Determination of compressive strength of rock using rebound test hammer and uniaxial compression tests

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Schmidt hammer and uniaxial tests were used to determine the compressive strength of rock at the construction site of the Forsmark Power Plant. A comparison of the results obtained by the two methods is presented. The correspondence is surprisingly good, the mean values obtained at the tests being within 10 per cent. The tests were also performed in different directions with respect to the rock foliation of the gneiss granite. The foliated granite proved to have an anisotropic compressive strength, the anisotropy being a pure effect of the foliation. Moreover a hammer test round was made in order to produce a qualitative pattern of the influence of mineral coatings on the compressive strength of the rock adjacent to natural fractures. The result shows no actual difference between coated versus non-coated fractures. As regards the strength of different rock types, the greenstones and the pegmatites present substantially lower values than the gneiss granite.

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Introduction

The mechanical properties of a crystalline rock mass are related first and foremost to the mechanical properties of existing geological discontinuities, and to a lesser extent dependent on those of the intact rock material. However, the strength of the rock material may be crucial for the deformability of rock masses under certain circumstances. Rock material properties will influence the behaviour of the rock mass if there is a wide spacing of discontinuities and the rock material is weak. Under the same confining pressure, the strength of rock material constitutes the highest strength limit of the rock mass (Bieniawski 1974).

Furthermore, the compressive strength of the fracture walls is of great importance as the mechanical properties of the existing discontinuities largely control the mechanical properties of the rock mass. It is mainly the thin layers of rock adjacent to fracture walls that control the strength and deformation properties of the rock mass as a whole, and if the fracture walls are weathered, the significance of this parameter is accentuated (Barton & Choubey 1977). Hence for practical application it is essential to determine the compressive strength of rock material in connection with underground works and rock foundations.

The compressive strength of rock can be determined directly by uniaxial compression tests, and it can also be estimated from field tests, such as the Schmidt hammer test. The hammer test is particularly valuable when testing the thin layers of rock on the fracture walls. Originally, the rebound test hammer was designed for testing concrete constructions at building sites, but also proved suitable as a field test method for rock mechanical studies (Miller 1965 and others).

The use of the rebound hammer test in order to obtain quantitative values of the compressive strength of rock was described by e.g. Miller (1965) and Barton & Choubey (1977). The investigations show that the Schmidt hammer test is a rapid, simple and relatively reliable method of estimating the rock strength. Uniaxial compression tests of drill-cores are both time-consuming and expensive, wherefore the hammer test offers great advantages especially in connection with civil engineering projects.

Results from both Schmidt hammer tests and uniaxial compression tests were used for the determination of the compressive strength of rock at the construction of the Forsmark Power Plant. The results of the two tests are presented together with a comparison of the results of the two methods.

