

Case Study

Internal and External Collapse Analysis of Twin-Tubes Tunnel in the Initial Support Stage

Houssam KHELALFA^{1,2,*}, U. SAKALLI³, E. B. AYGAR³, O. ŞİMŞEK³, B. AYKAN³¹ Civil Engineering and Environment Laboratory (LGCE), University of Jijel, Jijel, Algeria² Faculty of engineering and technology, Selinus university of science and literature (SUSL), Bologna, Italy³ MAPA İNŞAAT AŞ, Ankara, Turkey

*Correspondence: Houssam KHELALFA (khelalfahoussam@gmail.com)

Abstract: The characterization of rock mass along the tunnel alignment based on physical, geological and geotechnical data of the project area was used in this work. The support systems were recommended for all geotechnical units using RMR and tunneling quality index (Q-system) support chart. The paper also consists in making a two-dimensional numerical study of the stability of the left lateral slope of the Portal of the tunnel with the Slide 6.0 software and inside provisional support with the Phase.2 2D program. The study shows good results of the internal rock mass stability of the tunnel and satisfactory safety factor (FoS) in terms of collapse analyzes of the lateral slope of the tunnel portals.

Keywords: Tunnel Portal Slope, Primary Support, Stability, Phase 2D, Slide 2D, Strength Factor.

How to cite this paper:

KHELALFA, H., SAKALLI, U., AYGAR, E. B., ŞİMŞEK, O., & AYKAN, B. (2022). Internal and External Collapse Analysis of Twin-Tubes Tunnel in the Initial Support Stage. *World Journal of Civil Engineering and Architecture*, 1(1), 33–40. Retrieved from <https://www.scipublications.com/journal/index.php/wjcea/article/view/317>

Received: May 08, 2022

Accepted: June 25, 2022

Published: June 27 2022



Copyright:© 2022 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The soil deformations and the modifications created by the stresses of the soil during the digging of the tunnel, are closely linked with the digging technique. [1,2]. The basic principle of tunneling with the new Austrian method is to have the rock transported by itself. Allowing the rock to deform slightly (as long as it remains within the admissible safety limits) considerably reduces the loads weighing on the load-bearing system. The rock released under control transfers the load to the sides and thus uses its transport capacity to the maximum by forming a transport chain around the excavation [3-7]. The three-dimensional support at the working face becomes two-dimensional as it moves away from the working face. Instead of carrying all the load of the rock, the support systems are instead used to control plastic deformation while maintaining the integrity of the transport chain around the excavation and avoiding excessive relaxations. Thus the flexibility of the system to the point of adapting to the rock deformations is one of the most important criteria of the method. If the rock is too weak to carry its own load, the support used stabilizes the system by providing additional pressure still needed to reach equilibrium after approaching rock carrying capacity [8-10]. The main feature of NATM is the application of support at the right time. Tunnel ground deformation monitoring is the main means for selecting the appropriate methods of excavation and retaining from among those provided in the design to ensure the safety of the tunnel construction (including the safety of personnel in the tunnel and the safety of structures on the ground surface). The empirical and numerical design approaches are considered very important in the viable and efficient design of support systems, stability analysis for tunnel, and underground excavations [11]. During stages of excavation projects, the empirical methods like rock mass classification systems are considered to be used for solving engineering problems [12,13]. The 2D and 3D finite element method was used to analyze the behavior of the rock mass, the in situ stresses and redistribution, the plastic thickness around the

tunnel and the performance of the design trusses in order to compare the results of the calculations with the field monitoring to validate the numerical models [14-17].

