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Barton-Bandis Criterion

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Definition

A series of rock-joint behavior routines which, briefly stated, allow the *shear strength and normal stiffness* of rock joints to be estimated, graphed, and numerically modelled, for instance, in the computer code UDEC-BB. Coupled behavior with deformation and changes in conductivity is also included (Barton 2016).

A key aspect of the criterion is the quantitative characterization of the joint, joints, or joint sets in question, in order to provide three simple items of input data. These concern the joint-surface roughness (*JRC: joint roughness coefficient*), the joint-wall compressive strength (*JCS: joint compressive strength*), and an empirically derived estimate of the *residual friction angle* (φ_r). These three parameters have typical ranges of values from: JRC = 0 to 20 (smooth-planar to very rough-undulating), JCS = 10 to 200 MPa (weak-weathered to strong, unweathered) and $\varphi_r = 20°$ to 35° (strongly weathered to fresh-unweathered). Each of these parameters can be obtained from simple, inexpensive index tests or can be estimated by those with experience.

The three parameters JRC, JCS, and φ_r form the basis of the nonlinear peak shear-strength equation of Barton (1973) and Barton and Choubey (1977). This is a *curved shear strength envelope* without cohesion (c). It will be contrasted to the linear Mohr-Coulomb "c and φ" (with apparent cohesion) criterion later. To be strictly correct the original Barton equation utilized the basic friction angle φ_b of flat, unweathered rock surfaces (in 1973), while φ_r was substituted for φ_b following 130 direct shear tests on fresh and partly weathered rock joints (in 1977).

As well as peak and residual shear strength envelopes for laboratory-scale joint samples, Barton's cooperation with Bandis (from 1978) resulted in corrections (reductions) of JRC and JCS to allow for the *scale effect* and reduced strength as rock-block size is increased (Banton and Bandis 1982). The laboratory-scale parameters, written as JRC_0 and JCS_0 for laboratory-size samples of length L_0 (typically 50–250 mm), are written as JRC_n and JCS_n for in situ rock block lengths of L_n (typically 250–2500 mm, or even larger in massive rock).

Bandis is also responsible for utilizing JRC and JCS in empirical equations to describe *normal closure and normal stiffness*. Normal stiffness (Kn) has units of MPa/mm and might range from 20 to 200 MPa/mm. The Barton-Bandis (B-B) criterion includes the related modelling of *physical joint aperture E* (typically varying from 1 mm down to 50 μm, or 0.05 mm) as a result of the normal loading (or unloading). B-B also includes the theoretically equivalent smooth-wall *hydraulic aperture e* (typically 1 mm down to 5 μm, or 0.005 mm). Usually E > e, and the two are empirically inter-related, using the small-scale joint roughness JRC_0.

Finally the stiffness in the direction of shearing has also to be addressed. It is called *peak shear stiffness (Ks).* It has typical values of 0.1 MPa to 10 MPa/mm, i.e., 1/10th to 1/100th of normal stiffness. The concept of *mobilized roughness* ($JRC_{mobilized}$) developed by Barton (1982) allows both the peak shear-stiffness and the *peak dilation angle* (giving an effective aperture increase with shearing) to be calculated. The full suite of Barton-Bandis joint behavior figures includes *shear stress-displacement-dilation, stress-closure, and the change of estimated conductivity* in each case. Examples of these will be given, following diagrams illustrating joint index testing (Figs. 1, 2, 3, 4, 5, 6, 7, and 8) (Barton and Bandis 2017).

