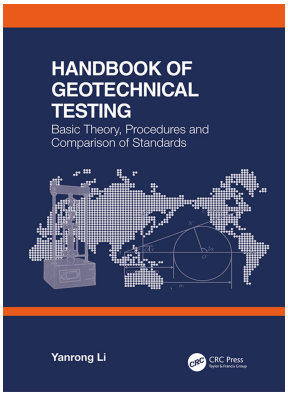

Handbook of Geotechnical Testing
Basic Theory, Procedures and Comparison of Standards

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Procedures of tests on rocks

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Chapter 7

Procedures of tests on rocks

In this chapter, the procedures of rock tests are described according to *the Standard for Engineering Rock Mass Determination Methods GB/T 50266-2013*. Combining with the industrial standards, e.g., highways and water conservancy, we have made revisions for some key steps of rock tests. The preparation and specific requirements of rock specimens are unified and standardized in Sections 7.1 and 7.2. The overviews of the test procedures are provided in the form of flowcharts.

7.1 Requirements of specimen

7.1.1 Water content

(1) Take the specimen on sites and maintain its natural moisture content during handling, transporting, storing and preparing process. The blasting method is used for this test.
(2) The specimen should be more than 10 times the diameter of the largest mineral particles of the rock, and the mass of each specimen should be in the range from 40 to 200 grams. At least five specimens are required in each test group.
(3) Determination of the water content of the structural surface filling should comply with the National Standard of Determination Methods for Geotechnical Engineering (GB/T 50123)

7.1.2 Determination of grain density

(1) Crush the rock into powder by a shredding machine and then pass through a mesh with a hole diameter of 0.25 mm, and then remove iron scraps with magnet.
(2) The rock containing the magnetic minerals should be crushed with a porcelain mortar or agate mortar and then passed through a mesh with a hole diameter of 0.25 mm.

7.1.3 Density

(1) Method A-Direct measurement

1) The specimen should be 10 times larger than the diameter of the largest mineral particle of the rock. The minimum size of the specimen should not be less than 50 mm.
2) The cylinder, a square cylinder or a cube specimen are needed in the test.
3) The deviation in diameter along the height of the specimen shall be within 0.3 mm;

4) The non-parallelism deviation at both end faces of specimen shall be within 0.05 mm.
5) Both end faces of the specimen shall be perpendicular to the axis of the specimen and the deviation shall not exceed 0.25 degrees.
6) Adjacent sides of the square cylinder or cube specimen should be perpendicular to each other and the deviation shall not exceed 0.25 degrees.

(2) Method B-Water displacement

The side length of the wax seal rock specimen should be in the range of 40~60 mm.

7.1.4 Water absorption

(1) Regular specimen should comply with the specimen requirements of the volume method in section 7.1.3.
(2) Irregular specimen in a round rock should have a side length of 40–60 mm.
(3) Three samples in each test group are required.

7.1.5 Slake durability

(1) Take specimens with natural water content by on-the-spot sampling method and seal them well.
(2) Mass of each specimen in round shape should be in the range from 40 to 60 g.
(3) Ten samples in each test group are required.

7.1.6 Swelling properties

(1) Take the specimen by on-the-spot sampling method. The specimen should be kept in a natural water-containing state and processed by dry method.
(2) For the free swelling test of the cylinder or square specimen, the diameter of specimen is in the range of 48–65 mm, the height should be equal to the diameter, and the top and bottom surfaces should be parallel. The side length of the specimen should be in the range of 48–65 mm. Three samples in each test group are required.
(3) For the lateral restraint swelling test and the swell pressure test under the condition of constant volume, the height of specimen should not be less than 20 mm, or smaller than 10 times the maximum mineral particle size of the constituent rock, and the top and bottom surfaces should be parallel to each other. The specimen should have a diameter of 50–65 mm and be less than the inner diameter of the metal collar. Three samples in each test group are required.

7.1.7 Uniaxial compressive strength

(1) Diameter of the cylindrical specimen should be in the range from 48 to 54 mm.
(2) Diameter of the specimen should be greater than 10 times the diameter of the largest particle in the rock.
(3) The ratio of the height to the diameter for the specimen piece should be in the range from 2.0 to 2.5.

(4) Top and bottom surfaces of the specimen should be parallel.
(5) Deviation in diameter along the height of the specimen shall be within 0.7 mm.
(6) Top and bottom surfaces of specimen should be perpendicular to the axis of the specimen and with the deviation shall be within 0.25°.

Specimen requirements for durability under freezing and thawing conditions and deformability in uniaxial compression should comply with the requirements 1–6.

7.1.8 Strength in triaxial compression

(1) Diameter of the cylinder specimen should be in the range from 0.96 to 1.00 times the diameter of the bearing plate of the test machine.
(2) Five specimens having the same water content are required.
(3) Other requirements should comply with 7.1.7.

7.1.9 Indirect tensile strength by Brazilian test

(1) Diameter of the cylindrical specimen should be 48–54 mm. The thickness of the specimen is 0.5–1.0 times the diameter of specimen and greater than 10 times the maximum particle diameter of the rock.
(2) Other requirements should comply with 7.1.7.

7.1.10 Shear strength of rock joints

(1) Side length of the cube specimen is greater than 50 mm;
(2) Structural surface should be parallel to the applied shear stress and located in the middle of the specimen;
(3) At least 5 specimens are required in each test group. They are used to determine the shear strength under different normal loads.

7.1.11 Point load strength

(1) For the specimen of rock core, the ratio of length to diameter of the specimen should be more than 1.0. However, for those used for axial test, the ratio of length to diameter of the specimen should be 0.3–1.0.
(2) The size of block specimen should be 15–85 mm, and the ratio of the distance between the two loading points to the average width of specimen at the loading points should be in the range from 0.3 to 1.0.

7.1.12 Wave velocity by ultrasonic pulse transmission technique

(1) Diameter of the cylindrical specimen should be in the range from 48 to 54 mm.
(2) Diameter of the specimen should be greater than 10 times the diameter of the largest particle in the rock.
(3) The ratio of the height to the diameter for the specimen piece should be in the range from 2.0 to 2.5.

(4) Top and bottom surfaces of the specimen should be parallel.
(5) Deviation in diameter along the height of the specimen shall be within 0.3 mm.
(6) Top and bottom surfaces of specimen should be perpendicular to the axis of the specimen and with the deviation shall be within 0.25°.

7.2 Description of specimens

7.2.1 Water content

(1) Rock type, color, mineral constituents, structure, texture, weathering degree and cementing properties.
(2) Moisture conditions and the methods of saturation and drying.

7.2.2 Grain density

(1) Rock type, color, mineral constituents, structure, texture, weathering degree and cementing properties.
(2) Moisture conditions and the methods of saturation and drying.

7.2.3 Density and water absorption

(1) Rock type, color, mineral constituents, structure, texture, weathering degree and cementing properties.
(2) Moisture conditions and the methods of saturation and drying.
(3) Development degree and distribution of joint fissures.
(4) Shape of the specimen.

7.2.4 Slake durability

Rock type, color, mineral constituents, structure, texture, weathering degree and cementing properties.

7.2.5 Swelling properties

(1) Rock type, color, mineral constituents, structure, texture, weathering degree and cementing properties.
(2) Relation among loading orientation and stratifications, joints and fissures of the specimen.
(3) Phenomena in specimen processing

7.2.6 Uniaxial compressive strength

(1) Rock type, color, mineral constituents, structure, texture, weathering degree and cementing properties.
(2) Relation among loading orientation and stratifications, joints and fissures of the specimen.
(3) Moisture conditions and the methods of saturation and drying.
(4) Describe phenomena such as crack, peel or split in the processing specimen.

7.2.7 Shear strength of rock joints

(1) Rock type, color, mineral constituents, structure, texture, weathering degree and cementing properties.
(2) Development degree of the layers, the texture, and the joint fissures.
(3) Relationship between the shear direction and the layer (texture or joint fissure)
(4) Filling properties and filling degree of the structural surface.
(5) Methods to take the specimen and disturbance degree in the preparation process.

7.2.8 Point load strength

(1) Rock type, color, mineral constituents, structure, texture, weathering degree and cementing properties.
(2) Specimen shape and methods of specimen preparation.
(3) Relationship between loading direction and bedding, phylogeny or joints.
(4) Water content of specimen and Moisture conditions.

