General engineering geological characteristics of the Kaštela (Croatia) flysch deposits

D. Pollak & R. Buljan
Croatian Geological Survey, Zagreb, Croatia

A. Toševski
Faculty of Civil Engineering and Architecture, University of Split, Croatia

ABSTRACT

Most of the Eocene flysch clastite bedrocks in the wider area of the city of Kaštela near Split are urbanized and densely populated. Northern parts of the flysch terrain are mainly covered with thin rockfall breccia and other slope material originated from the Mesozoic carbonate overthrust nappe. Therefore, there are very limited possibilities for outcrop research. On the other side, in the last several years geotechnical investigations and construction of infrastructural projects enabled us to identify some engineering geological properties and problems of the flysch complex. The obtained facts and numbers will be incorporated into the Basic Engineering Geological map of Croatia in the scale of 1:100,000.

The flysch in wider area is comprised of limestone breccia, calcirudites, calcarenites, marl, clayey limestones and rarely of large limestone olistolithe blocks. The investigated area is mainly built of marl with local interbedding of calcitic siltstone, calcarenite and clayey limestone. In general, lower part of the apparently 800 m thick flysch complex is dominantly built of coarser grained clastites.

According to the available laboratory, geophysical, borehole and limited surface data several conclusions can be made. Based on dominant component at least two flysch types can be identified. Marly type of flysch with dominant properties of marl and clay rich marl with rare coarser grained interbeds, is characterized by mild morphology. More resistant type of flysch with dominant interbeds of coarser grained sediments or with calcite rich marl can be determined thanks to its jutted or steeper morphology.

Rapid weathering of the cuttings is one of the biggest engineering problems in the area. It is also evident that the weathering processes are related to mineral content, grain size and distribution of individual components. In the coastal plain, natural weathered zones of marly flysch are regular and gradual. In average, total thickness of the weathered marl is between 1 m and 4 m. It is also evident that in the areas with predominant content of other flysch components weathering zones vary greatly.

For all these reasons the GSI classification for heterogeneous rock masses was applied. Following the principles of that classification, rock mass quality of the flysch varies in wide range. The GSI values fluctuate with mineral composition, rate and distribution of individual flysch components.

Keywords:
flysch, engineering properties, GSI, weathering, Kaštela

1 INTRODUCTION

The investigated area belongs to the western part of the Split flysch basin, and is located between the cities of Split and Trogir. In that area, northern part of the flysch deposits is bordered with Cretaceous carbonate nappe of Kozjak mountain (780 m). Southern boundary limit of the investigated area is defined with coastal boundary along Kaštela bay.

The paper presents geological and engineering geological characteristics of the flysch in outlined area which is expected to have a lot of similarities with very well defined and investigated flysch deposits in Split. The data presented here are collected during limited engineering-geological mapping at the rare outcrops and cuttings for the Basic Engineering-geological Map of Croatia (in the scale 1:100,000), and from the boreholes, geophysical and laboratory investigations performed for “ECO Kaštela” project. Some other, especially laboratory data are adopted from the considerable amount of data collected in the city of Split (Šestanović 1998, Miščević 1998, Toševski 2004).

2 GEOLOGY

In the wider Kaštela region two morphologically and geologically diverse lithological complexes could be distinguished. The northern complex is a typical karst area with rough morphology - dolines and karst polje built up mainly of the Cretaceous and Eocene limestones. The southern complex represents Eocene to Oligocene flysch (Marjanac 1993) –clastic sediments of variable grain size with limestone interbeds.

The mentioned zones are, in Kaštela region, divided with the Kozjak reversed and overthrust fault which literally overhangs limestones over the flysch.

2.1 *Geological history of the area*

In wider area carbonate sedimentation (dominantly limestones) during Mesozoic continuously took place at the shallow and stable carbonate platform. The end of the Mesozoic period is marked with Laramian orogeny and formation of Dinarides (Magaš & Marinčić 1973). Then strong karstification and creation of irregular karst relief started. In deeper depressions the bauxite deposits had been formed.

