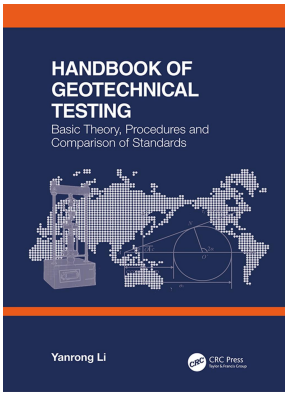


Handbook of Geotechnical Testing
Basic Theory, Procedures and Comparison of Standards

Yanrong Li

Comparison of rock tests

Publication details
https://test.routledgehandbooks.com/doi/10.1201/9780429323744-13
Yanrong Li
Published online on: 10 Dec 2019

Chapter 10

Comparison of rock tests

This chapter analyzes and compares rock tests in Chinese Standard (GB), American Standard (ASTM) and ISRM suggested methods (International Society of Rock Mechanics). This chapter covers both physical and mechanical tests of rocks. The physical tests include moisture test, water absorption, density, particle density, freezing-thawing, expansion and disintegration. Mechanical tests consist of acoustic wave, Brazilian splitting, uniaxial compression, triaxial compression, direct shear of structural plane, point load and rebound tests.

10.1 Physical tests on rocks

10.1.1 Water content

The water content of rock refers to the ratio of mass of water in rock to mass of rock solid, which indirectly reflect the characteristics of voids in rock. The commonly used method for determining water content of rock is to dry the sample in an oven to a constant mass, and then calculate the ratio of the lost mass to the final mass. The drying method is included in GB, ASTM and ISRM. The main difference among these three methods is the criterion to cease the test. GB asks for drying the rock specimen for a certain time period, while ASTM and ISRM require a constant mass to be achieved. A detailed comparison is given in Table 10.1.

10.1.2 Grain density

Grain density of rock refers to the ratio of the mass of grain to its volume, which depends on the density and content of minerals in rock. Commonly used methods for determining rock grain density are pycnometer method and water weighing method. The pycnometer method requires the specimen to be made into small particles. The water weighing method requires a block specimen and the volume of specimen are calculated by the difference between the mass of the dry specimen and the mass of the saturated specimen. The water weighing method has a relatively low accuracy compared to the pycnometer method since the closed/isolated voids in rock are not considered, which leads to relatively small values. Both pycnometer and water weighing methods are included in GB. A detailed comparison of the test methods in GB and ISRM is given in Table 10.2.

10.1.3 Dry density

Dry density of rock refers to the mass of rock of unit volume. Measuring dry density of rocks involves a variety of methods for precisely determining the volume of the specimen. For specimens with regular shape, the volume method is usually measured with a caliper.

Table 10.1 Comparison of water content tests

Item	*GB*	*ASTM*	*ISRM*
Designation	GB 50266-2013	ASTM D2216-10	Suggested methods for determining water content, porosity, density, absorption and related properties and swelling and slake-durability index properties
Scope	All kinds of rocks	Soil, rock and solid conglomerates	Same as GB
Apparatus	Drying oven, desiccator, balances	In addition to the instrument in GB, there is specimen containers	
Specimen	Sample obtained by blasting cannot be used, and wet drilling is allowed in areas with abundant groundwater.	—	—
	Store: The water content of the sample shall be maintained at the natural water content.	The samples shall be stored prior to testing in non-corrodible airtight containers at a temperature between approximately 3 and 30 °C and in an area that prevents direct contact with sunlight.	The change in water content must not exceed 1%.
	Size: The minimum specimen size shall be more than 10 times the diameter of the largest mineral particle.	—	Same as GB
	Quality: 40–200 g	≥500 g	≥50 g
	Quantity: 5	—	10
Test Operation	Drying Temperature: 105–110 °C	110 ± 5 °C	105 ± 3 °C
	Criterion to cease drying: Dry a specimen for 24 h	At least 12–16 h (break the sample into small particles and place in a container with large surface area). The mass loss is less than 1% in 2 hours.	At least 24 h, and the successive mass determinations at intervals of 4 h yield values differing by less than 0.1% of the sample mass.
	Weighing Accuracy: 0.01 g	0.1 g	0.01% of the sample mass
Calculation	$\omega = \frac{m_0 - m_s}{m_s} \times 100$	$\omega = \left[\frac{M_{cms} - M_{cds}}{M_{cds} - M_c}\right] \times 100$	
	ω – water content (%); m_0 – wet sample mass (g); m_s – dry sample mass (g).	ω – water content (%); M_{cms} – total mass of weighing box and wet sample (g); M_{cds} – total mass of weighing box and dry sample; M_c – mass of weighing box.	
	Accuracy: 0.01	1% or 0.1%	0.1%

