Excavation of Open Pit “Zagrad” in Rijeka, Croatia, A Case History

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ABSTRACT

On the location Zagrad in Rijeka, Croatia, an open pit has been designed and constructed for the purpose of building the garage-accommodation-business complex. The location of the open pit is situated in the central area of the town Rijeka, and closely surrounded by the existing accommodation buildings, a traffic line and a railway. The open pit was designed and constructed four levels below the terrain surface, adjacent to the existing buildings and a traffic line. To secure the open pit walls during excavation, a support system with the self-drilling rock bolts for the reinforcing of the rock mass and reinforced concrete grid structure on the excavated surface was designed. This paper presents the construction method for the open pit, with the application of active design concept during works execution. It also presents the set-up system for measuring, observing and monitoring of the support system behavior. This enabled, on the basis of the measurement results and performed back analysis, an active designing of the suitable support system during works execution, for the in situ conditions of the rock mass in excavation. Performed back analysis showed need for the additional correction in the correlation between deformation characteristics of the rock mass and rock mass classification.

INTRODUCTION

On the location Zagrad, in Rijeka, Croatia, a garage-accommodation-business complex is under construction. The existing accommodation buildings and traffic lines closely surround the construction location. In the first phase, an open pit was constructed, four levels below the terrain surface, adjacent to the existing buildings and a traffic line in the northern part. Geological composition of the location is very complex: on the lateral sides limestone rock mass is present, while the central part of the location crosses a gully with thick clay deposits. On the northern side of the site, with the maximum cuttings of the existing terrain, is a contact of limestone and flysch deposits.

Excavation of the open pit has been constructed in phases, with soil and rock mass reinforcement by the rock bolts and suitable reinforced system: mesh construction in the very vicinity of the around-site buildings or multi-layered reinforced sprayed concrete. During the works execution, a measuring, observing and monitoring system for the substructure system behavior was established, with implement of vertical inclinometers and horizontal deformeters as well as geodetic marks and performed measurements by phases of excavation. An active design procedure was established which made possible changes required in the rock mass reinforcement system in cuts.

GEOTECHNICAL PROPERTIES OF LOCATION

On the location Zagrad in Rijeka the garage-accommodation-business complex is under construction, which predict on its underground part a construction of a public garage, and on its aboveground part accommodation-business constructions. The location is placed in the area of Zagrad, between a railway on the south and a traffic line on the north part (Pomerio Street). Layout dimensions of a construction are approximately 90×60 m, and the existing accommodation buildings, having up to 7 stories surround it.

A geotechnical investigation works determined a soil composition on the location of a future open pit and a construction complex. They consisted on results of geotechnical drilling, geophysical surveys, laboratory testing of rock mass samples, engineering-geological and geotechnical works.

The investigated location has a shape of a depression, with the direction of striking in the SW-NE. The natural terrain surface was significantly changed by the filling and cutting during the several centuries of construction in Rijeka. Due to a cutting, and especially filling, the terrain has a cascade-look. The elevation above the sea level in the sinkhole ranges from 6.0 to 17.5 m, and the elevation of the traffic line above the construction site is 24

m a.s.l. Outcrops of the bedrock were partly visible. It was determined that the terrain consists of a cover: fill and red soil (terra rossa) in the central part, and carbonate rock mass on the lateral sides, composed of dolomitic limestone.

The fill is composed of a mixture of rock fragments and brown muddy clay in different proportions. Red soil (terra rossa) is composed of a brown to red muddy clay of high consistency as well as fragments of bedrock's origin.

The bedrock consists of dolomitic limestones with noticeable bedding. Measured Rock Quality Designation (RQD) as an indicator of rock disintegration degree, is low and ranges from 0-16% on the surface up to 50% in depth.

Geomechanical or RMR classification (Bieniawski, 1989) was made for two types of carbonate rock mass: averagely fractured and karstified rock as well as extremely fractured to crushed and markedly karstified rock. As input data for RMR classification, data from measurements on the outcrops on surface as well as data from boreholes, were selected (ISRM, 1978). According to the results of drilling and geophysical surveys, deposits of flysch were expected in the west part (Marinos et al., 2001).