2. Geological conditions along the tunnel

The study area is located at the southern limit of the Petite Kabylie massifs; it spreads across a major geodynamic limit of northern Algeria. Geologically speaking, this limit is associated with several strongly tectonized structural units framed by the largest tectonic contacts of Alpine age in northern Algeria. These contacts are at the origin of the formation of the Maghrebian orogen [18]. The building of the latter results from the structuring of the Maghreb basin and its margins, a basin which was located between the European and African continental margins [19]. The South Kabyle accident (South Kabyle backbone) is considered as the major geodynamic limit of northern Algeria. The geological conditions of the Texana Tunnel site are composed of the Mauritanian Flysh (Figure 1), which are essentially formed of alternations of sandstone and sandstone with passages of hard quartzite, resting on fractured and weathered schists at the surface [20]. All of these formations cover the formation of hard argillite (clay-stone) little altered and fractured whose upper part, and depth it is very hard and little fractured. This clay-stone is present almost all along the tunnel.

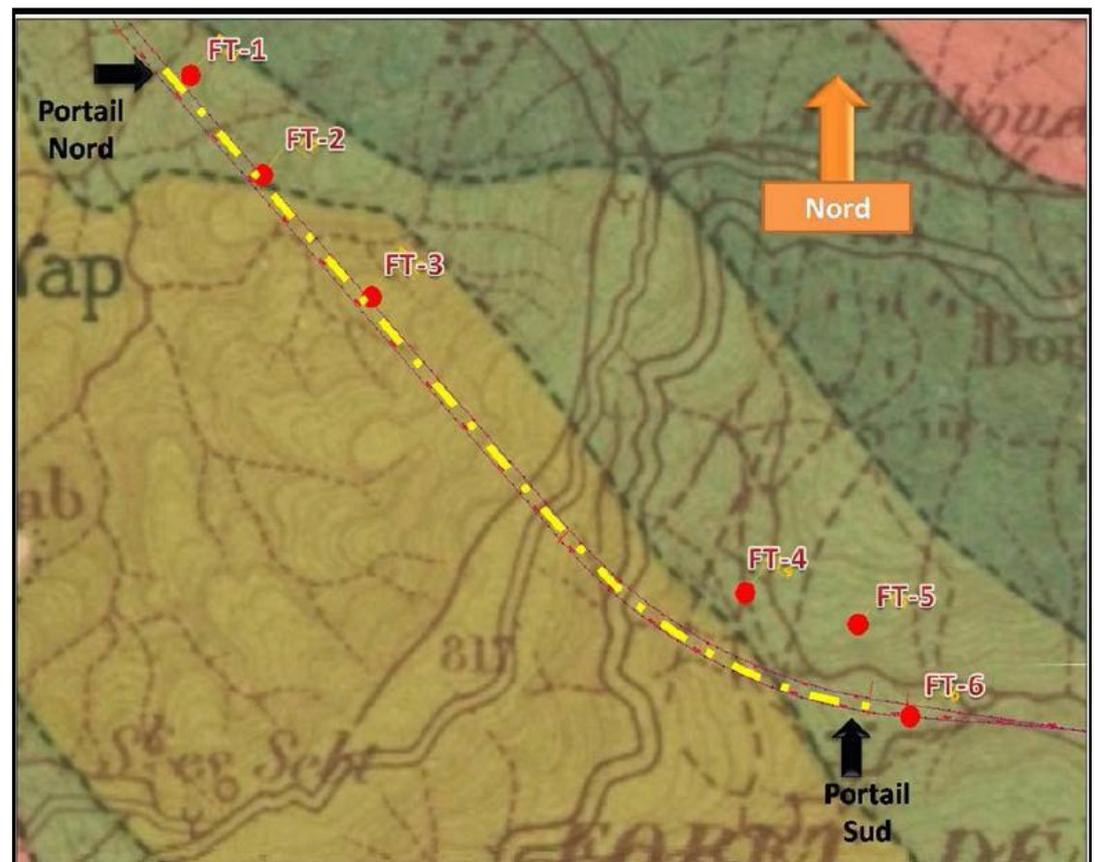


Figure 1. Geological view of tunnel alignment of this study.