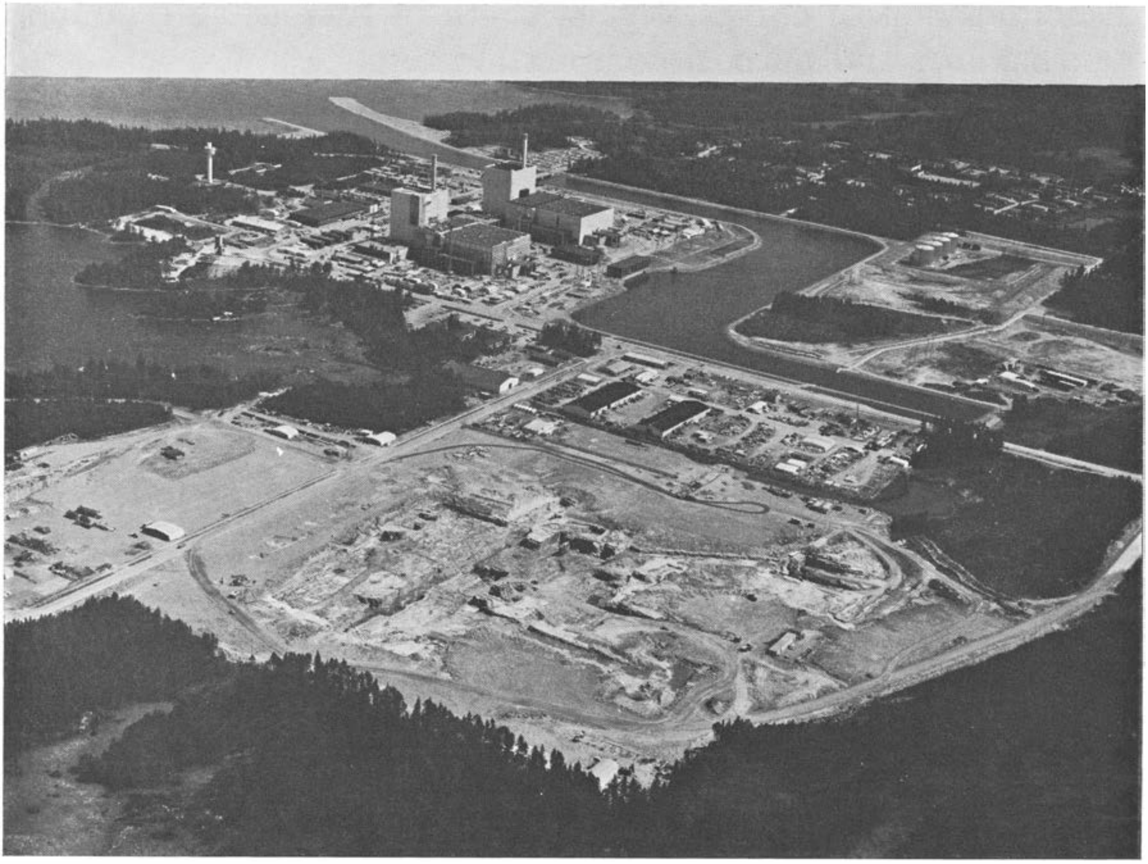

Figure 1. Aerial photograph of the Forsmark area. The investigation area of the present study, Unit 3, is the construction area in the foreground. Units 1 and 2 are shown in the background. Photograph by G. Hansson/N. Permission for publication of the photograph given by the Defence Staff and by the Swedish State Power Board 17th October, 1979.

Investigation program

The chief aim of the present study is to compare the results obtained with both the Schmidt hammer and the uniaxial compression test. With this in mind a drilling program was carried out in the excavated shafts at Forsmark Unit 3. The drilling was performed at different sites in the shafts and in different directions with respect to the rock foliation. Then the Schmidt hammer test was executed at the same sites as the drillings, and in the same directions in order to have identical rock masses for a valid comparison of the result.

In all, 12 core drillings were made and 600 Schmidt hammer measurements taken which give the compressive strength of the rock material at 12 different sites.

Another 600 hammer measurements were made for an earlier study, and as the moisture conditions were very different on the two occasions, it was judged to be of importance to evaluate to what extent the surface moisture affects the Schmidt hammer result. For this reason these 600 measurements too are included in the present study. The original aim of the latter series of measurements was however to test the strength with respect to different rock types and mineral coatings.

Investigation area

The test site, the Forsmark Power Plant, is situated on the east coast of Sweden in northeastern Uppland. The station is a nuclear power

