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# DEVELOPMENT OF DEVICE FOR MEASURING THE FORCE IN GROUND ANCHORS USING TRIZ METHOD

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**ABSTRACT:** *Prestressing ground anchor is very important structural element which is usually used during building process of much different kind of civil engineering structures: bridge piers, steel barrier wiles etc. Supporting constructions changes resulting from geological instability of rocks or weakening of anchor can have catastrophic consequences. It is therefore necessary that the load of supporting constructions, that are supporting prestressing ground anchors, be sufficient. Because of the importance for the stability of the objects to this issue is devoted special attention. In this paper is shown methodology of testing of prestressing force of ground anchor on arch dam of Grncarevo Hydroelectric Power Station. New device is developing for control of prestressing force using TRIZ method and their validation has been done by experimental testing.*
**KEYWORDS:** *ground anchor, prestressing bolts force, TRIZ method*

## INTRODUCTION

*Ground anchors are commonly used in civil and mining engineering. They function as temporary or permanent structural members to ensure the stability of various structural systems such as slopes, retaining walls, bridge abutments, tunnels, underground excavations, and reinforced concrete foundations [1]. They can be also used for the strengthening and rehabilitation of existing structures. Safety of arch dam of Grncarevo Hydroelectric Power Station (high 123m, width 440m) depends largely on stability of supporting construction of left downstream riverside which is stabilized with ground anchors (field of ground anchors) with 93 anchors which have length from 45m to 65m [2] and [3].*

*Figure 1: Field of ground anchors Grncarevo Hydroelectric Power Station*

*Permanent monitoring of prestressing force of ground anchor is necessary because of its great importance for structure stability. Eventual changes in supporting structures caused by geological instability of the rocks, or loosening anchorages anchors, can be detected on time, so possible consequences could be prevented.*

*Contractor, Austrian company Zollner-Polensky, during works, prescribed a methodology for periodic monitoring of the state of anchorages, by measuring the force in the ground anchor in the whole field of ground anchors [5]. Dimensions of existing device for measuring force in prestressing ground anchor were very large and unsuitable for use on dangerous ground, so that the measuring, which usually need to be performed 25-30 days, was carried out relatively rare. New device for measuring the force of prestressing in the ground anchors has been developed in order to increase safety of object by reducing the time interval between tests of prestressing force. This paper presents the methodology for testing of prestressing force in ground anchors, the development of a new device for the control of the prestressing force, as well as test results of prestressing force with a newly developed device.*

## METHODOLOGY OF MEASUREMENTS

*Ground anchors produced by Polensky & Zoellner have common structure, with conical anchorage and steel cord. Ground anchors have different lengths, from 45m to 65m. On the outer end of the anchor there is threaded screw Tr68x4. Tension force is achieved by nut twisting, which rests is on moving washer, which than rests on the immovable washer which poured in concrete base. During installation, the prestressing of the anchors was done in three steps, up to force of 210 t (2100kN).*

*Experimental determination of the prestressing force in ground anchors of Grncarevo Hydroelectric Power Station was measured according to the methodology prescribed by the producer of anchors. According to the above methodology, the tightening of an anchor is done by force on the free end of the anchor, until the moment of separation of nuts from a supporting mounting i.e., by the* *time when the intensity of tensile force reaches a value of anchor prestressing force (Figure 2). In Figure 2 with $\delta$ is marked clearance between the nut and the support.*

*The measurement of movement is performed during the loading of ground anchor, and measured is distance between the nut and fixed washer. Figure 3 shows the characteristic diagram of movement depending on the intensity of tensile force in ground anchor, on which can be clearly identify three characteristic phases of force during tensile of ground anchor:*

