SUGGESTED METHOD FOR DETERMINING ROCK MASS DEFORMABILITY USING A RADIAL JACK CONFIGURATION

Scope

1. (a) This test determines the deformability of a rock mass by subjecting the cylindrical wall of a tunnel or chamber to uniformly distributed radial jack loading and measuring the resultant rock displacements. Elastic or deformation moduli are calculated in turn.

(b) The test loads a large volume of rock so that the results may be used to represent the true properties of the rock mass, taking into account the influence of joints and fissures. The anisotropic deformability of the rock can also be measured.

(c) The results are usually employed in the design of dam foundations and for the proportioning of pressure shaft and tunnel linings.

(d) Two other methods are available for tunnel-scale deformability. See RTH-361 and RTH-366 to compare details. The large impacts, especially in terms of cost, of variations at this scale justify the separation of methods.

(e) This test is expensive to perform, and therefore, should only be used in cases where the information to be gained is of critical importance to the success or failure of the project. Laboratory tests, together with plate bearing and borehole jack tests and seismic surveys may provide adequate estimates of deformability at less cost.

(f) This method largely follows the method in the ISRM and ASTM references listed at the end of this method.

Apparatus

2. Equipment for excavating and lining the test chamber including:

(a) Drilling and blasting materials or mechanical excavation equipment.[1*]

*Numbers refer to NOTES at then end of the text.

(b) Concreting materials and equipment for lining the tunnel, together with strips of weak jointing material for segmenting the lining.[2]

3. A reaction frame (Figure 1) composed of a set of steel rings of sufficient strength and rigidity to resist the force applied by flat jacks. The frame must be provided with smooth surfaces; hardwood planks are usually inserted between the flat jacks and the steel rings.

4. Loading equipment to apply a uniformly distributed radial pressure to the inner face of the concrete lining, including:

(a) A hydraulic pump capable of applying the required pressure and of holding this pressure constant within 5% over a period of at least 24 hr together with all necessary hoses, connectors, and fluid.

(b) Flat jacks, designed to load the maximum of the full circumference of the lining, with sufficient separation to allow displacement measurements, and with a bursting pressure and travel consistent with the anticipated loads and displacements.

5. Load measuring equipment comprising one or more hydraulic pressure gages or transducers[3] of suitable range and capable of measuring the applied pressure with an accuracy better than ±2%.

6. Displacement measuring equipment to monitor rock movements radial to the tunnel with a precision better than 0.01 mm. Single or multiple position extensometers are suggested but joint meters and other measuring devices are also available. Measured movements must be related to fixed reference points, outside the zone of influence of the test section.

