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# ENGINEERING GEOLOGICAL RESEARCH FOR THE STREČNO CASTLE SAVING

*(Figs. 14, Tab. 1)*

Abstract: The steep rock wall of the lithologically and tectonically heterogeneous calcareous-dolomitic bluff, on the top of which stand the protected ruins of the Strečno castle, is affected by rock falls and rock blocks, which pulled down already one part of the peripheral walls and threaten the remaining ones. In order to secure them, it was necessary to carry out a pretentious, time-limited engineering geological research of stability of the rock wall below the castle, to evaluate the extent and measure of threatening of the castle foundations and to suggest efficient measures to secure them within the course of reconstruction works on the castle. The most important results of the research form the content of this contribution.

Резюме: Крутая каменная стена литологически и тектонически неоднородного известняк-доломитического утеса, на вершине которого находятся заповедные развалины замка Стречно, затронута паданием скал и каменных блоков, которые уже увлекли часть окружных стен и угрожают другим. Для их закрепления необходимо было сделать трудное, временно ограниченное инженерно-геологическое исследование стабильности каменной стены под замком, дать оценку размеру и степени угрозы фундаментов замка и предложить действенные меры для их закрепления в течение восстановительных работ на замке. Самые важные результаты исследования находятся в этой статье.

## Introduction

The Strečno castle is built in the river Váh valley on the northern boundary of the Malá Fatra mountain range. It is one of the National cultural monuments of Slovakia. Its foundation is atributed to Matúš Čák 1290—1321. However, it was built probably on older foundations. The castle is presently in ruins, because under the reign of Leopold II. in 1698, the castle was demolished by force.

The castle walls, as well as their subsoil, are considerably weathered at present, gravitationally loosened and deformed by dynamic effects by blasting works in the near-by quarry. In the past, several parts of the castle walls, built on rock overhangs, collapsed. Presently its conservation and partial reconstruction are realized within the frame of care of cultural monuments.

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The reconstruction, conservation and saving works on the castle are realized by Ingstav, n. p. Brno, the Kojetín enterprise, on the basis of the project of static securing, prepared by the State Institute for the reconstruction of historic towns and objects in Brno. The project was prepared on the basis of a preliminary geological account made by RNDr. L. H u d e c (1976).

The project assumed the construction of scaffolding of considerable dimensions to cover the 103 m high castle rock wall. From this scaffolding a detailed engineering geological investigation of the rock wall was to be carried out and to be used after for the stabilization works. However, the construction of the scaffolding met with unsolvable technical problems and the works on its construction were stopped in 1981. The constructed scaffolding covered solely 1/10 of the surface of the rock wall (Fig. 4, 10).

The investor of the reconstruction works asked for preparing and expert's account, in which it was necessary to evaluate, whether it is necessary to save the entire castle rock wall from the security stand point and to present eventually another suggestion for a static securing of the subsoil of the Strečno castle eastern periphery.

For a safe and economic suggestion to secure the castle subsoil and the blocks of the castle rock, it was necessary to have at hand the most complete knowledge possible of the physical state, mechanical properties and stability of the castle rock wall. As suitable topographic document of the almost perpendicular eastern wall was acquired by earth photogrammetry, which offered us also other possibilities of use. The photographs were made by a wide-angle camera UMK 10/1318 of the Carl Zeiss Jena firm. The castle rock profiles on scale M = 1 : 470 and the profiles for the suggestion of saving measures on scale M = 1 : 200 were made on the Stereometrograph of the same firm by the workers of the Department of Geodesy, Building Faculty of the Slovak Technical College. The geological evaluation, apart from field works, was based also on the geologic interpretation of stereophotographs by simple mirror stereoscopes and by stereocomparators.

The measurement of surfaces of mechanical discontinuity of rocks were carried out in respective places by a current method (B r e k k e et al., 1978). The strengths of joint walls were carried out by Schmidt's hammer of L type. On unaccessible rock walls the measurement was made by mountain climbing and by calculation from the evaluating calculators.

### *Geological structure, tectonic and geomorphologic development*

In the gological build up of the Strečno wider surrounding the following geologic units are taking part: 1. granitoids of the Malá Fatra mountain range core, 2. sedimentary mantle, 3. the križňanský nappe and 4. the chočský nappe (Fig. 1 and 2).

The Varissian orogene formed the spacing of the lower structure of the crystalline core. A structure of the SW-NE strike took place in it with the principal thrust tendency to the south. As a result of the alpine orogeneous process the Mesozoic of the sedimentary mantle in the Strečno immediate vicinity was strongly reduced. Emerging here are only the Lower Triasic quartzites. A n d r u s o v (1944) assumes that the squeezed out places in the Strečno surrounding, corresponded in the nappe thrusting to the ridge zone with the strongest mechanical effects of wear. Strongly reduced are also the members of the križňanský nappe. The chočský nappe is developped in the form of a nappe block and slices which are tectonically limited among themselves and disharmoniously folded. All the fundamental units of the core mountain ranges in the Strečno castle area are reduced into a zone about 600 m wide, which affects considerably the physical state of rocks in the castle the area itself.

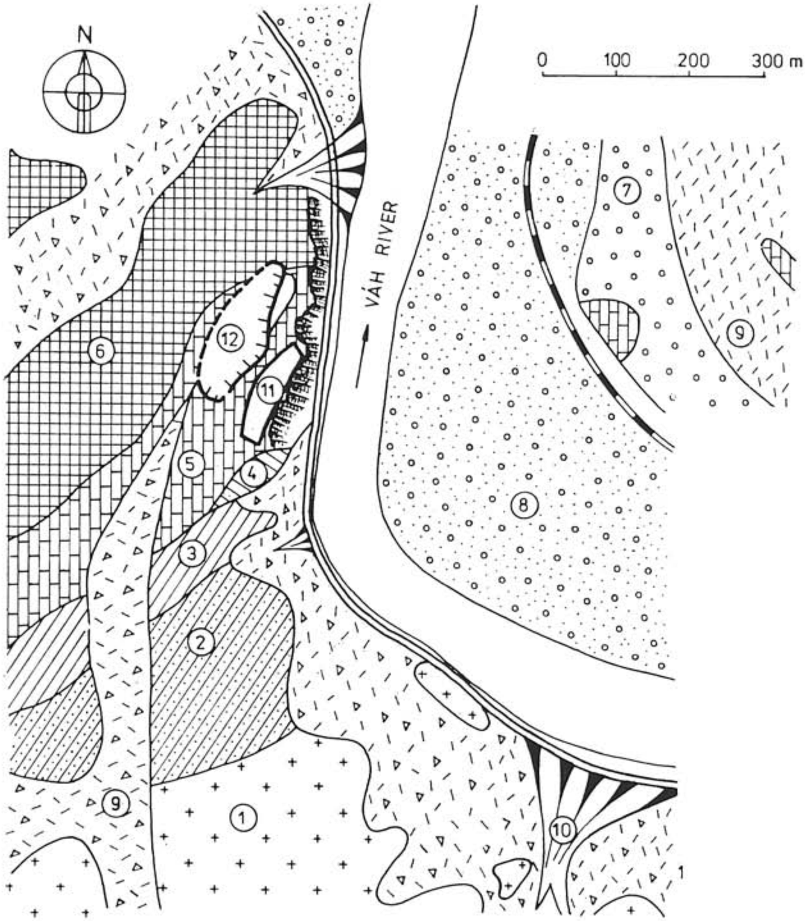



Fig. 1. Geological map of the Strečno surrounding.

*Explanations:* 1 — granitoids of the Malá Fatra Mts. range core; 2 — quartzites of the mantle unit (Lower Trias); 3 — blotchy marls (Lias), 4 — marly limestones (Neocomian); 3–4 — the Krížna unit; 5 — limestones with positions of dolomites (Middle Trias); 6 — dolomites (Upper Trias, 5–6, the Choč unit); 7 — river terraces (Pleistocene); 8 — alluvial plain; 9 — deluvium loams and debris; 10 — debris and alluvial cones; (8–10 Holocene); 11 — the Strečno castle object; 12 — abandoned quarry.

Of not a lesser affect than tectonics on the state of tension in the rock mass is also the geomorphologic development of the river Váh valley. The Strečno break-through is formed predominantly in the crystalline rock, only in the castle space it is cut in the Mesozoic units. Mazúr (1963) and others consider the Strečno break-through as an antecedent phenomenon older than the mountain range in the present sense.

