Gerd Stefan Sackl, BSc

Determination of the rock mass stiffness by evaluating gripper forces of an open gripper TBM

Executed in the exploratory tunnel "Tulfes – Pfons" of the Brenner Base Tunnel

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Supervisor

Univ.-Prof. Dipl.-Ing. Dr.-Ing.,Thomas Marcher

Institute of Rock Mechanics and Tunnelling

Graz University of Technology

Dr.-Ing., Chris Reinhold

Galleria di Base del Brennero – Brenner Basistunnel BBT SE

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Abstract

The knowledge of rock mass parameters is of utmost importance to ensure an economical tunnel design. In order to gain detailed information about the properties and the mechanical behaviour of the surrounding rock mass, an in-situ test program would be necessary. An open gripper TBM continuously records the gripper force. The goal of the thesis is to explore if and how monitored gripper forces can be used to determine the rock mass stiffness of the surrounding ground.

Distributed over a length of 520 m and a time span of 1,5 months, 20 gripper tests have been executed in the exploratory tunnel at the construction lot H33 Tulfes – Pfons of the Brenner Base Tunnel.

Due to the comparability to the gripper tests, a literature research on the double plate load test had been done, in order to find a suitable approach for the data evaluation of the gripper tests.

A description of the investigated section in the exploratory tunnel is given and technical specifications and limitations of the open gripper TBM are discussed.

The concept of the gripper tests and how it was derived is explained. The process in finding a suitable approach for the determination of the rock mass stiffness and the evaluation of the recorded data, is described. Two different test procedures had been developed upon constant agreement with the construction company and the site supervision. Realistic deformation moduli of the rock mass could be determined. Compared to the recommended young’s moduli of the rock mass, which are given in the ground types data sheets, most results are in a similar range.

Numerical studies on two topics had been performed. For all computations PLAXIS 2D and finite element models had been used. An additional approach on the depth of influence and a parameter back-calculation for the rock mass stiffness had been performed. For all analytical and numerical calculations, an isotropic-homogeneous rock mass behaviour had been assumed.

The data and results of the gripper tests are discussed and an interpretation on the meaningfulness of the different results is given.

This thesis represents a first basis for the determination of the rock mass stiffness, using monitored gripper forces of an open gripper TBM. In order to increase the meaningfulness of the results, modifications on the TBM and further research on the evaluation of the monitored data would be necessary.

Kurzfassung

Kenntnisse über Gebirgsparameter sind für eine wirtschaftliche Planung eines Tunnels von großer Bedeutung. Um detaillierte Informationen über die Eigenschaften und das mechanische Verhalten des umliegenden Gebirges zu erhalten, wäre ein in-situ Versuchsprogramm erforderlich. Die Gripperkräfte einer offene Gripper-TBM werden kontinuierlich erfasst. Das Ziel dieser Arbeit ist es zu untersuchen, ob und wie aufgezeichnete Gripperkräfte zur Bestimmung der Gebirgssteifigkeit des umliegenden Gebirges verwendet werden können.

Auf einer Länge von 520 m und einer Zeitspanne von 1,5 Monaten, wurden im Erkundungsstollen des Bauloses H33 Tulfes – Pfons am Brennerbasistunnels, 20 Gripperversuche durchgeführt.

Um einen geeigneten Ansatz für die Datenauswertung der Gripperversuche zu finden, wurde Aufgrund der Vergleichbarkeit zu den Gripperversuchen, eine Literaturrecherche zum Doppellastplattenversuch gemacht.

Es wird ein kurzer Überblick über die Geologie des untersuchten Abschnitts im Erkundungstollen gegeben. Des Weiteren werden technische Spezifikationen der offenen Gripper-TBM erläutert.

In ständiger Abstimmung mit dem Bauunternehmen und der örtlichen Bauaufsicht, wurden zwei unterschiedliche Versuchsabläufe entwickelt. Es konnten realistische Verformungsmodule des Gebirges ermittelt werden. Verglichen mit den empfohlenen Elastizitätsmodulen des Gebirges, die in den Datenblättern der Gebirgsarten angegeben sind, liegen die meisten Ergebnisse in einem ähnlichen Bereich.

Es wurden numerische Studien zu zwei Themen durchgeführt. Für alle Berechnungen wurden PLAXIS 2D und Finite-Elemente-Modelle verwendet. Ein zusätzlicher Ansatz zur Einwirktiefe und eine Parameterrückrechnung für die Gebirgssteifigkeit wurden durchgeführt. Für alle analytischen und numerischen Berechnungen wurde ein isotropes-homogenes Gebirgsverhalten angenommen.

Die Daten und Ergebnisse der Gripperversuche werden interpretiert und die Aussagekraft der verschiedenen Ergebnisse diskutiert.

Diese Arbeit stellt eine erste Grundlage für die Bestimmung der Gebirgssteifigkeit anhand der Auswertung von aufgezeichneten Gripperkräften einer offenen Gripper-TBM dar. Um die Aussagekraft der Ergebnisse zu erhöhen, wären diverse Modifikationen an der TBM und weitere Untersuchungen zur Auswertung der aufgezeichneten Daten erforderlich.

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Abbreviations

DPLT ....double plate load test
GT ....ground type
LC..................load cycle
LS..................load step
HS ....Hardening Soil model
MC.................Mohr Coulomb model
MP ....measuring point
PLT................plate load test
TBM...............tunnel boring machine
TM ....tunnel meter
UCS...............uniaxial compressive strength [MPa]

Symbols

Scalars

ΔN ....applied normal force [MN]

Δp_{cyl} ....hydraulic pressure in the gripper cylinders [bar]

Δs ....displacement in the direction of the applied load [m]

a ....spacing between wires [m]

A_{cont}...............contact area between gripper and rock mass [m²]

A_{grip} ....theoretical contact area of gripper [m²]

A_{piston} ....piston area of the gripper cylinders [m²]

b ....width [m]

c' ....effective cohesion [MPa]

d ....diameter [mm]

E ....young's modulus of rock mass [MPa]

E_{50}^{ref}..............secant reference stiffness in standard drained triaxial test [MPa]

E_{def}................deformation modulus of rock mass [MPa]

E_{oed}^{ref}.............tangent reference stiffness for primary oedometer loading [MPa]

E_{ur}^{ref} ....un-/reloading reference stiffness [MPa]

E_z..................instant modulus of rock mass [MPa]

E_{z1-z2} ....interval modulus of rock mass [MPa]

F ....force [MN]

h ....overburden [m]

K_0..................earth pressure coefficient [-]

K_z..................coefficient accounting for the corresponding depth from the surface z [m]

I ....depth of influence [m]

m ....power for stress-level dependency of stiffness [-]

p^{ref}.................reference stress for stiffness moduli [MPa]

r ....radius [m]

z ....depth of a point where displacements are measured [m]

Greek letters

ω...................dimensionless coefficient, accounting for the type of loading and the location where displacements are measured [-]

ν ....Poisson's ratio [-]

$\Delta\varepsilon$...................strain in the direction of the applied load [-]

$\Delta\sigma_m$................mean normal stress on the loaded surface [MPa]

σ_3'..................effective horizontal stress [MPa]

$\sigma'_{in\text{-}situ}$.............effective primary in-situ stress [MPa]

$\sigma'_{in\text{-}situ,\ 20\%}$........20% of effective primary in-situ stress [MPa]

ν_{ur}..................Poisson's ratio for un-/reloading [-]

γ_{sat}.................specific weight saturated [kN/m³]

γ_{unsat}...............specific weight unsaturated [kN/m³]

φ'...................effective friction angle [°]

ψ....................dilatancy angle [°]

1 Introduction

Tunnel boring machines continuously record a variety of parameters. In case of an open gripper TBM one of the datasets is the gripper force. The knowledge of rock mass parameters is of utmost importance to ensure an economical tunnel design. In order to gain detailed information about the properties and the mechanical behaviour of the surrounding rock mass an in-situ test program would be necessary. The goal of the thesis is to explore if and how monitored gripper forces can be used to determine the rock mass stiffness of the surrounding ground.

Distributed over a length of 520 m and a time span of 1,5 months, 20 gripper tests been executed in the exploratory tunnel at the construction lot H33 Tulfes – Pfons of the Brenner Base Tunnel.

Due to the comparability to the gripper tests, a literature research on the double plate load test, particularly on the test concept, the test set-up/execution and the data evaluation, had been done.

The geology of the investigated section in the exploratory tunnel and the technical specifications of the open gripper TBM are discussed.

The concept of the gripper tests and how it was derived is explained. The process in finding a suitable approach for the determination of the rock mass stiffness and the evaluation of the recorded data is given. Two different test procedures had been developed upon constant agreement with the construction company and the site supervision.

In order to confirm or specify the analytical approach on the depth of influence of a gripper test, a numerical study on this topic had been performed. Beside the analytical approach for the determination of the rock mass stiffness, a numerical model had been developed. This had been done in order to execute a parameter back-calculation for the rock mass stiffness. All computations had been performed with PLAXIS 2D. For all analytical and numerical calculations, an isotropic-homogeneous rock mass behaviour had been assumed.

The results of the analytical evaluation of the gripper tests and the numerical studies are shown and compared. The data and results of the gripper tests are discussed and an interpretation on the meaningfulness of the different results is given.

During the gripper tests and the evaluation of the data, numerous problems have been encountered. Problems concerning the limitations of the TBM, as well as problems which have been encountered during the data evaluation and the numerical computations, are discussed.

In order to get a complete overview of the recorded and evaluated data, as well as on the results, the evaluated data sheets and the raw data of all gripper tests are attached in the appendix.

2 State of the art in-situ tests to determine the rock mass stiffness

In-situ tests in rock mechanics are mainly used to gain information about rock mass parameters.

State of the art in-situ tests for deformation properties of rock are:

- Double plate load test (DPLT)
- Radial press test (Kastner, 1962) (Wieland, 2008)
- Triaxial test (Fecker, 2018)
- Borehole expansion tests (Fecker, 2018)

Due to the comparability to the gripper tests which have been executed at the Brenner Base Tunnel, this chapter is primarily concerned with the DPLT, particularly with the test purpose, the concept, the test set-up/execution and the data evaluation.
For this literature research, several different sources have been incorporated. The used literature in this chapter is following: (DGEG, 1985) (Fecker, 2018) (Kastner, 1962) (Pilgerstorfer, 2014) (Rezaei, et al., 2016) (Ünal, 1997).
Literature references for the other mentioned tests are indicated above.

2.1 Double plate load test

2.1.1 Purpose and concept

The DPLT is an in-situ test in the field of rock mechanics and is used for the investigation and determination of deformation parameters of rock mass. The DPLT shares a very similar concept compared to the plate load test (PLT), which finds frequent use in the field of soil mechanics. While for soils the counterweight of a plate load test is coming from dead weight, this is generally not enough for a usage in rock, since the applied loads are much higher. The needed resistance during the test is given by the rock mass itself. This is the reason why DPLTs are carried out in small tunnels or adits. For a schematic sketch of a DPLT set-up, please see Figure 2.1. Through hydraulic cylinders, both plates are pushed into the rock mass, while the applied load and the deformations are measured. Normally several load cycles (primary-, un- and reloading) are executed in order to gain information about the stress dependency of rock mass stiffness.

2.1.2 Test set-up and execution

As mentioned above, DPLTs are executed in small tunnels and adits. According to (Ünal, 1997), the width of the test adit (b), or height in the case of a horizontal test, should be at least two times greater than the plate diameter (d), in order to reduce the restraining effect. A ratio of $\frac{b}{d} = 6$ is said to be ideal. Figure 2.1 shows a schematic sketch of a typical set-up for a DPLT. The basic equipment which is needed for a DPLT is explained in the following points from 1 to 5:

1. **Extensometers:** three to five extensometers, parallel to the loading direction and with measuring points in different depths are the norm; one central extensometer and three equally distributed at the circumferential of the plate, or even outside of the plate, are a common way for measuring the displacements; depending on the applied load and the geological circumstances, the extensometers are installed to a depth of 2 to 6 m.
2. **Abutment cones with plates and thin layers of mortar:** in general, plates with a diameter of 300 to 1300 mm are used; the diameter of the plates depend on the size of the tunnel/adit and the geological situation (mean joint distance, UCS, etc.) and of course have an influence on the scale effect of the test; a few centimetre of mortar between the plate and the rock mass, is used to achieve an even load distribution into the rock mass.
3. **Universal ball joints:** these joints are needed, to prevent unwanted tensions in the system and ensure an even load distribution during the test.
4. **Press unit featuring hydraulic cylinders:** depending on the diameter of the plate, one or generally more hydraulic cylinders are used as a press unit; a stroke of 200 mm and the ability of a linear load in- and decrease is standard.
5. **Reaction beam:** consisting of several pieces, the reaction beam is adjustable in length and fills the remaining gap of the unit.

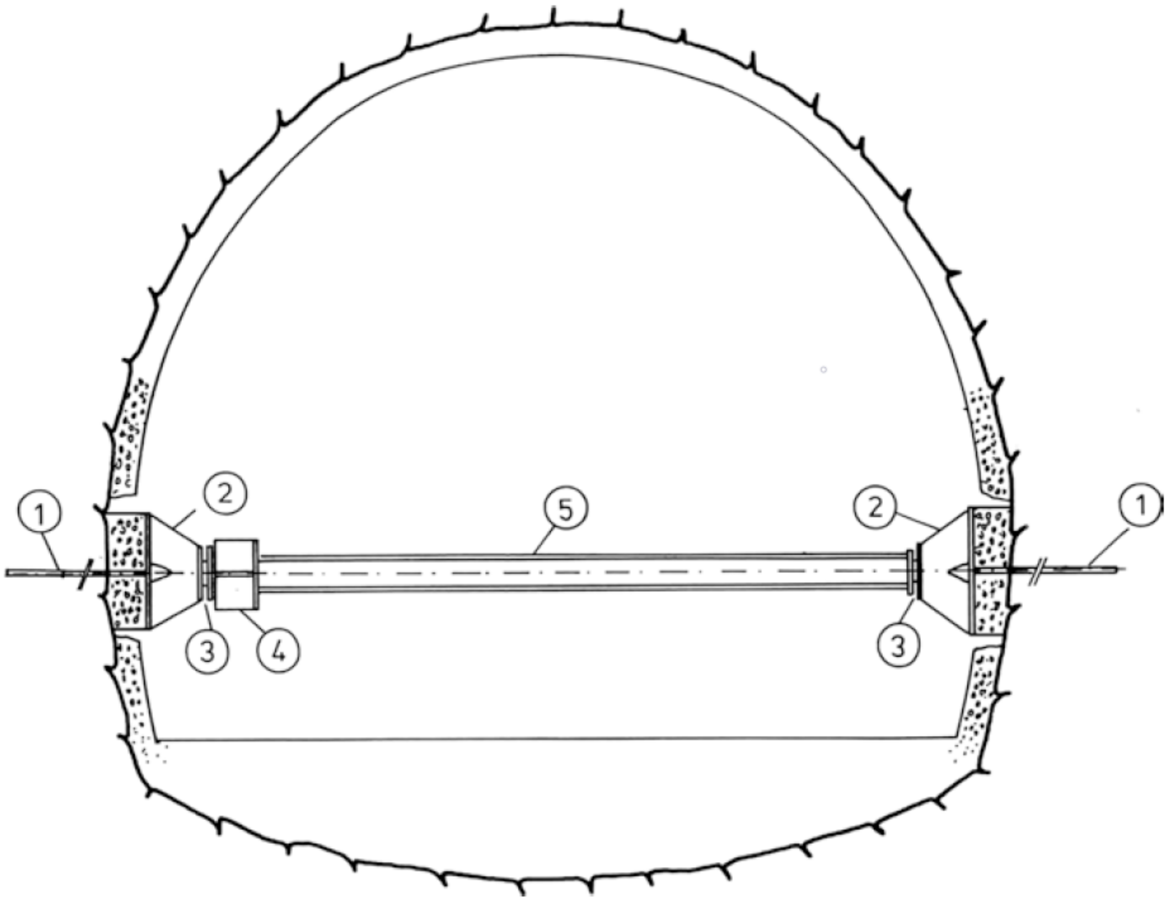


Figure 2.1: Schematic sketch of a double plate load test set-up (Fecker, 2018)

The test unit, which is perpendicular orientated to the tunnel axis, can be rotated as needed. In most cases, the deformation properties of rock mass are highly dependent on the direction of the applied load. In Figure 2.2 a vertical oriented DPLT can be seen. This photo (Rezaei, et al., 2016) was taken at the Khersan II dam site in Iran.

Figure 2.2: Photo of a double plate load test at Khersan II dam site (Rezaei, et al., 2016)

After everything had been set up, the execution of the test can start. Before the actual test procedure starts, the first step is to apply a prestress into the system and wait until the resulting displacements are steady. This prestress depends on factors such as dimensions of the test unit, geology, etc.. During the entire test procedure, the applied stress must not be less than the prestress.

The rock mass gets repeatedly loaded and unloaded, whereby the load gets increased after each loading cycle. At least three load cycles are recommended. If the loading and unloading process is performed in a linear in- and decrease, a rather slow than fast operation is recommended. If the in- and decrease is performed step by step, the load needs to be kept constant until the displacement rates become almost zero for every step. After reaching the maximum load of a load cycle, the load must be kept constant until the displacement rates become almost zero.

2.1.3 Data evaluation

In terms of data evaluation, different approaches can be found in literature. In this thesis the approaches according to (Ünal, 1997) and (DGEG, 1985) are discussed. Both methods are based on the theory of elastic-isotropic half space after Boussinesq.
According to (Ünal, 1997) the determination of an instant and an interval modulus of the rock mass is possible.
The instant modulus (E_z) can be calculated for the rock surface or for any point inside the rock mass by Equation (2.1). This can either be representative as deformation or young's modulus. The instant modulus can be calculated for the depths corresponding to locations where displacements had been measured.

$$E_z = K_z * \frac{\Delta\sigma_m}{\Delta s_z} \tag{2.1}$$

E_z... *instant modulus [MPa]*
K_z... *coefficient accounting for the corresponding depth from the surface z [m]*
$\Delta\sigma_m$... *mean normal stress on the loaded surface [MPa]*
Δs_z... *displacement in the direction of the applied load [m]*

The coefficient K_z is calculated by Equation (2.2).

$$K_z = \frac{r}{2} * \left[2 * (1 - \upsilon^2) * arcsin\left(\frac{1}{\sqrt{z^2+1}}\right) + (1 + \nu) * \frac{z}{z^2+1}\right] \tag{2.2}$$

r... *radius of the load plate [m]*
ν... *Poisson's ratio [-]*
z... *depth of a point where displacements are measured [m]*

The interval modulus ($E_{z1\text{-}z2}$) represents the deformation or young's modulus of a rock mass between two measuring points. By calculating K_z at any two depths, e.g. z_1 and z_2, and using the measured displacements s_1 and s_2 respectively, the interval modulus can be expressed through Equation (2.3).

$$E_{z_1-z_2} = \left(K_{z_1} - K_{z_2}\right) * \frac{\Delta\sigma_m}{(\Delta s_{z_1} - \Delta s_{z_2})} \tag{2.3}$$

According to (DGEG, 1985) the deformation modulus (E_{def}) can be calculated by Equation (2.4), using the displacements measured at the surface of the rock mass.

$$E_{def} = \omega * (1 - \upsilon^2) * r * \frac{\Delta\sigma_m}{\Delta s} \quad (2.4)$$

E_{def}... *deformation modulus of rock mass [MPa]*

ω... *dimensionless coefficient, accounting for the type of loading and the location where displacements are measured (according to* Table 2.1*) [-]*

Table 2.1: Dimensionless coefficient ω for Equation (2.4) (DGEG, 1985)

Type of loading	**Location of measurements**	**ω**
evenly distributed mean normal stress (flexible load plate)	in centre	$\omega = 2$
	at edge	$\omega = \frac{4}{\pi} = 1{,}27$
evenly distributed displacements (stiff load plate)	in centre	$\omega = \frac{\pi}{2} = 1{,}57$
	at edge	$\omega = \frac{\pi}{2} = 1{,}57$

3 TBM-drive Tulfes – Pfons at the Brenner Base Tunnel

The gripper tests have been executed at the construction lot H33 Tulfes – Pfons of the Brenner Base Tunnel. In July 2019 the construction work had finished, and 41,5 km of tunnels and caverns were excavated. The 15 km long exploratory tunnel, was excavated by an open gripper TBM (please find enclosed Figure 3.1 (Herrenknecht AG)). This TBM was also used for the gripper test.
This chapter describes the investigated section of the exploratory tunnel, the technical specifications of the TBM, as well the used measuring instruments and some of the problems related to the TBM.

3.1 Exploratory tunnel

The 15077 m long part of the exploratory tunnel is located between and 12 m beneath the two main tubes. Additionally, to the exploration purpose of the tunnel, it will be used as an intervention tunnel during the excavation of the main tubes and as a service tunnel after the construction has finished. Table 3.1 shows a geological description of the investigated section.

Table 3.1: Description of the investigated section in the exploratory tunnel

Investigated section	TM 14378 - 14898[1] (520 m)
Diameter	7,93 m
Overburden	710 - 780 m
Lithology	calcareous schist (primary)
	calcareous phyllite (secondary)
Ground types (GT)	SH-KS-3b (TM 14378 - 14545)
	SH-KS-4b (TM 14545 - 14898)
Geological unit	upper schist shell
Foliation spacing and orientation	2 - 6 cm
	250 - 260°/10 - 20°
Heading direction	170° (north = 0°)

The theoretical diameter of the tunnel is 7,93 m. During construction an overcut of approximately 10 cm was excavated. The data sheets for the GTs SH-KS-3b and SH-KS-4b have been taken from the technical report for ground types and ground behaviour (GeoTeam, 2008) and can be found in Appendix A. During the excavation of the investigated section, no fault zones or any major problems were encountered. With some exceptions, the faced geological conditions were very good and similar all along.

3.2 Open gripper TBM

Figure 3.1 (Herrenknecht AG) shows the open gripper TBM, which was used for the excavation and the gripper tests. The outer diameter of the cutter head is 7,93 m. As mentioned above, an overcut of 10 cm was excavated. The distance between the tunnel face and the gripper axis is approximately 18 m. Figure 3.2 shows three cross sections of a gripper. Cross section A-A shows the gripper looking from the tunnel sidewall into the middle of the tunnel. Cross section B-B cuts through the gripper cylinders, looking outwards to the tunnel sidewall and C-C shows the cross section perpendicular to the tunnel axis/parallel to the gripper axis. All dimensions are in centimetre.

[1] Every information in context with a given tunnel meter (TM) in this thesis, is referred to the position of the grippers and not to the position of the tunnel face.

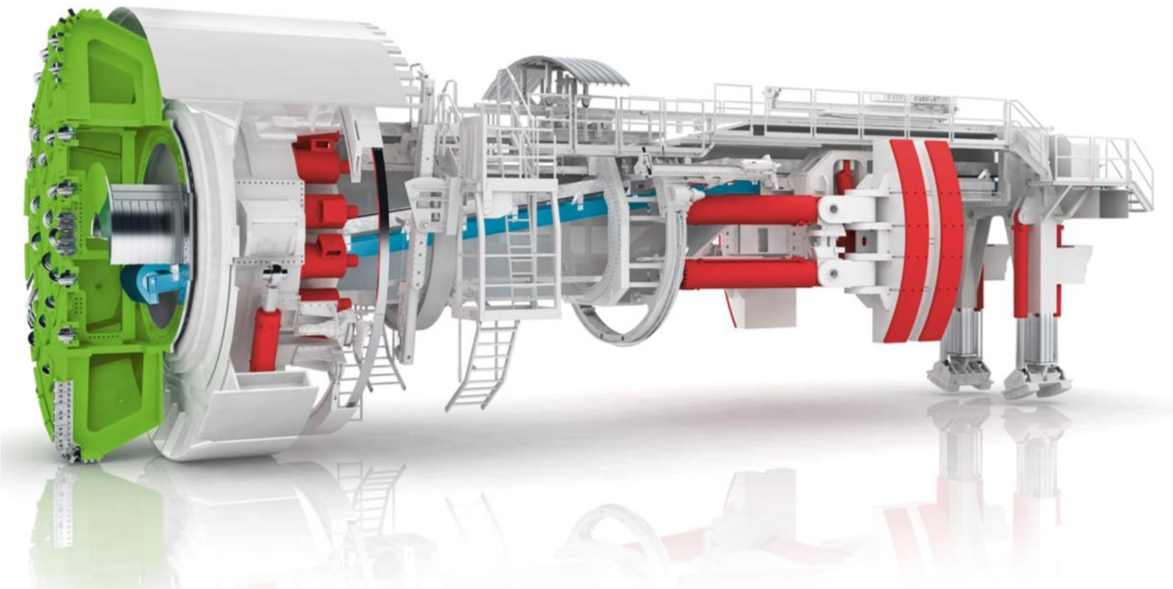


Figure 3.1: Open gripper TBM (Herrenknecht AG)

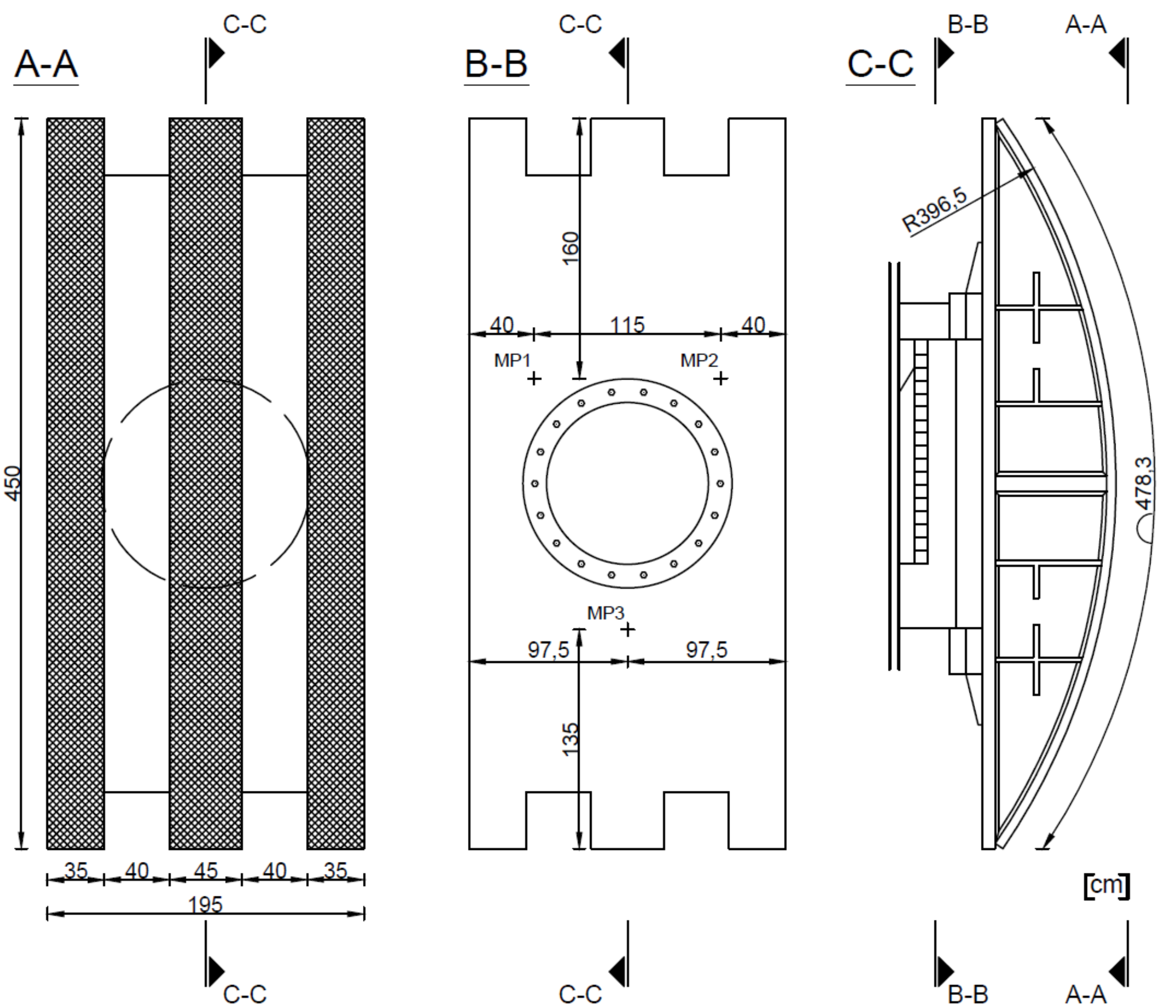


Figure 3.2: Cross sections of gripper

The hatched areas in cross section A-A indicate the contact area of the grippers. The theoretical contact area per gripper (A_{grip}) is 5,50 m². The contact area between the gripper and the rock mass is influenced by several different factors. For example, the unevenness of the rock surface, the reinforcement between the gripper and the rock mass, as well as possible breakouts and more. The term "theoretical" indicates, that those factors had not been considered for this parameter.

In cross section B-B, the locations of the measuring points (MP) can be seen. Each gripper is mounted to a ball joint, like they were also described in chapter 2.1.2 for the DPLT. Because this ball joint allows the gripper to freely move in space, three measuring points per gripper are used to determine the exact orientation of the gripper. Unfortunately, the measuring accuracy of the laser points could not be verified. A typical measuring accuracy for such laser points, is 1 mm. Equally to the DPLT, these joints are used to prevent unwanted tensions in the system and ensure an even load distribution during bracing the grippers.

Furthermore, cross section C-C shows the radius of the gripper, which is the same radius as the theoretical excavation radius ($r = \frac{7,93}{2} = 3,965\ m$). However, the radius of the gripper does not take the 10 cm overcut into account, which means it doesn't perfectly fit together with the tunnel sidewall. Figure 3.3 shows an out of scale sketch to illustrate the described problem.

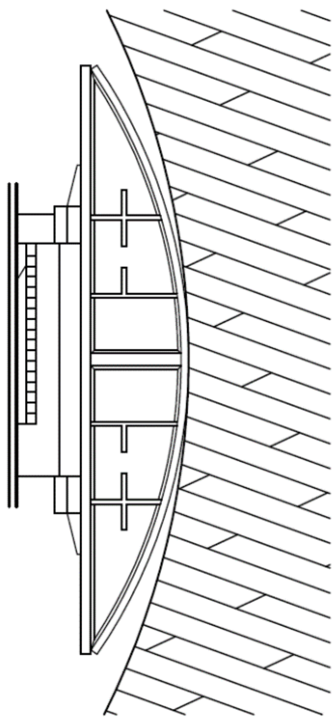


Figure 3.3: Radius problem between gripper and tunnel sidewall

Each gripper has a hydraulic cylinder with the following specifications: 1000/720-1000 mm, 350 bar ($Ø_{piston}$/$Ø_{piston\ rod}$-piston stroke, max. pressure). A piston diameter of 1000 mm results in an area of $A_{piston} = 0{,}785\ m^2$ where hydraulic pressure can act upon. This results in a force of 78,5 kN per 1 bar pressure increase. Both cylinders are connected to the same hydraulic system, which means that both grippers experience the same pressure increase while bracing. Therefore, the cylinders are pushing with the same force into the rock mass.

Every 10 sec, the TBM records the data from its over 500 sensors.

4 Gripper tests to determine the rock mass stiffness

Distributed over a length of 520 m and a time span of 1,5 months, 20 gripper tests have been executed for this thesis.

The development process for a suitable approach, was a big part of the project. The explanation of the approach is given in this chapter. Used equations and parameters are listed, as well the explanations on how those equations and parameters are derived and which problems had been faced during the process.

Two different test procedures have been developed, in order to use the full potential of the available instruments of the TBM. Upon constant agreement with the construction company and the site supervision, a test with one load cycle (LC) and three LCs have been developed.

The analytical evaluation of the received data from the instruments, will be explained by an example. A step by step explanation on the evaluation process will be given and exemplary results will be shown.

4.1 Explanation of the approach

The concept of a gripper test is very similar to a DPLT (please see chapter 2.1). Compared to the set-up of a DPLT, the equipment provided by the TBM is basically the same, only much bigger. The load plates are the grippers themselves. The press unit are the hydraulic gripper cylinders. Both instruments/machines are equipped with ball joints and measuring devices. Only the mortar which would provide an even surface between the gripper and the rock mass is missing. However, this topic will be elaborated later in this chapter. Figure 4.1 shows a simple sketch of the principle how the grippers are pushed into the rock mass.

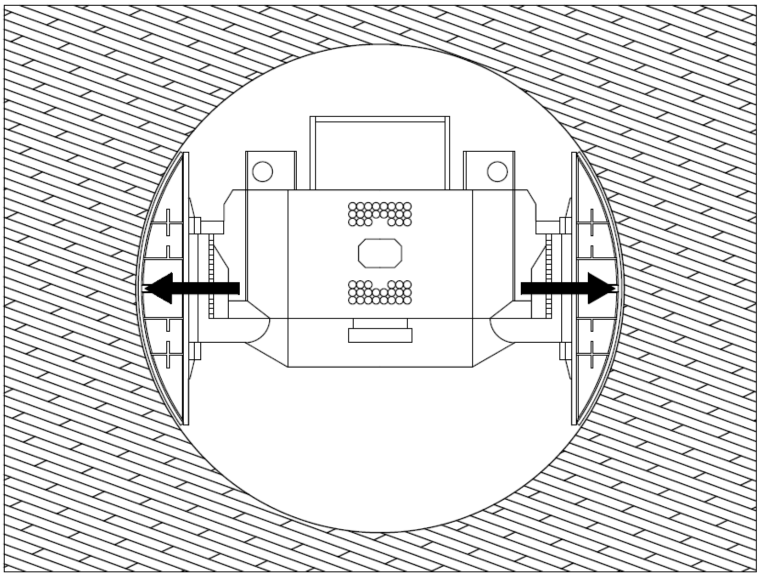


Figure 4.1: Basic principle of a gripper test

Due to the described similarities between the DPLT and the gripper tests, a very similar approach for the analytical calculations of the deformation modulus had been followed. According to (DGEG, 1985) the deformation modulus (E_{def}) can be calculated by Equation (4.1), using the displacements measured at the surface of the rock mass.

$$E_{def} = (1 - \upsilon^2) * \omega * r * \frac{\Delta\sigma_m}{\Delta s} \tag{4.1}$$

The parameters of Equation (4.1) are explained and defined below.

E_{def}… deformation modulus of rock mass [MPa]

Figure 4.2 (Adam, 2016a) shows an exemplary representation of a stress-strain curve, where different stress dependent rock mass moduli can be derived. Two un- and reloading cycles can be seen. In the section of the un- and reloading cycles, a nearly elastic behaviour can be observed. The moduli derived from the un- and reloading cycles are called young's moduli (E). The deformation modulus (E_v) instead, shows an elastic and plastic behaviour and can be derived as a secant- or tangent modulus. For Figure 4.2, the German symbol E_v instead of E_{def} had been used for the deformation modulus. (Adam, 2016a)

The different stiffness moduli shown in Figure 4.2 are the following:

E_1… *young's modulus at the first un- and reloading cycle [MPa]*

E_2… *young's modulus at the second un- and reloading cycle [MPa]*

E_V^s… *deformation modulus at σ_B (secant modulus) [MPa]*

E_V^t… *deformation modulus at σ_B (tangent modulus) [MPa]*

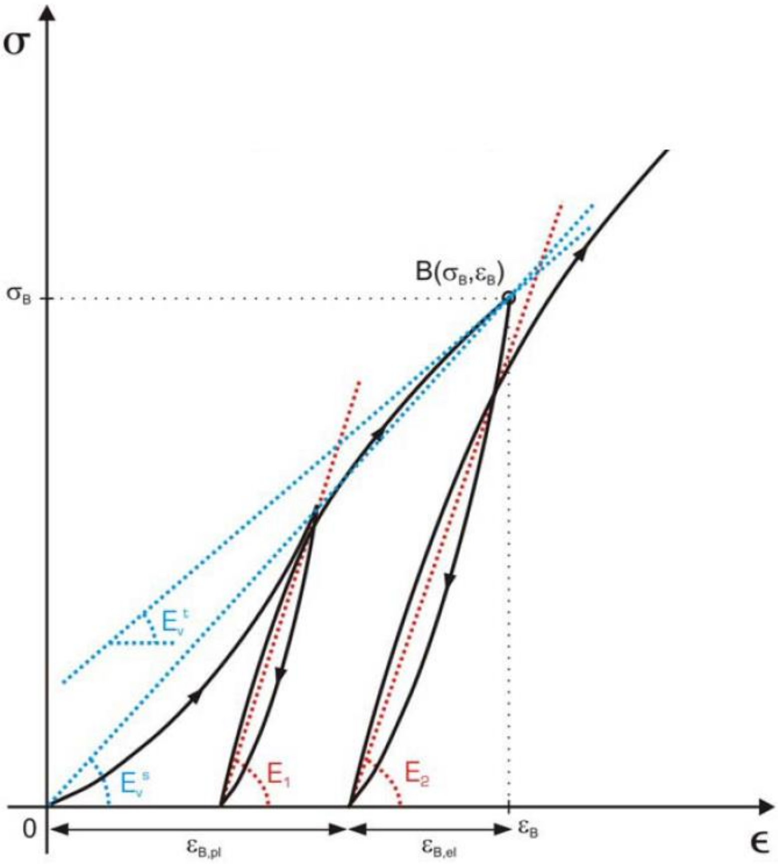


Figure 4.2: Exemplary representation of a stress-strain curve with two un- and reloading cycles (Adam, 2016a)

Due to the given complexity of different stiffness moduli, it is important to clarify and define which stiffness parameters are evaluated. In the course of this thesis, the secant deformation modulus (E_{def}) had been calculated for all gripper tests.

$\Delta\sigma_m$… mean normal stress on the loaded surface [MPa]

The mean normal stress on the loaded surface is defined by Equation (4.2) and depends on the applied normal force (ΔN) as well as the contact area between the gripper and the rock mass (A_{cont}).

$$\Delta\sigma_m = \frac{\Delta N}{A_{cont}} \tag{4.2}$$

ΔN… applied normal force [MN]

Both gripper cylinders are connected to the same hydraulic system, which means that both grippers experience the same pressure increase while bracing. Therefore, the cylinders are pushing with the same force into the rock mass. The applied normal force is calculated by Equation (4.3) and is dependent on the measured hydraulic pressure and the piston area where hydraulic pressure can act upon. Per 1 bar pressure increase, a force of $0{,}0785\ MN = 1\ bar * 0{,}785\ m^2$ is applied into the rock mass. The stiffness of the TBM and the internal friction losses of the hydraulic cylinders are not considered.

$$\Delta N = \Delta p_{cyl} * A_{piston} \tag{4.3}$$

Δp_{cyl}... hydraulic pressure in the gripper cylinders [bar]
A_{piston}... piston area of the gripper cylinders [m^2]

A_{cont}…contact area between gripper and rock mass [m²]

The contact area is influenced by several factors and quite difficult to define. In general, the tunnel sidewall has an uneven surface and possible breakouts must be considered. Chapter 3.2 and Figure 3.3 describe the influence of the differing excavated tunnel radius and the radius of the gripper on the contact area. Last but not least, the reinforcement mesh between the gripper and the rock mass, also influences the contact area. Figure 4.3 shows a sketch of this issue.

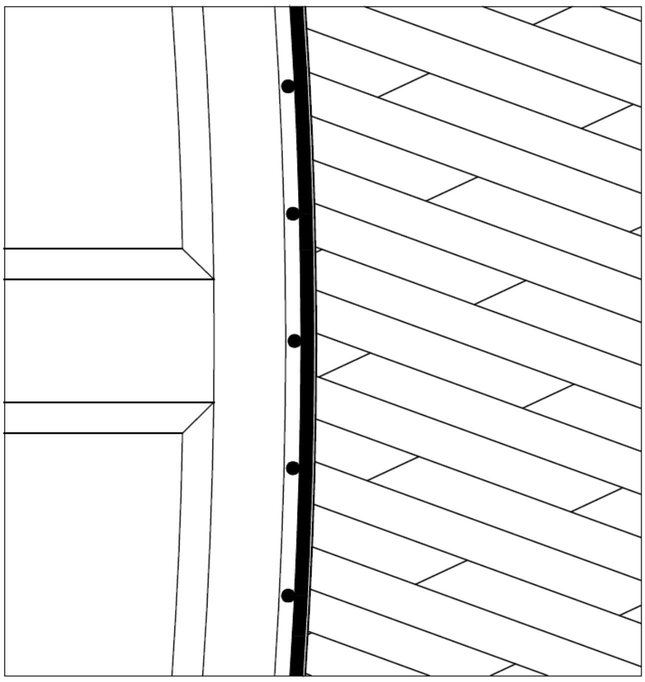


Figure 4.3: Reinforcement mesh between gripper and rock mass

For the investigated section in the exploratory tunnel a BSt 550 AQ60 mesh was installed. Specifications for this mesh are: 100x100 mm spacing and 6 mm wire diameter in both directions and a yield strength of 550 MPa. 2x6 mm results into a total height of 12 mm for the mesh. This means in theory, the first contact between the gripper and the rock mass, happens after 12 mm of displacements have been occurred. According to the data sheets for the GTs SH-KS-3b and SH-KS-4b, which can be found in Appendix A, the intact rock UCS is 50 MPa for both rock types. The big difference in strength and stiffness assures that the reinforcement is not getting deformed and all measured displacements must occur at the rock mass. Figure 4.4 shows a photo, where this phenomenon is clearly visible.

Figure 4.4: Imprint of the reinforcement mesh in the rock mass

In the photo, a very distinct imprint of the vertical wire and a less deep imprint of the horizontal wire, is visible. Additionally, one can see that there was no contact between the gripper and the rock mass at any time. Although only one photo is shown here, the described situation could be obtained in most cases.

Due to the given insights, the following assumption had been made. For all gripper tests, a contact area of 0,64 m² per gripper had been defined. It is assumed that only the reinforcement mesh is in contact with the rock mass. A_{cont} is calculated by Equation (4.4).

$$A_{cont} = A_{grip} * \left[\frac{d}{a} + \frac{\left(d - \frac{d^2}{a}\right)}{a}\right] \tag{4.4}$$

A_{cont}... *contact area between gripper and rock mass [m^2]*

A_{grip}... *theoretical contact area of gripper [m^2]*

d... *diameter of wires [m]*

a... *spacing between wires [m]*

$\Delta\varepsilon$… strain in the direction of the applied load [-]

The strain is calculated by Equation (4.5). It depends on the displacements and the depth of influence.

$$\Delta\varepsilon = \frac{\Delta s}{l} \quad (4.5)$$

Δs… displacement in the direction of the applied load [m]

The movement of the grippers is measured at three points per gripper (MP1/2/3). The locations of those points can be seen in Figure 3.2. For further calculations, the mean value of all three points is used. Another challenge one has to face when measuring the displacements during a gripper test, is the missing fixed point on the TBM. This makes it impossible (at least with the available devices on the TBM) to determine how much displacements come from the left, and how much come from the right gripper. Again, the mean value of the left and the right gripper is used, reducing the number of measuring values from six in the beginning to only one at the end.

l… depth of influence [m]

The depth of influence is, according to the theory of elastic-isotropic half space, defined by Equation (4.6) and dependent on the coefficient ω and the radius r. The application of the theory of elastic-isotropic half space is an assumption and dose not represent the real rock mass behaviour in the tunnel.

$$\mathrm{l} = \omega * \mathrm{r} \quad (4.6)$$

For the analytical evaluation, a depth of influence of $l = 1{,}57 * 1{,}32\ m = 2{,}08\ m$ had been defined for all tests. For the numerical computation of l, please see chapter 5.2.

ω… dimensionless coefficient, accounting for the type of loading and the location where displacements are measured (according to Table 2.1) [-]

According to the theory of elastic-isotropic half space, ω and therefore E_{def} is influenced by the type of loading and the location of measurements. The grippers are assumed to act as a stiff "load plate", producing evenly distributed settlements during loading. According to Table 2.1, $\omega = 1{,}57$ [-] is used.

r… radius of the circle with the same area as the theoretical gripper area [m]

Normally the radius of the load plate is used for this parameter, but since the grippers contact area is not a circle, a different approach had to be found. By considering the theoretical contact area of a gripper (5,50 m²) not being a rectangular, but a circle, the radius for this equally sized circle is $r = \sqrt{\frac{5{,}50}{\pi}} = 1{,}32\ m$.

ν… Poisson's ratio [-]

The Poisson's ratio was given by the technical report for ground types and ground behaviour (GeoTeam, 2008). In the data sheets for the GTs SH-KS-3b and SH-KS-4b (please see Appendix A), a Poisson's ratio of 0,2 [-] for intact rock is given. Since there is no value for the rock mass given and the influence of this parameter on the result is relatively small (0 to 4 %), the Poisson's ratio for intact rock had been used for the calculations.

4.2 Test procedure

The first idea for a test procedure was not to develop a specific concept but use the available data from the previously excavated part of the tunnel. During the excavation, the grippers are pushed into the rock mass, in order to generate enough frictional resistance to push the TBM forward. This procedure is called bracing. The data of the standard bracing procedures during excavation should be used for the calculation of the deformation modulus. After evaluating the first few bracings, it got clear that a specific concept needs to be developed. A standard bracing happens too fast and too uncontrolled, in order to get meaningful data and results.
Two different test procedures have been developed, constantly upon agreement with the construction company and the site supervision.
The following terms were made by the construction company and the site supervision:

- The hydraulic pressure in the gripper cylinders must not exceed 300 bar (=24 MN).
- The duration of the test should be kept to a minimum (<15 min).
- If the geological conditions are not good, no test or a test with reduced maximum pressure, shall be executed.

4.2.1 Test with one load cycle

The required time for a test with one LC is about 5 min.

For all tests, these points had been followed during the execution:

- The test shall be executed at a position, where no bracing happened in the past. Meaning, that after a stroke is completed and the grippers are moved forward, no bracing shall happen before the test starts.
- During the entire test, the support feet of the TBM must remain down and in place. The support feet are used to support the TBM, while the grippers are moved forward and are not braced into the rock mass.
- A prestress of 100 bar (=7,85 MN) in the hydraulic gripper cylinders shall be applied.
- Starting at 100 bar, the hydraulic pressure gets increased in 40 bar (=3,1 MN) steps. After each increase, the pressure shall be hold for 30 to 60 sec.
- In order to not damage the tunnel, the maximum pressure shall be defined, according to the geological condition. The assessment is done by the machine operator according to engineering judgment.

Figure 4.5 shows an example of the cylinder pressure over time for a test with one LC.

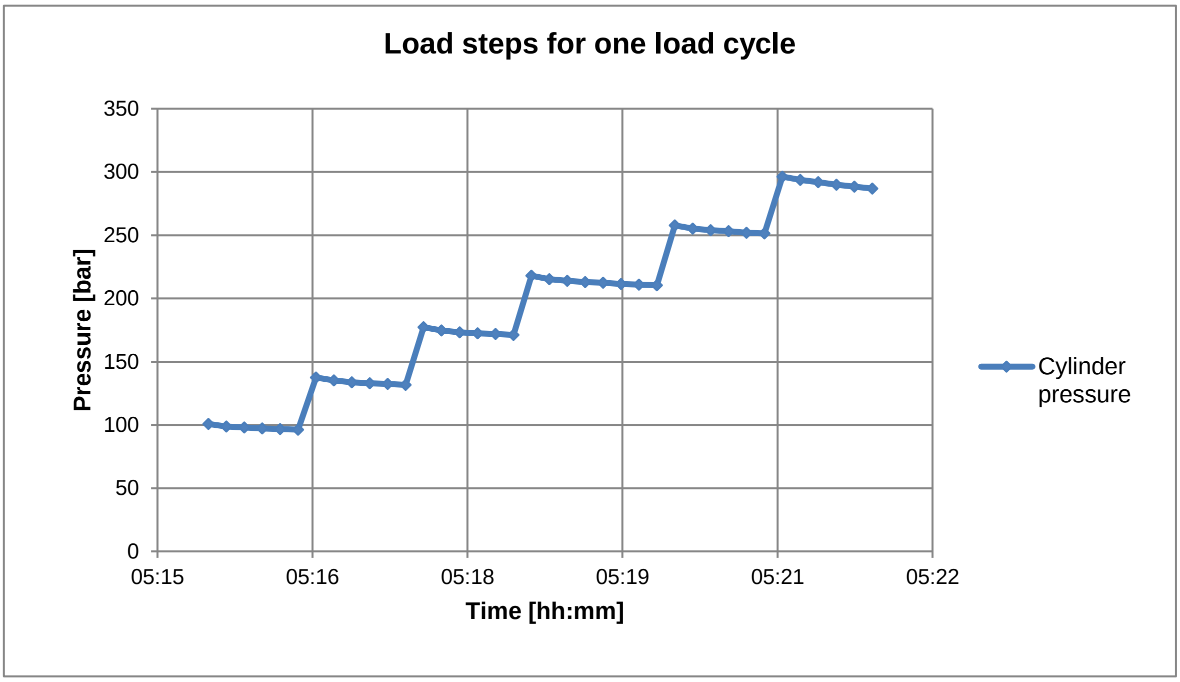


Figure 4.5: Load steps for one load cycle

4.2.2 Test with three load cycles

The required time for a test with three LCs is about 10 min.
For all tests, these points had been followed during the execution:

- The test shall be executed at a position, where no bracing happened in the past. Meaning, that after a stroke is completed and the grippers are moved forward, no bracing shall happen before the test starts.
- During the entire test, the support feet of the TBM must remain down and in place. The support feet are used to support the TBM, while the grippers are moved forward and are not braced into the rock mass.
- A prestress of 100 bar (=7,85 MN) in the hydraulic gripper cylinders shall be applied.
- 1. LC: starting at 100 bar, the hydraulic pressure gets increased in 40 bar (=3,1 MN) steps to 180 bar. After each increase, the pressure shall be hold for 30 to 60 sec.
- 2. LC: the pressure in the cylinders gets released and the defined prestress is applied again. The hydraulic pressure gets increased in 40 bar (=3,1 MN) steps to 260 bar. After each increase, the pressure shall be hold for 30 to 60 sec.
- 3. LC: the pressure in the cylinders gets released and the defined prestress is applied again. The hydraulic pressure gets increased in 40 bar (=3,1 MN) steps to 300 bar or less.
- In order to not damage the tunnel, the maximum pressure shall be defined, according to the geological condition. The assessment is done by the machine operator according to engineering judgment.

Figure 4.6 shows an example of the cylinder pressure over time for a test with three LCs.

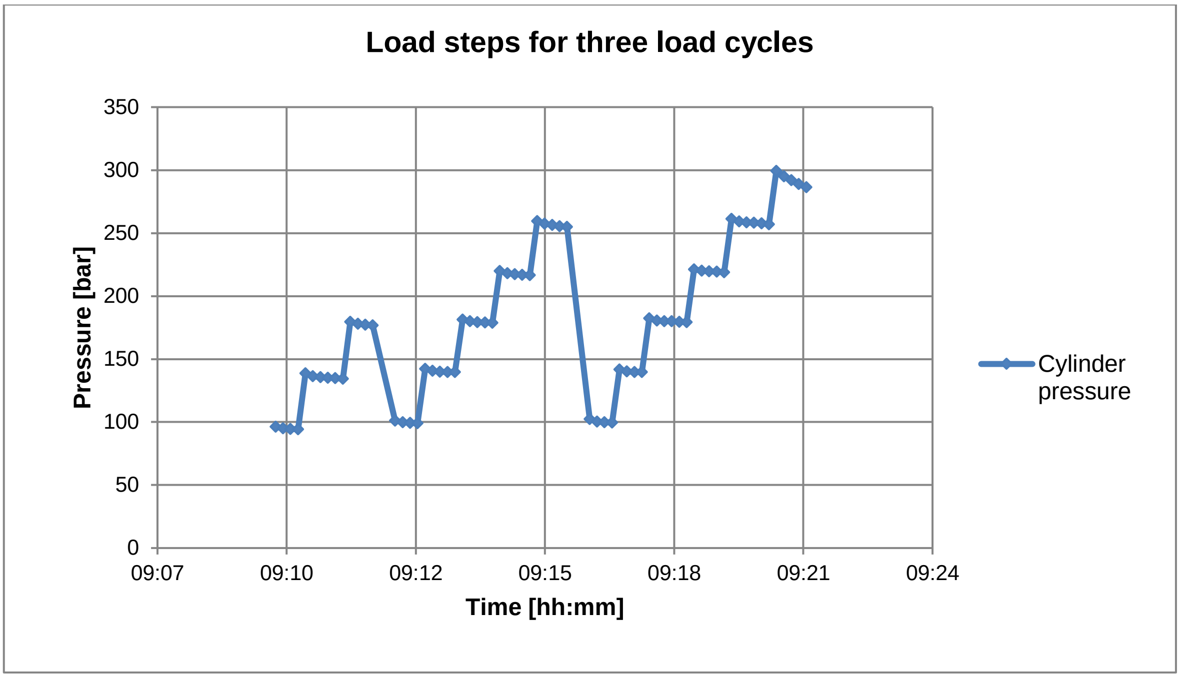


Figure 4.6: Load steps for three load cycles

4.3 Data evaluation

Distributed over a length of 520 m and a time span of 1,5 months, 20 gripper tests had been executed for this thesis. 15 tests with one LC (two of them without reinforcement mesh) and five tests with three LCs had been executed.

Please see Appendix B and C for the data sheets and raw data of all gripper tests, in order to get a complete overview of the recorded and evaluated data.

The analytical evaluation of the received data from a gripper test, will be explained by an example. The exemplary data is from the test number 11, executed on May 24th 2019 at TM 14486. A step by step explanation on the evaluation of the data will be given. Starting with the raw data, which is received from the TBM and can be seen in Table 4.1. Further on, the raw data gets evaluated and compressed, which can be seen in Table 4.2 and Table 4.3.

Table 4.1: Received data from gripper test 11

Loadstep	Time	Pressure cylinders [bar]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
LS1.0	14:48	92	677	687	730		622	638	714
	14:48	90	677	688	732		623	638	714
	14:49	89	677	688	732		623	638	714
	14:49	89	677	688	732		623	638	714
LS1.1	14:49	136	682	688	733		623	636	718
	14:49	132	683	688	733		624	638	718
	14:49	130	683	688	733		623	638	717
	14:49	129	683	688	733		624	638	718
LS1.2	14:50	177	683	688	735		625	640	721
	14:50	173	684	688	736		625	641	721
	14:50	171	685	689	736		624	641	721
	14:50	170	684	689	736		625	641	721
	14:50	170	684	688	737		625	641	721
LS1.3	14:50	215	685	688	737		623	643	724
	14:51	213	685	688	737		623	644	723
	14:51	212	685	688	737		623	643	724
	14:51	211	685	688	737		623	643	724
LS1.4	14:51	255	686	688	740		624	642	727
	14:51	253	686	688	741		623	642	726
	14:52	251	686	688	740		623	642	727
	14:52	251	686	689	741		623	643	726
LS1.5	14:52	295	688	689	741		623	643	728
	14:52	294	688	689	741		623	643	728
	14:52	291	688	689	741		622	643	728
	14:52	289	688	688	742		622	643	728
	14:53	288	688	689	742		623	643	728

Table 4.2: Evaluated data from gripper test 11

Loadstep	$Pressure_{cyl}$ [bar]		$Displ._{left}$ [mm]				$Displ._{right}$ [mm]				$Displ._{mean}$ [mm]	Δs [mm]	$\Delta\varepsilon$ [-]	$\Delta\sigma_m$ [MPa]
LS1.0	90	0	677	688	732	0,0	623	638	714	0,0	0,0	0,0	0,0000	11,1
LS1.1	131	41	683	688	733	2,5	624	638	718	1,3	1,9	1,9	0,0009	16,1
LS1.2	172	41	684	688	736	1,5	625	641	721	2,6	2,1	4,0	0,0019	21,1
LS1.3	213	41	685	688	737	0,5	623	643	724	1,1	0,8	4,8	0,0023	26,1
LS1.4	252	40	686	688	741	1,6	623	642	727	0,7	1,1	6,0	0,0029	31,0
LS1.5	291	39	688	689	741	1,1	623	643	728	0,5	0,8	6,8	0,0033	35,8
		201				7,3				6,3	6,8			

Table 4.3: Results from gripper test 11

ν	0,2	-
Δp_{cyl}	201	bar
A_{piston}	0,79	m²
ΔN	15,8	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	24,7	MPa
Δs	6,8	mm
ω	1,57	-
r	1323	mm
$\Delta\varepsilon$	0,0033	-
E_{def}	7200	MPa

4.3.1 Received data from a gripper test

For this test, one LC with 1+5 load steps (LS) had been executed. As mentioned in chapter 3.2, the TBM records data every ten seconds. This means, for a duration of 30 to 60 sec per LS, 4 to 7 values per sensor and LS are received. For the evaluation of a gripper test, the time, the hydraulic pressure in the gripper cylinders and the gripper movement are needed. The following explanations refer to Table 4.1.

