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Izvorni znanstveni članak

GEOTECHNICAL MODELS OF THE ARCH FOUNDATIONS OF THE MASLENICA BRIDGE

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Key-words: Engineering geological characteristics, Foundation of the bridge, Geotechnical models, Structural tectonic relationships

On the site of Maslenica bridge structural tectonic, geophysical and engineering geological investigations, geotechnical drilling and laboratory sample testings were performed. Maslenica anticline is characteristic for the investigated area. It is built from the limestone of Cretaceous age. The anticline has an asymmetrical form with the vergence of the axial plane towards the north. Reverse faults with recent activities are present. The recent activity was proved by the discovery of the broken stalactite with the displacement of 11 cm, whose age is 36000 years. On quite young stalactites (stalagmites) in the cave on the west side, no displacements were noticed. For the next period of 500 years the maximal possible displacement of 2.0 cm is foreseen. Smaller caves with the dimensions of 1 m^3, were formed on the intersections of the reverse faults and greater joints. The canyon Novsko ždrilo was formed in the fault shear zone with tectonic transport to the right.

According to the range of fracture, three characteristic types of rock masses were separated by engineering geological investigations. According to »Geomechanical classification« (RMR) the first type corresponds to II to III class, while the second type corresponds to IV class, and the third type corresponds to V class (mylonite).

Because of the complexity of the terrain structure, original engineering geological bases of design have not enabled the direct application of the analysis of stress-strain behaviour. Because of that the simplified geotechnical models were done. They enabled the projecting of foundation in the rock mass and renewal of poor quality rock mass.

Ključne riječi: Inženjerskogeološke značajke, Temeljenje mosta, Geotehnički modeli, Strukturno-tektonski odnosi

Na lokaciji Masleničkog mosta urađena su strukturno-tektonska, geofizička i inženjerskogeološka istraživanja, istražna bušenja i laboratorijska ispitivanja uzoraka. Za istraživano područje karakteristična je Maslenička antiklinala. Izgrađena je od vapnenaca kredne starosti. Antiklinala ima asimetričan oblik s vergencijom osne ravnine prema sjeveru. Prisutni su reversni rasjedi s recentnom aktivnošću. Recentna aktivnost dokazana je nalazom presječene sige s pomakom od 11 cm, čija starost je 36000 god. Na sasvim mladim sigama u špilji na zapadnoj strani nisu uočeni pomaci. Za povratni period od 500 godina prognoziran je mogući maksimalni pomak veličine do 2,0 cm. Manje špilje dimenzija do 1 m^3 nastale su na presjecištima reversnih rasjeda i većih pukotina. Kanjon Novsko ždrilo nastao je u zoni smicanja rasjeda s desnim tektonskim transportom.

Prema stupnju razlomljenosti izdvojene su inženjerskogeološkim istraživanjem tri karakteristične sredine. Prema »Geomehaničkoj klasifikaciji« (RMR) prva sredina odgovara II. do III. klasi, druga sredina odgovara IV. klasi, a treća sredina odgovara V. klasi (milonit).

Originalne inženjerskogeološke podloge nisu omogućile, zbog složenosti građe terena, direktnu primjenu u analizi odnosa naprezanja i deformacija. Zbog toga su izrađeni simplificirani geotehnički modeli. Oni su omogućili projektiranje temeljenja u stijenskoj masi i saniranja dijelova slabe kvalitete.

Introduction

Maslenica bridge is built over Novska ždrilo the narrow channel which connects Velebit channel and Novigrad sea. Total length of the bridge is 300 m. The arch overlaying Novsko ždrilo is 200 m. The building of bridge was preceded by large investigation (Novosel et al., 1994, Vrkljan et al., 1994, Andrić et al., 1994). It was necessary to determine in details structural geology, sesimotectonic and engineering geological properties on the site of the bridge. The necessary bases of design for rock foundations were made (Kuk et al., 1994, Mulabdić et al., 1994, Novosel et al., 1994). But, explicitly unhomogeneous and anisotropic type causes that bases of design, in their original form, have not made possible prognostic analyses of the rock mass behaviour during the excavation and after the building of foundation. Therefore, simplified models of geological properties on the sites of foundations were made. Simplified geotechnical model was made on the site of foundation, which enabled analyses of stress-strain behaviour in the interaction between future bridge foundations and rock mass (Vrkljan et al., 1994).

