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Control of the Stability and Protection of Cut Slopes in Flysch

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Ključne riječi: fliš, kosine, kontrola stabilnosti, zaštitne konstrukcije, kompjutorski programi

Abstract

Due to the presence of different layers in the Eocene flysch in the region of Split, it is possible to determine from the petrography and engineering-geology the series where the slopes should be protected by various methods. During the construction process and then upon its completion , it is possible to use a suitable computer programme to establish the degree of the stability of the deposits by considering their composition, the position of the layers in relation to the cutting line and possible plane of failure. In addition, nine alternative solutions have been proposed for the protection of the slope which all take into account the specific features of flysch. The reliability of the selection is ensured by the proposed computer programme especially developed for this purpose.

Sažetak

Na temelju pojavljivanja petrografski i inženjerskogeološki različitih naslaga, u eocenskom flišu šireg područja Splita izdvojene su serije u kojima izvedene kosine treba zaštititi na različite načine. U uvjetima izvođenja graditeljskih zahvata i nakon njih moguće je utvrditi stupanj stabilnosti naslaga - s obzirom na njihovu građu, položaj slojeva u prostoru prema liniji zasijecanja i moguću plohu loma - odabranom pogodnom metodom koja je za flišne naslage obrađena i prilagođena za rad na kompjutoru. Uz to, predloženo je devet mogućih rješenja zaštite kosina koja respektiraju specifičnosti fliša, a objektivnost izbora omogućuje predloženi, posebno za tu svrhu kreirani kompjutorski program.

1. INTRODUCTION

When cutting into flysch terrains (e. g. by construction measures / road buildings etc.) it is necessary to ensure that the slopes are stable and will be permanently protected and/or supported. Due to the different lithological elements present in flysch (which can appear in series) and their structural-tectonic characteristics, the stability analysis, protection and support, if necessary, of the cut slopes should be carefully considered. This particularly refers to the sections where the layers are stable under natural conditions but where any cutting can lead to instability.

The induced dis-equilibrium in the cuts requires measures to be taken to achieve permanent stability. In order to find a satisfactory solution the input data should accurately describe the terrain and its layers. This presents a complex problem in flysch since each segment (i.e. lithological element with all its features) needs specific treatment. Thus, engineering works in flysch have been the subject of a great number of scientific studies. The results and experience contribute to the definition of the findings necessary in seeking new solutions which can differ from case to case. This makes general statements impossible. Only comprehensive studies which include mineralogical-petrographical and engineering-geological characteristics yield relevant data necessary for geostatic computations for each specific case; this means that optimal results can be achieved only by interdisciplinary and multidisciplinary procedures (MAGDALENIĆ et al., 1980). The fact that such procedures have been accepted can be confirmed by those papers published on the problems of construction in flysch, stability control and protection of flysch layers co-authored by geologists and civil engineers (ČAGALJ et al., 1980, 1987; JAŠAREVIĆ et al., 1986; BOJANIĆ et al., 1986; JURAK et al., 1987; SAMARDŽIJA et al., 1987; ŠESTANOVIĆ et al., 1989). These papers represent the basis for defining the approach to investigations dealt with in this paper.

By defining the mineralogical-petrographical and engineering-geological features of the rocks and terrain it is possible to obtain data in order to analyse the stability of the slope at a given angle and then to adopt the appropriate solution for its protection, stabilisation and support. Therein it is necessary to take into account not only the safety-technical criteria but also those criteria which include the structural stability, construction and maintenance cost, efficiency and also aesthetic aspects. Consequently, starting from the identification of the safety factor for any particular example, and respecting the principles of efficiency and function, it is necessary to analyse several alternative solutions and then to select the best one.

The objective of this paper is to present the following factors: variety of lithological elements in flysch in

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the region of Split and their principal mineralogical-petrographical and engineering-geological features, the possibility of applying a method for an analysis of the stability of the cut slopes in the flysch terrains (SARMA, 1979) with necessary modifications (developed and adapted for computers), as well as the possible types of protection which are dependent upon the lithological and structural-tectonic features of the layers with a specially developed computer programme for selecting the optimal solution.

2. MAIN ASSUMPTIONS FOR THE DETERMINATION OF STABILITY AND PROTECTION OF THE CUT SLOPES

The mineralogical-petrographical composition and faults in the structure of minerals and rocks directly influence the general physical-structural and physical-mechanical features of the flysch layers. The characteristics of the coarse clastic rocks depend mainly upon the composition of the binding agent (matrix), whereas the features of marls and siltitstones depend upon the quantity and type of clay minerals in their composition (MAGDALENIĆ et al., 1980). In the region of Split, in the Eocene flysch, there are fragments of calcareous breccias and breccia-conglomerates and of the calcarenites and detrital limestones bound by biocalcarenite and calcite cement, whereas the marls are mainly composed of calcite and clay minerals (illite, illite-muscovite and montmorillonite) with some quartz, feldspars and plagioclase (MAGAŠ et al., 1973; MARINČIĆ et al., 1977).

From their formation to the present the flysch layers have been exposed to repeated stresses and deformation (MARINČIĆ, 1981; MAGAŠ et al., 1973; MARINČIĆ et al., 1977; MARJANAC, 1987, 1991). During these processes numerous crystal-faults and micro-faults have formed in the minerals and influenced the total physico-mechanical features of the layers. These features are also the result of processes whereby minerals are broken down by exodynamic factors (CRNKOVIĆ, 1983). Since rocks are mineral aggregates, it is obvious that by identifying the mineral composition and the physico-mechanical features of the minerals it is possible to obtain important data for estimating the stability of cut slopes in flysch; this applies particularly to the resistance of certain lithological elements to the effects of exodynamic forces and the possibility of shearing along the diagenetic and tectonically caused surfaces of discontinuity.