7.2.9 Wave velocity by ultrasonic pulse transmission

(1) Rock type, color, mineral constituents, structure, texture, weathering degree and cementing properties.
(2) The relationship between loading direction and rock specimen bedding, joints and fissures.
(3) The state of water and the method used to prepare the specimens.
(4) The phenomenon that occurs during the processing of the specimens.

7.3 Physical tests

7.3.1 Water content

Water content of rock is expressed as the ratio of the lost water mass to rock solid particle mass when the rock is dried to have a constant mass at 105–110 °C. Water content of rock indirectly reflects its voids and the compactness of the rock. The test process is shown in Figure 7.1.

Procedures:

Step 1: Determine the mass of the container. Place the specimen in the container and determine the total mass of the specimen and container with accuracy of 0.01 g.
Step 2: Place the container containing the specimen in an oven and dry at 105–110 °C for 24 hours. For rocks having crystallization water and volatile minerals, the specimen is usually dried at 55–65 °C or by vacuum evacuation at room temperature.
Step 3: Cool down to room temperature and determine the total mass of the specimen and the container with accuracy of 0.01 g.
Step 4: Calculate the water content according to the formula with accuracy of 0.01. Take the average of five specimens as water content in rock.

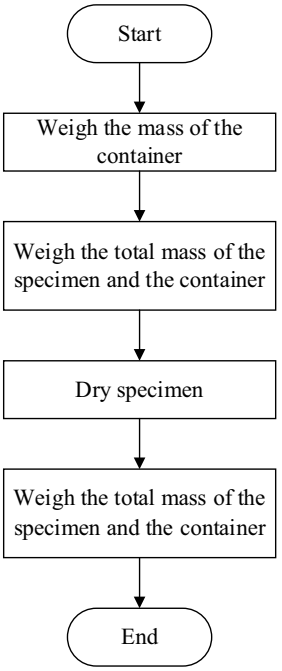

Figure 7.1 Flowchart of determining water content

7.3.2 Grain density

The grain density of rock is the ratio of the mass of rock to its volume when the rock is baked to have a constant mass at 105–110 °C. Pycnometer method and weighing method in water are usually used to determine the rock grain density. In this section, the pycnometer method is present for determining the grain density of various rocks. The test process is shown in Figure 7.2.

Procedures:

Step 1: Take two samples of rock powder by the quadruple method. Each sample of rock powder is 15 g.

Step 2: Put the rock powder into the dried pycnometer. Add the test solution to half of the volume of the pycnometer and mix the rock powder and water thoroughly. Plug the stopper.

Step 3: Remove the gas in the solution by boiling method or vacuum pumping method when water is used in the test. When kerosene is used, only the vacuum can be used to remove the gas in the solution. Place the pycnometer in a sand bath and heat the solution to boil. Then, heat the solution at a relatively low temperature and keep at a slow boil for about 1 hour. In vacuum pumping method, the vacuum gauge reading should be the same as the local atmospheric pressure. Continuously pump the water solution for more than 1 h after bubbles are completely removed.

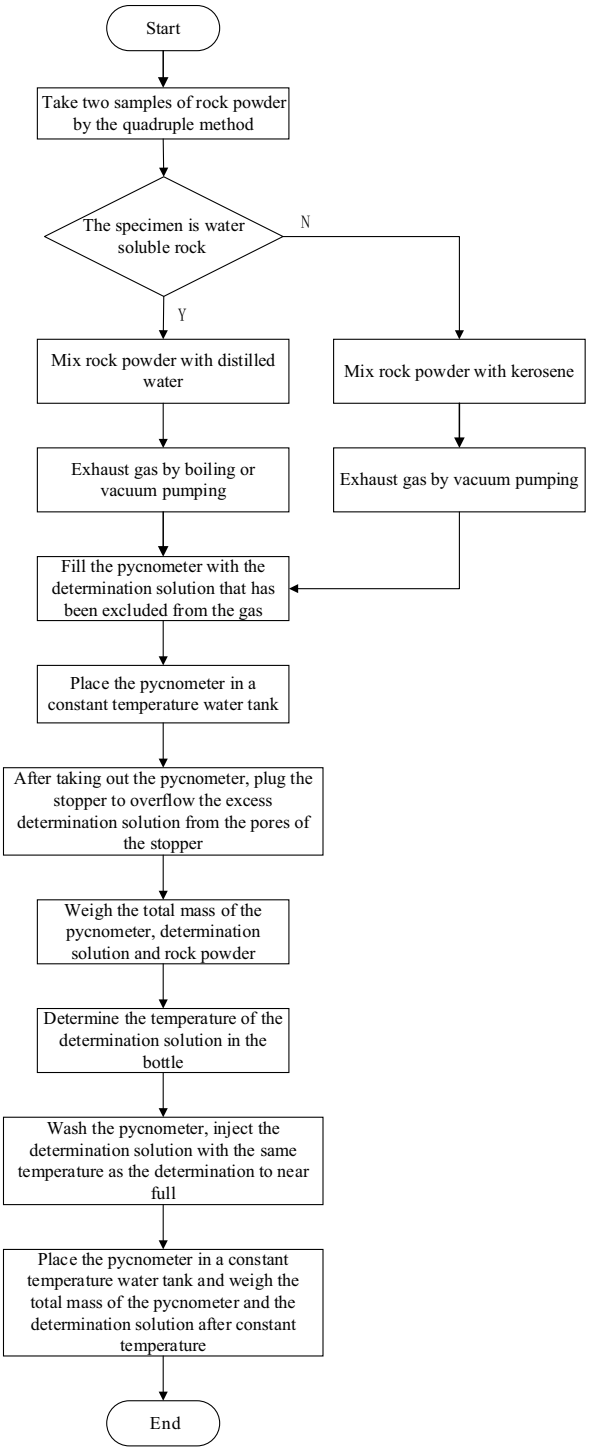

Figure 7.2 Flowchart of determining grain density

Step 4: The distilled water without gas was filled into the pycnometer and placed in a constant temperature water tank to keep the temperature inside the bottle stable and the upper suspension clarified. Then, take out the pycnometer and plug the stopper to overflow the excess test solution from the pores of the stopper.
Step 5: Dry the pycnometer and determine the total mass of the pycnometer, test solution and rock powder with accuracy of 0.001 g. Record the temperature of the solution with accuracy of 0.5 °C.
Step 6: Add the distilled water having the same temperature as the solution to a clean pycnometer, and then place them in a water tank at constant temperature. Determine the total mass of the pycnometer and the test solution at a constant temperature.
Step 7: Calculate the grain density according to the formula with accuracy of 0.01.

7.3.3 Density

Rock density is rock mass per unit volume. It is composed of natural density, saturated density and dry density. The index of rock density is used to calculate the rock's own weight stress. Method A (Figure 7.3) and Method B (Figure 7.4) are generally employed in the determination of the rock density. Method A covers the procedure by means of the direct measurement of the dimensions and mass of a specimen, usually one of cylindrical shape. Method B covers the procedure for measuring the volume of wax coated specimens by determining the quantity of water displaced.

(1) Method A-Direct measurement

Procedures:

Step 1: The diameters or side lengths of the middle and two ends of the specimen are determined by the Vernier caliper with accuracy of 0.02 mm.
Step 2: Determine the heights of the four symmetrical center points on the end surface by a Vernier caliper with accuracy of 0.02 mm.
Step 3: Dry the specimen in an oven at 105–110 °C for 24 hours. Then, determine the mass of the specimen at room temperature with accuracy of 0.01 g.
Step 4: Calculate the average of the cross-sectional area and the height of the specimen with accuracy of 0.01.

(2) Method B-Water displacement

Procedures:

Step 1: Tie the specimen by a thin line and determine its mass with accuracy of 0.01 g.
Step 2: Take out the wax liquid in the oven and immerse the specimen in a molten wax of about 60 °C for 1–2 seconds, thereby a wax film with the thickness of 1 mm is coated uniformly on the surface of the sample. Break the bubbles in the wax membrane by a hot needle, if necessary. After cooling, determine the mass of the wax seal specimen with accuracy of 0.01 g.

