EARTHQUAKE EFFECTS ON THE GROUND IN THE ROCK BOLT AREA - A 3D COMPUTATIONAL MODEL

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Summary: *The subject of this research work are the rock bolts that are used to stabilise the ground around the tunnel. The idea is that the anchors, being loaded by tensioning force, impose compressive stress to the rock, and by that, strengthen and stabilise the ground. It is obvious that the stress–strain state in the anchorage zone becomes significantly changed due to the installation of rock bolts. There is a number of researches and expressions that define the change of this state under the static loading condition. What is much more complicated, however, is to determine the stress–strain state in the anchorage zone under dynamic loads, in particular considering the 3D model. In this paper, the given problem under the dynamic/seismic load is modelled by the finite element method using the software ANSYS WORKBENCH. A full transient dynamic analysis is performed. With respect to the loading, along with geostatic stress and prestressing force, a part of the acceleration record of the El Centro Earthquake has also been considered in the analysis.*

Keywords: *tunnel, rock bolt, seismic excitation, stress state, displacements, 3D model*

1. INTRODUCTION

In order to provide a safe environment during the excavation stage (and construction in general) and during the operation, it is often necessary to stabilise the ground. One of the most frequently applied procedures for enhancement of ground characteristics is installation of rock bolts. Most researches dealt with the analysis of the anchors under static loads. However, the rock bolts analysis under the dynamic loads such as blast mining, seismic effects, etc., is of considerable importance. In this paper, the seismic

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effects on the ground in the anchor zone and on the anchor itself were analysed, using a 3D model.

TYPES OF ANCHORS

There are several classifications of the anchors. According to the way the load is transferred from the anchor to the surrounding soil, they can be classified as [1]:

- *Continuously Mechanically Coupled* or *CMC* anchors. In these elements, the transfer of load from the anchor onto the surrounding soil is effected continuously, by means of mechanical elements;
- *Continuously Frictionally Coupled* or *CFC* anchors. The transfer of load to the surrounding soil is effected by friction;
- *Discretely Mechanically or Frictionally Coupled* or *DM(F)C* anchors. These elements are connected with the surrounding soil in discrete points (most frequently in one point).

The appearance of characteristic *DM(F)C* and *CM(F)C* anchors along with the elements constituting them is provided in Figure 1.

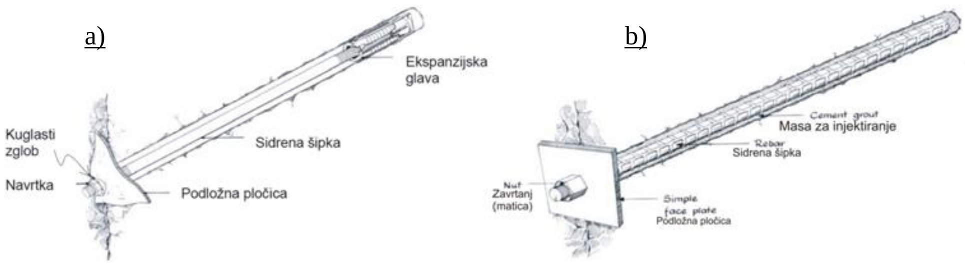

Figure 1 - DM(F)C and CM(F)C anchors

The anchors where the load is transferred continuously, along the entire anchor body, are constructed by fully grouting the bolts, so as to induce friction between the bolt and the surrounding ground. The materials, which are most frequently used for such anchors, are the mixtures on the basis of cement (mortar) and epoxy glues. They are constructed by grouting the bore hole with the previously placed anchor in order to bond it with the surrounding soil, and for that reason such anchors are called the grouted anchors. In case of the other type of anchors, where load transfer is effected in one point, the mutual interaction can be achieved using the material coating the anchor at the end of the element, or mechanically. The latter method can be found in patented anchors, where the bond between the anchor and the surrounding ground is accomplished in another way: when the cone part at the end of the anchor is rotated, it expands. If it is allowed by the surrounding soil (or rock), the expanding piece will create the bond. For this reason, the anchors of this type are alternatively called the expansion anchors and mechanical anchors.

