CASE HISTORIES IN DESIGN AND CONSTRUCTION OF UNDERGROUND STRUCTURES

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Introduction

A case history related to rock design and construction is the documentation of ground conditions and experience gained from the construction of the structure and its behaviour during usage. Also documentation of test results as well as results from back analysis are topics included in such case histories.

In the report "Definition of the most promising lines of research " presented by ISRM (1971) 'correlation between the mechanical properties of rocks and geological and petrographic data' was among the highest priority research subjects defined. In the same report it was also stated that: *"At present time most geologic and petrographic descriptions of specimens or bodies of rock are qualitative, whereas rock mechanics determination of mechanical properties of rock are quantitative.*
Because many engineering decisions are based on a combination of geologic and rock mechanics data, it is important that a more systematic means of combining and correlating this information should be developed.
There is a need for better documentation and correlation of geological and petrographic data, and corresponding mechanical property data obtained from both laboratory specimens and/or rock masses, together with operating experience in the same rock mass, or the subsequent performance of structure in the rock mass created by excavation."

Thus, already early in the development of rock mechanics the importance of establishing general methods and systems for improved characterization of rock masses together with a common language for those engaged in engineering and construction in rock was clearly expressed. This request has to some extent, been met by some of the classification systems, but few of them are of a general character as they are mainly directed towards a specific engineering function or design.

As there is no standard or specified standard how to work out case histories, the way they have been presented varies. This partly depends on the purpose they shall serve which can be:
- -for internal use for a specific excavation only, as a documentation for later use;
- -for a certain purpose or project of scientific character; or
- -in connection with standard procedures, requirements or regulation connected to the project, which may involve compilation of works or data found during planning, follow-up and/or construction.

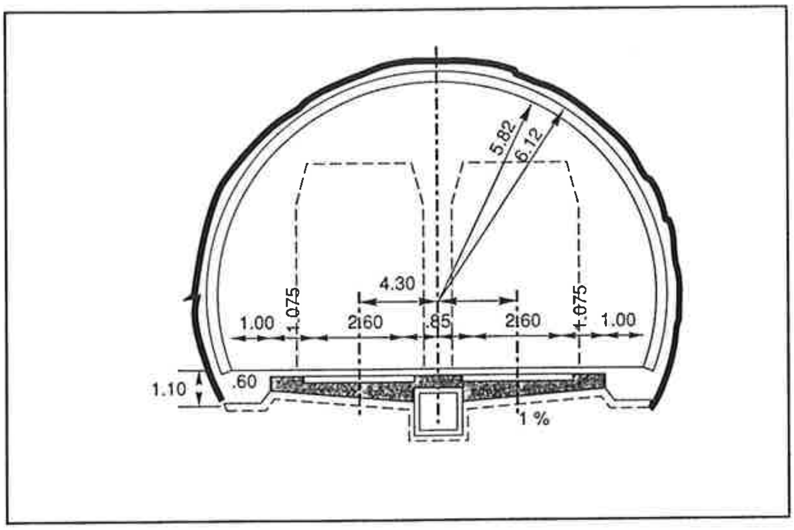
Thus, case histories generally consist of experience gained during construction or measurement, and include ground characterization, geometric dimensions, the type of works carried

Types and applications of case histories

In many papers presented at conferences case histories are presented for example as "Construction experience from the excavations works at a certain site" where contractors give an overview of his execution of the works and what challenges he had to cope with. Such cases (see Fig. 1) would be significantly improved if they had been worked out in cooperation with engineering geologists who could contribute with information of the ground conditions.

On the 104 km new stretch through the Sierra Morena mountaineous region between Brazatortas and Cordoba, there are no less than 15 tunnels between 300 m and 2,5 km long totalling 15 km.

Rock quality in the Sierra Morena is problematic. The mountains are composed of an old quartzite formation which has weathered and eroded heavily through the ages. Nevertheless, all the tunnels have been designed as double track tubes of up to 100 m² in excavated cross-section and finished to a 75 m² internal cross-section.