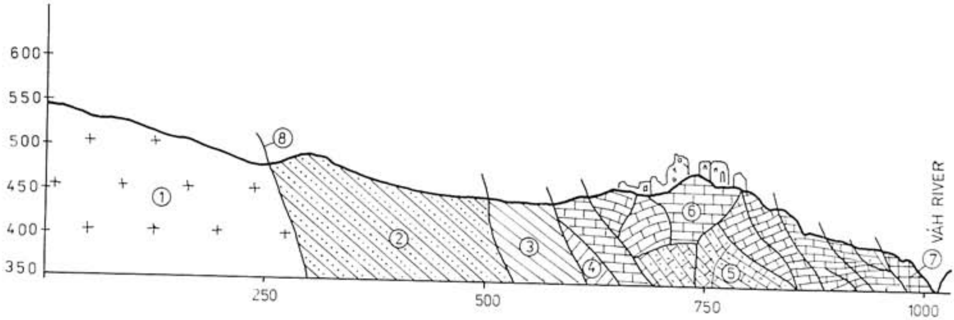



Fig. 2. Geological profile of the Malá Fatra Mts. range lateral fork with the Strečno castle.
*Explanations:* 1 – granitoids of the Malá Fatra Mts. range core; 2 – quartzites (Lower Trias – mantle series); 3 – blotchy marls (Lias); 4 – marly limestones (Neocomian 3–4 the Krížna unit); 5 – dark massive limestones; 6 – limestones with intercalations of dolomites (5–6 Middle Trias); 7 – dolomites (Upper Trias, 5–7 – the Choč unit); 8 – more significant tectonic lines.

In periods of intense tectonics and predominant depth erosion alternating with periods of relative tectonic quietness, the Strečno break-through underwent several development steps, to which the remnants of denudation levels are pointing. First of all they are the remnants of the middlemountain system, which indicates that a wide rampart in the area of the present break-through existed well in the Pannonian, which belong to the big course. Deep below this system fragments of seven Quaternary river terraces are preserved (from the Donau to the Würmian). In the studied area we found the remnants of the old terrace in the quarry cut belonging probably to the Mindelian (Fig. 7 and 8).

The terrace level points to the fact that a rapid upheaval and a deep erosion of the Váh took place in the Quaternary. The castle wall lies in the place, where important deformations are intersecting, which predetermined the direction of the Váh, so that during the entire erosional development it formed a buffer bank within the frame of the tectonically predetermined entrenched meanders (Fig. 1 and 3).

The castle wall relative height is 80–103 m, dip 65–90°, with numerous overhangs.

In the castle area carbonatic complex almost perpendicular tectonic systems predominate with approximate N-S strike. This system in co-action with the Váh lateral erosion caused that the dip and strike of the rock wall during the entire erosional development was adapting predominantly to this tectonics.

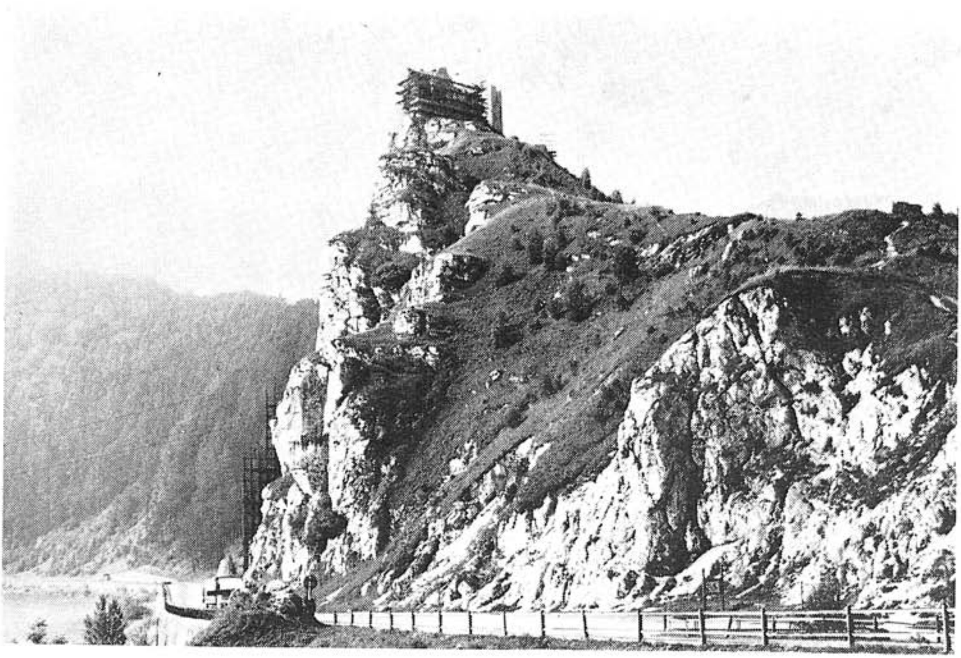


Fig. 3. North lateral view on the castle rock on the buffer bank of the Váh entrenched meandre.
*Explanations:* 1 — calcareous-dolomitic complex (Middle Trias); 2 — dolomites (Upper Trias, 2—3 the Choč unit); 3 — the course of tectonics.

The gradual disintegration of the rock mass of the castle took place along this system. The strongly broken dolomitic intercalations weathered out gradually. There were formed on them rock overhangs, which in a deep reaching tectonics of the N-S strike were gradually falling out. This process is continuing also at present.

Substantial changes in the state of tension on the surfaces of mechanical discontinuity are taking place as a result of the Váh erosional sinking. An increased horizontal tension appears on the slope in its lower parts, which is connected with the gradual disintegration of the rock mass, with its loosening and occurrence of large tension joints.

*Engineering Geological conditions of the castle rock*

In detecting the engineering geological conditions of the castle rock, which affect considerably the stability of the castle object, we made a detailed study of the petrographic composition of rocks, of the extent of tectonic deformation and of their deposition conditions. We studied also the degree of weathering and karstification and detected their physical-mechanical properties. The research was made on the eastern rock wall (Fig. 4 and 5), on the wall of the old quarry, which lies to the West of the castle (Fig. 7 and 8), as well as inside

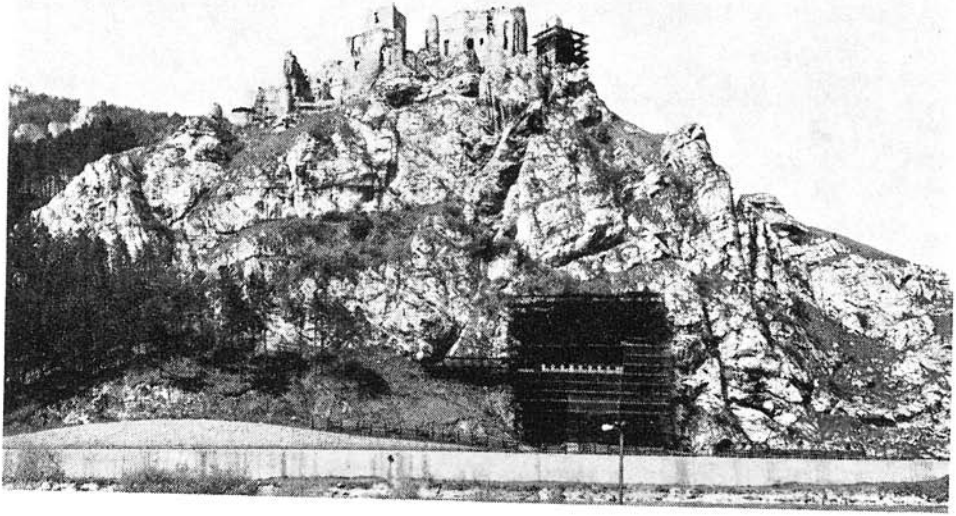


Fig. 4. Left photograph from the photogrammetric stereocouple, into which we made the evaluation of geology of the castle rock eastern wall in Fig. 5.

the castle (Fig. 11). Thus we succeeded to portray a spatial model of subsoil of the whole castle, which is of considerable importance for suggesting its geotechnical securing.

The engineering geological conditions of the eastern wall were evaluated into the photogrammetric documents (Fig. 4). Fig. 5 shows that the geologic conditions of the wall are unusually complicated and differ considerably from the conceptions published till now (Urban, 1965; Mišík, 1976).

