Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 28, issue 1 / 2022, pp. 1-23

MONITORING OF TUNNEL ROCK MASS DEFORMATIONS DURING PROVISIONAL SUPPORT STAGE: A CASE STUDY

Houssam KHELALFA [1], B. AYKAN[2], H. BOULMAALI[3]*

[1] University of Jijel, Civil Engineering and Environment Laboratory (LGCE), Jijel, Algeria
Selinus University of Science and Literature (SUSL), Faculty of Engineering and Technology, Bologna, Italy
[2] MAPA İNŞAAT AŞ, Ankara, Turkey
[3] CTTP, Kouba - Algiers, Algeria

DOI: 10.2478/minrv-2022-0001

Abstract: *The present study evaluates on site the effects of provisional support on the rate of deformation (convergence) of clay-stone of a twin-tube tunnel. The combination of shotcrete, steel lattice, steel retaining, pre-supporting iron bar and Rock bolts can act as structural support in the form of provisional support for new or existing tunnels. Applications of provisional supports as confinement mechanisms to decrease the capacity of convergence can be helpful for distressed rock mass during tunnels digging. Real-size and real-time field monitoring over a period of approximately one (01) year was carried out with a Tachometer "Leica, TS 09" and 3D Displacement Monitoring Objectives fixed on the top heading and on the invert/bench. Wherefore; a sketch of the same cross-section of the tunnel was used in order to define the deformations of the rock mass of the tunnel measured in 3D in successive periods in all directions along the weak rock mass of the fourth class (IV) after the installation of the provisional support. The study shows good results in terms of deformation of the rock mass of the tunnel and satisfactory stability in terms of confinement. Consequently; it was noticed, that there is a relation between the deformations (convergence) in the two tubes along tunnel - when the deformation of the left tube increases the deformation of the right tube decreases -, and that the deformation of the tunnel is a deformation overall of the rock mass and it is the same along the tunnel relative to its rock mass. It can be concluded that there is a reciprocal effect between the two tunnel tubes, which can be considered as a conservation principle of the rock mass.*
Keywords: *Twin Tube Tunnel, Clay-Stone, Provisional Support, Deformations, Monitoring.*

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, 4, 5, 6, 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, 9, 10]. The main feature of NATM is the application of support at the right time. In this case, it is accepted that there will be no load transfer on the coating concrete since the pressure from the ground is supported by the primary support system.

[*] Corresponding author: Houssam Khelalfa, Assoc.Prof. PhD., Selinus University of Science and Literature (SUSL), Faculty of Engineering and Technology, Bologna, Italy, contact details (Tel.: +213697601497, khelalfahoussam@gmail.com, ORCID: 0000-0002-8052-6947)

vol. 28, issue 1 / 2022
pp. 1-23

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 monitoring program includes the specification of the measurement procedure, the location of the monitoring devices and the monitoring schedule [11, 12, 13]. Attention is given to the fact that monitoring results are often affected by instrumentation, installation and environmental effects. The type of instrumentation chosen must ensure the following conditions:

- A feasible installation procedure,
- Sustainability during the monitoring period,
- Protection against damage during construction,
- Simple processing of measurements (acquisition and transmission of data),
- Precision is required.

In general, close readings of excavation activities are taken daily; the frequency is reduced with the distance to the forehead and the decrease of the displacement rates. Shorter monitoring intervals may be required due to the specific project requirements. Monitoring sections in tunnels and shafts are usually located at distances of 5 to 20 m depending on the conditions and requirements limits. A possible concept might display minimum reading frequencies and ranges for surface and underground monitoring for a summit-wings-bottom sequence. Usually, there are types of failure that cannot be detected in time by deformations monitoring, it is recommended to use additional monitoring of absolute displacements, but in a small extent. Thus the presence of an emergency surveillance system in case of adverse field conditions is ensured [14, 15]. In the case of block rock mass tunnels, the characteristic hazards are the detachments caused by the discontinuity of the blocks; therefore the observations must concentrate on the soil structure, the location and the orientation of the discontinuity with respect to the alignment of the tunnel. In the case of tunnels with moderate to high overload in the bedrock or foliar mass, the characteristic risks are; the orientation of the stratification or foliation, the displacement of the pavement, the displacements of the soil and the structure of the soil [16, 17, 18, 19]. Consequently, the observation focused on: visual inspections, laboratory tests, absolute displacement monitoring.

2. Geotechnical characteristics and geology of the project area

The geological and geotechnical model of the tunnel is established using geological mapping and borehole investigation data. Six (06) boreholes in 2012-2013 and three (03) boreholes in 2015 are drilled in order to determine the structural and engineering characteristics of the geological units of the tunnel path and the state of the groundwater (figure 1) within the framework of a project in Algeria of a highway linked to the port of DjenDjen in Jijel province and El-eulma in Setif province. The path of the tunnel is located completely in the flysch made up of the alternation of mudstone and aged Albo-Aptian sandstone. The flysch is composed of mudstone which has a folded, weakly-moderately decomposed, weak-very weak rock nature and fine-grained sandstone which has a medium-thick, weakly decomposed, moderately solid-solid rock nature [20, 21]. The tunnel support systems can be modified depending on the geological and geotechnical conditions encountered [22, 23, 24]. The classification of rock masses on the tunnel path is determined according to RMR and Q System [25, 26, 27, 28, 29].

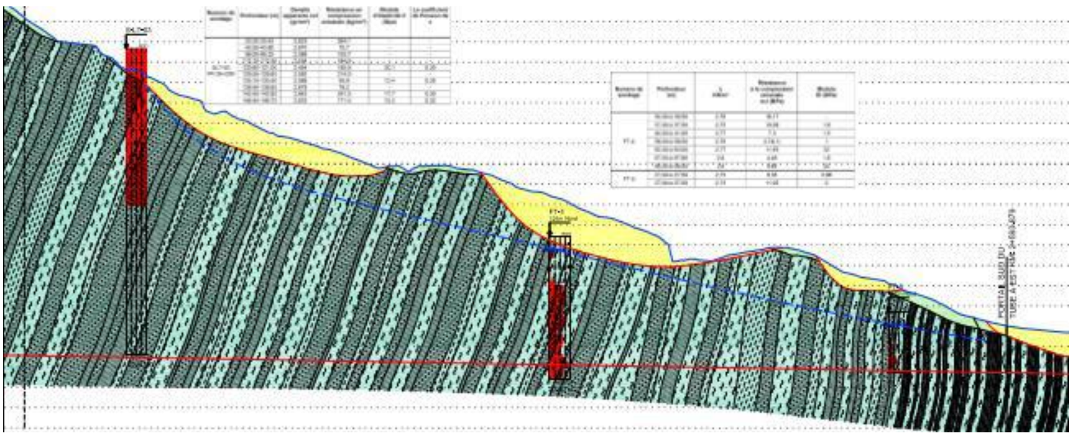

Figure 1. Location of the tunnel (red line) on an extract from the geological map of Tamesguida, between KP. 26 + 100 - KP. 26 + 650 (scale 1 / 50,000)

vol. 28, issue 1 / 2022
pp. 1-23

The geological and geotechnical details of the tunnel route having been developed, the studies of 6 boreholes opened in the period 2012-2013 (FT-1, FT-2, FT-3, FT-4, FT-5 and FT-6) and of 3 boreholes opened in 2015 (S-LT-01, S-LT-02 and S-LT-03) were evaluated in order to determine the engineering specifications of the units located in this part. The coordinates relating to the surveys carried out, the dimensions of the opening and their depths have been listed. As part of this work, three surveys in total were carried out; borehole numbers BH-26 at 50 meters deep on the left tube and borehole numbers TBH-1 at 80 meters deep on the left tube at PK 26 + 638 then borehole numbers TBH-2 at 50 meters deep on the coordinates 747372.526 (E), 4060873.833 (N), about 150m east of the passage of the valley which is located on the axis of the tunnel between PK 25 + 250 - PK 25 + 300, which are the upper elevations (+ 630m) from the same valley form a valley. The borehole number TBH-1 (figure 2), was carried out to analyze the thickness of its topography of the landslide and its influence on the tunnel identified between KP 24 + 955 - KP 25 + 125 on the axis of the tunnel (PK 25-030) and a landslide zone containing pieces of rock belonging to a flysch pile with the dimensions of fine-coarse gravel in a sandy clay matrix 21.50 m thick was identified. From 21.50 m up to 80 m which is the bottom of the bure, mudstone - siltstone - alternating sandstone was discovered with a pile of flysch in the boring. These units are decomposed to a resistance of average low degree and of low-average resistance between 21.50 - 35.50 m and fresh little decomposition to a resistance of average degree after 35.50 m.

Figure 2. View of the decomposed new-low degree flysch units from the TBH-1 survey

As indicated in the geological context, the part is located (figure 3) between the entrance of the right tube of Texanna tunnel (in Jijel province) and PK: 24 + 840 and between the entrance of the left tube of Texanna tunnel and PK: 0 +761.82, tunnel level passes in the old Albo-Aptian Flysch unit.

Figure 3. Photo of the tunnel portal

The geotechnical parameters were designated for the unit encountered in this part using data obtained from borehole S-LT-02 and borehole S-LT-01 located in this part of the tunnel. The evaluations carried out show that the unit located at the level of the tunnel is part of the "Low Rock IV" class according to the RMR classification. In addition, the KP: 24 + 840 part where the maximum coverage height is observed can be qualified as "critical part". The cross sections taken from part PK: 24 + 840 are shown below (figure 4). The design parameters of this part exposed above are summarized in table (1).

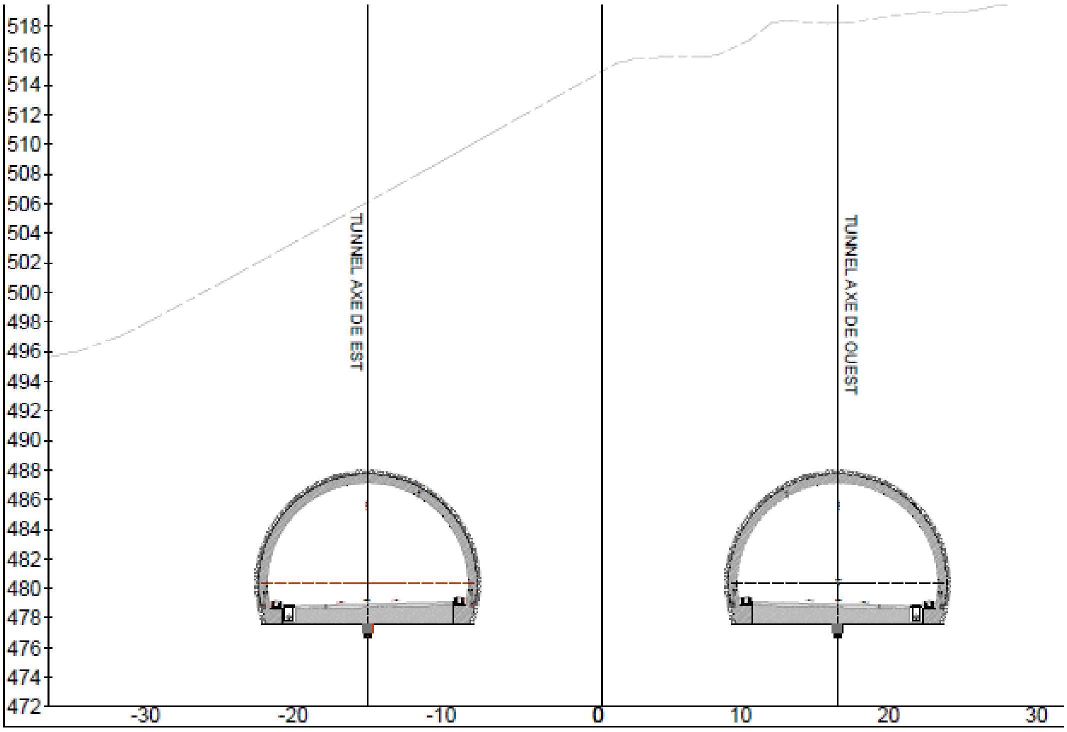

Figure 4. Inner cross section of twin-tube tunnel

3. Material and methodology

3.1. Excavation steps of low rock and monitoring

In order to ensure the smooth progress of the tunnel digging, the opening of the gallery will be in half-section. An upper half (calotte/ top heading), a half lower left and right (Strozze/Bench) and the bottom (invert). During each excavation phase, the topographic team will always be on site for the various controls. The station setup of the total station instrument can be done in two (02) methods;

- The free station method consists in setting the station on a fictitious point located as close as possible to the vertical plane passing through the hanger and to orientate itself on a minimum of 02 terminals (bounds).
- The setting up of the device on a known terminal and oriented on another terminal while avoiding the maximum tangential sights.

