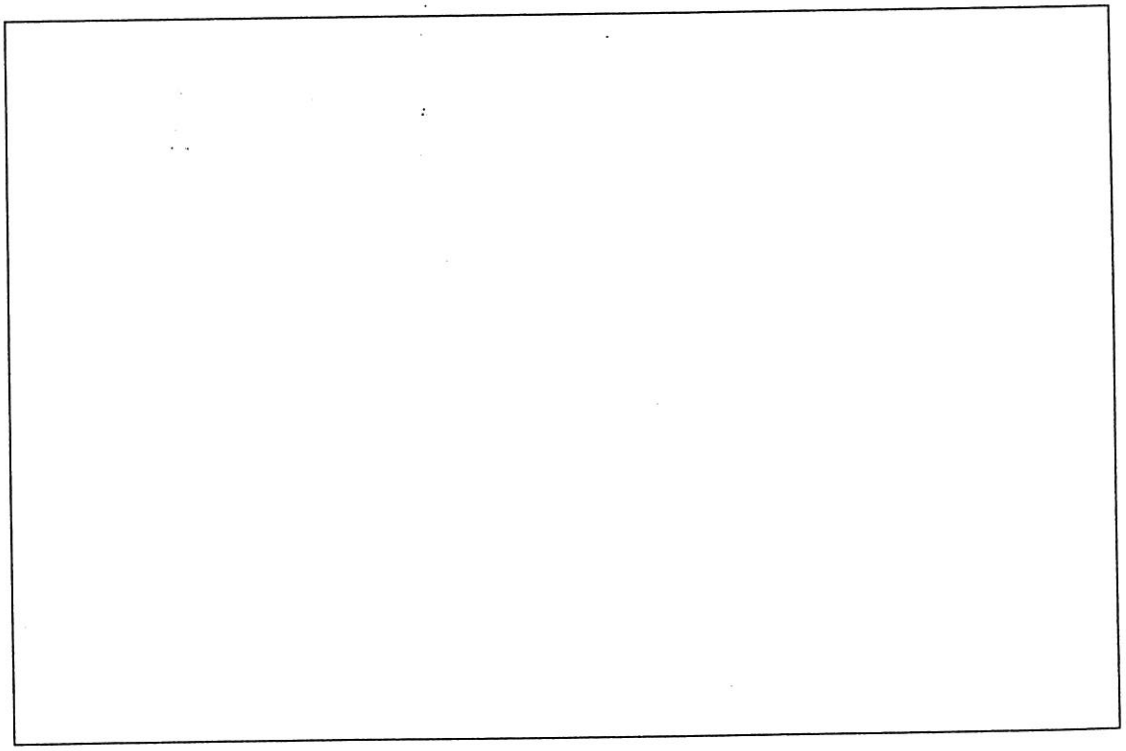
รูปตัวอย่างหินหลังการทดสอบ



กราฟความเค้นเฉือน-ความเคลื่อนตัว



กราฟความเค้นเฉือน-ความเค้นตั้งฉาก



วิจารณ์ผลการทดสอบ

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สรุปการทดสอบ

ตามกฎของ Coulomb

1) แรงยึดติดสูดยอด (Peak Cohesion)

c_p = ...

2) มุมเสียดทานสำหรับความเค้นฉือนสุดยอด (Peak Friction Angle)

ϕ_p = ...

3) มุมเสียดทานสำหรับความเค้นฉือนคงเหลือ (Residual Friction Angle)

ϕ_r = ...

ปฏิบัติการที่ 6

การทดสอบดัชนีจุดกด

วัตถุประสงค์การทดสอบ

เพื่อหาค่าดัชนีจุดกด (Point Load Strength Index) และประเมินหาค่าความเค้นกดสูงสุดในแกนเดียวของหินตัวอย่าง

มาตรฐานการทดสอบ

ASTM D 5731 – 07 และ ISRM Suggested Methods

เครื่องมือการทดสอบ

1) เครื่องทดสอบดัชนีจุดกด (Point Load Tester)

2) เวอร์เนีย อ่านละเอียดอย่างน้อย 0.01 นิ้ว

ตัวอย่างหิน

หินตัวอย่างที่นำมาทดสอบสามารถแบ่งเป็น 4 แบบการทดสอบ คือ

1) ทดสอบแบบตามแนวเส้นผ่านศูนย์กลาง (Diametral Core Test)

2) ทดสอบแบบตามแนวแกน (Axial Test)

3) ทดสอบแบบทรงสี่เหลี่ยม (Block Test)

4) ทดสอบแบบรูปทรงไม่เป็นเรขาคณิต (Irregular Lump Test)

ข้อกำหนดของรูปร่างแบบต่าง ๆ ได้แสดงไว้ในรูปที่ 6-1 โดยหินตัวอย่างที่เป็นหินทรงกระบอกใช้อย่างน้อยจำนวน 10 ตัวอย่าง แต่ถ้าหินตัวอย่างมีรูปทรงไม่เป็นเรขาคณิตใช้อย่างน้อยจำนวน 20 ตัวอย่าง

วิธีการทดสอบ

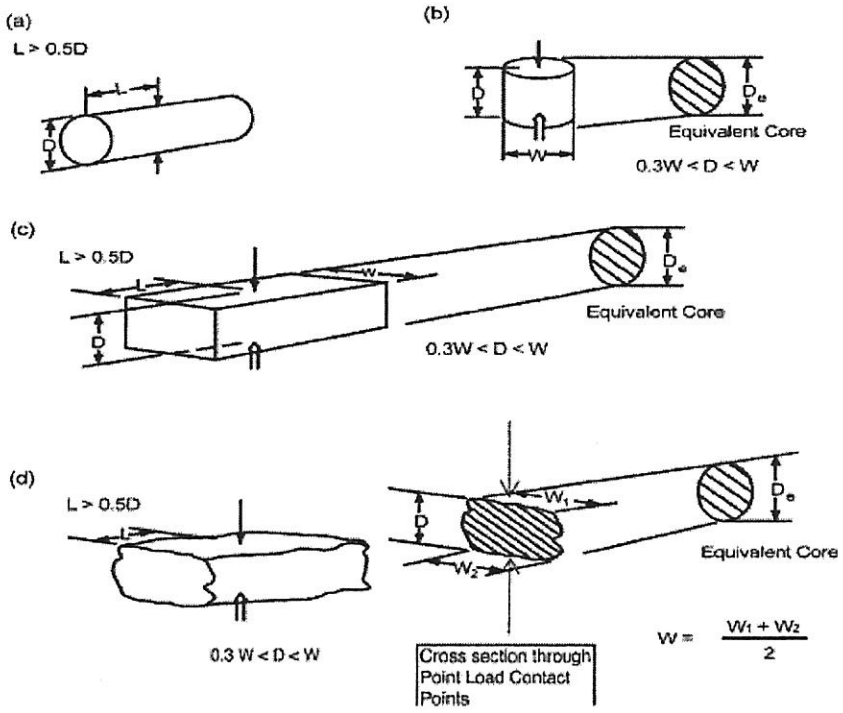
1) ใช้เวอร์เนียวัดขนาดตามรูปร่างที่กำหนดตามรูปที่ 6-1 โดยมีความละเอียดอย่างน้อย 0.01 นิ้ว

2) ติดตั้งตัวอย่างหินในเครื่องทดสอบดัชนีจุดกด (รูปที่ 6-2) โดยให้ตัวอย่างหินอยู่ในแนวกึ่งกลางของแนวกด

3) ติดตั้งอุปกรณ์ป้องกันเศษหินกระเด็น

4) ให้แรงกดในแนวแกนด้วยอัตราเร็วคงที่โดยให้หินวิบัติ (แตก) ภายใน 10 – 60 วินาที (ASTM)

5) บันทึกค่าแรงกดสูงสุดที่หินวิบัติ และวาดรูปแนวการวิบัติหรือบันทึกภาพตัวอย่างหิน



NOTE 1—Legend: L = distance between contact points and nearest free face, and D_e = equivalent core diameter (see 10.1).

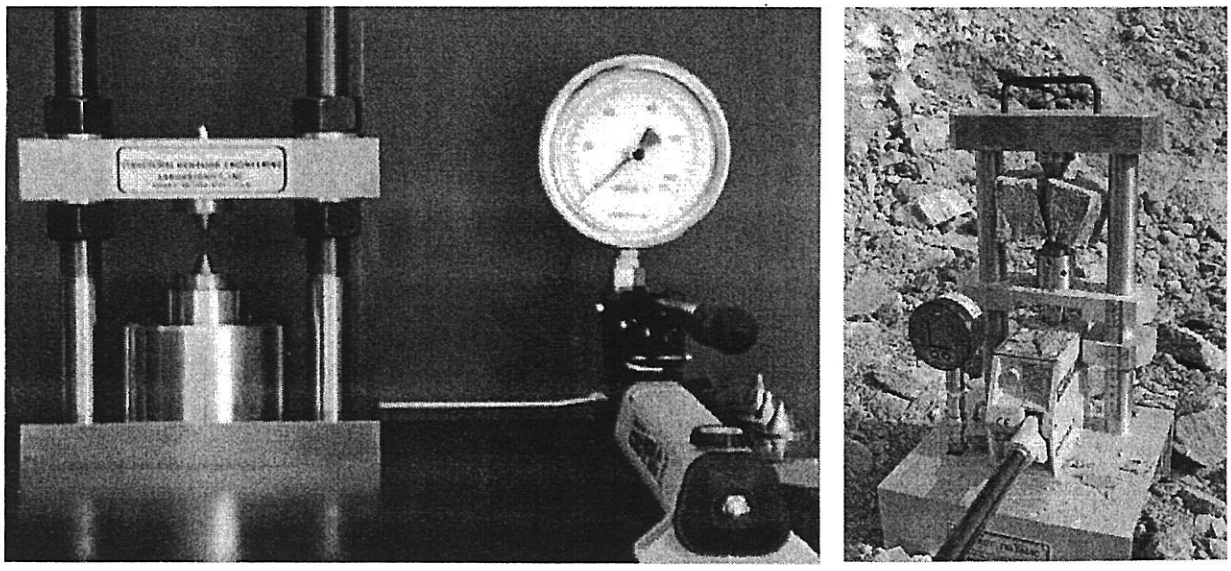
รูปที่ 6-1 ข้อกำหนดขนาดและรูปร่างของตัวอย่างหินในการทดสอบในแต่ละแบบ

(a) ทดสอบแบบตามแนวเส้นผ่านศูนย์กลาง (Diametral Core Test)

(b) ทดสอบแบบตามแนวแกน (Axial Test)

(c) ทดสอบแบบทรงสี่เหลี่ยม (Block Test)

(d) ทดสอบแบบรูปทรงไม่เป็นเรขาคณิต (Irregular Lump Test)



(a) **(b)**

รูปที่ 6-2 เครื่องทดสอบจุดกด (a) สำหรับใช้ในห้องปฏิบัติการ (b) สำหรับใช้ในภาคสนาม

การคำนวณ

ค่าดัชนีจุดกด, I_s (Point Load Strength Index)

$$I_s = P/D_e^2 \qquad \text{(MPa)}$$

โดย P = แรงกดสูงที่สุดวัดที่จุดวิบัติ (N)

D_e = เส้นผ่านศูนย์กลางเทียบเท่า (Equivalent Core Diameter) ของหินตัวอย่าง (mm)

$D_e^2 = D^2$ ในกรณีที่ทดสอบแบบตามแนวเส้นผ่านศูนย์กลาง (Diametral Core Test) (mm^2)

$D_e^2 = 4A/\pi$ ในกรณีที่ทดสอบแบบตามแนวแกน (Axial), แบบทรงสี่เหลี่ยม (Block), และแบบรูปทรงไม่เป็นเราขาคณิต (Irregular Lump) (mm^2)

$A = WD$ = พื้นที่หน้าตัดที่น้อยที่สุดของระนาบที่ผ่านจุดกด ดูรูปที่ 6-1 (mm^2)

ค่าปรับเทียบขนาดหินตัวอย่าง (Size Correction Factor)

$$I_{s(50)} = F \times I_s$$

โดย $I_{s(50)}$ = ค่าดัชนีจุดกดที่ถูกปรับเทียบแล้วให้มีเส้นผ่านศูนย์กลางเทียบเท่ากับ 50 mm

F = ค่าปรับเทียบขนาดมีค่าเท่ากับ $(D_e/50)^{0.45}$

ค่าประเมินความเค้นกดสูงสุดในแกนเดียว

$$\sigma_c = K \times I_{s(50)}$$

โดย σ_c = ค่าความเค้นกดสูงสุดในแกนเดียว (MPa)

K = ค่าคงที่ (Index to Strength Conversion Factor) แสดงในตารางที่ 6-1

ตารางที่ 6-1 ค่าคงที่ Index to Strength Conversion Factor, K = C (ASTM D5731-07)

Core Size, mm	Value of "C" (Generalized)
21.5 (Ex Core)	18
30	19
42 (Bx Core)	21
50	23
54 (Nx Core)	24
60	24.5

[A]Bieniawski, Z.T. The Point-Load Test in Geotechnical Practice, Engineering Geology (9) 1-11.

ผลการทดสอบ

ชนิดหิน..

เตรียมตัวอย่างวันที่..ทดสอบวันที่..

อุณหภูมิห้องทดสอบ.......................................(°C).........

รูปแบบการทดสอบ

☐ ทดสอบแบบตามแนวเส้นผ่านศูนย์กลาง (Diametral Core Test)

☐ ทดสอบแบบตามแนวแกน (Axial Test)

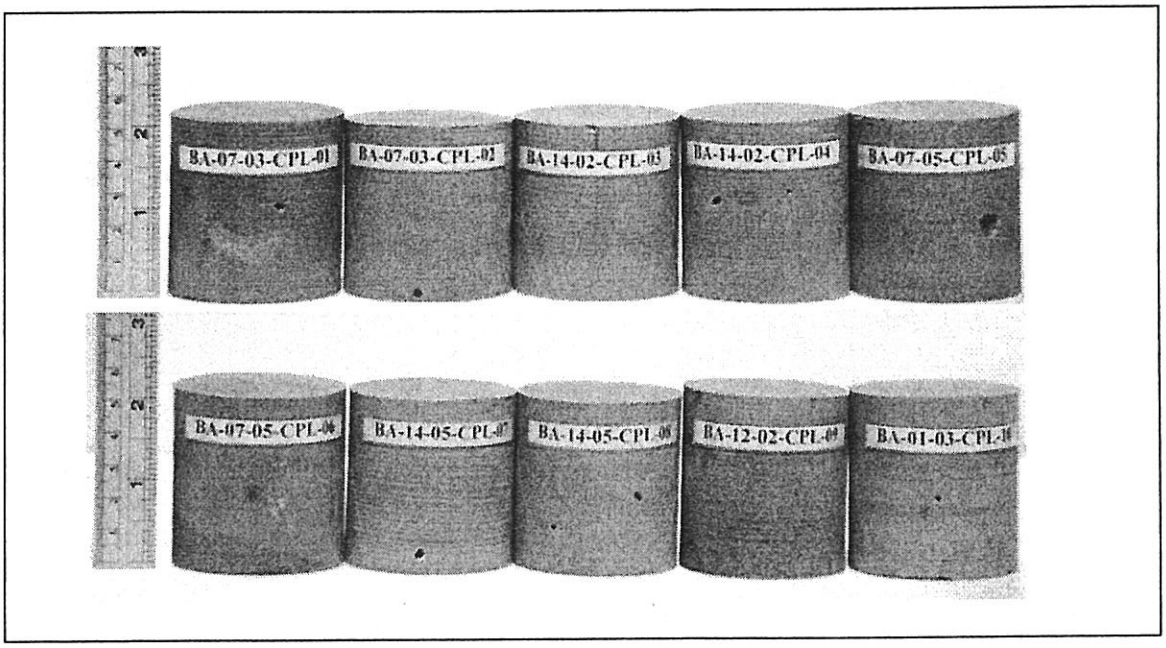
☐ ทดสอบแบบทรงสี่เหลี่ยม (Block Test)

☐ ทดสอบแบบรูปทรงไม่เป็นเรขาคณิต (Irregular Lump Test)

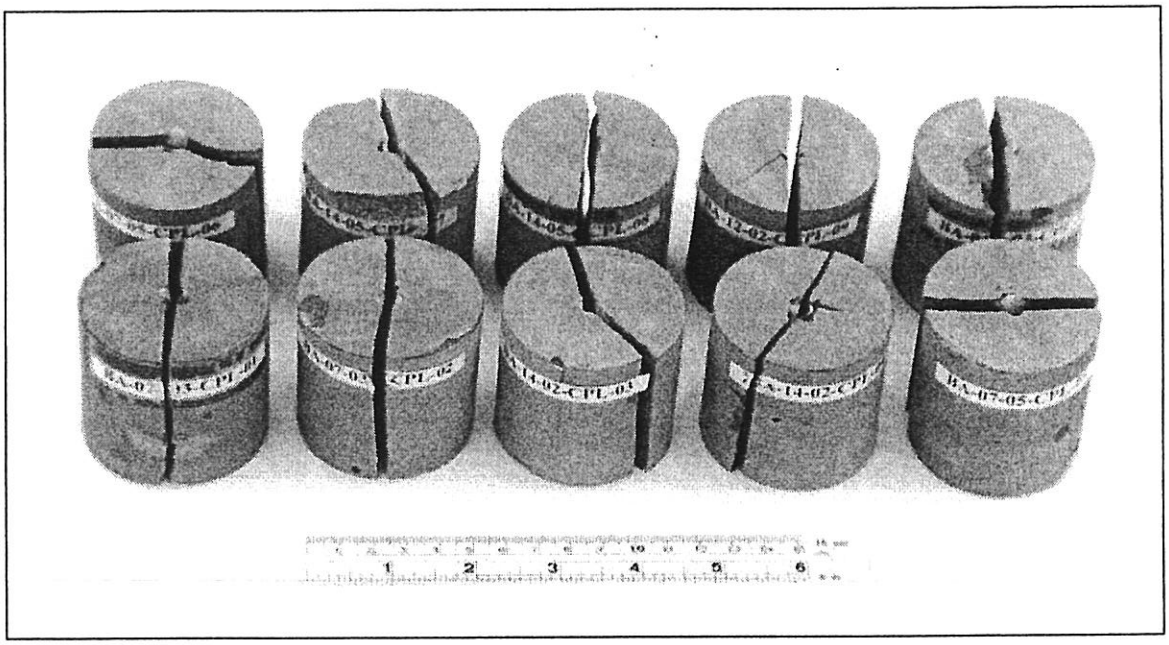
หมายเลขหินตัวอย่าง	เส้นผ่านศูนย์กลางเฉลี่ย D (mm)	ความกว้างเฉลี่ย W (mm)	ความหนาแน่น (g/cc)	D_e^2	แรงกดสูงสุด P (kN)	ค่าดัชนีจุดกด $I_s = P/D_e^2$ (MPa)	ค่าปรับเทียบขนาด $F = (D_e/50)^{0.45}$	ค่าดัชนีจุดกด $I_{s(50)} = F \times I_s$ (MPa)

-- ตัวอย่าง--

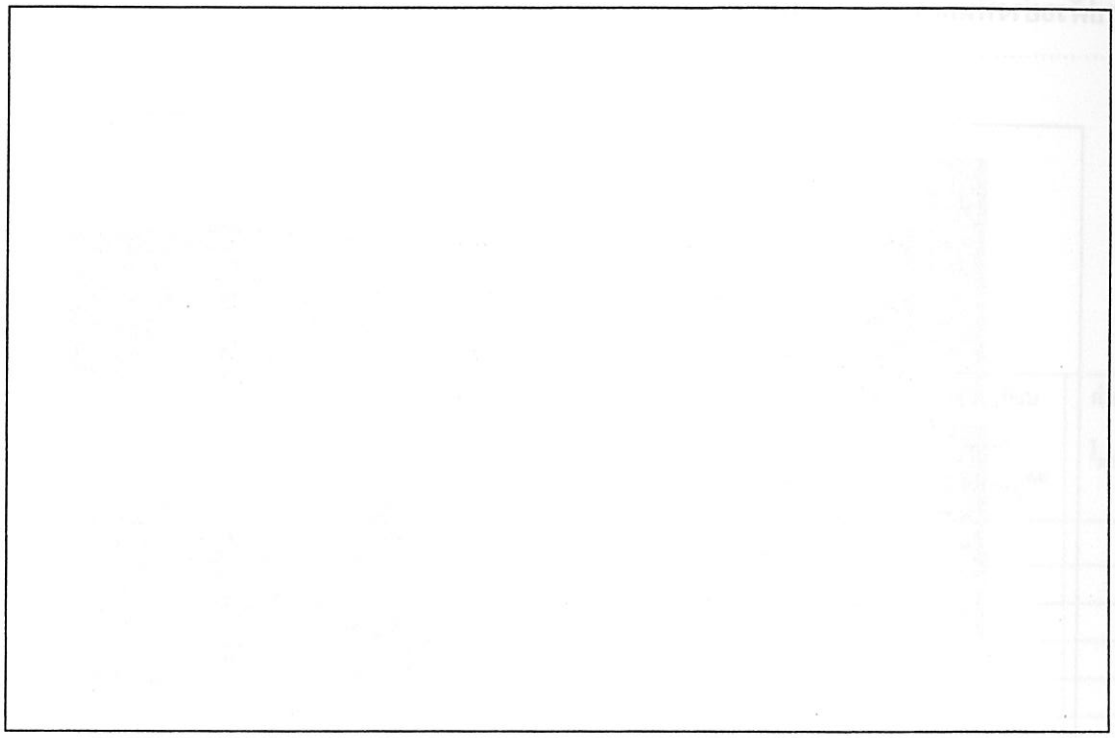
รูปตัวอย่างหินก่อนการทดสอบ



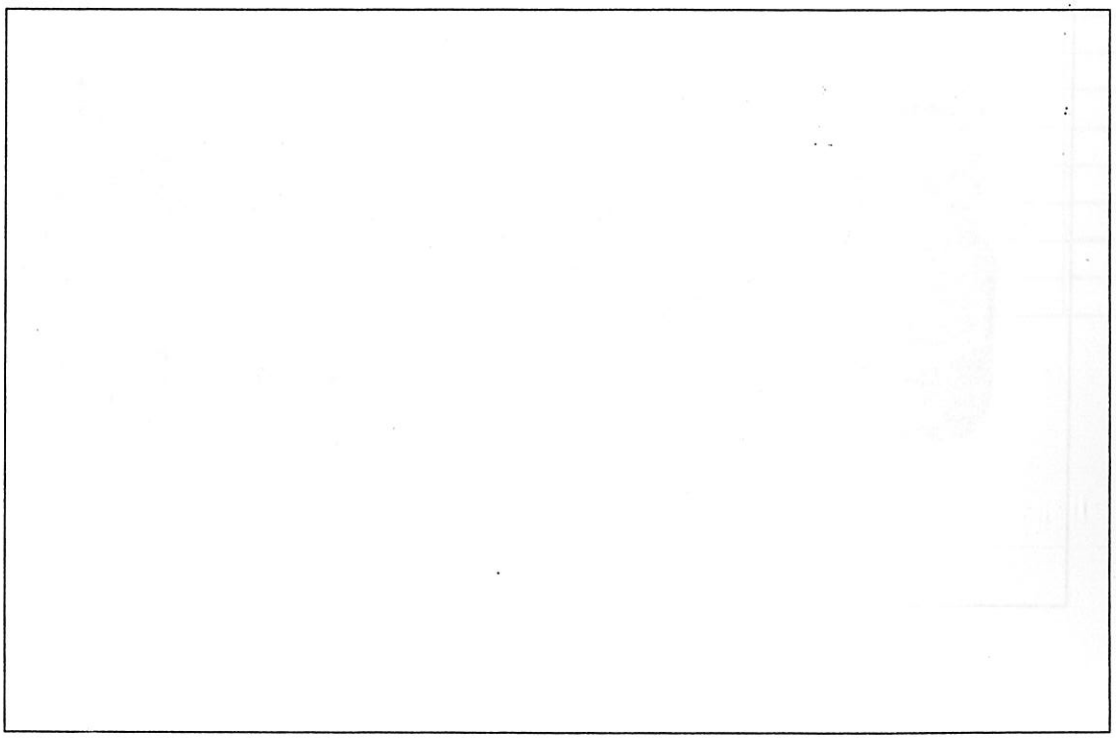
รูปตัวอย่างหินหลังการทดสอบ



รูปตัวอย่างหินก่อนการทดสอบ



รูปตัวอย่างหินหลังการทดสอบ



วิจารณ์ผลการทดสอบ

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สรุปการทดสอบ

ค่าดัชนีจุดกด, I_s (Point Load Strength Index)

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

หมายเลขตัวอย่าง..... = ... MPa

ค่าเฉลี่ย (Average) = ... MPa

ค่าเบี่ยงเบนมาตรฐาน (S.D.) = ... MPa

ค่าประเมินความเค้นกดสูงสุดในแกนเดียว

K (Index to Strength Conversion Factor) = ...

$\sigma_c = K \times I_{s(50)}$(ค่าเฉลี่ย) = ...×..... MPa

= ..... MPa

ปฏิบัติการที่ 7

การทดสอบดัชนีความทนทาน

วัตถุประสงค์การทดสอบ

เพื่อหาค่าดัชนีทนทาน (Slake Durability Index) ของหินตัวอย่าง

มาตรฐานการทดสอบ

ASTM D 4644 – 04 และ ISRM Suggested Methods

เครื่องมือการทดสอบ

1) เครื่องทดสอบดัชนีความทนทาน (Slake Durability Tester) ประกอบด้วย
   - ชุดตะแกรงทรงกระบอก (Drum) ขนาดตะแกรงสี่เหลี่ยมจตุรัส 2.00 mm (No.10) ตามรูปที่ 7-1 โดยมีขนาดเส้นผ่านศูนย์กลาง 140 mm ความยาว 100 mm มีฝากรมปิดทั้งสองก้าน
   - ชุดอุปกรณ์ใส่น้ำตามรูปที่ 7-1 โดยมีที่ยึดแกนกลางตะแกรงทรงกระบอก และมีที่ว่างระหว่างตะแกรงและพื้นอย่างน้อย 40 mm
   - ชุดมอร์เตอร์หมุนแกนตะแกรงด้วยความเร็วคงที่ 20 รอบต่อนาที
2) เตาอบควบคุมอุณหภูมิคงที่ 110 ± 5 องศาเซลเซียส
3) ตาชั่งอ่านละเอียด 1 g (2000 g Capacity)
4) ค้อนสำหรับทุบเพื่อย่อยตัวอย่างหิน และแปรงทำความสะอาด
5) เทอร์โมมิเตอร์สำหรับวัดอุณหภูมิของน้ำ

ตัวอย่างหิน

การเตรียมตัวอย่างหินให้ใช้ค้อนทุบให้ได้รูปร่างและขนาดตามรูปที่ 7-2 ใช้ค้อนลบเหลี่ยมมุมที่คมออกและใช้แปรงปัดฝุ่นที่ติดอยู่ออกให้แต่ละตัวอย่างมีน้ำหนัก 40 g ถึง 60 g จำนวน 10 ตัวอย่าง น้ำหนักรวมอยู่ระหว่าง 450 g ถึง 550 g

วิธีการทดสอบ

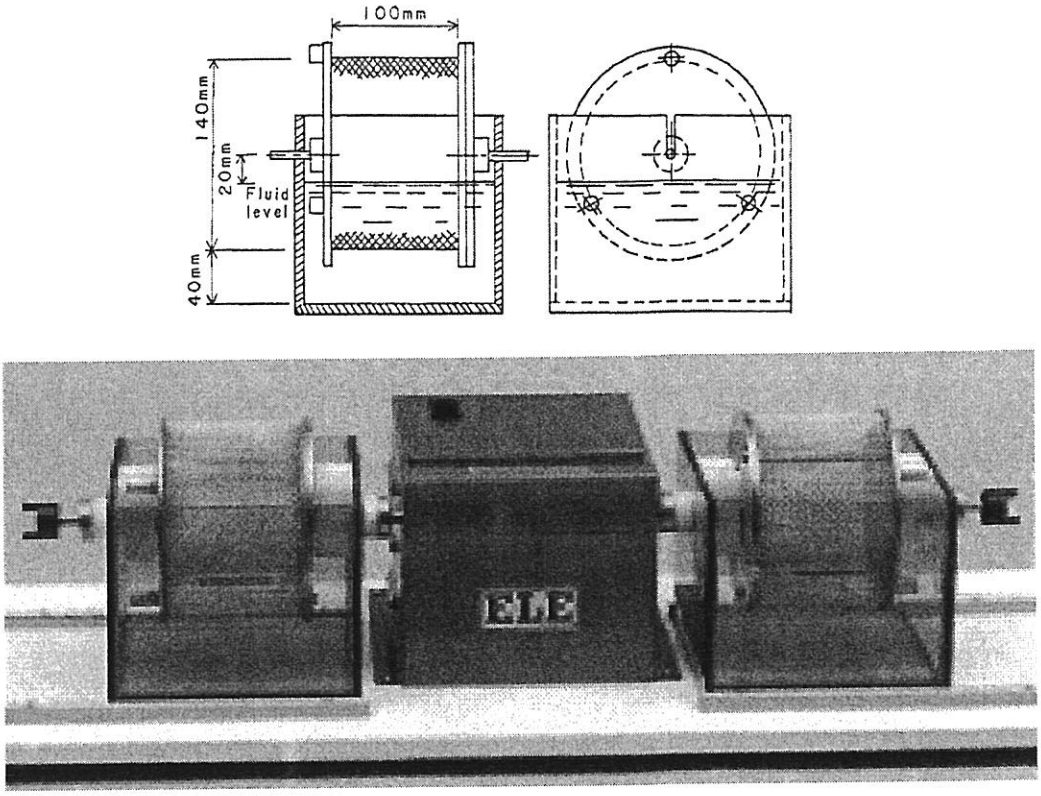
1) บันทึกรูปหินตัวอย่างแล้วใส่ลงในชุดตะแกรงทรงกระบอก (Drum) แล้วชั่งน้ำหนักก่อนทดสอบ

2) นำไปหาความชื้น (Water Content) ตาม ASTM D2216 แล้วนำตัวอย่างที่แห้งสนิทไปทดสอบ

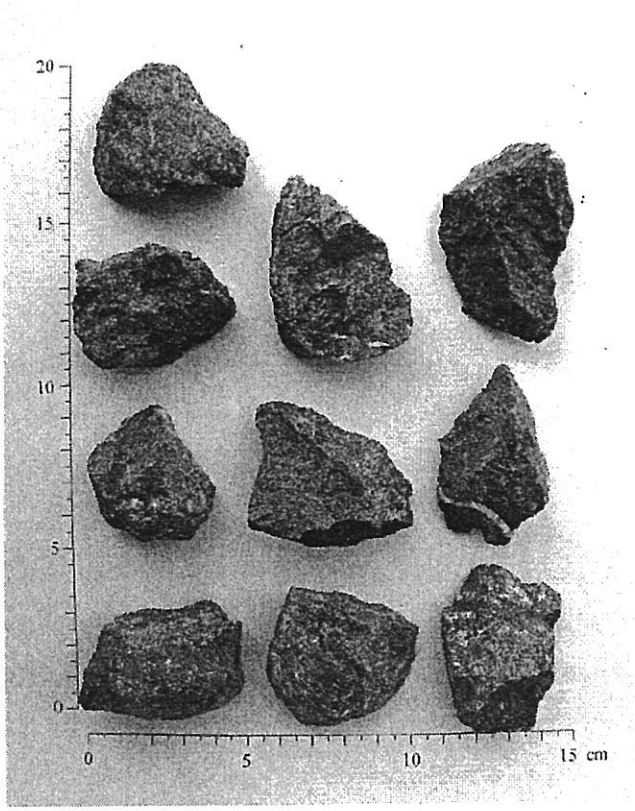
3) ติดตั้งชุดตะแกรงทรงกระบอกลงในชุดอุปกรใส่น้ำ และเติมน้ำ (อุณหภูมห้อง) ให้มีระดับต่ำกว่าแกนหมุน 20 mm พร้อมบันทึกอุณหภูมิทั้งตอนเริ่มต้นและหลังทดสอบเสร็จในแต่ละรอบ

4) ทบสอบรอบที่ 1 โดยการหมุนด้วยความเร็วคงที่ 20 รอบต่อนาที ใช้เวลา 10 นาที จากนั้นนำไปอบควบคุมอุณหภูมิคงที่ 110 ± 5 องศาเซลเซียส อย่างน้อย 12 ชั่วโมง ชั่งน้ำหนักหลังอบแล้วพร้อบบันทึกรูป

5) ทบสอบรอบที่ 2 ทดสอบเหมือนรอบที่ 1



รูปที่ 7-1 ขนาดและรูปร่างของเครื่องทดสอบดัชนีความทนทาน (ASTM 4644-04)



รูปที่ 7-2 รูปร่างหินตัวอย่างสำหรับทดสอบค่าดัชนีความทนทานจำนวน 10 ตัวอย่าง

การคำนวณ

ค่าดัชนีความทนทาน, I_d (Slake Durability Index)

$$I_d(2) = [(W_f\text{-}C)/(B\text{-}C)] \times 100 \quad (\%)$$

โดย $I_d(2)$ = ค่าดัชนีความทนทาน (รอบที่ 2)

B = น้ำหนักรวมของตะแกรงและตัวอย่างหินที่อบแห้งแล้วก่อนทำการทดสอบ (g)

W_f = น้ำหนักรวมของตะแกรงและตัวอย่างหินที่อบแห้งแล้วหลังทำการทดสอบในรอบที่ 2 (g)

C = น้ำหนักของชุดตะแกรงทรงกระบอก (g)

ผลการทดสอบ

หมายเลขตัวอย่างหิน.....ชนิดหิน.....

เตรียมตัวอย่างวันที่.....ทดสอบวันที่.....

อุณหภูมิห้องทดสอบ.....(°C).....

น้ำหนักของชุดตะแกรงทรงกระบอก(Drum) C =.....(g).....

น้ำหนักรวมของตะแกรงและตัวอย่างหินที่อบแห้งแล้วก่อนทำการทดสอบ B =.....(g).....

รอบที่ 1

อุณหภูมิน้ำก่อนเริ่มทดสอบ.....(°C).....อุณหภูมิน้ำหลังทดสอบ.....(°C).....

น้ำหนักรวมของตะแกรงและตัวอย่างหินที่อบแห้งแล้วหลังทำการทดสอบในรอบที่ 1

W_f =.....(g).....

ค่าดัชนีความทนทาน รอบที่ 1 $I_d(1) = [(W_f\text{-}C)/(B\text{-}C)] \times 100\%$ $I_d(1)$ =.....(%).....

รอบที่ 2

อุณหภูมิน้ำก่อนเริ่มทดสอบ.....(°C).....อุณหภูมิน้ำหลังทดสอบ.....(°C).....

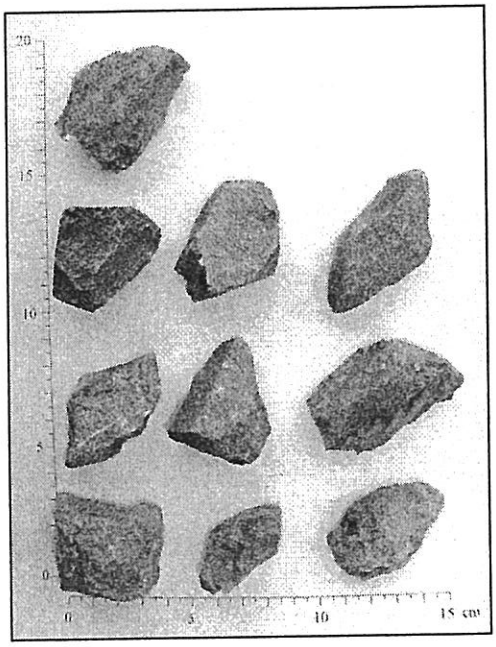
น้ำหนักรวมของตะแกรงและตัวอย่างหินที่อบแห้งแล้วหลังทำการทดสอบในรอบที่ 2

W_f =.....(g).....

ค่าดัชนีความทนทาน รอบที่ 2 $I_d(2) = [(W_f\text{-}C)/(B\text{-}C)] \times 100\%$ $I_d(1)$ =.....(%).....

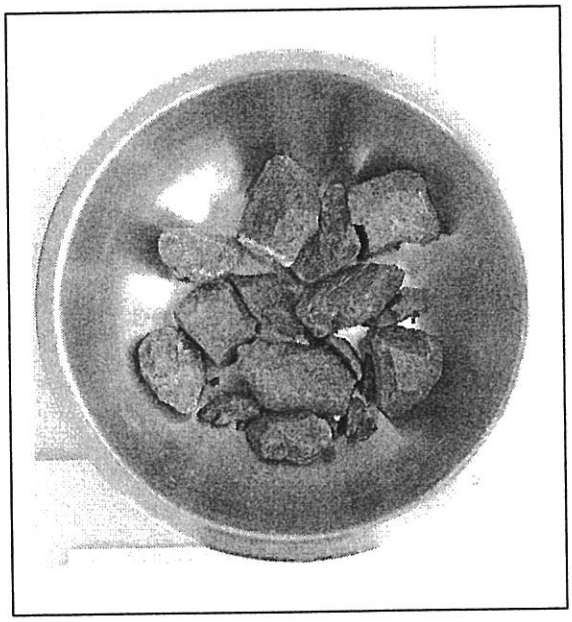
-- ตัวอย่าง--

รูปตัวอย่างหินก่อนการทดสอบ

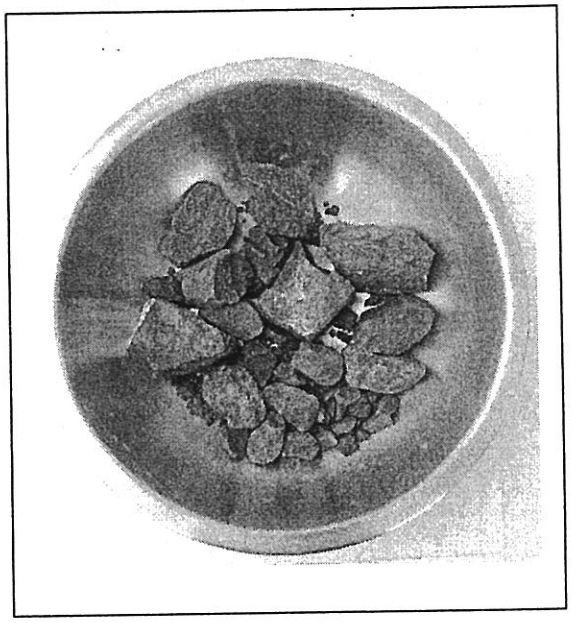


รูปตัวอย่างหินหลังการทดสอบ

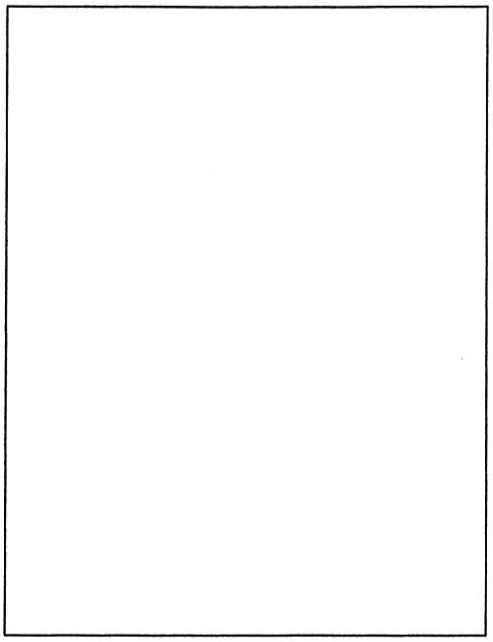
รอบที่ 1



รอบที่ 2

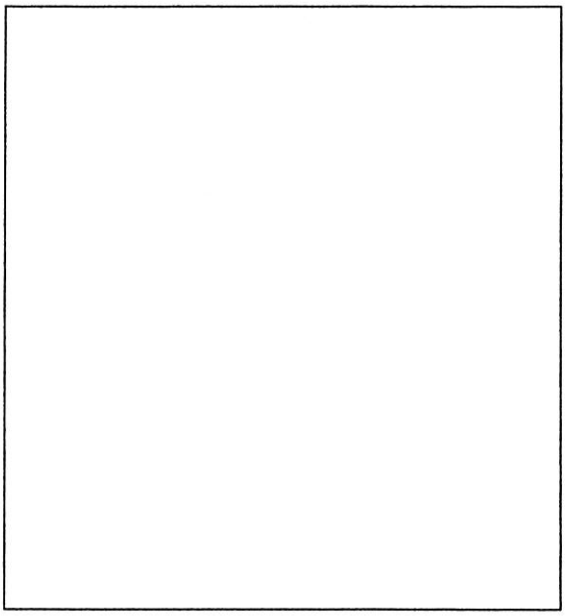


รูปตัวอย่างหินก่อนการทดสอบ

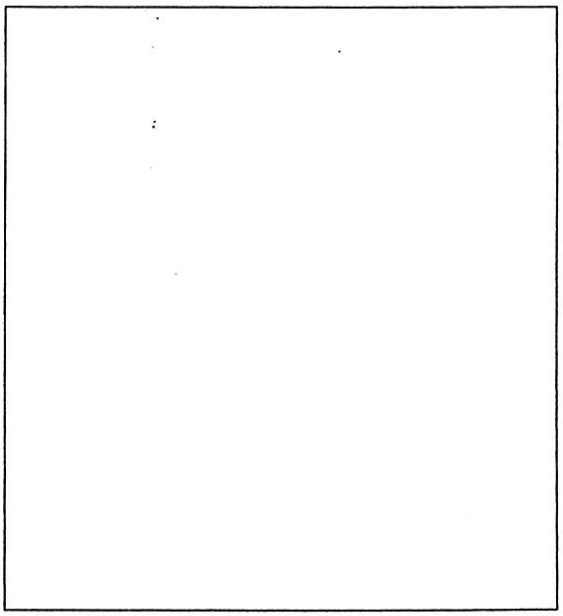


รูปตัวอย่างหินหลังการทดสอบ

รอบที่ 1



รอบที่ 2



วิจารณ์ผลการทดสอบ

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สรุปการทดสอบ

ค่าดัชนีความทนทาน, I_d (Slake Durability Index)

ค่าดัชนีความทนทาน รอบที่ 1 $I_d(1) =$ .....(%).....

ค่าดัชนีความทนทาน รอบที่ 2 $I_d(1) =$ .....(%).....

ปฏิบัติการที่ 8

การทดสอบความเร็วคลื่นและคุณสมบัติเชิงพลศาสตร์

วัตถุประสงค์การทดสอบ

เพื่อวัดค่าความเร็วคลื่นที่ผ่านเนื้อหิน (Pulse Velocities) และหาค่าของคุณสมบัติเชิงพลศาสตร์ (Dynamic Constants Tests) ของหินตัวอย่าง อยู่ในรูปของค่าสัมประสิทธิ์ความยืดยุ่น (Elastic Modulus) และค่าอัตราส่วนของปัวซ์ซอง (Poisson's ratio)

มาตรฐานการทดสอบ

ASTM D 2845 – 05 และ ISRM Suggested Methods

เครื่องมือการทดสอบ

1) ชุดเครื่องทดสอบ Sonicviewer 170 (รูปที่ 8-1)

2) เวอร์เนีย อ่านละเอียดอย่างน้อย 0.01 นิ้ว

ตัวอย่างหิน

เป็นแท่งหินทรงกระบอก (Core Specimen) มีขนาดเส้นผ่านศูนย์กลางไม่น้อยกว่า 47 มิลลิเมตร (ASTM) อัตราส่วนระหว่างความยาวต่อเส้นผ่านศูนย์กลาง (L/D) ไม่เกิน 5 โดยตัวอย่างหินจัดเตรียมตามมาตรฐาน ASTM D 4543 – 07

วิธีการทดสอบ

<u>ขั้นตอนการวัด P-Wave</u>

1) ต่อเครื่อง Sonicviewer เข้ากับแบตเตอรี โดยให้สายแดงต่อกับขั้วแดง สายดำต่อกับขั้วดำ ตามรูปที่ 8-2 แล้วเปิดสวิตช์

2) ต่อสาย transducer เข้ากับเครื่อง Sonicviewer โดยใช้หัวรับและหัวส่งเป็นเครื่องชนิดเดียวกัน และมีความถี่เท่ากัน โดยจะเริ่มที่หัว P-Wave ก่อน (แนะนำให้ใช้หัวที่มีความถี่ต่ำๆ เพราะ core ที่นำมาทดสอบมีความยาวไม่มาก)

3) Setting the gain โดยกดที่ F2 เครื่องจะปรากฏค่าที่หน้าจอตั้งแต่ 2-1,000 (แนะนำให้เลือกค่าที่อยู่ระหว่าง 10-50)

4) Setting the filter โดยกดไปที่ F3 ค่า filter เป็นการแสดงภาพของคลื่นให้อยู่ใน Amplitude ที่กำหนด (แนะนำให้ใช้ High cut 200 kHz และ Low cut 500 Hz)

5) Setting pretrigger โดยกดที่ F4 ขั้นตอนนี้เราวัดค่าจาก core ไม่จำเป็นต้องใช้ External trigger ดังนั้นให้ตั้งค่าไปที่ 0 word

6) Setting sampling range โดยกดไปที่ค่า F5 ค่า Range มีความสำคัญเพราะเป็นตัวกำหนดช่วงความยาวของลูกคลื่นที่เหมาะสมในการหาตำแหน่งของ First break

7) เมื่อทำการ set ค่าต่าง ๆที่กล่าวมาแล้ว ทำการ Zero adjustment โดยประกบหัว P-wave เข้าหากันตามรูปที่ 8-3 กด Ready เครื่องจะทำการวัดค่า ในขณะที่ทำการวัดหน้าจอจะกระพริบตลอดเวลาเมื่อกด Ready ซ้ำอีกครั้งหนึ่งเครื่องจะ

หยุดการวัด ภาพที่ปรากฏจะหยุดนิ่ง รูปคลื่นที่ออกมาควรจะเป็นเหมือนรูปที่ 8-4 ถ้ารูปที่ออกมาไม่เป็นไปตามรูปที่ 8-4 ให้ย้อนกลับไป set ค่า Gain และ Range ใหม่แล้วทำการวัดอีกครั้ง

8) เมื่อได้รูปคลื่นตามรูปที่ 8-4 แล้วกด Zero (F1) หน้าจอจะปรากฏตามรูปที่ 8-5 ให้เลื่อน Cursor ไปยังตำแหน่ง First break ในขณะที่เลื่อน Cursor ไปยังเส้นตรงที่ปรากฏจะเป็นเส้นประ (ตอนนี้ค่า TA ≠ 0) เมื่อได้ตำแหน่ง First break ที่แน่นอนแล้วให้กด # เส้นประจะกลายเป็นเส้นทึบพร้อมกับค่า TA = 0.00 μsec.

9) จากขั้นตอนที่ 8 เมื่อ set ค่า First break เรียบร้อยแล้วกด Esc อกมายังหน้าจอ นำ core ติดตั้งดังรูปที่ 8-6 เพื่อทำการวัดค่า

10) ทำการวัดโดยกด Ready จะเห็นได้ว่ารูปที่ปรากฏออกมายังหน้าจอจะไม่สามารถทำการหาค่า Tp ได้ (รูปที่ใช้ได้ควรมีลักษณะคล้ายกับรูปที่ 8-7) ต้องกลับไปเปลี่ยนค่า Gain และ Range ใหม่ (แนะนำให้ใช้ Gain อยู่ในช่วงระหว่าง 200-1,000 และ Range อยู่ในช่วงระหว่าง 100-500 ηsec)

11) ทำการวัดค่าใหม่ (กด Ready) เมื่อได้รูปคล้ายคลึงกับรูปที่ 8-7 แล้วทำการเลื่อน Cursor ไปยังตำแหน่ง First break ค่า Tp ที่ได้จะนำไปใช้ในการคำนวณของเครื่องมือ

12) กด Length เพื่อป้อนค่าความยาวของ core มีหน่วยเป็น mm ตามรูปที่ 8-8

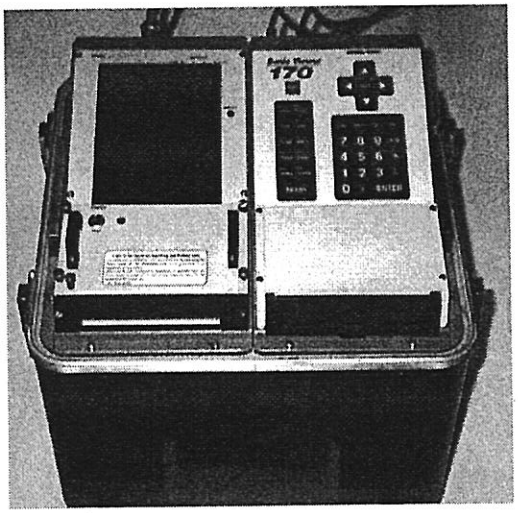
13) กดปุ่ม Vp เพื่อทำการหาค่า Vp โดยหน้าจอจะแสดงตามรูปที่ 8-9 กดค่าหมายเลข 1 ค่า Vp จะปรากฏออกมา (กรณีที่วัดอยู่ใน channel A) จากนั้นป้อนค่า Density โดยกดปุ่ม * ค่า Density มีหน่วยเป็น g/cc.