Geological, seismotectonical, engineering geological and geophysical data

On the surface, there are carbonate sediments of Createaceous age (Ivanović et al., 1973; 1976). In the structure area, the site of the bridge is placed on the boundary of the Velebit fault zone (Fig. 2a). This is the boundary fault of two regional structural units: Adriatic unit (Ravni kotari) and Dinaric one (Mt. Velebit). Fault zone is seismotectonically active.

Tectonical structural measurements showed two periods of forming of local structures surrounding Novsko ždrilo (Kuk et al., 1994, Prelogović et al., 1995). During the older period the folding of sediments began. The anticline with NW–SE orientation is formed

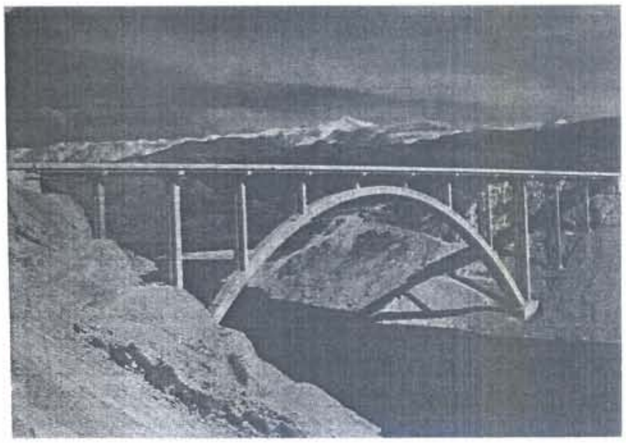

Fig. 1. Maslenica bridge

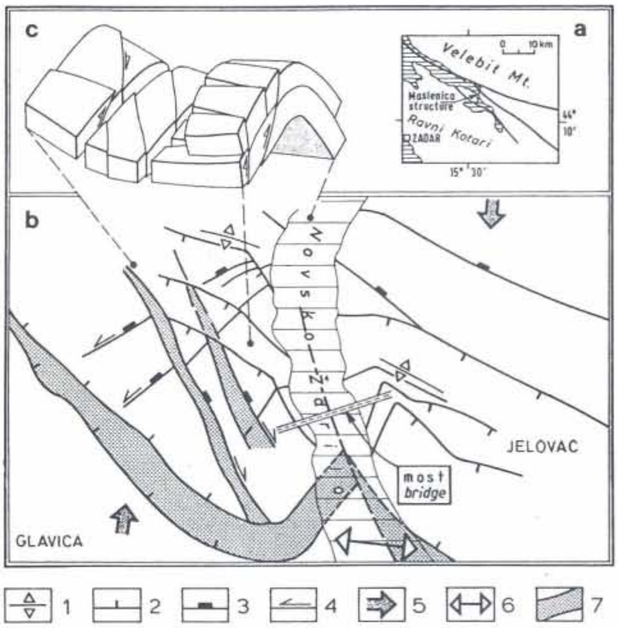

Fig. 2. Local structural relationships
Legend:
1 – Anticline axis; 2 – Reverse faults; 3 – Normal faults; 4 – Faults with horizontal movement; 5 – Local stress; 6 – Local extension of Novsko ždrilo; 7 – Fault zones