3. The RMR and Q classification systems

The Rock mass classification systems are considered as an integral part of the designing of underground structure, support systems, stability analysis and in determination of input parameters for numerical modeling within the rock mass environment [21]. Various rock mass classification system has been developed based on civil and mining engineering case studies by different researchers [22, 23]. In this research, RMR and Q systems were

used due to its flexibility in terms of input parameters and widespread range for selection of support systems. The values of this system indicate the quality of rock mass and give description about the stability of an excavation within the rock mass environment [24]. The maximum value of Q-system indicates good quality of rock meaning good stability and the minimum value indicates poor quality of rock meaning poor stability [25]. The rock mass along the tunnel axis (Figure 2) were classified into different categories based on Geo-mechanical classification system also called Rock mass rating (RMR- system) [26]. The used physical and geotechnical properties of rock mass along the tunnel alignment were already determined by H. Khelalfa *et al.* [27, 28].



Figure 2. Photography of the twin-tubes tunnel of this study.

4. Internal Collapse Analysis of the Tunnel

The numerical analyzes were performed with the Phase 2 2D program (Version 8.0). The program is progressively modeling the underground excavation, providing support with bolts, steel retaining, steel lattice and shotcrete. In addition, the load split between the excavation phases and the material softening can be applied to the model (Figure 3). The designation of support systems based on practice and experience, numerical analyzes were considered as a guide for practical decisions. The support system will have to be revised according to the actual field situation and the geological mapping and the footage results. The calculation sections are taken on the part represented by the rock formation between the determined KP (kelometric point). The calculations for these sections are valid for the part represented by the section. The parameters of the rock mass are estimated with these calculation sections according to the recommendations and approaches of the literature. Excavation coordinates are given in the X-Y system that accepts the center of the tunnel in the zero coordinate (O1). These units are given in meters in the program. Relevant soil modeling is very difficult in soil excavations given the many uncertainties and complexity. The numerical analyzes are performed according to the elastic-plastic solution. Thus the detailed modeling which includes all the conditions is neither possible nor this modeling is useful. The relaxation of material used in the weak rock masses as indicated above is applied at 0.65 (65%) in the excavation of the upper half and 0.35 (35%) is reflected in the model with the installation of the supports of the upper half and when excavating the lower half. The purpose of this distribution is to determine the rate of load

to be carried by the rock and the rate of load to bear by the supports. The linear composite is applied in 3 layers on the model in the excavations of the upper part, the lower part and the slab. In the excavation levels, the first layer of shotcrete lining and the steel retaining (HEB) and the second layer of shotcrete liner and steel lattice are entered into the model. Simplification of the model may be possible under the following conditions;

- Reduction of three-dimensional conditions to two dimensions,
- Acceptance of the symmetry of the section with the axis,
- Simplification of the soil with simple descriptions,
- Simple and comprehensive description of the progress conditions of the tunnel and the excavation,
- Soil is considered homogeneous and isotropic.

4.1 Situation without earthquake:

The results of the Phase 2D software analysis without seismic situation are shown in the (Figure 3a). The examination of the Strength Factor around the tunnel indicates a values of 6.0 in the ceiling, of 3.79 and 6.0 in the left and right wings of the tunnel, of 1.26 and 1.26 in the lower left and right parts of the tunnel and of 6.0 in the slab (base) of the right tunnel. In the left tunnel, there is a values of 6.0 in the ceiling of the tunnel, of 6.0 and 6.0 in the left and right wings, of 1.26 and 1.26 in the left and right lower halves and of 3.16 on the slab. The strength factor around the tunnel being more than 1 around the tunnel and increase with distance.