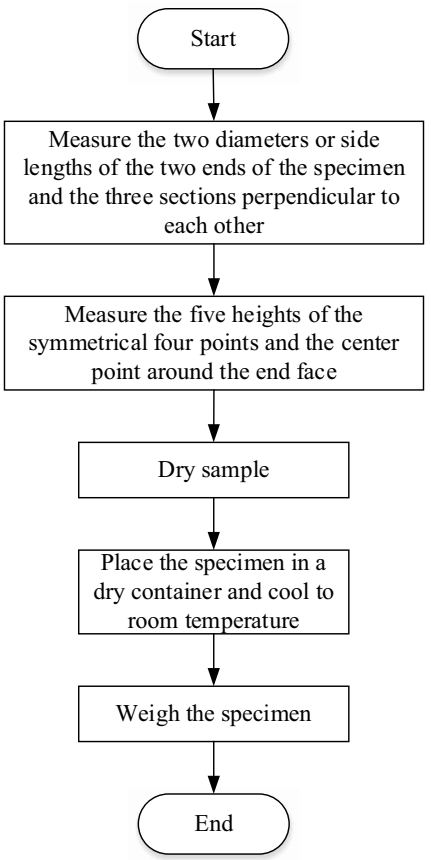

Figure 7.3 Flowchart of determining rock density (direct measurement)

Step 3: Hang the wax seal specimen in an electro-optical analytical balance and immerse the specimen in a beaker containing distilled water without touching the beaker wall. Adjust the balance and record the readings.

Step 4: Take out the specimen, wipe the water on the wax surface, and then determine the mass of the wax seal specimen with accuracy of 0.01 g. If the mass of the specimen increases after immersion, the wax film of specimen should be stripped and the test should be re-conducted.

Step 5: Determine the water content of the rock.

Step 6: calculate the wet density of the rock according to the formula with accuracy of 0.01. For dry density of the rock, the specimen should be dried at 105–110 °C for 24 hours. Store the specimen in a dry container. Determine the mass of dried specimen at room temperature. Re-conduct step 1–4 and calculate the wet density of the specimen with accuracy of 0.01.

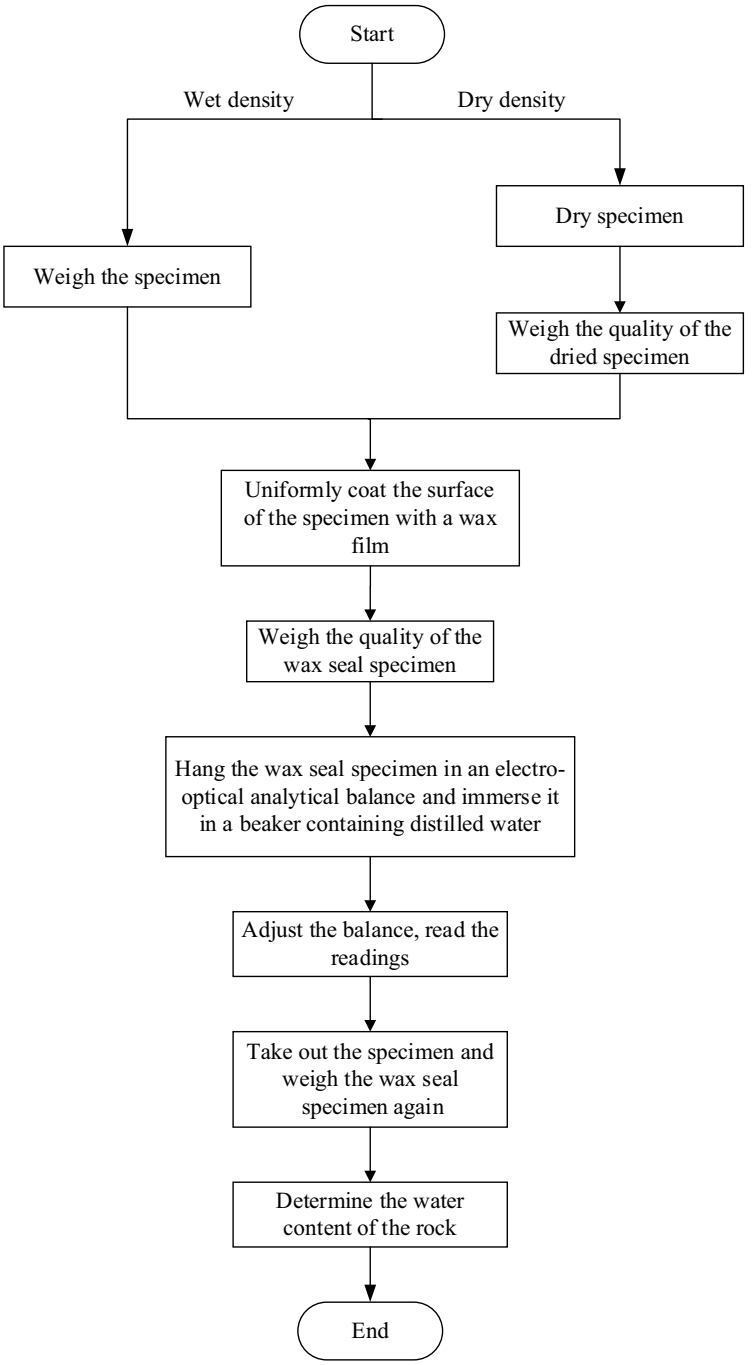

Figure 7.4 Flowchart of determining rock density (water displacement)

7.3.4 Water absorption

Rock absorption includes rock water absorption test and rock saturated water absorption test. The water absorption of rock is the ratio of the mass of water being absorbed by rock at atmospheric pressure and room temperature to the mass of rock solid particles. Natural water immersion method is applicable to the rock water absorption. The saturated water absorption of rock is expressed as the mass ratio of the maximum water absorption of rock under forced conditions to rock solid particles. Rock water absorption is determined by boiling method or vacuuming saturation method. The test process is shown in Figure 7.5.

Procedures:

Step 1: Dry the specimen in an oven at 105–110 °C for 24 hours. Transfer the dried specimen into a dry container and cool down to room temperature. Determine the mass of the specimen.

Step 2: Freely immerse the specimen in pure water. Put the specimen into the water tank and fill the water to the 1/4 height of the specimen. And then fill the water to the half-height of the specimen after 2 hours, and finally add water to the 3/4 height of

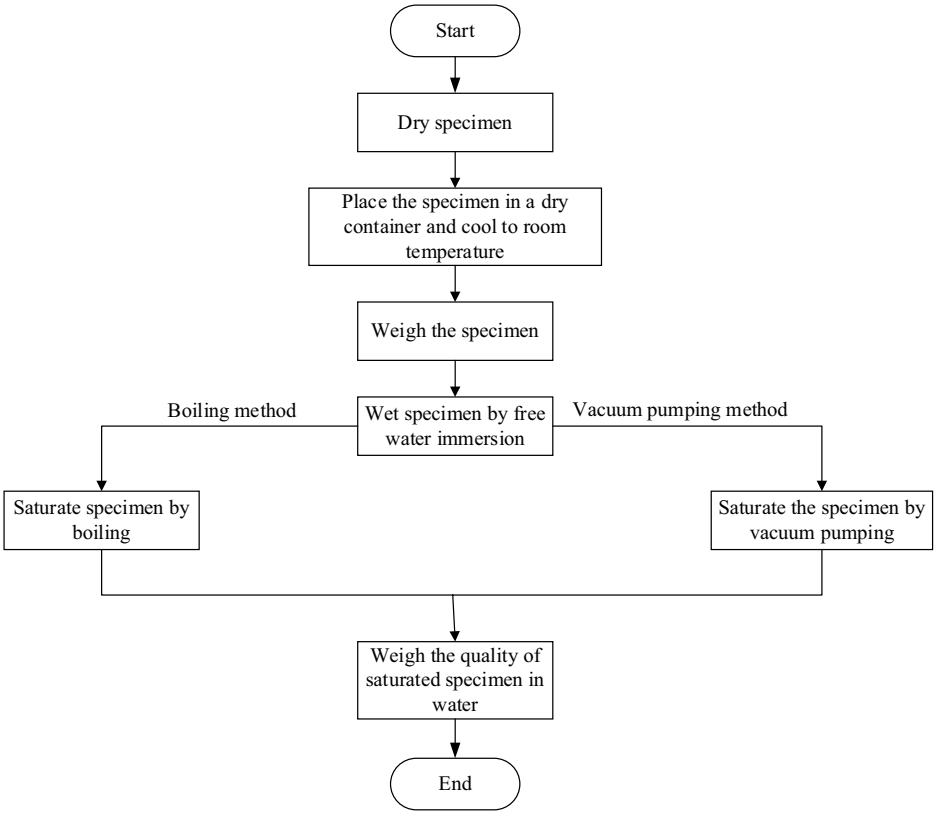

Figure 7.5 Flowchart of determining water absorption

the specimen after 4 hours. Fully immerse the specimen in the water after 6 hours. When the specimen is immersed in water for 48 hours, take out the specimen and remove water on the surface of specimen. Determine the mass of the specimen with accuracy of 0.01 g.

