

# Better Understanding the Strengths of Serpentinite Bimrock and Homogeneous Serpentinite

By Ulrich Glawe and Bishal N. Upreti

This paper describes two projects in which serpentinite caused significant problems: during design of the Kusan-3 HEPP dam in Indonesia; and during construction of the Berke powerhouse access tunnel in Turkey.

## Case history 1: Kusan-3 HEPP dam, Indonesia

The principal features of the Kusan-3 HEPP, which is located in the Meratus Mountain Range in South Kalimantan, Indonesia, are the 100 m high RCC-dam and the 130 MW surface powerhouse at the toe of the dam. The general arrangement of the project is shown in Figure 1. The foundation rock mass consists of serpentinite, pyroxenite, peridotite, and diorite dykes (Figure 2).

The investigations described below were performed in the tender design stage of the project. However, although the design is economical and technically viable, the construction of the dam

has been delayed. The dam was eventually designed with a trapezoidal shape, with a vertical upstream face and a downstream slope of 0.7 H : 1 V. It was necessary to introduce a curve in the axis of the dam to optimize foundation conditions. As described below, the geology has influenced the dam design: The axis (see Figure 1) has been selected to ensure that the dam height and footprint area on the serpentinite is minimized. For the selected axis, the maximum height of the section founded on serpentinite is only 72 m. The structure was designed as a two-dimensional body, perpendicular to the dam axis, since the arching action induced by the curvature will not be significant.

Field investigation indicated that about 28 % of the dam footprint is within serpentinite, despite serpentinite being recognized as an unsatisfactory and occasionally unacceptable foundation material. In fact, rock engineering literature warns the engineer: "Dams should not be placed

## Zum besseren Verständnis der Festigkeiten von Melange Serpentinitt und homogenem Serpentinitt

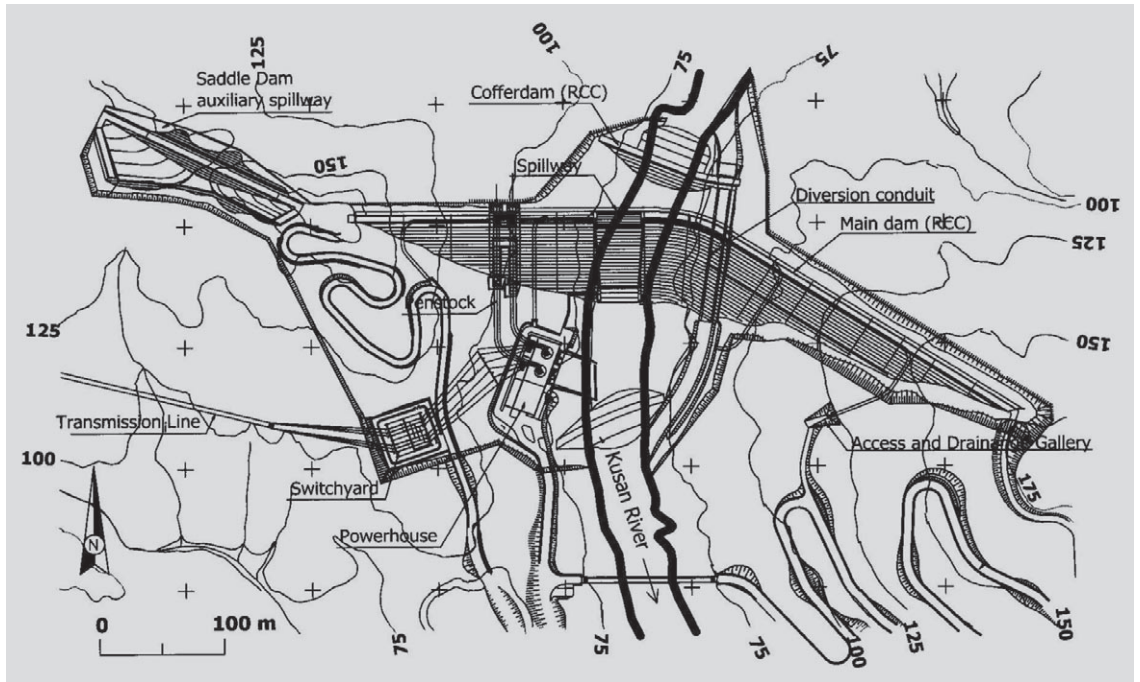
*Die vorliegende Arbeit umfasst zwei Projekte, in denen Serpentinitt, jeweils geologisch unterschiedlich ausgebildet, erhebliche Probleme in der Planungsphase beziehungsweise in der Bauphase darstellte. Im Wasserkraftprojekt Kusan-3 besteht die Aufstandsfläche der geplanten 100 m hohen Schwergewichtsmauer zu 28 % aus Serpentinitt. Serpentinitt, der an der Sperrenstelle eine Bimrock-Struktur aufweist, stellt im Allgemeinen ein fragwürdiges Gründungsmaterial dar. Zur Bestimmung des felsmechanischen Datensatzes (Festigkeit) wurden Feld- und Laboruntersuchungen durchgeführt. Die Ableitung des Design-Parametersatzes basierte auf Ergebnissen der Labortests und erfolgte unter Einbezug des Maßstabeffekts und der Trennflächeneigenschaften. Die so ermittelten unerwartet hohen Materialfestigkeiten, die mit der Anwendung der GSI-Klassifikation bestätigt wurden, lassen sich nur mit lokal ausgeprägten mineralogischen und strukturellen Faktoren erklären, wobei insbesondere die Trennflächeneigenschaften innerhalb der Matrix eine wesentliche Rolle spielen.*

