MASTER THESIS

Design of a Large Oedometer for the Determination of Stress Dependent Moduli on Fault Rocks

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Statutory Declaration

I herewith declare that I have completed the present master thesis independently making use only of the specified literature and aids. Sentences or part of sentences quoted literally are marked as quotations; identification of other references with regard to the statement and scope of the work is quoted. The thesis in this form or in any other form has not been submitted to an examination body and has not been published.

Graz, October 2011

Paul Wieser

... por Os uma y pere,
por Osc sostëgn y amur.

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Abstract

The knowledge of the deformation properties, especially of fault zones, is of tremendous importance for the selection of appropriate support measures and for minimizing risks in tunnelling. However, current laboratory techniques for the determination of Young's moduli or constraint moduli are fraught with restrictions: In rock mechanics laboratories the elastic properties are usually determined on small samples (h=100 mm, d=50 mm), while in soil mechanics laboratories the amount of maximum normal stress is usually limited with 1 MPa in standard oedometer tests, hence those conditions do not reflect the stress conditions for tunnels with high overburden.

In order to circumvent those deficiencies a *large oedometer* for the determination of stress dependent elastic parameters on fault rocks was designed and manufactured at the Institute for Rock Mechanics and Tunnelling at Graz University of Technology (A).

The main parts of the new laboratory apparatus are the oedometer ring, a base plate, two filter plates (to ensure drained test conditions), and a head plate. The oedometer ring has an inner diameter of 300 mm. The specimen height can be varied between 60 to 100 mm, allowing a maximum grain size of 20 mm. The maximum normal stress that can be applied on the specimen is 28,3 MPa.

The test set up is designed to conduct tests with fixed ring as well as with a floating ring. In order to minimize the friction between specimen and ring, the inner wall surface of the ring is greased and a high diameter-to-height ratio of the specimen is provided. The ring is situated on three 50 kN load cells to determine the amount of friction force between ring and specimen. The vertical displacements are measured by three displacement transducers and the axial force is measured by a 1 MN load cell. The oedometer ring is equipped with three strain gauges at different heights to determine the circumferential strains, which allows the calculation of Poisson's ratio.

The Master Thesis describes the design and development of the large oedometer test apparatus, including all components and instrumentation. The data evaluation techniques are shown exemplarily, highlighting the features of the apparatus.

Kurzfassung

Bei der Tunnelplanung ist unter anderem die Kenntnis über die elastischen Eigenschaften des Gebirges, insbesondere in Störungszonen, für eine wirtschaftliche Ausbaufestlegung und der Gewährleistung eines minimalen Sicherheitsrisikos von großer Bedeutung. Die gängigen Labormethoden zur Bestimmung von Elastizitätsmoduln oder Steifemoduln sind mit Einschränkungen behaftet: In felsmechanischen Labors werden die elastischen Eigenschaften in der Regel an Kleinproben bestimmt (h=100 mm, d=50 mm). In bodenmechanischen Labors ist die Größe der maximal aufzubringenden Vertikalspannung in Standard Ödometer Versuchen meist mit 1 MPa beschränkt und spiegelt somit nicht die Spannungssituation auf Tunnelniveau wieder.

Um diese Nachteile zu beseitigen wurde ein *Großödometer* für die Bestimmung von spannungsabhängigen Steifemoduln an Störungsgesteinen am Institut für Felsmechanik und Tunnelbau der Technischen Universität Graz (A) entwickelt und gefertigt.

Die Hauptteile dieses neue Laborgerätes sind ein Ödometer Ring, eine Fußplatte, zwei Filterplatten (um drainierte Verhältnisse zu gewährleisten) und eine Kopfplatte. Der Ödometer Ring hat einen Durchmesser von 300 mm. Die Höhe des Probekörpers liegt zwischen 60 und 100 mm und erlaubt einen Größtkorn von 20 mm. Die maximale vertikale Spannung, die auf einem Probekörper aufgebracht werden kann, beträgt 28,3 MPa.

Der Versuchsaufbau erlaubt die Verwendung eines Ödometers sowohl mit festem Ring als auch mit schwebendem Ring. Um die Reibung zwischen Probekörper und Ring Innenwand zu minimieren, wird die Innenwand des Ringes eingefettet und ein hohes Verhältnis zwischen Durchmesser und Höhe des Probekörpers eingehalten. Der Ring stützt sich auf drei 50 kN Kraftaufnehmer, um die Reibungskräfte zwischen Probekörper und Ring zu ermitteln. Die vertikalen Verschiebungen werden von drei induktiven Wegaufnehmern, die aufgebrachte Last von einem 1 MN Kraftaufnehmer gemessen. Der Ödometer Ring ist mit drei Dehnungsmessstreifen auf verschiedenen Höhen ausgestattet, um die seitlichen Ausdehnungen messen zu können, welche zur Bestimmung der Querdehnungszahl dienen.