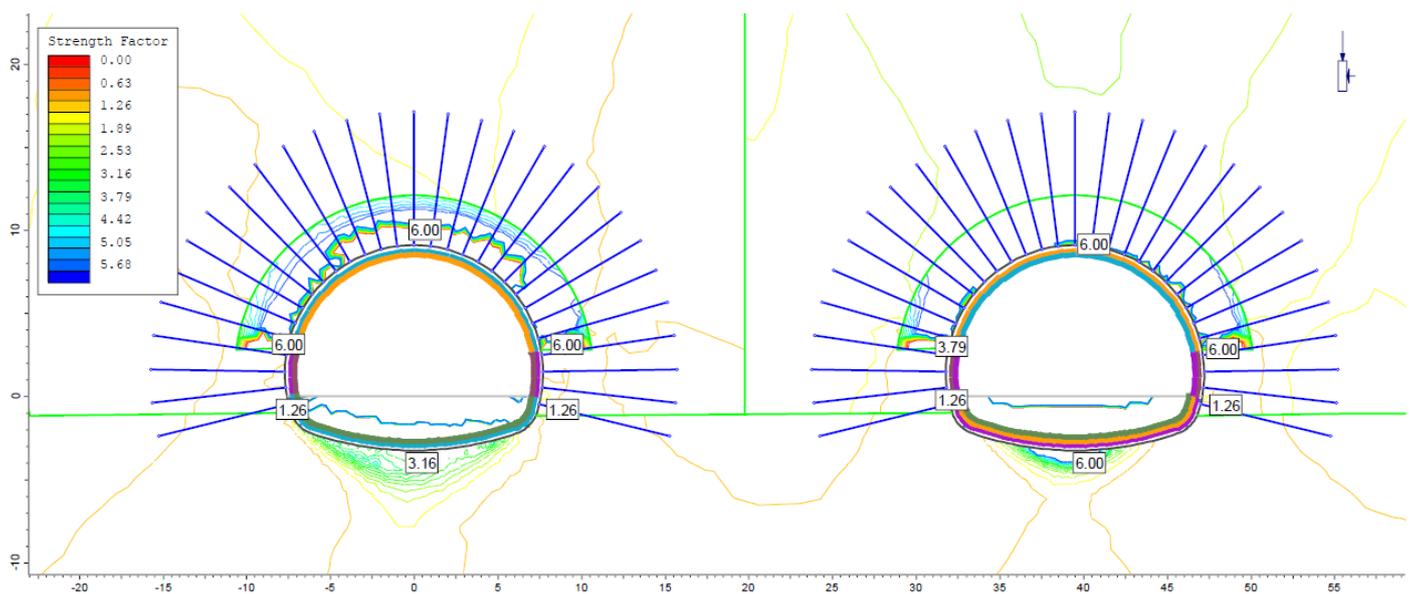


Figure 3a. Strength Factor without seismic situation.

4.2 Situation with earthquake:

The results of the Phase 2D software analysis in seismic situation are shown in the (Figure 3b). In the right tunnel, the examination of the Strength Factor around the tunnel indicates a values of 6.0 in the tunnel ceiling, 3.79 and 1.58 in the left and right wings, 1.26 and 1.58 in the left and right lower halves and 6.0 on the slab. In the left tunnel; The examination of the Strength Factor around the tunnel indicates a values of 6.0 in the tunnel ceiling, 6.0 cm and 6.0 in the left and right wings, 1.26 and 1.26 in the left and right lower

halves and 6.0 on the slab. The strength factor around the tunnel being more than 1 around the tunnel and increase with distance.