They are excavated in the main by drill + blast on a top heading and bench program and supported principally by Dramix steel fibre reinforced shotcrete, steel sets and rock bolts according to the NATM concept.

Support comprised a 5 - 15 cm layer of immediate Dramix ZP 30/.50 steel fibre reinforced shotcrete. The dry shotcreting method is the one used mostly in Spain.

The final lining consists of a 30 cm thick unreinforced in situ concrete layer.

Fig. 1 Example of a case history used in the book on shotcrete issued by Bekaert (1994)

Other cases are dealing with the ground conditions and the works made to solve stability problems as is shown in the next section.

Designs in rock construction are very often based on earlier experience gained from 1) constructions of similar projects or 2) in similar rock conditions. The accumulated use of this vast amount of experience is applied among others in the classification systems. Other applications are the use of old construction experience in new projects.

The most valuable use of case histories is, perhaps, the sharing and exchange of experience among researchers.

To sum up, case histories are mainly used for:

- Documentation of features and conditions to be applied in possible later renovation/repairs/maintenance during the project's life. Such case histories are generally not available and therefore of limited interest to others.
- Advancing the state of the art in rock mechanics and rock engineering, for example as:
  > further development of classification systems;
  > development or improvement of engineering methods/calculations; and
  > improving analytical methods in rock mechanics.
- Communication/exchange of geo data and experience.
- The use of earlier experience in new constructions for assessment of the geological and ground conditions.

Examples

In some text books, mainly older issues (Stini, 1950, Müller, 1963) the author has given examples, as shown in Fig. 2, of cases to illustrate how ground conditions may influence on the tunnel excavation and stability.

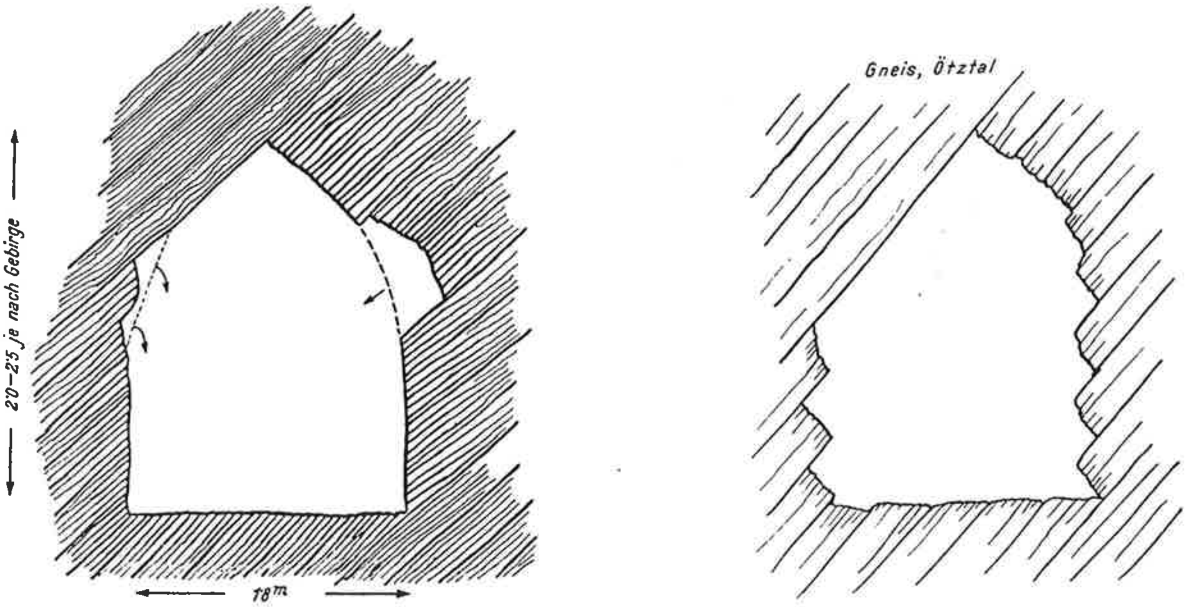


Fig. 2 Two examples of cases presented by Stini 1950).

