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A Novel Approach to the Modelling of Deep Complex Landslides with Several Sliding Planes

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INTRODUCTION

Formation of a spatial geotechnical model for a deep, multilayer landslide is an extremely delicate task. It requires successful definition of: sliding-body geometry, pore pressures along slip surface, and shear strength parameters for materials along the zones of minimum shear resistance. Several new procedures have been developed in the dissertation based on the example of the Podsused landslide in Zagreb, Croatia (*Ortolan 1996*). Their organized and consistent application method has been named the reference level of correlation (RNK method). A group of authors *(Jurak et al. 1996)* suggested inclusion of this landslide into the WLI (World Landslide Inventory) because of its complexity.

The exact geotechnical modeling strives towards a full correlation of layers, to obtain a meaningful vertical sequence. Based on layer correlation possibilities, it has been demonstrated (*Ortolan 1990, 1996*) that all results of geotechnical research in a relatively homogeneous environment may be interpolated into a correlational geotechnical column. This is obtained by means of reference layers, one of which is selected as the reference level of correlation - RNK (*Ortolan 1996*).

BASIC NOTIONS OF RNK-METHOD AND PRINCIPAL DEFINITIONS

The reference level of correlation (RNK) is an unequivocally recognizable reference plane, in the relation to which altitudes of all point test results for any material can be defined without ambiguity, in a single vertical sequence, i.e. in a correlational geotechnical column. It serves as a "key" to the explanation of overall geotechnical relations in space, in a required number of profiles selected at will. A more detailed definition of the RNK and the correlational geotechnical column is given by *Ortolan (1996)* and *Ortolan & Mihalinec (1998)*.

DETERMINING POSITION OF TEST RESULTS WITH RESPECT TO "RNK"

The general equation for determining the depth of test results with respect to the selected RNK value is:

$$\mathbf{d = RNK - D} \qquad (1)$$

The symbols used in equation (1) have the following meanings: **d** = "apparent" mean depth of the sample (or field result) from the observed borehole, as related to RNK (reference level of correlation), expressed in meters; **RNK** = RNK depth (in meters) in the observed borehole; **D** = mean depth of sample in the observed borehole (in meters). After calculation of **d** (m), the real position of the sample (regarded as perpendicular to bedding planes) - **d'** (m), with respect to RNK , can be calculated using the following equation:

$$\mathbf{d' = d \cos \alpha} \qquad (2)$$

At that, α is the inclination of layers (°) in the borehole (or outcrop) zone. If a visually recognizable reference layer can not be identified, the procedure of determining position of test results becomes somewhat more complex. The results (plasticity indices along the depth!) are first drawn in the form of soil profiles, on transparent oleates. After that, by overlapping oleates from individual boreholes (adjacent boreholes must penetrate in at least a portion of the same group of formations), test results are brought to a coinciding position (position of maximum correspondence), for portions of the same group of formations. The RNK is selected at will on one of the oleates and is then transferred, in the coinciding position, to other boreholes. After that, following definition of RNK depth for each of the boreholes, the results are united in one correlational geotechnical column. Examples of the correlational geotechnical column are presented in Figures 2 and 3. If we have the RNK position for at least three neighboring boreholes which are not situated in the same line, then the position of layers can be determined by identifying the plane through three points.

PLASTICITY INDEX - A RELIABLE SHEAR STRENGTH INDICATOR

The plasticity index has proven to be a reliable strength indicator for coherent materials (*Ortolan 1996, Ortolan & Mihalinec 1998)*. The principle involving angle of internal friction reduction with the increase in plasticity index, is valid for the peak angle, the full softening angle of friction and the residual angle of friction. For that reason, more frequent testing of Atterberg limits of plasticity on point samples is recommended for defining zones of minimum shear strength. The thickness of sampling intervals must not be greater than 10 cm (usually several cm, but sometimes as little as several mm). The sampling frequency of every 0.5 - 1.0 m is considered sufficient. The diagram of correlation between the residual and peak angles of friction on the one side, and the plasticity index on the other, has been proposed by *Ortolan & Mihalinec (1998)*.