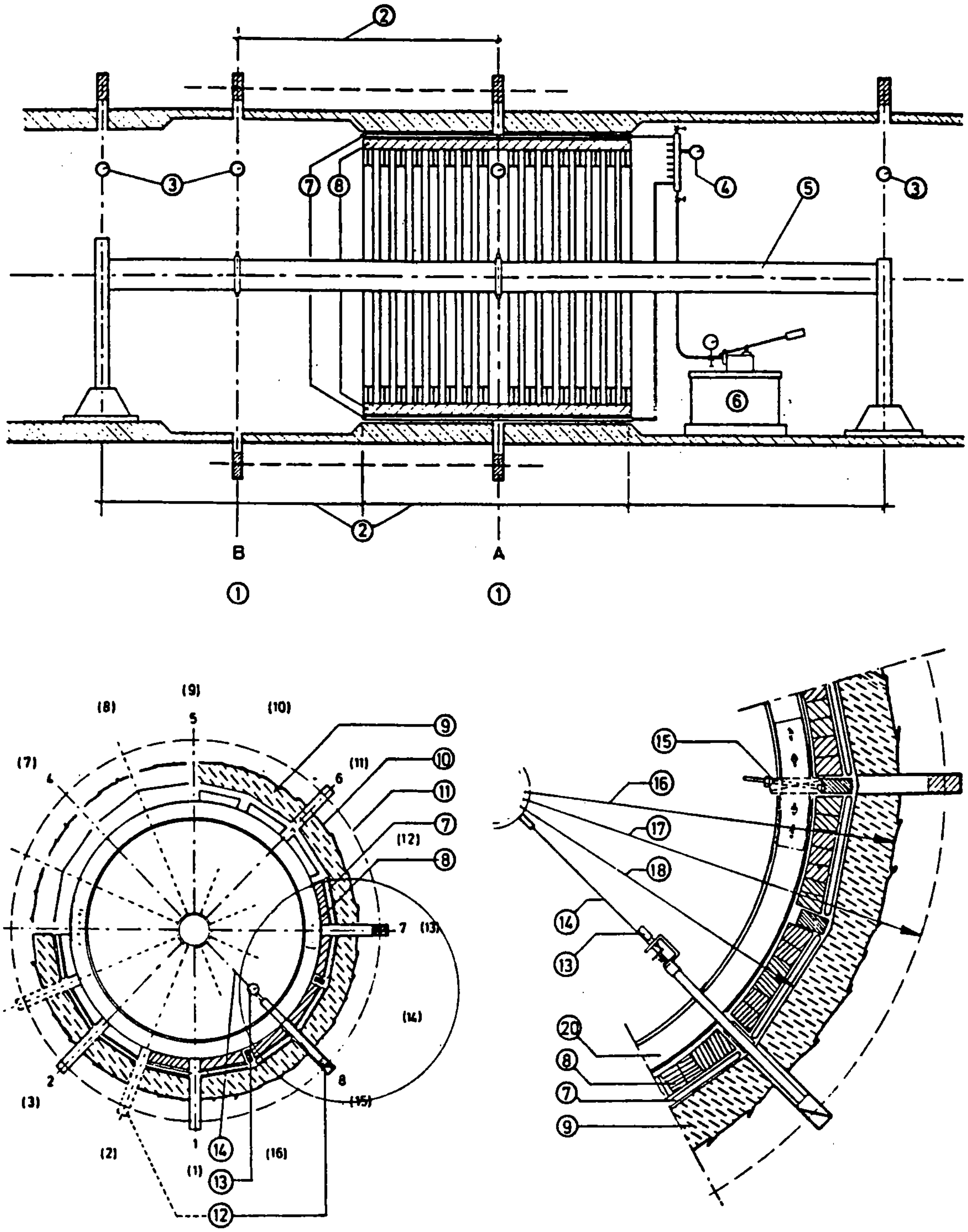
Procedure

7. Preparation

(a) The test chamber location is selected taking into account the rock conditions, particularly the orientation of the rock fabric elements such as joints, bedding and foliation in relation to the orientation of the proposed tunnel or opening for which results are required.

(b) The test chamber is excavated to the required dimensions.[1,4] Generally, the test chamber is about 3 m diam and 9 m long or longer.

(c) The geology of the chamber is mapped and recorded and specimens taken for testing as required, e.g. laboratory strain gaged uniaxial and triaxial testing.



1. Measuring profile. 2. Distance equal to the length of active loading. 3. Control extensometer. 4. Pressure gage. 5. Reference beam. 6. Hydraulic pump. 7. Flat jack. *. Hardwood lagging. 9. Shotcrete. 10. Excavation diameter. 11. Measuring diameter. 12. Extensometer drill holes. 13. Dial gage extensometer. 14. Steel rod. 15. Expansion wedges. 16. Excavation radius. 17. Measuring reference circle. 18. Inscribed Circle. 19. Rockbolt anchor. 20. Steel ring.

Figure 1. Radial jacking test schematic.

(d) The chamber is lined with concrete.[2]

(e) The reaction frame and loading equipment are assembled.

