Applicability of the RNK-method for geotechnical 3D-modelling in soft rocks

Applicabilité de la RNK-méthode pour la modélisation géotechnique en 3D en roches tendres

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ABSTRACT: The RNK-method or the Reference Level of Correlation method represents a procedure for spatial engineering-geological and/or geotechnical modeling, that was tested on many landslides in Croatia. The method gives the opportunity of differentiation of minimum shear strength zones, zones of different hydraulic conductivities, and zones of various soil densities. The application and verification of the RNK-method in soft rock formations found on the landslide area in Gorica Svetojanska (Croatia) is presented. The presentations providing the full set of relevant information needed to develop representative geotechnical profiles are also shown. The established geotechnical sliding model is verified by measurements of lateral movements in the landslide area and by results of corresponding stability analyses

RÉSUMÉ : La RNK-méthode (méthode du niveau de corrélation de référence) représente une procédure de modélisation spatiale en génie géologique et/ou géotechnique, qui a été testée sur plusieurs glissements de terrain en Croatie. La méthode permet la différenciation des zones de la résistance de cisaillement minimale, des zones des conductivités hydrauliques différentes, et des zones de densité du sol diverse. L'application et la vérification de la méthode RNK aux formations rocheuses tendres, trouvés sur un site de glissement de terrain á Gorica Svetojanska (Croatie) sont présentées. On présente aussi un ensemble complet d'informations pertinentes pour développer les profils géotechniques représentatifs. Le modèle géotechnique de glissement établi est vérifié par les mesures de mouvements latéraux dans la zone de glissement, et par les résultats d'analyse de stabilité correspondante.

KEYWORDS: RNK-method, plasticity index, shear strength, slope stability, spatial geotechnical model.

1 INTRODUCTION

1.1 *The site description*

The village Gorica Svetojanska is located in hills area in north-western part of Croatia. In last several years the intensive cracking of the walls of local church has been observed. Also, the soil movements at the slope with graveyard down the church have been noticed, as well as damages of the small mortuary structure.

The church of St. Anastasia (St. Ana, "Jana" in local dialect) is situated at the plateau of narrow ridge dominating the nearby valley (Figure 1). The church at this position is mentioned in historical parish records from second half of 18th century. It was several times reconstructed and strengthened after damages caused by stronger earthquakes in late 19th century.

Figure 1. The St. Ana church with graveyard.

1.2 *Local conditions*

The site is in seismically active region and in Figure 2 the frequency of earthquakes (with I > 4º) in last 200 years is shown, supporting the parish records.
The seismic intensities at the church location have been estimated by common attenuation function compiling the catalogue records of earthquakes with epicentres in radius R = 75 km from the site (GZ, 2005).

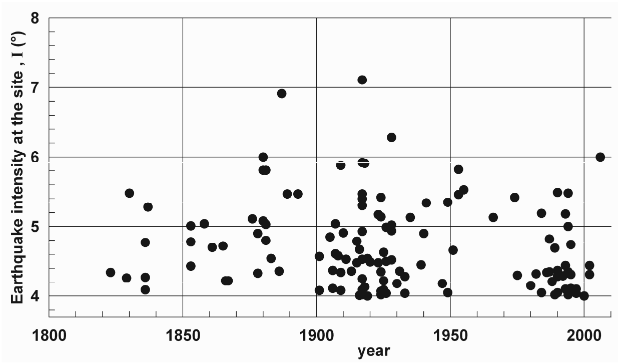

Figure 2. The frequency of moderate and strong earthquakes at the site

In geological profile, generally, the ridges and hills in the vicinity have the less permeable soft rocks and clayey soils in upper part, and older, permeable aquifers in lower part of profile. The aquifers are recharging at higher elevations, producing artesian or sub artesian groundwater pressures at the village site. Also, in the vicinity, the mineral water is commercially extracted and bottled.

The complex investigations at the location have been made, including borings and sampling, laboratory tests, water level measurements and monitoring of church wall movements.

The thorough engineering geology investigations were also performed, and, in order to obtain reliable geotechnical model of landslide, the so-called RNK method was used.