Table 10.2 Comparison of grain density tests

Item	*GB*	*ISRM*
Designation/ name	GB 50266-2013	Suggested methods for determining water content, porosity, density, absorption and related properties and swelling and slake-durability index properties
Scope	All kinds of rocks	Rock that swells or decomposes when immersed in water
Specimen preparation	The rock was pulverized into rock powder and sieved with a 0.25 mm sieve. If the specimen contains magnetic minerals, the mortar shall be ceramic or agate.	The specimen was crushed into grains with sizes not exceeding 150 μm.
Drying temperature	105–110 °C	105 °C
Drying time	At least 6 h	Dry to constant mass
Cooling time	No explicit requirements	30 min
Vacuum time	When there is no air bubble in the test solution, continue to pump for no less than 1 h.	20 min
Accuracy	The mass is accurate to 0.001 g and the temperature is accurate to 0.5 °C.	Same as GB
Calculation of particle density	$\rho_s = \frac{m_s}{m_1 + m_s - m_2}\rho_{WT}$ ρ_s – grain density (g/cm^3); ρ_{WT} – test solution density under test temperature (g/cm^3); m_s – dry mass of the rock meal (g); m_1 – total mass of bottle and test solution (g); m_2 – total mass of bottle, test solution, and rock powder (g).	$\rho_s = \frac{F - D}{V_f\left(1 - \frac{G - F}{E - D}\right)}$ ρ_s – grain density (g/cm^3); V_f – Volumetric flask volume, usually 50 cm^3; D – mass of volumetric flask (g); E – total mass of bottle and test solution (g); F – total mass of bottle and specimen (g); G – Total mass (g) of specimen, bottle and test solution.
Accuracy	0.01	

For irregular specimens, wax-sealing and buoyancy methods are normally used. These two methods take the difference of weight of saturated specimen in air and in the water to back calculate the volume. A detailed comparison of dry density test in different standards is given in Table 10.3.

10.1.4 Absorption

Rock absorption reflects ability of rock absorbing water under certain conditions (pressure and temperature).

Table 10.3 Comparison of dry density tests

Item	*GB*			*ISRM*			
Designation	GB 50266-2013			Suggested methods for determining water content, porosity, density, absorption and related properties and swelling and slake-durability index properties			
Method to measure the volume	Caliper	Wax-sealing	Water weighing	Saturated & caliper	Saturated and buoyancy method	Mercury	Mercury & Boyle's Law
Scope	Rock that can be machined	All kinds of rocks	Rock that does not disintegrate, dissolve, or swell in contact with water.	non-friable, coherent rocks that can be machined and do not appreciably swell or disintegrate when oven dried or immersed in water.	The method shall only be used for rocks that do not appreciably swell or disintegrate when oven-dried and immersed in water.	rock material that is liable to swell or disintegrate if being immersed in water.	The method shall only be used for rocks that do not shrink appreciably during oven-drying.
Specimen size	The minimum size shall not be less than 50 mm;	with a side length of 40–60 mm		The minimum size of each specimen shall be such that its mass is at least 50 g (a cube with a side length of 27 mm is sufficient) and its minimum size is at least 10 times the maximum grain size.			
Specimen shape	Regular	Round rock block	Same as wax-sealing method	Cylinder or prism	The sample is washed in water to remove dust.	The size shall be consistent with the chamber.	
Number of specimens	3			At least 3	At least 10	At least 10	At least 3

Calculation	$\rho_d = \frac{m_s}{AH}$ A – sample cross-sectional area (cm^2); H – sample height (cm); m_s – dry mass of the specimen (g).	$\rho_d = \frac{m_s}{\frac{m_1 - m_2}{\rho_w} - \frac{m_1 - m_s}{\rho_p}}$ $\rho = \frac{m}{\frac{m_1 - m_2}{\rho_w} - \frac{m_1 - m}{\rho_p}}$ ρ – the wet density of specimen (g/cm^3); m – mass of the wet specimen (g); m_1 – mass of the specimen with wax (g); m_2 – mass of the waxed specimen in water (g); ρ_w – density of water (g/cm^3); ρ_p – density of wax (g/cm^3); ω – water content (%).	$\rho_d = \frac{m_s}{m_p - m_w}\rho_w$ m_s – Drying sample mass (g); m_p – mass after forced saturation of the test piece (g); m_w – mass of the forced saturated test piece in water (g).	Volume method as in GB.	Water weighing method as in GB.	$\rho_d = \frac{M_s}{V}$ M_s – dry mass (g); V – volume of specimen (cm^3), which is determined by the mercury displacement.

Free water absorption of rock is generally determined by measuring the mass of absorbed water and that of dry rock under normal atmospheric pressure and at room temperature. The saturated water absorption is usually determined by boiling or vacuum the specimen to get it saturated. The free water absorption test is included in GB and ASTM and ISRM, while the saturated water absorption test is only stipulated in GB.

GB requires the specimen to be dried prior to being immersed in water. ASTM requires the specimen of natural state to be immersed in water. GB asks for a regular cylinder specimen, as in uniaxial compression test. There is no special requirement for shape and size of specimen in ASTM. In GB, the specimen is dried for a certain time period, which may not ensure a 100% drying. See specific comparisons of GB and ASTM for absorption tests in Table 10.4.

10.1.5 Slake durability

The slake durability of rock reflects the ability of rock to resist disintegration under dry-wet cycles. In GB, ASTM and ISRM, the rock is experienced two wet-dry cycles for the measurement. The three standards require very much similar specimen and procedures. Noteworthy, in GB and ISRM, the temperature is required to be maintained at 20 °C, whereas in ASTM, there is no specific requirement for temperature. A detailed comparison of the tests in different standards is given in Table 10.5.

10.2 Mechanical tests on rocks

10.2.1 Swelling properties

Rocks containing hydrophilic and easily swelling minerals (i.e. montmorillonite) can absorb water to lead its volume swelling. The rock swelling indexes are composed of an unconfined swelling strain index, a swelling strain index and a swelling pressure index.

