Engineering-Geological Properties of Carbonate Rocks in Relation to Weathering Intensity

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Abstract:

For most of the purposes engineering-geological explorations are done on the surface. Afterwards the surface data get correlated with other exploration results in order to produce rock mass quality model.

The modeling of subsurface and deeper zones in karst areas in Croatia is usually a difficult task because of a complex geology. The evaluation of rock mass quality in those zones is even more demanding mainly because of the specific weathering processes of carbonate rocks. Since karstification significantly changes engineering-geological properties of carbonate rocks, it is of vital importance to determine the degree of weathering in surface and subsurface zones.

Engineering-geological properties of carbonate rocks in the surface zone, subsurface and deeper zones are compared and discussed in the paper. Facts and examples are taken from recent highway projects in Croatia. From those data it has been recognized, that depending on the basic block size, two basic weathering models can be established. Each of the models has its specific engineering-geological properties.

Introduction

An engineering geological model of the underground, which is made for the purpose of determining the rock mass quality, is a complex work that requires multidisciplinary approach. In the regions built of carbonate rocks, the rock mass quality assessment is more difficult, within other things, because of the fact that they are weathered in a specific way. Great part of Croatia is built of carbonate rocks that are intensively karstified. According to engineering classification by Waltham and Fookes (2003), the area mostly belongs to mature (kIII) and complex (kIV) karst.

Most carbonate sediments in this region were formed by shallow water sedimentation on the carbonate platform during Mesozoic age. After that period the climate was changing and today moderate continental and Mediterranean climate prevails. As opposed to various karst regions formed in different geological and climate conditions (Amin and Bankher 1997; Tang

2002), Croatian karst region presented in this paper is characteristic for frequent appearance of pits, sinkholes and well developed dolinas and karst poljes. Besides that, numerous areas are intensively tectonized (Herak 1991).

Weathering influence on the intact rock properties

For the understanding of the engineering geological properties of any terrain in hard carbonate rocks, it is very important to determine physical and mechanical properties of the intact rock. In many areas of Croatia carbonate rocks are surely "touched" by secondary and diagenetic processes and disturbances. It has been observed that, under the effects of various tectonic phases, many samples are fractured, recrystallized, dolomitized, dedolomitized and karstified and such are the true representatives of the material that builds the terrain. Because of that, the 'intact' rock samples in many areas of Croatia show the significant deviations of physical and mechanical properties from the ideal equivalents that were not influenced by the tectonic disturbances and diagenetic processes (Pollak and Braun 1998).

Porosity

Primary porosity eases and enables the accelerated weathering of the intact carbonate rock. In that way, more porous rocks differentiate from carbonate rocks of lower porosity with the appearance of the outcrops. Among others, it is known that increasing porosity of rocks generally results in the decrease of their strength.
According to previous tests Tomašić and Ženko (1993), it is obvious that, depending on structure (but on texture and diagenetic properties as well) of the carbonate rocks, primary porosity can be significant (even up to 15%) and in that way it can influence the engineering geological properties of carbonate rocks.

Uniaxial compressive strength

Putting into relation the uniaxial compressive strength and the weathering zone where the sample was taken from, it can be seen to which extent the sample is weathered. Such thing is predictable for granite and sandstone (Beavis 1985). However, greater amount of the carbonate rocks with small porosity represents the exception.
Based on the available data from several areas and lithostratigraphic units, mainly limestones with low porosity, it is obvious that the carbonate rocks in the surface zone don't have lower strength values of intact samples from those collected from greater depths (Figure 1).

Based on past experience and numerous data of strength testing of carbonate rocks with low porosity, the intact sample strength depends much more on fracturing, structure (Figure 2) and texture of sediments and of diagenetic processes than on weathering processes.