Step 3: In boiling method, the boiling water surface should always be higher than the height of specimen, and the boiling time should be more than 6 hours. After boiling, cool the specimen down to room temperature. Remove water on the surface of specimen and determine the mass of the specimen with accuracy of 0.01 g.

Step 4: In vacuum pumping method, keep the initial water surface in the saturated container to be higher than the height of specimen. Pump the saturated specimen about 4 hours until no bubbles are found. After the pumping is completely accomplished, the saturated specimen is allowed to stand for 4 hours at atmospheric pressure. Remove water on the surface of specimen and determine the mass of the specimen with accuracy of 0.01 g.

Step 5: Calculating rock water absorption, saturated water absorption, dry density and grain density according to the formula.

7.3.5 Slake durability

The rock slake durability test is used to mimic the natural wetting and drying process of rock by means of mechanic force. For common rocks, two standard cycles of loading mechanic force should be conducted in the test, however, for the rock with large hardness, three or more standard cycles of loading mechanic force should be conducted. Rocks with high clay content are easily disintegrated and spalled under short-term humidity and long-term air drying. The test process is shown in Figure 7.6.

Procedures:

Step 1: Fill the cylinder with specimens and heat in the oven at 105–110 °C for about 24 hours. Transfer drum from the oven into a desiccator and cool to room temperature. Finally, the total mass of the cylinder and the specimen is determined at room temperature with an accuracy of 0.01 g.

Step 2: Place the sieve cylinder containing the sample in a water tank. Install the apparatus. Pour the distilled water into the water tank to ensure that the water level was about 20 mm under the cylinder axis. Set the cylinder to rotate for 10 minutes at the speed of 20 rpm. Then, heat the cylinder with residual specimen in the oven at 105–110 °C for about 24 hours. Transfer drum from the oven into a desiccator and cool down to room temperature. Determine the total mass of the cylinder and residual specimen at room temperature with accuracy of 0.01 g.

Step 3: Conduct step 2 to obtain the mass of the cylinder and oven-dried residual specimen for the second cycle. Conduct the step 2 for 5 times according to engineering requirements.

Step 4: Describe the residual specimen, water color and the sediments after the test. If necessary, determine grain size of the sediments in water, mineral components in clay and the Atterberg limits.

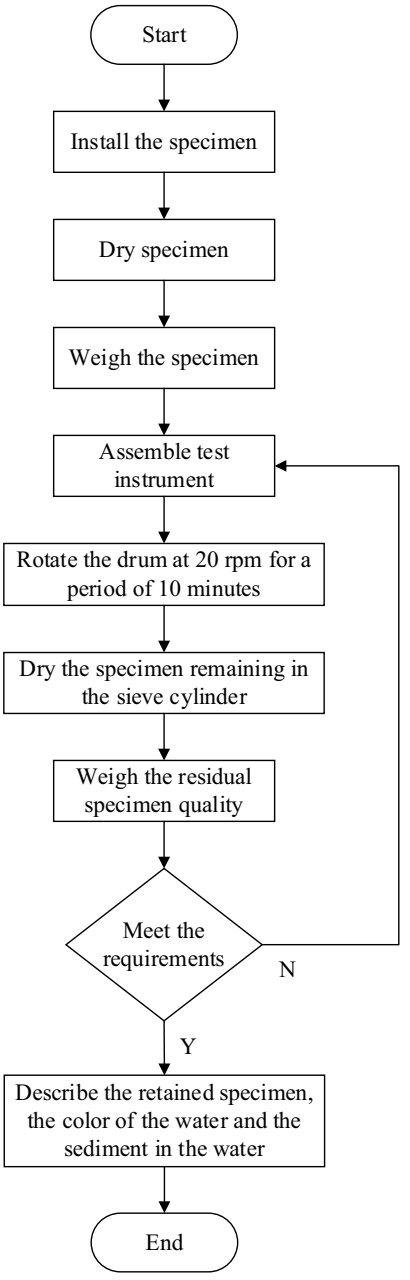

Figure 7.6 Flowchart of determining slake durability

7.4 Mechanical tests

7.4.1 Swelling properties

Rocks that contain hydrophilic and easily expandable minerals can absorb an amount of water, thereby leading to volume swelling of rocks. The rock swelling indexes are composed of an unconfined swelling strain index, a swelling strain index and a swelling pressure index.

(1) Swelling strain developed in an unconfined rock specimen

This test is intended to measure the swelling strain developed when an unconfined, undisturbed rock specimen is immersed in water. The test process is shown in Figure 7.7.

Procedures:

Step 1: Place the specimen in the free swelling device. Put a water permeable plate is on the upper and lower ends of the specimen, respectively. Additionally, put a metal plate on the top of the specimen.

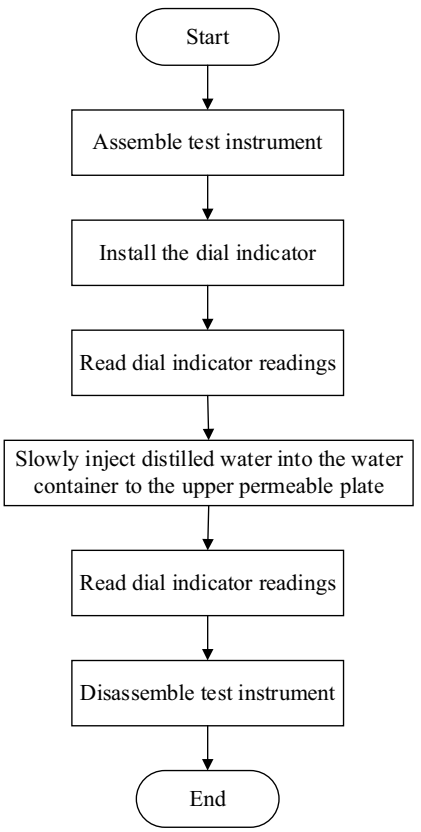

Figure 7.7 Flowchart of determining the free swelling strain of unconfined specimen

Step 2: Install the dial gauges on the center of the specimen and the symmetrical center of the four sides. Measure the axial deformation and radial deformation of the specimen. A piece of thin copper is required between the specimen and the dial gauges of four sides.
Step 3: Record the dial indicator readings every 10 minutes until three consecutive readings are very close.
Step 4: Slowly inject distilled water into the water container to the upper permeable plate and record the dial reading immediately. Immerse the sample should be immersed in water for about 48 hours. Record the dial gauge readings every 10 minutes at the first hour of the test; and then, Record the dial gauge readings every 1 hour until the difference between three consecutive readings is less than 0.001 mm, indicating that the sample swelling is stable.
If the specimen is disintegrated, cracked, dropped, softened or has surface muddy after the test, describe the specimen in detail.
Step 5: Calculate the axial and radial swelling strain of the rock according to the formula.

(2) Swelling strain index for a radially confined rock specimen with axial surcharge

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. The test process is shown in Figure 7.8.

Procedures:

Step 1: Apply a thin layer of petroleum jelly to the inner wall of the metal collar and transfer the specimen of the known size into the metal collar, and then put the filter paper and the permeable plate on the upper and lower ends of the specimen, respectively.
Step 2: Put a metal load block with a pressure of 5 kPa on the top of the upper permeable plate. Install a dial gauge.
Step 3: Record the dial indicator reading every 10 minutes until three consecutive readings are very close.
Step 4: Slowly inject distilled water into the water container and record the dial indicator reading immediately. Immerse the specimen in water for less than 48 hours. Record the dial gauge reading every 10 minutes during the first hour of test; and then, record the reading every 1 hour until the difference of three consecutive readings was smaller than 0.001 mm. This indicates that the specimen swelling is stable. If the specimen has muddy surface or is softened after the test, describe the specimen in detail.
Step 5: Calculate the swelling strain index for a radially confined specimen with axial surcharge according to the formula.

(3) Swelling pressure index under conditions of zero volume change

This test is intended to measure the pressure is required to keep the original volume of the rock specimen after water immersion. The test process is shown in Figure 7.9.