In lower Paleogene a regional transgression enabled sedimentation of breccia and platy limestones. During lower and middle Eocene the sea became deeper with sedimentation of foraminiferal limestones. Upper Eocene is marked with maximum sea level and sedimentation of turbidite flysch. The end of the Eocene is marked with strong uprising and orogenic breccia sedimentation. Then started an intensive deformation and faulting of flysch complex as well as strong karstification of adjacent carbonates. A terrestrial phase lasts until today.

2.2 *Tectonic*

The main tectonic characteristic of the flysch complex during geological history has been a strong compression of the region which caused intensive folding, faulting and creation of frequent fissures, cracks and crushed zones. Intensive tectonics also formed tilted and overturned folds with frequent fold faults - imbricated structure. Structures are monoclinal with Dinaric strike NW-SE. General dip direction of the bedding planes are to the north-northeast with dip angle from 20 to 75°.

2.3 *Sedimentology of the flysch deposits*

The flysch sediments in Kaštela represents a distal facies of Adriatic flysch complex in regional scale (Marinčić 1981). It is comprised of limestone breccia, calcirudites, calcarenites, siltites, marl, clayey limestones and rarely of large limestone olistolithe blocks.

Coarser grained sediments frequently represent the basis, calcarenite layers middle part and marly deposits the upper part of the many graduated sequences.

The mineral and petrographical composition of the deposits is variable and depends on its grain size. Breccias and breccia-conglomerates have limestone fragments with biocalcarenite or locally marly matrix. Sandstones are also comprised of calcitic and limestone detritus with calcite cement.

X-ray diffraction analysis of the undissolved fraction of marl in Split determined: quartz, illite, plagioclase, potassuim feldspar, smectite, vermiculite, pyrite and amorphous component (Toševski 2004).

Lateral and vertical alterations of described components in flysch are frequent. Total thickness of the flysch deposits in this area is supposed to have approximately 800 m (Marinčić et al. 1971).

2.4 *Hydrogeology*

In accordance with the lithology of wider area, two basic hydrogeologic units can be separated:

- permeable carbonate rocks, dominantly karstified limestones;
- impermeable or poorly permeable rock mass, clastic flysch deposits.

Permeable limestones are highly karstified with well developed hydrographic net and secondary porosity. Precipitation waters are immediately drained to the water table and generally flow toward south.

Impermeable, watertight flysch complex represent a water barrier directing a groundwater collected in carbonate hinterland toward Jadro and Pantan springs. There are also numerous smaller springs within flysch complex too.

3 ENGINEERING GEOLOGICAL PROPERTIES

3.1 *Morphology and engineering properties*

Described geological conditions influenced on today's morphology of the investigated area. The coastal area is plane and fertile with thicker soil cover. Inward part of the investigated area is locally hilly with gentle slopes and occasional jutted outcrops of more resistant clastites. The northern margin of the investigated area is defined with steep slopes of rigid flysch layers and vertical walls of limestone overthrusted nappe of Kozjak mountain.

The morphology of the flysch itself enables us to differentiate (in scale 1:100,000) at least two segments of flysch with different engineering properties. The flysch differentiation is in concordance with early and recent sedimetological investigations (Kerner 1903, Marjanac 1993).

The "lower flysch zone" is more rigid, resistant to weathering with dominantly coarse grained and predominantly carbonate sediments. In that zone carbonate breccia, calcarenites, limestones, clayey limestones and calcite rich marls dominate.

The "upper flysch zone" is much softer, prone to weathering in which engineering properties of pelite and clayey sediments dominate. The zone is represented with marls and clayey marls with occasional thin interbeds of coarser grained carbonate sediments, mostly calcarenites.

The boundary between mentioned flysch zones is named "middle unit" (Marjanac 1987) represented with single olistostrome - a chaotic mass consisting of an intimately mixed heterogeneous materials such as: olistolithe blocks, calcarenites and calcite rich marls. The calcite rich marls are valuable reserve for cement production and are excavated at present. The maximum thickness of whole "middle unit" is 170 m.