*Beim Bau des Zugangstunnels zur Zentrale der Berke-Wasserkraftanlage im Südosten der Türkei wurden Erfahrungen mit einem Serpentinitt gemacht, der andere strukturelle und mechanische Eigenschaften aufweist. Im Gegensatz zum Kusan-3 Serpentinitt erscheint das Material selbst im kleinen Maßstab homogen. Die Feldbeobachtungen und Berechnungen erbrachten Hinweise auf eine sehr*

*geringe Gebirgsfestigkeit. Dies hatte wesentlichen Einfluss auf die Baumethode, die dann den vorherrschenden Gebirgsverhältnissen angepasst werden musste.*

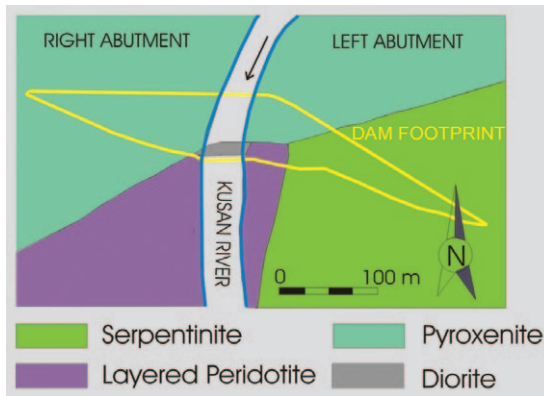
This paper describes two projects wherein serpentinite caused significant problems during design and construction, respectively. Serpentinite extends over 28 % of the dam footprint of the proposed 100 m high Kusan-3 gravity dam located in Indonesia and is well known to be a questionable foundation material. Both laboratory and in situ field tests were carried out on the serpentinite, which exhibits a bimrock structure. An estimate of the shear strength of the rock mass was conservatively developed from the laboratory data, taking scale effects and discontinuity characteristics into account. This resulted in a surprisingly high shear strength, which can only be explained with highly localized mineralogical and structural factors, particularly with the discontinuity characteristics in the matrix rock. However, applying the GSI-system to quantify the physical parameters of the serpentinite provided satisfactory confirmation of the selected values.

In the Berke HEPP in SE Turkey, a low-strength and homogeneous (even at small-scale) form of serpentinite was encountered during the construction of the powerhouse access tunnel. Field observation and results of numerical analyses indicated a very low strength rock, as one would expect for a serpentinite. The low strength resulted in considerable tunnel construction problems. On the basis of analysis the construction method was then tailored to the prevailing rock conditions.



**Fig. 1** General arrangement of the Kusan-3 HEPP.

**Bild 1** Auslegung der Wasserkraftanlage Kusan-3



**Fig. 2** Simplified geological map of the dam footprint area.

**Bild 2** Schematisierte geologische Karte des Bereichs der Sperrenaufstandsfläche.

on serpentinite” and that the material is “... unusable and unsuitable as the foundation for a dam” (1, page 239). Taking into account these legitimate published cautions, geotechnical inves-

tigations were focused on quantifying the mechanical properties of the serpentinite rock mass.

**Serpentinite: mineralogy, micro-structure and macro-structure**

Serpentinite consists of three minerals, namely Chrysotile, Lizardite and Antigorite. X-ray diffraction analyses indicated only Chrysotile and Lizardite in the serpentinite (2) at the dam site. Thin section analyses revealed that the original rocks have undergone complete serpentinization and have fractured into blocks by cataclases, making a form of “fault breccia”. The blocks have been cemented by precipitated serpentinite minerals forming a block-in-matrix structure or bimrock (3) even at microscopic scale. The rocks can be designated as “cohesive cataclases” with blocks ranging from a few mm in diameter to about 1 m<sup>3</sup> in volume.