When determining the angle of the cut slope, its stability and the allowed working load in this zone, it is necessary to take into account a great number of parameters which are the result of diagenetic and post diagenetic processes such as: heterogeneity, anisotropic features, discontinuity, water influence and natural stresses, i.e. to define the layers as if they were actually real. This approach requires a great number of numerical data which, using a suitable computer method, can successfully describe the layers and their stability under the altered conditions caused by cuts.

Input data on the characteristics of rocks and terrain can be partly collected by engineering-geological field investigations, wherein special attention should be paid to the lithologic and structural-tectonic features, the layer's thickness, the influence of infiltrating water and groundwater, and to the micro-climatic conditions influencing the flysch layers.

In addition, the input data of special interest for the stability and selection of the protection design should include the results obtained by laboratory experiments and requirements of the planned structures (e.g. dimensions of the road cut) and the constraints such as the slope loading and the problems related to the boundary of the defined expropriation belt. This set of data is very important since in some situations it can directly influence the selection of the design method if the engineering-geological and spatial conditions are complex.

To facilitate the identification of a series of sediments with the layers in a specific position, the flysch deposits have been classified according to the relevant features of the lithological elements present in those deposits, including six typical cases (Table 1). Each case has several alternatives which depend upon the position of the layers with regard to cuts; hence, three general cases can be distinguished:

Case a: unfavourable position of the layers (parallel to the line of the cut excavations with a deviation up to 45°, with their slope oriented in the cut direction with an angle less steep than the cut slope angle);

Case b: favourable position of the layers (excavation line is perpendicular to the line of the layers stretching with a deviation of up to 45°);

Case c: from a favourable to unfavourable position of layers (with faults, presence of fault zones and fissures and tectonic zones with expressed schistose texture caused by weak dynamo-metamorphic processes. Either the layers are not visible or small areas occur on the cut surface along their extension with favourably or unfavourably inclined layers).

After a detailed engineering-geological study of the terrain the recorded flysch layers can be easily classified into one of the above types, according to the respective series of layers where the cuts are made.

The Eocene flysch in the region of Split includes the following series:

1. Thin-layered marls, clayey marls and calcareous marls alternating with thin-layered calcarenites (and marl clay in inter-layer fissures). The total thickness of this series is 500 m.

2. Marls with layers of various thickness (with marl clay in inter-layer fissures). The depth of this series does not exceed 150 m.

3. Clastic layered limestones with a total thickness of 20 m.

4. Calcarenites alternating with calcareous breccias (and breccia conglomerates), with a total thickness up to 60 m.

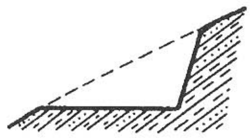
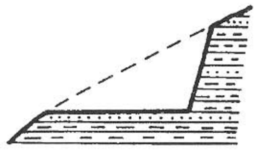
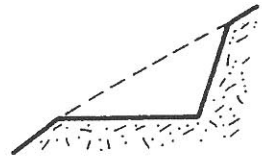
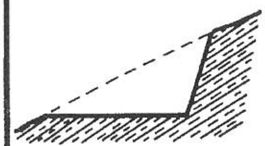
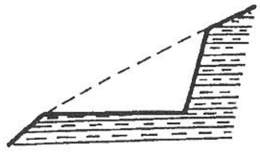
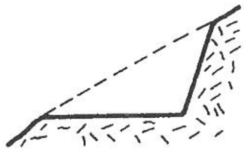
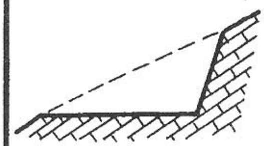
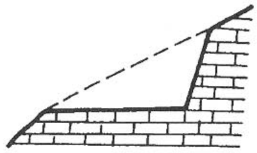
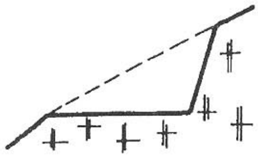
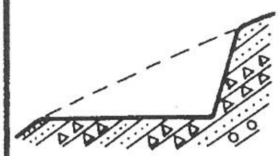
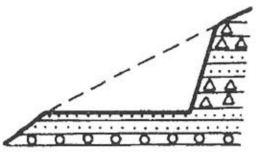
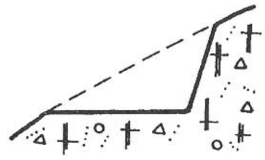
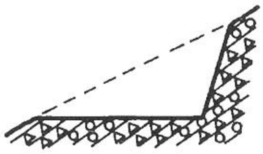
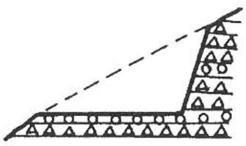
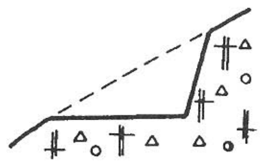
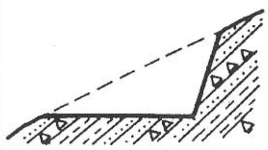
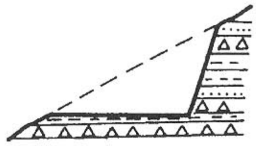
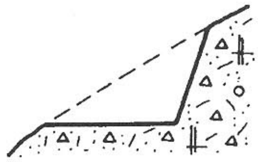
	Position of layers with regard to the cut line → Sediment series ↓	a) Unfavourable bedding	b) Favourable bedding	c) Favourable to unfavourable bedding (folds, fractured zones without evident bedding)
1.	Thin-layered marls, clayey marls and calcareous marls in combination with thin-layered calcarenites			
2.	Marls with different layer thickness			
3.	Clastic layered limestones			
4.	Calcarenites alternating with calcareous breccias (and breccia conglomerates)			
5.	Calcareous breccias (and breccia conglomerates)			
6.	Calcarenites, breccias and marls in combinations			