2 RNK METHOD - FUNDAMENTAL NOTIONS AND BASIC DEFINITIONS

The RNK method (RNK-the acronym in Croatian language) or the *Reference Level of Correlation Method* (Ortolan 1996) is a fully developed method for engineering-geological and geotechnical modelling. It is primarily intended for the landslide recognition and the analysis of the slope stability of soils and soft rock formations. However, the “sedimentation fingertip” obtained by geotechnical correlation column can be also used for reliable association of other test results in clayey sloppy profiles (Ivsic et al., 2005)

The RNK (Reference Level of Correlation) is defined as an unequivocally recognizable and visually identifiable (or graphically defined!) bedding plane or any other reference plane within a structural feature, in relation to which an altitude of all studied profiles can be unambiguously defined, with individual point analysis of any material property. Such plane is a part of a single vertical lithostratigraphical i.e. engineering geological and/or geotechnical sequence (engineering-geological and/or geotechnical correlation column).

The importance of correlation for the slip-surface and/or slip-zone determination is emphasized by Ortolan (1990).

The plasticity index has proven to be a reliable strength indicator for cohesive materials (Ortolan 1996, Ortolan & Mihalinec 1998, Ortolan et al., 2009). The highest values of plasticity index, but also the liquid limit, correspond to the lowest expected values of friction angle. This fact allows a new approach to exact geotechnical modelling. Therefore, testing of Atterberg plasticity limits on point samples can be recommended for the identification of zones with lowest shear strengths. The sample length should not exceed 10cm (sometimes it should be aslittle as several centimetres, and even several millimetres). The sampling interval of 0.5–1.0m is usually considered sufficient.

The correlation between the plasticity index and angle of internal friction is given in Figure 3, as developed by various authors, systemized by Ortolan & Mihalinec (1998) and enriched by new carefully obtained data.

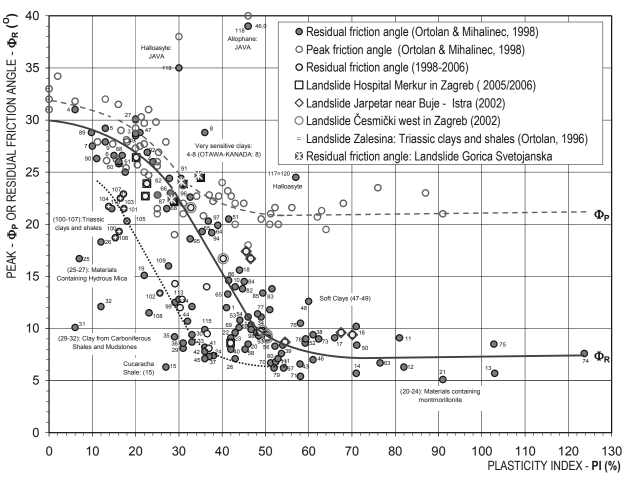

Figure 3. Correlation between index of plasticity and angle of internal friction – both peak and residual.

The following supporting documents are most often used in the study of landslides: general geological map of the wider area under study, geotechnical correlation column, and engineering-geological map with slip-plane contour lines and with clearly delineated slip areas and hydro-isohypses or hydro-isopiestic lines at the slip-plane level (Ortolan 1996, 2000).

The *geotechnical correlation column* is a consistent engineering-geological and/or geotechnical soil model (design cross section) in which adequate parameters (defined in laboratory or in situ either by point method or continuously) can reasonably be allocated to every defined layer (and portions of such layers) along the entire height of the vertical sequence of formations covered by the study. From such geotechnical correlation column we may in principle differentiate zones of minimum residual shear resistance, with their thicknesses and continuities, but also layers with different moisture content, hydraulic conductivity, natural compaction, compressibility, etc. The engineering-geological and/or geotechnical correlation column of an analyzed area is the "key" to the interpretation of overall engineering-geological and/or geotechnical relationships in a required number of profiles selected at will for 2D and spatial analysis, which is especially significant in 3D analysis of stability.