3.2 *Properties of rock and soil material*

Mineralogical and petrographical compositions in different flysch components are variable. Coarser grained sediments like calcarenites and breccias have dominantly carbonate content. Still, its physical and mechanical properties vary and are dominantly influenced with matrix quality, grain size and fabric of the sediment. Consequently, carbonate breccia with firm carbonate detrital matrix has much better mechanical properties than limestone breccia with marlaceous matrix (Figure 2). Its tensile strength (Brazilian test) varies greatly in accordance with matrix quality from 0.94 to 12.47 MPa (Šestanović et al. 1993).

The uniaxial compression strength (UCS) and tensile strength of limestones greatly diminishes with share of marly content in it (Figure 2). Tensile strength (Brazilian test) varies from 4.85 to 18.16 MPa (Šestanović et al. 1993).

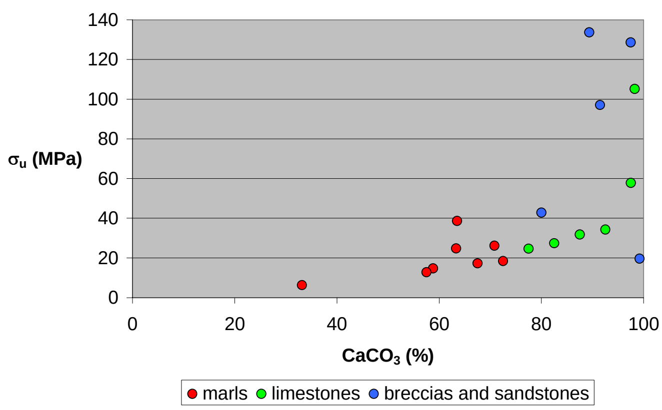

Figure 2. Average uniaxial compression strength in relation to average carbonate content. Samples from diverse clastic rocks of Split and wider region (Roje-Bonacci et al. 1985, Šestanović et al. 1993, Šestanović 1989, Barčot & Bojanić 1998).

Carbonate percentage in pelite sediments, like siltite and marl, varies greatly. Accordingly with increase of the carbonate content ascends the UCS (Figure 2) and tensile strength. Still, mentioned trend can be noticed on great amount of data only, because of multiple other factors which also have the influence on rock material strength (Roje-Bonacci et al. 1985) like: quantity and mineral composition of clay minerals (Šestanović et al. 1994); diagenetic and postdiagentic processes (Šestanović 1989).

The average tensile strength of different marls in Split are: clay rich marls – 0.5 MPa, marls – 1.3 MPa and calcite rich marls - 3.0 MPa (Šestanović 1998).

In wider Kaštela area there are several types of soils which can be determined at the field (Figure 4):

- clay or silty clay as a final weathering product of marlaceous sediments;
- clay with flysch bedrock fragments – highly weathered flysch;
- clay rich marl – soft rock-hard soil weathered marlaceous rock with higher clay content;
- terra rossa – a red clayey soil as a mixture of final weathering product of carbonates and eolian transport;
- clay with limestone rubbles on top of limestones – highly or completely weathered zone on top of carbonates
- organic mud – a recent marine sediment in the wider area of Trogir;
- rockfall material – a mixture of clay, silt and rockfall breccia of variable sizes underneath the overthrusted carbonate nappe.

According to the laboratory data, the eluvial soil material on top of limestones has much higher plasticity than on top of flysch sediments (Figure 3).