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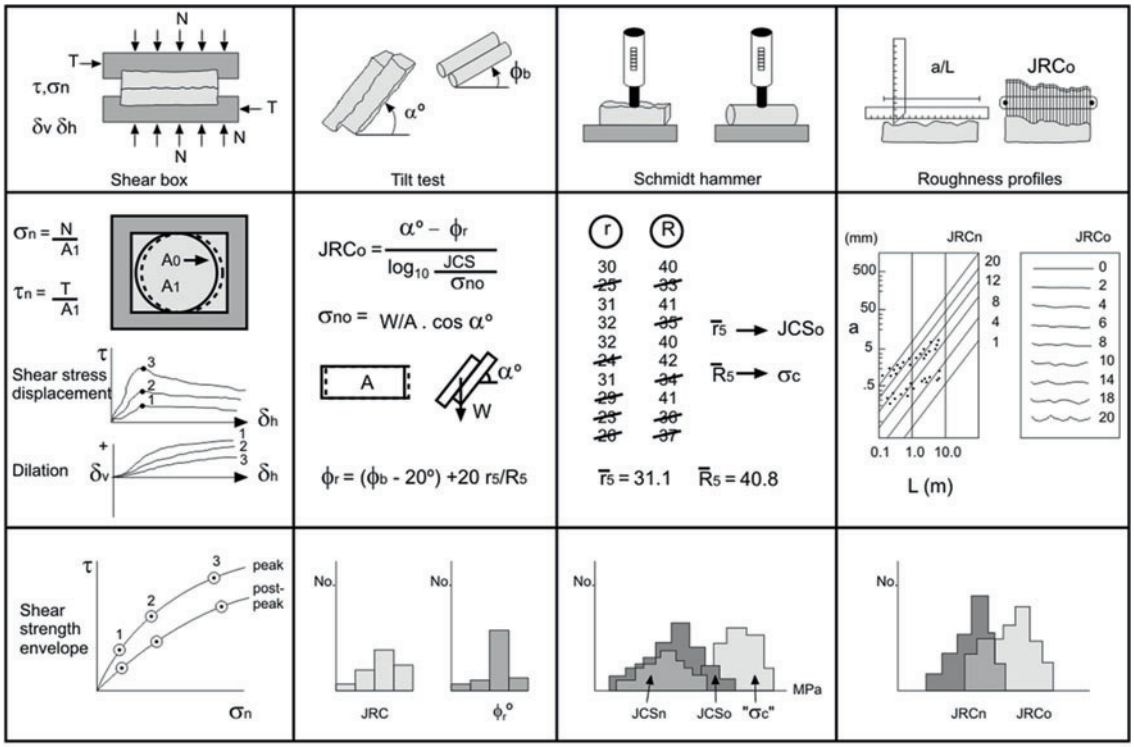
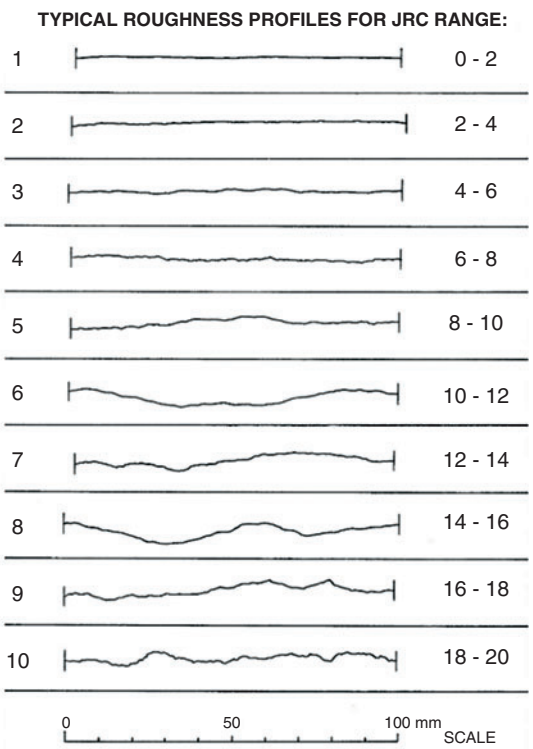
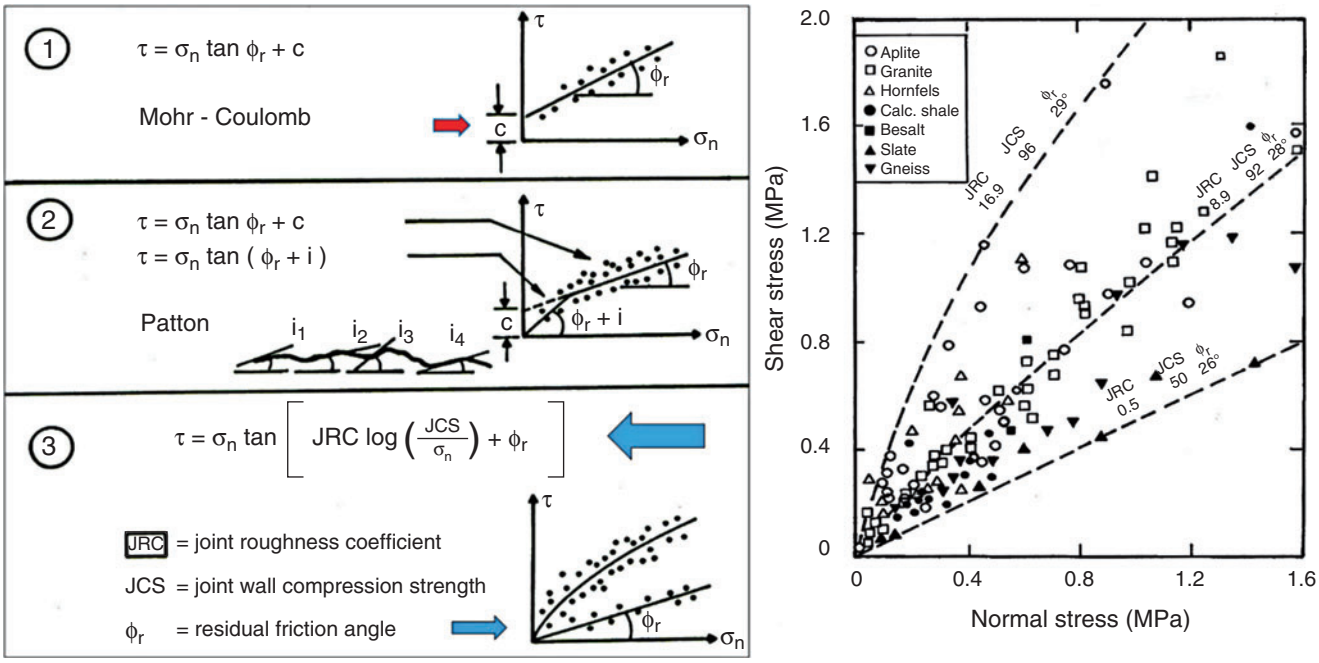
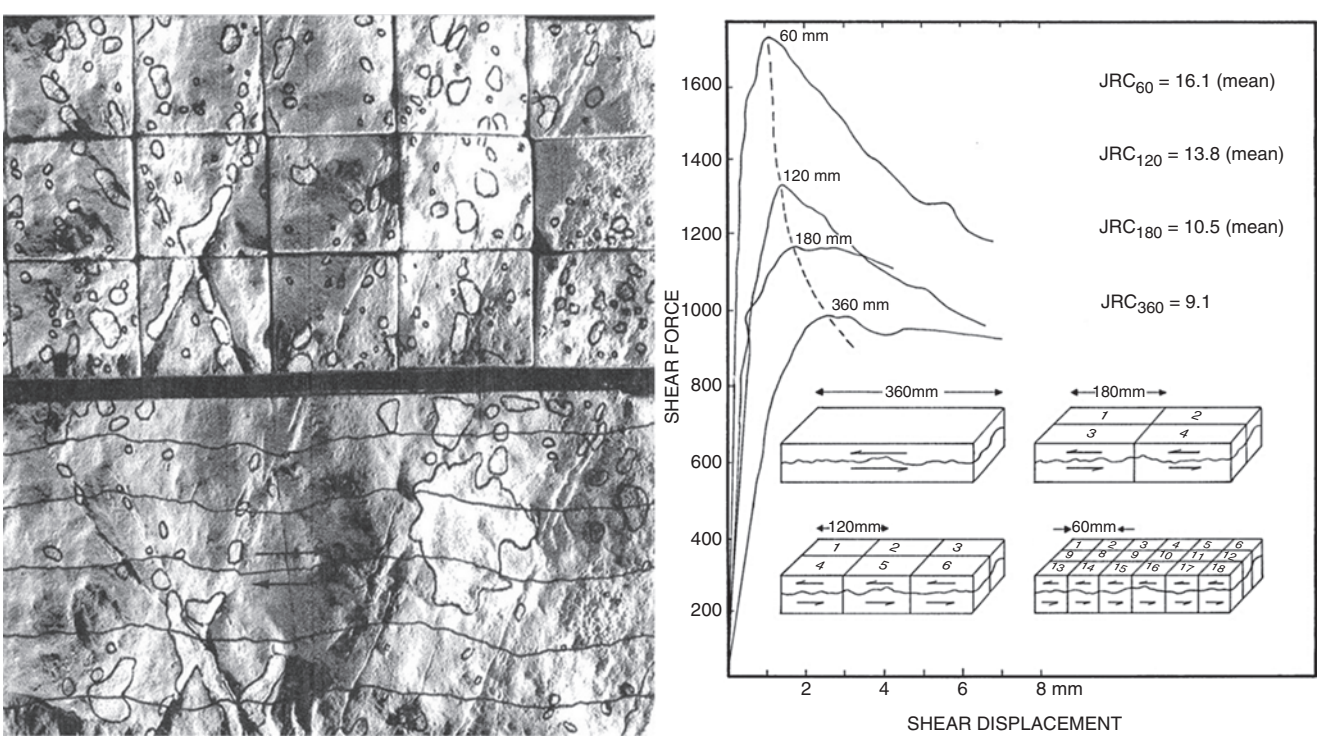