<u>ทำการวัด S-Wave</u>

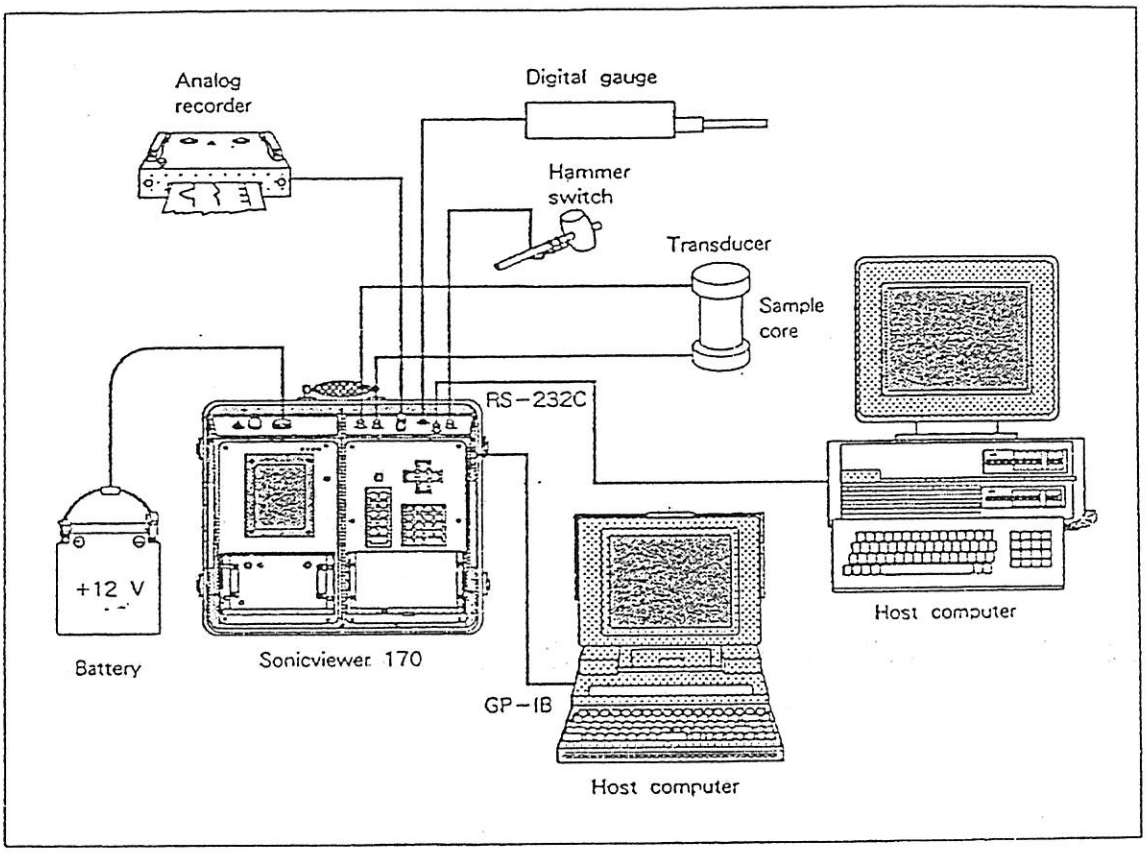
ให้ทำตามขั้นตอนคล้ายกับ P-Wave แต่ต้องเปลี่ยนหัว Transducer เป็น S-Wave ที่มีค่าเท่ากันและเปลี่ยน Cannel จาก A เป็น B โดยกดปุ่ม A/B แนะนำให้ใช้ค่า Gain และ Range ที่เท่ากันกับที่ใช้กับ P-Wave เมื่อถึงขั้นตอนการวัดค่า Vs ให้กดปุ่ม Vs แทน Vp ค่า Vs ที่ถูกต้องจะอยู่ในตำแหน่งเลข 2 ของ B เมื่อได้ค่า Vs และ Vp แล้วกด Enter ค่าที่ต้องการจะแสดงออกมเป็นไปตามรูปที่ 8-10

หมายเหตุ

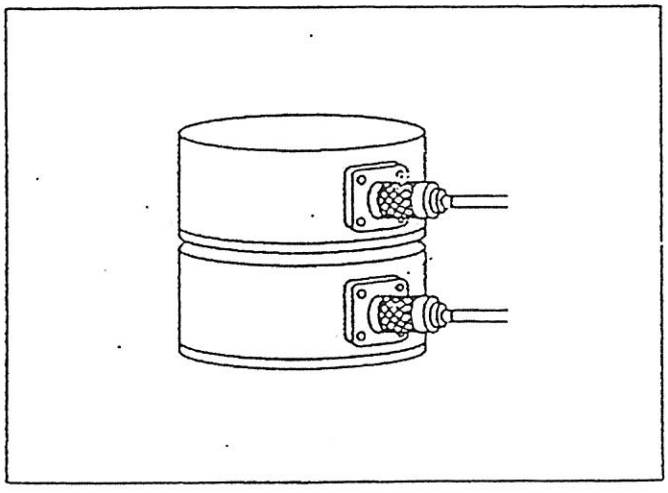
- ค่า Vp ควรมากกว่า Vs และค่า Tp จะน้อยกว่า Ts โดยค่า Poisson's ratio จะมีค่าอยู่ในช่วง 0.0-0.5
- ก่อนทำการประกบ core กับ Transducer ควรทาซิลิโคนที่ผิวสัมผัสของ core และควรทำความสะอาด Transducer หลังจากเลิกใช้งาน



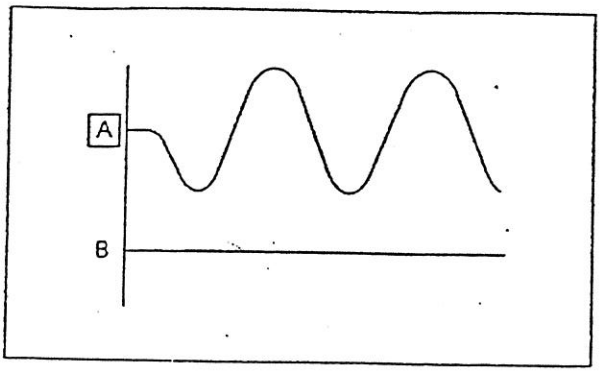
รูปที่ 8-1 ชุดเครื่องทดสอบ Sonicviewer 170



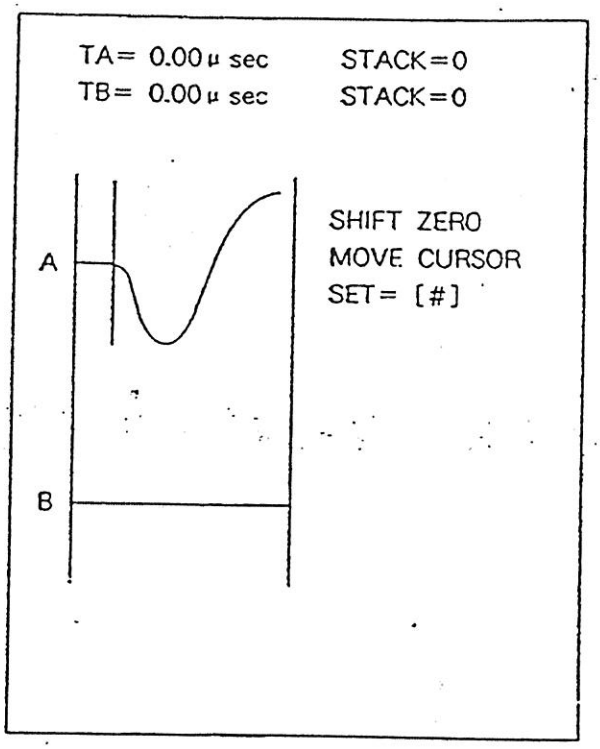
รูปที่ 8-2 ส่วนประกอบต่าง ๆ ของชุดเครื่องทดสอบ Sonicviewer 170



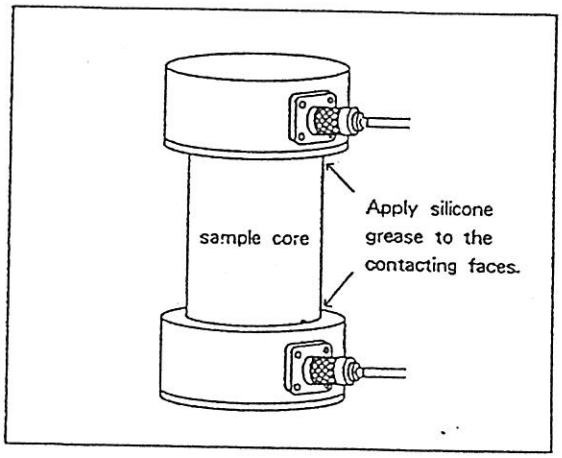
รูปที่ 8-3 ประกบหัวรับและหัวส่งเข้าหากันเพื่อทำการ Zero adjustment



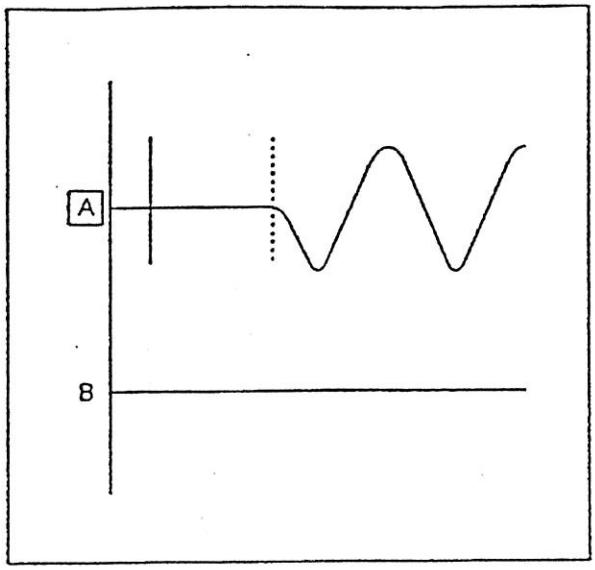
รูปที่ 8-4 รูปคลื่นที่เครื่อง Sonicviewer 170 ตรวจวัดได้



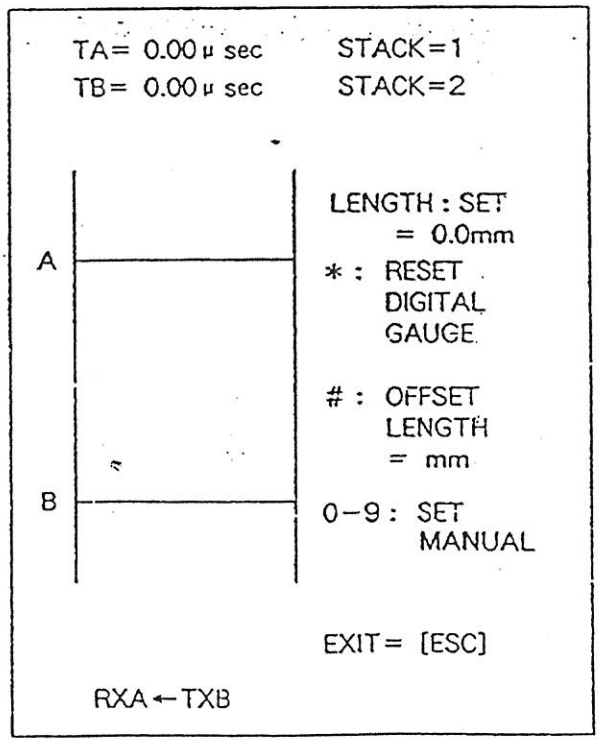
รูปที่ 8-5 เลื่อนตำแหน่งของ Cursor ไปยังตำแหน่ง First break



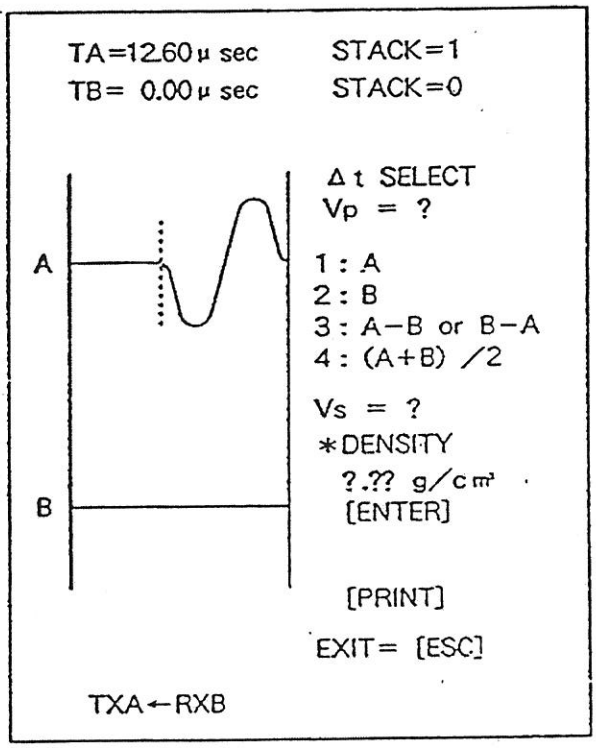
รูปที่ 8-6 ติดตั้งแท่งหินตัวอย่างเพื่อวัดค่าความเร็วคลื่นที่เดินทาง



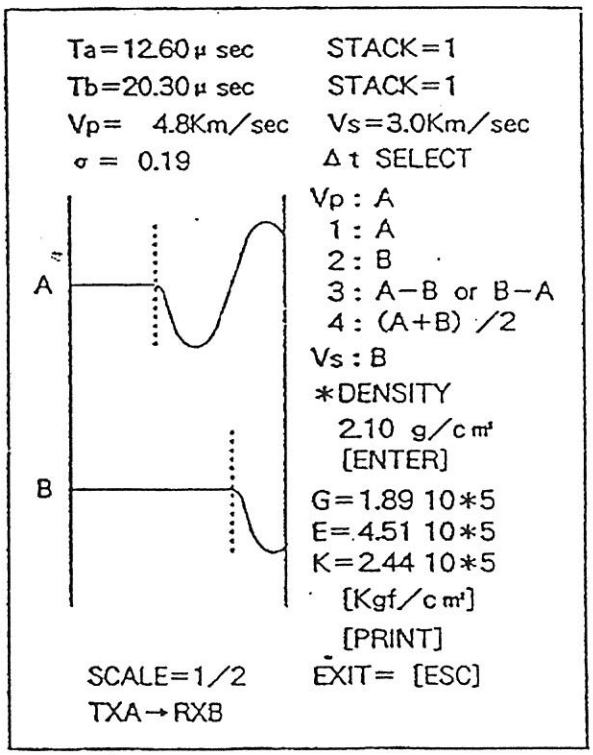
รูปที่ 8-7 วัดค่าความเร็วคลื่นที่เดินทางผ่านหินตัวอย่างโดยเลื่อน Cursor ไปยังตำแหน่ง First break



รูปที่ 8-8 กด Length เพื่อป้อนค่าความยาวของ core มีหน่วยเป็น mm



รูปที่ 8-9 ทำการหาค่า Vp (กรณีที่วัดอยู่ใน channel A)



รูปที่ 8-10 ผลการทดสอบที่ได้เมื่อวัดความเร็วคลื่นทั้ง P-wave และ S-wave

การคำนวณ

ความเร็วคลื่น V (Pulse-propagation velocity)

$$V_p = L_p/T_p$$

และ

$$V_s = L_s/T_s$$

โดย V_p = ความเร็วคลื่น P-wave (in./s หรือ m/s)

V_s = ความเร็วคลื่น S-wave (in./s หรือ m/s)

L = ระยะทางที่คลื่นเดินทาง (Pulse-travel distance) (in. หรือ m)

T = เวลาที่คลื่นเดินทาง (Effective pulse-travel time) (s)

ค่าสัมประสิทธิ์ความยืดยุ่นเชิงพลศาสตร์ (Dynamic Elastic Modulus)

$$E_d = [\rho V_s^2(3V_p^2 - 4V_s^2)] / (V_p^2 - V_s^2)$$

โดย E_d = ค่าสัมประสิทธิ์ความยืดยุ่นเชิงพลศาสตร์ (psi หรือ Pa)

ρ = ความหนาแน่นของหินตัวอย่าง (Rock Density) (lb/in.^{3} หรือ kg/m^3)

ค่าอัตราส่วนของปัวซ์ซองเชิงพลศาสตร์ (Dynamic Poisson's ratio)

$$\nu_d = (V_p^2 - 2V_s^2) / [2(V_p^2 - V_s^2)]$$

ผลการทดสอบ

ชนิดหิน.....

เตรียมตัวอย่างวันที่.....ทดสอบวันที่.....

อุณหภูมิห้องทดสอบ.....(°C).....

หมายเลขหินตัวอย่าง	เส้นผ่านศูนย์กลางเฉลี่ย D (mm)	ความยาวเฉลี่ย L (mm)	L/D	ความหนาแน่น (kg/m^3)	ความเร็วคลื่น P-wave V_p (m/s)	ความเร็วคลื่น S-wave V_s (m/s)	Dynamic Elastic Modulus E_d (GPa)	Dynamic Poisson's Ratio ν_d

รูปการทดสอบ

วิจารณ์ผลการทดสอบ

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สรุปการทดสอบ

1) ค่าสัมประสิทธิ์ความยืดหยุ่นเชิงพลศาสตร์, E_d (Dynamic Elastic Modulus)

หมายเลขตัวอย่าง..... = ... GPa

หมายเลขตัวอย่าง..... = ... GPa

หมายเลขตัวอย่าง..... = ... GPa

หมายเลขตัวอย่าง..... = ... GPa

หมายเลขตัวอย่าง..... = ... GPa

ค่าเฉลี่ย (Average) = ... GPa

ค่าเบี่ยงเบนมาตรฐาน (S.D.) = ... GPa

2) ค่าอัตราส่วนของปัวซ์ซองเชิงพลศาสตร์, ν_d (Dynamic Poisson's Ratio)

หมายเลขตัวอย่าง..... = ...

หมายเลขตัวอย่าง..... = ...

หมายเลขตัวอย่าง..... = ...

หมายเลขตัวอย่าง..... = ...

หมายเลขตัวอย่าง..... = ...

ค่าเฉลี่ย (Average) = ...

ค่าเบี่ยงเบนมาตรฐาน (S.D.) = ...

เอกสารอ้างอิง

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ภาคผนวก

เอกสารมาตรฐานการทดสอบ ASTM

ASTM D4543-07 ..... A-1

ASTM D7012-07 ..... A-7

ASTM D3967-05 ..... A-15

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ASTM D2845-05 ..... A-46

เอกสารแนะนำทดสอบของ ISRM

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Designation: D 4543 – 07

Standard Practices for Preparing Rock Core as Cylindrical Test Specimens and Verifying Conformance to Dimensional and Shape Tolerances[1]

This standard is issued under the fixed designation D 4543; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This practice specifies procedures for laboratory rock core test specimen preparation of rock core from drill core and block samples for strength and deformation testing and for determining the conformance of the test specimen dimensions with tolerances established by this practice. Cubical, rectangular, or other shapes are not covered by this practice. However, some of the information contained with in this practice and in standard Test Method C 170 may still be of use to preparing other test specimen shapes.

1.2 Rock is a complex engineering material that can vary greatly as a function of lithology, stress history, weathering, moisture content and chemistry, and other natural geologic processes. As such, it is not always possible to obtain or prepare rock core specimens that satisfy the desirable tolerances given in this practice. Most commonly, this situation presents itself with weaker, more porous, and poorly cemented rock types and rock types containing significant and/or weak structural features. For these and other rock types which are difficult to prepare, all reasonable efforts shall be made to prepare a specimen in accordance with this practice and for the intended test procedure. However, when it has been determined by trial that this is not possible, prepare the rock specimen to the closest tolerances practicable and consider this to be the best effort (Note 1) and report it as such and if allowable or necessary for the intended test, capping the ends of the specimen as discussed in this practice is permitted.

NOTE 1—Best effort in surface preparation refers to the use of a well-maintained surface grinder, lathe or lapping machine by an experienced operator in which a reasonable number of attempts has been made to meet the tolerances required in this procedure.

1.3 This practices covers some, but not all of the curatorial issues that should be implemented. For curatorial issues that should be followed before and during specimen preparation refer to Practices D 5079 and to the specific test standards in section 2.1 for which the specimens are being prepared.

1.4 This practice also prescribes tolerance checks on the length-to-diameter ratio, straightness of the elements on the cylindrical surface, the flatness of the end bearing surfaces, and the perpendicularity of the end surfaces with the axis of the core.

1.5 The requirement for specifying the moisture condition of the test specimen is also stated. However, the requirements in the specific test standards in section 2.1 should be followed too.

1.6 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026, unless superseded by this standard.

1.6.1 The practices /procedures used to specify how data are collected/recorded and calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analysis methods for engineering design.

1.7 *Units*—The dimensional values stated in either inch-pound units or SI units are to be regarded as standard, such as 4 to 12 in. or 100 to 300 mm. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the

[1] These practices are under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

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*A Summary of Changes section appears at the end of this standard.

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two systems may result in non-conformance with the standard. (Note, when mass measurements are added to determine densities or unit weights, add the following.)

1.7.1 Only the SI units are used for mass determinations, calculations and reported results. However, the use of balances or scales recording pounds of mass (lbm) shall not be regarded as nonconformance with this standard.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.9 *This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgement. Not all aspects of this practice may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

C 170 Test Method for Compressive Strength of Dimension Stone

C 617 Practice for Capping Cylindrical Concrete Specimens

D 653 Terminology Relating to Soil, Rock, and Contained Fluids

D 2113 Practice for Rock Core Drilling and Sampling of Rock for Site Investigation

D 2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D 5079 Practices for Preserving and Transporting Rock Core Samples

D 6026 Practice for Using Significant Digits in Geotechnical Data

D 7012 Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

D 7070 Test Method for Creep of Rock Core Under Constant Stress and Temperature

3. Terminology

3.1 For terminology used in this test method, refer to Terminology D 653

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

4. Significance and Use

4.1 The dimensional, shape, and surface tolerances of rock core specimens are important for determining rock properties of intact specimens. Dimensional and surface tolerance checks are required in Test Methods D 7012 and D 7070. To simplify test procedures in laboratories, the parts of those procedures that are common to the test methods are given in this standard.

NOTE 2—The quality of the result produced by this standard is dependent upon the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing and sampling. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors

5. Apparatus

5.1 *Flat Surface*—The tolerances of a flat test surface on which a rock specimen is rolled, a V-block placed, or the end of a rock core is placed shall not depart from a plane by more than 0.0005 in. (13 µm).

5.2 *V-block*—The V-block shall be machinist quality with all bearing faces surfaces ground flat, smooth to within 0.0005 in. (13 µm) and with a 90° included angle.

5.3 *Dial Gage*—The sensitivity of the dial gage shall be at least 0.001 in. (25 µm) for measurement of cylindrical surfaces. The measurement contact tip of the dial gage shall be round in shape. A dial gage readable to 0.0001 in. (2.5 µm) is required for measurements on the end surfaces.

5.4 *Feeler Gage*—The feeler gage 3 in. (76 mm) "leaves" must include sizes beginning at 0.0015 in. (38 µm).

5.5 *Surface Grinder*—A manual or automatic machinist's surface grinder equipped with a magnetic flat surface and a V-block.

5.6 *Diamond Saw*—A manual or automatic rock saw equipped with a segmented circular diamond saw blade, and appropriate cooling and cutting agents.

6. Specimens

6.1 Test specimens shall be right circular cylinders within the tolerances specified herein.

6.2 The specimen shall have a length-to-diameter ratio (L/D) of 2.0 to 2.5 and a diameter of not less than 1-⅞ in. (47 mm).

NOTE 3—It is desirable that the diameter of rock test specimens be at least ten times the diameter of the largest mineral grain. For weak rock types which behave more like soil (for example, weakly cemented sandstone), the specimen diameter should be at least six times the maximum particle diameter. It is considered that the specified minimum specimen diameter of approximately 1-⅞ in. (47 mm) will satisfy this criterion in the majority of cases. When cores of diameter smaller than the specified minimum must be tested because of the unavailability of larger diameter core or prohibitive large drilling equipment siting costs, as is often the case in the mining industry, suitable notation of this fact shall be made in the report.

6.3 The sides of the specimen shall be generally smooth and free of abrupt irregularities, with all the elements straight to within 0.020 in. (0.50 mm) over the full length of the specimen, as determined by 7.1.

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6.4 The ends of the specimen shall be cut parallel to each other and at right angles to the longitudinal axis. The end surfaces shall be surface ground or lapped flat to a tolerance not to exceed 0.001 in. (25 μm), as determined by 7.2.[3]

6.5 Sections 6.6 and 6.7 describe laboratory core drilling and cutting specimens from blocks of rock samples. Practice D 2113 describes rock core drilling and sampling of rock for site investigations. Water is normally a suitable fluid for rock cutting and grinding operations. However, some rock materials are sensitive to water and thus alternate suitable cooling and flushing fluids should be used. In sections 6.8 and 6.9 an air-cooled grinding unit with a dust collector is recommended for weak rocks and rocks that may react to fluids.

6.6 *Core Drilling Block Samples*—At least a 10 horsepower drill, with a GFI for electrical powered drills is recommended. A thin walled core barrel with a water swivel and adaptors for hooking up the drill are recommended. Surface set diamond thin-wall bits are suited for soft rock. Impregnated diamond thin-wall bits are better suited for hard rock. Install the thin-wall bit into the drill press chuck. Give the end of the thin-wall bit a tap with a rubber mallet to ensure it is snug. Lower the thin-wall bit to the drill table and mark the bit core barrel for reference for sufficient drilling depth. Connect the cooling fluid hose to the swivel and tie it out of the way. Place a sheet of ½ in. (12.7 mm) plywood on the drill table, then clamp the rock block securely to the table with clamping devices such as chain vise locks. Block with wood wedges as necessary to ensure the rock is secure and has a relatively flat drilling surface. Turn on the cooling fluid with sufficient flow to cool the bit and to flush the cuttings. With the bit raised off the sample, turn on the drill using a slow speed. Lower the bit slowly onto the sample using a slow rotation speed until a groove is started. Use enough down force to prevent chatter but do not allow the motor to slow so much as to buzz. A loss of drill cooling fluid and the reference position mark indicates the end of the run. After breaking through, back the bit out of the hole and turn off the drill. If the core is not completely drilled through, remove the block and tap the bottom gently, then remove the core. Code and store the core.

6.7 *Specimen Cutting*—Use a segmented diamond saw for cutting core. Apply cooling fluid continuously to cool the blade and flush cuttings from the cut. Automatic feed diamond saws are recommended for cutting large rock specimens. Clamp the specimen in the jig. Turn on the saw and manually or automatically cut the specimen perpendicular to its axis (see 6.2 and 6.4) slowly avoiding blade chatter. Once the specimen is cut, back off the blade and turn off the saw. Remove, code and store the specimen. When cutting weak or friable rock such as potash, shale, etc., it is recommended the core be first encapsulated in polyolefin heat shrink tubing before cutting.

6.8 *Cylindrical Surface Grinding*—The quality of the circumferential surfaces of core specimens is usually acceptable for most rock types, and no further surface finishing is required. If the drilled surface contains abrupt irregularities however, further finishing is recommended. This can be accomplished by surface grinding in a lathe in much the same way as dog bone specimens are prepared for direct tensile tests. The lathe chuck and center spindle are fitted with brass centers having knurled end bearing surfaces. The specimen is held between the brass centers by end pressure. A tool post grinder equipped with a diamond impregnated wheel is used to grind the cylindrical surfaces. Diamond impregnated grinding wheels are best suited for grinding rock surfaces. Use cooling fluid to cool the surfaces and wash away cuttings.

6.9 *End Surface Grinding/Lapping*—There are several ways to prepare the end surfaces of a specimen. Using a machinist table grinder, the core is clamped in a V-block and the V-block is placed on the magnetic table. The specimen ends are typically colored with a waterproof marker. Grind the end with a diamond impregnated grinding wheel. Silica carbide grinding wheels may also be used. Use cooling fluid to cool the surfaces and wash off the cuttings. Grind in increments of 0.002 in. (0.50 mm). Grinding is completed as evidenced by grinding striations covering the whole end surface and the waterproof coloring is completely removed. Reverse the core and grind the other end. Alternatively the core may be secured in the chuck of a lathe, and the end surfaces finished using a tool post diamond grinding wheel. Lapping devices are available that lap both ends of the core simultaneously using slurried grit. For large specimens, 4 to 12 in. (100 to 300 mm) a machinist shaper may be used. The shaper is retrofitted with a segmented diamond saw blade mounted on a tool post grinder. Cooling fluid is used to cool the surfaces and wash away the cuttings.

7. Procedure

7.1 Determine the deviation from straightness of the elements by either Procedure A or Procedure B, as follows:

7.1.1 *Procedure A*—Roll the cylindrical specimen on a smooth, flat surface and measure the height of the maximum gap between the specimen and the flat surface with a feeler gage. If the maximum gap exceeds 0.020 in. (0.50 mm), the specimen does not meet the required tolerance for straightness of the elements.

7.1.2 *Procedure B*—Place the cylindrical surface of the specimen on a V-block that is laid on a flat surface. The length of the V-block shall be sufficient that the specimen will not project over its ends during movement. Place a dial gage in contact with the top of the specimen cylindrical surface, as shown in Fig. 1, and observe the dial reading as the specimen is moved from one end of the V-block to the other along a straight line, without rotation. Record the maximum and minimum readings of the dial gage and calculate the difference, Δ_0. If the dial gage traverses a natural cavity in the rock, readings in this region shall not be included in the determination of Δ_0. Repeat the same operations by rotating the specimen for every 120 ± 1°, and obtain the differences Δ_{120} and Δ_{240}. The maximum value of these three differences shall be less than 0.020 in (0.50 mm).

7.2 Check the end flatness and parallelism tolerance by either Procedure A or Procedure B, as follows:

7.2.1 *Procedure A*—Place the specimen in a V-block with the dial gage mounted at the end as shown in Fig. 2. Move the mounting pad horizontally so that the dial gage measurement

[3] Hoskins, J. R., and Horino, F. G., "Effects of End Conditions on Determining Compressive Strength of Rock Samples," *Report of Investigations U.S. Bureau of Mines 7171*, 1968.

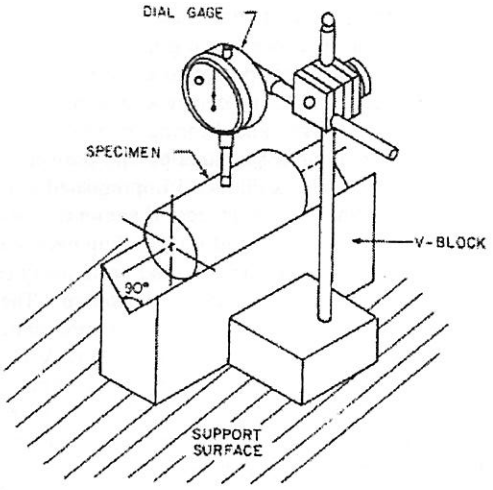


FIG. 1 Assembly for Determining the Straightness of Elements on the Cylindrical Surface (7.1.2, Procedure B)

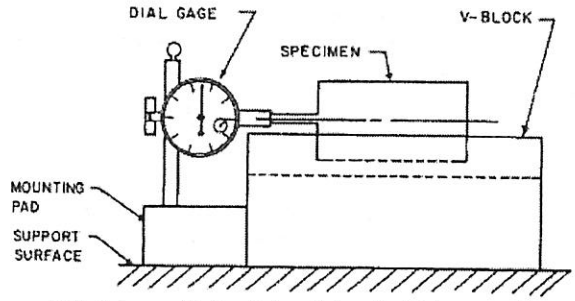
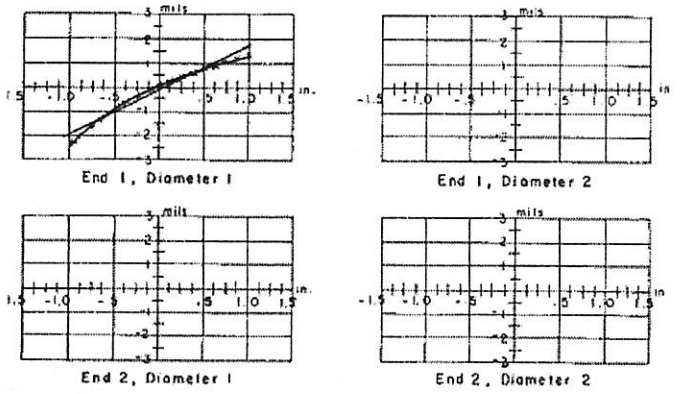


FIG. 2 Assembly for Determining the Flatness and Perpendicularity of End Surfaces to the Specimen Axis (7.2.1, Procedure A)

tip runs across a diameter of the specimen end surface. Ensure that the dial gage base maintains intimate contact with the end surface of the V-block during movement. Record the dial gage readings every ⅛ in. (3 mm) across the diameter. These readings may be recorded in tabular form, or to simplify the procedure, they may be plotted directly on a graph as shown for End 1, Diameter 1, in Fig. 3. Data recording is simplified if the dial gage is set to zero when it is in contact with the center of the end face. Plot the readings and draw a smooth curve through the points to represent the surface profile along the specified diametrical plane, as shown for End 1, Diameter 1, in Fig. 3. Do not plot dial gage readings taken when the gage tip drops into a natural cavity in the rock. Rotate the specimen 90 ± 1° about its longitudinal axis and repeat the same operations and tolerance checks for the new diametrical plane. Turn the specimen end for end and repeat the same measurement procedures and tolerance checks for the other end surface. The flatness tolerance is met when each smooth curve so determined does not depart from a visual best-fit straight line by more than 0.001 in. (25 µm). The parallelism tolerance is met when the maximum angular difference between the opposing best-fit straight line on each specimen end is not more than 0.25° for spherically seated test machines and 0.13° for fixed end test machines. These measurements are also used to check perpendicularity in 7.3.1.

7.2.2 *Procedure B*—Set the specimen upright on a flat surface. Place a dial gage measurement tip in contact with the top of the specimen. Move the dial gage measurement tip across the top of the specimen along at least three different diameters. Note the maximum and minimum dial gage readings. Do not include dial gage readings taken when the measurement tip drops into a natural cavity in the rock. Scribe lines on the specimen at the measurement locations. Turn the specimen end-for-end and repeat. The flatness tolerance is met when the smooth curve so determined does not depart from a visual best-fit straight line by more than 0.001 in. (25 µm). The parallelism tolerance is met when the maximum angular difference between the opposing best-fit straight line on each



Difference between maximum and minimum readings for Diameter 1, End 1 = Δ_1 = _____
Difference for Diameter 2, End 1 = Δ_2 = _____
Difference for Diameter 1, End 2 = Δ_1' = _____
Difference for Diameter 2, End 2 = Δ_2' = _____
Use the largest of the four Δ, Δ_{max} = _____
Perpendicularity tolerance is met when $\frac{\Delta_{max}}{diam} \leq 0.0043$

FIG. 3 Suggested Format for Presenting Tolerance-Check Data

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specimen end is not more than 0.25° for spherically seated test machines and 0.13° for fixed end test machines.

7.3 The ends of the specimen shall not depart from perpendicularity to the axis of the specimen by more than 0.25°, which is a slope of 1 part in 230.[3,4] Check this tolerance using either Procedure A or Procedure B, as follows:

7.3.1 *Procedure A*—Use the measurements taken in 7.2.1. Calculate the difference between the maximum and the minimum readings on the dial gage along Diameter 1. This difference is denoted as Δ_1. Calculate the corresponding difference for Diameter 2, which is 90° from Diameter 1. Denote the difference for Diameter 2 as Δ_2. Calculate the corresponding differences for the other end of the specimen, Δ_1 and Δ_2. The perpendicularity tolerance will be considered to have been met when:

$$\frac{\Delta_i}{d} \text{ and } \frac{\Delta_i'}{d} \leq \frac{1}{230} = 0.0043 \qquad (1)$$

where:
i = 1 or 2,
d = diameter, and
Δ_i = diameter difference.

7.3.2 *Procedure B*—Set the specimen upright on a smooth flat surface. Place the base of a true square on the test surface and in contact with the bottom of the specimen. Rotate the specimen, keeping contact with the square, until the maximum gap between the square and the top of the specimen is found. Determine the width of the gap using a feeler gage. The perpendicularity tolerance is met if the gap, Δ, divided by the specimen length, L, is less than 1 part in 230, that is,

$$\frac{\Delta}{L} \leq \frac{1}{230} = 0.0043 \qquad (2)$$

where:
L = length, and
Δ = length difference.

Repeat for other end of specimen unless the specimen ends were checked for parallelism in 7.2.2.

7.4 The measurements described in 7.1.2, 7.2.1, and 7.2.2 are taken with a mechanical dial gage. An optical or electronic device with an equivalent or better readout sensitivity and accuracy may be used in place of the dial gage, if desired.

7.5 The measurements taken on the ends of the specimen in 7.2.1 and 7.2.2 may also be made with the specimen clamped upright in a V-block. The measuring tip of the dial gage would then contact the upper end surface of the specimen. Either the V-block and specimen may be moved as a unit under a stationary dial gage, or the dial gage may be moved while the V-block and specimen remain stationary. The readings to be taken with such a vertical configuration are the same as those specified for the horizontal configuration in 7.2.1 and 7.2.2.

7.6 Determine the diameter of the test specimen to the nearest 0.01 in. (0.25 mm) by averaging two diameters measured at right angles to each other at about midheight of the specimen. Use this average diameter for calculating the cross-sectional area. Determine the length of the test specimen to the nearest 0.01 in. (0.25 mm) at the centers of the end faces.

7.7 The use of capping materials or end surface treatments other than the grinding and lapping specified herein is not permitted, except as noted in 7.9. Lubricants are not permitted on the specimen-platen interfaces.

7.8 There are some rock types with physical characteristics or low strengths which preclude preparing specimens to the flatness tolerance specified in 6.4, even with the best effort (Note 4). In these instances, first cut to length the core specimen and apply end caps to the end surfaces of the specimen.

7.9 The specifications for the capping compound, capping plates, and alignment devices and the procedure for capping weak rock core specimens shall be the same as those established for compression testing of concrete in Practice C 617; however, melted sulfur capping compounds are not permitted because of the possible detrimental effects of the high temperature on the rock.

NOTE 4—Best effort in surface preparation refers to the use of a well-maintained surface grinder, lathe or lapping machine by an experienced operator.

7.10 The moisture condition of the specimen shall be determined using Test Method D 2216 and reported as required in 8.1.6.

NOTE 5—The moisture condition of the specimen at the time of the sample preparation can have a significant effect upon the strength and deformation characteristics of the rock. Good practice generally dictates that laboratory tests be made upon specimens representative of field conditions. Thus, it follows that the field moisture condition of the specimen should be preserved until the time of the test. In some instances, however, there may be reasons for testing specimens at other moisture contents, from saturation to dry. In any case, the moisture content of the test specimen should be tailored to the problem at hand. Excess moisture will affect the adhesion of resistance strain gages, if used, and the accuracy of their performance. Adhesives used to bond the rock to steel end pieces in the direct tension test will also be affected adversely by excess moisture.

8. Report

8.1 Report the following along with other data required for the particular test method in 2.1 being performed:

8.1.1 Source of test specimen, including project name and location. Often the location is specified in terms of the drill hole number and depth of specimen from collar of hole. Include curatorial record number if any.

8.1.2 Date test is performed.

8.1.3 Physical description of test specimen including: rock type such as sandstone, limestone, granite, etc.; location and orientation of inherent rock structural features and any discontinuities; and large inclusions or inhomogeneities, if any. A sketch of the test specimen is recommended for other than homogeneous rock types.

8.1.4 Specimen diameter and length, and conformance or best effort conformance with dimensional requirements (6.2, 6.3, and 6.4).

8.1.5 Data to substantiate the following three tolerances:

8.1.5.1 Straightness surfaces by either Procedure A (7.1.1) or Procedure B (7.1.2).

[4] Podnieks, E. R., Chamberlain, P. G., and Thill, R. E.," Environmental Effects on Rock Properties," *Basic and Applied Rock Mechanics, Proceedings of Tenth Symposium on Rock Mechanics*, AIME, 1972, pp. 215–241.

8.1.5.2 Parallelism by either Procedure A (7.2.1) or Procedure B (7.2.2).

8.1.5.3 Perpendicularity by either Procedure A (7.3.1) or Procedure B (7.3.2).

8.1.6 The moisture condition of the sample at the time of the test, such as as-received, saturated, laboratory air-dry, or oven dry. It is recommended that the moisture conditions be more precisely determined when possible and reported as either water content or degree of saturation.

8.1.7 The equipment used.

9. Keywords

9.1 conformance; core; diameter; dimensional tolerances; dimensions; length; rock; specimen preparation (for testing); specimen shape; specimen size

SUMMARY OF CHANGES

*(1)*Revised title.

(2) Revised sections 1.1, 1.2, 1.3, and 1.4.

Added sections 1.6, 1.6.1, 1.7, 1.7.1, 3..

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Designation: D 7012 – 07

Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures[1]

This standard is issued under the fixed designation D 7012; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the strength of intact rock core specimens in uniaxial compression and confined compression. The tests provide data in determining the strength of rock, namely: the uniaxial strength, shear strengths at varying pressures and varying temperatures, angle of internal friction, (angle of shearing resistance), and cohesion intercept. The test method specifies the apparatus, instrumentation, and procedures for determining the stress-axial strain and the stress-lateral strain curves, as well as Young's modulus, E, and Poisson's ratio, υ. It should be observed that this method makes no provision for pore pressure measurements and specimens are undrained (platens are not vented). Thus the strength values determined are in terms of total stress, that is, are not corrected for pore pressures. This test method does not include the procedures necessary to obtain a stress-strain curve beyond the ultimate strength.

1.1.1 This standard replaces and combines the following Standard Test Methods for: D 2664 Triaxial Compressive Strength of Undrained Rock Core Specimens Without Pore Pressure Measurements; D 5407 Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements; D 2938 Unconfined Compressive Strength of Intact Rock Core Specimens; and D 3148 Elastic Moduli of Intact Rock Core Specimens in Uniaxial Compression.

1.1.2 The original four standards are now referred to as Methods in this standard as follows: Method A — Triaxial Compressive Strength of Undrained Rock Core Specimens Without Pore Pressure Measurements; Method B — Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements; Method C — Unconfined Compressive Strength of Intact Rock Core Specimens; Method D — Elastic Moduli of Intact Rock Core Specimens in Uniaxial Compression; and Option A — Elevated Temperatures.

1.2 For an isotropic material, the relation between the shear and bulk moduli and Young's modulus and Poisson's ratio are:

$$G = \frac{E}{2(1+\upsilon)} \quad (1)$$

$$K = \frac{E}{3(1-2\upsilon)} \quad (2)$$

where:

G = shear modulus,
K = bulk modulus,
E = Young's modulus, and
υ = Poisson's ratio.

1.2.1 The engineering applicability of these equations decreases with increasing anisotropy of the rock. It is desirable to conduct tests in the plane of foliation, cleavage or bedding and at right angles to it to determine the degree of anisotropy. It is noted that equations developed for isotropic materials may give only approximate calculated results if the difference in elastic moduli in two orthogonal directions is greater than 10 % for a given stress level.

NOTE 1—Elastic moduli measured by sonic methods (Test Method D 2845) may often be employed as preliminary measures of anisotropy.

1.3 This test method given for determining the elastic constants does not apply to rocks that undergo significant inelastic strains during the test, such as potash and salt. The elastic moduli for such rocks should be determined from unload-reload cycles, that are not covered by this test method.

1.4 The values stated in SI units are to be regarded as the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

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2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D 2845 Test Method for Laboratory Determination of Pulse Velocities and Ultrasonic Elastic Constants of Rock

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D 4543 Practices for Preparing Rock Core as Cylindrical Test Specimens and Verifying Conformance to Dimensional and Shape Tolerances

E 4 Practices for Force Verification of Testing Machines

E 122 Practice for Calculating Sample Size to Estimate, With a Specified Tolerable Error, the Average for a Characteristic of a Lot or Process

2.2 *ASTM Adjunct:*[3]

Triaxial Compression Chamber Drawings (3)

3. Summary of Test Method

3.1 A rock core specimen is cut to length and the ends are machined flat. The specimen is placed in a loading frame and if required, placed in a loading chamber and subjected to confining pressure. In an elevated temperature test the specimen is heated to the desired test temperature. Axial load is increased continuously on the specimen, and deformation is measured as a function of load until peak load and failure are obtained.

4. Significance and Use

4.1 The parameters obtained from these procedures are in terms of undrained total stress (as already mentioned in 1.1.1.). However, there are some cases where either the rock type or the loading condition of the problem under consideration will require the effective stress or drained parameters be determined.

4.2 Unconfined compressive strength of rock is used in many design formulas and is sometimes used as an index property to select the appropriate excavation technique. Deformation and strength of rock are known to be functions of confining pressure. The confined compression test is commonly used to simulate the stress conditions under which most underground rock masses exist. The elastic constants are used to calculate the stress and deformation in rock structures.

4.3 The deformation and strength properties of rock cores measured in the laboratory usually do not accurately reflect large-scale *in situ* properties because the latter are strongly influenced by joints, faults, inhomogeneities, weakness planes, and other factors. Therefore, laboratory values for intact specimens must be employed with proper judgment in engineering applications.

NOTE 2—Notwithstanding the statements on precision and bias contained in this test method; the measures of precision of these test methods are dependent on the competence of the personnel performing them, and on the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing. Users of this test method are cautioned that compliance with Practice D 3740 does not in itself assure reliable testing. Reliable testing depends on many factors; Practice D 3740 provides a means for evaluating some of those factors.

5. Apparatus

5.1 *Loading Device*—The loading device shall be of sufficient capacity to apply load at a rate conforming to the requirements specified in 9.6. It shall be verified at suitable time intervals in accordance with the procedures given in Practices E 4 and comply with the requirements prescribed in the method. The loading device may be equipped with a displacement transducer that can be used to advance the loading ram at a specified rate.

NOTE 3—If the load-measuring device is located outside the confining compression apparatus, calibrations to determine the seal friction need to be made to ensure the accuracy specified in Practices E 4.

5.2 *Confining Apparatus*[3]—The confined pressure apparatus shall consist of a chamber in which the test specimen may be subjected to a constant lateral fluid pressure and the required axial load. The apparatus shall have safety valves, suitable entry ports for filling the chamber, and associated hoses, gages, and valves as needed.

5.3 *Flexible Membrane*—This membrane encloses the rock specimen and extends over the platens to prevent penetration by the confining fluid. A sleeve of natural or synthetic rubber or plastic is satisfactory for room temperature tests; however, metal or high-temperature rubber (for example, viton) jackets are usually required for elevated temperature tests. The membrane shall be inert relative to the confining fluid and shall cover small pores in the specimen without rupturing when confining pressure is applied. Plastic or silicone rubber coatings may be applied directly to the specimen provided these materials do not penetrate and strengthen or weaken the specimen. Care must be taken to form an effective seal where the platen and specimen meet. Membranes formed by coatings shall be subject to the same performance requirements as elastic sleeve membranes.

5.4 *Pressure-Maintaining Device*—A hydraulic pump, pressure intensifier, or other system shall have sufficient capacity to maintain constant the desired lateral pressure. The pressurization system shall be capable of maintaining the confining pressure constant to within ±1 % throughout the test. The confining pressure shall be measured with a hydraulic pressure gage or electronic transducer having an accuracy of at least ±1 percent of the confining pressure, including errors due to readout equipment, and a resolution of at least 0.5 % of the confining pressure.

5.5 *Confining-Pressure Fluids*—For room temperature tests, hydraulic fluids compatible with the pressure-maintaining device shall be used. For elevated temperature tests, the fluid must remain stable at the temperature and pressure levels designated for the test.

5.6 *Elevated-Temperature Enclosure*—The elevated temperature enclosure shall be either an internal system that fits

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from: ASTM International Headquarters. Order Adjunct No. ADJD2664. Original adjunct produced in 1982.

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inside the loading apparatus or the confining pressure apparatus, an external system enclosing the entire confining pressure apparatus, or an external system encompassing the complete test apparatus. For high temperatures, a system of heaters, insulation, and temperature-measuring devices are normally required to maintain the specified temperature. Temperature shall be measured at three locations, with one sensor near the top, one at midheight, and one near the bottom of the specimen. The "average" specimen temperature, based on the midheight sensor, shall be maintained to within ±1°C of the required test temperature. The maximum temperature difference between the midheight sensor and either end sensor shall not exceed 3°C.

NOTE 4—An alternative to measuring the temperature at three locations along the specimen during the test is to determine the temperature distribution in a specimen that has temperature sensors located in drill holes at a minimum of six positions: along both the centerline and specimen periphery at midheight and each end of the specimen. The specimen may originate from the same batch as the test specimens and conform to the same dimensional tolerances and to the same degree of intactness. The temperature controller set point may be adjusted to obtain steady-state temperatures in the specimen that meet the temperature requirements at each test temperature (the centerline temperature at midheight may be within ±1°C of the required test temperature, and all other specimen temperatures may not deviate from this temperature by more than 3°C). The relationship between controller set point and specimen temperature can be used to determine the specimen temperature during testing provided that the output of the temperature feedback sensor (or other fixed-location temperature sensor in the triaxial apparatus) is maintained constant within ±1°C of the required test temperature. The relationship between temperature controller set point and steady-state specimen temperature may be verified periodically. The specimen is used solely to determine the temperature distribution in a specimen in the triaxial apparatus. It is not to be used to determine compressive strength or elastic constants.

5.7 *Temperature Measuring Device*—Special limits-of-error thermocouples or platinum resistance thermometers (RTDs) having accuracies of at least ± 1°C with a resolution of 0.1°C shall be used.

5.8 *Platens*—Two steel platens are used to transmit the axial load to the ends of the specimen. They shall be made of tool-hardened steel to a minimum Rockwell Hardness of 58 on the "C" scale. One of the platens shall be spherically seated and the other shall be a plain rigid platen. The bearing faces shall not depart from a plane by more than 0.015 mm when the platens are new and shall be maintained within a permissible variation of 0.025 mm. The diameter of the spherical seat shall be at least as large as that of the test specimen, but shall not exceed twice the diameter of the test specimen. The center of the sphere in the spherical seat shall coincide with that of the bearing face of the specimen. The spherical seat shall be properly lubricated to assure free movement. The movable portion of the platen shall be held closely in the spherical seat, but the design shall be such that the bearing face can be rotated and tilted through small angles in any direction. If a spherical seat is not used, the bearing faces of the blocks shall be parallel to 0.0005 mm/mm of platen diameter. The platen diameter shall be at least as great as that of the specimen and have a length-to-diameter ratio of at least 1:2.

5.9 *Strain/Deformation Measuring Devices*—The strain/deformation measuring system shall measure the strain with a resolution of at least 25×10^{-6} strain and an accuracy within 2 % of the value of readings above 250×10^{-6} strain and accuracy and resolution within 5×10 -6 for readings lower than 250×10^{-6} strain, including errors introduced by excitation and readout equipment. The system shall be free from non-characterized long-term instability (drift) that results in an apparent strain of 10^{-8}/s or greater.

NOTE 5—The user is cautioned about the influence of pressure and temperature on the output of strain and deformation sensors located within the confining pressure apparatus.

5.9.1 *Determination of Axial Strain*—The axial deformations or strains may be determined from data obtained by electrical resistance strain gages, compressometers, linear variable differential transformers (LVDTs), or other suitable means. The design of the measuring device shall be such that the average of at least two axial strain measurements can be determined. Measuring positions shall be equally spaced around the circumference of the specimen, close to midheight. The gage length over which the axial strains are determined shall be at least ten grain diameters in magnitude.

5.9.2 *Determination of Lateral Strain*—The lateral deformations or strains may be measured by any of the methods mentioned in 5.9.1. Either circumferential or diametric deformations (or strains) may be measured. A single transducer that wraps around the specimen can be used to measure the change in circumference. At least two diametric deformation sensors shall be used if diametric deformations are measured. These sensors shall be equally spaced around the circumference of the specimen close to midheight. The average deformation (or strain) from the diametric sensors shall be recorded.

NOTE 6—The use of strain gage adhesives requiring cure temperatures above 65°C is not allowed unless it is known that microfractures do not develop and mineralogical changes do not occur at the cure temperature.

6. Safety Precautions

6.1 Danger exists near confining pressure testing equipment because of the high pressures and loads developed within the system. Test systems must be designed and constructed with adequate safety factors, assembled with properly rated fittings, and provided with protective shields to protect people in the area from unexpected system failure. The use of a gas as the confining pressure fluid introduces potential for extreme violence in the event of a system failure.

6.2 Many rock types fail in a violent manner when loaded to failure in compression. A protective shield shall be placed around the unconfined test specimen to prevent injury from flying rock fragments.

6.3 Elevated temperatures increase the risks of electrical shorts and fire. The flash point of the confining pressure fluid shall be above the operating temperatures during the test.

7. Sampling

7.1 The specimens for each sample shall be selected from cores representing a valid average of the type of rock under consideration. This can be achieved by visual observations of mineral constituents, grain sizes and shape, partings and defects such as pores and fissures, or by other methods such as ultrasonic velocity measurements. The diameter of rock test

specimens shall be at least ten times the diameter of the largest mineral grain. For weak rock types, which behave more like soil (for example, weakly cemented sandstone), the specimen diameter shall be at least six times the maximum particle diameter. The specified minimum specimen diameter of approximately 47 mm satisfy this criterion in the majority of cases. When cores of diameter smaller than the specified minimum must be tested because of the unavailability of larger diameter core, as is often the case in the mining industry, suitable notation of this fact shall be made in the report.

7.2 The number of specimens required to obtain a specific level of statistically results may be determined using Test Method E 122. However, it may not be economically possible to achieve a specific confidence levels and professional judgment may be required too.

8. Test Specimens

8.1 *Preparation*—Test specimens shall be prepared in accordance with Practice D 4543.

8.2 Moisture condition of the specimen at the time of test can have a significant effect upon the deformation of the rock. Good practice generally dictates that laboratory tests shall be made upon specimens representative of field conditions. Thus, it follows that the field moisture condition of the specimen shall be preserved until the time of test. On the other hand, there may be reasons for testing specimens at other moisture contents, including zero. In any case, the moisture content of the test specimen shall be tailored to the problem at hand and reported in accordance with 11.1.3. If the moisture content of the specimen is to be determined, follow the procedures given in Method D 2216. If moisture condition is to be maintained, and the elevated temperature enclosure is not equipped with humidity control, the specimen shall be sealed using a flexible membrane or by applying a plastic or silicone rubber coating to the specimen sides. If the specimen is to be saturated, porous sandstones may present little or no difficulty. For siltstone, saturation may take longer. For tight rocks such as intact granite, saturation by water may be impractical.

9. Procedure

9.1 The spherical seat shall rotate freely in its socket before each test.

9.2 The lower platen shall be placed on the base or actuator rod of the loading device. The bearing faces of the upper and lower platens and of the test specimen shall be wiped clean, and the test specimen shall be placed on the lower platen. The upper platen shall be placed on the specimen and aligned properly. When appropriate, the membrane shall be fitted over the specimen and platens to seal the specimen from the confining fluid. The specimen shall be placed in the test chamber, ensuring proper seal with the base, and connection to the confining pressure lines. A small axial load, <1 % of anticipated ultimate strength, may be applied to the confining compression chamber by means of the loading device to properly seat the bearing parts of the apparatus.

9.3 When appropriate, install elevated-temperature enclosure and deformation transducers for the apparatus and sensors used.

9.4 If the test is in confined compression, the chamber shall be filled with confining fluid and the confining stress shall be raised uniformly to the specified level within 5 min. The lateral and axial components of the confining stress shall not be allowed to differ by more than 5 percent of the instantaneous pressure at any time.

9.5 If testing at elevated temperature, the temperature shall be raised at a rate not exceeding 2°C/min until the required temperature is reached (Note 7). The test specimen shall be considered to have reached pressure and temperature equilibrium when all deformation transducer outputs are stable for at least three readings taken at equal intervals over a period of no less than 30 min (3 min for tests performed at room temperature). Stability is defined as a constant reading showing only the effects of normal instrument and heater unit fluctuations. Record the initial deformation readings, which are to be taken as zeroes for the test.

NOTE 7—It has been observed that for some rock types microcracking will occur for heating rates above 1°C/min. The operator is cautioned to select a heating rate such that microcracking does not significantly affect the test result.

9.6 The axial load shall be applied continuously and without shock until the load becomes constant, is reduced, or a predetermined amount of strain is achieved. The load shall be applied in such a manner as to produce either a stress rate or a strain rate as constant as feasible throughout the test. The stress rate or strain rate shall not be permitted at any given time to deviate by more than 10 % from that selected. The stress rate or strain rate selected shall be that which will produce failure of a cohort test specimen in unconfined compression, in a test time between 2 and 15 min. The selected stress rate or strain rate for a given rock type shall be adhered to for all tests in a given series of investigation (Note 8). The predetermined confining pressure shall be maintained approximately throughout the test. Readings of deformation shall be observed and recorded at a minimum of ten load levels that are evenly spaced over the load range. Continuous data recording shall be permitted provided that the recording system meets the precision and accuracy requirements of 5.9. The maximum load sustained by the specimen shall be recorded. Load readings in kilonewtons shall be recorded to 2 decimal places. Stress readings in megapascals shall be recorded to 1 decimal place.

NOTE 8—Results of tests by other investigators have shown that strain rates within this range will provide strength values that are reasonably free from rapid loading effects and reproducible within acceptable tolerances. Lower strain rates may be permissible, if required by the investigation. The drift of the strain measuring system (see 5.9) may be constrained more stringently, corresponding to the longer duration of the test.

NOTE 9—Loading a high-strength specimen to failure in a loading frame that is not stiff will often result in violent failure, which will tend to damage the strain/deformation measuring devices and be hazardous to the operator.

9.7 To make sure that no confining fluid has penetrated into the specimen, the specimen membrane shall be carefully checked for fissures or punctures and the specimen shall be examined with a hand lens at the completion of each confining test.

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10. Calculations

10.1 The compressive strength of the test specimen shall be calculated as follows:

$$\sigma = (\sigma_1 - \sigma_3) \quad (3)$$

where:

σ = differential failure stress,
σ_1 = total failure stress, and
σ_3 = confining stress.

10.1.1 1 Desirable specimen length to diameter ratios are between 2:1 and 2.5:1. Specimen length to diameter ratios of less than 2:1 are unacceptable.

NOTE 10—Laboratory specimen length to diameter ratios must be employed with proper judgment in engineering applications.

NOTE 11—Tensile stresses and strains are normally recorded as being positive. A consistent application of a compression-positive sign convention may be employed if desired. The sign convention adopted needs to be stated explicitly in the report. The formulas given are for engineering stresses and strains. True stresses and strains may be used, provided that the specimen diameter at the time of peak load is known.

NOTE 12—If the specimen diameter is not the same as the piston diameter through the triaxial apparatus, a correction may be applied to the measured load to account for the confining pressure acting on the difference in area between the specimen and the loading piston where it passes through the seals into the apparatus.

10.2 Axial strain, ϵ_a and lateral strain, ϵ_l, shall be obtained directly from strain-indicating equipment or shall be calculated from deformation readings, depending on the type of apparatus or instrumentation employed. Strain readings shall be recorded to six decimal places.

10.2.1 Axial strain, ϵ_a shall be calculated as follows:

$$\epsilon_a = \frac{\Delta L}{L} \quad (4)$$

where:

L = original undeformed axial gage length, and
ΔL = change in measured axial length (negative for decrease in length).

NOTE 13—If the deformation recorded during the test includes deformation of the apparatus, suitable calibration for apparatus deformation shall be made. This may be accomplished by inserting into the apparatus a steel cylinder having known elastic properties and observing differences in deformation between the assembly and steel cylinder throughout the loading range. The apparatus deformation is then subtracted from the total deformation at each increment of load to arrive at specimen deformation from which the axial strain of the specimen is computed. The accuracy of this correction should be verified by measuring the elastic deformation of a cylinder of material having known elastic properties (other than steel) and comparing the measured and computed deformations.

10.2.2 Lateral strain, ϵ_l, shall be calculated as follows:

$$\epsilon_l = \frac{\Delta D}{D} \quad (5)$$

where:

D = original undeformed diameter, and
ΔD = change in diameter (positive for increase in diameter).