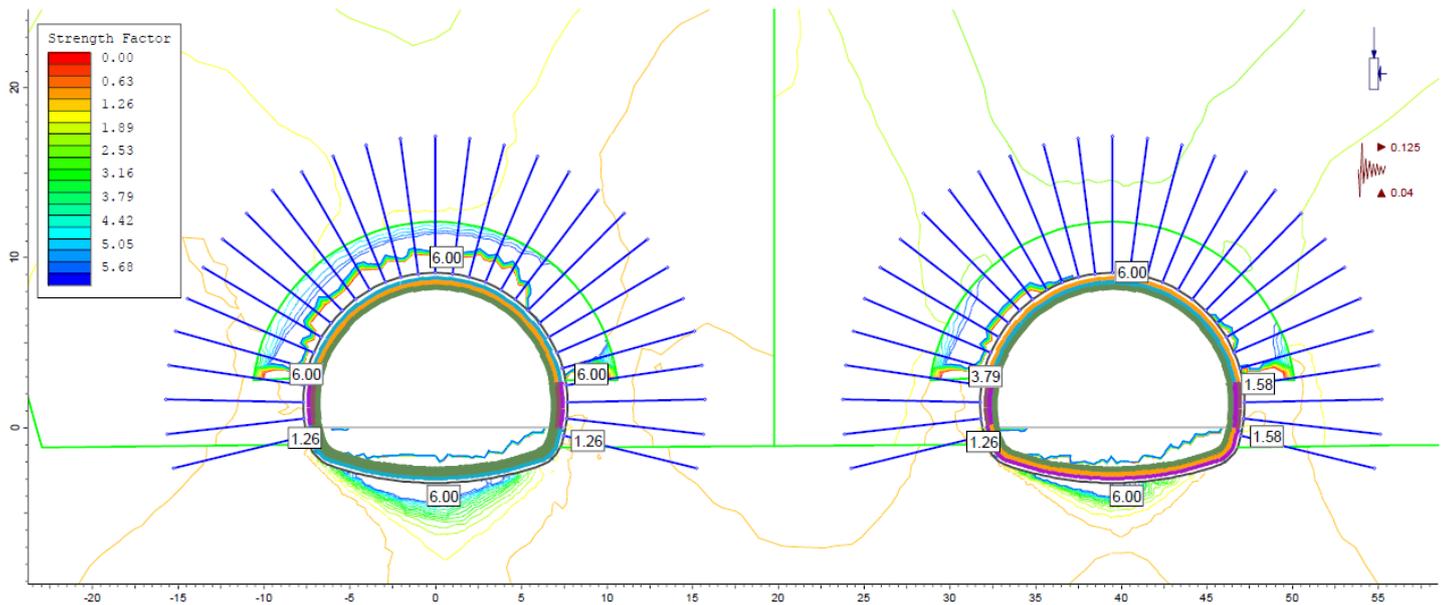


Figure 3b. Strength Factor in seismic situation.

5. Stability of the Left lateral slope of the tunnel south Portal

As part of the report, the left lateral slope of the tunnel portal (Figure 4) is designed at the rate of 1H: 1V and single slope.



Figure 4. The south portal and a shallow landslide west of the south portal.

According to the results of the kinematic analyzes, it has been determined that there is no slip potential under discontinuity control in the lateral slope of the exit portal. In addition, the total collapse analyzes for the left lateral slope are performed with the Slide 6.0 software and presented below (Figure 5a). The minimum safety factor obtained is 2.8 in an unsupported situation in the analysis performed for the left lateral slope. The safety factor 1.5 is sufficient for the stability; we observe that there is no problem of stability in the slope in unsupported situation. Furthermore, the seismic situation being examined, the acceleration coefficient obtained being 0.125 g, the acceleration coefficient is 0.0375

and the over-design factor is 1.6 (Figure 5b). The safety factor 1.1 being sufficient for the stability in seismic situation, there is no problem of stability in this case.