The consistent use of the RNK-method in the period from 1995 to the present day has resulted in the elaboration of three-dimensional geotechnical models for some fifty landslides. In all of these cases the following parameters were successfully defined: sliding body geometry, pore pressures and shear strength parameters for materials along zones of minimum shear resistance. In combination with existing topographical documents, this enabled accurate stability analyses and definition of optimum improvement procedures. The Podsused landslide may be described as one of the most complex urban landslide projects in the world (Ortolan 1996, 2000). It is precisely on this project that the RNK-method has been developed in full detail, and the reliability of the model was confirmed with photogrammetric measurements (Ortolan et al. 1995) as well as with three-dimensional stability analyses (Mihalinec & Stanić, 1991).

Most of the studied landslides have been stabilized, in all cases with great success, and the supervisory work conducted during remedial works provided positive feedback information about the correctness of adopted engineering-geological and geotechnical landslide models, (e.g. at the Granice landslide; Jurak et al., 2004), and about reliability of the engineering-geological and geotechnical correlation column (design cross section). On some projects the reliability of the model was checked and confirmed by appropriate inclinometer, piezometer and benchmark measurements.

3 DESCRIPTION OF THE LANDSLIDE AND GEO-TECHNICAL PROPERTIES OF MATERIALS

The topographic presentation of the neighboring terrain in Gorica Svetojanska with the contour of the landslide is given in detailed engineering geology map of the area (Figure 4). Results of laboratory and in situ investigations, presented in form of geotechnical correlation column are presented in Figure 5. Plasticity chart with encircled critical geotechnical zone-2 is presented in Figure 6. Formations found on the landslide (calcitic clays and clayey marls) date back to the Pontian**.**

4 ANALYSES

4.1 *Wall movements*

The investigation program included the measurements of relative rotation of church walls using several horizontal and vertical tilt meters, and, also the change of crack widths during monitoring period (originally found cracks were 15-20mm wide). The particular results are shown in Figure 7.