ROCK MASS MASS SUPPORT SYSTEMS

On the basis of the results of geotechnical investigation works, designing of a constuction of open pit as well as an execution of open pit started. For a construction of a subject complex, on the major part of the location, excavation on +3.20 m a. s. level was predicted. Regarding the location morphology, the deepest excavations had to be made on lateral sides and on the northern part of open pit, and the lowest in the central part of the open pit. The most complicated works in execution of the open pit were on the north part, where the design predicted cutting under the existing traffic line, Pomerio St. (cut "North") and by the existing accommodation building Pomerio St. No.19 (cut "East").

On the cut "North", a hill of the existing traffic line on Pomerio St. is on +24.00 m a.s.l. The south part of the traffic line is secured by stone retaining wall up to 7.0 m height founded on a terrace on +17.00 m a.s.l.

Similar problem appeared also on the north part of the cut "East". An existing accommodation building, of 6 stories, was founded on the +17.00 m a.s.l. and by which, an excavation on the +3.20 m a.s.l., was predicted. In the other parts of the construction, designed solutions were less complicated due to lower heights of cuts and a larger distance of the construction from the edge of the excavation.

A total height of the cut "North" towards Pomerio St. is 21 m. Geotehnical profile consists of an road fill embankment in the upper part as well as a rock mass in the base. Strength of a rock mass was determined according to the empirical strength low for the rock mass with RMR=34 (Hoek, 1994; Hoek et al., 1995) to the excavation depth of 9.00 m (the +6.50 m a.s.l.), and for deeper with RMR=56, and with the value of uniaxial compressive strength of σ_c =50 MN/m^2. Depths of particular weathered zones of rock mass were determined from results of geophysical surveys.

Stability analysis for a total cut made for the purpose of achieving a required security factors, showed that there is a need for additional secure of the cut in a rock mass by the self-drilling rock bolts of nominal bearing capacity 500 kN, and calculated bearing capacity 100 kN/m', 16.0 m length, in the distance of 4.00 m, in 8 rows as well as the self-drilling rock bolts of nominal bearing capacity 880 kN, and calculated bearing capacity 180 kN/m', 12.0 m length, in the distance of 4.00 m, in 2 rows. Shift of rock bolts loading on a wider area, was predicted by execution of reinforced sprayed concrete in two layers, each 5 cm thick and adequate grid structure, Fig. 1,2.

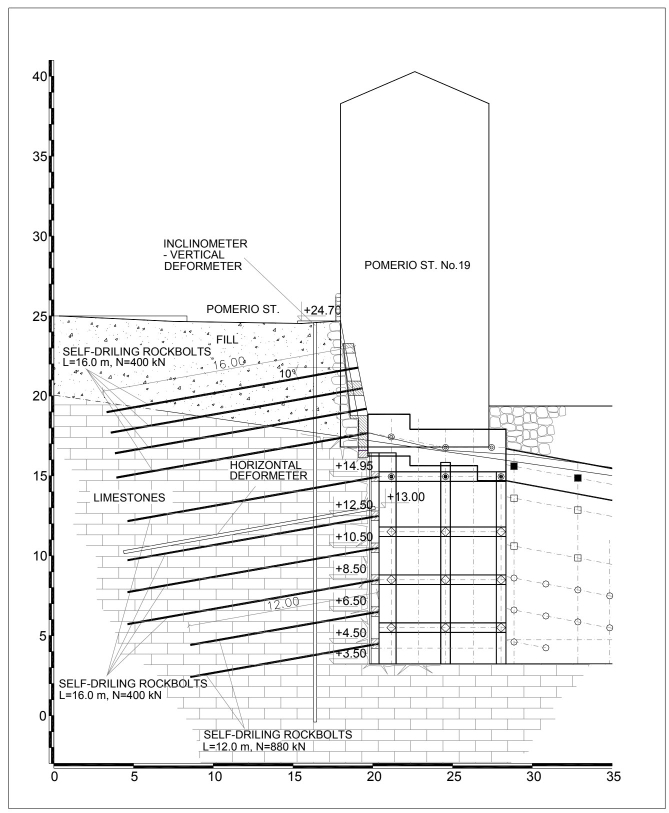

Fig. 1. Cross-section of the cut "North", on a calculated and measured profile

Analysis were performed for failure in a rock mass and for circular slip plane by methods of equilibrium analysis according to Spencer (Spencer, 1967) and Bishop (Bishop, 1955) with a program package *Slope/W, GEO-Slope* (GEO-Slope Int., 1998a).