NOTE 14—Many circumferential transducers measure change in chord length and not change in arc length (circumference). The geometrically nonlinear relationship between change in chord length and change in diameter must be used to obtain accurate values of lateral strain.

10.3 The stress-versus-strain curves shall be plotted for the axial and lateral directions (see Fig. 1). The complete curve gives the best description of the deformation behavior of rocks having nonlinear stress-strain relationships at low- and high-stress levels.

10.4 The value of Young's modulus, E, shall be calculated using any of several methods employed in engineering practice. The most common methods, described in Fig. 2, are as follows:

10.4.1 Tangent modulus at a stress level that is some fixed percentage (usually 50 %) of the maximum strength.

10.4.2 Average slope of the more-or-less straight-line portion of the stress-strain curve. The average slope shall be calculated either by dividing the change in stress by the change in strain or by making a linear least squares fit to the stress-strain data in the straight-line portion of the curve.

10.4.3 Secant modulus, usually from zero stress to some fixed percentage of maximum strength.

10.5 The value of Poisson's ratio, υ, is greatly affected by nonlinearities at low-stress levels in the axial and lateral stress-strain curves. It is desirable that Poisson's ratio shall be calculated from the following equation:

$$\upsilon = -\frac{\text{slope of axial curve}}{\text{slope of lateral curve}} = -\frac{E}{\text{slope of lateral curve}} \quad (6)$$

where the slope of the lateral curve is determined in the same manner as was done in 10.4 for Young's modulus, E.

NOTE 15—The denominator in the equation in 10.5 will usually have a negative value if the sign convention is applied properly.

10.6 The Mohr stress circles shall be constructed on an arithmetic plot with shear stress as the ordinate and normal stress as the abscissa. At least three confined compression tests shall be conducted, each at a different confining pressure, on the same material to define the envelope to the Mohr stress circles. Because of the heterogeneity of rock and the scatter in results often encountered, good practice requires making at least three tests on essentially identical specimens at each confining pressure or single tests at nine different confining pressures covering the range investigated. Individual stress circles shall be plotted and used in drawing the envelope.

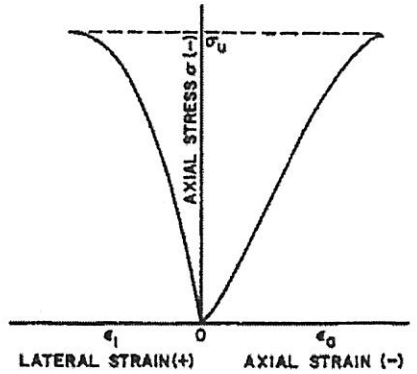

FIG. 1 Format for Graphical Presentation of Data

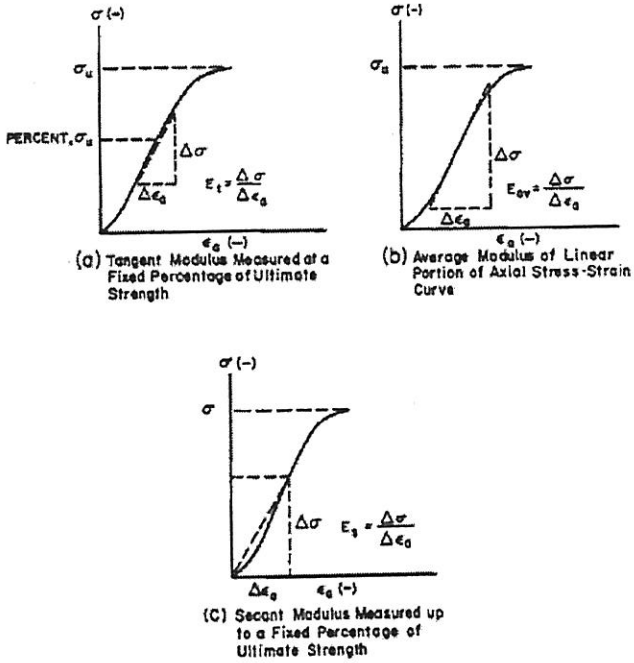

FIG. 2 Methods for Calculating Young's Modulus from Axial Stress-Axial Strain Curve

10.6.1 A "best-fit," smooth curve or straight line (Mohr envelope) shall be drawn approximately tangent to the Mohr circles, as shown in Fig. 3. The figure shall also include a brief note indicating whether a pronounced failure plane was or was not developed during the test and the inclination of this plane with reference to the plane of major principal stress. If the envelope is a straight line, the angle the line makes with the horizontal shall be reported as the angle of internal friction, ϕ (or the slope of the line as tan ϕ depending upon preference), and the intercept of this line at the vertical axis reported as the cohesion intercept, c. If the envelope is not a straight line, values of ϕ (or tan ϕ) shall be determined by constructing a

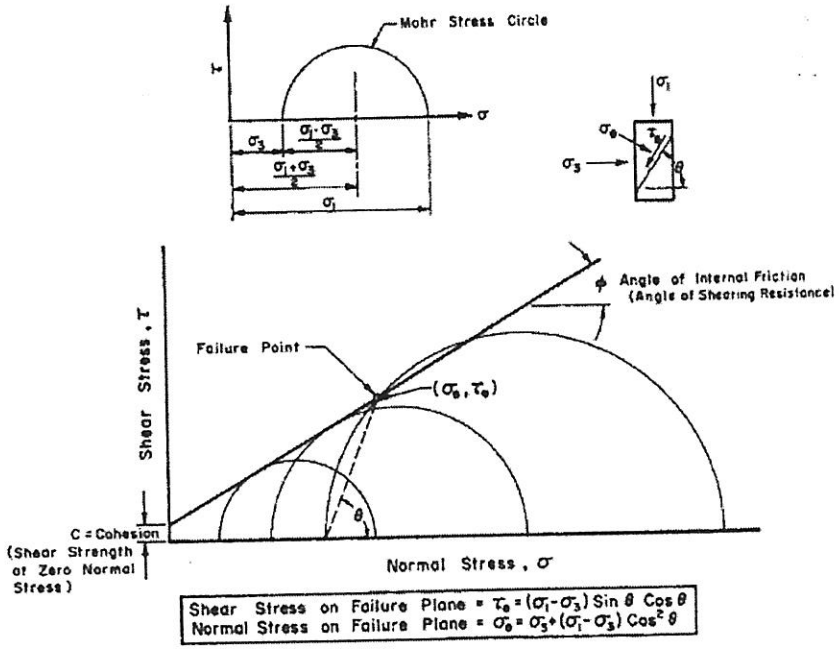

FIG. 3 Typical Mohr Stress Circles

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tangent to the Mohr circle for each confining pressure at the point of contact with the envelope and the corresponding cohesion intercept noted.

11. Report

11.1 The report shall include the following depending on test parameters:

11.1.1 Source of sample including project name and location (often the location is specified in terms of the drill hole number and depth of specimen from the collar of the hole).

11.1.2 Lithologic description of the rock, formation name, and load direction with respect to lithology,

11.1.3 Moisture condition of specimen before test,

11.1.4 Specimen diameter and height, conformance with dimensional requirements,

11.1.5 Confining stress level at which a confined test was performed,

11.1.6 Temperature at which test was performed,

11.1.7 Rate of loading or deformation rate,

11.1.8 Unconfined compressive strength,

11.1.9 Plot of the stress-versus-strain curves (see Fig. 1).

11.1.10 Plot of the Mohr stress circles (see Fig. 3Table 1Table 2Table 3Table 4Table 5),

11.1.11 Young's modulus, E, method of determination as given in Fig. 2, and at which stress level or levels determined,

11.1.12 Poisson's ratio, υ, method of determination in 10.5, and at what stress level or levels determined,

11.1.13 Description of physical appearance of specimen after test, including visible end effects such as cracking, spalling, or shearing at the platen-specimen interfaces. A sketch of the fractured specimen is recommended, and

NOTE 16—If failure is ductile, with the load on the specimen still increasing when the test is terminated; the strain at which the compressive strength was calculated may be reported.

11.1.14 If the actual equipment or procedure has varied from the requirements contained in this test method, each variation and the reasons for it shall be presented in detail.

12. Precision and Bias

12.1 The data in Tables 1-5 are the products of the Interlaboratory Testing Program. Table 1 is the product of the work of seven laboratories with five replications. Table 5 is the product of the work of eight laboratories with five replications. Round 1 involved four rock types, but only the data from three were displayed here that were rock types used in all the series of tests. The remaning tables (Tables 6-10) are the products of Round 2 in which six laboratories each tested five specimens of three different rocks, three confining pressures and four replication. Details of the study are references in Section 2.2. The tables give the repeatability (within a laboratory) and reproducibility (between laboratories) for the compressive and confined methods and values for Young's Modulus and Poisson's ratio calculated for the intervals from 25 to 50 % and 40 to 60 % of the maximum differential stress at confining

TABLE 1 Compressive Strength (MPa) at 0 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	62.0	142.0	217.0
Repeatability	15.8	20.4	15.7
Reproducibility	22.4	38.0	27.7

TABLE 2 Compressive Strength (MPa) at 10 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	127.0	173.0	282.0
Repeatability	5.29	32.2	13.5
Reproducibility	22.5	38.3	25.7

TABLE 3 Compressive Strength (MPa) at 25 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	179.0	206.0	366.0
Repeatability	8.69	43.3	22.5
Reproducibility	34.7	51.8	31.0

TABLE 4 Compressive Strength (MPa) at 40 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	215.0	237.0	N/A
Repeatability	7.95	42.4	N/A
Reproducibility	52.0	73.5	N/A

TABLE 5 Young's Modulus (GPa) at 0 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25 %	50 %	25 %	50%	25 %	50 %
Average Value	12.4	16.7	76.3	74.2	46.9	54.2
Repeatability	3.37	4.15	14.8	10.1	6.12	6.75
Reproducibility	4.17	5.18	17.2	12.3	6.45	7.77

TABLE 6 Young's Modulus (GPa) at 25 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25-50 %	40-60 %	25-50 %	40-60 %	25-50 %	40-60 %
Average Value	23.5	22.5	71.1	65.2	60.4	59.8
Repeatability	0.90	1.28	11.4	9.15	2.53	2.49
Reproducibility	3.34	3.47	13.9	11.6	6.80	6.12

TABLE 7 Young's Modulus (GPa) at 40 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25-50 %	40-60 %	25-50 %	40-60 %	25-50 %	40-60 %
Average Value	24.2	22.8	70.0	63.4	61.9	60.6
Repeatability	1.09	0.79	9.60	9.57	2.27	2.49
Reproducibility	3.82	3.57	9.69	9.57	5.95	5.34

TABLE 8 Poisson's Ratio at 10 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25-50 %	40-60 %	25-50 %	40-60 %	25-50 %	40-60 %
Average Value	0.28	0.34	0.30	0.33	0.26	0.30
Repeatability	0.03	0.04	0.03	0.07	0.03	0.03
Reproducibility	0.05	0.05	0.06	0.09	0.04	0.04

TABLE 9 Poisson's Ratio at 25 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25-50 %	40-60 %	25-50 %	40-60 %	25-50 %	40-60 %
Average Value	0.23	0.27	0.31	0.34	0.28	0.33
Repeatability	0.02	0.02	0.05	0.05	0.03	0.03
Reproducibility	0.04	0.04	0.06	0.05	0.04	0.05

TABLE 10 Poisson's Ratio at 40 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25-50 %	40-60 %	25-50 %	40-60 %	25-50 %	40-60 %
Average Value	0.20	0.24	0.32	0.34	0.29	0.33
Repeatability	0.01	0.02	0.04	0.05	0.03	0.04
Reproducibility	0.03	0.03	0.04	0.05	0.05	0.06

pressures of 10, 25, and 40 Mpa and 25 % and 50 % for the compressive test case. Additional Reference Material found in ASTM Geotechnical Journal.[4,5]

12.1.1 The probability is approximately 95 % that two test results obtained in the same laboratory on the same material will not differ by more than the repeatability limit r. Likewise, the probability is approximately 95 % that two test results obtained in different laboratories on the same material will not differ by more than the reproducibility limit R. The precision statistics are calculated from:

$$r = 2(\sqrt{2})s_r \quad (7)$$

where:

s_r = the repeatability standard deviation.

$$R = 2(\sqrt{2})s_R \quad (8)$$

where:

s_R = the reproducibility standard deviation.

12.2 *Bias*—Bias cannot be determined since there is no standard value of each of the elastic constants that can be used to compare with values determined using this test method.

13. Keywords

13.1 compression testing; compressive strength; confined compression; loading tests; modulus of elasticity; repeatability; reproducibility; rock; uniaxial compression; Young's Modulus

[4] ASTM Geotechnical Journal, "Interlaboratory Testing Program for Properties: Round One- Longitudinal and Transverse Pulse Velocities, Unconfined Compressive Strength, Uniaxial Modulus, and Splitting Tensile Strength" by Howard J. Pincus, Vol. 16, No.1, March 1993 and Addendum Vol. 17, No. 2, June 1993; pp. 138–163 and 256–258.

[5] ASTM Geotechnical Testing Journal, "Interlaboratory Testing Program for Rock Properties: Round Two- Confined Compression: Young's Modulus, Poisson's Ratio, and Ultimate Strength" by Howard J. Pincus, Vol. 19, No.3, September 1996; pp. 321–336

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Designation: D 3967 – 05

Standard Test Method for Splitting Tensile Strength of Intact Rock Core Specimens[1]

This standard is issued under the fixed designation D 3967; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method covers testing apparatus, specimen preparation, and testing procedures for determining the splitting tensile strength of rock by diametral line compression of a disk.

NOTE 1—The tensile strength of rock determined by tests other than the straight pull test is designated as the "indirect" tensile strength and, specifically, the value obtained in Section 9 of this test is termed the "splitting" tensile strength.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 All dimension and force measurements, and stress calculations shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 653 Terminology Relating to Rock, Soil, and Contained Fluids

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D 6026 Practice for Using Significant Digits in Geotechnical Data

E 4 Practices for Force Verification of Testing Machines

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 Refer to Terminology D 653 for specific definitions.

4. Significance and Use

4.1 By definition the tensile strength is obtained by the direct uniaxial tensile test. But the tensile test is difficult and expensive for routine application. The splitting tensile test appears to offer a desirable alternative, because it is much simpler and inexpensive. Furthermore, engineers involved in rock mechanics design usually deal with complicated stress fields, including various combinations of compressive and tensile stress fields. Under such conditions, the tensile strength should be obtained with the presence of compressive stresses to be representative of the field conditions. The splitting tensile strength test is one of the simplest tests in which such stress fields occur. Since it is widely used in practice, a uniform test method is needed for data to be comparable. A uniform test is also needed to insure positively that the disk specimens break diametrally due to tensile pulling along the loading diameter.

NOTE 2—Notwithstanding the statements on precision and bias contained in this test method; the precision of this test method is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing. Reliable testing depends on many factors; Practice D 3740 provides a means of evaluating some of these factors.

5. Apparatus

5.1 *Loading Device*, to apply and measure axial load on the specimen, of sufficient capacity to apply the load at a rate conforming to the requirements in 8.3. It shall be verified at suitable time intervals in accordance with Practices E 4 and shall comply with the requirements prescribed therein.

5.2 *Bearing Surfaces*—The testing machine shall be equipped with two steel bearing blocks having a Rockwell hardness of not less than 58 HRC (see Note 3).

NOTE 3—False platens, with bearing faces conforming to the requirements of this standard, may be used. These shall be oil hardened to more than 58 HRC, and surface ground. With abrasive rocks these platens tend to roughen after a number of specimens have been tested, and hence need to be surfaced from time to time.

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved Aug. 15, 2005. Published September 2005. Originally approved in 1981. Last previous edition approved in 2004 as D 3967 – 95a (2004).

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard.

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5.2.1 *Flat Bearing Blocks*—During testing the specimen can be placed in direct contact with the machine bearing plates (or false platens, if used) (see Fig. 1). The bearing faces shall not depart from a plane by more than 0.0125 mm when the platens are new and shall be maintained within a permissible variation of 0.025 mm. The bearing block diameter shall be at least as great as the specimen thickness.

5.2.2 *Curved Bearing Blocks*. may be used to reduce the contact stresses. The radius of curvature of the supplementary bearing plates shall be so designed that their arc of contact with the specimen will in no case exceed 15° or that the width of contact is less than $D/6$, where D is the diameter of the specimen.

NOTE 4—Since the equation used in 9.1 for splitting tensile strength is derived based on a line load, the applied load shall be confined to a very narrow strip if the splitting tensile strength test is to be valid. But a line load creates extremely high contact stresses which cause premature cracking. A wider contact strip can reduce the problems significantly. Investigations show that an arc of contact smaller than 15° causes no more than 2 % of error in principal tensile stress while reducing the incidence of premature cracking greatly.

5.2.3 *Spherical Seating*—One of the bearing surfaces should be spherically seated and the other a plain rigid block. The diameter of the spherical seat shall be at least as large as that of the test specimen, but shall not exceed twice the diameter of the test specimen. The center of the sphere in the spherical seat shall coincide with the center of the loaded side of the specimen. The spherical seat shall be lubricated to assure free movement. The movable portion of the platen shall be held closely in the spherical seat, but the design shall be such that the bearing face can be rotated and tilted through small angles in any direction.

5.2.4 *Rigid Seating*—If a spherical seat is not used, the faces of the bearing blocks shall be parallel to 0.0005 mm/mm of the block diameter. This criterion shall be met when the blocks are in the loading device and separated by approximately the diameter of the test specimen.

5.3 *Bearing Strips* 0.01 D thick cardboard cushion, where D is the specimen diameter; or up to 0.25 in. thick plywood cushion are recommended to place between the machine bearing surfaces (or supplementary bearing plates; if used) and the specimen to reduce high stress concentration.

NOTE 5—Experiences have indicated that test results using the curved supplementary bearing plates and bearing strips, as specified in 5.2.2 and 5.3, respectively, do not significantly differ from each other, but there may be some consistent difference from the results of tests in which direct contact between the specimen and the machine platen is used.

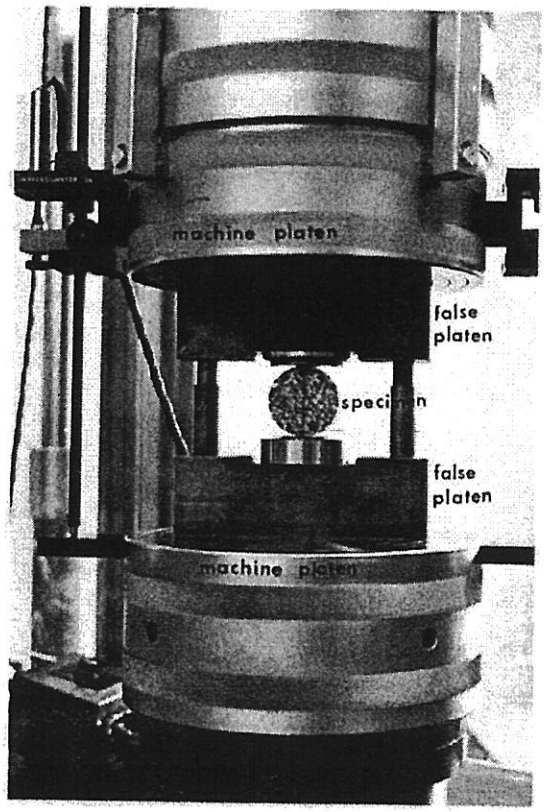

FIG. 1 One Proposed Testing Setup for Splitting Tensile Strength

6. Sampling

6.1 The specimen shall be selected from the core to represent a true average of the type of rock under consideration. This can be achieved by visual observations of mineral constituents, grain sizes and shape, partings, and defects such as pores and fissures.

7. Test Specimens

7.1 *Dimensions*—The test specimen shall be a circular disk with a thickness-to-diameter ratio (t/D) between 0.2 and 0.75. The diameter of the specimen shall be at least 10 times greater than the largest mineral grain constituent. A diameter of 50 mm (1-15/16 in.) (NX wireline core) will generally satisfy this criterion.

NOTE 6—When cores smaller than the specified minimum must be tested because of the unavailability of material, notation of the fact shall be made in the test report.

NOTE 7—If the specimen shows apparent anisotropic features such as bedding or schistosity, care shall be exercised in preparing the specimen so that the orientation of the loading diameter relative to anisotropic features can be determined precisely.

7.2 *Number of Specimens*—At least ten specimens shall be tested to obtain a meaningful average value. If the reproducibility of the test results is good (coefficient of variation less than 5 %), a smaller number of specimens is acceptable.

7.3 The circumferential surface of the specimen shall be smooth and straight to 0.50 mm (0.020 in.).

7.4 Cut the ends of the specimen parallel to each other and at right angles to the longitudinal axis. The ends of the specimen shall not deviate from perpendicular to the core axis by more than 0.5°. This requirement can be generally met by cutting the specimen with a precision diamond saw.

7.5 Determine the diameter of the specimen to the nearest 0.25 mm (0.01 in.) by taking the average of at least three measurements, one of which shall be along the loading diameter.

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7.6 Determine the thickness of the specimen to the nearest 0.25 mm (0.01 in.) by taking the average of at least three measurements, one of which shall be at the center of the disk.

7.7 The moisture conditions of the specimen at the time of test can have a significant effect upon the indicated strength of the rock. The field moisture condition for the specimen shall be preserved until the time of test. On the other hand, there may be reasons for testing specimens at other moisture contents, including zero, and preconditioning of specimen when moisture control is needed. In any case, tailor the moisture content of the test specimen to the problem at hand and report it in accordance with 10.1.6.

8. Procedure

8.1 *Marking*—The desired vertical orientation of the specimen shall be indicated by marking a diametral line on each end of the specimen. These lines shall be used in centering the specimen in the testing machine to ensure proper orientation, and they are also used as the reference lines for thickness and diameter measurements.

NOTE 8—If the specimen is anisotropic, take care to ensure that the marked lines in each specimen refer to the same orientation.

8.2 *Positioning*—Position the test specimen to ensure that the diametral plane of the two lines marked on the ends of the specimen lines up with the center of thrust of the spherically seated bearing surface to within 1.25 mm (0.05 in.).

NOTE 9—A good line loading can often be attained by rotating the specimen about its axis until there is no light visible between the specimen and the loading platens. Back lighting helps in making this observation.

8.3 *Loading*—Apply a continuously increasing compressive load to produce an approximately constant rate of loading or deformation such that failure will occur within 1 to 10 min of loading, which should fall between 0.05 and 0.35 MPa/s (500 and 3000 psi/min) of loading rate, depending on the rock type.

NOTE 10—Results of tests by several investigators indicate that rates of loading at this range are reasonably free from rapid loading effects.

9. Calculation

9.1 The splitting tensile strength of the specimen shall be calculated as follows:

$$\sigma_t = 2P/\pi LD \quad (1)$$

and the result shall be expressed to the appropriate number of significant figures (usually 3),

where:

σ_t = splitting tensile strength, MPa (psi),
P = maximum applied load indicated by the testing machine, N (or lbf),
L = thickness of the specimen, mm (or in.), and
D = diameter of the specimen, mm (or in.).

10. Report

10.1 The report shall include as much of the following as possible:

10.1.1 Sources of the specimen including project name and location, and if known, storage environment. The location is frequently specified in terms of the borehole number and depth of specimen from collar of hole.

10.1.2 Physical description of the specimen including rock type; location and orientation of apparent weakness planes, bedding planes, and schistosity; large inclusions or inhomogeneities, if any.

10.1.3 Dates of sampling and testing.

10.1.4 Specimen diameter and length, conformance with dimensional requirements, direction of loading if anisotropy exists. Type of contact between the specimen and the loading platens.

10.1.5 Rate of loading or deformation rate.

10.1.6 General indication of moisture condition of the specimen at time of test such as as-received, saturated, laboratory air dry, or oven dry. It is recommended that the moisture condition be more precisely determined when possible and reported as either water content or degree of saturation.

10.1.7 Splitting tensile strength of each specimen as calculated, average splitting tensile strength of all specimens, standard deviation or coefficient of variation.

10.1.8 Type and location of failure. A sketch of the fractured specimen is recommended.

10.1.9 For purposes of comparing calculated values with specified limits, the calculated values shall be rounded to the nearest decimal given in the specification limits in accordance with the provisions of Practice D 6026.

11. Precision and Bias

11.1 An interlaboratory study was conducted in which seven laboratories each tested five specimens of four different rocks. The specimens were cored by a single laboratory from a common set of samples and randomly distributed to the testing laboratories for testing. The study was carried out in accordance with Practice E 691. Details of the study are given in ISR Research Report No. PS #D18.12-R01, 1992, and its Addendum, 1994. The table below gives the repeatability limit (within a laboratory) and reproducibility limit (between laboratories) for the method.

11.1.1 The probability is approximately 95 % that two test results obtained in the same laboratory on the same material will not differ by more than the repeatability limit. Likewise, the probability is approximately 95 % that two test results obtained in different laboratories on the same material will not differ by more than reproducibility limit.

TABLE 1 Splitting Tensile Strength (MPa)

	Berea Sandstone	Salem Limestone	Tennessee Marble	Barre Granite
Average Value	3.85	4.92	9.39	13.66
Repeatability Limit	1.24	1.56	3.63	4.31
Reproducibility Limit	1.37	1.74	5.38	4.98

11.2 The variability of rock and resultant inability to determine a true reference value prevent development of a meaningful statement of bias.

12. Keywords

12.1 compression testing; indirect tensile strength; loading tests; rock; splitting tensile strength; tension (tensile) properties/tests

D 3967 – 05

SUMMARY OF CHANGES

In accordance with Committee D18 policy. this section identifies the location of changes to this standard since the last edition (D 3967 – 95a (2004)) that may impact the use of this standard.

(*1*) Added D 6026 caveat in Section 1.
(*2*) Added D 653, D 3740, and D 6026 in Section 2.
(*3*) Inserted Section 3 Terminology.
(*4*) Renumbered all subsequent sections.
(*5*) Inserted Summary of Changes.
(*6*) Added Note 2 D 3740 caveat and renumbered all subsequent notes.
(*7*) Added D 6026 caveat in Section 10.
(*8*) Deleted "of the" in Fig. 1 caption
(*9*) In section 10.1.9, changed decimeal to decimal.

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Designation: D 5607 – 02 (Reapproved 2006)

Standard Test Method for Performing Laboratory Direct Shear Strength Tests of Rock Specimens Under Constant Normal Force[1]

This standard is issued under the fixed designation D 5607; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method establishes requirements and laboratory procedures for performing direct shear strength tests on rock specimens. It includes procedures for both intact rock strength and sliding friction tests which can be performed on specimens that are homogeneous, or have planes of weakness, including natural or artificial discontinuities. Examples of an artificial discontinuity include a rock-concrete interface or a lift line from a concrete pour. Discontinuities may be open, partially or completely healed or filled (that is, clay fillings and gouge). Only one discontinuity per specimen can be tested. The test is usually conducted in the undrained state with an applied constant normal load. However, a clean, open discontinuity may be free draining, and, therefore, a test on a clean, open discontinuity could be considered a drained test. During the test, shear strength is determined at various applied stresses normal to the sheared plane and at various shear displacements. Relationships derived from the test data include shear strength versus normal stress and shear stress versus shear displacement (shear stiffness).

NOTE 1—The term "normal force" is used in the title instead of normal stress because of the indefinable area of contact and the minimal relative displacement between upper and lower halves of the specimen during testing. The actual contact areas during testing change, but the actual total contact surface is unmeasurable. Therefore nominal area is used for loading purposes and calculations.

NOTE 2—Since this test method makes no provision for the measurement of pore pressures, the strength values determined are expressed in terms of total stress, uncorrected for pore pressure.

1.2 This standard applies to hard rock, soft rock, and concrete.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids

D 2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

E 4 Practices for Force Verification of Testing Machines

E 122 Practice for Calculating Sample Size to Estimate, With a Specified Tolerable Error, the Average for a Characteristic of a Lot or Process

3. Terminology

3.1 For common definitions of terms used in this standard, refer to Terminology D 653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *apparent stress*—nominal stress, that is, external load per unit area. It is calculated by dividing the externally applied load by the nominal area.

3.2.2 *Asperity*:

3.2.2.1 *quality*—the roughness of a surface.

3.2.2.2 *feature*—a surface irregularity ranging from sharp or angular to rounded or wavy.

3.2.2.3 *asperities*—the collection of a surface's irregularities that account for the surface's roughness.

3.2.3 *Discontinuity*:

3.2.3.1 An abrupt change, interruption, or break in the integrity or physical properties of rock, such as a bedding plane, fracture, cleavage, crack, joint, or fault.

3.2.3.2 A *gapped discontinuity* consists of opposing rock surfaces separated by an open or filled space. A *tight discontinuity* consists of opposing rock surfaces in intimate and generally continuous contact; it may be valid to treat such a discontinuity as a single surface.

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved May 1, 2006. Published June 2006. Originally approved in 1994. Last previous edition approved in 2002 as D 5607 – 02.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard.

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3.2.3.3 A discontinuity's opposing rock surfaces may be *planar* to *nonplanar* and *matching* to *misfit*.

3.2.4 *intact shear strength*—the peak shear resistance (in units of stress) of an intact rock specimen or of a specimen containing a completely healed discontinuity.

3.2.5 *nominal area*—area obtained by measuring or calculating the cross-sectional area of the shear plane. It is calculated after its relevant cross-sectional dimensions are determined.

3.2.6 *residual shear strength*—the shear stress, (see Fig. 1), corresponding to a specific normal stress, for which the shear stress remains essentially constant with increasing shear displacement. In most cases, the shear stress after reaching Point A is the residual shear strength.

3.2.7 *shear stiffness*—represents the resistance of the specimen to shear displacements under an applied shear force prior to reaching the peak shear strength. It is calculated by dividing the applied apparent shear stress by the resulting shear displacement (slope of the curve prior to peak shear strength, Fig. 1).

3.2.8 *sliding friction shear strength*—the peak shear resistance (in units of stress) of a rock specimen containing an open discontinuity.

4. Summary of Test Method

4.1 While maintaining a constant force normal to the nominal shear plane of the specimen, an increasing external shear force is applied along the designated shear plane to cause shear displacement. The applied normal and shear forces and the corresponding normal and shear displacements are measured and recorded. These data are the basis for calculating the required parameters.

5. Significance and Use

5.1 Determination of shear strength of a rock specimen is an important aspect in the design of structures such as rock slopes, dam foundations, tunnels, shafts, waste repositories, caverns for storage, and other purposes. Pervasive discontinuities (joints, bedding planes, shear zones, fault zones, schistocity) in a rock mass, and genesis, crystallography, texture, fabric, and other factors can cause the rock mass to behave as an anisotropic and heterogeneous discontinuum. Therefore, the precise prediction of rock mass behavior is difficult.

5.2 For nonplanar joints or discontinuities, shear strength is derived from a combination base material friction and overriding of asperities (dilatancy), shearing or breaking of the asperities, and rotations at or wedging of the asperities. Sliding on and shearing of the asperities can occur simultaneously. When the normal force is not sufficient to restrain dilation, the shear mechanism consists of the overriding of the asperities. When the normal load is large enough to completely restrain dilation, the shear mechanism consists of the shearing off of the asperities.

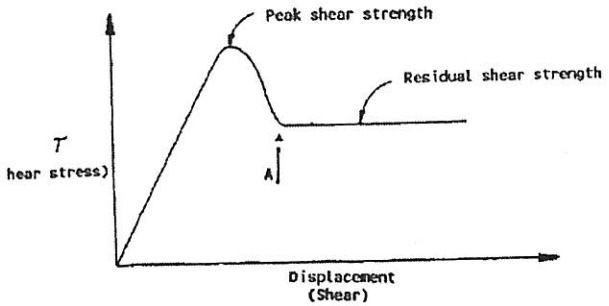

FIG. 1 Generalized Shear Stress and Shear Displacement Curve

5.3 Using this test method to determine the shear strength of an intact specimen may generate overturning moments which could result in an inclined shear break.

5.4 Shear strength is influenced by the overburden or normal pressure; therefore, the larger the overburden pressure, the larger the shear strength.

5.5 In some cases, it may be desirable to conduct tests in situ rather than in the laboratory to determine the representative shear strength of the rock mass, particularly when design is controlled by discontinuities filled with very weak material.

NOTE 3—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. AGencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing/sampling/inspection and the like. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors, Practice D 3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Testing Machine*—Loading device, to apply and register normal and shear forces on the specimens. It must have adequate capability to apply the shear force at a rate conforming to the specified requirements. It shall be verified at suitable time intervals in accordance with the procedures given in Practices E 4, and comply with the requirements prescribed therein. The resultant of the shear force passes through the center of the intended shear zone or the centroid of the shear plane surface area to minimize adverse moments.

NOTE 4—There are many different direct shear device designs. Although details may vary concerning how to encapsulate specimens into shear boxes as well as details for assembling the machine, the determinations are usually similar.

6.2 Fig. 2 is a schematic of an example shear box, an integral part of the machine.

6.3 *Pressure-Maintaining Device*—A hydraulic component that will hold a pressure, within specified tolerances, within the hydraulic system.

6.4 *Specimen Holding Rings*—Aluminum or steel holding rings (see Fig. 3) with internal dimensions sufficient to accommodate specimens mounted in an encapsulating medium.

6.5 *Spacer Plates*:

6.5.1 *Split Spacer Plates*—Plastic (or other suitable material) plates of varying thicknesses for isolating an intact specimen's shear zone from the encapsulating compound (see Fig. 3).

6.5.2 *Non-split Spacer Plates*—Plastic (or other suitable material) plates of varying thicknesses that have a circular or oval hole in the center and are used for non-intact specimens.

6.6 *Displacement Measuring Device*— Linear variable differential transformers (LVDTs) may be used as normal and shear displacement measuring devices. Other devices such as

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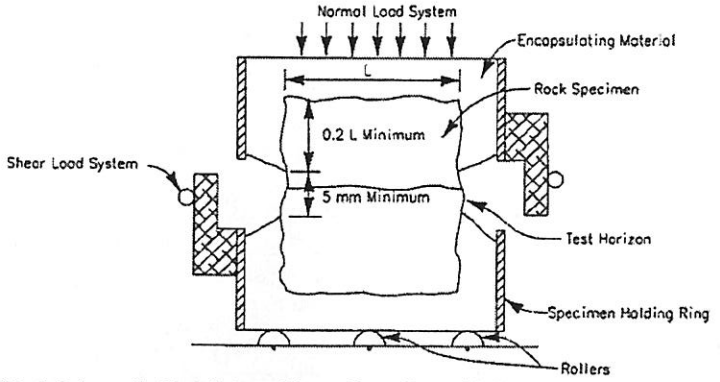
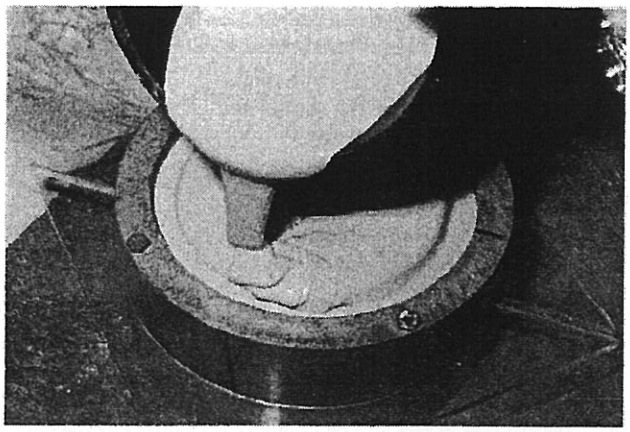


FIG. 2 Schematic Test Setup—Direct Shear Box with Encapsulated Specimen



NOTE 1—Note the split plastic plates for isolating the shear zone.
FIG. 3 View Showing Pouring Encapsulating Material Around Upper Half of Specimen

dial indicators and DCDTs, are satisfactory. Four devices are used to measure the normal displacement and provide a check on specimen rotation about an axis parallel to the shear zone and perpendicular to the shearing direction. Another device measures the shear displacement. These displacement devices should have adequate ranges of travel to accommodate the displacements, ±13 mm (±0.5 in.). Sensitivities of these devices should be 0.025 mm (0.001 in.) for shear displacement and 0.0025 mm (0.0001 in.) for normal displacement. Ensure that the devices are located away from the loading direction so as not to be damaged in sudden failures.

6.7 *Data Acquisition Equipment*—A computer may be used to control the test, collect data, and plot results.

7. Reagents and Materials

7.1 *Miscellaneous Items*—Carpenter's contour gage for measuring joint surface roughness, roughness chart (see Fig. 4[3]), filler or modelling clay, calipers, spatula, circular clamps,

[3] Barton, N., and Choubey, V., *The Shear Strength of Rock Joints in Theory and Practice*, Rock Mechanics, 10, 1977.

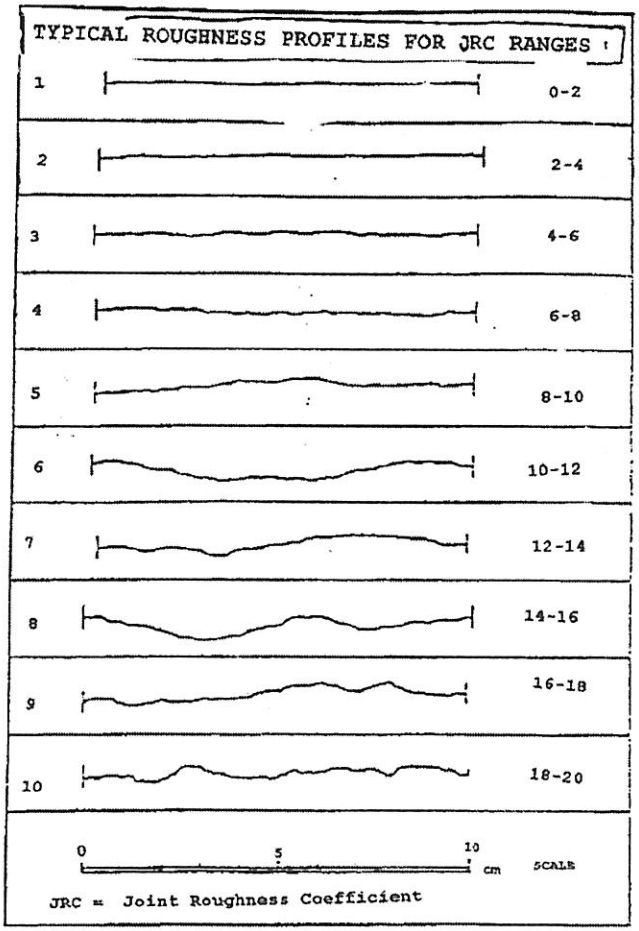


FIG. 4 Roughness Profiles and Corresponding JRC Values Associated With Each One[5]

utility knife, towels, markers, plotting papers, encapsulating compound, and camera.

8. Test Specimens

8.1 *Sampling*:

8.1.1 *Intact Specimen*—Care should be exercised in core drilling, handling, and sawing the samples to minimize mechanical damage to test specimens. No liquids other than water should be in contact with a test specimen.

NOTE 5—To obtain relevant parameters for the design, construction, or maintenance of major engineering structures, test specimens should be representative of the host properties as nearly as practicable.

8.1.2 *Specimen with a Single Discontinuity*—Rock samples are collected and shipped using methods that minimize disturbance of test zones. A specimen's dimensions and the location of a discontinuity to be tested should allow sufficient clearance for adequate encapsulation. The in situ integrity of discontinuities in a sample is to be maintained from the time of sampling until the discontinuity is tested. Tape, plastic wrap, or other means may be utilized to preserve the in situ moisture content along the test zone. Plastic half rounds, core boxes, freezing, or other methods may be utilized to bridge the discontinuities and prevent differential movement from occurring along the discontinuity. This is especially important for discontinuities containing any soft, or weak material.

8.2 *Size and Shape*—The height of specimen shall be greater than the thickness of the shear (test) zone and sufficient to embed the specimen in the holding rings. Specimens may have any shape such that the cross-sectional areas can be readily determined. In most cases the least cross-sectional dimension of the specimen should be at least 10 times the largest grain size in the specimen. The test plane should have a minimum area of 1900 mm^2 (3 $in.^2$).

8.3 *Storage*—Samples should be stored out of the weather after they are obtained at the work site (field) in order to preserve their integrity.

8.4 *Moisture Condition*—If specimens are to be tested near the natural moisture condition of the host material, they should be stored and transported in moisture-proof containers, or coated with thin sheets of plastic film and wax.

9. Calibration and Standardization

9.1 *Load Monitoring Devices*—The load monitoring devices (such as load cells, proving rings, hydraulic gages) should be calibrated according to Practices E 4.

9.2 *Displacement Measuring Devices*— Measuring devices are to be calibrated at least once a year.

10. Procedure

10.1 *Moisture Condition*—If required, the moisture condition of the shear zone are determined and reported according to Test Method D 2216.

10.2 *Test Specimen*:

10.2.1 *Measurements*:

10.2.1.1 *Cross-Sectional Area of Regular Geometrical Shapes*—The relevant dimensions of the specimen at the shear zone cross section are measured to the nearest 0.025 mm (0.001 in.) using caliper or micrometer. Then, the apparent cross-sectional area of the intact specimen is calculated. For inclined core the apparent area can be determined by measuring the diameter and angle of tip θ.

10.2.1.2 *Cross-Sectional Area of Nongeometrical Shapes*—The outline of the cross-sectional area of the specimen or shear plane is traced on paper and the area measured with a planimeter.

10.2.1.3 *Joint Roughness of a Clean Discontinuity*—Before and after testing, a carpenter contour gage is used to measure joint roughness in the direction of anticipated shear displacement. When all the prongs of the gage are lowered on a flat and hard surface, the tips of the prongs will fall on a straight line. Place this straight line pronged gage onto the shear plane and lower all the prongs to make contact with the shear surface. Remove the gage. The tips of the gage trace the shear plane surface along the line of shearing. Trace the tips of the prongs onto paper, and compare this tracing to match with one of the lines on Fig. 4; then, select and record the corresponding joint roughness coefficient.

10.2.1.4 *Joint Roughness for Partially or Fully Healed Discontinuity*—After failure occurs in a shear test, contour gages and the standard roughness chart are used to determine the joint roughness coefficient.

10.2.1.5 Take before and after test photographs of each specimen.

10.2.2 *Encapsulation*:

10.2.2.1 *Specimen Encapsulation*—Place a thick plastic sheet on a suitable level surface. Place the lower half of the specimen holding ring on the plastic sheet.

(a) (*a*) Porous rock that is to be tested at its natural water content should be coated with a nonabsorbing sealer to prevent absorption of water from the encapsulating compound.

(b) (*b*) *Encapsulating Compound*—Prepare the encapsulating compound in accordance with the directions of the manufacturer. The preparation is necessary to impart required properties of quick setting and adequate strength to the cured encapsulating compound. A super strength gypsum cement is recommended for best results.

(c) (*c*) *For a Specimen Containing a Discontinuity*—Position the lower half of the specimen (if the discontinuity is gapped, that is, open jointed) centrally in the lower half of the specimen holder. Ensure that the shear horizon to be tested is secured in the correct position and orientation so that the shear force will be in the same plane as the test zone. Ensure that the bottom of the lower half of the specimen is resting on the plastic sheet. Provide adequate support to the specimen so that it is maintained in its position while the encapsulating material cures (see Fig. 5). Pour the encapsulating material carefully into the annular space between the lower half of specimen and the lower half of the specimen holding ring. Stop pouring just below the general plane of the test zone (see Fig. 6). Do not disturb the specimen holding ring assembly after pouring the encapsulating compound. After the bottom encapsulated material has sufficiently cured, place a split spacer plate of specified thickness on the lower ring such that its cutout edge encircles the encapsulated lower half of the specimen and encompasses the test zone thickness. If needed, apply a layer of silicon grease over the surface of the encapsulated material. Place the

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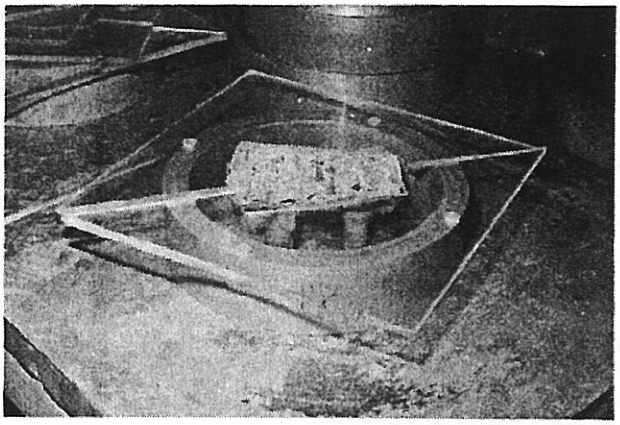
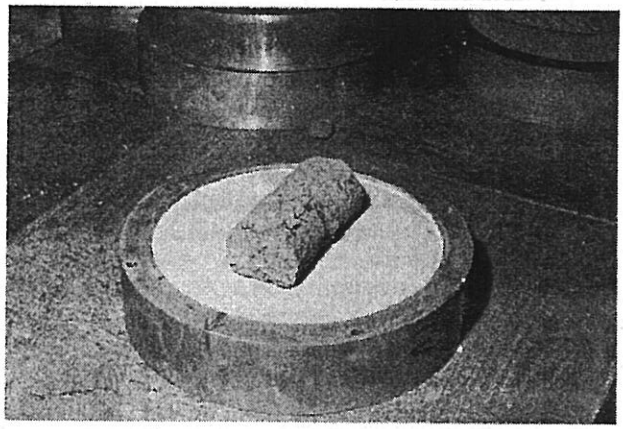


FIG. 5 Specimen Supported in Place By Modeling Clay Pins Which Are Removed After Encapsulating Material Cures and the Resulting Holes Filled With Encapsulating Material



NOTE 1—In both Fig. 5 and Fig. 6 the shear box is cylindrical. Square boxes work just as well.

FIG. 6 Lower Half of a Specimen Encapsulated in Holding Ring

upper half of the test specimen onto the encapsulated lower half. Fill the annular space between the specimen testing surface and the semicircular or circular edge of the spacer plate with modeling clay. Adjust the position of the upper half of the specimen until the surfaces of the test horizon are correctly mated. Lower the upper half of the specimen holder onto the split spacer plate without disturbing the position of the top half of the specimen. Connect the two halves of the specimen holding ring with bolts. Pour encapsulating compound into the annular space between the top half of the specimen holder and the top half of the specimen. Do not disturb the assembly until the encapsulating compound cures. Remove the spacer plates to expose the test horizon for shear testing (see Fig. 7).

(d) (*d*) *For a Specimen With A Partially or Fully Tight Discontinuity or an Intact Specimen*—Position the specimen concentrically into the lower half of the holding ring, and pour the prepared encapsulating compound into the annular space between the specimen and the lower half of the specimen

FIG. 7 Removing Spacer Plates After Encapsulating Material Has Cured

holding ring. Allow the compound to cure without disturbing the assembly. Place a split spacer plate of a thickness equal to the height of the shear test zone, and fill the annular space between the circular or semicircular edge of the spacer plate and the specimen with clay. Place the upper half of the specimen holding ring onto the lower half, and connect the two halves of the specimen holding ring with bolts, while not disturbing the encapsulated lower half of the specimen. Pour the encapsulating compound into the annular space between the upper half of the bolted holding ring and the upper half of the specimen (see Fig. 3). Allow the encapsulating compound to cure without disturbance. Remove the spacer plate, and expose the test zone for shear testing.

(e) (*e*) Discard the specimen if the test zone is contaminated with the encapsulating compound.

10.3 *Soaking of Encapsulated Specimen*— If the shear strength of a saturated specimen is desired, allow the encapsulated specimen to soak in water for at least 48 h before testing. The soaking period can be altered. Soaking is not recommended for rocks that may react with water such as evaporites.

10.4 *Mounting into the Shear Box*—Mount and orient the encapsulated specimen with its top and bottom holding rings in the bottom shear box of the testing machine. Lower the top half of the shear box onto the upper half of the specimen. Remove the bolts that connect the upper and lower halves of the specimen holding rings.

10.5 *Mounting of Displacement Devices*— Place four displacement measuring devices on the lower surface of the testing machine, at the four corners of the lower half of the shear box and contacting the upper half of the shear box. These devices are used to measure normal displacement and to provide a check on rotation of the specimen during testing. Mount one displacement device on the machine in such a manner to measure the shear displacement of the specimen during the test. Ensure sufficient travel and contact for the device to measure displacements.

10.6 *Load Application*:

10.6.1 *Seating Load*—Apply a small seating normal load on the order of 450 to 900 N (100 to 200 lb), depending on

specimen size. Account for the mass of the normal load system when placing a specified normal stress on the specimen.

10.6.2 *Sliding Friction Test*:

10.6.2.1 *Normal Load*—Continuously increase the load normal to the shear zone at a constant rate until the lowest selected load is attained, and record consequent normal displacements. Do not apply the shear load until normal displacement has stabilized. Stabilization is complete when the change in consequent normal displacement is less than 0.05 mm (0.002 in.) in 10 min. Maintain a constant normal load (force) during shear testing.

10.6.2.2 *Shear Load*—After the selected normal load has been stabilized, apply the shear load continuously at the selected rate of shear displacement. A minimum of 10 sets of readings is suggested to be taken before reaching the peak shear strength. After reaching the peak shear strength, loading should continue and readings taken until a residual shear strength is established (Fig. 1). An *X-Y* recorder may be used if continuous readings are required.

10.6.2.3 *Normal Load Increment*—Establish the residual shear strength. This may require reversing the shear load or resetting to account for travel restrictions of the displacement measuring instruments. Remove the shear load, and increase the normal load to another level. Again, apply the shear load to establish a second level of peak shear strength and residual shear strength. Bear in mind that with each repeat test the surface will be further damaged. Repeat the procedures in 10.6.2.1 and 10.6.2.2, as required. Prior to each repeat ensure that adequate travel is available for each displacement device.

10.6.2.4 *Measurements of Normal Displacements*—Measure normal displacements with the four vertical displacement measuring devices at each shear load observation. Compare the four readings and determine possible specimen rotation which would be indicated by differences in the readings of the four devices. Report the normal displacement of the specimen as the average of the four readings. Degree of joint closure and dilation angle can be determined from these measurements.

10.6.2.5 *Measurements of Shear Displacements*—Measure and record shear displacement at suitable intervals, that is, 0.025 or 0.05 mm (0.001 or 0.002 in.), with the horizontal displacement measuring device mounted on the shear box.

10.6.3 *Intact Shear Strength Test*:

10.6.3.1 *Normal Load*—Continuously increase normal load at a constant rate until the selected load is attained. Maintain a constant normal load on the shear surface during the test.

10.6.3.2 *Shear Load*—After stabilization of normal load, increase the shear load continuously in such a way as to attain failure. An *X-Y* recorder may be used if continuous readings are required.

10.6.3.3 Sliding friction tests (10.6.2) may then be performed.

10.6.3.4 Repeat procedures in 10.6.3.1 and 10.6.3.3 on other specimens. The number of specimens to be tested depends upon material availability, however, a minimum of three is recommended.

10.7 *Photographic Record*—Photograph each specimen before and after testing.

NOTE 6—In situations of seismic loading, a specimen may slide back and forth along joints or other discontinuities. Reversed shearing can also occur following vibrations of rock slopes or tunnels that may cause new shear stresses on discontinuities in a direction opposite to the initial shear stress. In such cases, determination of shear strength properties under reversible shear loads will be required.

11. Calculations

11.1 Calculate the nominal cross-sectional areas of test specimens from initial cross-sectional dimensions (see 10.2.1.1 or 10.2.1.2), and express results to the nearest 6.5 mm^2 (0.01 $in.^2$). For specimens which have a test feature which is not normal to the core axis, the area is determined by:

$$A = \frac{\pi D^2}{4\cos\Theta} \quad (1)$$

where:

D = core diameter, and

Θ = angle of tip.

11.2 Calculate the following engineering stresses:

$$\text{Apparent normal stress } \sigma = \frac{P_n}{A} \quad (2)$$

$$\text{Apparent shear stress } \tau = \frac{P_s}{A} \quad (3)$$

where:

P_n = normal load,

P_s = shear load, and

A = nominal initial cross-sectional area (see Note 1).

11.3 Make the following data plots:

11.3.1 Curves to depict relationships of (a) shear stress versus shear displacement, (b) peak shear strength versus normal stress as shown on Fig. 8, and (c) residual shear strength versus shear displacement.

11.3.2 Curves for preselected normal stresses to show the relationships between (a) shear stress versus shear sisplacement, and (b) normal displacement versus shear displacement as shown in the example plot on Fig. 9.

12. Report

12.1 Report the following information:

12.1.1 Source of specimen including project name, feature, location, depth, drill hole number and angle, and conditions of storage environment. Also describe how specimens were prepared for storage, handling, and transportation.

12.1.2 Physical description of specimen including material type, and location and orientation (strike, dip) of discontinuities, such as: apparent weakness planes, bedding planes, schistocity, and large inclusions, if any.

12.1.3 General indication of the moisture condition of the test specimen at the time of testing, such as, moist, saturated, as-received, laboratory air dry, or oven dry. In some cases, it may be necessary to report the actual moisture content as determined using Test Method D 2216.

12.1.4 The initial shape and nominal cross-sectional area of the specimen. Include joint roughness coefficient from chart.

12.1.5 Date of sampling and testing.

12.1.6 The number of specimens tested.

12.1.7 The type of encapsulating material used.

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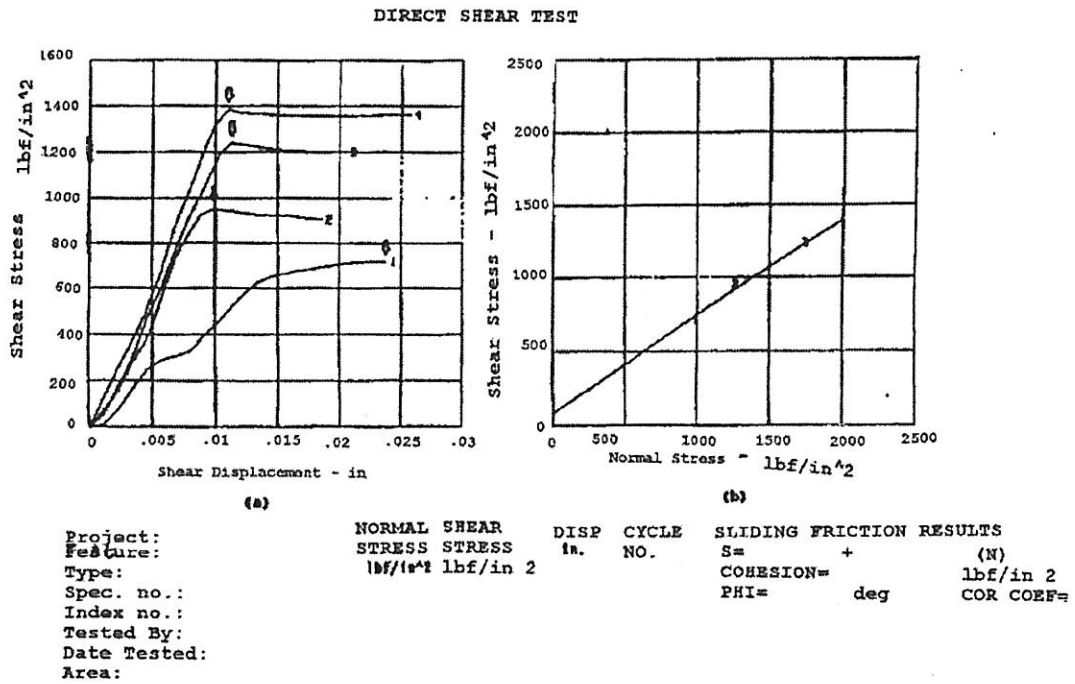

FIG. 8 Typical Presentation Sliding Friction Test Results: (a) Shear Stress and Shear Displacement and (b) Shear Strength and Normal Stress

12.1.8 The displacement measuring device readings and reduced displacements.

12.1.9 The applied loads (normal and shear) during testing.

12.1.10 Description of failure, including photographs of the specimen before and after the test.

12.1.11 Tables and graphical plots of individual and combined test results of testing as follows:

Fig. 8 Typical Presentation Sliding Friction Test Results (a) Shear Stress and Shear Displacement, and (b) Shear Strength and Normal Stress.