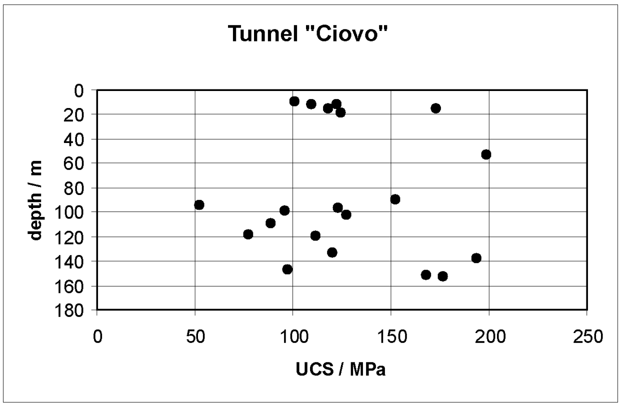


Figure 1. Dependence of uniaxial compressive strength of intact samples on depth. Upper Cretaceous (Turonian, Senonian) limestones in the "Čiovo" tunnel.

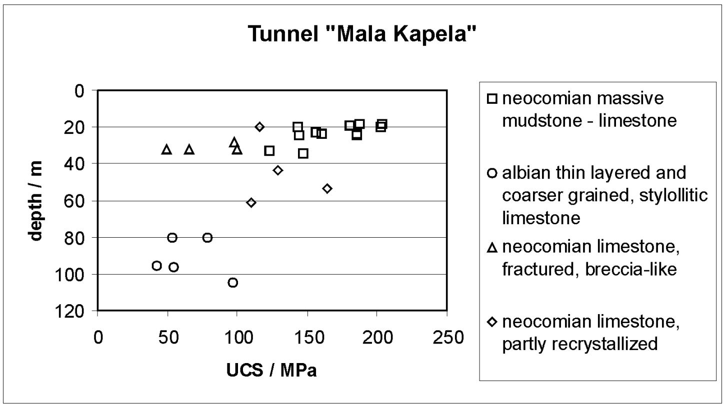


Figure 2. Dependence of uniaxial compressive strength of intact samples on depth and structure. Tunnel "Mala Kapela".

Weathering influence on rock mass properties

In many areas even the first overview of the terrain can determine that almost every lithostratigraphic unit is weathered in a specific way. Such fact is hard to determine by surface investigations, but it can very often be presumed because of the thickness and the properties of cover, of the number and morphology of karst phenomena, of the appearance and intensity of karstified surfaces and similar.

The differences in ways of weathering, and consequently in morphologic phenomena that are characteristic for individual units in the same weathering conditions, are primarily defined by petrologic composition, structure, texture and diagenetic processes which the rocks have passed through (Tišljar and Velić, 1991). The distribution or exchange of lithofacies in space is also important, as well as the tectonic activity of the region.

Weathering zones

It is hard and unreliable to compare the karstification intensity of lithostratigraphic units and to establish weathering zones only by survey of the terrain. The data gathered by geological and engineering-geological mapping, geophysical measuring, core drilling and laboratory testing are most commonly used for that purpose.

Depending on all the properties of investigated area, weathering zones in karst have very different characteristics, spreading and mutual relations. Because of the specific weathering of the carbonate rocks the zones in the extremely karstified areas are mostly very irregular. Regardless of the fact that using the expression "weathering zone" clearly determined regular zoning is presumed, which is not very often the fact in the karst regions. It is very often the case that the separated environments mutually interlace and irregularly exchange vertically and laterally. Irregular "zoning" appears on the large faults or in tectonically fractured areas, where borders with other geotechnical units could be even vertical.

Properties of discontinuities

The weathering in karst areas takes place mostly along the preferred directions, i.e. cracks, joints, faults, bedding discontinuities and so on. Therefore, one of the most important steps for the assessment and determination of weathering zones, but for the assessment of rock mass category as well, is the determination of all discontinuity properties on the surface and in the deeper weathering zones.