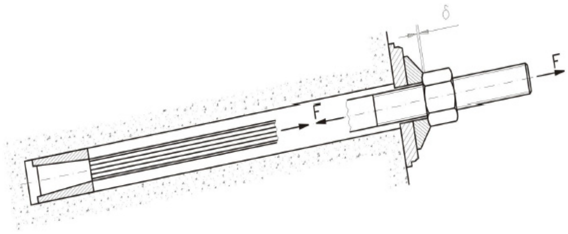


*Figure 2. Measurement method in ground anchors*

1. *Initial phase of stress*
2. *Phase where exist a linear dependence between force and displacement. In this phase, only stretching of the outer part of anchor occurs, i.e. the part of the anchor where exist the trapezoidal thread. Slope of the line represents the stiffness of the outer part of ground anchors, i.e. the trapezoidal thread.*
3. *Separation phase in which can be clearly seen a sudden increase in displacement while incensement of tension is small. In this phase, anchor is stretched throw its entire length because separation of nuts from immovable support has occurred. The slope of this line represents a stiffness of the whole anchor.*

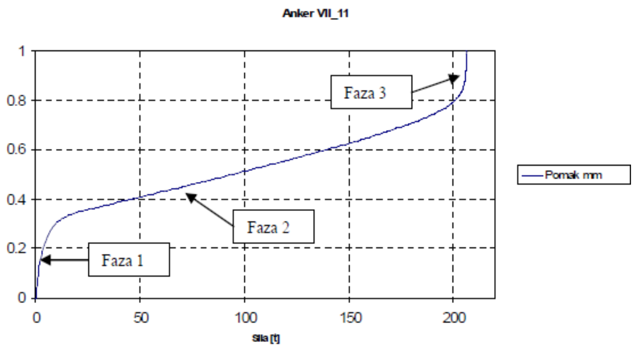


*Figure 3. Force diagram – prestressing of ground anchor*

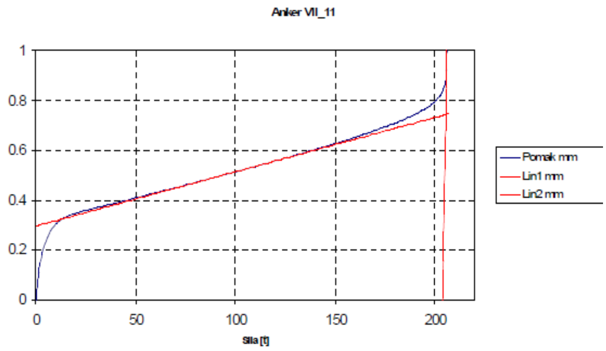


*Figure 4. Force diagram – prestressing force of ground anchor after regression analysis*

*Although in Figure 3 can be clearly seen the differences between anchor load phases, by direct readout from the figure is difficult to reliably determine moment of separation of nuts from immovable support i.e. determine the intensity of prestressing force in anchor. Figure 4 is made by implementing of regression analysis by drawing straights using method of least squares through the parts curve corresponding to the linear part of phase 2 and phase 3, respectively marked with Lin1 and Lin2.*

*Moment of separation of nuts from immovable support, in which the stretching force is equal to the prestressing force of the ground anchor, is taken to be in the intersection of these two lines. Methodology of experimental determination of the prestressing force in the anchor produced by company Zollner-Polensky, described above, was conducted using the measurement system shown in Figure 5.*

*The measuring device unit consists of an annular hydro-cylinder which through an adapter relies on a concrete support. Hydro cylinder is connected with the anchor via bolts on his backside. Measuring the force intensity in the anchor was performed indirectly, by measuring the pressure in the hydro-cylinder with a mechanical gauge with a visual readout. A moment of separation nut from washer is registered by means comparators hours. The results were visually read and enrolled in the diagram, in which the later graphical method of assessment was used to determine the moment of separation. By analyzing construction and measuring procedure using a device described above it can be observed several shortcomings, which are reflected in:*