Table 1. Series of sediments in Eocene flysch in the region of Split showing boundary position of layers with regard to the cut line.

5. Calcareous breccias (and breccia conglomerates) whose thickness never exceeds 20 m.

6. Calcarenites, breccias and marls repeatedly alternating among themselves, with a total thickness of up to 100 m.

Each of the described series can appear in greater or smaller lengths in cuts for all of the three characteristic positions of layers. Consequently, the stability of the given cut can become questionable, and a fracture can occur in any surface (flat, inclined or circular). This fact accounts for the necessity of finding a suitable method for computing the global stability, wherein the method developed by SARMA (1979) was selected. The determination of global stability by the Sarma method requires data on cohesion (c), angle of internal friction (φ), spatial weight (γ), piezometric level (h), surface loading (p), if it exists, and homogeneity. As adapted to the flysch slopes, the required data refer to each lithological element in the series.

After the determination of the global stability the protective structural type is selected which in turn depends upon the stability of the layers and their mineralogical-petrographical and physico-mechanical characteristics.

3. DETERMINATION OF GLOBAL STABILITY

In the first design phase, i.e. preliminary design, the engineering-geological investigations should yield basic data on the reliability of the suggested solution regarding the stability and bearing capacity of the layers both under natural conditions and after engineering works. In the second phase, during the development of the preliminary design, all details on the terrain, layers and influence of current engineering-geological processes and other phenomena exerted upon the structures should be identified and professionally evaluated. The final design phase requires completion of all the data not available in the preceding phases. During the implementation process it is necessary to monitor the situation on the terrain, to compare it with the suggested solutions and then to either modify or expand the suggested solutions as necessary. The inclination of the cut slope, depending upon all the previously mentioned features, is determined in the preliminary design phase with the determination of its global stability. For the series of flysch layers, in which a fracture (failure) can occur along any surface (due to their distinctive lithological features and well expressed fractures) the suggested method implies the application of the stability analysis (SARMA, 1979) which includes all the flysch characteristics and the potential failure (fracture) surfaces.

3.1. MAIN METHODS

There are two main approaches to the analysis of the stability of the cut slope (NONVEILLER, 1987): the methods of limit equilibrium and analysis of the stress-strain type. The solution of the stability problem developed by SARMA (1979) belongs to the methods of limit equilibrium, but at the same time it offers interesting possibilities when compared to other known methods from the same group: absence of constraints regarding the shape of the sliding surface, inclusion of the kinematic mechanism-possibility of defining arbitrary inclined slices, inclusion of the influence of the internal material strength, and the possibility of considering the problem with regard to earthquakes. The method can be described as an extended wedge method and is applicable also beyond this paper (cut slopes and any other slopes).

By applying the above mentioned method to a small extent and limiting it to the actual problems, it was possible to develop the NASKO1 programme which yields information on the global stability of the slope and is adaptable to specific features of the given class of problems such as: non-homogeneity and presence of layers with the existence of inter-layered fillings of various thickness, previously defined fracture plane along the existing discontinuities, possible external forces; water in the tension crack (fracture) and any other loads transported across the surface.

The derived result is the critical factor of acceleration K_c, which in the form K_c*W, where W is the weight, gives the horizontal force at which the slope (sliding mass) is transferred to the state of limit equilibrium, i.e. the usual or static safety factor takes the value 1.0. K_c itself can be considered as the unit of measurement of the safety factor of the slope.

In addition, NASKO1 gives the usual (static) safety factor against the sliding slippage of the considered mass along the slope.

3.2. NASKO1 - DESCRIPTION AND FLOW OF THE PROCESS

The explanation of the main system and the results will be presented along with the process flow.

Figure 1 presents the main system - sliding mass with a slip surface of the general form, divided into a finite number of vertical or inclined slices or blocks. For such a basic system NASKO1 gives the result with the main characteristics shown in Fig. 2.

The value K appears here as the factor of horizontal acceleration whose function can be seen in the following: K multiplied by weight yields the horizontal inertia force which brings the slope to the state of equilibrium with the respective safety factor FS. On the other hand, the safety factor can be here defined as the quantity which should be used to reduce the strength parameters so that the factor of horizontal acceleration is K.