### *Lithological characteristics*

Three lithological complexes (Fig. 4 and 5) emerge in the exposed rock wall:

1. The Guttenstein type limestones of the Middle Anissian form the foot of the castle rock. They are massive, with slight indications of bedding. The deposition conditions and the system of their tectonic deformation are seen from the profiles in Fig. 6a, 6b. The limestones present a strong tectonic deformation, in some places even schistosity.

2. In the overlier emerges a varied complex of gray limestones, which alternate with beds of dolomitic limestones and dolomites. This varied strata-series forms the major part of the castle rock.

The limestones predominate in the strata-series. The dolomitic positions form strata 0.5 to 2.0 m thick. In the castle subsoil this strata-series is thinly layered. In the accessible parts in it predominate dolomitic limestones and dolomites, which led many authors (Urban, 1965; Mišík, 1976), who studied the rock mass without using the mountain climbing and photogrammetric techniques, to consider them as the Anisian dolomites. However, a detailed study has shown that it is a complex built predominantly by sheeting

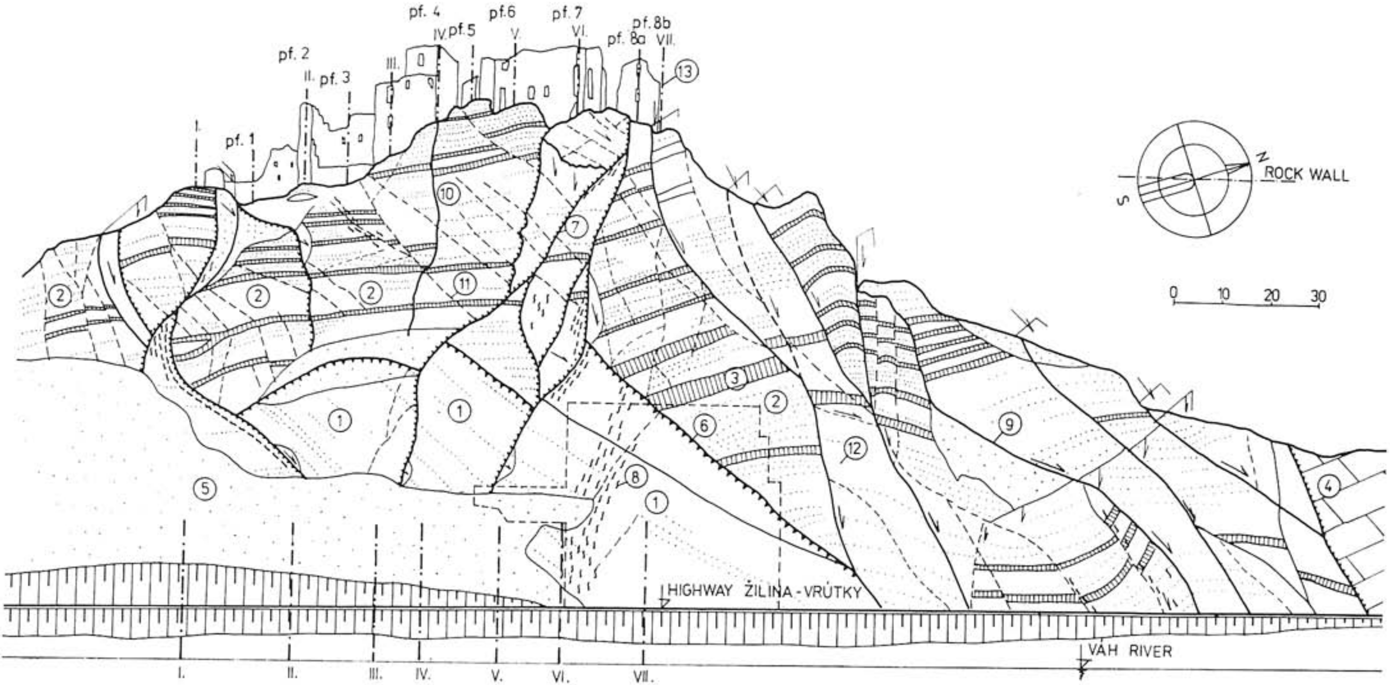



Fig. 5. Geologic interpretation of the photogrammetric photograph (from Fig. 4) made on the basis of evaluation in the stereo-comparator STEKO 1318 and direct geological mapping.

*Explanations:* 1 dark limestones; 2 – limestones and dolomitic limestones; 3 – dolomites (1–3 Middle Trias); 4 – dolomites (Upper Trias of the Choč unit); 5 – slope débris (Qauternary); 6 – subhorizontal thrust; 7 – subvertical displacement; 8 – disintegrated zone; 9 – subsidences-gravitational slips; 10 – mo-re significant joints; 11 – other joints; 12 – more significant planes of bedding; 13 – profile lines.

limestones and the dolomites in it form only positions and intercalations. This entire strata-series, in accordance with Mišík (1976) we include in the Choč nappe.

Samples were taken from this varied carbonatic strata-series for chemical analyses in the places shown by profile No. VII (Fig. 6). Tab. 1 gives the results.

3. The Choč type dolomites belonging by age to the Upper Trias emerge solely in the right part (northern) of the castle rock and are without influence on the castle stability.

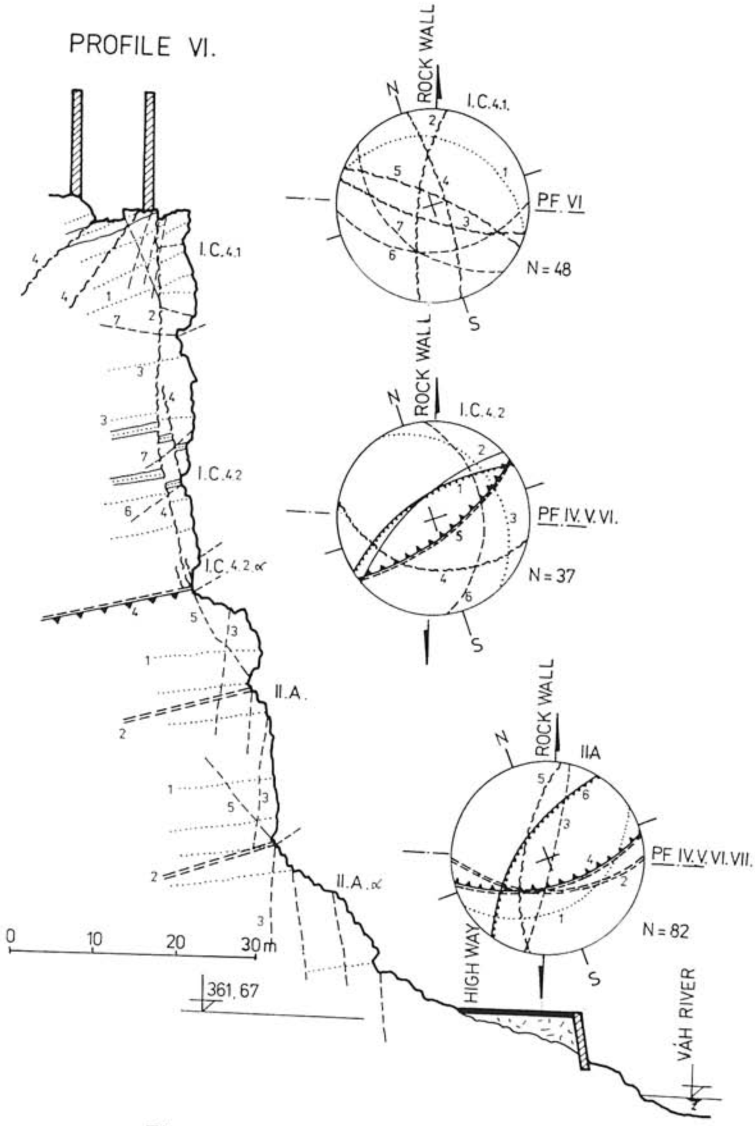



Fig. 6 a. Profile of the castle rock No. VI.

*Deposition conditions of rocks and their tectonic deformation*

The rock mass as a result of the described processes is expressively faulted by tectonics, which affects markingly mainly the stability. For this purpose a detailed research of the castle rock discontinuities was carried out.