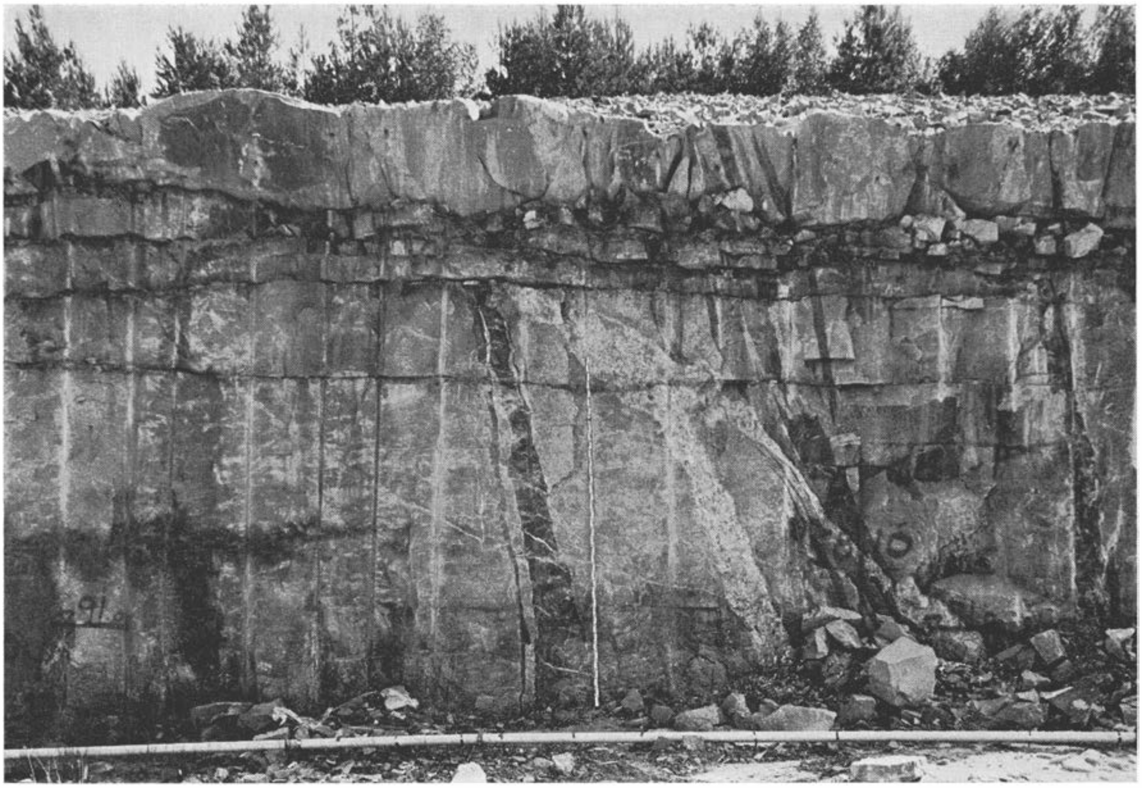

Figure 2. Amphibolitic greenstones and pegmatites forming dikes and isolated bodies in the gneiss granite. Photograph by G. Hansson/N.

plant, two units being complete and one under construction. The study is based on the result from measurements performed in excavated shafts at the site of Unit 3 (Fig. 1).

The bedrock at Unit 3 consists in the main of gneiss granite, which from the engineering point of view is an orthogneiss. It has a fairly well defined foliation and anisotropy. Dikes and basic layers of amphibolitic composition and dikes and small massifs of pegmatite also occur (Fig. 2). The fractures are normally coated with chlorite (Fig. 3). Figure 4 presents a quantitative description of the rock distribution within the investigated area, while the mineral composition of the gneiss granite is illustrated in Table 1.

The greenstone contains albite and an amphibole of the tremolite-actinolite series as the predominant minerals. Other minerals are potassium felspar, chlorite, and quartz and secondary zirkon and titanite. The primary grain size of the main mineral is about 0,5—1,0 mm. The pegmatite, which is coarse-grained, has a mineral composition of quartz, potassium felspar, plagioclase, biotite, muscovite, and hornblende. Some of the pegmatites show a slight lineation of the dark minerals.

Table 1. The mineral composition of the gneiss granite based on modal analysis. Median values of three samples. The analyses were carried out by K. Rëshoff at the University of Luleå.

Minerals	Content in per cent
Quartz	23
Plagioclase	30
Potassium felspar	32
Biotite	11
Other minerals	4