Column "Loadsteps" indicates the LS. The definition of the abbreviation $LSX_1.X_2$ is the following:

- LS… load step
- X_1… number of LC
- X_2… number of LS

The zero in LS1.0, indicates that this is the step, where the prestress of 100 bar gets applied. After the prestress had been applied, the displacements were set to zero and the incremental pressure increase (which is explained in chapter 4.2) starts. Column "Time" shows the time of the recorded data set. Column "Pressure cylinders" displays the hydraulic pressure in the gripper cylinders. The remaining columns show the movement of each MP on the left and right gripper.

4.3.2 Evaluated data from a gripper test

The following explanations refer to Table 4.2. As mentioned, 4 to 7 values per sensor and LS are received.

For the hydraulic pressure, only one value per LS is needed. Therefore, the mean value for each LS is calculated, which can be seen in the left column of "$Pressure_{cyl}$". The incremental increase of the mean normal stress "$\Delta\sigma_m$", can now be calculated. The right column illustrates the pressure increase between the LSs. Beneath, the total pressure difference (Δp_{cyl}) between LS1.0 and LS1.5 is shown.

The evaluation of the displacement measurements is done according the following steps. For each MP, a mean value per LS is calculated. Since each gripper has three MPs, the mean value for all three MPs is calculated, resulting in one value per LS and gripper. With those values, the incremental increase of the displacements between the LSs can be calculated (in the very right column of “$Displ._{left}$” and “$Displ._{right}$”). Beneath this column, the total displacements for each gripper are calculated. Due to the problem with the missing fixed point on the TBM (explained in chapter 4.1), the mean value of the displacements from both grippers is calculated in “$Displ._{mean}$”. The incremental increase of the total displacements “Δs” and the total strain “$\Delta \varepsilon$” can now be calculated.

Table 4.3 shows the final values, which are used in Equation (4.1).

The stress-strain curve of the gripper test 11 with one LC, is shown in Figure 4.7. The deformation modulus (E_{def}) is defined with a secant, intersecting at the applied prestress and the maximum mean normal stress. Figure 4.9 and Figure 4.10 show the displacement-time curves for MP1/2/3 of the left and the right gripper for the gripper test 11. These curves can be used as a monitoring tool. If the curves are fluctuating a lot, insufficient measurement accuracy could be an explanation and a reason for an exclusion for further evaluations.

In terms of a gripper test with three LCs, the data evaluation follows basically the same procedure. Each LC is evaluated separately. The unloading phase is controlled by the gripper movement and not by the hydraulic pressure in the gripper cylinders. Meaning, the grippers are manually and rapidly moved away from the rock mass. Therefore, no meaningful measurements can be recorded during this process. Figure 4.8 shows the stress-strain curves of the gripper test 6 with three LCs. The deformation modulus (E_{def}) is defined with a secant, intersecting at the applied prestress and the maximum mean normal stress. This is done for each LC. The final value for E_{def}, is the mean value of the three deformation moduli.

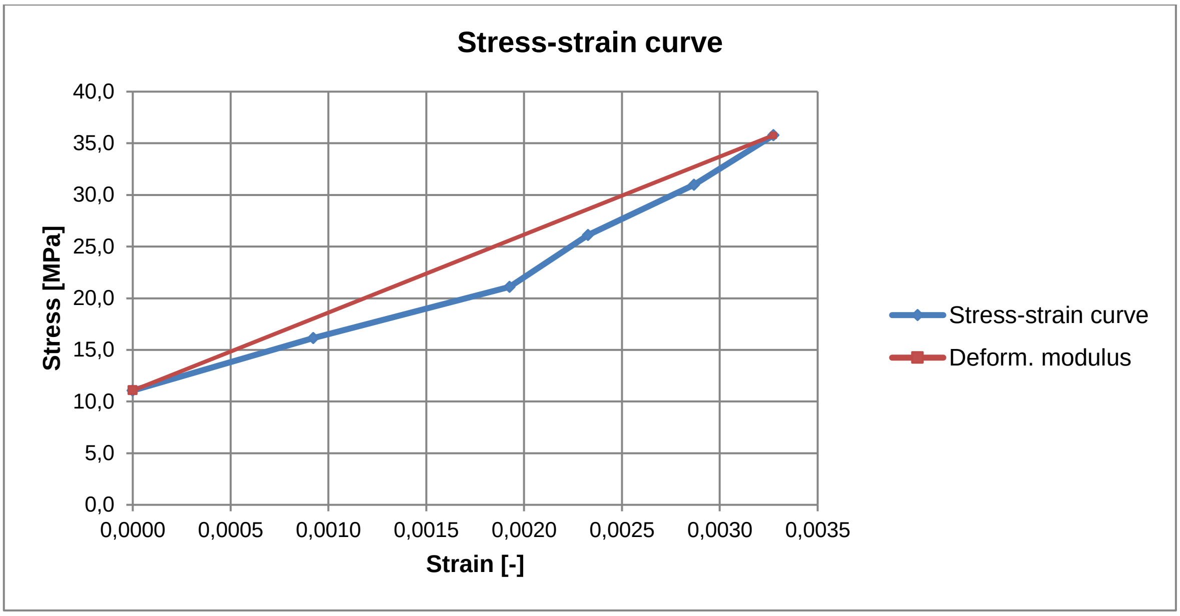


Figure 4.7: Stress-strain curve of gripper test 11 with one LC

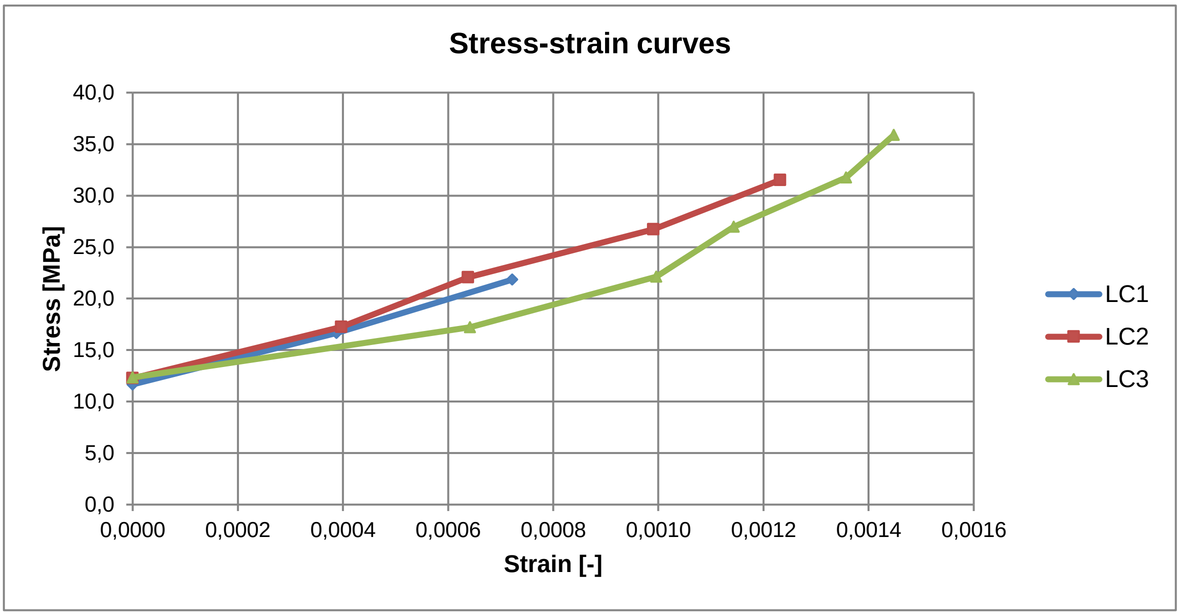


Figure 4.8: Stress-strain curve of gripper test 6 with three LC

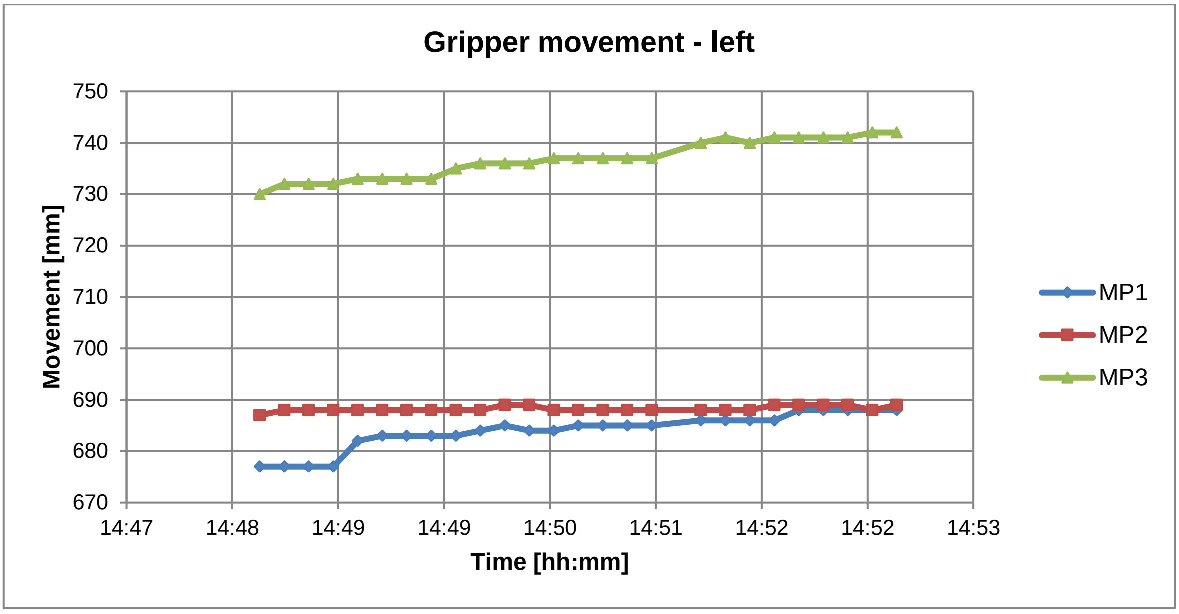


Figure 4.9: Displacement-time curve of gripper test 11 with one LC (left gripper)

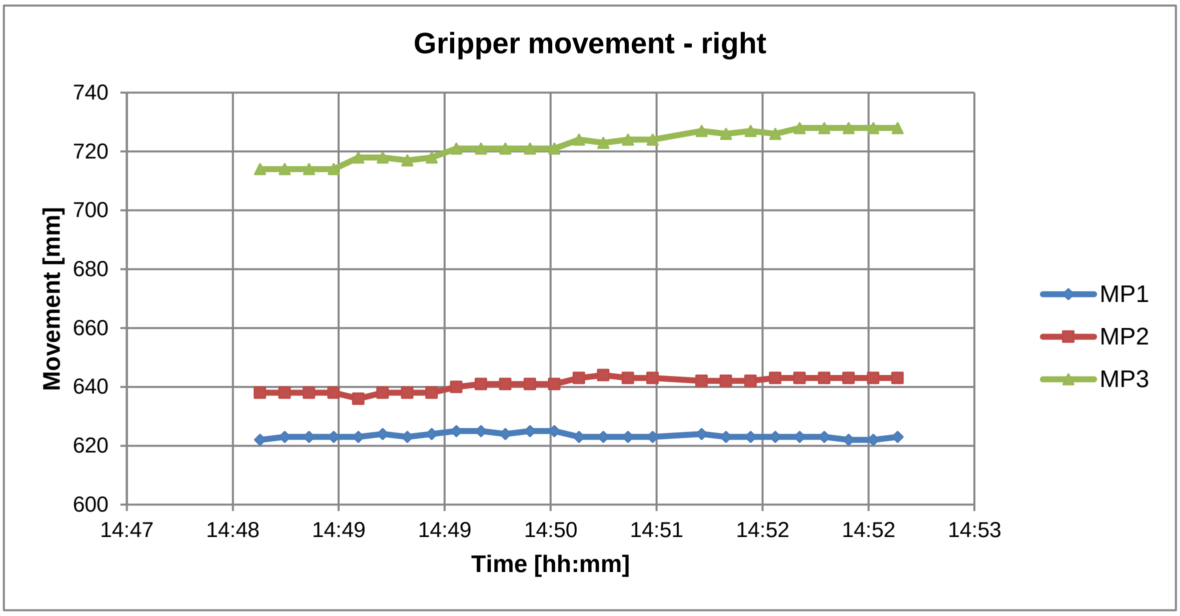


Figure 4.10: Displacement-time curve of gripper test 11 with one LC (right gripper)

5 Numerical studies

In the course of this thesis, two different numerical studies have been performed. All computations have been performed with PLAXIS 2D, using finite element models.
On the one hand, since the analytical approach for the depth of influence follows some assumptions and simplifications, a numerical study had been done on this topic. The goal was either to confirm the analytical approach, or to get a second result for this parameter and compare both options. A step by step explanation on the creation of the numerical models and the evaluation of the results will be given in this chapter.
On the other hand, (beside the analytical approach for the determination of the rock mass stiffness) a numerical model was developed, in order to execute a parameter back-calculation for the rock mass stiffness. A numerical model was created, in order to simulate a gripper test like they were executed at the Brenner Base Tunnel.
The derivations and the values of the used parameters of the different constitutive models are shown hereafter.

5.1 Parameter sets of constitutive models

During the numerical studies, the linear-elastic perfectly plastic Mohr-Coulomb model (MC) and the more advanced Hardening Soil model (HS), accounting for isotropic hardening, was used. Literature about these material models can be found in (PLAXIS, 2019c) and (Voit, 2016).

5.1.1 Mohr-Coulomb model

Table 5.1 shows the parameter set, which was used for all computations with the MC model. The data sheet for GT SH-KS-3b can be found in Appendix A. For parameters which were not given in the GT data sheet, assumptions have been made.

Table 5.1: Parameters for Mohr-Coulomb model

Symbol	SH-KS-3b	Unit	Defined by
Model	MC	[-]	-
Type	drained	[-]	Assumption
γ_{unsat}	27	[kN/m³]	Assumption
γ_{sat}	27	[kN/m³]	Assumption
E'	10000	[MPa]	GT data sheet
ν'	0,2	[-]	GT data sheet
c'	2,5	[MPa]	GT data sheet
φ'	33	[°]	GT data sheet
ψ	0	[°]	Assumption
K_0	1,0	[-]	Assumption

5.1.2 Hardening Soil model

Table 5.2 shows the parameter set, which was used for all computations with the HS. The data sheet for GT SH-KS-3b can be found in Appendix A. For parameters which were not given in the GT data sheet, assumptions have been made. "Standard", indicates that the default value of PLAXIS 2D had been used. The overburden (h) is the mean value of the overburden from the investigated section.

Table 5.2: Parameters for Hardening Soil model

Symbol	SH-KS-3b	Unit	Defined by
Model	HS	[-]	-
Type	drained	[-]	Assumption
γ_{unsat}	27	[kN/m³]	Assumption
γ_{sat}	27	[kN/m³]	Assumption
E	10000	[MPa]	GT data sheet
E_{50}^{ref}	2550	[MPa]	Equation (5.1)
E_{oed}^{ref}	2550	[MPa]	Equation (5.2)
E_{ur}^{ref}	7650	[MPa]	Equation (5.3)
c'	2,5	[MPa]	GT data sheet
φ'	30	[°]	GT data sheet
ψ	0	[°]	Assumption
ν_{ur}	0,15	[-]	Assumption
p^{ref}	0,1	[MPa]	Standard
m	0,8	[-]	Assumption
K_0	1,0	[-]	Assumption

h	-750,0	[m]	-
σ_3'	-20,3	[MPa]	Equation (5.4)

$$E_{50}^{ref} = E * \left(\frac{c' * \cos\varphi' + p^{ref} * \sin\varphi'}{c' * \cos\varphi' - \sigma_3' * \sin\varphi'}\right)^m \quad (5.1)$$

$$E_{oed}^{ref} = E_{50}^{ref} \quad (5.2)$$

$$E_{ur}^{ref} = 3 * E_{50}^{ref} \quad (5.3)$$

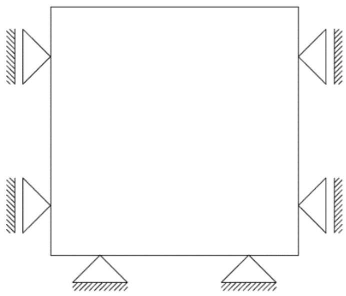
$$\sigma_3' = \gamma_{unsat} * h * K_0 \quad (5.4)$$

5.2 Computation of the depth of influence

The analytical approach for the depth of influence is defined by Equation (4.6) in chapter 4.1. A step by step explanation on the creation of the numerical approach and the evaluation of the results will be given here.

For the first model (reinforcement model), the goal was to derive at the force, which is needed to push the entire reinforcement mesh into the rock mass. Afterwards it is assumed that the theoretical gripper area (A_{grip}) is in full contact with the rock mass. Table 5.3 shows the properties of the reinforcement model.

Table 5.3: Properties of reinforcement model and plate model

Model type	plane strain
Element type	15-noded
Contours	x_{min} = -2,5 m x_{max} = 2,5 m y_{min} = -5,0 m y_{max} = 0,006 m
Mesh	fine with local refinements
Boundaries	x_{min} = normally fixed x_{max} = normally fixed y_{min} = fully fixed y_{max} = free 

For the rock mass, the MC model had been used (please see Table 5.1 for the used parameters). Figure 5.2 shows an extract of the model where the vertical wires of the reinforcement mesh and a stiff plate on top, acting as gripper, can be seen. The parameters of the wires are defined according to the specifications of the installed BSt 550 AQ60 mesh, which can be found in chapter 4.1. For the wires, the linear-elastic model had been used. Figure 5.1 shows the calculation phases of the model, which are also explained in the following steps. After the initial phase, the wires and the elastic plate are activated. It is assumed, that for the first 6 mm of displacement, only the vertical wires are in contact with the rock mass. Therefore, prescribed displacements of 6 mm are applied on top of the plate. The force needed to push the vertical wires 6 mm into the rock mass is evaluated and can be seen in Figure 5.4. It is assumed, that after the vertical wires are pushed into the rock mass, the horizontal wires get in contact with the rock mass for the first time. Figure 5.3 shows the vertical and horizontal wires of the reinforcement mesh. Since a 2D model is used, the vertical and horizontal wires are placed next to each other and not perpendicular to each other. Prescribed displacements of 6 mm are applied again. The required force is evaluated in Figure 5.5.

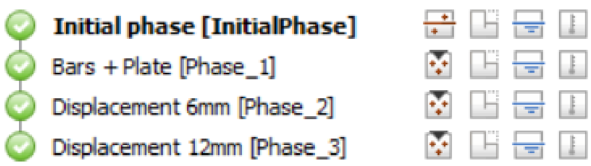


Figure 5.1: Phases for the reinforcement model

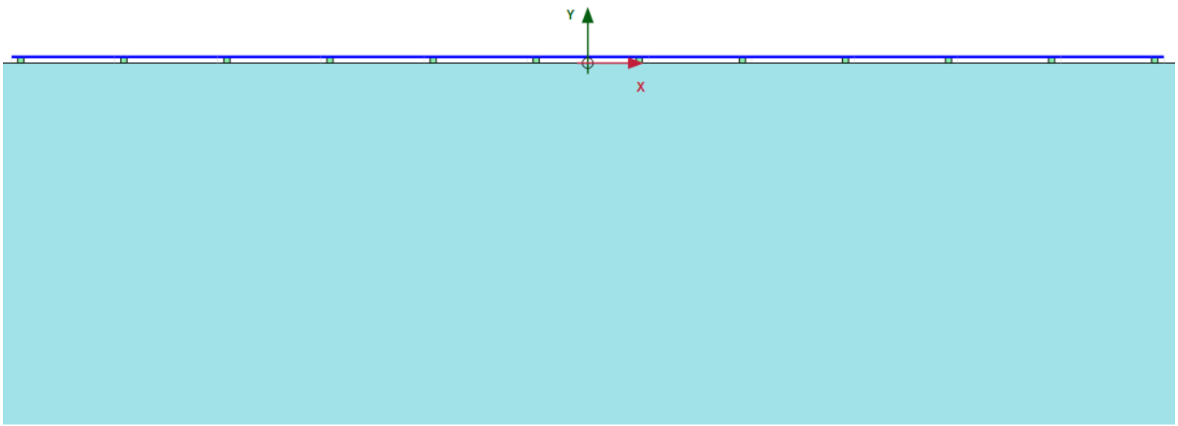


Figure 5.2: Vertical wires of reinforcement mesh

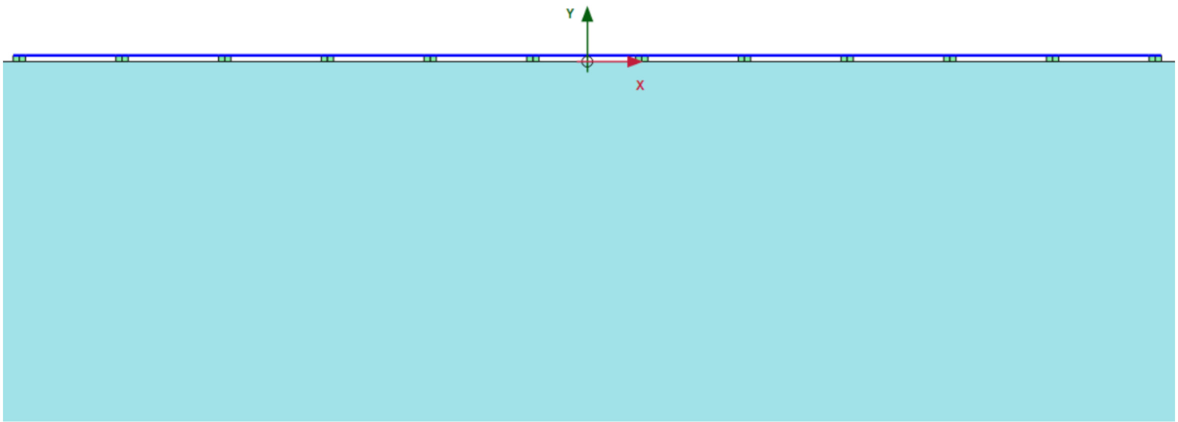


Figure 5.3: Vertical and horizontal wires of reinforcement mesh

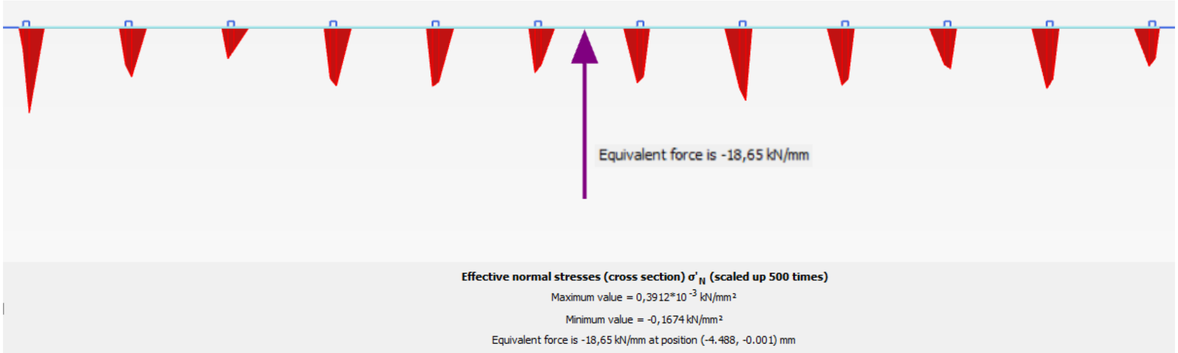


Figure 5.4: Resultant force which is needed for the first 6 mm of displacement

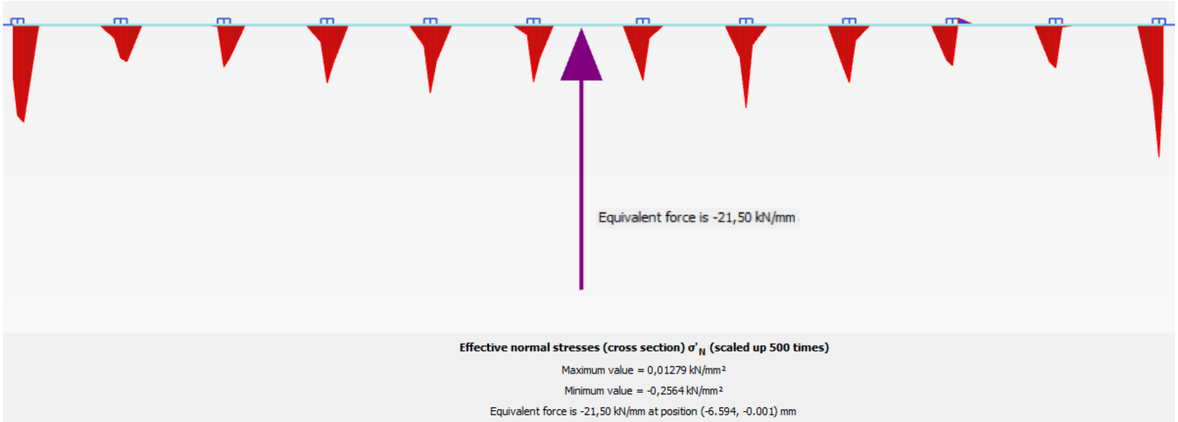


Figure 5.5: Resultant force which is needed for the second 6 mm of displacement

The total force needed, to push the entire reinforcement mesh into the rock mass is 41 kN.

Figure 5.6 shows the plastic points after 12 mm of displacement. The local plasticity beneath the reinforcement (red points), could be a reason why the required force, to push the reinforcement into the rock mass, is so small.

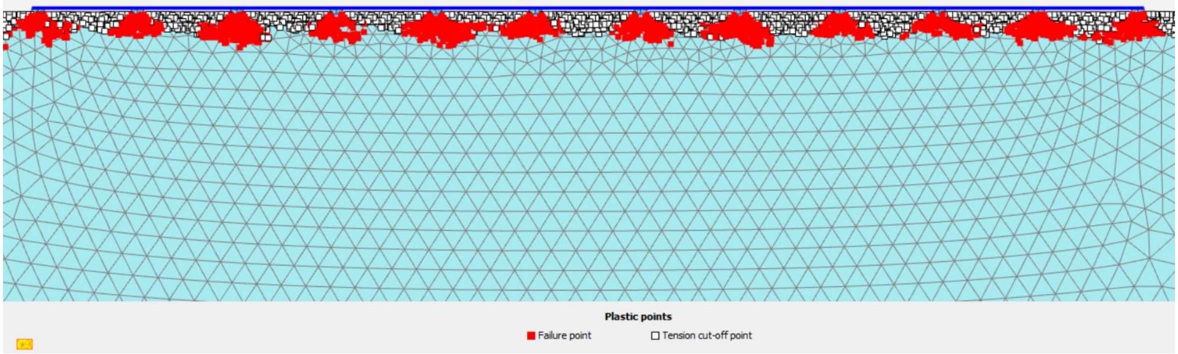


Figure 5.6: Plastic points after 12 mm of displacement

The second model (plate model) simulates the loading process, after the reinforcement mesh got pushed into the rock mass and the entire gripper is in contact with the rock mass. Table 5.3 shows the properties of the plate model.
For the rock mass, the HS model had been used (please see Table 5.2 for the used parameters). Figure 5.7 shows the force ($F = 16000\ kN - 41\ kN$), which is applied as a line load onto a stiff and elastic plate. 16000 kN was a frequently applied normal force during the gripper tests.

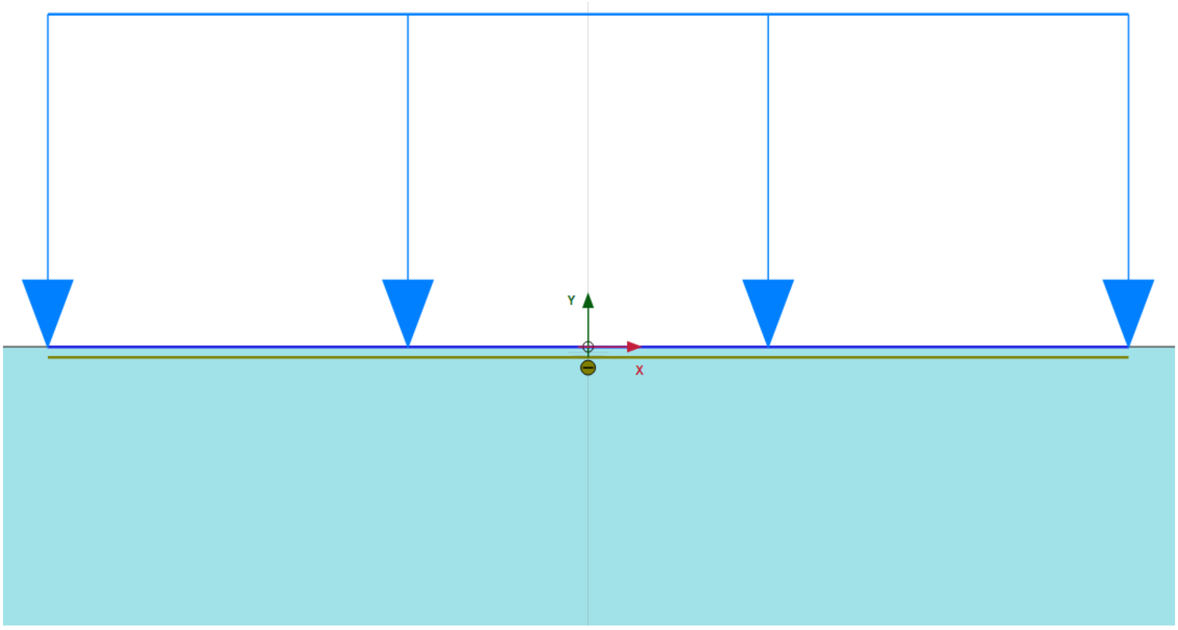


Figure 5.7: Line load on stiff plate, acting as gripper

In order to derive at the depth of influence, the following approach had been applied. The depth of influence is defined by the point, where the additionally applied mean normal stress ($\Delta\sigma_m$) equals 20% of the primary in-situ stress ($\sigma'_{in\text{-}situ}$). Figure 5.8 (Adam, 2016b) shows how the depth of influence is derived.

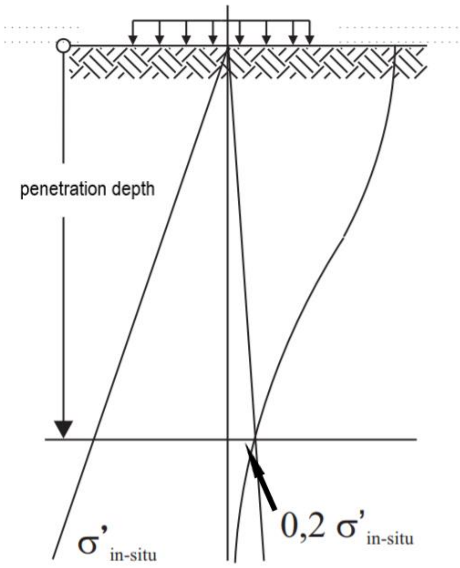


Figure 5.8: Depth of influence according to (Adam, 2016b)

The cut off criteria for the depth of influence, is defined by Equation (5.5).

$$\sigma'_{in-situ,20\%} = \gamma_{unsat} * h * 0{,}2 \quad (5.5)$$

Figure 5.9 shows the vertical stress distribution and the cut off criteria for the depth of influence. The point where the mean normal stress curve and the 20% primary in-situ stress line intersect, defines the depth of influence. Please note, that this approach is only meaningful for an elastic-isotropic half space.

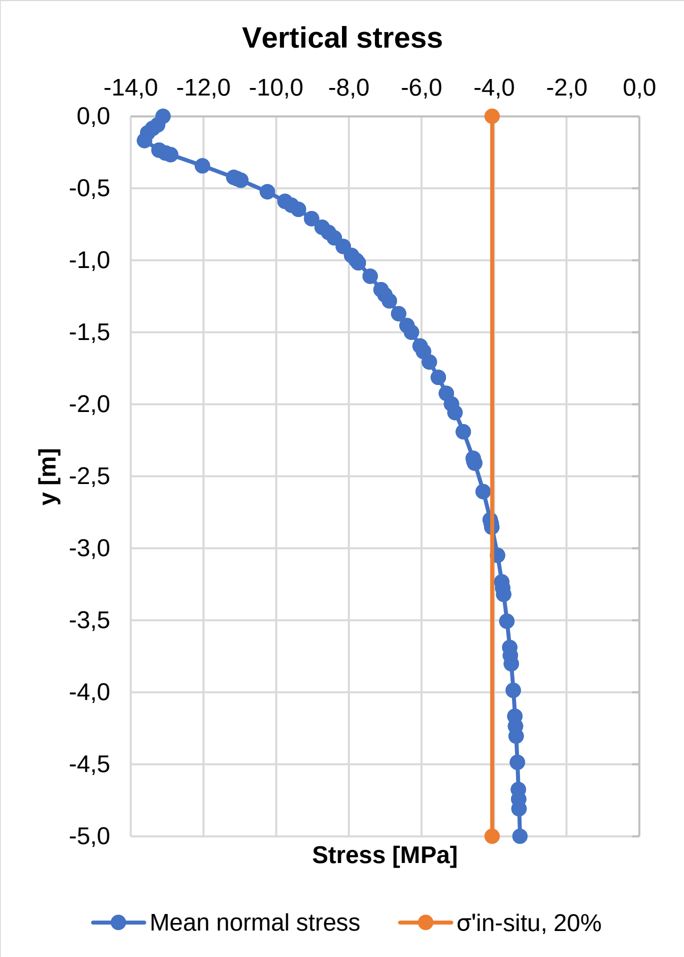


Figure 5.9: Vertical stress distribution and cut off criteria for depth of influence

The depth of influence is 2,86 m. Compared to the analytical approach, the depth of influence from the numerical computations is 38% bigger.

5.3 Back-calculation of the rock mass stiffness

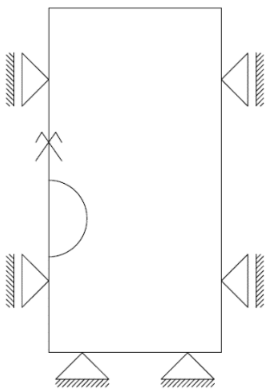
Besides the analytical approach for the determination of the rock mass stiffness, a numerical model had been developed, in order to execute a parameter back-calculation for the rock mass stiffness.

A numerical model was created, in order to simulate a gripper test like they were executed at the Brenner Base Tunnel. The model simulates a gripper test with one LC. A simulation of a test with three LCs had not been done. Because of differing geological conditions, the maximum load during the 3rd LC, was not consistent within the tests. Also explained in chapter 4.2, the machine operator decides the maximum load during each gripper test.

A parameter back-calculation would not be comparable due to the differing maximum loads. Additionally, only five tests with three LCs, compared to 15 tests with one LC, had been executed. During the gripper tests, the displacements were measured and afterwards evaluated (please see chapter 4.3). The basic principal of this back-calculation is the following. By adjusting the rock mass stiffness in the numerical model, similar displacements in the numerical model compared to the real gripper tests are achieved. This adjusting process is once done for the minimum and once for the maximum displacement value out of all 15 tests with one LC. A range for the rock mass stiffness can now be defined.

Table 5.4 shows the properties of the reinforcement model.

Table 5.4: Properties of tunnel model

Model type	plane strain
Element type	15-noded
Contours	x_{min} = 0,0 m x_{max} = 36,0 m y_{min} = -28,0 m y_{max} = 44,0 m
Mesh	medium with local refinements
Boundaries	x_{min} = normally fixed x_{max} = normally fixed y_{min} = fully fixed y_{max} = free 

In order to keep the calculation time to a minimum, a symmetrical plane along the vertical tunnel axis had been created. The model width and height are 36 m (4,5 tunnel diameters) and 72 m (9d) respectively. With the height being separated in 44 m (5,5d) above and 28 m (3,5d) beneath the horizontal tunnel axis. The tunnel diameter is 7,93 m. The numerical model is shown in Figure 5.10. For the rock mass, the HS model had been used as constitutive law. The used parameters can be found in Table 5.2, except for the stiffness parameters. For the gripper, a linear-elastic material behaviour had been assumed. The parameters had been chosen very high, assuming the gripper behaves as a totally stiff frame. The contact area of the gripper is 5,50 m², which is the theoretical contact area of the gripper (A_{grip}). In order to create a primary stress state equal to an overburden of 750 m, a line load had been applied on top of the model. Accounting for the missing 710 m of overburden, 19,2 MN/m had been applied.

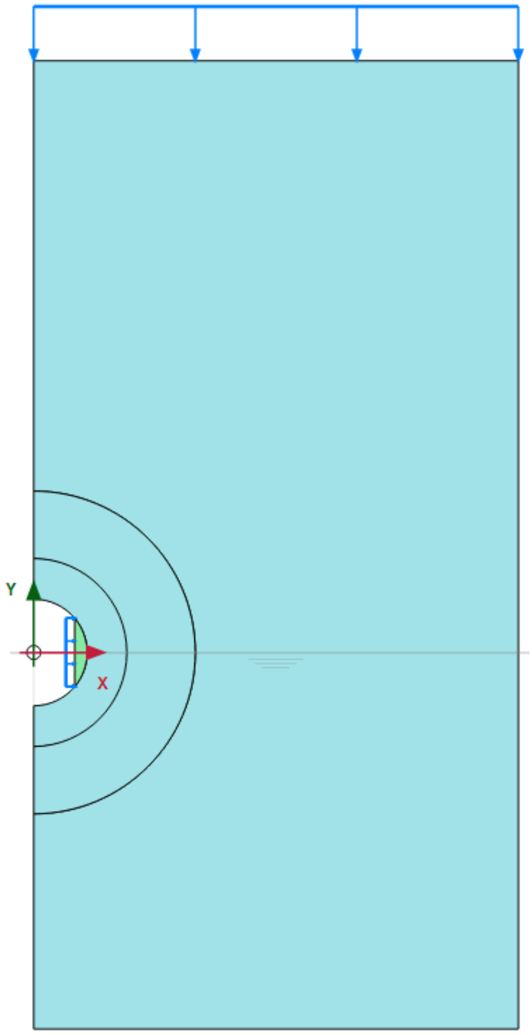


Figure 5.10: Numerical model for the simulation of a gripper test

Figure 5.11 shows the calculation phases of the model. Due to the line load on top of the model, two initial phases are needed. The excavation of the tunnel was done in phase 2 and 3. Further on, the displacements were set to zero, the gripper was activated, and the load was applied. The LS were identical to the procedure of the real gripper tests with one LC.

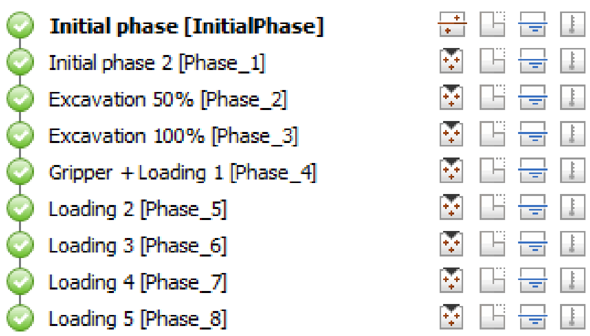


Figure 5.11: Phases for numerical model for the simulation of a gripper test

After the last LS, the displacements, created by the gripper, were observed and compared to the displacement values of the real gripper tests. The rock mass stiffness was adjusted until the displacements from the model, were the same as the displacements of the real gripper tests. Since the HS model uses reference stiffness moduli, the young's modulus E was derived by Equation (5.7).

$$\mathrm{E} = E_{50,adj}^{ref} * \left(\frac{c' * \cos' \varphi - \sigma_3' * \sin \varphi'}{c' * \cos \varphi' + p^{ref} * \sin \varphi'} \right)^m \tag{5.7}$$

$E_{50,\,adj}^{ref}$... *adjusted secant reference stiffness in standard drained triaxial test [MPa]*

For the minimum displacement value (3,9 mm) and for the maximum displacement value (9,2 mm), the young's moduli are 1200 MPa and 2800 MPa respectively.

6 Results and interpretation

In this chapter, the results of the analytical evaluation of the gripper tests and the numerical studies are shown and compared. General data and results of the gripper tests are given and an interpretation of the meaningfulness of the different results is given.
During the gripper tests and the evaluation of the data, numerous problems have been encountered. Problems concerning the limitations of the TBM's hydraulic system and measurement system, as well as problems, which have been faced during the data evaluation, are discussed.

Figure 6.1 shows the distribution of the different rock mass moduli along the longitudinal tunnel axis of the investigated section in the exploratory tunnel. Important to note is, that deformation moduli as well as young's moduli are compared. How those two stiffness moduli are defined and differ from each other, is explained in chapter 4.1 according to (Adam, 2016a).
The different rock mass moduli shown in Figure 6.1 are the following:

E_{rec}... *recommended young's modulus from the technical report for ground types (data sheets in Appendix A) and ground behaviour* (GeoTeam, 2008) *[MPa]*

$E_{def,1}$... *determined deformation modulus from gripper tests using the analytical approach for the depth of influence [MPa]*

$E_{def,2}$... *determined deformation modulus from gripper tests using the numerical approach for the depth of influence [MPa]*

E_1... *determined young's modulus from the parameter back-calculation for the minimum displacement (3,9 mm) [MPa]*

E_2... *determined young's modulus from the parameter back-calculation for the maximum displacement (9,2 mm) [MPa]*

Table 6.1 shows some of the general data and results of the gripper tests. Please see Appendix B and C for the data sheets and raw data of all gripper tests, in order to get a complete overview of the recorded and evaluated data.

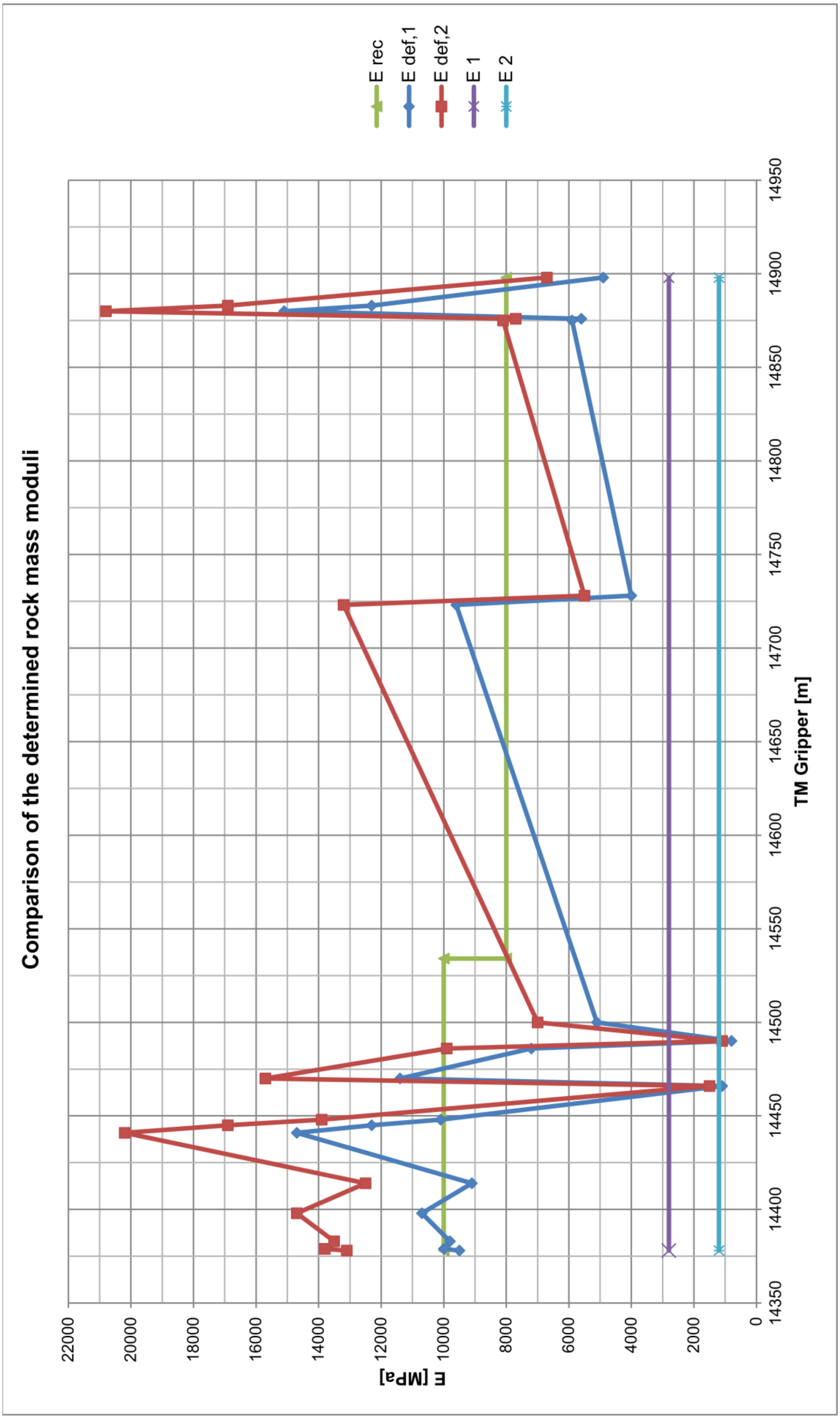


Figure 6.1: Comparison of the determined rock mass moduli

Table 6.1: General data and results of gripper tests

Nr.	Date/Time	TM Face [m]	TM Gripper [m]	LC	LS	Reinforcement Mesh	$E_{def,1}$ [MPa]	$E_{def,2}$ [MPa]	E_{rec} [MPa]
1	16.05.2019 09:30	14396	14378	1	5	yes	9500	13100	10000
2	16.05.2019 11:15	14397	14379	1	5	yes	10000	13800	10000
3	16.05.2019 16:15	14401	14383	1	5	yes	9800	13500	10000
4	17.05.2019 15:40	14416	14398	1	5	yes	10700	14700	10000
5	18.05.2019 18:00	14432	14414	1	5	yes	9100	12500	10000
6	20.05.2019 09:20	14459	14441	3	2/4/5	yes	14700	20200	10000
7	20.05.2019 14:00	14463	14445	1	5	yes	12300	16900	10000
8	20.05.2019 16:00	14466	14448	1	5	yes	10100	13900	10000
9	23.05.2019 01:50	14484	14466	1	5	no	1100	1500	10000
10	24.05.2019 01:50	14488	14470	1	5	yes	11400	15700	10000
11	24.05.2019 14:50	14504	14486	1	5	yes	7200	9900	10000
12	24.05.2019 23:55	14508	14490	1	5	no	800	1100	10000
13	25.05.2019 21:45	14518	14500	1	5	yes	5100	7000	10000
14	12.06.2019 11:20	14741	14723	1	4	yes	9600	13200	8000
15	12.06.2019 22:20	14746	14728	1	4	yes	4000	5500	8000
16	26.06.2019 10:10	14893	14875	3	1/4/4	yes	5900	8100	8000
17	26.06.2019 14:30	14894	14876	1	4	yes	5600	7700	8000
18	27.06.2019 00:30	14898	14880	3	2/4/5	yes	15100	20800	8000
19	27.06.2019 19:20	14901	14883	3	2/4/5	yes	12300	16900	8000
20	29.06.2019 13:30	14916	14898	3	2/4/4	yes	4900	6700	8000

E_{rec} is the parameter, which describes the rock mass stiffness in the GT data sheets (please see Appendix A). E_{rec} is determined by laboratory tests and engineering judgement. It is used as a reference value for this comparison.

For $E_{def,1}$ and $E_{def,2}$, realistic values could be determined. The only difference between those parameters are the different depths of influences (l), which were used for Equation (4.1). The deeper depth of influence for $E_{def,2}$, leads to results, 38% higher compared to $E_{def,1}$.

With the parameter back-calculation for E_1 and E_2, no meaningful results could be determined. 2800 MPa for E_1 and 1200 MPa for E_2, are unrealistic values for the conditions which were faced throughout the investigated section. The reason for such small values is discussed later in this chapter.

The gripper tests number nine and twelve had been executed without reinforcement mesh between the grippers and the rock mass. Therefore, the approach on the contact area, which is explained in chapter 4.1, wasn't meaningful anymore. For both tests was assumed, that the theoretical gripper area A_{grip} is in contact with the rock mass. This resulted in very small values for the deformation modulus of the rock mass. Unfortunately, the determined values are very unrealistic and therefore have no meaningfulness.

By comparing gripper tests with one LC and three LCs, the following insights had been found. The dispersions of the determined deformation moduli are approximately 300% for both test types. For tests with three LCs, an increase of the rock mass stiffness could be observed after every un-/reloading cycle. In the course of this test series, tests with one LC seemed to be more meaningful than tests with three LCs. The reasons for this are the following. 15 tests with one LC compared to only five tests with three LCs had been executed. Because of the uncontrolled unloading and the repeated prestressing during the test, simply more sources of error are present. For big scale tests like these, high pressure differences during a LC are more advantageous than small ones. Meaning, that the first and second LC, with a pressure increase of 80 bar and 160 bar respectively, are less meaningful than the third LC with 200 bar.

During the gripper test series and the evaluation of the data, numerous problems have been encountered.

For the test series, no modifications on the TBM had been made. Therefore, some restrictions on the test procedure had to be made. The hydraulic system of the gripper cylinders had not been able to increase the pressure constantly over time. Therefore, the pressure increase had to be done in steps. Additionally, the hydraulic system had not been able to keep the pressure constant between the LS. In general, a pressure decrease between the LS of approximately 5%, could be observed. With a more accurate hydraulic system and the possibility of a constant pressure increase during the LC, the received data would be more meaningful. Besides the hydraulic system, the measurement system also brought some challenges with it. The measurement accuracy of the laser points and the influence of TBM stiffness during the test is unknown. Due to the missing fixed point on the TBM and the three MPs on each gripper, a lot of mean values had to be evaluated. This had to be done in order to reduce the data to one displacement value.

Concerning the evaluation of the received data and the determination of the deformation modulus, most problems had already been discussed in this thesis. The general approach which had been derived from the DPLT, according (DGEG, 1985), is suitable for the determination of the deformation modulus. It is a matter of specifying assumptions and reducing uncertainties. Parameters like the contact area A_{cont} and the depth of influence l, do have a big influence on the deformation modulus, but are purely based on assumptions. During the test series, it was tried to determine the contact area of the gripper by placing a plastic foil/membrane between the gripper and the rock mass. The foil/membrane would have had a white and black side, in order to get an imprint of the contact area between the gripper and the rock mass. Unfortunately, the construction company declined this request due to health and safety concerns.

For the depth of influence an additional numerical approach had been tried. The applicability of the result though, could be discussed. For the analytical approach it was always assumed, that at any time, only the reinforcement mesh is in contact with the rock mass. On the other hand, the numerical approach assumes the opposite. Only a very small force is needed to push the reinforcement into the rock mass. Afterwards, the entire gripper is in contact with the rock mass. This inconsistency, surly reduces the meaningfulness of the results.

For the parameter back-calculation, a similar situation is encountered. For the simulation of the gripper tests, it was assumed that the theoretical gripper area is in contact with the rock mass. This resulted in very small deformation moduli. Would have been assumed that only the reinforcement is in contact with the rock mass, much higher deformation moduli would have been determined.

During the elaboration of this thesis an isotropic and homogeneous rock mass behaviour had been assumed. Therefore, some rock mass mechanisms had been neglected, which would have had an influence on the results.

Anisotropy and inhomogeneity have an influence on the displacements and on the depth of influence. Dependent on the location, the anisotropic and inhomogeneous behaviour of a rock mass is differing. Due to this behaviour, the displacements of the left and the right gripper are most likely not similar. Therefore, it is important to implement such material behaviours in the models. Since it is assumed that only the reinforcement is in contact with the rock mass, the area where force is applied, is relatively small. This raises the question of whether the joint system of the rock mass can be activated during the gripper tests or if the measured displacements are purely dependent on the intact rock stiffness.

For further research these mechanisms need to be specified and the influence on the results needs to be determined.

7 Conclusion and outlook

The knowledge of rock mass parameters is of utmost importance to ensure an economical tunnel design. In order to gain detailed information about the properties and the mechanical behaviour of the surrounding rock mass, an in-situ test program would be necessary. An open gripper TBM continuously records the gripper force. The goal of the thesis was to explore if and how monitored gripper forces can be used to determine the rock mass stiffness of the surrounding ground.

Distributed over a length of 520 m and a time span of 1,5 months, 20 gripper tests have been executed in the exploratory tunnel at the construction lot H33 Tulfes – Pfons of the Brenner Base Tunnel.

Due to the comparability to the gripper tests, a literature research on the double plate load test had been done. The basic concept of a double plate load test is always very similar. In terms of data evaluation, different approaches can be found in literature. In this thesis the approaches according to (Ünal, 1997) and (DGEG, 1985) were discussed. The basic idea was, to find an approach suitable for the data evaluation of the gripper tests. Due to the capabilities of the TBM's measuring system, the approach according (DGEG, 1985) had been used for the data evaluation of the gripper tests.

A short overview on the investigated section in the exploratory tunnel was given. For the test series, no modifications on the TBM had been made. Technical specifications and limitations of the open gripper TBM were discussed. The biggest limitations were the hydraulic system and the measuring system. The hydraulic system of the gripper cylinders was not able to increase the pressure constantly over time. Another issue was keeping the pressure constant after the increases stopped. These issues could be discussed with the manufacturer of the TBM. Unfortunately, the measuring accuracy of the measuring system could not be verified. A typical measuring accuracy for the installed laser points, is 1 mm. Due to the high loads, the stiffness of the TBM influences the measuring results. Unfortunately, the amount of influence is unknown and would need additional research. Also, an additional measuring device, like a total station in combination with targets mounted on the grippers, could be investigated. Further, a measuring system, which can measure the displacements of each gripper independently, would be of utmost importance.

A concept for the gripper test series had been developed. For the data evaluation used equations and parameters were listed, as well the explanations on how those equations and parameters were derived were given. The general approach for the determination of the deformation modulus of the rock mass is suitable for the evaluation of the gripper tests. Realistic deformation moduli could be determined. Compared to the recommended young's moduli of the rock mass, which are given in the ground types data sheets (please see Appendix A), most results are in a similar range. It is a matter of specifying assumptions and reducing uncertainties. Parameters like the contact area A_{cont} and the depth of influence l, do have a big influence on the deformation modulus of the rock mass, but are purely based on assumptions. In order to determine more meaningful deformation moduli, additional research on those parameters needs to be done. A numerical approach on the radius problem (please see chapter 3.2 for explanation) could give additional information on the contact area.