2. ANCHORS UNDER DINAMIC LOADS

When a structure is exposed to dynamic excitation, in addition to the static loads, inertial loads will be induced in it as a result of the way of loading. Therefore, another variable is included in the entire problem, that being time. This variable considerably complicates an already complex calculation. In order to determine the structural response to some dynamic excitation, as accurately as possible, it is necessary to calculate dynamic characteristics of the observed structure (circular frequency, oscillation forms, damping effects, ...). In case of the most frequently built surface structures (buildings, bridges, dams, ...) there is a wide spectrum of methods for calculation of these characteristics with various approximations and simplifications, which produce the results of satisfactory degree of accuracy. Such computations considering anchors are very difficult. For that reason, more concrete solutions were obtained only by using computers and the full engagement of numerical methods in the computations. The investigations in this research field are very recent. In the paper [7] the response of the ground strengthened using one *CFC* anchor was analysed. Disposition, boundary conditions, and dynamic excitation of the anchor are presented in Figure 2.

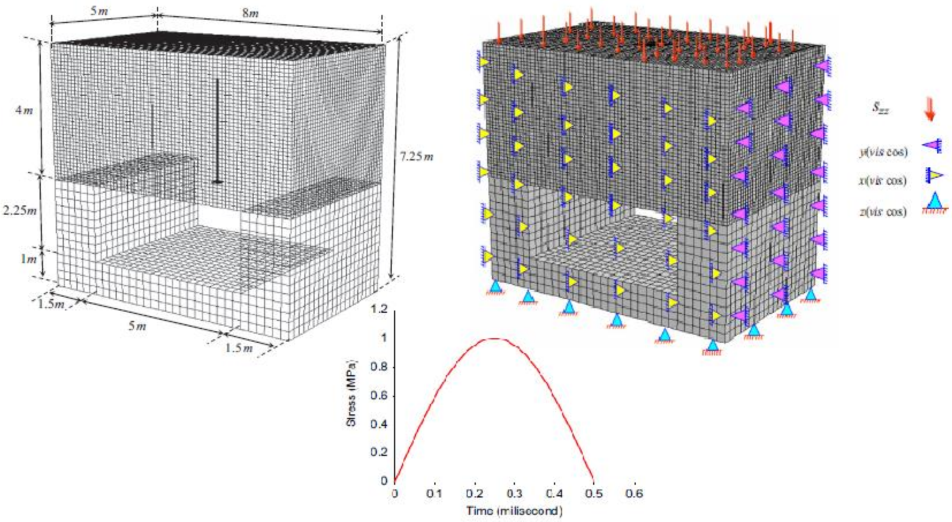

Figure 2 - Disposition, boundary conditions, and dynamic excitation of the anchor [7]

3. THE 3D COMPUTATIONAL MODEL AND ANALYSIS OF EARTHQUAKE EFFECTS ON THE GROUND IN THE ANCHOR ZONE

Application of the finite elements method in simulation of all types of physical problems, in particular with the development of computer technology, is indispensable in contemporary engineering. Depending on the adopted approximations, the models are of different level of complexity. In this work the ANSYS WORKBENCH software package was used. This software has a wide spectrum of finite elements, which can be used for modelling of various mechanical problems. Owing to the *solid* elements, it is possible to model the problems with realistic geometry in the 3D model. The model geometry of the anchor, used for excavation stabilisation, is presented in Figure 3.