Geological mapping revealed several slopes higher than 10 m and steeper than 45° within the serpentinite rock mass, with no visual signs of instability. On the left abutment, an adit (2 m x 2 m) was driven more than 20 m into a serpentinite rock mass by drilling and blasting: It required no rock reinforcement or support and showed no signs of instability even after being open for more than six months, and after the adit was widened at three locations to spans of more than 4 m. These extensions, made for the purpose of conducting in-situ direct shear tests, were excavated with great difficulty by pick and other hand tools.

The serpentinite rock mass in the adit appeared as a “mega-breccia”, a mixture of strong, joint-bounded rock blocks embedded in weaker matrix rock, and as such conformed in appearance to other bimrocks (3). The rock mass structure within the adit is considered to be similar to that found in borehole cores drilled at several locations elsewhere in the serpentinite.

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Matrix and blocks demonstrated a considerable difference in strength: Laboratory tests revealed the blocks to have average UCS of 66.5 MPa and the matrix rock to have an average UCS of 14.8 MPa. The ratio of block UCS to matrix UCS, being greater than 2, thus qualified the serpentinite to be considered a bimrock (3).

### Serpentinite blocks, matrix and discontinuities

The volume of the individual blocks in outcrops ranges from 0.001 to approximately 1 m<sup>3</sup>. In general, the edges of individual blocks are not longer than 0.4 m. Block shapes are random, although block edges typically are round and seldom angular. Blocks surfaces are generally undulated, some being concave, and with randomly oriented slickensides.

Site matrix rock is a "mini-breccia" or a fine-grained cataclasite, but it has the visual appearance of a homogeneous weak material. It was practically impossible to conventionally sample representative specimens for laboratory tests at outcrops or in the adit. Core recovery with conventional diamond drilling using triple-tube core barrels was very difficult. Intact core samples failed if bent with force by hand, or disintegrated into pieces at a light hammer blow. This fact is considered to reflect very low tensile strength of pre-existing discontinuities. The broken rock pieces exhibit slickensided and undulating fracture surfaces (Figure 3).

Despite the difficulties, the 60 mm drilled cores were further drilled along core axes to obtain eight 41 mm cores specimens of serpentinite matrix for laboratory testing. The success of this careful drilling, in the laboratory, to produce cores of the serpentinite matrix without "joints", clearly indicates that the serpentinite matrix lacked "joints", which are formally defined as "discontinuities without tensile strength". Consequently, the visible discontinuities in the serpentinite matrix are not considered as „joints”, but as undulating or curvilinear surfaces of weakness. When tool-excavated or when exposed in laboratory testing, after failure, these undulating surfaces were observed to be randomly oriented, polished, glossy or slickensided. Some of the surfaces coincide with block surfaces or run through the serpentinite matrix.

Similar observations were made in-situ. Several thousands of discontinuity measurements were performed at outcrops and in the adit, which clearly showed that there are no dominant discontinuity orientations in the serpentinite at a scale larger than 0.2 m x 0.2 m. The surfaces of weakness are closed, tight and nearly entirely slickensided (88%) and undulated (90%). They exhibit a relatively small persistence, represented by trace lengths on exposures generally less than 1 m, with a maximum of 4 m.



**Fig. 3** Drilled core specimen of the Kusan serpentinite.

**Bild 3** Bohrkernmaterial des Kusan Serpentinits.

### Determination of rock mass strength

Back-analyses of the relatively steep cliffs was considered as being inappropriate, because the actual failure mode and the theoretically analysed strengths might be different due to the existence of larger blocks in the serpentinite rock mass.

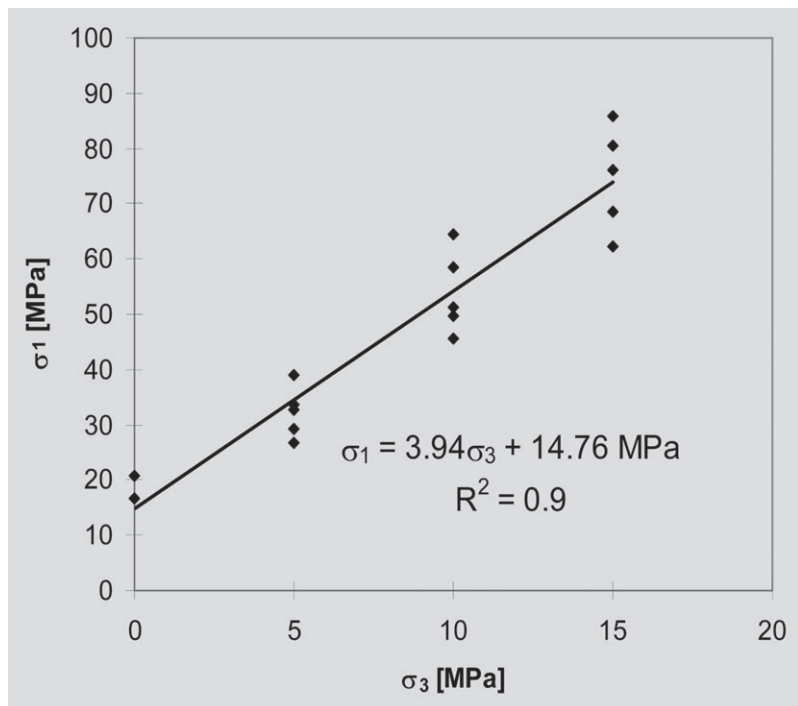
For the serpentinite rock mass at the dam site, the volumetric block portion in outcrops is estimated to be in the range of 10 to 15 %. This pro-