Upon constant agreement with the construction company and the site supervision, two different test procedures have been developed. Both procedures were explained, and their advantages and disadvantages were compared. In the course of this test series, it turned out that gripper tests with one load cycle were more meaningful than tests with three load cycles. Mainly because tests with one load cycle were more often executed and simpler, leaving less room for errors.

The analytical evaluation of the received data is explained step by step with an example. In order to get a complete overview of the recorded and evaluated data, as well as on the results, the evaluated data sheets and the raw data of all gripper tests are attached in Appendix B and C respectively.

Numerical studies on two topics had been performed. For all computations PLAXIS 2D and finite element models had been used.

On the one hand, an additional approach on the depth of influence had been tried. The determined depth of influence led to 38% higher deformation moduli compared to the fully analytical approach. Although the determined deformation moduli were realistic, contradictions in assumptions for the contact area are reducing the meaningfulness of the results.

On the other hand, a parameter back-calculation for the rock mass stiffness had been performed. Unfortunately, only unrealistic deformation moduli could be determined. The model followed too many simplifications. More meaningful results could have been determined, by introducing anisotropy and inhomogeneity to the models. Also, a district element model would have been more suitable for this matter.

This thesis represents a first basis for the determination of the rock mass stiffness, using monitored gripper forces of an open gripper TBM. In order to increase the meaningfulness of the results, modifications on the TBM and further research on the evaluation of the monitored data would be necessary.

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Appendix A

Data sheets for ground types

Kriterien	Gebirgsart GA SH-KS-3b		
Criterio	**Tipo dell'ammasso roccioso GA SH-KS-3b**		
Lithologie	kalkreicher Bündner Schiefer: Kalkschiefer, Kalkmarmor, Karbonatquarzit, Phyllit		
Litologia	Calcesiti calcarei: Micascisti calcarei, marmi calcarei, filladi		
Schieferung: Orientierung/Abstand Scistosità: Orientamento/Distanza	310-350/20-70 abschnittsweise verfalltet		0,2 - 1 m
Trennflächenorientierung Orientamento della discontinuità	RTF 2e: 65-100/50-90 RTF 2w: 250-280/60-90		
Trennflächenabstände Distanza della discontinuità	RTF 2e: 0,2 - 1 m RTF 2w: 2,0-5,0 m		
Trennflächenlänge Lunghezza di discontinuità	RTF 2e: 0-2,0m RTF 2w: 2,0-5,0 m		
Trennflächenöffnung Apertura della discontinuità	RTF 2e: 0 RTF 2w: 0		
Trennflächenbeschaffenheit Caratterizzatione della discontinuità	RTF 2e: 1-2 RTF 2w: 1-2		
Gesteinskennwerte	Mittelwert	Standardabweichung	Versuchsanzahl
Parametri dell' roccia	Valori medio	deviazione standard	Numero dello prove
UCS [Mpa]	50	18	5
mi [-] (Hoek&Brown)	10	2	9
E [Gpa]	40	2	5
ν [-]	0,2	0,08	5
CAI [-]	2		2
Quellpotential Potenziale di swelling	keines niente		
Quelldaten (Labor) [MPa]/% Dati di swelling			
Trennflächenkennwerte	Bandbreite		
Parametri dell' discontinuità	Range		
Reibungswinkel [°] l'angolo di attrito [°]	17 - 23°		
Kohäsion [Mpa] Coesione [Mpa]	0,3 - 0,5		
Gebirgskennwerte	Mittelwert		Bandbreite
Parametri dell' amasso roccioso	Valori medio		Range
RQD (ISRM)	75		50 - 100
GSI [-] (Hoek)	60		50 - 70
RMR (Bieniawski, 1999)	69		
σ_{cm} / UCS [MPa] (Hoek&Brown)	10,92 / 5,35		
c [MPa] (Mohr - Coulomb)	2,3 (H=700) / 3,1 (H=1200)		
φ [°] (Mohr - Coulomb)	37°(H=700) / 33° (H=1200)		
E [MPa] (Hoek 2005 / 2002)	20.300 / 12.600		
E [MPa] (Serafim / Boyd)	29.800 / 27.500		
E [MPa] BLA			
E [MPa] empfohlen/raccomandati	10000		
c [Mpa] (Mohr - Coulomb) empf./rac.	2,5		
φ [°] (Mohr - Coulomb) empf./rac.	30		
Hinweise	keine Laborversuche, Werte wie KS-5b		
Annotazioni	nessun esperimento di laboratorio, valori come KS-5b		

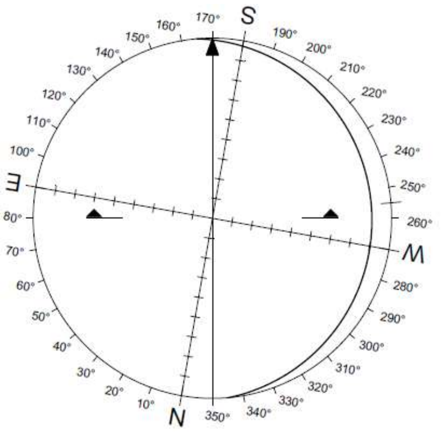
Kriterien	Gebirgsart GA SH-KS-4b		
Criterio	**Tipo dell'ammasso roccioso GA SH-KS-4b**		
Lithologie	kalkreicher Bündner Schiefer: Kalkschiefer, Kalkmarmor, Karbonatquarzit, (Kalk-)Phyllit		
Litologia	Calcesiti calcarei: Micascisti calcarei, marmi calcarei, filladi		
Schieferung: Orientierung/Abstand Scistosità: Orientamento/Distanza	305-350/30-60 abschnittsweise verfalltet		0,2 - 1 m
Trennflächenorientierung Orientamento della discontinuità	RTF 2w: 260-280/70-90 RTF 4: 170-200/65-90		
Trennflächenabstände Distanza della discontinuità	RTF 2w: >60 cm RTF 4: 2,0-5,0 m		
Trennflächenlänge Lunghezza di discontinuità	RTF 2w: 0,5-5 m RTF 4: 0-0,5 m		
Trennflächenöffnung Apertura della discontinuità	RTF 2w: 0 RTF 4: 0		
Trennflächenbeschaffenheit Caratterizzatione della discontinuità	RTF 2w: 5 RTF 4: 1		
Gesteinskennwerte	Mittelwert	Standardabweichung	Versuchsanzahl
Parametri dell' roccia	Valori medio	deviazione standard	Numero dello prove
UCS [Mpa]	50		
mi [-] (Hoek&Brown)	10		
E [Gpa]	40		
ν [-]	0,2		
CAI [-]			
Quellpotential Potenziale di swelling	keines niente		
Quelldaten (Labor) [MPa]/% Dati di swelling			
Trennflächenkennwerte	Bandbreite		
Parametri dell' discontinuità	Range		
Reibungswinkel [°] l'angolo di attrito [°]	17 - 23°		
Kohäsion [Mpa] Coesione [Mpa]	0,3 - 0,5		
Gebirgskennwerte	Mittelwert		Bandbreite
Parametri dell' amasso roccioso	Valori medio		Range
RQD (ISRM)	80		60 - 100
GSI [-] (Hoek)	55		45 - 65
RMR (Bieniawski, 1999)	71		
σ_{cm} / UCS [MPa] (Hoek&Brown)	9,74 / 4,02		
c [MPa] (Mohr - Coulomb)	2,1 (H=700)		
φ [°] (Mohr - Coulomb)	35° (H=700)		
E [MPa] (Hoek 2005 / 2002)	14.000 / 9.400		
E [MPa] (Serafim / Boyd)	33.500 / 30.600		
E [MPa] BLA			
E [MPa] empfohlen/raccomandati	8000		
c [Mpa] (Mohr - Coulomb) empf./rac.	2		
φ [°] (Mohr - Coulomb) empf./rac.	32		
Hinweise	keine Laborversuche, Werte wie KS-3b		
Annotazioni	nessun esperimento di laboratorio, valori come KS-3b		

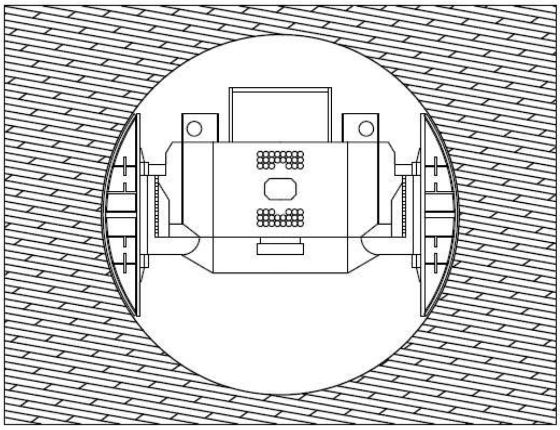
Appendix B

Data sheets for gripper tests

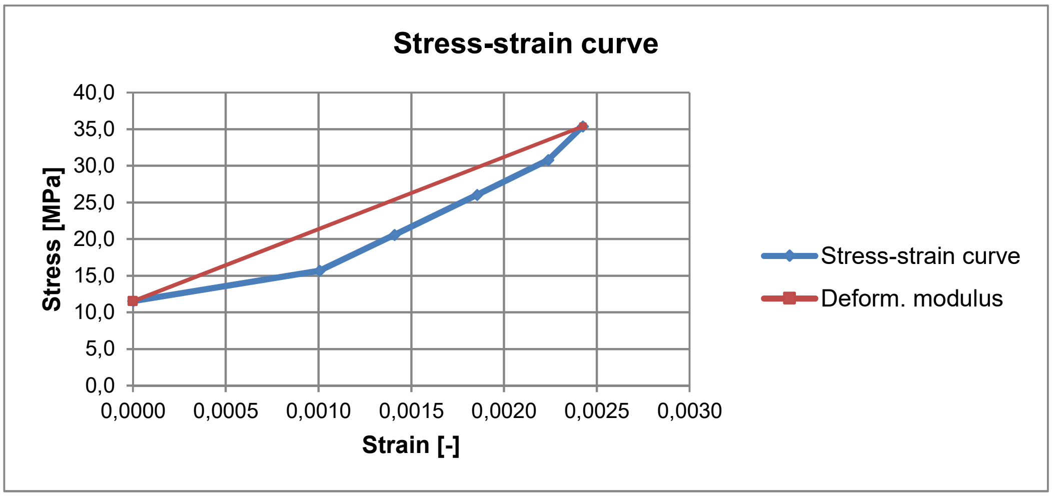
Data Sheet Gripper Test

General	Number		1
	Date/Time		16.05.2019 09:30
	Tunnel meter [m]	Face	14396
		Gripper	14378
	Load cycles		1
	Load steps		5
	Reinforcement mesh		yes
Geology	Overburden [m]		764
	Lithology		Calcareous Schist
	Ground type		SH-KS-3b
	Heading direction [°]		170
	Foliation [°/°]; [cm]	Orientation	255/10
		Spacing	2 - 6

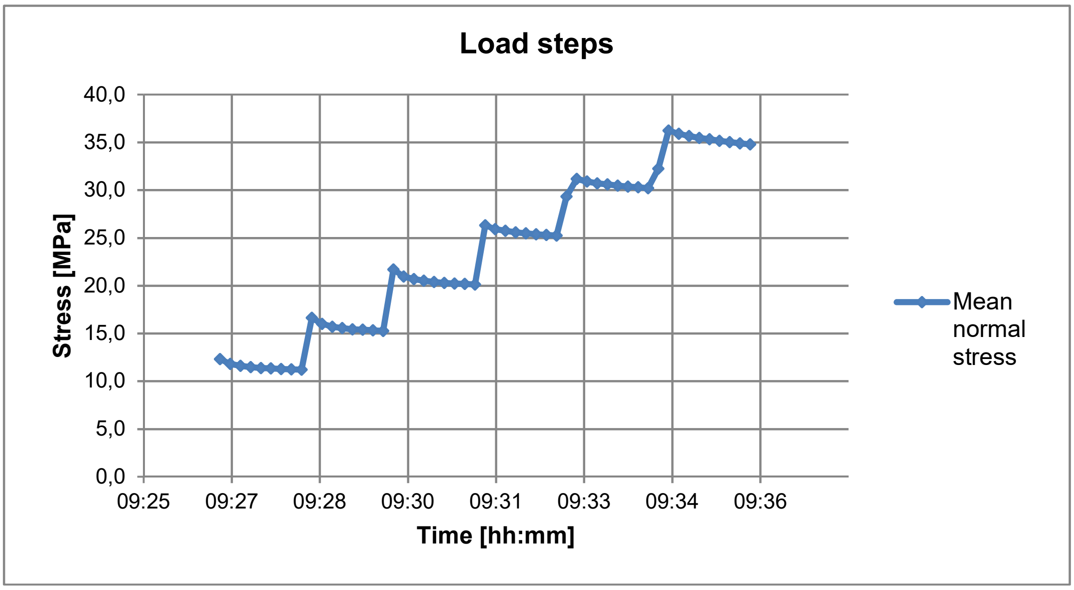


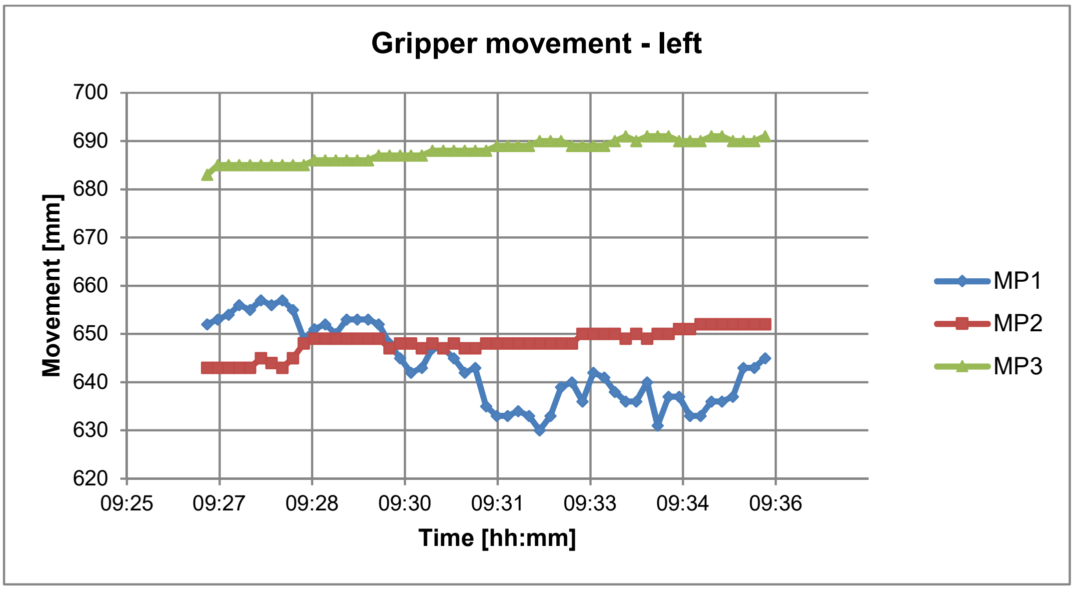


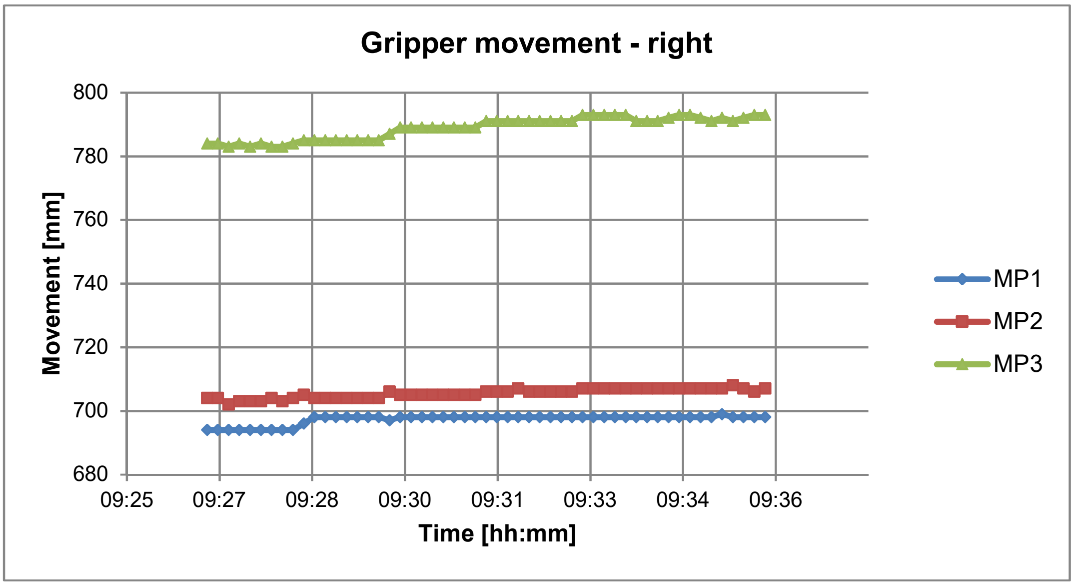
Results / Measurements	Contact area [m²]		0,64
	Displacement [mm]	Left	4,6
		Right	5,5
		Mean	5,0
	Mean normal stress [MPa]	Start	11,5
		End	35,4
		Delta	23,9
	Strain [-]		0,0024
	Deformation modulus [MPa]		9500



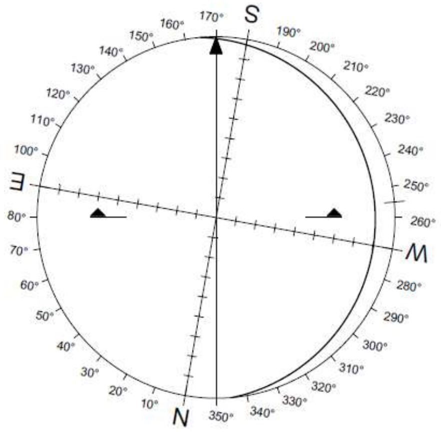
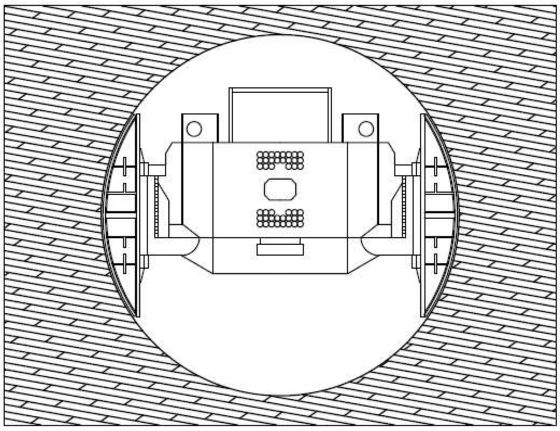
Results / Measurements

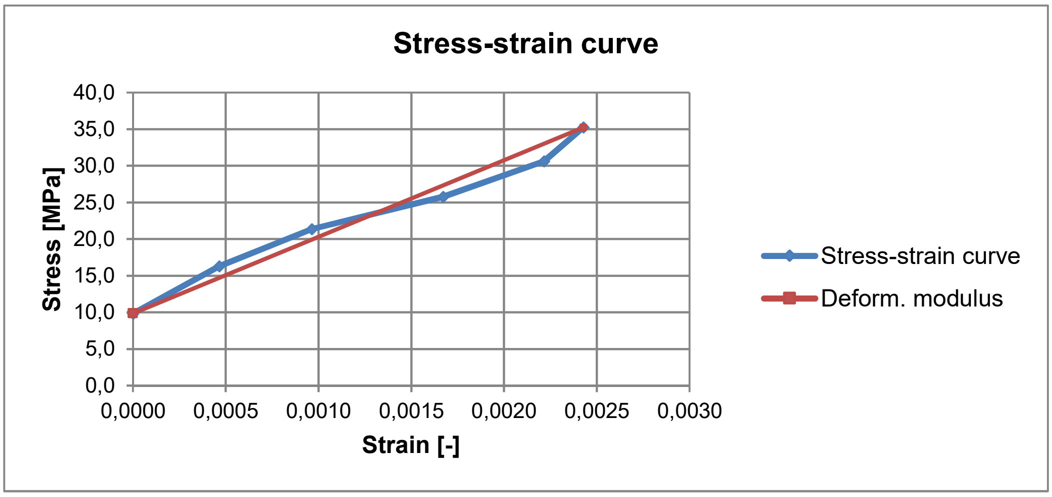




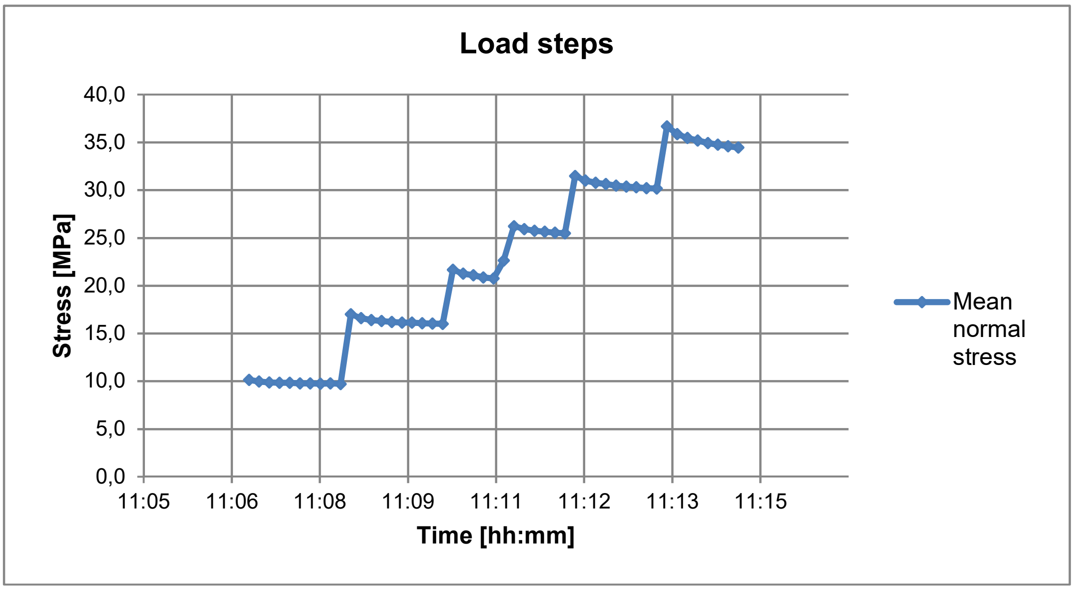


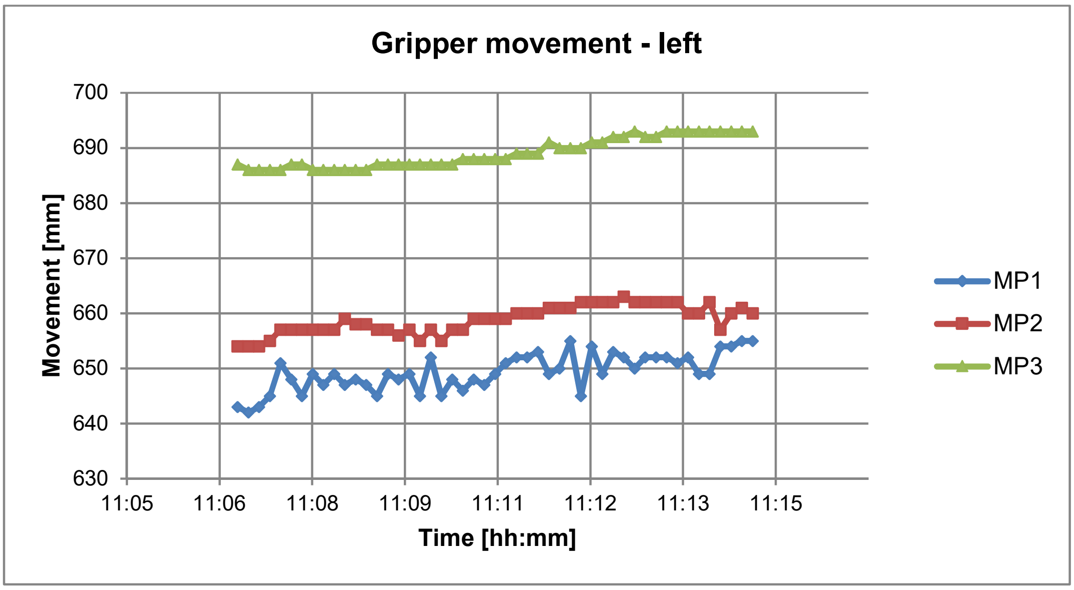
Data Sheet Gripper Test

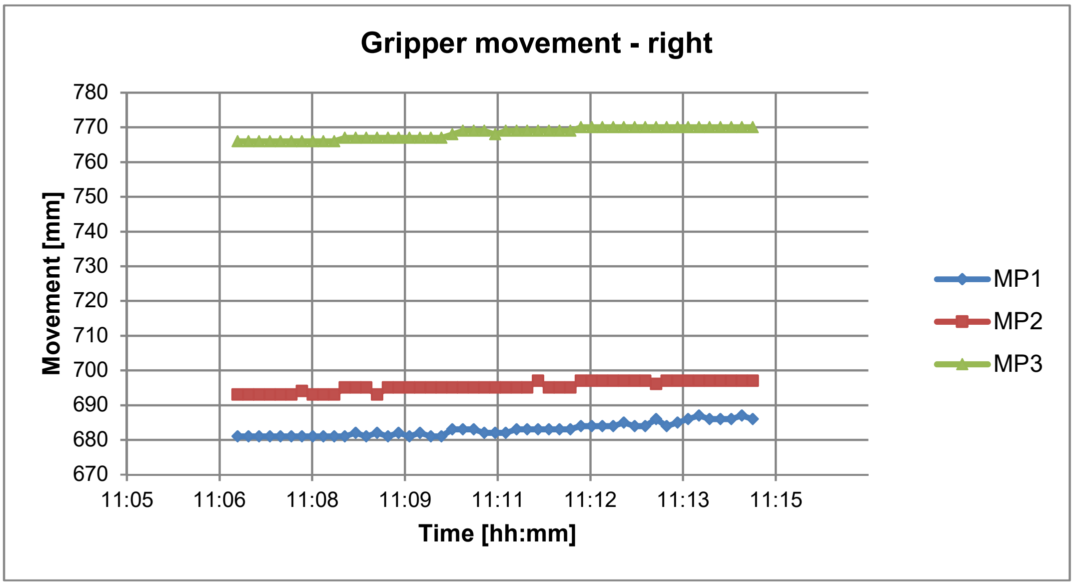
General	Number		2
	Date/Time		16.05.2019 11:15
	Tunnel meter [m]	Face	14397
		Gripper	14379
	Load cycles		1
	Load steps		5
	Reinforcement mesh		yes
Geology	Overburden [m]		764
	Lithology		Calcareous Schist
	Ground type		SH-KS-3b
	Heading direction [°]		170
	Foliation [°/°]; [cm]	Orientation	255/10
		Spacing	2 - 6
			
Results / Measurements	Contact area [m²]		0,64
	Displacement [mm]	Left	5,7
		Right	4,3
		Mean	5,0
	Mean normal stress [MPa]	Start	9,8
		End	35,2
		Delta	25,4
	Strain [-]		0,0024
	Deformation modulus [MPa]		10000



Results / Measurements

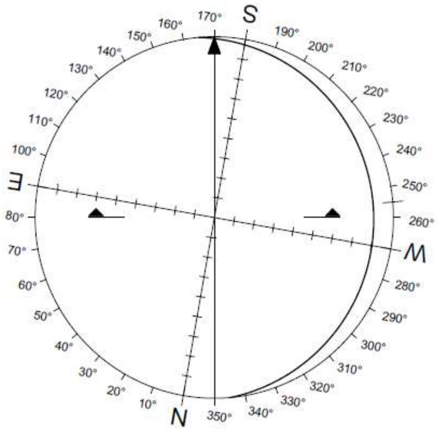


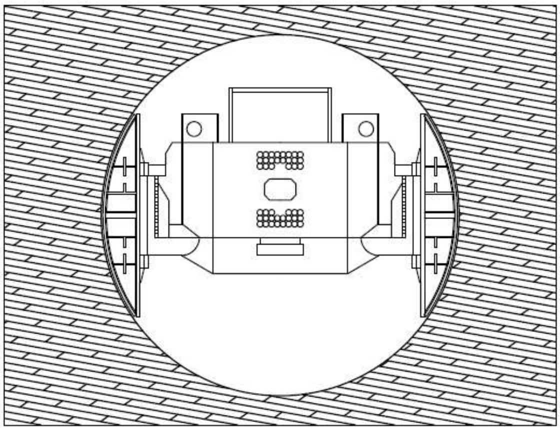


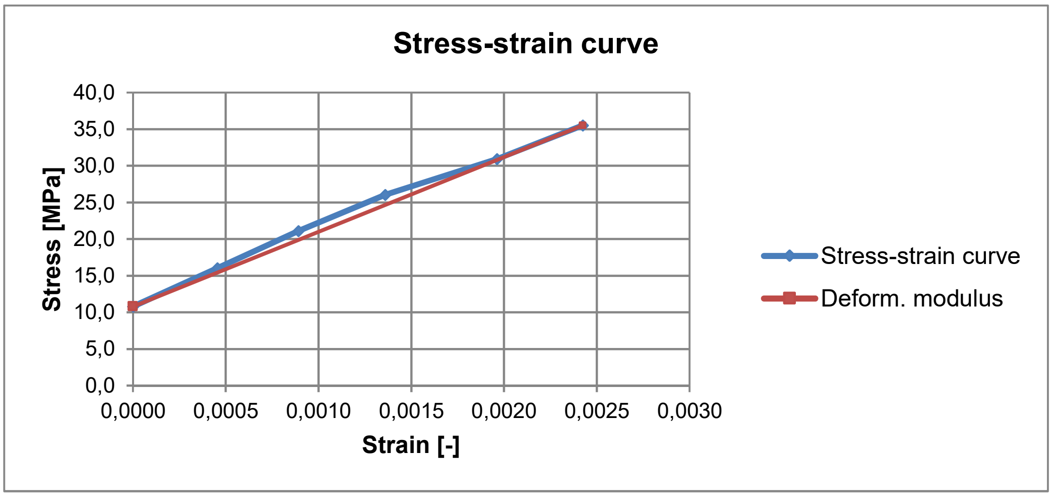


Data Sheet Gripper Test

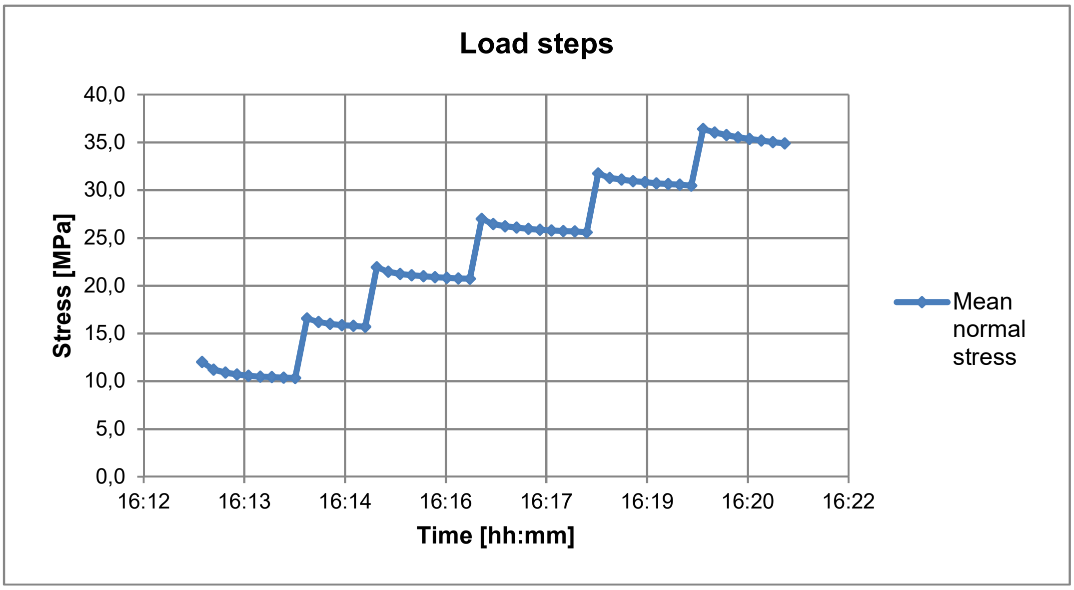
General	Number		3
	Date/Time		16.05.2019 16:15
	Tunnel meter [m]	Face	14401
		Gripper	14383
	Load cycles		1
	Load steps		5
	Reinforcement mesh		yes
Geology	Overburden [m]		766
	Lithology		Calcareous Schist
	Ground type		SH-KS-3b
	Heading direction [°]		170
	Foliation [°/°]; [cm]	Orientation	255/10
		Spacing	2 - 6
Results / Measurements	Contact area [m²]		0,64
	Displacement [mm]	Left	3,1
		Right	7,0
		Mean	5,0
	Mean normal stress [MPa]	Start	10,8
		End	35,5
		Delta	24,7
	Strain [-]		0,0024
	Deformation modulus [MPa]		9800

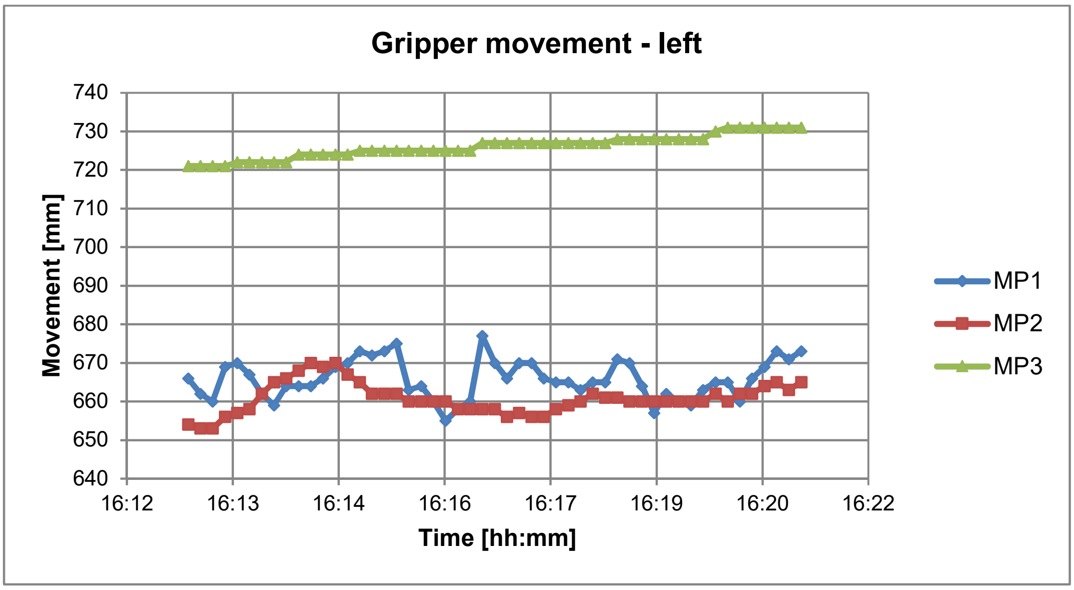


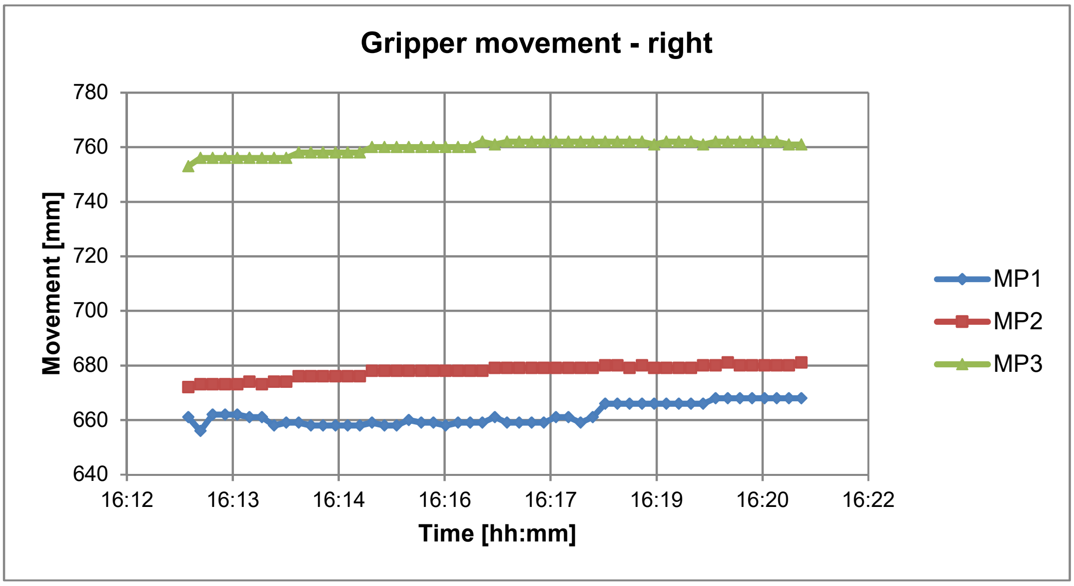




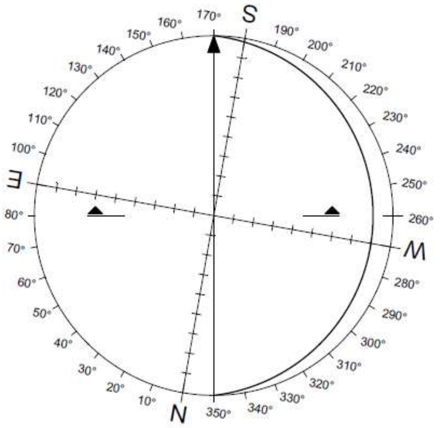
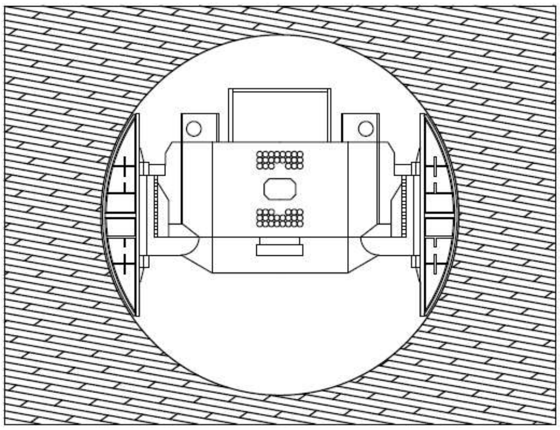
Results / Measurements

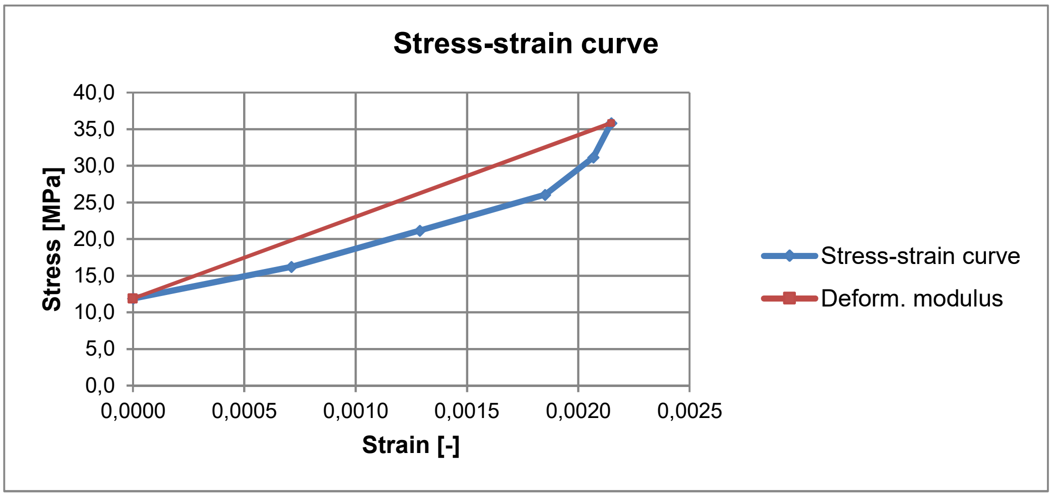




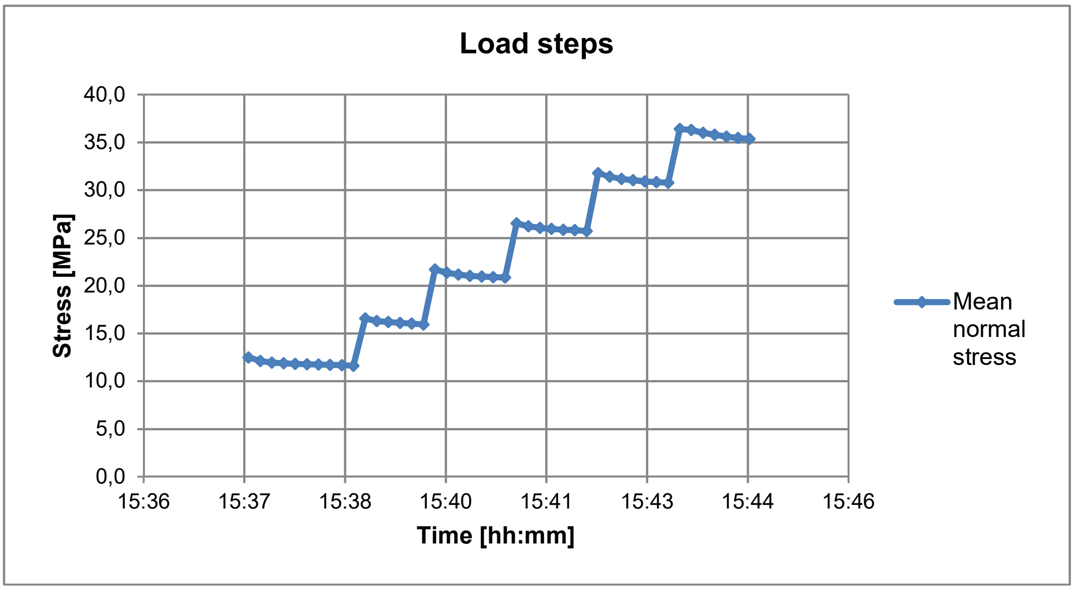


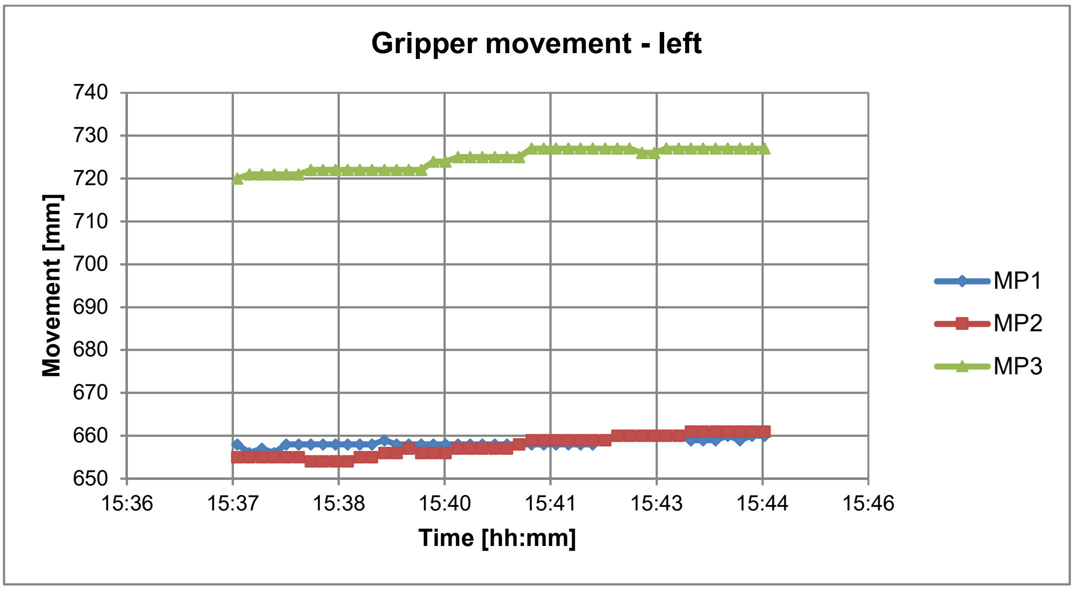
Data Sheet Gripper Test

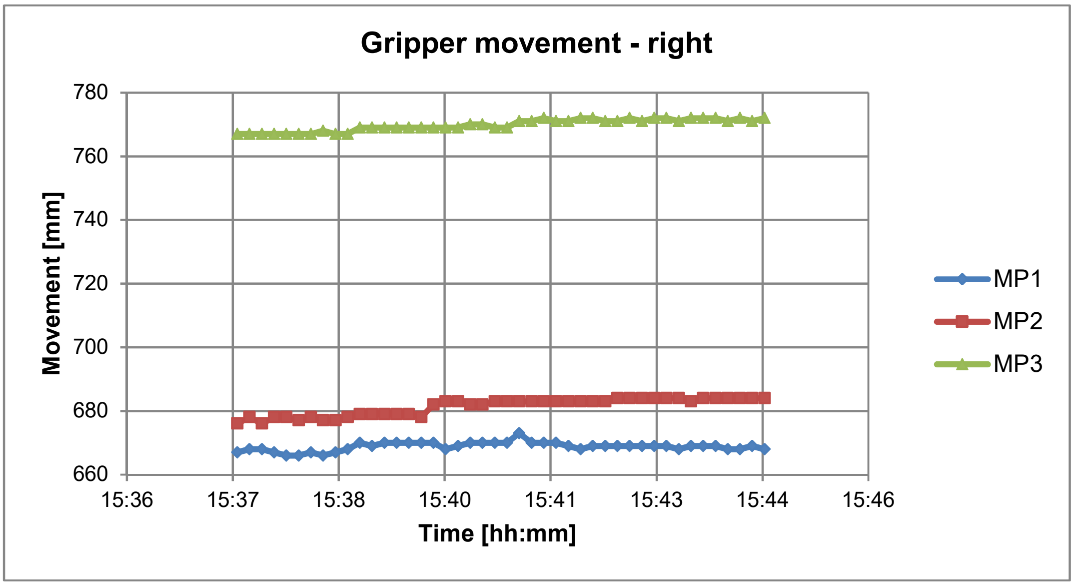
General	Number		4
	Date/Time		17.05.2019 15:40
	Tunnel meter [m]	Face	14416
		Gripper	14398
	Load cycles		1
	Load steps		5
	Reinforcement mesh		yes
Geology	Overburden [m]		769
	Lithology		Calcareous Schist
	Ground type		SH-KS-3b
	Heading direction [°]		170
	Foliation [°/°]; [cm]	Orientation	260/10
		Spacing	2 - 6
			
Results / Measurements	Contact area [m²]		0,64
	Displacement [mm]	Left	4,7
		Right	4,2
		Mean	4,5
	Mean normal stress [MPa]	Start	11,9
		End	35,9
		Delta	24,0
	Strain [-]		0,0021
	Deformation modulus [MPa]		10700



Results / Measurements

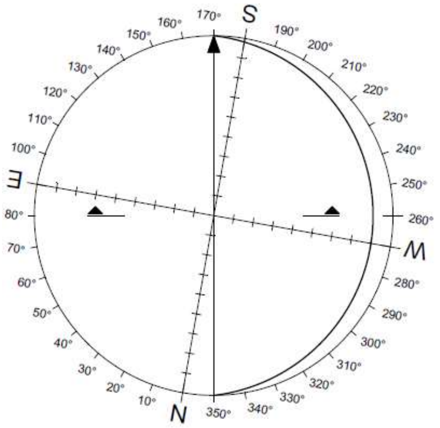


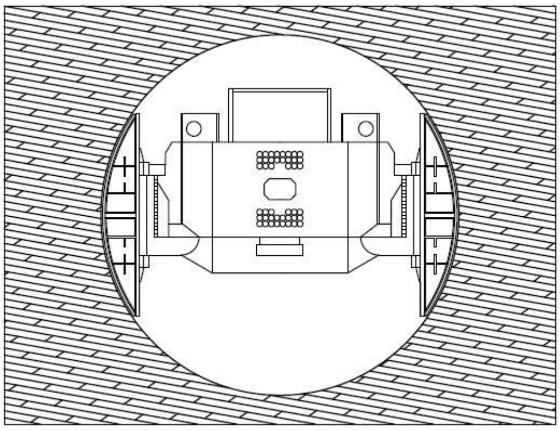




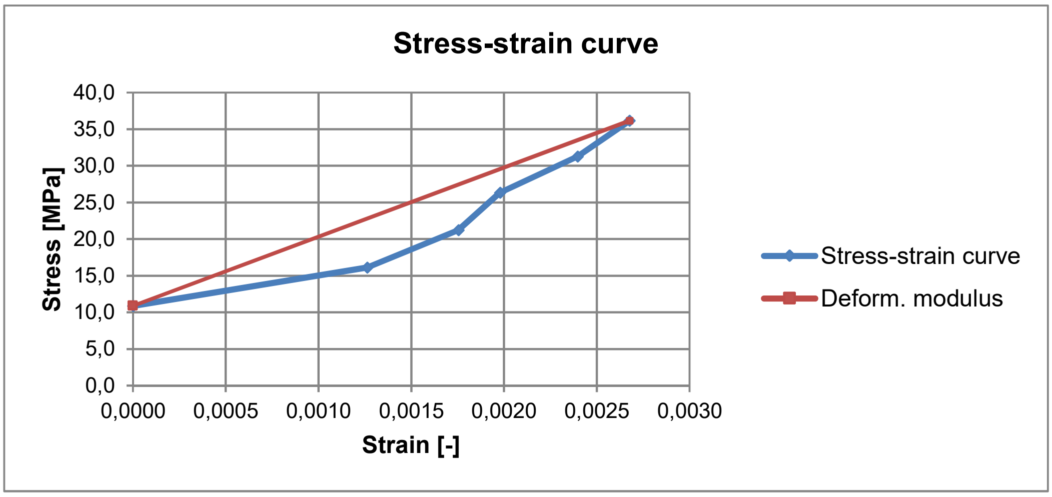
Data Sheet Gripper Test

General	Number		5
	Date/Time		18.05.2019 18:00
	Tunnel meter [m]	Face	14432
		Gripper	14414
	Load cycles		1
	Load steps		5
	Reinforcement mesh		yes
Geology	Overburden [m]		771
	Lithology		Calcareous Schist
	Ground type		SH-KS-3b
	Heading direction [°]		170
	Foliation [°/°]; [cm]	Orientation	260/10
		Spacing	2 - 6

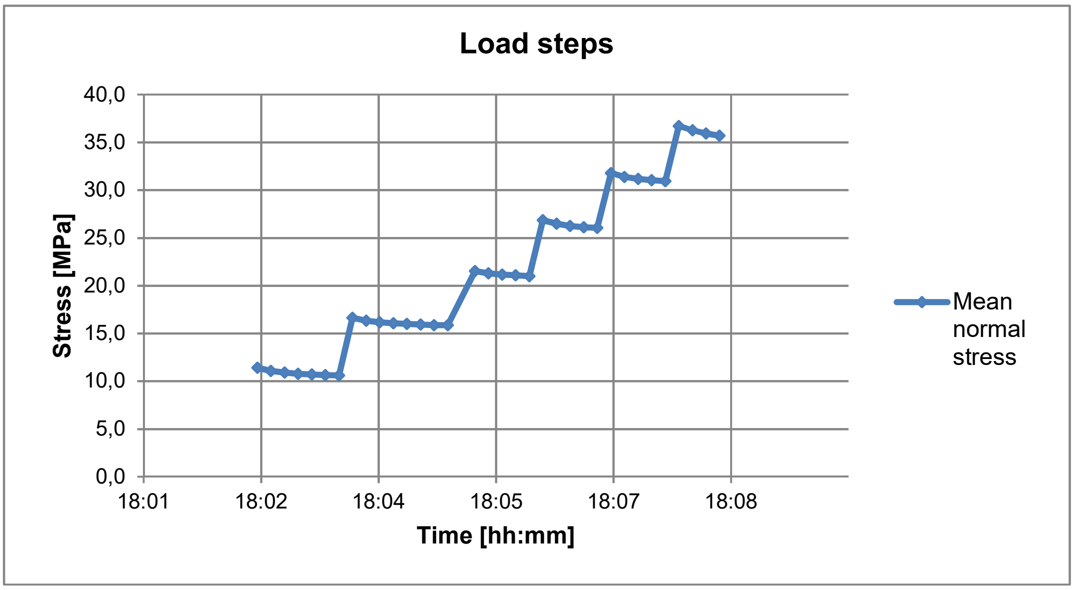


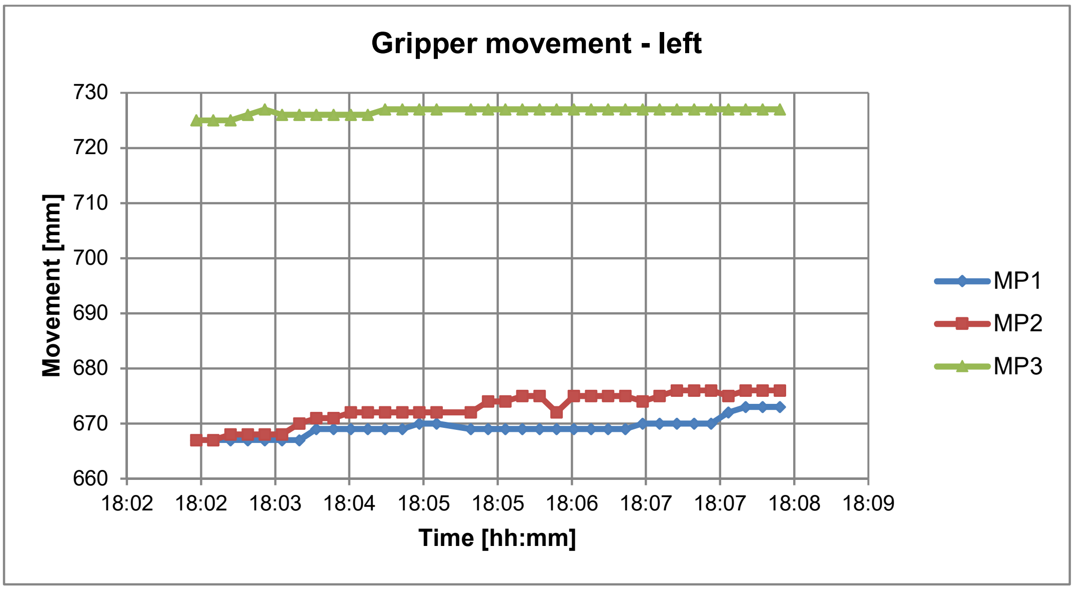


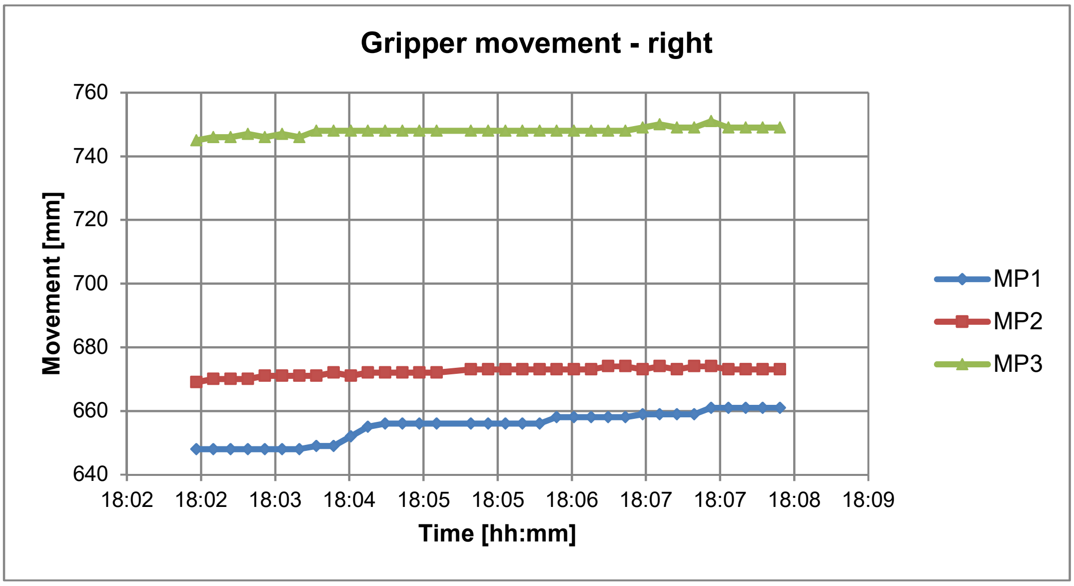
Results / Measurements	Contact area [m²]		0,64
	Displacement [mm]	Left	4,9
		Right	6,2
		Mean	5,6
	Mean normal stress [MPa]	Start	10,9
		End	36,2
		Delta	25,3
	Strain [-]		0,0027
	Deformation modulus [MPa]		9100