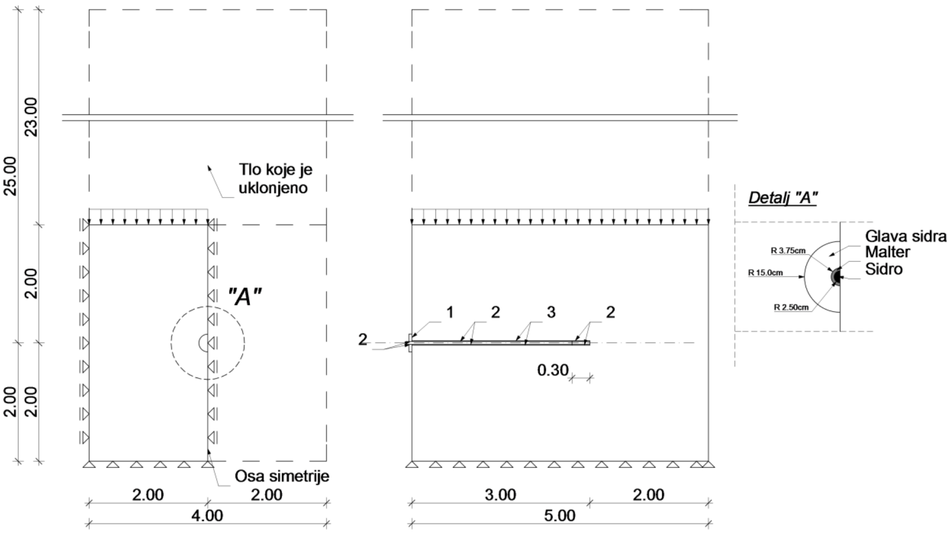

Figure 1 - Anchor model geometry

The example analyses the anchor at the depth of 25m from the ground surface. The diameters of the anchor, cement grout (interior and exterior), and anchor head are presented in the detail *„A“* (Fig. 3). In order to save computer memory, and thus accelerate the computation, only one half of the ground with the anchor is modelled, which means the symmetry was used. In order the symmetry to be fully employed, the load must be symmetrical as well. This condition is satisfied only if the load (in this case acceleration record) is applied in the direction of the lengthwise axis of the anchor, which actually was performed in this example. In order to additionally decrease the number of finite elements, the ground layer down to the depth of 23m was removed from the model. The removed soil is replaced by the load, which is equal to the product of the bulk density and height of the soil which was removed. The mutual interaction of the anchor and the surrounding ground has a special importance for this model. This interaction was achieved by implementing the contact finite elements. The method used for modelling the contacts can be seen in Figure 3. The meaning of the designations in the figure is as follows:

1 – *No Separation*: this is the contact between the anchor head and the ground supporting the head. Considering that the prestressing force was set in the anchor, this condition is satisfied.

2 – *Bonded*: this contact models the bonds of the elements which were joined rigidly, such as the bond of the anchor and the head, bond of the anchor and cement grout, and the bond of the cement grout and the rock at the section where this bond was effected, which is 30cm from the end of the anchor (*DFC* anchor).

3 – *Frictionless*: the bond of the remaining part of the anchor and the surrounding ground, which was modeled as frictionless.
The mechanical characteristics were defined through the material model, and for the used materials, they are:

Rock:	Modulus of elasticity:	E = 5 000 MPa
	Poisson's coefficient:	ν = 0.30
	Shear Modulus:	G = 1 923.10 MPa
Cement grout:	Modulus of elasticity:	E = 12 000 MPa
	Poisson's coefficient:	ν = 0.22
	Shear modulus:	G = 4 918 MPa
Steel:	Modulus of elasticity:	E = 210 000 MPa
	Poisson's coefficient:	ν = 0.29
	Shear Modulus:	G = 81 395 MPa

Since the material models defined only the parameters in the linear area, the computation was performed in the material linear domain. Geometric non-linearity was also included considering that the contact elements must be calculated according to this principle.
The load applied in the model is prestressing force of the anchor of 150kN, the pressure which should compensate for the removed layer of the rock, and a part of the El Centro acceleration record. The earthquake record is provided in Figure 4.