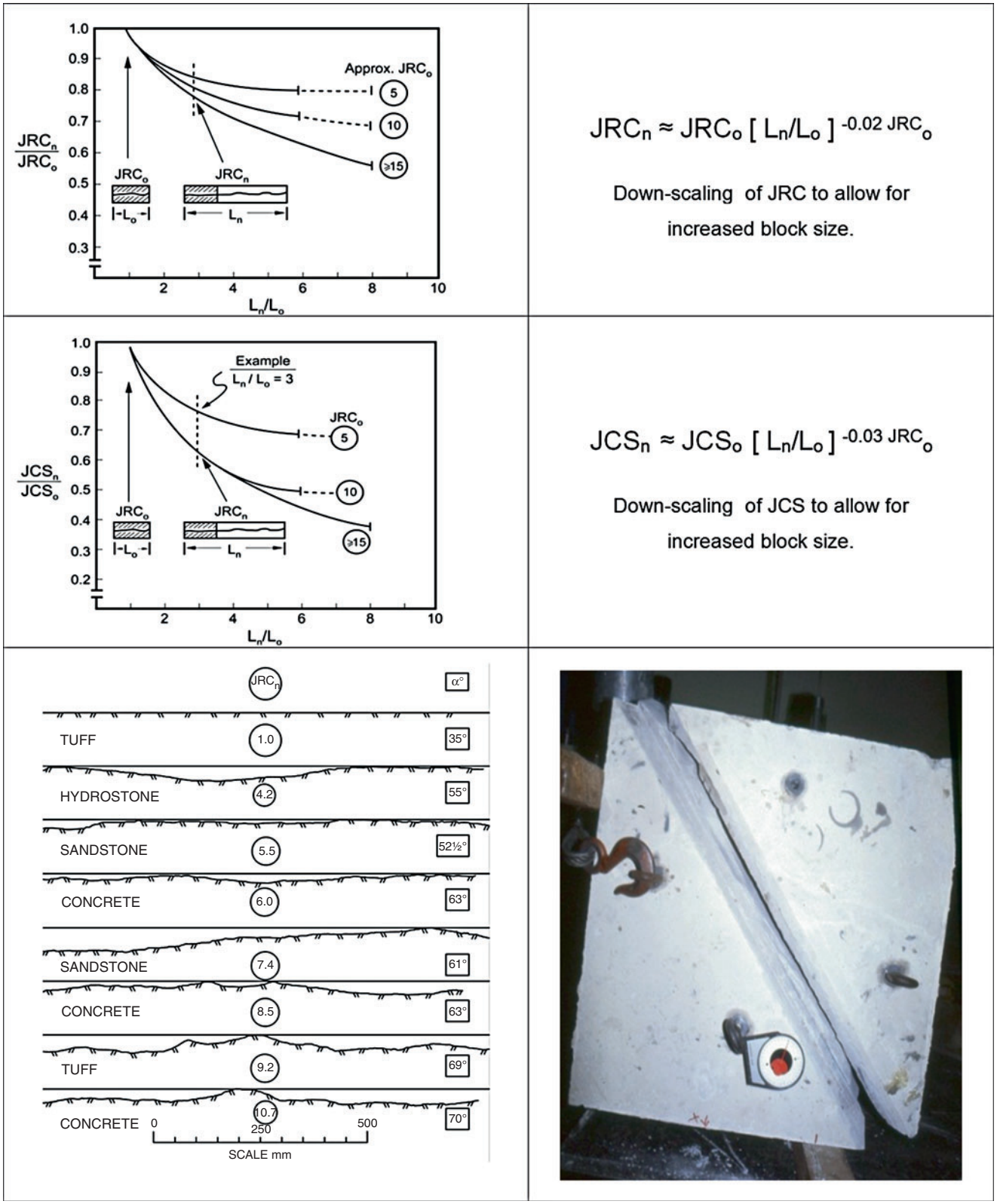
Barton-Bandis Criterion, Fig. 1 Top: Four columns of diagrams showing *1*. direct shear tests principles (Note: apply shear force T "in-line" to avoid creating a moment), *2*. tilt test principles for measuring JRC_0 with jointed-block samples, and ϕ_b with drill-core *3*. Schmidt hammer test principles for measuring JCS, and *4*. roughness recording with profile gauge, and a/L (amplitude/length) method for estimating JRC_n at larger scale (Barton 1999). Bottom: Example roughness profiles and the ten samples with JRC ranges, tilt tests for JRC and φ_b. (Barton and Choubey 1977)