In order to be able to evaluate statistically the measured values, we divided the whole rock mass into homogeneous units according to criteria which we

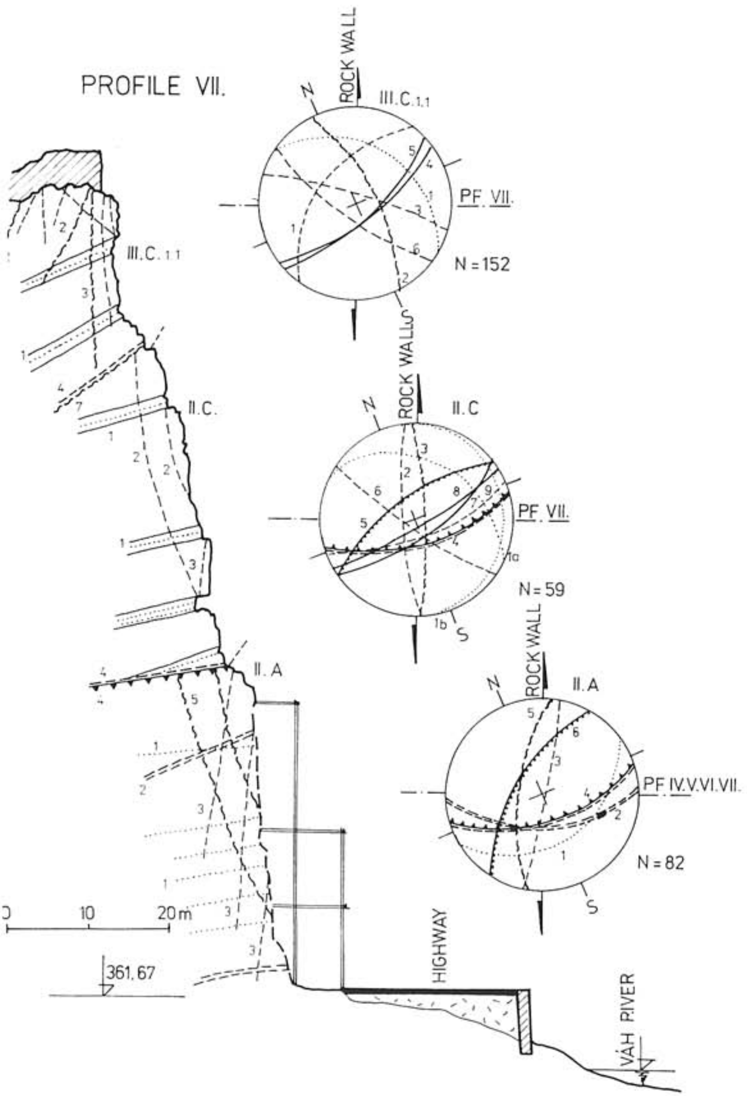



Fig. 6 b. Profile of the castle rock No. VII.

Table 1

| Sample No. | Calcite % | Dolomite % | Admixtures % | Rock name |
|---|---|---|---|---|
| 1 | 90.23 | 1.84 | 7.93 | limestone |
| 2 | 75.07 | 20.02 | 4.91 | dolomitic limestone |
| 3 | 76.60 | 14.20 | 9.20 | detto |
| 4 | 73.77 | 18.09 | 8.14 | detto |
| 5 | 23.11 | 61.68 | 5.21 | calcareous dolomite |
| 6 | 80.37 | 14.40 | 5.23 | dolomitic limestone |
| 7 | 63.62 | 31.51 | 4.87 | detto |

discribe further on. For each delineated homogeneous rock mass the measured values of the main discontinuities were treated statistically by graphic methods in tectonograms constructed according to Lambert control. On the tectonograms we drew the average courses of characteristical discontinuities by projecting their intersections with the upper hemisphere onto the equator plane. In order to be able to compare mutually the individual discontinuities represented in the tectonograms and in the profiles, these are distinguished graphically and also numbered. In applying them to the profiles with the orientation correspondig to the wall, it is possible to find at first sight the data of the real orientation of each discontinuity, which is drawn in the respective part of the profile (Fig. 6).

From the evaluation of discontinuities in Fig. 5, 7 and 8 it results that the rock mass of the rock wall is tectonically faulted by deformations of a varied type and rank of importance.

The limestones of the Guttenstein type are separated from the varied carbonatic strata-series by an expressive line, which presents a character of a sub-horizontal overthrust. The Choč dolomites again are separated from them by tectonics of a subsidence character. This fundamental tectonic division is expressively differentiated by a younger tectonics of a vertical, lateral, displacement characteristic of the N-S strike, which deforms the indicated tectonic contacts.

The course of dislocations inside the castle area (Fig. 11) shows that these minute partial vertical displacements present a moderate slant course with regard to the general strike of the castle rock. The tectonic lines detected either on the rock wall, or on the castle ground-plan present a convergent character. They end approximately in the centre of the wall and form on it a morphologically significant dislocation, which presents almost a perpendicular course, well visible in Fig. 4.

The right part of the castle rock presents substantially a different character. It is faulted by tectonics of a subsidence character. The whole rock mass here is divided into a set of blocks along almost perpendicularly striated tectonic surfaces (polishes).

The areas of subsidence are the youngest tectonic element. They correspond with the young upheaval of the Malá Fatra mountain range and with the subsidence of the Žilina basin. Therefore they represent a typical gravitational tectonics corresponding with the neoid movements. They are marking not only

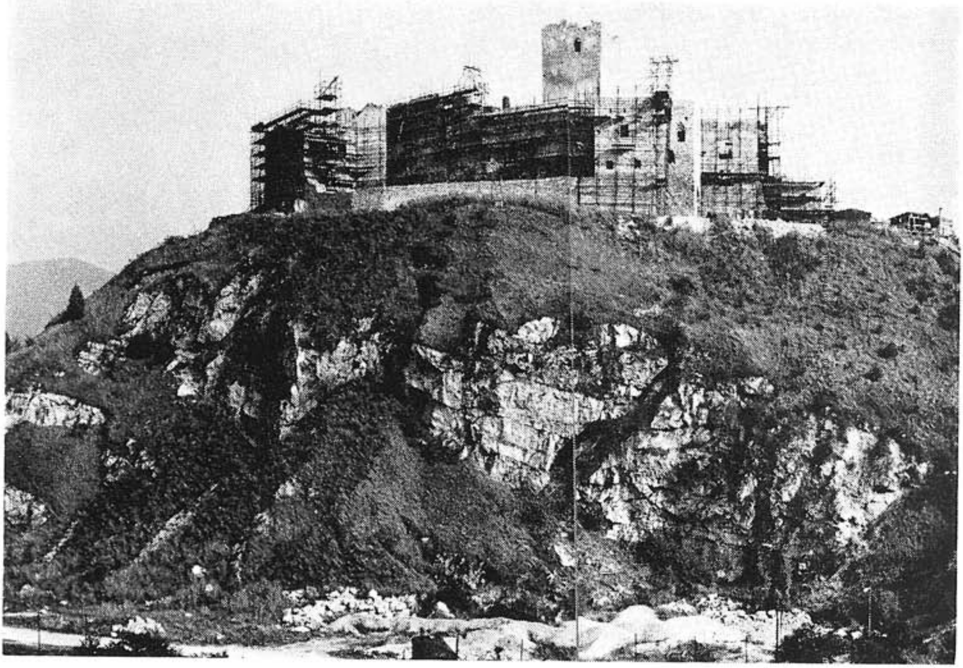


Fig. 7. View of the quarry wall, limiting the castle area from the West.

on the front wall (Fig. 4 and 5), but also on the wall of the former quarry west of the castle area (Fig. 7 and 8). They are correlated with the deformations on the castle rock wall in Fig. 11.

The central part of the rock wall represents a certain interblock which is but slightly deformed by lateral effects either of the main vertical displacement tectonics, or by tectonics of a gravitational- subsidence character.

### *Degree of weathering and karstification*

The speed of mechanical weathering on the eastern wall was substantially affected by a varied resistance of dolomitic and calcareous rocks against weathering. The more brittle dolomites of a strong tectonic deformation weather more rapidly than limestones. It is why rock overhangs took place on the rock wall above the positions of dolomites.