For acquired geometry of reinforcement, stress-strain analysis were performed by a program package Slope/W, GEO-Slope (GEO-Slope Int., 1998b) by a finite elements method and by FLAC (Itasca, 1995) by finite difference method. In performed stress-strain analysis for rock mass, elastic-plastic model of rock mass behavior was used. Values of Young's modulus, which were obtained by a correlation with RMR classification of rock mass, and equivalent values of parameters of Mohr-Coulomb strength criteria (Hoek et al., 1980), were used for analysis. Excavation in six phases, each of 2.0 height, was analyzed. By the end of each single phase of excavation, rock bolts were implemented. Predicted values of displacements were determined by stress-strain analysis, and were based on estimated parameters of strength and deformability of rock mass.

Fig. 2. Cut "North" and "East", in an excavation phase of the bottom of the open pit

In other parts of the open pit, complicated requests to secure rock cuts were also dealt, particularly in the excavation under the building Pomerio St. No. 19, Fig. 3.

On the south part of the open pit, with lower height of rock cuts, usual methods of reinforcement of rock mass by rock bolts and multi-layered reinforced sprayed concrete, were used, Fig. 2,3.

WORKS EXECUTION

During the works execution on the excavation and insuring a stability of open pit walls through designer's supervision of construction works, an active design procedure was established.

A measuring, observing and monitoring system for the substructure system behavior was established. This enabled to obtain the data necessary for the stress-strain back analysis of the real behavior of excavated rock mass as well as reinforcement system. An active design procedure was established which made possible changes required in the rock mass reinforcement system in cuts. A designed primary reinforcement system of rock mass was applied.

Fig. 3. A view of the open pit during the execution

The monitoring and observing system included observations of a geodetic marks mesh, which were set successively with works execution, on totally eight geodetic control profiles as well as measurements of displacements on two vertical inclinometers-extensometers (deformeters) and three horizontal extensometers (deformeters) which were set on locations that enable observation of cuts during the works execution. Geodetic observations as well as measurements of displacements on inclinometers and extensometers were performed by phases, according to calculated phases of excavations. A testing of rock strength was performed (ISRM, 1979; ISRM, 1981) on samples, which were taken from the excavated material.

Works execution on cut "North", as the most complicated geotehnical contruction of the open pit, were performed by excavation in phases, in longitudinal stories of 2.0 m height and a successive construction of a grid support system reinforced by a self-drilling rock bolts from top to bottom of the excavation. Performing of stress-strain back analysis, based on the measured deformations and performed tests of bearing capacity of rock bolts, enabled observation and prediction of rock mass behavior in cut, in the future phases of excavation.

Designed works on the cut "North", were performed with the minor interventions in secondary and tertiary reinforcements (Hoek at al., 1997) in the support system within designed measures of rock mass reinforcement. Primary reinforcement was doubled in the area of flysch.

Already after the starting excavation phase in that part of the pit it was obvious that the rock base is in significantly poorer condition than it was presumed on the basis of the geotechnical investigation works in the contact zone of limestone rock mass and flysch. The investigation works quite precisely established the position of the fault between the limestone material and flysch rock base. The fault zone is very wide, thus influencing the poor rock quality in the limestone area as well as in the flysch area. The limestone rock mass can be described as extremely crushed and carstified, with great amount of wide cracks filled with high plasticity clay. Flysch deposits are constituted of completely disintegrated sandstone deposits loosely bonded sand particles with limestone blocks. It was very difficult to define the parameters of this deposits, for the purpose of geostatic back analyses; deposits being classified as difficult terrains: hard soils–soft rocks (Hoek et al., 1998; Marinos et al., 2001). After the excavation, an RMR rock mass classification was made for the deposits based on the results from the engineering-geological mapping of the cut and laboratory testing of the rock mass. For the extremely crushed and carstified rock mass an RMR=28 was estimated (GSI=23) (Hoek et al., 1997), and for the flysch deposits RMR=25 (GSI=20) (Marinos et al., 2001). The strength of the rock was determined by the PLT test in limestone (ISRM; 1985) σ_c=50 MPa, and estimated for the flysch deposits according to the recommended values (Hoek et al., 1998; Marinos et al., 2001) σ_c=5 MPa. By the categorization of the deposits, following parameters have been assigned to the flysch deposits: c=15 kN/m^2 and ϕ=34^o.