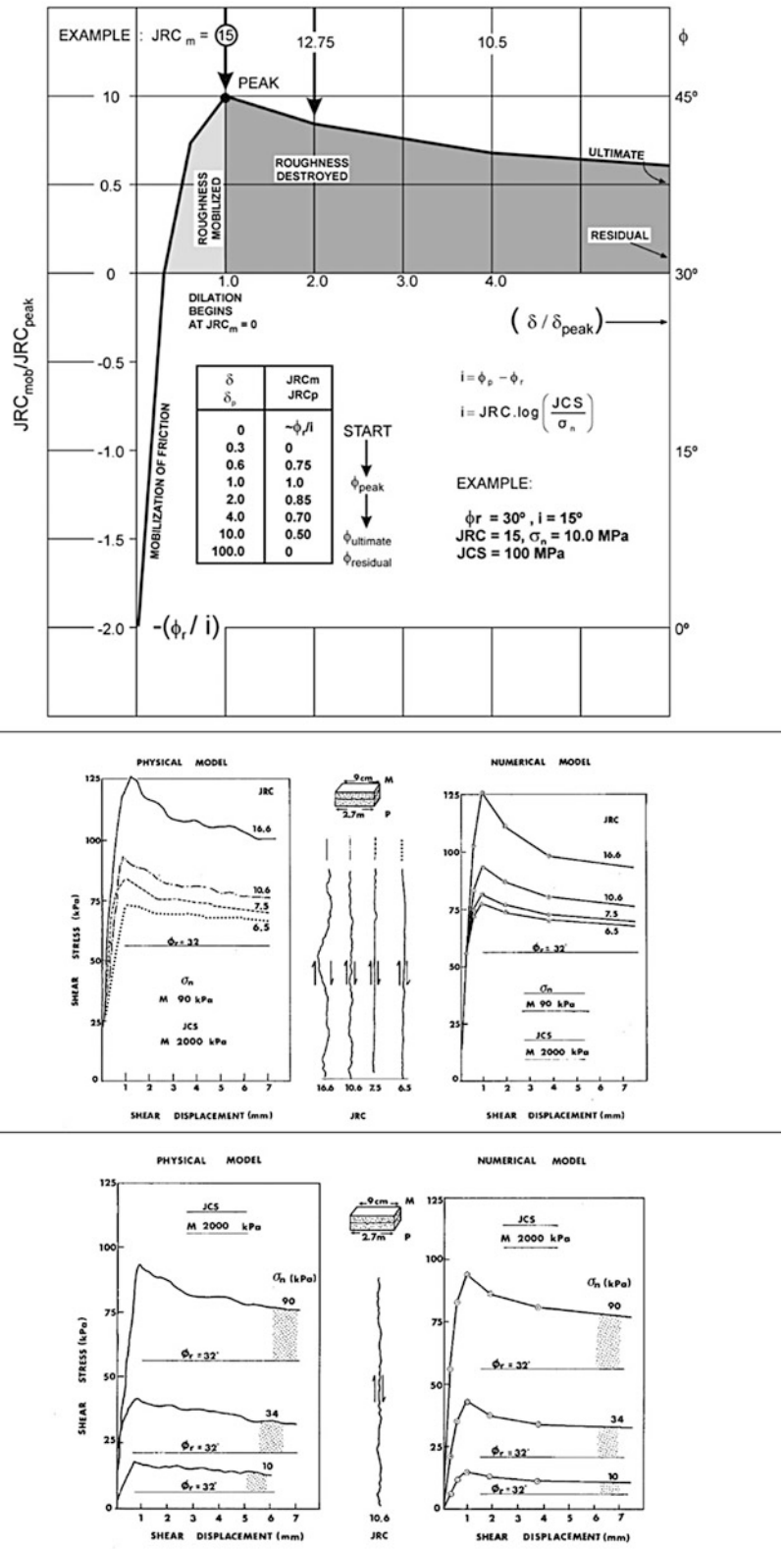
Barton-Bandis Criterion, Fig. 2 Left: Three shear strength criteria compared: *1*. Linear Mohr-Coulomb (with an assumed cohesion intercept c), *2*. Bi-linear Patton (φ + i) and *3*. Continuously curved Barton formula, termed Barton-Bandis when scale-effects are included. Right: The peak shear strengths of 130 joint samples, and examples of the maximum, mean and minimum strength envelopes, with JRC, JCS and φ_r values. (Barton and Choubey 1977)