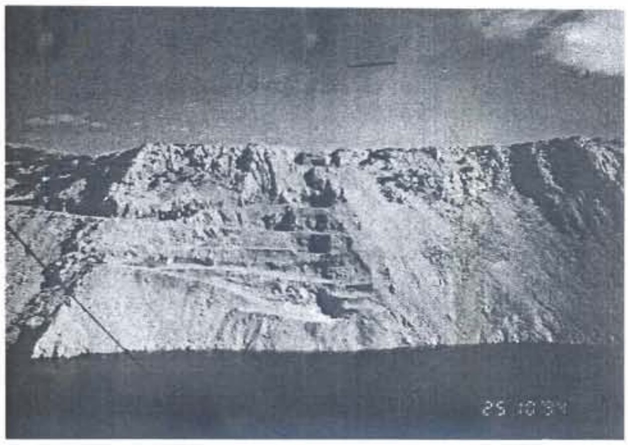

Fig 3. East side of Novsko ždrilo

Table 1 Rock mass categorisation according to "Geomechanical classification" (simplified model) (Bieniawski, 1979)

DESCRIPTION OF PARAMETERS	CHARACTERISTIC VALUES FOR DIFFERENT TYPES OF ROCK MASS		
	TYPE I	TYPE II	TYPE III
A1 UNIAXIAL COMPRESSION STRENGTH OF THE SPECIMEN	151 MPa	68 MPa	≈ 1 MPa
NUMBER OF POINTS	12	7	1
A2 R. Q. D.	50 - 70 %	25 - 40 %	0
NUMBER OF POINTS	13	8	3
A3 DISTANCE BETWEEN DISCONTINUITIES	0.2 - 2.0 m	0.06 - 0.6 m	< 0.06 m
NUMBER OF POINTS	16	7	5
A4 CHARACTERISTIC OF DISCONTINUITIES	3-10 m length; <0.5mm aperture; soft filling	1-8 m length; 0.25-2.5 mm aperture	mylonite
NUMBER OF POINTS	16	12	0
A5 UNDERGROUND WATER	wet-dry seepage	wet-dry seepage	wet
NUMBER OF POINTS	10	10	7
A6 ORIENTATION OF DISCONTINUITIES (foundations)	satisfying	satisfying	satisfying
NUMBER OF POINTS	-7	-7	-7
TOTAL POINTS (RMR)	60	37	9
NUMBER OF CLASS	II - III	IV	V
CHARACTERISTIC OF ROCK MASS	Hard rock mass	Jointed rock mass	Soil

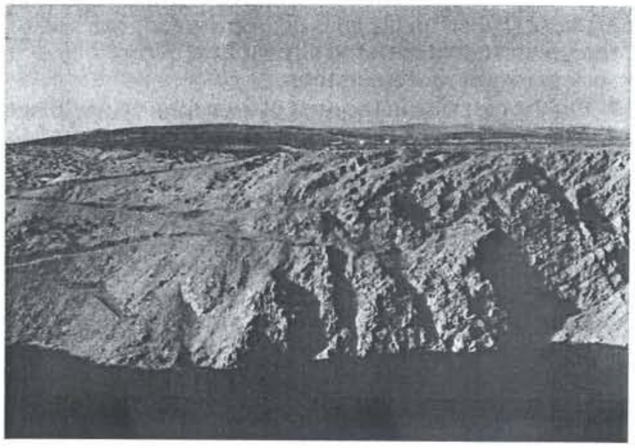

Fig. 4. West side of Novsko ždrilo

accompanied by reverse faults SW vergence. Joint systems characteristic for compression regime appearing also. A set of normal faults occurred towards the Velebit fault (Fig. 2b). During younger (and recent) period discontinuous change in local stress orientation to N–S direction was noticed (Fig. 2c). The anticline structure is deformed into asymmetric shape with axial plane vergence towards north. The fault systems with horizontal displacemnt were specially active. On several places, on the intersections with the layers, cavities and caves were formed, which were lately filled with Quaternary sediments. Occurrence of faults with vergence towards north is significant. The proof that the faults have recently been active are foundings of the stalactites inside their zones. On the eastern side of Novsko ždrilo the faulted stalactite with displacement of 11 cm was found. Using C^{14} radiometric method the accurate age of 36000 years was established. Novsko ždrilo channel was formed in the zone of horizontal fault with tectonic transport to the right. Orientation of the local stress has shown the recently present movements in that fault zone (Fig. 2b). Generally, west side of Novsko ždrilo is structurally more stabile then the east side. On that side there are less marked fault zones filled with mylonite material. However, on both sides, there are highly jointed zones with the width of a few meters (Figs. 3, 4).