Results / Measurements

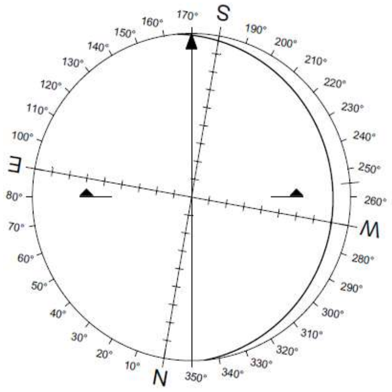


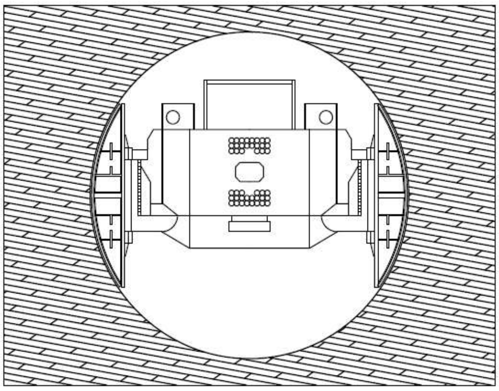




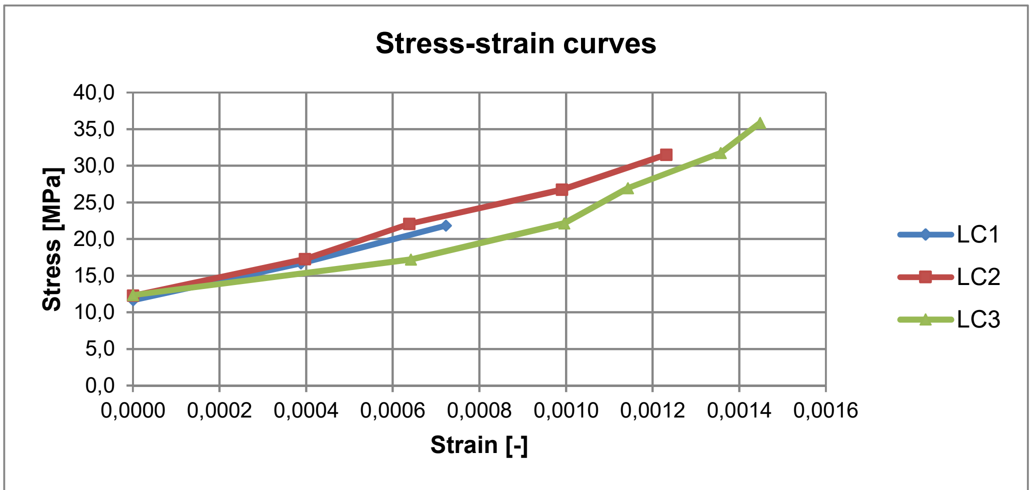
Data Sheet Gripper Test

General	Number		6		
	Date/Time		20.05.2019 09:20		
	Tunnel meter [m]	Face	14459		
		Gripper	14441		
	Load cycles		3		
	Load steps		2/4/5		
	Reinforcement mesh		yes		
Geology	Overburden [m]		780		
	Lithology		Calcareous Schist		
	Ground type		SH-KS-3b		
	Heading direction [°]		170		
	Foliation [°/°]; [cm]	Orientation	255/10		
		Spacing	2 - 6		

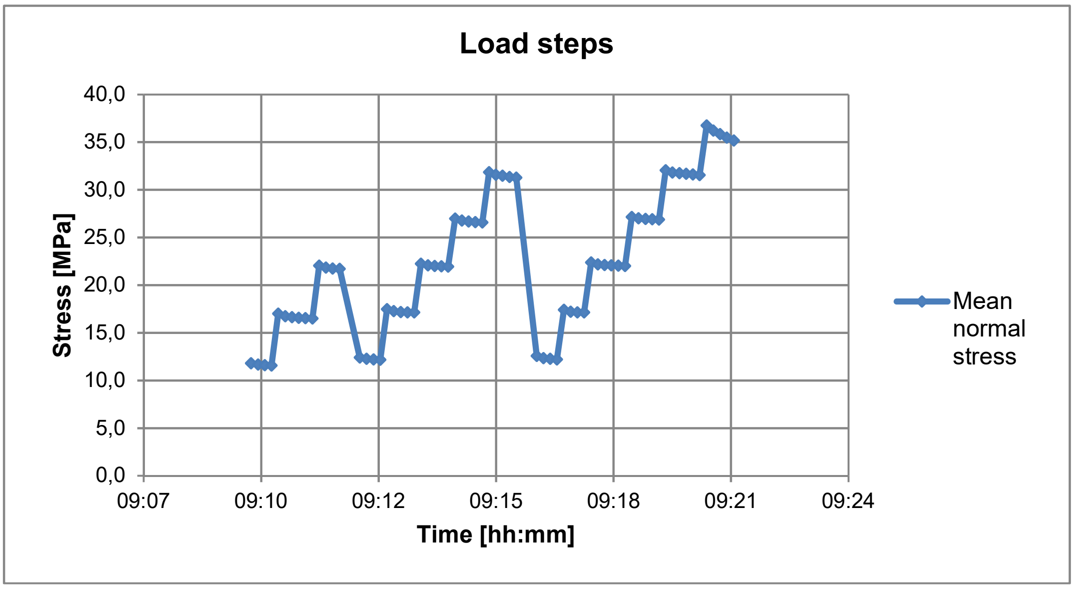


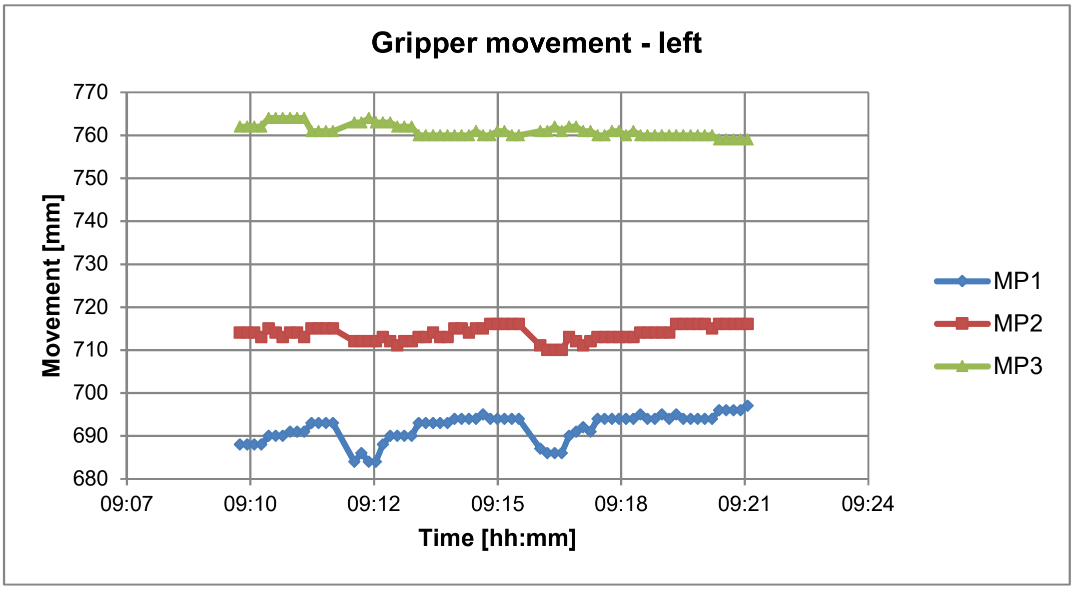


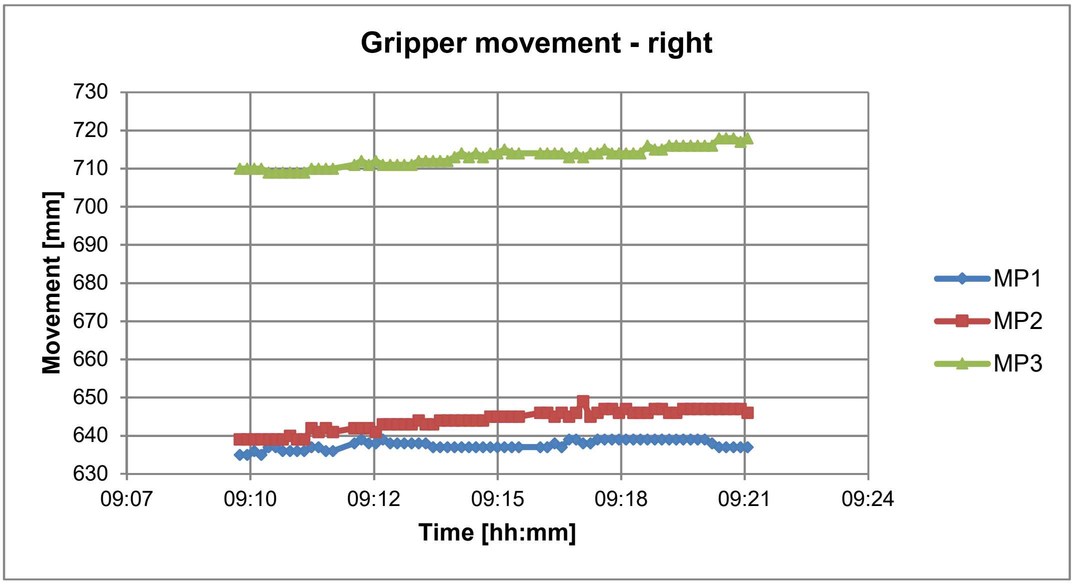
Results / Measurements	Contact area [m²]		0,64		
	Load cycle		LC1	LC2	LC3
	Displacement [mm]	Left	1,8	3,5	4,5
		Right	1,3	1,6	1,5
		Mean	1,5	2,6	3,0
	Mean normal stress [MPa]	Start	11,7	12,3	12,3
		End	21,8	31,5	35,9
		Delta	10,2	19,2	23,5
	Strain [-]		0,0007	0,0012	0,0014
	Deformation modulus [MPa]		13500	15000	15600



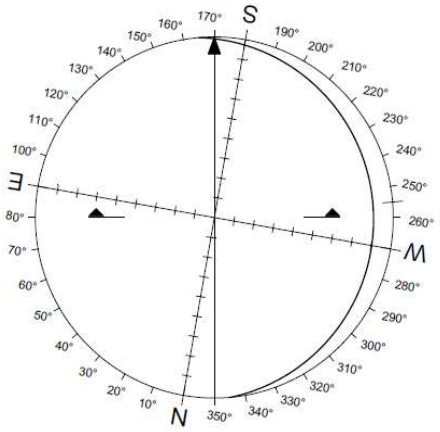
Results / Measurements

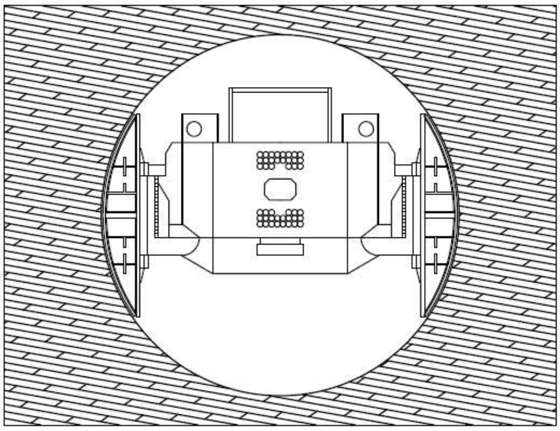




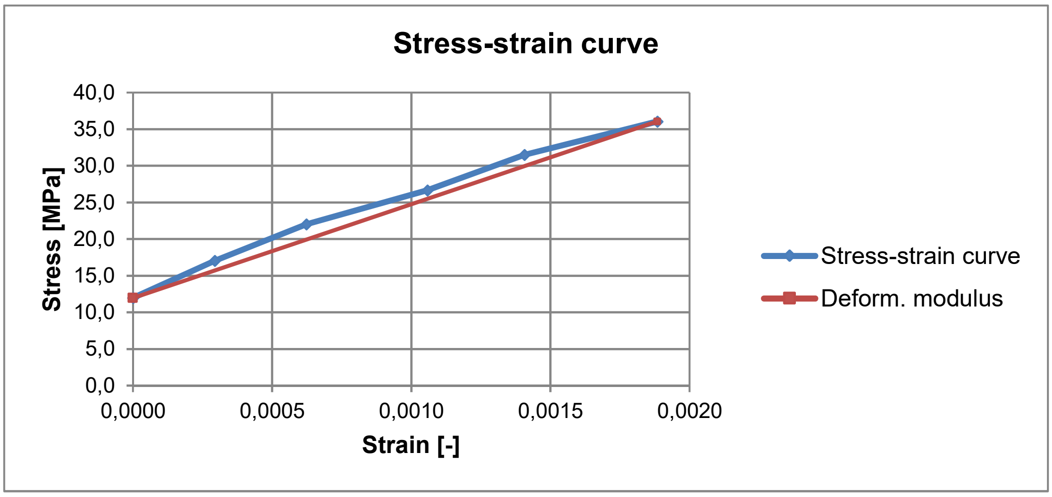


Data Sheet Gripper Test			
General	Number		7
	Date/Time		20.05.2019 14:00
	Tunnel meter [m]	Face	14463
		Gripper	14445
	Load cycles		1
	Load steps		5
	Reinforcement mesh		yes
Geology	Overburden [m]		780
	Lithology		Calcareous Schist
	Ground type		SH-KS-3b
	Heading direction [°]		170
	Foliation [°/°]; [cm]	Orientation	255/10
		Spacing	2 - 6

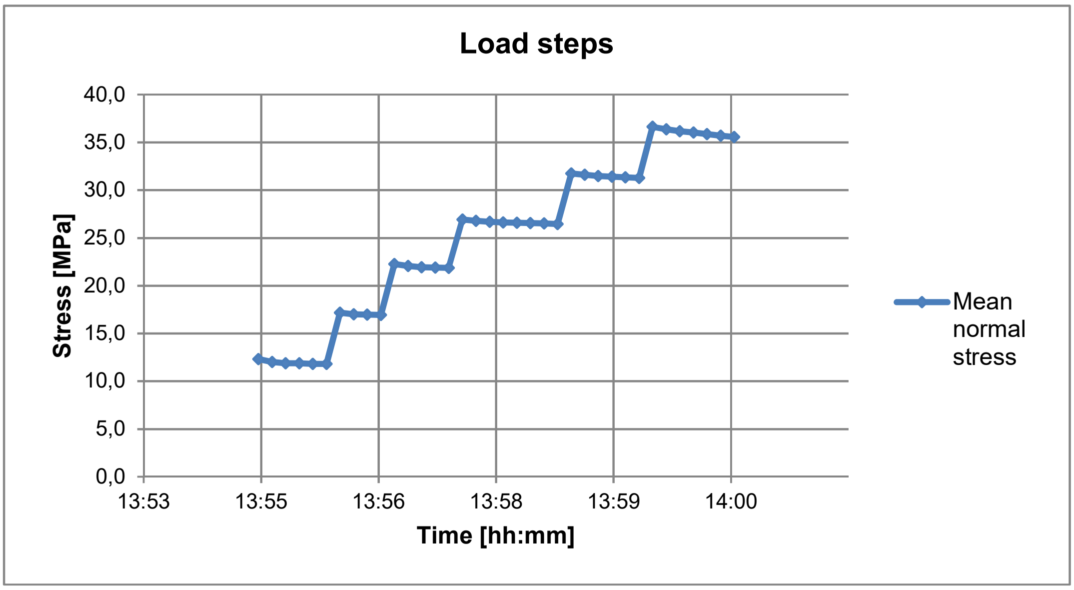


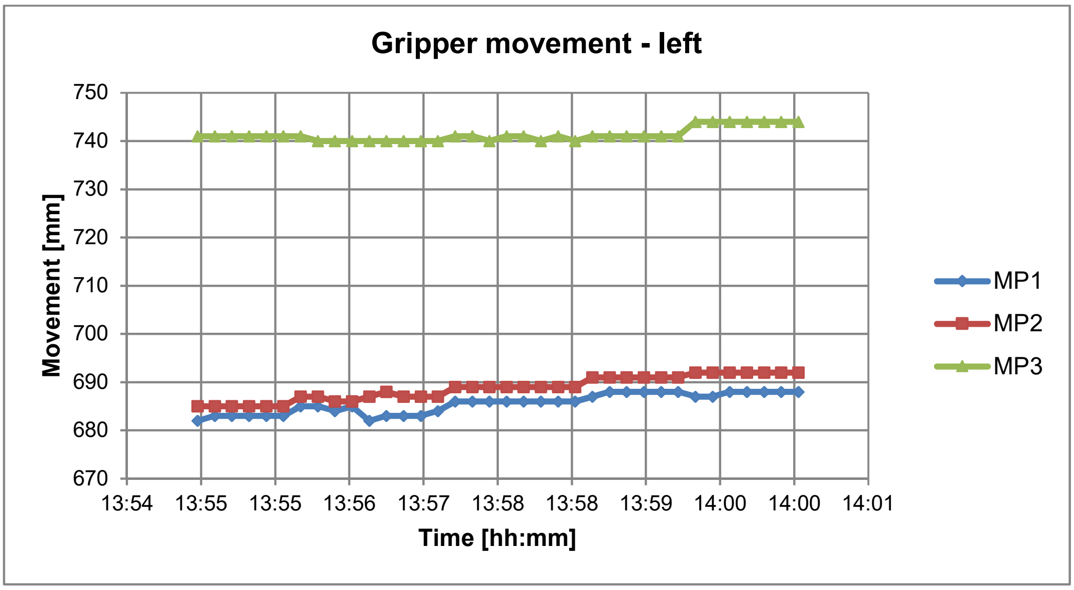


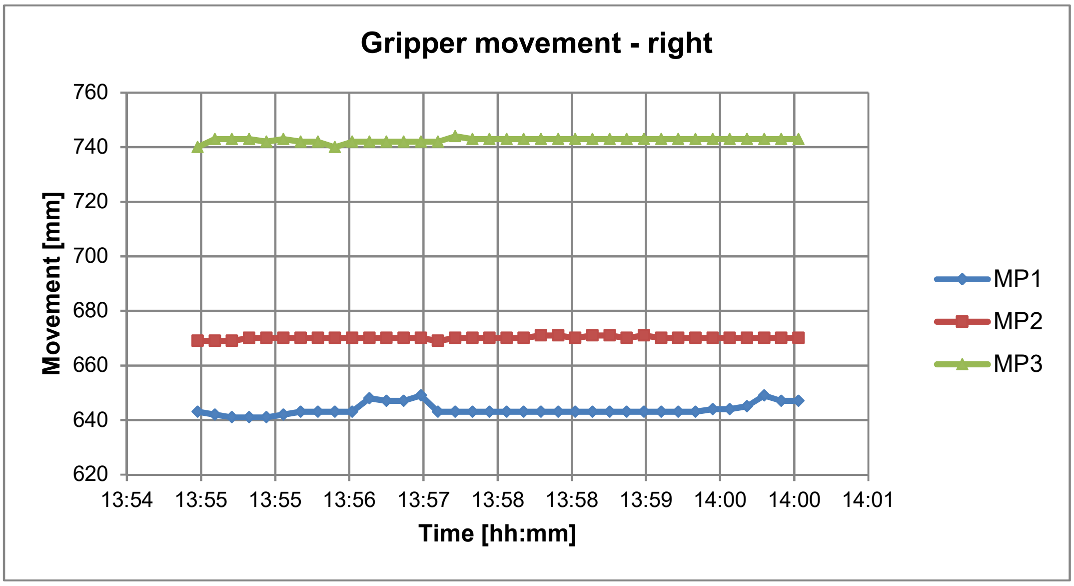
Results / Measurements			
	Contact area [m²]		0,64
	Displacement [mm]	Left	5,4
		Right	2,4
		Mean	3,9
	Mean normal stress [MPa]	Start	12,0
		End	36,1
		Delta	24,1
	Strain [-]		0,0019
	Deformation modulus [MPa]		12300

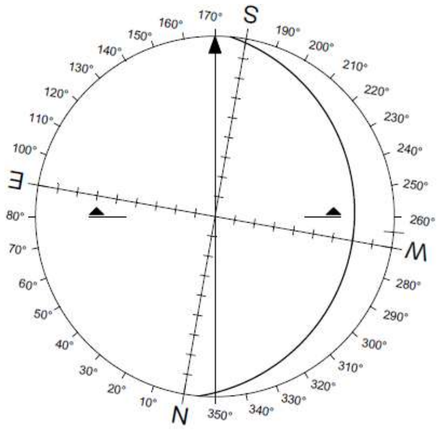
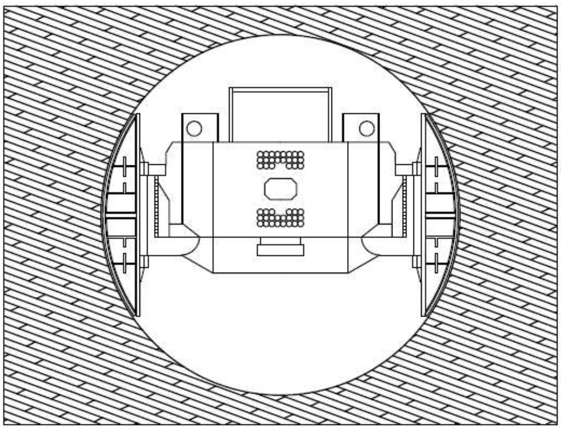
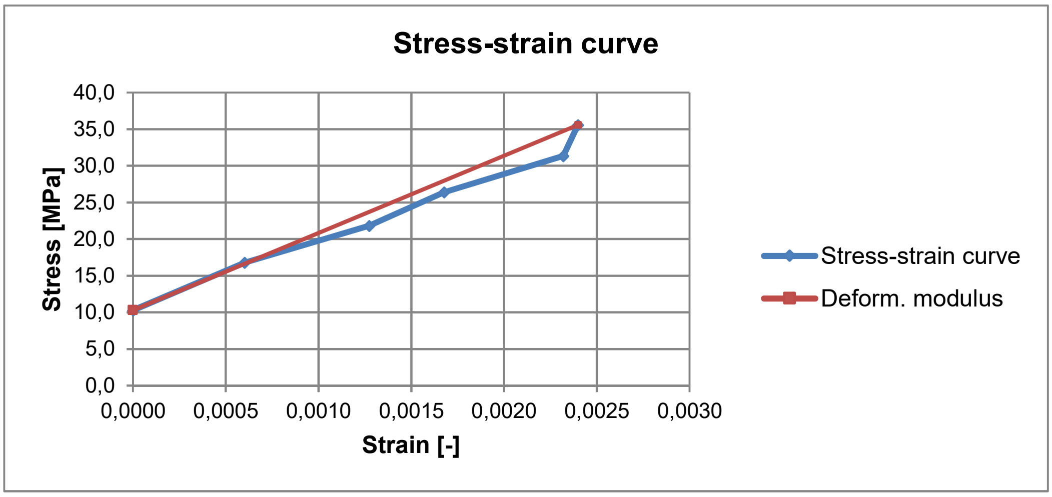


Results / Measurements

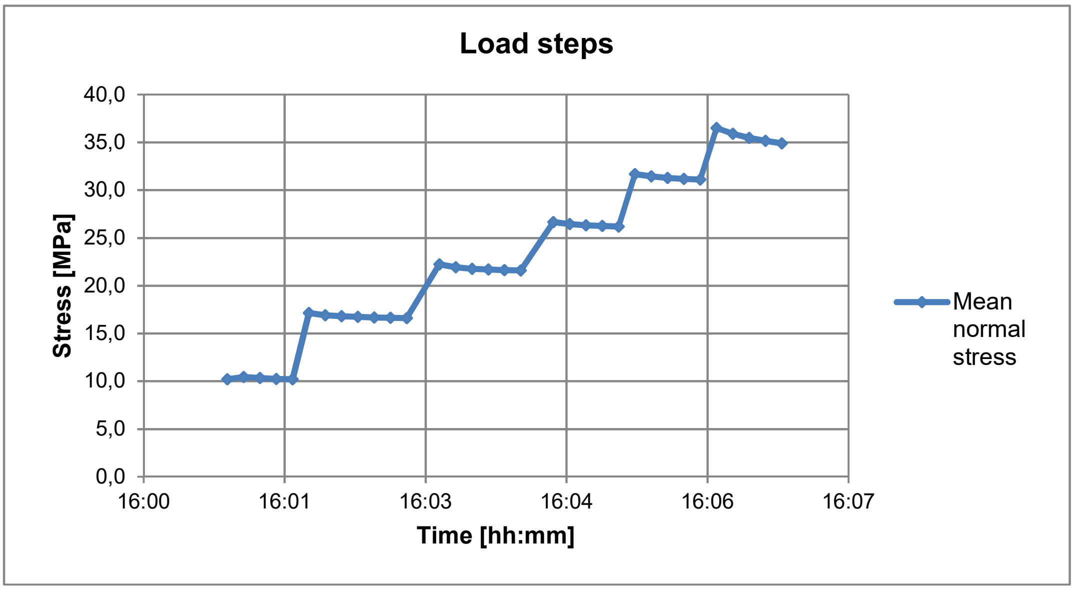


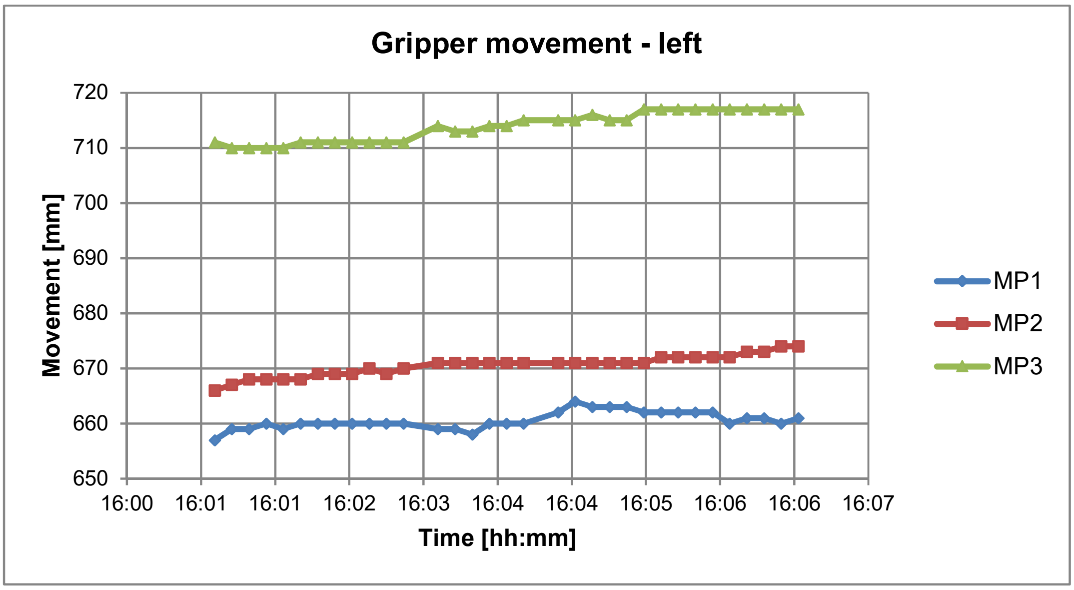


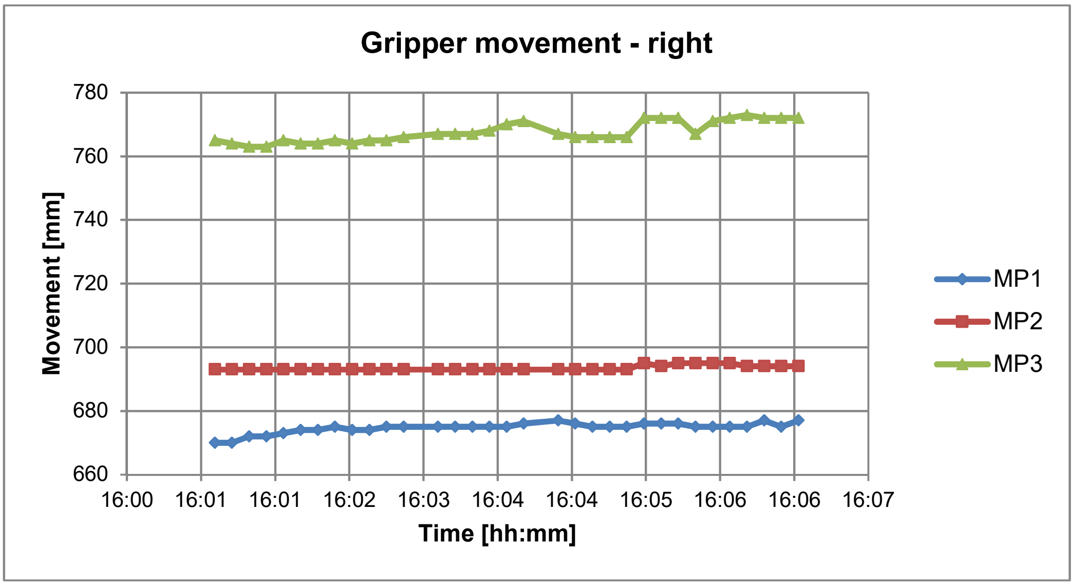


Data Sheet Gripper Test			
General	Number		8
	Date/Time		20.05.2019 16:00
	Tunnel meter [m]	Face	14466
		Gripper	14448
	Load cycles		1
	Load steps		5
	Reinforcement mesh		yes
Geology	Overburden [m]		776
	Lithology		Calcareous Schist
	Ground type		SH-KS-3b
	Heading direction [°]		170
	Foliation [°/°]; [cm]	Orientation	265/20
		Spacing	2 - 6
			
Results / Measurements	Contact area [m²]		0,64
	Displacement [mm]	Left	4,8
		Right	5,2
		Mean	5,0
	Mean normal stress [MPa]	Start	10,3
		End	35,6
		Delta	25,3
	Strain [-]		0,0024
	Deformation modulus [MPa]		10100
			

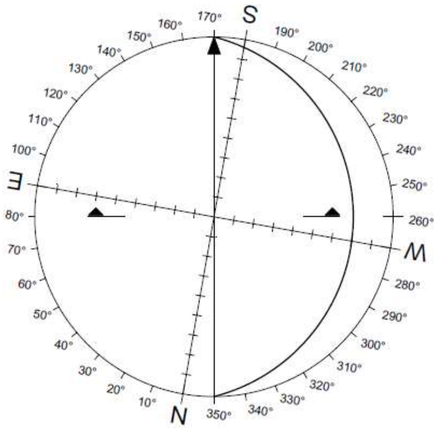
Results / Measurements

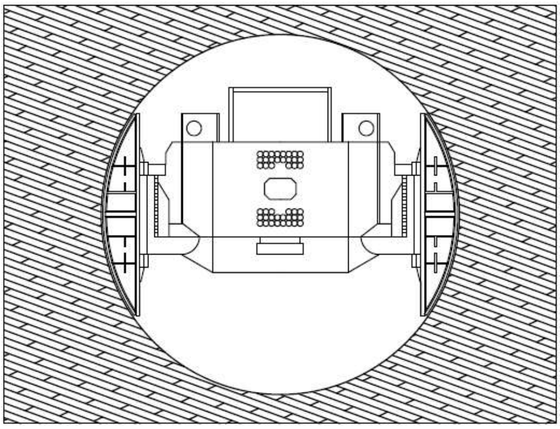


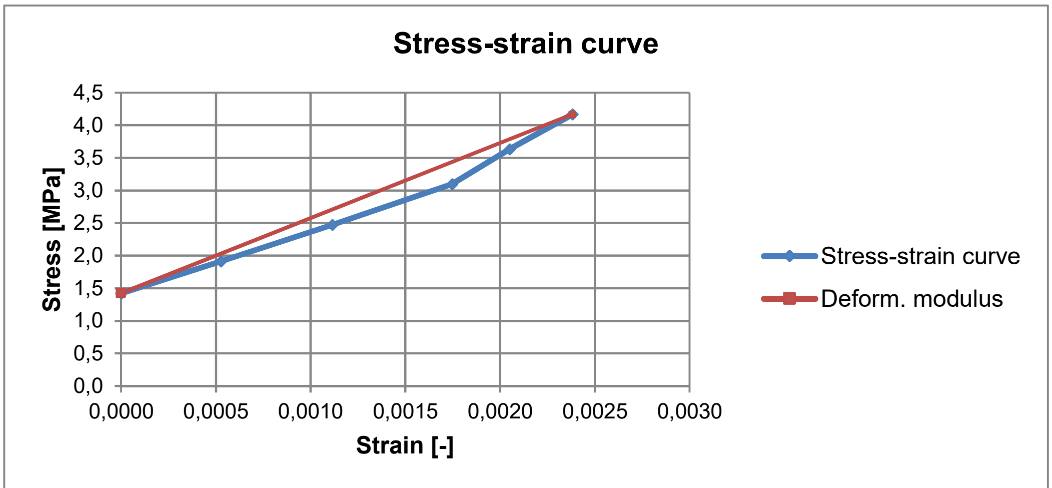




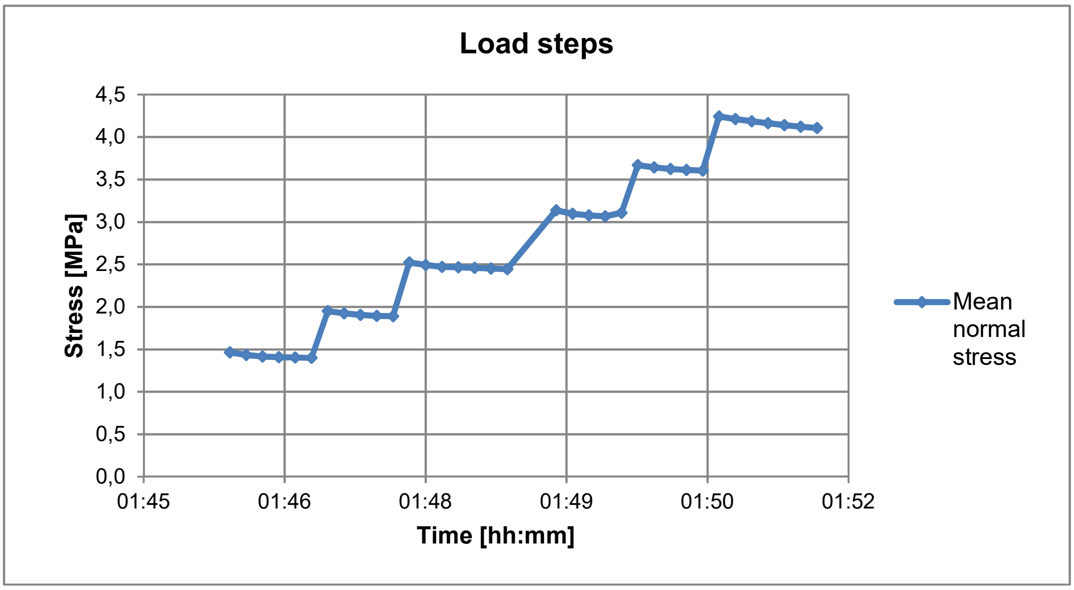
Data Sheet Gripper Test			
General	Number		9
	Date/Time		23.05.2019 01:50
	Tunnel meter [m]	Face	14484
		Gripper	14466
	Load cycles		1
	Load steps		5
	Reinforcement mesh		no
Geology	Overburden [m]		772
	Lithology		Calcareous Schist
	Ground type		SH-KS-3b
	Heading direction [°]		170
	Foliation [°/°]; [cm]	Orientation	260/20
		Spacing	2 - 6
Results / Measurements	Contact area [m²]		5,50
	Displacement [mm]	Left	7,1
		Right	2,8
		Mean	4,9
	Mean normal stress [MPa]	Start	1,4
		End	4,2
		Delta	2,7
	Strain [-]		0,0024
	Deformation modulus [MPa]		1100

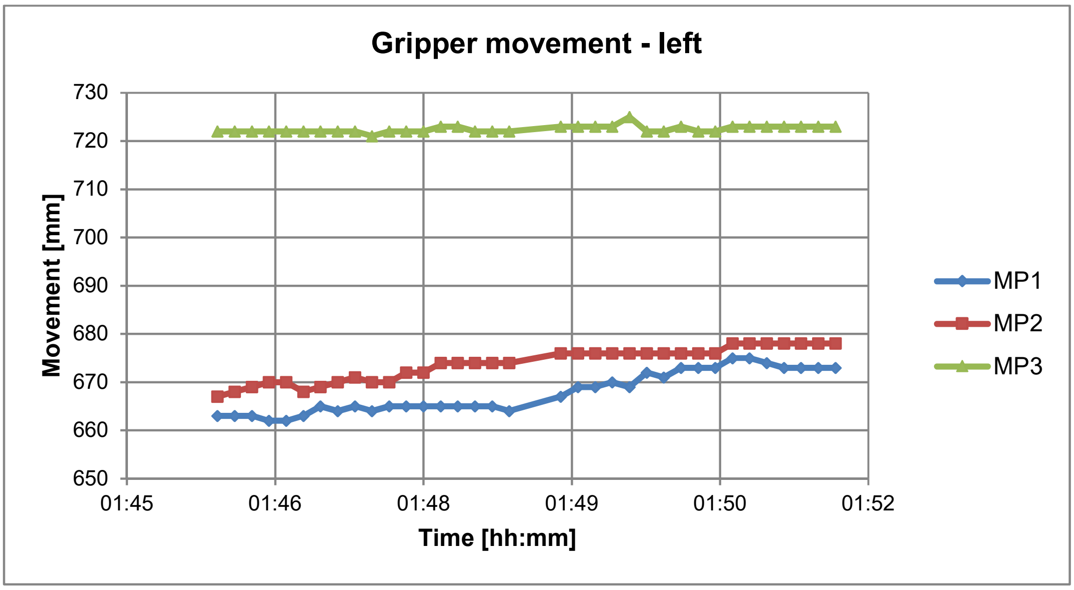


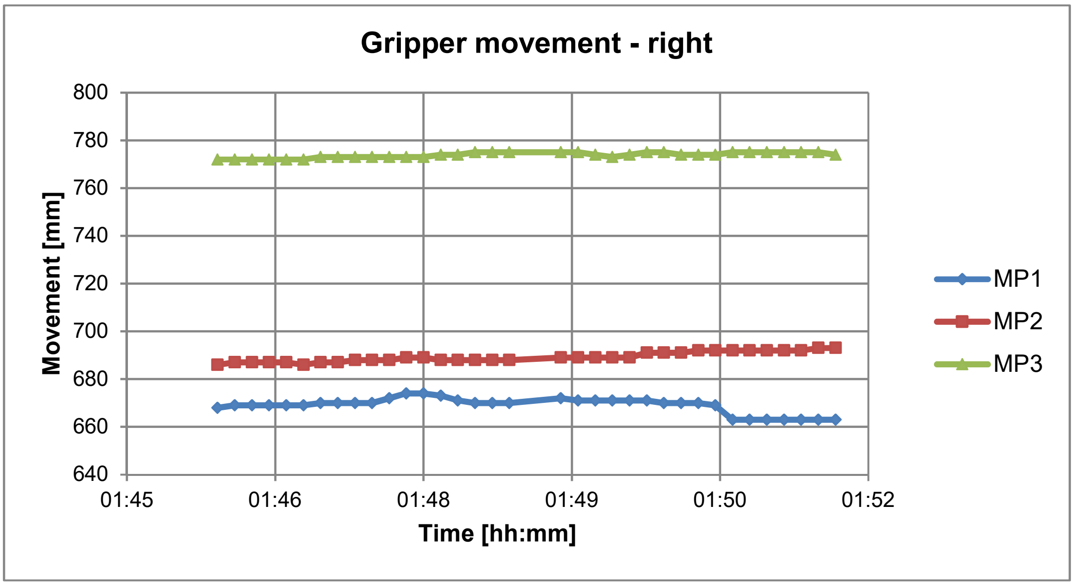




Results / Measurements

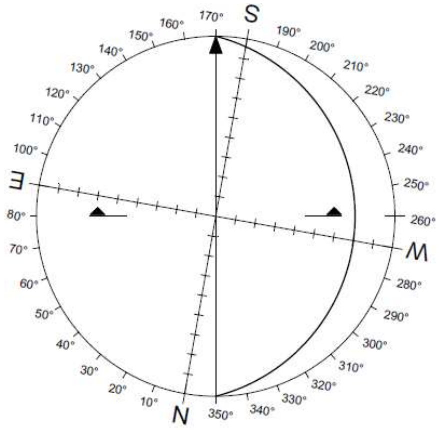


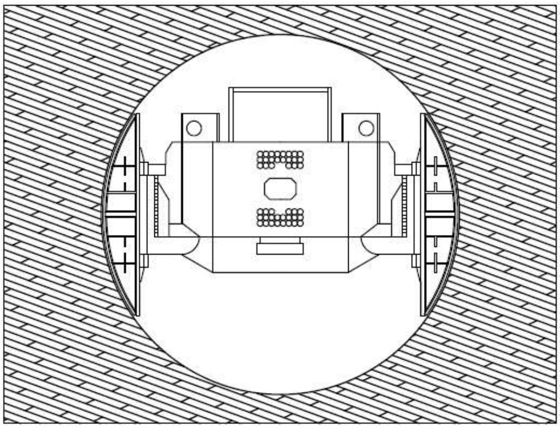


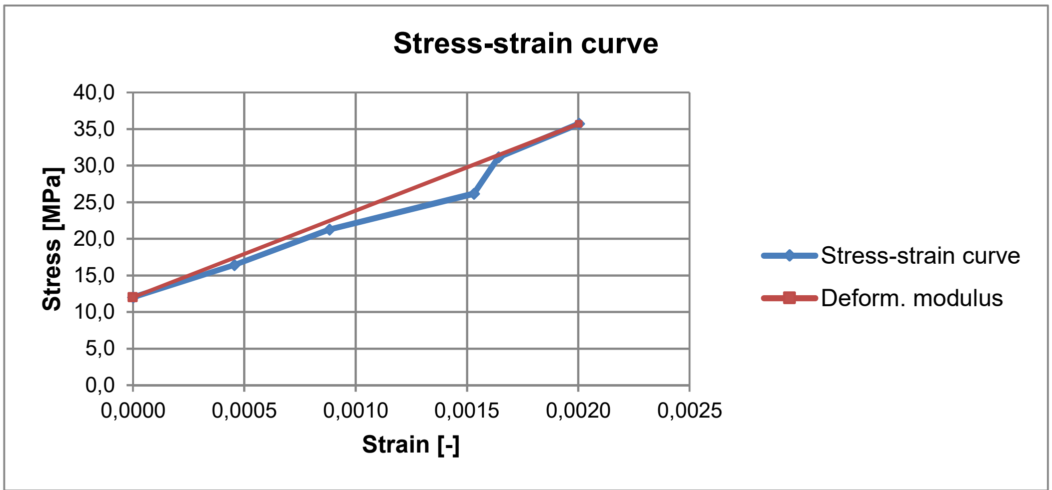


Data Sheet Gripper Test

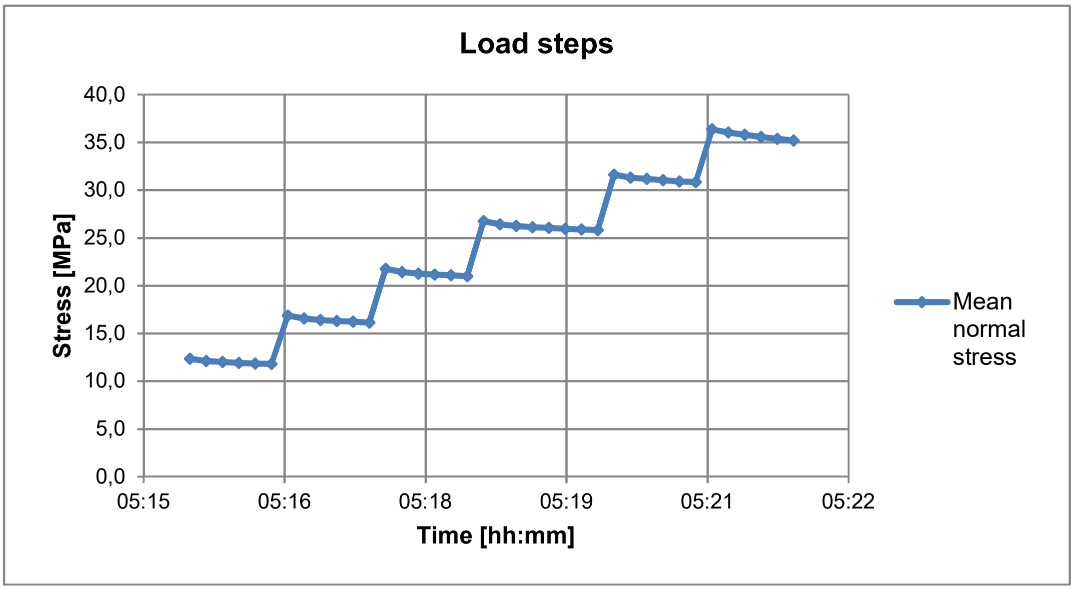
General	Number		10
	Date/Time		24.05.2019 01:50
	Tunnel meter [m]	Face	14488
		Gripper	14470
	Load cycles		1
	Load steps		5
	Reinforcement mesh		yes
Geology	Overburden [m]		769
	Lithology		Calcareous Schist
	Ground type		SH-KS-3b
	Heading direction [°]		170
	Foliation [°/°]; [cm]	Orientation	260/20
		Spacing	2 - 6
Results / Measurements	Contact area [m²]		0,64
	Displacement [mm]	Left	4,6
		Right	3,7
		Mean	4,2
	Mean normal stress [MPa]	Start	12,0
		End	35,7
		Delta	23,7
	Strain [-]		0,0020
	Deformation modulus [MPa]		11400

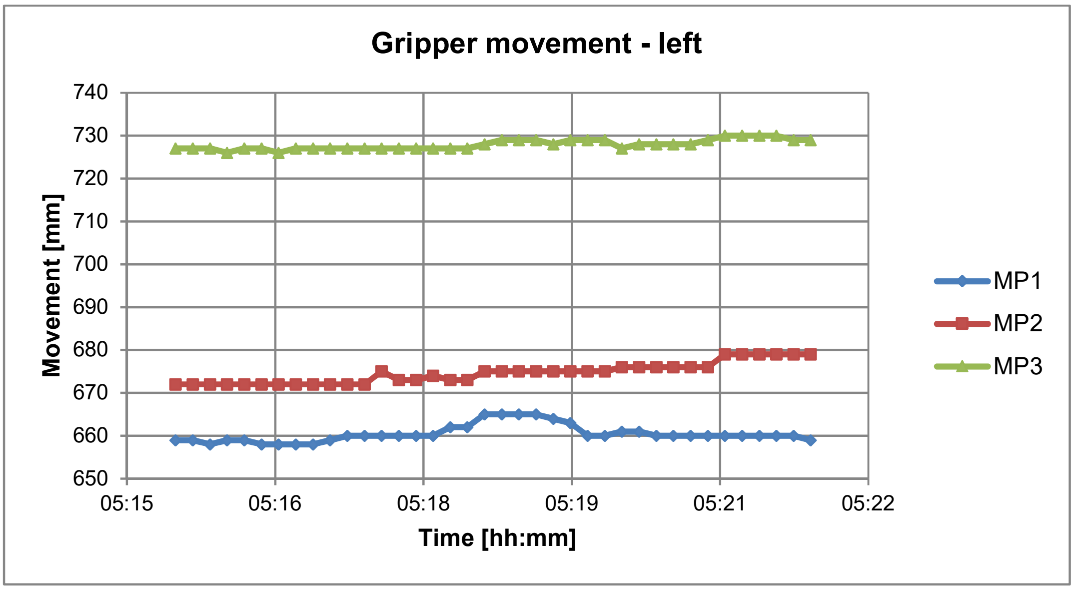


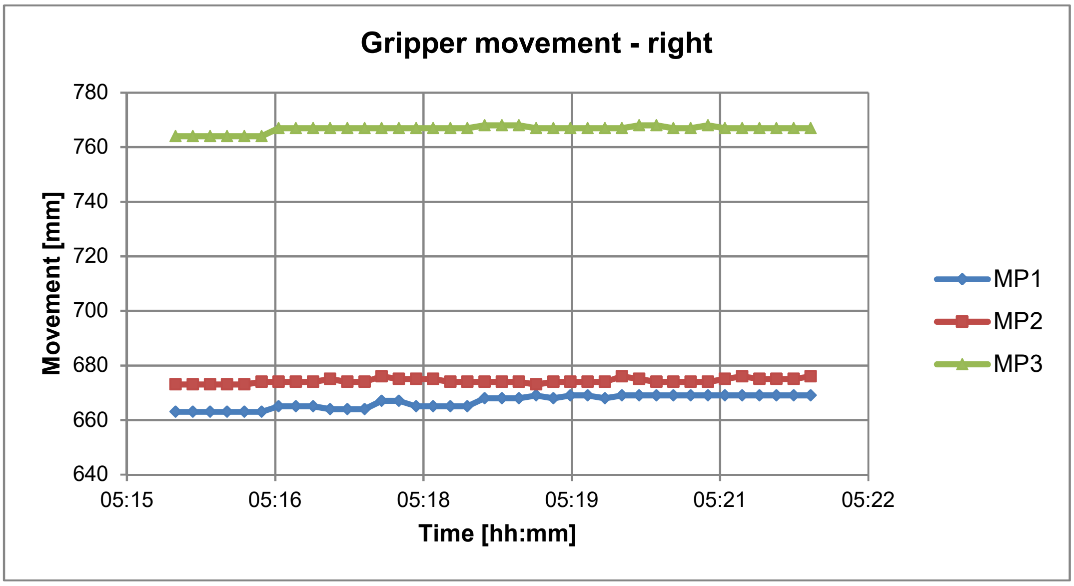




Results / Measurements

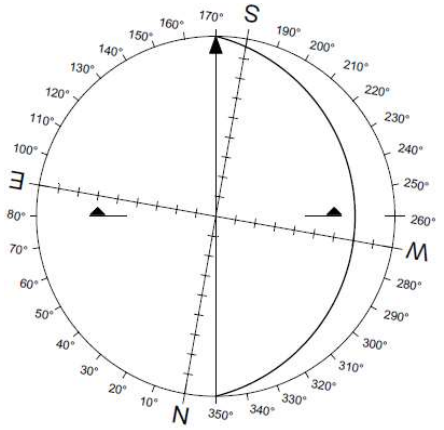


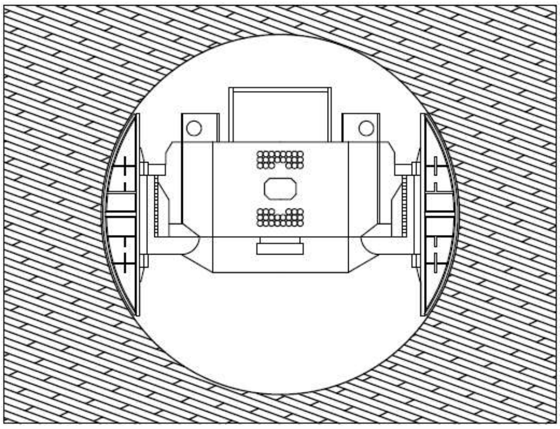




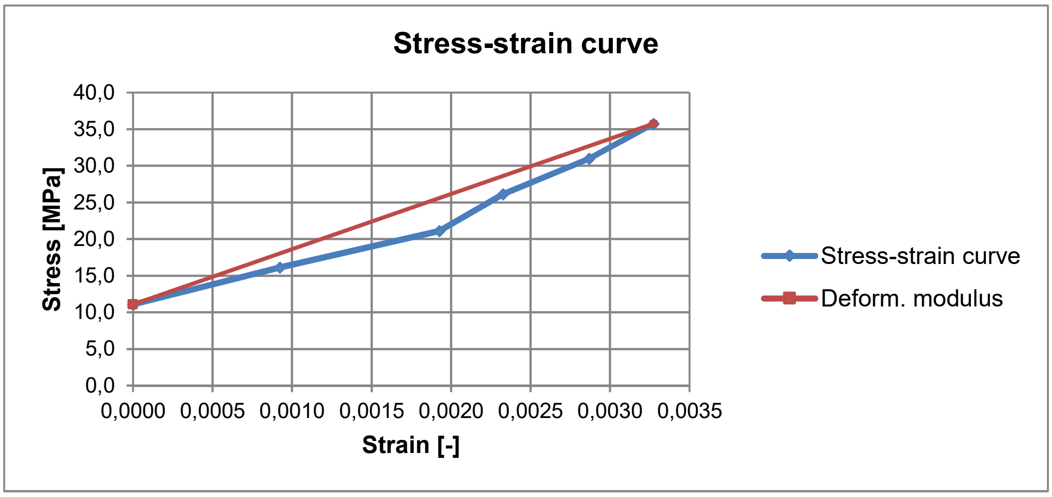
Data Sheet Gripper Test

General	Number		11
	Date/Time		24.05.2019 14:50
	Tunnel meter [m]	Face	14504
		Gripper	14486
	Load cycles		1
	Load steps		5
	Reinforcement mesh		yes
Geology	Overburden [m]		763
	Lithology		Calcareous Schist
	Ground type		SH-KS-3b
	Heading direction [°]		170
	Foliation [°/°]; [cm]	Orientation	260/20
		Spacing	2 - 6