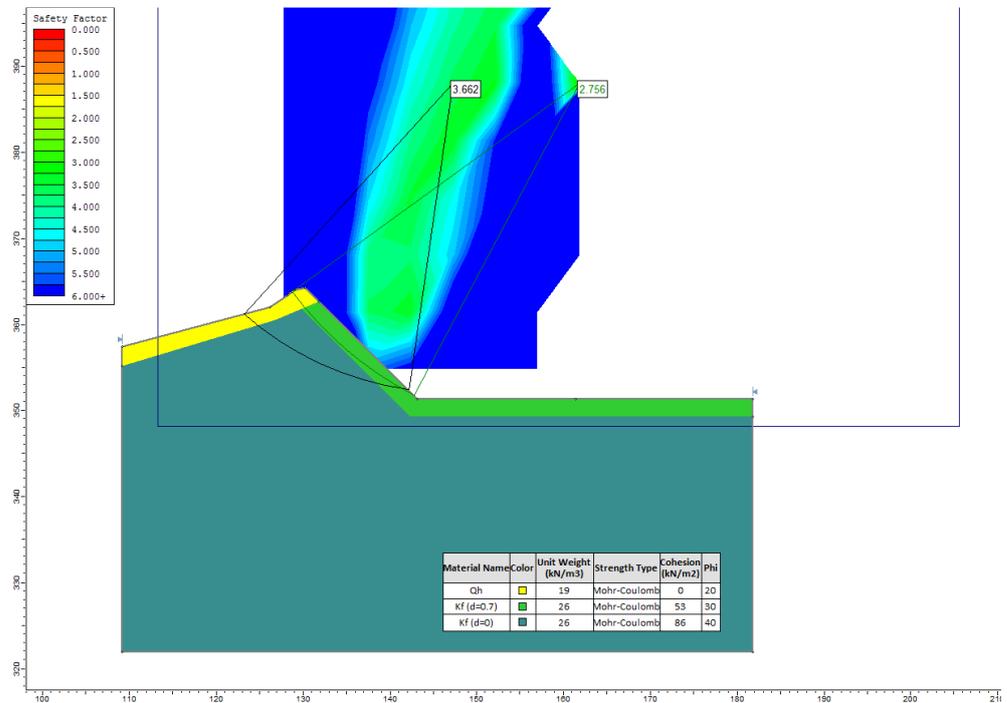


Figure 5a. Total collapse analysis in a static situation without support of the left lateral slope of the south Portal (FS : 2.8).

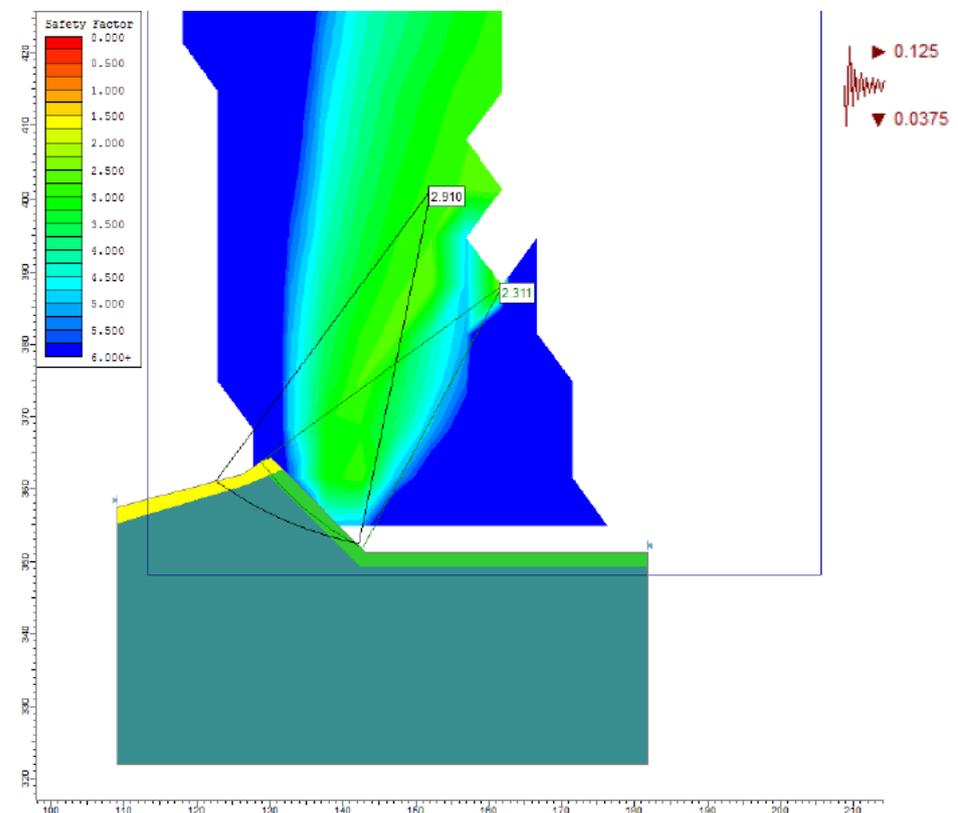


Figure 5b. Total collapse analysis in seismic situation without support of the left lateral slope of the south Portal (FS : 2.3).