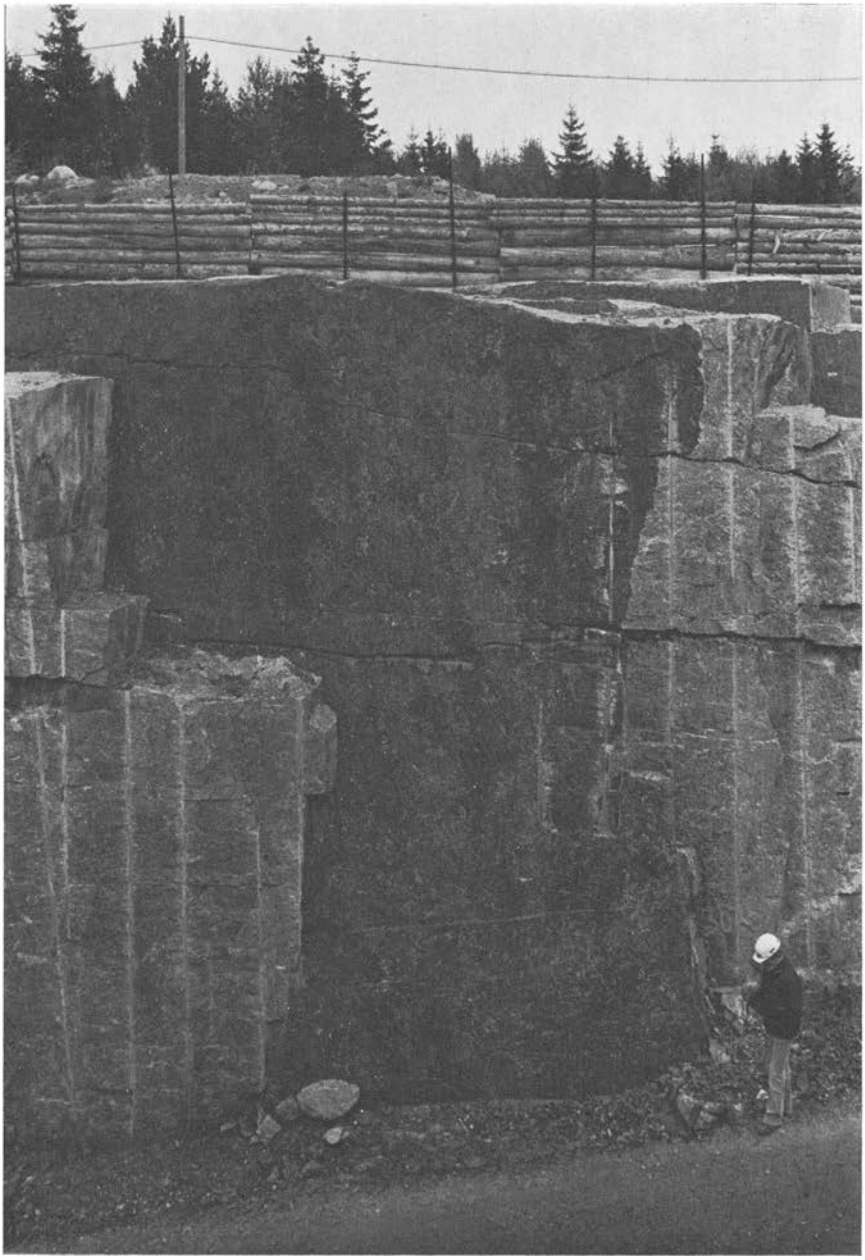

Figure 3. Vertical fracture surface coated with chlorite. Photograph by G. Hansson/N.

Compressive strength determinations

Uniaxial compression test

The strength of rock material can be directly determined by a simple uniaxial compression test. The test is made on samples of drill-cores, which are loaded along the core axis between platens in a testing machine. The compressive strength is expressed as the relation between the applied force at failure and the initial cross-sectional area transverse to the direction of force. This very common method of determining the compressive strength of rock is described in e.g. ISRM (1972).

For testing samples of the rock mass in the

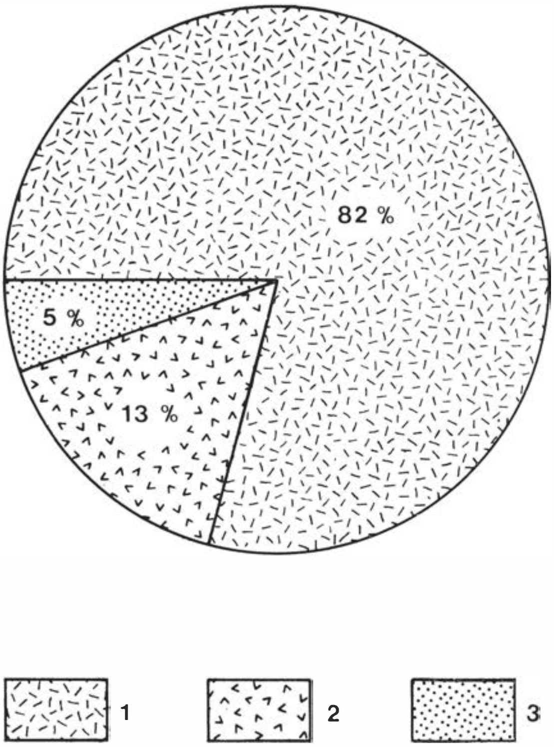

Figure 4. A quantitative description of the rock distribution within the area of Unit 3. 1. Gneiss granite. 2. Pegmatite. 3. Greenstone.

test area, using uniaxial compression tests, twelve core drillings were made both parallel and perpendicular to the rock foliation. Three drillings were also carried out vertically downwards along the foliation. The mean depth of the drillings was about 1 m, and the cores which were sampled at least 300 cm in length with no visible fractures. The diameter of the cores was 42 mm, and for the compression test a length to diameter ratio of 1:1 was used. One compression test was made with each core.

The Schmidt hammer test

A rebound test hammer (Schmidt hammer) was used at the investigation. In the first stage, 600 in situ measurements were made in the excavated shafts of Unit 3 on newly blasted rock surfaces of gneiss granite, pegmatite, and greenstone, but also on fracture surfaces containing mineral coatings. The mineral coatings mainly consists of calcite and chlorite, their mean thickness being about 1 mm (cf. Fig. 3).

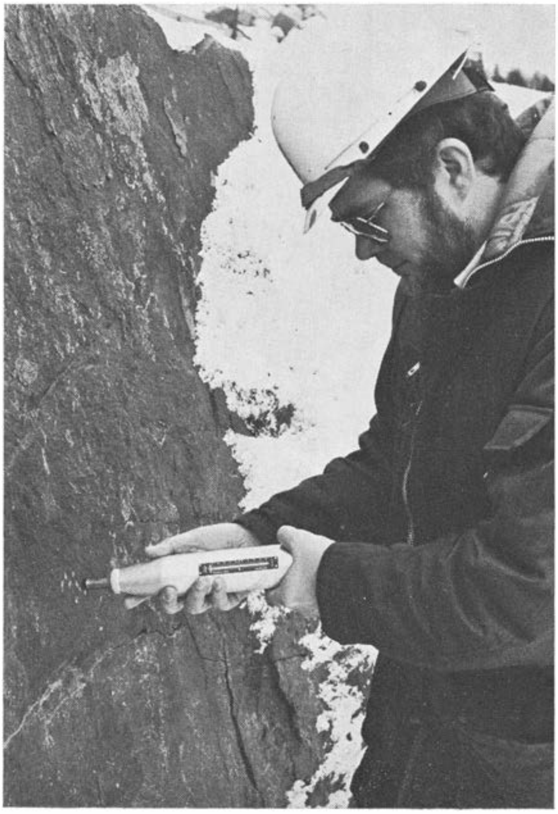

Figure 5. The handling of the rebound hammer. The hammer is pressed to the rock surface, while the spring-loaded projectile is slided into the hammer. Then the projectile is released and a rebound number obtained. Photograph by A. Carlsson.