Die Master Arbeit beinhaltet die Planung und Entwicklung eines Großödometers mit allen Komponenten und dazugehöriger Messtechnik. Die Versuchsauswertung ist exemplarisch dargestellt und es wird großes Augenmerk auf die Funktionen des Laborgerätes gelegt.

Sommario

Nella progettazione di gallerie, la conoscenza dei parametri elastici delle rocce, specialmente di rocce di faglia, è di grande importanza per una realizzazione economica e per garantire la sicurezza durante lo scavo. Le attuali modalità per la determinazione di moduli di elasticità e di moduli di compressibilità in laboratorio ha dei limiti: nei laboratori di meccanica delle rocce la sperimentazione viene effettuata su provini di dimensione ridotte (l=100 mm, d=50 mm). Nei laboratori di geotecnica, il carico assiale massimo apportato al provino in condizioni edometriche, è di 1 MPa, il quale non rispecchia le condizioni tensionali reali per gallerie profonde.

Per far fronte a questi limiti è stato progettato e construito presso l'Istituto di Meccanica delle Rocce e Tunnel dell'Università Tecnologica di Graz (A) un *edometro gigante* per la determinazione di moduli di compressibilità dipendenti dallo stato tensionale, su provini di rocce di faglia.

I componenti principali del nuovo strumento sperimentale sono: una cella edometrica, una piastra di base, due dischi drenanti (per favorire il drenaggio) ed una piastra di testata. La cella edometrica ha un diametro di 300 mm. In altezza il provino misura tra i 60 e 100 mm, permettendo un diametro dei grani massimo di 20 mm. La compressione assiale efficace massima attribuita al provino è di 28,3 MPa.

L'assetto sperimentale consente l'utilizzo di un edometro sia con cella edometrica fissa che con cella edometrica sospesa. Per minimizzare le tensioni tangenziali indesiderate di attrito e di aderenza fra il provino e la parete della cella edometrica si lubrifica la parete della cella e si mantiene un rapporto alto tra diametro e altezza del provino. La cella edometrica è appoggiata su tre celle di carico da 50 kN per determinare la forza di attrito fra il provino e la cella. Le deformazioni assiali vengono misurate da tre trasduttori di spostamento induttivi e il carico assiale applicato viene misurato da una cella di carico da 1 MN. La cella é dotata di tre estensimetri applicati a diverse altezze, per la registrazione delle deformazioni radiali della cella, necessarie per il calcolo del modulo di Poisson del provino.

Questa tesi di laurea contiene la progettazione e lo sviluppo di un edometro gigante con tutti i componenti aggiuntivi e la relativa tecnica di misurazione. L'analisi degli esperimenti è a titolo esemplicativo e viene data particolare attenzione alle funzioni dello strumento sperimentale.

List of Symbols

A_0 .... Initial Specimen Area
A_{OR} .... Ring Area
d_0 .... Initial Specimen Diameter
Δu_{c} .... Circumferential Displacements
Δu_{r} .... Radial Displacements
d_{FP} .... Filter Plate Diameter
D_{max} .... Maximum Grain Size
$d_{\mathrm{OR,i}}$ .... Inner Ring Diameter
$d_{\mathrm{OR,o}}$ .... Outer Ring Diameter
E .... Young's Modulus
e_0 .... Initial Void Ratio
ϵ_{a} .... Axial Strain
ϵ_{c} .... Circumferential Strain
E_{s} .... Constrained Modulus
$E_{\mathrm{s,sec}}$ .... Constrained Secant Modulus
$E_{\mathrm{s,tan}}$ .... Constrained Tangent Modulus
E_{Steel} .... Young's Modulus of Steel
F_{R} .... Friction Force
F_{v} .... Axial Force
$F_{\mathrm{v,LC}}$ .... Axial Force measured by Load Cell
g .... Acceleration of Earth's Gravity
γ .... Unit Weight of Soil
γ_{d} .... Unit Weight of Dry Soil
γ_{s} .... Unit Weight of Soil Particles
γ_{w} .... Unit Weight of Water
h_0 .... Initial Specimen Height
$h_{\mathrm{av,1}}$ .... Distance Between Upper Edge of the Ring and the Lower Filter Plate With Geotextile