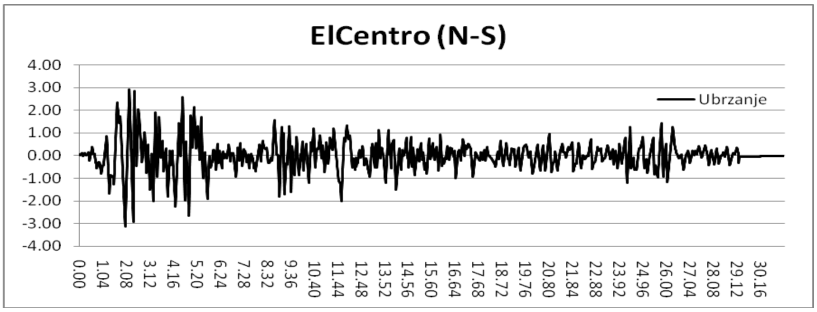

Figure 4 - El Centro earthquake record

The acceleration values are given in the intervals of 0.02 seconds. The computation employed full transient dynamic analysis. Since this type of analysis requires considerable computer resources, only one segment of the acceleration record lasting one second was chosen, and considering the size of the increments, it means a total of 50 steps. The part of the acceleration record used in the analysis is that where maximum acceleration was recorded, which is between 1.60 and 2.60 seconds. This analysis calculates the forces that depend on the way, i.e. rate of load application. In order to avoid this in case of the pressure that should replace the removed ground layers, this load is set in a longer period of time, specifically in this case, the interval is 10 seconds, so in this way the inertial effects are minimised, which is verified by comparing the computation results both of the static and the dynamic modes. The appearance of a discretised model is provided in Figure 5.

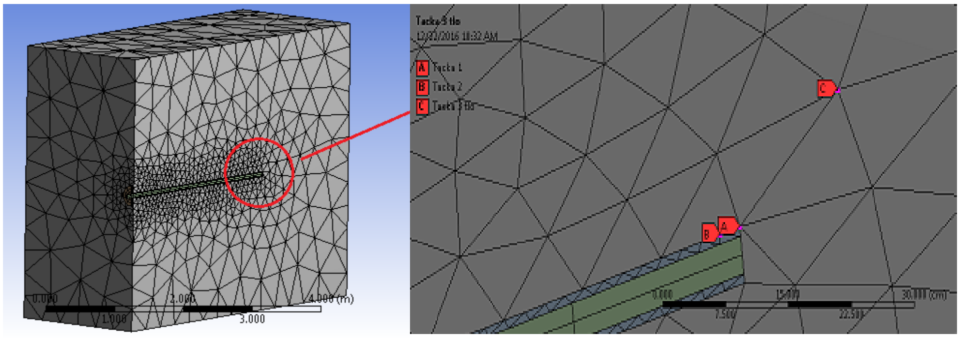

Figure 5 - Discretised model

In the following diagrams, the results in the characteristic cross-sections marked in Figure 5 are presented (points 1 and 2 at the end of the anchor, and point 3 in the rock mass nearby the anchorage zone). In the provided diagrams (Figs. 6, 7, and 8) only the results of the earthquake effects analysis are shown. It is interesting to present the stress and strain in the anchorage zone. Since it was set that the acceleration acts in the direction along the rock bolt's length, which in the model coincides with the direction of the global *X*-axis, the variation of displacements, normal stresses in the direction of this axis, and the variation of equivalent (*Von-Mises*) stresses in the function of time will be displayed.