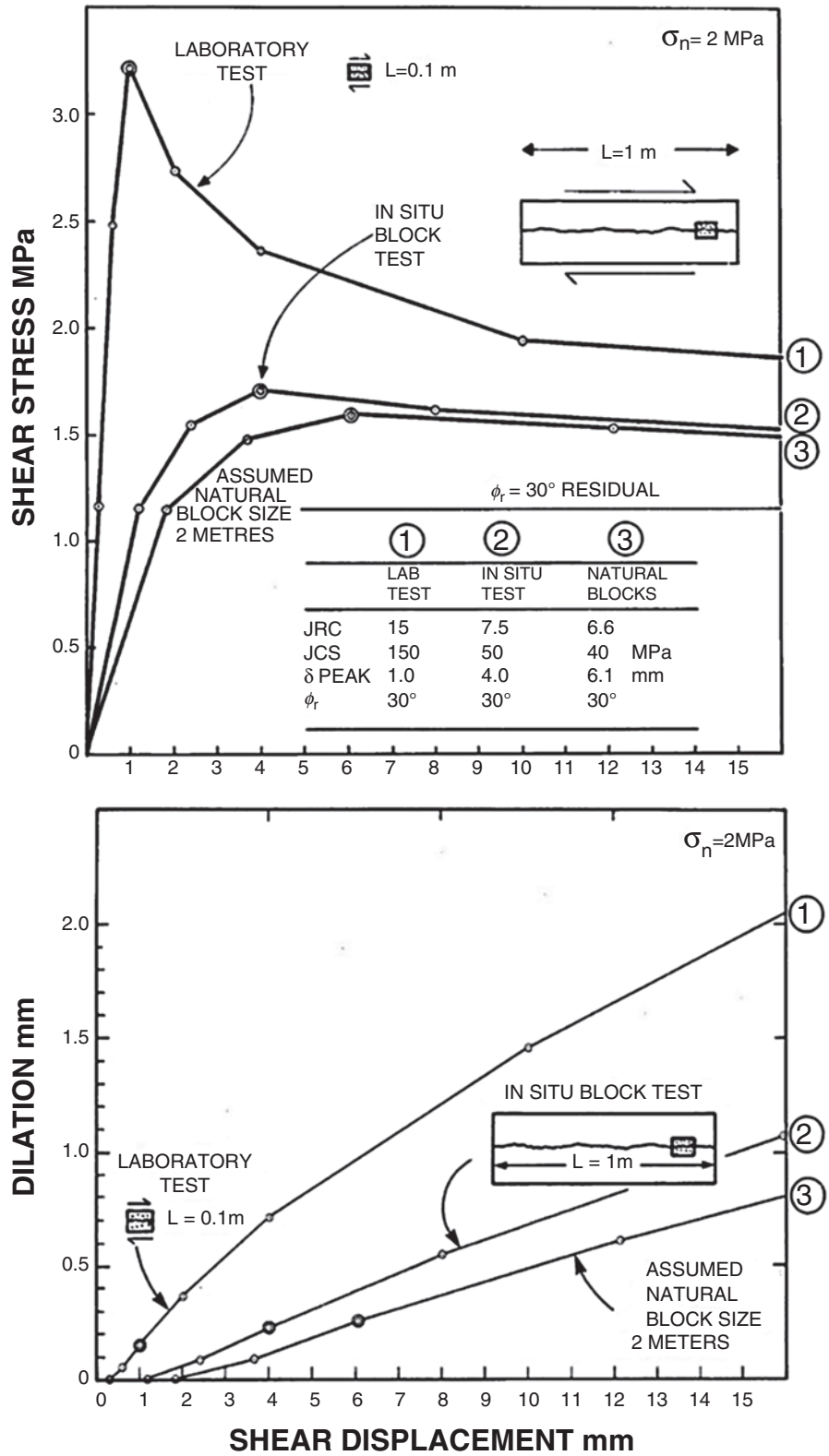
Barton-Bandis Criterion, Fig. 3 One example of the scale-effect studies by Bandis 1980 using replica castings of rock joints, which were direct shear-tested at different scale. (Effect on JRC greatest for the roughest joints) (Bandis et al. 1981)