NASKO1 gives the evaluation of global stability using both important points on the diagram K=f (FS):

- point "A": **limiting state of equilibrium**
  FS = 1.0
  K = K_c (critical acceleration factor, measure of the safety factor);
- point "B": **static equilibrium**
  K = 0
  FS = FS_{static} (required value of the reduction

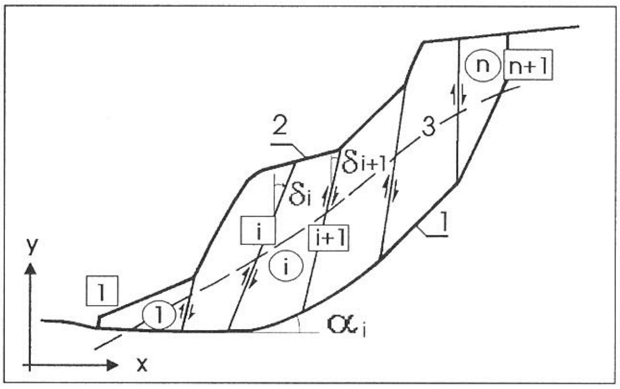


Fig. 1. The main system. 1 - slip surface; 2 - free ground surface; 3 - piezometric surface.

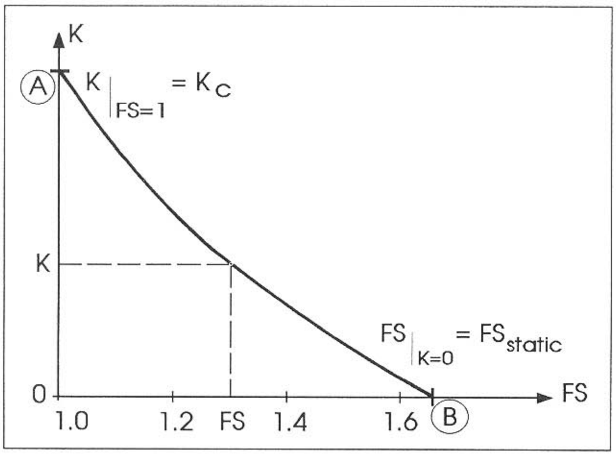


Fig. 2. Relationship between Safety Factor (FS) and Acceleration Factor (K).

of the available shear strength in order to bring it in equilibrium by mobilized shear stresses).

Since K_c is dependent upon the assumed set of inclinations of the lateral sides δ_i, i=1,...,n+1 (Fig. 1), in the computational alternative with inclined slices it is possible to note that the initial values δ_i are not those which cause sliding and yield $K_c = K_{c, min}$. This is not of particular importance for the evaluation of the global stability itself, where it is necessary, according to the order of magnitude FS, just to determine whether or not it has been threatened. At the same time, in the damaging inclined boundaries of the slices, present in practice (e.g. along the rock discontinuities), the observation of another set of inclinations δ_i is not necessary, since critical inclinations correspond just to the possible kinematic mechanism.

However, if it is necessary to carry out the entire procedure, the critical set of angles δ_i can be found (for the previously determined critical type of the slippage surface) using the method described by SARMA (1979) as follows.

1. By varying δ_i on the lateral side i, with simultaneous fixing of the remaining δ, until we achieve $K_c=K_{c,min}$ at point i. Accordingly, if the inclined plane passes through that side at point i+1, then δ_{i+1} is also changed simultaneously; δ_{i-1} is fixed (obtained in the previous step at point i-1).

2. By repeating the procedure for all the lateral sides i=1...n+1.

The computational alternative with vertical slices (δ_i = 0) is fast and simplified; hence it should be used as often as possible, particularly when a great number of slip surfaces (slips) should be analysed. Definition of the local safety factor FL on the lateral sides of the slices compensates for the fact that the critical set of values has not been sought. The reasonable value is FL=1.1.

The flow chart of the process for NASKO1 is presented in Fig. 3.

3.3. AN EXAMPLE AND SOME OBSERVATIONS

Figure 4 presents a cut slope composed of approximately two-thirds marl and one-third calcarenites, with the layers sloping at $\alpha = 25°$ and a varying slope of the cut surface (face); $\beta = 45°, 60°, 75°$. The cut height is H = 6 m. The layers extend parallel to the alignment of the cut, with an unfavourable slope 10-20 cm thick, and an inter-bedded 3-5 mm clayey filling. Infiltrating water can appear in the calcarenite due to precipitation.

In this simple example, typical for the considered class of problems, the NASKO1 program was used to compute the stability for slippage surfaces (slips) 1, 2, and 3 and for $\beta = 45°, 60°, 75°$. The following influences were considered:

• the influence of the parameters of the shear strength (c, φ) on the slip surface;

• the influence of "internal" resistance, by using the average values ($c_{average}$, $\varphi_{average}$) for all the materials occurring on the lateral sides of the slices, both with and without the influence of the interbedded filling;

• influence of the cut slope;

• influence of the pore pressure, apparent in calcarenites, i.e. for slip surfaces 2 and 3.

Some of the obtained results are presented in Table 2. It can be noted that the greatest influence upon the result was exerted by parameters c and φ on the slip; already a slight increase in cohesion leads to significant improvement. The estimation of the planned c and φ, after the investigations, requires caution and consideration of influential factors such as: thickness of the filling, sensitivity to the water action, size of shearing surface, time factor, particularly when the filling material is treated as a representative of the discontinuity cohesion (thick filling) and when the filler material is cohesive.

Accordingly, in this example the values $c_{average}$ and $\varphi_{average}$ have an evident, though not great influence upon the safety factor. It should be noted that the method presented herein is one of the rare methods which uses the internal strength of materials for obtaining solutions. In addition it is possible to note the expected, unfavourable (often significant) effects of water circulation and of the increase in the cut slope upon the safety factor.