The manifestations of karstification can be seen on the quarry wall and on the eastern rock wall. Smaller cavities are related to bedding and paraclases. Also transposed karst cavities several meters long were found in the castle base.

The weathering processes degrade also the strength of rocks on the joint walls. The value of rebound strength measured by Schmidt hammer on discontinuity planes of limestones ranged within R = 53–57 ($\tau_d$ = 103–206 MPa), which corresponds to the degradation. The average R value was 47.7 ($\tau_d$ = = 156 MPa). On the joints of the Guttenstein limestones the average measured value of R was 55.5, but on the most expressive subvertical large deformation we found R = 45 ($\tau_d$ = 141 MPa).

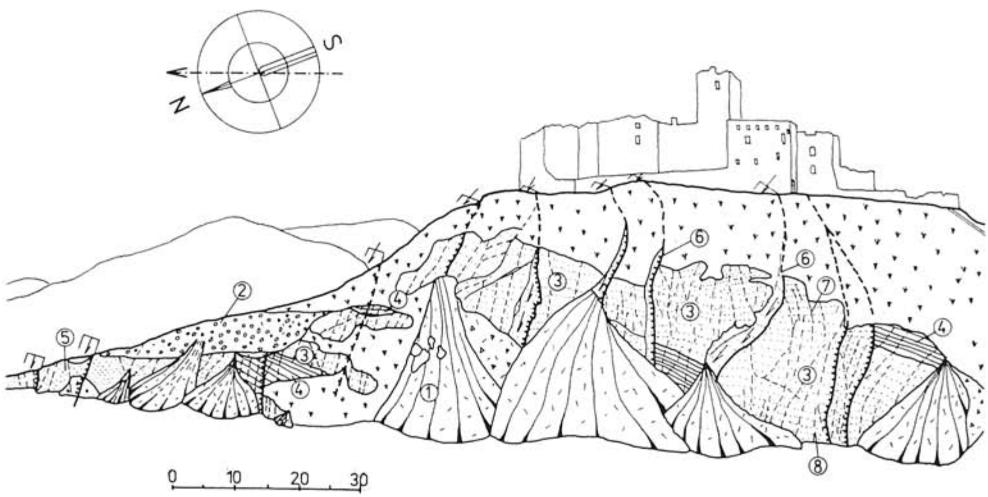



Fig. 8. Geological evaluation of the quarry wall from Fig. 8.
*Explanations:* 1 – débris from digging in the castle; 2 – terrace gravels (Mindelian); 3 – limestones; 4 – dolomites (4–5 Middle Trias); 5 – the Choč dolomites (Upper Trias); 6 – gravitational subsidences; 7 – more significant joints; 8 – bedding.

## *Physical-mechanical properties*

In determining the physical-mechanical properties we started from the results of laboratory tests, given for rocks in the near vicinity by M a t e j k a et al. (1981).

For the calcareous strata-series in the castle area it is possible to consider the following values: Volume density $\rho$ = 2.70 g/cm$^3$, natural humidity w = = 0.13 %, absorption capacity $n_h$ = 1.38 %, porosity n = 4.07 %, compressive strength $\tau_d$ = 57.5 MPa, modulus of deformation $E_o$ = 8100 MPa, modulus of elasticity E = 11 140 MPa, Poisson's ratio $\gamma$ = 0,253.

Pressiommetric tests were made in the dolomitic complex (M a t e j k a et al. 1981). The pressiometric moduli of deformation range within $E_o$ = 300–740 MPa (predominantly 450–680 MPa).

## *Engineering geological zoning of the castle rock*

In judging the total state of the rock wall we started from its detailed engineering geological zoning. For the basic criterium of zoning we used the character and degree of tectonic deformation but we took into consideration also the lithologic composition of rocks.

In delineating the homogeneous rock masses we kept to the classification of solid rocks published by Golodkovskaya—Matula—Šaumjanová, 1979 (in Matula, 1981). This classification considers the degree of homogeneity of rocks on four hierarchically superposed levels, from homogeneous units of regional nature to homogeneous units with equal blockyness, degree of deformation, or transformations.

The whole castle rock forms part of the Choč nappe as a regional geologic unit, which presents here the character of a mass of a complicated fault zone (rock mass of the first order). Within it we delineated in the castle rock four simpler rock masses of the second order — the so-called local rock masses of fault deformations which we marked by roman numbers (I—IV). In the zonation of the castle rock representing are the homogeneous units of the highest level.

Rock mass I is affected by the vertical displacement-fault tectonics, rocks mass II is of a transitory type, rock mass III is affected by gravitational slips and rock mass IV represents tectonically disintegrated rocks. Within their frame we distinguished the so-called 4 local rock masses on the basis of lithologic differences. The local rock mass A is represented by limestones, B by dolomites, C by calcareous-dolomitic rocks and D is the rock mass of mantle formations (see Fig. 9).

As units of the lower (third) order we delineated the rock masses of the fault zones (indicated by arabic numbers). The lowest units (fourth order) are the homogeneous rock masses. They are indicated by decimal arab numbers (e. g. 3.1), in the case of tectonic jointing of rocks and in the case of schistosity by small greek letters. The petrological types are indicated in Fig. 9 by hatching.

The limits between the rock masses of all levels are given by tectonic positions. Tectonic are also limites between the local rock masses. The limits between the lithologic types are given by bedding planes.

*The characteristic of delineated rock masses*

I. Rock mass deformed by vertical displacement-fault tectonics. It is formed by little folded, tectonically deformed rocks of two lithologic local rock masses A, C. In the rock mass structure dominating are the running almost perpendicular tectonic deformations of the NE-SW strike. Along them the rock mass was faulted into individual blocks and their mutual slice displacement took place.

II. Rock mass of a transitory type. It is formed by little folded, tectonically and gravitationally deformed rocks of the local rock masses A, C. The limits between the local rock masses present the nature of tectonic overthrust. The rock mass arises as an independent compact unit, recalling by its character the individual blocks in the rock mass I. However, it differs from this one by the course of expressive joint and schistose systems, which follow the rock mass tectonic limitation. Their origin corresponds obviously to the gravitational slips, which are characteristical mainly to the rock mass III. With the rock mass III corresponds also the dip of layers in the calcareous-dolomitic local rock mass.

III. Rock mass deformed by gravitational slips. It is built by a local rock mass of tectonically deformed limestones and dolomites. By

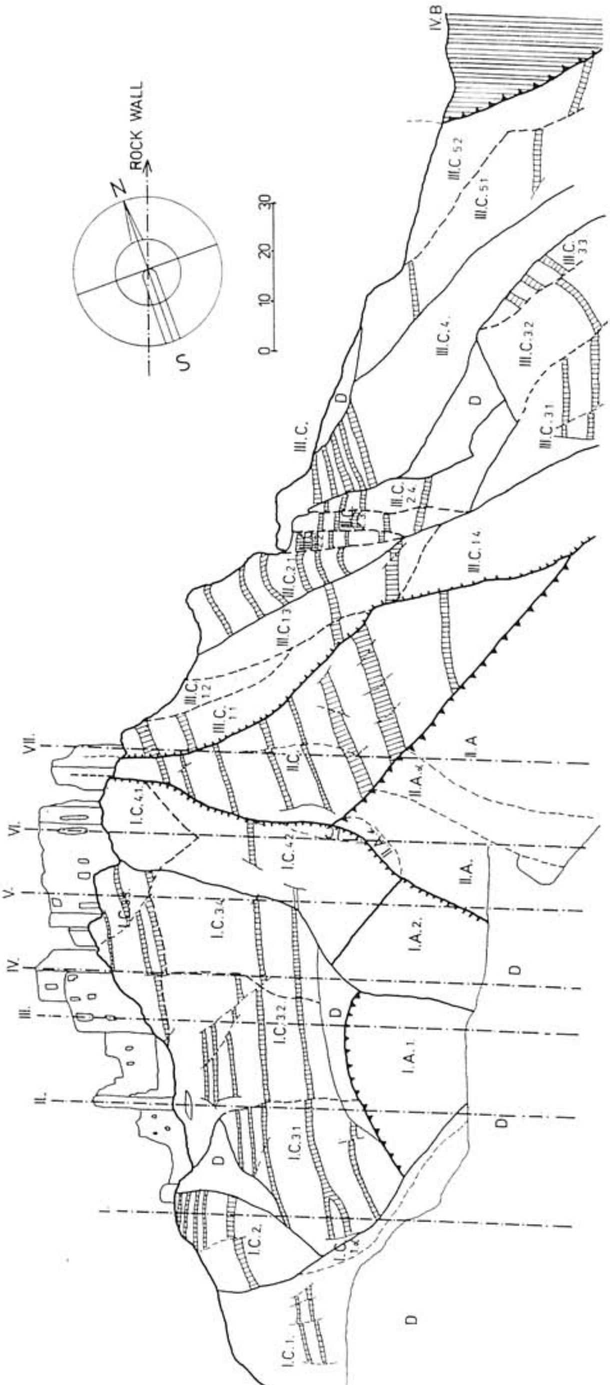



Fig. 9. Engineering geological zoning of the Strečno castle rock.

significant deformations, presenting the nature of gravitational slips, it is disintegrated into series of independent, mutually displaced blocks. The individual blocks are distinguished among themselves by the dip of layers.