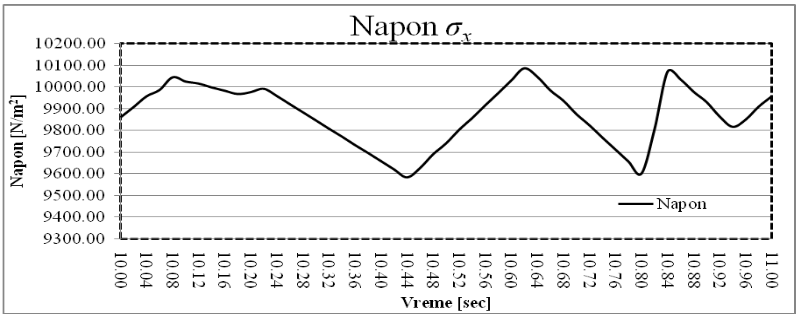

Figure 6 - Variation of normal stress in point 3

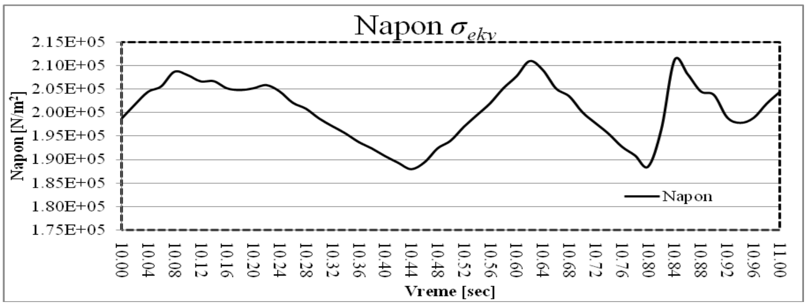

Figure 7 - Variation of equivalent stress in point 3

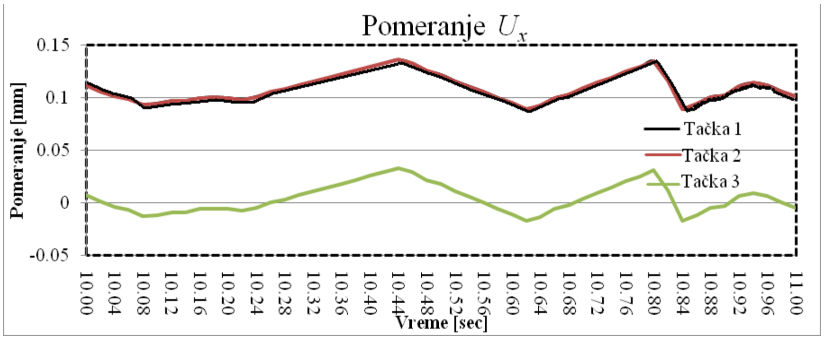

Figure 8 - Variation of displacement in the direction of X-axis in points 1, 2, and 3

By analysing the results illustrated by the diagrams, it can be concluded that prestressing force has a considerable role in redistribution of stresses, considering the intensity of normal stresses, i.e., their sign. The variation with time of the normal stress in the direction of the *X*-axis (Fig. 6) and of the equivalent stress (Fig. 7) in the ground in the vicinity of the anchorage zone is, excluding intensity, rather uniform, i.e. the diagrams are of the same form. The case is similar regarding the displacements in the direction of *X*-axis, with respect to Figure 8 in which the displacement curves for all three observed points are provided. It can be observed that the displacements of points 1 and 2 coincide, which was expected, considering their location (at the end of the rock bolt), whereas the displacement curve of point 3 is by form similar to the curve of displacements of points 1 and 2, but, due to the drop in prestressing effects, it is shifted towards the *X*-axis (lower displacement values that vary around the value of zero).

4. CONCLUSION

In this paper, an analysis of the seismic behaviour of the rock bolt and the ground in the anchorage zone is performed on one 3D model, assuming the linear-elastic behaviour of material. There are, however, the soil models where the dependence of the stress and strain is in nonlinear relationship, which much more realistically than the material model used in this analysis represent the actual behaviour of media in which such structures are constructed. Investigations in this research field could use the advantage of contemporary software packages, because they offer a possibility to define the nonlinear material models, so such computation, in addition to the geometrical nonlinearity, which is common regarding the contact elements, would include the material nonlinearity as well. Such researches would offer the engineers a better insight into the structural behaviour under the dynamical load, and thus the opportunity to design seismically safer structures.

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DEJSTVO ZEMLJOTRESA NA TLO U ZONI SIDRA - 3D PRORAČUNSKI MODEL

Rezime: *Predmet istraživanja ovog rada su sidra koja služe za stabilizaciju tla u okolini tunela. Ideja je da se sidra napregnu silom zatezanja kako bi u stenu uneli napone pritiska, i na taj način stabilizovali stensku masu oko tunelskog iskopa. Jasno je da ugradnja sidara značajno menja naponsko-deformacijsko stanje u sidrišnoj zoni. Postoje istraživanja i izrazi koji definišu promenu ovog stanja pri statičkom opterećenju. Ono što je znatno složenije jeste određivanje naponsko-deformacijskog stanja u sidrišnoj zoni usled dinamičkog opterećenja, posebno u 3D modelu. U ovom radu problem dinamičkog/seizmičkog opterećenja je modeliran primenom metode konačnih elemenata u programskom paketu ANSYS WORKBENCH. Sprovedena je Full Transient dinamička analiza. Kao opterećenje, osim geostatičkih napona i sile prednaprezanja, zadat je deo akcelerogramskog zapisa zemljotresa El Centro.*

Ključne reči: *tunel, sidro, seizmičko opterećenje, naponi, pomeranja, 3D model*