4. DISCUSSION

Depending upon the input data and the results obtained by the global stability analysis, the slopes in flysch can be protected using several methods. Taking into account their efficiency, simplicity, aesthetic aspects and economic justifiability, nine characteristic solutions have been considered (Table 3). It should be noted that each of these solutions have some constraints which have imposed the necessity of defining the problem with boundary conditions, particularly with lithological features and cut slopes. Accordingly, the selec-

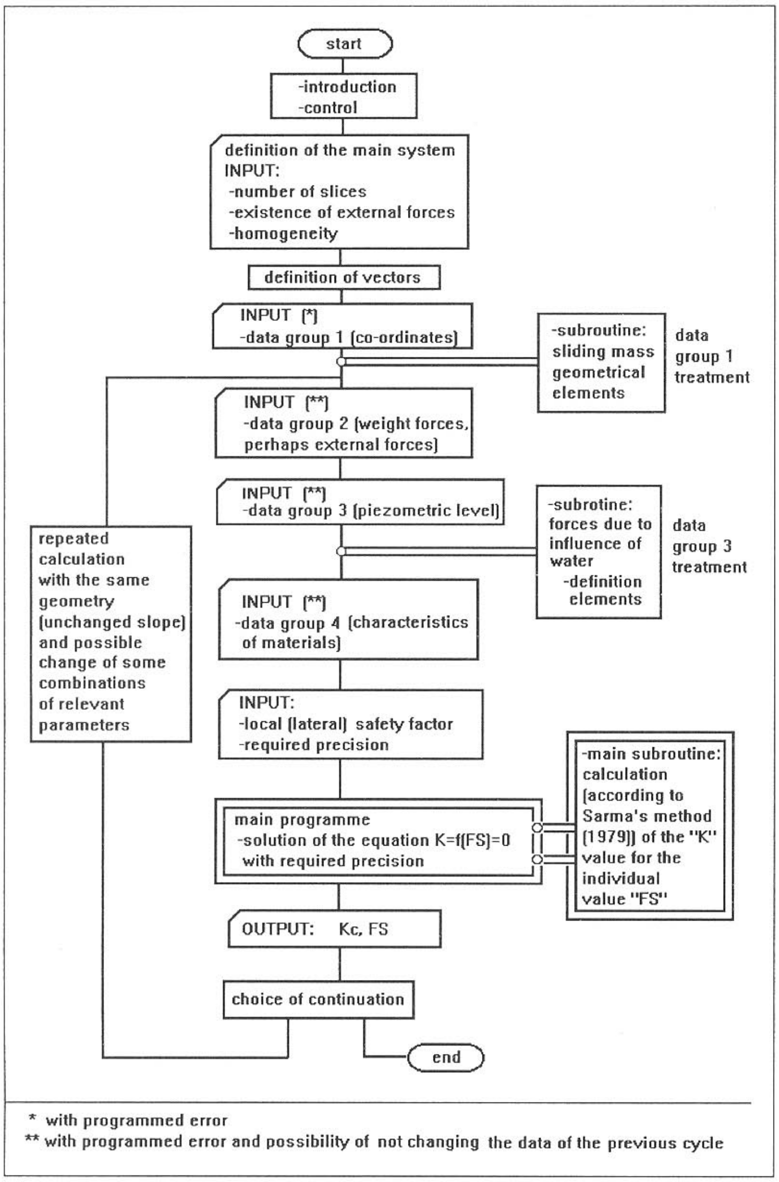


Fig. 3. NASKO1 - The process flow.

tion and application of protective structures have been described according to a series of layers, as follows:

In the series where **thin-bedded marls, clayey marls and calcareous marls alternate with thin-bedded calcarenites and marly clay in interbedded fissures (series 1)** the solution depends upon the dimensions of the cut, i.e. its height and the design of the slope. If protection against surface erosion is required, this material can be efficiently and permanently protected by shotcrete in combination with short rod anchors. The cut slope should be formed with a ratio of 2:1 to 5:1 and a potential maximum cut height of 12 m. If the conditions on the terrain allow cut slopes with 1:1.5 to 1:1, then visually attractive solutions, i.e. vegetation cover, can be used. Accordingly, it is suggested that applying linings of grass grating and anti-erosion bio-mattresses efficiently form the fertile basis for hydro-seeding. The maximum cut height in such solutions is 6-10 m. In areas of local instability of some sections of the cut area and in the problems with surface erosion it is possible to apply lining-supporting structures of reinforced concrete and sprayed concrete in combination with rod anchors. In this case the maximum cut height should not exceed 10 m, and the cut slope should have a ratio of 3:1 up to 5:1. In some very unfavuorable situations (sliding) cut protection is ensured

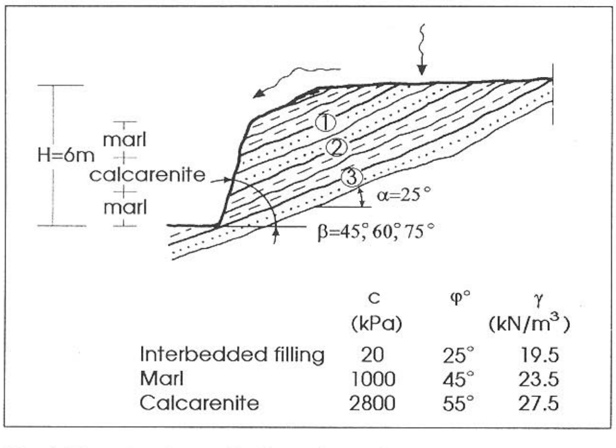


Fig. 4. Example: slope with alternating marl and calcarenite layers. 1, 2, 3 - slip surfaces.