Engineering geological investigation showed specially big differences in rock mass quality (ISRM, 1976; Deere, D. U. & Deere, D. W., 1988). Highly crushed zones are related to faults. Occasionally, wide mylonite zones occur. Along with shattering mylonite formed during the compression, there are shear mylonites highly enriched with high plasticity coherent material with. Pale blue colour of those mylonites, opposite to brownish yellow colour of surrounding material, shows the recent activity of faults. Because of the shear processes along particular fault systems, existence of thin plated blocks was noticed, together with the debris and small grain sized material or clayey-silty material. The most important general conclusion is the emphasised influence of tectonic processes and wathering to the rock mass, which is explicitly unhomogeneous and anisotropic (Novosel et al., 1994).

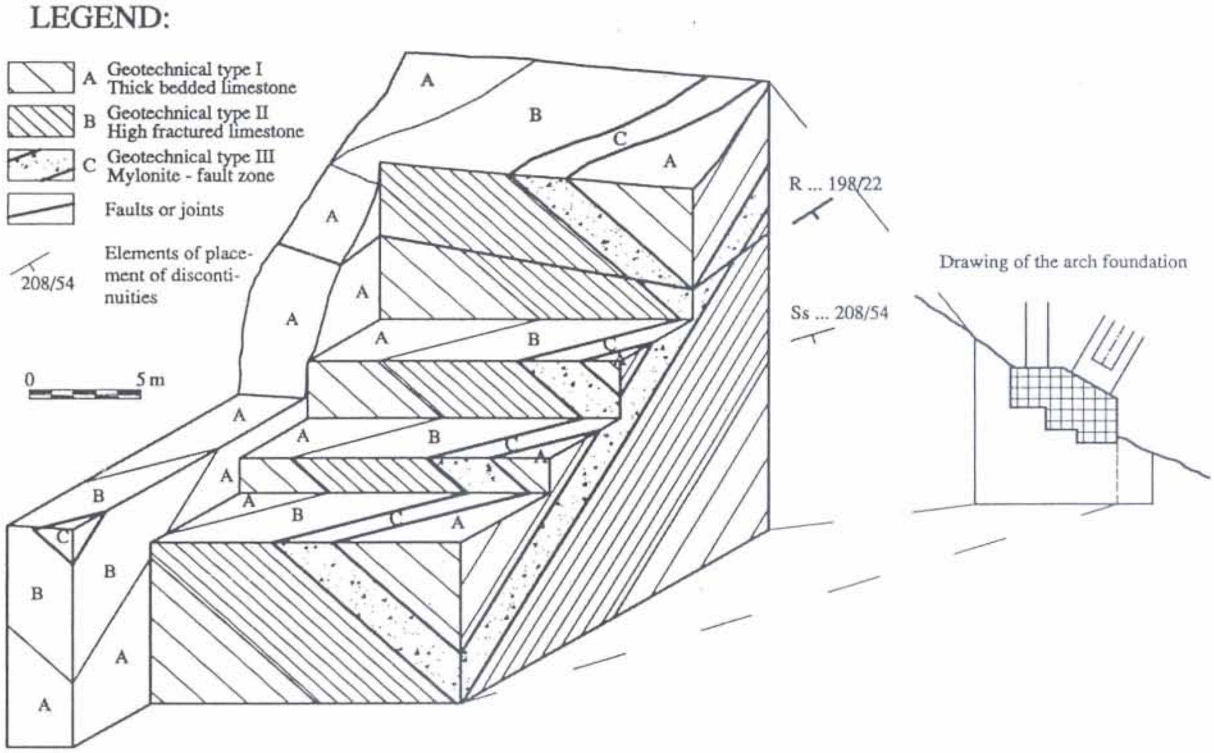

Fig. 5. Geotechnical model of the arch foundations on the east side of Novsko ždrilo