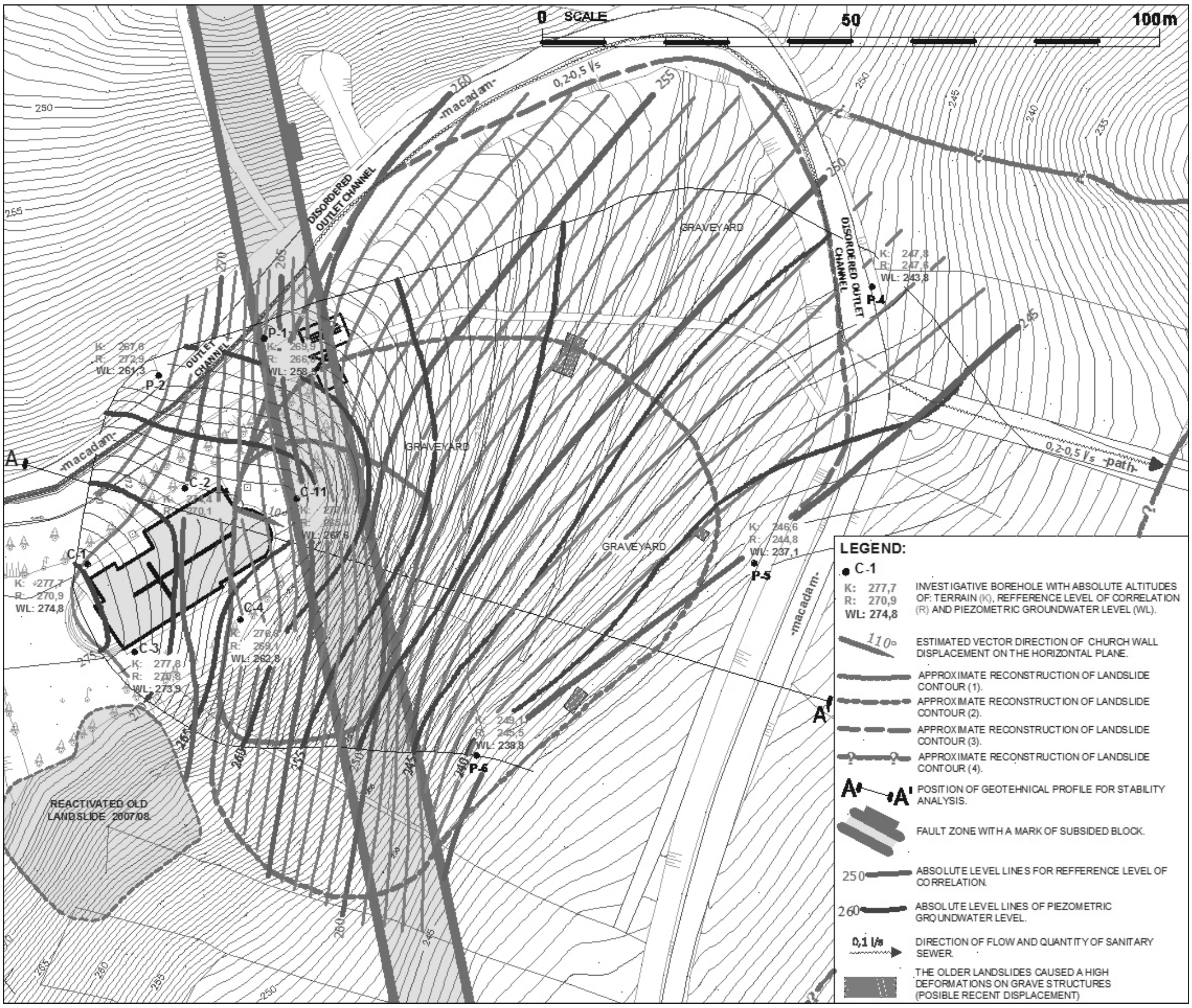

Figure 4. Detailed engineering geology map of the investigated area

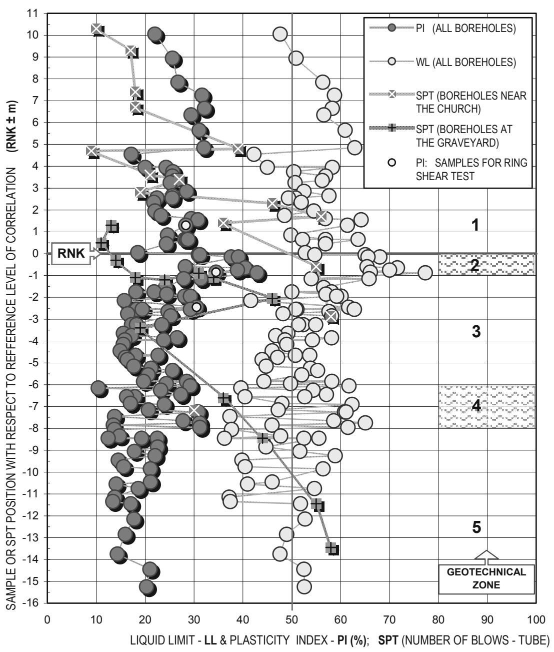

Figure 5. Geotechnical correlation column of the landslide.

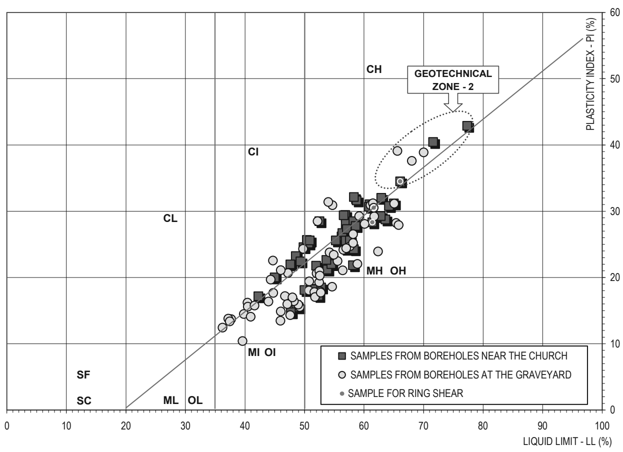

Figure 6. Plasticity chart of materials from the landslide. The encircled zone contains samples from preferred slip-zone

The unexpected "swaying" of eastern part of church was recorded (i.e. the movements of whole church block had alterative directions). This has been confirmed by independent records in horizontal and vertical tilt meters on neighbouring east and south wall, also accompanied with relative closing or opening of cracks.

The ground water levels were not measured in the same frequency, but the collected data indicate possible correlation of seasonal variations of water levels with the directions of wall movements.