FS or Kc / FS		u = 0, φ = 25°, c = 5 (kPa)	u = 0, φ = 25°, c = 10 (kPa)	u = 0, φ = 25°, c = 20 (kPa)	u ≠ 0, φ = 25°, c=20 (kPa)
slip surface 1	β=45°	1.94	2.86	1.419 / 4.70	
	β=60°	1.65	2.27	0.959 / 3.50	
	β=75°	1.49	① 1.96 ② 1.97	0.742 / 2.93	
slip surface 2	β=45°	1.47	1.94	0.720 / 2.88	0.657 / 2.72
	β=75°	1.32	① 1.54 ② 1.66	0.402 / 2.26	0.38 / 1.998
slip surface 3	β=45°	1.34	1.69	0.530 / 2.39	0.478 / 2.25
	β=75°	1.24	① 1.41 ② 1.45	0.332 / 1.86	0.284 / 1.74
		FS	FS	Kc/FS	Kc/FS

Table 2. FS and K_c values for different variations of parameters. K_c behaves in the same manner as FS. (1) Values $c_{average}$ and $\varphi_{average}$ on the lateral boundaries are assumed to be equal to c and φ of the inter-bedded filling. (2) Values $c_{average}$ and $\varphi_{average}$ on the lateral boundaries are assumed to be equal to c and φ of the rock.

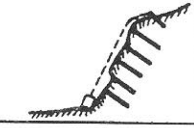
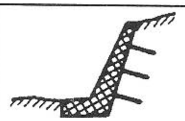
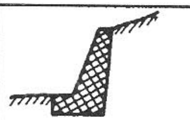
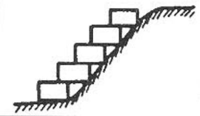
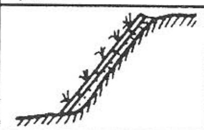
Ord. num	Type of protective structure	Description of the characteristics of protective structures	Soil type and position of layers (table 1)			Effects after the application of the protective structure	Allowable maximum cut height	The effects of infiltrating water	Allowed cut slope min.	max	Evaluation of suitability
I.		Protection of the cut against local landslides using knitted zinc nets. Suspended net is hung by steel cables.		3b 4b 5b 6b		Minimum additional works on the protection of the cut slope.	8-10 m and beyond that height a cascade should be built with a minimum width of 3-4 m.	Insignificant	4:1	10:1	Very efficient solution requiring additional maintenance.
II.		Protection of the cut using zinc nets in combination with short rod anchors or prestressed anchors.	3a 4a 5a 6a		3c 5c	Local anchorage of unstable blocks ensures efficient solution of protection.	6-8 m and beyond that height a cascade should be built with a minimum width of 3-4 m.	Problem of anti-corrosion protection of anchors to ensure durability of the structure.	3:1	5:1	Satisfactory solution with necessary additional maintenance.
III.		Protection of the cut wall using a net slightly reinforced with sprayed concrete d=8-10 cm.		1b 2b	4c 6c	Protection against surface erosion and weathering effects - efficient use of concrete linings.	to 12 m	Problem of the drainage of seepage water through discontinuities and problem of soil freezing.	3:1	5:1	Very efficient solution without the necessity of maintenance.
IV.		Protection of the cut by using sprayed concrete as reinforcement, d=8-10 cm, in combination with short rod anchors.	1a 2a		1c 2c 3c 4c 5c 6c	Protection against erosion and local landslides and the effects of lining-retaining self-supporting structure.	to 12 m	Problem of the drainage of seepage water, soil freezing and anti-corrosion protection of anchors.	2:1	5:1	Very efficient solution without the necessity of maintenance.
V.		Protection of the cut wall by using a lining wall, mounted or monolithic, in combination with short rod anchors.	1a 2a		1c 2c 3c 4c 5c 6c	Possibility of creating aesthetic appearance, permanent protection against surface erosion.	to 10 m	Insignificant (proper drainage of infiltrating water is required).	3:1	5:1	Satisfactory solution without the necessity of maintenance.
VI.		Protection of the cut by retaining walls, reinforced concrete or gravity type	1a 2a 3a 4a 5a 6a		1c 2c 3c 4c 5 6c	Application under unfavourable engineering - geologic conditions (potential sliding) and in specific conditions.	to 12 m	Insignificant (proper drainage of infiltrating water is required).	3:1	10:1	Satisfactory solution without the necessity of maintenance.
VII.		Protection of the cut with gabion walls with baskets of plastic or zinc nets.	1a 2a		1c 2c	Simple structure offering permanent and optimal solution.	6-8 m	Insignificant.	1.5:1	3:1	Very satisfactory and aesthetically acceptable solution without additional maintenance.
VIII.		Protection of the cut by a lining of concrete elements (grass surfaces) with the possibility of vegetation cover.	1a 2a	1b 2b	1c 2c	Permanent solution which ensures protection against erosion with simple maintenance.	To 6 m and beyond that height a cascade should be built with a minimum width of 3 m.	Insignificant.	1:1.5	1.5:1	Very satisfactory solution with desirable maintenance.
IX.		Protection of the cut by anti-erosion bio-mattresses with plastic net (netlon) filled with hay as a basis for hydroseeding.		1b 2b	1c 2c	Immediate protection against erosion with the possibility of subsequent intervention with horticulture.	8-10 m and beyond that height a cascade should be built with a minimum width of 3 m.	Insignificant.	1:1.5	1.5:1	Very satisfactory natural solution, technically and aesthetically, with obligatory maintenance.