The handling of the hammer is illustrated in Fig. 5, the procedure being briefly as follows. The hammer is used perpendicular to the rock surface and pressed slowly to the surface. In so doing, the spring-loaded projectile is forced into the hammer. When about 5 mm remains, the projectile is released and the rebound number obtained can be recorded. The orientation of the hammer influences the result, and when the hammer is used in an other direction than vertically downwards, the obtained values must be corrected according to the correction factors shown in Fig. 6.

According to the recommendations given by ISRM (ISRM 1977), the tests should be performed in series on ten readings. A mean value of the rebound number is then based on the five highest readings in each series, while the five lowest are excluded. The obtained mean value of the rebound number is used to determine the compressive strength of the rock.

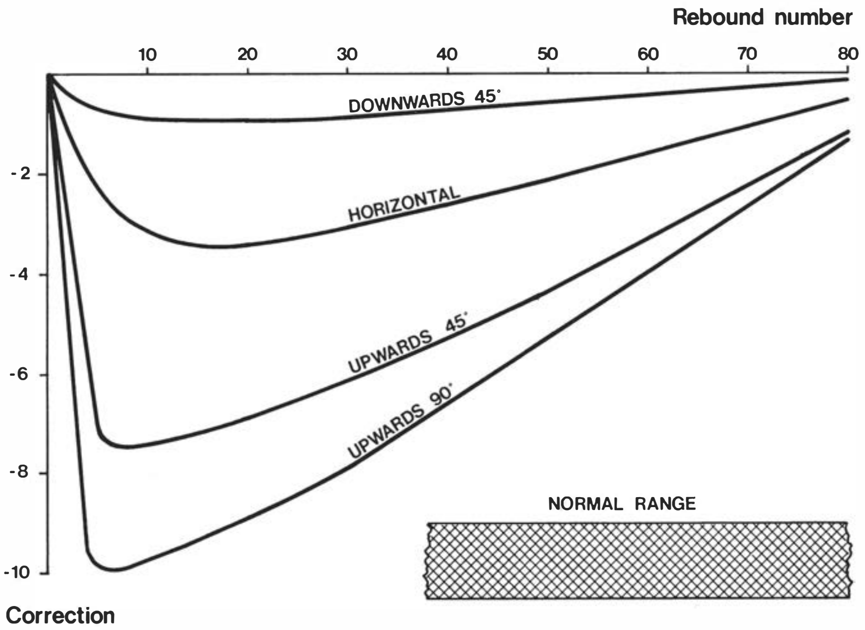

Figure 6. Correction values for the obtained rebound number. When the hammer is used 90° downwards no correction is needed, but any other position of operation needs a reduction of the reading.

Miller (1965) found the following correlation between the rebound number value and the unconfined compression strength:

$$\log(\sigma) = 0{,}00088\,\varrho\,\mathrm{R} + 1{,}01, \quad (1)$$

where σ = unconfined compression strength (MPa)
ϱ = dry density of rock (kN/m^3)
R = rebound number.

This relation is graphically shown in Fig. 7 for some normal density values for Swedish rock types.

As seen from the equation both the density and the rebound number carry great weight for the obtained value of the compressive strength. Thus, as the density varies with porosity and water content, it is also obvious that the moisture conditions at testing may influence the result.

Although the relation includes the dry density of the rock, it was originally found for rock material saturated with water. Here the presence of water has a number of effects on the result obtained.

- The thin water film on the surface subdues the rebound of the projectile. The water causes suction at the reflection of the projectile and consequently a lower rebound number.
- Water within the fissures gives the rock a more rigid response to any mechanical impact.

According to ISRM (1977) the most conservative result ensues if the rock is tested under saturated conditions. Consequently, tests made on dry surfaces will probably yield too high a rebound number and hence too high a value of the compressive strength.

For the present study each measurement was made in situ on intact rock units, all of which exceeded 200×200 mm. If the tested surface had a loose skin, the value obtained was excluded and a new measurement made on the intact surface. For practical reasons, all the measurements were taken on naturally wet or dry surfaces. For this study, this means that the rock surfaces were wet due to precipitation on one testing occasion and dry on the other.