High variability in almost every property of discontinuity can be seen very quickly in the regions built of carbonate rocks. Aperture, gouge and roughness of discontinuity in carbonate rocks can often vary in high ranges. In any case, that significantly hardens any assessment or prognosis. Because the mechanical properties of discontinuities depend mostly on these properties (Rongqiang et al. 1993), their determination is of primary importance for rock mass classifications.

Weathering zones and engineering geological characteristics

Regardless of the fact that the weathering in carbonate rocks is conditioned with numerous factors and their engineering geological characteristics vary in wide range, the regularities that can be shown on simplified and idealized model have been noticed.

Taking into consideration all the particularities of weathering in carbonate rocks in highly developed karst and in moderate continental-mediterranean climate of Croatia, two totally different and opposite theoretical models can be schematically presented. The models are defined by the characteristics of intact rock and by the size of the basic block, i.e. the block that is physically separated with discontinuities. The cover influence has not been considered. On one side there are thick bedded, almost massive carbonate rocks with rare but highly distinguished discontinuities and almost undisturbed intact rock (Figure 3, model A). On the other side there are thin bedded or laminated, fractured or massive carbonate rocks with dense distribution of numerous discontinuities with low persistency and in great extent with disturbed 'intact' rock (Figure 3, model B).

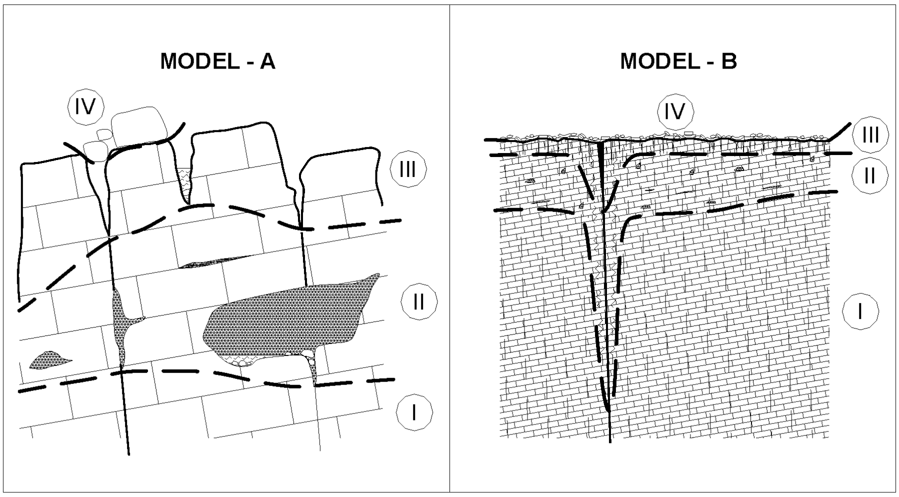


Figure 3. Schematic display of model of weathering in carbonate rocks of developed and mature karst in Croatia.

Model A

Intact rock is represented by carbonate rocks of various structures, low porosity, homogeneous or quasi-homogeneous and isotropic one. They are completely lithified rocks that have not been weakened by recrystallization or other post-diagenetic processes. In the laboratory sample without cracks and joints show maximal mechanic properties for intact rocks, which are almost the same in all the separated zones. The layer thicknesses are high (for example the reef and fore-reef development of Senonian deposits, Croatia) or the rock has no distinguished layer discontinuities (for example massive mudstone / limestones of Neocomian age or non bedded, massive limestone Jelar breccias, Croatia – Vlahović et al. 1999).

Zone I

Rock mass is massive or consists of great blocks limited by discontinuities with high persistence with no traces of karstification. Walls of discontinuities are fresh, closed or with aperture of max. 1 cm, mostly filled with calcite. Bedding discontinuities are closed. The media is anisotropic or isotropic. The depth of this zone is variable, but it can reach the surface very rarely and locally.

Zone II

Basic rock mass from the zone I with the appearances of karstification along the most expressed discontinuities. By means of karstification some discontinuities are widened up to aperture of several centimetres, often covered with the layer of crystalline calcite and partially filled with clay. Layer discontinuities are still mostly closed or with the aperture of less than 1 cm. Caverns, pits and caves of various dimensions are frequent.