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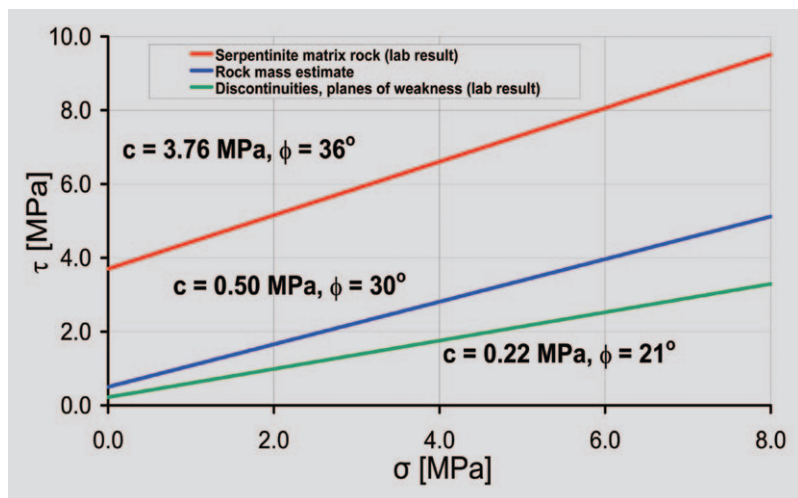
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**Fig. 4** Results of two uniaxial and five triaxial tests on the Kusan serpentinite.  
**Bild 4** Resultate von zwei einachsialen und fünf triaxialen Druckversuchen des Kusan Serpentinits.



**Fig. 5** Mohr-Coulomb strength envelopes for the Kusan serpentinite.  
**Bild 5** Mohr-Coulomb Bruchgeraden des Kusan Serpentinits.

**Table 1** Ranges of shear strength parameters surfaces of weakness in serpentinite.

**Tabelle 1** Scherfestigkeitsparameter der Trennflächen im Serpentinitt.

Peak cohesion [MPa]	Peak friction angle [°]	Residual cohesion [MPa]	Residual friction angle [°]
0.22 - 0.64	21.0 - 23.1	0.00 - 0.24	18.5 - 24.2

**Table 2** Derivation of shear strength parameters for the serpentinite rock mass.

**Tabelle 2** Abgeleitete Scherfestigkeitsparameter des Serpentinitt-Gebirges.

	Laboratory results on intact matrix rock samples (0.041 m)	Extrapolating intact matrix strength to a large scale (80 m)	Final estimate considering intact matrix strength and discontinuities
Cohesion ... [MPa]	3.7	0.83	0.5
Friction angle .. [°]	36	36	30
Corresponding UCS .....	14.8	3.25	1.7

portion is also based on the evaluation of relative areas of exposed blocks and matrix rock in the left bank adit and is considered to be the upper bound for a relevant scale, such as the thickness of a potential failure zone beneath the dam.

Lindquist and Goodman (4) concluded that below 25 % block volumetric proportion the strength and deformation properties of the rock mass will be approximately that of the matrix rock. Accordingly, the serpentinite rock mass strength to be adopted for design purposes is the strength of the matrix.

Eight samples of the matrix rock were tested to determine the serpentinite matrix rock strength: Two in uniaxial compression and five in multistage triaxial compression (Figure 4). The strength parameters, derived by simple stress transformation, are 36° for the friction angle and 3.76 MPa for the cohesion (Figure 5).

In addition to the laboratory tests on intact rock, five direct shear tests on the surfaces of the undulating discontinuities in serpentinite were performed (2). The test areas ranged from approximately 0.02 to 0.06 m<sup>2</sup>. The tests were carried out with five incremental load stages at 1, 2, 4, 6 and 8 MPa normal stresses. The results are summarized in Table 1.

The tests were carried out on actual rock-block surfaces (block to block contacts in outcrop scale), which are considered to represent the weakest discontinuities in the serpentinite. These discontinuities exhibited geological appearances (surface condition) apparently similar to other surfaces of weakness in the serpentinite, such as those found in drill cores.