Schmidt hammer test

Hammer tests were performed on two different occasions with originally different aims. A first test round was made mainly in order to obtain a

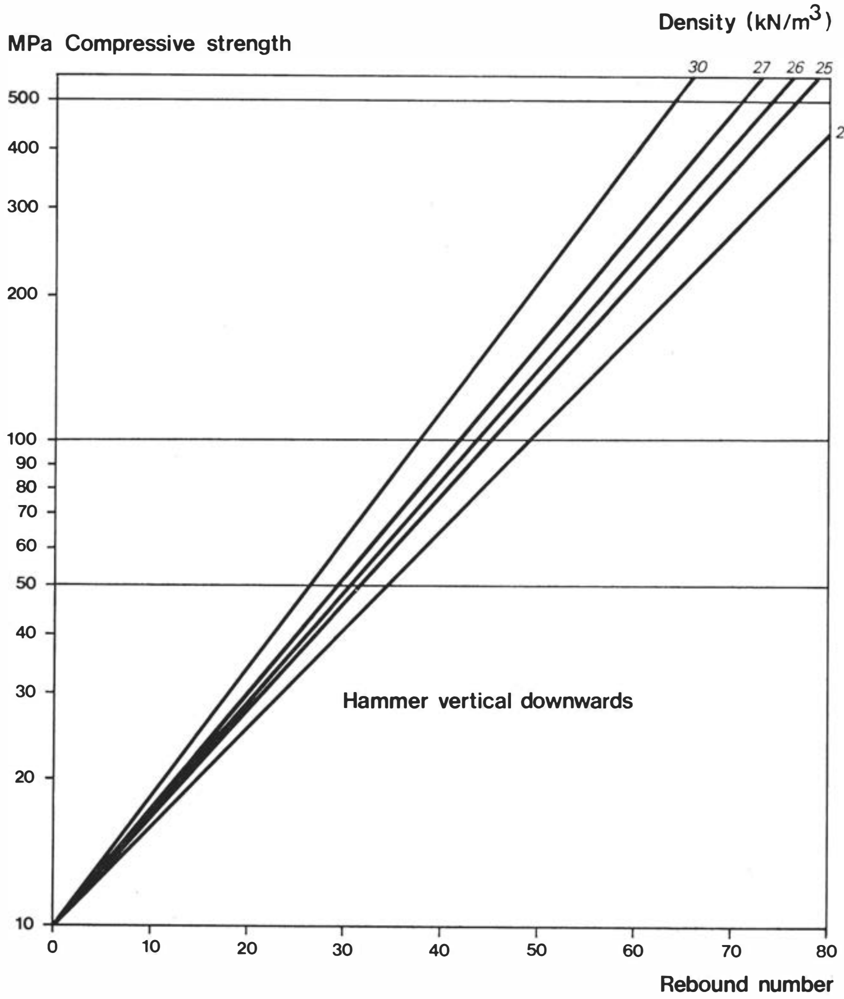

Figure 7. Compressive strength of the rock versus the corrected rebound number for different values of the dry density of the rock. Modified after Miller (1965).

qualitative pattern of the influence of mineral coatings on the compressive strength of the rock adjacent to natural fractures. This was achieved by testing both natural fracture surfaces coated with secondary minerals and fresh, newly exposed, blasted surfaces. On this occasion different rock types in the area were also studied. The test round was carried out on a rainy day after a long period of precipitation, so that the rock surfaces were saturated with water.

A second test round was made in order to compare the results of the Schmidt hammer test with those of uniaxial compression tests. This was done by making the hammer test at the same drilling sites as for the compression tests. All measurements were exclusively made on rough, blasted rock surfaces. The tests were carried out on a day without precipitation, in fact there had been no rain for some weeks, wherefore the tested surfaces were all very dry.

At both test rounds about 60 series of 10 readings were taken which gives more than 600 readings for each.

In order to study the effect on the difference in surface moisture between the test rounds, all series made on rough blasted rock surfaces were studied. Figure 8 shows the distribution in rebound numbers for both test conditions, and the tests made on dry surfaces demonstrably yield higher values. The mean values of the tests are

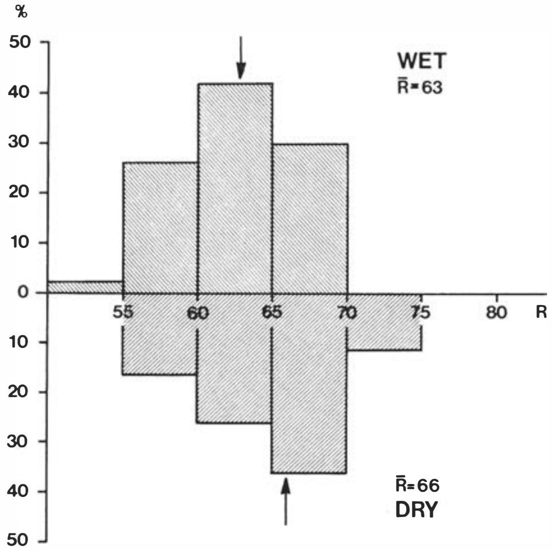

Figure 8. Distribution of the rebound numbers for tests made under wet and dry conditions. The mean values (63 and 66) for the tests are marked of the arrows.