USE OF PALMER METHOD FOR EVALUATION OF PORE PRESSURES IN SOIL

Ortolan (1996) has developed the method for defining relevant piezometric levels of ground water based on multiple piezometers and interpolation (extrapolation) of measurement results to the levels of determined slip planes. The possibility of extrapolating measured piezometric levels to the limit of permanent artesian ground water pressures has been demonstrated, in a deep artesian water-bearing band, which was proven to be the main generator of high pore pressures along the slip planes. In addition, the *Palmer's (1965)* procedure for balancing water in soil has proven to be an ideal basis and an objective criterion for realistic evaluation of pore pressures in soil. The mechanisms controlling soil filling with rainwater and deep penetration of such water (*Ortolan 1996)* are explained in more detail. It is demonstrated that they are the required and sufficient condition for the beginning of either fall or rise of piezometric water levels in soil, for the activation or cease of surface evacuation - RO, as defined by Palmer method for calculating components of water balance in soil *(Ortolan 1996)*.

INTERPRETATION OF REPEATED PHOTOGRAMMETRIC MEASUREMENTS

Repeated photogrammetric measurements are considered to be an excellent tool for measuring displacement on landslides. The advantages presented by this method in urban areas are presented from a significant time perspective (*Ortolan & Pleško 1992, Ortolan & al. 1995)*. The interpretation of photogrammetric measurements has undoubtedly pointed to the existence of multilayer sliding. After compilation of all measurement results, the size, mechanism and intensity of displacements along the deepest slip plane has been reconstructed, from the onset of sliding in 1963 to 1995 *(Ortolan 1996)*.

RESULTS OBTAINED BY RNK-METHOD

The result of the use of RNK-method is the spatial geotechnical model of Podsused landslide. The following features were successfully defined: sliding-body geometry, pore pressures along slip plane, and shear strength parameters for materials along the zones of minimum shear resistance. Although the progressive failure with uncontrolled displacement did not occur in the beginning, the study of tectonic features has shown that the residual shear strength parameters along the tectonic shear zone, formed earlier in shale type sediments, i.e. in thin intercalations of highly plastic calcitic clay, were relevant for the beginning of the landslide. The spatial stability analyses (*Mihalinec & Stanić 1991, Stanić & Mihalinec 1991)* have