Following the geological constraints of the soil and the eventual use of the explosives, the so-called "B" line of the actual excavation line will be lifted and checked in a contradictory way, this one allows the quantification of the excavated materials and the volumes of the shotcrete to put.

If the rock is friable/ poor/ loose, the excavation is carried out by a machine that attacks the soil punctually and progressively. These self-propelled machines on wheels or tracks are equipped with adjustable arms, at the end of which is placed the attacking apparatus (excavating bucket, breaker, cutting head with longitudinal or transverse axis). The cuttings are evacuated towards the rear. The wall is equipped with the advancement of a temporary support. This technique is suitable for all excavation profiles. The excavation steps are as following (figure 5):

- Excavations of the upper half (Top heading):
  - Excavations,
  - The surface will be coated with 7cm shotcrete,
  - Injection pre-support bars will be anchored (one (1) per each three (5) hanger,

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590 vol. 28, issue 1 / 2022
pp. 1-23

- The steel wire mesh will be implemented (Q589/443),
- Steel hanger will be set up (HEB 220),
- Shotcrete will be completed up to 29cm,
- The steel wire mesh will be implemented (Q589/443),
- The shotcrete will be completed up to 35cm,
- IBO bolts will be implemented.

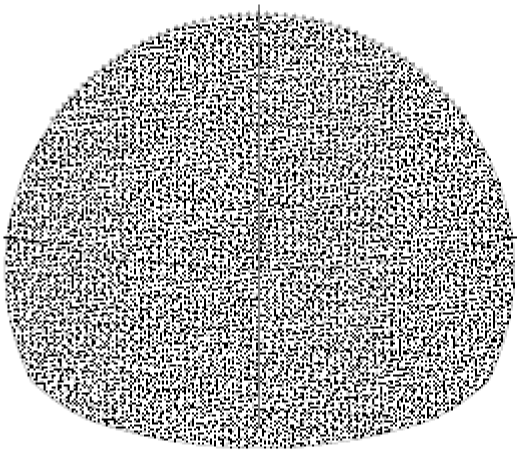


Figure 5. (a)- Phase 1: Application of 3 “injection sinking pipes” to the cutting face in 30-40 cm intervals prior to excavation

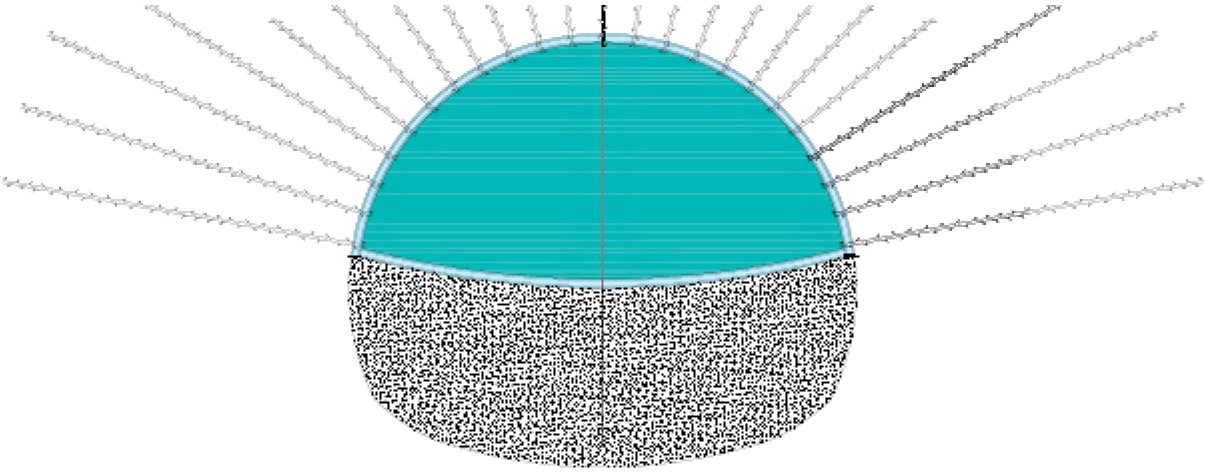


Figure 5. (b)- Phase 2: Making an excavation along the recommended circle on the upper half,
Application of a wire mesh (150 * 150 * 6.5 mm). HEB 220 steel cladding, Surface coating with 35 cm shotcrete,
Temporary Slab, wire mesh and shotcrete casting and IBO bolt application

 vol. 28, issue 1 / 2022
pp. 1-23

- Excavations of the lower half (Bench):
    - Excavations in 2 steps,
    - The surface will be coated with 7cm shotcrete,
    - The steel wire mesh will be implemented (Q589/443),
    - Steel hanger will be set up (HEB 220),
    - Shotcrete will be completed up to 29cm,
    - The steel wire mesh will be implemented (Q589/443),
    - The shotcrete will be completed up to 35cm,
    - IBO bolts will be implemented.

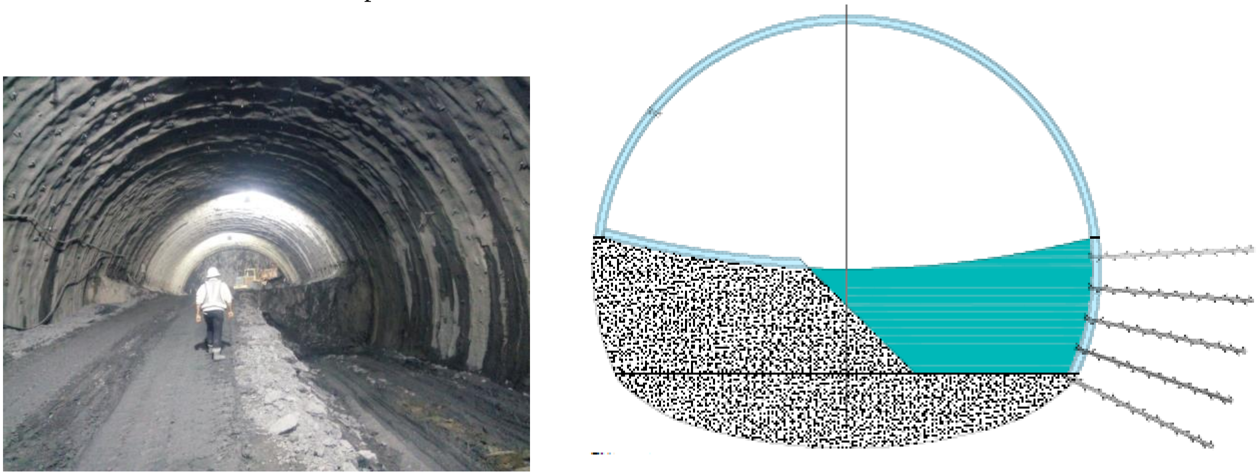

Figure 5. (c)- Phase 3: Excavation along the recommended circle on the lower right-lateral half, Application of wire mesh (150 * 150 * 6.5 mm). HEB 220 steel cladding, Surface coating with 35 cm shotcrete, and IBO bolt application

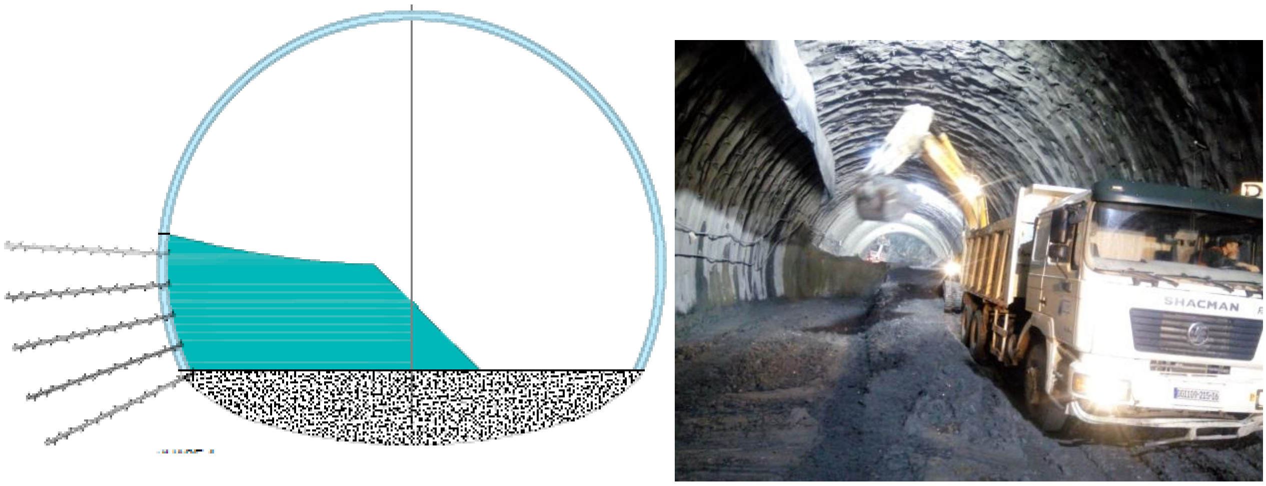

Figure 5. (d)- Phase 4: Making an excavation along the recommended circle on the lower left-lateral half, Application of a wire mesh (150 * 150 * 6.5 mm). HEB 220 steel cladding, Surface coating with 35 cm shotcrete, and IBO bolt application

- Excavations of Bottom (Invert):
    - Excavations; Max. in 4 steps,
    - The surface will be coated with 7cm shotcrete,
    - The steel wire mesh will be implemented (Q589/443),
    - Steel hanger will be set up (HEB 220),
    - Shotcrete will be completed up to 29cm,
    - The steel wire mesh will be implemented (Q589/443),
    - The shotcrete will be completed up to 35cm,
    - IBO bolts will be implemented.
    - Backfilling.

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 28, issue 1 / 2022
pp. 1-23

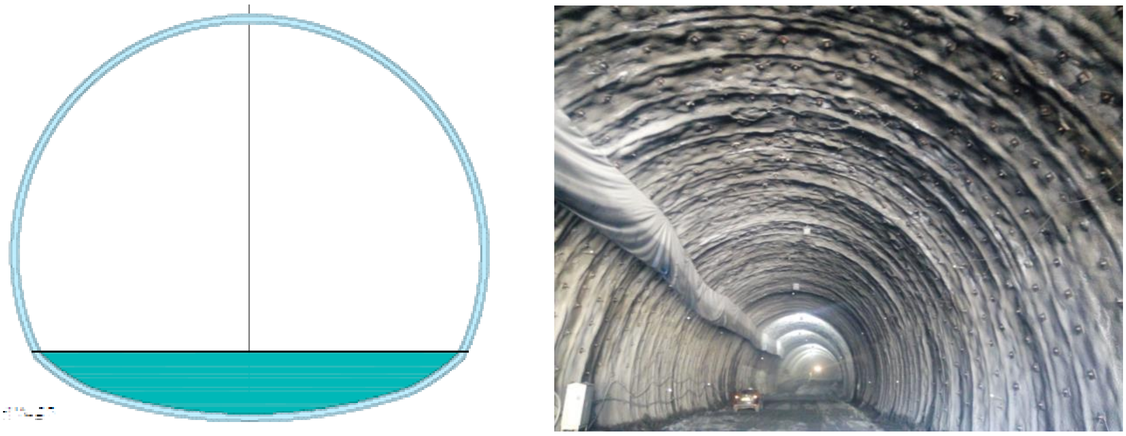

Figure 5. (e)- Phase 5: Execution of an excavation along the recommended circle on the base/ Slab, Application of a wire mesh (150 * 150 * 6.5 mm). HEB 220 steel cladding, Surface coating with 35 cm shotcrete, and IBO bolt application

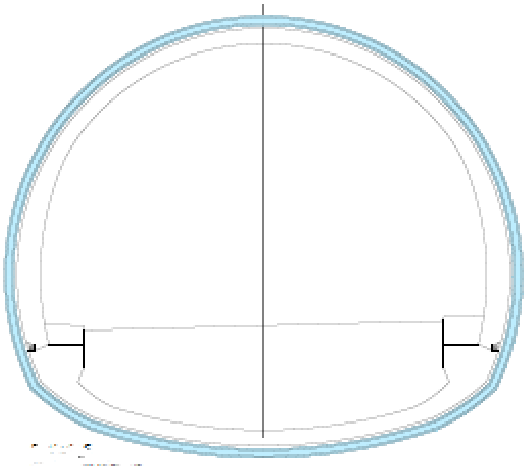

Figure 5. (f)- Phase 6: final coating

As detailed above and in the geotechnical report, this part of the tunnel passes through weak (poor) rock conditions (IV). Supports planned for use in the analyses in this part of the tunnel and the characteristics of the tunnel are given in the table (1).