1. *Annular hydraulic cylinder for load applying has very large size and large mass (more than 200kg), because of that, work in the field of ground anchors is extremely difficult and unsafe.*
2. *Hydraulic cylinder have a large volume, so a large quantity of oil is needed in order to effect necessary burdening anchor to the point of separation of nut from washer. Required flow of hydraulic oil requires the use of hydraulic pump unit, which measuring process in the field of ground anchors makes even more complex.*
3. *Measurement of forces in the anchor is performed indirectly by measuring the pressure in the hydro-cylinder with visual readout, which makes the measurements unreliable.*

*Because of these shortcomings of the existing measurement system, testing of all in the field of ground anchors lasted 25-30 days, and was conducted in relatively rare intervals. To increase the safety* *of the facility by reducing the interval between tests of prestressing force in ground anchors, there was a demand for development of a new device for measuring of prestressing force in ground anchors.*

## DEVELOPMENT OF THE MEASURING SYSTEM FOR EXPERIMENTAL MEASUREMENT FOR PRESTRESSING FORCE OF GROUND ANCHOR

*The introduction of innovative products, processes and services is a very complex procedure that requires the application of integrated development strategies that are based on modern systems, methods and processes [6].*

*TRIZ method is a modern method which is used for solving technical problems and contradictions, developed by Altsulera (G. Altshuller) in the USSR [6].*

*Construction of the model function and the correct formulation of the problem are the first steps towards the solution of technical problems using the TRIZ. After the formulation of technical problems and contradictions arising from technical problems with Altshuller`s matrix, which contains 39 principles for solving technical contradictions, the contradiction solutions are obtained. (Example: increase the volume and structure without increasing the weight of structure). Responses to the contradiction are offered by the principles which differ depending on the contradictions.*

*First step for overcoming the technical contradictions using TRIZ method is formulation of system function. Defined are known useful function and harmful function of system and they are mutually connected with relation (Table 1). Known functions and new introduced function of system are assigned suitably technological parameter for input in Altshuller matrix for solving of technical contradictions as it is shown in Table 2. In accordance with the selected technological parameters, from Altshuller matrix are set system characteristics (B↓) which are unallowed changed with change of characteristic (A↑) and based on that is chosen solving principle of technical contradictions from Table 3.*

*Table 1. Defining of functions and their relations*

| | | |
|---|---|---|
| ... known harmful function | ... causes... | harmful function... |
| large dimensions of annular hydro cylinder | ... causes... | large mass of load unit |
| large dimensions of annular hydro cylinder | ... causes... | great capacity of hydraulic aggregate |
| visual readout of measured device | ... causes... | unreliable measurement |
| visual readout of measured device | ... causes... | slow results obtaining |
| ... existing harmful function | ... causes... | new harmful function... |
| large mass of load unit | ... causes... | difficult manipulation on field |
| large dimensions of hydraulic aggregate | ... causes... | difficult manipulation on field |
| ... known harmful function | ... causes... | useful function... |
| large dimensions of annular hydro cylinder | ... causes... | high stiffness of the load system |
| large dimensions of annular hydro cylinder | ... causes... | relatively low work cylinder pressure |
| ... introduction of new function | | |
| automatization of results readout | ... introduction for reduction of... | unreliable measurement |
| possibility of load device disassembly | ... introduction for reduction of... | difficult manipulation on field |
| automatization of results readout | ... causes... | higher system complexity |
| possibility of load device disassembly | ... causes... | higher system complexity |

*Table 2. Assignment of technological parameters*

| Known function... | | ... suitable technological parameter |
|---|---|---|
| large dimensions of annular hydro cylinder | -> | 1. Mass of moving object<br>11. Stress and pressure |
| possibility of load device disassembly | -> | 36. Structure complexity |
| automatization of results readout | -> | 27. Reliability<br>39. Productivity |