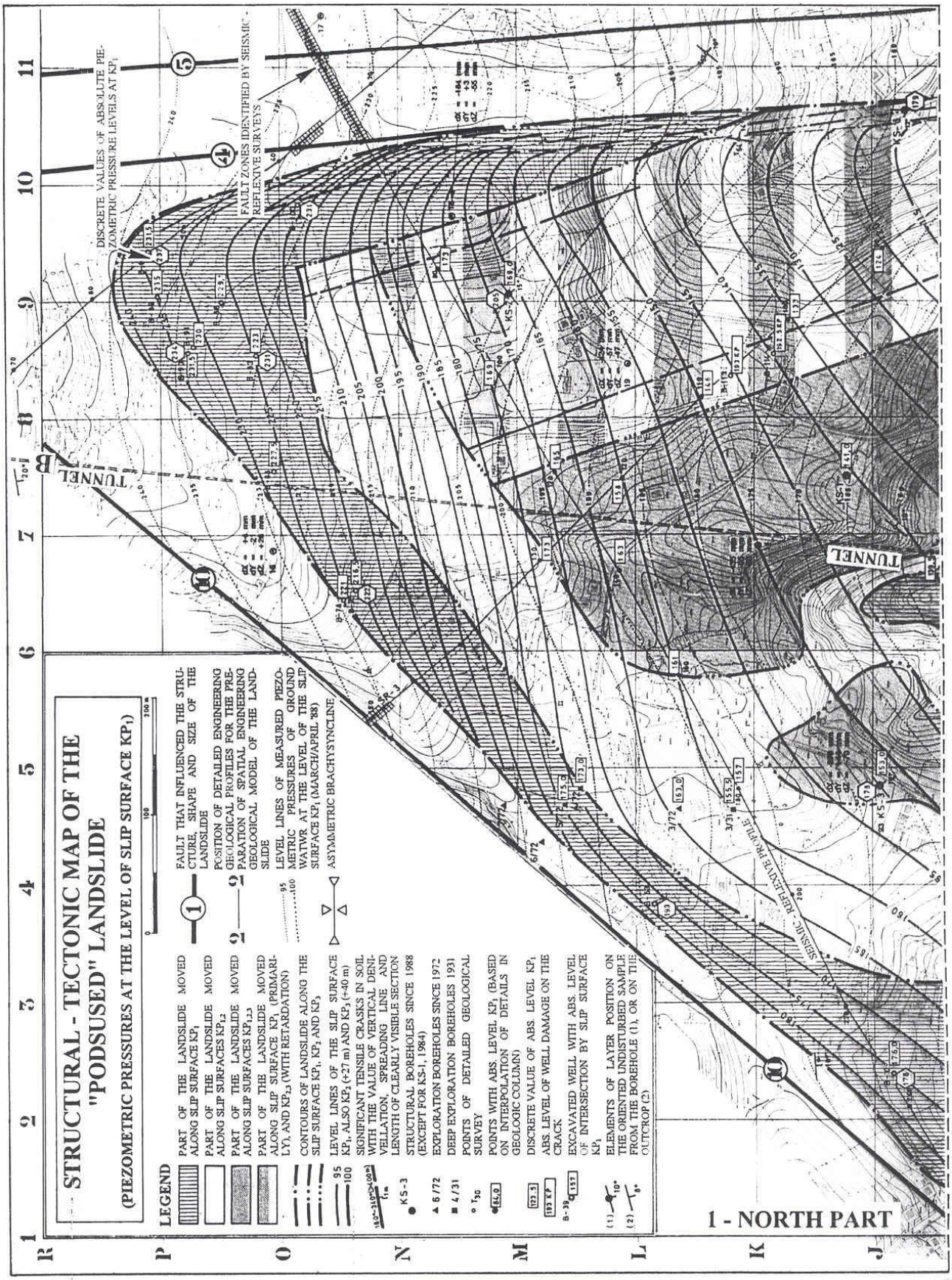


Figure 1 (part 1). Structural-tectonic map of the "Podsused" landslide in Zagreb - Croatia *(Ortolan, 1996)*

pointed - already in first iterations - to the accuracy of the geotechnical model, with residual shear strength parameters. The sliding occurred in a zone of about 1.2 square kilometers with about 500 structures, out of which approximately one hundred was either heavily damaged or destroyed (Figure 1). The characteristic hydrogeological section A-B is presented in figure 4.