One of the most useful collections of case histories has been presented by Cecil in his Ph.D thesis (Cecil, 1970) where he presented a documentation of the ground conditions and rock support for 97 tunnels and caverns in Scandinavia. Figs. 4-5 give two examples of his work. These cases were in fact an important source of data for the development of the Q method and this was strongly acknowledged by the Barton et al. (1974): *"It is not usual to acknowledge the contribution of publications. However, the field work performed by Cecil (1970) has proved such a valuable source of information for developing this method that his contribution must be specially acknowledged."*

Cecil developed the following guidelines for his mapping of the ground conditions:

INFORMATION FORMAT FOR CASE HISTORIES

1. Project, location
2. Type of tunnel or room
3. W = width of opening, meters
4. H = height of opening, meters
5. A = area of opening, square meters
6. Nature of instability (roof fall, wall slip-out, overbreak, etc.); (stability classification, see legend below)
7. L = length of condition under consideration, meters
8. Geologic features responsible for condition, rock type
9. Support or remedial measure
10. D = depth of overburden (soil and rock), meters
11. RQD, location, method; RQD_v; RQD_a
12. V = seismic velocity, m/sec;*
13. SVR = seismic velocity ratio
14. Regional tectonics or major structural geology features
15. Ground water condition
16. Other notes

LEGEND FOR TIME-STABILITY-SUPPORT CLASSIFICATION

A stable at blasting, no anticipated falls, no support

B minor falls or overbreak at blasting, support not considered necessary for prevention of loosening

C stable at blasting, support in anticipation of loosening

D stable at blasting, unsupported, gradual deterioration and subsequent support

E falls at blasting, support in anticipation of progressive loosening

F falls at blasting, no support immediately after blasting, progressive loosening, support applied to prevent further loosening

G falls at blasting, support shortly after blasting to prevent or stop progressive loosening

H support shortly after blasting, failure of support thereafter, additional support

*Values given in parentheses have been taken from projected ground surface data.

Fig. 3 The list of information and documentation applied by Cecil (1975)

A frequent documentation of ground conditions and tunnel support is made in the form of tunnel mapping schemes like the example presented in Fig. 6.

Fig. 7 shows example of a case history showing construction experience of some large underground caverns. Such cases form NGI's data bank used as documentation in the Q-system.

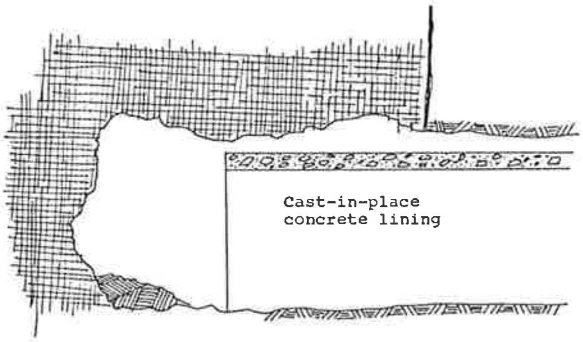
Where to search for case histories?

An important task when using case histories is to find out or detect where the data of interest are located. A search on the topic 'case histories' which was performed in a geotechnical data base on the headings/titles of published papers gave 90 references. When 'rock' was included in the search only 13 references were found. Similarly, in second search using the same keywords in another data base 120 and 9 references were found. Thus, general data bases may not give much help in finding case histories. Today, the best source is probably in proceedings from conferences and in the reference list given in conference articles.

A data bank or a special group in the geomechanics abstract would help to increase the interest to publish and use the valuable information stored in many case histories.