During the excavation of the last level, from elevation +5.50 to +3.50 m, there were some organizational problems on the Contractor's account (Arbanas at al., 2003). The last excavation level has been left without reinforcement substructure constructed for 5 days, and repeated demands coming from the designers and supervision engineer regarding the necessity and urgency to construct the substructure (or fill the excavation) have been ignored by the contractor. Adding to that, since there was no dewatering made at the bottom of the excavation and great amount of rain fell, the water level by the very slope of the cut rose to the +5.00 m level. All that resulted in occurrence of unexpectedly great deformations on the cut "West", measured in the horizontal deformeter, but also in the, until then absolutely still, vertical inclinometer. Deformations measured in the horizontal deformeter pointed that a deformation occurred in the soil outside the rockbolt-bonding zone of 9.0 m, which led to the conclusion that the overall stability of the slope has been endangered. These deformations have spread under the existing building in Pomerio St. No. 21, therefore endangering its stability too.

Right after these deformations have been determined, the designer and the supervision engineer have ordered the excavation to be filled up to the +10.50 m level, increasing the normal strains at the excavation foot in this way as well as the additional horizontal loads on the executed cut. These actions have stopped further progress of the deformations on the cut, as it was acknowledged by the measurements.

The new analyses of the slope stability have been made, which were used at first to determine the strength parameters on the cut after these deformations using the back analyses. For that way determined strength parameters stability analyses have been made and new reinforcement substructure systems defined. Stable reinforcement systems demanded the construction of the anchors reaching out of the occurred-deformations-zone– additional self-drilling rock bolts with bearing capacity of 500 kN at 3.0 m spacing, 16.0 m long in the upper part of the slope and 12.0 m long in the lower part, have been designed. The additional layer of sprayed concrete 5 cm thick has strengthened the existing slope reinforcement made to transfer the forces unto the cut, reinforced with one mesh. These procedures were undertaken in levels, construction of the reinforcement system and the excavation of the placed fill, until designed bottom elevation of the open pit was reached. Measurements during these works determined minimum deformations, which points to the adequate selection of the reinforcement system that assured the cut under construction secure (Arbanas at al., 2003).

RESULTS OF PERFORMED BACK ANALYSIS

Back analysis indicated some variations of usual standard procedure of designing the security of rock cuts reinforced by rock bolts from real behavior of *in situ* made constructions. That is primarily referring to a magnitude of real deformations in the limestone rock mass comparing to values calculated on the base of recommended values of deformation characteristics, which are based on a corelation with values from rock mass clasification (Serafim et al., 1983; Hoek et al., 1980; Bieniawski, 1979). All proposed calculations gave higher values of Young's elasticity modulus for rock mass comparing to values obtained by back analysis that is based on a measured displacements during the excavation.

For the measured and calculated profile on the cut "North", stress-strain analysis were performed in phases, for the excavation and implementation of rock bolts by the end of each phase. Deformation characteristics of rock mass were determined for each store of the excavation, based on a correlation with RMR classification of rock mass for each store (Hoek et al., 1997). Strength of the rock mass was determined by laboratory testing of rock samples from each subject store. Calculated deformations, obtained by stress-strain analysis, reach the maximum value of 0.50 mm, Fig. 4 (Arbanas, 2002).

Measured values of real displacements are significantly higher than those obtained by calculations. Based on the measured values of displacements on the horizontal deformeter on the cut "North", stress-strain analysis were performed, which determined average values of deformation characteristics of rock mass by a single storey (Arbanas, 2002). Maximum displacements measured on deformeter reach 6.0 mm and the largest displacements are on the top of the cut and are approximately 8.0 mm large, Fig. 5.