(f) Holes for extensometers or other measuring devices are accurately marked and drilled, ensuring no interference between loading and measuring system. Locations of radial measurement should be chosen with regard to the rock fabric and any other anisotropy. These holes should be continuously cored and all core carefully logged. These holes may be drilled before the test section is lined, but this complicates the lining formwork.

(g) Measuring equipment is installed and checked. With multiple position extensometers the deepest anchor may be used as a reference provided it is situated at least 2 chamber diameters from the lining. Alternatively the measurements may be related to a rigid reference beam passing along the axis of the chamber and anchored not less than 1 diameter from either end of the test section (Figure 1).

8. Testing

(a) The test is carried out in at least three loading and unloading cycles, a higher maximum pressure being applied at each cycle.[5] Maximum test pressures are typically about 1000 psi (7 MPa), but should correspond to expected actual loads.

(b) For each cycle the pressure is increased at an average rate of 0.05 to 0.7 MPa/min to the maximum for the cycle. Three to 10 or more intermediate sets of load-displacement readings are taken for each load increment to define a set of pressure-displacement curves (e.g. Figure 2). Data acquisition may be automated.

(c) On reaching the maximum pressure for the cycle the pressure is held constant (±2% of maximum test pressure) while recording displacements as a function of time until approximately 80% of the estimated long-term displacement has been recorded (Figure 3).[6] Each cycle is completed by reducing the pressure to near-zero at the same average rate, taking a further three sets of pressure-displacement readings.

(d) For the final cycle the maximum pressure is held constant for 24 hr of displacement are observed to evaluate creep.[6] The cycle is completed by unloading in stages while taking readings of pressure and corresponding displacements.

(e) The test equipment is then dismantled and moved.[4]