Procedures:

Step 1: Apply a thin layer of petroleum jelly to the inner wall of the metal collar and install the specimen into the metal collar. Put the filter paper and metal permeable plate on the top of the specimen.

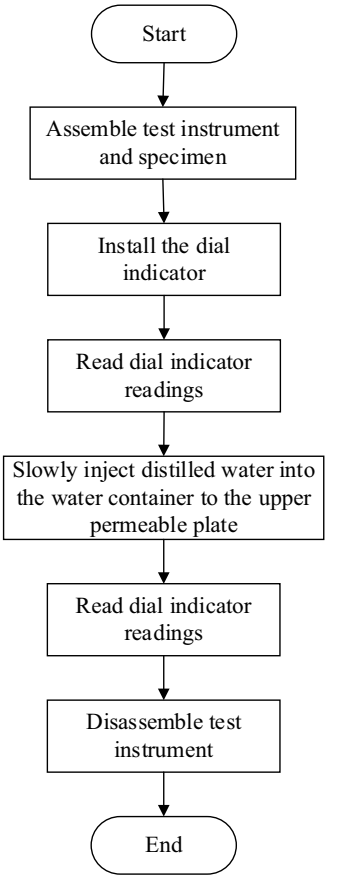

Figure 7.8 Flowchart of determining the swelling strain index of confined specimen

Step 2: The pressurization system and the dial gauge are installed. The instrument and the specimen should be installed on the same axis without eccentric load.

Step 3: Apply a load of 10 kPa to the specimen and record the dynamometer and dial gauge readings every 10 minutes until three consecutive readings are very close.

Step 4: Slowly inject pure water into the water container to the upper metal permeable plate. When the observed deformation is more than 0.001 mm, adjust the applied load to ensure that no swelling deformation or thickness change of the specimen take place. Record the dynamometer reading.

Immerse the specimen in water for less than 48 hours. Record the dial gauge reading every 10 minutes during the first hour of test; and then, record the reading every 1 hour until the difference of three consecutive readings was less than 0.001 mm. If the specimen has muddy surface or is softened after the test, describe the specimen in detail.

Step 5: Calculate the swelling pressure index under conditions of zero volume change according to the formula.

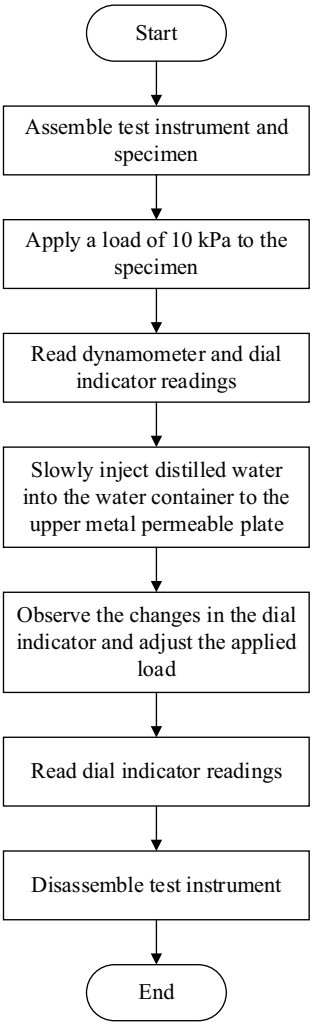

Figure 7.9 Flowchart for determining the swelling pressure

7.4.2 Uniaxial compressive strength

The uniaxial compressive strength of rock is the ultimate compressive stress when the rock sample breaks under unidirectional pressure, and is usually used for the strength grading and lithological description of the rock. This test method is applicable for rocks that can be made into regular specimens. Parameters to be measured are the dimensions of specimen and failure load. The specimens could be made into regular shape by drilling cores or rock blocks. Avoid making any cracks on the rock during the process of collection, transportation and preparation. Specimens with natural moisture state, dry state, saturated state and other moisture states are selected according to engineering requirements. In this method, the

specimen is loaded by a microcomputer controlled electro-hydraulic servo pressure testing machine. The test process is shown in Figure 7.10.

Procedures:

Step 1: Turn on the microcomputer control electro-hydraulic servo pressure testing machine. Measure the diameter and height of the specimen at different positions by a Vernier caliper. Record the average of the diameter and height of the specimen and input these data to the computer system.

Step 2: Place the specimen on the center of the pressure plate of the testing machine and lower the screw of the testing machine. When the upper plate is 2–3 mm away from the top of the specimen, stop the screw of the testing machine and then manually

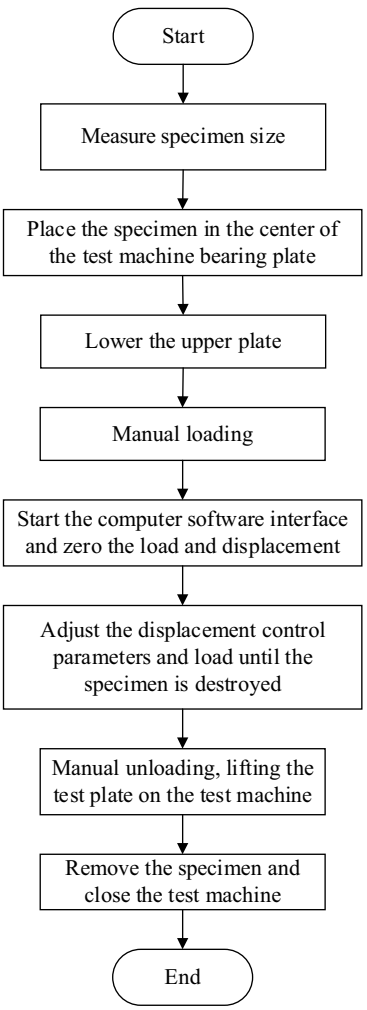

Figure 7.10 Flowchart for determining uniaxial compressive strength

apply the load to contact the two ends of the specimen snugly with the upper and lower plates of the testing machine.

Step 3: Start the computer and set the load and displacement to zero. Adjust the displacement control parameters and apply the load on the specimen until failure. Record the testing data, the phenomenon and the load until it is damaged.

Step 4: After test, describe the failure mode of the specimen.

Step 5: Calculate the uniaxial compressive strength and softening coefficient of the rock according to the data and formula.

7.4.3 Durability under freezing and thawing conditions

The ratio of the compressive strength of the rock specimen before and after freezing and thawing is defined as freeze-thaw coefficient. In this test, the rock is frozen and heated to dissolve for several times at ±25 °C. Rock freezing-thawing resistance is an index of the saturated rock to prevent its damage from freezing-thawing cycles. The test process is shown in Figure 7.11.

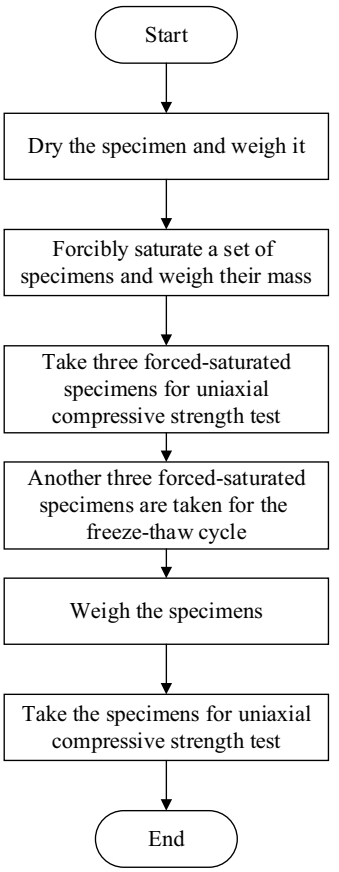

Figure 7.11 Flowchart for determining slake durability under freezing and thawing conditions

Procedures:

Step 1: Determine the mass of dried specimen with accuracy of 0.01 g. A group of specimens is saturated. The method of which can refer to rock water absorption test. Then determine the mass of saturated specimen with an accuracy of 0.01 g. Each group of tests should contain at least six samples. Three of them are used to the compressive strength test after saturation, and another three samples are used for the compressive strength test after freeze-thaw cycle.

Step 2: Place the specimen in a tin box and cool at –22 to –18 °C for 4 hours.

Remove the tin box and fill the box with water to immerse the specimen. Then, place the tin box in the test box and heat at 18–22 °C for 4 hours.

The freezing-thawing cycles can be conducted for 25, 50 or 100 times in term of the engineering environment. After each cycle, check the specimen if it has any blockage or cracks, etc. Record the test results after all freezing-thawing cycles.