$h_{\mathrm{av,2}}$ .... Distance Between Upper Edge of the Ring and Upper Edge of Specimen

h_{OR} .... Ring Height

h_{z} .... Depth of Recovery

k_0 .... Coefficient of Earth Pressure at Rest

m_0 .... Initial Specimen Mass

$m_{0,\mathrm{as}}$ .... Assumed Specimen Mass

m_{OE} .... Large Oedometer Mass

m_{SP} .... Moist Specimen Mass

$m_{\mathrm{SP,d}}$ .... Dry Specimen Mass

$m_{\mathrm{SP,w}}$ .... Specimen Water Mass

n_0 .... Initial Porosity

ν .... Poisson's Ratio

P_{100} .... Specimen with a height of 100 mm

P_{60} .... Specimen with a height of 60 mm

r .... Radius

r_{i} .... Inner Ring Radius

r_{o} .... Outer Ring Radius

s .... Compression

$\overline{s}$ .... Average Displacements

s_{c} .... Correction Inner System Stiffness

σ_{r} .... Radial Stress

$\sigma^{'}_{\mathrm{v,i}}$ .... Effective Axial Stress

$\sigma^{'}_{\mathrm{v,0}}$ .... Effective Overburden Pressure

$\sigma^{'}_{\mathrm{z,P100}}$ .... Dead Load for P_{100} Specimens

$\sigma^{'}_{\mathrm{z,P60}}$ .... Dead Load for P_{60} Specimens

S_{r} .... Degree of Saturation

$S_{\mathrm{r,0}}$ .... Initial Degree of Saturation

u .... Radial Deformation

U_{o} .... Outer Ring Perimeter

V_0 .... Initial Specimen Volume

W_0 .... Initial Specimen Weight

w_0 .... Initial Liquid Water Content

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1 Introduction

In tunnelling the knowledge of rock mass behavior and its description by means of mechanical parameters is essential for the design and construction of tunnelling and underground structures. The knowledge of deformation properties, especially in fault zones, is of essential importance for the selection of appropriate and economical construction methods. The determination of these rock mass properties occurs on site with in-situ test methods or ex-situ with laboratory test methods.

In rock mechanics laboratories elastic moduli are usually determined on small-size specimens with a height to width ratio of 1:2 such as in *unconfined compression tests*. The specimen preparation mode for rock mass samples is not applicable on fault rock samples because of the soft and weak material which will disintegrate during cutting and grinding.
In soil mechanics laboratories the elastic moduli are determined by using an *one-dimensional compression test* in a standard oedometer apparatus with an inside radius of 70 mm and approximately 20 mm in height, but should at least have a minimum height of the fivefold of the maximum grain size [see 1, P. 14]. The maximal applicable axial stress usually does not exceed 1 MPa which does not reflect the stress situation for tunnels with higher overburden.

Due to these restrictions the current test methods to define the *Young's modulus* or the *constrained modulus* are limited and not suitable to determine these parameters on fault rocks. A new test method for determining stress dependent moduli on fault rocks has to be developed. Thereby it is important to consider the following requirements:

- Test as accurately as possible represents the situation in nature.
- Acceptable production and maintenance costs.
- Uncomplicated and reliable functionality of the test device.
- Easy test set up.
- Automatic evaluation.

In order to achieve the best results and fulfill the mentioned requirements a *large oedometer* was designed at the *Institute for Rock Mechanics and Tunnelling* at *Graz University of Technology*.

This master thesis is about the design of a *large oedometer* for the determination of stress dependent *Young's moduli* and *constrained moduli* on fault rocks. Large scale tests on sand, gravel, and fault rocks samples were conducted in the *Rock Mechanics Laboratory* at TU-Graz. The functionality of the new apparatus was tested by changing specimen parameters such as water content, specimen height, compaction work at assembly, and also different types of loading sequences. An appropriate specimen preparation and test set up was developed.

The definitions and symbols in this work are based on the *E DIN-18135* standard [see 1, p. 3]. The calculation method is also based on the last mentioned standard, on the *ÖNORM CEN ISO/TS 17892-5* [2], and on the *ASTM D 2435-04* [3] standards.

1.1 Large Oedometer and Stress Dependent Moduli

The *large oedometer test* or *large consolidation test* is a well known experimental type in geotechnical engineering. Many researchers studied and developed different devices and test set-ups searching for solutions for defined geotechnical problems (see figure 1.1 on page 6). Depending on the purpose and the tested materials a variety of *large oedometers* were designed. The main reason for a new method for laboratory testing of fault rocks is to eliminate the disadvantages of the standard oedometer test and to standardize laboratory testing procedures [4; 5]. Thereby some important aspects have to be taken into consideration.