Table 2. Compressive strength of different rock types obtained by Schmidt hammer tests.

Rock type	Estimated density	Compressive strength	Standard deviation
Geniss granite	26		
Fresh rock		280	52
Mineral-coated fractures		280	63
Greenstone	27	215	25
Pegmatite	26	225	50

63 for wet and 66 for dry surfaces. The actual ratio between the tests is 1:1,04 which indicates that dry conditions exaggerate the rebound by about 4 per cent. Thus assuming that the wet surfaces give the most accurate readings, tests perfomed under wet conditions should be reduced by a factor of 0,96 in order to balance the moisture condition. However, the factor 0,96 may be attributed either to the rebound number or to the dry density of the rock, and both these parameters are probably affected by differences in surface moisture. Considering the effect of surface moisture, the relation between rebound number and compressive strength then will be

$$\sigma = 10^{0{,}00088\,\zeta\,\varrho\,R\,+\,1{,}01},$$

where ζ = the moisture constant (0,96).

The difference in compressive strength between different rock types is summarized in Table 2. There appears to be no actual difference in the gneiss granite whether the tests are performed on fresh rock material or on mineral coatings. The standard deviations is however greater for the coatings, indicating a greater dispersion in compressive strength. The strength of the greenstones and of the pegmatites is considerably lower than the main rock type implying that these structures are potential zones of weakness.

Comparison between Schmidt hammer test and uniaxial compression test

In all twelve cores were assigned to an uniaxial compression test. Ten cores were taken in different directions with respect to the rock foliation of the gneiss granite and another two were taken

Table 3. Compressive strength according to rebound hammer test (σ_R) and compression test (σ_T) of gneiss granite and greenstone. In the gneiss granite the strength was determined in different directions with respect to the foliation.

Rock type	σ_T			σ_R			σ_R/σ_T
Sampling direction	Mean (MPa)	Standard (MPa)	deviation (%)	Mean MPa	Standard MPa	deviation %	
Gneiss granite, total	284	49	17	293	77	26	1,03
Parallel, horizontal	257	41	16	251	82	33	0,98
Parallel, vertical	280	59	21	316	67	21	1,13
Perpendicular	324	31	10	327	76	23	1,01
Greenstone	240	30	13	255	62	24	1,06