Fig. 9 (a) Shear Stress and Shear Displacement, and (b) Normal Displacement and Shear Displacement.

Fig. 10 General Information

Fig. 11 Test Records

Fig. 12 Final Reduced Data

Fig. 13 Data Summary

13. Precision and Bias

13.1 *Precision*—Data are proposed to be evaluated by means of an interlaboratory test program for rock properties to determine the precision of this test method.

13.2 *Bias*—There is no accepted reference value for this test method; therefore, bias cannot be determined.

14. Keywords

14.1 asperity; direct shear strength; discontinuity; displacement; rock; roughness; sliding friction; stress

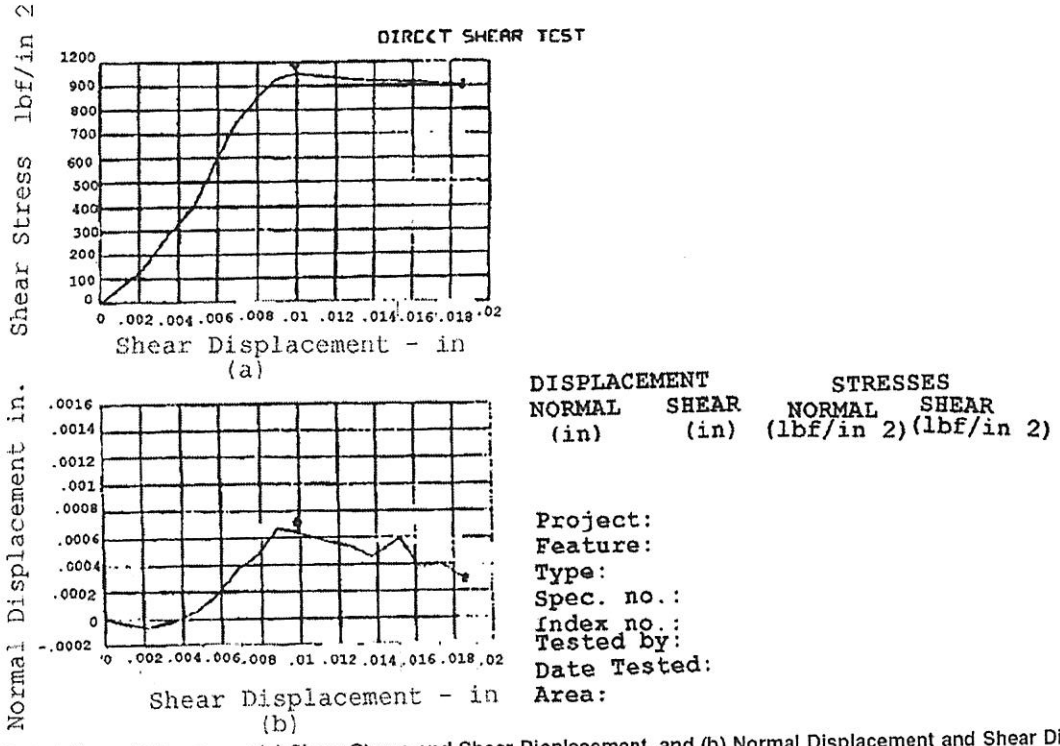

FIG. 9 At Selected Normal Stress σ_{L1}: (a) Shear Stress and Shear Displacement, and (b) Normal Displacement and Shear Displacement

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Bureau of Reclamation	Direct Shear Test Data Sheet	
Project:	Feature:	
Tested by: Date:	Calculated by: Date:	Checked by: Date:
Sample Number	Type of Feature:	
Drill Hole	Surface Description:	
Depth feet meters	Angle from Core Axis	

Data from drill logs (if available)

Rock type:
Angle:
Infillings:
Roughness:
Photographs Taken:

	before	after
Surface	__ y __ n	__ y __ n
Profile	__ y __ n	__ y __ n

__ Calculated
__ Digitized

dia 1 _____ average dia _____ area _____
dia 2 _____

Surface Contours:

Parallel to Shearing:

top

bottom

Perpendicular to Shear:

top

bottom

Surface Contour Rating: _____
(See Chart on Reverse)

FIG. 10 General Information

PROJECT	CONT.	FEATURE	CONT.	SPEC. NO.	TESTED BY	DATE
SIXTH WATE	R AQUEDUCT	JOINT BEHA	VIOR TESTS	702-79 4	JSM	6/20/90
D DISTANCE	DIAMETER	AREA	B OR S	DELTA LOAD	DELTA DISP	NorDeadLoa
0.22	NX	2.344	S	100	0.001	78
TYPE	CONT	CONT	SYS 2 L/S	SCALE Y/N	BREAK ONLY	ClosureY/N
SMOOTH-2				Y		Y
INDEX NO.	CONT	CONT				
641-94						
ARROW L#1	ARROW L#2	ARROW L#3	ARROW L#4	ARROW L#5	ARROW L#6	ARROW L#7
A	A	A	A	A	A	A
ARROW L#8	ARROW L#9	ARROW L#10				
A	A	A				

NORMAL lbs	SHEAR lbs	DISP ins	TOUCH ins	2a ins	2b ins	2c ins	2d ins	S/LIN		DATE	TIME
75	-23	-.5607	.3092	.3911	.2516	.3293	.2649	3	1	20 Jun	14:31:0
250	-27	-.5598	.3103	.3913	.2526	.3308	.2665	3	2	20 Jun	14:31:3
500	-29	-.5591	.3111	.3913	.2520	.3344	.2667	3	3	20 Jun	14:32:1
1000	39	-.5657	.3171	.3913	.2485	.3436	.2849	3	4	20 Jun	14:33:4
1249	41	-.5655	.3175	.3916	.2498	.3442	.2846	3	5	20 Jun	14:35:4
1750	39	-.5660	.3180	.3914	.2510	.3458	.2839	3	6	20 Jun	14:37:1
2000	35	-.5655	.3184	.3915	.2513	.3472	.2836	3	7	20 Jun	14:37:5
1750	37	-.5660	.3180	.3910	.2513	.3462	.2836	3	8	20 Jun	14:38:1
1251	40	-.5659	.3179	.3917	.2505	.3451	.2842	3	9	20 Jun	14:38:5
-1000	44	-.5661	.3175	.3914	.2511	.3429	.2848	3	10	20 Jun	14:39:3
1000	88	-.5308	.3182	.3915	.2500	.3450	.2863	3	11	20 Jun	14:42:5
1001	102	-.5297	.3183	.3919	.2502	.3449	.2863	3	12	20 Jun	14:43:0
1009	240	-.5286	.3183	.3918	.2497	.3451	.2866	3	13	20 Jun	14:43:1
1022	452	-.5275	.3184	.3917	.2492	.3453	.2872	3	14	20 Jun	14:43:2
1033	659	-.5263	.3183	.3916	.2488	.3454	.2876	3	15	20 Jun	14:43:3
1038	763	-.5251	.3184	.3916	.2484	.3459	.2877	3	16	20 Jun	14:43:3
1038	794	-.5241	.3183	.3914	.2479	.3460	.2879	3	17	20 Jun	14:43:4
1031	856	-.5228	.3184	.3919	.2476	.3462	.2881	3	18	20 Jun	14:43:4
1020	1000	-.5218	.3184	.3916	.2469	.3467	.2883	3	19	20 Jun	14:43:5
1007	1138	-.5207	.3183	.3915	.2464	.3467	.2885	3	20	20 Jun	14:43:5
1004	1287	-.5197	.3183	.3916	.2459	.3472	.2887	3	21	20 Jun	14:44:0
1001	1427	-.5185	.3183	.3914	.2453	.3477	.2888	3	22	20 Jun	14:44:1
1001	1554	-.5174	.3182	.3914	.2446	.3479	.2889	3	23	20 Jun	14:44:1
1001	1612	-.5164	.3183	.3913	.2438	.3486	.2894	3	24	20 Jun	14:44:2
1001	1637	-.5154	.3184	.3913	.2433	.3492	.2898	3	25	20 Jun	14:44:2
1001	1664	-.5143	.3185	.3914	.2426	.3496	.2903	3	26	20 Jun	14:44:3
999	1686	-.5131	.3186	.3915	.2422	.3499	.2907	3	27	20 Jun	14:44:3
999	1712	-.5121	.3187	.3916	.2417	.3501	.2913	3	28	20 Jun	14:44:3
1000	1734	-.5109	.3187	.3915	.2413	.3503	.2917	3	29	20 Jun	14:44:4
1000	1756	-.5094	.3188	.3915	.2407	.3508	.2923	3	30	20 Jun	14:44:4
1000	1764	-.5082	.3189	.3916	.2400	.3510	.2931	3	31	20 Jun	14:44:5
-1000	1766	-.5070	.3190	.3918	.2396	.3511	.2936	3	32	20 Jun	14:44:5
1251	74	-.5076	.3202	.3916	.2399	.3535	.2959	3	33	20 Jun	14:46:4
1252	217	-.5066	.3203	.3916	.2394	.3542	.2959	3	34	20 Jun	14:46:4
1256	399	-.5054	.3203	.3918	.2388	.3545	.2961	3	35	20 Jun	14:46:5
1268	724	-.5042	.3202	.3918	.2385	.3544	.2963	3	36	20 Jun	14:46:5
1275	1001	-.5029	.3202	.3915	.2381	.3547	.2964	3	37	20 Jun	14:46:5
1281	1391	-.5019	.3200	.3917	.2380	.3544	.2961	3	38	20 Jun	14:46:5
1278	1797	-.5008	.3199	.3917	.2378	.3542	.2957	3	39	20 Jun	14:46:5
1277	2035	-.4998	.3197	.3916	.2377	.3541	.2956	3	40	20 Jun	14:46:5
1277	2242	-.4988	.3196	.3915	.2374	.3539	.2954	3	41	20 Jun	14:46:5
1272	2300	-.4977	.3196	.3916	.2370	.3540	.2957	3	42	20 Jun	14:46:5
1272	2273	-.4963	.3196	.3917	.2369	.3538	.2962	3	43	20 Jun	14:46:5
1268	2249	-.4949	.3197	.3917	.2365	.3539	.2967	3	44	20 Jun	14:46:5
1264	2234	-.4939	.3198	.3919	.2362	.3538	.2971	3	45	20 Jun	14:47:0
1262	2229	-.4924	.3196	.3912	.2360	.3537	.2976	3	46	20 Jun	14:47:0
1261	2220	-.4914	.3198	.3918	.2359	.3535	.2981	3	47	20 Jun	14:47:0
1261	2203	-.4903	.3198	.3916	.2356	.3534	.2986	3	48	20 Jun	14:47:0
-1261	2188	-.4889	.3199	.3916	.2355	.3536	.2991	3	49	20 Jun	14:49:2
1749	73	-.4922	.3215	.3918	.2372	.3560	.3009	3	50	20 Jun	14:49:2
1749	191	-.4911	.3215	.3917	.2373	.3562	.3008	3	51	20 Jun	14:49:2
1750	477	-.4899	.3214	.3919	.2368	.3561	.3007	3	52	20 Jun	14:49:3
1754	775	-.4888	.3213	.3915	.2364	.3567	.3006	3	53	20 Jun	14:49:3
1760	1140	-.4877	.3214	.3919	.2364	.3569	.3003	3	54	20 Jun	14:49:3
1765	1494	-.4865	.3211	.3917	.2361	.3566	.3001	3	55	20 Jun	14:49:3
1759	1857	-.4855	.3209	.3921	.2361	.3559	.2997	3	56	20 Jun	14:49:4
1756	2217	-.4843	.3209	.3920	.2359	.3563	.2994	3	57	20 Jun	14:49:4
1740	2555	-.4830	.3207	.3919	.2355	.3562	.2992	3	58	20 Jun	14:49:4
1740	2856	-.4819	.3205	.3918	.2354	.3559	.2990	3	59	20 Jun	14:49:4
1746	2974	-.4809	.3205	.3920	.2355	.3553	.2991	3	60	20 Jun	14:49:4
1748	2948	-.4795	.3205	.3918	.2352	.3556	.2994	3	61	20 Jun	14:49:4
1750	2930	-.4785	.3206	.3918	.2352	.3556	.2997	3	62	20 Jun	14:49:4
1757	2912	-.4772	.3207	.3917	.2352	.3558	.2999	3	63	20 Jun	14:49:4
1757	2896	-.4762	.3207	.3918	.2352	.3556	.3002	3	64	20 Jun	14:49:5

FIG. 11 Test Records

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FINAL DATA

Project	SIXTH WATER AQUEDUCT
Feature	JOINT BEHAVIOR TESTS
Type	SMOOTH-2
Spec no.	702-79.4
Tested By	JSM
Date Tested	6/20/90
Area	2.344 Sq. in.

NORMAL STRESS lbf/in^2	SHEAR STRESS lbf/in^2	DISPLACEMENT SHEAR ins	DISPLACEMENT NORMAL ins
75	0	0.0000	0.0000
250	-2	.0009	-.0011
500	-3	.0016	-.0019
1000	27	-.0051	-.0078
1249	27	-.0048	-.0083
1750	26	-.0053	-.0088
2000	25	-.0048	-.0092
1750	26	-.0053	-.0088
1251	27	-.0053	-.0086
1000	29	-.0054	-.0083
1000	0	0.0000	-.0090
1001	6	.0011	-.0091
1009	65	.0023	-.0091
1022	155	.0033	-.0091
1033	243	.0045	-.0091
1038	288	.0057	-.0091
1038	301	.0067	-.0091
1031	328	.0080	-.0092
1020	389	.0090	-.0092
1007	448	.0102	-.0091
1004	512	.0112	-.0091
1001	571	.0123	-.0091
1001	626	.0135	-.0090
1001	650	.0145	-.0090
1001	661	.0155	-.0092
1001	672	.0165	-.0093
999	682	.0177	-.0094
999	693	.0188	-.0095
1000	702	.0200	-.0095
1000	711	.0214	-.0096
1000	715	.0226	-.0097
-1000	716	.0238	-.0098
1251	0	0.0000	-.0110
1252	61	.0011	-.0110
1256	139	.0022	-.0110
1268	277	.0034	-.0110
1275	395	.0047	-.0109
1281	562	.0058	-.0108
1278	735	.0068	-.0106
1277	836	.0078	-.0105
1277	925	.0089	-.0103

FIG. 12 Final Reduced Data

```
DATA SUMMARY

Project       SIXTH WATER AQUEDUCT
Feature       JOINT BEHAVIOR TESTS
Type          SMOOTH-2
Spec no.      702-79.4
Index no.     64L-94
Tested By     JSM
Date Tested   6/20/90
Area          2.344 Sq. in.

NORMAL  SHEAR     DISPACEMENT      NORMAL     SHEAR
 LOAD    LOAD     NORMAL  SHEAR    STRESS     STRESS
(lbf)   (lbf)     (ins)   (ins)  (lbf/in^2) (lbf/in^2)

    0       0  0.0000  0.0000          0          0
 2344    1677   .0008   .0238       1000        715
 2982    2226  -.0006   .0099       1272        950
 4093    2901  -.0010   .0113       1746       1238
 4679    3243  -.0013   .0110       1996       1384


SUM X*X =   9650516
SUM Y*Y =   4859596
SUM X*Y =   6845839
SUM X =        6014
SUM Y =        4286


SLIDING FRICTION RESULTS
S=    80  + .660 (N)
COHESION =    80 lbf/in^2
PHI=  33 degrees     COR COEF= .9968
```

FIG. 13 Data Summary

REFERENCES

(1) Part 2: Suggested Method for Laboratory Determination of Shear Strength, *Rock Characterization Testing and Monitoring*, Editor E. T. Brown, Pergamon Press, 1981, pp. 135–137.

(2) RTH NO 203 Direct Shear Strength of Rock Core Specimens, *Rock Testing Handbook*, Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 1980.

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition that may impact the use of this standard.

(1) Added required footnote for Summary of Changes Section.
(2) Standards D 653 and D 3740 were added to Referenced Document Section.
(3) Reference to Terminology D 653 was added to 3.1.
(4) The required caveat for D 3740 was added.
(5) Summary of Changes section was added.

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Designation: D 5731 – 07

Standard Test Method for Determination of the Point Load Strength Index of Rock and Application to Rock Strength Classifications[1]

This standard is issued under the fixed designation D 5731; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method covers the guidelines, requirements, and procedures for determining the point load strength index of rock. This is an index test and is intended to be used to classify rock strength.

1.2 Specimens in the form of rock cores, blocks, or irregular lumps with a test diameter from 30 to 85 mm can be tested by this test method.

1.3 This test method can be performed in either the field or laboratory. The test is typically used in the field because the testing machine is portable, little or minimal specimen preparation is required, and specimens can be tested within a short time frame of being collected.

1.4 This test method applies to medium strength rock (compressive strength over 15 MPa (2200 psi)).

1.5 This test method does not cover which type of specimen should be tested or whether anisotropic factors should be considered. The specifics of the point load test program need to be developed prior to testing and possibly even before sampling. Such specifics would be dependent on the intended use of the data, as well as possible budgetary constraints and possible other factors, which are outside the scope of this test method.

1.6 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

1.7 The method used to specify how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which the data can be applied in design or other uses, or both. How one applies the results obtained using this standard is beyond its scope.

1.8 The values stated in the SI units are to be regarded as standard.

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids

D 2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D 5079 Practices for Preserving and Transporting Rock Core Samples

D 6026 Practice for Using Significant Digits in Geotechnical Data

D 7012 Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

E 18 Test Methods for Rockwell Hardness of Metallic Materials

E 122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

2.2 *ISRM Standard:*

Suggested Methods for Determining Point Load Strength[3]

3. Terminology

3.1 For definitions of terms used in this test method refer to Terminology D 653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *diameter—D, for point load tests,* the dimension of the specimen between the opposing conical, test platens when placed in the test machine

3.2.2 *point load strength anisotropy index—$I_{a(D)}$,* the strength anisotropy index is defined as the ratio of mean $I_{s\,(D)}$ values measured perpendicular and parallel to planes of weakness, that is, the ratio of greatest to least point load strength

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved Feb. 1, 2007. Published April 2007. Originally approved in 1995. Last previous edition approved in 2005 as D 5731–05.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] "Suggested Methods for Determining Point Load Strength", International Society for Rock Mechanics Commission on Testing Methods, *Int. J. Rock. Mech. Min. Sci. and Geomechanical Abstr.*, Vol 22, No. 2, 1985, pp. 51–60.

*A Summary of Changes section appears at the end of this standard.

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indices on different axes that result in the greatest and least ratio of point load strengths values.

3.2.3 *size-corrected point load strength index*—$I_{s\ (D)}$, the original point load strength index value multiplied by a factor to normalize the value that would have been obtained with diametral test of diameter (*D*).

3.2.4 *uncorrected point load strength index*—(I_s), an indicator of strength (see 10.1) obtained by subjecting a rock specimen to an increasingly concentrated point load, applied through a pair of truncated, conical platens, until failure occurs.[3]

4. Summary of Test Method

4.1 This index test is performed by subjecting a rock specimen to an increasingly concentrated load until failure occurs by splitting the specimen. The concentrated load is applied through coaxial, truncated conical platens. The failure load is used to calculate the point load strength index.

4.2 The point load strength index can be used to classify the rocks. A common method used is by estimating the uniaxial compressive strength.

5. Significance and Use

5.1 The uniaxial compression test (see Test Method D 7012) is used to determine compressive strength of rock specimens. However, it is a time-consuming and expensive test that requires significant specimen preparation and the results may not be available for a long time after the samples are collected. When extensive testing and/or timely information is required for preliminary and reconnaissance information, alternative tests such as the point load test can be used to reduce the time and cost of compressive strength tests, when used in the field. Such data can be used to make timely and more informed decisions during the exploration phases and more efficient and cost effective selection of samples for more precise and expensive laboratory tests.

5.2 The point load strength test is used as an index test for strength classification of rock materials. The test results should not be used for design or analytical purposes.

5.3 This test method is performed to determine the point load strength index of rock specimens and, if required, the point load strength anisotropy index.

5.4 Rock specimens in the form of either core (the diametral and axial tests), cut blocks (the block test), or irregular lumps (the irregular lump test) are tested by application of concentrated load through a pair of truncated, conical platens. Little or no specimen preparation is required and can therefore be tested shortly after being obtained and any influence of moisture condition on the test data minimized. However, the results can be highly influenced by how the specimen is treated from the time it is obtained until the time it is tested. Therefore, it may be necessary to handle specimens in accordance with Practice D 5079 and to document moisture conditions in some manner in the data collection.

NOTE 1—The quality of the result produced by this standard is dependent upon the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing and sampling. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *General*—A basic point load tester (see Fig. 1) consists of a loading system typically comprised of a loading frame, platens, a measuring system for indicating load, *P*, (required to break the specimen), and a means for measuring the distance, *D*, between the two platen contact points at the start of testing and after failure. The equipment shall be resistant to shock and vibration so that the accuracy of readings is not adversely affected by repeated testing. Any special operational, maintenance or calibrations instructions provided by the manufacturer for the particular apparatus being used shall be followed.

6.2 *Loading System*:

6.2.1 The loading system shall have a loading frame with a platen-to-platen clearance that allows testing of rock specimens in the required size range. Typically, this range is between 30 to 100 mm, or the maximum opening size of the load frame, so that an adjustable distance is available to accommodate both small and large specimens.

NOTE 2—It is generally accepted that specimens smaller than 42 mm (BX cores) are not recommended because for smaller diameters the loading points can not be considered as theoretical "points" in relation to specimen size.[4]

6.2.2 The loading capacity shall be sufficient to break the largest and strongest specimens to be tested. Point load strength of rock is usually an order of magnitude lower than the compressive strength of rock.

6.2.3 The load frame shall be designed and constructed so that it does not permanently distort during repeated applications of the maximum test load, and so that the platens remain coaxial within ±0.2 mm throughout testing. No spherical seat or other nonrigid component is permitted in the loading system. Loading system rigidity is essential to avoid slippage when specimens of irregular geometry are tested.

6.2.4 Truncated, conical platens, as shown on Fig. 2, are to be used. The 60° cone and 5-mm radius spherical platen tip shall meet tangentially. The platens shall be of hard material (Rockwell 58 HRC, as explained in Test Method E 18) such as tungsten carbide or hardened steel so they remain undamaged during testing.

6.3 *Load Measuring System*:

6.3.1 A load measuring system, for example a load cell or a hydraulic pressure gage, that will indicate failure load, *P*, required to break specimen. The system should conform to the requirements of 6.3.2-6.3.4.

6.3.2 Measurements of failure load, *P*, shall be to a precision of ±5 % or better of full-scale load-measuring system, irrespective of the size and strength of specimen that is tested.

6.3.3 Failure is often sudden, therefore, and a peak load indicator is required so the failure load can be recorded after each test.

[4] Bieniawski, Z.T., The Point Load Test in Geotechnical Practice, Engineering Geology (9), pages 1-11, 1975.

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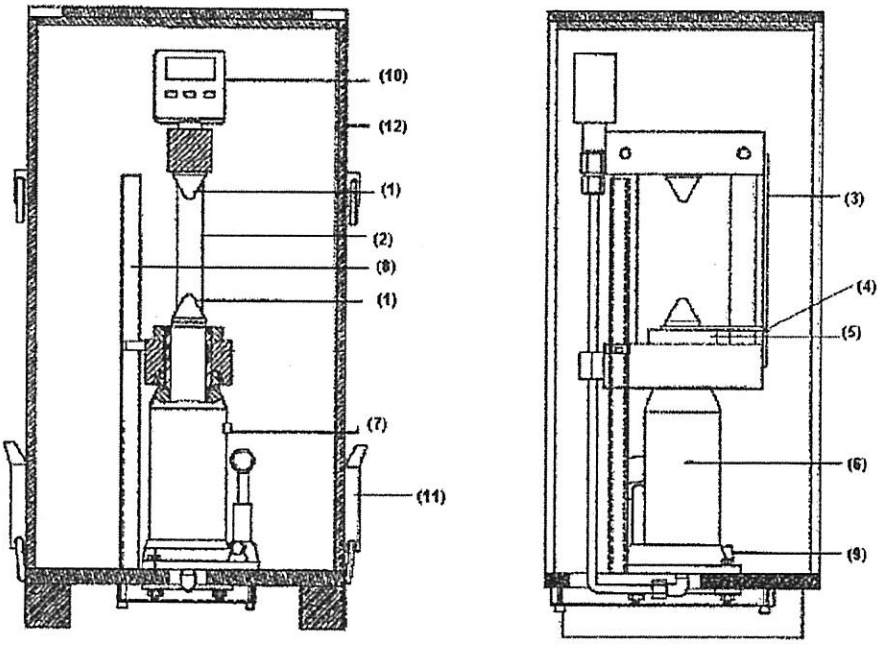


NOTE—Load frame general information (figure 1)Load is applied to the specimens through two standard hardened points (1)Two column fixed crosshead frame (2)Scale (3)Scale pointer (4)Attached by a bolt (5) to the hydraulic pump body (6)Oil filler cap (7)The hydraulic piston assembly incorporated the oil reservoir, a single acting pump, pressure relief valve (9), and a handle (8)Pump handle (8)Pressure release valve (9)Case latched for top cover (10)Digital pressure readout (11)Point load tester top cover(12)

FIG. 1 Example of a Light-Weight Point Load Test Apparatus

6.3.4 If required, the system should be capable of using interchangeable, mechanical or electronic gauge, load measuring devices in order to be consistent with the estimated strength of rock and have the desired reading accuracy.

6.4 *Distance Measuring System*:

6.4.1 The distance measuring system, an electronic or vernier direct reading scale, should connect to the loading frame for measuring the distance, *D*, between specimen-platen contact points at the start of testing and just prior to failure and conform to requirements 6.4.2 and 6.4.3.

6.4.2 Measurements of *D* shall be to an accuracy of ±2 % or better of distance between contact points, irrespective of the size and strength of specimen that is tested.

6.4.3 The measuring system shall allow a check of the "zero displacement" value when the two platens are in contact and should include a zero adjustment and a means to record or measure any penetration of the specimen by the point load platens during testing.

6.4.4 An instrument such as a caliper or a steel rule is required to measure the width, *W*, (with an accuracy of ±5 %) of specimens for all but the diametral test.

6.5 *Miscellaneous Items*—Depending on the type of samples (core or non core) and the type of specimens to be tested (diametral, Block, Axial, etc.), the following items may be needed: diamond saw, chisels, towels, marking pens, and plotting paper.

7. Test Samples

7.1 Rock samples are grouped on the basis of rock type, test direction if rock is aniasotropic, and estimated strength.

7.2 *Sample Size*

7.2.1 When testing core or block samples at least ten specimens are selected for the samples.

7.2.2 When testing irregular-shaped specimens obtained by other means at least 20 specimens are selected for the samples.

7.2.3 Sample sizes may need to be larger if the rock is anisotropic or heterogeneous.

7.2.4 If needed, Practice E 122 can be used to more precisely determine the sample size.

7.3 Samples in the form of core are preferred for a more precise classification.

7.4 For anisotropic rocks the best results for core samples is when the core axis is perpendicular to the plane of weakness.

8. Test Specimens

8.1 *Test Diameter*—The specimen's external test diameter shall not be less than 30 mm and not more than 85 mm with the preferred test diameter of about 50 mm.

8.2 *Size and Shape*—The size and shape requirements for diametral, axial, block, or irregular lump testing shall conform with the recommendations shown on Fig. 3. The sides of the specimens shall be free from abrupt irregularities that can

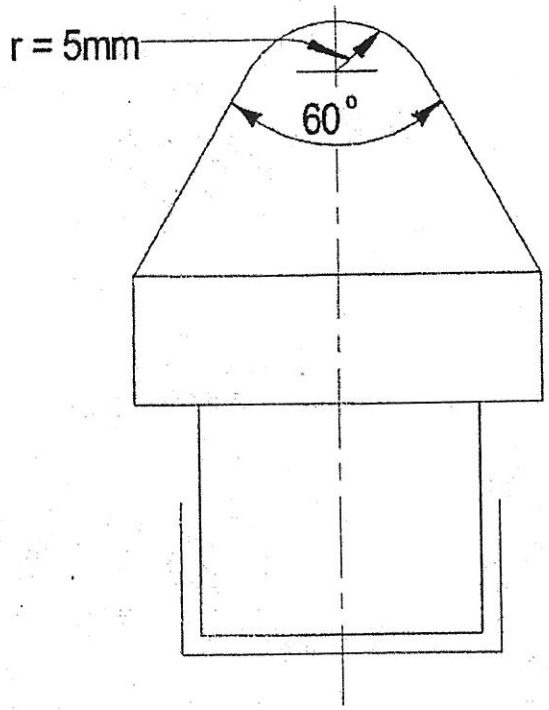
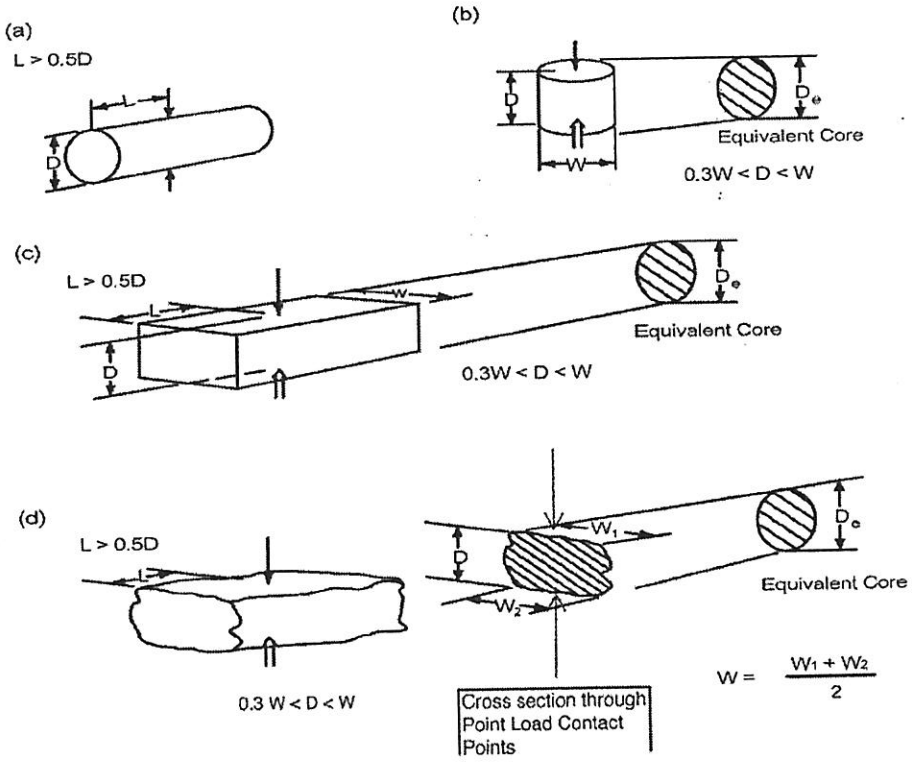


FIG. 2 Truncated, Conical Platen Dimensions for Point Load Apparatus



NOTE 1—Legend: L = distance between contact points and nearest free face, and D_e = equivalent core diameter (see 10.1).

FIG. 3 Load Configurations and Specimen Shape Requirement for (a) the Diametral Test, (b) the Axial Test, (c) the Block Test, and (d) the Irregular Lump Test[3]

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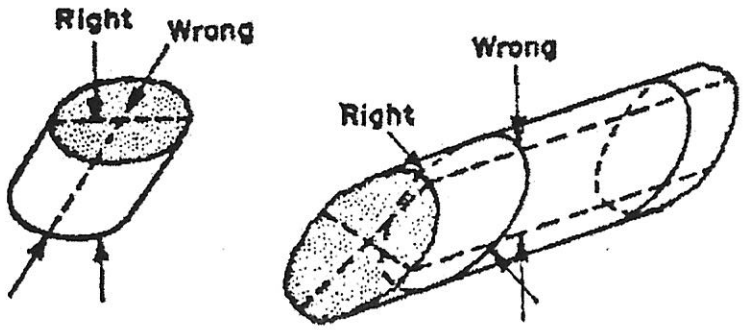

FIG. 4 Anisotropy measurements and testing for maximum and minimum indices

generate stress concentrations. No specimen preparation is required, however a rock saw or chisels may be required for block or irregular specimens. Proper planning of diametral tests on rock cores can produce suitable lengths of core for subsequent axial testing provided they are not weakened by the diametral test. Otherwise, suitable specimens can be obtained from the cores by saw-cutting, or core splitting.

NOTE 3—While there are no established specimen guidelines for grain size versus specimen size this subject is still important and must be included in the testing and use of the data. Concrete testing using a point load tester recommends that a minimum ratio of core diameter to maximum aggregate size of 4 be used.[5] This ratio may be used until guidelines are developed for rock.

8.3 *Water Content*—Water content of the specimen can affect the value of the point load strength. Therefore, the testing plan shall include how water content will be included in the point load testing program . This may include the recording, controlling, and measurement of water content.

8.4 *Marking and Measuring Specimens*—The specimens shall be properly marked and measured as shown in Fig. 4.

8.4.1 *Marking*—The desired test orientation of the specimen shall be indicated by marking lines on the specimen. These lines are used for centering the specimen in the testing machine, and to ensure proper orientation during testing, including any issues involving anisotrophic rocks (see Fig. 3). These lines may also be used as reference lines for measuring width, length, and diameter.

8.4.2 *Measuring*—Measure each dimension of a specimen at three different places, and calculate the averages.

9. Procedure

9.1 Develop a testing plan and, if needed, sampling plan to provide specimens for point load testing according to the following procedures for the specific specimen shape (diametral, axial, block or irregular).

9.2 *Diametral Test*

9.2.1 Core specimens with length/diameter ratio greater than one are suitable for diametral testing.

9.2.2 Insert a specimen in the test device and close the platens to make contact along a core diameter. Ensure that the distance, *L*, between the contact points and the nearest free end is at least 0.5 times the core diameter (see Fig. 3 and Fig. 4(*a*)).

9.2.3 Determine and record the distances *D* and *L* (see Fig. 3).

9.2.4 Steadily increase the load such that failure occurs within 10 to 60 s, and record failure load, *P*. The test should be rejected if the fracture surface passes through only one platen loading point (see Fig. 5(*d*)).

9.2.5 The procedures in 9.2.2-9.2.4 are repeated for each specimen of the rock type.

9.3 *Axial Test*

9.3.1 Core specimens with length/diameter ratio of ⅓ to 1 are suitable for axial testing (see Fig. 3(*b*)). Suitable specimens can be obtained by saw-cutting or chisel-splitting the core sample, or by using suitable pieces produced by carefully planned diametral tests (see 9.2).

9.3.2 Insert a specimen in the test machine and close the platens to make contact along a line perpendicular to the core end faces (in the case of isotropic rock, the core axis, but see Fig. 5 and 9.5 for anisotropic rock).

9.3.3 Record the distance, *D*, between platen contact points (see Fig. 3). Record the specimen width, *W*, perpendicular to the loading direction, with an accuracy of ±5 %.

9.3.4 Steadily increase the load such that failure occurs within 10 to 60 s, and record the failure load, *P*. The test should be rejected if the fracture surface passes through only one loading point (see Fig. 6(*e*)).

9.3.5 Procedures 9.3.2-9.3.4 are repeated for each test specimen of the rock type.

9.4 *Block and Irregular Lump Tests*:

9.4.1 Rock blocks or lumps, 30 to 85 mm, and of the shape shown in Fig. 3(*c*) and (*d*) are suitable for the block and the irregular lump tests. The ratio, *D/W*, should be between ⅓ and 1, preferably close to 1. The distance *L* should be at least 0.5 *W*. Suitable specimens can be obtained by saw-cutting or chisel-splitting larger samples or specimens if needed.

9.4.2 Insert a specimen in the testing machine and close the platens to make contact with the smallest dimension of the lump or block, away from edges and corners (see Fig. 3(*c*) and (*d*).

9.4.3 Record the distance *D* between platen contact points. Record the smallest specimen width, *W*, perpendicular to the loading direction. If the sides are not parallel, then calculate *W*

[5] Robins, P.J., The Point Load Strength Test for Concrete Cores, Magazine of Concrete Research, Vol. 32, No. 111, June 1980.

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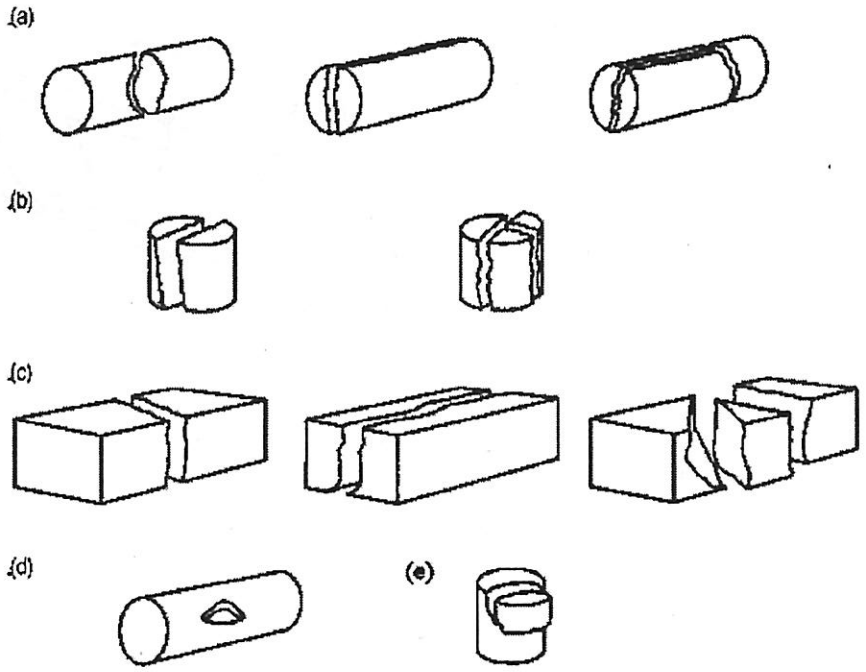

FIG. 5 Typical Modes of Failure for Valid and Invalid Tests—(a) Valid diametral tests; (b) valid axial tests; (c) valid block tests; (d) invalid core test; and (e) invalid axial test (point load strength index test).[5]

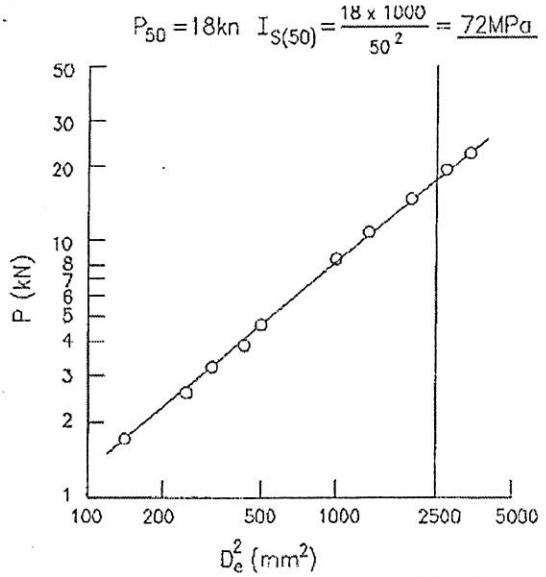

FIG. 6 Procedure for Graphical Determination of $I_{s(50)}$ from a Set of Results at D_e Values Other Than 50 mm [6]

as $(W_1 + W_2)/2$ as shown on Fig. 3. This width, W, is used in calculating point load strength index irrespective of the actual mode of failure (see Fig. 5 (*c*).

9.4.4 Steadily increase the load such that failure occurs within 10 to 60 s, and record the failure load, P. The test should be rejected if the fracture surface passes through only one loading point (see examples for other shapes in Fig. 5(*d*) or (*e*).

9.4.5 Procedures 9.4.2-9.4.4 are repeated for each test specimen in the sample.

9.5 *Anisotropic Rock*:

9.5.1 When a rock sample is shaly, bedded, schistose, or otherwise observably anisotropic, it should be tested in directions that will give the greatest and least strength values, in general, parallel and normal to the planes of anisotropy.

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9.5.2 If the sample consists of core drilled through weakness planes, a set of diametral tests may be completed first, spaced at intervals that will yield pieces that can then be tested axially.

9.5.3 Strongest test results are obtained when the core axis is perpendicular to the planes of weakness; therefore, when possible, the core should be drilled in this direction. The angle between the core axis and the normal to the direction of least strength should preferably not exceed 30°.

9.5.4 For measurement of the point load strength index (I_s) value in the direction of least strength, ensure that load is applied along a single weakness plane. Similarly, when testing for the I_s value in the direction of greatest strength, ensure that the load is applied perpendicular to the direction of least strength (see Fig. 4).

9.5.5 If the sample consists of blocks or irregular lumps, it should be tested as two subsamples, with load first applied perpendicular to, then along the observable planes of weakness. Again, the required minimum strength value is obtained when the platens make contact and are loaded to failure along a single plane of weakness.

9.6 If significant platen penetration occurs, the dimension D to be used in calculating point load strength should be the value D' measured at the instant of failure, that will be smaller than the initial value suggested in 9.2.3, 9.3.3, and 9.4.3. The error in assuming D to be its initial value is negligible when the specimen is large or strong. The dimension at failure may always be used as an alternative to the initial value and is preferred.

9.7 *Water Content*

9.7.1 For precise measurements, follow Test Method D 2216 to determine the water content of each rock specimen and report the moisture condition (see Section 11).

9.7.2 At the minimum, water content shall be recorded as air-dried, saturated, as-received, etc.

10. Calculation

10.1 *Uncorrected Point Load Strength Index*—The uncorrected point load strength, I_s , is calculated as:

$$I_s = P/D_e^2, \text{MPa} \quad (1)$$

where:

P = failure load, N,

D_e = equivalent core diameter (see Fig. 3), mm, and is given by:

D_e^2 = D^2 for diametral core tests without penetration, mm^2, or

D_e^2 = $4A/\pi$ for axial, block, and lump tests, mm^2;

where:

A = WD = minimum cross-sectional area of a plane through the platen contact points (see Fig. 3).

NOTE 4—If significant platen penetration occurs in the test, such as when testing weak sandstones, the value of D should be the final value of the separation of the loading points, D'. Measurements of core diameter, D, or specimen width, W, made perpendicular to the line joining the loading points are not affected by this platen penetration and should be retained at the original values. The modified values of D_e can be calculated from:

$$D_e^2 = D \times D' \text{ for cores} = 4/\pi\ W \times D' \text{ for other shapes} \quad (2)$$

10.2 *Size Corrected Point Load Index*:

10.2.1 The point load index, I_s, varies as a function of D in the diametral test, and as a function of D_e in axial, block, and irregular lump tests, so that a size correction must be applied, if the D values for all the specimens are not the same, to obtain an unique point load strength value for the rock specimen and one that can be used for purposes of rock strength classification. See Fig. 7.

10.2.2 The size corrected point load strength index, $I_{s(D)}$, of a rock specimen is defined in this procedure as the value of I_s that would have been measured by a diametral test with D = 50 mm and given the symbol $I_{s(50)}$. The diameter of 50 mm has been the preferred diameter since that diameter is associated with rock quality designations (RQD) and predominance of NX core samples.

10.2.3 When a precise rock classification is essential, the most reliable method of obtaining $I_{s(50)}$ is to conduct diametral tests at or close to D = 50 mm. Size correction is then unnecessary. For example, in case of diametral tests on NX, core diameter = 54 mm and size correction to D = 50 mm is not necessary. Most point load strength tests are in fact performed using other specimen sizes or shapes. In such cases, the size correction described in 10.2.4 or 10.2.5 must be applied.

10.2.4 The most reliable method of size correction is to test the specimen over a range of D or D_e values and to plot graphically the relation between P and D_e. If a log-log plot is used, the relation is a straight line (see Fig. 6). Points that deviate substantially from the straight line may be disregarded (although they should not be deleted). The value of $I_{s(50)}$ corresponding to $D_e^2 = 2500\ mm^2$ ($D_e = 50$ mm) can be obtained by interpolation and use of the size-corrected point load strength index calculated as shown in 10.2.5.

10.2.5 When neither 10.2.3 nor 10.2.4 is practical (for example when testing single-sized core at a diameter other than 50 mm or if only a few small pieces are available), size correction may be accomplished using the formula:

$$I_{s(50)} = F \times I_s \quad (3)$$

The "Size Correction Factor F" can be obtained from the chart in Fig. 8, or from the expression:

$$F = (D_e/50)^{0.45} \quad (4)$$

where:

F = size correction factor

For tests near the standard 50-mm size, only slight error is introduced by using the approximate expression:

$$F = \sqrt{(D_e/50)} \quad (5)$$

instead of using the procedure outlined in 10.2.4on Fig. 6.

10.3 *Mean Value Calculation*:

10.3.1 Mean values of $I_{s(50)}$, as defined in 10.3.2, are to be used when classifying samples with regard to their point load strength and point load strength anisotropy indices.

10.3.2 The mean value of $I_{s(50)}$ is to be calculated by deleting the two highest and two lowest values from the ten, or more, valid tests, and calculating the mean of the remaining values. If significantly fewer specimens are tested, only the

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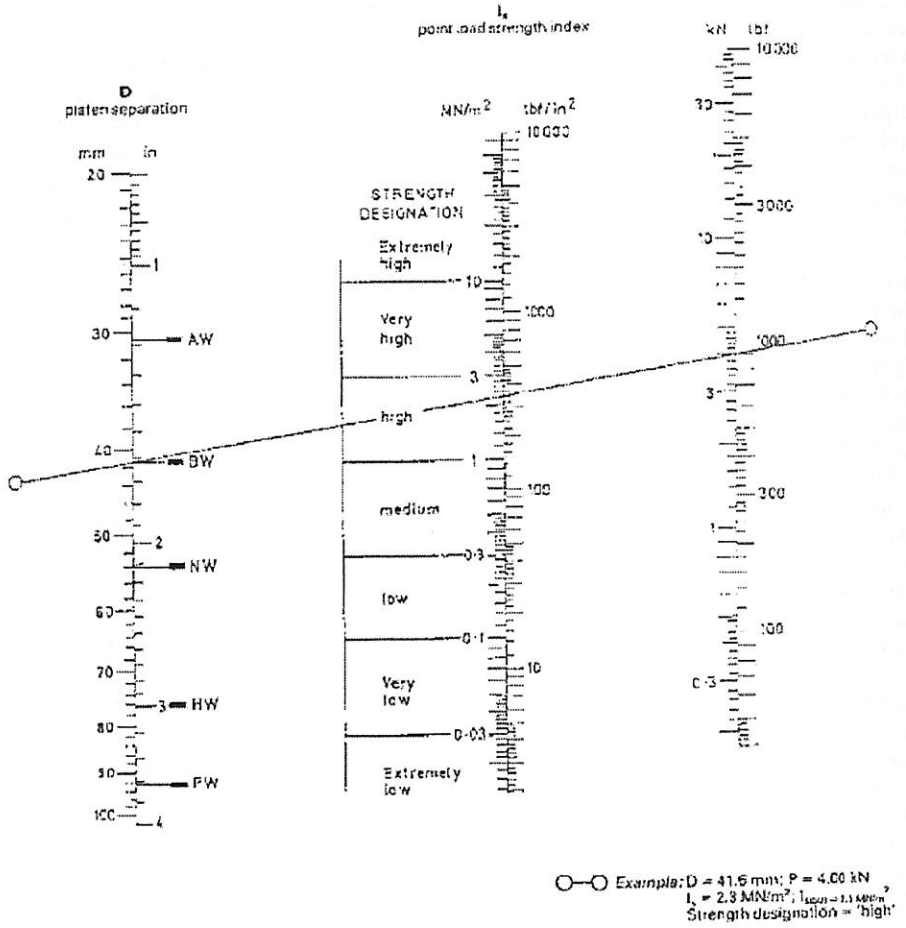

FIG. 7 Example of Descriptive Strength Classification and Using a Nomograph to Compute the Point Load Index. Other Strength Classifications May be Used.

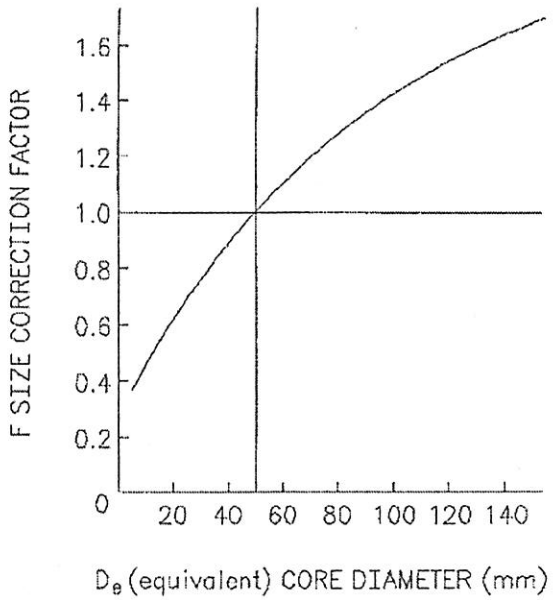

FIG. 8 Size Correction Factor Chart [8]

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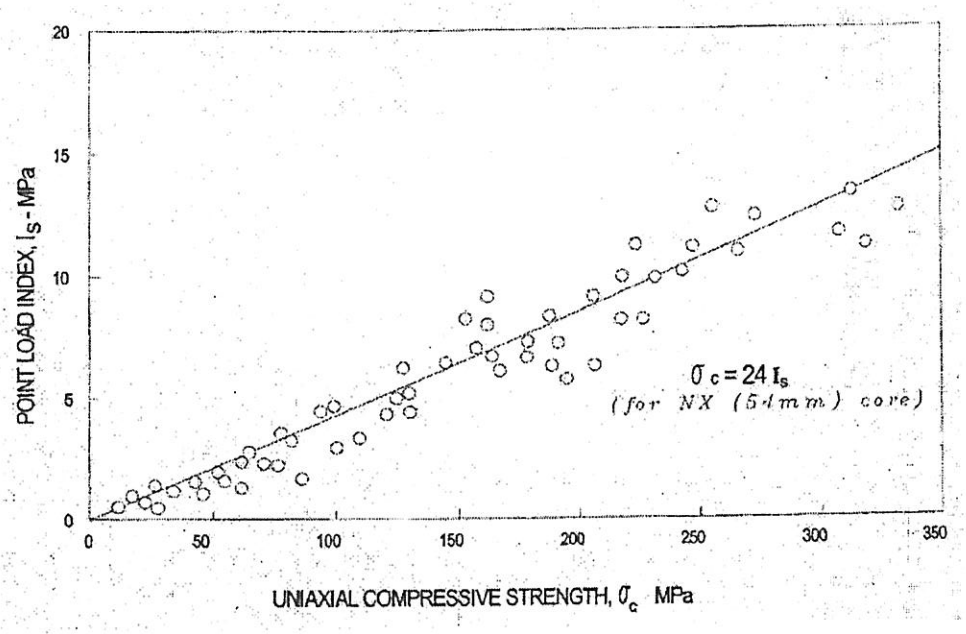

FIG. 9 Relationship Between Point Load Strength Index and Uniaxial Compressive Strength from 125 Tests On Sandstone, Quartzite, Marikana, Norite, and Belfast Norite[9]

highest and lowest values are to be deleted and the mean calculated from those remaining.

10.4 *Point Load Strength Anisotropy Index*—The strength anisotropy index $I_{a(50)}$ is defined as the ratio of mean $I_{s(50)}$ values measured perpendicular and parallel to planes of weakness, that is, the ratio of greatest to least point load strength indices. See Fig. 9[6].

10.5 *Estimation of Uniaxial Compressive Strength*—The estimated uniaxial compressive strength can be obtained by using Fig. 8 or using the following formula:

$$\sigma_c = K^* I_{s(D)} \quad (6)$$

where:

σ_c = uniaxial compressive strength, MPa
K = index to strength conversion factor that depends on site-specific correlation between σ_c and $I_{s(D)}$, MPa and
$I_{s(D)}$ = corrected point load strength index at a given (D).

10.5.1 If site-specific correlation factor "K" is not available, the generalized values may be used in Table 1.

10.5.2 If any specimen in a rock type gives a value 20 % under the average, it should be examined for defects and a decision made on the validity of the results.

11. Report

11.1 A typical report (example shown in Fig. 10) may include the following:

[6] D'Andrea, D.V., Fisher, R.L., and Fogelson, D.E., Prediction of Compressive Strength of Rock from Other Rock Properties, *U.S. Bureau of Mines Rep. Invest.*, 6702, 1965.

TABLE 1 Generalized Index to Strength Conversion Factor (K) for[A]

Core Size, mm	Value of "C" (Generalized)
21.5 (Ex Core)	18
30	19
42 (Bx Core)	21
50	23
54 (Nx Core)	24
60	24.5

[A] Bieniawski, Z.T. The Point-Load Test in Geotechnical Practice, Engineering Geology (9) 1-11.

11.1.1 Source of sample including project name, location, how collected (drill hole, block sample, etc.) and, if known, storage (curatorial history) environment. The location may be specified in terms of borehole number and depth of specimen from the collar of the hole,

11.1.2 Physical description of sample including rock type and location and orientation of discontinuities, such as, apparent weakness planes, bedding planes, schistosity, or large inclusions, if any,

11.1.3 Date and personnel involved with sampling, specimen preparation, and testing,

11.1.4 Test apparatus used, model number, and calibrations,

11.1.5 As a minimum, a general indication of the moisture condition of test specimens at the time of testing, such as, saturated, as received, laboratory air dry, or oven dry. In some cases, especially where the results are sensitive to water content, it may be necessary to report the actual water content as determined in accordance with Test Method D 2216,

11.1.6 Average thickness and average diameter of the test specimen,

11.1.7 The maximum applied load "P",

11.1.8 The distance "D" or D', or both, if required,

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POINT LOAD TEST DATA

PROJECT:_____ LOCATION:_____

Tested By:_____ DATE:_____

TEST DEVICE AND SERIAL # USED: _____

SAMPLE DETAILS: 3 block sample from Gimblethorpe Opencast site.