Table 1. Geotechnical Design Parameters for Interval Right Tube Entrance Portal – KP:24+840
& Left Tube Entrance Portal –KP:0+761.682.

Rock Mass Parameters		**Primary Support Parameters**		
		Total		
Tunnel Radius r_0	7.5 m	Maximum support pressure		1.791 MPa
		Maximum support strain		0.2 %
		Installed at distance from tunnel face		1 m
In-situ Stress P_0	1.62 MPa	Initial tunnel convergence		1.04 %
		Initial wall displacement		78.15 mm
		Longitudinal deformation profile		Vlachopoulos and Diederichs (2009)
		Rock bolts		
		Type		34 mm Rock bolt
Young's Modulus of Rock Mass E	404 MPa	Maximum support pressure		0.354 MPa
		Maximum support strain		0.2 %
		Rock bolt circumferential spacing		1 m
		Rock bolt longitudinal spacing		1 m
Poisson Ratio υ	0.3	**Steel set**		
		Type		Wide flange rib
		Properties	Area	216 mm^2
			Section Depth	9100 mm
			Weight	71 kg/m

<table>
<tr><td rowspan="5">Compressive Strength of Rock Mass σ_m</td><td rowspan="5">0.119 MPa</td><td colspan="2">Maximum support pressure</td><td>0.297 MPa</td></tr>
<tr><td colspan="2">Maximum support strain</td><td>0.118 %</td></tr>
<tr><td colspan="2">Steel set out-of-plane spacing</td><td>1 m</td></tr>
<tr><td colspan="3">Shotcrete</td></tr>
<tr><td colspan="2">Type</td><td>Custom</td></tr>
<tr><td rowspan="6">Friction Angle Ø</td><td rowspan="6">32°</td><td rowspan="4">Properties</td><td>Thickness</td><td>350 mm</td></tr>
<tr><td>UCS</td><td>25 MPa</td></tr>
<tr><td>Young's modulus</td><td>30250 MPa</td></tr>
<tr><td>Poisson ratio</td><td>0.2</td></tr>
<tr><td colspan="2">Maximum support pressure</td><td>1.139 MPa</td></tr>
<tr><td colspan="2">Maximum support strain</td><td>0.076 %</td></tr>
</table>

3.2. *Monitoring methods of deformation inside the tunnel (convergence)*

3.2.1 Fundamental principles of 3D monitoring of absolute displacements

Over the past two decades, 3D monitoring of travel has become a common practice and, because of the high information content, has gradually replaced other techniques. Measurements are performed using a total station (tachometer) and objectives. Precise prism lenses as well as bi-reflex lenses (reflectors) are used and their spatial position in the overall coordinate system or project is determined. Discrete three-dimensional displacement measurements are performed by repeated measurements (usually on a daily basis). Since full monitoring cannot usually be performed from one position, an interconnected observation scheme is required, which is established using identical reference points (Figure 6-a). Stable reference points are differentiated from points that always move (Figure 6-b). Points with a defined maximum displacement rate (usually <1mm / month) can be used as reference points.

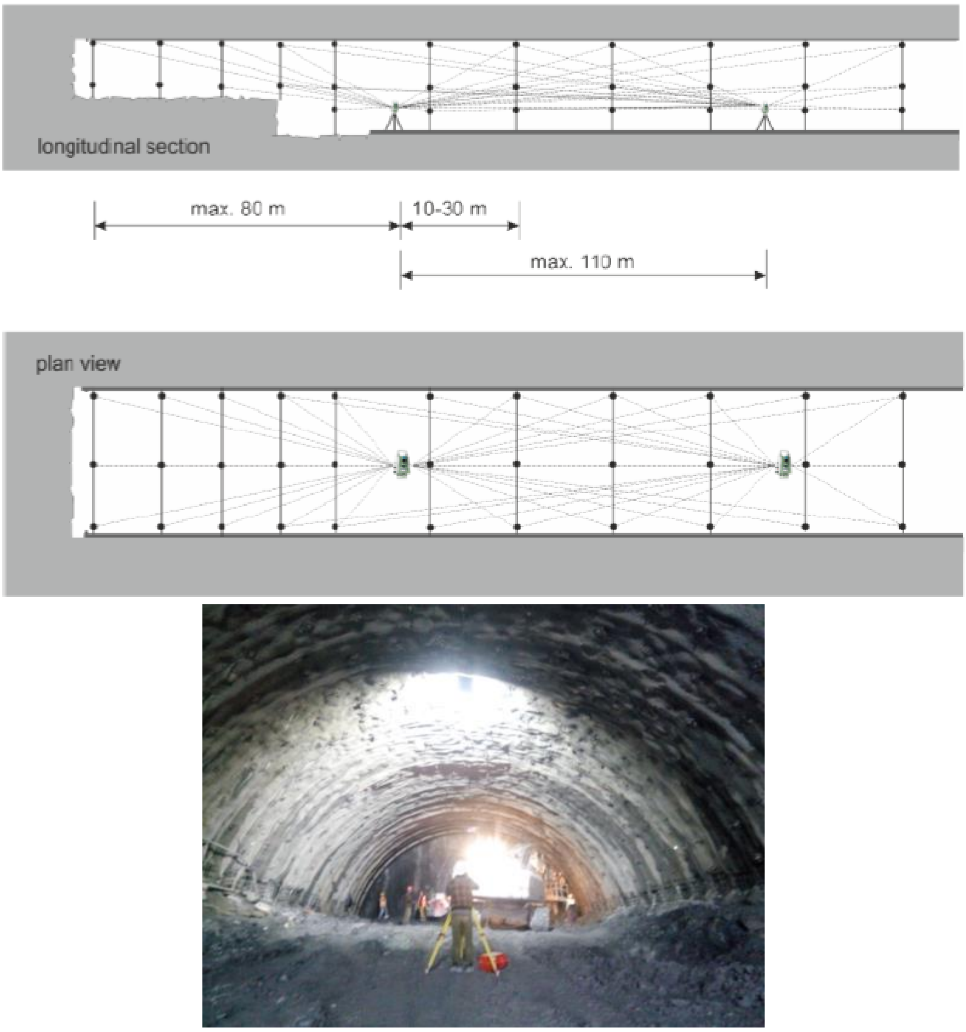

Figure 6. (a): Sketch of an interconnected free station method in the tunnel

vol. 28, issue 1 / 2022
pp. 1-23

3.2.2. Requirements

The principle of "free parking determined" is used to obtain the position of the instrument. The absolute position of all coordinate components of the marked measuring points shall be determined with an accuracy of +/- 1 mm (standard deviation) with respect to the neighboring measuring sections over the entire observation period. To achieve this accuracy, the following conditions must be met;

- Distance between the instrument and the nearest reference point: 10 - 30 m.
- Minimum distance to the reference point furthest: 90 m.
- Maximum distance to monitoring points: 80 m.
- Maximum distance between monitoring positions: 110 m.
- Approximate use of the same instrument positions for consecutive readings.
- Positioning the instrument on stable ground.
- Initiate the nearest free parking and finish the most distant goals.
- The movement measurement starts from the farthest lens.
- Make connection observations approximately symmetrical to the tunnel axis.
- Intermediate orientation measures and closure verification at selected reference points.
- Perform zero reading immediately after lens installation (before the next excavation).
- The measurement of all the points of a section (in the case of reading at zero in the bench, the summit objectives must also be measured).
- Registration of weather conditions taken into account in the assessment.
- Acclimation of the instrument to avoid deviations due to temperature change.

The following sources of errors should be avoided;

- Observations near the tunnel wall (minimum wall distance of 0.5 m to 1 m),
- Measurement errors due to refraction (e.g. observation through or near heat sources),
- Position of the instrument near the side/ lateral walls,
- Observations in asymmetrical connection (see Figure 6-b),
- Measurements in a very dusty environment or during severe vibrations (i.e. caused by machinery).

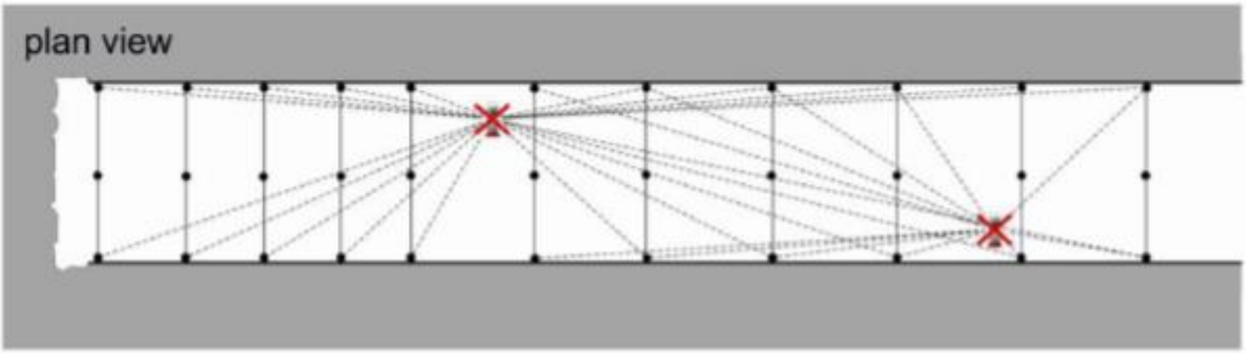

Figure 6. (b): Sketch of asymmetrical connection observations (to be avoided)

The surveyor must record and submit the following items after each measurement action: Measurement sequence system (relative to the measurement section or along the tunnel). Unmeasured points and indication of motive (destroyed, not visible, etc.). Significant displacements (measurement error, rapid increase in displacements);

- Readings at zero,
- Monitoring conditions (air quality, vibration, limited visibility, heat sources, etc.).

3.2.3 Tachometer

An electronic total station (Figure 6-c) with an automatic recording unit with the following minimum details shall be used;

- Measuring the horizontal angle: +/- 1’’ (0.3 mgon),
- Measuring the vertical angle: +/- 1’’ (0.3 mgon),
- Distance from measure: +/- (1 mm + 1.5 ppm).

 vol. 28, issue 1 / 2022
pp. 1-23

Figure 6. (c): Photograph of the Tachometer, e.g. "Leica, TS 09" of the tunnel underground monitoring

3.2.4. Objectives

The lenses are installed on special bolts with an adapter (see Figure 6-d).

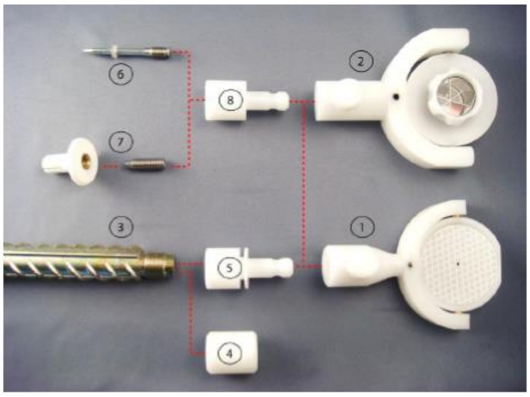

Figure 6. (d): Components of 3D Displacement Monitoring Objectives; Bi-reflex (1) and prism lens (2), bolt (3) with protective cap (4) and predetermined breaking point (5), mounting bolts (6 + 7) with adapter (8)

The minimum manufacturing accuracies required are as follows;

- Adapter with breaking point: +/- 0.1 mm,
- Triple prism lens: +/- 0,01 mm,
- Bi-reflex lens: +/- 0.1 mm.