System Stiffness

The inner system stiffness by means of deformation and friction of the apparatus is not negligible [6; 7; 8] if the measured deformations exceed a specific value [9], which is not defined in a standard or elsewhere. The system stiffness depends on the maximal applicable load, the test assembly, and is more relevant for stiff specimens [2].

Friction Losses

The friction between specimen and the *oedometer ring* vertical wall surface leads to an overestimation of the *constrained modulus* if disregarded [10; 9]. Two practical solutions are given in the studied literature.

The first one is based on the suggestions by *E DIN 18135* [see 1, p. 14], *ÖNORM CEN*

ISO/TS 17892-5 [see 2, p. 10], and *ASTM D 2435-04* [see 3, p. 3] standards to observe a high diameter-to-height ratio (D:H) of 3 to 5 to minimize the effects of friction. *Ng* et al. [4] and *Unal* and *Cakmakci* [5] recommend a smooth wall surface of the *oedometer ring* and to line the surface with a plastic or rubber sheet greased on both sides. However, by utilizing this method no elimination of the friction influence is possible, only a reduction of it is achievable [9].

The second practical solution is a direct way to measure the friction force influence on the test procedure. The measured values have to be subtracted from the applied axial load. *Elbinger* and *Pfeifer* [11] applied three load cells of 150 kN each under the lower *filter plate*. *Düsterloh* [9] followed a similar approach and mounted 3 load cells of 500 kN each between the base plate and the ring. He expected friction losses between 20 % to 40 % of the applied axial load. The actually measured friction losses are not mentioned in his dissertation [9].

Lateral Displacements

To ensure the oedometric conditions of uniaxial loading and lateral constraint, the change in diameter of the ring should not exceed 0,03 % of the diameter under the greatest load applied [see 1, p. 14]. The amount of lateral expansion of the confinement can be controlled by measuring the lateral displacements utilizing displacement transducers with a high resolution [5; 4]. *Düsterloh* [9] suggested not only to take account of the lateral displacements but also to utilize the measured data to calculate the *Poisson's ratio* and deduce the *Young's modulus* of the examined specimen. For this purpose he designed a special *oedometer ring* with three diaphragm loading cells on the basis of strain gauge rosettes placed on the wall and shifted by 120°.

Specimen Preparation

Considering the fact, that the recovery of large undisturbed samples is difficult and expensive, mostly disturbed samples are available. The specimen preparation procedure subjected to high disturbance should be developed according to the purpose focused [4].

Düsterloh [9] used a cone to fill the *large oedometer* with dry material to a fine packing density to exclude the effect of different initial densities on the test results.

In *Elbinger* and *Pfeifer* [11] and *Günther* and *Mäding* [6; 7] the loose soil was placed with its natural moisture content in layers and compacted to the specified void ratio by a hand tamper.

Reinhold and *Kudla* [8] dumped the specimen with its natural moisture in the *oedometer ring* to the target height and compacted the granular soil by vibration to achieve different initial densities. After leveling the surface the specimen was saturated through the filter plates.

Ng et al. [4] first filled the cell with water to about one third of the specimen thickness, deposited weighed portions of soil until the selected height was reached and then submerged the specimen in water.

Drainage

Using moist or saturated specimens each stress level is maintained until excess pore water pressures are completely dissipated [3]. To allow water to drain freely during consolidation, *filter plates* have to be placed on top and bottom of the specimen. They shall consist of ceramic or a noncorrosive material [1] and be fine enough to prevent intrusion of soil into the pores [3].
The large diameter of the specimen used makes it difficult to find standard *filter plates* suitable for the *large oedometer test*. *Elbinger* and *Pfeifer* [11] built two *filter plates* with a diameter of 695 mm consisting of a mixture of grit (10 mm) and cement at the rate of 3:1 and screw them on the top and bottom steel plates.
Ng et al. [4] constructed a drainage composite plate with a diameter of 420 mm and a height of 18,7 mm. It consists of a 5 mm thick steel plate, a 1 mm thick porous steel plate, and 12,7 mm diameter steel bearing balls sandwiched between the two steel plates and confined by a 5 mm high and 5 mm wide curb. The composite plate is held by screws and positioned on the top of the specimen.