In GB, the free swelling test is to measure the swelling ratio of each side of the specimen when the specimen is immersed freely in water. The confined swelling test is to measure the axial swelling of the specimen. The swelling pressure test is to determine the axial swelling pressure needed to maintain the height of the specimen when the laterally confined specimen is immersed in water. Detailed comparisons of these tests in GB and ISRM are given in Tables 10.6–10.8.

10.2.2 Uniaxial compressive strength

Uniaxial compressive strength of rock refers to the maximum axial stress that the rock with no confining can withstand. In the tests for rock uniaxial compressive strength, cylindrical specimens are normally used. It is found that the size of specimen has influence on the tested results. The larger the height-to-diameter ratio of the specimen, the less the measured strength. When the height-to-diameter ratio of the specimen is greater than 2, the size effect could be ignored. In addition, the diameter of specimen shall be 10 times greater than the maximum size of mineral particles in the specimen. Loading rate also effects the test results, as the higher the loading rate, the higher the strength will be achieved. The uniaxial compression test for rocks is included in GB, ASTM and ISRM. Main differences among these standards is given in Table 10.9.

Table 10.4 Comparison of absorption tests

Item	*GB*	*ASTM*	*ISRM*
Designation	GB 50266-2013	ASTM D6473-15	Suggested methods for determining water content, porosity, density, absorption and related properties and swelling and slake-durability index properties
Scope	Rock that does not disintegrate, is insoluble, and does not shrink and expand in contact with water.	This test is appropriate for breakwater stone, armor stone, riprap, and gabion sized rock materials.	Rock that does not disintegrate in contact with water.
Apparatus	Drying oven, Desiccator, balance, water tank, water weighing device and vacuum pumping or boiling equipment.	Balance, specimen container, water weighing device, water tank, drying oven and Desiccator.	Balance, specimen container, dehydrated silica gel.
Specimen	Shape: Generally, it is regular, and it is possible to use round and irregular specimens when it is difficult to prepare.	—	—
	Size and Mass: The minimum size shall not be less than 50 mm; the error of the height, diameter or side length of the specimen shall not exceed 0.3 mm; the error of non-parallelism on both ends of the specimen shall not exceed 0.05 mm; the end sides of the specimen shall be perpendicular to the axis of the specimen; the maximum deviation shall not be more than 0.25. No requirement for mass.	No special requirements for size. The mass of specimen shall be at least 1 kg.	Each piece shall be sized to have a mass of more than 50 g or a minimum size of at least ten times the maximum particle size, take whichever is bigger.
	Quantity: 3	At least 5 specimens equal in size. At least 8 specimens unequal in size.	At least 10
Water absorption	Dry the specimen first, and then submerge it in water.	Submerge the specimen at its natural state.	Dry first, and then submerge in water.

(Continued)

Table 10.4 (Continued)

Item	*GB*	*ASTM*	*ISRM*
	Drying: Dry the specimen at 105–110 °C for 24 h.	Dry the specimen at least for 24 h at a temperature of 110 ± 5 °C. Constant mass will be considered to have been achieved when weight loss is less than 0.1% in four hours of drying.	The specimen shall be placed in a container filled with dehydrated silica gel at room temperature and left for 24 hours.
	Water immersion requirements: Absorption for 48 h	24 ± 4h in 20–30 °C water	Absorption for 1 h
Saturated water absorption	Saturating the specimen by boiling or vacuum pumping	Not included	not included
Accuracy	Weighing accuracy: 0.01 g	5 g or 0.1% of the specimen mass (whichever is less)	0.5 g
Water absorption calculation	$\omega_s = \frac{m_0 - m_s}{m_s} \times 100$ ω_s – absorption (%); m_0 – saturated dry mass of specimen surface (g); m_s – dry mass of the specimen (g).		Iv= (B-A)/A×100% Iv – void index of rock. A – mass of rock after drying (g); B – mass (g) of specimen after water absorption.
Other Calculations	$\omega_{sa} = \frac{m_p - m_s}{m_s} \times 100$ $\rho_d = \frac{m_s}{m_p - m_w} \rho_w$ $\rho_s = \frac{m_s}{m_s - m_w} \rho_w$ ω_{sa} – saturation water absorption (%); ρ_d – rock mass density (g/cm3); ρ_s – grain density (g/cm3); m_p – mass after forced saturation of the specimen (g); m_s – dry mass of the specimen (g); m_w – mass of the saturated specimen in water (g); ρ_w – density of water (g/cm3).	Bulk specific gravity=*A*/ (*B*-*C*) Bulk specific gravity (SSD) = *B*/(*B*-*C*) Apparent specific gravity = A/ (A-C) *A* – mass of oven-dry test specimen in air, g; *B* – mass of saturated-surface dry test specimen in air, g; *C* – buoyant mass of submerged test specimen in water, g.	—