Minimum repeatability required of readings;

- Triple prism lens: +/- 0,1 mm,
- Bi-reflex lens: +/- 0.3 mm.

This precision applies to repeated readings when the orientation of the lenses is changed or the lenses / adapters are replaced. Figure (6-e) and Figure (6-f) show the common practice installation and protection of a bolt monitoring against damage in the shotcrete coatings. Monitoring bolt and protective cap are attached to wire mesh. During the project, the bolt must be covered appropriately. The bolt head must be recessed a minimum of 10 mm from the surface of the shotcrete coating.

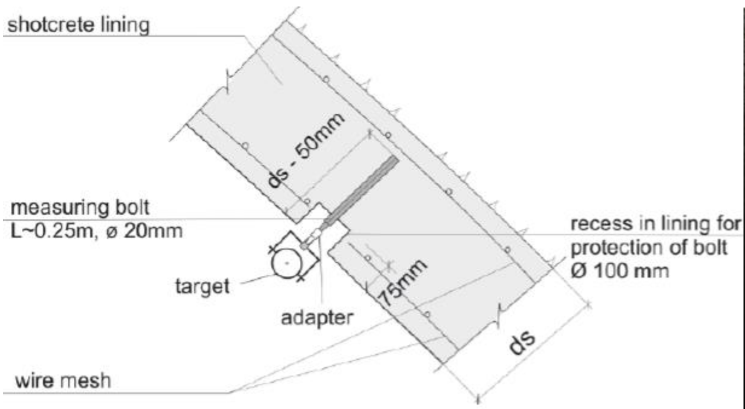

Figure 6. (e): Sketch of the monitoring bolt unit mounted in the shotcrete liner.
(f): Bolt and adapter with prism lens mounted in a niche

vol. 28, issue 1 / 2022
pp. 1-23

3.2.5 Installation and measurement procedure

To achieve maximum efficiency with the measured data and to ensure comparable measurement results, the following points should be observed during underground monitoring and surface monitoring;

- A predefined break point must be provided between the bolt and the lens, to avoid damage caused by bolts.
- Solid mounting of the bolt.
- Protection against damage during the application of shotcrete.
- Existing installations must be taken into account when positioning objectives to ensure observations of the tachometer.
- In the case of surface objectives, the foundations must be integrated under the frost or permafrost zone.
- For surface objectives, the height of the objective above the ground must be between 50 and 100 cm.
- (Refraction influence).

3.2.6 Underground

- The objectives of a monitoring station must be;
    - Install immediately behind the front of the last turn and zero reading taken without delay; the maximum deviations from the planned installation of the station +/- 1 m are acceptable.
    - Install in the same position as those of the previous phases of construction, that is to say sum, bench (tolerance +/- 1 m).
    - Install at the same station as surface surveillance points (tolerance +/- 1 m).
- Concurrent registration of the construction phase (for example, face positions) and exact assignment to measurements;
    - The position of the front is determined by the average value of at least three measures of the position of the front (figure 6-g).
    - The position of the forehead can be determined without a objectives (precision + - 10 cm).
    - The new front position is valid as soon as more than 25% of the face is excavated.

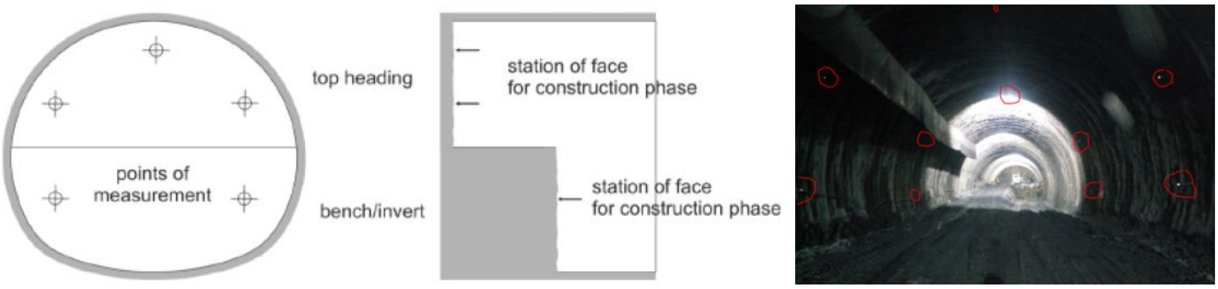

Figure 6. (g): Determination of the frontal position

4. Results and discussions

It was observed in the whole of the rock mass of left tube of the tunnel on the kelomitric point KP. 2,501 (figure 7-a) during a period of 330 days; a total deformation of 4 mm at the Left Waist (it is a punctual deformation which is not distributed towards the different directions), a total deformation of 23 mm at the Left Shoulder (a descending deformation distributes most to the front and some may to the left and to the right), a total deformation of 71 mm at the Crown (a descending deformation distributing most towards the left and a little towards the front), a total deformation of 134 mm at the Right Shoulder (a descending deformation distributing completely towards the front) and a total deformation of 5 mm at the Right Waist (it is a punctual deformation which is not distributed towards the different directions). Also, what remarkable; is that the minimum deformation is located in the waists, and that the maximum deformation is in the Right Shoulder (exactly in the "Crown-Right Shoulder" line on the upper right side of the tunnel's tube), followed by the deformation on the Crown and on the Left Shoulder respectively.

 vol. 28, issue 1 / 2022
pp. 1-23

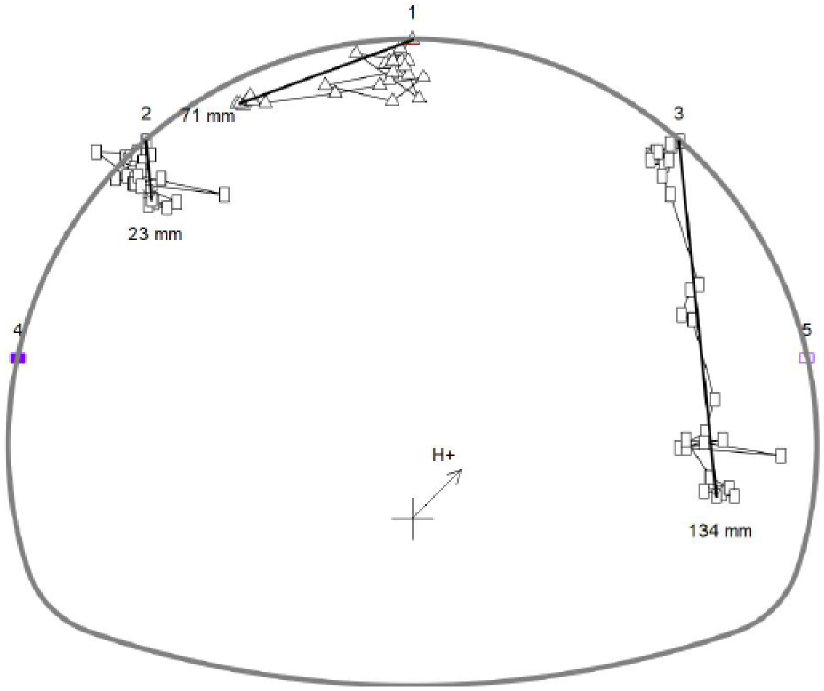

Figure 7. (a): Left tube Tunnel Cross section KP 2,501.000/ First measure: 15.05.-2017, Last measure: 7.04.2018

Afterwards, on the kelomitric point KP. 2,516 (figure 7-b) during a period of 427 days; a total deformation of 5 mm at the Left Waist (an almost punctual deformation with a small distribution to the right), a total deformation of 107 mm at the Left Shoulder (an ascending deformation distribute completely towards the right rear), a total deformation of 30 mm at the Crown (an ascending deformation mostly towards the right rear with a partial deformation directly towards the front), a total deformation of 44 mm at the Right Shoulder (a deformation distributed totally to the left in a half-dispersed way towards rear and front) and a total deformation of 25 mm at the Right Waist (a deformation distributed in a dispersed way in right and left halves towards the front). Also, what remarkable; is that there are significant deformations in all five (05) measuring points, and that the minimum deformation is located in the waists, and that the maximum deformation is in the Left Shoulder (exactly in the "Left Shoulder- Crown" line on the upper left side of the tunnel's tube), followed by the deformation on the Right Shoulder and on the Crown respectively.

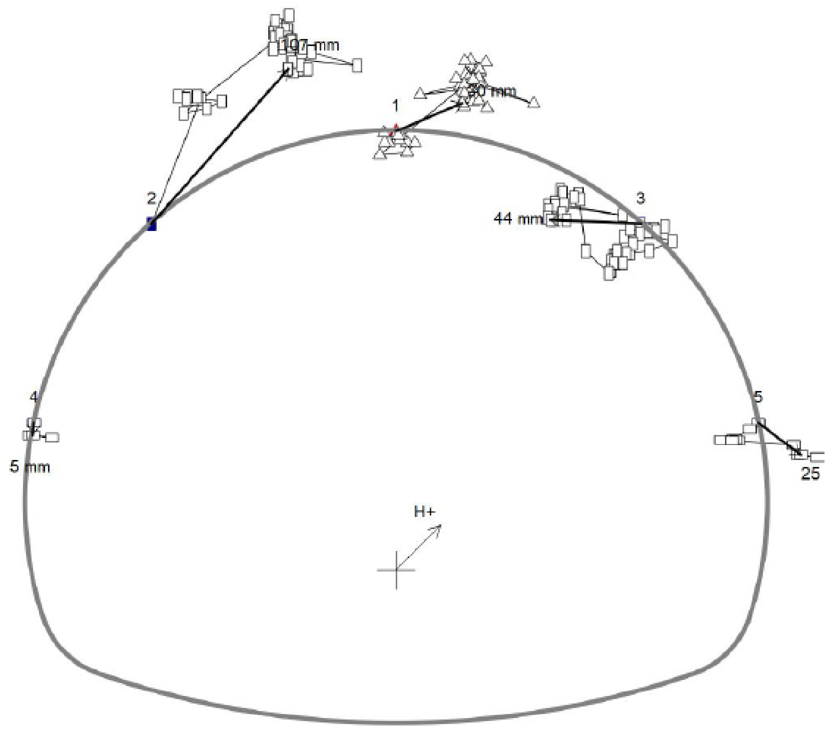

Figure 7. (b): Left tube Tunnel Cross section KP 2,516.000/ First measure: 17.01.2017, Last measure: 21.03.2018

 vol. 28, issue 1 / 2022
pp. 1-23

Afterwards, on the kelomitric point KP. 2,541 (figure 7-c) during a period of 270 days; a total deformation of 4 mm at the Left Waist (a minor almost punctual deformation distributed in all directions in an equal way), a total deformation of 32 mm at the Left Shoulder (a descending deformation distributing almost completely towards the front), a total deformation of 48 mm at the Crown (a descending deformation distributing almost completely towards the front of the left side), a total deformation of 51 mm at the Right Shoulder (A descending deformation distributing almost totally to the left of the front) and a total deformation of 2 mm at the Right Waist (a minor almost punctual deformation distributed in all directions in an equal way). Also, what remarkable; is that there is a closeness deformation value between three (03) measuring points (1, 2 and 3), and that the minimum deformation is located also in the waists, and that the maximum deformation is in the Right Shoulder (exactly in the "Right Shoulder- Core" line on the upper right side of the tunnel's tube), followed by the deformation on the Crown and on the Left Shoulder respectively.