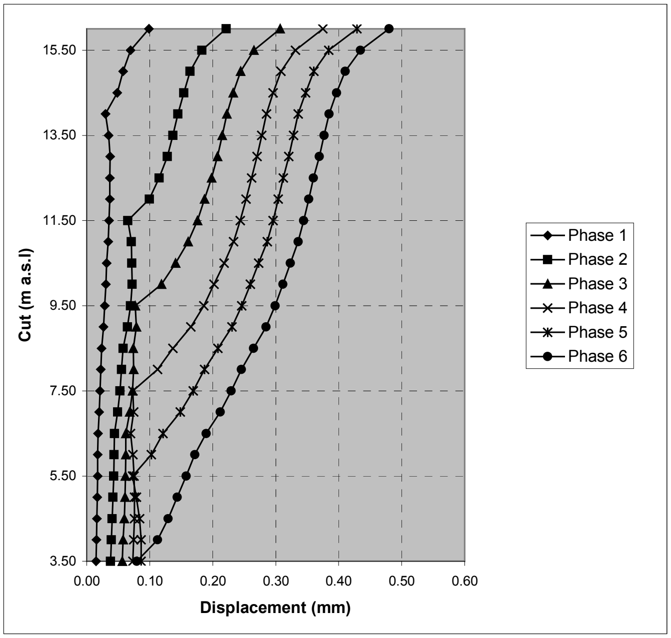

Fig. 4. Diagram of calculated horizontal displacements on the cut "North" (Arbanas, 2002)

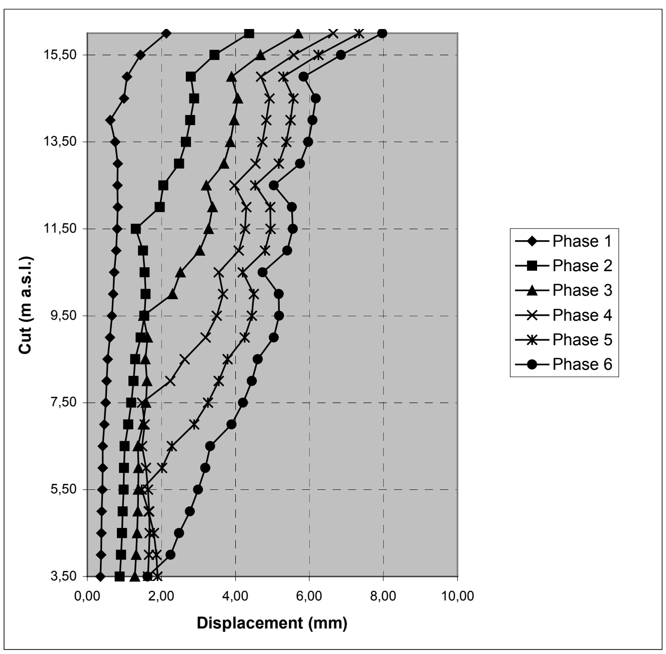

Fig. 5. Diagram of horizontal displacements on the cut "North", obtained by the back stress-strain analysis (Arbanas, 2002)

Back stress-strain analysis resulted in values of Young's elasticity modulus for limestone rock mass, that was 20 and more times lower then those obtained from correlations with clasifications of rock mass (Hoek et al., 1997). Those differences are most likely the result of inadequate correlations in domains of lower values of RMR clasification of rock mass because of a small base of measured data in that area.

Maximum displacements, which were much higher than those predicted by stress-strain analysis can't activated calculated forces in rock bolts. As it was pointed out earlier (Serafim et al., 1983; Hoek et al., 1980; Bieniawski, 1979), existing correlations for the rock mass with low clasification values (RMR<50) and low values of strength (σ_c<100 MPa), are probably be more advanced in future. Future development of those correlations for very fractured rock mass, with low strength, such as limestone, should be based on the large base of data, obtained by a back analysis from in situ measurments.

CONCLUSIONS

On location Zagrad in Rijeka, in the center of urban area, a construction of garage-living-business complex "Zagrad", strated. In the first phase of the construction, works on excavation and security of open pit were made.

The open pit was made in the complex geotehnical conditions, right by the existing traffic lines and accomodation buildings. To secure the cut in the rock mass, reinforcement of rock mass by rock bolts and adequate supporting systems, were used. During the work execution, and throughut the geotechnical supervision, an active designing approach was applied.

Performed analyses indicated a significant difference in values of predicted and measured deformations. The significant problem is a use of correlation between rock mass clasification and deformation characteristics, for which measurments indicated lower values. Existing correlations for the rock mass with low clasification values (RMR<50) and low values of strength (σ_c<100 MPa), are probably be more advanced in future. Future development of those correlations for very fractured rock mass, with low strength, such as limestone, should be based on the large base of data, obtained by a back analysis from in situ measurments.

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