Grain Size

The ratio between the height of the *oedometer ring* and the maximum grain size of the sample influences the compression behavior of the entire specimen [9]. To reduce the influence, the specimen height shall not be less than 5 times the maximum grain diameter [1; 2]. In the *ASTM D 2435-04* [3] standard a higher ratio of 1:10 between granulate diameter and specimen height is demanded.
The *large oedometer* by *Elbinger* and *Pfeifer* [11] has an inner diameter of 695 mm and a height of 600 mm while having 30 mm of the maximum grain size tested, which follows a ratio of 1:20.
Düsterloh [9] takes account of a grain diameter to ring diameter of 1:10 and a grain diameter to ring height of 1:5 using a maximal grain size of 30 mm.
Unal and *Cakmakci* [5] used in their test setup specimens with a diameter of 600 mm, a maximum grain size up to 125 mm with a ratio of 1:4,8. Neither specimen nor ring height is mentioned in their paper.
The inner diameter of the *large oedometer* fabricated by *Ng* et al. [4] amounts to 425 mm. Two cells with different heights, 220 mm and 370 mm, are used. The specimen height is between 80 mm to 230 mm and the maximum grain size is 5 mm. The ratio between grain size and specimen height is about 1:16 and 1:46.

1.2 Thesis Contributions

The main purpose of this master thesis is the determination of the stress dependent *Young's modulus* and *constrained modulus* on fault rocks. For this reason a *large oedometer* has to be designed and manufactured. The testing samples and the available compression test machine at the *Institute for Rock Mechanics and Tunnelling* determine the assembly and dimensions of the apparatus. An adequate *large oedometer test* procedure has to be developed to achieve useful results to calculate elastic parameters of fault rocks.

Referring to section 1.1 and to the literature review in figure 1.1 on page 6 no *large oedometer apparatus* has been developed for testing fault rocks in tunnelling in the past. The main contribution is to eliminate the disadvantages of previous testing methods and to include all significant parameters to develop an easy and clear testing technique.

It is worthwhile to solve this problem because of the high importance of knowing elastic parameters of fault rocks in the design of tunnels and underground projects in fault zones. A standardized testing procedure can be implemented in the laboratory testing program and executed by every operator after a short training.

LITERATURE REVIEW MATRIX

LEGEND
- # Case Study
- @ Theoretical Approach
- S Standard

RELEVANCE
- * few
- * * satisfactory
- * * * good
- * * * * high
- * * * * * essential

				TARGETS								
				Large Oedometer		Test Preparation				Evaluation		
Nr.	Year	Authors	Title	Design	Fabrication	Specimen Preparation	Consideration of Wall Friction	Measurement of Circumferential Strain	Experimental Procedure	Mathematical Models	Stress Dependancy on Constrained Modulus	Relevance
01	2007	Reinhold C. & Kudla W.	Großödometerversuche und spannungsabhängige Steifemoduli bei hohen Überlagerungsspannungen für nichtbindige, tertiäre Grundwasserleiter des Lausitzer Tagebaureviers	#		#			#	#	#	* * * *
02	2006	Ng A.M.Y., Yeung A.T., Lee P.K.K., & Tham L.G.	Design, Fabrication, and Assembly of a Large Oedometer	#	#	#			#			* * * * *
03	1990	Al Awad S. & Günther G.	Abschätzung des Erdruhedruckwertes aus Großoedometerversuchen				@			@		* * *
04	1980	Elbinger K. & Pfeifer M.	Ein Großödometer zur Bestimmung der Steifezahl gemischtkörniger Lockergesteine	#	#		#					* * *
05	1985	Collumbi A.	Ein Großödometer für Vergleichsuntersuchungen von Vertikaldräns									*
06	1988	Inoue S.	Consolidation Behaviors of Compacted Soils Using a Large Scale Oedometer	@		@				@		* *
07	1984	Günther G. & Mäding H.	Verformungsverhalten gemischtkörniger Lockergesteine			#	#		#	#		* * *
08	2004	Castellanza R. & Nova R.	Oedometric Tests on Artificially Weathered Carbonatic Soft Rocks	#			#	#	#			* *
09	2003	Grozic J.L.H., Lunne T., & Pande S.	An oedometer test study on the preconsolidation stress of glaciomarine clays							#	#	* * * *
10	2000	Reznik Y.M.	Engineering approach to interpretation fo oedometer tests performed on collapsible soils				@					*
11	2004	Lim W.L., McDowell G.R., & Collop A.C.	Quantifying the relative strenghts of railway ballasts									*
12	2008	Barros P.L.A. & Pinto P.R.O.	Oedometer Consolidation Test Analysis by Nonlinear Regression						@	@		* *
13	1987	Günther G. & Mäding H.	Einflußgrößen auf die Steifezahl gemischtkörnig-bindiger Lockergesteine			@	@		@			* * *
14	2003	Oldecop L.A. & Alonso E.E.	Suction effects on rockfill compressibility									*
15	2002	Aversa S. & Nicotera M.V.	A Triaxial and Oedometer Apparatus for Testing Unsaturated Soils									*
16	2001	Riedmüller G., Brosch F.J., Klima K. & Medley E.W.	Engineering Geological Characterization of Brittle Faults and Classification of Fault Rocks									*
17	1993	Düsterloh U.	Gebirgsmechanische Untersuchungen zum Nachweis der geotechnischen Sicherheit von Deponiekavernen	#			#	#		#	#	* * *
18	2000	Erdal U. & Guray C.	Laboratory Evaluation of Cemented Backfill Materials for Mines	#		#	#	#				* * * *
19	2007	Kolymbas D.	Geotechnik - Bodenmechanik, Grundbau und Tunnelbau						@	@		* *
20	2004	ÖNORM CEN ISO/TS 17892-5 (Vornorm)	Geotechnische Erkundung und Untersuchung - Laborversuche an Bodenproben. Teil5: Oedometerversuch mit stufenweiser Belastung			S			S			* * * *
21	1999	DIN 18135 (Entwurf)	Eindimensionaler Kompressionsversuch			S			S	S		* * * * *
22	1989	ÖNORM B 4420	Erd- und Grundbau. Untersuchung von Bodenproben. Grundsätze für die Durchführung und Auswertung von Kompressionsversuchen			S			S			* *
23	2004	ASTM D 2435-04	Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading			S			S	S		* * * * *
24	2006	ASTM D 4186-06	Standard Test Methods for One-Dimensional Consolidation Properties of Saturated Cohesive Soils Using Controlled-Strain Loading			S			S	S		* * * *