Zone III

Surface karstification zone with huge blocks on the outcrops, which are separated by joints with even metric aperture and without gouge. Bedding discontinuities are also often highly karstified, with aperture up to several centimetres, very often without gouge (Figure 4a). Walls of the majority of discontinuities has become rough-undulating or smooth-undulating because of the weathering. Joints with large aperture connected to the surface, as well as the thickness of this zone can reach up to dozen meters in depth. Open joints correspond to over 10% of total rock volume.

Such rocks on the surface often build steep slopes or cliffs (Figure 4b) and the openings of caves or pits with greater dimensions can be found. Sinkholes of various dimensions are frequent.

Zone IV

Unbounded blocks of huge dimensions. Cover depends on climate. It is often missing or it fills the depressions.

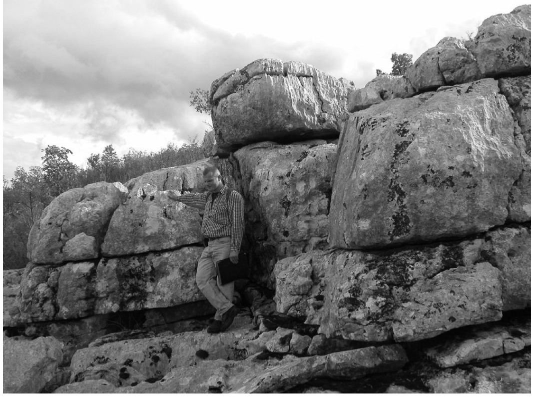
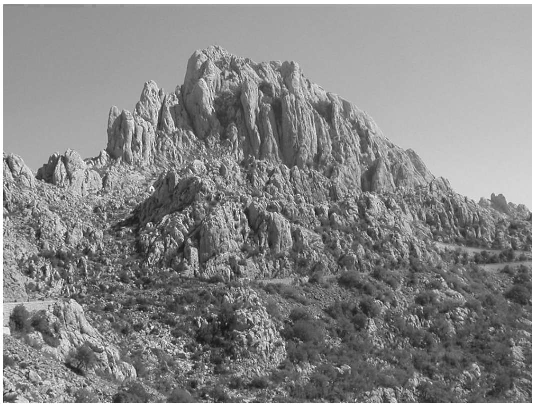
a)  b) 

Figure 4. Surface weathering: a) of metric blocks of very well bedded limestones of Senonian age (Bisko, Croatia); b) of huge and massive blocks of carbonate "Jelar" breccias of Upper Eocene - Lower Oligocene (Tulove grede, Velebit Mt., Croatia)

Model B

Opposite to model A, which is built mostly of undisturbed rock, the other extreme is represented by model B. That means, the intact rock of model B is exceptionally heterogenous due to: structure and texture of the rock (lamination, thin layers - figure 5a, stromatolites - figure 5b, numerous stylolites and so on), tectonic fracturing (cracks, veins, joints) or it is homogeneous but significantly weakened by the activities of various processes (recrystallization, dolomitization - figure 5b or dedolomitization).
Opposite to intact rock of the model A, the weathering influence on physical and mechanical properties can often be seen on these samples.

Zone I

Thin bedded, laminated or massive rock with numerous discontinuities of various genesis. Discontinuities are so frequent, but poorly distinguished, with no aperture, that the media can be taken as quasi-isotropic. There is no aperture on the discontinuities and, if there is gouge, it is exclusively carbonate. There are no traces of karstification.