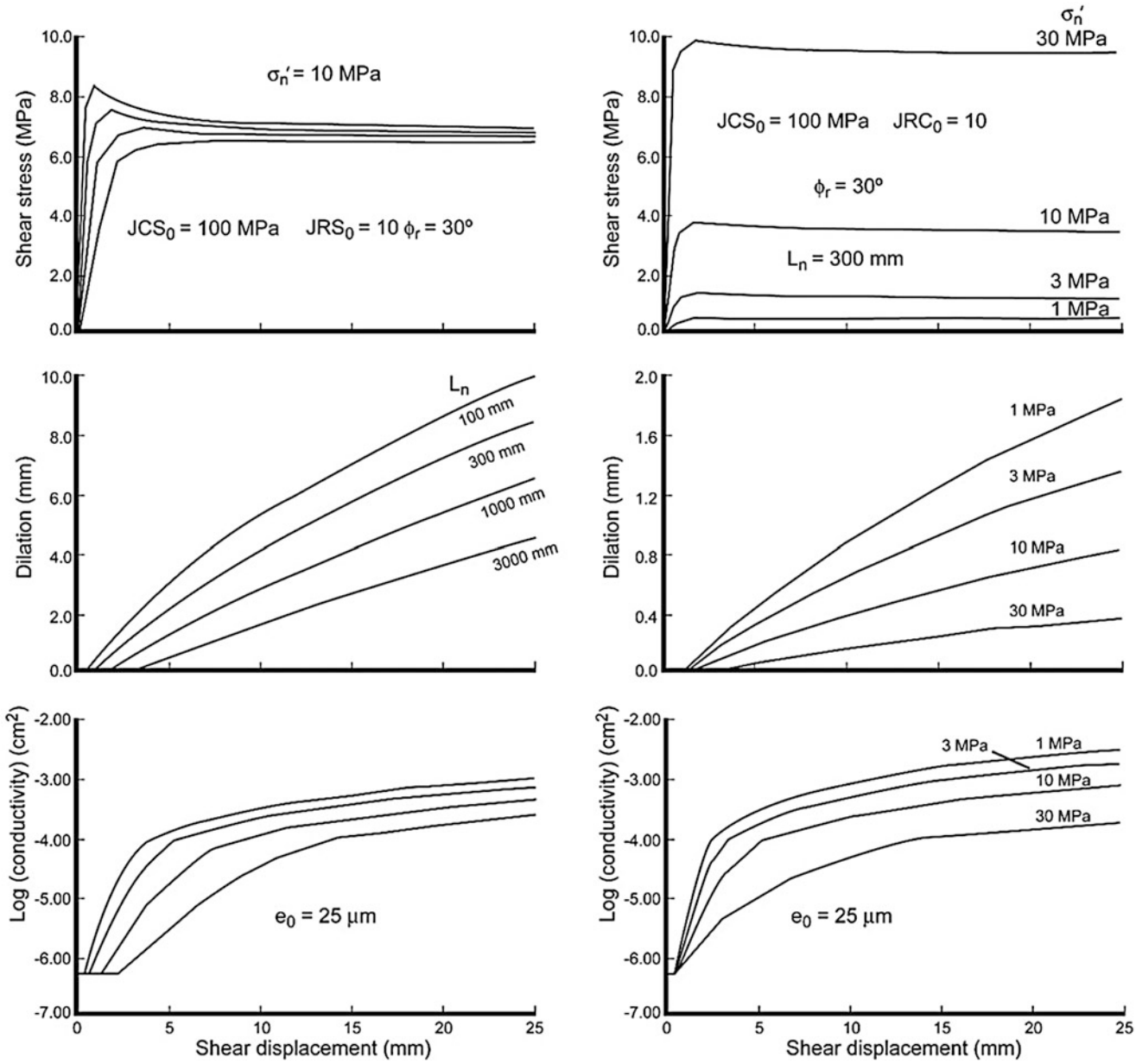
Barton-Bandis Criterion, Fig. 4 Formal allowance for the scale-effect on JRC and JCS which depends on the block length Ln (in practice the mean spacing of a crossing set of rock joints) (Barton and Bandis 1982). Roughness profiles measured on 1,300 mm long diagonally-jointed 1 m^3 blocks, with tilt angles (α) and measured JRC_n values (Bakhtar and Barton 1984)