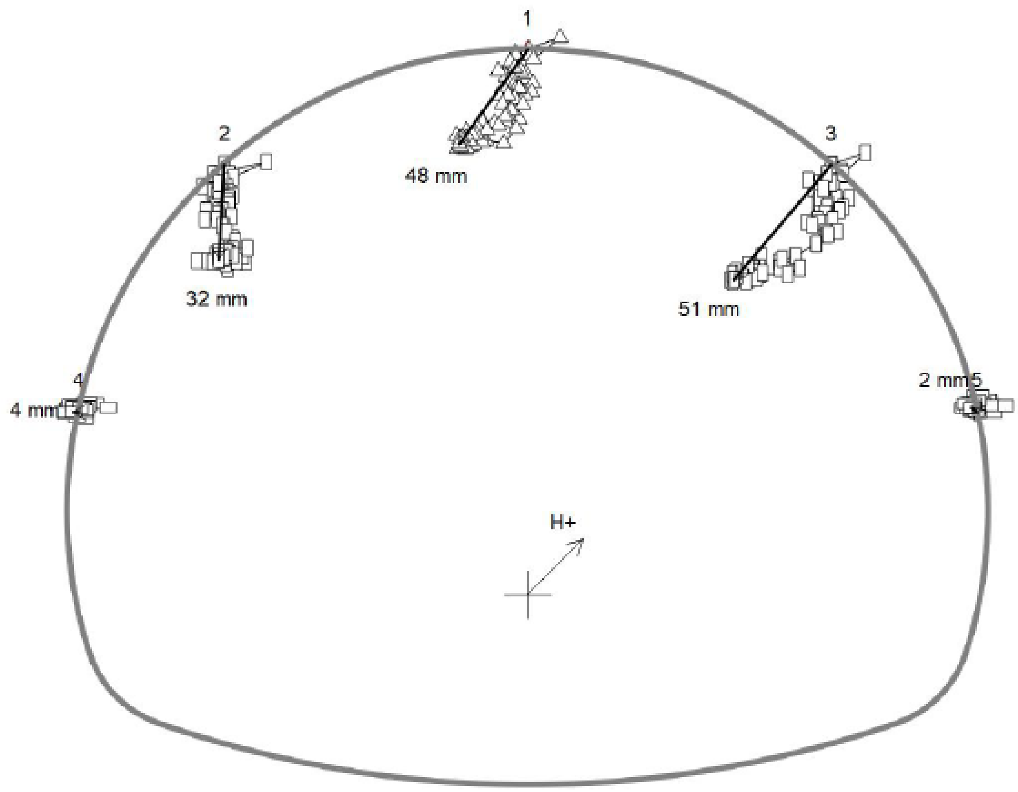

Figure 7. (c): Left tube Tunnel Cross section KP 2,541.000/ First measure: 21.06.2017, Last measure: 26.03.2018

Afterwards, on the kelomitric point KP. 2,555 (figure 7-d) during a period of 387 days; a total deformation of 43 mm at the Left Waist (a deformation to distribute completely to the rear right with a small punctual deformation), a total deformation of 25 mm at the Left Shoulder (a descending deformation distribute equally to the front, left and right), a total deformation of 24 mm at the Crown (a descending deformation distributing almost completely evenly to the front, left and right with a small deformation towards the rear), a total deformation of 29 mm at the Right Shoulder (a deformation distribute halfway evenly to the front and rear) and a total deformation of 5 mm at the Right Waist (a minor punctual deformation distributed in all directions in an equal way). Also, what remarkable; is that there is a first appearance of a significant deformation on the left waist since the first monitoring in this tunnel tube, and that the minimum deformation is located this time only on the Right Waist, and that the maximum deformation for the first time is in the Left Waist (exactly in the " Left Waist - Crown" line on the middle left side of the tunnel's tube), followed by the deformation on the Right Shoulder, Left Shoulder and on the Crown respectively.

vol. 28, issue 1 / 2022
pp. 1-23

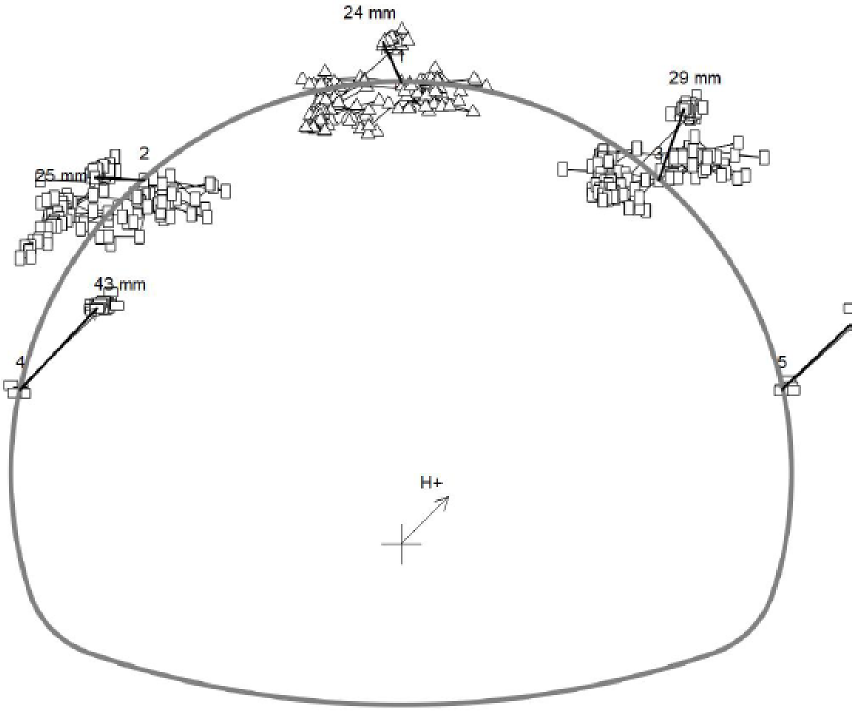

Figure 7. (d): Left tube Tunnel Cross section KP 2,555.000/ First measure: 4.03.2017, Last measure: 26.03.2018

Afterwards, on the kelomitric point KP. 2,566 (figure 7-e) during a period of 354 days; a total deformation of 36 mm at the Left Waist (a descending deformation distributing to the front left and the front right in an equal manner with a small almost punctual deformation), a total deformation of 49 mm at the Left Shoulder (a descending deformation distribute totally towards the front left in an expansive way towards the core), a total deformation of 76 mm at the Crown (a descending deformation distribute a little to the front and most to the front right in a progressive manner), a total deformation of 61 mm at the Right Shoulder (a descending deformation distribute towards the right rear in a balanced manner) and a total deformation of 78 mm at the Right Waist (an ascending deformation distribute a little towards the right rear and most towards the front). Also, what remarkable; is that for the first time since the monitoring started; there are significant deformations in all five (05) measurement points (1, 2, 3, 4 and 5), and that the maximum deformation for the second time is in the Waist (exactly in the "Right Waist - Core" line on the middle right side of the tunnel's tube), followed by the deformation on the Crown, Right Shoulder, Left Shoulder and on the Left Waist respectively.

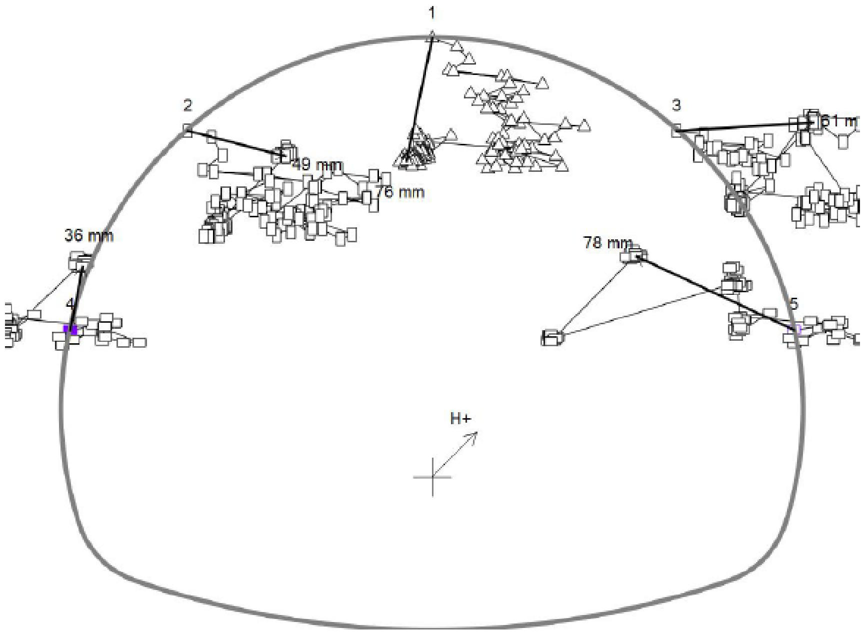

Figure 7. (e): Left tube Tunnel Cross section KP 2,566.000/ First measure: 19.02.2017, Last measure: 8.02.2018

Revista Minelor – Mining Revue vol. 28, issue 1 / 2022
ISSN-L 1220-2053 / ISSN 2247-8590 pp. 1-23

Then lastly, on the kelomitric point KP. 2,577 (figure 7-f) during a period of 377 days; a total deformation of 44 mm at the Left Waist (a deformation distributed equally towards almost all directions with a small deformation towards the rear), a total deformation of 67 mm roughly at the Left Shoulder (a descending deformation distribute totally towards the right front and left front in an equal and progressive manner), a total deformation of 33 mm at the Crown (a descending deformation distribute almost completely towards the left front in a progressive manner), a total deformation of 45 mm at the Right Shoulder (a descending deformation distributing almost completely in an expansive manner to the front left with a small ascending deformation towards the rear) and a total deformation of 55 mm roughly at the Right Waist (a deformation distributed towards all directions in an almost equal way). Also, what remarkable; is that the deformations at the level of the five (05) measurement points (1, 2, 3, 4 and 5) are closeness, and that the maximum deformation is in the Left Shoulder (exactly in the Left " Shoulder - Waist" line on the left side of the tunnel's tube), followed by the deformation on the Right Waist, Right Shoulder, Left Shoulder and on the Crown respectively.

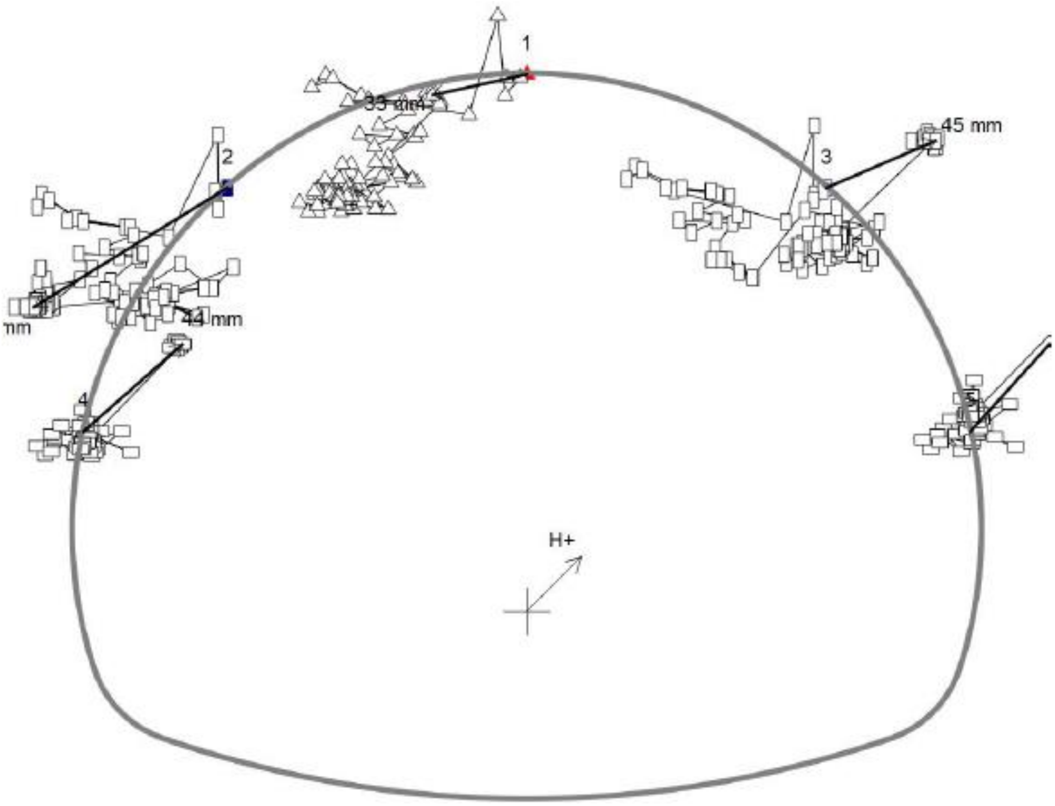

Figure 7. (f): Left tube Tunnel Cross section KP 2,577.000/ First measure: 26.01.2017, Last measure: 8.02.2018

Secondly; it was marked in the whole of the rock mass of right tube of the tunnel on the kelomitric point KP. 26,562 (figure 8-a) during a period of 155 days; a total deformation of 25 mm at the Left Waist (a non-diffuse and non-expanded almost punctual deformation distribute slightly to the right front), a total deformation of 26 mm at the Left Shoulder (a deformation concentrate descending distribute slightly most towards the front right), a total deformation of 28 mm at the Crown (a non-diffuse and non-expanded deformation almost punctual distribute totally towards the front in a slight manner), a total deformation of 29 mm at the Right Shoulder (a non-diffuse and non-expanded deformation almost punctual distribute slightly towards the front left) and a total deformation of 28 mm roughly at the Right Waist (it is a punctual deformation which is not distributed towards the different directions). Also, what remarkable; is that the deformations at the level of the five (05) measurement points (1, 2, 3, 4 and 5) are almost all punctual and had almost the same values, and that the maximum deformation is in the Right Shoulder, followed equally by the deformation on the Right Waist and the Crown, then on the Left Shoulder and Left Waist respectively.