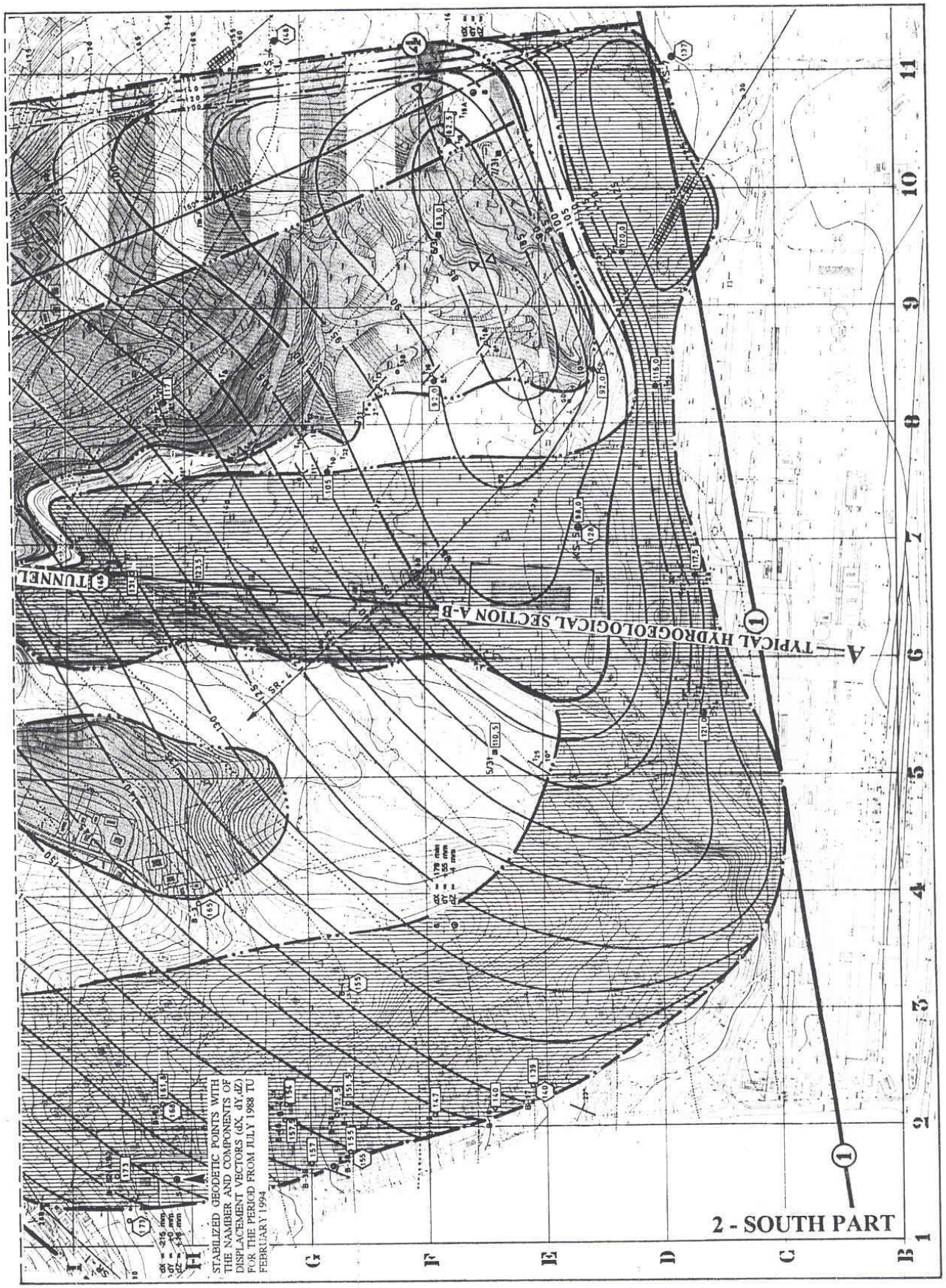
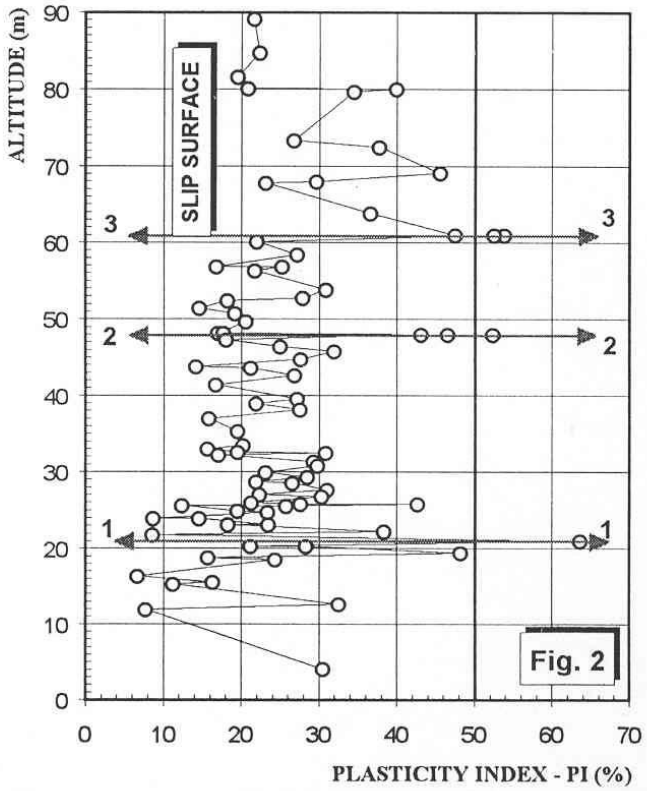


Figure 1 (part 2). Structural-tectonic map of the "Podsused" landslide in Zagreb - Croatia *(Ortolan, 1996)*

A detailed view of the landslide is presentedin figure 1. A detailed explanation of geotechnical zones including the procedure for determining zones of minimum shear resistance parametres is given by *Ortolan (1990, 1996), Ortolan & Mihalinec (1998)* and in figure 2.