*Table 3. Part of Altshuller matrix for concrete example*

| System changes that need to be improved (A↑) | System parameter that is unallowed changed (B↓) | 1<br>Mass of moveable object | ... | 27<br>Reliability | ... | 39<br>Productivity |
|---|---|---|---|---|---|---|
| 1 | Mass of moveable object | | | 3, 11, 1, 17 | | 35, 3, 24, 37 |
| ... | ... | ... | ... | ... | ... | ... |
| 11 | Stress and pressure | 10, 36, 37, 40 | | | | |
| ... | ... | ... | ... | ... | ... | ... |
| 36 | Structure complexity | 35, 26, 24, 37 | | 10, 13, 19, 35 | | 10, 14, 35, 37 |
| ... | ... | ... | ... | ... | ... | ... |
| 27 | Reliability | 3, 8, 10, 40 | | | | 1, 35, 29, 38 |
| ... | ... | ... | ... | ... | ... | ... |
| 39 | Productivity | 35, 26, 34, 37 | | 1, 35, 10, 28 | | |

*In table are marked principles 1, 3, 24 and 28 that are used during development of new system for measuring of prestressing force.*

*Based on these principles for solving technical contradictions, a new device has been developed for anchor tightening which is shown in Figure 6.*

*Measuring system consists of three short track hydro-cylinders which are attached with the anchor through the hydro-cylinder bracket which is built in the shape of a nut, which is then connected* *with the anchor by screwing at free end. Over adapter washers hydro-cylinder rely on fixed anchors washer. Extraction of Hydro-cylinder is performed by tightening of anchor bolts until the moment of separation. The pressure in hydro-cylinder is obtained with a two-stage hand hydraulic pump. Device is equipped with mounted electronic system for pressure and displacement measuring in hydro-cylinder, i.e. the distances between the fixed nut and washer, the electronic system is connected to a data acquisition system and portable computer. Diagram of anchor loading is monitored in real time and determination of the point of separation is done by numerical methods and it is fully automatic.*

*Table 4. Recommended principles for solving technical contradictions*

| | Principle description | application of a specific model |
|---|---|---|
| 1 | Principle of decomposition | applied to the new solution |
| 3 | Principle of local quality | applied to the new solution |
| 8 | Principle of a counter weight | inapplicable to the new solution |
| 10 | Principle of prior actions | inapplicable to the new solution |
| 11 | Principle of previously "soft supported" | inapplicable to the new solution |
| 14 | Principle of spherical similarity | inapplicable to the new solution |
| 17 | Principle of transition to more dimensions | inapplicable to the new solution |
| 24 | principle of mediator | applied to the new solution |
| 26 | Principle of coping | inapplicable to the new solution |
| 28 | Principle of mechanical system change | partially applied to the new solution |
| 35 | Principle of state of matter transition | inapplicable to the new solution |
| 36 | principle of changing phase transition | inapplicable to the new solution |
| 37 | principle of changing thermal elongation | inapplicable to the new solution |
| 38 | Principle of strong oxidizing agent use | inapplicable to the new solution |
| 40 | Principle of composite materials use | inapplicable to the new solution |

*Measuring and data acquisition system consists of:*

1. *Pressure sensor: HBM P8AP/500bar, accuracy 0.3%*
2. *Movement sensor: HBM WI/2MM-T, the measuring range ± 1 mm, 1% accuracy*
3. *Universal digital measuring amplifier: HBM Spider 8*
4. *Notebook computer for receiving and signal processing*
5. *Software for parameterization and data acquisition: HBM Catman AP*

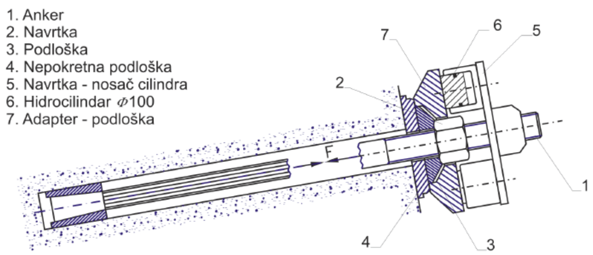



*Figure 6. New developed system (1. – ground anchor, 2. – nut, 3. – washer, 4. – unmoveable washer, 5. Hydro-cylinder, 7. adapter)*