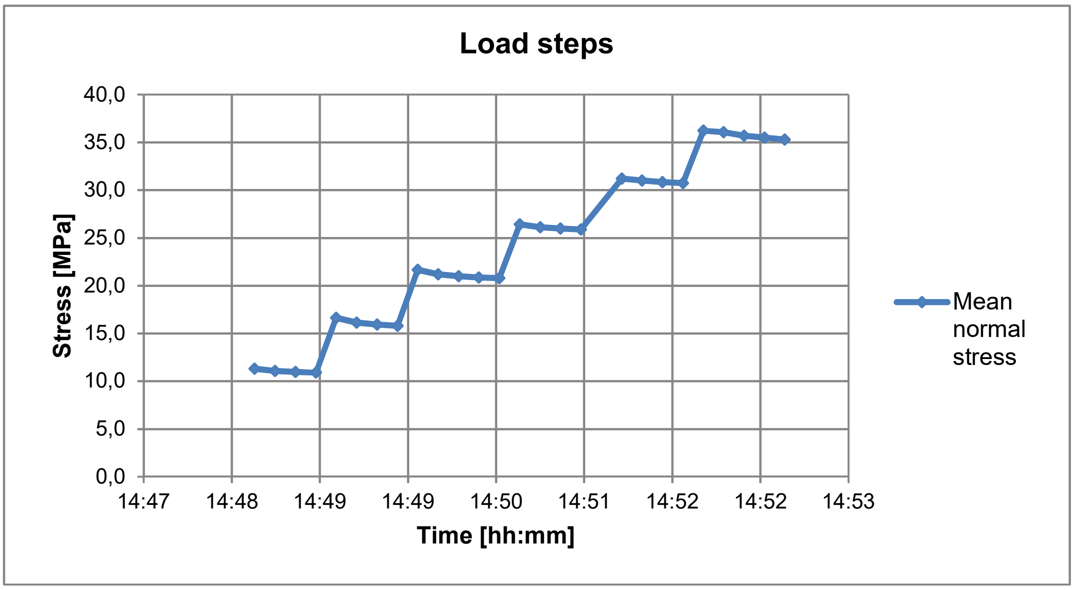


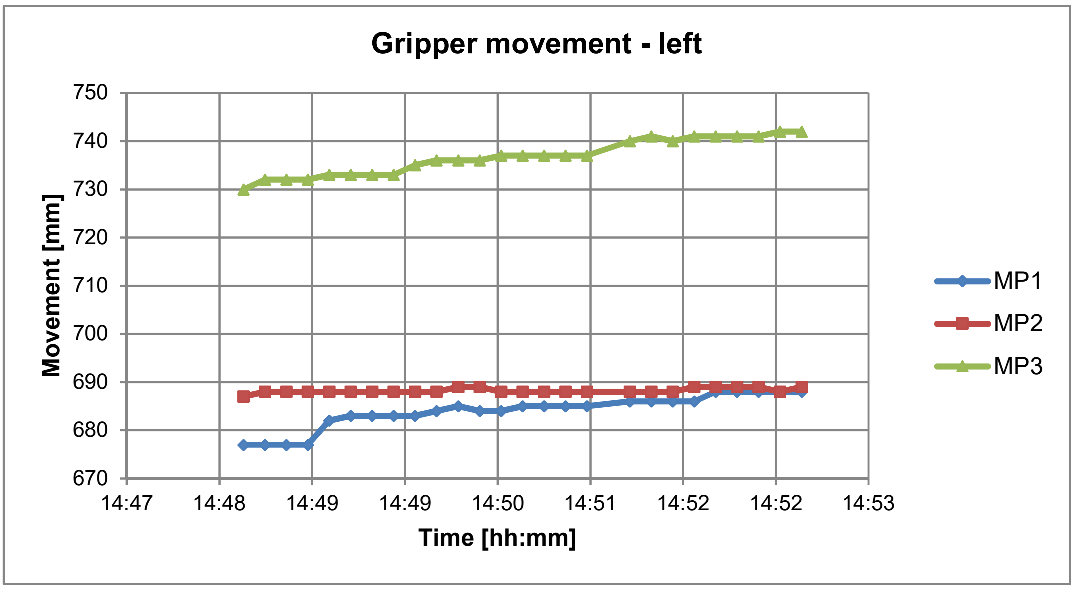


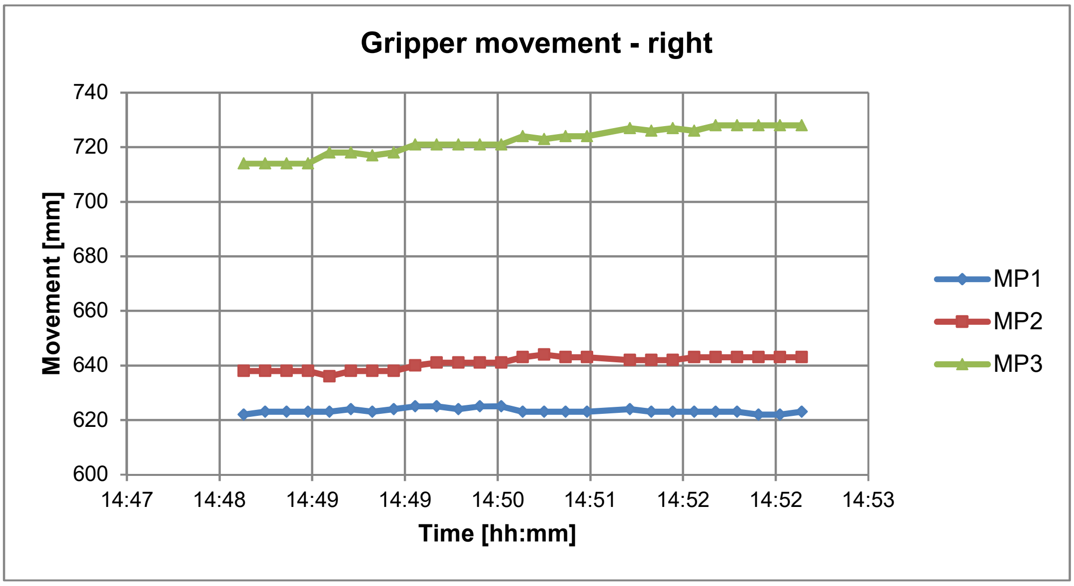
Results / Measurements	Contact area [m²]		0,64
	Displacement [mm]	Left	7,3
		Right	6,3
		Mean	6,8
	Mean normal stress [MPa]	Start	11,1
		End	35,8
		Delta	24,7
	Strain [-]		0,0033
	Deformation modulus [MPa]		7200



Results / Measurements

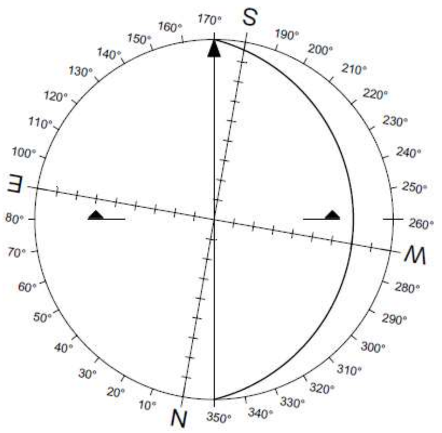


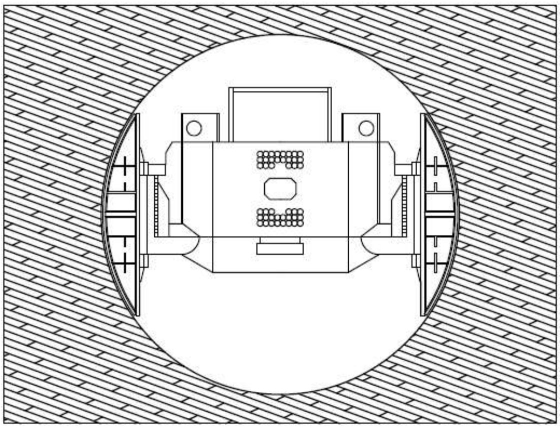




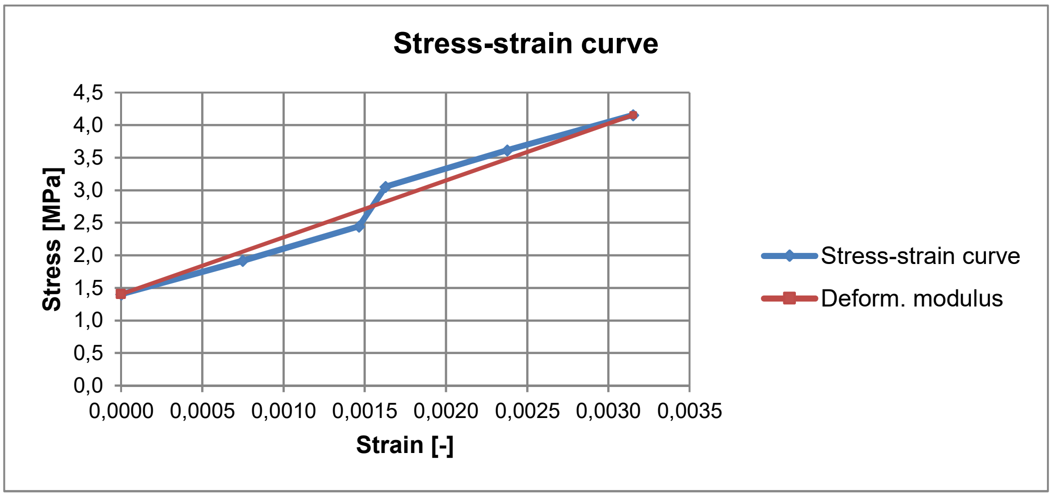
Data Sheet Gripper Test

General	Number		12
	Date/Time		24.05.2019 23:55
	Tunnel meter [m]	Face	14508
		Gripper	14490
	Load cycles		1
	Load steps		5
	Reinforcement mesh		no
Geology	Overburden [m]		762
	Lithology		Calcareous Schist
	Ground type		SH-KS-3b
	Heading direction [°]		170
	Foliation [°/°]; [cm]	Orientation	260/20
		Spacing	2 - 6

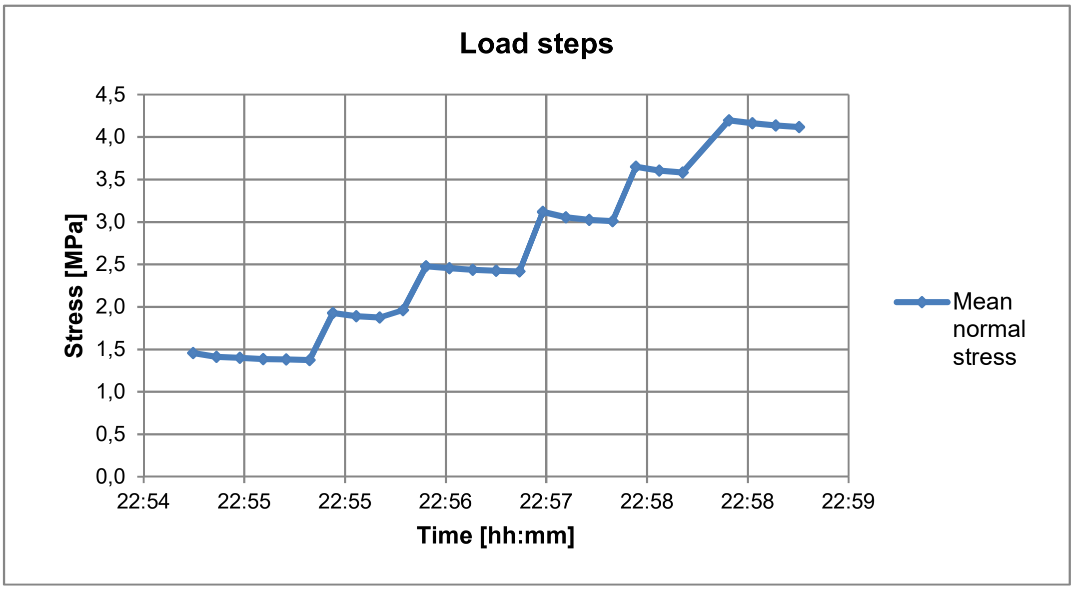


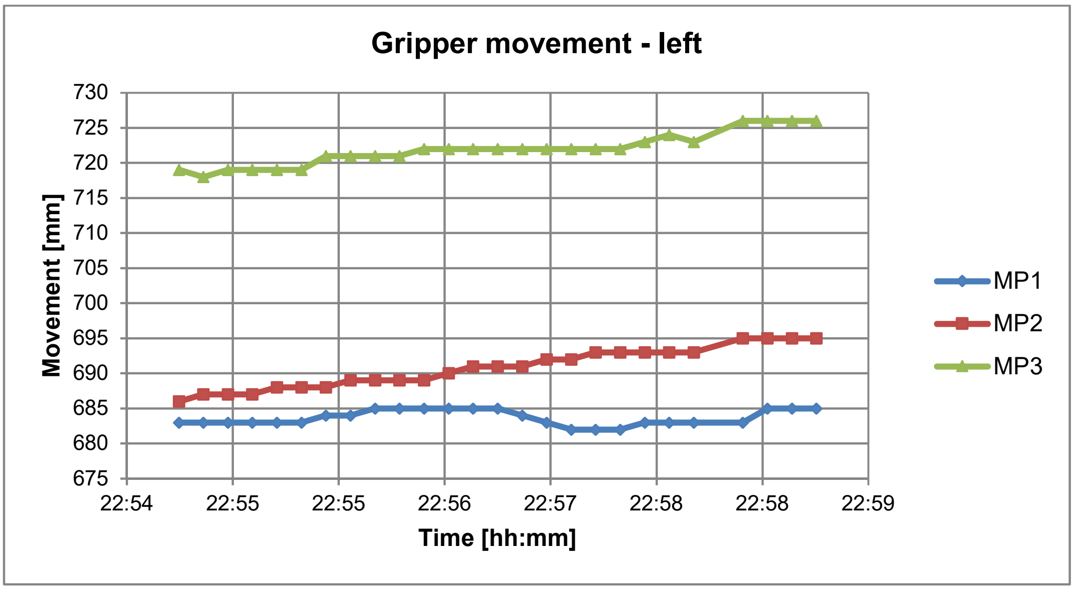


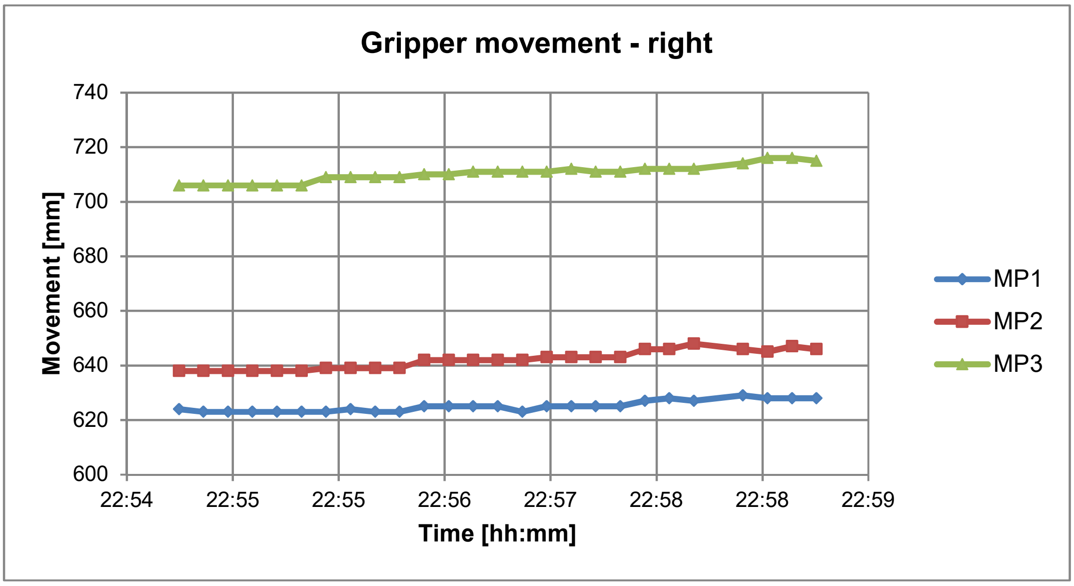
Results / Measurements	Contact area [m²]		5,50
	Displacement [mm]	Left	5,6
		Right	7,4
		Mean	6,5
	Mean normal stress [MPa]	Start	1,4
		End	4,2
		Delta	2,8
	Strain [-]		0,0032
	Deformation modulus [MPa]		800



Results / Measurements

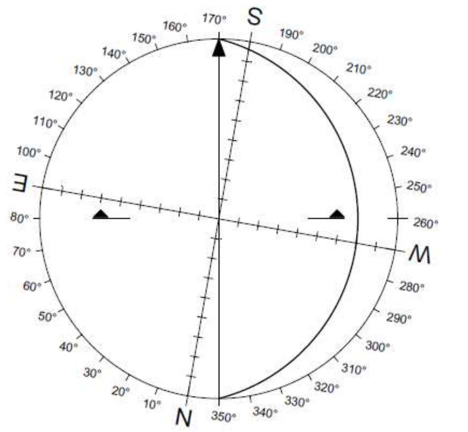


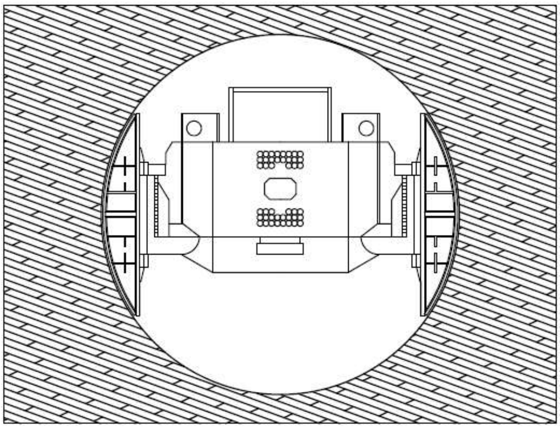




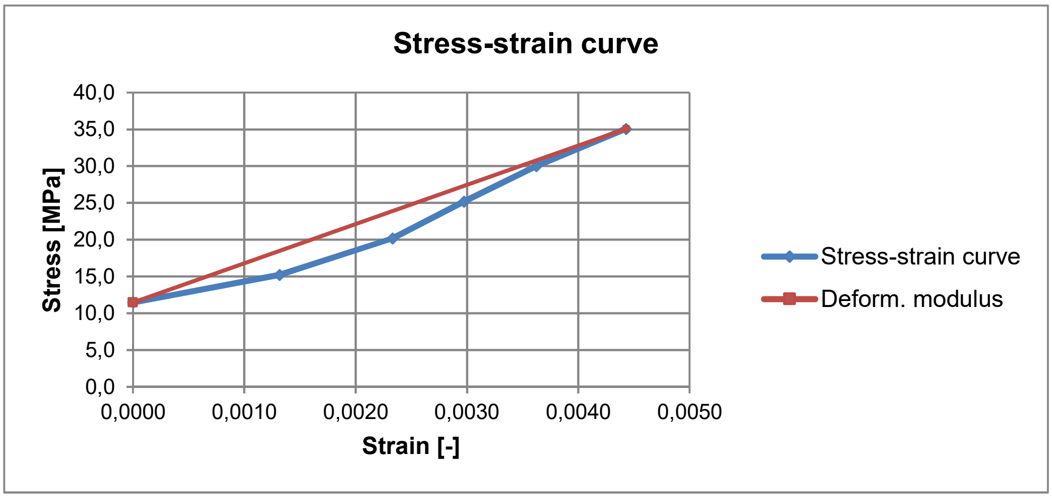
Data Sheet Gripper Test

General	Number		13
	Date/Time		25.05.2019 21:45
	Tunnel meter [m]	Face	14518
		Gripper	14500
	Load cycles		1
	Load steps		5
	Reinforcement mesh		yes
Geology	Overburden [m]		759
	Lithology		Calcareous Schist
	Ground type		SH-KS-3b
	Heading direction [°]		170
	Foliation [°/°]; [cm]	Orientation	260/20
		Spacing	2 - 6

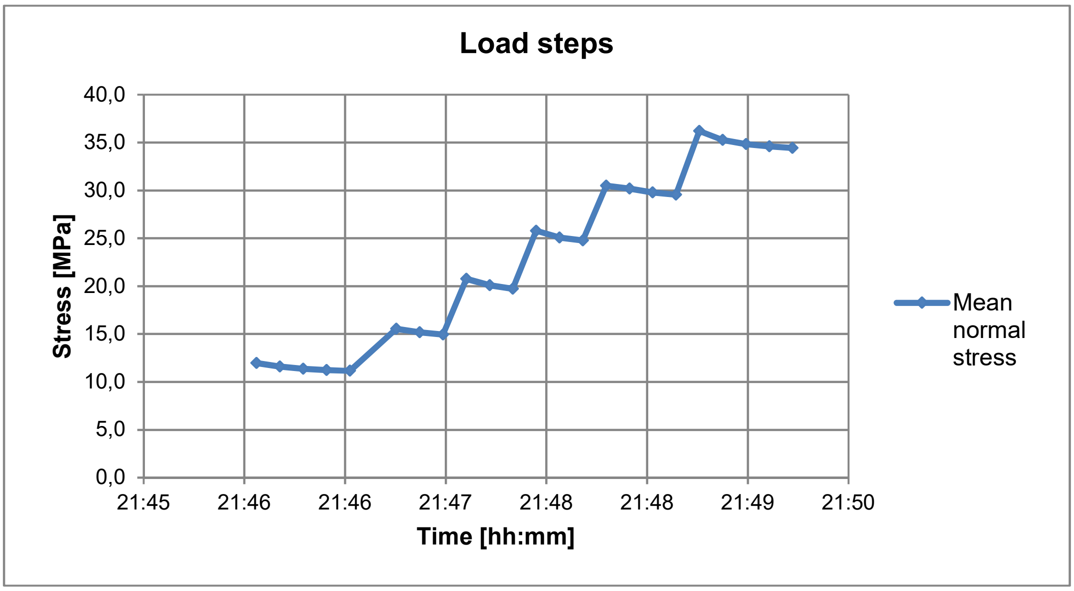


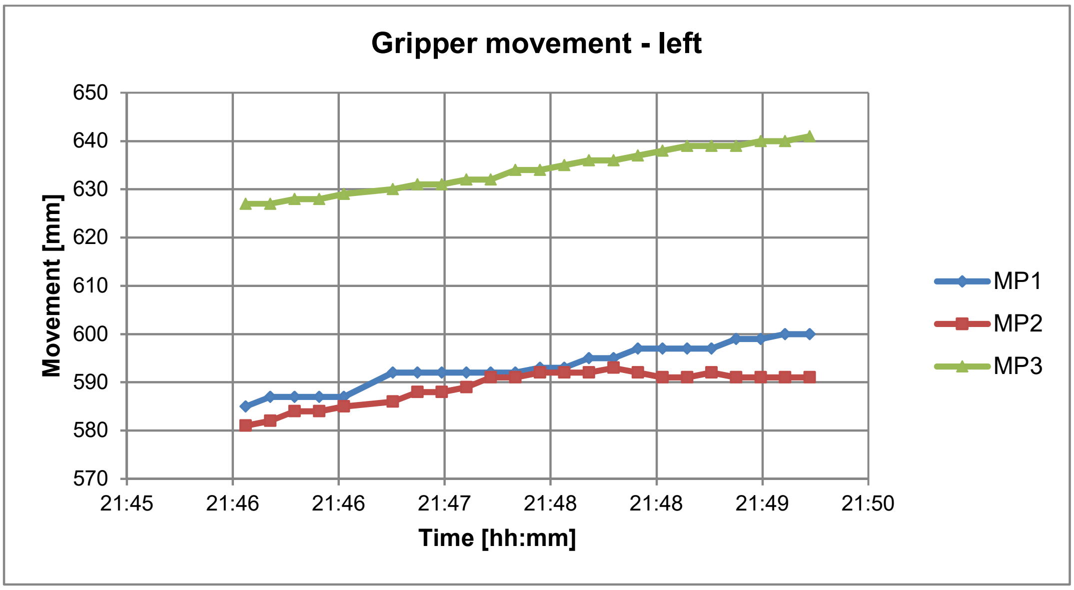


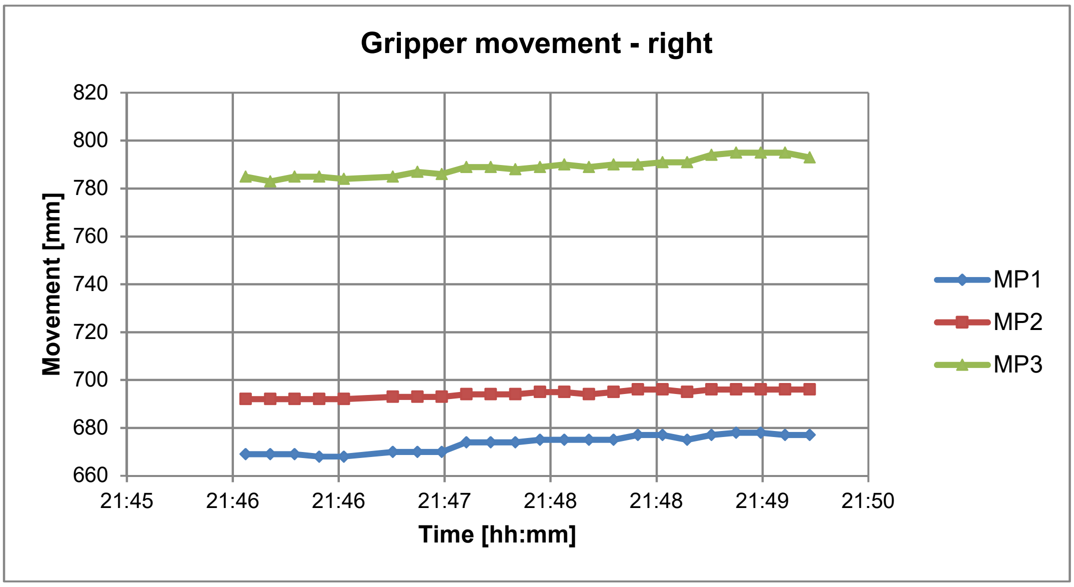
Results / Measurements	Contact area [m²]		0,64
	Displacement [mm]	Left	10,8
		Right	7,6
		Mean	9,2
	Mean normal stress [MPa]	Start	11,5
		End	35,1
		Delta	23,6
	Strain [-]		0,0044
	Deformation modulus [MPa]		5100



Results / Measurements

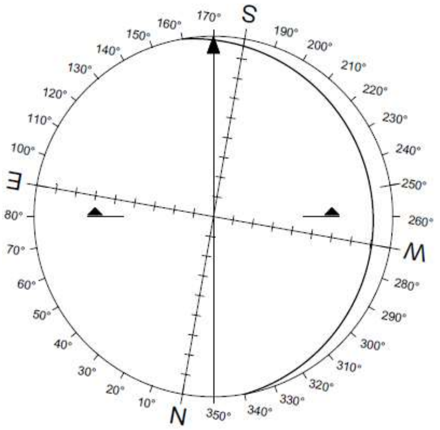


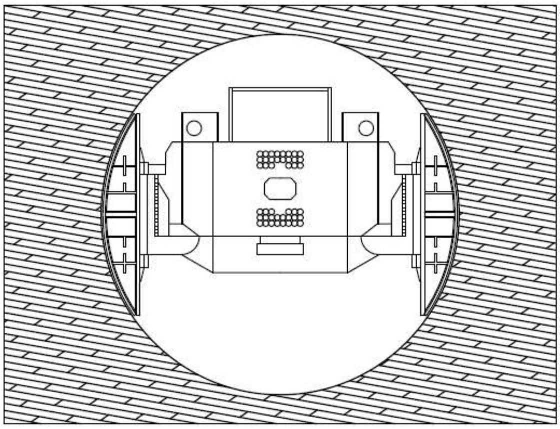


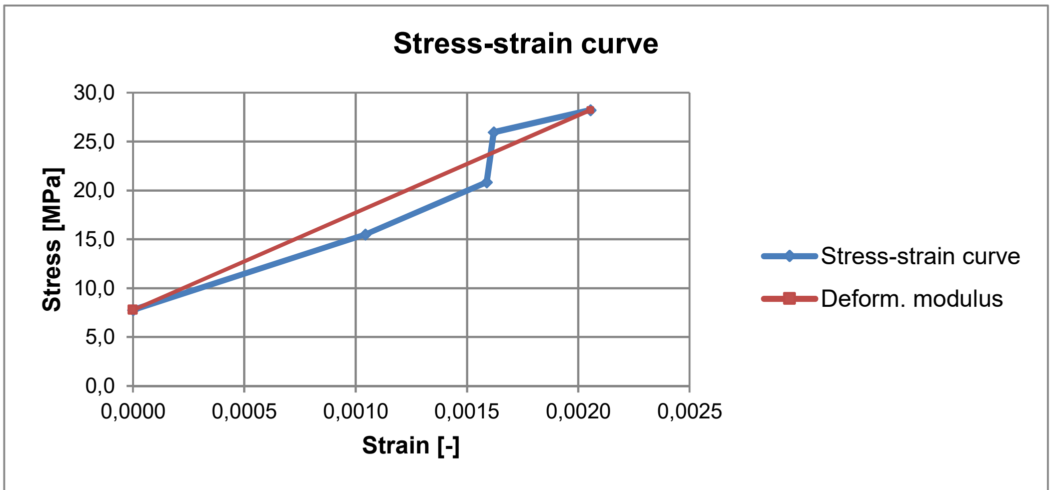


Data Sheet Gripper Test

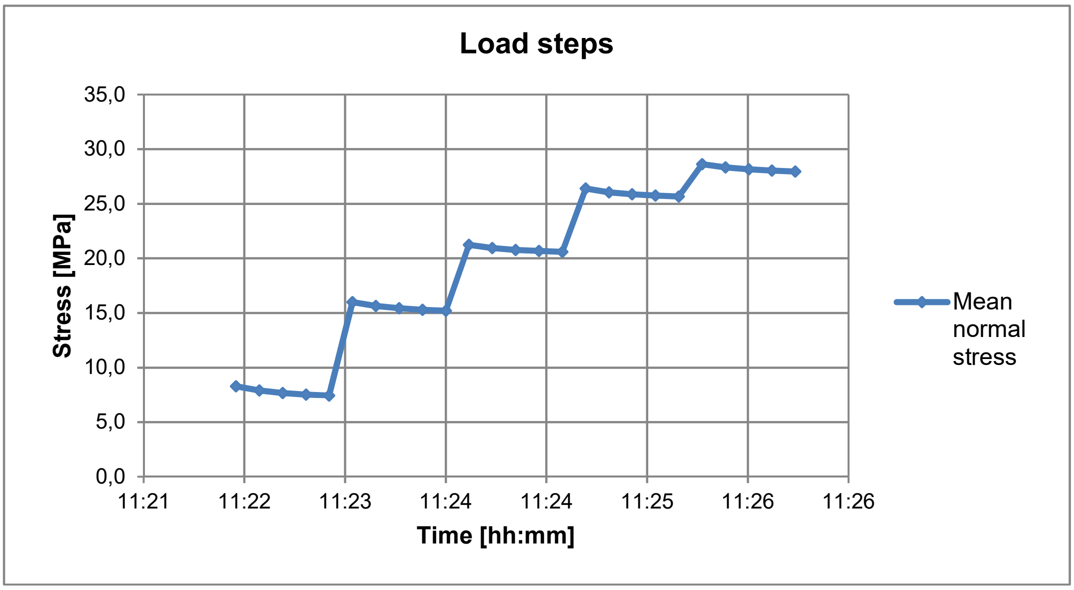
General	Number		14
	Date/Time		12.06.2019 11:20
	Tunnel meter [m]	Face	14741
		Gripper	14723
	Load cycles		1
	Load steps		4
	Reinforcement mesh		yes
Geology	Overburden [m]		718
	Lithology		Calcareous Schist
	Ground type		SH-KS-4b
	Heading direction [°]		170
	Foliation [°/°]; [cm]	Orientation	250/10
		Spacing	2 - 6
Results / Measurements	Contact area [m²]		0,64
	Displacement [mm]	Left	5,9
		Right	2,7
		Mean	4,3
	Mean normal stress [MPa]	Start	7,8
		End	28,2
		Delta	20,5
	Strain [-]		0,0021
	Deformation modulus [MPa]		9600

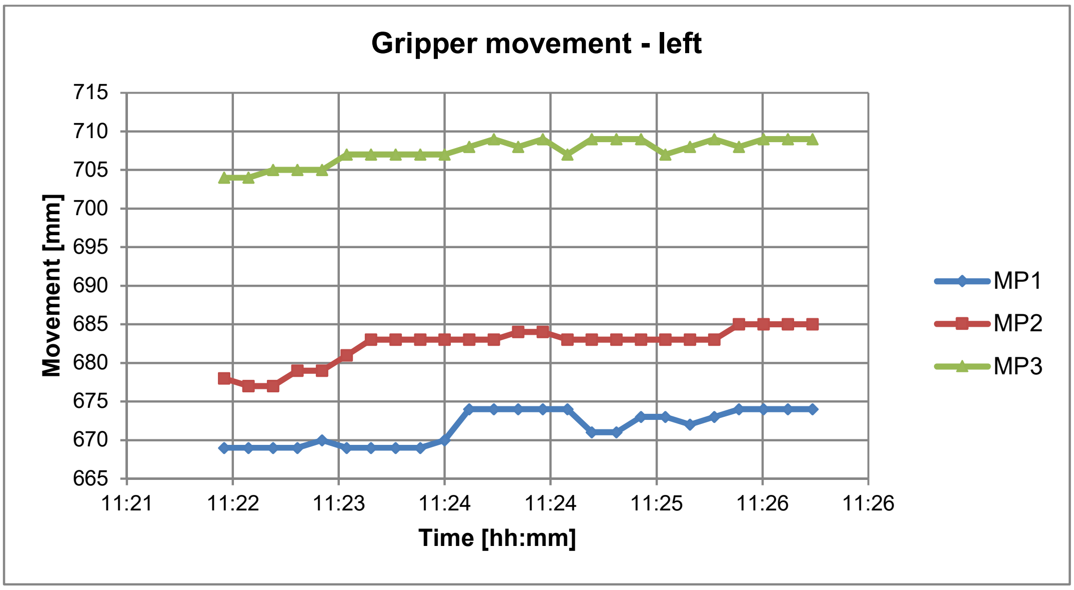


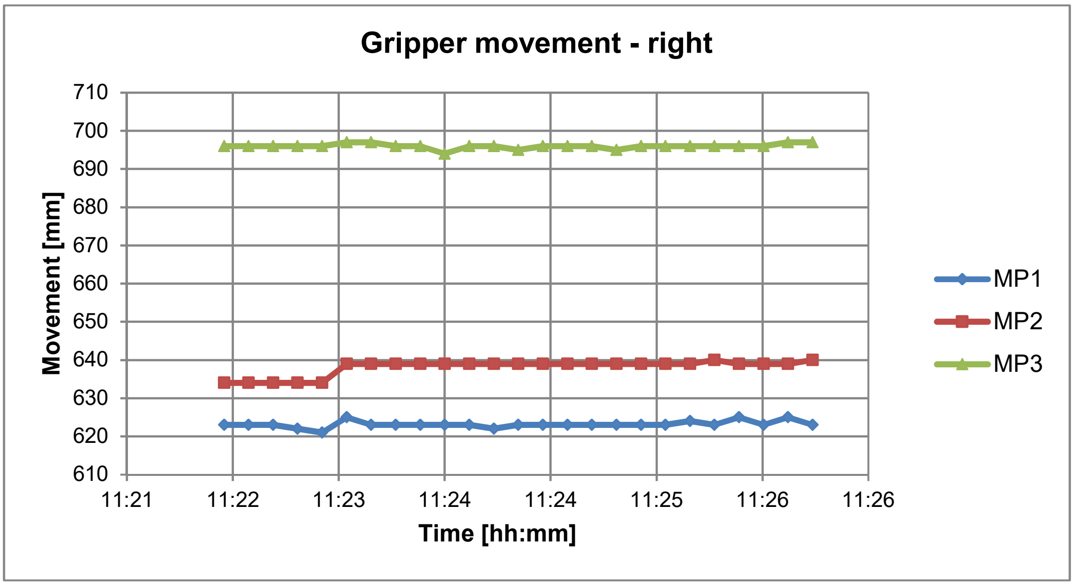




Results / Measurements

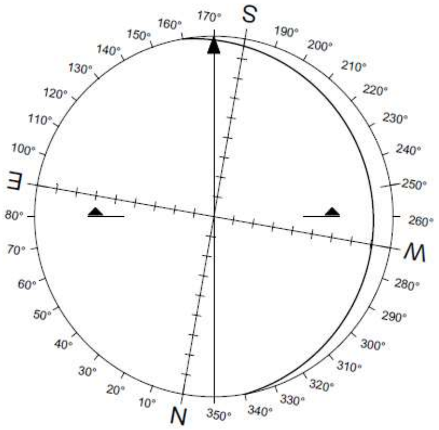


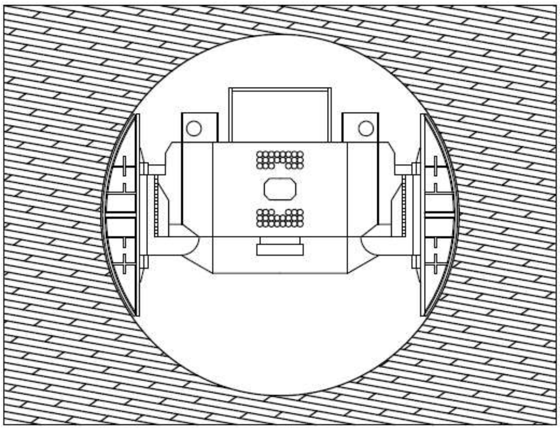


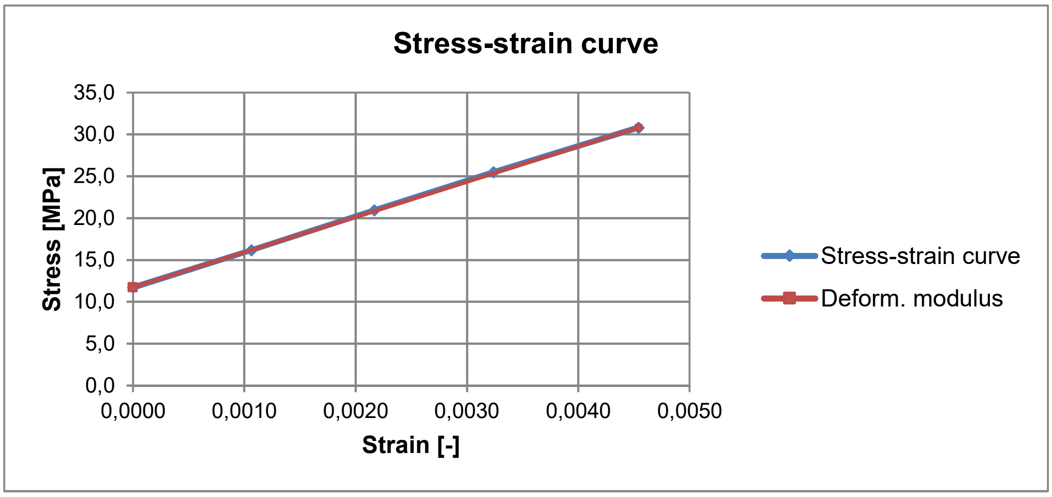


Data Sheet Gripper Test

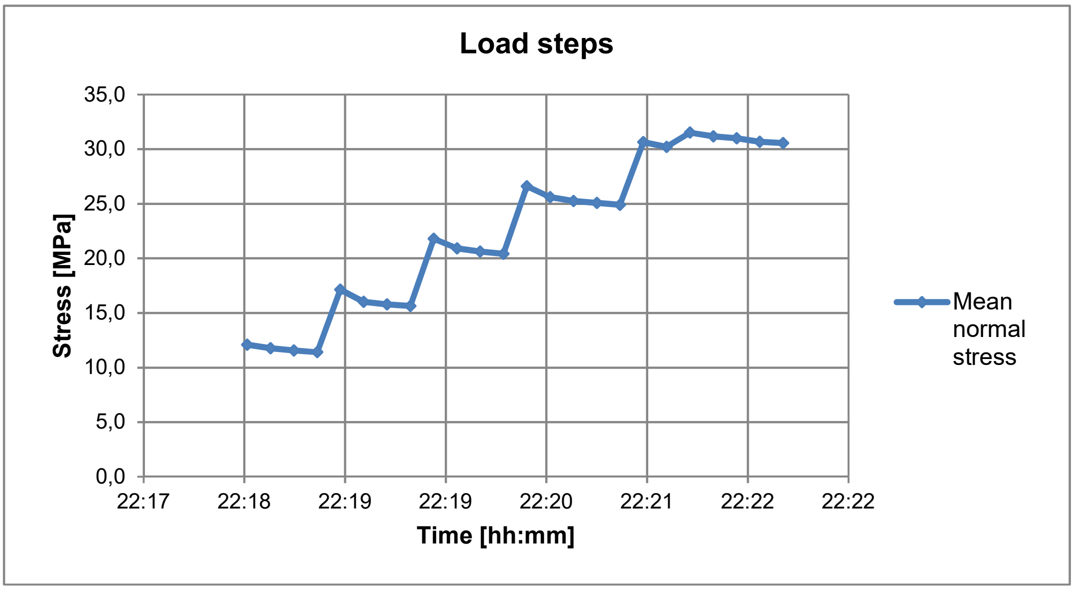
General	Number		15
	Date/Time		12.06.2019 22:20
	Tunnel meter [m]	Face	14746
		Gripper	14728
	Load cycles		1
	Load steps		4
	Reinforcement mesh		yes
Geology	Overburden [m]		718
	Lithology		Calcareous Schist
	Ground type		SH-KS-4b
	Heading direction [°]		170
	Foliation [°/°]; [cm]	Orientation	250/10
		Spacing	2 - 6
Results / Measurements	Contact area [m²]		0,64
	Displacement [mm]	Left	6,7
		Right	12,2
		Mean	9,4
	Mean normal stress [MPa]	Start	11,7
		End	30,8
		Delta	19,1
	Strain [-]		0,0045
	Deformation modulus [MPa]		4000

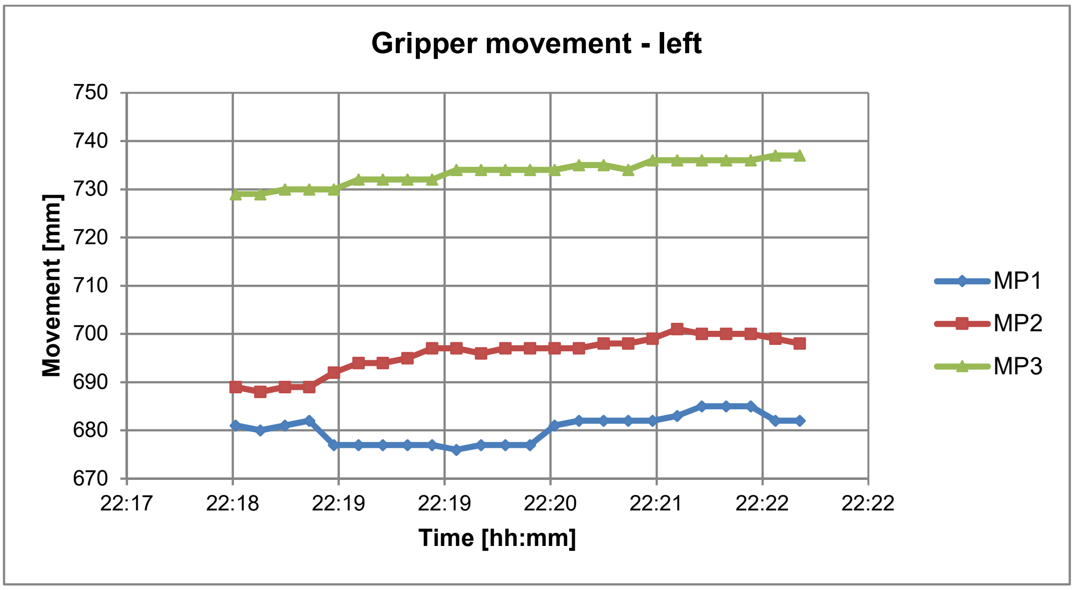


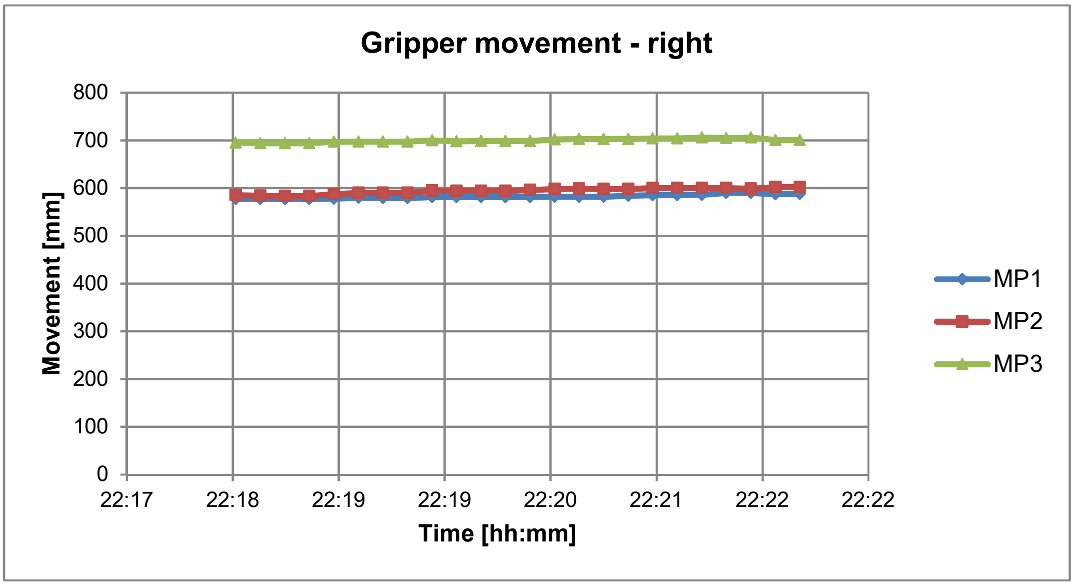




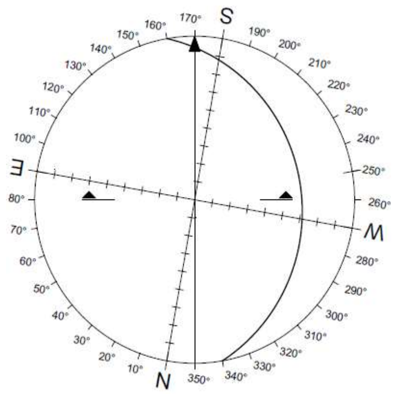
Results / Measurements

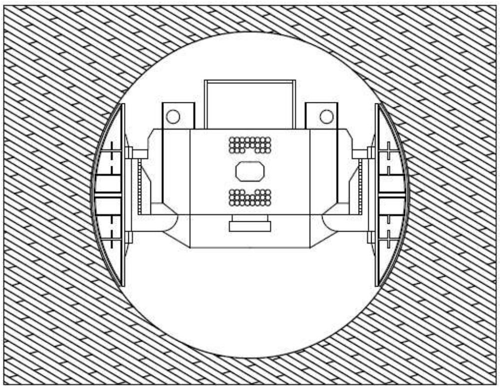


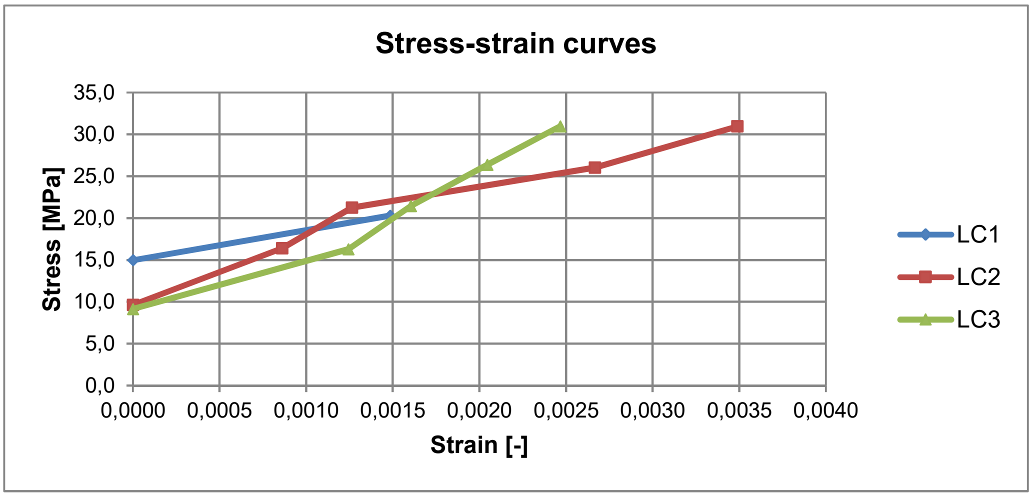




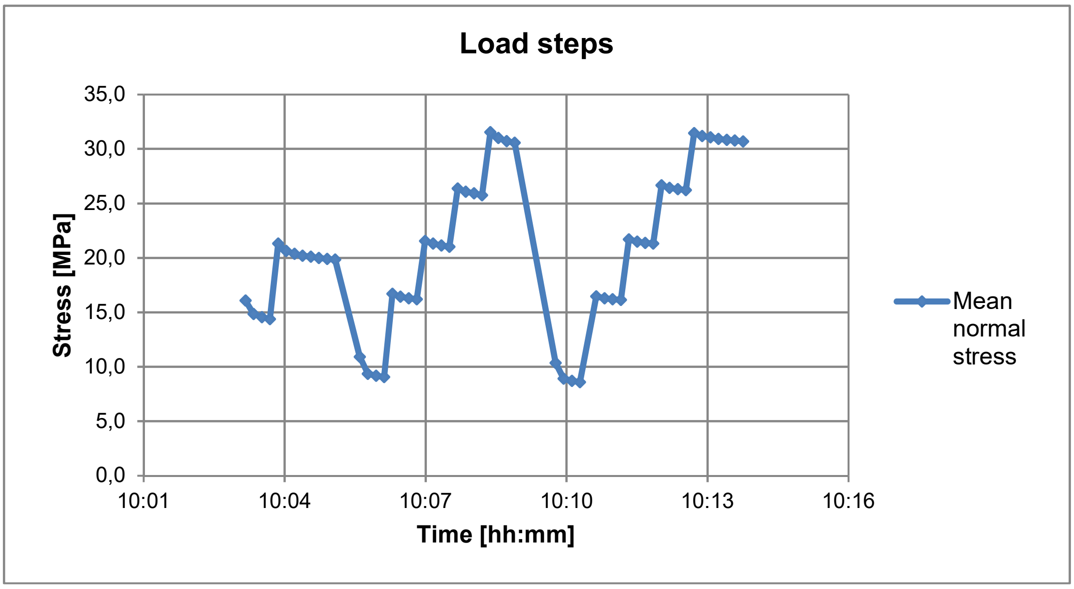
Data Sheet Gripper Test					
General	Number		16		
	Date/Time		26.06.2019 10:10		
	Tunnel meter [m]	Face	14893		
		Gripper	14875		
	Load cycles		3		
	Load steps		1/4/4		
	Reinforcement mesh		yes		
Geology	Overburden [m]		713		
	Lithology		Calcareous Schist		
	Ground type		SH-KS-4b		
	Heading direction [°]		170		
	Foliation [°/°]; [cm]	Orientation	250/30		
		Spacing	2 - 6		
Results / Measurements	Contact area [m²]		0,64		
	Load cycle		LC1	LC2	LC3
	Displacement [mm]	Left	3,7	8,8	3,3
		Right	2,5	5,7	7,0
		Mean	3,1	7,3	5,1
	Mean normal stress [MPa]	Start	15,0	9,6	9,1
		End	20,3	31,0	31,0
		Delta	5,3	21,3	21,9
	Strain [-]		0,0015	0,0035	0,0025
	Deformation modulus [MPa]		3400	5900	8500

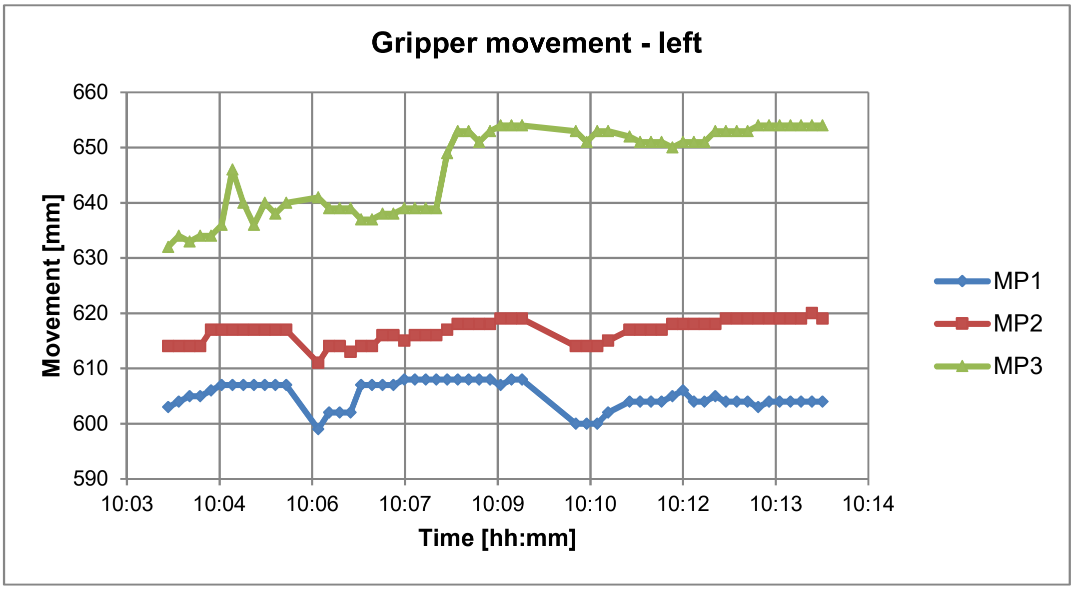


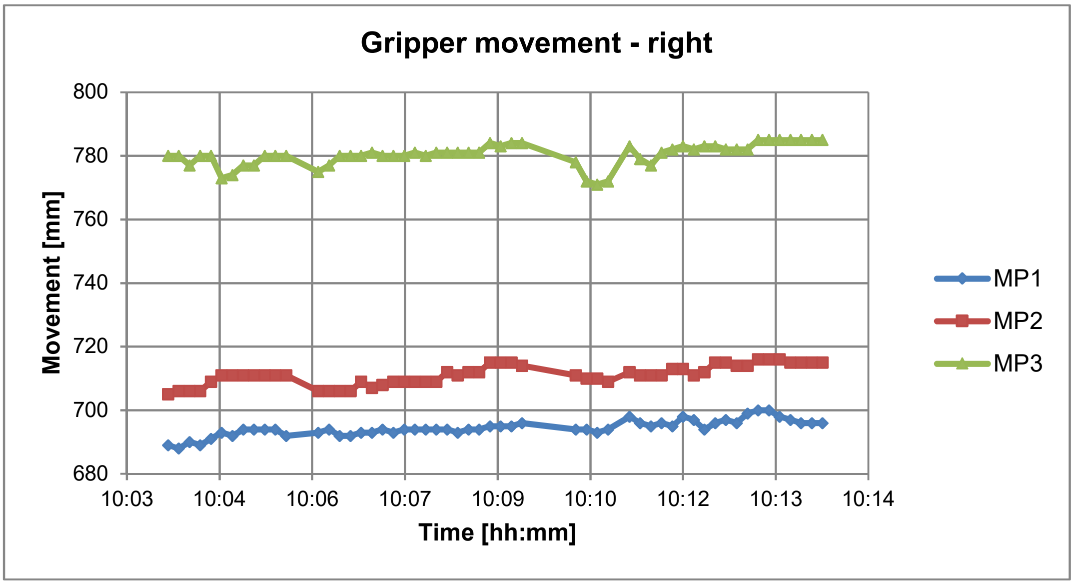




Results / Measurements

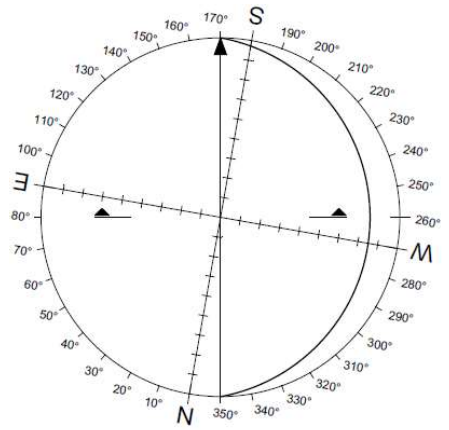


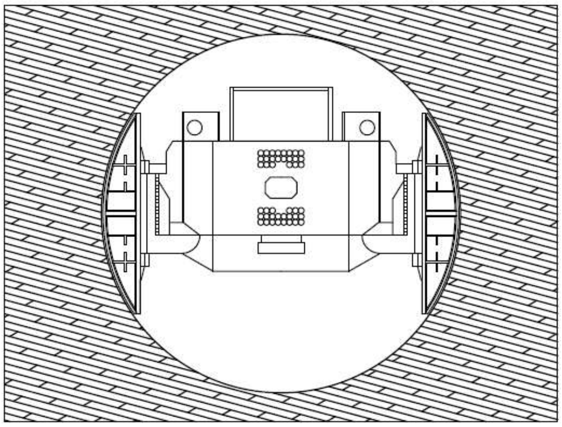




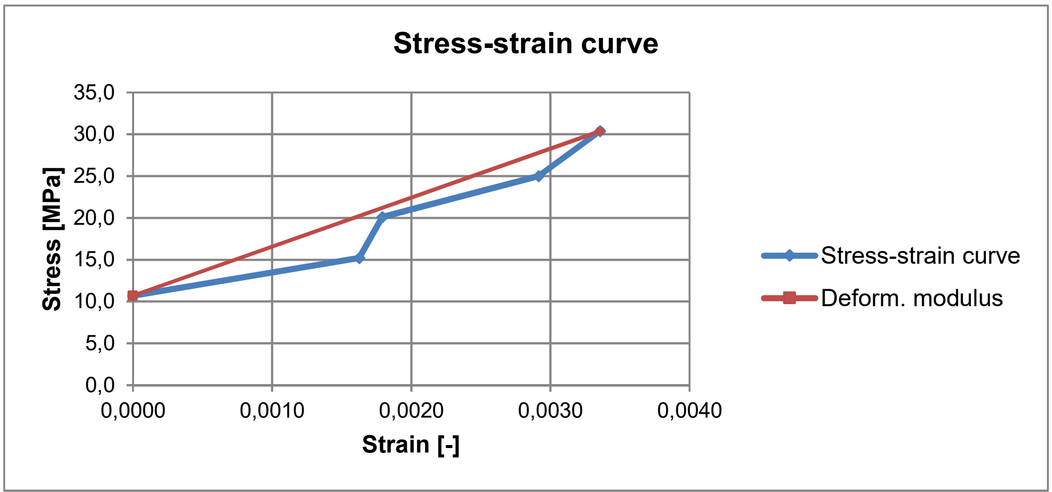
Data Sheet Gripper Test

General	Number		17
	Date/Time		26.06.2019 14:30
	Tunnel meter [m]	Face	14894
		Gripper	14876
	Load cycles		1
	Load steps		4
	Reinforcement mesh		yes
Geology	Overburden [m]		729
	Lithology		Calcareous Schist
	Ground type		SH-KS-4b
	Heading direction [°]		170
	Foliation [°/°]; [cm]	Orientation	260/15
		Spacing	2 - 6