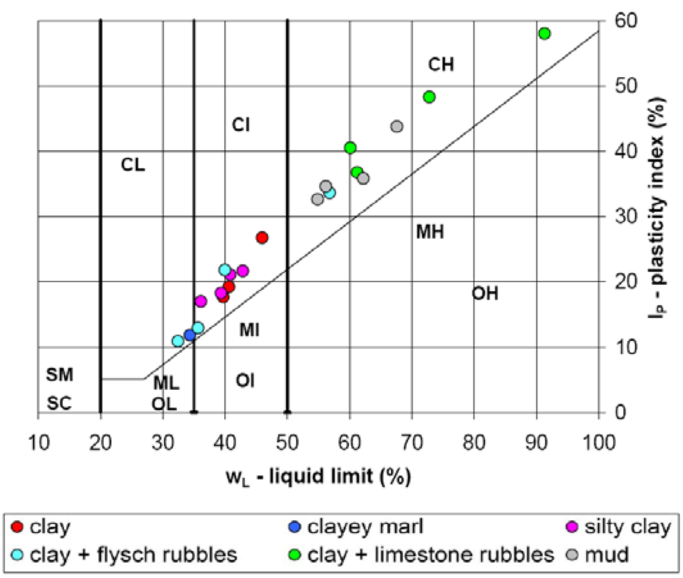

Figure 3. Plasticity chart of soil material on top of bedrock in Kaštela plane and wider area. The legend represents field work determination of materials.

3.3 *Exogenetic processes*

3.3.1 *Rock material weathering in engineering time*

Weathering processes of the marls at the freshly exposed cuttings of Split had already been investigated and are well documented (Miščević 1994, 1997, 1998). According to the author's research, rapid weathering of marl rock material at the cuttings is an outcome of its consequent wetting and drying. The progress of the weathering therefore can be significantly decelerated with prompt and effective moisture protection.

3.3.2 *Floodwater erosion*

Clastites with marlaceous content and eluvial sediments are prone to torrent erosion. In Kaštela flysch there are nearly 25 torrent streams flowing directly toward sea which periodically but intensely erode incompetent parts of flysch complex (Barbarić & Pejaković 1998).

Torrent streams, and rivers Jadro and Pantan are considered as the most important source for recent sedimentation in Kaštela bay. Holocene sediments in the bay are from 0 to 4 meters thick. Average sedimentation velocity is 0,4 mm a year (Crmarić et al. 1998).

3.3.3 *Rock mass weathering in geological time*

Coarser clastic sediments, like calcarenite, limestone breccia or limestones are not prone to such rapid weathering. It can be easily determined by examining the morphology of the area. Namely, areas with dominant coarser and carbonate sediment interbeds are much steeper and locally jutted ("lower flysch"). The sediments in "lower flysch" usually have irregular weathered zone with differing composition and boundaries.

Marlaceous parts of the flysch complex are even and plane ("upper flysch"). Weathering processes in it produce a uniform layer of eluvial soil on top of it. The soil is generally composed of two zones: lower zone is a mixture of clayey and marly material and bedrock rubbles; upper zone contains more clay and is without bedrock rubble (Figure 4). Weathered zone on top of marlaceous sediments is very consistent and uniform. Its thickness is between 1 m and 4 m. The boundary with fresh bedrock is regular and gradual.

3.3.4 *Swelling*

The processes of swelling of marls were investigated during research of weathering and settlement of marlaceous embankments. The swelling of marls is a consequence of the swelling clay minerals (vermiculite and smectite; Toševski 2004) and locally the crystallization of gypsum (Miščević 1998).

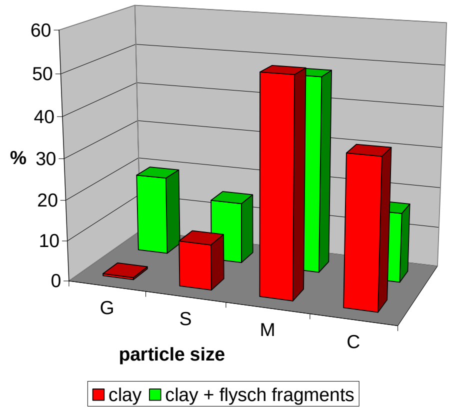

Figure 4. Granulometry chart of "lower flysch" eluvial soil. Two zones are present: lower with flysch rubbles (green) and upper clayey soil (red).

Weathering zones in marlaceous sediments were differentiated using a borehole core and geophysical data. The zones could be differentiated thanks to obvious change in rock material and discontinuities properties. Namely, weathering of marlaceous rock masses is leading toward leaching of carbonates and causes modification in mineral constituent ratio. Leaching of carbonate minerals leads toward enrichment of rock material with clay minerals in upper zones and degradation of its mechanical properties. In highly weathered zones most of the discontinuities are also filled with clay minerals.