6. Conclusions

This present article is established in order to determine the rock mass deformation behavior of the Texanna twin-tube tunnel on Jijel province in Algeria planned within the framework of the project "Penetrating highway linking the Port Of Djen Djen to the East-West highway", whose tubes will be built between the kilometric points KP: 24+818.845 – KP:26+648.352 and the left tube between KP:0+711.683 – KP:2+593.879. According to survey data and fieldwork, there is a flysch unit which consisted of thin-medium stratified mudstone, medium-thick stratified intercalated sandstone, aged Albo-Aptian. It was recommended to dig the Texanna Tunnel by the mechanical excavation method, and to develop the support systems according to the New Austrian Tunneling Method (NATM). The planning of this tunnel is carried out in upper half, in lower half and in raft. The provisional support reduces the internal deformations and decreases the portal slope instability of the tunnel. In conclusion; the confinement capacity and the tunnel portal slope significantly improves when the provisional supports installed.

Acknowledgements

This work is under the auspices of the General Directorate of Scientific Research and Technological Development (DGRSDT) of the Algerian Ministry of Higher Education and Scientific Research (MESRS).

References

- [1] D. Wu, K. Xu, P. Guo, G. Lei, K. Cheng, and X. Gong, "Ground deformation characteristics induced by mechanized shield twin tunnelling along curved alignments," *Advances in Civil Engineering*, vol. 2021, Article ID 6640072, 17 pages, 2021. DOI: 10.1155/2021/6640072.
- [2] Peck, R.B. (1969): Deep excavations and tunnelling in soft ground, State of the art report, in proceedings of the VII Int. Conf. on Soil Mechanics and Found. Eng., Mexico city, State of the art volume, pp. 225-290.
- [3] Golser J, Mussger K. New Austrian Tunnelling Method (NATM), contractual aspects. In: *Tunnelling under Difficult Conditions*, Proceedings of the International Tunnel Symposium, Tokyo. Pergamon Press; 1979. p. 387-92.
- [4] Brown ET. Putting the NATM into perspective. *Tunnels & Tunnelling International* 1981; 13(10):7-13.
- [5] Aygar EB, Evaluation of new Austrian tunnelling method applied to Bolu tunnel's weak rocks, *Journal of Rock Mechanics and Geotechnical Engineering*, <https://doi.org/10.1016/j.jrmge.2019.12.011>.
- [6] U.S. Army Corps of Engineers, "Engineering and Design Tunnels and Shafts in Rock (e-book)", Chapter 5, May 1997
- [7] Ulusay, R. Ve Sönmez H., (2007), *Propriétés mécaniques des massifs rocheux: 2ème édition mise à jour – étendue*, Publications de la Chambre des Ingénieurs en Géologie de TMMOB, No:60
- [8] Rasouli, M. 2009. "Engineering Geological Studies of the Diversion Tunnel, Focusing on Stabilization Analysis and Support Design, Iran." *Engineering Geology* 108: 208-224.
- [9] Ali, W. Rock Mass Characterization for Diversion Tunnels at Diامر Basha Dam, Pakistan – a design perspective. *International Journal of Scientific Engineering and Technology*; 2014; 1292-1296.
- [10] Genis, M., H. Basarir, A. Ozarslan, E. Bilir, and E. Balaban. 2007. "Engineering Geological Appraisal of the Rock Masses and Preliminary Support Design, Dorukhan Tunnel, Zonguldak, Turkey." *Engineering Geology* 92: 14-26.
- [11] Rasouli, M. 2009. "Engineering Geological Studies of the Diversion Tunnel, Focusing on Stabilization Analysis and Support Design, Iran." *Engineering Geology* 108: 208-224.
- [12] Ali, W. Rock Mass Characterization for Diversion Tunnels at Diامر Basha Dam, Pakistan – a design perspective. *International Journal of Scientific Engineering and Technology*; 2014; 1292-1296
- [13] Genis, M., H. Basarir, A. Ozarslan, E. Bilir, and E. Balaban. 2007. "Engineering Geological Appraisal of the Rock Masses and Preliminary Support Design, Dorukhan Tunnel, Zonguldak, Turkey." *Engineering Geology* 92: 14-26
- [14] Yoo C (2009) Performance of multi-faced tunnelling–A 3D numerical investigation. *Tunn Undergr Space Technol* 24(5):562-573. <https://doi.org/10.1016/j.tust.2009.02.005>
- [15] Karakus M, Fowell RJ (2006) 2-D and 3-D finite element analyses for the settlement due to soft ground tunnelling. *Tunn Undergr Space Technol* 21(3):392-392
- [16] A. Ghadimi Chermahini & H. Tahghighi (2019) Numerical finite element analysis of underground tunnel crossing an active reverse fault: a case study on the Sabzkouh segmental tunnel, *Geomechanics and Geoengineering*, 14:3, 155-166, DOI: 10.1080/17486025.2019.1573323