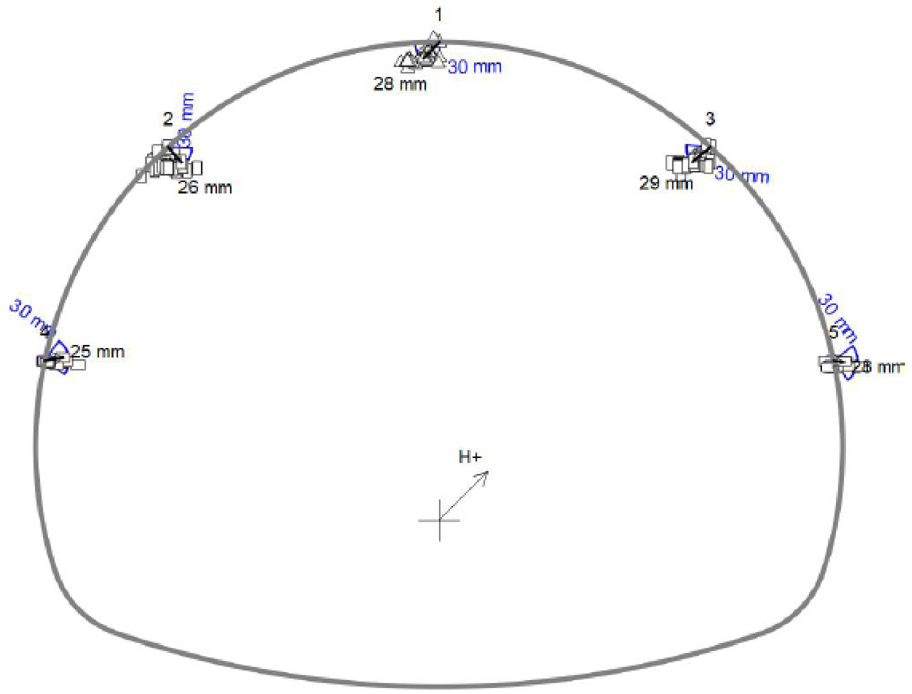

Figure 8. (a): Right tube Tunnel Cross section KP 26,562.000/ First measure: 21.11.2017, Last measure: 26.03.2018

Afterwards, on the kelomitric point KP. 26,576 (figure 8-b) during a period of 346 days; a total deformation of 00 mm at the Left Waist (null deformation), a total deformation of 55 mm at the Left Shoulder (a direct and non-expanded deformation almost punctual distribute completely to the front right), a total deformation of 52 mm at the Crown (a deformation concentrate descending distributes totally towards the front right in a slight manner), a total deformation of 37 mm at the Right Shoulder (a concentrated deformation distribute to half equally to the front and to the rear) and a total deformation of 11 mm at the Right Waist (a non-diffuse and non-expanded deformation almost punctual distribute towards the different directions). Also, what remarkable; is the absence of deformation in the left waist, and that the maximum deformation is in the Left Shoulder, followed by the deformation on the Crown, Left Shoulder and Left Waist respectively.

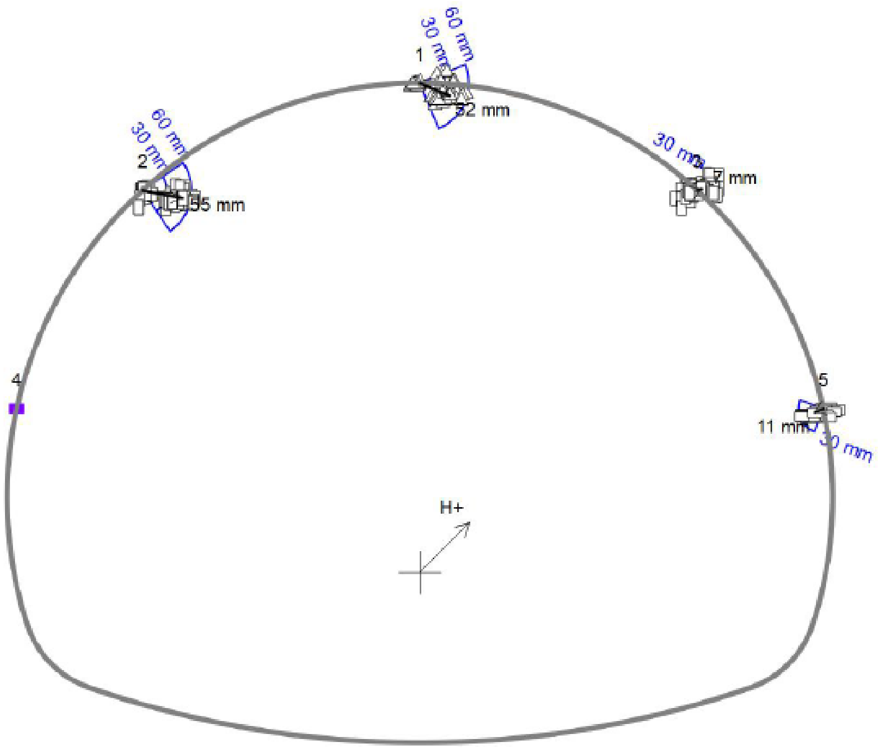

Figure 8. (b): Right tube Tunnel Cross section KP 26,576.000/ First measure: 15.05.-2017, Last measure: 26.03.2018

vol. 28, issue 1 / 2022
pp. 1-23

Afterwards, on the kelomitric point KP. 26,588 (figure 8-c) during a period of 346 days; a total deformation of 09 mm at the Left Waist (a concentrated non-defused and non-expanded deformation distribute to the front), a total deformation of 51 mm at the Left Shoulder (a concentrated descending deformation distribute almost completely to the front with a small part towards the rear in a slight manner), a total deformation of 57 mm at the Crown (a concentrated deformation distribute most to the front with a rest part to the rear in a slight manner), a total deformation of 70 mm at the Right Shoulder (a non-defused and non-expanded deformation concentrated distribute almost totally to the front) and a total deformation of 67 mm at the Right Waist (a concentrated descending deformation distribute almost completely to the front slightly left). Also, what remarkable; is that almost all the deformations in the five (05) measurement points are concentrated and unexpanded and are closeness in the four points (1, 2, 3 and 5), and that the maximum deformation is in the Right Shoulder, followed by the deformation on the Right Waist, Crown, Left Shoulder and Left Waist respectively.

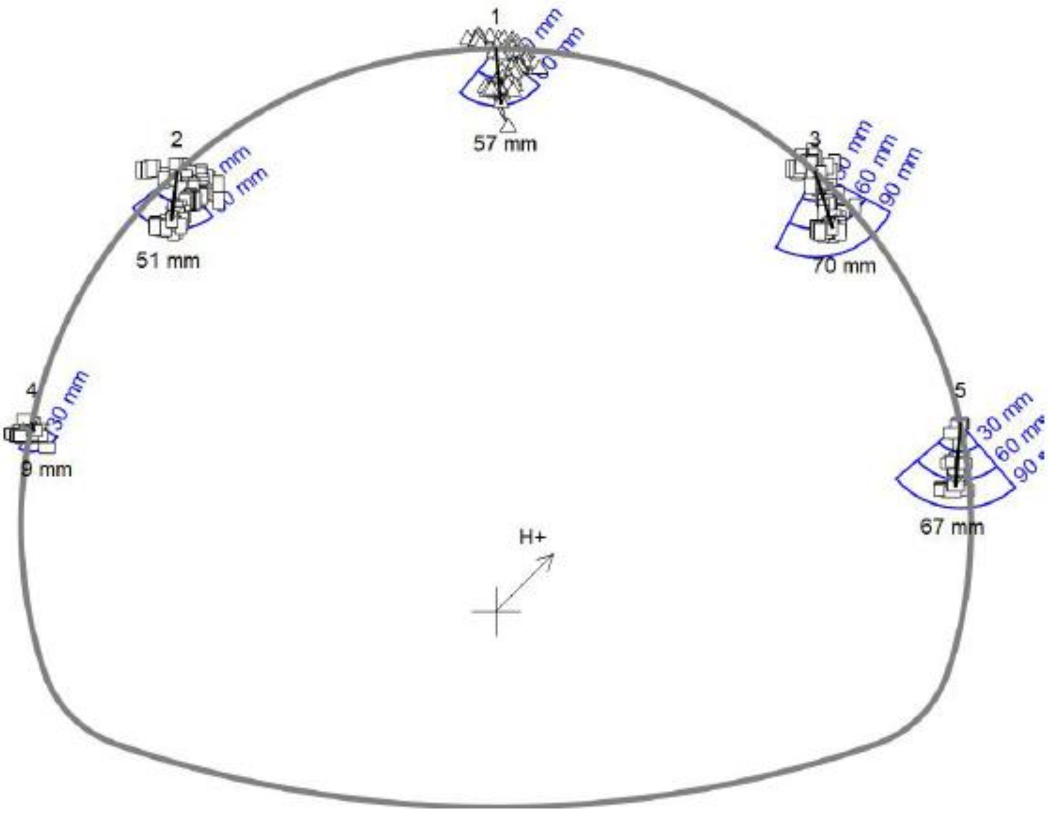

Figure 8. (c): Right tube Tunnel Cross section KP 26,588.000/ First measure: 15.05.-2017, Last measure: 26.03.2018

Afterwards, on the kelomitric point KP. 26,603 (figure 8-d) during a period of 305 days; a total deformation of 07 mm at the Left Waist (a concentrated non-defused and non-expanded deformation distribute to the front left), a total deformation of 00 mm at the Left Shoulder (null deformation), a total deformation of 66 mm at the Crown (a concentrated non-defused deformation distribute totally to the front in a slight manner), a total deformation of 73 mm at the Right Shoulder (a non-defused and non-expanded deformation concentrated distribute totally to the front left) and a total deformation of 25 mm at the Right Waist (a concentrated punctual deformation). Also, what remarkable; is the absence of the deformation in the Left Shoulder since the first monitoring in this tunnel tube, and that the maximum deformation is in the Right Shoulder, followed by the deformation on the Crown, Right Waist and Left Waist respectively.