Step 3: Take out the specimen, remove water on the surface of specimen, and determine its mass of specimen with accuracy of 0.01 g.

7.4.4 Deformability in uniaxial compression

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. The test process is shown in Figure 7.12.

Procedures:

Step 1 Take the prepared specimen, select two ends and the middle of the specimen, these three different positions to separately measure two diameters perpendicular to each other with the caliper for three times. Choose four symmetrical points and the center point around two sides to measure five height. Calculate the average of the diameter and height, and input the average in the computer.

Step 2: Select an appropriate range of multimeter and connect with the strain gauge. Measure the resistance of the strain gauge. The resistance value shall be around 120 Ω.

Step 3: Stick the strain gauge in the middle of the specimen. The place to stick the strain gauge should be polished to be even and smooth, and cleaned with cleaner fluid. Apply a layer of moisture-proof glue solution at the place, with a thickness less than 0.1 mm and an area bigger than the strain gauge. The place should also avoid cracks or patches. The strain gauge should be stuck along the radial and axial direction in relative faces. 2 or 4 strain gauges can be used along the radial and axial direction. Insulation resistance of the strain gauges should not be less than 200 MΩ. Mark the two lateral sides of A and B that need to be measured.

Step 4: Weld the conductor on each strain gauge and mark the conductor. Place the specimen on the center of the loading plate of testing machine and connect the conductor to the instrument of static resistance strain gauge. Set instrument parameters of resistance strain gauge.

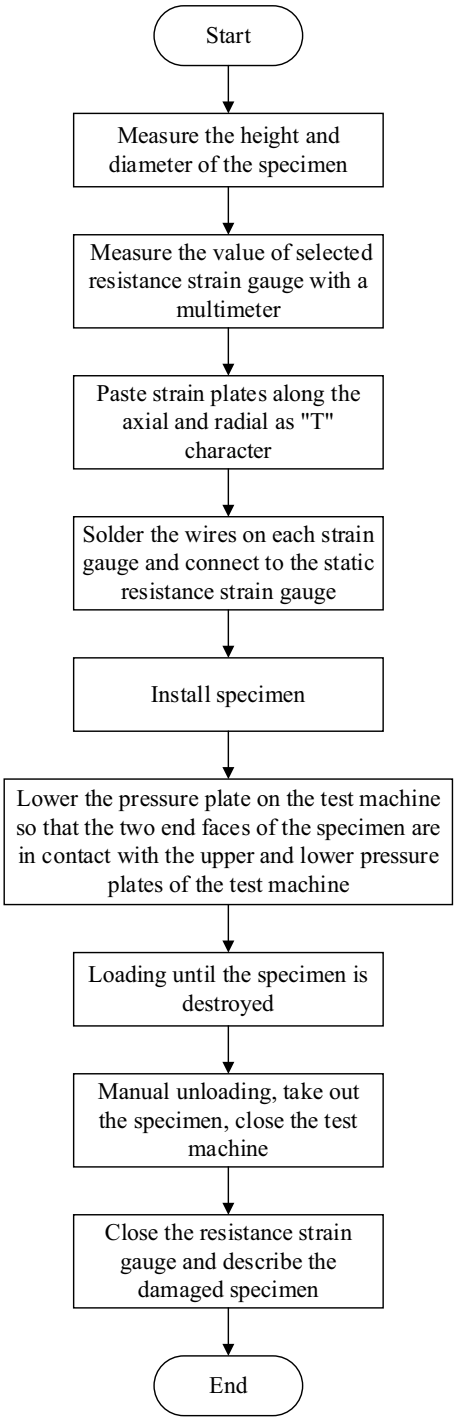

Figure 7.12 Flowchart for determining the deformability in uniaxial compression

Step 5: Start the test machine. Low down the upper loading plate until it is 2–3 mm to the top of the specimen. Then add load manually until the upper plate contact snugly to the top of the specimen, then adjust the loading plate to make load attribute evenly.

Step 6: Set the load and displacement to zero. Set the load rate of 0.002 mm/s (load rate of 0.5–1 MPa/s may be used according to the engineering requirement) Apply the load and record the phenomenon of crack, peel or split during the loading process, plot the relationship curve between load and displacement, and the deformation relationship curve between axial and radial direction. As the load increases the deformation of the specimen increases gradually. When the specimen is failure and stop the load then. Record the failure load, axial deformation and radial deformation.

Step 7: Unload. Lift the upper pressure plate, turn off the test machine and remove the conductor. Switch off the instrument of electrical resistance strain gauges. Remove the specimen and describe the destruction of specimen.

Step 8: Calculate the uniaxial compressive strength and the stress of every level according to the data in the table. Plot the relationship curve between stress and axial strain and radical strain. Calculate the average elastic modulus and Poisson's ratio. The elastic modulus should calculate to three significant digits. The Poisson's ratio shall be accurate to 0.01. Calculate the secant elastic modulus and the corresponding Poisson ratio. Repeat the step 1 to 8 to conduct parallel tests to other specimens.

It should be noted that:

(1) Protective measures should be taken during the test, such as wearing safety glasses.
(2) During the pressurization phase, the performer must keep a safe distance from the test machine.

7.4.5 Strength in triaxial compression

The strength of rock in triaxial compression is the maximum axial stress that a specimen can resist under triaxial compressive strength. This test is intended to measure the triaxial compression strength of a series of rock specimens at different confining pressure, and calculate the shear strength of the rock in triaxial compression. This test is applicable for all kinds of rocks that can be made into a cylindrical specimen. Parameters to be measured include the dimensions and the failure load of specimen. The specimens could be made into regular shape by drilling cores or rock blocks. Any cracks on the rock should not be made as possible during the process of collection, transportation and preparation. Specimens with different moisture conditions should be selected according to the engineering requirements. Under the same water content and loading direction, 5 specimens are needed in each test group. The test process is shown in Figure 7.13.

Procedures:

Step 1: Take the prepared specimen, measure diameters, which is perpendicular to each other, respectively at the three positions of ends and middle of specimen following the schematic. And five heights should be obtained from circumferential and middle points at both ends. Calculate the average of the diameters and heights, and input the average dimensions.

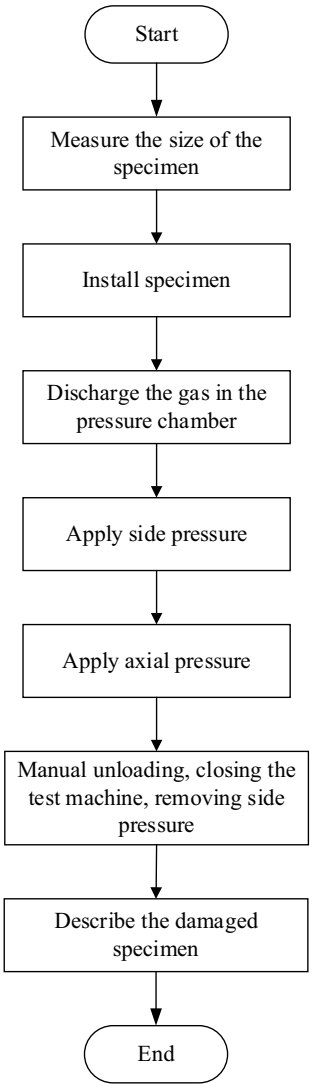

Figure 7.13 Flowchart for determining the rock strength in triaxial compression

Step 2: Assemble the specimen

Put the specimen between two platens and wind the insulating tape on the connection of the platen and the specimen. Oil proof measures shall be used. Cut 140 to 150 mm heat-shrinkable sleeve and wrap the specimen and the platens. Heat the sleeve thoroughly and repeatedly using a hot blower until no bubble exist between the sleeve and the specimen and then tighten both ends of the sleeve by iron wire.

Lift the confining pressure chamber. Insert the specimen into the confining base. Mount the confining base with specimen on base plate of the chamber. Install axial

and radial displacement sensor successively. Connect the conductor of the sensor. Mount the confining cap and load-transfer block on the specimen. Place the pressure chamber carefully and fix the pressure chamber on the base plate of chamber using a clamping band.

Step 3: Exhaust air in the chamber.