Table 10.5 Comparison of slake durability tests

Comparison	*GB*	*ASTM*	*ISRM*
Designation	GB 50266-2013	ASTM D4644-16	Suggested methods for determining water content, porosity, density, absorption and related properties and swelling and slake-durability index properties
Scope	Rocks tend to disintegrate in water.	Shale or other weak rocks	—
Specimen storage	—	Store in a non-corrosive airtight container at a temperature of 3 to 30 °C, and direct sunlight shall be avoided.	—
Specimen shape	Break off any possible existing sharp corners.		Same as in GB, while the maximum diameter shall not exceed 3 mm.
Specimen number	10		
Mass of each specimen	40–60 g		
Height of filling water	20 mm below the drum axis		
Speed of rotation	20 r/min		
Time of rotation	10 min		
Temperature	20±2 °C	No proper requirements, but measure the water temperature before and after every cycle.	20 °C
Accuracy of balance	0.01 g	0.1 g	0.5 g
Calculation	$I_{d2}=\frac{m_r}{m_s}\times 100$ I_{d2} – slake durability index after 2 cycles (%); m_s – mass of oven-dried specimen (g); m_r – residue oven-dried mass after 2 cycles (g).	$I_{d1}=\left[\frac{W_{f1}-C}{W_i-C}\right]\times 100$ $I_{d2}=\left[\frac{W_{f2}-C}{W_i-C}\right]\times 100$ I_{d1}, I_{d2} – slake durability index after first and second cycles, respectively (g), W_i – mass of drum plus oven-dried specimen before the first cycle (g), W_{f1}, W_{f2} – mass of drum plus oven-dried specimen retained after the first and the second cycles respectively (g), C – mass of drum (g).	
	Keep 3 valid digits	0.1%	

Table 10.6 Comparison of determining the swelling strain developed in an unconfined rock specimen

Item	*GB*	*ISRM*
Designation	GB 50266-2013	Suggested methods for determining water content, porosity, density, absorption and related properties and swelling and slake-durability index properties
Scope	Rocks that don't disintegrate in water.	Rocks that don't change geometry in slaking.
Specimen shape	Cylinder or square	Cylinder or rectangle
Specimen size	The diameter of the cylindrical specimen shall be 48–65 mm, the height shall be equal to the diameter, and both ends shall be parallel to each other. The side length of cubic specimen shall be 48–65 mm.	The minimum size of the specimen shall be greater than 15 mm and ten times the maximum particle size.
Number of specimens	3	2
Time of immersion	No less than 48 h	—
Test temperature	Variation of water temperature shall not exceed 2 °C.	—
Accuracy of readings	—	At least 0.1% of the original length
Calculation formula	$V_H = \frac{\Delta H}{H} \times 100$ $V_D = \frac{\Delta D}{D} \times 100$ V_H – axial free swelling ratio (%); V_D – radial free swelling ration (%); ΔH – figure of specimen axial strain (mm); H – height of specimen (mm); ΔD – average figure of specimen radial strain (mm); D – diameter or length of specimen (mm).	Unconfined swelling strain in direction X = $d/L \times 100\%$. Where: X – 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.
Calculation accuracy	Keep 3 valid digits	—

Table 10.7 Comparison of determining the swelling strain index for a radially confined rock specimen with axial surcharge

Item	*GB*	*ISRM*
Designation	GB 50266-2013	Suggested methods for determining water content, porosity, density, absorption and related properties and swelling and slake-durability index properties
Scope	All kinds of rocks	
Water content of specimen	—	Test at in-situ water content, and place the specimen in a constant humidity environment.
Shape	Cylinder	
Dimension	The height shall be greater than 20 mm, or 10 times greater than the maximum mineral particle size of the rock. The two ends shall be parallel. The diameter of the specimen shall be 50–65 mm, and be 0.0–0.1 mm less than the diameter of the metal collar.	The diameter shall not be less than 4 times its thickness. The thickness shall be greater than 15 mm and 10 times the maximum particle size. The specimen shall be a close fit in the ring.
Number of specimens	3 specimens for each loading direction.	Duplicate specimens shall be prepared from the same sample, one being used for determination of the water content and the other for swelling testing.
Seating pressure	5 kPa	3 kPa
Criterion of stable swelling	Difference between 3 successive readings is less than 0.001 mm.	—
Time of immersion	No less than 48 hours.	—
Test temperature	Variation of water temperature shall not exceed 2 °C.	—
Accuracy of readings	—	At least 0.1% of the original length
Calculation	$V_{HP} = \frac{\Delta H_1}{H} \times 100$ V_{HP} – lateral confined swelling ratio (%); ΔH_1 – axial deformation (mm); H – original height of specimen (mm). Keep 3 valid digits	Swelling strain index = $d/L \times$ 100% d – maximum swelling deformation recorded during the test; L – initial thickness of the specimen. —

Table 10.8 Comparison of determining the swelling pressure index under conditions of zero volume change

Item	*GB*	*ISRM*
Designation	GB 50266-2013	Suggested methods for determining water content, porosity, density, absorption and related properties and swelling and slake-durability index properties
Scope	All kinds of rocks	
Water content of specimen	—	Test at in-situ water content, and place specimen in a constant humidity environment.
Shape	Cylinder	
Dimension	The height of the specimen shall be greater than 20 mm, or greater than 10 times the maximum particle size of the rock. The two ends shall be parallel. The diameter of the specimen shall be 50–65 mm, and shall be 0.0–0.1 mm less than the diameter of the metal collar.	The diameter of sample is not less than 2.5 times its thickness. The thickness shall exceed 15 mm or ten times the maximum grain diameter. The specimen shall be a close fit in the ring.
Number of specimens	3 for each loading direction.	Duplicate specimens shall be prepared from the same sample, one being used for water content determination and the other for swell testing.
Seating pressure	10 kPa	
Criterion of stable swelling	The difference of three consecutive readings is less than 0.001 mm.	—
Time of immersion	No less than 48 hours	—
Test temperature	Change of water shall not exceed 2 °C.	—
Calculation	$P_e = \frac{F}{A}$ P_e – swelling pressure at constant volume (MPa); F – axial load (N); A – cross-sectional area of specimen (mm^2).	Swelling pressure index = F/A F – maximum axial swelling force A – cross-sectional area of the specimen.
	Keep 3 valid digits	—