Case 39

1. Rendal Hydroelectric, central Norway
2. headrace tunnel
3. W = 8m
4. H = 6m
5. $A = 43m^2$
6. major roof falls, progressive formation of dome- and vault-shaped crown; falls from face (see sketch); (G)
7. L = 50m
8. shear zone in quartzite; "sugar cube" rock structure
9. cast concrete arch immediately after mucking
10. D = 200m
11. RQD = 20% all directions, estimated
12. ----
13. ----
14. major regional normal faulting is responsible for horst-graben topography in area
15. 5-10 lit/min water inflows



Case 52

1-5. same as Case 47
6. stable section, minor overbreak, no falls; (A)
7. L = 50m
8. very closely jointed metamorphosed claystone (see photo); similar to rock in Case 51, but contains no slickensides, structure is very tight
9. no structural support required; light shotcrete or gunite for protection against small pieces of falling rock
10. D = 70m
11. RQD = 0% all directions, measured
12. ----
13. ----
14. same as Case 47
15. insignificant inflows
16. location about 200m from Case 51

Fig. 4 - 5 Two examples from the case histories presented by Cecil (1970)

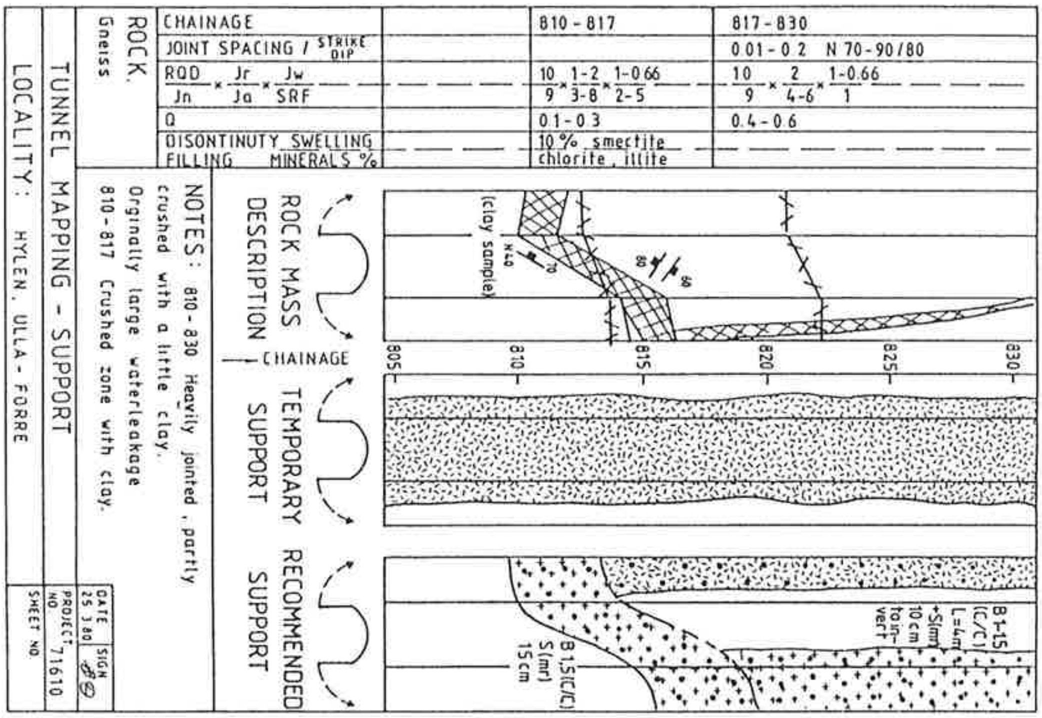


Fig. 6 Example of tunnel mapping (from Barton et al., 1980)