*Figure 7. Developed device at field*

*The developed measuring system device has many advantages compared to existing, as measured by:*

1. *Reduced weight and dimensions of the measurement system*
2. *The system consists of several parts (three hydro-cylinders, adapter- washers and cylinders carrier), so the handling, transportation and installation is much easier while working in the field of ground anchors.*
3. *Due to small volume of hydro-cylinder, and therefore required small flow of hydraulic oil, it is not necessary to use a hydraulic pump with electric drive, which makes measurement process a lot easier and significantly increase productivity.*
4. *The reliability of measurements is increasing by introducing an automated measuring and data acquisition system.*

## VALIDATION AND CALIBRATION OF SYSTEM FOR MEASURING PRESTRESSING FORCE IN GROUND ANCHORS

*To make the developed system useful for measuring of prestressing force in ground anchors, it is very necessary to validate its features, and to do its calibration. Calibration procedure was performed on the test presses through the comparative method (Figure 8).*

*The system is set up in the press along with a massive steel plate and the reference force sensor. The test press is used as a frame for load receiving. As a reference force sensor was used force sensor type C6 with measuring range of 2 MN, accuracy class 0.5, produced by company Hottinger Baldwin Messtechnik.*

*Under the influence of pressure from hydraulic hand pump the pressure in the hydro-cylinder increases and thereby causes massive steel plates to lift off and apply pressure to the force sensor. Signals from pressure and force sensors were distributed in the measuring amplifier Spider 8 connected with notebook. Based on the recorded graph of dependency of force in function of pressure, and by using the regression analysis, a calibration coefficient was calculated. Figure 9 represents time record obtained during the calibration process, and in Figure 10 a p-F (Pressure-Force) diagram in shown with the results of regression analysis.*

*Figure 8. System calibration*

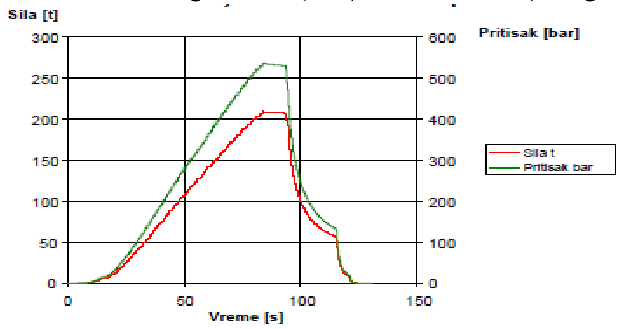



*Figure 9. Calibration of hydraulic system*

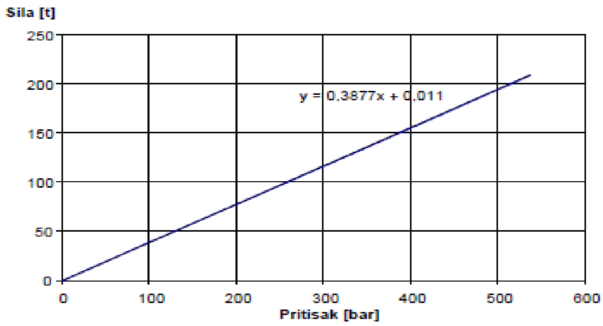



*Figure 10. Dependence of force and hydro-cylinder*

*The adopted force calibration coefficient is K = 0.39 whereas the F [t] = p [bar] x K*

*Validation of the system is carried out by measuring of anchor prestressing force at the site of Grncarevo Hydroelectric Power Station. Each ground anchor is tightened to the point of separation of nut from washer at the order of magnitude of one millimeter. Figure 11 shows the diagram of force in function of path of one of the anchors and automated procedure for determining the anchor prestressing force.*