3.3.5 *Abrasion*

Despite of very low coastal energy in Kaštela bay, abrasion of the coastline had been intensive at the locations with domination of marlaceous sediments. Therefore today, most of the natural coastline is represented with more resistant calcarenites, breccias and limestones. Other parts of the coastline prone to abrasion are protected with embankments and waterfronts.

3.3.6 *Rockfalls*

Most of the overthrust fault is overlied with rockfall breccia and other slope material originated from the Mesozoic carbonate overthrusted nappe. The estimated thickness of the rockfall material is from several to twenty meters.

3.3.7 *Landslides*

Landslides in natural slopes of flysch sediments of Kaštela and its eluvium hadn't been noted up to now, but there is one in Split flysch - inactive landslide at Žnjan (Šestanović 1989).

3.4 *The engineering-geological properties of rock mass*

The engineering properties of Kaštela flysch are greatly variable and depend on numbers of factors. Most of the factors are actually sedimentological properties like: mineral composition, texture, structure, particle size, thickness and ratio of particular interbeds, degree of cementation, cement or matrix quality, thickness of the magabeds and beds. The other also very important factors are degrees of tectonic disturbance and weathering.

Following the procedure of Marinos and Hoek (2001) the Geological strength index (GSI) estimation for heterogeneous rock masses was carried out. Because of the soil cover on top of flysch bedrock the GSI estimation was done at the cuttings and the borehole cores.

According to the field estimations, sediments of a flysch complex have a large range of GSI values (Figure 5). Coarser grained and carbonate sediments, mostly fresh and well cemented calcarenites, have GSI from 42-70. Its GSI values are influenced with block size, namely bedding thickness or tectonics. In weathered zones, calcarenites usually have smaller block sizes than fresh ones and therefore are located downward in the GSI chart ranging from 33-45 (Figure 5).

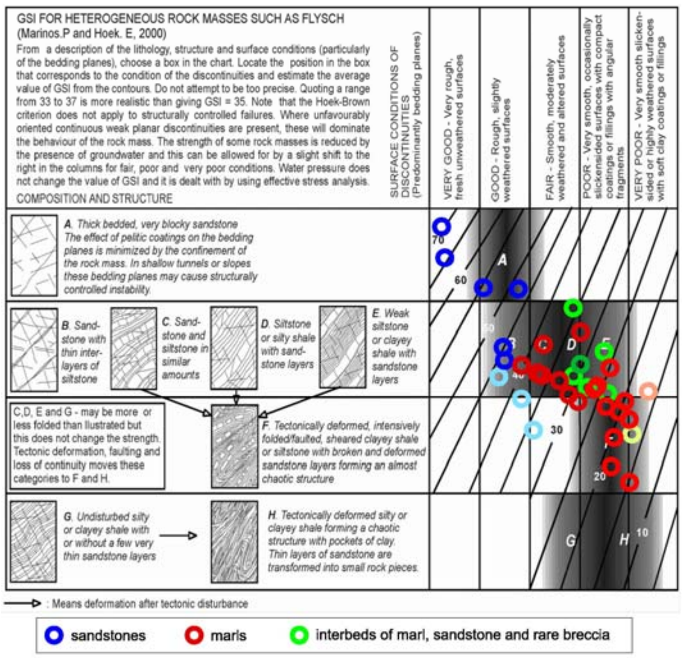

Figure 5. Range of GSI values of different flysch components estimated at the cuttings and boreholes. Lighter hues represent weathered rock mass.

The GSI range of fresh marls is very broad because of variable carbonate content and different tectonic impact 27-42. Weathered marls are located more to the right in the GSI chart because of dramatic decrease in discontinuities quality. They have GSI from 18-28 (Figure 5).