Push the pressure chamber from the slide into testing position. Connect displacement data acquisition lines with the displacement sensors. Connect the oil barrel (i.e. chamber liquid) with the bottom of chamber and open the vent valve and the oil switch. Open the air pump to add pressure to upper of the oil surface. Transfer oil into the pressure chamber until oil overflows from top of the vent pipe. Stop the air pump and close the top vent valve, bottom oil switch and other valves connected to the oil line immediately. Open the data acquisition system. Turn on the testing machine and low down the upper platen until it is 2 to 3 mm to the loading piston of the chamber. Lower the upper platen slowly until it fits snugly with the loading piston.

Step 4: Open the valve of confining pressure and apply the axial load and the confining pressure simultaneously with a rate of 0.5 MPa per second until reaching the predetermined confining pressure. The confining pressure on each specimen shall be applied according to the arithmetic progression or the geometric progression. The maximum confining pressure shall be determined by the engineering requirements, the characteristics of rock specimen and the performance of triaxial testing machine. Set the load and displacement sensor of the apparatus to zero.

Step 5: Apply axial load. Increase the axial load with a rate of 0.5 to 1.0 MPa per second and observe the load versus displacement curve during loading until the specimen is failure. Stop loading and record the failure load.

Step 6: Unload manually, switch off the testing machine and unload the confining pressure. Connect the vent pipe to the air pump, and connect the bottom oil pipe of chamber to the oil barrel. Turn on the exhaust valve and air pump and start removing the oil. After the oil return, remove the data collection conductor and move out the pressure chamber. Dismantle the pressure chamber, load transfer block and confining cap. Remove the axial and radial displacement sensor. Dismantle the confining base, cut the heat-shrinkable sleeve and take out the damaged specimen.

Describe or sketch the damaged specimen. If the damaged specimen has an intact failure surface, measure the inclination between the destroyed plane and the axial direction.

Step 7: Repeat steps 1–6 and measure the failure load for other specimens at different confining pressures.

Calculate the maximum principal stress under different confining pressures according to the failure load.

Construct the Mohr's circles according to the calculated maximum axial loads and the corresponding confining pressures on the specimens.

According to the Mohr-Coulomb criterion, determine the shear strength parameters of rock, including the friction coefficient, f, and the cohesion, c, under triaxial stress.

7.4.6 Indirect tensile strength by Brazilian test

This test is intended to measure the uniaxial tensile strength of prepared rock specimens indirectly by the Brazilian test. This test is used for all kinds of rocks that can be made into regular shape. Parameters to be measured include the dimensions of specimen and the failure

load. The specimens could be made into regular shape by drilling cores or rock blocks. It should be avoided to introduce any damage of samples during the process of collection, transportation and preparation. Specimens with different moisture conditions should be selected according to the engineering requirements. At least three specimens shall be tested to obtain a meaningful average value under the same water content and loading direction. The test process is shown in Figure 7.14.

Procedures:

Step 1: Take the prepared specimen and measure diameters at the three positions of ends and middle of specimen. And five heights should be obtained from circumferential and middle points at both ends. Calculate the average of the diameters and heights,

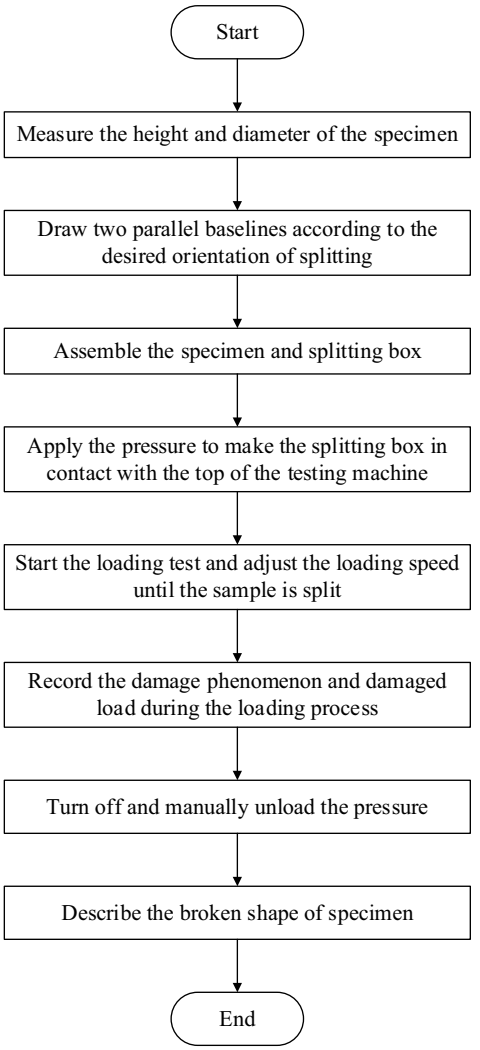

Figure 7.14 Flowchart for determining the indirect tensile strength (Brazilian test)

and input the average dimensions. According to the engineering requirements of the splitting direction, mark two parallel loading baselines passing the diametric ends of the specimen.

Step 2: Assemble split box and specimen. Put the split box at the center of the loading plate, then put the bottom bearing strip in the split box and place the specimen. Tighten the screws at both ends so as to fix the specimen. Put the top bearing strip on the specimen and make sure that both strips are fixed along the marked loading reference line on both sides of the specimen. Install the top bearing block. Ensure that bearing strips and the specimen are on the same loading axis.

Step 3: Open the universal testing machine. Add load manually to lift up the split box. When the top bearing strip is 2 to 3 mm above the upper plate of the testing machine, switch off the manual loading rotary switch. Then switch to computer control, when the load reading changes significantly, then stop loading immediately. Loosen the screws on the split box. Apply the load with a rate of 0.3 to 0.5 MPa per second. At the same time, the load versus displacement curve is being obtained and record the behavior of specimen until failure occurs. Record the failure load then.

Step 4: Stop loading. Adjust the platen manually so as to separate the platen from the load transfer block above the split box completely. Remove the load transfer block and the top bearing strip. Take out the damaged specimen, then record the type and location of failure.

Repeat the step one to four to test the other specimens in this group.

Step 5: Calculate the tensile strength of the rock to three significant digits according to dimensions and maximum load on the specimen.

It should be noted that:

The fracture surface should pass through and be perpendicular to the diameter, otherwise, the test should be invalid.

7.4.7 Shear strength of rock joints

The shear strength of rock joints is the maximum shear stress that can be resisted by the rock when subjected to a certain normal load along the existing rock joints. The flat push method is applicable for determination of the direct shear test of rocks. In this method, the relationship curve of shear stress against time and that of shear stress against horizontal displacement could be plotted. The test process is shown in Figure 7.15.

Procedures:

Step 1: Place the specimen in a metal shear box. Pass the loading shear stress through the geometric center of the structural plane. Symmetrically install the normal displacement sensors.

Step 2: Input the specimen parameters. Add the consolidation module and the standard shear module. Set the normal load to be less than 1.2 times the engineering pressure. Set the shear rate (typically 0.05–0.2 mm/min according to engineering practice), the maximum shear displacement and time interval of recording data t as well.

Step 3: Set the shear displacement and normal displacement to zero. The y1, y2, x axis is set as the shear stress, the normal stress and time, respectively. When the normal load is applied to the pre-specified value, shear stress is loaded to specimen until it

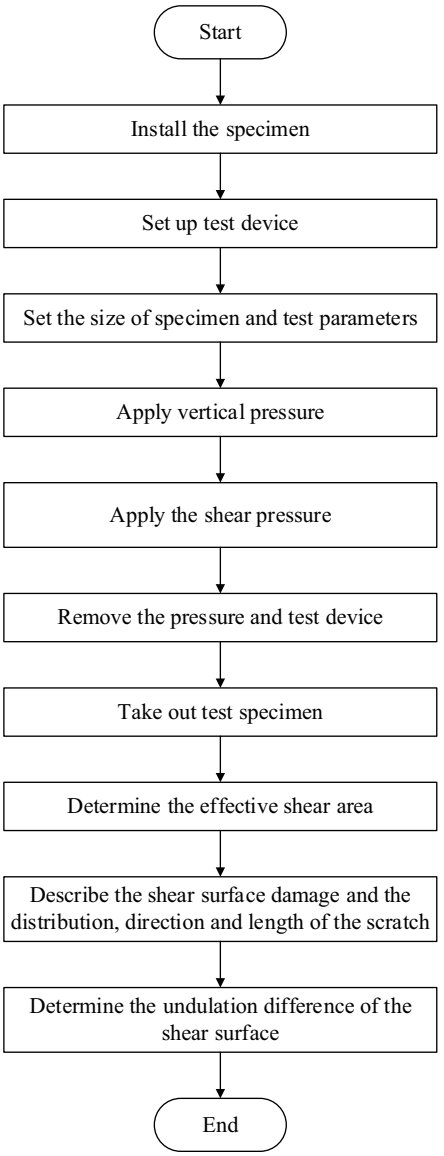

Figure 7.15 Flowchart for determining the shear strength of rock joints

features the maximum horizontal displacement. Plot the relationship curve of shear stress against time and that of shear stress against horizontal displacement.