Zone II

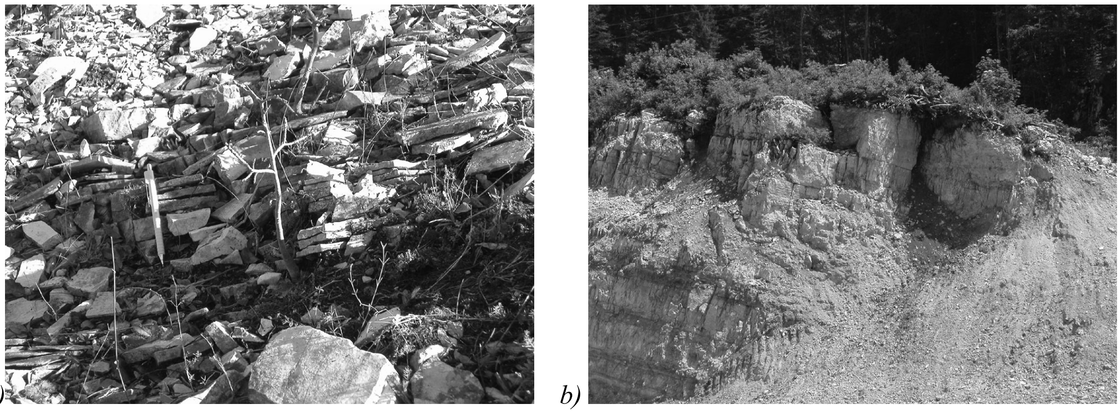
Rock mass properties are the same as in zone I, but on more expressed discontinuities the weathering processes are visible and smaller caverns are also possible. Aperture of discontinuities almost does not exist. Besides the numerous cracks and joints the diagenetic changes are visible (recrystallization, dolomitization, etc.). The intact rock is locally porous, and the separation of blocks along the bedding planes is possible.

Zone III

Only some secondary discontinuities are filled with clay, max. up to several centimetres thick. Many of them are planar or stepped, very clearly expressed. Only in some places, the wider discontinuities (over 10 cm) connected with surface, filled with clay or cover material are possible. The rock is often cavernous, porous. Bedding planes are highly expressed and in places the interlayer joints are opened. Unbounded material that fills open joints represents over 10 % of total rock mass volume.

Zone IV

In the areas with no cover, rock debris and fragments are exposed at the surface (figure 5a). The areas with cover are often overgrown by vegetation and below the humus layer there is a mixture of fragments, debris and cover material in various ratios (figure 5b).
The areas built of rocks shown in this model are often flattened or with mild slopes, almost without sinkholes, or they are very shallow with mild brims.



a) *b)*

Figure 5. Surface weathering: a) platy limestones of Turonian age (Stupi, Vranjica, Croatia); b) exchange of early diagenetic and stromatolite late diagenetic 'hauptdolomite' (Gorski Kotar, Croatia).

The thickness of all the mentioned zones on both models depends on local conditions and varies within wide range. Depending on geological, morphologic or climatic conditions, some zones can be completely missing or even have the inverse order.

Conclusion

Development of an engineering geological model of the underground is a complex task that includes numerous investigations and requires interdisciplinary approach.
The facies type of rocks and their structure and texture determine the way and the intensity of weathering of the carbonate rocks. Because of that, for the determination of weathering characteristics of carbonate rocks it is very important to study the microfacies characteristics.

Unique way of weathering of carbonate rocks is mostly connected to relatively good solubility of minerals that build them, so they are weathered along the preferred directions. Because of that, studying of all discontinuity properties in surface and subsurface weathering zones is of exceptional importance.

It is obvious that the variations of weathering ways are very wide, depending on the structure and texture of the rocks, fracturing intensity, morphology of area and climatic conditions. Nevertheless, depending on the basic block size, two basic weathering models can be separated. On one side there are thick layered, almost massive carbonate rocks with rare, but highly distinguished discontinuities and almost undisturbed intact rock (model A). On the other side there are thin layered or laminated, fractured or massive carbonate rocks with dense distribution of numerous discontinuities with low persistency (model B).

It is important to mention that in nature, frequent changes in sedimentation conditions, the activity of various diagenetic and post diagenetic processes and tectonic activity, can produce mixing and various combinations of weathering models.

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