In the majority of the "upper flysch" area marlaceous part of the clastic complex is irregularly interbeded with thin layers of siltstones, calcarenites or even breccia. Number, size and nature of the interbeds of coarser sediments in marl have great influence at the properties of the complex itself. As a result the GSI values in such complexes can vary greatly. In the investigated area, the rigidness of the competent layers decreased the weathering potential of marls. Therefore, weathered parts of the clastic complexes have better GSI then pure marls, from 22-37 (Figure 5).

The shallow seismic refraction profiles in "upper flysch" along the Kaštela coast generally show regular and uniform zonation. Eluvian soil on top of flysch is 1-4 m thick with primary seismic waves velocities (Vp) up to 1000 m/s. Highly weathered zone is generally 1-3 m thick with Vp from 700-1500 m/s. Weathered zone is not so uniform, with general thickness from 2-5 m, but locally varying from 1.5 to even 10 m and depends on composition of rock mass. The Vp are generally from 1500-2500 m/s. Fresh "upper flysch" sediment complexes have Vp from 2000 to maximum 3500 m/s.

The data from seismic profiles are in accordance with borehole cores from the same locations. Therefore it was possible to compare the estimated GSI values from the boreholes and primary seismic wave velocities (Figure 6). The chart displays no direct correlation but dependence of the two parameters in some extent.

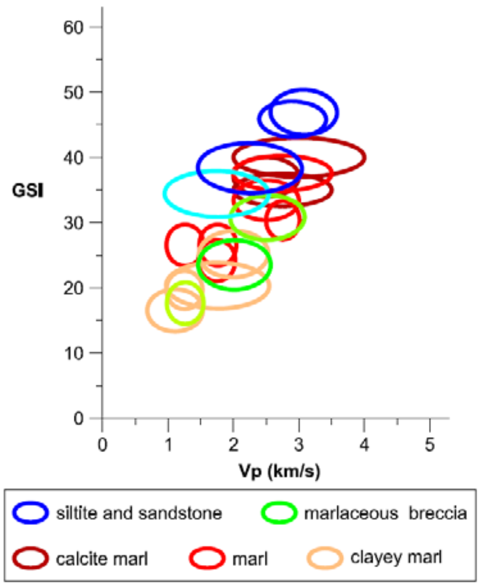

Figure 6. The comparison of estimated GSI values from boreholes and velocities of primary seismic waves (seismic refraction results).

In general, lowering of the rock mass quality (regardless it is due to weathering, tectonic or change in rock material properties) causes decreasing of the primary seismic wave velocities (Vp). It could be noted that weathered calcarenites (light blue) and marlaceous breccia (light green) have slower Vp than fresh ones. It is also evident that change in mineral composition of marls has some impact on Vp velocities. It can be noted that decrease of the Vp velocity is usually followed with reduction of GSI value, but that doesn't mean that GSI values in flysch sediments can be determined with seismic explorations.

4 CONCLUSIONS

Diversity of the Kaštela flysch deposits causes a great heterogeneity of its physical and mechanical properties. Heterogeneity is dominantly caused by differing grain size and mineral composition of clasts and matrix. Variable ratio of different clastic rock interbeds is also causing entirely opposite engineering behavior of flysch rock mass packages.

Still, according to its general sedimentological and engineering geological properties it is proposed to distinguish two complexes of flysch at the Basic Engineering Geological Map of the Croatia in the scale of 1:100,000: the "lower" and "upper flysch". Each of the complexes is defined with recognizable morphology and different engineering properties.

The various exogenetic processes in flysch deposits are abundant. The consequences of the mentioned processes can be diminished with mindful engineering respecting all of the engineering geological properties mentioned here and in previous researches.

Weathering of the flysch in general is also variable and in accordance with mineral composition and grain size. Weathered zones in coarser and carbonate sediments are irregular. Pelite and marlaceous sediments with higher clay mineral content have uniform and regular weathering zones.

The application of GSI for engineering geological properties estimation of flysch deposits seems to be appropriate. Still, minor changes in descriptions of the properties in GSI chart would ease its use in this particular region. GSI of flysch deposits varies in great range from hard calcarenites having maximum of 70 and weathered clay rich marls having 18 in minimum. Therefore it is necessary to perform GSI estimation in each locality and weathering zone separately.

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