Table 10.9 Comparison of uniaxial compressive strength tests

Item	*GB*	*ASTM*	*ISRM*
Designation	GB 50266-2013	ASTM D7012-14	Suggested methods for determining the uniaxial compressive strength and deformability of rock materials
Scope	Various types of rocks that can be made into cylinders	Complete core	Same as GB
Apparatus	Material testing machine	Compression apparatus, platens (one plain rigid platen, one spherically seated), timing device	A suitable machine shall be used for applying and measuring axial load to the sample, a disc-shaped steel platen, a spherical seat
Specimen shape	Cylinder		
Diameter	It shall be 48–54 mm, no less than 10 times the maximum mineral particle size in the rock.	The diameter of rock test specimens shall be at least 10 times the diameter of the largest mineral grain. for weak rock types, the specimen diameter shall be at least six times the maximum particle diameter. The minimum diameter is 47 mm.	No less than 54 mm, and the diameter of rock test specimens shall be at least 10 times the diameter of the largest mineral grain
Height-to-diameter ratio	2.0–2.5		2.5–3.0
Parallelism of both ends	<0.05 mm	—	<0.02 mm
Error of diameter along the height of the specimen	<0.3 mm	—	Same as GB
Vertical deviation of the end face to the axis of the sample	<0.25°	—	<3.5’
Number of specimens	3	Determined according to test method ASTM E122	At least 5
Loading rate	0.5–1.0 MPa/s	stress rate is the same as GB, or constant strain rate	Same as GB
Loading time	—	2–15 min	5–10 min
Calculation	$\sigma_u = P/A$ σ_u – uniaxial compressive strength (MPa); P – failure load (kN); A – cross-sectional area (mm^2).		
	3 valid digits	—	Same as GB

10.2.3 Durability under freezing and thawing conditions

This test is intended to measure the frost resistance index of rock, indicated by mass loss ratio after freezing-thawing cycles and the freezing-thawing coefficient. The former refers to the ratio of the mass loss after freezing-thawing to the original dry mass. The latter is the ratio of compressive strength of rock specimen after freezing-thawing cycles to that before freezing-thawing. Detailed comparison of GB and ASTM is given in Table 10.10.

10.2.4 Deformability in uniaxial compression

The deformability of rocks can be determined via measuring the axial and radial strains of rock specimen under conditions of uniaxial compression. The parameter indicating deformability of rocks include the elastic modulus and Poisson's ratio. The former is the ratio of stress to strain in the regime of elastic deformation. The latter is the ratio of transverse strain to axial strain of the specimen.

In the test, the stress-strain relationship curve can be obtained by measuring the load and corresponding strain of the specimen during the compression process. GB, ASTM and ISRM have similar requirements for carrying out uniaxial compression test. The main differences are specimen size as shown in Table 10.11.

10.2.5 The strength in triaxial compression

Triaxial compression test is used to determine the shear strength of rocks. GB, ASTM and ISRM all cover the triaxial compression tests of rocks. GB introduces the method which requires a set of specimens being tested under different confining pressures. ASTM and ISRM also describe the test method, which employs a single specimen and tested at multistage confining pressures. A detailed comparison between the three standards is given in Table 10.12.

10.2.6 Splitting tensile strength

Commonly used methods for determining the tensile strength of rocks are direct tensile test and Brazil test. In the Brazil test, the cylindrical specimen is radially compressed until it is failed. These two test methods are all included in GB, ASTM and ISRM. Differences between these three standards are given in Table 10.13.

10.2.7 Point load strength

The point load strength index is normally used to estimate the uniaxial compressive strength of rocks. It can also be used for rock classification. Compared with the uniaxial compression test, the point load strength test is simple and easy to conduct. GB, ASTM and ISRM all cover the point load strength test. There are no many differences among these three standards. A detailed comparison is given in Table 10.14.

Table 10.10 Comparison of determining the durability under freezing and thawing conditions

Item	*GB*	*ASTM*
Designation	GB 50266-2013	ASTM D5312/D5312M - 12
Scope	All kinds of rocks that can be made into cylindrical shape.	All kinds of rocks.
Preparation of test samples	Shape: cylinder	slab
	Materials: Rock of drilling core or block	Rock sources from mine, quarry, outcrop, or field boulders.
	Dimensions: Diameter of the specimen shall be 48–54 mm; The diameter shall be greater than 10 times the largest mineral particle; The ratio of height to diameter is 2.0–2.5, and the parallelism error of the end faces shall not exceed 0.05 mm.	In no case shall the specimen be less than 125 mm (5 in.) on a side.
	Number: 6	At least 5
Special solutions	—	0.5% isopropanol alcohol/water solution.
Freezing temperature	-20±2 °C	-18±2.5 °C
Freezing time	4h	At least 12 hours
Thawing temperature	20±2 °C	32±2.5 °C
Thawing time	4 h	8–12 h
Freezing-thawing cycles	Generally, 25 cycles.	—
Quality measured after the freezing and thawing cycle	The quality after drying the specimen.	Quality of largest piece of each slab.
Weighing accuracy	0.01 g	0.1% of the total mass of the specimen.
Data processing	$M = \frac{m_p - m_{fm}}{m_s} \times 100$ $K_{fm} = \frac{\bar{R}_{fm}}{\bar{R}_w}$ M – mass loss rate (%); K_{fm} – freezing-thawing coefficient; m_p – mass of the saturated sample before freezing and thawing (g); m_{fm} – Mass of specimen after freezing-thawing (g); m_s – Dry mass of the specimen before test (g); $\bar{R}_{fm}$ – Average uniaxial compressive strength of rock after freezing-thawing (MPa); $\bar{R}_w$ – Average uniaxial compressive strength before freezing-thawing (MPa).	Quantitative examination: For each slab perform the following calculation: % loss = (A-B)/A × 100 A – oven-dried mass of the specimen prior to test (g); B – oven-dried mass of the largest remaining piece of each slab after test (g).
	Accurate to 0.01.	0.1%