Fine grained pale grey Coal Measures sandstone with numerous coaly streaks along horizontal bedding planes.

Specimens: 1-6 chisel cut blocks, air-dried 2 weeks;
7-10 sawn blocks, air-dried 2 weeks;
11-15 cores, air-dried 2 weeks;
16-20 cores, air dried 2 weeks;
- tested in laboratory.

No.	Type	W (mm)	D(mm)	P (kN)	D^2(mm2)	D_e (mm)	I_s	F	$I_{s(50)}$
1	i ⊥	30.4	17.2	2.687	666	25.8	4.03	0.75	
2	i ⊥	16	8	0.977	165	12.8	5.99	0.54	3.24
3	i ⊥	19.7	15.6	1.962	393	19.8	5.02	0.56	3.31
4	i ⊥	35.8	18.1	3.648	825	28.7	4.41	0.765	3.46
5	i ⊥	42.5	21	6.118	1569	39.6	3.90	0.875	3.49
6	i ⊥	42	35	7.398	1872	43.3	3.95	0.935	
7	b ⊥	44	21	4.602	1176	34.3	3.91	0.84	
8	b ⊥	40	30	5.943	1528	39.1	3.88	0.89	
9	b ⊥	19.5	15	2.043	372	19.3	5.48	0.655	
10	b ⊥	33	18	2.87	672	25.9	4.21	0.75	
11	d //	-	49.92	5.102	-	-	-	-	
12	d //	-	49.88	4.615	-	-	-	-	
13	d //	-	49.82	5.682	-	-	-	-	
14	d //	-	49.82	4.139	-	-	-	-	
15	d //	-	49.86	4.546	-	-	-	-	1.83
16	d //	-	25.23	1.832	-	-	2.89	0.74	2.14
17	d //		25.00	1.891	-	-	3.62	0.735	2.22
18	d //	-	25.07	2.118	-	-	3.37	0.735	
19	d //	-	25.06	1.454	-	-	2.32	0.735	
20	d //	-	25.00	1.540	-	-	2.46	0.735	1.81

d = diametral;
i = axial;
b = block;
I = irregular lump test;
⊥ = perpendicular;
// = parallel to planes of weakness

Mean $I_{s(50)}$ ⊥	3.38
Mean $I_{s(50)}$ //	1.98
$I_{s(50)}$	1.73

FIG. 10 Test Record Example[11]

11.1.9 Direction of loading (parallel to or normal to plane of weakness or anisotrophy directions),

11.1.10 The number of specimens tested and how prepared,

11.1.11 The calculated uncorrected (I_s) and corrected (D=50 mm), $I_{s(50)}$ *point load strength index values,*

11.1.12 The estimated value of uniaxial compressive strength (σ_c) and the strength classification,

11.1.13 The calculated value of strength anisotropy index ($I_{a(50)}$), *and*

11.1.14 Type and location of failure, including any photographs of the tested specimens before and after the test.

12. Precision and Bias

12.1 *Precision*—Due to the nature of rock materials tested by this test method, multiple specimens that have uniform physical properties have not been produced for testing. Since specimens that would yield the same test results have not been tested, Subcommittee D18.12 cannot determine the variation between tests since any variation observed is just as likely to be due to specimen variation as to operator or testing variation. Subcommittee D18.12 welcomes proposals to resolve this problem and would allow for development of a valid precision statement.

12.2 *Bias*—There is no accepted reference value for this test method; therefore, bias cannot be determined.

13. Keywords

13.1 compressive strength; index test; point load; rock; rock classification

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SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (2002) that may impact the use of this standard.

(1) Deleted Test Method D 2938 in Section 2 and 5.1 and replaced with Test Method D 7012

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Designation: D 4644 – 04

Standard Test Method for Slake Durability of Shales and Similar Weak Rocks[1]

This standard is issued under the fixed designation D 4644; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method covers the determination of the slake durability index of a shale or other similar rock after two drying and wetting cycles with abrasion.

1.2 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

1.2.1 The method used to specify how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which the data can be applied in design or other uses, or both. How one applies the results obtained using this standard is beyond its scope.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are provided for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids

D 2113 Practice for Diamond Core Drilling for Site Investigation

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Rock and Soil

D 3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D 5079 Practices for Preserving and Transporting Rock Core Samples

D 6026 Practice for Using Significant Digits in Geotechnical Data

E 11 Specification for Wire Cloth and Sieves for Testing Purposes

3. Terminology

3.1 For terminology used in this test method, refer to Terminology D 653

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *slake durability index*—the percentage by dry mass retained of a collection of shale pieces on a 2.00 mm (No. 10) sieve after two cycles of oven drying and 10 min of soaking in water with a standard tumbling and abrasion action.

4. Significance and Use

4.1 The test method is used to estimate qualitatively the durability of weak rocks in the service environment.(1-7)[3].

4.2 This test method is used to assign quantitative durability values to weak rocks. A primary example is the Franklin Rating System (1).

NOTE 1—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing, sampling, inspection, and so forth. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

5. Apparatus

5.1 *Slake Durability Device*—The drum (Fig. 1) shall be made of 2.00 mm (No. 10) square-mesh, woven-wire cloth, conforming to the requirements of Specification E 11. It shall be cylindrical in shape, with a diameter of 140 mm (5.5 in.) and a length of 100 mm (3.9 in.). The ends shall be rigid plates, with one removable end. It must be sufficiently strong to retain its shape during use, but neither the exterior of the mesh nor the interior of the drum shall be obstructed by a support. The drum shall be able to withstand a temperature of 110 ± 5°C (230 ± 9°F). A trough shall support the drum in a horizontal manner such that the drum is free to rotate about its axis. The trough shall be capable of being filled with slaking fluid to 20 mm (0.8 in.) below the drum axis, and shall allow at least 40 mm (1.6 in.) unobstructed clearance between the trough and the bottom

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The boldface numbers in parentheses refer to the list of references at the end of this standard.

*A Summary of Changes section appears at the end of this standard.

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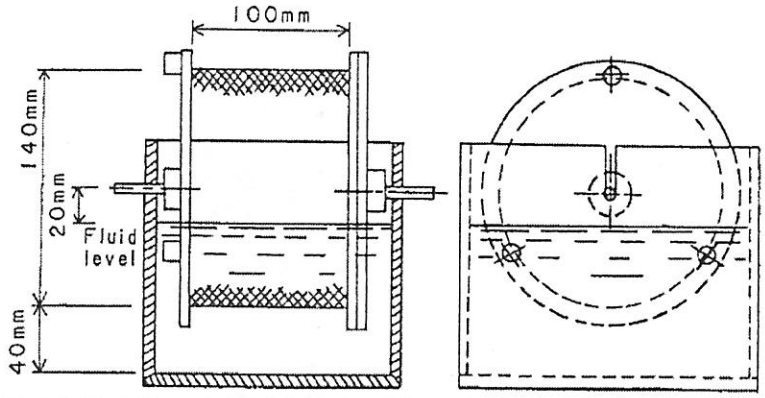

FIG. 1 Critical Dimensions of Slake Durability Device Showing Critical Dimensions

of the mesh. The drum shall be rotated by a motor capable of maintaining a speed of 20 rpm, constant to within 5 %, for a period of 10 min. Devices conforming to these requirements are commercially available.

5.2 *Drying Oven*, thermostatically controlled, capable of maintaining a temperature of 110 ± 5°C (230 ± 9°F).

5.3 *Balance*, sensitive to 1 g and having a 2000-g capacity.

5.4 *Miscellaneous Apparatus*, including a brush and hammer.

5.5 *Distilled Water*.

6. Test Sample and Specimen—

6.1 Collect, transport, and store test samples and test specimens in such a manner as to retain the natural water content using the guidelines in Practices D 2113 and D 5079 and Test Method D 2216.

6.2 The test specimen shall consist of ten representative, intact, roughly equidimensional shale fragments weighing 40 g to 60 g each. These fragments may be naturally occurring or may be produced by breaking with a hammer. Such fragments may be obtained from rock cores or from test pits, and their sizes will vary with the method of sampling. Break off any sharp corners, if possible, and remove any dust by brushing the fragment just prior to weighing. The total test specimen shall weigh 450 to 550 g.

7. Procedure

7.1 Photograph specimen prior to placement in drum.

7.2 *Water Content*—Using Test Method D 2216, determine the water content of each test specimen before testing. This shall be done with the shale fragments in the drum to be used for the actual testing.

7.3 Mount the drum in the trough and couple to the motor. Fill the trough with distilled water at room temperature to 20 mm (0.8 in.) below the drum axis. Rotate the drum at 20 rpm for a period of 10 min. Record the water temperature at the beginning and end of the run.

7.4 Remove the drum from the trough immediately after the rotation period is complete and dry the drum and the specimen retained in the oven the same as in 7.2 and obtain the oven-dried mass.

7.5 Repeat 7.3 and 7.4 to obtain a final oven-dried mass for the second cycle.

7.6 Photograph specimen retained and file a copy of the photo with the laboratory report, or record standard verbal descriptions, as follows:

7.6.1 *Type I*—Retained specimen remain virtually unchanged.

7.6.2 *Type II*—Retained specimen consist of large and small fragments.

7.6.3 *Type III*—Retained specimen is exclusively small fragments.

7.7 See Fig. 2 for representative photographs of the three types.

8. Calculations

8.1 Calculate the slake durability index (second cycle), as follows:

$$I_d(2) = [(W_F - C)/(B - C)] \times 100 \quad (1)$$

where:

$I_d(2)$ = slake durability index (second cycle),
B = mass of drum plus oven-dried specimen before the first cycle, g,
W_F = mass of drum plus oven-dried specimen retained after the second cycle, g, and
C = mass of drum, g.

9. Report

9.1 The report shall include the following:

9.1.1 Description of the specimen and where it was obtained.

9.1.2 Slake durability index (second cycle) to the nearest 0.1 %.

9.1.3 Range and average value of the water temperature.

9.1.4 Natural water content.

9.1.5 Description of the appearance of the fragments retained in the drum (see 7.6).

10. Precision and Bias

10.1 Test data on precision is not presented due to the nature of shale and other similar rock tested by this test method. It is either not feasible or too costly at this time to produce multiple specimens which have uniform physical properties. Any variation observed on the data is just as likely to be due to specimen

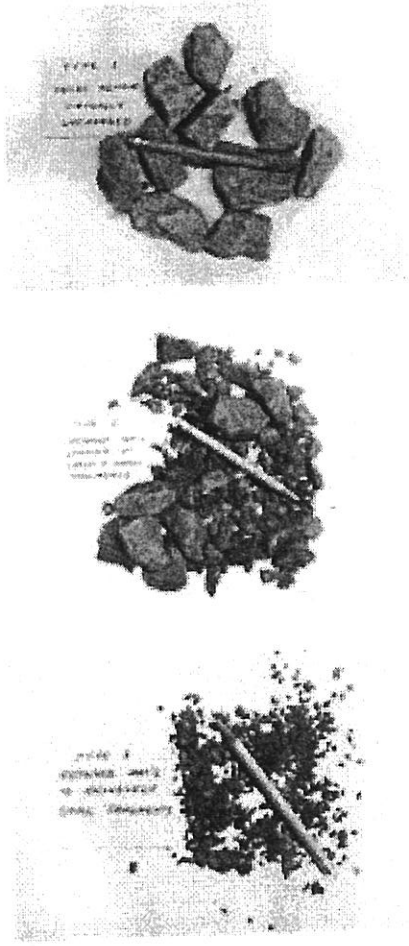

FIG. 2 Illustration of Fragment Types Retained

variation as to operator or laboratory testing variation: Subcommittee D18.12 welcomes proposals that would allow for development of a valid precision statement. There is no accepted reference value of shale or weak rock for this test method; therefore, bias cannot be determined.

11. Keywords

11.1 abrasion resistance; shale; slake durability; weak rocks

REFERENCES

(1) Franklin Trow Associates, "Field Evaluation of Shales for Construction Projects," Research and Development Project No. 1404, Ministry of Transportation and Communications, Research and Development Branch, Downsview, Ontario, March 1979.

(2) Chapman, D. R., "Shale Classification Tests and Systems: A Comparative Study," MSCE Thesis and Joint Highway Research Project No. 75-11, Purdue University, West Lafayette, IN, June 1975, 90 pp.

(3) Deo, P., "Shales as Embankment Materials," Ph.D. Thesis and Joint Highway Research Project No. 45, Purdue University, West Lafayette, IN, December 1972, 202 pp.

(4) International Society for Rock Mechanics, "Suggested Methods for Determining Slake-Durability Index Properties," Commission on Standardization of Laboratory and Field Tests, November 1972.

(5) Lutton, R. J., "Design and Construction of Compacted Shale Embankments, Volume 3, Slaking Indexes for Design," Report No. FHWA-RD-77-1, Federal Highway Administration, Washington, DC, February 1977.

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(7) Oakland, M. W., and Lovell, C. W., "Classification and Other Standard Tests for Shale Embankment," Joint Highway Research Project No. 82-4, Purdue University, West Lafayette, IN, February 1982, 171 pp.

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D 4644 – 04

SUMMARY OF CHANGES

In accordance with Committee D18 policy. this section identifies the location of changes to this standard since the last edition (D 4644 – 87 (1998)) that may impact the use of this standard.

(1) As required, a footnote about Summary of Changes was added to the title of Section 1.
(2) Added standard paragraphs for significant digits and rounding established by Practice D 6026
(3) Added Terminology D 653 , Practice D 2113, Test Method D 2216, Practice D 3740, Practice D 5079, Practice D 6026.
(4) Added 3.1 referencing Terminology D 653, and renumbered section accordingly.
(5) Added Note 1 referencing Practice D 3740.
(6) Moved 6.2 up to 6.1 and added reference to Practice D 2113, Test Method D 2216, and Practice D 5079.
(7) Section 7. Changed all reference to material to specimen and changed pieces to fragments.
(8) Added 7.1 about photographing test specimen before testing and renumbered accordingly.
(9) Took out section in 7.1 on calculating initial water content and referred user to Test Method D 2216 for determining water content.
(10) Reworded 7.3 and 7.4 to remove instructions contained in Test Method D 2216.
(11) Changed sample to specimen in 8.1.
(12) The word "material" was changed to "specimen" in 9.1.1.
(13) Section 10 was re-worded to conform with the D18 standards preparations manual.
(14) Added Summary of Changes section.

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Designation: D 2845 – 05

Standard Test Method for Laboratory Determination of Pulse Velocities and Ultrasonic Elastic Constants of Rock[1]

This standard is issued under the fixed designation D 2845; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method describes equipment and procedures for laboratory measurements of the pulse velocities of compression waves and shear waves in rock (1)[2] and the determination of ultrasonic elastic constants (Note 1) of an isotropic rock or one exhibiting slight anisotropy.

NOTE 1—The elastic constants determined by this test method are termed ultrasonic since the pulse frequencies used are above the audible range. The terms sonic and dynamic are sometimes applied to these constants but do not describe them precisely (2). It is possible that the ultrasonic elastic constants may differ from those determined by other dynamic methods.

1.2 This test method is valid for wave velocity measurements in both anisotropic and isotropic rocks although the velocities obtained in grossly anisotropic rocks may be influenced by such factors as direction, travel distance, and diameter of transducers.

1.3 The ultrasonic elastic constants are calculated from the measured wave velocities and the bulk density. The limiting degree of anisotropy for which calculations of elastic constants are allowed and procedures for determining the degree of anisotropy are specified.

1.4 The values stated in inch-pounds are to be regarded as the standard. The SI values given in parenthesis are provided for information purposes only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [3]

D 653 Terminology Relating to Rock, Soil, and Contained Fluids

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D 6026 Practice for Using Significant Digits in Geotechnical Data

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 For common definitions of terms in this standard, refer to Terminology D 653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *compression wave velocity*—the dilational wave velocity which is the propagation velocity of a longitudinal wave in a medium that is effectively infinite in lateral extent. It is not to be confused with bar or rod velocity.

4. Summary of Test Method

4.1 Details of essential procedures for the determination of the ultrasonic velocity, measured in terms of travel time and distance, of compression and shear waves in rock specimens include requirements of instrumentation, suggested types of transducers, methods of preparation, and effects of specimen geometry and grain size. Elastic constants may be calculated for isotropic or slightly anisotropic rocks, while anisotropy is reported in terms of the variation of wave velocity with direction in the rock.

5. Significance and Use

5.1 The primary advantages of ultrasonic testing are that it yields compression and shear wave velocities, and ultrasonic values for the elastic constants of intact homogeneous isotropic rock specimens (3). Elastic constants are not to be calculated for rocks having pronounced anisotropy by procedures described in this test method. The values of elastic constants often do not agree with those determined by static laboratory methods or the *in situ* methods. Measured wave velocities likewise may not agree with seismic velocities, but offer good approximations. The ultrasonic evaluation of rock properties is

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved June 1, 2005. Published July 2005. Originally approved in 1969. Last previous edition approved in 2000 as D 2845 – 00.

[2] The boldface numbers in parentheses refer to the list of references at the end of this test method.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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useful for preliminary prediction of static properties. The test method is useful for evaluating the effects of uniaxial stress and water saturation on pulse velocity. These properties are in turn useful in engineering design.

5.2 The test method as described herein is not adequate for measurement of stress-wave attenuation. Also, while pulse velocities can be employed to determine the elastic constants of materials having a high degree of anisotropy, these procedures are not treated herein.

NOTE 2—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing and sampling. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *General*—The testing apparatus (Fig. 1) should have impedance matched electronic components and shielded leads to ensure efficient energy transfer. To prevent damage to the apparatus allowable voltage inputs should not be exceeded.

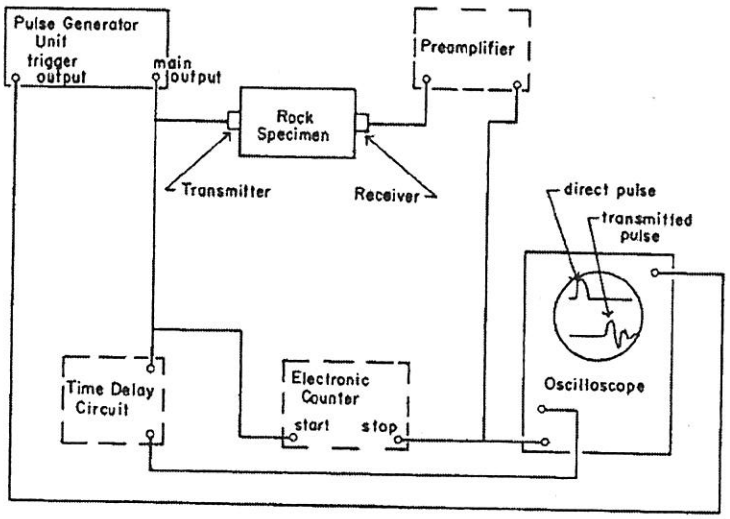
6.2 *Pulse Generator Unit*—This unit shall consist of an electronic pulse generator and external voltage or power amplifiers if needed. A voltage output in the form of either rectangular pulse or a gated sine wave is satisfactory. The generator shall have a voltage output with a maximum value after amplification of at least 50 V into a 50-Ω impedance load. A variable pulse width, with a range of 1 to 10μ *s* is desirable. The pulse repetition rate may be fixed at 60 repetitions per second or less although a range of 20 to 100 repetitions per second is recommended. The pulse generator shall also have a trigger-pulse output to trigger the oscilloscope. There shall be a variable delay of the main-pulse output with respect to the trigger-pulse output, with a minimum range of 0 to 20 μs.

6.3 *Transducers*—The transducers shall consist of a transmitter that converts electrical pulses into mechanical pulses and a receiver that converts mechanical pulses into electrical pulses. Environmental conditions such as ambient temperature, moisture, humidity, and impact should be considered in selecting the transducer element. Piezoelectric elements are usually recommended, but magnetostrictive elements may be suitable. Thickness-expander piezoelectric elements generate and sense predominately compression-wave energy; thickness-shear piezoelectric elements are preferred for shear-wave measurements. Commonly used piezoelectric materials include ceramics such as lead-zirconate-titanate for either compression or shear, and crystals such as a-c cut quartz for shear. To reduce scattering and poorly defined first arrivals at the receiver, the transmitter shall be designed to generate wavelengths at least 3 × the average grain size of the rock.

NOTE 3—Wavelength is the wave velocity in the rock specimen divided by the resonance frequency of the transducer. Commonly used frequencies range from 75 kHz to 3 MHz.

6.3.1 In laboratory testing, it may be convenient to use unhoused transducer elements. But if the output voltage of the receiver is low, the element should be housed in metal (grounded) to reduce stray electromagnetic pickup. If protection from mechanical damage is necessary, the transmitter as well as the receiver may be housed in metal. This also allows special backings for the transducer element to alter its sensitivity or reduce ringing (4). The basic features of a housed element are illustrated in Fig. 2. Energy transmission between the transducer element and test specimen can be improved by (*1*) machining or lapping the surfaces of the face plates to make them smooth, flat, and parallel, (*2*) making the face plate from a metal such as magnesium whose characteristic impedance is close to that of common rock types, (*3*) making the face plate as thin as practicable, and (*4*) coupling the transducer element to the face plate by a thin layer of an electrically conductive adhesive, an epoxy type being suggested.

6.3.2 Pulse velocities may also be determined for specimens subjected to uniaxial states of stress. The transducer housings in this case will also serve as loading platens and should be



NOTE 1—Components shown by dashed lines are optional, depending on method of travel-time measurement and voltage sensitivity of oscilloscope.

FIG. 1 Schematic Diagram of Typical Apparatus

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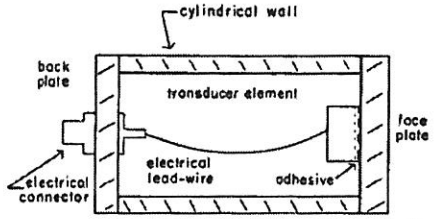


FIG. 2 Basic Features of a Housed Transmitter or Receiver

designed with thick face plates to assure uniform loading over the ends of the specimen (5).

NOTE 4—The state of stress in many rock types has a marked effect on the wave velocities. Rocks *in situ* are usually in a stressed state and therefore tests under stress have practical significance.

6.4 *Preamplifier*—A voltage preamplifier is required if the voltage output of the receiving transducer is relatively low or if the display and timing units are relatively insensitive. To preserve fast rise times, the frequency response of the preamplifier shall drop no more than 2 dB over a frequency range from 5 kHz to 4 × the resonance frequency of the receiver. The internal noise and gain must also be considered in selecting a preamplifier. Oscilloscopes having a vertical-signal output can be used to amplify the signal for an electronic counter.

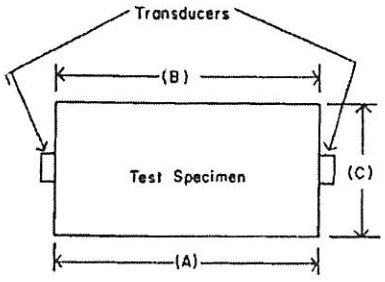
6.5 *Display and Timing Unit*—The voltage pulse applied to the transmitting transducer and the voltage output from the receiving transducer shall be displayed on a cathode-ray oscilloscope for visual observation of the waveforms. The oscilloscope shall have an essentially flat response between a frequency of 5 kHz and 4 × the resonance frequency of the transducers. It shall have dual beams or dual traces so that the two waveforms may be displayed simultaneously and their amplitudes separately controlled. The oscilloscope shall be triggered by a triggering pulse from the pulse generator. The timing unit shall be capable of measuring intervals between 2 μs and 5 ms to an accuracy of 1 part in 100. Two alternative classes of timing units are suggested, the respective positions of each being shown as dotted outlines in the block diagram in Fig. 1: (*1*) an electronic counter with provisions for time interval measurements, or (2) a time-delay circuit such as a continuously variable-delay generator, or a delayed-sweep feature on the oscilloscope. The travel-time measuring circuit shall be calibrated periodically with respect to its accuracy and linearity over the range of the instrument. The calibration shall be checked against signals transmitted by the National Institute of Standards and Technology radio station WWV, or against a crystal controlled time-mark or frequency generator that can be referenced back to the signals from WWV periodically. It is recommended that the calibration of the time measuring circuit be checked at least once a month and after any severe impact that the instrument may receive.

7. Test Specimens

7.1 *Preparation*—Exercise care in core drilling, handling, sawing, grinding, and lapping the test specimen to minimize the mechanical damage caused by stress and heat. It is recommended that liquids other than water be prevented from contacting the specimen, except when necessary as a coupling medium between specimen and transducer during the test. The surface area under each transducer shall be sufficiently plane that a feeler gage 0.001 in. (0.025 mm) thick will not pass under a straightedge placed on the surface. The two opposite surfaces on which the transducers will be placed shall be parallel to within 0.005 in./in. (0.1 mm/20 mm) of lateral dimension (Fig. 3). If the pulse velocity measurements are to be made along a diameter of a core, the above tolerance then refers to the parallelism of the lines of contact between the transducers and curved surface of the rock core. Moisture content of the test specimen can affect the measured pulse velocities. Pulse velocities may be determined on the velocity test specimen for rocks in the oven-dry state (0 % saturation), in a saturated condition (100 % saturation), or in any intermediate state. If the pulse velocities are to be determined with the rock in the same moisture condition as received or as exists underground, care must be exercised during the preparation procedure so that the moisture content does not change. In this case it is suggested that both the sample and test specimen be stored in moisture-proof bags or coated with wax and that dry surface-preparation procedures be employed. If results are desired for specimens in the oven-dried condition, refer to Test Method D 2216. The specimen shall remain submerged in water up to the time of testing when results are desired for the saturated state.

7.2 *Limitation on Dimensions*—It is recommended that the ratio of the pulse-travel distance to the minimum lateral dimension not exceed 5. Reliable pulse velocities may not be measurable for high values of this ratio. The travel distance of the pulse through the rock shall be at least 10 × the average grain size so that an accurate average propagation velocity may be determined. The grain size of the rock sample, the natural resonance frequency of the transducers, and the minimum lateral dimension of the specimen are interrelated factors that affect test results. The wavelength corresponding to the dominant frequency of the pulse train in the rock is approximately related to the natural resonance frequency of the transducer and the pulse-propagation velocity, (compression or shear) as follows:

$$\Lambda \approx V/f, \tag{1}$$



NOTE 1—(A) must be within 0.1 mm of (B) for each 20 mm of width (C).

FIG. 3 Specification for Parallelism

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where:

Λ = dominant wavelength of pulse train, in. (or m),
V = pulse propagation velocity (compression or shear), in./s (or m/s), and
f = natural resonance frequency of transducers, Hz.

The minimum lateral dimension of the test specimen shall be at least 5 × the wavelength of the compression wave so that the true dilational wave velocity is measured (Note 5), that is,

$$D \geq 5\Lambda, \tag{2}$$

where:

D = minimum lateral dimension of test specimen, in. (or m).

The wavelength shall be at least 3 × the average grain size (See 6.3) so that

$$\Lambda \geq 3d, \tag{3}$$

where:

d = average grain size, in. (or m).

Eq 1, Eq 2, and Eq 3 can be combined to yield the relationship for compression waves as follows:

$$D \geq 5(V_p/f) \geq 15\,d, \tag{4}$$

where:

V_p = pulse propagation velocity (compression), in./s (or m/s).

Since V_p and d are inherent properties of the material, f and D shall be selected to satisfy Eq 4 (Fig. 4) for each test specimen. For any particular value of V_p/f the permissible values of specimen diameter D lie above the diagonal line in Fig. 4, while the permissible values of grain size d lie below the diagonal line. For a particular diameter, the permissible values for specimen length L lie to the left of the diagonal line.

NOTE 5—Silaeva and Shamina (6) found the limiting ratio of diameter to wavelength to be about 2 for metal rods. Data obtained by Cannady (3) on rock indicate the limiting ratio is at least 8 for a specimen length-to-diameter ratio of about 8.

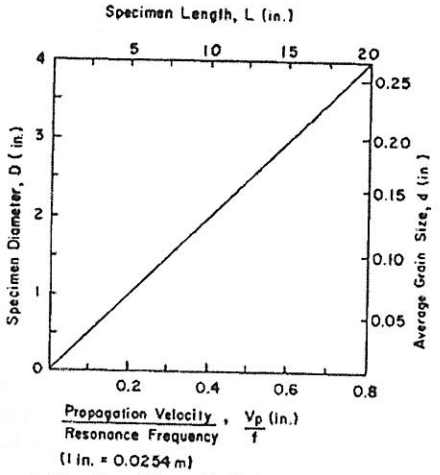

FIG. 4 Graph Showing Allowable Values of Specimen Diameter, Specimen Length and Average Grain Size Versus the Ratio of Compression Propagation Velocity to Resonance Frequency

8. Procedure

8.1 *Determination of Travel Distance and Density*—Mark off the positions of the transducers on the specimen so that the line connecting the centers of the transducer contact areas is not inclined more than 2° (approximately 0.1 in. in 3 in. (1 mm in 30 mm)) with a line perpendicular to either surface. Then measure the pulse-travel distance from center to center of the transducer contact area to within 0.1 %. The density of the test specimen is required in the calculation of the ultrasonic elastic constants (see 8.2). Determine the density of the test specimen from measurements of its mass and its volume calculated from the average external dimensions. Determine the mass and average dimensions within 0.1 %. Calculate the density as follows:

$$\rho = m/V$$

where:

ρ = density, lb sec^2/in.^{4}(or kg/m^3),
m = mass of test specimen, lb sec^2/386.4 in. (or kg), and
V = volume of test specimen, in^3(or m^3).

8.2 *Moisture Condition*—The moisture condition of the sample shall be noted and reported as explained in 10.1.3.

8.3 *Determination of Pulse-Travel Time*:

8.3.1 Increase the voltage output of the pulse generator, the gain of the amplifier, and the sensitivity of the oscilloscope and counter to an optimum level, giving a steeper pulse front to permit more accurate time measurements. The optimum level is just below that at which electromagnetic noise reaches an intolerable magnitude or triggers the counter at its lowest triggering sensitivity. The noise level shall not be greater than one tenth of the amplitude of the first peak of the signal from the receiver. Measure the travel time to within 1 part in 100 for compression waves and 1 part in 50 for shear waves by (*1*) using the delaying circuits in conjunction with the oscilloscope (see section 8.3.1.1) or (*2*) setting the counter to its highest usable precision, (see section 8.3.1.2).

8.3.1.1 The oscilloscope is used with the time-delay circuit to display both the direct pulse and the first arrival of the transmitted pulse, and to measure the travel time. Characteristically, the first arrival displayed on the oscilloscope consists of a curved transition from the horizontal zero-voltage trace followed by a steep, more or less linear, trace. Select the first break in a consistent manner for both the test measurement and the zero-time determination. Select it either at the beginning of the curved transition region or at the zero-voltage intercept of the straight line portion of the first arrival.

8.3.1.2 The counter is triggered to start by the direct pulse applied to the transmitter and is triggered to stop by the first arrival of the pulse reaching the receiver. Because a voltage change is needed to trigger the counter, it can not accurately detect the first break of a pulse. To make the most accurate time interval measurements possible, increase the counter's triggering sensitivity to an optimum without causing spurious triggering by extraneous electrical noise.

8.3.2 Determine the zero time of the circuit including both transducers and the travel-time measuring device and apply the correction to the measured travel times. This factor remains constant for a given rock and stress level if the circuit

characteristics do not change. Determine the zero time accordingly to detect any changes. Determine it by (*1*) placing the transducers in direct contact with each other and measuring the delay time directly, or (*2*) measuring the apparent travel time of some uniform material (such as steel) as a function of length, and then using the zero-length intercept of the line through the data points as the correction factor.

8.3.3 Since the first transmitted arrival is that of the compression wave, its detection is relatively easy. The shear-wave arrival, however, may be obscured by vibrations due to ringing of the transducers and reflections of the compression wave. The amplitude of the shear wave relative to the compression wave may be increased and its arrival time determined more accurately by means of thickness shear-transducer elements. This type of element generates some compressional energy so that both waves may be detected. Energy transmission between the specimen and each transducer may be improved by using a thin layer of a coupling medium such as phenyl salicylate, high-vacuum grease, or resin, and by pressing the transducer against the specimen with a small seating force.

8.3.4 For specimens subjected to uniaxial stress fields, first arrivals of compression waves are usually well defined. However, the accurate determination of shear-wave first arrivals for specimens under stress is complicated by mode conversions at the interfaces on either side of the face plate and at the free boundary of the specimen (4). Shear-wave arrivals are therefore difficult to determine and experience is required for accurate readings.

8.4 *Ultrasonic Elastic Constants*—The rock must be isotropic or possess only a slight degree of anisotropy if the ultrasonic elastic constants are to be calculated (Section 9). In order to estimate the degree of anisotropy of the rock, measure the compression-wave velocity in three orthogonal directions, and in a fourth direction oriented at 45° from any one of the former three directions if required as a check. Make these measurements with the same geometry, that is, all between parallel flat surfaces or all across diameters. The equations in 9.2 for an isotropic medium shall not be applied if any of the three compression-wave velocities varies by more than 2 % from their average value. The error in E and G (see 9.2) due to both anisotropy and experimental error will then normally not exceed 6 %. The maximum possible error in μ, λ, and K depends markedly upon the relative values of V_p and V_s as well as upon testing errors and anisotropy. In common rock types the respective percent of errors for μ, λ, and K may be large as or even higher than 24, 36, and 6. For greater anisotropy, the possible percent of error in the elastic constants would be still greater.

9. Calculation

9.1 Calculate the propagation velocities of the compression and shear waves, V_p and V_s respectively, as follows:

$$V_p = L_p/T_p$$
$$V_s = L_s/T_s$$

where:
V = pulse-propagation velocity, in./s (or m/s),
L = pulse-travel distance, in. (or m),
T = effective pulse-travel time (measured time minus zero time correction), s,

and subscripts $_p$ and $_s$ denote the compression wave and shear wave, respectively.

9.2 If the degree of velocity anisotropy is 2 % or less, as specified in 8.4, calculate the ultrasonic elastic constants as follows:

$$E = [\rho V_s^2(3V_p^2 - 4V_s^2)]/(V_p^2 - V_s^2)$$

where:
E = Young's modulus of elasticity, psi (or Pa), and
ρ = density, lb/in.^{3} (or kg/m^3);

$$G = \rho V_s^2$$

where:
G = modulus of rigidity or shear modulus, psi (or Pa);

$$\mu = (V_p^2 - 2V_s^2)/[2(V_p^2 - V_s^2)]$$

where:
μ = Poisson's ratio;

$$\lambda = \rho\,(V_p^2 - 2V_s^2)$$

where:
λ = Lamé's constant, psi (or Pa); and

$$K = \rho(3V_p^2 - 4V_s^2)/3$$

where:
K = bulk modulus, psi (or Pa).

9.3 All calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

10. Report

10.1 The report shall include the following:

10.1.1 Identification of the test specimen including rock type and location,

10.1.2 Density of test specimen,

10.1.3 General indication of moisture condition of sample at time of test such as as-received, saturated, laboratory air dry, or oven dry. It is recommended that the moisture condition be more precisely determined when possible and reported as either water content or degree of saturation,

10.1.4 Degree of anisotropy expressed as the maximum percent deviation of compression-pulse velocity from the average velocity determined from measurements in three directions,

10.1.5 Stress level of specimens,

10.1.6 Calculated pulse velocities for compression and shear waves with direction of measurement,

10.1.7 Calculated ultrasonic elastic constants (if desired and if degree of anisotropy is not greater than specified limit),

10.1.8 Coupling medium between transducers and specimen, and

10.1.9 Other data such as physical properties, composition, petrography, if determined.

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10.2 For purposes of comparing measured or calculated values with specified limits, the measured or calculated values shall be rounded to the nearest decimal given in the specification limits in accordance with the provisions of Practice D 6026.

11. Precision and Bias

11.1 An interlaboratory study of longitudinal and transverse pulse velocity (LPV and TPV) of intact specimens of four rock types was conducted in accordance with Practice E 691 in six laboratories with five replications per rock type. The results of this study are reported in ISR Research Report No. PS D18.12-R01, 1992, and its Addendum, 1994.

11.2 The repeatability and reproducibility statistics reported in Table 1 refer to within-laboratory and between-laboratory precision, respectively. Each entry in the tables has the dimensions of km/s.

11.3 The probability is approximately 95 % that two test results obtained in the same laboratory on the same material will not differ by more than the repeatability limit r. Likewise, the probability is approximately 95 % that two test results obtained in different laboratories on the same material will not differ by more than the reproducibility limit R. The precision statistics are calculated from:

$$r = 2\sqrt{2s_r}$$

where:

s_r = the repeatability standard deviation, and

$$r = 2\sqrt{2s_R}$$

where:

s_R = the reproducibility standard deviation.

11.4 It should be noted here that the anisotropy for TPV in Barre Granite is about 5 %, depending on the orientation of the plane of polarization for shear waves. The data presented here are" average" results.

11.5 *Bias*—There is no accepted reference value for this test method; therefore bias cannot be determined.

12. Keywords

12.1 compression testing; anisotropy; ultrasonic testing; velocity-pulse

TABLE 1 Repeatability and Reproducibility Statistics

	Barre Granite	Berea Sandstone	Salem Limestone	Tennessee Marble
		LPV, km/s		
Mean *x*	3.47	2.28	4.15	6.15
Repeatability limit *r*	0.22	0.15	0.27	0.44
Reproducibility limit *R*	0.48	0.30	0.58	0.45
		TPV, km/s		
Mean *x*	2.37	1.45	2.30	3.33
Repeatability limit *r*	0.14	0.07	0.21	0.25
Reproducibility limit *R*	0.80	0.58	0.61	0.55

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SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (2000) that may impact the use of the standard.

(1) Changes section references in 8.3.1. In the last sentence changes section 7.1.1 to 8.3.1.1 and section 6.3.2 to 8.3.1.2
(2) Deleted Note 2 and renumbered other notes
(3) Reworded section 1.4 caveat.
(4) Inserted Practice D 6026 reference under section 2.1
(5) Corrected spelling of anisotropy in section 1.3
(6) Corrected spelling in section 8.4, first sentence.
(7) Inserted Practice D 6026 reference under section 9.2.
(8) Inserted Practice D 6026 reference under section 10.2.
(9) Corrected spelling of anisotropy in section 12
(10) Corrected rho density symbol in section 8.1.
(11) Corrected referral in 8.2.
(12) Added new section 9.3.
(13) Deleted (7.2) in 7.1.
(14) Under Equation 1 changed (Note 6) to (Note 5).

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Rock Characterization Testing and Monitoring

ISRM Suggested Methods

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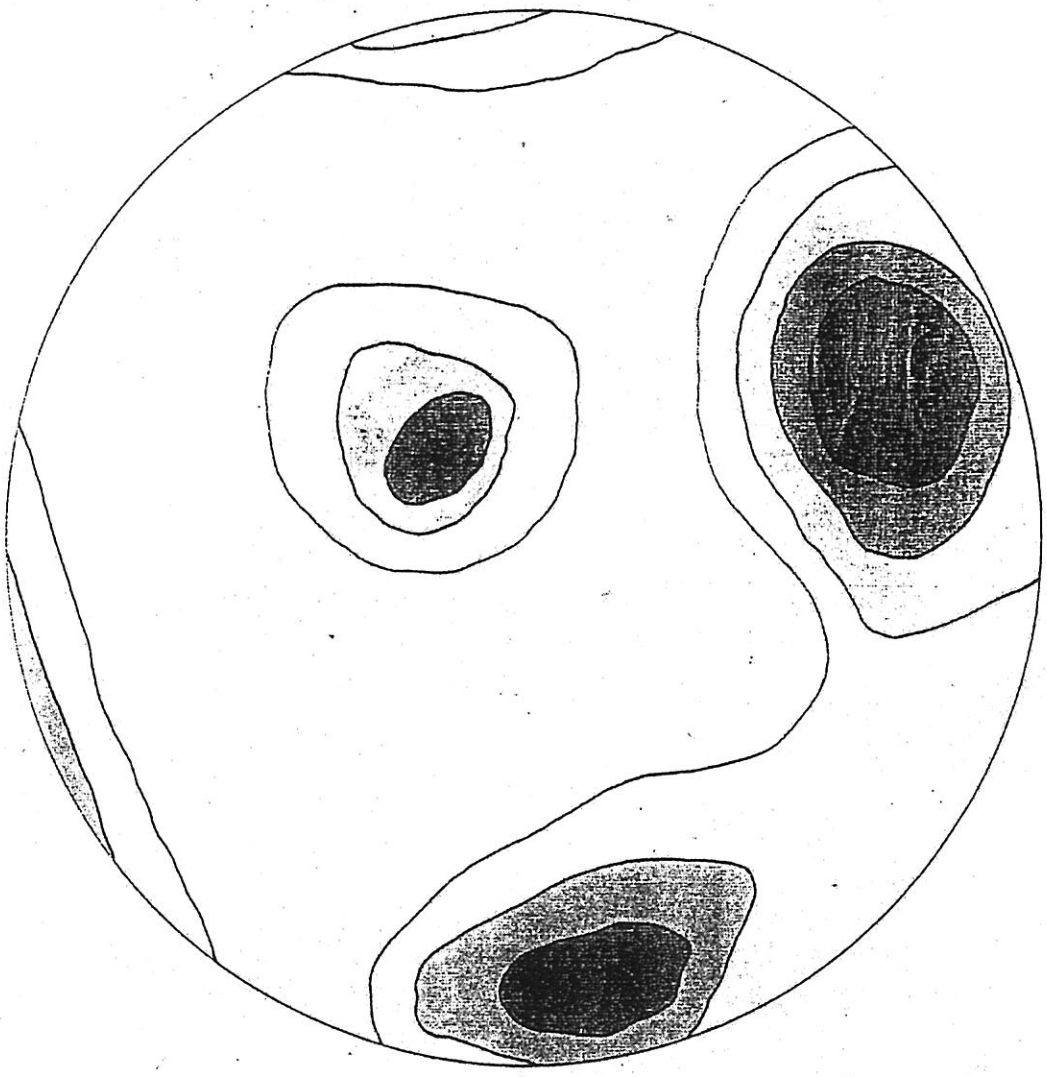

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COMMISSION ON
STANDARDIZATION OF LABORATORY AND FIELD TESTS

Suggested Methods for Determining Water Content, Porosity, Density, Absorption and Related Properties and Swelling and Slake-Durability Index Properties

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Suggested Methods for Determining Water Content, Porosity, Density, Absorption and Related Properties and Swelling and Slake-Durability Index Properties

PART 1: SUGGESTED METHODS FOR DETERMINING WATER CONTENT, POROSITY, DENSITY, ABSORPTION AND RELATED PROPERTIES

NOTES

(i) Mechanical significance of porosity and density data

The presence of pores in the fabric of a rock material decreases its strength, and increases its deformability. A small volume fraction of pores can produce an appreciable mechanical effect.

Information on the porous nature of rock materials is frequently omitted from petrological descriptions, but is required if these descriptions are to be used as a guide to mechanical performance. Sandstones and carbonate rocks in particular occur with a wide range of porosities and hence of mechanical character; igneous rocks that have been weakened by weathering processes also have typically high porosities.

Most rocks have similar grain densities and therefore have porosity and dry density values that are highly correlated (see note (v) equation 4). A low density rock is usually highly porous. It is often sufficient, therefore, to quote values for porosity alone, but a complete description requires values for both porosity and density.

Microscopic techniques used to determine volumetric content of mineral grains, do not provide a sufficiently accurate estimate of volumetric pore content, and experimental techniques are required. However, microscopy and also techniques such as mercury injection and permeability testing, can provide useful supplementary information on the shape and size of pores.

(ii) Nature of the rock sample

A representative sample for testing should generally comprise several rock lumps, each an order of magnitude larger than the largest grain or pore size. Microfissures of similar size to that of a rock will cause erratic results; their presence should be noted and if possible the lump size increased or reduced to specifically include or exclude the influence of such fissures.

The sample should if possible be large, to minimise the influence of experimental error. Alternative test methods are available calling for samples in different form; selection from among these should be based on the nature of rock to be tested.

(iii) Rock constituents

The following terms and symbols will be used to denote the masses and volumes of rock constituents when calculating physical properties such as porosity or density.

Grains (the solid component of the sample), mass M_s, volume V_s

Pore water, mass M_w and volume V_w

Pore air, zero mass and volume V_a

Pores (voids), with volume $V_v = V_w + V_a$

Bulk sample mass $M = M_s + M_w$

Bulk sample volume $V = V_s + V_v$

Density of water ρ_w = mass of water per unit volume

(iv) Definitions, terminology and preferred S.I. units

Those physical properties pertinent to the methods of test about to be described may be defined in terms of the rock sample constituents listed above.

Water content w	$= \frac{M_w}{M_s} \times 100$	(%)
Degree of saturation S_r	$= \frac{V_w}{V_v} \times 100$	(%)
Porosity n	$= \frac{V_v}{V} \times 100$	(%)
Void ratio e	$= \frac{V_v}{V_s}$	(–)
Density = bulk density ρ (mass density)	$= \frac{M}{V} = \frac{M_s + M_v}{V}$	$\frac{(kg)}{(m^3)}$

Relative density d (specific gravity)	$= \frac{\rho}{\rho_w}$	(–)
Dry density ρ_d	$= \frac{M_s}{V}$	$\frac{(kg)}{(m^3)}$
Dry relative density (dry) d_d (specific gravity)	$= \frac{\rho_d}{\rho_w}$	(–)
Saturated density ρ_{sat}	$= \frac{M_s + V_v\rho_w}{V}$	$\frac{(kg)}{(m^3)}$
Saturated relative density d_{sat} (saturated specific gravity)	$= \frac{\rho_s}{\rho_w}$	(–)
Grain density ρ_s (density of solids)	$= \frac{M_s}{V_s}$	$\frac{(kg)}{(m^3)}$
Grain relative density d_s (grain specific gravity)	$= \frac{\rho_s}{\rho_s}$	(–)
Unit weight γ	$= \rho g$	$\frac{(N)}{(m^3)}$

(v) Interdependence equations

The physical properties defined above are interrelated, so that any one property may be calculated if others are known.

For simplicity only three properties will be referred to in the text, namely, water content, porosity and dry density of rock. The equations listed below may be used to calculate any of the remaining properties from these three.

Whereas water content, degree of saturation and porosity are usually expressed as percentages, the void ratio is usually expressed as a dimensionless ratio. The following interdependence equations have been given to conform to the above.

$$S_r = \frac{100w\rho_d}{n\rho_w} \quad (\%)$$

$$e = \frac{n}{100 - n} \quad (-)$$

$$\rho = \left(1 + \frac{w}{100}\right)\rho_d \quad \frac{(kg)}{(m^3)}$$

$$\rho_s = \frac{100\rho_d}{100 - n} \quad \frac{(kg)}{(m^3)}$$

(vi) Determination of the grain mass M_s

The grain mass M_s of the sample is defined as the equilibrium mass of the sample after oven drying at a temperature of 105°C.

A thermostatically controlled, ventilated drying oven capable of maintaining a temperature of 105°C accurate to 3°C for a period of at least 24 h is required.

The sample is regarded as 'oven dry' when successive mass determinations at intervals of 4 hr yield values differing by less than 0.1% of the sample mass.

The sample should not take up water in the interval between drying and mass determination. Where necessary the sample container should be covered with an airtight lid and stored in a desiccator during cooling.

(vii) Determination of the bulk volume V

Caliper method. The bulk volume of specimens in the form of regularly shaped prisms or cylinders may be calculated from vernier or micrometer caliper measurements. An average of several readings for each dimension, each accurate to 0.1 mm, should be used in the calculation of bulk volume.

Buoyancy method. The bulk volume of regular or irregular specimens may be calculated using Archimedes principle, from the difference between saturated-surface-dry and saturated-submerged sample weights. The method is not suited to friable, swelling or slaking rocks.

The sample is saturated by water immersion in a vacuum of less than 800 Pa (6 torr) for a period of at least one hour, with periodic agitation to remove trapped air.

The sample is then transferred underwater to a basket in an immersion bath. Its saturated-submerged mass M_{sub} is determined to an accuracy of 0.1 g from the difference between the saturated-submerged mass of the basket plus sample and that of the basket alone.

The sample is then removed from the immersion bath and surface dried with a moist cloth, care being taken to remove only surface water and to ensure that no rock fragments are lost. Its saturated-surface-dry mass M_{sat} is determined to an accuracy of 0.1 g.

The sample bulk volume is calculated as

$$V = \frac{M_{sat} - M_{sub}}{\rho_w}.$$

Mercury displacement method. High surface tension prevents mercury penetrating all but the largest pores in rock. The specimen is forced under mercury and its volume determined from the displaced fluid volume. A calibrated tube may be incorporated in the apparatus for this purpose, or the displacement may be measured by a micrometer screw gauge—electric contact technique. Alternatively a technique may be employed where the displaced mercury volume is obtained by mass determination. The apparatus should give results accurate to 0.5% of the specimen bulk volume, and should be periodically calibrated using a standard sphere or cylinder.

Water displacement method. The bulk volume of a saturated-surface-dry sample may be determined by water displacement using a technique similar to that for mercury displacement. Alternatively the dry or partially dry sample may be coated in wax or plastic and its bulk volume determined from the water volume displaced by the coated sample, corrected for the volume of coating material. The method requires accurate determination of coating volume and is best applied to large bulk samples where other techniques are impractical.

Suggested Methods for Determining Water Content

(viii) Determination of pore volume (volume of voids) V_v

Saturation method. The pore volume of a rock sample may be determined from the difference between saturated-surface-dry and oven-dry masses. The sample is saturated by water immersion in a vacuum and its saturated-surface-dry mass M_{sat} is determined. It is then oven dried to determine the grain mass M_s.

The pore volume V_v is calculated as

$$V_v = \frac{M_{sat} - M_s}{\rho_w}.$$

The Washburn–Bunting method (Washburn & Bunting, 1922). A rock specimen is oven-dried and immersed in mercury. The pressure on the mercury is reduced so that the pore air expands, leaves the rock and is trapped above the mercury column. The volume of pore air V_a is measured directly in a calibrated tube, after pressure has been equalised with that of the atmosphere. The method is rapid but is best suited to rocks with high porosity.

(ix) Determination of grain volume V_s

Boyle's law method. The pressure-volume relationship for a container filled with gas only is obtained, then for the same container filled with specimen plus gas. The difference in compressibility is due to the volume V_s of incompressible grains, and this volume may be calculated from the results. One type of Boyle's law single-cell porosimeter employs a graduated mercury pump to measure volume displacement, together with a Bourdon gauge to measure pressure change. Boyle's law double cell techniques employ pressure equalization between two containers at different initial pressures.

Pulverization method. After determination of bulk volume and grain mass, the oven-dry sample is pulverized and its grain volume G_v determined by displacement of an equivalent volume of liquid (e.g. toluene) in a volumetric flask.

Porosity calculated from bulk volume and grain volume using the pulverization method is termed *total* porosity, since the pore volume obtained includes that of 'closed' pores. Other techniques give *effective* porosity values since they measure the volume of interconnected pores only.

1. SUGGESTED METHOD FOR DETERMINATION OF THE WATER CONTENT OF A ROCK SAMPLE

1. SCOPE

This test is intended to measure the mass of water contained in a rock sample as a percentage of the oven-dry sample mass.

2. APPARATUS

(a) An oven capable of maintaining a temperature of 105°C to within 3°C for a period of at least 24 hr.

(b) A sample container of non-corrodible material, including an airtight lid.

(c) A desiccator to hold sample containers during cooling.

(d) A balance of adequate capacity, capable of weighing to an accuracy of 0.01% of the sample weight.

3. PROCEDURE

(a) The container with its lid is cleaned and dried, and its mass A determined.

(b) A representative sample comprised at least 10 lumps each having either a mass of at least 50 g or a minimum dimension of ten times the maximum grain size, whichever is the greater, is selected. For *in situ* water content determination sampling, storage and handling precautions should be such that water content remains within 1% of the *in situ* value.

(c) The sample is placed in the container, the lid replaced and the mass B of sample plus container determined.

(d) The lid is removed and the sample dried to constant mass at a temperature of 105°C.

(e) The lid is replaced and the sample allowed to cool in the desiccator for 30 min. The mass C of sample plus container is determined.

4. CALCULATION

$$\text{Water content } w = \frac{\text{pore water mass } M_v}{\text{grain mass } M_s} \times 100\%$$

$$= \frac{B - C}{C - A} \times 100\%.$$

5. REPORTING OF RESULTS

The water content should be reported to the nearest 0.1% stating whether this corresponds to *in situ* water content, in which case precautions taken to retain water during sampling and storage should be specified.

2. SUGGESTED METHOD FOR POROSITY/DENSITY DETERMINATION USING SATURATION AND CALIPER TECHNIQUES

1. SCOPE

(a) This test is intended to measure the porosity, the dry density and related properties of a rock sample in the form of specimens of regular geometry.

(b) The method should only be used for non-friable, coherent rocks that can be machined and do not appreciably swell or disintegrate when oven dried or immersed in water. The method is recommended when regularly shaped specimens are required for other test purposes.

2. APPARATUS

(a) An oven capable of maintaining a temperature of 105°C to within 3°C for a period of at least 24 hr.

(b) A desiccator to hold specimens during cooling.

(c) A measuring instrument such as vernier or micrometer caliper, capable of reading specimen dimensions to an accuracy of 0.1 mm.

(d) Vacuum saturation equipment such that the specimens can be immersed in water under a vacuum of less than 800 Pa (6 torr) for a period of at least one hour.

(e) A balance of adequate capacity, capable of determining the mass of a specimen to an accuracy of 0.01%.

3. PROCEDURE

(a) At least three specimens from a representative sample of a material are machined to conform closely to the geometry of a right cylinder or prism. The minimum size of each specimen should either be such that its mass is at least 50 g (for an average density rock a cube with sides of 27 mm will have sufficient mass) or such that its minimum dimension is at least ten times the maximum grain size, whichever is the greater.

(b) The specimen bulk volume V is calculated from an average of several caliper readings for each dimension. Each caliper reading should be accurate to 0.1 mm.

(c) The specimen is saturated by water immersion in a vacuum of less than 800 Pa (6 torr) for a period of at least 1 hr, with periodic agitation to remove trapped air.

(d) The specimen is removed and surface dried using a moist cloth, care being taken to remove only surface water and to ensure that no fragments are lost. Its saturated-surface-dry mass M_{sat} is determined.