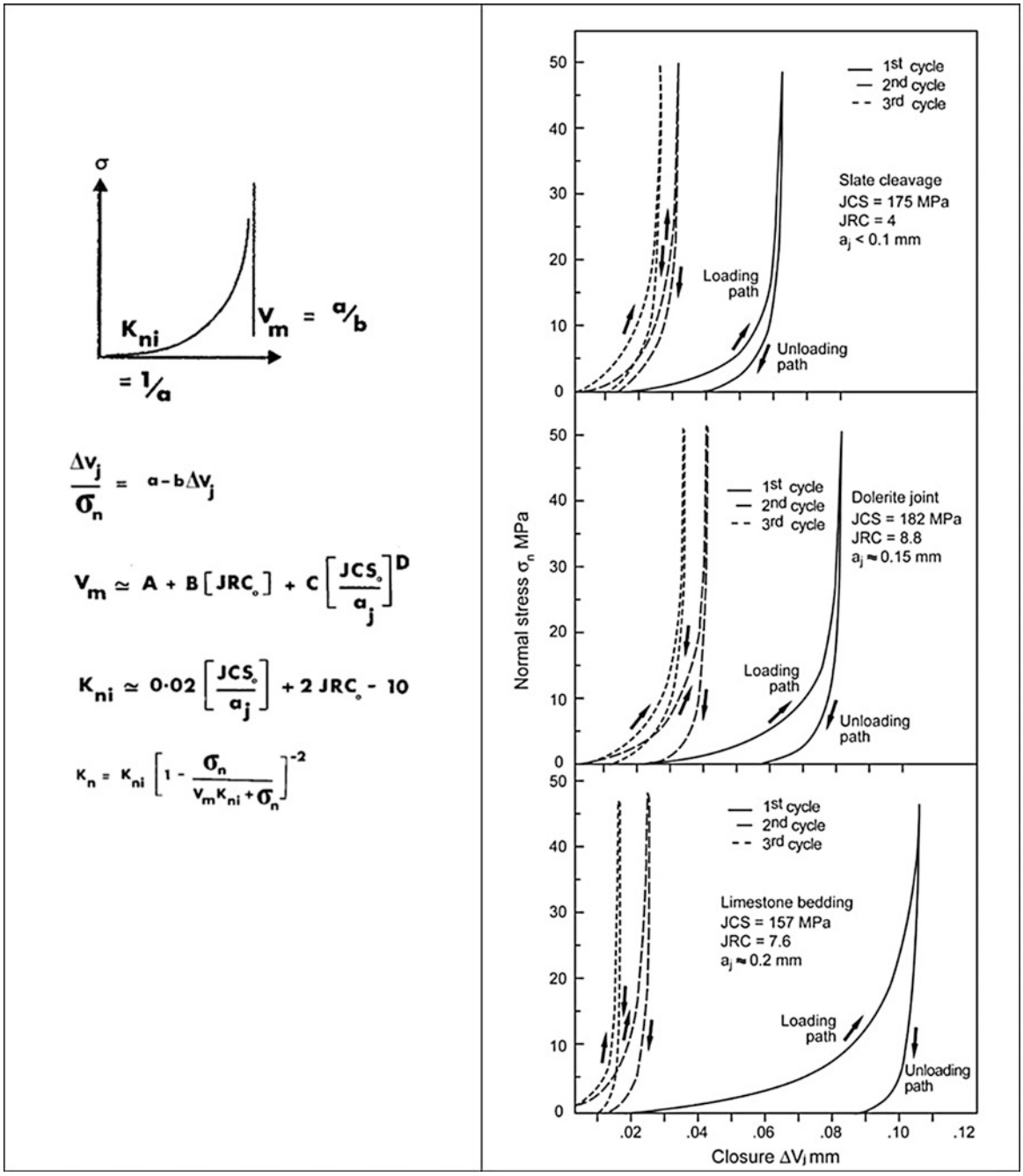
Barton-Bandis Criterion, Fig. 5 The $JRC_{mobilized}$ concept illustrated in the upper diagram allows shear-strength-displacement (and accompanying dilation and conductivity changes) to be modelled. This coupled behavior is modelled in the distinct element (jointed-media) code UDEC-BB. (Barton 1982; Barton and Bandis 2017)