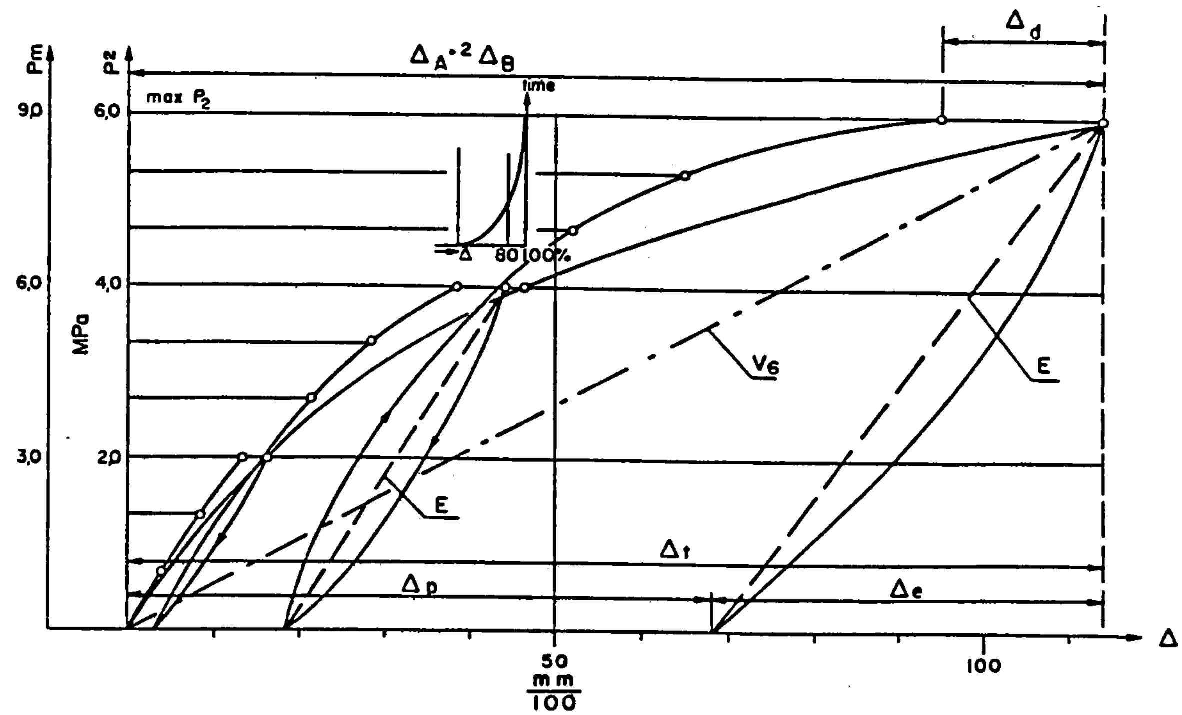


Figure 2. Typical pressure-displacement curves.

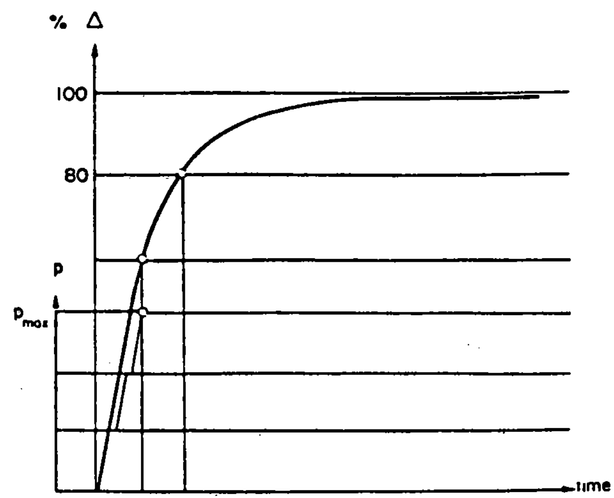


Figure 3. Typical displacement-time curves at constant applied pressure.

Calculations

9. (a) A solution is given only for the case of a single measuring circle with extensometer anchors immediately behind the lining. This solution, which also assumes linear-elastic behavior for the rock, is usually adequate in practice although it is possible to analyze more complex and realistic test configurations using for example finite element analysis.

(b) The load applied through the flat jacks are first corrected to given an equivalent distributed pressure p_1 on the test chamber lining.

$$p_1 = \frac{\Sigma b}{2 \cdot \pi \cdot r_1} p_m$$

p_1 = distributed pressure on the lining at radius r_1

p_m = manometric pressure in the flat jacks

b = flat jack width (see Figure 4)

r_1 = inner radius of lining

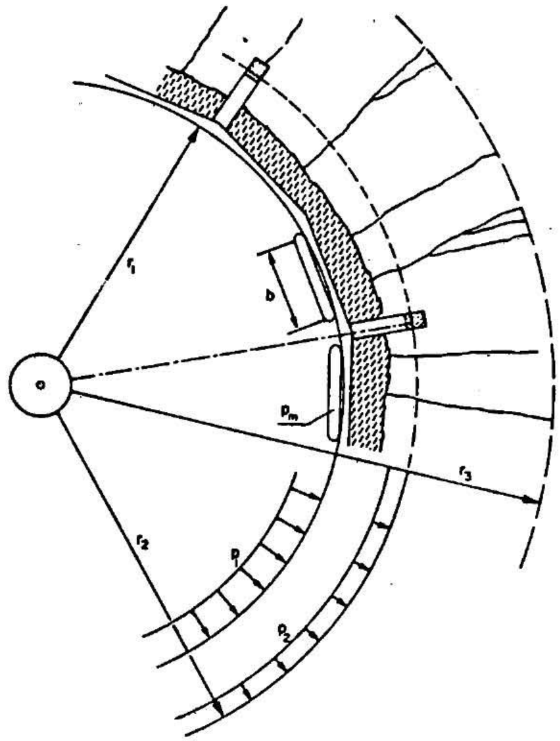
The equivalent pressure p_2 at a "measuring radius" r_2 just beneath the lining is calculated, this radius being outside the zone of irregular stresses beneath the flat jacks and the lining and loose rock.