vol. 28, issue 1 / 2022
pp. 1-23

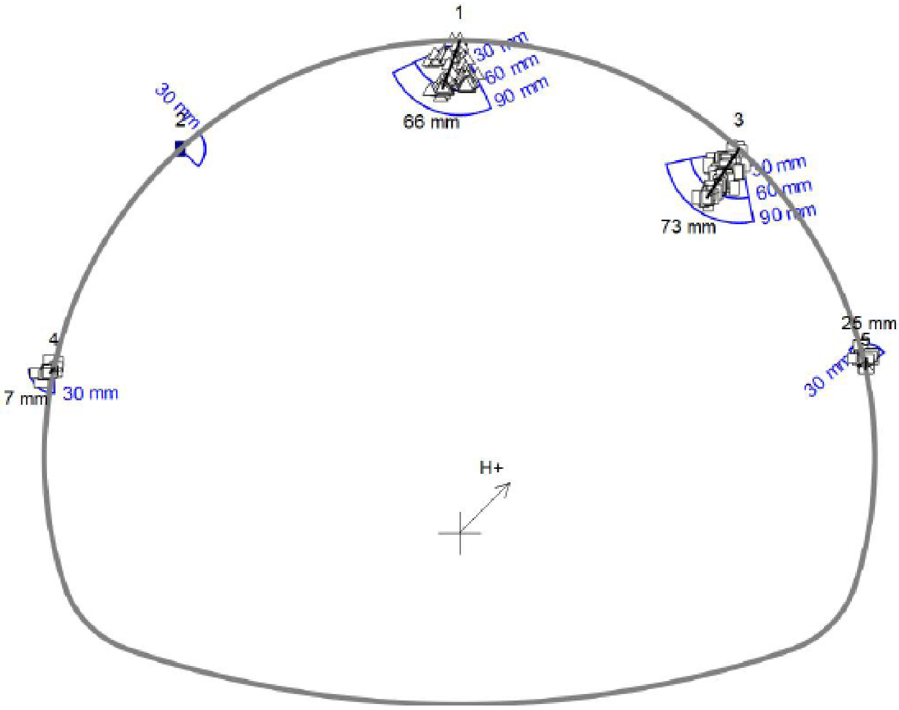

Figure 8. (d): Right tube Tunnel Cross section KP 26,603.000/ First measure: 15.05.-2017, Last measure: 8.02.2018

Afterwards, on the kelomitric point KP. 26,616 (figure 8-e) during a period of 305 days; a total deformation of 53 mm at the Left Waist (an ascending non-defused and non-expanded deformation distributed towards the right rear in a slight manner), a total deformation of 126 mm at the Left Shoulder (a descending non-defused deformation distribute totally to the front), a total deformation of 126 mm at the Crown (a descending non-defused deformation distribute totally to the front), a total deformation of 83 mm at the Right Shoulder (a descending non-defused deformation distribute totally to the front) and a total deformation of 09 mm at the Right Waist (an almost concentrated punctual deformation with small deformation towards the left in a slight manner). Also, what remarkable; is the values increased in a significant way especially in the three upper measuring points (1, 2 and 3) in this tunnel tube since the start of these monitoring, and that the maximum deformation is in the Left Shoulder and Crown equally, followed by the deformation on the Left Shoulder, Left Waist and Right Waist respectively.

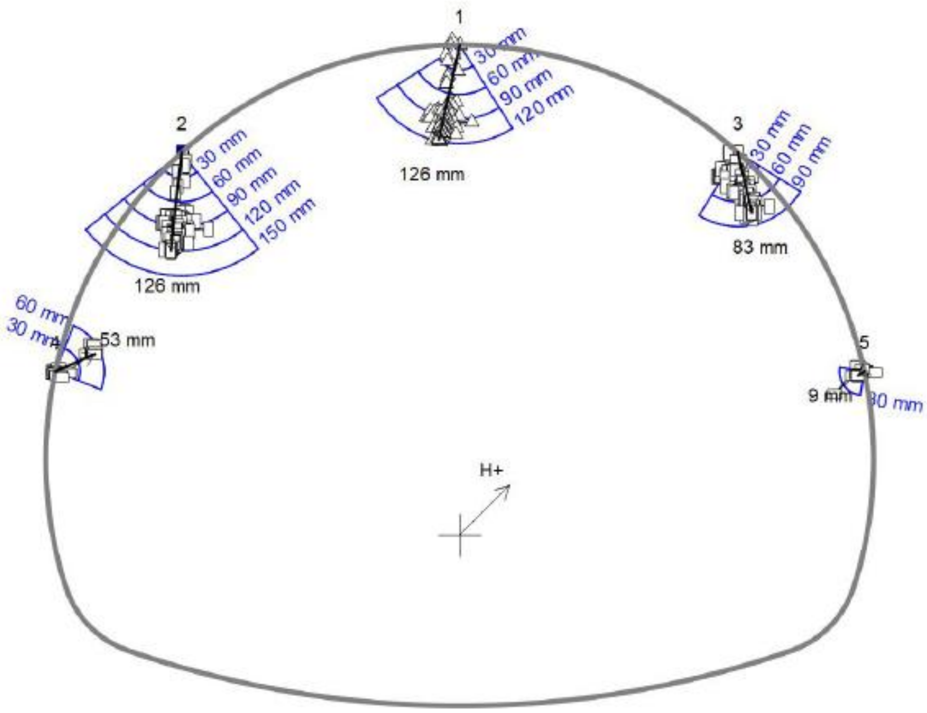

Figure 8. (e): Right tube Tunnel Cross section KP 26,616.000/ First measure: 15.05.2017, Last measure: 8.02.2018

vol. 28, issue 1 / 2022
pp. 1-23

Afterwards, on the kelomitric point KP. 26,626 (figure 8-f) during a period of 305 days; a total deformation of 09 mm at the Left Waist (a concentrated punctual deformation), a total deformation of 108 mm at the Left Shoulder (a descending non-defused deformation distribute totally towards the front slightly left), a total deformation of 102 mm at the Crown (a descending non-defused deformation distribute totally to the front slightly left), a total deformation of 149 mm at the Right Shoulder (a descending non-defused deformation distribute totally to the front slightly left) and a total deformation of 07 mm at the Right Waist (an almost concentrated punctual deformation). Also, what remarkable; is that the values of the three previous upper measuring points (1, 2 and 3) remain increased, and that the maximum deformation is in the Right Shoulder, followed by the deformation on the Left Shoulder, Crown, Left Waist and Right Waist respectively.

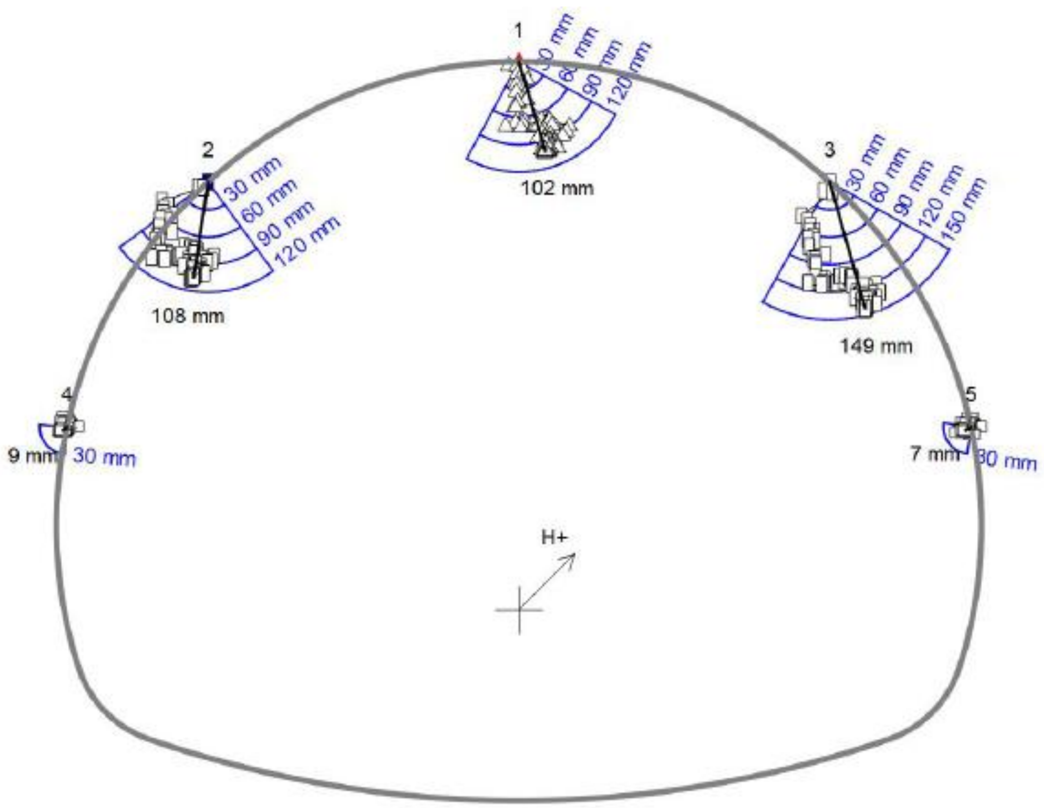

Figure 8. (f): Right tube Tunnel Cross section KP 26,626.000/ First measure: 15.05.2017, Last measure: 8.02.2018

Afterwards, on the kelomitric point KP. 26,635 (figure 8-g) during a period of 305 days; a total deformation of 09 mm at the Left Waist (a concentrated punctual deformation), a total deformation of 115 mm at the Left Shoulder (a descending non-defused deformation distribute totally towards the front left), a total deformation of 152 mm at the Crown (a descending non-defused deformation distribute totally to the front left), a total deformation of 151 mm at the Right Shoulder (a descending deformation distribute totally to the front left) and a total deformation of 07 mm at the Right Waist (a concentrated punctual deformation). Also, what remarkable; is the continued increase in deformation values of the three previous upper measuring points (1, 2 and 3) and that the values of the Waists remain constant without any evolution, and that the maximum deformation is in the Crown, followed by the deformation on the Right Shoulder, Left Shoulder, Left Waist and Right Waist respectively.

 vol. 28, issue 1 / 2022
pp. 1-23

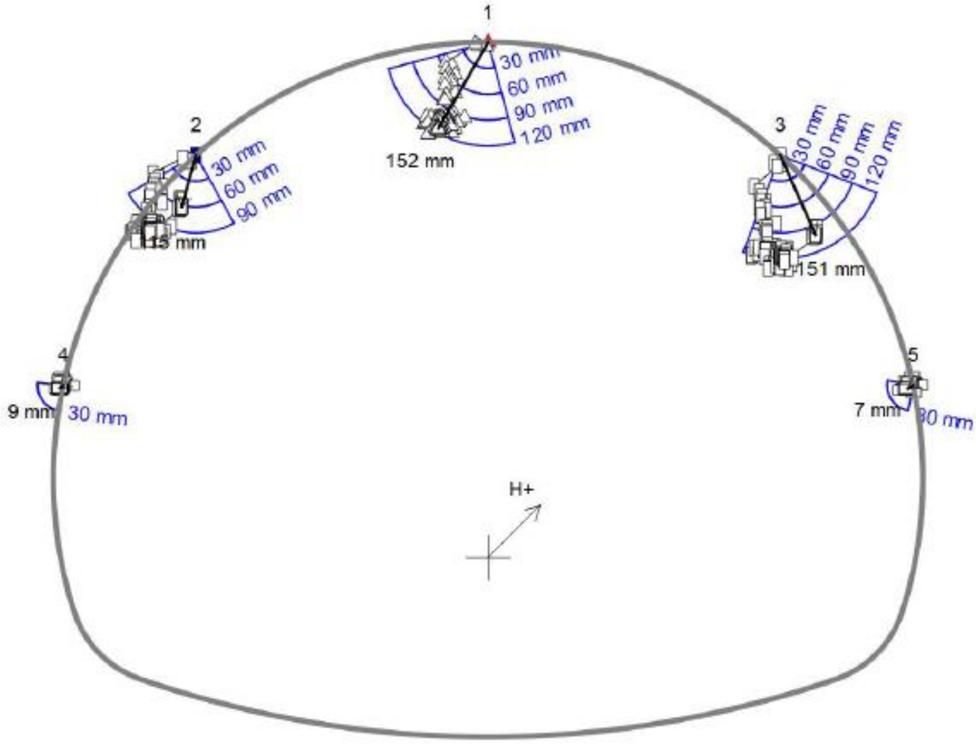

Figure 8. (g): Right tube Tunnel Cross section KP 26,635.000/ First measure: 15.05.2017, Last measure: 8.02.2018

Finally, on the kelomitric point KP. 26,641 (figure 8-h) during a period of 305 days; a total deformation of 51 mm at the Left Waist (an almost punctual deformation with a small distribution towards the right rear), a total deformation of 00 mm at the Left Shoulder (null deformation), a total deformation of 00 mm at the Crown (null deformation), a total deformation of 00 mm at the Right Shoulder (null deformation) and a total deformation of 52 mm at the Right Waist (an almost punctual deformation with a small distribution towards the right rear). Also, what remarkable; is that there is no deformation in the upper three measuring points (1, 2 and 3) and that the values of the waists increase and they are almost equal.