Homogeny and isotropy of the rock mass was possible to define, thans to wide geophysical survey (shallow reflection and refraction, down-hole and cross-hole measurements, and measurements of seismic waves by polar method on the slopes, using the boreholes) (Andrić et al., 1994). The logging of borehole was per-

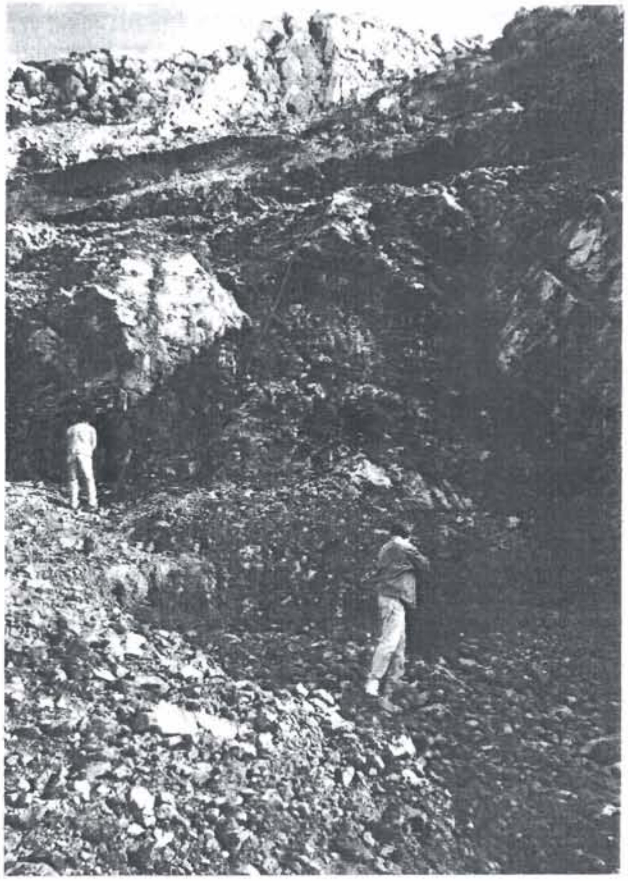

Fig. 6. Excavation for the arch foundations on the east side of Novsko ždrilo

formed, using radioactive technique, and ultrasound testing of the specimens of rocks in laboratory.

The qualitative difference between different parts of rock mass enabled categorisation into three characteristic groups (types). simplified form of categorisation of rock mass according to »Geomechanical classification« (Bieniawski, 1979) is given in the table 1.

Morphological characteristic and consequences of tectonic activities had essential influence on development of rock mass weathering. Advancing of weathering on the platoes above the canyon Novsko ždrilo is different than that on the slopes of canyon.

In the narrower area of investigation, on the slopes of canyon, several zones of weathering were determined. The surface weathering zone goes to the depth of 0.5–4.5 m. In that zone rock mass is completely to high weathered. The following one is the upper weathering zone, from 2.0–5.0 m thick, in which the rock mass is high to middle wathered. Using reflective seismic method distinguished lower border of weathering was determined at the depth of 35.0–50.0 m (Andrić et al., 1994).

Seismic parameters were of special importance for the projecting of foundations. Deterministic and probability approach were used, including seismic risk, amplification factor (DAF) and velocity of secondary seismic waves (Kuk et al., 1994).

Developing of models

Accepting all the investigation results, the simplified 3D geotechnical models were made, which enabled the analysis of the interactive stress-strain behaviour in contact zones foundations – rock mass. Geotechnical models were shaped on the sites of arch foundations because the greatest concentrated stress of the future object on rock mass were foreseen there.