Table 10.11 Comparison of determining the deformability in uniaxial compression

Item	*GB*	*ASTM*	*ISRM*
Designation	GB 50266-2013	ASTM D7012-14	Suggested methods for determining the uniaxial compressive strength and deformability of rock materials
Scope	Rocks that can be made into cylinders.	Complete core	Rocks that Same as GB.
Specimen shape	Cylinder		
Diameter	It shall be 48–54 mm. Greater than 10 times the maximum mineral particle size in the rock.	Greater less than 47 mm The diameter shall be at least 10 times larger than the largest mineral grain. For weak rocks, the diameter shall be no less than at least 6 times the biggest particle.	No less than 54 mm. No less than 10 times the biggest mineral particle size in the rock.
Height-to-diameter ratio	2.0–2.5		2.5–3.0
Parallelism of both ends	<0.05 mm	—	<0.02 mm
Error of diameter along the height of the specimen	<0.3 mm	—	Same as GB
Vertical deviation of end faces to the axis of the specimen	<0.25°	—	<3.5’
Loading rate	0.5–1.0MPa/s		
Loading time	—	2–15 min	5–10 min

Accuracy	—	The load is in kN and is retained in two decimal places; the gauge reading is accurate to one decimal place.	The height is accurate to 1.0 mm, the diameter is accurate to 0.1 mm, and the maximum load is accurate to 1%.
Calculation	$E_{Av} = \frac{\sigma_b - \sigma_a}{\varepsilon_{lb} - \varepsilon_{la}}$ $\mu_{Av} = \frac{\sigma_{Db} - \sigma_{Da}}{\varepsilon_{Lb} - \varepsilon_{La}}$ $E_{50} = \frac{\sigma_{50}}{\varepsilon_{l50}}$ $\mu_{50} = \frac{\varepsilon_{d50}}{\varepsilon_{l50}}$ E_{Av} and μ_{Av} are the average elastic modulus and average Poisson's ratio, respectively; E_{50} and μ_{50} are the secant elastic modulus and the corresponding Poisson's ratio; ε_d and ε_l are axial and radial strain, respectively; Subscripts a, b, 50 correspond to the stress states.	The tangent modulus E_t is the tangent slope measured at 50% of the peak strength; The average elastic modulus E is the average slope of the linear portion in the curve; The secant modulus E_s is the secant slope from zero to 50% of the intensity value;	The volumetric strain $\varepsilon_v = \varepsilon_a + 2\varepsilon_d$ ε_a is the axial strain, and ε_d is the radial strain.
	The modulus takes 3 valid digits and the Poisson's ratio is accurate to 0.01.	—	Both keep 3 valid digits.

Table 10.12 Comparison of determining the strength in triaxial compression

Item	*GB*	*ASTM*	*ISRM*
Designation	GB 50266-2013	ASTM D7012-14	Suggested methods for determining the strength of rock materials in triaxial compression: Revised version
Scope	Rocks that can be made into cylinder.	Complete core	Same as GB
Specimen shape	Cylinder		
Diameter	The diameter of specimen is 48–54 mm, which should be 0.96–1.00 times the bearing platen, and 10 times larger than the largest mineral grain.	The diameter shall be greater than 47 mm and at least 10 times the largest mineral grain.	The diameter shall be ≥54 mm, and no less than 10 times the biggest particle.
Height-to-diameter ratio	2.0–2.5		2.0–3.0
Parallelism of both ends	<0.05 mm	—	<0.02 mm
Error of diameter along the height of the specimen	<0.3 mm	—	Same as in GB
Vertical deviation of the end faces to the axis of the specimen	<0.25°	—	<3.5’
Number of specimens	5	At least 9	At least 5
Temperature	—	Raise to the desired temperature at a rate not exceeding 2 °C/min.	—
Axial loading rate	0.5–1.0 MPa/s		
Axial loading time	—	2–15 min	5–15 min
Measurement accuracy	—	The load is in kN and is retained in two decimal places; the gauge reading is accurate to one decimal place.	Height is accurate to 1.0 mm, and diameter is accurate to 0.1 mm, maximum load is accurate to 1%.