$$p_2 = \frac{r_1}{r_2} \cdot p_1 = \frac{\Sigma\, b}{2 \cdot \pi \cdot r_2} \cdot p_m.$$

(c) Superposition of displacements (Figure 5) for two "fictitious" loaded lengths is used to approximate the equivalent displacements for an "infinitely long test chamber,"[7] based on the measured displacements of the relatively short test chamber with respect to its diameter.

$$\Delta = \Delta A_1 + \Delta A_2 + \Delta A_3 = \Delta A_1 + 2 \cdot \Delta B_1$$

(d) The result of the long duration test (Δ_d) under maximum pressure (max p_2) is plotted on the displacement graph (Figure 2). Test data for each cycle are proportionally corrected to give the complete long-term pressure-displacement curve. The elastic and plastic components of the total



$$p_m \sum b = p_1 2 r_1 \Pi$$

$$p_1 = \frac{\sum b}{2 \Pi r_1} p_m$$

$$p_2 = \frac{r_1}{r_2} p_1$$

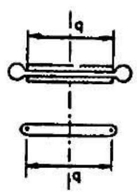


Figure 4. Schematic of loading with symbols used in calculations.

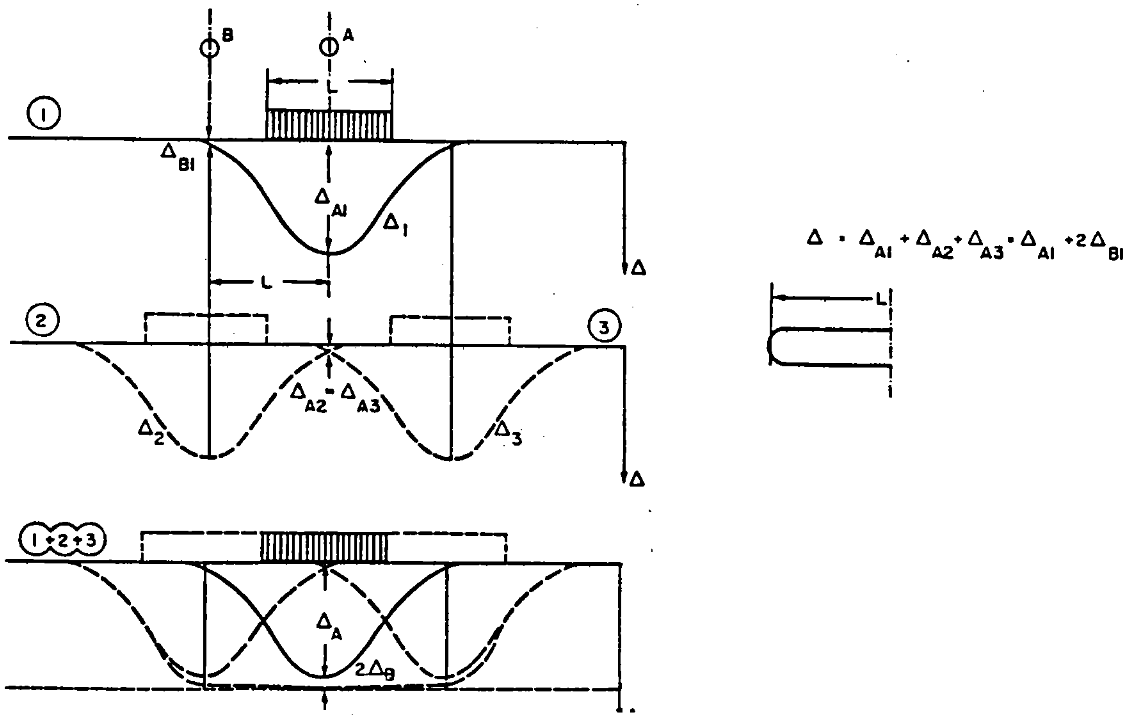


Figure 5. Method of superpositioning of displacements to eliminate end effects.