On the east side in the area of arch foundation, diagonal to the sides of the rectangular ground-plan of the basis surface, there is the mylonite zone (material C) of the reverse fault zone parallel to the layer position (Figs. 5, 6). The zone is built from the mixture of small blocks of limestone, debris and preconsolidated clay. The position of the bedding plane in the space (down the slope) is unfavourable too. The reverse fault zone, and bedding planes are priority discontinuities which can essentially influence the stability of the rock mass at stress mobilising during bridge building as well as during the exploiting phase. After the extensive field investigations it was estimated that the average thickness of the fault discontinuity was 0.8 m. The distance of the boundary planes of the fault zone in the rock mass varies from 0.0 to 1.6 m. Under the fault zone there is a very fractured limestone (material B) which is characterised by plate bedding to the irregular blocks (dm area). The average thickness of these layers is estimated to about 4.0 m. Both zones (B and C) are placed inside the quality rock mass, thick bedded limestone and fractured limestone with the blocks of medium sizes (material A).

The foundation arch on the west side is placed in the quality rock mass (A). The zone of weakened rock mass (B) is above the foundation bottom, and the registered discontinuities have favourable position in relation to the morphological characteristics and to the forces direction which will be activated in the rock mass after the building of the bridge (Figs. 7, 8). As the main problem the stability problem of the cutting appeared during the excavation of the foundation pit. The height of the excavation is about 30 m and the excavation is done partly in a quality rock mass (A) and partly in very fractured limestone (B). In the middle of the cutting, the cave was registered, which because of the cutting, in the shape of a wedge had considerably more unfavourable engineering geological characteristics, and it was separated in the model.

Conclusion

After the performed wide investigations for the needs of the main project of Maslenica bridge foundation the engineering geological bases of design were made. Because of the explicitly unhomogeneity and anisotropy of the rock mass it was not possible to use directly the made bases of design and the simplified geotechnical models were done in order to enable the analysis of the influence of the future object on the rock mass. Geotechnical models were presented (Figs. 5, 7). Three classes of the rock mass were separated. On the basis of the manifold investigations, parameters of strength and deformability of the rocks mass (Table 1) were determined for each class of the rock mass (A, B, C) and all the necessary geotechnical analyses were done. Renewal interventions with the aim of cancelling the negative implications on the future object were done.

Observing the cave on the west side of Novsko ždrilo it is estimated that its direction is vertical to the slope, and the height does note exceed 1 m. During the natural cave formation the stabile condition with all present effects of semicircular vault was established so the slope performing and removal of the definite volume of the rock mass will not imperil the slope stability. Observing the cave phenomena it was possible to estimate the