Sixty three point load tests were performed on the serpentinite rock cores. The mean Point Load Strength Index IS50 is 4.1 (standard deviation 1.9), which corresponds to a UCS of more than 50 MPa. During testing no distinction was made between matrix and blocks.

Plate loading tests and direct shear tests (0.8 m x 0.8 m) were performed in the adit. The results are discussed in (5). It was concluded from these results, however, that in both the in-situ direct shear tests and the plate loading tests there were possibilities for test specimen disturbance by routine handling during test preparation, leading to erroneous results. This is particularly true for tests in the serpentinite, which was considered to be highly sensitive to the vibrations from the blasting operations performed for the tunnelling of the adit. Therefore, for the derivation of the design parameters of the serpentinite, these results were not considered.

**Derivation of Design Parameters**

The compression tests carried out on 41 mm diameter cylinders of matrix rock resulted in selection of a design cohesion of 3.76 MPa and design friction angle of 36°. Research on the scale effect (6, 7, 8 and 9, all summarised in 10) suggested that for the extrapolation of laboratory

results from the UCS of small samples  $\sigma_{c, \text{small}}$  to the UCS on the larger scale  $\sigma_{c, \text{large}}$ , a reduction factor, such as the following, should be used:

$$\sigma_{c, \text{large}} = \sigma_{c, \text{small}} \cdot (D_{\text{small}}/D_{\text{large}})^n$$

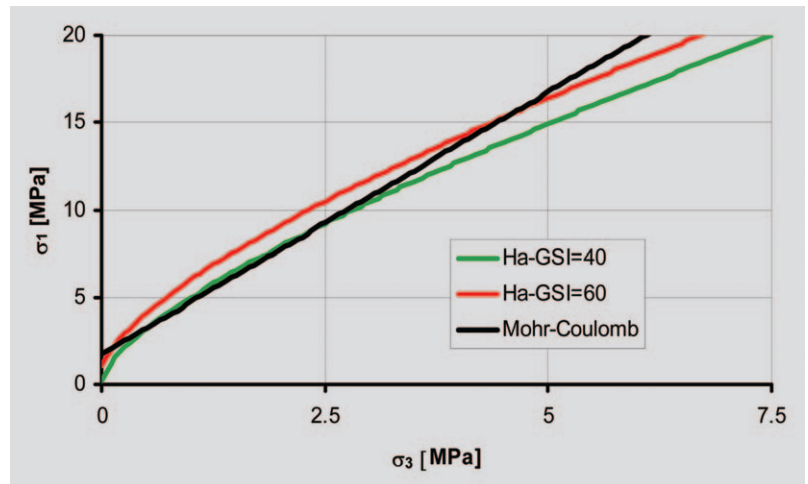
where  $D_{\text{large}}$  is the sample diameter considered in the large scale,  $D_{\text{small}}$  is the diameter of the laboratory sample and  $n$  ranges between 0.15 and 0.25. Assuming  $D_{\text{small}} = 41 \text{ mm}$ ,  $D_{\text{large}} = 80 \text{ m}$  (which exceeds the maximum width of the dam footprint in serpentinite and a mean value of  $n = 0.2$  yields a UCS  $\sigma_{c, \text{large}} = 3.25 \text{ MPa}$ . This corresponds to the Mohr-Coulomb cohesion of  $0.83 \text{ MPa}$ , assuming that the friction angle remains constant at  $36^\circ$ . The laboratory direct shear tests on discontinuities in serpentinite indicated peak cohesion on the surfaces of weakness of  $0.22 \text{ MPa}$  and peak friction angle of  $21^\circ$  (lowest values, see Table 1). Taking into account the limited surface-area persistence of the discontinuities in the matrix and the fact that the laboratory tests were performed on test samples with a size similar to that of the discontinuity persistence, the scale effect of discontinuity strength becomes negligible. The discontinuities are randomly oriented and their persistence is small. Hence, it would be unduly conservative to consider discontinuity strength as being representative of the strength of the rock mass. The strength parameters of the rock mass should lie between those of the matrix rock and those of individual discontinuity surfaces. On a large scale of more than a few metres, as must be considered for the dam foundation, the values should be closer to those of the matrix rock.

In design, the uncertainties were accommodated by the application of reduction factors that were selected based on guidelines suggested by European standards. Hence factors of 0.6 for the cohesion, and 0.8 for the friction ( $\tan \phi$ ) were adopted since the uncertainties were considered to be greater for cohesion than for the friction angle. Accordingly, the reduced cohesion was  $0.5 \text{ MPa}$  the reduced friction angle  $30^\circ$ . These values were used for the structural analyses of the dam section, assuming rigid-body sliding.

The derivation of the strength parameters are summarized in Table 2. The shear strength envelopes for the serpentinite are presented in Figure 5. These represent the peak shear strength of intact matrix rock and discontinuities, both as measured in the laboratory. The selected strength for the serpentinite rock mass for design purposes is also indicated.