deformation are obtained graphically from the plotted deformation measurements at the final unloading:

$$\Delta t = \Delta_p + \Delta_e$$

(e) The elastic modulus E and the deformation modulus V are obtained from the pressure-displacement graphs (Figure 2) using the following formulas based on the theory of elasticity:

$$E = \frac{p_2 \cdot r_2}{\Delta_e} \cdot \frac{(\nu + 1)}{\nu}$$

$$V = \frac{p_2 \cdot r_2}{\Delta_t} \cdot \frac{(\nu + 1)}{\nu}$$

where p_2 is the maximum test pressure and ν is an estimated value for Poisson's ratio.

(f) Alternatively to (e) above, the moduli of undisturbed rock may be obtained taking into account the effect of a fissured and loosened region by using the following formulas:

$$E = \frac{p_2 \cdot r_2}{\Delta_e} \quad \frac{\nu + 1}{\nu} + \ln \frac{r_3}{r_2}$$

$$V = \frac{p_2 \cdot r_2}{\Delta_t} \quad \frac{\nu + 1}{\nu} + \ln \frac{r_3}{r_2}$$

Where Δt is the total deformation, from all loading cycles, and Δe is the rebound deformation from the last loading cycle. Other variables are as previously defined. Where r_3 is the radius to the limit of the assumed fissured and loosened zone.

(g) As one example of the application of radial jack tests, the dimensions of pressure linings can be determined directly by graph. See Lauffer and Seeber 1961. However, such empirical applications should only be applied with caution and good judgement.

Reporting

10. The report should include the following:

(a) Drawings, photographs, and detailed description of the test equipment, chamber, chamber preparation, lining, and testing.

(b) Geological plan and section of the test chamber showing and describing features that may affect the test results. Logs of borings made for the extensometer installations, and indexed photographs of the rock cores.

(c) Tabulated test observations together with graphs of displacement versus applied pressure p_m or p_2, and displacement versus time at constant pressure for each of the displacement measuring locations including displacements at the rock to lining interface. Tabulated "corrected" values together with details of the corrections applied. See Figures 2 and 3 and Table 1 (graphs are usually drawn only for the maximum and minimum displacements).

(d) Transverse section of the test chamber showing the total plastic displacements resulting from the maximum pressure (Figure 6). The orientations of significant geological fabrics should be shown on this figure for comparison with any anisotropy of test results.

(e) Detailed test procedure actually used and any variations and reasons for these from the method described herein, as well as any pertinent or unusual observations.

(f) The graphs showing displacements as a function of applied pressure (Figure 2) should be annotated to show the corresponding elastic and deformation moduli and data from which these were derived.

(g) Equations and methods used to reduce and interpret results should be clearly presented, along with one worked out example.

(h) All simplifying assumptions should be listed, along with discussion of pertinent variations between assumptions and actual size conditions and their possible influence on the results measured. Any corrections should be fully documented.

(i) Results summary table, including test location, rock type, test pressure range, and modulus values for different depth increments around the chamber.

(j) Individual test summary tables for each measurement point.

(k) Results of complementary tests, such as laboratory modulus.

Table 1. Suggested Layout for Test Data Sheet

1	2	3	4	5	4 + 5	6	7	4 + 5 + 7	8	9
NR	time	p_2	Δ_A	Δ_B	$\Delta_A + \Delta_B$	Δ_d	Δ_d corr.	Δ_t	Δ_e	Δ_p
1						—	—			
2						—	—			
3a							—			
3b							—			
3c										
4										
5										
6a							—			
6b							—			
6c										
7										
8										
9a										
9*							—			

$$E = \frac{p_2 \cdot r_2}{\Delta_e} \cdot \frac{\mu + 1}{\mu} = \text{----------------}$$

$$V = \frac{p_2 \cdot r_2}{\Delta_t} \cdot \frac{\mu + 1}{\mu} = \text{----------------}$$