Figure 1.1: Literature Review Matrix

2 Large Oedometer Design

In the *large oedometer* design the interaction between every single component has to be planned in detail to prevent malfunctions of the apparatus, unreliable test results, complex handling, and high costs. The knowledge about the requirements and the boundary conditions is essential for a successful planning.

2.1 General Requirements

The definition of an *oedometer test* is given in the *ASTM D 2435-04* standard [see 3, p. 2]:

> „In this test method a soil specimen is restrained laterally and loaded axially with total stress increments. Each stress increment is maintained until excess pore water pressures are completely dissipated. During the consolidation process, measurements are made of change in the specimen height and these data are used to determine the relationship between the effective stress and void ratio or strain, [...].“

This definition and the following three main boundary conditions defined the starting point for designing the *large oedometer*:

1. The effective overburden pressure which the sample has undergone ($\sigma'_{\mathrm{v},0}$).
2. The grain-size distribution and maximum grain size of the sample ($D_{\max}$).
3. The available compression test machine.

For testing fault rocks in underground structures with high overburden high stress levels have to be imposed on the specimen. These stress levels have to be at least as high as the effective overburden pressure the sample has undergone, which depends on the sampling point. The grain size distribution and maximum grain size of the sample vary by the ground condition on site. The maximum pressure that can be applied on a specimen is limited by the compression test machine which in this case has a maximal test load of 3.000 kN. Further the clear dimensions of the machine are restricted and show a maximum height of 320 mm and a maximum width of 350 mm.

Once the inner diameter of the *oedometer ring* is fixed, a maximum grain size and a maximum effective pressure can be established. On the basis of the above mentioned main requirements and the definition of the oedometer test a first draft was made in accordance to the proposals of the *E DIN-18135* standard [1]. After reflecting on the test set-up and test procedure the draft was then enhanced to considerate the following needs:

- A method to measure and taking account of the inner *system stiffness*.
- A direct way to measure the friction force between specimen and *oedometer ring*.
- A wise to gauge the lateral displacements.

2.2 Design

The new *large oedometer* (figure 2.2) was designed at the *Institute for Rock Mechanics and Tunnelling* at *Graz University of Technology*. The design derives from the standard *Casagrande oedometer* and in all its criteria observes the state of the art. The new apparatus can measure the actual axial force imposed on the specimen, the vertical and lateral displacements, and the friction force between *oedometer ring* and specimen.
Its compact and cylindrical shape allows a space-saving and clear assembly. All components matched with the test procedure and the compression test machine. The apparatus consists of the following components (see also figure 2.1):

- Large Oedometer Ring
- Base Plate
- Two Filter Plates
- Head Plate
- Big Load Cell
- Three Displacement Transducers
- Three Strain Gauges
- Three Plunger Suspensions
- Three small Load Cells
- Computerized Data Acquisition System
- Compression Test Machine