IV. Rock mass of tectonically disintegrated rocks. It is situated outside the castle area. It is built by intensely disintegrated dolomites of the Choč nappe.

### *Evaluation of zoning*

All the measured discontinuities in the individual delineated rock masses of the I. to IV. order were treated statistically in tectonograms according to the described method. In order to obtain a picture as complete as possible of the spatial delineation of the individual blocks, we constructed a series of seven fundamental profiles, which intersect all the more important rock masses from the wall stability stand point. Their system of spacing is evident from Fig. 5 and 11.

In the profiles are indicated sectors which intersect the individual numbered rock masses. Each homogeneous rock mass in its profile is appended the tectonogram oriented so as to enable to obtain an idea on the relationship between the plane of the profile cross-section and the respective discontinuity. For a correct orientation the discontinuities are distinguished by numbers and graphically. Examples of characteristic profiles are in Fig. 6.

By a detailed analysis of the delineated homogeneous rock masses we came to the conclustions which influenced the suggestion of geotechnical securing of the castle rock and subsoil.

a) With regard to the orientation of individual perpendicularly running dangerous discontinuities obliquely to the course of the rock wall, to the possibility of mutual wedging of rock blocks and to the morphologic particularities of the rock wall, we can state that these deformations are not threatening the rock wall stability as a whole.

b) Differentiation of the rock mass by discontinuity planes forms the predisposed grid along which only a gradual falling out of bigger or smaller rock blocks takes place. Meanwhile an important role is played mainly by the characteristic vertical displacement tectonics, whose general strike deviates by 5—10° from the direction of the rock wall. As a result of it falling away of rocks takes place only from the end parts of such tectonically predisposed slices.

c) As a result of a quicker weathering process of disintegrated dolomitic positions, overhangs occur above them in the layers of limestones. These, in the subsequent process, loosen gradually along the vertical tectonics of a displacement character, whose dip is 75—90°. Falling of overhangs takes place only when the depth of weathering of dolomites reaches similar more significant discontinuity.

d) Eventual falls of loosened blocks and overhangs along predisposed planes on the lower and middle parts of the rock wall do not directly endanger the castle stability.

e) However, the caste walls in their numerous sectors are seriously endangered by the possibility of a local fall of overhangs described in item c), on which the castle walls are directly built up.

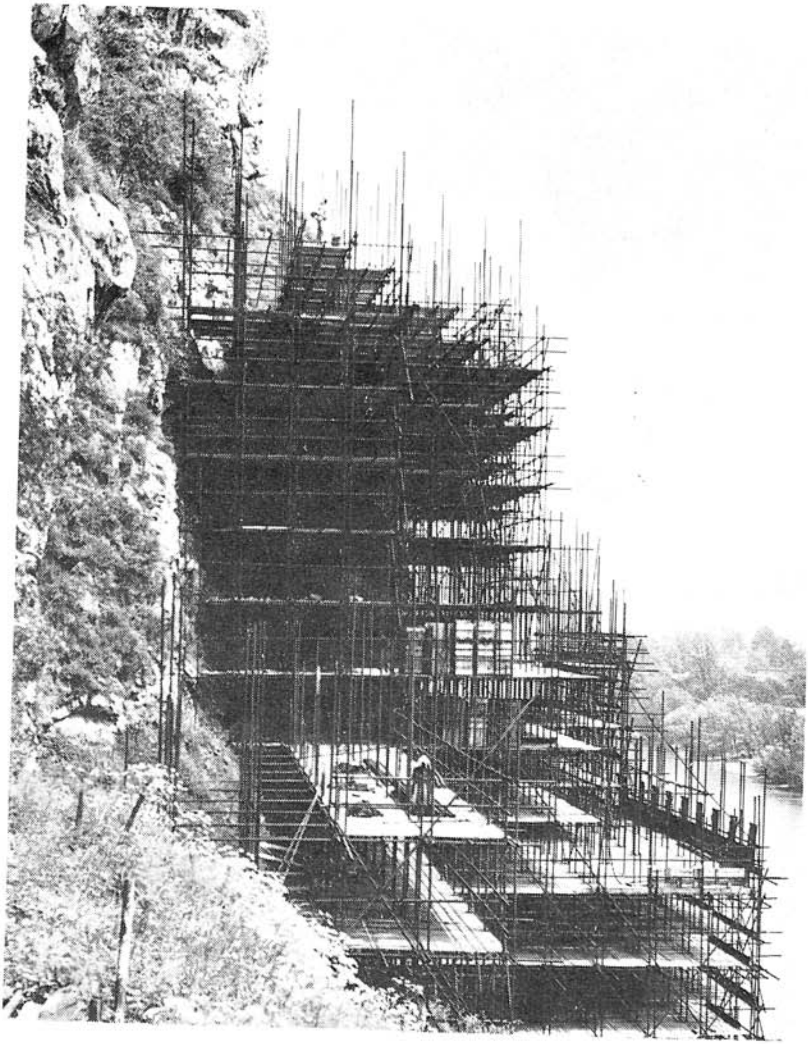


Fig. 10. Lateral view of the scaffolding, constructed according to the original project for saving the castle rock. Front view of the scaffolding is in Fig. 4.

From the above conclusions it results explicitly that from the castle foundations stability securing stand point, it is not necessary to undertake saving of the whole castle rock to the extent considered originally by the project which was prepared without the preliminary detailed engineering geological investigation. An important result of our investigation was the fact we did not recommend to continue in the construction of an extremely complicated and expensive scaffolding (Fig. 4 and 10), which was to cover the whole surface of the rock wall and which at this present stage (covering approximately 1/10 of its surface) met with unsolvable technical problems.