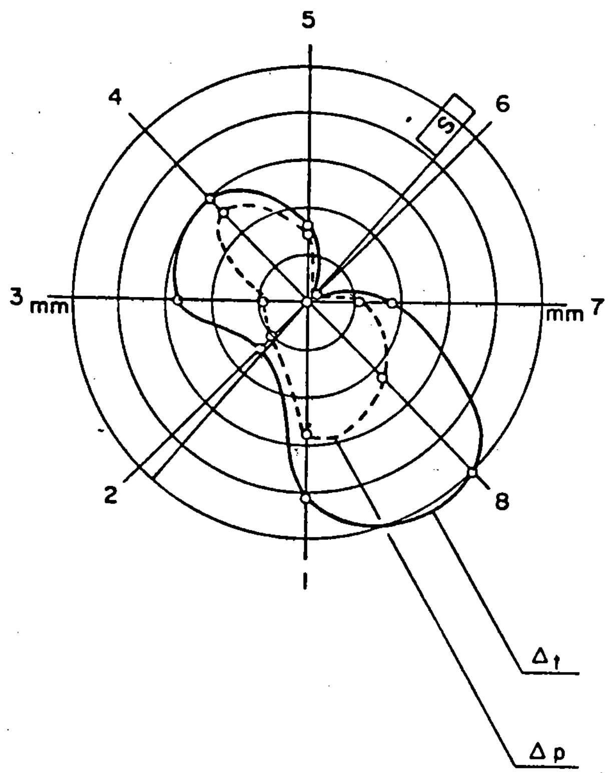


Figure 6. Typical illustration for showing displacement as a function of direction.

Notes

[1]The recommended diameters is 2.5 to 3 m, with a loaded length equal to 3 times this diameter. The chamber should be excavated with as little disturbance as possible, which implies the use of controlled blasting methods, such as line drilling or channel drilling. Alternatively, partial face mechanical excavation equipment may be used if available.

[2]When testing only the rock, the lining should be segmented so that it has negligible resistance to radial expansion; in this case the composition of the lining is relatively unimportant, and it may be of either shotcrete or concrete. Alternatively when it is required to test the lining together with the rock, the lining should not be segmented and its properties should be modeled according to those of the prototype.

[3]Measurements are usually made with mechanical gages. Particular care is required to guarantee the reliability of electric transducers and recording equipment.

[4]To assess the effectiveness of grouting, two test chambers may be prepared adjacent to each other. Grouting is carried out after completion of testing in the ungrouted chamber, and the equipment is then transferred to the grouted chamber. Alternatively the same chamber may be retested after grouting.

[5]Typically the maximum pressure applied in this test is 5 - 10 MPa.

[6]In the case of "creeping" rock it may be necessary to stop loading even though the displacements continue. Not less than 80% of the anticipated long-term displacement should have been reached.

[7]This superposition is made necessary by the comparatively short length of test chamber in relation to its diameter. Superposition is only strictly valid for elastic deformations but also give a good approximation if the rock is moderately plastic in its behavior.

References

International Society for Rock Mechanics, "Suggested Method for Measuring Rock Mass Deformability Using a Radial Jacking Test," International Journal of Rock Mechanics and Mining Sciences, v. 16, 1979, pp. 208-214.

American Society for Testing and Materials, 1986 Annual Book of ASTM Standards, Section 4, Construction; Volume 4.08 Soil and Rock; Building Stones, Standard D 4506-85, "Standard Test Method for Determining the In Situ Modulus of Deformation of Rock Mass Using a Radial Jacking Test."

Lauffer, H. and Seeber, G., "Design and Control of Linings in Pressure Tunnels and Shafts," 7th International Conference on Large Dams, 1961.