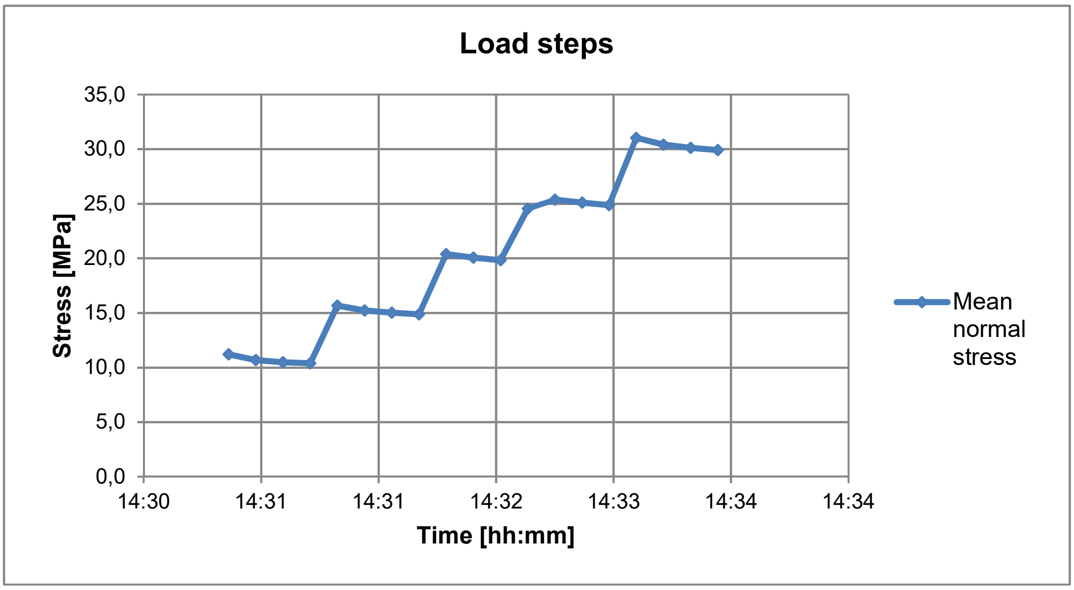


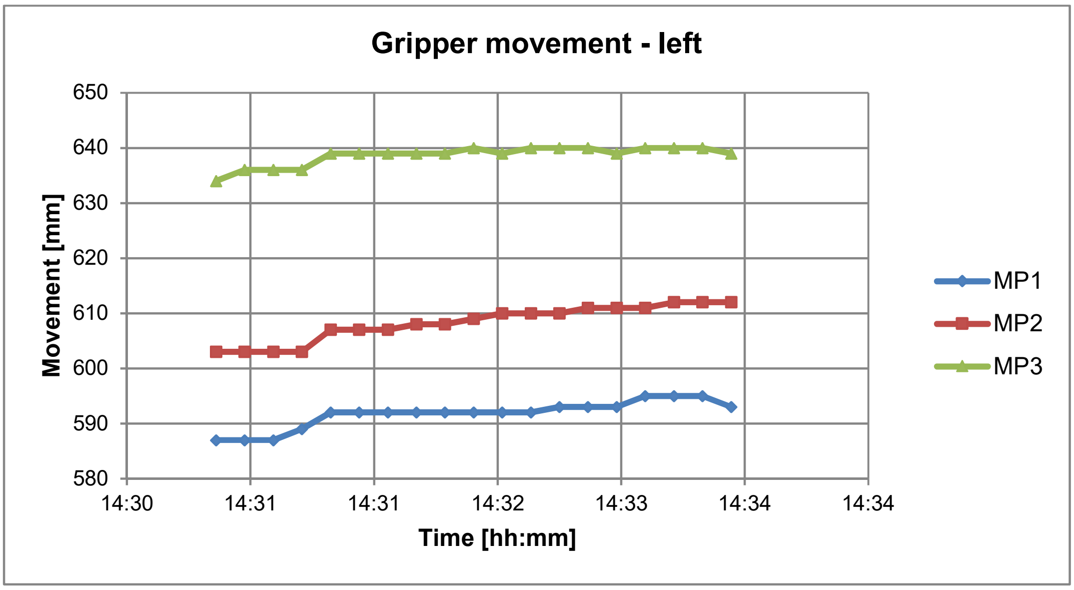


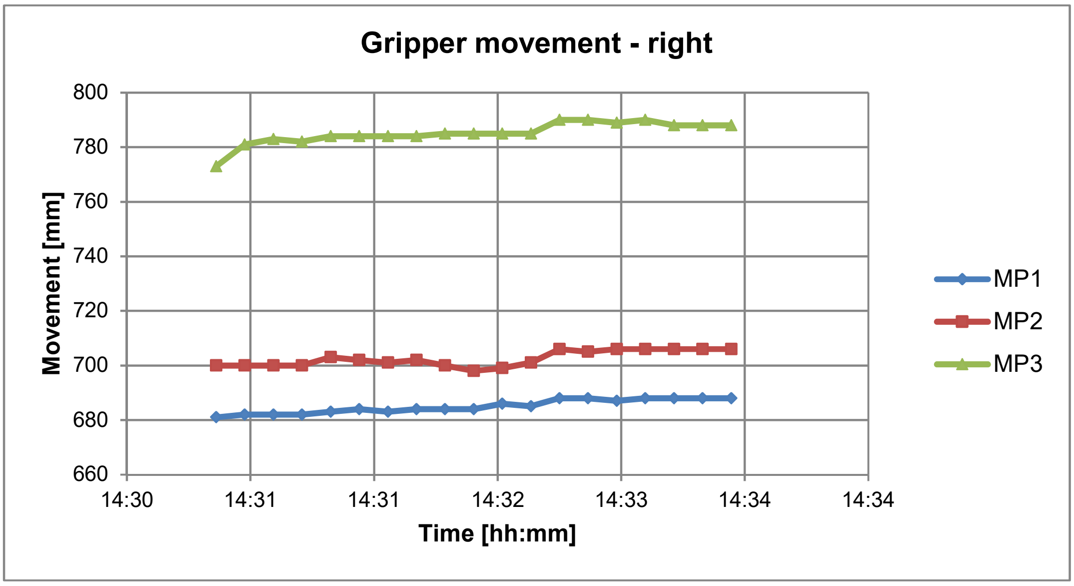
Results / Measurements	Contact area [m²]		0,64
	Displacement [mm]	Left	6,7
		Right	7,3
		Mean	7,0
	Mean normal stress [MPa]	Start	10,7
		End	30,4
		Delta	19,7
	Strain [-]		0,0034
	Deformation modulus [MPa]		5600



Results / Measurements

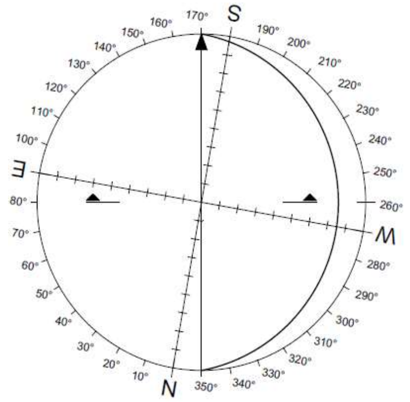


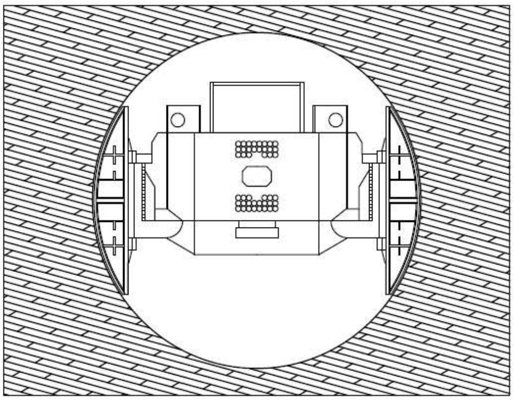




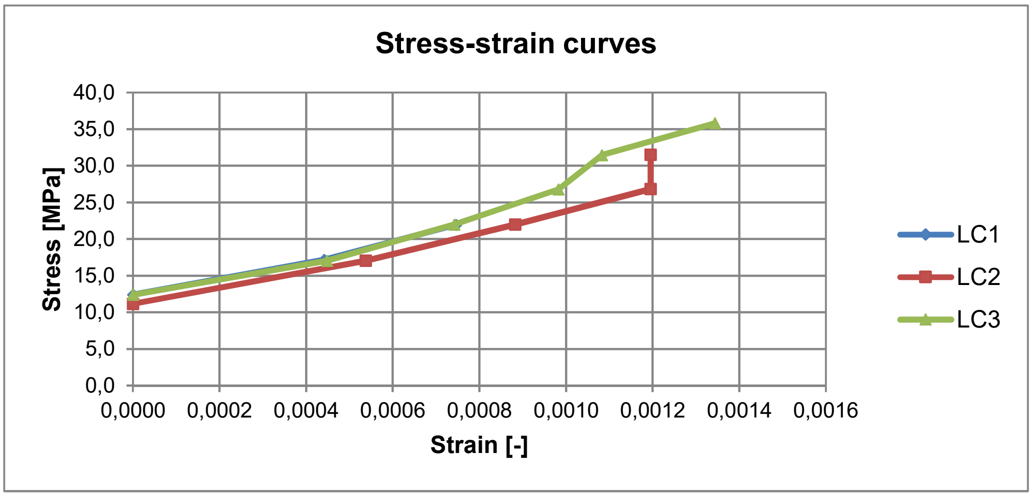
Data Sheet Gripper Test

General	Number		18
	Date/Time		27.06.2019 00:30
	Tunnel meter [m]	Face	14898
		Gripper	14880
	Load cycles		3
	Load steps		2/4/5
	Reinforcement mesh		yes
Geology	Overburden [m]		729
	Lithology		Calcareous Schist
	Ground type		SH-KS-4b
	Heading direction [°]		170
	Foliation [°/°]; [cm]	Orientation	260/15
		Spacing	2 - 6

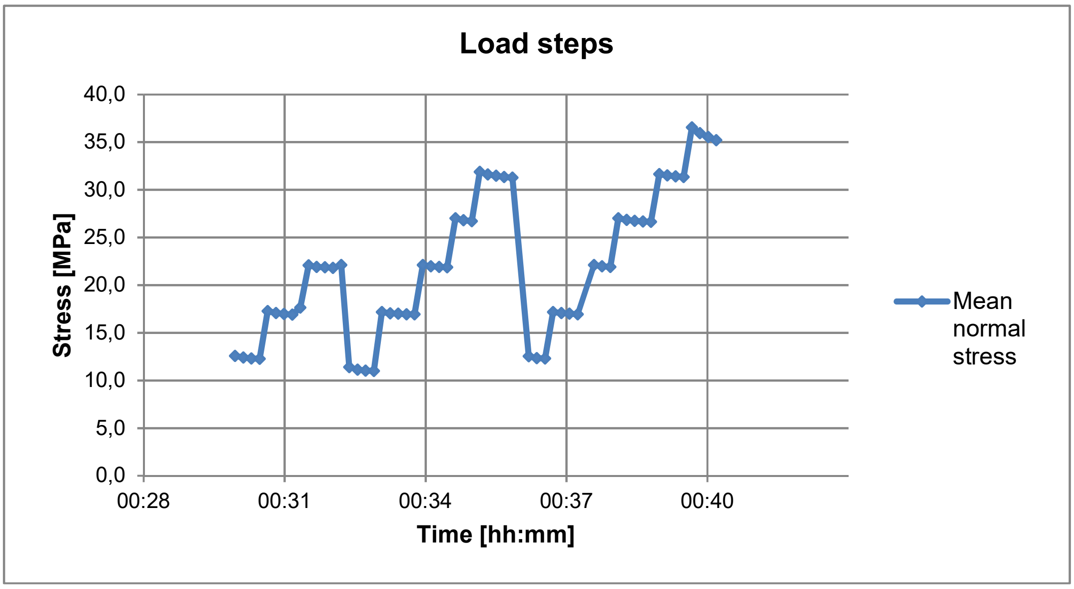


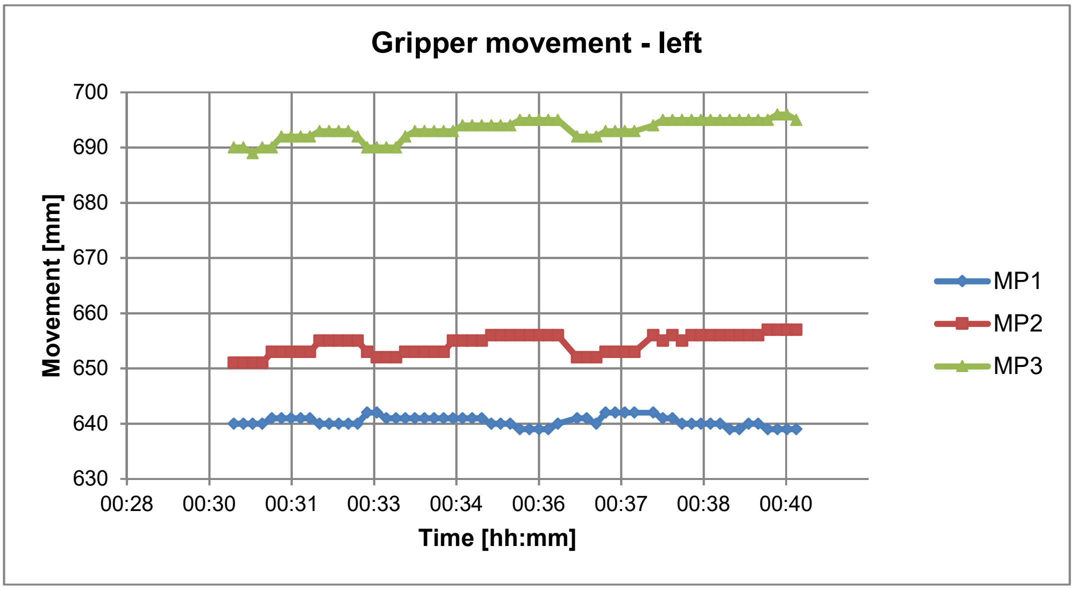


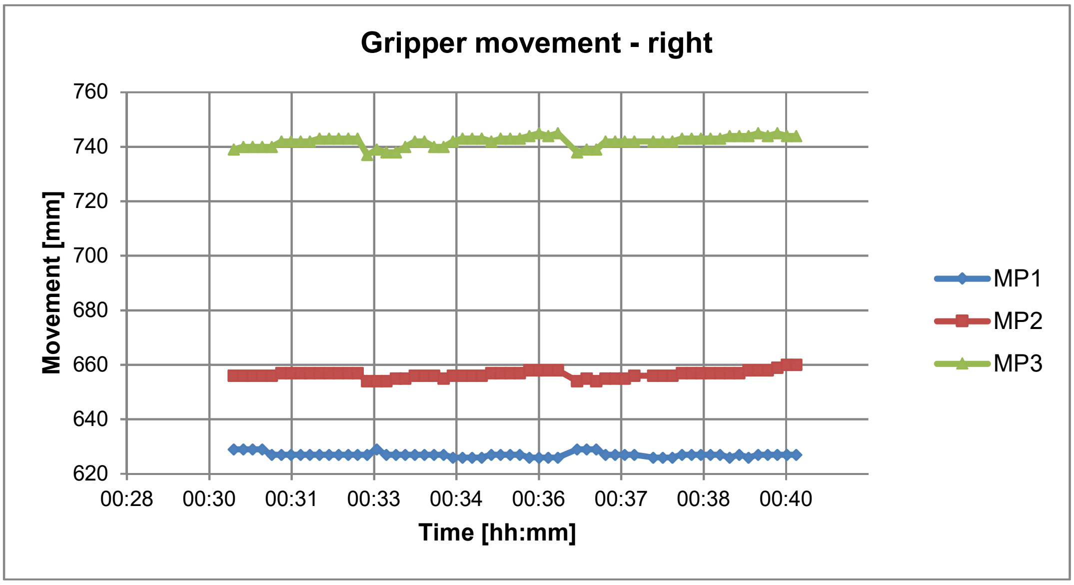
Results / Measurements	Contact area [m²]		0,64		
	Load cycle		LC1	LC2	LC3
	Displacement [mm]	Left	2,3	2,2	2,7
		Right	0,8	2,8	2,9
		Mean	1,5	2,5	2,8
	Mean normal stress [MPa]	Start	12,4	11,1	12,4
		End	22,0	31,5	35,8
		Delta	9,6	20,4	23,4
	Strain [-]		0,0007	0,0012	0,0013
	Deformation modulus [MPa]		12300	16400	16700



Results / Measurements







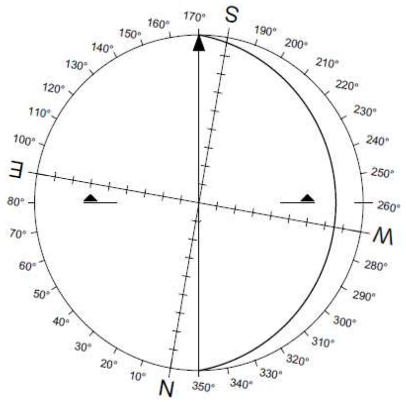
Data Sheet Gripper Test

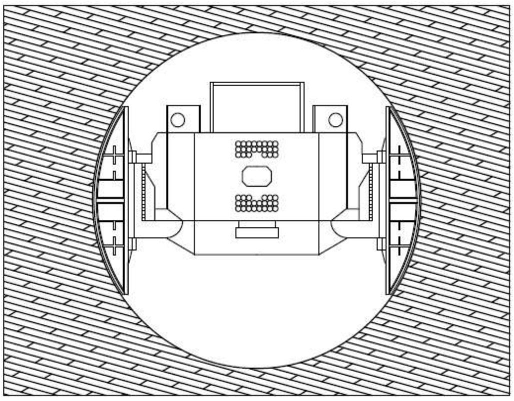
General

Number		19
Date/Time		27.06.2019 19:20
Tunnel meter [m]	Face	14901
	Gripper	14883
Load cycles		3
Load steps		2/4/5
Reinforcement mesh		yes

Geology

Overburden [m]		729
Lithology		Calcareous Schist
Ground type		SH-KS-4b
Heading direction [°]		170
Foliation [°/°]; [cm]	Orientation	260/15
	Spacing	2 - 6

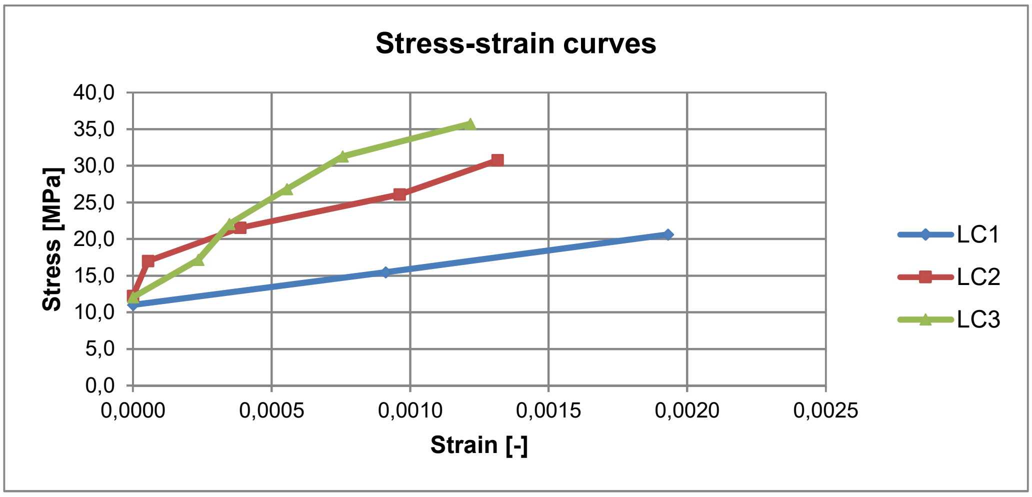




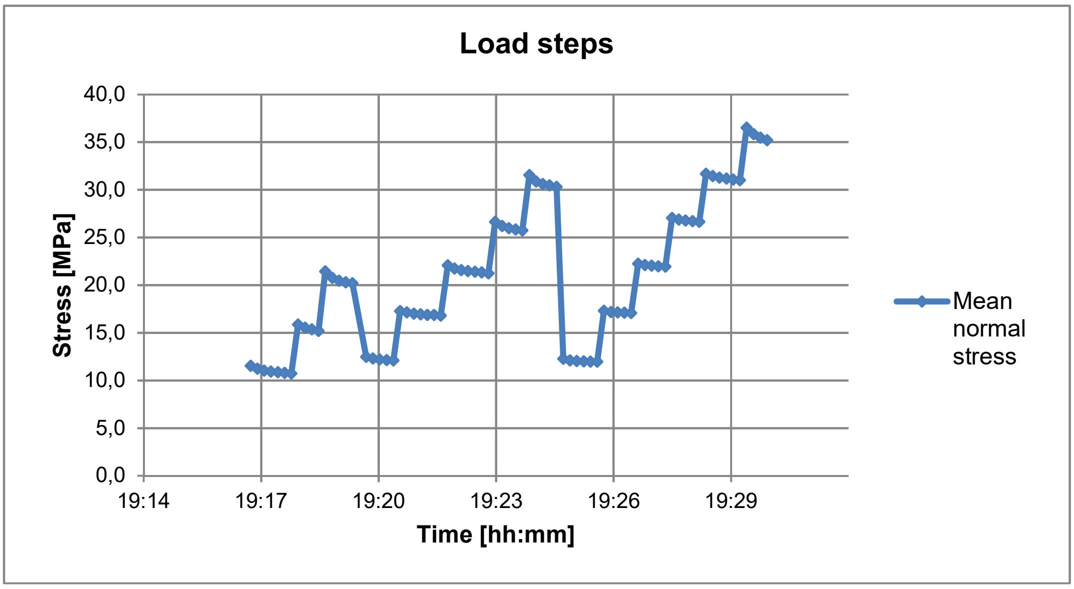
Results / Measurements

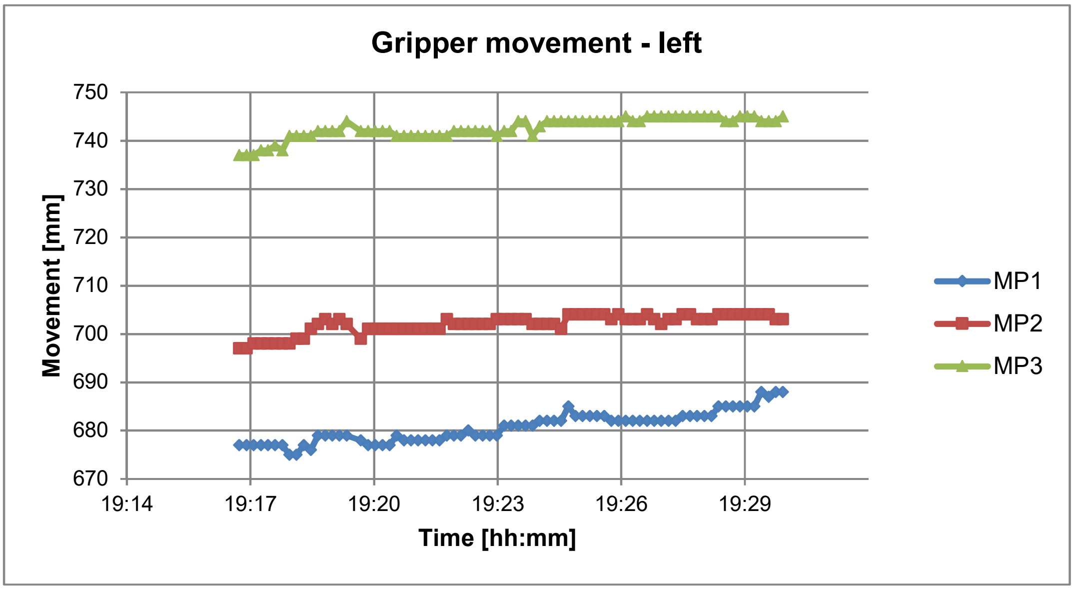
Contact area [m²]		0,64

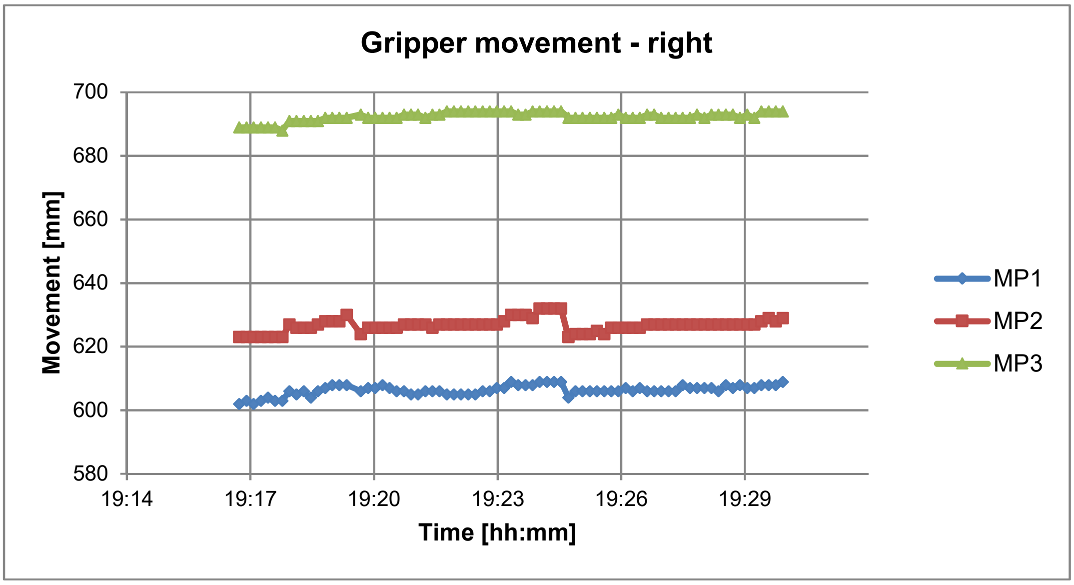
Load cycle		LC1	LC2	LC3
Displacement [mm]	Left	3,8	2,3	2,0
	Right	4,2	3,1	3,0
	Mean	4,0	2,7	2,5
Mean normal stress [MPa]	Start	11,0	12,3	12,1
	End	20,6	30,8	35,8
	Delta	9,6	18,5	23,7
Strain [-]		0,0019	0,0013	0,0012
Deformation modulus [MPa]		4800	13500	18700



Results / Measurements

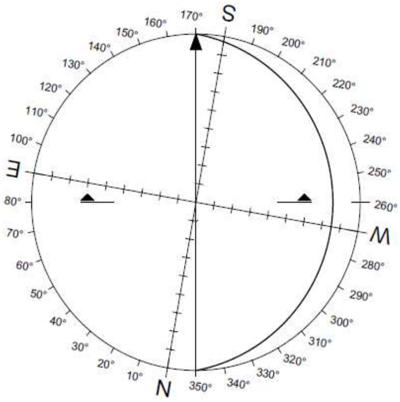
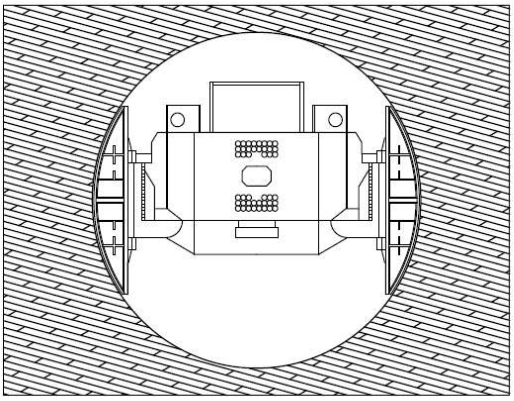




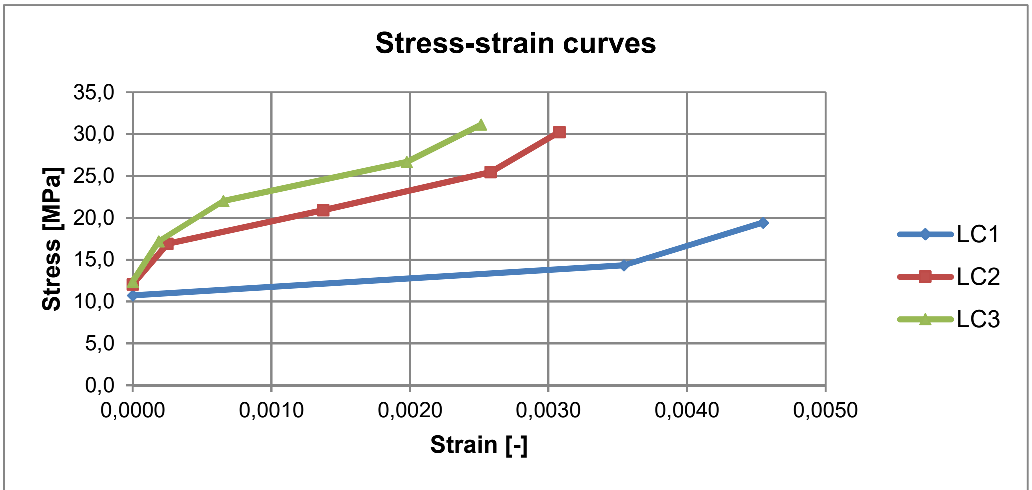


Data Sheet Gripper Test

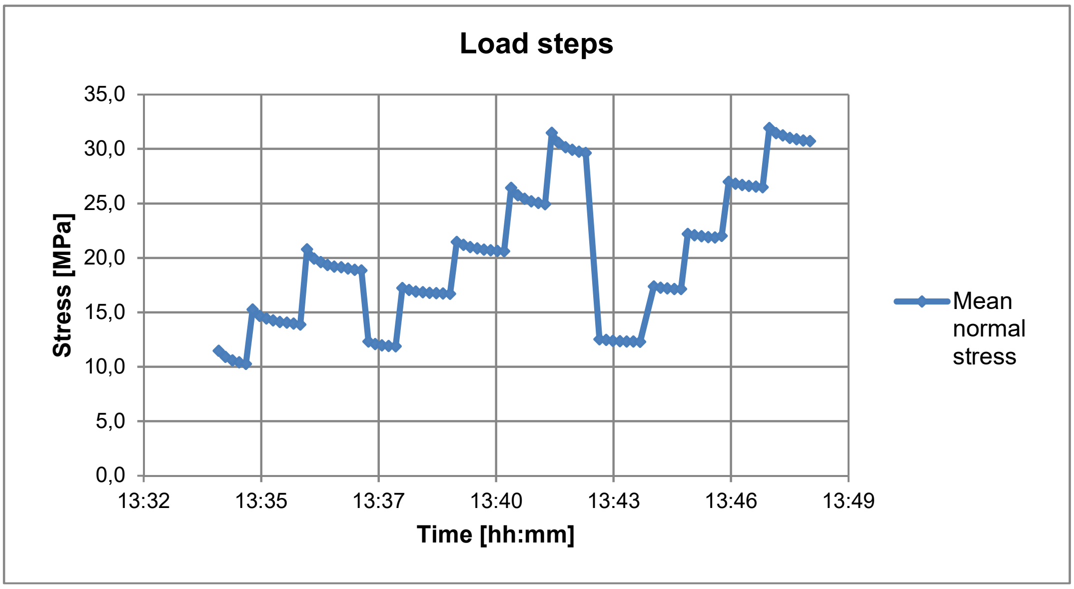
General	Number		20	
	Date/Time		29.06.2019 13:30	
	Tunnel meter [m]	Face	14916	
		Gripper	14898	
	Load cycles		3	
	Load steps		2/4/4	
	Reinforcement mesh		yes	
Geology	Overburden [m]		729	
	Lithology		Calcareous Schist	
	Ground type		SH-KS-4b	
	Heading direction [°]		170	
	Foliation [°/°]; [cm]	Orientation	260/15	
		Spacing	2 - 6	

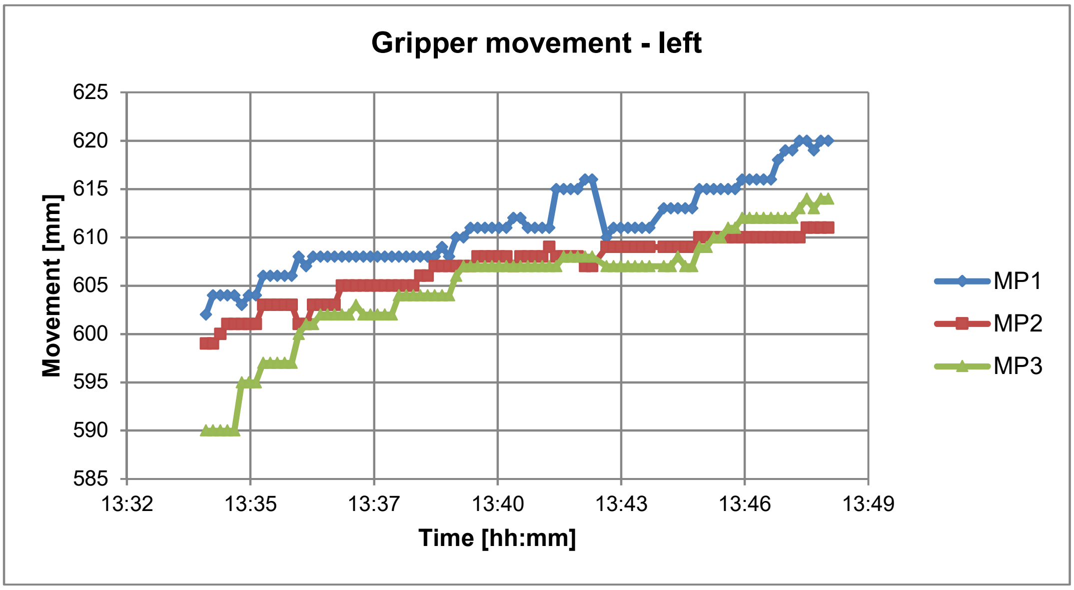



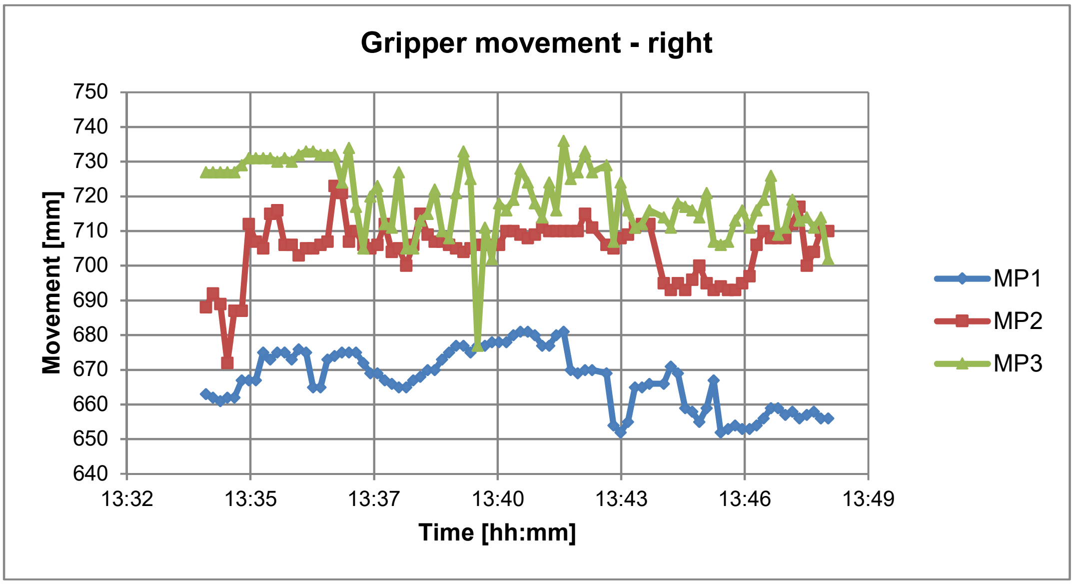
Results / Measurements	Contact area [m²]		0,64		
	Load cycle		LC1	LC2	LC3
	Displacement [mm]	Left	6,4	5,3	5,5
		Right	12,5	7,5	5,0
		Mean	9,4	6,4	5,2
	Mean normal stress [MPa]	Start	10,7	12,0	12,4
		End	19,4	30,3	31,1
		Delta	8,7	18,2	18,8
	Strain [-]		0,0045	0,0031	0,0025
	Deformation modulus [MPa]		1800	5700	7200



Results / Measurements







Appendix C

Raw data of gripper tests

Gripper Test 1

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
16.05.2019 09:27	**09:27**	**14395,8**	**100,4**	**12,3**	**652**	**643**	**683**		**694**	**704**	**784**
16.05.2019 09:27	09:27	14395,8	96,3	11,8	653	643	685		694	704	784
16.05.2019 09:27	09:27	14395,8	94,6	11,6	654	643	685		694	702	783
16.05.2019 09:27	09:27	14395,8	93,5	11,5	656	643	685		694	703	784
16.05.2019 09:27	09:27	14395,8	92,7	11,4	655	643	685		694	703	783
16.05.2019 09:28	09:28	14395,8	92,5	11,4	657	645	685		694	703	784
16.05.2019 09:28	09:28	14395,8	92	11,3	656	644	685		694	704	783
16.05.2019 09:28	09:28	14395,8	91,7	11,3	657	643	685		694	703	783
16.05.2019 09:28	09:28	14395,8	91,4	11,2	655	645	685		694	704	784
16.05.2019 09:28	**09:28**	**14395,8**	**135,6**	**16,6**	**649**	**648**	**685**		**696**	**705**	**785**
16.05.2019 09:28	09:28	14395,8	130,4	16,0	651	649	686		698	704	785
16.05.2019 09:29	09:29	14395,8	128	15,7	652	649	686		698	704	785
16.05.2019 09:29	09:29	14395,8	127	15,6	650	649	686		698	704	785
16.05.2019 09:29	09:29	14395,8	125,9	15,5	653	649	686		698	704	785
16.05.2019 09:29	09:29	14395,8	125,4	15,4	653	649	686		698	704	785
16.05.2019 09:29	09:29	14395,8	124,9	15,3	653	649	686		698	704	785
16.05.2019 09:29	09:29	14395,8	124,4	15,3	652	649	687		698	704	785
16.05.2019 09:30	**09:30**	**14395,8**	**176,9**	**21,7**	**648**	**647**	**687**		**697**	**706**	**787**
16.05.2019 09:30	09:30	14395,8	170,8	21,0	645	648	687		698	705	789
16.05.2019 09:30	09:30	14395,8	168,7	20,7	642	648	687		698	705	789
16.05.2019 09:30	09:30	14395,8	167,4	20,5	643	647	687		698	705	789
16.05.2019 09:30	09:30	14395,8	166,2	20,4	647	648	688		698	705	789
16.05.2019 09:30	09:30	14395,8	165,5	20,3	647	647	688		698	705	789
16.05.2019 09:31	09:31	14395,8	164,9	20,2	645	648	688		698	705	789
16.05.2019 09:31	09:31	14395,8	164,6	20,2	642	647	688		698	705	789
16.05.2019 09:31	09:31	14395,8	164,1	20,1	643	647	688		698	705	789
16.05.2019 09:31	**09:31**	**14395,8**	**214,6**	**26,3**	**635**	**648**	**688**		**698**	**706**	**791**
16.05.2019 09:31	09:31	14395,8	211,2	25,9	633	648	689		698	706	791
16.05.2019 09:31	09:31	14395,8	209,8	25,7	633	648	689		698	706	791
16.05.2019 09:32	09:32	14395,8	208,4	25,6	634	648	689		698	707	791
16.05.2019 09:32	09:32	14395,8	207,6	25,5	633	648	689		698	706	791
16.05.2019 09:32	09:32	14395,8	206,9	25,4	630	648	690		698	706	791
16.05.2019 09:32	09:32	14395,8	206,2	25,3	633	648	690		698	706	791
16.05.2019 09:32	09:32	14395,8	205,7	25,2	639	648	690		698	706	791
16.05.2019 09:32	09:32	14395,8	239	29,3	640	648	689		698	706	791
16.05.2019 09:33	**09:33**	**14395,8**	**254,1**	**31,2**	**636**	**650**	**689**		**698**	**707**	**793**
16.05.2019 09:33	09:33	14395,8	251,9	30,9	642	650	689		698	707	793
16.05.2019 09:33	09:33	14395,8	250,3	30,7	641	650	689		698	707	793
16.05.2019 09:33	09:33	14395,8	249,4	30,6	638	650	690		698	707	793
16.05.2019 09:33	09:33	14395,8	248,4	30,5	636	649	691		698	707	793
16.05.2019 09:33	09:33	14395,8	247,5	30,4	636	650	690		698	707	791
16.05.2019 09:34	09:34	14395,8	247	30,3	640	649	691		698	707	791
16.05.2019 09:34	09:34	14395,8	246,3	30,2	631	650	691		698	707	791
16.05.2019 09:34	09:34	14395,8	262,8	32,3	637	650	691		698	707	792
16.05.2019 09:34	**09:34**	**14395,8**	**295,4**	**36,3**	**637**	**651**	**690**		**698**	**707**	**793**
16.05.2019 09:34	09:34	14395,8	292,5	35,9	633	651	690		698	707	793
16.05.2019 09:34	09:34	14395,8	290,8	35,7	633	652	690		698	707	792
16.05.2019 09:35	09:35	14395,8	289,1	35,5	636	652	691		698	707	791
16.05.2019 09:35	09:35	14395,8	287,9	35,3	636	652	691		699	707	792
16.05.2019 09:35	09:35	14395,8	286,5	35,2	637	652	690		698	708	791
16.05.2019 09:35	09:35	14395,8	285,4	35,0	643	652	690		698	707	792
16.05.2019 09:35	09:35	14395,8	284,5	34,9	643	652	690		698	706	793
16.05.2019 09:35	09:35	14395,8	283,7	34,8	645	652	691		698	707	793

ν	0,2	-
Δp_{cyl}	194,5	bar
A_{piston}	0,79	m²
ΔN	15,3	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	23,9	MPa
Δs	5,0	mm
l	2077	mm
$\Delta\varepsilon$	0,002	-
E_{def}	9500	MPa

Loadstep	Time	Pressure$_{cyl.}$ [bar]		Displ.$_{left}$ [mm]				Displ.$_{right}$ [mm]				Displ.$_{mean}$ [mm]	Δs [mm]	$\Delta\varepsilon$ [-]	$\Delta\sigma_m$ [MPa]
LS1.0	09:27	94	0	655	644	685	0,0	694	703	784	0,0	0,0	0,0	0,0000	11,5
LS1.1	09:29	128	34	652	649	686	2,2	698	704	785	2,0	2,1	2,1	0,0010	15,7
LS1.2	09:30	168	40	645	647	688	0,0	698	705	789	1,6	0,8	2,9	0,0014	20,6
LS1.3	09:32	212	44	634	648	689	0,7	698	706	791	1,1	0,9	3,9	0,0019	26,0
LS1.4	09:33	251	39	637	650	690	0,9	698	707	792	0,7	0,8	4,6	0,0022	30,8
LS1.5	09:35	288	38	638	652	690	0,7	698	707	792	0,0	0,4	5,0	0,0024	35,4
			195				**4,6**				**5,5**	**5,0**			

Gripper Test 2

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
16.05.2019 11:07	**11:07**	**14397,37**	**82,7**	**10,1**	**643**	**654**	**687**		**681**	**693**	**766**
16.05.2019 11:07	11:07	14397,37	81,4	10,0	642	654	686		681	693	766
16.05.2019 11:07	11:07	14397,37	80,6	9,9	643	654	686		681	693	766
16.05.2019 11:07	11:07	14397,37	80,2	9,8	645	655	686		681	693	766
16.05.2019 11:07	11:07	14397,37	80,1	9,8	651	657	686		681	693	766
16.05.2019 11:07	11:07	14397,37	79,7	9,8	648	657	687		681	693	766
16.05.2019 11:08	11:08	14397,37	79,7	9,8	645	657	687		681	694	766
16.05.2019 11:08	11:08	14397,37	79,4	9,7	649	657	686		681	693	766
16.05.2019 11:08	11:08	14397,37	79,6	9,8	647	657	686		681	693	766
16.05.2019 11:08	11:08	14397,37	79,2	9,7	649	657	686		681	693	766
16.05.2019 11:08	**11:08**	**14397,37**	**138,6**	**17,0**	**647**	**659**	**686**		**681**	**695**	**767**
16.05.2019 11:08	11:08	14397,37	135,3	16,6	648	658	686		682	695	767
16.05.2019 11:09	11:09	14397,37	133,8	16,4	647	658	686		681	695	767
16.05.2019 11:09	11:09	14397,37	132,8	16,3	645	657	687		682	693	767
16.05.2019 11:09	11:09	14397,37	132	16,2	649	657	687		681	695	767
16.05.2019 11:09	11:09	14397,37	131,6	16,1	648	656	687		682	695	767
16.05.2019 11:09	11:09	14397,37	131,4	16,1	649	657	687		681	695	767
16.05.2019 11:09	11:09	14397,37	130,9	16,1	645	655	687		682	695	767
16.05.2019 11:10	11:10	14397,37	130,7	16,0	652	657	687		681	695	767
16.05.2019 11:10	11:10	14397,37	130,4	16,0	645	655	687		681	695	767
16.05.2019 11:10	**11:10**	**14397,37**	**176,6**	**21,7**	**648**	**657**	**687**		**683**	**695**	**768**
16.05.2019 11:10	11:10	14397,37	173,4	21,3	646	657	688		683	695	769
16.05.2019 11:10	11:10	14397,37	171,8	21,1	648	659	688		683	695	769
16.05.2019 11:10	11:10	14397,37	170,1	20,9	647	659	688		682	695	769
16.05.2019 11:11	11:11	14397,37	169,1	20,8	649	659	688		682	695	768
16.05.2019 11:11	11:11	14397,37	184,4	22,6	651	659	688		682	695	769
16.05.2019 11:11	**11:11**	**14397,37**	**213,6**	**26,2**	**652**	**660**	**689**		**683**	**695**	**769**
16.05.2019 11:11	11:11	14397,37	211,3	25,9	652	660	689		683	695	769
16.05.2019 11:11	11:11	14397,37	210	25,8	653	660	689		683	697	769
16.05.2019 11:11	11:11	14397,37	209	25,6	649	661	691		683	695	769
16.05.2019 11:12	11:12	14397,37	208,3	25,6	650	661	690		683	695	769
16.05.2019 11:12	11:12	14397,37	207,8	25,5	655	661	690		683	695	769
16.05.2019 11:12	**11:12**	**14397,37**	**256,5**	**31,5**	**645**	**662**	**690**		**684**	**697**	**770**
16.05.2019 11:12	11:12	14397,37	252,8	31,0	654	662	691		684	697	770
16.05.2019 11:12	11:12	14397,37	250,8	30,8	649	662	691		684	697	770
16.05.2019 11:12	11:12	14397,37	249,7	30,6	653	662	692		684	697	770
16.05.2019 11:13	11:13	14397,37	248,5	30,5	652	663	692		685	697	770
16.05.2019 11:13	11:13	14397,37	247,5	30,4	650	662	693		684	697	770
16.05.2019 11:13	11:13	14397,37	247	30,3	652	662	692		684	697	770
16.05.2019 11:13	11:13	14397,37	246,2	30,2	652	662	692		686	696	770
16.05.2019 11:13	11:13	14397,37	245,8	30,2	652	662	693		684	697	770
16.05.2019 11:13	**11:13**	**14397,37**	**298,8**	**36,7**	**651**	**662**	**693**		**685**	**697**	**770**
16.05.2019 11:14	11:14	14397,37	292,2	35,9	652	660	693		686	697	770
16.05.2019 11:14	11:14	14397,37	289	35,5	649	660	693		687	697	770
16.05.2019 11:14	11:14	14397,37	286,9	35,2	649	662	693		686	697	770
16.05.2019 11:14	11:14	14397,37	284,7	34,9	654	657	693		686	697	770
16.05.2019 11:14	11:14	14397,37	283,3	34,8	654	660	693		686	697	770
16.05.2019 11:14	11:14	14397,37	281,9	34,6	655	661	693		687	697	770
16.05.2019 11:15	11:15	14397,37	280,9	34,5	655	660	693		686	697	770

ν	0,2	-
Δp_{cyl}	207,0	bar
A_{piston}	0,79	m²
ΔN	16,3	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	25,4	MPa
Δs	5,0	mm
l	2077	mm
$\Delta\varepsilon$	0,002	-
E_{def}	10000	MPa

Loadstep	Time	$Pressure_{cyl.}$ [bar]		$Displ._{left}$ [mm]				$Displ._{right}$ [mm]				$Displ._{mean}$ [mm]	Δs [mm]	$\Delta\varepsilon$ [-]	$\Delta\sigma_m$ [MPa]
LS1.0	11:07	80	0	646	656	686	0,0	681	693	766	0,0	0,0	0,0	0,0000	9,8
LS1.1	11:09	133	52	648	657	687	0,9	681	695	767	1,0	1,0	1,0	0,0005	16,3
LS1.2	11:10	174	41	648	658	688	1,1	683	695	769	1,0	1,0	2,0	0,0010	21,4
LS1.3	11:11	210	36	652	661	690	2,6	683	695	769	0,4	1,5	3,5	0,0017	25,8
LS1.4	11:13	249	39	651	662	692	1,0	684	697	770	1,3	1,1	4,6	0,0022	30,6
LS1.5	11:14	287	38	652	660	693	0,2	686	697	770	0,6	0,4	5,0	0,0024	35,2
			207				**5,7**				**4,3**	**5,0**			

Gripper Test 3

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
16.05.2019 16:12	**16:12**	**14400,84**	**98**	**12,0**	**666**	**654**	**721**		**661**	**672**	**753**
16.05.2019 16:13	16:13	14400,84	91,4	11,2	662	653	721		656	673	756
16.05.2019 16:13	16:13	14400,84	88,8	10,9	660	653	721		662	673	756
16.05.2019 16:13	16:13	14400,84	87,3	10,7	669	656	721		662	673	756
16.05.2019 16:13	16:13	14400,84	86,3	10,6	670	657	722		662	673	756
16.05.2019 16:13	16:13	14400,84	85,5	10,5	667	658	722		661	674	756
16.05.2019 16:13	16:13	14400,84	85,2	10,5	662	662	722		661	673	756
16.05.2019 16:14	16:14	14400,84	84,7	10,4	659	665	722		658	674	756
16.05.2019 16:14	16:14	14400,84	84,3	10,3	664	666	722		659	674	756
16.05.2019 16:14	**16:14**	**14400,84**	**135,1**	**16,6**	**664**	**668**	**724**		**659**	**676**	**758**
16.05.2019 16:14	16:14	14400,84	132	16,2	664	670	724		658	676	758
16.05.2019 16:14	16:14	14400,84	130,4	16,0	666	669	724		658	676	758
16.05.2019 16:14	16:14	14400,84	129,4	15,9	669	670	724		658	676	758
16.05.2019 16:15	16:15	14400,84	128,7	15,8	670	667	724		658	676	758
16.05.2019 16:15	16:15	14400,84	127,9	15,7	673	665	725		658	676	758
16.05.2019 16:15	**16:15**	**14400,84**	**178,7**	**21,9**	**672**	**662**	**725**		**659**	**678**	**760**
16.05.2019 16:15	16:15	14400,84	174,9	21,5	673	662	725		658	678	760
16.05.2019 16:15	16:15	14400,84	173,1	21,2	675	662	725		658	678	760
16.05.2019 16:15	16:15	14400,84	172	21,1	663	660	725		660	678	760
16.05.2019 16:16	16:16	14400,84	171,1	21,0	664	660	725		659	678	760
16.05.2019 16:16	16:16	14400,84	170,3	20,9	660	660	725		659	678	760
16.05.2019 16:16	16:16	14400,84	169,8	20,8	655	660	725		658	678	760
16.05.2019 16:16	16:16	14400,84	169,1	20,8	658	658	725		659	678	760
16.05.2019 16:16	16:16	14400,84	168,9	20,7	660	658	725		659	678	760
16.05.2019 16:16	**16:16**	**14400,84**	**219,9**	**27,0**	**677**	**658**	**727**		**659**	**678**	**762**
16.05.2019 16:17	16:17	14400,84	215,6	26,5	670	658	727		661	679	761
16.05.2019 16:17	16:17	14400,84	213,6	26,2	666	656	727		659	679	762
16.05.2019 16:17	16:17	14400,84	212,5	26,1	670	657	727		659	679	762
16.05.2019 16:17	16:17	14400,84	211,5	26,0	670	656	727		659	679	762
16.05.2019 16:17	16:17	14400,84	210,8	25,9	666	656	727		659	679	762
16.05.2019 16:17	16:17	14400,84	210,2	25,8	665	658	727		661	679	762
16.05.2019 16:18	16:18	14400,84	209,5	25,7	665	659	727		661	679	762
16.05.2019 16:18	16:18	14400,84	209,2	25,7	663	660	727		659	679	762
16.05.2019 16:18	16:18	14400,84	208,6	25,6	665	662	727		661	679	762
16.05.2019 16:18	**16:18**	**14400,84**	**258,7**	**31,7**	**665**	**661**	**727**		**666**	**680**	**762**
16.05.2019 16:18	16:18	14400,84	255	31,3	671	661	728		666	680	762
16.05.2019 16:18	16:18	14400,84	253,5	31,1	670	660	728		666	679	762
16.05.2019 16:19	16:19	14400,84	252,3	31,0	664	660	728		666	680	762
16.05.2019 16:19	16:19	14400,84	251,3	30,8	657	660	728		666	679	761
16.05.2019 16:19	16:19	14400,84	250,4	30,7	662	660	728		666	679	762
16.05.2019 16:19	16:19	14400,84	249,7	30,6	660	660	728		666	679	762
16.05.2019 16:19	16:19	14400,84	249,2	30,6	659	660	728		666	679	762
16.05.2019 16:19	16:19	14400,84	248,4	30,5	663	660	728		666	680	761
16.05.2019 16:20	**16:20**	**14400,84**	**296,6**	**36,4**	**665**	**662**	**730**		**668**	**680**	**762**
16.05.2019 16:20	16:20	14400,84	293,6	36,0	665	660	731		668	681	762
16.05.2019 16:20	16:20	14400,84	291,5	35,8	660	662	731		668	680	762
16.05.2019 16:20	16:20	14400,84	289,5	35,5	666	662	731		668	680	762
16.05.2019 16:20	16:20	14400,84	288,1	35,4	669	664	731		668	680	762
16.05.2019 16:20	16:20	14400,84	286,9	35,2	673	665	731		668	680	762
16.05.2019 16:21	16:21	14400,84	285,4	35,0	671	663	731		668	680	761
16.05.2019 16:21	16:21	14400,84	284,4	34,9	673	665	731		668	681	761