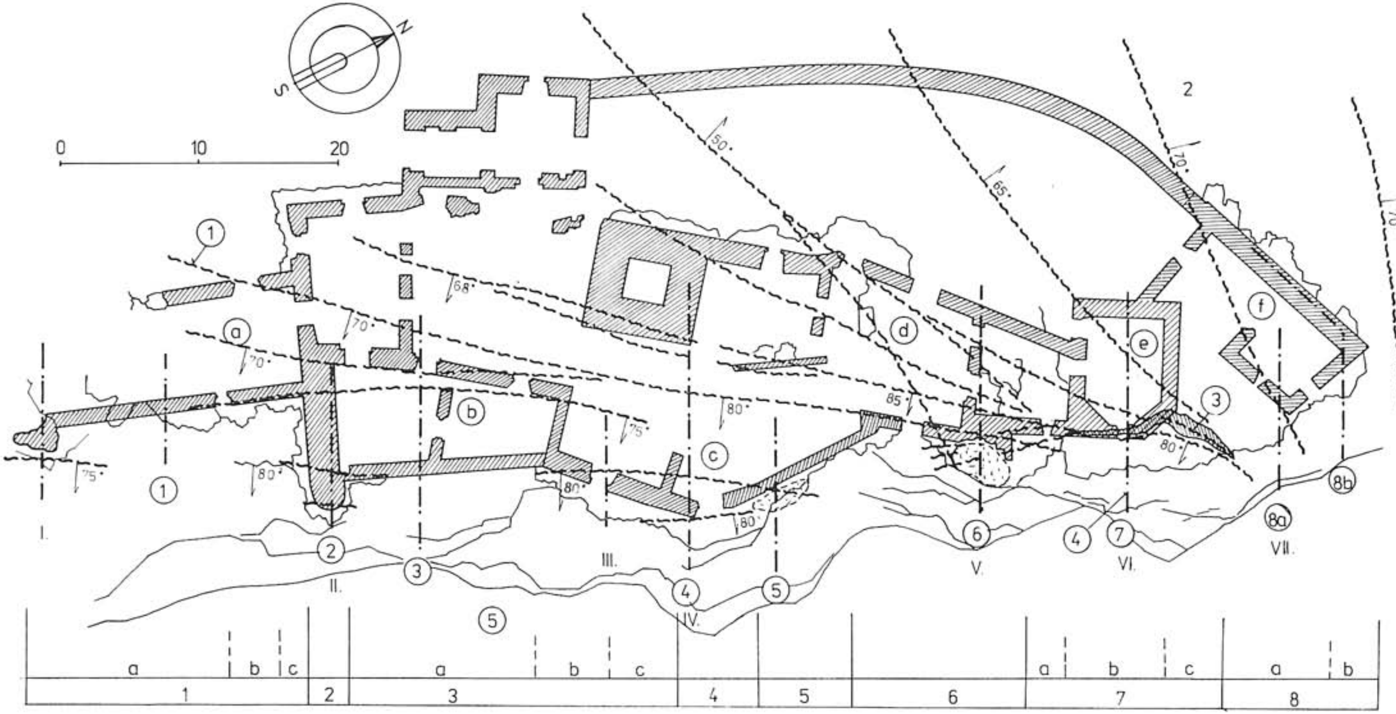



Fig. 11. Tectonic structure of the castle area.
*Explanations:* 1 – subvertical displacements; 2 – subsidences-gravitational slips; 3 – joint-karstic cave; 4 – profile lines; 5 – contours of the rock wall foot and of individual overhangs; 6 – division of the eastern periphery of the castle into sections with homogenous geotechnical conditions (section No. 1 to 8 b.); 7 – contours of the castle foundation. Division of the castle objects: a) gun fortification, b) the southern palace, c) the eastern palace, d) the northern palace, e) the chapel, f) the small tower.

The engineering geological research of the rock wall showed the necessity of saving works only on the immediate subsoil of the castle walls. The saving of the highest part of the castle rock wall in the castle base can be made from a scaffolding lowered to a depth of 4–10 m below the level of the castle foundations. For the saving suggestion of the castle subsoil we made a detailed engineering geological research in the whole castle area.

### *Engineering geological evaluation of the castle subsoil and suggestion for its geotechnical securing*

The detailed research of the castle walls subsoil inside the castle area showed that since the destruction of the castle in 1698, when the exposures of rocks in the subsoil were covered by ruins, the foundation soil was not damaged by weathering. Even in spite of it, however, the subsoil is reinforced by injection and micropilots, suggested in the original project.

Substantially worse are the conditions in the subsoil of the eastern castle periphery. The castle walls here, in some sections, are founded on overhangs, from which some parts fell out already in past. Apart from weathering, also effects of seismicity (the territory belongs to 8° M.C.S.) acted unfavourably on their stability, as well as the dynamic effects of blasting works in the near-by quarry.

In order to be able solve the stability of the eastern castle walls, it was necessary to know the courses of more important deformations in the whole castle area. Outcrops of tectonic planes on the rock wall (Fig. 4), the running of faults in the profiles (Fig. 6) and in the quarry (Fig. 8) were correlated with those detected in the subsoil of the castle area. The result is the tectonic deformation diagram of the castle area, which contains all the detected tectonic planes mutually correlated (Fig. 11). The spatial model of the tectonic deformation was an important document for the suggestion of geotechnical measures for securing the endangered foundations of the eastern castle parts. The precise detection of courses of dangerous discontinuities was necessary mainly for suggesting the system of micropilots, the length and positioning of anchors, the strengthening of the base by injection, etc.

In the research a particular attention was paid to a detailed study of the rock walls in the immediate subsoil of the eastern castle walls. Based on the similarity of engineering geological conditions we delineated here 8 sections, in which the castle foundations are on similar relations. The division of the castle periphery into 8 fundamental sections and further subsections is indicated in Fig. 11.

In each of the delineated sections we constructed by a stereocomparator a detailed profile on scale 1:200. Then in each we drew all the principal discontinuities detected in the direct field research, which are affecting more significantly the stability of the castle subsoil. All the studied discontinuities have their indication in the profiles and in the tectonograms. The profiles enabled us to make a diagram representation of the suggested saving and stabilization works. For illustration we append also a photograph to each profile. The examples of typical detailed profiles of the castle subsoil with the suggestion for saving and the characteristic photograph are in Fig. 12, 13, 14.

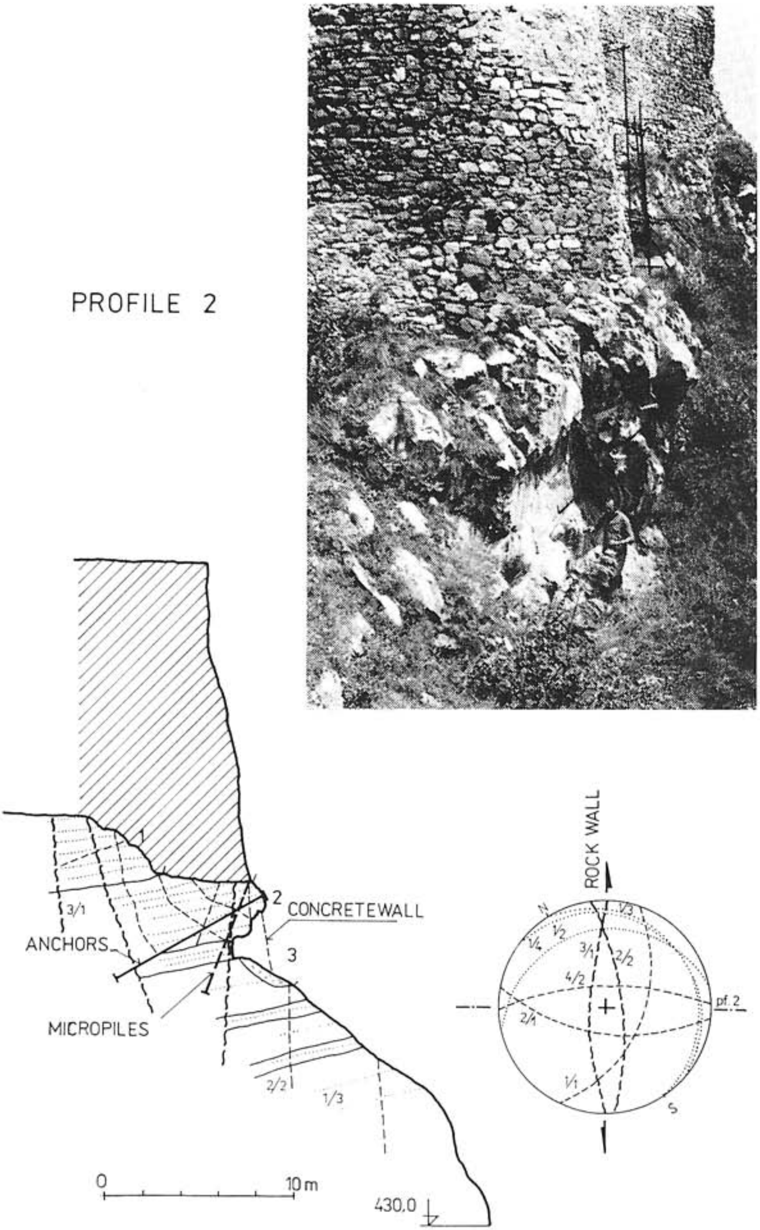



Fig. 12. Profile of the base of the Large rampart (section 2) threatened by the overhang fall. Saving-anchors, micropilots and bricking up. Orientation of anchors is suggested according to tectogram. On the photograph we can see the system of deformation of the rampart base.

The extent of the suggested stabilization works is relatively large. The castle subsoil is in such a bad state that its saving will require the following works:

a) Wall cleaning of the products of weathering, which threaten falling out.

b) Sealing of crevices, cracks and joints of the bedding planes by cement finish so as to prevent infiltration of rain waters.