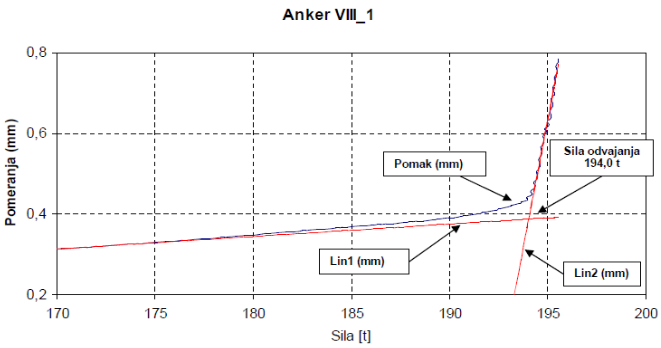



*Figure 11. Diagram force-path ofground achor VIII_1 and regression line, separation force is in point of intersection of Lin1 and Lin2*

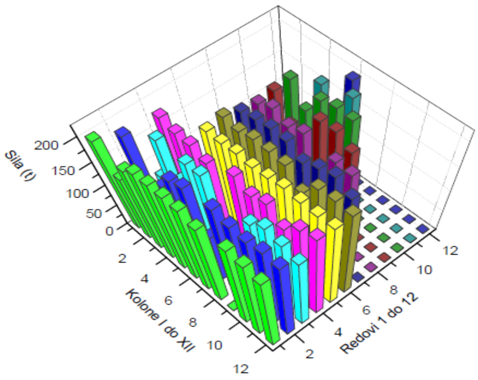
*Table T.5 presents the results of measurements on all of the processed anchors in the field of ground anchors. For a certain number of ground anchors it was not possible to conduct the measurement because of physical damage of the mechanical protection on anchors or because of inability to access anchors. These ground anchors are marked with X in the table.*

*Table 5. Numerical results of measurements of force in field of ground anchors*

| Column | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Row 12 | | | | | | 200.6 | | | | | | |
| Row 11 | | | | | 193.2 | 162.3 | 205.5 | | | | | |
| Row 10 | | | | 201.4 | 164.2 | 200.2 | 206.2 | 203.6 | | | | |
| Row 9 | | | | 198.8 | 154.9 | 144.5 | 201.8 | 203.1 | 185.2 | | | |
| Row 8 | | | | 193.9 | 204.5 | 191.2 | 199.5 | 154.5 | 188.6 | 185.8 | | |
| Row 7 | | | | 197.6 | 203.9 | 207.4 | 205.5 | 186.6 | 197.9 | 205.3 | 186.4 | |
| Row 6 | | | | 207.0 | 200.9 | 207.7 | 206.7 | 203.8 | 171.5 | 204.3 | 206.5 | 202.9 |
| Row 5 | | | | 200.8 | 199.9 | 202.2 | 198.4 | 201.0 | 205.8 | 202.0 | 200.7 | 202.2 |
| Row 4 | | 204.9 | 196.3 | 195.1 | 182.6 | X | 203.7 | 187.7 | 197.9 | 170.5 | 196.8 | 206.2 |
| Row 3 | | 107.0 | 204.0 | 144.9 | 202.6 | 204.2 | X | X | 179.5 | 199.3 | 190.5 | 179.3 |
| Row 2 | | 209.7 | 35.0 | 155.2 | 191.9 | 202.1 | 117.5 | 210.3 | 200.7 | 197.5 | 204.5 | 201.2 |
| Row 1 | 200.0 | 146.1 | 186.4 | 204.7 | 206.5 | 206.7 | 206.2 | 194.0 | X | 207.8 | 202.9 | 196.0 |

*Tabular presentation of force gives accurate but unclear information. On the pictures 11 and 12 graphical overview of measurement results is presented, where we can observed the zones of force declining in ground anchors in relation to the initial condition from dam construction period, when all the ground anchors been strained by force of 190 to 210 tons.*