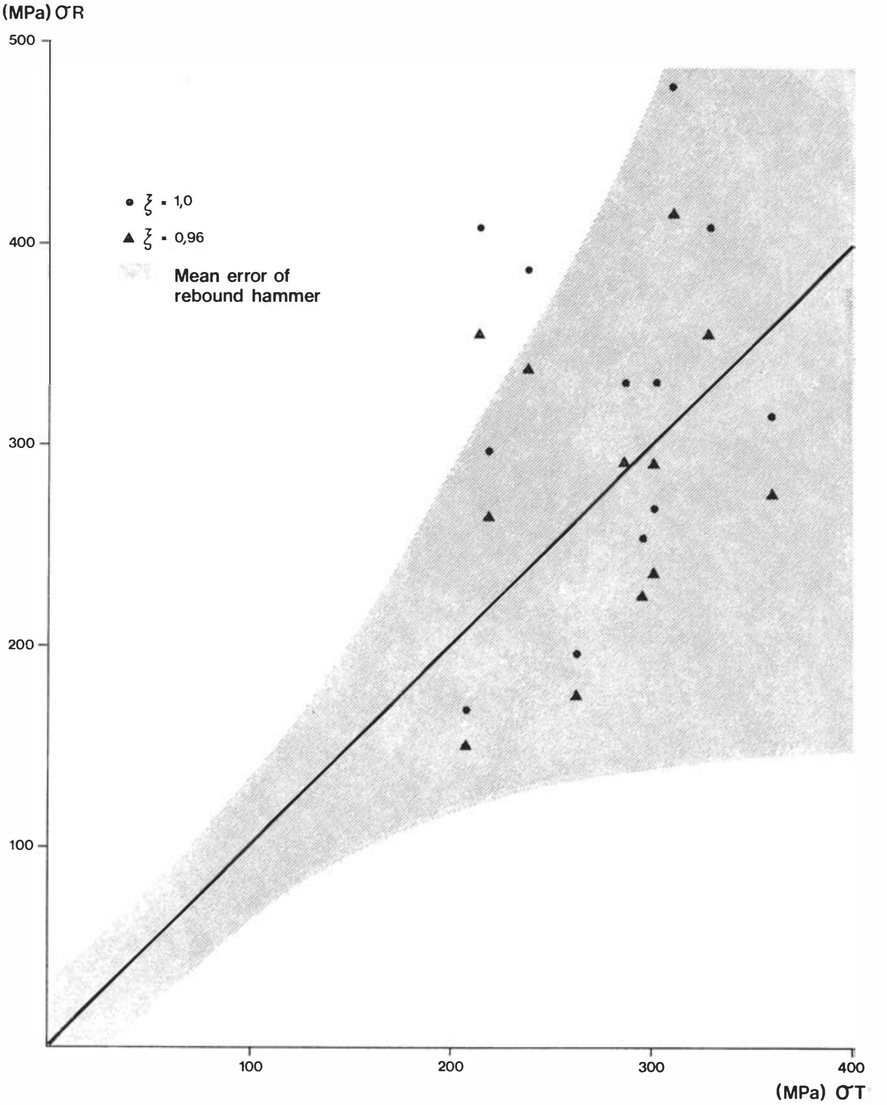

Figure 9. Values of the compressive strength from hammer tests (σ_R) versus strength values from uniaxial compression tests (σ_T). The linear relation represents on ideal correspondence between the methods, while the actual results are marked with ● and ▲, representing different moisture correction factors (ζ).

in massifs of greenstones. Disregarding the different directions, the ten tests on the gneiss granite gave a mean value of 284 MPa compared with 240 MPa on greenstone.

Five sets of Schmidt hammer tests were made at each drilling point with the same directions as for the drilling; i.e. in all 600 readings were made.

According to the discussion above, the rebound numbers from the tests were treated according to the ISRM recommendations. As the surfaces were very dry during the testing, the obtained values will overestimate the compressive strength of the rock. The strength was therefore determined by means of the aforesaid reduction by a factor of 0,96. This correction of the equation yielded the compressive strength for the rock material.

The hammer tests give a mean compressive strength of the gneiss granite of 293 MPa compared with 219 MPa for the greenstones.

Table 3 summarizes the results from both compression tests and hammer test, and the mean values show a close correspondence both in total and for the different test directions. The ratio of σ_R/σ_T is for most values close to 1, and the greatest discrepancy amounts to 13 per cent. The standard deviation is on the whole much higher for the hammer test than for the compression test, which indicates that the former gives less reliable results. However, due to inhomogeneity of the rock material, the standard deviations obtained from various strength tests are usually high (Jaeger 1972).

It is obvious that the Schmidt hammer test gives a far higher standard deviation than the uniaxial test. This is a consequence of the test method in that the precision of the hammer test is lower than that of the uniaxial test.

As both the hammer test and the compression test are performed on the same test sites and in the same directions, it is also possible to compare the individual test results. In Fig. 9 the Schmidt hammer values of the compressive strength are plotted versus the values from the compression tests. This treatment shows that the differences between different values may be great, but all individual values (except one) fall within the mean error of the hammer method.

As regards the results obtained in different directions, it is clear that the compressive strength is highest perpendicular to the foliation and lowest parallel to it in a horizontal direction. The results of the tests carried out vertically, parallel to the foliation, gave intermediate strength. The same tendency appears with both methods. The compressive strength parallel to the foliation in the horizontal direction is about 79 per cent of that of the perpendicular direction (77 per cent from the hammer test) and the downward, parallel strength is about 86 per cent (97 per cent from the hammer test). Thus, the tests performed show that the rock mass is anisotropic with respect to the compressive strength with a ratio of 1:1,2:1,3 between the main directions.

Conclusions

Firstly, it is possible to conclude that the Schmidt hammer test seems to be a fairly accurate method for rock strength determinations. It also has several advantages compared with uniaxial compression tests. The hammer test is cheap, and a great number of tests can be made in a specific area, the result being available on the spot. The method needs no drilling and no sample preparation which is responsible for much of the cost for the uniaxial compression test.

The correspondence between the methods is surprisingly good, and the mean obtained are within 10 per cent for all tests.

When using the hammer it seems to be most convenient to perform the test on water saturated surfaces in order to minimize the corrections which must be made. The water seems to be highly significant, far more important than indicated by the correction factor 0,96. This importance is of course due to the fact that the correction factor is exponentially related to the compressive strength.

As regards the strength of the rock material in the test area, it is obvious that the foliated gneiss granite has an anisotropic compressive strength, and that the anisotropy is a pure effect of the foliation. The main potential weak zones are however not created by the foliation, but by the dikes of greenstone and pegmatite which cut through the gneiss granite. Both these rock features have compressive strengths below those of the foliattion.

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