Table 3. Area of application of various types of protective structures.

by reinforced-concrete walls (the cutting and the construction are carried out in sections with a recommended cut height of up to 12 m; for lower heights (6-8 m) gabion walls are used. The advantage of the concrete support structure is that it is possible to get an almost vertical cut (10:1), whereas in gabion walls the maximum slope should not exceed a ratio of 3:1. The water influence is closely related to microclimatic conditions; hence, it is necessary to take into account erosion, the possibility of the soil freezing, and the possible destruction of the protective lining.

Marls of varying thickness with inter-beds of marly clay (series 2) differ from **series 1** since there are no firm layers of sandstone which function in the terrain as a reinforcement (BOJANIĆ et al., 1986), but this can be considered as a more homogeneous material. The type of the protective (supporting) structure will depend upon the problem under consideration. The structures are identical as for **series 1** and thus the suggested solutions can be almost fully used. An exception is the rod anchors since their efficiency will depend upon the physico-mechanical features of marls. This means that the bearing capacity of anchors is significantly reduced in marls, unlike its application in series 1 where there are strong sandstone layers.

In **clastic layered limestones (series 3)** the position of the layers in relation to to the line of the cut is important, as well as the presence of tectonic damage and karst morphological phenomena. The problem of cut slope protection in this series is quite frequent in engineering practice. Several alternative solutions can be applied. In favourable cut slopes it is possible to apply a very simple solution, i.e. a knitted network for the prevention of local landslides. This type of protection can be applied only if the mining has been professionally carried out ("smooth mining"), i.e. the rock mass should not be exposed to additional damage.

For unfavorable cut slopes it is possible to apply short rod anchors which are used to stabilize the locally unstable rock blocks in combination with protective nets. Quite frequently, when the rock mass has a great number of fractures, shotcrete is applied, which is a very efficient solution but is not easily acceptable from the aesthetic standpoint. In cases of more serious fracture problems while respecting the visual effects, the best protection is achieved by revetment and supporting structures of slightly reinforced concrete in combination with short anchor rods. The cut height in limestones should not exceed 12 m, and when it does, the slope surface should be formed in cascades at a height of 8-10 m with a minimum horizontal width of 3-4 m. The cut slope can be very steep, even 10:1 in high-quality material, whereas in all other cases the slope should have a ratio of 3:1 up to 5:1 (BRAUN et al., 1992).

Calcarenites alternating with calcareous breccias belong to **series 4**. The problems of cut slope support and solutions for such materials are identical to those described in **series 3**, the only difference being that the material in this case is heterogeneous considering its strength and stability. Consequently, it is necessary to take into account not only engineering-geological, but also the mineralogical-petrographical features of the terrain in order to get a comprehensive insight into the state of the sediments and to note all critical zones which could, in the course of time, have significant influence upon the stability. In such a complex composition, the breccia layer frequently behaves as a weak link in the chain between the sandstone layers, particularly if clay minerals are present. Such problematic zones can be partially protected or the entire cut surface can be covered by one of the types of protective structures suggested for the layers in **series 3**.

In **calcareous breccias (series 5)** the approach to cut slope support is identical to that for **series 3** and **4**. The solution depends upon the quality of the rock mass, i.e. the degree of fractures and rock weathering, crack filler, mineralogical-petrographical characteristics of the fragments and cement, as well as upon the degree of karstification. There are certain differences in the approach and treatment of surface erosion and in the methods of protection in limestone diluvial breccias, weakly bonded by the clay-silt binding agent, frequently found above the flysch layers on the slopes of Kozjak, Mosor and Biokovo.

These **alternating layers of calcarenites, breccias and marls** belong to **series 6**. The main difference between this series and **series 1** lies in the fact that the layers are generally thicker. This heterogeneous composition requires the separate analysis of each lithological element on the cut surface; hence, several different types of support may be applied along the cut. The other possible approach is the application of the solution for the weakest, i.e. most critical lithological element, to all other elements. Thus, the same type of protection i.e. support can be applied to the entire cut surface.

The identification of all the relevant mineralogical-petrographical and engineering-geological features of the rock mass and the terrain, and of the results obtained by the analysis of the global stability, make it possible to select the optimal solution (among the nine suggested alternatives) by using the RZAKO1 computer programme. This programme selects the possible technical solution for the cut slope protection in flysch with regard to it's practical application on the terrain. According to the main input data: the series of layers (1 - 6) and the position of layers according to the newly-formed space of the cut (cases a, b and c), it is possible to obtain a set of all alternative solutions. Subsequently, taking into account possible threats to global and local stability, further selection is performed and a spectrum of suitable solutions obtained. Consequently, after defining the threats to the local stability (certain blocks are unstable) it is preferable to apply the anchor solution, whereas if there is no threat to global and local stability it is possible to select a set of anti-erosion measures as potential, suitable solutions. For each of the suggested solutions a display of the description and