Step 4: Dismantle the testing device and take out the specimen. Determine the effective shear surface area of the specimen and the damage degree of shear surface and describe the distribution, direction and length of the scratch. Determine the shear surface undulation to plot the relation curve of the shear surface height again the shear direction.

7.4.8 Point load strength

This test is to place the specimen between the two cone ends and apply an increasingly concentrated load until failure occurs. The failure load is used to calculate the point load strength index and the point load strength anisotropy index. This test is applicable for all kinds of rocks. Parameters to be measured include the dimensions and failure load of specimen. The specimens could be made by drilling cores or rock blocks from outcrops, exploration pits, tunnels, roadways or other underground chamber. Any cracks on the specimens should be avoided to occur during the process of collection, transportation and preparation. The test process is shown in Figure 7.16.

Procedures:

Step 1: Measure specimen size

Take prepared specimen. Measure the heights at three different positions with a Vernier caliper and record the data. Measure the diameters at three different positions with a Vernier caliper and record the data.

Step 2: specimen installation

(1) Axial Test

Place the specimen on the lower cone of the tester, lift the lower cone until the upper plate of the specimen is contact closely with the upper cone. The loading direction shall be perpendicular to the both ends of the specimen, the connection line

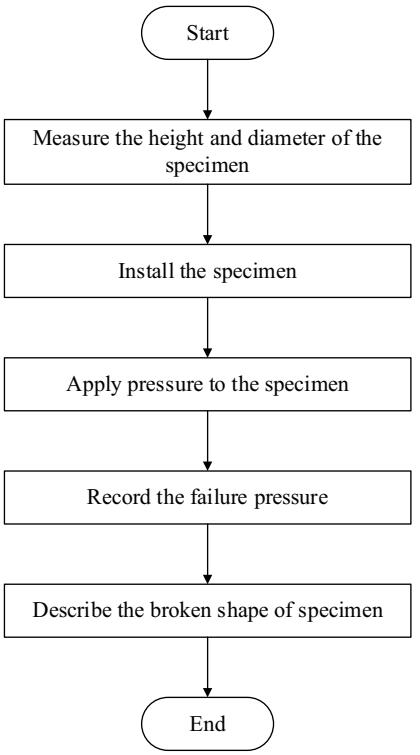

Figure 7.16 Flowchart for determining point load strength

between the upper and lower conical tip shall pass through the center of the cross section of the specimen.

(2)Radial Test

Insert a specimen in the truncated conical plates of the tester. The upper and lower cone end shall closely contact with the diameter of the core specimen. Make sure that the distance 'L', between the contact points and the nearest free end is at least half of the distance between the loading points.

(3)Block and Irregular Lump Tests:

The loading direction shall be along the direction with the smallest size of the specimen. The distance between the loading point and the width or average width of the minimum cross section through the two loading points shall be measured. The distance between the loading point and the free end of the specimen shall not be less than half of the loading point spacing.

Step 3: Steadily increase the load to make sure that failure occurs within 10 to 60 s, and record failure load. If condition permitted, measure the distance between two contact points at the moment specimen failure occurs. Describe the shape of the specimen after destruction. The fracture surface should pass through two loading point and throughout the specimen

Step 4: Calculate the value of equivalent core diameter of different specimens to three significant digits according to the formula.

7.4.9 Wave velocity by ultrasonic pulse transmission

Ultrasonic testing is intended to measure the spread time of the longitudinal and transverse acoustic waves in the specimen. Accordingly, the velocity of the ultrasonic in the rock could be calculated. The transmission of elastic waves is highly related to the compactness degree of the medium. In general, the longitudinal wave velocity in the intact rock block is faster than in the rock mass with various structural planes. The test process is shown in Figure 7.17.

Procedures:

Step 1: Apply the couplant (petroleum jelly or butter) to the surface of the transmitter and receiver. For the shear wave velocity test, the couplants should be solid materials such as aluminum foil, copper foil or salicylic acid phenolate.

Step 2: Determine the heights of the specimen at three different positions with accuracy of 1 mm. Take the average of the determined specimen heights as the distance between the two transducers. Apply couplant on the surface of the transducer.

Step 3: Place the specimen on the testing frame and the transducer on both ends of the specimen. Apply a certain amount of pressure to contact the transducer snugly with the rock mass.

Create a new project is created on the rock ultrasonic measuring device, including the project name, specimen number and transducer distance.

Step 4: Determine the ultrasonic of the longitudinal wave in the specimen is determine ten times and take the average of determined velocities. Under the same water content and the same loading direction, three specimens should be tested in each group.

The method of rock transverse wave velocity test is similar to that of longitudinal wave velocity test.

Step 5: Calculate elastic parameters of rocks according to the measured longitudinal and shear wave velocities.

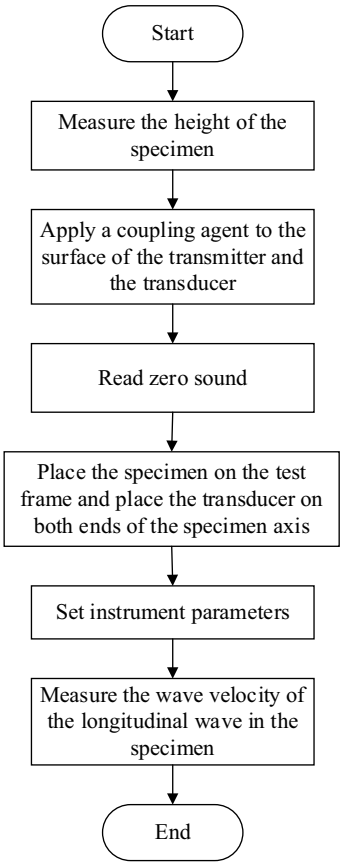

Figure 7.17 Flowchart for determining the wave velocity (ultrasonic pulse transmission)

7.4.10 Rebound hardness

Rebound distance of the elastic rod is defined as the rebound value when the rock surface is impacted by the elastic rod of the rebound apparatus which. Rebound distance reflects the surface hardness of the rock. The test process is shown in Figure 7.18.

Procedures:

Step 1: Measurement of the rock rebound hardness.

Support the surface of the specimen by the rebounding rod of the rebound apparatus, and slowly press the button of the rebound apparatus to extend rebounding main rod, as such, the rebound hammer is hung on the hook.

Hold the rebound tester and apply pressure to the specimen slowly and evenly. As the hammer is unhooked and impacted, the hammer moves the pointer backward. At this time, the rebound value on the scale is recorded. Change the measurement points and repeat the steps in Figure 7.18. Collect the test data of 16 points in each measuring area.

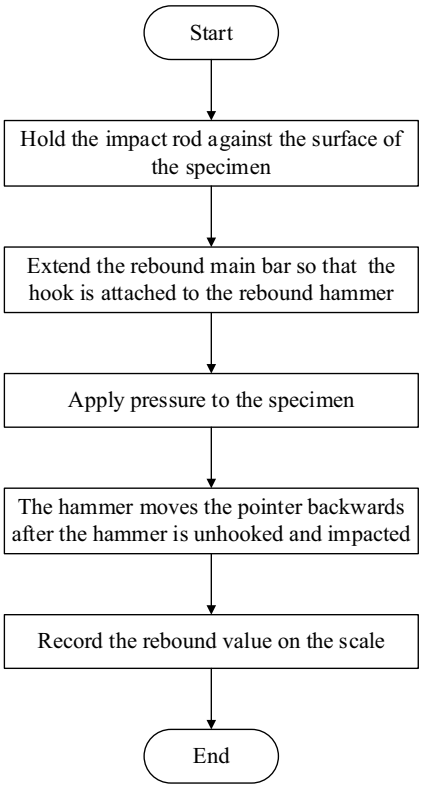

Figure 7.18 Flowchart for determining the rebound hardness of rocks

Step 2: Data processing

Among sixteen data of each measurement area, the three maximum values and three minimum values in the measurement area are discarded. The average of the remaining data could be used as the rebound value of rocks.