#### Application of rock mass classifications

Joint data (e.g. RQD, joint spacing) represent the principal input data for the rock mass classification systems of Bieniawski (11) and Barton et al. (12). As discussed above, rock-matrix serpentinite discontinuities cannot be classified as "joints" as would be required for use of the avail-



**Fig. 6** Strength envelopes for the Kusan serpentinite rock mass for the criterion for GSI 40 and 60 (after 15). The Mohr-Coulomb envelope with the derived design parameters ( $c = 0.5 \text{ MPa}$ ,  $\phi = 30^\circ$ ) is indicated for comparison.

**Bild 6** Hüllkurven für das Kusan Serpentin Gebirge bei Anwendung des Bruchkriteriums von (15) für GSI 40 und 60. Die Mohr-Coulomb Bruchgerade mit den abgeleiteten Entwurfsparametern ( $c = 0,5 \text{ MPa}$ ,  $\phi = 30^\circ$ ) ist zum Vergleich eingezeichnet.

able rock mass classifications schemes. Furthermore, due to the random orientation of the surfaces of weakness in the serpentinite, for this case, there is doubt about the use of an adjustment for the discontinuity orientation as required in Bieniawski's classification (which is applied after initial determination of the Rating).

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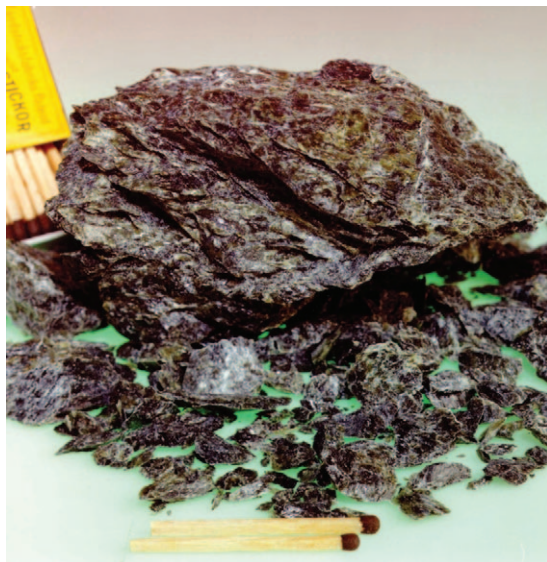
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**Fig. 7** Drilled core specimen of the Berke serpentinite.

**Bild 7** Handstück des Berke Serpentinits.

Hoek's GSI classification method (13, 14) was extended by (15) to account particularly for tectonized cataclastic rocks. It is understood that Hoek's classification and Habimana's extension must be considered as "work in progress". Following (15) and classifying the serpentinite rock mass as "tectonized" leads to a GSI of 40 to 60. Note however: Rock mass structures that actually meet the serpentinite bimrock structural condition are not available from this classification. In Figure 6, the failure envelopes for the serpentinite are presented based on the extended Hoek/Brown failure criterion and the Mohr-Coulomb criterion selected for the dam design.

Other important parameters such as deformability, bearing capacity, interface strength rock/concrete, rock mass permeability/groutability, and rippability of the serpentinite are discussed by (5) in detail. These issues are beyond the scope of this paper.

## Case history 2: Berke powerhouse access tunnel, Turkey

### Location, geology and tunnel method

The project is located in the southeast of Turkey, close to the Syrian border, about 100 km north-east of Adana. It comprises a 202 m high concrete arch dam, a 4.5 km long pressure tunnel, an underground powerhouse and other relevant structures for such a large HEPP. The investigations were performed to quantify the geotechnical reasons contributing to large tunnel deformations, and to suggest an appropriate construction method and support for the powerhouse access tunnel.

The geology of this 411 m long tunnel consists primarily of laminated, sheared limestone of moderate to poor rock mass quality. From tunnel metre (Tm) 170 to the powerhouse (Tm 411) serpentinite was encountered during tunnelling, which was not predicted by the geological investigations. This refers to the tunnel sections Tm 170 to Tm 225 and Tm 266 to Tm 364. In addition from Tm 364 to Tm 400 brecciated and mylonized serpentinite is intercalated with highly fractured diabase and calcareous schist. This zone is water-bearing and it is considered as a large tectonic fault zone. For the rest of the tunnel, laminated limestone is dominant. In other words, along the tunnel there is a diverse geology of limestone, serpentinite, and diabase, and the rock mass could be considered a bimrock at a scale much larger than the 411 m long structure. However, the investigations were focused on a smaller scale of metres to 10s of metres. The overburden thickness for the relevant tunnel sections in the serpentinite ranges from approximately 150 to 200 m.