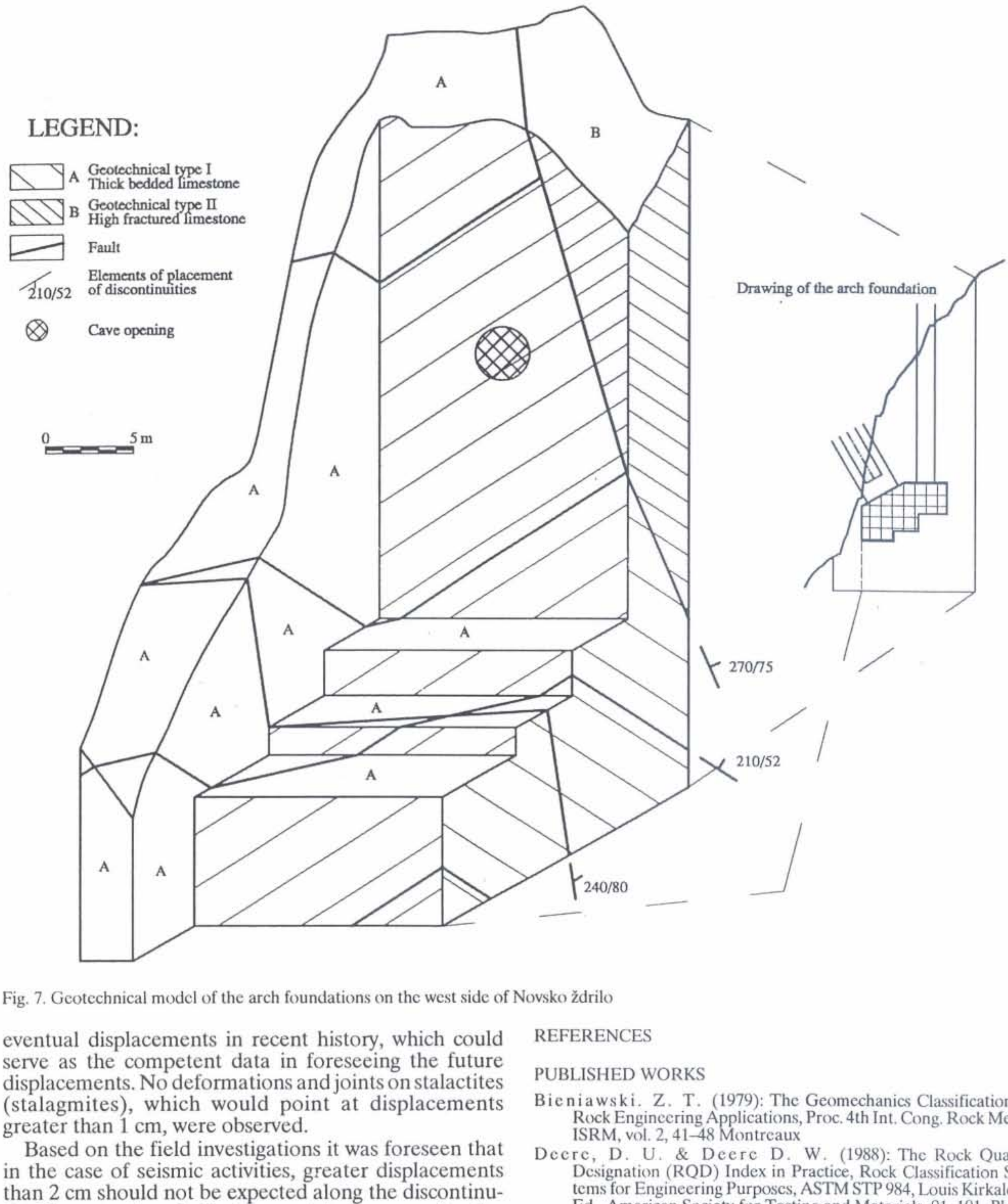

Fig. 7. Geotechnical model of the arch foundations on the west side of Novsko ždrilo

eventual displacements in recent history, which could serve as the competent data in foreseeing the future displacements. No deformations and joints on stalactites (stalagmites), which would point at displacements greater than 1 cm, were observed.

Based on the field investigations it was foreseen that in the case of seismic activities, greater displacements than 2 cm should not be expected along the discontinuity. The mentioned displacement is foreseen for the period of future bridge exploration.

Geotechnical models served as interphase between investigation and projecting and enabled more qualitative approach to foundation projecting and renewal of very week parts of rock mass before foundation building.

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REFERENCES

PUBLISHED WORKS

Bieniawski. Z. T. (1979): The Geomechanics Classification in Rock Engineering Applications, Proc. 4th Int. Cong. Rock Mech, ISRM, vol. 2, 41–48 Montreaux

Deere, D. U. & Deere D. W. (1988): The Rock Quality Designation (RQD) Index in Practice, Rock Classification Systems for Engineering Purposes, ASTM STP 984, Louis Kirkaldie, Ed., American Society for Testing and Materials, 91–101, Philadelphia.

Inter. Society for Rock Mechanics (1976): Suggested Methods for the Quantitative Description of Discontinuities in Rock Mass, Zürich.

Ivanović, A., Sakač, K., Marković, S., Sokač B., Šušnjar, M., Nikler L. & Šušnjara, A. (1973): Osnovna geološka karta SFRJ, 1:100000, list Obrovac, L 33–140, Inst. geol. istraž., Zagreb, 1962–1967., Sav. geol. zavod, Beograd.