ν	0,2	-
Δp_{cyl}	201,6	bar
A_{piston}	0,79	m²
ΔN	15,8	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	24,7	MPa
Δs	5,0	mm
l	2077	mm
$\Delta\varepsilon$	0,002	-
E_{def}	9800	MPa

Loadstep	Time	Pressure$_{cyl.}$ [bar]		Displ.$_{left}$ [mm]				Displ.$_{right}$ [mm]				Displ.$_{mean}$ [mm]	Δs [mm]	$\Delta\varepsilon$ [-]	$\Delta\sigma_m$ [MPa]
LS1.0	16:13	88	0	664	658	722	0,0	660	673	756	0,0	0,0	0,0	0,0000	10,8
LS1.1	16:14	131	43	668	668	724	0,9	658	676	758	1,0	0,9	0,9	0,0005	16,0
LS1.2	16:16	172	41	664	660	725	0,3	659	678	760	1,5	0,9	1,9	0,0009	21,1
LS1.3	16:17	212	40	668	658	727	0,7	660	679	762	1,3	1,0	2,8	0,0014	26,0
LS1.4	16:19	252	40	663	660	728	0,3	666	679	762	2,2	1,3	4,1	0,0020	30,9
LS1.5	16:20	290	37	668	663	731	1,0	668	680	762	0,9	1,0	5,0	0,0024	35,5
			202				**3,1**				**7,0**	**5,0**			

Gripper Test 4

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
17.05.2019 15:37	**15:37**	**14416,28**	**101,7**	**12,5**	**658**	**655**	**720**		**667**	**676**	**767**
17.05.2019 15:37	15:37	14416,28	98,7	12,1	656	655	721		668	678	767
17.05.2019 15:37	15:37	14416,28	97,5	12,0	657	655	721		668	676	767
17.05.2019 15:38	15:38	14416,28	96,8	11,9	656	655	721		667	678	767
17.05.2019 15:38	15:38	14416,28	96,3	11,8	658	655	721		666	678	767
17.05.2019 15:38	15:38	14416,28	96	11,8	658	655	721		666	677	767
17.05.2019 15:38	15:38	14416,28	95,8	11,8	658	654	722		667	678	767
17.05.2019 15:38	15:38	14416,28	95,4	11,7	658	654	722		666	677	768
17.05.2019 15:38	15:38	14416,28	95,1	11,7	658	654	722		667	677	767
17.05.2019 15:39	15:39	14416,28	94,8	11,6	658	654	722		668	678	767
17.05.2019 15:39	**15:39**	**14416,28**	**135**	**16,6**	**658**	**655**	**722**		**670**	**679**	**769**
17.05.2019 15:39	15:39	14416,28	133	16,3	658	655	722		669	679	769
17.05.2019 15:39	15:39	14416,28	132	16,2	659	656	722		670	679	769
17.05.2019 15:39	15:39	14416,28	131,2	16,1	658	656	722		670	679	769
17.05.2019 15:39	15:39	14416,28	130,7	16,0	658	657	722		670	679	769
17.05.2019 15:40	15:40	14416,28	130	16,0	658	656	722		670	678	769
17.05.2019 15:40	**15:40**	**14416,28**	**176,9**	**21,7**	**658**	**656**	**724**		**670**	**682**	**769**
17.05.2019 15:40	15:40	14416,28	174,1	21,4	658	656	724		668	683	769
17.05.2019 15:40	15:40	14416,28	172,5	21,2	658	657	725		669	683	769
17.05.2019 15:40	15:40	14416,28	171,3	21,0	658	657	725		670	682	770
17.05.2019 15:40	15:40	14416,28	170,8	21,0	658	657	725		670	682	770
17.05.2019 15:41	15:41	14416,28	170,3	20,9	658	657	725		670	683	769
17.05.2019 15:41	15:41	14416,28	170	20,9	658	657	725		670	683	769
17.05.2019 15:41	**15:41**	**14416,28**	**216,1**	**26,5**	**658**	**658**	**725**		**673**	**683**	**771**
17.05.2019 15:41	15:41	14416,28	213,6	26,2	658	659	727		670	683	771
17.05.2019 15:41	15:41	14416,28	212,4	26,1	658	659	727		670	683	772
17.05.2019 15:41	15:41	14416,28	211,5	26,0	658	659	727		670	683	771
17.05.2019 15:42	15:42	14416,28	210,7	25,9	658	659	727		669	683	771
17.05.2019 15:42	15:42	14416,28	210,3	25,8	658	659	727		668	683	772
17.05.2019 15:42	15:42	14416,28	209,7	25,7	658	659	727		669	683	772
17.05.2019 15:42	**15:42**	**14416,28**	**259,1**	**31,8**	**659**	**659**	**727**		**669**	**683**	**771**
17.05.2019 15:42	15:42	14416,28	255,9	31,4	660	660,000	727		669	684	771
17.05.2019 15:42	15:42	14416,28	254	31,2	660	660	727		669	684	772
17.05.2019 15:43	15:43	14416,28	253	31,0	660	660	726		669	684	771
17.05.2019 15:43	15:43	14416,28	251,9	30,9	660	660	726		669	684	772
17.05.2019 15:43	15:43	14416,28	251,3	30,8	660	660	727		669	684	772
17.05.2019 15:43	15:43	14416,28	250,8	30,8	660	660	727		668	684	771
17.05.2019 15:43	**15:43**	**14416,28**	**296,6**	**36,4**	**659**	**661**	**727**		**669**	**683**	**772**
17.05.2019 15:43	15:43	14416,28	295,9	36,3	659	661	727		669	684	772
17.05.2019 15:44	15:44	14416,28	293,4	36,0	659	661	727		669	684	772
17.05.2019 15:44	15:44	14416,28	291,8	35,8	660	661	727		668	684	771
17.05.2019 15:44	15:44	14416,28	290	35,6	659	661	727		668	684	772
17.05.2019 15:44	15:44	14416,28	289	35,5	660	661	727		669	684	771
17.05.2019 15:44	15:44	14416,28	288,3	35,4	660	661	727		668	684	772

ν	0,2	-
Δp_{cyl}	195,3	bar
A_{piston}	0,79	m²
ΔN	15,3	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	24,0	MPa
Δs	4,5	mm
l	2077	mm
$\Delta\varepsilon$	0,002	-
E_{def}	10700	MPa

Loadstep	Time	Pressure$_{cyl.}$ [bar]		Displ.$_{left}$ [mm]				Displ.$_{right}$ [mm]				Displ.$_{mean}$ [mm]	Δs [mm]	$\Delta\varepsilon$ [-]	$\Delta\sigma_m$ [MPa]
LS1.0	15:38	97	0	658	655	721	0,0	667	677	767	0,0	0,0	0,0	0,0000	11,9
LS1.1	15:39	132	35	658	656	722	0,9	670	679	769	2,1	1,5	1,5	0,0007	16,2
LS1.2	15:40	172	40	658	657	725	1,1	670	683	769	1,3	1,2	2,7	0,0013	21,1
LS1.3	15:41	212	40	658	659	727	1,4	670	683	771	1,0	1,2	3,8	0,0018	26,0
LS1.4	15:43	254	42	660	660	727	1,0	669	684	771	0,0	0,5	4,3	0,0021	31,1
LS1.5	15:44	292	38	659	661	727	0,3	669	684	772	0,0	0,2	4,5	0,0021	35,9
			195				**4,7**				**4,2**	**4,5**			

Gripper Test 5

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
18.05.2019 18:02	**18:02**	**14431,97**	**93**	**11,4**	**667**	**667**	**725**		**648**	**669**	**745**
18.05.2019 18:03	18:03	14431,97	90,3	11,1	667	667	725		648	670	746
18.05.2019 18:03	18:03	14431,97	88,8	10,9	667	668	725		648	670	746
18.05.2019 18:03	18:03	14431,97	87,9	10,8	667	668	726		648	670	747
18.05.2019 18:03	18:03	14431,97	87,3	10,7	667	668	727		648	671	746
18.05.2019 18:03	18:03	14431,97	86,8	10,7	667	668	726		648	671	747
18.05.2019 18:03	18:03	14431,97	86,4	10,6	667	670	726		648	671	746
18.05.2019 18:04	**18:04**	**14431,97**	**135,5**	**16,6**	**669**	**671**	**726**		**649**	**671**	**748**
18.05.2019 18:04	18:04	14431,97	133,1	16,3	669	671	726		649	672	748
18.05.2019 18:04	18:04	14431,97	131,8	16,2	669	672	726		652	671	748
18.05.2019 18:04	18:04	14431,97	131	16,1	669	672	726		655	672	748
18.05.2019 18:04	18:04	14431,97	130,4	16,0	669	672	727		656	672	748
18.05.2019 18:04	18:04	14431,97	129,9	15,9	669	672	727		656	672	748
18.05.2019 18:05	18:05	14431,97	129,4	15,9	670	672	727		656	672	748
18.05.2019 18:05	18:05	14431,97	129,4	15,9	670	672	727		656	672	748
18.05.2019 18:05	**18:05**	**14431,97**	**175,6**	**21,5**	**669**	**672**	**727**		**656**	**673**	**748**
18.05.2019 18:05	18:05	14431,97	173,6	21,3	669	674	727		656	673	748
18.05.2019 18:05	18:05	14431,97	172,5	21,2	669	674	727		656	673	748
18.05.2019 18:06	18:06	14431,97	171,8	21,1	669	675	727		656	673	748
18.05.2019 18:06	18:06	14431,97	171,1	21,0	669	675	727		656	673	748
18.05.2019 18:06	**18:06**	**14431,97**	**219**	**26,9**	**669**	**672**	**727**		**658**	**673**	**748**
18.05.2019 18:06	18:06	14431,97	215,9	26,5	669	675	727		658	673	748
18.05.2019 18:06	18:06	14431,97	214,1	26,3	669	675	727		658	673	748
18.05.2019 18:06	18:06	14431,97	212,9	26,1	669	675	727		658	674	748
18.05.2019 18:07	18:07	14431,97	212,2	26,0	669	675	727		658	674	748
18.05.2019 18:07	**18:07**	**14431,97**	**259**	**31,8**	**670**	**674**	**727**		**659**	**673**	**749**
18.05.2019 18:07	18:07	14431,97	255,7	31,4	670	675	727		659	674	750
18.05.2019 18:07	18:07	14431,97	254	31,2	670	676	727		659	673	749
18.05.2019 18:07	18:07	14431,97	253,1	31,1	670	676	727		659	674	749
18.05.2019 18:07	18:07	14431,97	252,3	31,0	670	676	727		661	674	751
18.05.2019 18:08	**18:08**	**14431,97**	**299,2**	**36,7**	**672**	**675**	**727**		**661**	**673**	**749**
18.05.2019 18:08	18:08	14431,97	295,6	36,3	673	676	727		661	673	749
18.05.2019 18:08	18:08	14431,97	292,9	35,9	673	676	727		661	673	749
18.05.2019 18:08	18:08	14431,97	291	35,7	673	676	727		661	673	749

ν	0,2	-
Δp_{cyl}	206,0	bar
A_{piston}	0,79	m²
ΔN	16,2	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	25,3	MPa
Δs	5,6	mm
l	2077	mm
$\Delta\varepsilon$	0,0027	-
E_{def}	9100	MPa

Loadstep	Time	Pressure$_{cyl.}$ [bar]		Displ.$_{left}$ [mm]				Displ.$_{right}$ [mm]				Displ.$_{mean}$ [mm]	Δs [mm]	$\Delta\varepsilon$ [-]	$\Delta\sigma_m$ [MPa]
LS1.0	18:03	89	0	667	668	726	0,0	648	670	746	0,0	0,0	0,0	0,0000	10,9
LS1.1	18:04	131	43	669	672	727	2,3	654	672	748	3,0	2,6	2,6	0,0013	16,1
LS1.2	18:05	173	42	669	674	727	0,8	656	673	748	1,2	1,0	3,6	0,0018	21,2
LS1.3	18:06	215	42	669	674	727	0,1	658	673	748	0,8	0,5	4,1	0,0020	26,4
LS1.4	18:07	255	40	670	675	727	0,7	659	674	750	1,1	0,9	5,0	0,0024	31,3
LS1.5	18:08	295	40	673	676	727	1,0	661	673	749	0,1	0,6	5,6	0,0027	36,2
			206				**4,9**				**6,2**	**5,6**			

Gripper Test 6

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
20.05.2019 09:09	**09:09**	**14459,38**	**96,3**	**11,8**	**688**	**714**	**762**		**635**	**639**	**710**
20.05.2019 09:10	09:10	14459,38	95,1	11,7	688	714	762		635	639	710
20.05.2019 09:10	09:10	14459,38	94,6	11,6	688	714	762		636	639	710
20.05.2019 09:10	09:10	14459,38	94,3	11,6	688	713	762		635	639	710
20.05.2019 09:10	**09:10**	**14459,38**	**138,6**	**17,0**	**690**	**715**	**764**		**637**	**639**	**709**
20.05.2019 09:10	09:10	14459,38	136,4	16,7	690	714	764		637	639	709
20.05.2019 09:10	09:10	14459,38	135,6	16,6	690	713	764		636	639	709
20.05.2019 09:11	09:11	14459,38	135,1	16,6	691	714	764		636	640	709
20.05.2019 09:11	09:11	14459,38	134,8	16,5	691	714	764		636	639	709
20.05.2019 09:11	09:11	14459,38	134,5	16,5	691	713	764		636	639	709
20.05.2019 09:11	**09:11**	**14459,38**	**179,7**	**22,1**	**693**	**715**	**761**		**637**	**642**	**710**
20.05.2019 09:11	09:11	14459,38	178	21,8	693	715	761		637	641	710
20.05.2019 09:11	09:11	14459,38	177,3	21,8	693	715	761		636	642	710
20.05.2019 09:12	09:12	14459,38	176,8	21,7	693	715	761		636	641	710
20.05.2019 09:12	**09:12**	**14459,38**	**101,1**	**12,4**	**684**	**712**	**763**		**638**	**642**	**711**
20.05.2019 09:12	09:12	14459,38	99,9	12,3	686	712	763		639	642	712
20.05.2019 09:12	09:12	14459,38	99,4	12,2	684	712	764		638	642	711
20.05.2019 09:13	09:13	14459,38	99,2	12,2	684	712	763		638	641	712
20.05.2019 09:13	**09:13**	**14459,38**	**142,3**	**17,5**	**688**	**713**	**763**		**639**	**643**	**711**
20.05.2019 09:13	09:13	14459,38	140,8	17,3	690	712	763		638	643	711
20.05.2019 09:13	09:13	14459,38	140	17,2	690	711	762		638	643	711
20.05.2019 09:13	09:13	14459,38	139,8	17,2	690	712	762		638	643	711
20.05.2019 09:13	09:13	14459,38	139,7	17,1	690	712	762		638	643	711
20.05.2019 09:14	**09:14**	**14459,38**	**181,3**	**22,2**	**693**	**713**	**760**		**638**	**644**	**712**
20.05.2019 09:14	09:14	14459,38	180	22,1	693	713	760		638	643	712
20.05.2019 09:14	09:14	14459,38	179,3	22,0	693	714	760		637	643	712
20.05.2019 09:14	09:14	14459,38	179	22,0	693	713	760		637	644	712
20.05.2019 09:14	09:14	14459,38	178,8	21,9	693	713	760		637	644	712
20.05.2019 09:14	**09:14**	**14459,38**	**219,9**	**27,0**	**694**	**715**	**760**		**637**	**644**	**713**
20.05.2019 09:15	09:15	14459,38	218,2	26,8	694	715	760		637	644	714
20.05.2019 09:15	09:15	14459,38	217,5	26,7	694	714	760		637	644	713
20.05.2019 09:15	09:15	14459,38	216,9	26,6	694	715	761		637	644	714
20.05.2019 09:15	09:15	14459,38	216,6	26,6	695	715	760		637	644	713
20.05.2019 09:15	**09:15**	**14459,38**	**259,5**	**31,8**	**694**	**716**	**760**		**637**	**645**	**714**
20.05.2019 09:15	09:15	14459,38	257,4	31,6	694	716	761		637	645	714
20.05.2019 09:16	09:16	14459,38	256,4	31,5	694	716	761		637	645	715
20.05.2019 09:16	09:16	14459,38	255,5	31,4	694	716	760		637	645	714
20.05.2019 09:16	09:16	14459,38	255	31,3	694	716	760		637	645	714
20.05.2019 09:16	**09:16**	**14459,38**	**102,5**	**12,6**	**687**	**711**	**761**		**637**	**646**	**714**
20.05.2019 09:17	09:17	14459,38	100,5	12,3	686	710	761		637	646	714
20.05.2019 09:17	09:17	14459,38	99,9	12,3	686	710	762		638	645	714
20.05.2019 09:17	09:17	14459,38	99,5	12,2	686	710	761		637	646	714
20.05.2019 09:17	**09:17**	**14459,38**	**141,8**	**17,4**	**690**	**713**	**762**		**639**	**645**	**713**
20.05.2019 09:17	09:17	14459,38	140,3	17,2	691	712	762		639	646	714
20.05.2019 09:17	09:17	14459,38	139,8	17,2	692	711	761		638	649	713
20.05.2019 09:18	09:18	14459,38	139,6	17,1	691	712	761		638	645	714
20.05.2019 09:18	**09:18**	**14459,38**	**182,4**	**22,4**	**694**	**713**	**760**		**639**	**646**	**714**
20.05.2019 09:18	09:18	14459,38	180,7	22,2	694	713	760		639	647	715
20.05.2019 09:18	09:18	14459,38	180,2	22,1	694	713	761		639	647	714
20.05.2019 09:18	09:18	14459,38	180	22,1	694	713	761		639	646	714
20.05.2019 09:18	09:18	14459,38	179,7	22,1	694	713	760		639	647	714
20.05.2019 09:19	09:19	14459,38	179,3	22,0	694	713	761		639	646	714
20.05.2019 09:19	**09:19**	**14459,38**	**221,1**	**27,1**	**695**	**714**	**760**		**639**	**646**	**714**
20.05.2019 09:19	09:19	14459,38	220,2	27,0	694	714	760		639	646	716
20.05.2019 09:19	09:19	14459,38	219,7	27,0	694	714	760		639	647	715
20.05.2019 09:19	09:19	14459,38	219,4	26,9	695	714	760		639	647	715
20.05.2019 09:19	09:19	14459,38	218,9	26,9	694	714	760		639	646	716
20.05.2019 09:20	**09:20**	**14459,38**	**261,3**	**32,1**	**695**	**716**	**760**		**639**	**646**	**716**
20.05.2019 09:20	09:20	14459,38	259,3	31,8	694	716	760		639	647	716
20.05.2019 09:20	09:20	14459,38	258,6	31,7	694	716	760		639	647	716
20.05.2019 09:20	09:20	14459,38	258,2	31,7	694	716	760		639	647	716
20.05.2019 09:20	09:20	14459,38	257,7	31,6	694	716	760		639	647	716
20.05.2019 09:20	09:20	14459,38	257	31,5	694	715	760		638	647	716

20.05.2019 09:21	**09:21**	**14459,38**	**299,5**	**36,8**	**696**	**716**	**759**		**637**	**647**	**718**
20.05.2019 09:21	09:21	14459,38	295,2	36,2	696	716	759		637	647	718
20.05.2019 09:21	09:21	14459,38	292	35,8	696	716	759		637	647	718
20.05.2019 09:21	09:21	14459,38	289	35,5	696	716	759		637	647	717
20.05.2019 09:21	09:21	14459,38	286,5	35,2	697	716	759		637	646	718

Loadstep	**Time**	**Pressure$_{cyl.}$ [bar]**		**Displ.$_{left}$ [mm]**				**Displ.$_{right}$ [mm]**				**Displ.$_{mean}$ [mm]**	**Δs [mm]**	**Δε [-]**	**$\Delta\sigma_m$ [MPa]**
LS1.0		95	0	688	714	762	0,0	635	639	710	0,0	0,0	0,0	0,0000	11,7
LS1.1		136	41	691	714	764	1,5	636	639	709	0,1	0,8	0,8	0,0004	16,7
LS1.2		178	42	693	715	761	0,2	637	642	710	1,2	0,7	1,5	0,0007	21,8
			83				**1,8**				**1,3**	**1,5**			
LS2.0		100	0	685	712	763	0,0	638	642	712	0,0	0,0	0,0	0,0000	12,3
LS2.1		141	41	690	712	762	1,4	638	643	711	0,2	0,8	0,8	0,0004	17,2
LS2.2		180	39	693	713	760	0,7	637	644	712	0,3	0,5	1,3	0,0006	22,1
LS2.3		218	38	694	715	760	1,0	637	644	713	0,5	0,7	2,1	0,0010	26,7
LS2.4		257	39	694	716	760	0,4	637	645	714	0,6	0,5	2,6	0,0012	31,5
			157				**3,5**				**1,6**	**2,6**			
LS3.0		101	0	686	710	761	0,0	637	646	714	0,0	0,0	0,0	0,0000	12,3
LS3.1		140	40	691	712	762	2,3	639	646	714	0,4	1,3	1,3	0,0006	17,2
LS3.2		180	40	694	713	761	1,0	639	647	714	0,5	0,7	2,1	0,0010	22,1
LS3.3		220	39	694	714	760	0,3	639	646	715	0,3	0,3	2,4	0,0011	27,0
LS3.4		259	39	694	716	760	0,5	639	647	716	0,4	0,4	2,8	0,0014	31,7
LS3.5		292	34	696	716	759	0,4	637	647	718	0,0	0,2	3,0	0,0014	35,9
			192				**4,5**				**1,5**	**3,0**			

ν	0,2	-
Δp_{cyl}	82,9	bar
A_{piston}	0,79	m²
ΔN	6,5	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	10,2	MPa
Δs	1,5	mm
l	2077	mm
Δε	0,001	-
E_{def}	13500	MPa

ν	0,2	-
Δp_{cyl}	156,9	bar
A_{piston}	0,79	m²
ΔN	12,3	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	19,2	MPa
Δs	2,6	mm
l	2077	mm
Δε	0,001	-
E_{def}	15000	MPa

ν	0,2	-
Δp_{cyl}	191,8	bar
A_{piston}	0,79	m²
ΔN	15,1	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	23,5	MPa
Δs	3,0	mm
l	2077	mm
Δε	0,001	-
E_{def}	15600	MPa

Gripper Test 7

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
20.05.2019 13:55	**13:55**	**14462,78**	**100,5**	**12,3**	**682**	**685**	**741**		**643**	**669**	**740**
20.05.2019 13:55	13:55	14462,78	98	12,0	683	685	741		642	669	743
20.05.2019 13:55	13:55	14462,78	96,8	11,9	683	685	741		641	669	743
20.05.2019 13:55	13:55	14462,78	96,8	11,9	683	685	741		641	670	743
20.05.2019 13:55	13:55	14462,78	96,3	11,8	683	685	741		641	670	742
20.05.2019 13:56	13:56	14462,78	96,3	11,8	683	685	741		642	670	743
20.05.2019 13:56	**13:56**	**14462,78**	**140**	**17,2**	**685**	**687**	**741**		**643**	**670**	**742**
20.05.2019 13:56	13:56	14462,78	138,6	17,0	685	687	740		643	670	742
20.05.2019 13:56	13:56	14462,78	138,4	17,0	684	686	740		643	670	740
20.05.2019 13:56	13:56	14462,78	138,1	16,9	685	686	740		643	670	742
20.05.2019 13:56	**13:56**	**14462,78**	**181,5**	**22,3**	**682**	**687**	**740**		**648**	**670**	**742**
20.05.2019 13:57	13:57	14462,78	179,8	22,1	683	688	740		647	670	742
20.05.2019 13:57	13:57	14462,78	178,8	21,9	683	687	740		647	670	742
20.05.2019 13:57	13:57	14462,78	178,5	21,9	683	687	740		649	670	742
20.05.2019 13:57	13:57	14462,78	178,2	21,9	684	687	740		643	669	742
20.05.2019 13:57	**13:57**	**14462,78**	**219,4**	**26,9**	**686**	**689**	**741**		**643**	**670**	**744**
20.05.2019 13:57	13:57	14462,78	218,4	26,8	686	689	741		643	670	743
20.05.2019 13:58	13:58	14462,78	217,5	26,7	686	689	740		643	670	743
20.05.2019 13:58	13:58	14462,78	216,9	26,6	686	689	741		643	670	743
20.05.2019 13:58	13:58	14462,78	216,8	26,6	686	689	741		643	670	743
20.05.2019 13:58	13:58	14462,78	216,4	26,6	686	689	740		643	671	743
20.05.2019 13:58	13:58	14462,78	216,1	26,5	686	689	741		643	671	743
20.05.2019 13:58	13:58	14462,78	215,6	26,5	686	689	740		643	670	743
20.05.2019 13:59	**13:59**	**14462,78**	**258,8**	**31,8**	**687**	**691**	**741**		**643**	**671**	**743**
20.05.2019 13:59	13:59	14462,78	257,6	31,6	688	691	741		643	671	743
20.05.2019 13:59	13:59	14462,78	256,5	31,5	688	691	741		643	670	743
20.05.2019 13:59	13:59	14462,78	256	31,4	688	691	741		643	671	743
20.05.2019 13:59	13:59	14462,78	255,5	31,4	688	691	741		643	670	743
20.05.2019 13:59	13:59	14462,78	255	31,3	688	691	741		643	670	743
20.05.2019 14:00	**14:00**	**14462,78**	**298,5**	**36,6**	**687**	**692**	**744**		**643**	**670**	**743**
20.05.2019 14:00	14:00	14462,78	296,3	36,4	687	692	744		644	670	743
20.05.2019 14:00	14:00	14462,78	294,9	36,2	688	692	744		644	670	743
20.05.2019 14:00	14:00	14462,78	293,7	36,0	688	692	744		645	670	743
20.05.2019 14:00	14:00	14462,78	292,2	35,9	688	692	744		649	670	743
20.05.2019 14:00	14:00	14462,78	291	35,7	688	692	744		647	670	743
20.05.2019 14:01	14:01	14462,78	289,8	35,6	688	692	744		647	670	743

ν	0,2	-
Δp_{cyl}	196,3	bar
A_{piston}	0,79	m²
ΔN	15,4	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	24,1	MPa
Δs	3,9	mm
l	2077	mm
$\Delta\varepsilon$	0,002	-
E_{def}	12300	MPa

Loadstep	Time	$Pressure_{cyl.}$ [bar]		$Displ._{left}$ [mm]				$Displ._{right}$ [mm]				$Displ._{mean}$ [mm]	Δs [mm]	$\Delta\varepsilon$ [-]	$\Delta\sigma_m$ [MPa]
LS1.0	13:55	97	0	683	685	741	0,0	642	670	742	0,0	0,0	0,0	0,0000	12,0
LS1.1	13:56	139	41	685	687	740	0,9	643	670	742	0,3	0,6	0,6	0,0003	17,0
LS1.2	13:57	179	41	683	687	740	0,0	647	670	742	1,4	0,7	1,3	0,0006	22,0
LS1.3	13:58	217	38	686	689	741	1,8	643	670	743	0,0	0,9	2,2	0,0011	26,6
LS1.4	13:59	257	39	688	691	741	1,4	643	671	743	0,0	0,7	2,9	0,0014	31,5
LS1.5	14:00	294	37	688	692	744	1,3	646	670	743	0,7	1,0	3,9	0,0019	36,1
			196				**5,4**				**2,4**	**3,9**			

Gripper Test 8

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
20.05.2019 16:01	**16:01**	**14466,09**	**83,2**	**10,2**	**657**	**666**	**711**		**670**	**693**	**765**
20.05.2019 16:01	16:01	14466,09	85	10,4	659	667	710		670	693	764
20.05.2019 16:01	16:01	14466,09	84,2	10,3	659	668	710		672	693	763
20.05.2019 16:01	16:01	14466,09	83,5	10,2	660	668	710		672	693	763
20.05.2019 16:02	16:02	14466,09	83,2	10,2	659	668	710		673	693	765
20.05.2019 16:02	**16:02**	**14466,09**	**139,6**	**17,1**	**660**	**668**	**711**		**674**	**693**	**764**
20.05.2019 16:02	16:02	14466,09	137,9	16,9	660	669	711		674	693	764
20.05.2019 16:02	16:02	14466,09	136,9	16,8	660	669	711		675	693	765
20.05.2019 16:02	16:02	14466,09	136,4	16,7	660	669	711		674	693	764
20.05.2019 16:02	16:02	14466,09	135,9	16,7	660	670	711		674	693	765
20.05.2019 16:03	16:03	14466,09	135,6	16,6	660	669	711		675	693	765
20.05.2019 16:03	16:03	14466,09	135,3	16,6	660	670	711		675	693	766
20.05.2019 16:03	**16:03**	**14466,09**	**181,3**	**22,2**	**659**	**671**	**714**		**675**	**693**	**767**
20.05.2019 16:03	16:03	14466,09	178,7	21,9	659	671	713		675	693	767
20.05.2019 16:03	16:03	14466,09	177,3	21,8	658	671	713		675	693	767
20.05.2019 16:04	16:04	14466,09	176,8	21,7	660	671	714		675	693	768
20.05.2019 16:04	16:04	14466,09	176,2	21,6	660	671	714		675	693	770
20.05.2019 16:04	16:04	14466,09	175,9	21,6	660	671	715		676	693	771
20.05.2019 16:04	**16:04**	**14466,09**	**217,2**	**26,7**	**662**	**671**	**715**		**677**	**693**	**767**
20.05.2019 16:04	16:04	14466,09	215,6	26,5	664	671	715		676	693	766
20.05.2019 16:05	16:05	14466,09	214,4	26,3	663	671	716		675	693	766
20.05.2019 16:05	16:05	14466,09	213,9	26,2	663	671	715		675	693	766
20.05.2019 16:05	16:05	14466,09	213,4	26,2	663	671	715		675	693	766
20.05.2019 16:05	**16:05**	**14466,09**	**258,2**	**31,7**	**662**	**671**	**717**		**676**	**695**	**772**
20.05.2019 16:05	16:05	14466,09	256,4	31,5	662	672	717		676	694	772
20.05.2019 16:05	16:05	14466,09	255	31,3	662	672	717		676	695	772
20.05.2019 16:06	16:06	14466,09	254,1	31,2	662	672	717		675	695	767
20.05.2019 16:06	16:06	14466,09	253,5	31,1	662	672	717		675	695	771
20.05.2019 16:06	**16:06**	**14466,09**	**297,5**	**36,5**	**660**	**672**	**717**		**675**	**695**	**772**
20.05.2019 16:06	16:06	14466,09	292,5	35,9	661	673	717		675	694	773
20.05.2019 16:06	16:06	14466,09	289	35,5	661	673	717		677	694	772
20.05.2019 16:06	16:06	14466,09	286,5	35,2	660	674	717		675	694	772
20.05.2019 16:07	16:07	14466,09	284,4	34,9	661	674	717		677	694	772

ν	0,2	-
Δp_{cyl}	206,2	bar
A_{piston}	0,79	m²
ΔN	16,2	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	25,3	MPa
Δs	5,0	mm
l	2077	mm
$\Delta\varepsilon$	0,002	-
E_{def}	10100	MPa

Loadstep	Time	Pressure$_{cyl.}$ [bar]		Displ.$_{left}$ [mm]				Displ.$_{right}$ [mm]				Displ.$_{mean}$ [mm]	Δs [mm]	$\Delta\varepsilon$ [-]	$\Delta\sigma_m$ [MPa]
LS1.0	16:01	84	0	659	667	710	0,0	671	693	764	0,0	0,0	0,0	0,0000	10,3
LS1.1	16:02	137	53	660	669	711	1,2	674	693	765	1,2	1,2	1,2	0,0006	16,8
LS1.2	16:03	178	41	659	671	714	1,3	675	693	768	1,5	1,4	2,6	0,0013	21,8
LS1.3	16:05	215	37	663	671	715	1,7	676	693	766	0,0	0,8	3,5	0,0017	26,4
LS1.4	16:05	255	41	662	672	717	0,5	676	695	771	2,1	1,3	4,8	0,0023	31,3
LS1.5	16:06	290	35	661	673	717	0,0	676	694	772	0,3	0,2	5,0	0,0024	35,6
			206				**4,8**				**5,2**	**5,0**			

Gripper Test 9

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
23.05.2019 01:46	**01:46**	**14484,31**	**102,5**	**1,5**	**663**	**667**	**722**		**668**	**686**	**772**
23.05.2019 01:46	01:46	14484,31	100,4	1,4	663	668	722		669	687	772
23.05.2019 01:46	01:46	14484,31	99,2	1,4	663	669	722		669	687	772
23.05.2019 01:46	01:46	14484,31	98,7	1,4	662	670	722		669	687	772
23.05.2019 01:46	01:46	14484,31	98,4	1,4	662	670	722		669	687	772
23.05.2019 01:46	01:46	14484,31	98	1,4	663	668	722		669	686	772
23.05.2019 01:47	**01:47**	**14484,31**	**136,6**	**2,0**	**665**	**669**	**722**		**670**	**687**	**773**
23.05.2019 01:47	01:47	14484,31	134,8	1,9	664	670	722		670	687	773
23.05.2019 01:47	01:47	14484,31	133,6	1,9	665	671	722		670	688	773
23.05.2019 01:47	01:47	14484,31	132,8	1,9	664	670	721		670	688	773
23.05.2019 01:47	01:47	14484,31	132,3	1,9	665	670	722		672	688	773
23.05.2019 01:47	**01:47**	**14484,31**	**176,8**	**2,5**	**665**	**672**	**722**		**674**	**689**	**773**
23.05.2019 01:48	01:48	14484,31	174,6	2,5	665	672	722		674	689	773
23.05.2019 01:48	01:48	14484,31	173,2	2,5	665	674	723		673	688	774
23.05.2019 01:48	01:48	14484,31	172,8	2,5	665	674	723		671	688	774
23.05.2019 01:48	01:48	14484,31	172,3	2,5	665	674	722		670	688	775
23.05.2019 01:48	01:48	14484,31	171,7	2,5	665	674	722		670	688	775
23.05.2019 01:48	01:48	14484,31	171,1	2,4	664	674	722		670	688	775
23.05.2019 01:49	**01:49**	**14484,31**	**219,9**	**3,1**	**667**	**676**	**723**		**672**	**689**	**775**
23.05.2019 01:49	01:49	14484,31	217	3,1	669	676	723		671	689	775
23.05.2019 01:49	01:49	14484,31	215,6	3,1	669	676	723		671	689	774
23.05.2019 01:49	01:49	14484,31	214,8	3,1	670	676	723		671	689	773
23.05.2019 01:50	01:50	14484,31	217,7	3,1	669	676	725		671	689	774
23.05.2019 01:50	**01:50**	**14484,31**	**256,9**	**3,7**	**672**	**676**	**722**		**671**	**691**	**775**
23.05.2019 01:50	01:50	14484,31	255,2	3,6	671	676	722		670	691	775
23.05.2019 01:50	01:50	14484,31	253,8	3,6	673	676	723		670	691	774
23.05.2019 01:50	01:50	14484,31	253,1	3,6	673	676	722		670	692	774
23.05.2019 01:50	01:50	14484,31	252,6	3,6	673	676	722		669	692	774
23.05.2019 01:51	**01:51**	**14484,31**	**297,1**	**4,2**	**675**	**678**	**723**		**663**	**692**	**775**
23.05.2019 01:51	01:51	14484,31	294,9	4,2	675	678	723		663	692	775
23.05.2019 01:51	01:51	14484,31	293,1	4,2	674	678	723		663	692	775
23.05.2019 01:51	01:51	14484,31	291,5	4,2	673	678	723		663	692	775
23.05.2019 01:51	01:51	14484,31	290,1	4,1	673	678	723		663	692	775
23.05.2019 01:51	01:51	14484,31	288,8	4,1	673	678	723		663	693	775
23.05.2019 01:52	01:52	14484,31	287,5	4,1	673	678	723		663	693	774

ν	0,2	-
Δp_{cyl}	192,3	bar
A_{piston}	0,79	m²
ΔN	15,1	MN
A_{cont}	5,50	m²
$\Delta\sigma_m$	2,7	MPa
Δs	4,9	mm
l	2077	mm
$\Delta\varepsilon$	0,002	-
E_{def}	1100	MPa

Loadstep	Time	$Pressure_{cyl.}$ [bar]		$Displ._{left}$ [mm]				$Displ._{right}$ [mm]				$Displ._{mean}$ [mm]	Δs [mm]	$\Delta\varepsilon$ [-]	$\Delta\sigma_m$ [MPa]
LS1.0	01:46	100	0	663	669	722	0,0	669	687	772	0,0	0,0	0,0	0,0000	1,4
LS1.1	01:47	134	34	665	670	722	1,0	670	688	773	1,2	1,1	1,1	0,0005	1,9
LS1.2	01:48	173	39	665	673	722	1,4	672	688	774	1,0	1,2	2,3	0,0011	2,5
LS1.3	01:49	217	44	669	676	723	2,5	671	689	774	0,1	1,3	3,6	0,0017	3,1
LS1.4	01:50	254	37	672	676	722	0,8	670	691	774	0,5	0,6	4,3	0,0021	3,6
LS1.5	01:51	292	38	674	678	723	1,4	663	692	775	0,0	0,7	4,9	0,0024	4,2
			192				**7,1**				**2,8**	**4,9**			

Gripper Test 10

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
23.05.2019 05:15	**05:15**	**14487,69**	**100,7**	**12,4**	**659**	**672**	**727**		**663**	**673**	**764**
23.05.2019 05:16	05:16	14487,69	98,7	12,1	659	672	727		663	673	764
23.05.2019 05:16	05:16	14487,69	98	12,0	658	672	727		663	673	764
23.05.2019 05:16	05:16	14487,69	97,1	11,9	659	672	726		663	673	764
23.05.2019 05:16	05:16	14487,69	96,6	11,9	659	672	727		663	673	764
23.05.2019 05:16	05:16	14487,69	96,3	11,8	658	672	727		663	674	764
23.05.2019 05:16	**05:16**	**14487,69**	**137,4**	**16,9**	**658**	**672**	**726**		**665**	**674**	**767**
23.05.2019 05:17	05:17	14487,69	135,1	16,6	658	672	727		665	674	767
23.05.2019 05:17	05:17	14487,69	133,6	16,4	658	672	727		665	674	767
23.05.2019 05:17	05:17	14487,69	133	16,3	659	672	727		664	675	767
23.05.2019 05:17	05:17	14487,69	132,3	16,2	660	672	727		664	674	767
23.05.2019 05:17	05:17	14487,69	131,6	16,1	660	672	727		664	674	767
23.05.2019 05:17	**05:17**	**14487,69**	**177,3**	**21,8**	**660**	**675**	**727**		**667**	**676**	**767**
23.05.2019 05:18	05:18	14487,69	174,7	21,4	660	673	727		667	675	767
23.05.2019 05:18	05:18	14487,69	173,2	21,3	660	673	727		665	675	767
23.05.2019 05:18	05:18	14487,69	172,5	21,2	660	674	727		665	675	767
23.05.2019 05:18	05:18	14487,69	171,8	21,1	662	673	727		665	674	767
23.05.2019 05:18	05:18	14487,69	171,1	21,0	662	673	727		665	674	767
23.05.2019 05:18	**05:18**	**14487,69**	**218**	**26,8**	**665**	**675**	**728**		**668**	**674**	**768**
23.05.2019 05:19	05:19	14487,69	215,3	26,4	665	675	729		668	674	768
23.05.2019 05:19	05:19	14487,69	213,9	26,2	665	675	729		668	674	768
23.05.2019 05:19	05:19	14487,69	212,9	26,1	665	675	729		669	673	767
23.05.2019 05:19	05:19	14487,69	212,4	26,1	664	675	728		668	674	767
23.05.2019 05:19	05:19	14487,69	211,5	26,0	663	675	729		669	674	767
23.05.2019 05:19	05:19	14487,69	211	25,9	660	675	729		669	674	767
23.05.2019 05:20	05:20	14487,69	210,5	25,8	660	675	729		668	674	767
23.05.2019 05:20	**05:20**	**14487,69**	**257,7**	**31,6**	**661**	**676**	**727**		**669**	**676**	**767**
23.05.2019 05:20	05:20	14487,69	255,2	31,3	661	676	728		669	675	768
23.05.2019 05:20	05:20	14487,69	254	31,2	660	676	728		669	674	768
23.05.2019 05:20	05:20	14487,69	253,1	31,1	660	676	728		669	674	767
23.05.2019 05:20	05:20	14487,69	251,9	30,9	660	676	728		669	674	767
23.05.2019 05:21	05:21	14487,69	251,4	30,9	660	676	729		669	674	768
23.05.2019 05:21	**05:21**	**14487,69**	**296,3**	**36,4**	**660**	**679**	**730**		**669**	**675**	**767**
23.05.2019 05:21	05:21	14487,69	293,6	36,0	660	679	730		669	676	767
23.05.2019 05:21	05:21	14487,69	291,8	35,8	660	679	730		669	675	767
23.05.2019 05:21	05:21	14487,69	289,8	35,6	660	679	730		669	675	767
23.05.2019 05:21	05:21	14487,69	288,3	35,4	660	679	729		669	675	767
23.05.2019 05:22	05:22	14487,69	286,9	35,2	659	679	729		669	676	767

ν	0,2	-
Δp_{cyl}	193,2	bar
A_{piston}	0,79	m²
ΔN	15,2	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	23,7	MPa
Δs	4,2	mm
l	2077	mm
$\Delta\varepsilon$	0,002	-
E_{def}	11400	MPa

Loadstep	Time	$Pressure_{cyl.}$ [bar]		$Displ._{left}$ [mm]				$Displ._{right}$ [mm]				$Displ._{mean}$ [mm]	Δs [mm]	$\Delta\varepsilon$ [-]	$\Delta\sigma_m$ [MPa]
LS1.0	05:16	98	0	659	672	727	0,0	663	673	764	0,0	0,0	0,0	0,0000	12,0
LS1.1	05:17	134	36	659	672	727	0,1	665	674	767	1,8	0,9	0,9	0,0005	16,4
LS1.2	05:18	173	40	661	674	727	1,2	666	675	767	0,6	0,9	1,8	0,0009	21,3
LS1.3	05:19	213	40	663	675	729	2,0	668	674	767	0,7	1,3	3,2	0,0015	26,2
LS1.4	05:20	254	41	660	676	728	0,0	669	675	768	0,5	0,2	3,4	0,0016	31,2
LS1.5	05:21	291	37	660	679	730	1,4	669	675	767	0,1	0,8	4,2	0,0020	35,7
			193				**4,6**				**3,7**	**4,2**			

Gripper Test 11

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
24.05.2019 14:48	**14:48**	**14504,38**	**92,2**	**11,3**	**677**	**687**	**730**		**622**	**638**	**714**
24.05.2019 14:48	14:48	14504,38	90,2	11,1	677	688	732		623	638	714
24.05.2019 14:49	14:49	14504,38	89,4	11,0	677	688	732		623	638	714
24.05.2019 14:49	14:49	14504,38	88,8	10,9	677	688	732		623	638	714
24.05.2019 14:49	**14:49**	**14504,38**	**135,6**	**16,6**	**682**	**688**	**733**		**623**	**636**	**718**
24.05.2019 14:49	14:49	14504,38	131,5	16,1	683	688	733		624	638	718
24.05.2019 14:49	14:49	14504,38	129,9	15,9	683	688	733		623	638	717
24.05.2019 14:49	14:49	14504,38	128,7	15,8	683	688	733		624	638	718
24.05.2019 14:50	**14:50**	**14504,38**	**176,6**	**21,7**	**683**	**688**	**735**		**625**	**640**	**721**
24.05.2019 14:50	14:50	14504,38	172,8	21,2	684	688	736		625	641	721
24.05.2019 14:50	14:50	14504,38	171,1	21,0	685	689	736		624	641	721
24.05.2019 14:50	14:50	14504,38	170,1	20,9	684	689	736		625	641	721
24.05.2019 14:50	14:50	14504,38	169,5	20,8	684	688	737		625	641	721
24.05.2019 14:50	**14:50**	**14504,38**	**215,3**	**26,4**	**685**	**688**	**737**		**623**	**643**	**724**
24.05.2019 14:51	14:51	14504,38	212,9	26,1	685	688	737		623	644	723
24.05.2019 14:51	14:51	14504,38	211,8	26,0	685	688	737		623	643	724
24.05.2019 14:51	14:51	14504,38	211	25,9	685	688	737		623	643	724
24.05.2019 14:51	**14:51**	**14504,38**	**254,5**	**31,2**	**686**	**688**	**740**		**624**	**642**	**727**
24.05.2019 14:51	14:51	14504,38	252,8	31,0	686	688	741		623	642	726
24.05.2019 14:52	14:52	14504,38	251,3	30,8	686	688	740		623	642	727
24.05.2019 14:52	14:52	14504,38	250,6	30,8	686	689	741		623	643	726
24.05.2019 14:52	**14:52**	**14504,38**	**295,2**	**36,2**	**688**	**689**	**741**		**623**	**643**	**728**
24.05.2019 14:52	14:52	14504,38	293,9	36,1	688	689	741		623	643	728
24.05.2019 14:52	14:52	14504,38	291	35,7	688	689	741		622	643	728
24.05.2019 14:52	14:52	14504,38	289,3	35,5	688	688	742		622	643	728
24.05.2019 14:53	14:53	14504,38	287,7	35,3	688	689	742		623	643	728

ν	0,2	-
Δp_{cyl}	201,3	bar
A_{piston}	0,79	m²
ΔN	15,8	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	24,7	MPa
Δs	6,8	mm
l	2077	mm
$\Delta\varepsilon$	0,003	-
E_{def}	7200	MPa

Loadstep	Time	Pressure$_{cyl.}$ [bar]		Displ.$_{left}$ [mm]				Displ.$_{right}$ [mm]				Displ.$_{mean}$ [mm]	Δs [mm]	$\Delta\varepsilon$ [-]	$\Delta\sigma_m$ [MPa]
LS1.0	14:48	90	0	677	688	732	0,0	623	638	714	0,0	0,0	0,0	0,0000	11,1
LS1.1	14:49	131	41	683	688	733	2,5	624	638	718	1,3	1,9	1,9	0,0009	16,1
LS1.2	14:50	172	41	684	688	736	1,5	625	641	721	2,6	2,1	4,0	0,0019	21,1
LS1.3	14:51	213	41	685	688	737	0,5	623	643	724	1,1	0,8	4,8	0,0023	26,1
LS1.4	14:51	252	40	686	688	741	1,6	623	642	727	0,7	1,1	6,0	0,0029	31,0
LS1.5	14:52	291	39	688	689	741	1,1	623	643	728	0,5	0,8	6,8	0,0033	35,8
			201				**7,3**				**6,3**	**6,8**			

Gripper Test 12

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
24.05.2019 22:54	**22:54**	**14507,71**	**102,2**	**1,5**	**683**	**686**	**719**		**624**	**638**	**706**
24.05.2019 22:55	22:55	14507,71	99	1,4	683	687	718		623	638	706
24.05.2019 22:55	22:55	14507,71	98	1,4	683	687	719		623	638	706
24.05.2019 22:55	22:55	14507,71	97,1	1,4	683	687	719		623	638	706
24.05.2019 22:55	22:55	14507,71	96,8	1,4	683	688	719		623	638	706
24.05.2019 22:55	22:55	14507,71	96,3	1,4	683	688	719		623	638	706
24.05.2019 22:55	**22:55**	**14507,71**	**135**	**1,9**	**684**	**688**	**721**		**623**	**639**	**709**
24.05.2019 22:56	22:56	14507,71	132,5	1,9	684	689	721		624	639	709
24.05.2019 22:56	22:56	14507,71	131,5	1,9	685	689	721		623	639	709
24.05.2019 22:56	22:56	14507,71	137,4	2,0	685	689	721		623	639	709
24.05.2019 22:56	**22:56**	**14507,71**	**173,7**	**2,5**	**685**	**689**	**722**		**625**	**642**	**710**
24.05.2019 22:56	22:56	14507,71	172	2,5	685	690	722		625	642	710
24.05.2019 22:56	22:56	14507,71	170,6	2,4	685	691	722		625	642	711
24.05.2019 22:57	22:57	14507,71	169,8	2,4	685	691	722		625	642	711
24.05.2019 22:57	22:57	14507,71	169,3	2,4	684	691	722		623	642	711
24.05.2019 22:57	**22:57**	**14507,71**	**218,5**	**3,1**	**683**	**692**	**722**		**625**	**643**	**711**
24.05.2019 22:57	22:57	14507,71	214,1	3,1	682	692	722		625	643	712
24.05.2019 22:57	22:57	14507,71	211,8	3,0	682	693	722		625	643	711
24.05.2019 22:57	22:57	14507,71	210,7	3,0	682	693	722		625	643	711
24.05.2019 22:58	**22:58**	**14507,71**	**255,7**	**3,7**	**683**	**693**	**723**		**627**	**646**	**712**
24.05.2019 22:58	22:58	14507,71	252,5	3,6	683	693	724		628	646	712
24.05.2019 22:58	22:58	14507,71	250,9	3,6	683	693	723		627	648	712
24.05.2019 22:58	**22:58**	**14507,71**	**293,9**	**4,2**	**683**	**695**	**726**		**629**	**646**	**714**
24.05.2019 22:58	22:58	14507,71	291,5	4,2	685	695	726		628	645	716
24.05.2019 22:59	22:59	14507,71	289,8	4,1	685	695	726		628	647	716
24.05.2019 22:59	22:59	14507,71	288,5	4,1	685	695	726		628	646	715

ν	0,2	-
Δp_{cyl}	192,7	bar
A_{piston}	0,79	m²
ΔN	15,1	MN
A_{cont}	5,50	m²
$\Delta\sigma_m$	2,8	MPa
Δs	6,5	mm
l	2077	mm
Δε	0,003	-
E_{def}	800	MPa

Loadstep	Time	$Pressure_{cyl.}$ [bar]		$Displ._{left}$ [mm]				$Displ._{right}$ [mm]				$Displ._{mean}$ [mm]	Δs [mm]	Δε [-]	$\Delta\sigma_m$ [MPa]
LS1.0	22:55	98	0	683	687	719	0,0	623	638	706	0,0	0,0	0,0	0,0000	1,4
LS1.1	22:56	134	36	685	689	721	1,8	623	639	709	1,4	1,6	1,6	0,0007	1,9
LS1.2	22:56	171	37	685	690	722	1,0	625	642	711	2,0	1,5	3,0	0,0015	2,4
LS1.3	22:57	214	43	682	693	722	0,0	625	643	711	0,7	0,3	3,4	0,0016	3,1
LS1.4	22:58	253	39	683	693	723	0,9	627	647	712	2,3	1,6	4,9	0,0024	3,6
LS1.5	22:58	291	38	685	695	726	2,1	628	646	715	1,2	1,6	6,5	0,0032	4,2
			193				**5,6**				**7,4**	**6,5**			

Gripper Test 13

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
25.05.2019 21:46	**21:46**	**14517,91**	**97,6**	**12,0**	**585**	**581**	**627**		**669**	**692**	**785**
25.05.2019 21:46	21:46	14517,91	94,6	11,6	587	582	627		669	692	783
25.05.2019 21:46	21:46	14517,91	92,7	11,4	587	584	628		669	692	785
25.05.2019 21:46	21:46	14517,91	91,7	11,3	587	584	628		668	692	785
25.05.2019 21:46	21:46	14517,91	90,9	11,2	587	585	629		668	692	784
25.05.2019 21:47	**21:47**	**14517,91**	**126,8**	**15,6**	**592**	**586**	**630**		**670**	**693**	**785**
25.05.2019 21:47	21:47	14517,91	123,6	15,2	592	588	631		670	693	787
25.05.2019 21:47	21:47	14517,91	121,9	15,0	592	588	631		670	693	786
25.05.2019 21:47	**21:47**	**14517,91**	**169,1**	**20,8**	**592**	**589**	**632**		**674**	**694**	**789**
25.05.2019 21:47	21:47	14517,91	163,8	20,1	592	591	632		674	694	789
25.05.2019 21:48	21:48	14517,91	160,9	19,7	592	591	634		674	694	788
25.05.2019 21:48	**21:48**	**14517,91**	**210**	**25,8**	**593**	**592**	**634**		**675**	**695**	**789**
25.05.2019 21:48	21:48	14517,91	204,3	25,1	593	592	635		675	695	790
25.05.2019 21:48	21:48	14517,91	201,8	24,8	595	592	636		675	694	789
25.05.2019 21:48	**21:48**	**14517,91**	**248,4**	**30,5**	**595**	**593**	**636**		**675**	**695**	**790**
25.05.2019 21:48	21:48	14517,91	246,1	30,2	597	592	637		677	696	790
25.05.2019 21:49	21:49	14517,91	242,9	29,8	597	591	638		677	696	791
25.05.2019 21:49	21:49	14517,91	241	29,6	597	591	639		675	695	791
25.05.2019 21:49	**21:49**	**14517,91**	**295,1**	**36,2**	**597**	**592**	**639**		**677**	**696**	**794**
25.05.2019 21:49	21:49	14517,91	287,5	35,3	599	591	639		678	696	795
25.05.2019 21:49	21:49	14517,91	284	34,9	599	591	640		678	696	795
25.05.2019 21:49	21:49	14517,91	282,1	34,6	600	591	640		677	696	795
25.05.2019 21:50	21:50	14517,91	280,6	34,4	600	591	641		677	696	793

ν	0,2	-
Δp_{cyl}	192,4	bar
A_{piston}	0,79	m²
ΔN	15,1	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	23,6	MPa
Δs	9,2	mm
l	2077	mm
$\Delta\varepsilon$	0,004	-
E_{def}	5100	MPa