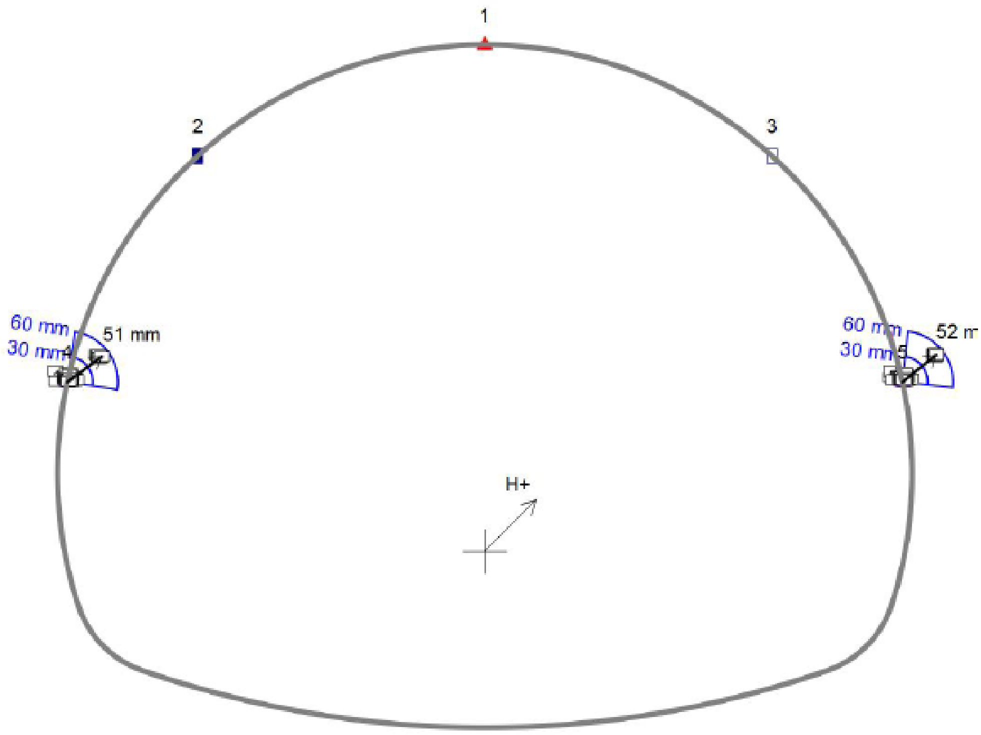

Figure 8. (h): Right tube Tunnel Cross section KP 26,641.000/ First measure: 15.05.2017, Last measure: 8.02.2018

vol. 28, issue 1 / 2022
pp. 1-23

After reaching the medium rock class (III) limits and completing the monitoring of the weak rock class (IV) inside the both tubes of Texanna tunnel, and after analyzing all the measurement points in each designed cross section in both tubes during a full year period, we summarize the results in the graphs of the figure 9.

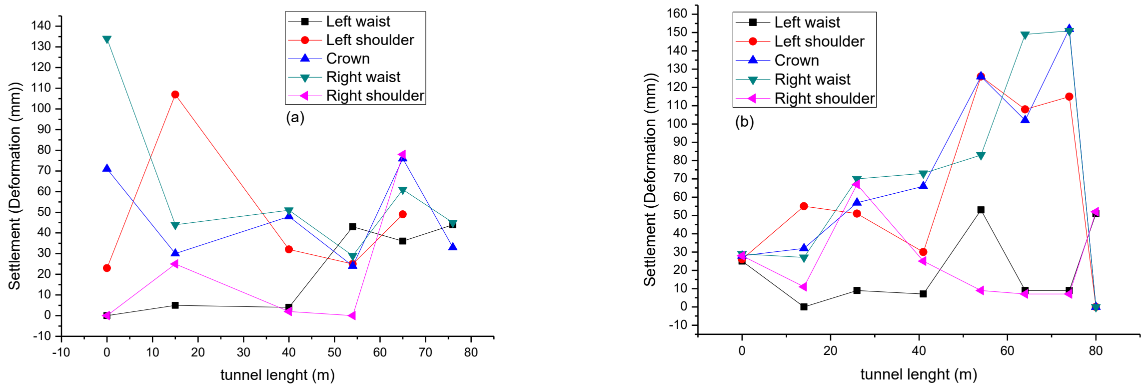

Figure 9. (a) Deformations of the left tube tunnel, (b); Deformations of the right tube tunnel;
- in the weak rock class (IV) from the beginning of the tunnel portal along to 80 m

We can notice, in a general way and initially, that there is a relationship of proportionality between the deformations at the different measurement points between the two tunnel tubes over a length of 80 meters for the weak rock mass (class IV); When the deformation is large in the right tube, we find that it is less in the left tube somehow, and when we calculate the total rock mass deformations at the same measurement cross-section between the two tubes, we find it somehow integrated; as if to maintain the same value of a complete deformation of rock mass of the both tubes.

4. Conclusions

This article was drawn up 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. 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 deformation and decreases the confinement capacity of the tunnel. The confinement capacity significantly improves when the provisional supports installed, but for the sake of complete guarantee, continuous field monitoring of each step in each stage is necessary. To ensure the confinement of the tunnel tubes, field monitoring was carried out on the rock mass for approximately 365 days. It was found that an increase in the deformation of a tunnel tube compensated by a decrease in the deformation of the opposite tube (the other one) of the same measurement cross-section (same kilometric point KP.), and vice versa. This effect between the two tubes of the deformations studied was apparently the explanation of a geological phenomenon of the conservation of the rock masses.

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] **Wu D., Xu K., Guo P., Lei G., Chengm K., Gong X.** 2021
Ground Deformation Characteristics Induced by Mechanized Shield Twin-Tunneling along Curved Alignments
in Advances in Civil Engineering, vol. 2021, Article ID 6640072, 17 pages, DOI: 10.1155/2021/6640072

[2] **Peck R.B.** 1969
Deep Excavations and Tunneling in Soft Ground, State of the Art Report in Proceedings of the 7th Int. Conf. on Soil Mechanics and Found. Eng., Mexico City, State of the Art volume, pp. 225-290

[3] **Golser J., Mussger K**. 1979
New Austrian Tunneling Method (NATM), Contractual Aspects, in Tunneling under Difficult Conditions, Proceedings of the International Tunnel Symposium, Tokyo, Pergamon Press, pp. 387–92

[4] **Brown E.T.** 1981
Putting the NATM into Perspective. Tunnels & Tunneling International, 13(10):7–13

[5] **Aygar E.B.** 2019
Evaluation of New Austrian Tunneling Method Applied to Bolu Tunnel's Weak Rocks, in Journal of Rock Mechanics and Geotechnical Engineering, https://doi.org/10.1016/ j.jrmge.2019.12.11

[6] **U.S. Army Corps of Engineers** 1997
Engineering and Design Tunnels and Shafts in Rock (e-book), Chapter 5

[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.** 2014
Rock Mass Characterization for Diversion Tunnels at Diamer Basha Dam, Pakistan – A Design Perspective in International Journal of Scientific Engineering and Technology, 1292–1296

[10] **Genis M., Basarir H., Ozarslan A., Bilir E., Balaban E.** 2007
Engineering Geological Appraisal of the Rock Masses and Preliminary Support Design, Dorukhan Tunnel, Zonguldak, Turkey." Engineering Geology, 92: 14–26

[11] **Michael K.** 2004
Monitoring Ground Deformation in Tunneling: Current practice in transportation tunnels. Engineering Geology 79(1):93-113. DOI: 10.1016/j.enggeo.2004.10.011

[12] **Bock H**. 2001
European Practice in Geotechnical Instrumentation for Tunnel Construction Control. Tunnels and Tunneling International, 51 – 54

[13] **Strauss A., Bien J., Neuner H., et al.** 2019
Sensing and Monitoring in Tunnels Testing and Monitoring Methods for the Assessment of Tunnels, Structural Concrete, 2020;21:1356–1376.https://doi.org/10.1002/suco.201900444

[14] **Sakurai S.** 1983
Displacement Measurements Associated with the Design of Underground Openings, in Proc. Int. Symp. Field Measurements in Geomechanics, Zurich, 1983, 2, 1163–1178

[15] **Kontogianni V., Stathis S.** 2005
Induced Deformation during Tunnel Excavation: Evidence from Geodetic Monitoring, Engineering Geology 79(1):115-126. DOI: 10.1016/j.enggeo.2004.10.012

vol. 28, issue 1 / 2022
pp. 1-23

[16] **Ulusoy R., Hudson J.A**. 2007
The complete ISRM Suggested Methods for Rock Characterization Testing and Monitoring: 1974-2006

[17] **Lee C.J., Wu B.R., Chen H.T., Chiang K.H.** 2006
Tunneling Stability and Arching Effects during Tunneling in Soft Clayey Soil, Tunneling and Underground Space Technology, 2006, 21(2):119-132, DOI: 10.1016/j.tust.2005.06.003

[18] **Burland J.B.** 1995
Assessment of Risk of Damage to Buildings due to Tunneling and Excavation, Proc. 1st Int. Conf. on Earthquake Geot. Eng., IS-Tokyo, pp. 611 – 628

[19] **Zhao Y.M., Feng X.T., Jiang, Q. et al.** 2021
Large Deformation Control of Deep Roadways in Fractured Hard Rock Based on Cracking-Restraint Method, Rock Mech Rock Eng., https://doi.org/10.1007/s00603-021-02384-4

[20] **Hamou Djellit** 1987
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 the University of Paris-Sud. Faculty of Sciences of Orsay (Essonne)

[21] **Joleaud L., Ferrand M., Ficheur E.** 1908
Algeria. S Carte géologique de l'Algérie 1:50,000. 74, El Aria. ervice de la carte géologique de l'Algérie

[22] **Hoek E., Kaiser P. K., Bawden W. F.** 2000
Support of Underground Excavations in Hard Rock. CRC Press

[23] **Schubert W**. 2004
Basics and Application of the Austrian Guideline for the Geomechanical Design of Underground Structures, in EUROCK 2004 & 53rd Geomechanics Colloquium

[24] **Evrim Sopac, 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

[25] **Biniawski Z.T.** 1989
Classification of Rock Masses for Engineering: The RMR System and Future Trends," in Rock Testing and Site Characterization, Pergamon, Oxford, UK

[26] **Bortan**, 2013
Using the Q-System, Sweden and Norway, Norwegian Geotechnical Institute, Oslo, Norway

[27] **Gomes M., Correia Nogueira T.A.** 2015
Alternative models for the calculation of the RMR and Q indexes for granite rock masses, Academia.edu. (P. Cortez, Producer) Retrieved on March, from http://www.academia.edu/3114361/

[28] **El-Naqa, A**. 2010
Application of RMR and Q Geomechanical Classification Systems along the Proposed Mujib Tunnel Route, Central Jordan, Bull Eng Geol Environ, 200, 60: 257. https://doi.org/10.1007/s100640100112

[29] **Choi S.Y., Park H.D.** 2002
Comparison among Different Criteria of RMR and Q-system for Rock Mass Classification for Tunneling in Korea, Volume 17, Issue 4, pages 391-401, doi.org/10.1016/S0886-7798(02)00063-9