Project: **NORZINK WASTE CAVERNS, Odda, Norway**

Cavern geometry: Span = 17.5 m Height = 23.5 m Length = 211 - 225 m (each cavern)
Cavern usage: Caverns for disposal of waste products from zinc production
Cavern depth below surface:
Vertical overburden 200 - 450 m. (Behind the caverns nearby mountains rise up to 1500 m above the caverns)
Descriptions of the ground conditions:
Precambrian medium to coarse grained gneiss with occasional veins of pegmatite, amphibolite and granite. Uniaxial compressive strength of rock is 145 MPa, point load index 16 MPa, E-modulus 25 GPa and a Poisson's ration of 0.1.
Generally 3 joint sets occur. The main set is along the the steep dipping foliation. Another set has near vertical dip and strikes normal to the foliation. Most joints are rough and planar.
Only minor fracture zones occur in the area.
In situ stress measurements $\sigma_1 = 6.7$ MPa, $\sigma_2 = 1.7$ MPa, $\sigma_3 = 0.6$ MPa.
Excavation method: Drill and blast. Excavation by 7 - 11 m high top heading, and two benches 6 - 8 m
Stability:
No stability problems during excavation, but rock burst sounds have been heard in the inner part of caverns.
Rock mass quality: Average Q = 13 - 25 (good)
(RQD = 80 - 100, Jn = 6 - 9, Jr = 1.5, Ja = 1, Jw = 1, SRF = 1)
Rock support (in cavern 1 - 6):
Spot bolting (125 - 1600 bolts in roof and walls give a bolt spacing of 3 - 11 m) and occasional shotcrete.
Completion date: 6 caverns had been excavated in 1993, 9 more are planned.
References:
Rohde, J. (1993): Storage of industrial waste in rock caverns at Norzink, Odda. Publ. No 9 issued by the Norwegian Soil and Rock Engineering Association.

Fig. 7 Example of a case history applied as documentation in the Q system.

The need for a 'language' to be used in case histories for documentation of the ground conditions

Generally, observations and measurements of geological and geotechnical data have been made by individuals, based on their personal experience rather than on any collective basis. Therefore, a common deficiency of both geologic and geotechnical literature has been the lack of an adequate and generally accepted means to transmit the rock mass conditions and stability experience in an overall assessment of the nature of rock masses to those who have not had an opportunity to observe them. ISRM (1971) finds it important that a more systematic means of combining and correlating this information should be developed. A 'language' common to rock mechanics specialists and experts from related fields should, according to ISRM (1980), be available. This need was, in fact, already presented by Matula (1969).

In this connection Deere et al. (1969) mention that a better language will help in accumulation of experience associated with various classification systems when the description of the parameters are quantitative and can be 'translated' from one system to another.

The quality of the documentation of ground conditions is paramount in most cases. Ideally, it should contain both the verbal description of the composition and structure of the rock mass as well as the numerical values of important parameters (see Fig. 8), based on well defined ratings. When such information is available the case histories present a significantly better source for developments in design of rock constructions.

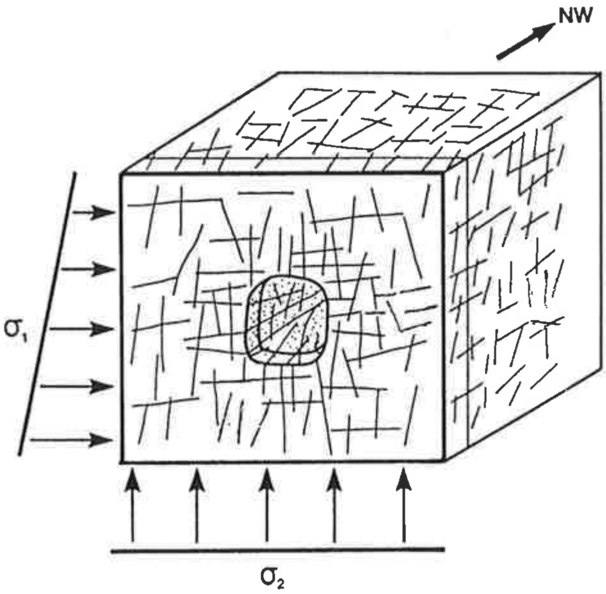


Fig. 8 The main features which influence the underground conditions (from Barton, 1990).

As a conclusion the following features may strongly improve the documentation of ground condition and the exchange of geo-data:

- The inclusion in the case history of a well defined rock mass characterization.
- A list of definitions of common rock mass features and terms to arrive at more concise descriptions which may be used to 'translate' qualitative descriptions into quantitative numbers.
- Guidelines/definitions of appropriate methods to improve the quality of observations used to determine input data applied in rock mass characterizations.

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