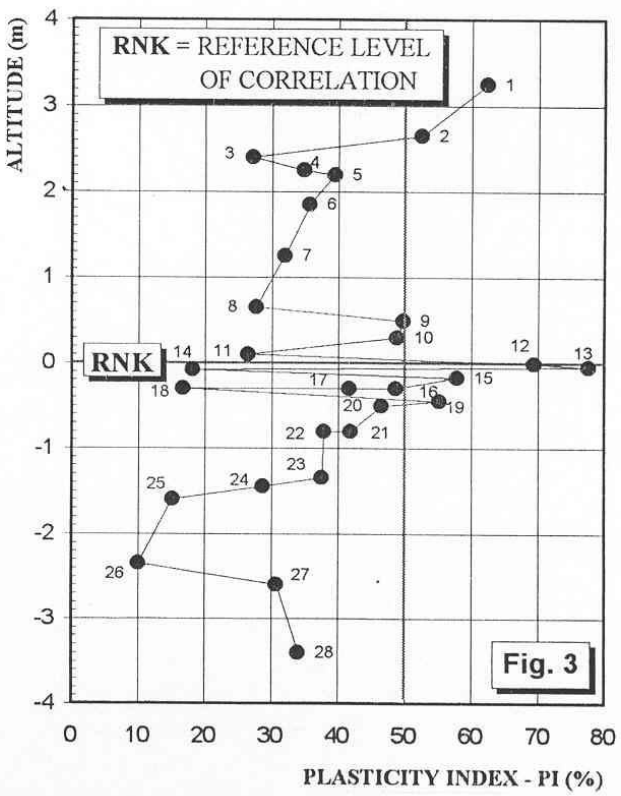


Figure 2. Variations of the plasticity index in the correlational geotechnical column for the "Podsused" landslide in Zagreb - Croatia *(Ortolan, 1996)*

Figure 3. Variations of the plasticity index in the correlational geotechnical column for the "Jagma - 2" landslide, near Lipik in Croatia *(Ortolan, 1998)*

It was established that the landslide occurred in three levels (*Ortolan & Pleško 1992, Ortolan 1996*). The deepest slip plane (KP_1) was formed in shale type sediments, while the intermediate (KP_2) and the shallow (KP_3) slip planes were formed in fine intercalations of highly plastic calcitic clay ranging from <1 mm to several mm in thickness. Maximum depths of the deepest, intermediate and shallow slip planes are 90 m, 63 m and 50 m, respectively. The total of about 32.6×10^6 cubic meters of rock mass is in movement along the deepest slip plane, while these values for the intermediate and the shallow slip planes are about 12.8×10^6 and 7×10^6 cubic meters, respectively. Slip planes are subparallel and they coincide with the position of layer discontinuities, while following the structural-tectonic elements of geological formations. The total displacement along the deepest slip plane (from 1963 to 1994) is 3.9 m. The corresponding total displacements along the intermediate and the shallow slip planes are 0.9 and 1.9 m, respectively. All three displacement values are related to the horizontal components of displacement vectors, which are approximately equal to spatial vectors, because of the low inclination of slip planes. From the time the cement factory first opened its doors in 1908 to 1963, about 2.1×10^6 m^3 of marl had been extracted from the bottom of the future landslide, while an additional quantity of 3.2×10^6 m^3 was excavated from the beginning of sliding to the time the factory was closed down in 1988. The diagram showing dependence of the magnitude and intensity of displacement on the quantity of material excavated from the passive zone of the landslide is a proof of the long-term linear dependence between the displacement and the quantity of marl extraction, while also showing that the marl excavation actually caused the landslide *(Ortolan 1996)*.

The following documents are indispensable for the study of most landslides (*Ortolan 1996*): geological map of the wider area of study, correlational geotechnical column (Figures 2 and 3), the map of level lines for slip plane with clear contours of sliding surfaces (Figure 1) and the map of level lines showing piezometric levels of ground water at the slip plane level (Figure 1). These documents guarantee the highest level of accuracy in sliding problem solving while also providing all necessary information for any selected number and position of detailed profiles needed in three-dimensional procedure of stability analysis.

