GEOTECHNICAL MODELS OF THE ARCH FOUNDATIONS OF THE MASLENICA BRIDGE

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Introduction

Maslenica bridge is built over Novska žrdilo the narrow channel which connects Velebit channel and Novigrad sea. Total length of the bridge is 300 m. The arch overlaying Novska žrdilo is 200 m. The building of bridge was preceded by large investigation (Novose l et al., 1994, Vrklijan et al., 1994, Andrić et al., 1994). It was necessary to determine in details structural geology, seismotectonic and engineering geological properties on the site of the bridge. The necessary bases of design for rock foundations were made (Kuk et al., 1994, Mulubić et al., 1994, Novose l 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 (Vrklijan et al., 1994).

Geological, seismotectonical, engineering geological and geophysical data

On the surface, there are carbonate sediments of Cretaceous 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 Novska žrdilo (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...
Table 1  Rock mass categorisation according to “Geomechanical classification” (simplified model) (Bieniawski, 1979)

<table>
<thead>
<tr>
<th>DESCRIPTION OF PARAMETERS</th>
<th>TYPE I</th>
<th>TYPE II</th>
<th>TYPE III</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 Uniaxial compression strength of the specimen</td>
<td>151 MPa</td>
<td>68 MPa</td>
<td>≈ 1 MPa</td>
</tr>
<tr>
<td>Number of points</td>
<td>12</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>A2 R. Q. D.</td>
<td>50 - 70 %</td>
<td>25 - 40 %</td>
<td>0</td>
</tr>
<tr>
<td>Number of points</td>
<td>13</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>A3 Distance between discontinuities</td>
<td>0.2 - 2.0 m</td>
<td>0.06 - 0.6 m</td>
<td>&lt;0.06 m</td>
</tr>
<tr>
<td>Number of points</td>
<td>16</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>A4 Characteristic of discontinuities</td>
<td>3-10 m length: ≤0.5 mm aperture; soft filling</td>
<td>1-5 m length: ≥0.25 mm aperture</td>
<td>mylonite</td>
</tr>
<tr>
<td>Number of points</td>
<td>16</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>A5 Underground water</td>
<td>wet-dry</td>
<td>wet-dry</td>
<td>wet</td>
</tr>
<tr>
<td>Number of points</td>
<td>10</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>A6 Orientation of discontinuities (foundations)</td>
<td>satisfying</td>
<td>satisfying</td>
<td>satisfying</td>
</tr>
<tr>
<td>Number of points</td>
<td>-7</td>
<td>-7</td>
<td>-7</td>
</tr>
<tr>
<td>Total points (RMR)</td>
<td>60</td>
<td>37</td>
<td>9</td>
</tr>
<tr>
<td>Number of class</td>
<td>II - III</td>
<td>IV</td>
<td>V</td>
</tr>
<tr>
<td>Characteristic of rock mass</td>
<td>Hard rock mass</td>
<td>Jointed rock mass</td>
<td>Soil</td>
</tr>
</tbody>
</table>
stalactite with displacement of 11 cm was found. Using C\textsuperscript{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 stable than 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

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 displacement 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 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).

Homogeneity and isotropy of the rock mass was possible to define, thanks 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-

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**LEGEND:**

- A Geotechnical type I
- B Geotechnical type II
- C Geotechnical type III
- Faults or joints
- 208/54
- 208/54

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

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Fig. 4. West 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 characteristics and consequences of tectonic activities had essential influence on development of rock mass weathering. Advancing of weathering on the plateaus above the canyon Novsko ždrišlo 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 weathered. Using reflective seismic method distinguished lower border of weathering was determined at the depth of 55.0-50.0 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 (Kuč 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 ždrišlo it is estimated that its direction is vertical to the slope, and the height does not exceed 1 m. During the natural cave formation the stable 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. 6. Excavation for the arch foundations on the east side of Novsko ždrišlo
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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PUBLISHED WORKS


UNPUBLISHED WORKS

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