(e) The specimen is dried to constant mass at a temperature of 105°C, allowed to cool for 30 min in a desiccator, and its mass is determined to give grain mass M_s. Specimens in this test are generally of sufficient coherence not to require containers, but these should be used if the rock is at all friable or fissile.

4. CALCULATIONS

Pore volume $$V_v = \frac{M_{sat} - M_s}{\rho_w}$$

Porosity $$n = \frac{100 V_v}{V}\%$$

Dry density of rock $$\rho_d = \frac{M_s}{V}.$$

5. REPORTING OF RESULTS

(a) Individual results for at least three specimens per rock sample should be reported, together with average results for the sample.

(b) Density values should be given to the nearest 10 kg/m^3 and porosity values to the nearest 0.1%.

(c) The report should specify that bulk volume was obtained by caliper measurement and that pore volume was obtained by water saturation.

3. SUGGESTED METHOD FOR POROSITY/DENSITY DETERMINATION USING SATURATION AND BUOYANCY TECHNIQUES

1. SCOPE

(a) The test is intended to measure the porosity, the dry density and related properties of a rock sample in the form of lumps or aggregate of irregular geometry. It may also be applied to a sample in the form of specimens of regular geometry.

(b) The method should only be used for rocks that do not appreciably swell or disintegrate when oven-dried and immersed in water.

2. APPARATUS

(a) An oven capable of maintaining a temperature of 105°C to within 3°C for a period of at least 24 hr.

(b) A sample container of non-corrodible material, including an air-tight lid.

(c) A desiccator to hold sample containers during cooling.

(d) Vacuum saturation equipment such that the sample can be immersed in water under a vacuum of less than 800 Pa (6 torr) for a period of at least 1 hr.

(e) A balance of adequate capacity, capable of determining the mass of a specimen to an accuracy of 0.01%.

(f) An immersion bath and a wire basket or perforated container, such that the sample immersed in water can be freely suspended from the stirrup of the balance to determine the saturated-submerged mass. The basket should be suspended from the balance by a fine wire so that only the wire intersects the water surface in the immersion bath.

3. PROCEDURE

(a) A representative sample comprising at least 10 lumps of regular or irregular geometry, each having either a mass of at least 50 g or a minimum dimension of at least 10 times the maximum grain size, whichever is the greater, is selected. The sample is washed in water to remove dust.

(b) The sample is saturated by water immersion in a vacuum of less than 800 Pa (6 torr) for a period of at least one hour, with periodic agitation to remove trapped air.

(c) The sample is then transferred under water to the basket in the immersion bath. Its saturated-submerged mass M_{sub} is determined to an accuracy of 0.1 g from the difference between the saturated-submerged

mass of the basket plus sample and that of the basket alone.

(d) The sample container with its lid is cleaned and dried, and its mass A is determined.

(e) The sample is removed from the immersion bath and surface-dried with a moist cloth, care being taken to remove only surface water and to ensure that no rock fragments are lost. The sample is transferred to the sample container, the lid replaced, and the mass B of saturated-surface-dry sample plus container is determined.

(f) The lid is removed and the sample dried to constant mass at a temperature of 105°C, the lid replaced and the sample allowed to cool for 30 min in a dessicator. The mass C of oven-dry sample plus container is measured.

4. CALCULATIONS

4. Saturated-surface-dry mass $M_{sat} = B - A$

Grain weight $M_s = C - A$

Bulk volume $V = \dfrac{M_{sat} - M_{sub}}{\rho_w}$

Pore volume $V_v = \dfrac{M_{sat} - M_s}{\rho_w}$

Porosity $n = \dfrac{100V_v}{V}\ \%$

Dry density of rock $\rho_d = \dfrac{M_s}{V}$.

5. REPORTING OF RESULTS

(a) The report should include porosity and dry density values for the sample, and should specify that bulk volume was obtained by a buoyancy technique and that pore volume was obtained by water saturation.

(b) Density values should be given to the nearest 10 kg/m^3 and porosity values to the nearest 0.1%.

4. SUGGESTED METHOD FOR POROSITY/DENSITY DETERMINATION USING MERCURY DISPLACEMENT AND GRAIN SPECIFIC GRAVITY TECHNIQUES

1. SCOPE

(a) The test is intended to measure the porosity, the dry density and related properties of a rock sample in the form of lumps or aggregate of irregular geometry. It is particularly suitable if the rock material is liable to swell or disintegrate if immersed in water. The test may also be applied to regularly shaped rock specimens or to coherent rock materials, but other techniques are usually found more convenient in these cases.

2. APPARATUS

(a) An oven capable of maintaining a temperature of 105°C to within 3°C for a period of at least 24 hr. It should have forced ventilation exhausting to outside atmosphere.

(b) Specimen containers of non-corrodible material, including airtight lids.

(c) A dessicator to hold specimen containers during cooling.

(d) A balance of adequate capacity, capable of mass determination to 0.001 g.

(e) A mercury-displacement volume measuring apparatus capable of measuring specimen volume to 0.5%.

(f) Grinding equipment to reduce the sample to a pulverized powder less than 150 μm in grain size.

(g) A calibrated volumetric flask and stopper (conveniently 50 cm^3).

(h) A constant temperature water bath.

(i) A vacuum apparatus capable of maintaining a vacuum with a pressure of less than 800 Pa (6 torr).

(j) A soft brush of camel hair or of a similar softness.

3. PROCEDURE

(a) A representative sample is selected comprising at least ten rock lumps, the shape and size of lumps suiting the capabilities of the volume measuring apparatus. The minimum size of each lump should preferably be either such that its mass exceeds 50 g or such that its minimum dimension is at least ten times the maximum grain size, whichever is the greater. Specimens of swelling or fissile rock should be sampled and stored to retain water content to within 1% of its *in situ* value prior to testing.

(b) Each specimen is brushed to remove loose material and its volume V is measured by mercury displacement. Mercury adhering to the specimen is carefully removed, ensuring that no rock fragments are lost.

(c) The specimen container with its lid is cleaned, dried and its mass A is determined.

(d) The specimen is placed in the container, the lid replaced and mass B of container plus specimen at initial water content is determined.

(e) The lid is removed and the specimen oven dried to constant mass at a temperature of 105°C and allowed to cool for 30 min in a desiccator. The mass C of container plus oven-dry specimen is determined.

(f) Steps (b)–(e) are repeated for each specimen in the sample.

(g) Together the specimens are crushed and ground to a grain size not exceeding 150 μm. A number of representative sub samples of about 15 g of the pulverized material are selected and oven-dried.

(h) The mass D of a clean, dry volumetric flask plus stopper is determined to 0.001 g.

(i) The flask is filled with a fluid such as toluene that is non-reactive with the rock, is brought to equilibrium temperature in the constant temperature bath, and the

liquid level is adjusted accurately to the 50 cm^3 graduation. The flask is removed, stoppered and its mass E determined to 0.001 g.

(j) The flask is emptied and dried, and the 15 g subsample of dry, pulverized rock added with the aid of a funnel. The mass F of flask, sample and stopper is measured to 0.001 g.

(k) The flask and subsample are evacuated for about 20 min and sufficient fluid added to thoroughly wet the sample. Further fluid is then added and the flask carefully evacuated to remove air. The flask is replaced in the constant temperature water bath and the liquid level adjusted accurately to the 50 cm^3 graduation.

(l) The stoppered flask with its contents is allowed to cool and its mass G is determined to 0.001 g.

(m) Steps (j)–(l) are repeated for each subsample of pulverized material.

4. CALCULATIONS

(a) Water content $$w = \frac{B - C}{C - A} \times 100\%$$

(b) Grain density $$\rho_s = \frac{F - D}{V_f\left(1 - \frac{G - F}{E - D}\right)}$$

where V_f = calibrated volume of flask, usually 50 cm^3

(c) Grain mass $$M_s = C - A$$

(d) Dry density of rock $$\rho_d = \frac{M_s}{V}$$

(e) Porosity $$n = \frac{100(\rho_s - \rho_d)}{\rho_s}\%.$$

5. REPORTING OF RESULTS

(a) Individual dry density values for each specimen in the sample should be reported, together with average values for the sample. Porosity values for each subsample should also be reported together with the average value.

(b) The report should specify that the bulk volume was obtained using a mercury displacement technique, and that the porosity was calculated from grain volume measurements using a pulverization technique.

(c) The grain density or grain specific gravity for the sample should be reported. The water content at which bulk volume measurement took place should be specified, stating whether this corresponds to *in situ* water content.

(d) Density values should be given to the nearest 10 kg/m^3 and porosity values to the nearest 0.1 percent.

5. SUGGESTED METHOD FOR POROSITY/DENSITY DETERMINATION USING MERCURY DISPLACEMENT AND BOYLE'S LAW TECHNIQUES

1. SCOPE

(a) This test is intended to measure the porosity, the dry density and related properties of a rock sample. A sample in the form of specimens of a specific size and shape to suit the apparatus is usually required to ensure accurate results.

(b) The method should only be used for rocks that do not shrink appreciably during oven-drying.

2. APPARATUS

The procedure given below relates to a test using the Kobe type of single cell Boyle's Law porosimeter (Fig. 1). Any similar apparatus of equivalent accuracy may however be used. The apparatus consists essentially of the following:

Oven drying equipment:

(a) An oven capable of maintaining a temperature of 105°C to within 3°C for a period of at least 24 hr.

(b) A specimen container of non-corrodible material including an airtight lid.

(c) A desiccator to hold specimen containers during cooling.

(d) A balance of adequate capacity, capable of determining the mass of a specimen to an accuracy of 0.01%.

A Boyle's law porosimeter such as a Kobe porosimeter having the following features:

(e) A mercury screw-piston pump with micrometer graduated to measure the volume of displaced mercury to an accuracy of 0.01 cm^3. Conveniently one turn of the screw pump changes the volume of the specimen chamber by 1 cm^3.

(f) A specimen chamber with removable cap to allow insertion of the specimen.

(g) A sight glass inscribed with a reference line, an electric indicator-contact or other means of registering a mercury datum level in the cap.

(h) A gas inlet and outlet, each with a shutoff valve, also a source of inert gas such as helium. Air may be used with some loss of accuracy, but must be adequately dried.

(i) A precision pressure gauge or pressure transducer with a range from 100 kPa to about 400 kPa, connected to measure the gas pressure in the specimen chamber.

3. PROCEDURE

(a) At least three specimens are selected from a representative sample of material and each specimen is tested separately to obtain an average result for the sample. The size and shape of a specimen should allow only a small clearance with the specimen chamber to

Suggested Methods for Determining Water Content

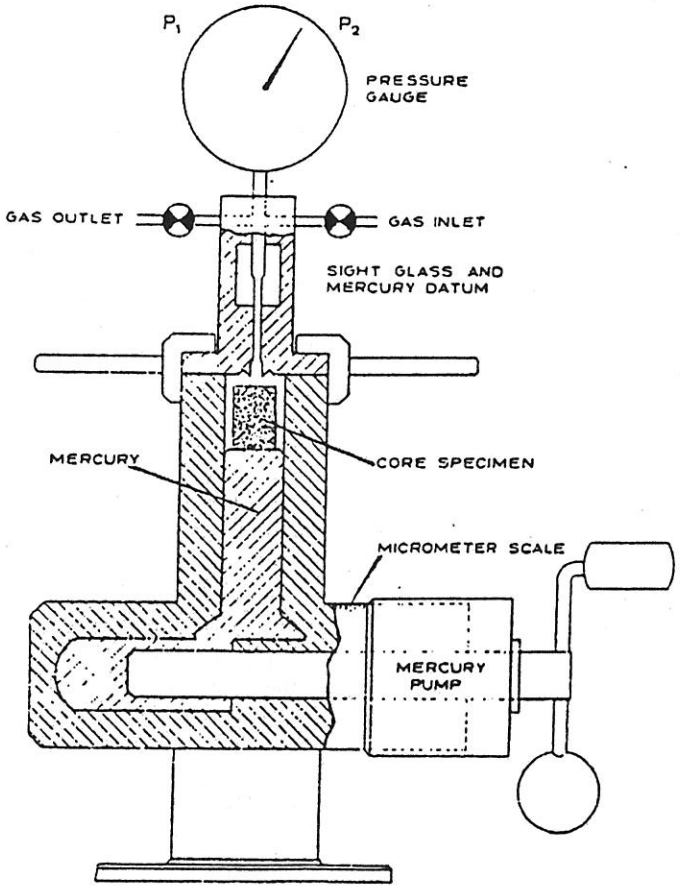

Fig. 1. Schematic diagram of a Kobe Boyle's law porosimeter.

ensure accurate results. The chamber is usually cylindrical and accepts a standard size of rock core. The size of each specimen should preferably be either such that its mass is a minimum of 50 g or that its minimum dimensions are at least ten times the maximum grain size, whichever is the greater.

(b) The specimen container with its lid is cleaned, dried and its mass A is determined.

(c) The specimen is placed in the container, dried to constant mass at a temperature of 105°C and the lid is replaced. It is allowed to cool for 30 min in a desiccator, and the mass B of oven-dry specimen plus container is determined.

(d) Use of the porosimeter: the mercury pump reading at the start of each compression or displacement cycle is termed the 'start point'. Inlet and outlet valves are closed at the start of a compression cycle so that the initial pressure P_1 is atmospheric. The start point and also the pressure P_2 at the end of a compression cycle are usually selected as standard for the apparatus, to ensure that the specimen still floats on mercury at the end of the cycle, hence avoiding imbibition that might occur if specimens became deeply immersed.

(e) To flush the specimen chamber with gas; inlet valve is closed, the outlet opened and the pump advanced until mercury reached the datum. The outlet is then half shut, the inlet opened and the pump retracted to beyond the start point. The inlet, then the outlet valve is closed.

(f) To determine the compression factor C_f for the cell: the specimen chamber is first flushed with gas, the outlet valve opened and the pump advanced to the start point. The outlet valve is shut with the specimen chamber at atmospheric pressure P_1. The pump is advanced and a micrometer reading C_0 taken when the pressure reaches P_2. The chamber is again flushed with gas, and with the outlet valve open the pump is advanced to a new start point 10 cm^3 beyond the original one. The outlet is closed with the chamber at atmospheric pressure P_1 and the pump advanced, a micrometer reading C_1 being taken when the pressure again reaches P_2.

The compression factor is computed from the formula:

$$C_f = \frac{10}{10 - (C_0 - C_1)}.$$

This factor is dependent on ambient pressure and should be periodically checked.

(g) Each test comprises a displacement stroke followed by a compression stroke with the specimen chamber empty (a blank run), then a displacement

stroke followed by a compression stroke with the specimen in the chamber. The procedure is as follows:

(h) With the inlet valve shut and the outlet open, the pump is advanced until the mercury reaches the datum. The micrometer reading R_1 is recorded.

(i) The chamber is flushed with gas, the pump advanced to the start point and the valves closed with the chamber at atmospheric pressure P_1. The pump is advanced and a micrometer reading R_2 recorded when the pressure reaches P_2.

(j) The specimen is removed from the desiccator and inserted in the chamber. The chamber is flushed with gas and step (h) repeated, recording the displacement stroke micrometer reading R_3 at which mercury reaches the datum.

(k) Step (i) is repeated, recording the compression stroke micrometer reading R_4 when the pressure again reaches P_2.

4. CALCULATIONS

Bulk volume $B_v = R_3 - R_1$

Grain volume $G_v = C_f(R_4 - R_2)$

Grain weight $G_w = B - A$

Porosity $$n = \frac{B_v - G_v}{B_v} \times 100\%$$

Dry density of rock $\rho_d = G_w/B_v$.

5. REPORTING OF RESULTS

(a) Individual dry density and porosity values for each specimen in the sample should be recorded, together with average values for the sample.

(b) The report should specify that the bulk volume was obtained using a mercury displacement technique, and that the porosity was calculated from grain volume measurements using a Boyle's law technique.

(c) Density values should be given to the nearest kg/m^3 and porosity values to the nearest 0.1 porosity percent.

6. SUGGESTED METHOD FOR VOID INDEX DETERMINATION USING THE QUICK ABSORPTION TECHNIQUE

1. SCOPE

(a) This test is intended to measure the void index, defined as the mass of water contained in a rock sample after a one hour period of immersion, as a percentage of its initial desiccator-dry-mass.

(b) The index is correlated with porosity, hence also with such properties as degree of weathering or alteration. The test is designed to call for a minimum of equipment. Where suitable equipment is available, however, the porosity and density of the rock material should be determined directly using techniques such as those proposed earlier (methods 2–5).

(c) The test should only be used for rocks that do not appreciably disintegrate when immersed in water.

2. APPARATUS

(a) A sample container of non-corrodible material, water tight and of sufficient capacity to contain the sample packed in dehydrated silica gel.

(b) A quantity of dehydrated silica gel.

(c) A balance of adequate capacity, accurate to 0.5 g.

3. PROCEDURE

(a) A representative sample is selected comprising at least ten rock lumps. The size of each lump should be such that its mass exceeds 50 g or such that its minimum dimension is at least ten times the maximum grain size, whichever is the greater.

(b) The sample in an air-dry condition is packed into the container, each lump separated from the next and surrounded by crystals of dehydrated silica gel. The container is left to stand for a period of 24 hr.

(c) The container is emptied, the sample removed, brushed clean of loose rock and silica gel crystals and its mass A determined to 0.5 g.

(d) The sample is replaced in the container and water is added until the sample is fully immersed. The container is agitated to remove bubbles of air and is left to stand for a period of one hour.

(e) The sample is removed and surface-dried using a moist cloth, care being taken to remove only surface water and to ensure that no fragments are lost. The mass B of the surface-dried sample is determined to 0.5 g.

4. CALCULATION

Void index $$I_v = \frac{B - A}{A} \times 100\%.$$

5. REPORTING OF RESULTS

(a) The void index for the sample should be reported to the nearest 1%.

(b) The report should specify that the void index is defined as the water content after desiccator drying followed by a one-hour period of immersion.

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PART 2: SUGGESTED METHODS FOR DETERMINING SWELLING AND SLAKE-DURABILITY INDEX PROPERTIES

NOTES

(i) Mechanical significance of swelling and slake-durability data

An abundant class of rock materials, notably those with high clay content, are prone to swelling, weakening or disintegration when exposed to short term weathering processes of a wetting and drying nature. Special tests are necessary to predict this aspect of mechanical performance. These tests are index tests; they are best used in classifying and comparing one rock with another. The swelling strain index should not, for example, be taken as the actual swelling strain that would develop *in situ*, even under similar conditions of loading and of water content.

These tests simulate natural wetting and drying processes. Other types of test are better suited to estimating resistance to such weathering agencies as frost, salt crystallization or attrition (De Puy, 1965).

(ii) Nature of the rock sample

Where possible undisturbed rock specimens should be tested, since rock fabric has an important effect on the other properties to be measured. Where the sample is too weak or too broken to allow preparation of undisturbed specimens, as is usually the case with joint-filling materials for example, the swelling tests may be carried out on remoulded specimens. Remoulding should be according to standard procedures for soil compaction, and the procedure followed should be described when reporting the test results.

(iii) Application of the tests to hard and soft rocks

These tests are commonly required for classification or characterization of the softer rock materials. They may also be used, however, for characterization of harder rocks where the rock condition, its advanced state of weathering for example, indicates that they are appropriate.

Rocks that disintegrate during the tests should be further characterized using soil classification tests such as determination of the liquid and plastic limits, the grain size distribution, or the content and type of clay minerals present.

1. SUGGESTED METHOD FOR DETERMINATION OF THE SWELLING PRESSURE INDEX UNDER CONDITIONS OF ZERO VOLUME CHANGE

1. SCOPE

This test is intended to measure the pressure necessary to constrain an undisturbed rock specimen at constant volume when it is immersed in water.

2. APPARATUS

The apparatus may be adapted from that used for soil consolidation testing, and consists essentially of the following:

(a) A metal ring for rigid radial restraint of the specimen, polished and lubricated to reduce side friction and of depth at least sufficient to accommodate the specimen.

(b) Porous plates to allow water access at top and bottom of the specimen, the top plate of such a diameter to slide freely in the ring. Filter papers may be inserted between specimen and plates.

(c) A cell to contain the specimen assembly, capable of being filled with water to a level above the top porous plate. The principal features of the cell and specimen assembly are illustrated in Fig. 2.

(d) A micrometer dial gauge or other device reading to 0.0025 mm, mounted to measure the swelling displacement at the central axis of the specimen.

(e) A load measuring device capable of measuring to an accuracy of 1%, the force required to resist swelling.

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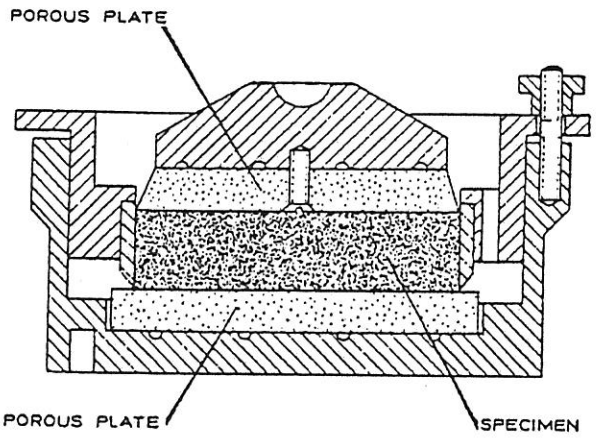

Fig. 2. Cell and specimen assembly for confined swelling tests.

(f) A loading device such as a screw jack, capable of continuous adjustment to maintain the specimen at constant volume as swelling pressure develops. The force should be applied through rigid members to ensure that the porous plates remain flat, a spherical seat allowing rotation of the top porous plate.

3. PREPARATION OF THE TEST SPECIMENS

(a) For testing at natural initial water content, preparation should be such as to retain water content to within 1% of its *in situ* value. Duplicate specimens should be prepared from the same sample, one being used for water content determination and the other for swell testing.

(b) For testing at an artificially controlled initial water content the sample may be brought to equilibrium mass in a constant humidity environment. Duplicate specimens should then be prepared from the same sample, one being used for water content determination and the other for swell testing.

(c) The specimen should conform closely to the geometry of a right cylinder. It should have a diameter not less than 2.5 times its thickness. The thickness should exceed 15 mm or ten times the maximum grain diameter, whichever is greater. The specimen should be a close fit in the ring.

(d) The inclination of bedding or foliation with respect to the specimen axis should be recorded.

4. PROCEDURE

(a) The apparatus is assembled and a small axial force say about 10 kPa is applied to the specimen.

(b) The cell is then flooded with water to cover the top porous plate, and the swelling force is recorded as a function of time elapsed.

(c) The applied force is regularly adjusted to maintain zero specimen swell throughout the test. The thickness of the specimen should be maintained to within 0.01 mm.

(d) Swelling force should continue to be recorded until it reaches a constant level or passes a peak.

5. CALCULATION

The swelling pressure index is calculated as follows:

$$\text{Swelling pressure index} = \frac{F}{A}$$

where: F = maximum axial swelling force recorded during the test; A = cross sectional area of the specimen.

6. REPORTING OF RESULTS

Results should be presented for at least three specimens per sample. The report should include the following information for each specimen:

(a) The swelling pressure index.

(b) The initial water content of the specimen; whether this corresponds to the natural water content, and if so the method of storage prior to testing.

(c) The diameter and thickness of the specimen, together with the inclination of bedding or foliation with respect to the specimen axis.

2. SUGGESTED METHOD FOR DETERMINATION OF THE SWELLING STRAIN INDEX FOR A RADIALLY CONFINED SPECIMEN WITH AXIAL SURCHARGE

1. SCOPE

This test is intended to measure the axial swelling strain developed against a constant axial pressure or surcharge, when a radially confined, undisturbed rock specimen is immersed in water.

2. APPARATUS

The apparatus may be adapted from that used for soil consolidation testing, and consists essentially of the following:

(a) A metal ring for rigid radial restraint of the specimen, polished and lubricated to reduce side friction and of depth at least sufficient to accommodate the specimen when fully swollen.

(b) Porous plates to allow water access at top and bottom of the specimen, the top plate of such a diameter to slide freely in the ring. Filter papers may be inserted between specimen and plates.

(c) A cell to contain the specimen assembly, capable of being filled with water to a level above the top porous plate. The principal features of the cell and specimen assembly are illustrated in Fig. 2.

(d) A micrometer dial gauge or other device reading to 0.0025 mm, mounted to measure the swelling displacement at the central axis of the specimen.

(e) A loading device such as a dead mass, or mass and lever system, capable of applying a sustained pressure of 5 kPa to the specimen, this pressure to be main-

men. The force should be applied through rigid members so as to ensure that the porous plates remain flat, a spherical seat allowing rotation of the top porous plate.

3. PREPARATION OF THE TEST SPECIMENS

(a) For testing at natural initial water content, preparation should be such as to retain water content to within 1% of its *in situ* value. Duplicate specimens should be prepared from the same sample, one being used for water content determination and the other for swell testing.

(b) For testing at an artificially controlled initial water content the sample may be brought to equilibrium mass in a constant humidity environment. Duplicate specimens should then be prepared from the same sample, one being used for water content determination and the other for swell testing.

(c) The specimen should conform closely to the geometry of a right cylinder. It should have a diameter not less than four times its thickness. The thickness should exceed 15 mm or ten times the maximum grain diameter, whichever is greater. The specimen should be a close fit in the ring.

(d) The inclination of bedding or foliation with respect to the specimen axis should be recorded.

4. PROCEDURE

(a) The initial thickness and diameter of the specimen are recorded to 0.1%.

(b) The apparatus is assembled and the specimen loaded axially to a surcharge pressure of 3 kPa.

(c) The cell is then flooded with water to cover the top porous plate, and the swelling displacement recorded as a function of time elapsed.

(d) Swelling displacement should continue to be recorded until it reaches a constant level or passes a peak.

5. CALCULATION

The swelling strain index is calculated as follows:

$$\text{Swelling strain index} = \frac{d}{L} \times 100\%$$

where: d = maximum swelling displacement recorded during the test; L = initial thickness of the specimen.

6. REPORTING OF RESULTS

Results should be presented for at least three specimens per sample. The report should clearly indicate that the specimen was radially confined during the swelling test. The report should include the following information for each specimen:

(a) The swelling strain index.

(b) The initial water content of the specimen; whether this corresponds to the natural water content, and if so the method of storage prior to testing.

(c) The initial diameter and thickness of the specimen, together with the inclination of bedding or foliation with respect to the specimen axis.

3. SUGGESTED METHOD FOR DETERMINATION OF THE SWELLING STRAIN DEVELOPED IN AN UNCONFINED ROCK SPECIMEN

1. SCOPE

This test is intended to measure the swelling strain developed when an unconfined, undisturbed rock specimen is immersed in water. The test should only be applied to specimens that do not change their geometry appreciably on slaking; less durable rocks are better tested using a confined swelling test.

2. APPARATUS

The apparatus consists essentially of the following:

(a) A cell to contain the specimen assembly, capable of being filled with water to a level above the top of the specimen. The principal features of the cell and specimen assembly are illustrated in Fig. 3.

(b) A micrometer dial gauge or other device reading to 0.0025 mm, mounted to measure the swelling displacement on the central axis of the specimen. Additional gauges may be employed to simultaneously measure swelling displacements in directions orthogonal to the first.

(c) Bearing plates of glass or other hard material which may be cemented to the specimen with water-stable adhesive. These plates should be small compared with the area of specimen exposed to water, and are positioned at points of gauging and of support to prevent indentation of the specimen.

3. PREPARATION OF THE TEST SPECIMENS

(a) For testing at natural initial water content, preparation should be such as to retain water content to within 1% of its *in situ* value. Duplicate specimens should be prepared from the same sample, one being used for water content determination and the other for swell testing.

(b) For testing at an artificially controlled initial water content the sample may be first prepared into specimens, then brought to equilibrium mass in a constant humidity environment. Duplicate specimens should be prepared from the sample, one being used for water content determination and the other for swell testing.

(c) The specimen may take the form of a right cylinder or a rectangular prism. The minimum speci-

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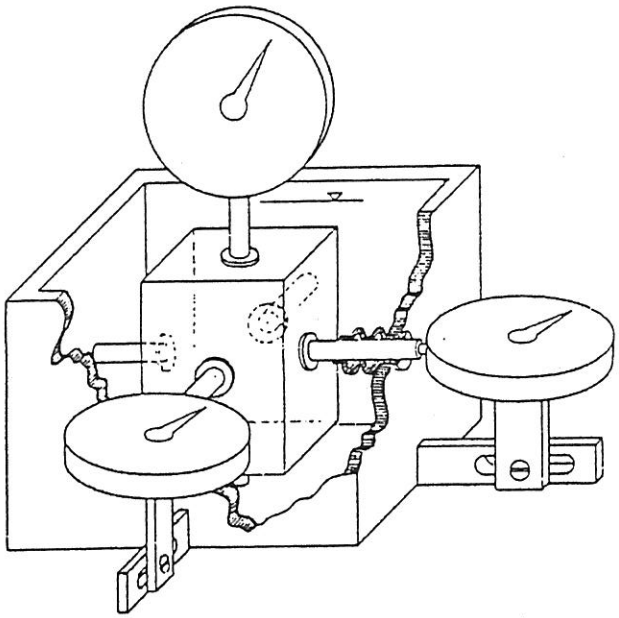

Fig. 3. Cell and specimen assembly for unconfined swelling tests.

men dimension should exceed 15 mm or ten times the maximum grain diameter, whichever is greater.

(d) The specimen should preferably be machined so that an axis is perpendicular to any bedding or foliation. The inclination of the directions of swell measurement with respect to this bedding or foliation should be recorded.

4. PROCEDURE

(a) Gauge points are marked to coincide with the axis or axes of the specimen. The initial specimen dimensions are measured between these gauge points to an accuracy better than 0.1%.

(b) Bearing plates are then positioned at each gauge point and the apparatus assembled. The specimen should be supported only at gauge points on the specimen axes.

(c) The cell is then flooded with water to cover the specimen, and the swelling displacement or displacements recorded as a function of time elapsed.

(d) Swelling displacement should continue to be recorded until it reaches a constant level or passes a peak.

5. CALCULATION

The unconfined swelling is calculated for each direction of measurement as follows:

$$\text{Unconfined swelling strain in direction X} = \frac{d}{L} \times 100\%$$

where:

X is a direction relative to the bedding or foliation

d = maximum swelling displacement recorded in direction X during the test

L = initial distance between gauge points in direction X.

6. REPORTING OF RESULTS

Results should be presented for at least three specimens per sample. The report should clearly indicate that the specimen was *not* radially confined during the swelling test. The report should include the following information for each specimen:

(a) Unconfined swelling strains and their directions with respect to bedding or foliation.

(b) The initial water content of the specimen: whether this corresponds to the natural water content, and if so the method of storage prior to testing.

(c) The shape and initial dimensions of the specimen.

(d) A description of any visible deterioration during slaking.

4. SUGGESTED METHOD FOR DETERMINATION OF THE SLAKE-DURABILITY INDEX

1. SCOPE

This test is intended to assess the resistance offered by a rock sample to weakening and disintegration when subjected to two standard cycles of drying and wetting.

2. APPARATUS

The apparatus consists essentially of the following:

(a) A test drum comprising a 2.00 mm standard mesh* cylinder of unobstructed length 100 mm and diameter 140 mm, with solid fixed base. The drum must withstand a temperature of 105°C. The drum has a

* International Standards Organization R 565 *Woven Wire Cloth and Perforated Plates in Test Sieves* (1967).

Suggested Methods for Determining Water Content

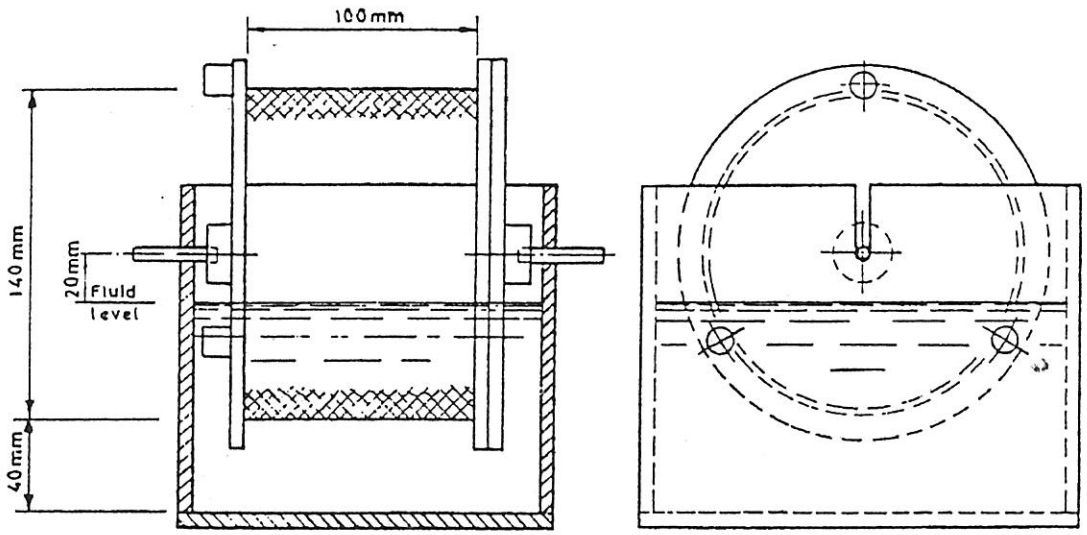

Fig. 4. Critical dimensions of slake-durability test equipment.

solid removable lid. The drum must be sufficiently strong to retain its shape during use, but neither the exterior of the mesh nor the interior of the drum should be obstructed, for example by reinforcing members.

(b) A trough, to contain the test drum supported with axis horizontal in a manner allowing free rotation, capable of being filled with a slaking fluid such as water to a level 20 mm below the drum axis. The drum is mounted to allow 40 mm unobstructed clearance between the trough and the base of the mesh. The principal features of the trough and drum assembly are illustrated in Fig. 4.

(c) A motor drive capable of rotating the drum at a speed of 20 rpm, the speed to be held constant to within 5% for a period of 10 min.

(d) An oven capable of maintaining a temperature of 105°C to within 3°C for a period of at least 12 hr.

(e) A balance capable of weighing the drum plus sample to an accuracy of 0.5 g.

3. PROCEDURE

(a) A representative sample is selected comprising ten rock lumps, each with a mass of 40–60 g, to give a total sample mass of 450–550 g. The maximum grain size of the rock should not be more than 3 mm. Lumps should be roughly spherical in shape, and corners should be rounded during preparation.

(b) The sample is placed in a clean drum and is dried to constant mass at a temperature of 105°C, usually requiring from 2 to 6 hr in the oven. The mass A of the drum plus sample is recorded. The sample is then tested after cooling.

(c) The lid is replaced, the drum mounted in the trough and coupled to the motor.

(d) The trough is filled with slaking fluid, usually tap water at 20°C, to a level 20 mm below the drum axis, and the drum rotated for 200 revolutions during a period of 10 min to an accuracy of 0.5 min.

(e) The drum is removed from the trough, the lid removed from the drum, and the drum plus retained portion of the sample dried to constant mass at 105°C. The mass B of the drum plus retained portion of the sample is recorded after cooling.

(f) Steps (c)–(e) are repeated and the mass C of the drum plus retained portion of the sample is recorded.

(g) The drum is brushed clean and its mass D is recorded.

4. CALCULATION

The slake-durability index (second cycle) is calculated as the percentage ratio of final to initial dry sample masses as follows:

$$\text{slake-durability index } I_{d2} = \frac{C - D}{A - D} \times 100\%.$$

5. REPORTING OF RESULTS

The report should include the following information for each sample tested:

(a) The slake-durability index (second cycle) to the nearest 0.1%.

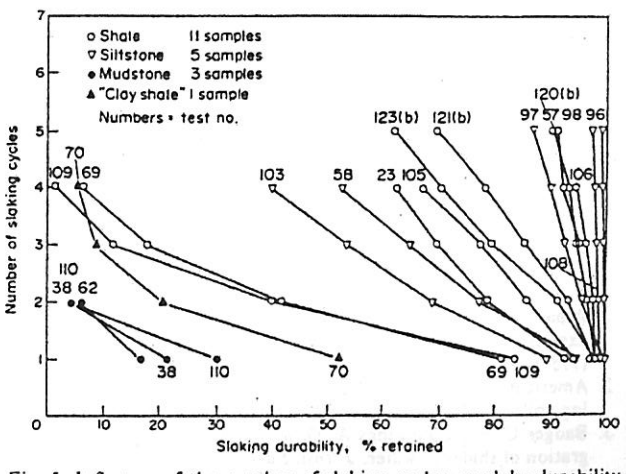

Fig. 5. Influence of the number of slaking cycles on slake-durability (Gamble, 1971).

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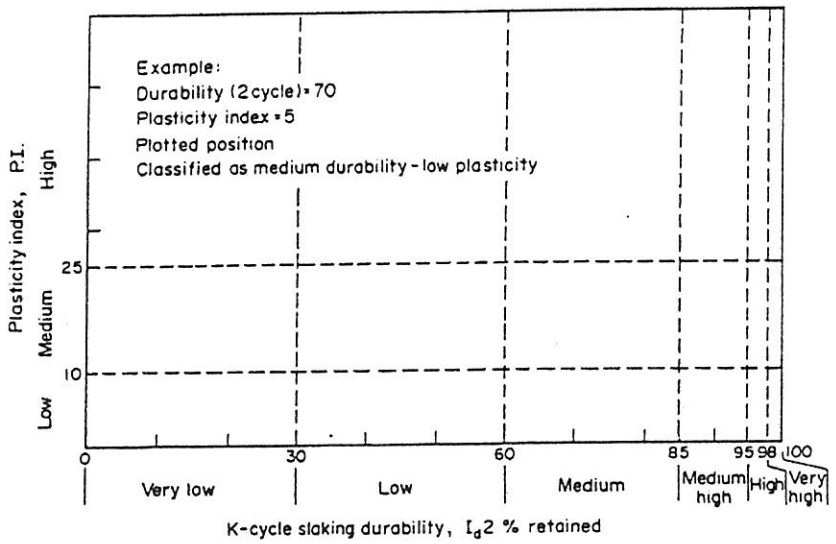

Fig. 6. A suggested durability-plasticity classification (Gamble, 1971).

(b) The nature and temperature of the slaking fluid: usually tap water at 20°C, but for example distilled water, natural ground water, sea water, a dilute acid or a dispersing agent may be specified.

(c) The appearance of fragments retained in the drum.

(d) The appearance of material passing through the drum.

6. NOTES

The second cycle slake-durability index, calculated as in para. 4 above, with tap water at 20°C, is proposed for use in rock classification. However, samples with second cycle indexes from 0 to 10% should be further characterized by their first cycle slake-durability indexes as follows:

$$\text{slake-durability index } I_{d1} = \frac{B - D}{A - D} \times 100\%.$$

Indexes taken after three or more cycles of slaking and drying may be useful when evaluating rocks of higher durability (Fig. 5).

7. Rocks giving low slake-durability results should be subjected to soils classification tests, such as determination of Atterberg limits or sedimentation-size analysis. A classification combining slake-durability index and plasticity index (Fig. 6) is suggested in cases where a greater depth of characterization, particularly of argillaceous rocks, is required.

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INTERNATIONAL SOCIETY FOR ROCK MECHANICS
COMMISSION ON
STANDARDIZATION OF LABORATORY AND FIELD TESTS

Suggested Methods for Determining Sound Velocity

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Suggested Methods for Determining Sound Velocity

1. SCOPE

This test is intended as a method to determine the velocity of propagation of elastic waves in laboratory rock testing. Three different variations of the method are given. These are: the high frequency ultrasonic pulse technique, the low frequency ultrasonic pulse technique and the resonant method.

2. APPARATUS

Although there are three different methods, the electronic components should, as far as possible, be chosen so as to be applicable to all three methods. The same rock or even the same sample can be used for all three methods. Consideration should of course be given to the respective frequencies used for the different methods. The electronic components should be impedance matched and have shielded leads to ensure efficient energy transfer. To prevent damage to the system allowable voltage inputs should not be exceeded.

First method

(a) Pulse generator unit:
pulse form: sine-, square, step-wave pulse;
pulse width: 1–10 s;
frequency range: 100 kHz–2 MHz;
repetition frequency: 10–10^3 repetitions per second;
pulse voltage: to be compatible to transducer used, as high as transducers allow.

The pulse generator must have a trigger-pulse output to trigger an oscilloscope (trigger-signal).

(b) Transducers:
transmitter: converts electrical pulses into mechanical pulses;
receiver: converts mechanical pulses into electrical pulses;
frequency response: flat from 100 kHz to 2 MHz, if possible.

Environmental conditions such as temperature, moisture, humidity and impact should be considered in selecting the transducer element.

Piezoelectric ceramics (e.g. barium titanate or lead-zirconate–titanate) in the form of plates, discs, rods, rings or spheres to generate pulses in the frequency range 100 kHz–2 MHz are recommended. It is usually necessary to use different piezoelectric transducers for compressional or shear-wave transmission and receiving, e.g. cylindrical discs (radius $\gg$ thickness) acting in the thickness and radial mode for transmitting and receiving compressional waves; shear plates operating in the shear mode for transmitting and receiving shear waves.

(c) Band pass or high pass filter suitable for the frequencies mentioned above.

(d) Wide band low noise pre-amplifier.

(e) Time mark generator to control pulse repetition and to give time marks at the CRO.

(f) Cathode ray oscilloscope (CRO):
dual beam CRO is recommended;
max. sweeprate: 0.1 μs/cm;
band width: must have essentially flat response from d.c. to 5 MHz or higher.

(g) Electronic counter with provisions for time interval measurements is desirable.

Two possible layouts of the electronic components are shown in Fig. 1.

Second method

Low frequency ultrasonic pulse technique for bar-like specimens with a maximum lateral dimension up to 10 cm.

(a) Pulse generator unit (e.g. function generator):
frequency range: 2–30 kHz (if the generator mentioned in the first method has a low frequency range it can obviously be used here);
repetition frequency: 10–100 repetitions per second;
pulse voltage: same as in first method.

(b) Transducers:

(i) Transmitter: piezo-electric ceramics or magneto-strictive elements, which are capable to generate high amplitude pulses (depending on the rock type and specimen dimensions) in the frequency range 2–30 kHz.

(ii) Receivers: piezo-electric ceramics with flat frequency response in the frequency range 2–30 kHz or magneto-strictive elements.

(c) Filters, amplifiers, CRO, time-marker analog to first method with consideration of the low frequency range.

Third method

(a) Sine-wave generator (e.g. function generator) with a frequency range of 1–100 kHz and pulse voltage as in first and second methods.

(b) Transducers:

(i) Transmitter: piezo-electric ceramics or magneto-strictive element with *flat* frequency response in the range 1–100 kHz.

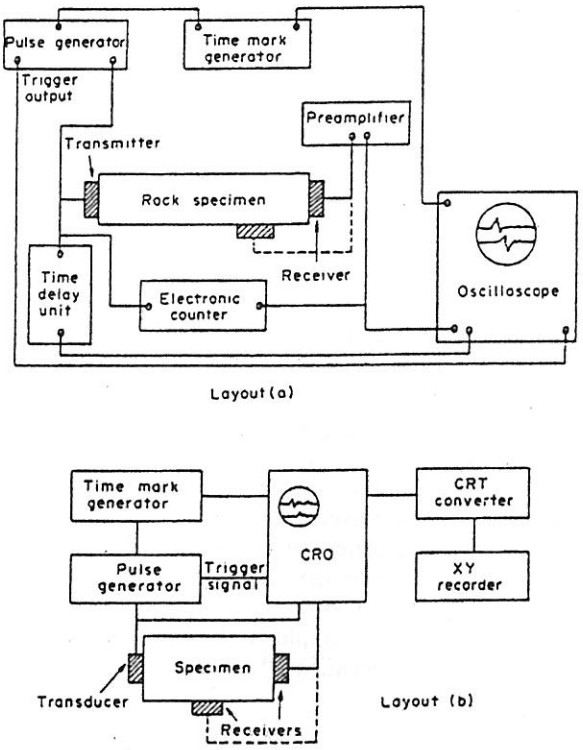

Fig. 1. Two possible layouts of electronic components for the first method.

(ii) Receiver: piezo-electric ceramics (similar to the transmitter) or capacitive pick-up (condensator microphone principle) with flat frequency response from 1–100 kHz (first possible resonant frequency of any mode should be greater than 100 kHz).

(c) CRO, amplifiers analog to record method.

The layout of the electronic components is shown in Fig. 2.

3. PROCEDURE

Care should be exercised in core drilling, handling, sawing, grinding and lapping the test specimen to minimize mechanical damage. The surface area under each transducer shall be sufficiently plane to provide good coupling.

Drying of specimens may be carried out by using a desiccator. Saturated specimens shall remain submerged in water up to the time of testing. If the velocity is to be determined with the *in-situ* condition, care must be exercised during the preparation procedure. It is also suggested that both the sample where the specimen is taken from as well as the specimen, be stored in moisture-proof bags. Dry surface-preparation procedures may be employed.

First method

This method is for the determination of velocities of compressional (dilatational, longitudinal, P-) and shear (rotational, transversal, S-) waves in rock specimens of effectively infinite extent compared to the wave length of the pulse used. The condition of infinite extent is satisfied if the average grain size < wave length of the pulse < minimum specimen dimension.

(a) Rectangular blocks, cylindrical cores or even spheres (for determination of elastic symmetry of anisotropic rocks) are recommended as specimens. The lateral minimum dimension (normal to the direction of wave propagation) is recommended to be not less than 10 times the wave-length.* The travel distance of the pulse through the rock shall be at least 10 times the average grain size.

(b) The transmitter is pressed to the centre of a plane normal to the direction of wave propagation by a stress of about 10 N/cm^2. Energy transmission between the transducers and the test specimen can be improved by:

(i) Lapping the surfaces of the end planes to make them smooth and flat;

(ii) Coupling the transducer elements to the end planes by a thin film of grease, vaseline, glycerin, putty or oil;

(iii) Hard coupling with an epoxy type adhesive or with phenyl salicylate;

(c) There are two possibilities to position the receivers:

(i) Pulse transmission technique: The receiver is positioned on a plane opposite to the plane to which the transmitter is pressed (Fig. 3a). The velocities of either P- or S-waves (v_p, v_s) are calculated from the measured travel time and the distance between transmitter and receiver.

(ii) "Seismic" profiling technique: The receiver is positioned on the side of the specimen (Fig. 3b). By varying the distance d between receiver and transmitter it is possible to obtain curves of travel time vs distance, d for both P- and S-waves. The velocities are calculated from these curves. This latter method is highly recommended if the specimen size is suitable.

(d) Increase the voltage output of the pulse generator, the gain of the amplifier, and the sensitivity of the oscilloscope and counter to an optimum level, giving a steeper pulse front to permit more accurate time measurements. The optimum level is just below that at which electromagnetic noise reaches an intolerable

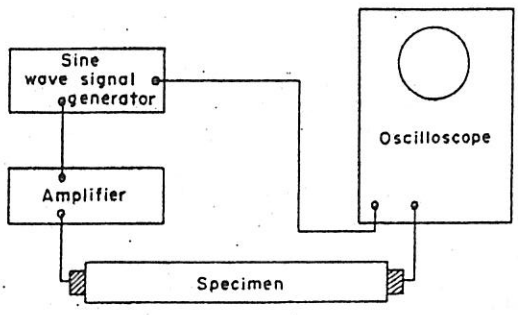

Fig. 2. Layout of components for the third method.

* ASTM recommendation D 2845-69 stipulates five times the wavelength.

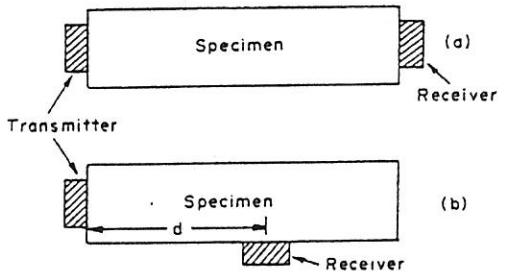

Fig. 3. Positions of transmitter and receiver on the specimen (first method).

magnitude or triggers the counter at its lowest triggering sensitivity. The noise level shall not be greater than one tenth of the amplitude of the first peak of the signal from the receiver. Measure the travel time to a precision and accuracy of 1 part in 100 for compression waves and 1 part in 50 for shear waves by using the delaying circuits in conjunction with the oscilloscope or setting the counter to its highest usable precision.

(e) The oscilloscope is used with the time-delay circuit to display both the direct pulse and the first arrival of the transmitted pulse, and to measure the travel time. Characteristically, the first arrival displayed on the oscilloscope consists of a curved transition from the horizontal zero-voltage trace followed by a steep, more or less linear, trace. Select the first break in a consistent manner for both the test measurement and the zero-time determination. Select it either at the beginning of the curved transition region or at the zero-voltage intercept of the straight line portion of the first arrival.

(f) The counter is triggered to start by the direct pulse applied to the transmitter and is triggered to stop by the first arrival of the pulse reaching the receiver. Because a voltage change is needed to trigger the counter, it cannot accurately detect the first break of a pulse. To make the most accurate time-interval measurements possible, increase the counter's triggering sensitivity to an optimum without causing spurious triggering by extraneous electrical noise.

(g) Determine the zero time of the circuit including both transducers and the travel-time measuring device and apply the correction to the measured travel times. This factor will remain constant for a given rock and stress level if the circuit characteristics do not change. Determine the zero time accordingly to detect any changes. Determine it by:

(1) Placing the transducers in direct contact with each other and measuring the delay directly (this method is not recommended for shear crystals where slight misalignment can produce large errors); or

(2) Measuring the apparent travel time of some uniform material (such as steel) as a function of length, and then using the zero-length intercept of the line through the data points as the correction factor. (This method is particularly recommended for shear waves.)

(h) Since the first transmitted arrival is that of the compression wave, its detection is relatively easy. The shear-wave arrival, however, may be obscured by vibrations due to ringing of the transducers and reflections of the compression wave. The amplitude of the shear wave relative to the compression wave may be increased and its arrival time determined more accurately by means of thickness shear-transducer elements. This type of element generates some compressional energy, so that both waves may be detected. Energy transmission between the specimen and each transducer may be improved by using a thin layer of a coupling medium such a phenyl salicylate, high-vacuum grease, or resin, and by pressing the transducer against the specimen with a small seating force.

(i) For specimens subjected to uniaxial stress fields, first arrivals of compression waves are usually well defined. However, the accurate determination of shear-wave first arrivals for specimens under stress is complicated by mode conversions at the interfaces on either side of the face plate and at the free surface.

(j) Distinguishing the shear wave arrival time can be performed more easily on specimens whose length is optimized. For example, a h/w ratio of 2:1 is often preferable to a specimen whose h/w ratio is 1:1.

Second method

This method is for the determination of the velocity of dilatational and torsional waves in bar or rod-like rock specimens (bar waves, one-dimensional wave propagation). This method is suitable for specimens which are long compared to the diameter (length to diameter ratio >3) and the wave length of the pulse should be long compared to the diameter (wave length to diameter ratio >5).

(a) Dimensions should be as stated above. For the pulse transmission technique and the resonant frequency technique both the end planes of the specimen should be flat and parallel to within 0.005 mm/mm of the lateral dimension.

(b) Rock cores are positioned on the sample holder of an acoustical bench. The cores have at least a length to diameter ratio of >3. The transmitter, generating a sine wave of a wave-length >5 times the core diameter, is pressed to a saw-cut flat end plane (normal to the core axis) by a stress of approx 10 N/cm^2 for v_p measurement. For v_s measurement positioning of the transmitter according to Fig. 4 is recommended.

(c) There are two possibilities in the positioning of the receiver (analog to (c) in first method):

(i) pulse transmission: the receiver is positioned at the opposite flat plane of the core. Both end planes should be parallel to within about one degree; ball joints may be used

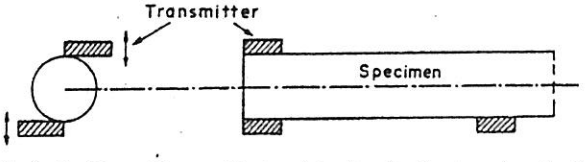

Fig. 4. Positions of transmitters and receiver for the second method.

(ii) seismic profiling: the receiver is moved along the surface of the core parallel to the core-axis.

(d) The remainder of the procedure is the same as for the first method.

Third method

By determination of the resonance frequency of both dilatational and torsional vibrations of bar or rod-like cylindrical rock specimens with length to diameter ratio >3 (wave-length to diameter ratio >6) the velocity of bar waves, both dilatational and torsional (one-dimensional wave propagation, see second method) can be calculated.

(a) Dimensions should be as stated above. For the pulse transmission technique and the resonant frequency technique both the end planes of the specimen should be flat and parallel to within 0.005 mm/mm of the lateral dimension.

(b) Rock cores with length to diameter ratio >3 are placed on the sample holder of an acoustical bench. Both end planes are ground plane to within 10^{-3} mm and parallel to within one degree.

(c) To determine the longitudinal resonant frequency both the transmitter and receiver are pressed to the centre of both the end planes by means of *soft* springs (maximum load: 10 N) to ensure free end condition for the specimen (capacitive receivers are recommended because of this purpose). Care should be taken in positioning the specimen on a sample holder to ensure free specimen condition.

(d) Transmitter frequency is varied to give maximum readings on the CRO. At least the first three modes of the resonant frequency are recorded.

(e) For the determination of torsional resonant frequency the transmitter should be positioned so as to introduce torsional vibrations.

4. CALCULATION

One- or three-dimensional equations of wave propagation are used.

First and second methods

(a) Velocities are calculated from travel times measured and the distance, d, between transmitter and receiver by using the equations:

$$v_p = d \cdot t_p^{-1}$$

$$v_s = d \cdot t_s^{-1}$$

where v_p is the velocity of the longitudinal wave, v_s is the velocity of the shear wave, t_p and t_s are the times which the P- and S-wave, respectively, took to travel the distance d.

(b) If seismic profiling technique was used the velocities are given by the slope of the curve travel time vs distance d.

Third method

The bar wave velocities are calculated from

$$v_d = 2 l f_0$$

where l is the length of the bar or rod, and f_0 is the resonant frequency of zero mode of either dilatation or torsional vibrations.

5. REPORTING OF RESULTS

The report should include the following information:

(a) Rock type, exact origin (e.g. country, area, geological formation, quarry, depth of drill holes, special geological or structural feature where taken from).

(b) Specimen dimensions and specimen geometry.

(c) How rock material was obtained (e.g. blasting in a quarry, drilling on fresh or weathered surface).

(d) Petrofabrical and petrographical description; micro-crack distribution.

(e) Sample preparation (quality of cores, of end-planes, number of cores taken from one larger block, orientation of cores in relation to major geological features).

(f) Description of experimental testing method: data of electrical pulse source; data of transducers (an amplitude-frequency plot is highly recommended); coupling of transducers to the specimen.

(g) Stress field applied to the specimen.

(h) All available physical properties of the rock (particularly density, porosity, permeability).