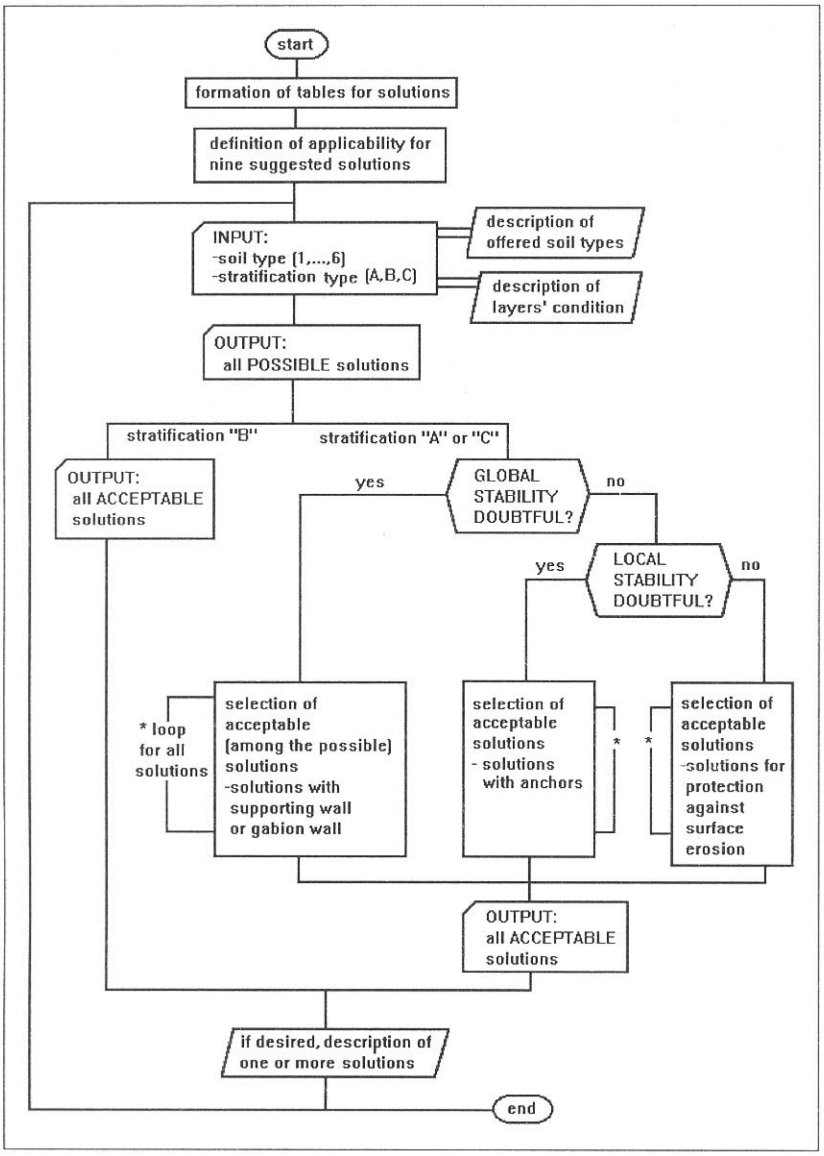


Fig. 5. RZAKO1 - The process flow.

technical characteristics can be required. The process flow diagram is presented in Fig. 5.

Finally, it is possible to select the optimal solution, out of the obtained spectrum of suitable solutions, considering the economic and aesthetic aspects and taking into account other possible constraints.

5. CONCLUSION

The determination of stability and the selection of the best possible solution to slope support in flysch undoubtedly belongs to a group of very complex engineering-geological problems due to the heterogeneous mineralogical-petrographical composition of the sediments and evident deformation of their layers. Engineering-geological investigations in the Eocene flysch in the region of Split revealed the presence of sediments with several series of varying thicknesses. The most frequently encountered and the thickest series is that of alternating thin-bedded marls and calcarenites, followed by the series of marls with layers of varying thickness. These are followed by a less thick series of dominant clastic limestones and breccias and also the series with interchanging calcarenites and breccias or marls, calcarenites and breccias. Mineralogical-petrographical analyses have proven that carbonate clastic flysch sediments are almost completely composed of calcites (both the fragments and the matrix), whereas the main components of marls are calcite and clay minerals (illite, illite-muscovite and montmorillonite). The current exodynamic factors result in the rapid weathering of marls, so that firm layers (sediments) frequently project above the terrain. This fast degradation of marls and projection of large or small blocks of more resistant elements have initiated a comprehensive and complex approach to the study and solution of the problems related to the stability and protection of slopes in flysch. The definition of the mineralogical-petrographical and engineering-geological features represented a starting point in seeking the methods for establishing the stability of the slope where fractures can occur along any surface. After determining the best method it was adapted, with only slight modifications, to the NASKO1 computer programme. Tests performed on several examples, one of which has been described in this paper, proved that the method is applicable for the quick determination of global stability of the engineered cuts in heterogeneous layers, actually in flysch, and that it can be efficiently used in engineering practice. The determination of the degree of global stability, taking into account mineralogical-petrographical and engineering-geological features of the sediments in flysch (including the diagenetic and post-diagenetic specific features and changes), made possible the selection of the type of cut support. Starting from a variety of approaches to the cut support, their height, the inclination and stability of the layers and the criteria of safety, feasibility, efficiency and aesthetic aspects, it was possible to suggest nine alternative solutions. In order to select the optimal solution quickly and efficiently the RZAKO1 computer programme was developed, requiring the input data from the project and the results obtained by engineering-geological investigations in the field and by laboratory tests. After defining the specific features of each of the mentioned series in the flysch sediments and by applying the suggested computer programme it was possible to prove the degree of stability and to offer either one solution or several alternative solutions to cut support already in the preliminary design phase. Therein it is recommended that each specific example with its characteristics be analysed in order to ensure that the obtained results describe the actual situation in the most reliable way and that the most efficient method of protection has been selected.

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