Table 10.13 Comparison of splitting tensile strength tests

Item	*GB*	*ASTM*	*ISRM*
Designation	GB 50266-2013	ASTM D3967-16	Suggested methods for determining tensile strength of rock materials
Specimen shape	Cylinder		
Diameter	Diameter of specimen shall be 48–54 mm, 10 times greater than the largest particle in the specimen.	Diameter of the specimen shall be at least 10 times greater than the largest grain. A diameter of 54 mm generally satisfies.	Diameter of the specimen shall be approximately 54 mm.
Height-to-diameter ratio	0.5–1.0	0.2–0.75	0.5
Accuracy	Parallelism error of the two ends of the specimen shall be less than 0.05 mm; Diameter error is less than 0.3 mm.	Parallelism error is less than 0.5 mm; Both ends shall be perpendicular to the mandrel and the deviation must not exceed 0.5°.	Diameter error is less than 0.025 mm; Parallelism error is less than 0.25 mm; Both ends shall be perpendicular to the mandrel and the deviation must not exceed 0.25°.
Number	3	At least 10	Generally 10
Preloading	—	The loading platen is lowered slowly until the top platen is almost to direct contact with the specimen with few or no loads.	—
Loading rate	0.3–0.5 MPa/s	0.05–0.35 MPa/s	Shall be at a constant rate, recommended as 200 N/s
Failure time	—	1–10 min	15–30 s
Calculation	$\sigma_t = \frac{2P}{\pi Dh}$ σ_t – tensile strength (MPa); P – failure load (N); D – specimen diameter (mm); h – specimen height (mm). Keep 3 valid digits	Flat bearing platen: $\sigma_t = \frac{2P}{\pi Dh}$ Curved bearing platen: $\sigma_t = \frac{1.272P}{\pi tD}$ σ_t – tensile strength (MPa); P – maximum applied load (N); t – specimen thickness (mm); D – Specimen diameter (mm).	$\sigma_t = \frac{0.636P}{\pi Dt} \approx \frac{2P}{\pi Dt}$ σ_t – tensile strength (MPa); P – maximum applied load (N); t – specimen thickness (mm); D – specimen diameter (mm).

Table 10.14 Comparison of point load strength tests

Item	*GB*	*ASTM*	*ISRM*
Designation	GB 50266-2013	ASTM D5731-16	Suggested method for determining point load strength
Scope	All kinds of rocks	Medium strength rock with compressive strength ≥15MPa	Same as GB
General requirements	—	The specimen diameter shall be 30–85 mm, preferably 50 mm.	—
Core	Radial test: Length-to-diameter ratio > 1. Axial test: Length-to-diameter ratio is 0.3–1.	In addition to the requirements in GB, the diameter is no less than 4 times the largest particle.	Same as GB
Block and irregular specimen	The ratio of the distance between the two loading points to the average width is preferably 0.3 to 1.0. The length of the specimen in the loading direction shall be 30 to 85 mm, preferably 50 mm.		
Number of specimens	Core: 5–10 Blocks and irregular samples: 15–20	Core or block: At least 10. Irregular: At least 20. More is needed if the rock is anisotropic.	At least 10. More is needed if the rock specimen is anisotropic.
Loading time	10–60s		
Measurement requirements	—	Diameter is accurate to ±2%, and width is accurate to ±5%.	
Radial test	$D_e^2 = D^2$ D_e – equivalent core diameter (mm); D – core diameter (mm).		
Other tests	$D_e^2 = \frac{4WD}{\pi}$ W – width (or average width) (mm) of the smallest section crossing the two loading points.		
Severe platen penetration	$D_e^2 = DD' = \frac{4WD'}{\pi}$ D' – distance between the loading points (mm) at which the specimen breaks.		
Uncorrected rock point load strength index	$I_s = \frac{P}{D_e^2}$ I_s – uncorrected rock point load strength (MPa); P – failure load (N).		

Size correction	Find the P_{50} value from the D_e^2 – P curve where D_e^2 is 2500 mm^2. Calculate the point load strength index: $I_{s(50)} = \frac{P_{50}}{2500}$ $I_{s(50)}$ – Size-corrected rock point-load strength (MPa). $I_{s(50)} = FI_s$ F – size correction factor: $F = \left(\frac{D_e}{50}\right)^m$ m is normally 0.4–0.45.	The D_e^2 – P curve is on double logarithmic scales.	
Anisotropy index	$I_{a(50)} = \frac{I'_{s(50)}}{I''_{s(50)}}$ $I_{a(50)}$ – anisotropy index of point load strength; $I''_{s(50)}$ – point load strength index (MPa). Loading direction is parallel to the weak surface (Figure 10.1a); $I'_{s(50)}$ – point load strength index (MPa). Loading direction is perpendicular to the weak surface (Figure 10.1b).		
Estimation of uniaxial compressive strength	—	$UCS = KI_{s(50)}$ Refer to Table 10.15 for K.	$UCS = KI_{s(50)}$ K is between 20 and 25.
Estimation of tensile strength	—	—	Tensile strength $=0.8\ I_{s(50)}$
Accuracy	Keep 3 valid digits		—