(i) velocity data at normal conditions (room temperature, atmospheric pressure, room temperature dried).

(j) Repeatability.

(k) Velocity variations among samples at constant testing parameters; average velocities; mean error; maximum deviations.

(l) In the case of "sesmic" profiling: travel-time–distance curves.

(m) One representative CRO-picture or outprint at the XY-recorder.

(n) Technique to obtain travel time readings (e.g. first deviation of transmitter pulse to first deviation of receiver pulse at CRO; first maximum of receiver wavelet, etc.).

(o) Velocity-stress data (if measured).

(p) Compressional wave velocity, v_p in m/s.

(q) Shear wave velocity, v_s in m/s.

(r) Bar wave velocity: dilatational, $v_{d;l}$ in m/s
torsional, $v_{d;t}$ in m/s.

(s) Density, in kg/m^3.

(t) Stress, in Pa.

(u) Geometrical dimensions, in mm.

Note

(i) A method introducing torsional and longitudinal vibrations in a rod or bar was developed by Obert (Obert L. S., Windes L. & Duvall W. I. Standardized tests for determining the physical properties of mine rock. *U.S. Bur. Mines Rep. Invest.* 3891 (1946).

(ii) Many rocks which are porous, slightly weathered or have micro-cracks are quite sensitive to stress levels (and/or saturation) and for practical problems it may be desirable to test them at the saturation and maximum principal stress level to which they will be subjected in the applied case.

INTERNATIONAL SOCIETY FOR ROCK MECHANICS
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STANDARDIZATION OF LABORATORY AND FIELD TESTS

Suggested Methods for Determining the Uniaxial Compressive Strength and Deformability of Rock Materials

Prepared by

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Suggested Methods for Determining the Uniaxial Compressive Strength and Deformability of Rock Materials

PART 1. SUGGESTED METHOD FOR DETERMINATION OF THE UNIAXIAL COMPRESSIVE STRENGTH OF ROCK MATERIALS

1. SCOPE

This method of test is intended to measure the uniaxial compressive strength of a rock sample in the form of specimens of regular geometry. The test is mainly intended for strength classification and characterization of intact rock.

2. APPARATUS

(a) A suitable machine shall be used for applying and measuring axial load to the specimen. It shall be of sufficient capacity and capable of applying load at a rate conforming to the requirements set in Section 3. It shall be verified at suitable time intervals and shall comply with accepted national requirements such as prescribed in either ASTM Methods E4: Verification of Testing Machines or British Standard 1610, Grade A or Deutsche Normen DIN 51 220, DIN 51 223, Klasse 1 and DIN 51 300.

(b) A spherical seat, if any, of the testing machine, if not complying with specification 2(d) below, shall be removed or placed in a locked position, the two loading faces of the machine being parallel to each other.

(c) Steel platens in the form of discs and having a Rockwell hardness of not less than HRC58 shall be placed at the specimen ends. The diameter of the platens shall be between D and D + 2 mm where D is the diameter of the specimen. The thickness of the platens shall be at least 15 mm or D/3. Surfaces of the discs should be ground and their flatness should be better than 0.005 mm.

(d) One of the two platens shall incorporate a spherical seat. The spherical seat should be placed on the upper end of the specimen. It should be lightly lubricated with mineral oil so that it locks after the deadweight of the cross-head has been picked up. The specimen, the platens and spherical seat shall be accurately centred with respect to one another and to the loading machine. The curvature centre of the seat surface should coincide with the centre of the top end of the specimen.

3. PROCEDURE

(a) Test specimens shall be right circular cylinders having a height to diameter ratio of 2.5–3.0 and a diameter preferably of not less than NX core size, approximately 54 mm. The diameter of the specimen should be related to the size of the largest grain in the rock by the ratio of at least 10:1.

(b) The ends of the specimen shall be flat to 0.02 mm and shall not depart from perpendicularity to the axis of the specimen by more than 0.001 radian (about 3.5 min) or 0.05 mm in 50 mm.

(c) The sides of the specimen shall be smooth and free of abrupt irregularities and straight to within 0.3 mm over the full length of the specimen.

(d) The use of capping materials or end surface treatments other than machining is not permitted.

(e) The diameter of the test specimen shall be measured to the nearest 0.1 mm by averaging two diameters measured at right angles to each other at about the upper-height, the mid-height and the lower height of the specimen. The average diameter shall be used for calculating the cross-sectional area. The height of the specimen shall be determined to the nearest 1.0 mm.

(f) Samples shall be stored, for no longer than 30 days, in such a way as to preserve the natural water content, as far as possible, and tested in that condition.* This moisture condition shall be reported in accordance with "Suggested method for determination of the water content of a rock sample", Method 1, ISRM Committee on Laboratory Tests, Document No. 2, First Revision, December 1977 (this volume, p. 83).

(g) Load on the specimen shall be applied continuously at a constant stress rate such that failure will occur within 5–10 min of loading, alternatively the stress rate shall be within the limits of 0.5–1.0 MPa/s.

(h) The maximum load on the specimen shall be

* It is recognized that in some cases for some materials it may be desired to test specimens in other moisture conditions, for example, saturated or oven dry at 105°C. Such conditions shall be noted in the test report.

recorded in newtons (or kilonewtons and meganewtons where appropriate) to within 1%.

(j) The number of specimens tested should be determined from practical considerations but at least five are preferred.

4. CALCULATIONS

(a) The uniaxial compressive strength of the specimen shall be calculated by dividing the maximum load carried by the specimen during the test, by the original cross-sectional area.

5. REPORTING OF RESULTS

(a) Lithologic description of the rock.

(b) Orientation of the axis of loading with respect to specimen anisotropy, e.g. bedding planes, foliation, etc.

(c) Source of sample, including: geographic location, depth and orientations, dates and method of sampling and storage history and environment.

(d) Number of specimens tested.

(e) Specimen diameter and height.

(f) Water content and degree of saturation at time of test.

(g) Test duration and stress rate.

(h) Date of testing and type of testing machine.

(i) Mode of failure, e.g. shear, axial cleavage, etc.

(j) Any other observations or available physical data such as specific gravity, porosity and permeability citing the method of determination for each.

(k) Uniaxial compressive strength for each specimen in the sample, expressed to three significant figures, together with the average result for the sample. The pascal (Pa) or its multiples shall be used as the unit of stress and strength.

(l) Should it be necessary in some instances to test specimens that do not comply with specifications as stated above these facts shall be noted in the test report.

REFERENCES

1. Obert L., Windes S. L. & Duvall W. I. Standardized tests for determining the physical properties of mine rocks. *U.S. Bureau of Mines Report of Investigations.* No. 3891, 1946, 67 p.
2. International Bureau for Rock Mechanics. Richtlinien zur Durchführung von Druckversuchen an Gesteinen im Bergbau. *Bericht, 5. Ländertreffen des I.B.G.*, Akademie-Verlag, Berlin, 1964, pp. 21–25.
3. U.S. Corps of Engineers. Strength parameters of selected intermediate quality rocks—testing procedures. *Missouri River Division Laboratory Reports.* No. 64/493, July 1966, pp. 1A–6A; 1B–7B.
4. ASTM. Standard method of test for unconfined compressive strength of rock core specimens. *American Society for Testing and Materials.* ASTM Designation D-2938-71a.
5. Hawkes I. & Mellor M. Uniaxial testing in rock mechanics laboratories. *Engng. Geol.* 4, July 1970, pp. 177–285.

PART 2. SUGGESTED METHOD FOR DETERMINING DEFORMABILITY OF ROCK MATERIALS IN UNIAXIAL COMPRESSION

1. SCOPE

This method of test is intended to determine stress-strain curves and Young's modulus and Poisson's ratio in uniaxial compression of a rock specimen of regular geometry. The test is mainly intended for classification and characterization of intact rock.

2. APPARATUS

(a) to (d)—See Part 1.

(e) Electrical resistance strain gauges, linear variable differential transformers, compressometers, optical devices or other suitable measuring devices. Their design shall be such that the average of two circumferential and two axial strain measurements, equally spaced, can be determined for each increment of load. The devices should be robust and stable, with strain sensitivity of the order of 5×10^{-6}.

Both axial and circumferential strains shall be determined within an accuracy of 2% of the reading and a precision of 0.2 percent of full scale.

If electrical resistance strain gauges are used, the length of the gauges over which axial and circumferential strains are determined shall be at least ten grain diameters in magnitude and the gauges should not encroach within D/2 of the specimen ends, where D is the diameter of the specimen.

If dial micrometers of LVDT's are used for measuring axial deformation due to loading, these devices should be graduated to read in 0.002 mm units and accurate within 0.002 mm in any 0.02 mm range and within 0.005 mm in any 0.25 mm range. The dial micrometer or LVDT's should not encroach within D/2 of the specimen ends.

(f) An apparatus for recording the loads and deformations; preferably an X–Y recorder capable of direct plotting of load-deformation curves.

3. PROCEDURE

(a) to (e)—See Part 1.

(f) Moisture can have a significant effect on the deformability of the test specimen. When possible, *in situ* moisture conditions should be preserved until the time of the test. When the characteristic of the rock material under conditions varying from saturation to dry is required, proper note shall be made of moisture conditions so that correlation between deformability and moisture content can be made. Excess moisture can create a problem of adhesion of strain gauges which may require making a change in moisture content of the sample. The moisture condition shall be reported

in accordance with "Suggested method for determination of the water content of a rock sample", Method 1, ISRM Committee on Laboratory Tests, Document No. 2, December 1977 (this volume, p. 83).

(g) Load on the specimen shall be applied continuously at a constant stress rate such that failure will occur within 5–10 min of loading, alternatively the stress rate shall be within the limits of 0.5–1.0 MPa/s.

(h) Load and axial and circumferential strains or deformations shall be recorded at evenly spaced load intervals during the test, if not continually recorded. At least ten readings should be taken over the load range to define the axial and diametric stress-strain curves.

(i) It is sometimes advisable for a few cycles of loading and unloading to be performed.

(j) The number of specimens instrumented and tested under a specified set of conditions shall be governed by practical considerations but at least five are preferred.

4. CALCULATIONS

(a) Axial strain, ϵ_a, and diametric strain, ϵ_d, may be recorded directly from strain indicating equipment or may be calculated from deformation readings depending upon the type of instrumentation such as discussed in paragraph 2(e).

(b) Axial strain is calculated from the equation

$$\epsilon_a = \frac{\Delta l}{l_0}$$

where

l_0 = original measured axial length

Δl = change in measured axial length (defined to be positive for a decrease in length)

(c) Diametric strain may be determined either by measuring the changes in specimen diameter or by measuring the circumferential strain. In the case of measuring the changes in diameter, the diametric strain is calculated from the equation

$$\epsilon_d = \frac{\Delta d}{d_0}$$

where

d_0 = original undeformed diameter of the specimen

Δd = change in diameter (defined to be negative for an increase in diameter)

In the case of measuring the circumferential strain ϵ_d, the circumference is $C = \pi d$, thus the change in circumference is $\Delta C = \pi \Delta d$. Consequently, the circumferential strain, ϵ_c, is related to diametric strain, ϵ_d, by

$$\epsilon_c = \frac{\Delta C}{C_0} = \frac{\Delta d}{d_0},$$

so that

$$\epsilon_c = \epsilon_d$$

where C_0 and d_0 are original specimen circumference and diameter, respectively.

(d) The compressive stress in the test specimen, σ, is calculated by dividing the compressive load P on the specimen by the initial cross-sectional area, A_0. Thus

$$\sigma = \frac{P}{A_0}$$

where in this test procedure, compressive stresses and strains are considered positive.

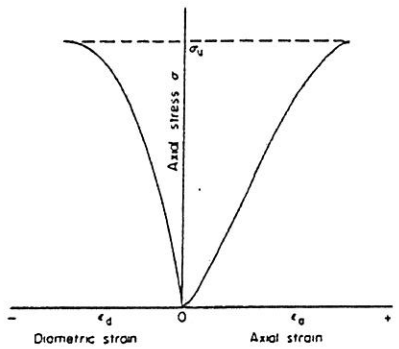

Fig. 1. Format for graphical presentation of axial and diametric stress-strain curves.

(e) Fig. 1 illustrates typical plot of axial stress versus axial and diametric strains. These curves show typical behaviour of rock materials from zero stress up to ultimate strength, σ_u. The complete curves give the best description of the deformation behaviour of rocks having non-linear stress-strain behaviour at low and high stress levels.

(f) Axial Young's modulus, E (defined as the ratio of the axial stress change to axial strain produced by the stress change) of the specimen may be calculated using any one of several methods employed in accepted engineering practice. The most common methods, listed in Fig. 2, are as follows:

(1) Tangent Young's modulus, E_t, is measured at a stress level which is some fixed percentage of the ulti-

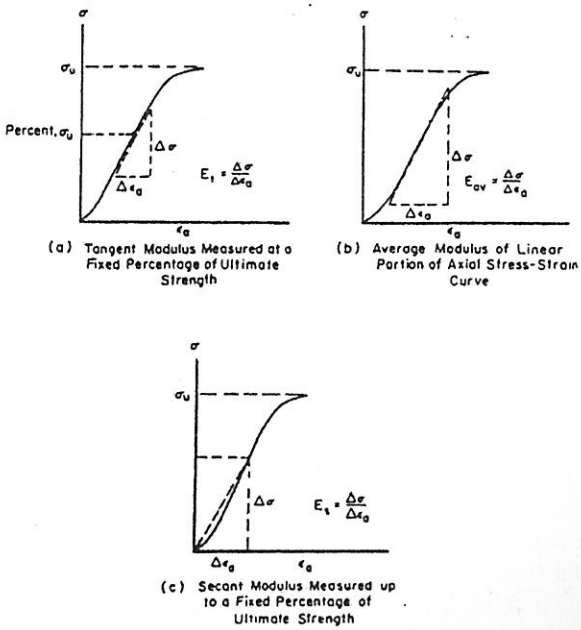

Fig. 2. Methods for calculating Young's modulus from axial stress-strain curve.

mate strength (Fig. 2a). It is generally taken at a stress level equal to 50% of the ultimate uniaxial compressive strength.

(2) Average Young's modulus, E_{av}, is determined from the average slopes of the more-or-less straight line portion of the axial stress-axial strain curve (Fig. 2b).

(3) Secant Young's modulus, E_s, is usually measured from zero stress to some fixed percentage of the ultimate strength (Fig. 2c), generally at 50%.

Axial Young's modulus E is expressed in units of stress i.e. pascal (Pa) but the most appropriate multiple is the gigapascal (GPa = 10^9 Pa).

(g) Poisson's ratio, ν, may be calculated from the equation

$$\nu = -\frac{\text{slope of axial stress–strain curve}}{\text{slope of diametric stress–strain curve}}$$

$$= -\frac{E}{\text{slope of diametric curve}}.$$

where the slope of the diametric curve is calculated in the same manner for either of the three ways discussed for Young's modulus in paragraph 4(f). Note that Poisson's ratio in this equation has a positive value, since the slope of the diametric curve is negative by the conventions used in this procedure.

(h) The volumetric strain, ϵ_v, for a given stress level is calculated from the equation

$$\epsilon_v = \epsilon_a + 2\epsilon_d.$$

5. REPORTING OF RESULTS

The report should include the following:

(a) to (j)—See Part 1.

(k) Values of applied load, stress and strain as tabulated results or as recorded on a chart.

(l) Young's modulus and Poisson's ratio for each specimen in the sample, expressed to three significant figures, together with the average result for the sample.

(m) Method of determination of Young's modulus and at what axial stress level or levels determined.

(n) Sould it be necessary in some instances to test specimens that do not comply with the above specifications, these facts shall be noted in the test report.

REFERENCE

Standard method of test for elastic moduli of rock core specimens in uniaxial compression. *American Society for Testing and Materials*, ASTM Designation D 3148-72.

INTERNATIONAL SOCIETY FOR ROCK MECHANICS
COMMISSION ON
STANDARDIZATION OF LABORATORY AND FIELD TESTS

Suggested Methods for Determining Tensile Strength of Rock Materials

Prepared by

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COMMITTEE ON LABORATORY TESTS
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Suggested Methods for Determining Tensile Strength of Rock Materials

PART 1: SUGGESTED METHOD FOR DETERMINING DIRECT TENSILE STRENGTH

1. SCOPE

This method of test is intended to measure directly the uniaxial tensile strength of a rock specimen of regular geometry. The test is mainly intended for classification and characterization of intact rock.

2. APPARATUS

(a) A suitable machine shall be used for applying and measuring the axial load to the specimen. It shall be of sufficient capacity and capable of applying load at a rate conforming to the requirements set in section 3. It shall be verified at suitable time intervals and shall comply with accepted national requirements such as prescribed in either ASTM Methods E4, Verification of Testing Machines or British Standard 1610, Grade A or Deutsche Normen DIN 51 220 and DIN 51 223, Klasse 1.

(b) Cylindrical metal caps shall be cemented to the specimen ends, providing a means through which the direct uniaxial tensile load can be applied. The diameter of the metal caps shall not be less than that of the test specimen nor shall it exceed the test specimen diameter by more than 2 mm. Caps shall have a thickness of at least 15 mm. Caps shall be provided with a suitable linkage system for load transfer from the loading device to the test specimen. The linkage system shall be so designed that the load will be transmitted through the axis of the test specimen without the application of bending or torsional stresses. The length of the linkages at each end shall be at least twice the diameter of the metal caps.*

3. PROCEDURE

(a) The test specimens shall be right circular cylinders having a height to diameter ratio of 2.5:3.0 and a diameter preferably of not less than NX core size, approximately 54 mm. The diameter of the specimen should be related to the size of the largest grain in rock by the ratio of at least 10:1.

(b) The ends of the specimen shall be generally smooth and flat.† The ends shall not depart from perpendicularity to the axis of the specimen by more than 0.001 radian (about 3.5 min) or 0.05 in 50 mm.

(c) The sides of the specimen shall be smooth and free of abrupt irregularities and straight to within 0.1 mm over the full length of the specimen.

(d) The diameter of the test specimen shall be measured to the nearest 0.1 mm by averaging two diameters measured at right angles to each other at about the mid-height of the specimen. The average diameter shall be used for calculating the cross-sectional area. The height of the specimen shall be determined to the nearest 1.0 mm.

(e) Samples shall be stored, for no longer than 30 days, in such a way as to preserve the natural water content, as far as possible, until the time of specimen preparation. Following their preparation, the specimens shall be stored prior to testing for 5–6 days in an environment of 20°C ± 2°C and 50% ± 5% humidity.‡ This moisture condition shall be reported in accordance with "Suggested method for determination of the water content of a rock sample", Method 1, Committee on Laboratory Tests, Document No. 2, First Revision, Dec. 1977 (this volume p. 83).

(f) The metal caps should be cemented to the specimen in such a manner as to ensure alignment of the cap axes with the longitudinal axis of the specimen. The thickness of the cement layer should not exceed 1.5 mm at each end. After the cement has hardened sufficiently to exceed the tensile strength of the rock, the test specimen shall be placed in the testing machine in such a way that the load transfer system is properly aligned.

(g) The tensile load on the specimen shall be applied continuously at a constant stress rate such that failure will occur within 5 min of loading; alternatively the stress rate shall be within the limits of 0.5 MPa/s to 1.0 MPa/s.

(h) The maximum load on the specimen shall be recorded to within 1%.

(i) The number of specimens per sample tested should be determined from practical considerations but at least five are preferred.

4. CALCULATIONS

The tensile strength of the specimen shall be calcu-

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* According to the *Annual Book of ASTM Standards*, Test D2936-71, a roller or link chain of suitable capacity has been found to perform quite well in this application. Because roller chain flexes in one plane only, the upper and lower segments are positioned at right angles to each other to reduce bending in the specimen. Ball-and-socket, cable or similar arrangements have been found to be generally unsuitable because their tendency for bending and twisting makes the assembly unable to transmit a purely direct tensile stress to the test specimen.

‡ In direct tension tests, the condition of the specimen ends with regard to the degree of flatness and smoothness is not as critical as in compression tests. End surfaces such as result from sawing with a diamond cut-off wheel are entirely adequate.

† It is recognised that in some cases for some materials (e.g. shale), it may be desired to test specimens in other moisture conditions, for example, saturated or oven dry at 105°C. Such conditions shall be noted in the test report.

lated by dividing the maximum load applied to the specimen by the original cross-sectional area.

5. REPORTING OF RESULTS

(a) Lithologic description of the rock.

(b) Orientation of the axis of loading with respect to specimen anisotropy, e.g. bedding planes, foliation, etc.

(c) Source of sample, including: geographic location, depth and orientation, dates of sampling and storage history and environment.

(d) Number of specimens tested.

(e) Specimen diameter and height.

(f) Water content and degree of saturation at time of test.

(g) Test duration and/or stress rate.

(h) Date of testing and type of testing machine.

(i) Mode of failure, e.g. location and orientation of failure surface.

(j) Any other observations or available physical data, such as specific gravity, porosity and permeability, citing the method of determination of each.

(k) The tensile strength for each specimen in the sample, expressed to three significant figures, together with the average result for the sample. The pascal (Pa) or kilopascal (kPa) or mega-pascal (MPa) shall be used as the unit of stress and strength.

(l) Should it be necessary in some instances to test specimens that do not comply with the above specifications, these facts shall be noted in the test report.

PART 2: SUGGESTED METHOD FOR DETERMINING INDIRECT TENSILE STRENGTH BY THE BRAZIL TEST

1. SCOPE

This test is intended to measure the uniaxial tensile strength of prepared rock specimens indirectly by the Brazil test. The justification for the test is based on the experimental fact that most rocks in biaxial stress fields fail in tension at their uniaxial tensile strength when one principal stress is tensile and the other finite principal stress is compressive with a magnitude not exceeding three times that of the tensile principal stress.

2. APPARATUS

(a) Two steel loading jaws designed so as to contact a disc-shaped rock sample at diametrically-opposed surfaces over an arc of contact of approx 10° at failure. The suggested apparatus to achieve this is illustrated in Fig. 1. The critical dimensions of the apparatus are the radius of curvature of the jaws, the clearance and length of the guide pins coupling the two curved jaws

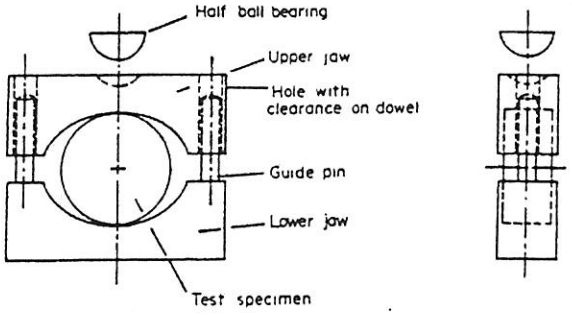

Fig. 1. Apparatus for Brazil test.

and the width of the jaws. These are as follows: Radius of jaws—1.5 × specimen radius; guide pin clearance—permit rotation of one jaw relative to the other by 4×10^{-3} rad out of plane of the apparatus (25 mm penetration of guide pin with 0.1 mm clearance); width of jaws—1.1 × specimen thickness. The remaining dimensions can be scaled from Fig. 1. The upper jaw contains a spherical seating conveniently formed by a 25-mm diameter half-ball bearing.

(b) Double thickness (0.2–0.4 mm) adhesive paper strip (masking tape) with a width equal to or slightly greater than the specimen thickness.

(c) A suitable machine for applying and measuring compressive loads to the specimen. It shall be of sufficient capacity and be capable of applying load at a rate conforming to the requirements set out in section 3. It shall be verified at suitable time intervals and shall comply with accepted national requirements such as prescribed in either ASTM Methods E4, Verification of Testing Machines or British Standard 1610, Grade A or Deutsche Normen DIN 51 220 and DIN 51 223, Klasse 1.

(d) A spherical seat, if any, of the testing machine crosshead shall be placed in a locked position, the two loading surfaces of the machine being parallel to each other.

(e) It is preferable but not obligatory that the testing machine be fitted with a chart recorder to record load against displacement to aid in the measurement of the failure load.

3. PROCEDURE

(a) The test specimens should be cut and prepared using clean water. The cylindrical surfaces should be free from obvious tool marks and any irregularities across the thickness of the specimen should not exceed 0.025 mm. End faces shall be flat to within 0.25 mm and square and parallel to within 0.25°.

(b) Specimen orientation shall be known and the water content controlled or measured and reported in accordance with the "Suggested method for determination of water content of a rock sample", Method 1, ISRM Committee on Laboratory Tests, Document No. 2, First Revision, Dec. 1977 (this volume p. 83).

(c) The specimen diameter shall not be less than NX

core size, approximately 54 mm, and the thickness should be approximately equal to the specimen radius.

(d) The test specimen shall be wrapped around its periphery with one layer of the masking tape and mounted squarely in the test apparatus such that the curved platens load the specimen diametrally with the axes of rotation for specimen and apparatus coincident.

(e) Load on the specimen shall be applied continuously at a constant rate such that failure in the weakest rocks occurs within 15–30 s. A loading rate of 200 N/s is recommended.

(f) Where the testing machine is fitted with a force/displacement recorder, a record should be taken during testing—so that the load for primary fracture can be precisely determined (in some cases load continues to increase after primary failure as the split specimen is still bearing load). If a load/displacement recorder is not available on the testing machine, then care must be taken by the operator to detect the load at primary failure. At primary failure there will be a brief pause in the motion of the indicator needle. However, the difference between the load at primary failure and ultimate load bearing capacity is at most only about 5%.

(g) The number of specimens per sample tested should be determined from practical considerations, but normally ten are recommended.

4. CALCULATIONS

The tensile strength of the specimen σ_t, shall be calculated by the following formula:

$$\sigma_t = 0.636\, P/Dt \text{ (MPa)}$$

where P is the load at failure (N), D is the diameter of the test specimen (mm), t is the thickness of the test specimen measured at the center (mm).

5. REPORTING OF RESULTS

(a) Lithologic description of the rock.

(b) Orientation of the axis of loading with respect to specimen anisotropy, e.g. bedding planes, foliation, etc.

(c) Source of sample, including: geographic location, depth and orientation, dates and method of sampling and storage history and environment.

(d) Number of specimens tested.

(e) Specimen diameter and height.

(f) Water content and degree of saturation at time of test.

(g) Test duration and stress rate.

(h) Date of testing and type of testing machine.

(i) Mode of failure.

(j) Any other observations or available physical data such as specific gravity, porosity and permeability, citing the method of determination for each.

(k) The tensile strength for each specimen in the sample, expressed to three significant figures, together with the average result for the sample.

REFERENCES

Mellor M. & Hawkes I. Measurement of tensile strength by diametral compression of discs and annuli. *Engng Geol.* 5, 173–225 (1971).

INTERNATIONAL SOCIETY FOR ROCK MECHANICS
COMMISSION ON
STANDARDIZATION OF LABORATORY AND FIELD TESTS

Suggested Methods for Determining the Strength of Rock Materials in Triaxial Compression

Prepared by

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COMMITTEE ON LABORATORY TESTS
DOCUMENT NO. 7

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Suggested Methods for Determining the Strength of Rock Materials in Triaxial Compression

1. SCOPE

This test is intended to measure the strength of cylindrical rock specimens subjected to triaxial compression. This provides the values necessary to determine the strength envelope and from this the value of the internal friction angle ϕ and the "apparent" cohesion C may be calculated.*

2. APPARATUS

The apparatus consists essentially of three parts (See Fig. 1): a triaxial cell, a loading device and a device for generating confining pressure.

2.1. *A triaxial cell*

This comprises:

(a) A triaxial cell body, into which the specimen may be placed in order to apply the confining pressure. The body of the cell should have an air bleeder hole and a connection for a hydraulic line.

(b) A flexible jacket of suitable material to prevent the hydraulic fluid from entering the specimen, and which shall not significantly extrude into abrupt surface pores.

(c) Steel platens having Rockwell hardness of not less than C30 shall be placed at both specimen ends. The diameter of the platens shall be between D and $D + 2$ mm, where D is the diameter of the specimen. The thickness of the platens shall be at least 15 mm or $D/3$. Surfaces of platens should be ground and their flatness should be 0.005 mm.

(d) Spherical seats which are incorporated in each of the platens.† The curvature centre of the seat surfaces should coincide with the centre of the specimen ends.

2.2. *A loading device for applying and controlling axial load*

(a) A suitable machine shall be used for applying, controlling and measuring the axial load on the rock specimen. It shall be of sufficient capacity and capable of applying the load at a rate conforming to the requirements as set out in section 4(e). It shall be verified at certain time intervals‡ and shall comply with the accepted national requirements such as prescribed in either ASTM Methods E 4, Verification of Testing Machines; British Standard 1610, 1964, Grade A or Deutsche Normen DIN 51 220 and DIN 51 223, Klasse 1 and DIN 51 300.

(b) The spherical seat of the loading machine, if any, and if it is not complying with specification 2.1 (d) above, shall be removed or placed in a locked position, the two loading faces of the machine being parallel to each other.

2.3. *Equipment for generating and measuring the confining pressure*

This includes:

(a) A hydraulic pump or pressure intensifier or other system of sufficient capacity and capable of maintaining constant confining pressure within 2% of the desired value.

(b) A pressure indicating device§ (pressure gauges or pressure transducers) which shall be accurate enough to allow the above to be observed or recorded.

3. PREPARATION OF THE TEST SPECIMENS

(a) Test specimens shall be right circular cylinders having a height to diameter ratio of 2.0–3.0 and a diameter preferably of not less than NX core size (approximately 54 mm). The diameter of the specimen should be related to the size of the largest grain in the rock by the ratio of at least 10:1.

(b) The ends of the specimen shall be flat to 0.02 mm and shall not depart from perpendicularity to the longi-

* No provision has been made for drainage of the pore water, nor for the measurement of its pressure. In certain rock types (e.g. shales) and under certain conditions the pore water pressure may influence the results. In such cases it is advisable to conduct tests on specimens with different degrees of saturation, e.g. saturated, oven dried at 105°C or any other. A comparison of the results allows an estimation of the influence of the pore water.

Such conditions shall be reported in accordance with "Suggested method for determination of the water content of a rock sample", Method 1, ISRM Committee on Laboratory Tests, Document 2. First Revision, Dec. 1977 (this volume p. 83).

† The concave halves of the spherical seats in triaxial machines usually have no freedom of movement in the direction perpendicular to the specimen axis. In order to align itself, the specimen must have two spherical seats. This is contrary to the uniaxial compression test where the top concave seat half has freedom in the lateral direction and where only one spherical seat is thus required.

‡ The procedure for, and time intervals between verifications are usually given in the National Standard specifications, e.g. ASTM E4; DIN 51300 and B.S. 1610.

§ In order to fulfil the requirements of section 2.3. (b) for the accuracy of the pressure indicating device, it may be necessary to use two or more interchangeable pressure indicating devices having different ranges. Their accuracy will generally have to be 4–5 times better than that of the pressure to be maintained.

tudinal axis of the specimen by more than 0.001 radian (about 3.5 minutes) or 0.05 mm in 50 mm.

(c) The sides of the specimen shall be smooth and free of abrupt irregularities and straight to within 0.3 mm over the full length of the specimen.

(d) The use of capping materials or end surface treatments other than machining is not permitted.

(e) The diameter of the test specimen shall be measured to the nearest 0.1 mm by averaging two diameters measured at right angles to each other at about the upper-height, the mid-height and the lower-height of the specimen. The average diameter shall be used for calculating the cross-sectional area. The height of the specimen shall be determined to the nearest 1.0 mm.

(f) Samples shall be stored for no longer than 30 days, in such a way as to preserve the natural water content, as far as possible, until the time of specimen preparation. Following their preparation, the specimens shall be stored prior to testing for 5–6 days in an environment of 20°C ± 2°C and 50% ± 5% humidity.* This moisture condition shall be reported in accordance with "Suggested method for determination of the water content of a rock sample", Method 1, ISRM Committee on Laboratory Tests, Document No. 2, Final Draft, November 1972.

(g) The number of specimens to be tested as well as the number of different confining pressure values should be determined from practical considerations, but at least five specimens per rock sample are preferred in addition to the uniaxial compressive strength tests conducted according to the relevant specifications.†

4. PROCEDURE

(a) The cell shall be assembled with the specimen aligned between steel platens and surrounded by the jacket.‡ The specimen, the platens and the spherical seats shall be accurately aligned so that each is coaxial with the others.

(b) The spherical seats should be lightly lubricated with mineral oil.

(c) The triaxial cell shall be filled with hydraulic fluid, allowing the air to escape through an air bleeder hole. Close air bleeder hole.

(d) The cell shall be placed into the axial loading device (Fig. 1).

(e) The axial load and the confining pressure must be increased simultaneously and in such a way that axial stress and confining pressure be approximately equal, until the predetermined test level for the confining pressure is reached. Subsequently, the confining pressure shall be maintained to within 2% of the prescribed value.

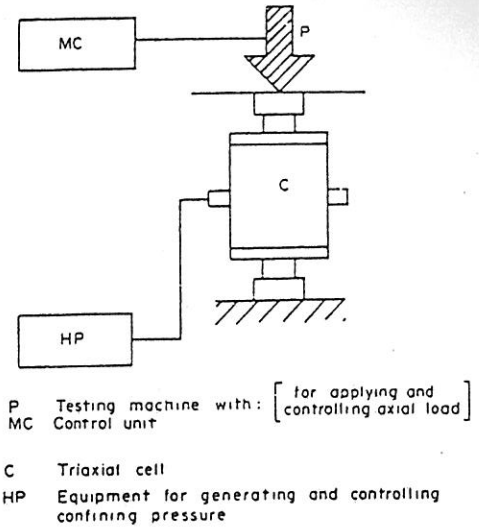

Fig. 1. Block diagram showing test arrangement for determining the triaxial compressive strength.

(f) The axial load on the specimen shall then be increased continuously at a constant stress rate such that failure will occur within 5–15 min of loading. Alternatively the stress rate shall be within the limits of 0.5 to 1.0 MPa/s.

(g) The maximum axial load and the corresponding confining pressure on the specimen shall be recorded.

5. CALCULATIONS

(a) The compressive strength of the specimen shall be calculated by dividing the maximum axial load, applied to the specimen during the test, by the original cross-sectional area.

(b) The confining pressures and the corresponding strength values for the different specimens are plotted with the confining pressures as abscissae and strengths as ordinates (Fig. 2).

(c) A strength envelope is obtained by fitting a mean curve to the above points. From practical considerations it may be advisable to fit a straight line to only the most relevant part of the curve, or to fit several straight lines to different parts of the curve. Each straight line is characterized by calculating its gradient (tangent of the inclination) m and its Y intercept, b. In each case the range in which the respective straight line is valid must be shown on the abscissa.

(d) Using parameters m and b, the internal friction angle ϕ and a value for the "apparent" cohesion C (in the sense of Coulomb's failure theory) may be calculated using the formulae:

$$\phi = \arcsin \frac{m-1}{m+1}; \quad C = b \frac{1-\sin\phi}{2\cos\phi}.$$

6. REPORTING OF RESULTS

The report should include the following:

(a) Lithologic description of the rock.

* See footnote * on p. 125.

† The test programme, i.e. the choice of the confining pressure values, depends on practical considerations regarding the purpose of the tests.

‡ The acceptable triaxial cells in use differ widely. No exact guidelines as how to install the rock specimen or how to assemble the cell can therefore be given.

The Strength of Rock Materials in Triaxial Compression

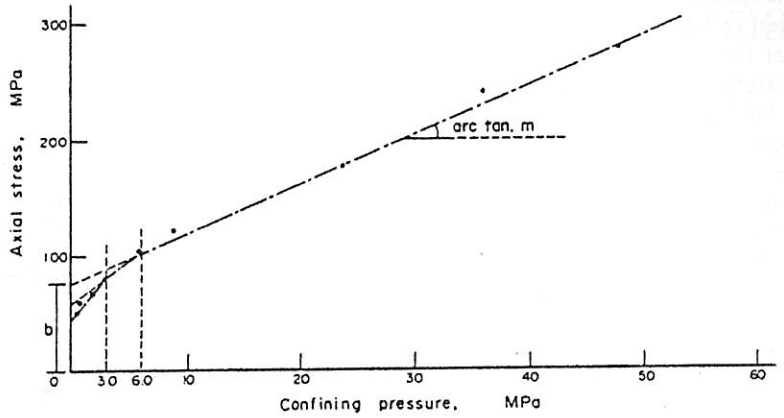

Fig. 2. Strength envelope.

(b) Orientation of the axis of loading of specimen with respect to anisotropy, bedding planes, foliation, etc.

(c) Source of sample including: geographic location, depth and orientation, data and method of sampling and storage history and environment.

(d) Water content and degree of saturation at time of test.

(e) Test duration and/or stress rate.

(f) Date of testing and description of testing machine, triaxial cell and equipment for creating and measuring of confining pressure.

(g) Number of specimens tested.

(h) Any other observations, e.g. mode of failure or available physical data, e.g. specific gravity, porosity, etc., citing the method of determination of each.

(i) A table giving specimen number, specimen height, specimen diameter, confining pressure and the corresponding axial strength to 3 significant figures.

(j) The plot of axial strength vs confining pressure as discussed in section 5(b) (Fig. 2).

(k) A table giving the values of C and ϕ together with the range of confining pressures in which they are valid.

(l) Should it be necessary in some instances to test specimens that do not comply with the above specifications, these facts shall be noted in the test report.

REFERENCES

1. International Society for Rock Mechanics. Committee on Laboratory Tests. Suggested method for determining the uniaxial compressive strength and deformability of rock materials. This volume pp. 111–116.
2. ASTM. Standard method of test for triaxial compressive strength of undrained rock core specimens without pore pressure measurements. ASTM Designation D 2664–67.
3. Kovari K. & Tisa A. *Höchstfestigkeit und Restfestigkeit von Gesteinen im Triaxialversuch.* Institut für Strassen- und Untertagbau an der ETH Zürich. Mitteilung Nr. 26.

INTERNATIONAL SOCIETY FOR ROCK MECHANICS
COMMISSION ON
STANDARDIZATION OF LABORATORY AND FIELD TESTS

Suggested Methods for Determining Shear Strength

Prepared by

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COMMITTEE ON FIELD TESTS
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Suggested Methods for Determining Shear Strength

PART 1. SUGGESTED METHOD FOR *IN SITU* DETERMINATION OF DIRECT SHEAR STRENGTH

SCOPE

1. (a) This test measures peak and residual direct shear strength as a function of stress normal to the sheared plane. Results are usually employed in limiting equilibrium analysis of slope stability problems or for the stability analysis of dam foundations [1–3*].

(b) The inclination of the test block and system of applied loads is usually selected so that the sheared plane coincides with a plane of weakness in the rock, for example a joint, plane of bedding, schistosity or cleavage, or with the interface between soil and rock or concrete and rock [4].

(c) A shear strength determination should preferably comprise at least five tests on the same test horizon with each specimen tested at a different but constant normal stress.

(d) In applying the results of the test, the pore water pressure conditions and the possibility of progressive failure must be assessed for the design case as they may differ from the test conditions.

APPARATUS

2. (a) Equipment for cutting and encapsulating the test block, rock saws, drills, hammer and chisels, formwork of appropriate dimensions and rigidity, expanded polystyrene sheeting or weak filler, and materials for reinforced concrete encapsulation.

3. Equipment for applying the normal load (i.e. Fig. 1) including:

(a) Flat jacks, hydraulic rams or dead load of sufficient capacity to apply the required normal loads [5].

(b) A hydraulic pump if used should be capable of maintaining normal load to within 2% of a selected value throughout the test.

(c) A reaction system to transfer normal loads uniformly to the test block, including rollers or a similar

* Numbers refer to Notes at the end of the text.

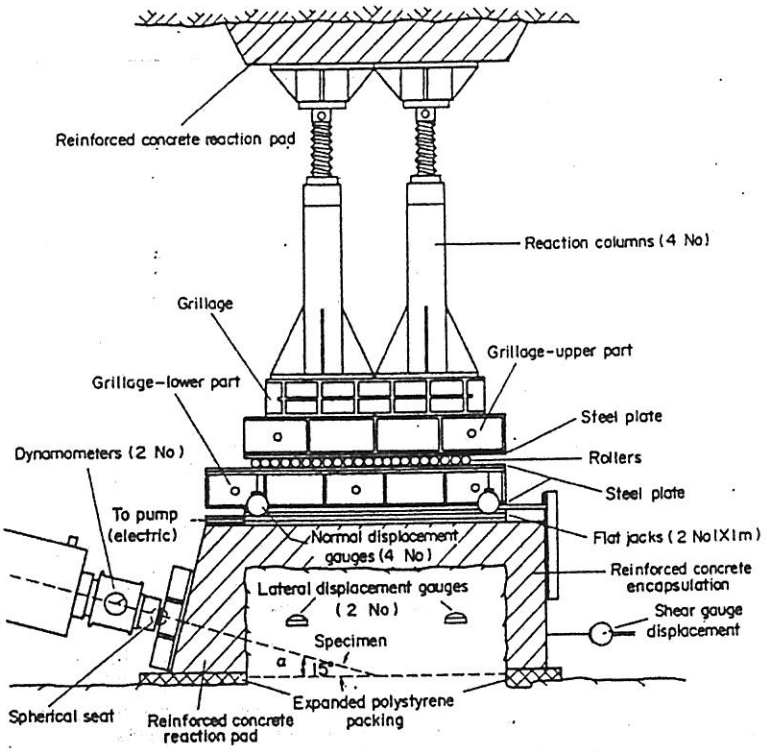


Fig. 1. Typical arrangement of equipment for *in situ* direct shear test.

International Society for Rock Mechanics

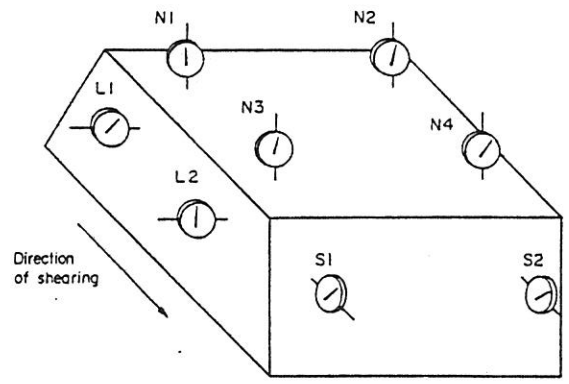


Fig. 2. Arrangement of displacement gauges: S1 and S2 for shear displacement, L1 and L2 for lateral displacement, N1–N4 for normal displacement.

low-friction device to ensure that at any given normal load the resistance to shear displacement is less than 1% of the maximum shear force applied in the test. Rock anchors, wire ties and turnbuckles are usually required to install and secure the equipment.

4. Equipment for applying the shear force (i.e. Fig. 1) including:

(a) One or more hydraulic rams [5] or flat jacks of adequate total capacity with at least 70 mm travel.

(b) A hydraulic pump to pressurize the shear force system.

(c) A reaction system to transmit the shear force to the test block. The shear force should be distributed uniformly along one face of the specimen. The resultant line of applied shear forces should pass through the centre of the base of the shear plane [6], with an angular tolerance of $\pm 5°$.

5. Equipment for measuring the applied forces including:

(a) One system for measuring normal force and another for measuring applied shearing force with an accuracy better than $\pm 2\%$ of the maximum forces reached in the test. Load cells (dynamometers) or flat jack pressure measurements may be used. Recent calibration data applicable to the range of testing should be appended to the test report. If possible the gauges should be calibrated both before and after testing.

6. Equipment for measuring shear, normal and lateral displacements:

(a) Displacements should be measured (for example using micrometer dial gauges [7]) at eight locations on the specimen block or encapsulating material, as shown in Fig. 2.

(b) The shear displacement measuring system should have a travel of at least 70 mm and an accuracy better than 0.1 mm. The normal and lateral displacement measuring systems should have a travel of at least 20 mm and an accuracy better than 0.05 mm. The measuring reference system (beams, anchors and clamps) should, when assembled, be sufficiently rigid to meet these requirements. Resetting of gauges during the test should if possible be avoided.

PROCEDURE

7. Preparation:

(a) The test block is cut to the required dimensions (usually 700 × 700 × 350 mm) using methods that avoid disturbance or loosening of the block [8,9]. The base of the test block should coincide with the plane to be sheared and the direction of shearing should correspond if possible to the direction of anticipated shearing in the full-scale structure to be analysed using the test results. The block and particularly the shear plane should unless otherwise specified be retained as close as possible to its natural *in situ* water content during preparation and testing, for example by covering with saturated cloth. A channel approximately 20 mm deep by 80 mm wide should be cut around the base of the block to allow freedom of shear and lateral displacements.

(b) A layer at least 20 mm thick of weak material (e.g. foamed polystyrene) is applied around the base of the test block, and the remainder of the block is then encapsulated in reinforced concrete or similar material of sufficient strength and rigidity to prevent collapse or significant distortion of the block during testing. The encapsulation formwork should be designed to ensure that the load-bearing faces of the encapsulated block are flat (tolerance ± 1 mm) and at the correct inclination to the shear plane (tolerance $\pm 2°$).

(c) Reaction pads, anchors, etc., if required to carry the thrust from normal and shear load systems to adjacent sound rock, must be carefully positioned and aligned. All concrete must be allowed time to gain adequate strength prior to testing.

8. Consolidation:

(a) The consolidation stage of testing is to allow pore water pressures in the rock and filling material adjacent to the shear plane to dissipate under full normal stress before shearing. Behaviour of the specimen during consolidation may also impose a limit on permissible rate of shearing (see paragraph 9(c)).

(b) All displacement gauges are checked for rigidity, adequate travel and freedom of movement, and a preliminary set of load and displacement readings is recorded.

(c) Normal load is then raised to the full value specified for the test, recording the consequent normal displacements (consolidation) of the test block as a function of time and applied loads (Figs 3 and 4).

(d) The consolidation stage may be considered complete when the rate of change of normal displacement recorded at each of the four gauges is less than 0.05 mm in 10 minutes. Shear loading may then be applied.

9. Shearing:

(a) The purpose of shearing is to establish values for the peak and residual direct shear strengths of the test horizon [2]. Corrections to the applied normal load may be required to hold the normal stress constant; these are defined in paragraph 10(c).

(b) The shear force is applied either in increments or continuously in such a way as to control the rate of shear displacement.

DIRECT SHEAR TEST DATA SHEET

Client: | Project: Concrete Dam | Location: Alcántara | Loc. No.: | Block No.:

TEST BLOCK SPECIFICATION | See drawings & photographs Nos.:

General rock description, index properties and water conditions
Phyllite, sound to moderately weathered | Normal conditions

Description and index properties of surface to be sheared | Type:
Dip: | Dip direction: | Roughness: | Filling & alteration:
Persistance: | Spacing of set: | Surface dimensions: 0.70 x 0.70 | Initial area A: 0.490 m^2

FORCES

$P_n = P_{na} + P_{sa} \sin\alpha$
$P_s = P_{sa} \cos\alpha$
$\sigma_n = P_n/A$
$\tau = P_s/A$

$\alpha = 15^0$ σ_n (nominal)

1 Time elapsed (min)	2 Applied normal force P_n Reading	2 Force (kN)	3 Normal displacement Δ_n Reading 1	2	3	4	Average (mm)	4 Applied shear force P_s Reading	Force (kN)	5 Shear displacement Δ_s Reading 1	2	Average (mm)	6 Contact area A (corrected) m^2	7 P_{na} (kN)	8 σ_n (MP_a)	9 P_{sa} (kN)	10 τ (MP_a)
10		196	0.100	0.070	0.130	0.070			0	0	0	-	0.490	196		0	
35		233	0.130	0.085	0.140	0.090			137	0.05	0.05	0.05		"		142	
48		270	0.050	0.065	0.285	0.290			275	0.35	0.35	0.45		"		284	
64		306	-0.200	0.010	0.435	0.495			412	1.35	1.10	1.22		"		426	
87		343	-0.710	-0.205	0.600	0.720			549	2.55	2.30	2.42		"		568	
109		380	-1.165	-0.445	0.680	0.850			686	3.90	3.50	3.70		"		710	
131		417	-1.675	-0.615	0.710	0.970			824	5.15	4.60	4.88		"		853	
154		453	-1.965	-0.745	0.720	1.050			961	6.10	5.50	5.80		"		995	
172		490	-2.245	-0.880	0.720	1.105			1098	7.20	6.50	6.85		"		1137	
189		527	-2.480	-1.055	0.695	1.165			1235	8.20	7.40	7.80		"		1279	
206		504	-2.750	-1.205	0.640	1.165			1373	9.45	8.45	8.95		"		1421	
234		601	-3.075	-1.505	0.465	1.100			1510	11.00	10.00	10.50		"		1563	
252		637	-3.350	-1.830	0.280	0.910			1647	12.45	11.40	11.92		"		1705	
264		674	-3.675	-2.185	0.050	0.720			1784	14.00	12.80	13.40		"		1847	
276		711	-4.005	-2.665	-0.290	0.360			1922	15.55	14.40	14.98		"		1989	
289		748	-4.585	-3.125	-0.890	-0.020			2059	17.60	16.45	17.02		"		2132	
293	Rupture	784	-4.975	-3.375	-1.250	-0.290			2196	20.00	19.55	19.78		"		2274	

Calibration data | Remarks | Tested by: | Dates: | Checked by: | Date:

Fig. 3. Example layout of direct shear test data sheet.

(c) Approximately 10 sets of readings should be taken before reaching peak strength (Figs 3 and 5). The rate of shear displacement should be less than 0.1 mm/min in the 10-minute period before taking a set of readings. This rate may be increased to not more than 0.5 mm/min between sets of readings provided that the peak strength itself is adequately recorded. For a 'drained' test, particularly when testing clay-filled discontinuities, the total time to reach peak strength should exceed 6 t_{100} as determined from the consolidation curve (see paragraph 10(a) and Fig. 4). If necessary the rate of shear should be reduced or the application of later shear force increments delayed to meet this requirement.

(d) After reaching peak strength, readings should be taken at increments of from 0.5 to 5 mm shear displacement as required to adequately define the force–displacement curves (Fig. 5). The rate of shear displacement should be 0.02–0.2 mm/min in the 10-minute

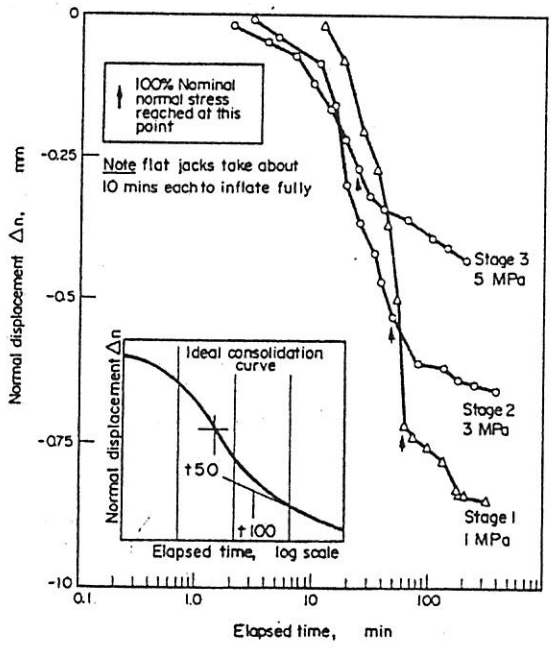


Fig. 4. Consolidation curves for a three-stage direct shear test, showing the construction used to estimate t_{100}.

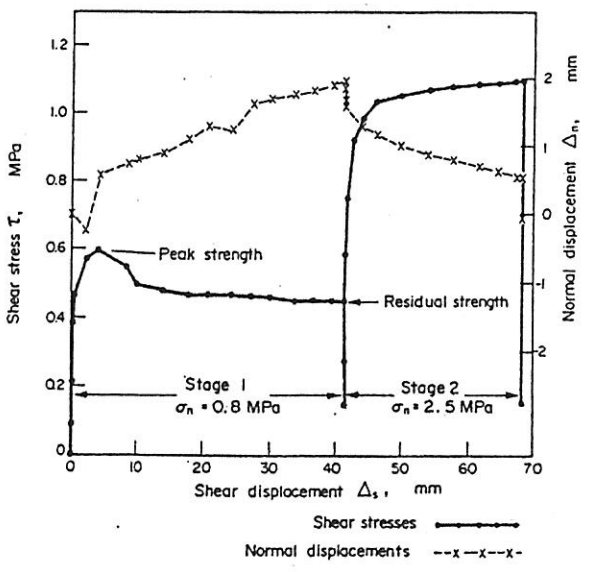


Fig. 5. Shear stress–displacement graphs.

period before a set of readings is taken, and may be increased to not more than 1 mm/min between sets of readings.

(e) It may be possible to establish a residual strength value when the sample is sheared at constant normal stress and at least four consecutive sets of readings are obtained which show not more than 5% variation in shear stress over a shear displacement of 1 cm [11].

(f) Having established a residual strength the normal stress may be increased or reduced [12] and shearing continued to obtain additional residual strength values. The specimen should be reconsolidated under each new normal stress (see paragraph 8(d)) and shearing continued according to criteria given in paragraphs 9(c)–9(e) above.

(g) After the test the block should be inverted, photographed in colour and fully described (see paragraph 11). Measurements of the area, roughness, dip and dip direction of the sheared surface are required, and samples of rock, infilling and shear debris should be taken for index testing.

CALCULATIONS

10. (a) A consolidation curve (Fig. 4) is plotted during the consolidation stage of testing. The time t_{100} for completion of "primary consolidation" is determined by constructing tangents to the curve as shown. The time to reach peak strength from the start of shear loading should be greater than $6\,t_{100}$ to allow pore pressure dissipation [10].

(b) Displacement readings are averaged to obtain values of mean shear and normal displacements Δ_s and Δ_n. Lateral displacements are recorded only to evaluate specimen behaviour during the test, although if appreciable they should be taken into account when computing corrected contact area.

(c) Shear and normal stress are computed as follows:

$$\text{Shear stress } \tau = \frac{P_s}{A} = \frac{P_{sa}\cos\alpha}{A}$$

$$\text{Normal stress } \sigma_n = \frac{P_n}{A} = \frac{P_{na} + P_{sa}\sin\alpha}{A}$$

where

P_s = total shear force; P_n = total normal force,
P_{sa} = applied shear force; P_{na} = applied normal force,
α = inclination of the applied shear force to the shear plane (if $\alpha = 0$, $\cos\alpha = 1$ and $\sin\alpha = 0$),
A = area of shear surface overlap (corrected to account for shear displacement).

If α is greater than zero the applied normal force should be reduced after each increase in shear force by an amount $P_{sa}\sin\alpha$ in order to maintain the normal stress approximately constant. The applied normal force may be further reduced during the test by an amount

$$\frac{\Delta_s(\text{mm}) \times P_n}{700}$$ to compensate for area changes.