-
- [17] Chu B, Lin Y. Mechanical behavior of a twin-tunnel in multi-layered formations. *Tunnelling and Underground Space Technology* 2007;22(3):351-62
- [18] L Joleaud; M Ferrand; E Ficheur; Algeria. S Carte géologique de l'Algérie 1:50,000. 74, El Aria. Service de la carte géologique de l'Algérie., 1908
- [19] Wildi, W. (1983) La chaîne tello-rifaine (Algérie, Maroc, Tunisie): Structure, Strati-Graphie et évolution du Trias au Miocène. *Revue de Géologie dynamique et de Géographie Physique*, 24, 201-297
- [20] Hamou Djellit, Évolution tectono-métamorphique du socle Kabyle et polarité de mise en place des nappes de flysch en petite Kabylie occidentale (Algérie), Supported in 1987 at Paris 11 university, in partnership with University of Paris-Sud. Faculty of Sciences of Orsay (Essonne)
- [21] Evrim Sopac, and Haluk Akgun (2008): Engineering geological investigations and the preliminary support design for the proposed Ordu Peripheral Highway Tunnel, Ordu, Turkey. *Engineering Geology*, 96: 43-61
- [22] Bortan, Using the Q-System, Sweden and Norway, Norwegian Geotechnical Institute, Oslo, Norway, 2013
- [23] Miranda, Gomes, T.A., Correia and Nogueira (2015): academia.edu. (P. Cortez, Producer) Retrieved March Monday, From [http://www.academia.edu/3114361/](http://www.academia.edu/3114361/Alternative_models_for_the_calculation_of_the_RMR_and_Q_indexes_for_granite_rock_masses) Alternative models for the calculation of the RMR and Q indexes for granite rock masses
- [24] El-Naqa, A. Application of RMR and Q geomechanical classification systems along the proposed Mujib Tunnel route, central Jordan. *Bull Eng Geol Environ* (2001) 60: 257. <https://doi.org/10.1007/s100640100112>
- [25] S.Y Choi and H.D Park, Comparison among different criteria of RMR and Q-system for rock mass classification for tunnelling in Korea, Volume 17, Issue 4, October 2002, Pages 391-401. doi.org/10.1016/S0886-7798(02)00063-9
- [26] Z. T. Biniawski, "Classification of Rock Masses for Engineering: The RMR System and Future Trends," in *Rock Testing and Site Characterization*, Pergamon, Oxford, UK, 1989
- [27] Khelalfa H., Aykan B. and Boulmaali H. (2022) Monitoring of Tunnel Rock Mass Deformations During Provisional Support Stage: A Case Study. *Mining Revue*, Vol.28 (Issue 1), pp. 1-23. <https://doi.org/10.2478/minrv-2022-0001>
- [28] H. KHELALFA , U.SAKALLI , E. B. AYGAR, O.ŞİMŞEK , B. AYKAN and H. Boulmaali. Numerical Modeling for Engineering Analysis, Designing and Monitoring of Support Systems for Twin-Tube Tunnel. *Revista Romana de Inginerie Civila* 13 (3), xxx-xxx. DOI: 10.37789/rjce.2022.13.3.x