Ivanović, A., Sakač, K., Marković, S., Sokač B., Šušnjar, M., Nikler L. & Šušnjara, A. (1976): Osnovna geološka karta SFRJ, Tumač za list Obrovac, L 33–140, Inst. geol. istra., Zagreb, 1967., Sav. geol. zavod, Beograd.

Prelogović, E., Jamičić, D. & Novosel, T. (1995): The dynamics of joint and fault modelling in carbonate rocks – Maslenica,

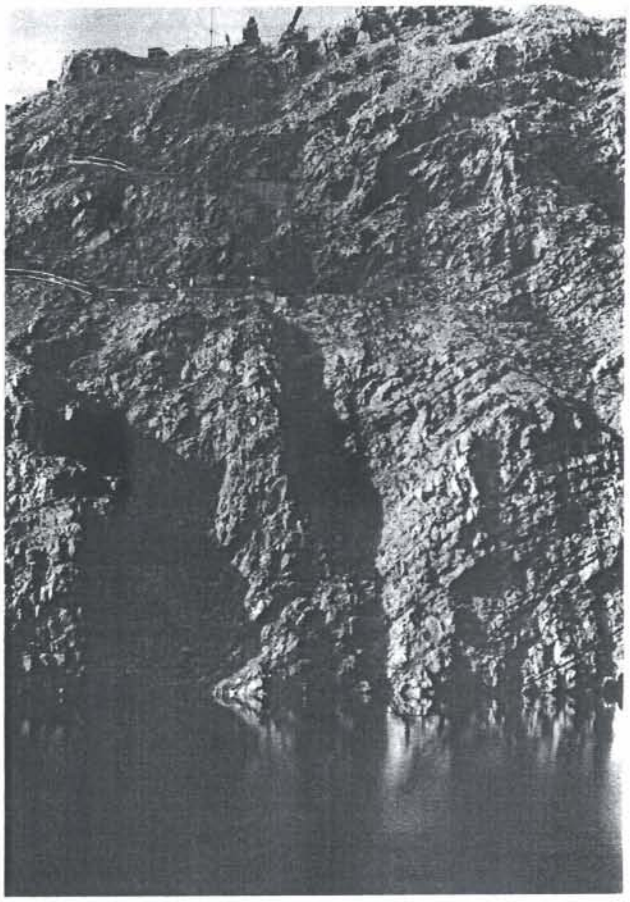

Fig. 8. Detail on the location of the arch foundations of the west side of Novsko ždrilo before the excavation of the foundation site

Second International Conference on the Mechanics of Jointed and Faulted Rock – MJFR-2, Vienna/Austria/10–14 April 1995, A. A. Balkema/Rotterdam/Brookfield/1995, 355–358.

UNPUBLISHED WORKS

Andrić, M. i suradnici (1994): Geotehnički istražni radovi. Knjiga 4 – Geofizička istraživanja, arhiv IGH, Zagreb.

Kuk, V., Prelogović, E., Marić, K., Skoko, D. Jamičić, D. & Markovac, Z. (1994): Geotehnički istražni radovi. Knjiga 3 – Seizmološka i seizmotektonska istraživanja, arhiv IGH, Zagreb.

Mulabdić, M. i suradnici (1994): Geotehnički istražni radovi. Knjiga 5 – Laboratorijska ispitivanja, arhiv IGH, Zagreb.

Novosel, J. & Bljaić, E. (1994): Geotehnički istražni radovi, Knjiga 1 – Geodetski radovi, arhiv IGH, Zagreb.

Novosel, T. i suradnici (1994): Geotehnički istražni radovi, Knjiga 6 – Inženjerskogeološka istraživanja, arhiv IGH, Zagreb.

Vrkljan, M. i suradnici (1994): Geotehnički istražni radovi, Knjiga 2 – Terenski istražni radovi, arhiv IGH, Zagreb.

Vrkljan, M. i suradnici (1994): Geotehnički istražni radovi. Knjiga 7 – Geotehnički elaborat, arhiv IGH, Zagreb.