In general the serpentinite at this site is extremely closely fractured, with chlorite and talc infilling. The serpentinite exhibits a flaky and cataclastic rock texture (Figure 7) and is at some locations completely mylonized. The serpentinite rock mass could be easily excavated with a pick and the remaining small blocks of the serpentinite could be disintegrated by hand to sandy gravel size. The contact with the limestone sections was water-bearing and is also heavily tectonized.

The tunnel was excavated full-face by a backhoe with a U-shaped horseshoe profile, 8 m wide and 7.5 m high. In the serpentinite

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sections, grouted rock bolts supported the tunnel, steel ribs (NPI 160) were placed at various spacings, and shotcrete and back-fill concrete was applied. As one would expect considering the geology, the selected profile and the support, the tunnel experienced large radial deformations of up to 1 m with unacceptable decrease in the free inner profile of this access tunnel, depending on the geological conditions encountered (Figure 8). As a result, re-design and reconstruction of the affected segments of the tunnel were required, which prompted the study summarized here.

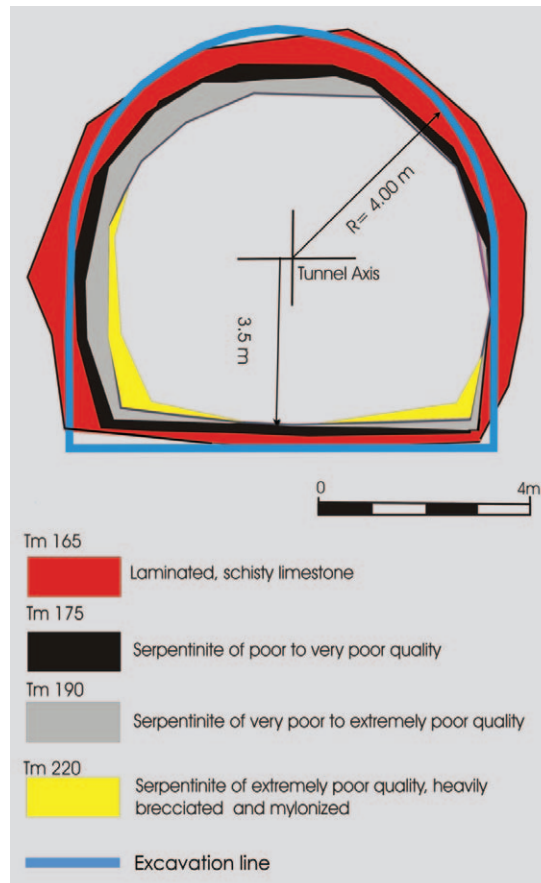
### Mechanical properties of the Berke serpentinite

No laboratory or in situ test data were available for the serpentinite. This is understandable, since core sampling in the serpentinite was practically impossible. However, sufficient data from convergence and cross-sectional profile measurements throughout the tunnel was available to back-calculate appropriate mechanical properties for re-design of tunnel support.

For stability calculations an estimate of the Mohr-Coulomb strength parameters was required: the peak friction angle was estimated at  $28^\circ$  based on the field observation of serpentinite muck piles which showed slope angles steeper than  $30^\circ$  and the residual friction angle was estimated to be  $25^\circ$ . The cohesion was estimated to be similar to that of stiff clay, because of the relative stability of the face, which suffered only minor collapses. Accordingly, the peak cohesion was assumed to be 30 kPa and the residual cohesion to be 10 kPa. The assumed drop in cohesion from peak to residual strength was considered to be justified by the observation that the serpentinite disintegrated to a quasi-granular material, when excavating it with a pick.

### Tunnel stability calculations

Using the finite difference code FLAC (17) rock pressures on the primary liner were determined following analysis of the monitored deformations in the tunnel. The acting rock pressure on the liner was so estimated to be approximately 0.4 MPa. Several runs were carried out with various serpentinite cohesive strengths, from which it appeared that incorporation of the higher possible strength of the serpentinite as in the range estimated above, resulted in less predicted deformation than actually measured in the tunnel; and the lower cohesion estimates resulted in predicted collapse of the structure. Accordingly, the estimated range (of  $c_p = 30$  kPa,  $c_r = 10$  kPa,  $\phi_p = 28^\circ$ ,  $\phi_r = 25^\circ$ ) were considered to be representative of serpentinite rock mass encountered in tunnelling. Based on these finding the tunnel was then re-designed. Reconstruction required a new profile and a curved excavation line to create stable conditions, while maintaining an acceptable amount of reinforcement in the concrete liner.



**Fig. 8** Tunnel inner cross sections for the Berke powerhouse access tunnel for different tunnel chainages and different geology.