The whole situation at the site can be described as unstable (labile) or at the limits of equilibrium. However, even the recent observations have shown that the net effect of "swaying" are slow irreversible displacements in direction of sliding, with cumulative displacements of 4 - 8 mm in last several years. Also, some cracks have opened at the western part of church which was "quiet" during the intensive monitoring period.

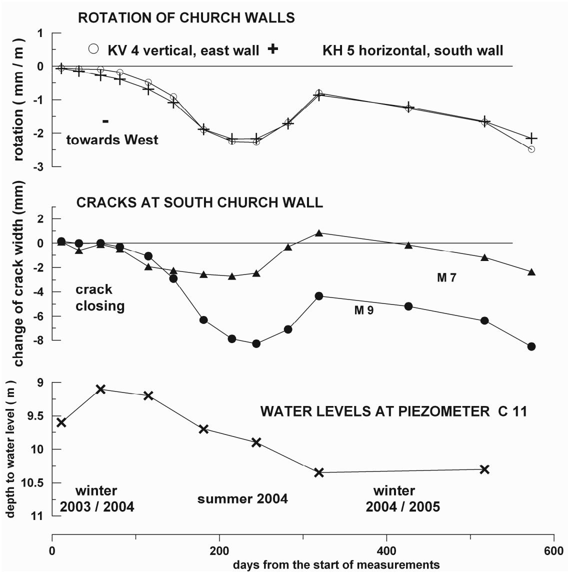

Figure 7. Monitoring of church wall displacements.

4.2 *Stability analyses*

The presented charts using the RNK method describe the landslide underground conditions and enable the construction of geotechnical models for engineering analyses in various cross-sections.

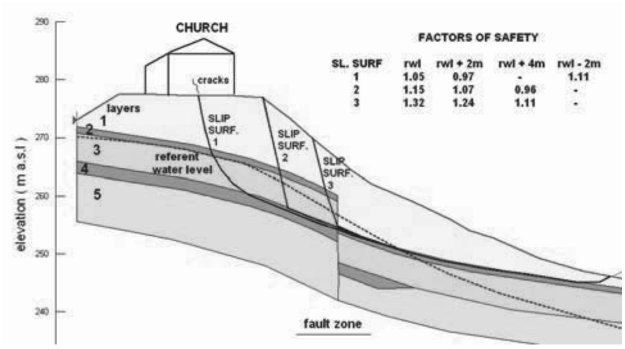

Figure 8. Model and results of stability analyses

The cross-section A-A (shown in Figure 4) which includes the church ridge and downhill slope was used for common stability analyses (Spencer limit equilibrium method). The layers corresponding to the geotechnical zones in Figure 4, with several slip surfaces in the layers of lowest strength are shown in Figure 8. The strength parameters taken in analyses were: cohesion c'=0 kPa (for all layers), and friction angle φ' = 28, 24, 30º (for zones 1, 2-4, 5, respectively). The minimal friction angle φ' = 24º corresponds to the results of ring shear test and correlation chart. The ground water levels were varied few meters from referent level to estimate the influence of possible variations.

This type of numerical modelling might be understood as too crude or too approximate for such a complex geologic situation at the site. However, the results (factors of safety) reveal that the established geotechnical model (with sequence of layers, friction angles, water levels) and slip surfaces respecting the established weakest zones, demonstrate the unstable conditions - by obtaining the safety factors near Fs = 1. Also shown is the expected trend of lowering of safety factor with rise of ground water level.

These rough estimates are demonstrated for static conditions, implying that even the low or moderate seismic activity can significantly reduce slope stability.

5 CONCLUSION

The interaction of engineering geology and geotechnics in the process of designing geotechnical structures is very important. In the study of landslides or stability levels of natural and artificially shaped slopes, unequivocal results can be obtained by the correlation of formations. This can be done by introducing the reference level of correlation (RNK-method) and by looking for the zone of minimum shear strength in the engineering-geological and geotechnical correlation column.

The creation of reliable geotechnical model is a center of this process, and it is crucial for the quality of the entire project. The correlation of the friction angle with the liquid limit or plasticity index is suggested for correct assessment of shear strength.

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