Barton-Bandis Criterion, Fig. 6 Shear-displacement-dilation behavior, for three different block sizes. Barton (1982). Note the inset showing the scaling assumptions from the Bandis et al. (1981) equations given in Fig. 3. Note increase in δ_{peak} as block size increases. Since there is also a reduction in peak shear strength, the peak shear stiffness Ks suffers a double scale-effect as block-size increases



Barton-Bandis Criterion, Fig. 7 Examples of "coupled" shear-dilation-conductivity modelling with the Barton-Bandis modelling assumptions. When block-size variations are involved (left) the delayed dilation and therefore delayed conductivity change can be noted. These curves were produced in 1983 by Bakhtar using a programmable HP calculator (Barton and Bakhtar1983, 1987) the BB equations by now assembled in Barton 1982. ONWI and AECL funded work were responsible for the "finalization" of the BB model prior to its programming (by Mark Christianson of Itasca) into the distinct element code UDEC-BB. (Barton and Bakhtar 1983, 1987), using (see also Barton and Bandis 2017)



Barton-Bandis Criterion, Fig. 8 The nonlinear modelling of joint closure by Bandis (1980) and Bandis et al. (1983). The three load-unload cycles are designed to mirror the experimental evidence of a large hysteresis on the first cycle due to the unavoidable effects of taking a (drill-core) sample which releases the original in situ normal stress. The first load cycle re-closes the joint. The properly consolidated (cycle 3) behavior is incorporated in the distinct-element (jointed) code UDEC-BB

Cross-References

- ▶ Mohr-Coulomb Failure Envelope
- ▶ Rock Mass Classification
- ▶ Shear Strength

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