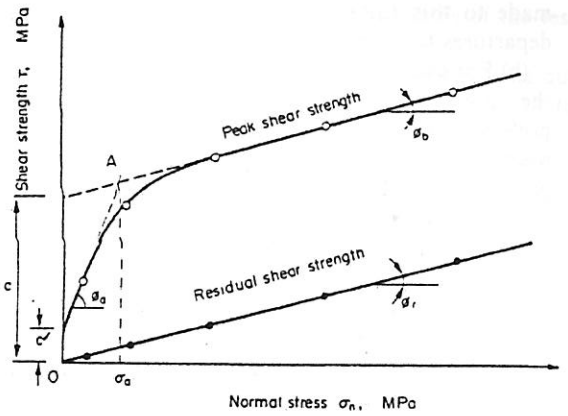
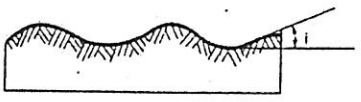


Fig. 6. Shear strength–normal stress graph.

(d) For each test specimen graphs of shear stress (or shear force) and normal displacement vs. shear displacement are plotted (Fig. 5), annotated to show the nominal normal stress and any changes in normal stress during shearing. Values of peak and residual shear strength and the normal stresses, shear and normal displacements at which these occur are abstracted from these graphs [2].

(e) Graphs of peak and residual shear strength vs. normal stress are plotted from the combined results for all test specimens. Shear strength parameters ϕ_a, ϕ_b, ϕ_r, c' and c are abstracted from these graphs as shown in Fig. 6.

ϕ_r = residual friction angle,
ϕ_a = apparent friction angle below stress σ_a; point A is a break in the peak shear strength curve resulting from the shearing off of major irregularities on the shear surface. Between points 0 and A, ϕ_a will vary somewhat; measure at stress level of interest. Note also $\phi_a = \phi_u + i$, where ϕ_u is the friction angle obtained for smooth surfaces of rock on rock and angle i is the inclination of surface asperities.



ϕ_b = apparent friction angle above stress level σ_a (point A); note that ϕ_a will usually be equal to or slightly greater than ϕ_r and will vary somewhat with stress level; measure at the stress level of interest.
c' = cohesion intercept of peak shear strength curve; it may be zero.
c = apparent cohesion at a stress level corresponding to ϕ_b.

REPORTING OF RESULTS

11. The report should include the following:

(a) A diagram, photograph and detailed description of test equipment and a description of methods used for specimen preparation and testing. (Reference may be

made to this ISRM "suggested method" stating only departures from the prescribed techniques.)

(b) For each specimen a full geological description of the intact rock, sheared surface, filling and debris preferably accompanied by relevant index test data (e.g. roughness profiles; Atterberg limits, water content and grain size distribution of filling materials).

(c) Photographs of each sheared surface together with diagrams giving the location, dimensions, area, dip and dip direction and showing the directions of shearing and any peculiarities of the blocks.

(d) For each test block a set of data tables, a consolidation graph and graphs of shear stress and normal displacement vs. shear displacement (e.g. Figs 3, 4 and 5). Abstracted values of peak and residual shear strength should be tabulated with the corresponding values of normal stress, shear and normal displacement.

(e) For the shear strength determination as a whole, graphs and tabulated values of peak and residual shear strength vs. normal stress, together with derived values for the shear strength parameters (e.g. Fig. 6).

PART 2. SUGGESTED METHOD FOR LABORATORY DETERMINATION OF DIRECT SHEAR STRENGTH

SCOPE

1. (a) This test measures peak and residual direct shear strength as a function of stress normal to the sheared plane. Results are employed, for example, in the limiting equilibrium analysis of slope stability problems or for the stability analysis of dam foundations [1–3*].

(b) The inclination of the test specimen with respect to the rock mass, and its direction of mounting in the testing machine are usually selected so that the sheared plane coincides with a plane of weakness in the rock, for example a joint, plane of bedding, schistosity or cleavage, or with the interface between soil and rock or concrete and rock [4].

(c) A shear strength determination should preferably comprise at least five tests on the same test horizon with each specimen tested at a different but constant normal stress.

(d) In applying the results of the test, the pore-water pressure conditions and the possibility of progressive failure must be assessed for the design case as they may differ from the test conditions.

APPARATUS

2. Equipment for taking specimens of rock, including:

(a) Equipment for cutting the specimen; for example a large-diameter core drill, percussive drills, rock saws or hammers and chisels, also equipment for measuring the dip, dip direction, roughness and other characteristic features of the test horizon.

* Numbers refer to Notes at the end of the text.

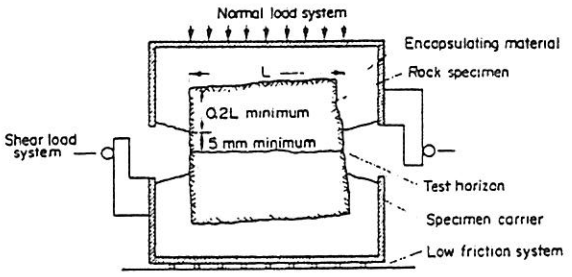


Fig. 7. Arrangement for laboratory direct shear test.

(b) Materials for holding the specimen together, for example binding wire or metal bands.

(c) Materials to protect the specimen against mechanical damage and changes in water content both during cutting and transit to the laboratory, for example protective packing and wax or similar waterproofing material.

3. Equipment for mounting the specimen including:

(a) Specimen carriers, forming a dismountable part of the test equipment.

(b) Cement, plaster, resin or similar strong encapsulating materials together with appropriate mixing utensils.

4. Testing equipment (a shear box, for example Fig. 7) incorporating:

(a) A means of applying the normal load, typically a hydraulic, pneumatic or dead-weight mechanical system, designed to ensure that the load is uniformly distributed over the plane to be tested. The resultant force should act normal to the shear plane, passing through its centre of area. The system should have a travel greater than the amount of dilation or consolidation to be expected, and should be capable of maintaining normal load to within 2% of a selected value throughout the test [5].

(b) A means of applying the shear force, typically a hydraulic jack or a mechanical gear-drive system, designed so that the load is distributed uniformly along one half-face of the specimen with the resultant applied shear force acting in the plane of shearing. The equipment should be designed for a shear travel greater than 10% of the specimen length. It should include rollers, cables or a similar low friction device to ensure that resistance of the equipment to shear displacement is less than 1% of the maximum shear force applied in the test.

(c) Equipment for independent measurement of the applied shear and normal forces, with an accuracy better than ±2% of the maximum forces reached in the test. Recent calibration data applicable to the range of testing should be appended to the test report.

(d) Equipment for measuring shear, normal and lateral displacement, for example micrometer dial gauges or electric transducers. Gauges may be mounted as shown in Fig. 2, or the four normal displacement gauges may be replaced by a single gauge mounted centrally. The shear displacement measuring system should have a travel greater than 10% of the specimen

length and an accuracy better than 0.1 mm. The normal and lateral displacement measuring systems should have a travel greater than 20 mm and an accuracy better than 0.05 mm. Resetting of gauges during the test should if possible be avoided. If electric transducers or an automatic recording system is used a recent calibration should be included in the report.

PROCEDURE

5. Preparation:

(a) The test horizon is selected and dip, dip direction and other relevant geological characteristics are recorded. Block or core specimens containing the test horizon are collected using methods selected to minimize disturbance, if possible in such a way as to retain natural water content. The specimen dimensions and the location of the test horizon within the block or core should if possible allow mounting without further trimming in the laboratory, and with sufficient clearance for adequate encapsulation [8]. The test plane should preferably be square with a minimum area of 2500 mm [2]. The mechanical integrity of the specimens should be preserved by binding tightly with wire or tape which is to be left in position until immediately before testing.

(b) Specimens that are not encapsulated immediately for testing should be given a waterproof coating, labelled and packaged to avoid damage in transit to the laboratory. Fragile specimens require special treatment, for example packaging in polyurethane foam (Stimpson, B., Metcalfe, F. G., and Walton, G., 1970. *Q. J. Engng Geol.* 3, No. 2, p. 127).

(c) The protective packaging, with the exception of the steel wire, is removed and the block supported in one of the carriers so that the horizon to be tested is secured in the correct position and orientation. The encapsulating material is poured and, after this has set, the other half-specimen is encapsulated in a similar manner. A zone at least 5 mm either side of the shear horizon should be free from encapsulating material.

6. Consolidation:

(a) The consolidation stage of testing is to allow pore water pressures in the rock and filling material adjacent to the shear plane to dissipate under full normal stress before shearing. Behaviour of the specimen during consolidation may also impose a limit on permissible rate of shearing (see paragraph 7(e)).

(b) Having mounted the specimen in the shear box, all gauges are checked and a preliminary set of load and displacement readings is recorded.

(c) Normal load is raised to the full value specified for the test, recording the consequent normal displacement (consolidation) of the specimen as a function of time and applied loads (Figs 3 and 4).

(d) The consolidation stage may be considered complete when the rate of change of normal displacement is less than 0.05 mm in 10 minutes. Shear loading may then be applied.

7. Shearing:

(a) The purpose of shearing is to establish values for the peak and residual direct shear strengths of the test horizon [2].

(b) The shear force may be applied in increments but is usually applied continuously in such a way as to control the rate of shear displacement.

(c) Approximately 10 sets of readings should be taken before reaching peak strength (Figs 3 and 5). The rate of shear displacement should be less than 0.1 mm/min in the 10-minute period before taking a set of readings. This rate may be increased to not more than 0.5 mm/min between sets of readings provided that the peak strength itself is adequately recorded. For a "drained" test [10] particularly when testing clay-filled discontinuities, the total time to reach peak strength should exceed $6\,t_{100}$ as determined from the consolidation curve (see paragraph 8(a) and Fig. 4). If necessary the rate of shear should be reduced or the application of later shear force increments delayed to meet this requirement.

(d) After reaching peak strength, readings should be taken at increments of from 0.5 to 5 mm shear displacement as required to adequately define the force–displacement curves (Fig. 5). The rate of shear displacement should be 0.02–0.2 mm/min in the 10-minute period before a set of readings is taken, and may be increased to not more than 1 mm/min between sets of readings.

(e) It may be possible to establish a residual strength value when the sample is sheared at constant normal stress and at least four consecutive sets of readings are obtained which show not more than 5% variation in shear stress over a shear displacement of 1 cm [11].

(f) Having established a residual strength the normal stress may be increased or reduced [12] and shearing contined to obtain additional residual strength values. The specimen should be reconsolidated under each new normal stress (see paragraph 6), and shearing continued according to criteria given in paragraphs 7(c) to 7(e) above.

(g) After the test the shear plane should be exposed and fully described (see paragraph 9). The area of the shear surface is measured and photographs may also be required. Samples of rock, infilling and shear debris should be taken for index testing.

CALCULATIONS

8. (a) A consolidation curve (Fig. 4) is plotted during the consolidation stage of testing. The time t_{100} for completion of "primary consolidation" is determined by constructing tangents to the curve as shown. The time to reach peak strength from the start of shear loading should be greater than $6\,t_{100}$ to allow pore pressure dissipation [10].

(b) Displacement readings are averaged to obtain values of mean shear and normal displacements Δ_s and Δ_n. Lateral displacements are recorded only to evaluate specimen behaviour during the test, although if appreciable they should be taken into account when computing corrected contact area.

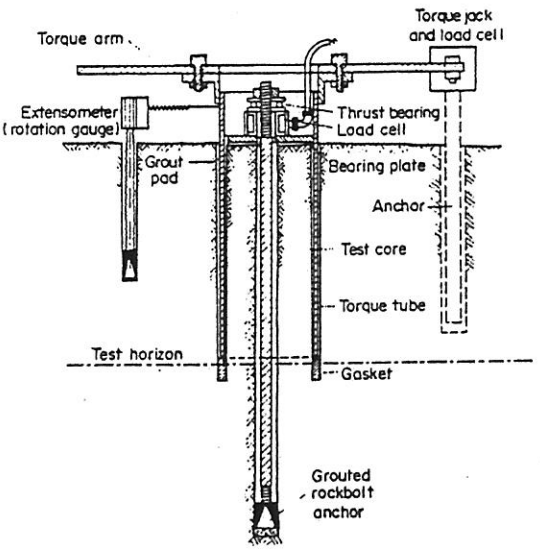


Fig. 8. Torsional shear test equipment.

(c) Shear and normal stress are computed as follows:

$$\text{Normal stress } \tau = \frac{P_s}{A}$$

$$\text{Shear stress } \sigma_n = \frac{P_n}{A}$$

where

P_s = total shear force; P_n = total normal force;
A = area of shear surface overlap (corrected to account for shear displacement).

(d) For each test specimen graphs of shear stress (or shear force) and normal displacement vs. shear displacement are plotted (Fig. 5), annotated to show the nominal normal stress and any changes in normal stress during shearing. Values of peak and residual shear strength and the normal stresses, shear and normal displacements at which these occur are abstracted from these graphs [2].

(e) Graphs of peak and residual shear strength vs. normal stress are plotted from the combined results for all test specimens. Shear strength parameters ϕ_a, ϕ_b, ϕ_r, c' and c are abstracted from these graphs as shown in Fig. 6.

REPORTING OF RESULTS

9. The report should include the following:

(a) A diagram and description of the test equipment and a description of the methods used for taking, packaging, transporting, storing, mounting and testing the specimen. (Reference may be made to this ISRM "suggested method" stating only departures from the prescribed techniques.)

(b) For each specimen a full geological description of the intact rock, sheared surface, filling and debris preferably accompanied by relevant index test data (e.g. roughness profiles; Atterberg limits, water content and grain size distribution of filling materials).

(c) Diagrams and preferably photographs showing the sampling location, dip and dip direction of the tested horizon, also the dimensions and any peculiarities of the specimens.

(d) For each test block a set of data tables, a consolidation graph and graphs of shear stress and normal displacement vs. shear displacement (e.g. Figs 3, 4 and 5). Abstracted values of peak and residual shear strength should be tabulated with the corresponding values of normal stress, shear and normal displacement.

(e) For the shear strength determination as a whole, graphs and tabulated values of peak and residual shear strength vs. normal stress, together with derived values for the shear strength parameters (e.g. Fig. 6).

PART 3. SUGGESTED METHOD FOR *IN SITU* DETERMINATION OF SHEAR STRENGTH USING A TORSIONAL SHEAR TEST

SCOPE

1. (a) This test measures the shear strength of the base of a rock core which is rotated in its drillhole.

(b) The results may be used as an approximation to the direct shear strengths measured by the *in situ* or laboratory methods given in Parts 1 and 2 of this document [13*].

APPARATUS

2. Drilling equipment, including:

(a) A diamond core drill, water or air flush to suit the rock, capable of coring at diameters of approximately 50 mm and 300 mm to a depth greater than the core length required (usually 0.5–3 m).

3. Equipment for applying and measuring the normal load (Fig. 8) including:

(a) A rockbolt at least 1 m longer than the required core length, with grouted anchor at one end and a nut, thread and washer at the other.

(b) A bearing plate with external diameter equal to that of the test core, and a central hole allowing the plate to pass freely over the rockbolt.

(c) A hollow centre load cell fitting over the rockbolt, measuring tension in the bolt to ±2%.

(d) A thrust bearing, concentric with the rockbolt and load cell, to prevent transmission of torque from the rockbolt to the core.

4. Equipment for applying and measuring the torque (Fig. 8) including:

(a) A torque tube to hold the rock core, fitting in the annular space around the core with an external clearance not less than 3 mm and an internal clearance sufficient to allow grouting between the tube and the core.

(b) A torque arm fixed rigidly across a diameter of the torque tube, perpendicular to the core axis and extending equally either side.

* Numbers refer to Notes at the end of the text.

(c) Two identical hydraulic jacks for applying the torque, pressurized by a single hydraulic pump, anchored rigidly to rockbolts equidistant from the core axis connected to the torque arm in such a way as to apply equal forces in opposite directions tangential to the core. Each jack is fitted with a load cell to measure to $\pm 2\%$ the applied force.

5. Equipment for measuring the rotation of the core, for example a dial gauge micrometer fixed to a rigid anchor and connected to the circumference of the torque tube by a wire and pulley system. The system should measure rotation within ± 0.001 radian and should have a travel greater than 0.1 radian.

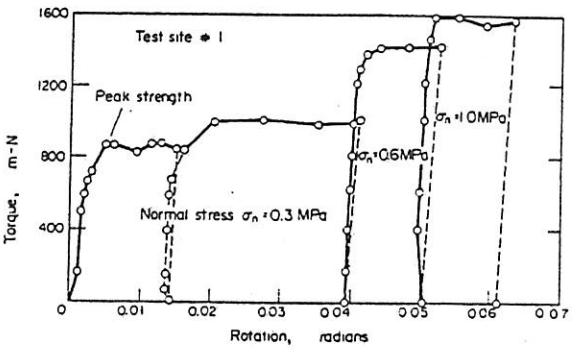


Fig. 9. Torque–rotation graph for the torsional shear test.

PROCEDURE

6. Preparation:

(a) The test site is selected and a firm flat surface prepared perpendicular to the test horizon, usually 0.5–3 m above it. The test horizon is usually a plane of weakness in the rock such as a joint, plane of bedding or schistosity or the junction between concrete and rock.

(b) A small-diameter core (e.g. 50 mm) is drilled perpendicular to the anticipated test horizon and at least 1 m beyond it. This core is logged in detail, the test horizon selected and its depth measured to ± 10 mm. Additional small-diameter holes are drilled to take anchors for the torque jacks and rotation-measuring equipment.

(c) The normal load anchor is installed, with the anchor grout entirely below the test horizon. The bearing plate is installed over the bolt on a bed of grout, the load cell and thrust bearing placed in position and a normal load sufficient to rigidly hold the test core during drilling is applied.

(d) The test core is drilled to a depth 20 mm $\pm$ 5 mm beneath the test horizon using the bearing plate to centralize the core barrel. The drilling method and drill fluid should be selected to minimize damage to the core.

(e) The annular space surrounding the test core is cleaned and filled with a weak material (e.g. sponge rubber gaskets) to a depth of 5–10 mm above the test horizon. The torque tube is greased on the outside, inserted to rest on the weak filler, and grouted to the core using resin or cement. The grout is left to gain strength and then the remaining apparatus is assembled and checked.

7. Testing:

(a) A selected normal load is applied by tightening the central rockbolt.

(b) The torque is gradually increased taking incremental readings of the torque and normal load cells and of the rotation gauge (e.g. Fig. 9). The rate of torque application should be such that 5–10 sets of readings are taken before reaching peak strength [2].

(c) Torsional loading is continued taking sets of readings at approximately 0.05 radian increments of rotation as shown in Fig. 9, until at least four sets of torque readings differing by less than 5% are obtained.

(d) The torsional loading is then removed, taking a further set of readings. The procedure 7(a) to 7(c) may then be repeated one or more times at successively greater normal loads depending on the maximum rotation permitted by the apparatus [12].

(e) The test core is removed and the sheared surface examined and described in detail. Samples of rock, filling material and shear debris may be taken for index testing.

CALCULATIONS

8. (a) Torque values are calculated using the load cell calibration curves to obtain the loads (kN) then multiplying by the torque radius (mm) to obtain the torque (m–N). The total torque T is the sum of the two applied torques.

(b) Normal loads are calculated from the load cell calibration curve, and converted into normal stresses σ_n using the equation:

$$\sigma_n = \frac{4P_n}{\pi(D^2 - d^2)}$$

where

P_n = applied normal load,
D = outer diameter of test core,
d = inner diameter of test core.

(c) Shear strengths τ corresponding to the peak and residual portions of the torque–displacement graph (Fig. 9, Notes 2 and 3) may be calculated using one of two assumptions:

(i) In strong, elastic rock assuming maximum stress at the outer circumference of the test core

$$\tau = \frac{0.5TD}{J}$$

(ii) In softer rock, assuming constant tangential stress at every radius across the failure plane

$$\tau = \frac{0.365TD}{J}$$

where

$$J = \frac{\pi(D^4 - d^4)}{32}$$

The latter assumption gives a more conservative estimate and should always be used for calculating residual shear strength, usually also for peak strength calculation.

(d) Graphs of peak and residual shear strength vs. normal stress are plotted from the combined results for all test specimens. Shear strength parameters may be abstracted from these graphs as shown in Fig. 6.

REPORTING OF RESULTS

9. The report should include the following:

(a) A diagram and detailed description of the test equipment and methods used for drilling and testing. (Reference may be made to this ISRM method stating only departures from the prescribed techniques.)

(b) For each test a full geological description of the test horizon, filling and shear debris preferably accompanied by relevant index test data.

(c) Photographs of the sheared surface together with diagrams giving the location, depth, dip and dip direction of the surface, the internal and external diameters and any peculiarities of the test core.

(d) For each test a set of data tables, graphs of shear stress and normal stress versus rotational displacement; abstracted values for peak and residual shear strengths and corresponding normal stresses with the assumptions made in their calculation.

(e) For the shear strength determination as a whole, graphs and tabulated values of peak and residual shear strength versus normal stress, together with derived values for the shear strength parameters (e.g. Fig. 6).

NOTES

1. Direct shear strength can be determined in the laboratory (using the method described in Part 2) if the plane to be tested is smooth and flat in comparison with the size of specimen, and if the specimen can be cut and transported without disturbance.

2. Definitions (clarified in Figs. 5 and 6):

Peak shear strength—the maximum shear stress in the complete shear stress–displacement curve.

Residual shear strength—the shear stress at which no further rise or fall in shear strength is observed with increasing shear displacement. A true residual strength may only be reached after considerably greater shear displacement than can be achieved in testing. The test value should be regarded as approximate and should be assessed in relation to the complete shear stress–displacement curve.

Shear strength parameters c and ϕ—respectively the intercept and angle to the normal stress axis of a tangent to the shear strength–normal stress curve at a normal stress that is relevant to design (see Fig. 6).

3. The measured peak strength can be applied directly to full-scale stability calculations only if the same type and size of roughness irregularities are present on the tested plane as on a larger scale. If this is not the case, the true peak strength should be obtained from the test data using appropriate calculations (for example, Patton, F. D., 1966, *Proc. 1st Int. Cong. Rock Mech. ISRM*, Lisbon, Vol. 1, pp. 509–512; Ladanyi, B. and Archambault, G., 1970. In *Rock Mechanics—Theory and Practice* (W. H. Somerton, ed.), AIME, New York, pp. 105–125; Barton, N. R., 1971, *Proc. Symp. ISRM*, Nancy, Paper 1–8).

4. Tests on intact rock (free from planes of weakness) are usually carried out using laboratory triaxial testing. Intact rock can, however, be tested in direct shear if the rock is weak and if the specimen block encapsulation is sufficiently strong.

5. If a dead load is used for normal loading precautions are required to ensure accurate centring and stability. If two or more hydraulic rams are used either for normal or shear loading care is needed to ensure that they are identically matched and are in exact parallel alignment. Each ram should be provided with a spherical seat. The travel of rams and particularly of flat jacks should be sufficient to accommodate the full anticipated specimen displacement. A normal displacement of $\pm$5–10 mm may be expected, depending on the clay content and roughness of the shear surface.

6. The applied shear force may act in the plane of shearing so that the angle α is 0 (Fig. 1). This requires a cantilever bearing member to carry the thrust from the shear jacks to the specimen. If a method is used where the shear force acts at some distance above the shear plane, the line of action of the shear jacks should be inclined to pass through the centre of area of the shear plane. The angle α for a specimen 700 × 700 × 350 mm approximates to 15° depending on the thickness of encapsulation. Tests where both shear and normal forces are provided by a single set of jacks inclined at greater angles to the shear plane are not recommended, as it is then impossible to control shear and normal stresses independently.

7. The surface of encapsulating material is usually insufficiently smooth and flat to provide adequate reference for displacement gauges, and glass plates may be cemented to the specimen block for this purpose. These plates should be of adequate size to accommodate movement of the specimen. Alternatively a tensioned wire and pulley system with gauges remote from the specimen can be used. The system as a whole must be reliable and conform with specified accuracy requirements. Particular care is needed in this respect when employing electric transducers or automatic recording equipment.

8. A test block size of 700 × 700 × 350 mm is suggested as standard for *in situ* testing. Smaller blocks may be permissible, for example, if the surface to be tested is relatively smooth; larger blocks may be needed when testing very irregular surfaces. The size and shape of the test block may for convenience be adjusted so that faces of the block coincide with natural joints or fissures; this minimizes block disturbance during preparation. Irregularities that would limit the thickness or emplacement of encapsulation material or reinforcement should be removed.

9. It is advisable particularly if the test horizon is

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inclined at more than 10°–20° to the horizontal to apply a small normal load to the upper face of the test specimen while the sides are cut, to prevent premature sliding and also to inhibit relaxation and swelling. The load, approximately 5–10% of that to be applied in the test, may, for example, be provided by screw props or a system of rock bolts and cross-beams, and should be maintained until the test equipment is in position.

10. The requirement that total time to reach peak strength should exceed $6\,t_{100}$ is derived from conventional soil mechanics consolidation theory (for example, Gibson and Henkel, *Geotechnique* **4**, pp. 10–11, 1954) assuming a requirement of 90% pore water pressure dissipation. This requirement is most important when testing a clay-filled discontinuity. In other cases it may be difficult to define t_{100} with any precision because a significant proportion of the observed "consolidation" may be due to rock creep and other mechanisms unrelated to pore pressure dissipation. Provided the rates of shear specified in the text are followed, the shear strength parameters may be regarded as having been measured under conditions of effective stress ("drained conditions").

11. An independent check on the residual friction angle should be made by testing in the laboratory two prepared flat surfaces of the representative rock. The prepared surfaces should be saw-cut and then ground flat with No. 80 silicon carbide grit.

12. The normal load should when possible be applied in increasing rather than decreasing stages. Reversals of shear direction or resetting of the specimen block between normal load stages, sometimes used to allow a greater total shear displacement than would otherwise be possible, are not recommended because the shear surface is likely to be disturbed and subsequent results may be misleading. It is generally advisable, although more expensive, to use a different specimen block for each residual strength determination.

13. The torsional shear test is inexpensive and has the advantage of causing a minimum of disturbance to the test horizon. However, shear stress and displacement gradients generally exist from the inner to the outer radius of the core so that the shear strength values obtained must be regarded as approximate. The test should not be used for testing horizons that have a pronounced directional roughness. There is generally no provision for monitoring normal displacements or consolidation of the specimen.

Suggested Method for Determining Point Load Strength

SCOPE

1.(a) The Point Load Strength test is intended as an index test for the strength classification of rock materials. It may also be used to predict other strength parameters with which it is correlated, for example uniaxial tensile and compressive strength.[1]*

(b) The test measures the Point Load Strength Index ($I_{s(50)}$) of rock specimens, and their Strength Anisotropy Index ($I_{a(50)}$) which is the ratio of Point Load Strengths in directions which give the greatest and least values.

(c) Rock specimens in the form of either core (the *diametral* and *axial* tests), cut blocks (the *block* test), or irregular lumps (the *irregular lump* test) are broken by application of concentrated load through a pair of spherically truncated, conical platens.[2] Little or no specimen preparation is needed.

(d) The test can be performed with portable equipment or using a laboratory testing machine, and so may be conducted either in the field or the laboratory.

APPARATUS

2. The testing machine (Fig. 1) consists of a loading system (for the portable version typically comprising a loading frame, pump, ram and platens), a system for measuring the load P required to break the specimen, and a system for measuring the distance D between the two platen contact points (but see 5(e) below).

Loading system

3.(a) The loading system should have a platen-to-platen clearance that allows testing of rock specimens in the required size range. Typically this range is 15–100 mm so that an adjustable clearance is needed to accommodate both small and large specimens.

(b) The loading capacity should be sufficient to break the largest and strongest specimens to be tested.[3]

(c) The test machine should be designed and constructed so that it does not permanently distort during repeated applications of the maximum test load, and so that the platens remain co-axial within $\pm$ 0.2 mm throughout the testing. No spherical seat or other non-rigid component is permitted in the loading system. Loading system rigidity is essential to avoid problems of slippage when specimens of irregular geometry are tested.

(d) Spherically-truncated, conical platens of the standard geometry shown in Fig. 2 are to be used. The 60° cone and 5 mm radius spherical platen tip should meet tangentially.[4] The platens should be of hard material such as tungsten carbide or hardened steel so that they remain undamaged during testing.

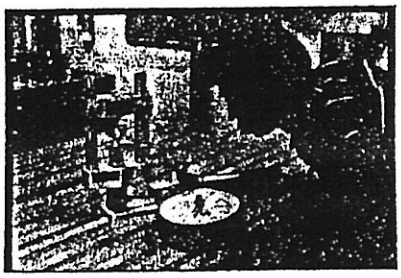

Fig. 1. Photograph of portable point load test machine.

Load measuring system

4.(a) The load measuring system, for example a load cell or a hydraulic pressure gauge or transducer connected to the ram, should permit determination of the failure load P required to break the specimen and should conform to the requirements (b) through (d) below.

(b) Measurements of P should be to an accuracy of $\pm$ 5%P or better, irrespective of the size and strength of specimen that is tested.[3,5]

(c) The system is to be resistant to hydraulic shock and vibration so that the accuracy of readings is not adversely affected by repeated testing.

(d) Failure is often sudden and a maximum load indicating device is essential so that the failure load is retained and can be recorded after each test.

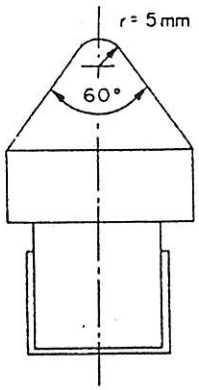

Fig. 2. Platen shape and tip radius.

* Superscript numbers refer to Notes at the end of the text.

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Distance measuring system

5.(a) The distance measuring system, for example a direct reading scale or displacement transducer, is to permit measurement of the distance D between specimen-platen contact points and should conform with requirements (b) through (d) below.[6]

(b) Measurements of D should be to an accuracy of $\pm 2\%D$ or better irrespective of the size of specimen tested.

(c) The system is to be resistant to hydraulic shock and vibration so that the accuracy of readings is not adversely affected by repeated testing.

(d) The measuring system should allow a check of the "zero displacement" value when the two platens are in contact, and should preferably include a zero adjustment.

(e) An instrument such as calipers or a steel rule is required, to measure the width W of specimens for all but the diametral test.

PROCEDURE

Specimen selection and preparation

6.(a) A test sample is defined as a set of rock specimens of similar strength for which a single Point Load Strength value is to be determined.

(b) The test sample of rock core or fragments is to contain sufficient specimens conforming with the size and shape requirements for diametral, axial, block or irregular lump testing as specified below.[7]

(c) For routine testing and classification, specimens should be tested either fully water-saturated or at their natural water content.[8]

Calibration

7. The test equipment should be periodically calibrated using an independently certified load cell and set of displacement blocks, checking the P and D readings over the full range of loads and displacements pertinent to testing.

The diametral test[2]

8.(a) Core specimens with length/diameter ratio greater than 1.0 are suitable for diametral testing.

(b) There should preferably be at least 10 tests per sample, more if the sample is heterogeneous or anisotropic.[7]

(c) The specimen is inserted in the test machine and the platens closed to make contact along a core diameter, ensuring that the distance L between the contact points and the nearest free end is at least 0.5 times the core diameter (Fig. 3a).

(d) The distance D is recorded $\pm .2\%$.[6]

(e) The load is steadily increased such that failure occurs within 10–60 sec, and the failure load P is recorded. The test should be rejected as invalid if the

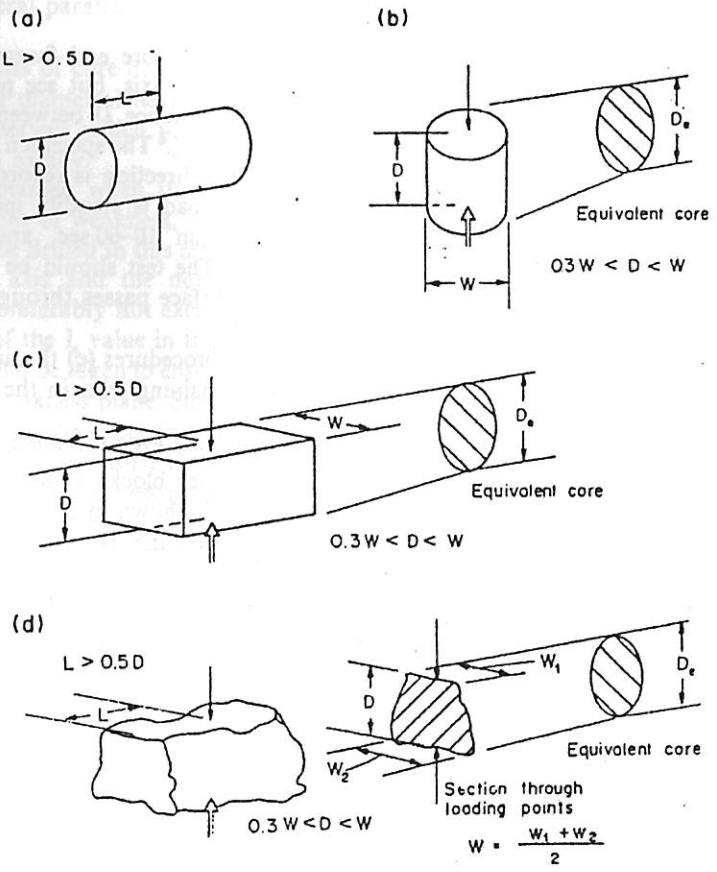

Fig. 3. Specimen shape requirements for (a) the diametral test, (b) the axial test, (c) the block test, and (d) the irregular lump test.

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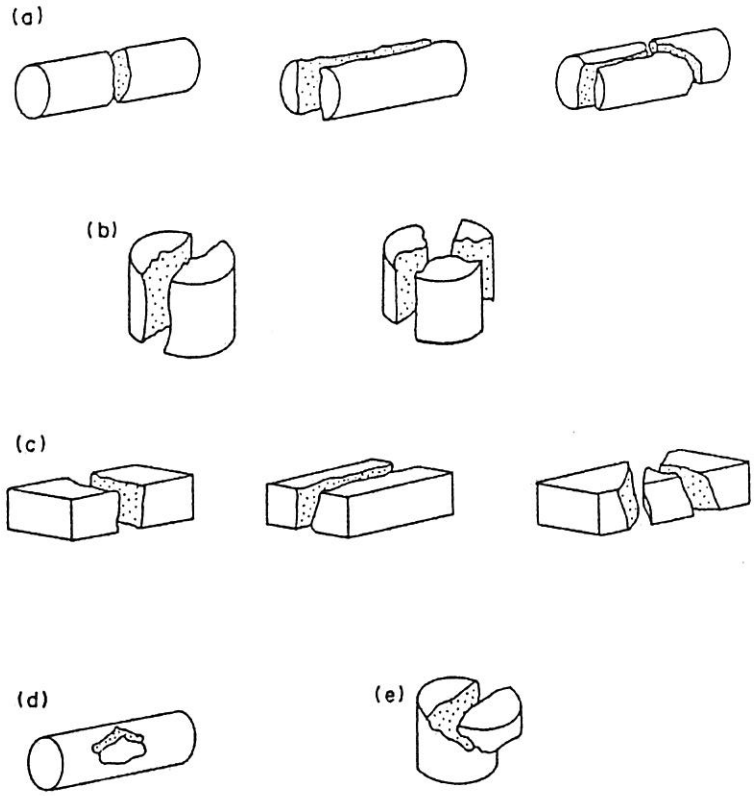

Fig. 4. Typical modes of failure for valid and invalid tests. (a) Valid diametral tests; (b) valid axial tests; (c) valid block tests; (d) invalid core test; (e) invalid axial test.

fracture surface passes through only one loading point (Fig. 4d).

(f) The procedure (c) through (e) above is repeated for the remaining specimens in the sample.

The axial test[2]

9.(a) Core specimens with length/diameter ratio of 0.3–1.0 are suitable for axial testing (Fig. 3b). Long pieces of core can be tested diametrally to produce suitable lengths for subsequent axial testing (provided that they are not weakend by this initial testing); alternatively, suitable specimens can be obtained by saw-cutting or chisel-splitting.

(b) There should preferably be at least 10 tests per sample, more if the sample is heterogeneous or anisotropic.[7]

(c) The specimen is inserted in the test machine and the platens closed to make contact along a line perpendicular to the core end faces (in the case of isotropic rock, the core axis, but see paragraph 11 and Fig. 5).

(d) The distance D between platen contact points is recorded $\pm 2\%$.[6] The specimen width W perpendicular to the loading direction is recorded $\pm 5\%$.[9]

(e) The load is steadily increased such that failure occurs within 10–60 sec, and the failure load P is recorded. The test should be rejected as invalid if the fracture surface passes through only one loading point (Fig. 4e).

(f) The procedures (c) through (e) above are repeated for the remaining tests in the sample.

The block and irregular lump tests

10.(a) Rock blocks or lumps of size 50 ± 35 mm and of the shape shown in Fig. 3(c) and (d) are suitable for the block and the irregular lump tests. The ratio D/W should be between 0.3 and 1.0, preferably close to 1.0.

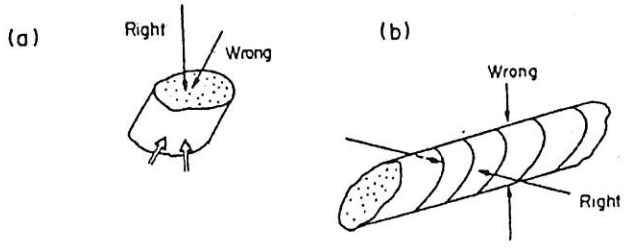

Fig. 5. Loading directions for tests on anisotropic rock.

The distance L (Fig. 3c and d) should be at least $0.5W$. Specimens of this size and shape may be selected if available or may be prepared by trimming larger pieces by saw-or chisel-cutting.

(b) There should preferably be at least 10 tests per sample, more if the rock is heterogeneous or anisotropic.[7]

(c) The specimen is inserted in the testing machine and the platens closed to make contact with the smallest dimension of the lump or block, away from edges and corners (Fig. 3c and d).

(d) The distance D between platen contact points is recorded $\pm 2\%$. The smallest specimen width W perpendicular to the loading direction is recorded $\pm 5\%$. If the sides are not parallel, then W is calculated as $(W_1 + W_2)/2$ as shown in Fig. 3d.[6] This smallest width W is used irrespective of the actual mode of failure (Figs 3 and 4)

(e) The load is steadily increased such that failure occurs within 10–60 sec, and the failure load P is recorded. The test should be rejected as invalid if the fracture surface passes through only one loading point (see examples for other shapes in Fig. 4d or e).

(f) The procedure (c) through (e) above is repeated for the remaining tests in the sample.

Anisotropic rock

11. (a) When a rock sample is shaly, bedded, schistose or otherwise observably anisotropic it should be tested in directions which give the greatest and least strength values, which are in general parallel and normal to the planes of anisotropy.

(b) If the sample consists of core drilled through the weakness planes, a set of diametral tests may be completed first, spaced at intervals which will yield pieces which can then be tested axially.

(c) Best results are obtained when the core axis is perpendicular to the planes of weakness, so that when possible the core should be drilled in this direction. The angle between the core axis and the normal to the weakness planes should preferably not exceed 30°.

(d) For measurement of the I_s value in the directions of least strength, care should be taken to ensure that load is applied along a single weakness plane. Similarly when testing for the I_s value in the direction of greatest strength, care should be taken to ensure that the load is applied perpendicularly to the weakness planes (Fig. 5).

(e) If the sample consists of blocks or irregular lumps, it should be tested as two sub-samples, with load applied firstly perpendicular to, then along the observable planes of weakness.[10] Again, the required minimum strength value is obtained when the platens make contact along a single plane of weakness.

CALCULATIONS

Uncorrected point load strength

12. The Uncorrected Point Load Strength I_s is calculated as P/D_e^2 where D_e, the "equivalent core diameter", is given by:

$D_e^2 = D^2$ for diametral tests;

$= 4A/\pi$ for axial, block and lump tests;

and

$A = WD$ = minimum cross sectional area of a plane through the platen contact points.[6]

Size correction

13.(a) I_s varies as a function of D in the diametral test, and as a function of D_e in axial, block and irregular lump tests, so that a size correction must be applied to obtain a unique Point Load Strength value for the rock sample, and one that can be used for purposes of rock strength classification.

(b) The size-corrected Point Load Strength Index $I_{s(50)}$ of a rock specimen or sample is defined as the value of I_s that would have been measured by a diametral test with $D = 50$ mm.

(c) The most reliable method of obtaining $I_{s(50)}$, preferred when a precise rock classification is essential, is to conduct diametral tests at or close to $D = 50$ mm. Size correction is then either unnecessary ($D = 50$ mm) or introduces a minimum of error. The latter is the case, for example, for diametral tests on NX core, $D = 54$ mm. This procedure is not mandatory. Most point load strength testing is in fact done using other sizes or shapes of specimen. In such cases, the size correction (d) or (e) below must be applied.

(d) The most reliable method of size correction is to test the sample over a range of D or D_e values and to plot graphically the relation between P and D_e^2. If a log–log plot is used the relation is generally a straight line (Fig. 6). Points that deviate substantially from the straight line may be disregarded (although they should not be deleted). The value of P_{50} corresponding to $D_e^2 = 2500$ mm^2 ($D_e = 50$ mm) can then be obtained by interpolation, if

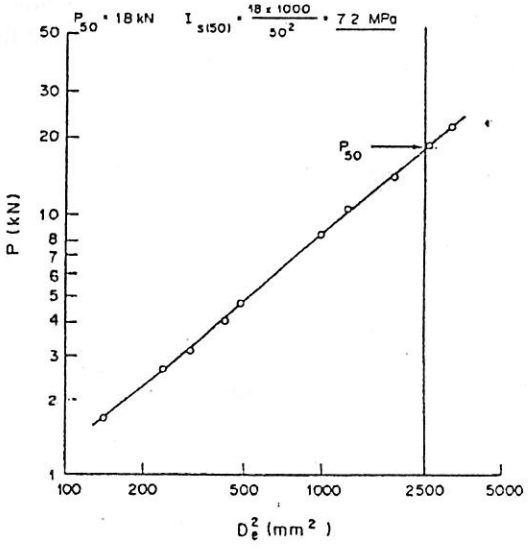

Fig. 6. Procedure for graphical determination of $I_{s(50)}$ from a set of results at D_e values other than 50 mm.

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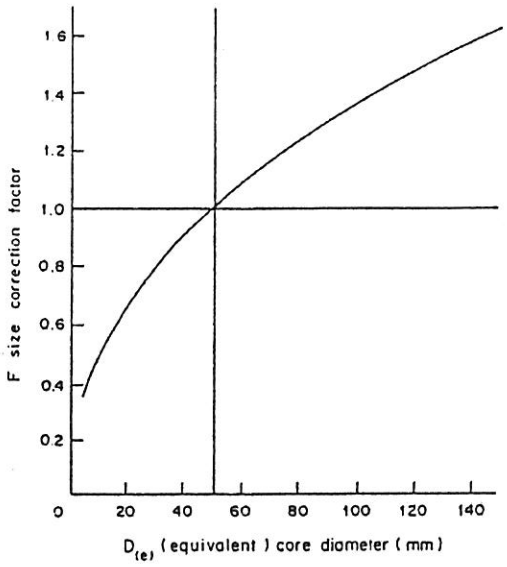

Fig. 7. Size correction factor chart.

necessary by extrapolation, and the size-corrected Point Load Strength Index calculated as $P_{50}/50^2$.

(e) When neither (c) nor (d) is practical, for example when testing single sized core at a diameter other than 50 mm or if only a few small pieces are available, size correction may be accomplished by using the formula:

$$I_{s(50)} = F \times I_s$$

The "Size Correction Factor F" can be obtained from the chart in Fig. 7,[11] or from the expression:

$$F = (D_e/50)^{0.45}$$

For tests near the standard 50 mm size, very little error is introduced by using the approximate expression:

$$F = \sqrt{(D_e/50)}$$

(f) The size correction procedures specified in this paragraph have been found to be applicable irrespective of the degree of anisotropy I_a and the direction of loading with respect to planes of weakness, a result that greatly enhances the usefulness of this test.

Mean value calculation

14.(a) Mean values of $I_{s(50)}$ as defined in (b) below are to be used when classifying samples with regard to their Point Load Strength and Point Load Strength Anisotropy Indices.

(b) The mean value of $I_{s(50)}$ is to be calculated by deleting the two highest and lowest values from the 10 or more valid tests, and calculating the mean of the remaining values. If significantly fewer specimens are tested, only the highest and lowest values are to be deleted and the mean calculated from those remaining.[12]

Point load strength anisotropy index

15. The Strength Anistropy Index $I_{a(50)}$ is defined as the ratio of mean $I_{s(50)}$ values measured perpendicular and parallel to planes of weakness, i.e. the ratio of greatest to least Point Load Strength Indices. $I_{a(50)}$ assumes values close to 1.0 for quasi-isotropic rocks and higher values when the rock is anisotropic.

REPORTING OF RESULTS

16. Results for diametral tests, axial tests, block tests and irregular lump tests, and for tests perpendicular and parallel to planes of weakness should be tabulated separately (see typical results form, Fig. 8). The report should contain calibration data for the test machine and at least the following information for each sample tested:

(a) The sample number, source location and rock type, and the nature and *in situ* orientation of any planes of anistropy or weakness.

(b) Information on the water content of the rock at the time of testing.

(c) Information on which specimens were loaded parallel (//), perpendicular (⊥), or at unknown or random directions with respect to planes of weakness.

(d) A tabulation of the values of P, D, (W, D_e^2 and D_e if required), I_s, (F if required) and $I_{s(50)}$ for each specimen in the sample.

(e) For all isotropic samples, a summary tabulation of mean $I_{s(50)}$ values.

(f) For all anisotropic samples, a summary tabulation of mean $I_{s(50)}$ values for sub-samples tested perpendicular and parallel to the planes of weakness, and of the corresponding $I_{a(50)}$ values.

NOTES

1. When first introduced, the point load strength test was used mainly to predict uniaxial compressive strength which was then the established test for general-purpose rock strength classification. Point load strength now often replaces uniaxial compressive strength in this role since when properly conducted it is as reliable and much quicker to measure. $I_{s(50)}$ should be used directly for rock classification, since correlations with uniaxial compressive strength are only approximate. On average, uniaxial compressive strength is 20–25 times point load strength, as shown in Fig. 9. However, in tests on many different rock types the ratio can vary between 15 and 50 especially for anisotropic rocks, so that errors of up to 100% are possible in using an arbitrary ratio value to predict compressive strength from point load strength. The point load strength test is a form of "indirect tensile" test, but this is largely irrelevant to its primary role in rock classification and strength characterization. $I_{s(50)}$ is approximately 0.80 times the uniaxial tensile or Brazilian tensile strength.

2. Of the four alternative forms of this test, the diametral test and the axial test with saw-cut faces are the most accurate if performed near the standard 50 mm size, and are preferred for strength classification when core is available. Axial test specimens with saw-cut faces can easily be obtained from large block samples by coring in the laboratory. Specimens in this form are

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Sample Details Point Load Test Date 17/11/83

1 block sample from Gamblethorpe Opencast site.

Fine grained pale grey Coal Measures sandstone with numerous coaly streaks along horizontal bedding planes.

Specimens 1-6 chisel cut blocks, air-dried 2 weeks;
7-10 sawn blocks, air-dried 2 weeks;
11-15 cores, air-dried 2 weeks;
16-20 cores, air-dried 2 weeks;
- tested in laboratory.

No.	Type	W (mm)	D (mm)	P (kN)	D_e^2 (mm^2)	D_e (mm)	I_s	F	I_s (50)
1	i ⊥	30.4	17.2	2.687	666	25.8	4.03	0.75	~~3.03~~
2	i ⊥	16	8	0.977	163	12.8	5.99	0.54	3.24
3	i ⊥	19.7	15.6	1.962	391	19.8	5.02	0.66	3.31
4	i ⊥	35.8	18.1	3.641	825	28.7	4.41	0.765	3.46
5	i ⊥	42.5	29	6.119	1569	39.6	3.90	0.875	3.49
6	i ⊥	42	35	7.391	1872	43.3	3.95	0.935	~~3.69~~
7	b ⊥	44	21	4.600	1176	34.3	3.91	0.84	3.29
8	b ⊥	40	30	5.940	1528	39.1	3.88	0.89	3.46
9	b ⊥	19.5	15	2.040	372	19.3	5.48	0.655	~~3.59~~
10	b ⊥	33	16	2.87	672	25.9	4.27	0.75	~~3.20~~
11	d //	-	49.93	5.107	-	-	-	-	2.05
12	d //	-	49.88	4.615	-	-	-	-	1.85
13	d //	-	49.82	5.682	-	-	-	-	~~2.29~~
14	d //	-	49.82	4.139	-	-	-	-	~~1.67~~
15	d //	-	49.86	4.546	-	-	-	-	1.83
16	d //	-	25.23	1.837	-	-	2.89	0.74	2.14
17	d //	-	25.00	1.891	-	-	3.02	0.735	2.22
18	d //	-	25.07	2.118	-	-	3.37	0.735	~~2.48~~
19	d //	-	25.06	1.454	-	-	2.32	0.735	~~1.70~~
20	d //	-	25.04	1.540			2.46	0.735	1.81

d = diametral;
a = axial;
b = block;
i = irregular lump test;
⊥ = perpendicular;
// = parallel to planes of weakness.

Mean $I_{s\ (50)}$ ⊥	3.38
Mean $I_{s\ (50)}$ //	1.98
$I_{a\ (50)}$	1.71

Fig. 8. Typical results form.

particularly suitable when the rock is anisotropic and the direction of weakness planes must be noted.

3. Loads of up to 50 kN are commonly required for the larger hard rock specimens. The maximum specimen size that can be tested by a given machine is determined by the machine's load capacity, and the smallest by the machine's load and distance measuring sensitivity. Tests on specimens smaller than $D = 25$ mm require particular precautions to ensure that the measuring sensitivity is sufficient. The range of required test loads should be estimated before testing, from approximate assumed strength values, to ensure that the load capacity and sensitivity of the equipment are adequate. It may be necessary to change the load measuring gauge or load cell, or to test smaller or larger specimens to conform with the capacity of available equipment or with the accuracy specifications for this test.

4. The conical platen design is intended to give standardized penetration of softer specimens. When testing is confined to hard rocks and small (less than 2 mm) penetrations the conical design is unimportant provided that the tip radius remains at the standard 5 mm. For such testing the platen can be manufactured by embedding a hard steel or tungsten carbide ball in a

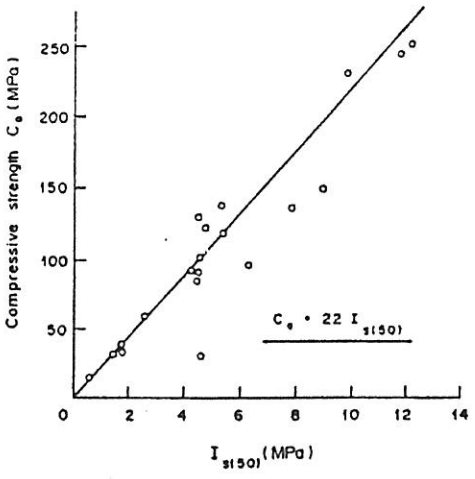

Fig. 9. Example of correlation between point load and uniaxial compressive strength results.

softer metal base of any geometry that will ensure that only the platen tip is in contact with the rock.

5. If a quick-retracting ram is used to reduce the delay between tests, either the ram return spring force and ram friction should together be less than about 5% of the smallest load to be measured during testing, or an independent load cell rather than an oil pressure gauge should be used for load determination. These forces can be significant when testing weaker and smaller specimens.

6. If significant platen penetration occurs, the dimension D to be used in calculating point load strength should be the value D' measured at the instant of failure, which will be smaller than the initial value suggested in paragraphs 8(d), 9(d) and 10(d). The error in assuming D to be its initial value is negligible when the specimen is large or strong. The failure value may always be used as an alternative to the initial value and is preferred if the equipment allows it to be measured (for example by electrical maximum-indicating load and displacement measurement). When testing specimens that are smaller than 25 mm, such as rock aggregate particles, equipment with electrical readout is usually necessary to obtain the required measuring accuracy, and should be designed to record D' at failure. Measurements of W or D made perpendicular to the line joining the platens are not affected and are retained at their original values. The value of D_e for strength calculation can then be found from:

$$D_e^2 = D \times D' \quad \text{for cores}$$

$$D_e^2 = \frac{4}{\pi}(W \times D') \quad \text{for other shapes}$$

7. Because this test is intended primarily as a simple and practical one for field classification of rock materials, the requirements relating to sample size, shape, numbers of tests etc, can when necessary be relaxed to overcome practical limitations. Such modifications to procedure should however be clearly stated in the report. It is often better to obtain strength values of limited reliability than none at all. For example, rock is often too broken or slabby to provide specimens of the ideal sizes and shapes, or may be available in limited quantities such as when the test is used to log the strength of drill core. In core logging applications, the concept of a "sample" has little meaning and tests are often conducted at an arbitrary depth interval, say one test every 1 m or 3 m depending on the apparent variability or uniformity of strength in the core and on the total length of core to be strength-logged.

8. As for all strength tests on rocks, point load strength varies with the water content of the specimens. The variations are particularly pronounced for water saturations below 25%. Oven dried specimens, for example, are usually very much stronger than moist ones. At water saturations above 50% the strength is less influenced by small changes in water content, so that tests in this water content range are recommended unless tests on dry rock are specifically required.

All specimens in a sample should be tested at a similar and well-defined water content, and one that is appropriate to the project for which the test data are required. Field testing of chisel-cut samples, not affected by drilling fluids, offers a method for testing at the *in situ* water content. If possible, numerical values should be given for both water content and degree of saturation at the time of testing. The ISRM Suggested Method for Water Content Determination should be employed. Whether or not water content measurements can be made, the sample storage conditions and delay between sampling and testing should be reported.

9. Some researchers argue in favour of measuring W' as the minimum dimension of the failure surface after testing rather than of the specimen before failure (the German standard for this test is an example). Point load strengths computed using the two alternative W definitions may differ slightly. The minimum specimen dimension alternative has been adopted in this Suggested Method mainly because it is quicker and easier to measure, particularly in the field when fragments of broken specimens are easily lost.

10. Commonly the shortest dimension of naturally occurring anisotropic rock lumps is perpendicular to the weakness planes.

11. The size correction factor chart (Fig. 7) is derived from data on cores tested diametrally and axially and from tests on blocks and irregular lumps, for rocks of various strengths, and gives an averaged factor. Some rocks do not conform to this behaviour, and size correction should therefore be considered an approximate method, although sufficient for most practical rock classification applications. When a large number of tests are to be run on the same type of rock it may be advantageous to first perform a series of tests at different sizes to obtain a graph of load vs D_e^2 as in Fig. 6. If the slope of such a log–log graph is determined as "n", the size correction factor is then $(D_e/50)^m$ where $m = 2(1 - n)$. This can either be calculated directly or a chart constructed.

12. Mean results for small populations are generally better measures when the extreme values are not included in the calculation.

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