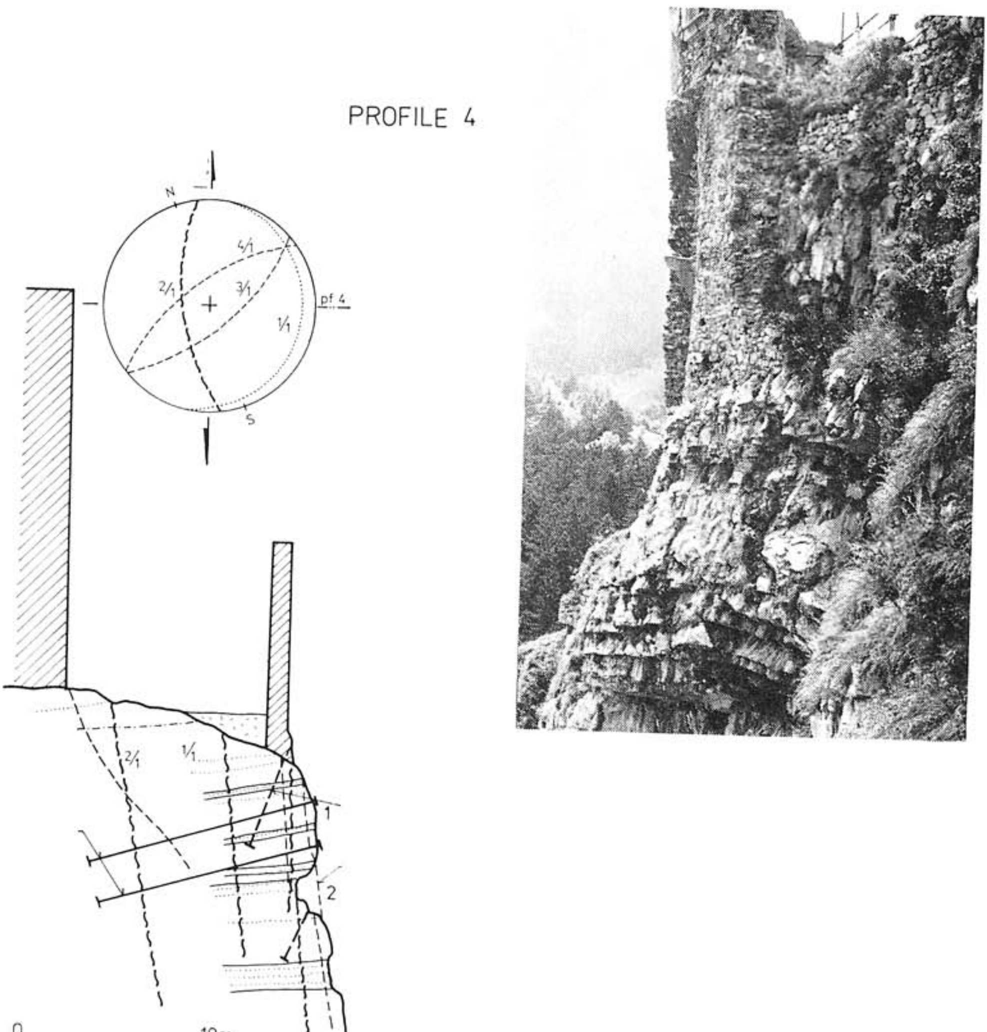
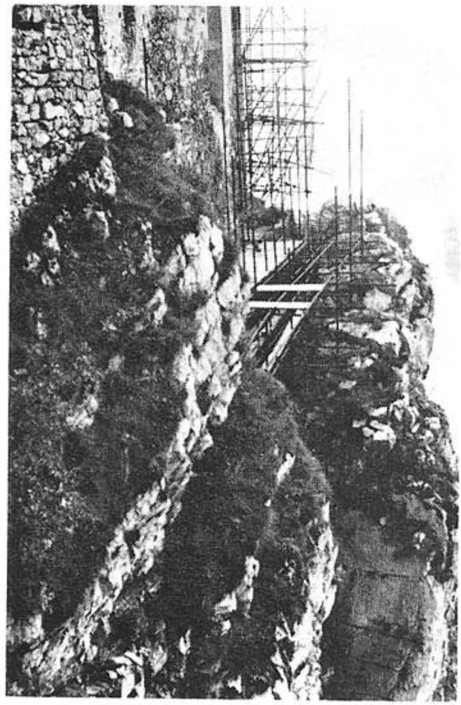



Fig. 13. Detailed profile of base of the southern palace (section 4). Discontinuities 2/1 and 1/1 were detected in the castle area. The anchors must reach beyond the last dangerous discontinuities. The photograph shows the overhang, which must be bricked up.

c) Sealing of cavities and caverns in the castle base by concrete.

d) Bricking up the overhangs by brickworks which must be monolithized with the rock mass by micropilots and anchors.

e) Injection of all the subsoil boreholes made for micropilots and anchors by a thin cement suspension.



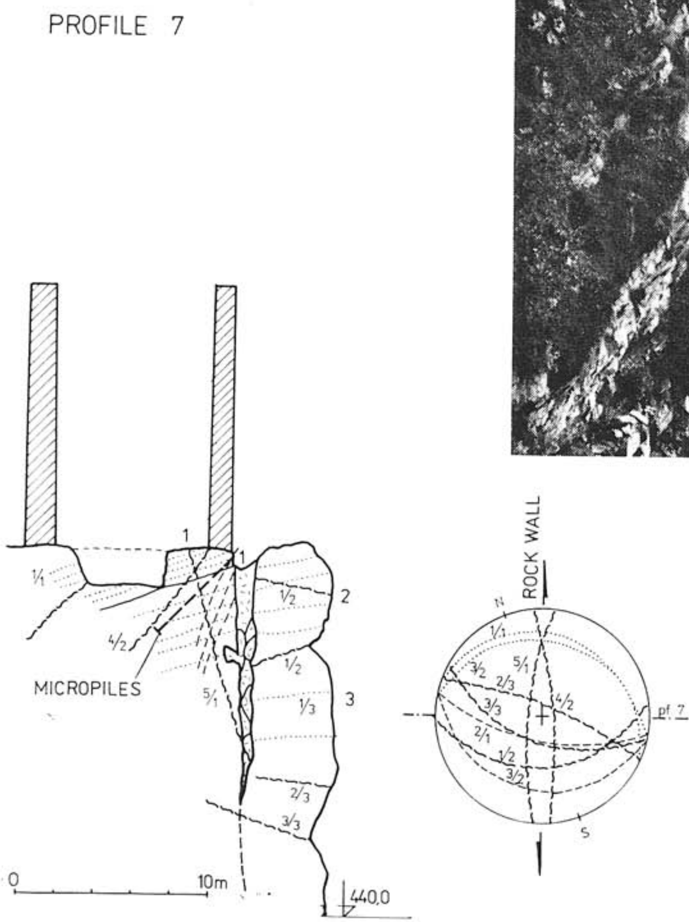



Fig. 14. Detailed profile of base of the Chapel (section 7). Saving the base by micropilots and injection. Unstable block in front of the Chapel of the volume of about 560 m³ cannot be technically saved.

f) Underpinning of the whole subsoil of the eastern castle periphery by micropilots 4–6 m long with 0.5 m spacing.

h) Anchorage of the rock overhangs by bar anchors 8–12 m long, according to the system of discontinuities indicated in the profiles. To incorporate in the overhangs a sensitive equipment for measuring eventual movements.

i) To displace some parts of the wall, in case it cannot be reconstructed in its original place as a result of falling out of its subsoil.

## *Conclusions*

The detailed engineering geological investigation by means of direct field and indirect photogrammetric methods brought in a series of new facts on the geological-tectonic structure, on the lithologic composition and on the system of planes of the mechanical discontinuities of rocks, building the whole castle area.

The research of the eastern castle rock wall showed that its stability here as a whole is not endangered. The castle rock is threatened solely by the falling out of relatively small blocks along its entire surface. Eventual falling of certain blocks along predisposed detected planes threatens the security of transport on the national road of I. class, which runs at the foot of the rock wall. The castle walls are seriously endangered by the possibility of the rock overhangs falling, on which the castle is directly founded.

From the castle static securing stand point it is necessary to concentrate above all on its immediate subsoil. The suggested saving works for the subsoil stabilization of the eastern castle periphery can be carried out from a scaffolding, which will be lowered directly along the castle outer periphery.

Translated by E. Bleho

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