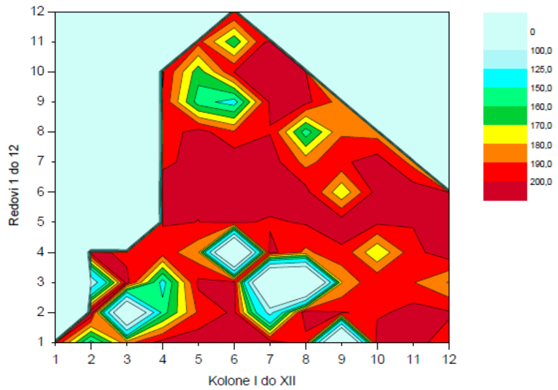




*Figure 12. Graphical 3D: force in field of ground anchor* *Figure 13. Control review of force in field of ground anchor*

*The measurement results obtained with new system are largely consistent with the measurement results obtained in earlier controls [4] thereby successful validation of the measurement system was carried out.*

## CONCLUSIONS

*Providing long-term stability of construction and mining structures is of great importance from the aspect of people safety, protection of property and environment. The objective in this work was problem analysis for securement of stability of arc dam at Grncarevo Hydroelectric Power Station using ground anchors. By application of TRIZ method, a new construction of system for measurement of force in ground anchors was developed, which have numerous advantages over existing systems. Functionality and effectiveness of the system is increased. The duration of measurements in the entire site was reduced from 20 to 25 days to 8 days, or reduced by factor of 3.*

*The data acquisition system with real time processing of measured results, and automatic calculation of the separation force based on the analysis of force / stroke made further speed up of the whole process and greatly increased the reliability of results in comparison with the previous method of instrument readings and visual interpolation of graphic results.*

*The results of measurements performed with the new system are largely consistent with the measurement results obtained with earlier controls [4], which confirm that, the new unit is suitable for the prescribed testing methodology.*

## REFERENCES

[1.] Burong Zhang, Brahim Benmokrane, Adil Chennouf, Phalguni Mukhopadhyaya, Adel El-Safty: TENSILE BEHAVIOR OF FRP TENDONS FOR PRESTRESSED GROUND ANCHORS, JOURNAL OF COMPOSITES FOR CONSTRUCTION, MAY 2001, pp. 85-93

[2.] D. Zubac, S. Petar, BEHAVIOUR OF FOUNDATION DURING THE TEST LOADING AND DISLOADING OF GRANCAREVO DAM, International Society for Rock Mechanics, Vol 3, No 8-26, PP 609-622, oktobar 1970.

[3.] R. Pejovic, R. Mrdak, R. Živaljevic, O. Mijuškovic, Proracun seizmicke otpornosti betonske brane Grncarevo, Originalni naucni rad, Gradavinar 58 / 6, pp. 446-453, jul 2006.

[4.] V. Vojinovic, M. Vuckovi, Z. Hriberšek, Kontrola prethodno napregnutih geotehnickih sidara sistema Zollner-Polensky na brani Grncarevo, Tehnika - Naše gradevinarstvo, vol. 56, br. 1, str. 1-6, 2002

[5.] V. Vojinovic, On methodology for controlling the implementation of geotechnical anchors of the IMS system, Geotechnical and anchor structures, Zagreb: DGITZ, DMSPRH, DTPKH, str. 331-356, 1987.

[6.] V. Miltenovic, Razvoj proizvoda - strategije, metode, primena. Univerzitet u Nišu – Mašinski fakultet, Niš, 2003.

[7.] Wolfgang R. Habel, Ingo Feddersen and Carsten Fitschen: Embedded Quasi-Distributed Fiber-Optic Sensors for the Long-Term Monitoring of the Grouting Area of Rock Anchors in a Large Gravity Dam, Journal of Intelligent Material Systems and Structures 1999 10: pp. 330-339

[8.] M. Jankovic, S. Radišic, Izveštaj o ispitivanju sila u geotehnickim ankerima HE Grncarevo, TRCpro Interni izveštaj, dokument br. Izv-07-09, Novembar 2009.

[9.] http://www.hbm.com/en/menu/support/hbmdoc-technical-documentation/

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