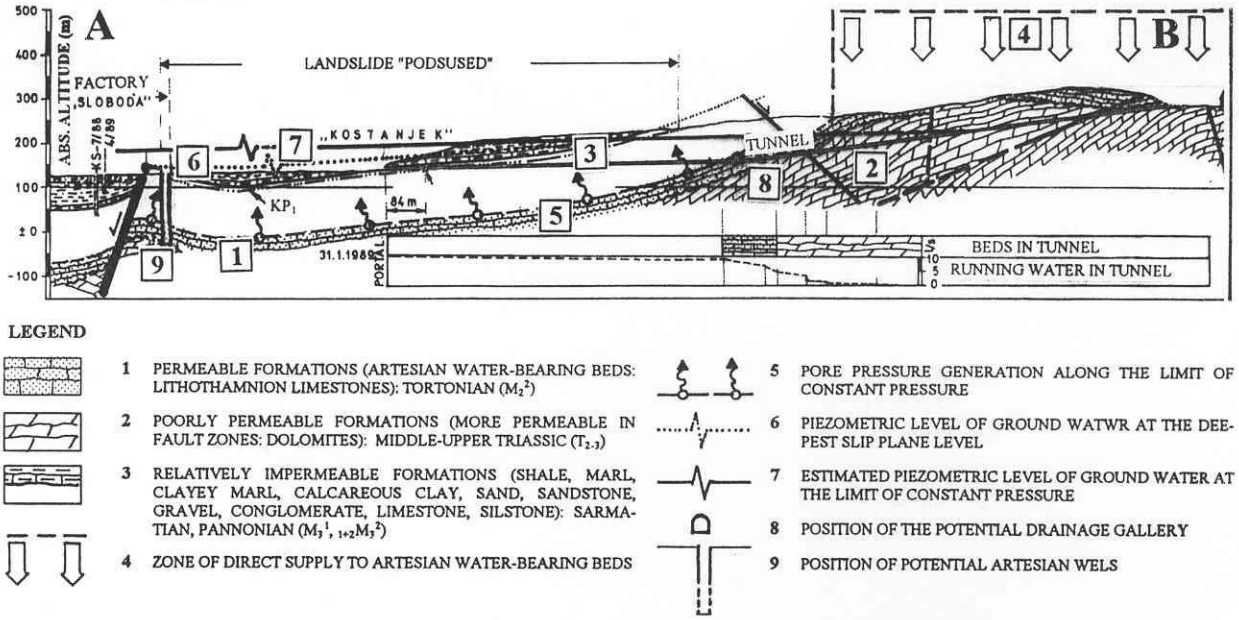


Figure 4. Typical hydrogeological section A-B for "Podsused" landslide in Zagreb-Croatia *(Ortolan, 1996)*

The results obtained show that the Podsused landslide may be repaired by restoring a part of the weight to the passive zone of the landslide, by draining the bottom landslide zone using artesian wells, or by realizing a drainage gallery at the entrance of the artesian water-bearing zone (from the existing tunnel - cf. Figure 4), or by any appropriate combination of these measures.

CONCLUSION

Unambiguous results can be obtained in the sphere of landslide improvement through correlation of layers by means of reference level of correlation (RNK method), by finding zones of minimum shear strength in the correlational geotechnical column using index of plasticity of material, and by means of Palmer's method for the evaluation of pore pressures in soil. The method is universally applicable in soft rock and in all types of soil.

REFERENCES

Jurak, V., Mihalić, S., Matković,I & Miklin,Ž. (1996): Data analysis of landslides in the Republic of Croatia: Present state and perspectives. *Proc. of the VII-th symposium on landslides/Trondheim/17-21 June 1996/ - Landslides*, 1923-1928, A.A. Balkema, Rotterdam, Netherlands.

Mihalinec, Z. & Stanić,B. (1991): Three-dimensional slide analysis procedure (in Croatian). *Građevinar* 9: 441-447. Zagreb.

Ortolan, Ž. (1990): The role of correlation methods in determining zones of minimum parameters of the shear resistance. *Proc. 6th Int. IAEG Congress:* 1675-1679. Rotterdam: Balkema.

Ortolan, Ž. (1996): The creation of a spatial engineering-geological model of deep multi-layered landslide on an example of the Podsused landslide in Zagreb (in Croatian). *PhD. Thesis*. Zagreb.

*Ortolan, Ž. (1999):*Engineering-geological report and geotechnical model of "Jagma-2" landslide (in Croatian). *RNK-Geomod*. Zagreb (unpubl.).

Ortolan, Ž. & Mihalinec, Z. (1998): Plasticity index - Indicator of shear strength and a major axis of geoteshnical modeling. *Proc. of the XI-th Danube-European conference on soil mechanics and geotechnical engineering/Poreč/Croatia/25-29 May 1998/ - Geotechnical hazards*, 743-750, A.A. Balkema, Rotterdam, Netherlands.

Ortolan, Ž., Z. Mihalinec, B. Stanić & Pleško, J. (1995): Application of repeated photogrammetric measure-ments at shaping geotechnical models of multi-layer landslides. *Proc. 6th Int. Symp. on Landslides:* 1685-1691. Rotterdam: Balkema.

Ortolan, Ž. & Pleško, J. (1992): Repeated photogrammetric measurements at shaping geotechnical models of multi-layer landslides. *Rudarsko-geološko-naftni zbornik* 4: 51-58. Zagreb.

Palmer, C.W. (1965): Meteorological drought. The US Department of Commerce, Research paper No 45, 58 p., Washington.