**Bild 8** Tunnelquerschnitte des Berke Zugangstunnels für verschiedene Tunnelbereiche und unterschiedliche Geologie.

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## Conclusions

The serpentinite encountered in Berke tunnel was an extremely weak rock, which caused significant problems during tunnel construction, as one would expect when engineering in serpentinite. Hence, why did the serpentinite of the Kusan-3 dam site exhibit higher strength than reported elsewhere for serpentinite? On the basis of the case histories reported in this paper, varying high strength values for serpentinite may result from differences in localized lithologic factors, micro and macro structures, mineralogical compositions, and variations of interlocking of smaller grains, sheared and angular rock fragments, and re-cementation of matrix in serpentinite with bimrock fabric. A comparison of the serpentinites shown in the photographs of the serpentinites in Figures 2 and 7 indicate how differences in structure may impact rock mass strength.

The Kusan serpentinite is apparently a bimrock in which the low volumetric block portion of only 10 to 15 % indicates that the appropriate strength and deformability parameters of the rock mass are those of the matrix material.

The characteristics of discontinuities in the matrix are the key to the serpentinite being acceptable dam foundation rock. These charac-


teristics include the relatively small degree of persistence and the random orientation of surfaces of weakness. These characteristics combined with the relatively high strength of the intact matrix material, result in unexpectedly higher shear strength design values for the rock mass.

## References

1. Goodman, R.E.: *Engineering Geology – Rock in Engineering Construction*. Singapore: Wiley, 1993.
2. Hollmann, F.: *Felsmechanische und mikrostrukturelle Untersuchungen an Serpentin-Proben aus SE-Kalimantan, Indonesien (in English: Rock Mechanics and Micro-structural investigations on serpentinite samples from SE-Kalimantan, Indonesia)*. MSc. thesis (2000); Institute of Geology, Department of Applied Geology, Ruhr-University Bochum, Germany.
3. Medley, E.W.: *Systematic Characterisation of Melange Bimrocks and Other Chaotic Soil/Rock Mixtures*. Felsbau 17 (1999), No. 3, pp. 152-162.
4. Lindquist, E.S.; Goodman, R.E.: *The Strength and Deformation Properties of a Physical Model Melange*. In Nelson, P.P.; Laubach, S.E. (eds.): *Proc. 1<sup>st</sup> North American Rock Mechanics Conference (NARMS)* Austin, Texas. Rotterdam: Balkema, 1994.
5. Glawe, U.; Linard, J.: *High concrete dam on serpentinite*. Quarterly Journal of Engineering Geology and Hydrogeology, 36 (2003), pp. 273-285.
6. Bieniawski, Z.T.; van Heerden, W.L.: *The significance of in situ tests of large rock specimens*. International Journal on Rock Mechanics and Mining Science 12 (1975), No. 4, pp. 101-113.
7. Einstein, H.H.; Baecher, G.B.; Hirschfeld, R.C.: *The effect of size on the strength of brittle rock*. Proceeding of the 2<sup>nd</sup> International Congress of the ISRM. Belgrade, Vol. 2, Paper 3-2, 1970.
8. Habib, P.; Vouille, G.: *Sur la disparition de l'effet d'échelle aux hautes pressions*. Proc. of the Académie des Sciences, Paris, 1966.
9. Herget, G.: *Stresses in Rock*. Rotterdam: Balkema, 1988.
10. Cunha, A.P.: *Scale effects in rock mechanics*. Proceedings of the 1<sup>st</sup> International Workshop on Scale Effects in Rock Masses. Loen, Norway, pp. 3-27. Rotterdam, Balkema, 1990.
11. Bieniawski, Z.T.: *Engineering Rock Mass Classification*. New York: Wiley, 1989.
12. Barton, N.R.; Lien, R. L.; Lunde, J.: *Engineering Classification of Rock Masses for the Design of Tunnel Support*. Rock Mechanics 6 (1974), No. 4, pp. 189-239.
13. Hoek, E.: *Strength of Rock and Rock Masses*. ISRM News Journal 2 (1994), pp. 4-16.
14. Hoek, E.; Marinos, P.; Benissi, M.: *Applicability of the Geological Strength Index (GSI) Classification for Very Weak and Sheared Rock Masses. The Case of the Athens Schist Formation*. Bull. Eng. Geol. Env., 57 (1998), pp. 151-160.
15. Habimana, J.; Labiouse, V.; Descoedres, F.: *Failure criterion for cataclastic rocks: Experience from the Cleuson-Dixence Project*. Proceedings of the 9<sup>th</sup> Int. Conf. on Rock Mech. (1999). Vol. 2, pp. 605-610.
16. Hoek, E.; Brown, E.T.: *Practical Estimates of Rock Mass Strength*. Int. J. Rock Mech. Min. Sci. 34 (1998), pp. 1165-1186.
17. Itasca: *FLAC code*. Itasca Consulting Group, Inc., Minneapolis, USA.

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