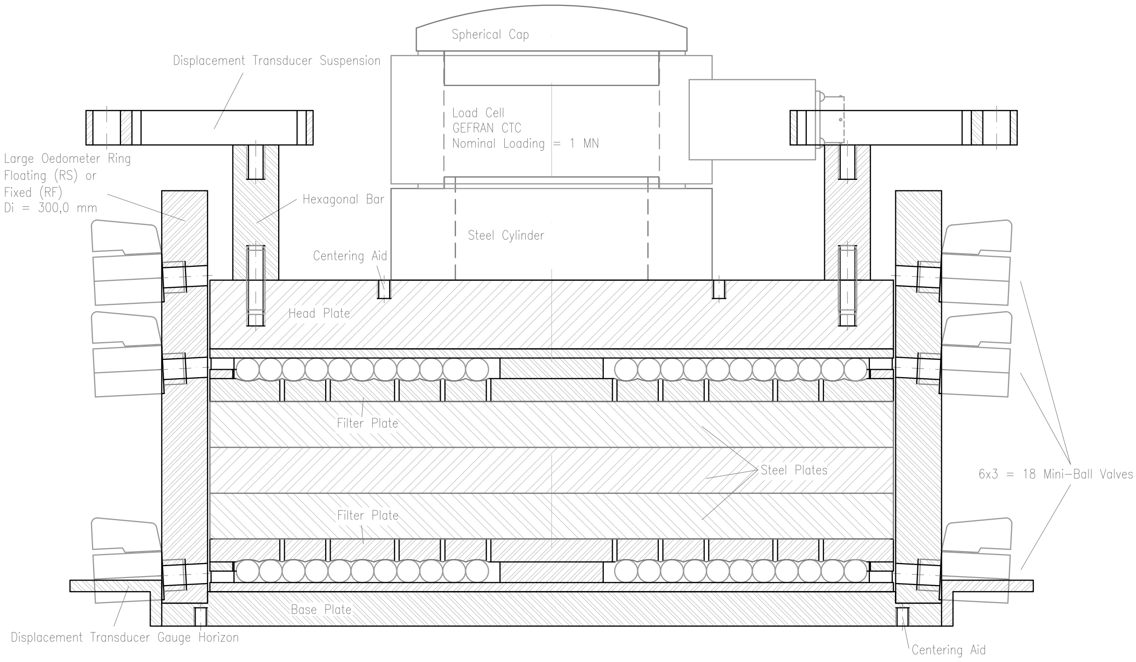


Figure 2.1: Large Oedometer Caption

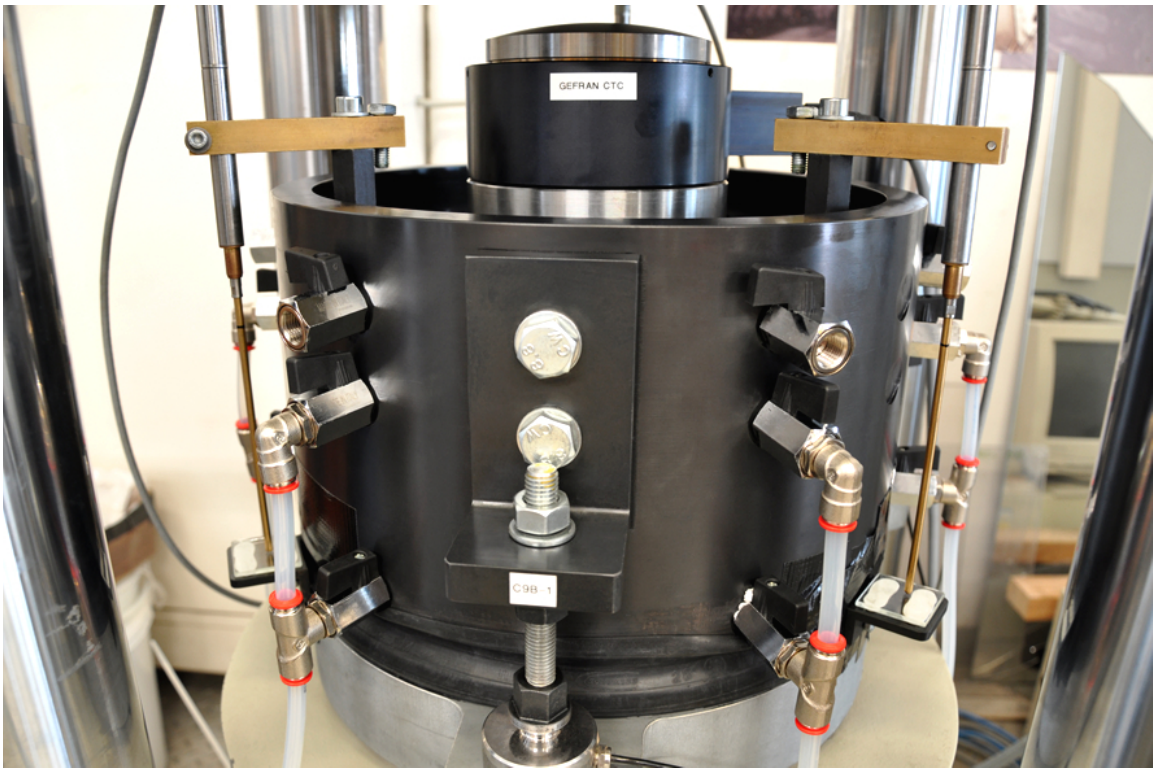


Figure 2.2: The Large Oedometer

The *large oedometer* has an outer diameter of 340 mm, an inner diameter of 300 mm, and a maximum height of 311 mm. The main dimensions are shown in figure 2.3 and figure 2.4. Dry and saturated specimens with a height between 60 mm (P_{60}) and 100 mm (P_{100}) containing a maximum grain-size up to 20 mm fulfilling all dimension criteria mentioned in the *E DIN-18135* standard [see 1, p. 14] can be tested. The ratio between inner diameter and maximum specimen height is 3, between specimen height and maximum grain size 5 (see also table 2.1). Four set-ups can be chosen, two with a fixed ring and two with a floating ring. The