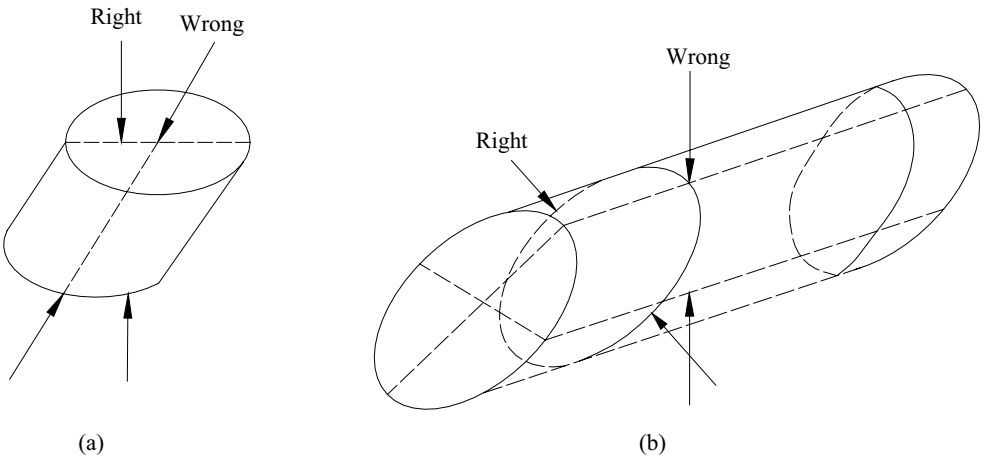


Figure 10.1 Correct loading to test the anisotropy of point load strength

Table 10.15 *K* values in ASTM

Core Size (mm)	21.5	30	42	50	54	60
K	18	19	21	23	24	24.5

10.2.8 The sound velocity by ultrasonic pulse transmission technique

This test is to measure the propagation velocity of longitudinal and transverse waves in rock. Longitudinal and transverse wave velocities can be used to calculate the dynamic elastic parameters of rocks and the integrity index of rock mass. Both GB and ISRM standardize the wave velocity test of rocks. A detailed comparison of these two standards is given in Table 10.16.

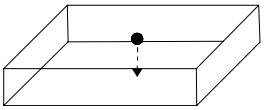
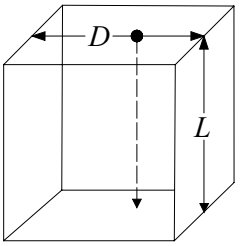
10.2.9 Rebound hardness

Rebound hardness can be used to estimate uniaxial compressive strength. The rebound test requires the specimen to be fixed to a backing plate and then to be hammered. GB, ASTM and ISRM are mainly compared in this section with the differences listed in Table 10.18.

Table 10.16 Comparison of determining the sound velocity by ultrasonic pulse transmission technique

Item	*GB*	*ISRM*
Designation	GB 50266-2013	Upgraded ISRM suggested method for determining sound velocity by ultrasonic pulse transmission technique
Scope	Rocks that can be made into regular specimens	
Apparatus	Ultrasonic tester, a longitudinal and transverse waves transducer, a test frame.	Ultrasonic testing system components including a signal generator, an oscilloscope, amplifiers and filters, a data acquisition unit interfacing with the apparatus.
Size of specimen	The diameter of cylinder specimen shall be 48–54 mm; The ratio of height to diameter shall be 2.0–2.5.	As specified in Table 10.17.
Coupling agent	Longitudinal waves: petroleum jelly or butter	Phenyl salicylate, high-vacuum grease, glycerin, putty, petroleum jelly, oil.
	Transverse waves: Solid materials such as aluminum foil, copper foil or phenyl salicylate.	A high viscosity medium (e.g., epoxy resin)
Requirements of transducer	The transmit frequency shall be $f \geq \frac{2v_p}{D}$ f – transmit frequency of transducer (Hz); v_p – velocity of rock longitudinal (m/s); D – diameter of specimen (m).	Specified in Table 10.17.
Seating load	0.05 MPa	Maintain a small coupling stress of 10 kPa.
Calibration of transducer	The wave delay shall be zero.	The system needs a calibration each time a new pair of transducers are used.
Accuracy of distance	1 mm	0.01 mm
Accuracy of time	0.1 μs	—
Calculation	$V_P = \frac{L}{t_P - t_0}$ $V_S = \frac{L}{t_S - t_0}$ V_P – velocity of the longitudinal wave (m/s); V_S – velocity of the transverse wave (m/s); L – travel path length (m); t_P – travel time for P-waves (s); t_S – travel time of S-waves (s); t_0 – zero delay of the system (s). Keep 3 valid digits	$V_P = L / t_P$ $V_S = L / t_S$ V_P – velocity of the longitudinal wave (m/s); V_S – velocity of transverse wave (m/s); L – travel path length (m); t_P – travel time of P-waves; t_s – travel time of S-waves. —

Table 10.17 ISRM requirements for specimens of different shapes

Slab	*Block*	*Bar*
		
$L/D \leq 0.1$ $\lambda \leq 0.1\ D$ $L \geq 10\ d_g$	$L/D \approx 1$ $\lambda \leq 0.1\ D$	$L/D \geq 10$ $\lambda \geq 5\ D$

Source: d_g: average grain size (equivalent spherical diameter)

Table 10.18 Comparison of rebound hardness tests

Item	*China's standard*	*ASTM*	*ISRM*
Source	In-situ tests for engineering geology	ASTM D5873-14	ISRM suggested method for determination of the Schmidt hammer rebound hardness: Revised version
Scope	Rocks with no significant defects	Rocks with uniaxial compressive strength of 1 to 100 MPa.	N-type Schmidt hammer is more suitable for field testing; L-type is more suitable for porous, weathered weak rocks.
Requirements of core specimens	Length-to-diameter ratio is 2 or 2.5; Length is no less than 10 cm.	Diameter is no less than 54 mm and the length is no less than 15 cm.	For L-type hammers, the diameter should be ≥ 54.7 mm; For N-type hammers, the diameter should be ≥ 84 mm.
Calculation	The first three and last three values of the measurement need be discarded. Take the remaining values to get their average.	Calculate the average of the ten readings obtained for each specimen. Discard the data that differ from the average by more than 7 units.	Use all 20 readings to get the average.