Loadstep	Time	$Pressure_{cyl.}$ [bar]		$Displ._{left}$ [mm]				$Displ._{right}$ [mm]				$Displ._{mean}$ [mm]	Δs [mm]	$\Delta\varepsilon$ [-]	$\Delta\sigma_m$ [MPa]
LS1.0	21:46	94	0	587	583	628	0,0	669	692	784	0,0	0,0	0,0	0,0000	11,5
LS1.1	21:47	124	31	592	587	631	4,1	670	693	786	1,3	2,7	2,7	0,0013	15,2
LS1.2	21:47	165	41	592	590	633	1,7	674	694	789	2,6	2,1	4,8	0,0023	20,2
LS1.3	21:48	205	41	594	592	635	1,9	675	695	789	0,8	1,3	6,2	0,0030	25,2
LS1.4	21:48	245	39	597	592	638	1,7	676	696	791	1,0	1,3	7,5	0,0036	30,0
LS1.5	21:49	286	41	599	591	640	1,4	677	696	794	1,9	1,7	9,2	0,0044	35,1
			192				**10,8**				**7,6**	**9,2**			

Gripper Test 14

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
12.06.2019 11:22	**11:22**	**14741,24**	**67,5**	**8,3**	**669**	**678**	**704**		**623**	**634**	**696**
12.06.2019 11:22	11:22	14741,24	64,5	7,9	669	677	704		623	634	696
12.06.2019 11:22	11:22	14741,24	62,5	7,7	669	677	705		623	634	696
12.06.2019 11:23	11:23	14741,24	61,4	7,5	669	679	705		622	634	696
12.06.2019 11:23	11:23	14741,24	60,7	7,4	670	679	705		621	634	696
12.06.2019 11:23	**11:23**	**14741,24**	**130,4**	**16,0**	**669**	**681**	**707**		**625**	**639**	**697**
12.06.2019 11:23	11:23	14741,24	127,4	15,6	669	683	707		623	639	697
12.06.2019 11:23	11:23	14741,24	125,8	15,4	669	683	707		623	639	696
12.06.2019 11:23	11:23	14741,24	124,6	15,3	669	683	707		623	639	696
12.06.2019 11:24	11:24	14741,24	123,9	15,2	670	683	707		623	639	694
12.06.2019 11:24	**11:24**	**14741,24**	**173,2**	**21,3**	**674**	**683**	**708**		**623**	**639**	**696**
12.06.2019 11:24	11:24	14741,24	170,8	21,0	674	683	709		622	639	696
12.06.2019 11:24	11:24	14741,24	169,3	20,8	674	684	708		623	639	695
12.06.2019 11:24	11:24	14741,24	168,6	20,7	674	684	709		623	639	696
12.06.2019 11:24	11:24	14741,24	167,9	20,6	674	683	707		623	639	696
12.06.2019 11:25	**11:25**	**14741,24**	**215,1**	**26,4**	**671**	**683**	**709**		**623**	**639**	**696**
12.06.2019 11:25	11:25	14741,24	212,4	26,1	671	683	709		623	639	695
12.06.2019 11:25	11:25	14741,24	210,8	25,9	673	683	709		623	639	696
12.06.2019 11:25	11:25	14741,24	209,8	25,7	673	683	707		623	639	696
12.06.2019 11:25	11:25	14741,24	209,2	25,7	672	683	708		624	639	696
12.06.2019 11:25	**11:25**	**14741,24**	**233,3**	**28,6**	**673**	**683**	**709**		**623**	**640**	**696**
12.06.2019 11:26	11:26	14741,24	231	28,3	674	685	708		625	639	696
12.06.2019 11:26	11:26	14741,24	229,5	28,2	674	685	709		623	639	696
12.06.2019 11:26	11:26	14741,24	228,6	28,1	674	685	709		625	639	697
12.06.2019 11:26	11:26	14741,24	227,9	28,0	674	685	709		623	640	697

ν	0,2	-
Δp_{cyl}	166,7	bar
A_{piston}	0,79	m²
ΔN	13,1	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	20,5	MPa
Δs	4,3	mm
l	2077	mm
$\Delta\varepsilon$	0,002	-
E_{def}	9600	MPa

Loadstep	Time	$Pressure_{cyl.}$ [bar]		$Displ._{left}$ [mm]				$Displ._{right}$ [mm]				$Displ._{mean}$ [mm]	Δs [mm]	$\Delta\varepsilon$ [-]	$\Delta\sigma_m$ [MPa]
LS1.0	11:22	63	0	669	678	705	0,0	622	634	696	0,0	0,0	0,0	0,0000	7,8
LS1.1	11:23	126	63	669	683	707	2,3	623	639	696	2,0	2,2	2,2	0,0010	15,5
LS1.2	11:24	170	44	674	683	708	2,3	623	639	696	0,0	1,1	3,3	0,0016	20,9
LS1.3	11:25	211	42	672	683	708	0,0	623	639	696	0,1	0,1	3,4	0,0016	26,0
LS1.4	11:26	230	19	674	685	709	1,3	624	639	696	0,5	0,9	4,3	0,0021	28,2
			167				**5,9**				**2,7**	**4,3**			

Gripper Test 15

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
12.06.2019 22:18	**22:18**	**14746,3**	**98,7**	**12,1**	**681**	**689**	**729**		**577**	**585**	**695**
12.06.2019 22:18	22:18	14746,3	96	11,8	680	688	729		577	584	694
12.06.2019 22:18	22:18	14746,3	94,3	11,6	681	689	730		577	583	694
12.06.2019 22:19	22:19	14746,3	93	11,4	682	689	730		577	583	694
12.06.2019 22:19	**22:19**	**14746,3**	**139,7**	**17,1**	**677**	**692**	**730**		**578**	**587**	**697**
12.06.2019 22:19	22:19	14746,3	130,7	16,0	677	694	732		580	590	697
12.06.2019 22:19	22:19	14746,3	128,7	15,8	677	694	732		579	590	697
12.06.2019 22:19	22:19	14746,3	127,4	15,6	677	695	732		579	590	697
12.06.2019 22:19	**22:19**	**14746,3**	**177,7**	**21,8**	**677**	**697**	**732**		**581**	**595**	**700**
12.06.2019 22:20	22:20	14746,3	170,6	20,9	676	697	734		581	594	698
12.06.2019 22:20	22:20	14746,3	168,1	20,6	677	696	734		581	594	699
12.06.2019 22:20	22:20	14746,3	166,4	20,4	677	697	734		581	594	699
12.06.2019 22:20	**22:20**	**14746,3**	**216,9**	**26,6**	**677**	**697**	**734**		**581**	**596**	**699**
12.06.2019 22:20	22:20	14746,3	208,7	25,6	681	697	734		582	598	702
12.06.2019 22:20	22:20	14746,3	205,9	25,3	682	697	735		582	599	703
12.06.2019 22:21	22:21	14746,3	204,3	25,1	682	698	735		582	598	703
12.06.2019 22:21	22:21	14746,3	203	24,9	682	698	734		584	598	703
12.06.2019 22:21	**22:21**	**14746,3**	**249,7**	**30,6**	**682**	**699**	**736**		**585**	**600**	**704**
12.06.2019 22:21	22:21	14746,3	246,3	30,2	683	701	736		585	600	704
12.06.2019 22:21	22:21	14746,3	256,9	31,5	685	700	736		586	600	706
12.06.2019 22:21	22:21	14746,3	254	31,2	685	700	736		590	600	705
12.06.2019 22:22	22:22	14746,3	252,6	31,0	685	700	736		590	599	706
12.06.2019 22:22	22:22	14746,3	250	30,7	682	699	737		587	602	701
12.06.2019 22:22	22:22	14746,3	249,2	30,6	682	698	737		588	602	701

ν	0,2	-
Δp_{cyl}	155,7	bar
A_{piston}	0,79	m²
ΔN	12,2	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	19,1	MPa
Δs	9,4	mm
l	2077	mm
$\Delta\varepsilon$	0,005	-
E_{def}	4000	MPa

Loadstep	Time	Pressure$_{cyl.}$ [bar]		Displ.$_{left}$ [mm]				Displ.$_{right}$ [mm]				Displ.$_{mean}$ [mm]	Δs [mm]	$\Delta\varepsilon$ [-]	$\Delta\sigma_m$ [MPa]
LS1.0	22:18	96	0	681	689	730	0,0	577	584	694	0,0	0,0	0,0	0,0000	11,7
LS1.1	22:19	132	36	677	694	732	1,0	579	589	697	3,4	2,2	2,2	0,0011	16,2
LS1.2	22:20	171	39	677	697	734	1,6	581	594	699	3,0	2,3	4,5	0,0022	20,9
LS1.3	22:20	208	37	681	697	734	1,9	582	598	702	2,6	2,2	6,7	0,0032	25,5
LS1.4	22:21	251	43	683	700	736	2,2	587	600	704	3,2	2,7	9,4	0,0045	30,8
			156				**6,7**				**12,2**	**9,4**			

Gripper Test 16

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
26.06.2019 10:04	**10:04**	**14892,64**	**131,2**	**16,1**	**603**	**614**	**632**		**689**	**705**	**780**
26.06.2019 10:04	10:04	14892,64	121	14,8	604	614	634		688	706	780
26.06.2019 10:04	10:04	14892,64	118,6	14,6	605	614	633		690	706	777
26.06.2019 10:04	10:04	14892,64	117,1	14,4	605	614	634		689	706	780
26.06.2019 10:04	**10:04**	**14892,64**	**173,6**	**21,3**	**606**	**617**	**634**		**691**	**709**	**780**
26.06.2019 10:04	10:04	14892,64	168,2	20,6	607	617	636		693	711	773
26.06.2019 10:05	10:05	14892,64	166	20,4	607	617	646		692	711	774
26.06.2019 10:05	10:05	14892,64	164,6	20,2	607	617	640		694	711	777
26.06.2019 10:05	10:05	14892,64	163,8	20,1	607	617	636		694	711	777
26.06.2019 10:05	10:05	14892,64	163	20,0	607	617	640		694	711	780
26.06.2019 10:05	10:05	14892,64	162,3	19,9	607	617	638		694	711	780
26.06.2019 10:05	10:05	14892,64	161,8	19,9	607	617	640		692	711	780
26.06.2019 10:06	**10:06**	**14892,64**	**88,9**	**10,9**	**599**	**611**	**641**		**693**	**706**	**775**
26.06.2019 10:06	10:06	14892,64	76,3	9,4	602	614	639		694	706	777
26.06.2019 10:06	10:06	14892,64	74,8	9,2	602	614	639		692	706	780
26.06.2019 10:06	10:06	14892,64	73,8	9,1	602	613	639		692	706	780
26.06.2019 10:07	**10:07**	**14892,64**	**136**	**16,7**	**607**	**614**	**637**		**693**	**709**	**780**
26.06.2019 10:07	10:07	14892,64	134	16,4	607	614	637		693	707	781
26.06.2019 10:07	10:07	14892,64	132,8	16,3	607	616	638		694	708	780
26.06.2019 10:07	10:07	14892,64	132	16,2	607	616	638		693	709	780
26.06.2019 10:07	**10:07**	**14892,64**	**175,7**	**21,6**	**608**	**615**	**639**		**694**	**709**	**780**
26.06.2019 10:07	10:07	14892,64	173,6	21,3	608	616	639		694	709	781
26.06.2019 10:08	10:08	14892,64	172,3	21,1	608	616	639		694	709	780
26.06.2019 10:08	10:08	14892,64	171,3	21,0	608	616	639		694	709	781
26.06.2019 10:08	**10:08**	**14892,64**	**214,9**	**26,4**	**608**	**617**	**649**		**694**	**712**	**781**
26.06.2019 10:08	10:08	14892,64	212,4	26,1	608	618	653		693	711	781
26.06.2019 10:08	10:08	14892,64	211,2	25,9	608	618	653		694	712	781
26.06.2019 10:08	10:08	14892,64	209,8	25,7	608	618	651		694	712	781
26.06.2019 10:09	**10:09**	**14892,64**	**256,9**	**31,5**	**608**	**618**	**653**		**695**	**715**	**784**
26.06.2019 10:09	10:09	14892,64	252,6	31,0	607	619	654		695	715	783
26.06.2019 10:09	10:09	14892,64	250,4	30,7	608	619	654		695	715	784
26.06.2019 10:09	10:09	14892,64	249	30,6	608	619	654		696	714	784
26.06.2019 10:10	**10:10**	**14892,64**	**84,3**	**10,3**	**600**	**614**	**653**		**694**	**711**	**778**
26.06.2019 10:10	10:10	14892,64	72,6	8,9	600	614	651		694	710	772
26.06.2019 10:10	10:10	14892,64	70,9	8,7	600	614	653		693	710	771
26.06.2019 10:10	10:10	14892,64	70	8,6	602	615	653		694	709	772
26.06.2019 10:11	**10:11**	**14892,64**	**134,3**	**16,5**	**604**	**617**	**652**		**698**	**712**	**783**
26.06.2019 10:11	10:11	14892,64	132,8	16,3	604	617	651		696	711	779
26.06.2019 10:11	10:11	14892,64	132	16,2	604	617	651		695	711	777
26.06.2019 10:11	10:11	14892,64	131,5	16,1	604	617	651		696	711	781
26.06.2019 10:11	**10:11**	**14892,64**	**176,8**	**21,7**	**605**	**618**	**650**		**695**	**713**	**782**
26.06.2019 10:12	10:12	14892,64	175,1	21,5	606	618	651		698	713	783
26.06.2019 10:12	10:12	14892,64	174,1	21,4	604	618	651		697	711	782
26.06.2019 10:12	10:12	14892,64	173,6	21,3	604	618	651		694	712	783
26.06.2019 10:12	**10:12**	**14892,64**	**217,2**	**26,7**	**605**	**618**	**653**		**696**	**715**	**783**
26.06.2019 10:12	10:12	14892,64	215,3	26,4	604	619	653		697	715	782
26.06.2019 10:12	10:12	14892,64	214,3	26,3	604	619	653		696	714	782
26.06.2019 10:13	10:13	14892,64	213,6	26,2	604	619	653		699	714	782
26.06.2019 10:13	**10:13**	**14892,64**	**256,4**	**31,5**	**603**	**619**	**654**		**700**	**716**	**785**
26.06.2019 10:13	10:13	14892,64	254,1	31,2	604	619	654		700	716	785
26.06.2019 10:13	10:13	14892,64	253,1	31,1	604	619	654		698	716	785
26.06.2019 10:13	10:13	14892,64	251,9	30,9	604	619	654		697	715	785
26.06.2019 10:13	10:13	14892,64	251,3	30,8	604	619	654		696	715	785
26.06.2019 10:14	10:14	14892,64	250,8	30,8	604	620	654		696	715	785
26.06.2019 10:14	10:14	14892,64	250	30,7	604	619	654		696	715	785

Loadstep	Time	$Pressure_{cyl.}$ [bar]		$Displ._{left}$ [mm]				$Displ._{right}$ [mm]				$Displ._{mean}$ [mm]	Δs [mm]	$\Delta\varepsilon$ [-]	$\Delta\sigma_m$ [MPa]
LS1.0	10:04	122	0	604	614	633	0,0	689	706	779	0,0	0,0	0,0	0,0000	15,0
LS1.1	10:05	165	43	607	617	639	3,7	693	711	778	2,5	3,1	3,1	0,0015	20,3
			43				**3,7**				**2,5**	**3,1**			
LS2.0	10:06	78	0	601	613	640	0,0	693	706	778	0,0	0,0	0,0	0,0000	9,6
LS2.1	10:07	134	55	607	615	638	1,9	693	708	780	1,7	1,8	1,8	0,0009	16,4
LS2.2	10:07	173	40	608	616	639	1,1	694	709	781	0,6	0,8	2,6	0,0013	21,3
LS2.3	10:08	212	39	608	618	652	4,8	694	712	781	1,0	2,9	5,5	0,0027	26,0
LS2.4	10:09	252	40	608	619	654	1,0	695	715	784	2,4	1,7	7,3	0,0035	31,0
			174				**8,8**				**5,7**	**7,3**			
LS3.0	10:10	74	0	601	614	653	0,0	694	710	773	0,0	0,0	0,0	0,0000	9,1
LS3.1	10:11	133	58	604	617	651	1,7	696	711	780	3,5	2,6	2,6	0,0012	16,3
LS3.2	10:12	175	42	605	618	651	0,4	696	712	783	1,1	0,8	3,3	0,0016	21,5
LS3.3	10:12	215	40	604	619	653	0,8	697	715	782	1,0	0,9	4,3	0,0020	26,4
LS3.4	10:13	253	37	604	619	654	0,3	698	715	785	1,4	0,9	5,1	0,0025	31,0
			178				**3,3**				**7,0**	**5,1**			

ν	0,2	-
Δp_{cyl}	43,4	bar
A_{piston}	0,79	m²
ΔN	3,4	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	5,3	MPa
Δs	3,1	mm
l	2077	mm
$\Delta\varepsilon$	0,001	-
E_{def}	3400	MPa

ν	0,2	-
Δp_{cyl}	173,8	bar
A_{piston}	0,79	m²
ΔN	13,6	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	21,3	MPa
Δs	7,3	mm
l	2077	mm
$\Delta\varepsilon$	0,003	-
E_{def}	5900	MPa

ν	0,2	-
Δp_{cyl}	178,1	bar
A_{piston}	0,79	m²
ΔN	14,0	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	21,9	MPa
Δs	5,1	mm
l	2077	mm
$\Delta\varepsilon$	0,002	-
E_{def}	8500	MPa

Gripper Test 17

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
26.06.2019 14:31	**14:31**	**14894,33**	**91,5**	**11,2**	**587**	**603**	**634**		**681**	**700**	**773**
26.06.2019 14:31	14:31	14894,33	87,1	10,7	587	603	636		682	700	781
26.06.2019 14:31	14:31	14894,33	85,5	10,5	587	603	636		682	700	783
26.06.2019 14:31	14:31	14894,33	84,7	10,4	589	603	636		682	700	782
26.06.2019 14:31	**14:31**	**14894,33**	**127,7**	**15,7**	**592**	**607**	**639**		**683**	**703**	**784**
26.06.2019 14:31	14:31	14894,33	124,1	15,2	592	607	639		684	702	784
26.06.2019 14:32	14:32	14894,33	122,4	15,0	592	607	639		683	701	784
26.06.2019 14:32	14:32	14894,33	121,2	14,9	592	608	639		684	702	784
26.06.2019 14:32	**14:32**	**14894,33**	**166,2**	**20,4**	**592**	**608**	**639**		**684**	**700**	**785**
26.06.2019 14:32	14:32	14894,33	163,6	20,1	592	609	640		684	698	785
26.06.2019 14:32	14:32	14894,33	161,6	19,8	592	610	639		686	699	785
26.06.2019 14:32	**14:32**	**14894,33**	**200,2**	**24,6**	**592**	**610**	**640**		**685**	**701**	**785**
26.06.2019 14:33	14:33	14894,33	206,9	25,4	593	610	640		688	706	790
26.06.2019 14:33	14:33	14894,33	204,6	25,1	593	611	640		688	705	790
26.06.2019 14:33	14:33	14894,33	202,8	24,9	593	611	639		687	706	789
26.06.2019 14:33	**14:33**	**14894,33**	**253**	**31,0**	**595**	**611**	**640**		**688**	**706**	**790**
26.06.2019 14:33	14:33	14894,33	248	30,4	595	612	640		688	706	788
26.06.2019 14:33	14:33	14894,33	245,6	30,1	595	612	640		688	706	788
26.06.2019 14:34	14:34	14894,33	243,9	29,9	593	612	639		688	706	788

ν	0,2	-
Δp_{cyl}	160,4	bar
A_{piston}	0,79	m²
ΔN	12,6	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	19,7	MPa
Δs	7,0	mm
l	2077	mm
$\Delta\varepsilon$	0,003	-
E_{def}	5600	MPa

Loadstep	Time	Pressure$_{cyl.}$ [bar]		Displ.$_{left}$ [mm]				Displ.$_{right}$ [mm]				Displ.$_{mean}$ [mm]	Δs [mm]	$\Delta\varepsilon$ [-]	$\Delta\sigma_m$ [MPa]
LS1.0	14:31	87	0	588	603	636	0,0	682	700	780	0,0	0,0	0,0	0,0000	10,7
LS1.1	14:31	124	37	592	607	639	4,1	684	702	784	2,7	3,4	3,4	0,0016	15,2
LS1.2	14:32	164	40	592	609	639	0,7	685	699	785	0,0	0,3	3,7	0,0018	20,1
LS1.3	14:33	204	40	593	611	640	0,9	687	705	789	3,8	2,3	6,1	0,0029	25,0
LS1.4	14:33	248	44	595	612	640	1,0	688	706	789	0,8	0,9	7,0	0,0034	30,4
			160				**6,7**				**7,3**	**7,0**			

Gripper Test 18

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
27.06.2019 00:30	**00:30**	**14898,19**	**102,5**	**12,6**	**640**	**651**	**690**		**629**	**656**	**739**
27.06.2019 00:30	00:30	14898,19	101,2	12,4	640	651	690		629	656	740
27.06.2019 00:31	00:31	14898,19	100,4	12,3	640	651	689		629	656	740
27.06.2019 00:31	00:31	14898,19	100	12,3	640	651	690		629	656	740
27.06.2019 00:31	**00:31**	**14898,19**	**140,8**	**17,3**	**641**	**653**	**690**		**627**	**656**	**740**
27.06.2019 00:31	00:31	14898,19	139,2	17,1	641	653	692		627	657	742
27.06.2019 00:31	00:31	14898,19	138,4	17,0	641	653	692		627	657	742
27.06.2019 00:31	00:31	14898,19	137,7	16,9	641	653	692		627	657	742
27.06.2019 00:32	00:32	14898,19	143,8	17,6	641	653	692		627	657	742
27.06.2019 00:32	**00:32**	**14898,19**	**179,8**	**22,1**	**640**	**655**	**693**		**627**	**657**	**743**
27.06.2019 00:32	00:32	14898,19	178,5	21,9	640	655	693		627	657	743
27.06.2019 00:32	00:32	14898,19	178,2	21,9	640	655	693		627	657	743
27.06.2019 00:32	00:32	14898,19	177,7	21,8	640	655	693		627	657	743
27.06.2019 00:32	00:32	14898,19	180,3	22,1	640	655	692		627	657	743
27.06.2019 00:33	**00:33**	**14898,19**	**93**	**11,4**	**642**	**653**	**690**		**627**	**654**	**737**
27.06.2019 00:33	00:33	14898,19	90,7	11,1	642	652	690		629	654	739
27.06.2019 00:33	00:33	14898,19	90	11,0	641	652	690		627	654	738
27.06.2019 00:33	00:33	14898,19	89,7	11,0	641	652	690		627	655	738
27.06.2019 00:33	**00:33**	**14898,19**	**140,1**	**17,2**	**641**	**653**	**692**		**627**	**655**	**740**
27.06.2019 00:33	00:33	14898,19	138,9	17,0	641	653	693		627	656	742
27.06.2019 00:34	00:34	14898,19	138,6	17,0	641	653	693		627	656	742
27.06.2019 00:34	00:34	14898,19	138,1	16,9	641	653	693		627	656	740
27.06.2019 00:34	00:34	14898,19	138,1	16,9	641	653	693		627	655	740
27.06.2019 00:34	**00:34**	**14898,19**	**180,2**	**22,1**	**641**	**655**	**693**		**626**	**656**	**742**
27.06.2019 00:34	00:34	14898,19	179	22,0	641	655	694		626	656	743
27.06.2019 00:34	00:34	14898,19	178,5	21,9	641	655	694		626	656	743
27.06.2019 00:35	00:35	14898,19	178,3	21,9	641	655	694		626	656	743
27.06.2019 00:35	**00:35**	**14898,19**	**220**	**27,0**	**640**	**656**	**694**		**627**	**657**	**742**
27.06.2019 00:35	00:35	14898,19	218,5	26,8	640	656	694		627	657	743
27.06.2019 00:35	00:35	14898,19	217,7	26,7	640	656	694		627	657	743
27.06.2019 00:35	**00:35**	**14898,19**	**259,8**	**31,9**	**639**	**656**	**695**		**627**	**657**	**743**
27.06.2019 00:35	00:35	14898,19	257,7	31,6	639	656	695		626	658	744
27.06.2019 00:36	00:36	14898,19	256,4	31,5	639	656	695		626	658	745
27.06.2019 00:36	00:36	14898,19	255,5	31,4	639	656	695		626	658	744
27.06.2019 00:36	00:36	14898,19	254,9	31,3	640	656	695		626	658	745
27.06.2019 00:36	**00:36**	**14898,19**	**102,1**	**12,5**	**641**	**652**	**692**		**629**	**654**	**738**
27.06.2019 00:36	00:36	14898,19	100,7	12,4	641	652	692		629	655	739
27.06.2019 00:37	00:37	14898,19	100,2	12,3	640	652	692		629	654	739
27.06.2019 00:37	**00:37**	**14898,19**	**140,1**	**17,2**	**642**	**653**	**693**		**627**	**655**	**742**
27.06.2019 00:37	00:37	14898,19	139,2	17,1	642	653	693		627	655	742
27.06.2019 00:37	00:37	14898,19	138,6	17,0	642	653	693		627	655	742
27.06.2019 00:37	00:37	14898,19	138,1	16,9	642	653	693		627	656	742
27.06.2019 00:38	**00:38**	**14898,19**	**180,2**	**22,1**	**642**	**656**	**694**		**626**	**656**	**742**
27.06.2019 00:38	00:38	14898,19	179	22,0	641	655	695		626	656	742
27.06.2019 00:38	00:38	14898,19	178,5	21,9	641	656	695		626	656	742
27.06.2019 00:38	**00:38**	**14898,19**	**220,2**	**27,0**	**640**	**655**	**695**		**627**	**657**	**743**
27.06.2019 00:38	00:38	14898,19	218,7	26,8	640	656	695		627	657	743
27.06.2019 00:38	00:38	14898,19	217,9	26,7	640	656	695		627	657	743
27.06.2019 00:39	00:39	14898,19	217,4	26,7	640	656	695		627	657	743
27.06.2019 00:39	00:39	14898,19	217	26,6	640	656	695		627	657	743
27.06.2019 00:39	**00:39**	**14898,19**	**257,9**	**31,6**	**639**	**656**	**695**		**626**	**657**	**744**
27.06.2019 00:39	00:39	14898,19	256,7	31,5	639	656	695		627	657	744
27.06.2019 00:39	00:39	14898,19	256	31,4	640	656	695		626	658	744
27.06.2019 00:39	00:39	14898,19	255,4	31,3	640	656	695		627	658	745
27.06.2019 00:40	**00:40**	**14898,19**	**297,8**	**36,5**	**639**	**657**	**695**		**627**	**658**	**744**
27.06.2019 00:40	00:40	14898,19	292,9	35,9	639	657	696		627	659	745
27.06.2019 00:40	00:40	14898,19	289,5	35,5	639	657	696		627	660	744
27.06.2019 00:40	00:40	14898,19	287	35,2	639	657	695		627	660	744

Loadstep	Time	Pressure$_{cyl.}$ [bar]		Displ.$_{left}$ [mm]				Displ.$_{right}$ [mm]				Displ.$_{mean}$ [mm]	Δs [mm]	Δε [-]	Δσ$_m$ [MPa]
LS1.0	00:30	101	0	640	651	690	0,0	629	656	740	0,0	0,0	0,0	0,0000	12,4
LS1.1	00:31	140	39	641	653	692	1,6	627	657	742	0,2	0,9	0,9	0,0004	17,2
LS1.2	00:32	179	39	640	655	693	0,7	627	657	743	0,5	0,6	1,5	0,0007	22,0
			78				**2,3**				**0,8**	**1,5**			
LS2.0	00:33	91	0	642	652	690	0,0	628	654	738	0,0	0,0	0,0	0,0000	11,1
LS2.1	00:34	139	48	641	653	693	1,0	627	656	741	1,2	1,1	1,1	0,0005	17,0
LS2.2	00:34	179	40	641	655	694	1,0	626	656	743	0,5	0,7	1,8	0,0009	22,0
LS2.3	00:35	219	40	639	656	695	0,2	626	658	744	1,2	0,7	2,5	0,0012	26,8
LS2.4	00:36	257	38	640	656	695	0,0	627	657	743	0,0	0,0	2,5	0,0012	31,5
			166				**2,2**				**2,8**	**2,5**			
LS3.0	00:36	101	0	641	652	692	0,0	629	654	739	0,0	0,0	0,0	0,0000	12,4
LS3.1	00:37	139	38	642	653	693	1,1	627	655	742	0,8	0,9	0,9	0,0004	17,1
LS3.2	00:38	179	40	641	656	695	1,2	626	656	742	0,0	0,6	1,5	0,0007	22,0
LS3.3	00:38	218	39	640	656	695	0,0	627	657	743	1,0	0,5	2,0	0,0010	26,8
LS3.4	00:39	257	38	640	656	695	0,0	627	658	744	0,4	0,2	2,3	0,0011	31,5
LS3.5	00:40	292	35	639	657	696	0,3	627	659	744	0,8	0,5	2,8	0,0013	35,8
			191				**2,7**				**2,9**	**2,8**			

ν	0,2	-
Δp$_{cyl}$	77,9	bar
A$_{piston}$	0,79	m²
ΔN	6,1	MN
A$_{cont}$	0,64	m²
Δσ$_m$	9,6	MPa
Δs	1,5	mm
l	2077	mm
Δε	0,001	-
E$_{def}$	12300	MPa

ν	0,2	-
Δp$_{cyl}$	166,0	bar
A$_{piston}$	0,79	m²
ΔN	13,0	MN
A$_{cont}$	0,64	m²
Δσ$_m$	20,4	MPa
Δs	2,5	mm
l	2077	mm
Δε	0,001	-
E$_{def}$	16400	MPa

ν	0,2	-
Δp$_{cyl}$	190,8	bar
A$_{piston}$	0,79	m²
ΔN	15,0	MN
A$_{cont}$	0,64	m²
Δσ$_m$	23,4	MPa
Δs	2,8	mm
l	2077	mm
Δε	0,001	-
E$_{def}$	16700	MPa

Gripper Test 19

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
27.06.2019 19:17	**19:17**	**14901,12**	**93,9**	**11,5**	**677**	**697**	**737**		**602**	**623**	**689**
27.06.2019 19:17	19:17	14901,12	91,5	11,2	677	697	737		603	623	689
27.06.2019 19:17	19:17	14901,12	90	11,0	677	698	737		602	623	689
27.06.2019 19:18	19:18	14901,12	89,1	10,9	677	698	738		603	623	689
27.06.2019 19:18	19:18	14901,12	88,4	10,8	677	698	738		604	623	689
27.06.2019 19:18	19:18	14901,12	87,9	10,8	677	698	739		603	623	689
27.06.2019 19:18	19:18	14901,12	87,4	10,7	677	698	738		603	623	688
27.06.2019 19:18	**19:18**	**14901,12**	**129,2**	**15,9**	**675**	**698**	**741**		**606**	**627**	**691**
27.06.2019 19:18	19:18	14901,12	126,6	15,5	675	699	741		605	626	691
27.06.2019 19:19	19:19	14901,12	125,1	15,4	677	699	741		606	626	691
27.06.2019 19:19	19:19	14901,12	123,8	15,2	676	701	741		604	626	691
27.06.2019 19:19	**19:19**	**14901,12**	**174,7**	**21,4**	**679**	**702**	**742**		**606**	**627**	**691**
27.06.2019 19:19	19:19	14901,12	169,3	20,8	679	703	742		607	628	692
27.06.2019 19:19	19:19	14901,12	166,7	20,5	679	702	742		608	628	692
27.06.2019 19:19	19:19	14901,12	165,4	20,3	679	703	742		608	628	692
27.06.2019 19:20	19:20	14901,12	164,6	20,2	679	702	744		608	630	692
27.06.2019 19:20	**19:20**	**14901,12**	**101,7**	**12,5**	**678**	**699**	**742**		**606**	**624**	**693**
27.06.2019 19:20	19:20	14901,12	100,4	12,3	677	701	742		607	626	692
27.06.2019 19:20	19:20	14901,12	99,5	12,2	677	701	742		607	626	692
27.06.2019 19:20	19:20	14901,12	98,9	12,1	677	701	742		608	626	692
27.06.2019 19:21	19:21	14901,12	98,7	12,1	677	701	742		607	626	692
27.06.2019 19:21	**19:21**	**14901,12**	**140,8**	**17,3**	**679**	**701**	**741**		**606**	**626**	**692**
27.06.2019 19:21	19:21	14901,12	139,6	17,1	678	701	741		606	627	693
27.06.2019 19:21	19:21	14901,12	138,6	17,0	678	701	741		605	627	693
27.06.2019 19:21	19:21	14901,12	138,1	16,9	678	701	741		605	627	693
27.06.2019 19:21	19:21	14901,12	137,6	16,9	678	701	741		606	627	692
27.06.2019 19:22	19:22	14901,12	137,4	16,9	678	701	741		606	626	693
27.06.2019 19:22	19:22	14901,12	136,9	16,8	678	701	741		606	627	693
27.06.2019 19:22	**19:22**	**14901,12**	**179,8**	**22,1**	**679**	**703**	**741**		**605**	**627**	**694**
27.06.2019 19:22	19:22	14901,12	177,3	21,8	679	702	742		605	627	694
27.06.2019 19:22	19:22	14901,12	175,9	21,6	679	702	742		605	627	694
27.06.2019 19:22	19:22	14901,12	174,9	21,5	680	702	742		605	627	694
27.06.2019 19:23	19:23	14901,12	174,4	21,4	679	702	742		605	627	694
27.06.2019 19:23	19:23	14901,12	173,9	21,3	679	702	742		606	627	694
27.06.2019 19:23	19:23	14901,12	173,2	21,3	679	702	742		606	627	694
27.06.2019 19:23	**19:23**	**14901,12**	**217**	**26,6**	**679**	**703**	**741**		**607**	**627**	**694**
27.06.2019 19:23	19:23	14901,12	213,6	26,2	681	703	742		607	628	694
27.06.2019 19:23	19:23	14901,12	211,7	26,0	681	703	742		609	630	694
27.06.2019 19:24	19:24	14901,12	210,5	25,8	681	703	744		608	630	693
27.06.2019 19:24	19:24	14901,12	209,8	25,7	681	703	744		608	630	693
27.06.2019 19:24	**19:24**	**14901,12**	**257**	**31,5**	**681**	**702**	**741**		**608**	**629**	**694**
27.06.2019 19:24	19:24	14901,12	251,6	30,9	682	702	743		609	632	694
27.06.2019 19:24	19:24	14901,12	249,4	30,6	682	702	744		609	632	694
27.06.2019 19:24	19:24	14901,12	248,2	30,5	682	702	744		609	632	694
27.06.2019 19:25	19:25	14901,12	247	30,3	682	701	744		609	632	694
27.06.2019 19:25	**19:25**	**14901,12**	**99,9**	**12,3**	**685**	**704**	**744**		**604**	**623**	**692**
27.06.2019 19:25	19:25	14901,12	98,7	12,1	683	704	744		606	624	692
27.06.2019 19:25	19:25	14901,12	98	12,0	683	704	744		606	624	692
27.06.2019 19:25	19:25	14901,12	97,8	12,0	683	704	744		606	624	692
27.06.2019 19:25	19:25	14901,12	97,6	12,0	683	704	744		606	625	692
27.06.2019 19:26	19:26	14901,12	97,5	12,0	683	704	744		606	624	692
27.06.2019 19:26	**19:26**	**14901,12**	**141**	**17,3**	**682**	**703**	**744**		**606**	**626**	**692**
27.06.2019 19:26	19:26	14901,12	140,1	17,2	682	704	744		606	626	693
27.06.2019 19:26	19:26	14901,12	139,7	17,1	682	703	745		607	626	692
27.06.2019 19:26	19:26	14901,12	139,4	17,1	682	703	744		606	626	692
27.06.2019 19:26	19:26	14901,12	139,1	17,1	682	703	744		607	626	692
27.06.2019 19:27	**19:27**	**14901,12**	**181,3**	**22,2**	**682**	**704**	**745**		**606**	**627**	**693**
27.06.2019 19:27	19:27	14901,12	180,2	22,1	682	703	745		606	627	693
27.06.2019 19:27	19:27	14901,12	179,5	22,0	682	702	745		606	627	692
27.06.2019 19:27	19:27	14901,12	179	22,0	682	703	745		606	627	692
27.06.2019 19:27	19:27	14901,12	178,8	21,9	682	703	745		606	627	692
27.06.2019 19:27	**19:27**	**14901,12**	**220,4**	**27,0**	**683**	**704**	**745**		**608**	**627**	**692**
27.06.2019 19:28	19:28	14901,12	219	26,9	683	704	745		607	627	692
27.06.2019 19:28	19:28	14901,12	218,2	26,8	683	703	745		607	627	693

27.06.2019 19:28	19:28	14901,12	217,7	26,7	683	703	745		607	627	692
27.06.2019 19:28	19:28	14901,12	217	26,6	683	703	745		607	627	693
27.06.2019 19:28	**19:28**	**14901,12**	**258,1**	**31,7**	**685**	**704**	**745**		**606**	**627**	**693**
27.06.2019 19:28	19:28	14901,12	256,2	31,4	685	704	744		608	627	693
27.06.2019 19:29	19:29	14901,12	254,9	31,3	685	704	744		607	627	693
27.06.2019 19:29	19:29	14901,12	254,1	31,2	685	704	745		608	627	692
27.06.2019 19:29	19:29	14901,12	253,3	31,1	685	704	745		607	627	693
27.06.2019 19:29	19:29	14901,12	252,8	31,0	685	704	745		607	627	692
27.06.2019 19:29	**19:29**	**14901,12**	**297,5**	**36,5**	**688**	**704**	**744**		**608**	**628**	**694**
27.06.2019 19:29	19:29	14901,12	292,2	35,9	687	704	744		608	629	694
27.06.2019 19:30	19:30	14901,12	289	35,5	688	703	744		608	628	694
27.06.2019 19:30	19:30	14901,12	287	35,2	688	703	745		609	629	694

Loadstep	Time	Pressure$_{cyl.}$ [bar]		Displ.$_{-left}$ [mm]				Displ.$_{-right}$ [mm]				Displ.$_{-mean}$ [mm]	Δs [mm]	Δε [-]	Δσ$_m$ [MPa]
LS1.0	19:18	90	0	677	698	738	0,0	603	623	689	0,0	0,0	0,0	0,0000	11,0
LS1.1	19:18	126	36	676	699	741	1,2	605	626	691	2,6	1,9	1,9	0,0009	15,5
LS1.2	19:19	168	42	679	702	742	2,6	607	628	692	1,6	2,1	4,0	0,0019	20,6
			78				**3,8**				**4,2**	**4,0**			
LS2.0	19:20	100	0	677	701	742	0,0	607	626	692	0,0	0,0	0,0	0,0000	12,3
LS2.1	19:21	138	39	678	701	741	0,1	606	627	693	0,1	0,1	0,1	0,0001	17,0
LS2.2	19:22	176	37	679	702	742	1,0	605	627	694	0,4	0,7	0,8	0,0004	21,6
LS2.3	19:23	213	37	681	703	743	1,0	608	629	694	1,4	1,2	2,0	0,0010	26,1
LS2.4	19:24	251	38	682	702	743	0,2	609	631	694	1,3	0,7	2,7	0,0013	30,8
			151				**2,3**				**3,1**	**2,7**			
LS3.0	19:25	98	0	683	704	744	0,0	606	624	692	0,0	0,0	0,0	0,0000	12,1
LS3.1	19:26	140	42	682	703	744	0,0	606	626	692	1,0	0,5	0,5	0,0002	17,2
LS3.2	19:27	180	40	682	703	745	0,2	606	627	692	0,3	0,2	0,7	0,0003	22,1
LS3.3	19:28	218	39	683	703	745	0,5	607	627	692	0,4	0,4	1,2	0,0006	26,8
LS3.4	19:29	255	36	685	704	745	0,8	607	627	693	0,1	0,4	1,6	0,0008	31,3
LS3.5	19:29	291	37	688	704	744	0,6	608	629	694	1,3	1,0	2,5	0,0012	35,8
			193				**2,0**				**3,0**	**2,5**			

ν	0,2	-
Δp_{cyl}	78,4	bar
A_{piston}	0,79	m²
ΔN	6,2	MN
A_{cont}	0,64	m²
Δ$σ_m$	9,6	MPa
Δs	4,0	mm
l	2077	mm
Δε	0,002	-
E_{def}	4800	MPa

ν	0,2	-
Δp_{cyl}	150,8	bar
A_{piston}	0,79	m²
ΔN	11,8	MN
A_{cont}	0,64	m²
Δ$σ_m$	18,5	MPa
Δs	2,7	mm
l	2077	mm
Δε	0,001	-
E_{def}	13500	MPa

ν	0,2	-
Δp_{cyl}	193,2	bar
A_{piston}	0,79	m²
ΔN	15,2	MN
A_{cont}	0,64	m²
Δ$σ_m$	23,7	MPa
Δs	2,5	mm
l	2077	mm
Δε	0,001	-
E_{def}	18700	MPa

Gripper Test 20

Time		Tunnelmeter [m]	Pressure cylinders [bar]	Mean normal stress [MPa]	Movement left gripper - MP1 [mm]	Movement left gripper - MP2 [mm]	Movement left gripper - MP3 [mm]		Movement right gripper - MP1 [mm]	Movement right gripper - MP2 [mm]	Movement right gripper - MP3 [mm]
29.06.2019 13:34	**13:34**	**14915,81**	**93,4**	**11,5**	**602**	**599**	**590**		**663**	**688**	**727**
29.06.2019 13:34	13:34	14915,81	88,9	10,9	604	599	590		662	692	727
29.06.2019 13:34	13:34	14915,81	86,3	10,6	604	600	590		661	689	727
29.06.2019 13:34	13:34	14915,81	84,8	10,4	604	601	590		662	672	727
29.06.2019 13:34	13:34	14915,81	83,8	10,3	604	601	590		662	687	727
29.06.2019 13:34	**13:34**	**14915,81**	**124,3**	**15,3**	**603**	**601**	**595**		**667**	**687**	**729**
29.06.2019 13:35	13:35	14915,81	119,7	14,7	604	601	595		667	712	731
29.06.2019 13:35	13:35	14915,81	117,6	14,4	604	601	595		667	707	731
29.06.2019 13:35	13:35	14915,81	116,3	14,3	606	603	597		675	705	731
29.06.2019 13:35	13:35	14915,81	115,1	14,1	606	603	597		673	715	731
29.06.2019 13:35	13:35	14915,81	114,5	14,1	606	603	597		675	716	730
29.06.2019 13:35	13:35	14915,81	113,8	14,0	606	603	597		675	706	731
29.06.2019 13:36	13:36	14915,81	113,2	13,9	606	603	597		673	706	730
29.06.2019 13:36	**13:36**	**14915,81**	**169,5**	**20,8**	**608**	**601**	**600**		**676**	**703**	**732**
29.06.2019 13:36	13:36	14915,81	162,5	19,9	607	601	601		675	705	733
29.06.2019 13:36	13:36	14915,81	159,7	19,6	608	603	601		665	705	733
29.06.2019 13:36	13:36	14915,81	157,7	19,4	608	603	602		665	706	732
29.06.2019 13:36	13:36	14915,81	156,5	19,2	608	603	602		673	707	732
29.06.2019 13:37	13:37	14915,81	155,9	19,1	608	603	602		674	723	732
29.06.2019 13:37	13:37	14915,81	155,1	19,0	608	605	602		675	721	724
29.06.2019 13:37	13:37	14915,81	154,1	18,9	608	605	602		675	707	734
29.06.2019 13:37	13:37	14915,81	153,6	18,8	608	605	603		675	710	717
29.06.2019 13:37	**13:37**	**14915,81**	**100,4**	**12,3**	**608**	**605**	**602**		**672**	**706**	**705**
29.06.2019 13:37	13:37	14915,81	98,5	12,1	608	605	602		669	705	720
29.06.2019 13:38	13:38	14915,81	97,6	12,0	608	605	602		669	706	723
29.06.2019 13:38	13:38	14915,81	97,1	11,9	608	605	602		667	712	712
29.06.2019 13:38	13:38	14915,81	96,8	11,9	608	605	602		666	704	711
29.06.2019 13:38	**13:38**	**14915,81**	**140,5**	**17,2**	**608**	**605**	**604**		**665**	**705**	**727**
29.06.2019 13:38	13:38	14915,81	138,9	17,0	608	605	604		665	700	705
29.06.2019 13:38	13:38	14915,81	137,9	16,9	608	605	604		667	706	705
29.06.2019 13:39	13:39	14915,81	137,2	16,8	608	606	604		668	715	713
29.06.2019 13:39	13:39	14915,81	136,9	16,8	608	606	604		670	709	715
29.06.2019 13:39	13:39	14915,81	136,7	16,8	608	607	604		670	707	722
29.06.2019 13:39	13:39	14915,81	136,4	16,7	609	607	604		673	707	710
29.06.2019 13:39	13:39	14915,81	136	16,7	608	607	604		675	706	708
29.06.2019 13:39	**13:39**	**14915,81**	**174,9**	**21,5**	**610**	**607**	**606**		**677**	**705**	**721**
29.06.2019 13:40	13:40	14915,81	172,7	21,2	610	607	607		677	704	733
29.06.2019 13:40	13:40	14915,81	171,1	21,0	611	607	607		675	705	725
29.06.2019 13:40	13:40	14915,81	170	20,9	611	608	607		677	706	677
29.06.2019 13:40	13:40	14915,81	169,1	20,8	611	608	607		677	706	711
29.06.2019 13:40	13:40	14915,81	168,7	20,7	611	608	607		678	706	702
29.06.2019 13:40	13:40	14915,81	168,2	20,6	611	608	607		678	706	718
29.06.2019 13:41	13:41	14915,81	167,9	20,6	611	608	607		678	710	716
29.06.2019 13:41	**13:41**	**14915,81**	**215,4**	**26,4**	**612**	**607**	**607**		**680**	**710**	**719**
29.06.2019 13:41	13:41	14915,81	209,8	25,7	612	608	607		681	709	728
29.06.2019 13:41	13:41	14915,81	207,3	25,4	611	608	607		681	708	724
29.06.2019 13:41	13:41	14915,81	205,4	25,2	611	608	607		680	709	718
29.06.2019 13:41	13:41	14915,81	204,2	25,1	611	608	607		677	711	714
29.06.2019 13:42	13:42	14915,81	203,2	24,9	611	609	607		677	710	724
29.06.2019 13:42	**13:42**	**14915,81**	**256,5**	**31,5**	**615**	**608**	**607**		**680**	**710**	**716**
29.06.2019 13:42	13:42	14915,81	249	30,6	615	608	608		681	710	736
29.06.2019 13:42	13:42	14915,81	245,8	30,2	615	608	608		670	710	725
29.06.2019 13:42	13:42	14915,81	243,9	29,9	615	608	608		669	710	727
29.06.2019 13:42	13:42	14915,81	242,4	29,7	616	607	608		670	715	733
29.06.2019 13:43	13:43	14915,81	241,5	29,6	616	607	608		670	711	727
29.06.2019 13:43	**13:43**	**14915,81**	**102,1**	**12,5**	**610**	**609**	**607**		**669**	**706**	**729**
29.06.2019 13:43	13:43	14915,81	101,6	12,5	611	609	607		654	705	707
29.06.2019 13:43	13:43	14915,81	100,9	12,4	611	609	607		652	708	724
29.06.2019 13:43	13:43	14915,81	100,7	12,4	611	609	607		655	709	716
29.06.2019 13:44	13:44	14915,81	100,4	12,3	611	609	607		665	711	711
29.06.2019 13:44	13:44	14915,81	100,4	12,3	611	609	607		665	712	712
29.06.2019 13:44	13:44	14915,81	100,2	12,3	611	609	607		666	712	716
29.06.2019 13:44	**13:44**	**14915,81**	**141,7**	**17,4**	**613**	**609**	**607**		**666**	**695**	**714**
29.06.2019 13:44	13:44	14915,81	140,6	17,3	613	609	607		671	693	711

29.06.2019 13:45	13:45	14915,81	140,1	17,2	613	609	608		669	695	718
29.06.2019 13:45	13:45	14915,81	139,7	17,1	613	609	607		659	693	717
29.06.2019 13:45	13:45	14915,81	139,6	17,1	613	609	607		658	696	716
29.06.2019 13:45	**13:45**	**14915,81**	**181**	**22,2**	**615**	**610**	**609**		**655**	**700**	**714**
29.06.2019 13:45	13:45	14915,81	180	22,1	615	610	609		659	695	721
29.06.2019 13:45	13:45	14915,81	179,2	22,0	615	610	610		667	693	707
29.06.2019 13:46	13:46	14915,81	178,5	21,9	615	610	610		652	694	706
29.06.2019 13:46	13:46	14915,81	178,3	21,9	615	610	611		653	693	707
29.06.2019 13:46	13:46	14915,81	179,5	22,0	615	610	611		654	693	713
29.06.2019 13:46	**13:46**	**14915,81**	**219,9**	**27,0**	**616**	**610**	**612**		**653**	**695**	**716**
29.06.2019 13:46	13:46	14915,81	218,4	26,8	616	610	612		653	697	711
29.06.2019 13:46	13:46	14915,81	217,4	26,7	616	610	612		654	706	716
29.06.2019 13:47	13:47	14915,81	216,8	26,6	616	610	612		656	710	719
29.06.2019 13:47	13:47	14915,81	216,4	26,6	616	610	612		659	708	726
29.06.2019 13:47	13:47	14915,81	215,9	26,5	618	610	612		659	708	709
29.06.2019 13:47	**13:47**	**14915,81**	**260,1**	**31,9**	**619**	**610**	**612**		**657**	**708**	**711**
29.06.2019 13:47	13:47	14915,81	256,2	31,4	619	610	612		658	712	719
29.06.2019 13:47	13:47	14915,81	254,5	31,2	620	610	613		656	717	713
29.06.2019 13:48	13:48	14915,81	252,8	31,0	620	611	614		657	700	714
29.06.2019 13:48	13:48	14915,81	251,8	30,9	619	611	613		658	704	711
29.06.2019 13:48	13:48	14915,81	250,9	30,8	620	611	614		656	710	714
29.06.2019 13:48	13:48	14915,81	250,2	30,7	620	611	614		656	710	702

Loadstep	**Time**	**Pressure$_{cyl.}$ [bar]**		**Displ.$_{left}$ [mm]**				**Displ.$_{right}$ [mm]**				**Displ.$_{mean}$ [mm]**	**Δs [mm]**	**Δε [-]**	**Δσ$_m$ [MPa]**
LS1.0	13:34	87	0	604	600	590	0,0	662	686	727	0,0	0,0	0,0	0,0000	10,7
LS1.1	13:35	117	29	605	602	596	3,3	672	707	731	11,4	7,4	7,4	0,0035	14,3
LS1.2	13:36	158	41	608	603	602	3,1	673	710	730	1,1	2,1	9,4	0,0045	19,4
			71				**6,4**				**12,5**	**9,4**			
LS2.0	13:38	98	0	608	605	602	0,0	669	707	714	0,0	0,0	0,0	0,0000	12,0
LS2.1	13:39	138	39	608	606	604	1,0	669	707	713	0,0	0,5	0,5	0,0003	16,9
LS2.2	13:40	170	33	611	608	607	2,4	677	706	713	2,3	2,3	2,9	0,0014	20,9
LS2.3	13:41	208	37	611	608	607	0,4	679	710	721	4,7	2,5	5,4	0,0026	25,5
LS2.4	13:42	247	39	615	608	608	1,5	673	711	727	0,6	1,0	6,4	0,0031	30,3
			148				**5,3**				**7,5**	**6,4**			
LS3.0	13:43	101	0	611	609	607	0,0	661	709	716	0,0	0,0	0,0	0,0000	12,4
LS3.1	13:45	140	39	613	609	607	0,8	665	694	715	0,0	0,4	0,4	0,0002	17,2
LS3.2	13:45	179	39	615	610	610	1,9	657	695	711	0,0	1,0	1,4	0,0007	22,0
LS3.3	13:46	217	38	616	610	612	1,1	656	704	716	4,4	2,8	4,1	0,0020	26,7
LS3.4	13:48	254	36	620	611	613	1,7	657	709	712	0,6	1,1	5,2	0,0025	31,1
			153				**5,5**				**5,0**	**5,2**			

ν	0,2	-
Δp_{cyl}	70,8	bar
A_{piston}	0,79	m²
ΔN	5,6	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	8,7	MPa
Δs	9,4	mm
l	2077	mm
Δε	0,005	-
E_{def}	1800	MPa

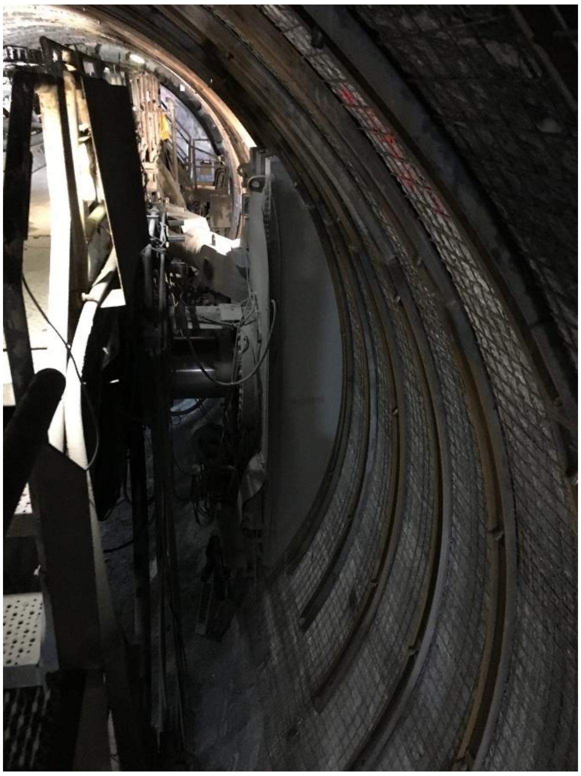
ν	0,2	-
Δp_{cyl}	148,4	bar
A_{piston}	0,79	m²
ΔN	11,7	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	18,2	MPa
Δs	6,4	mm
l	2077	mm
Δε	0,003	-
E_{def}	5700	MPa

ν	0,2	-
Δp_{cyl}	152,9	bar
A_{piston}	0,79	m²
ΔN	12,0	MN
A_{cont}	0,64	m²
$\Delta\sigma_m$	18,8	MPa
Δs	5,2	mm
l	2077	mm
Δε	0,003	-
E_{def}	7200	MPa

Appendix D

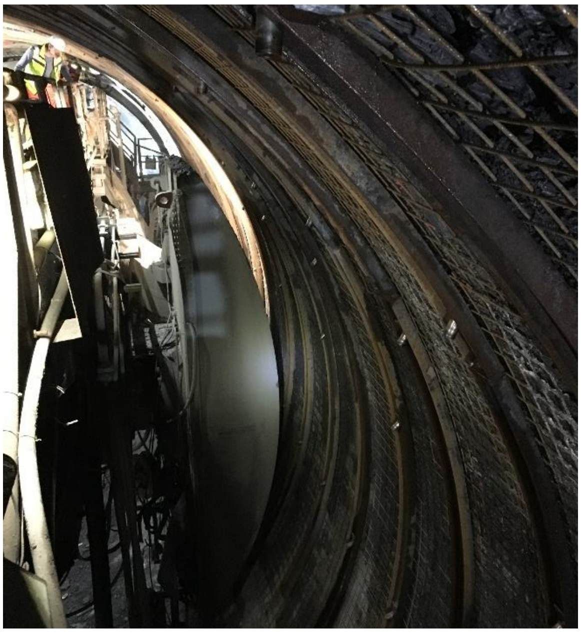
Photo documentation

Workspace beneath the TBM



Gripper extended

Gripper extended



Gripper pulled in