gap between *filter plate* and *large oedometer ring* is 1 mm. The vertical applied stress on the specimen is limited by the nominal loading of the load cell and is up to 14,15 MPa. The weight of the assembled oedometer without specimen is approximately 100 kg.

Due to the restricted dimensions of the compression test machine a special test set-up (see chapter 4) was developed. The *large oedometer* assembly follows a modular concept in which every single component is designed to be easily mounted. This advantage of flexibility is convenient for cleaning the single parts and for replacing elements in case of damage. The disadvantage of such assembly concept is the fact that the set-up is quite time consuming.

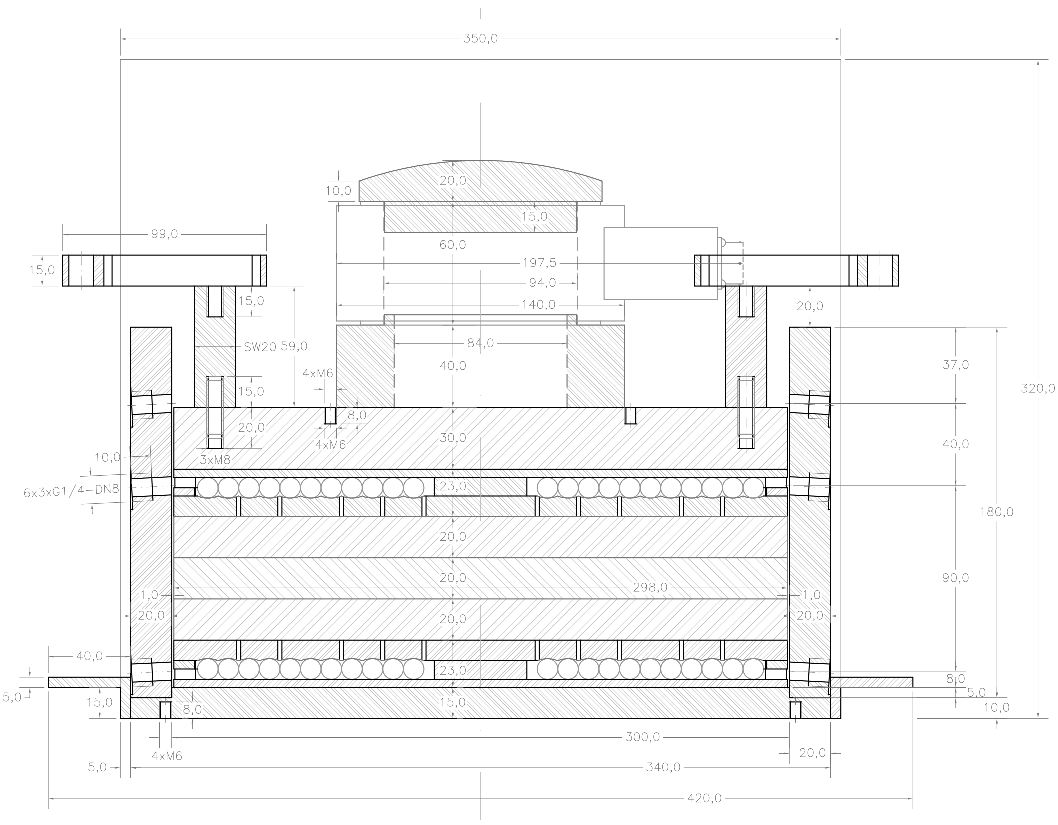


Figure 2.3: Cross Section

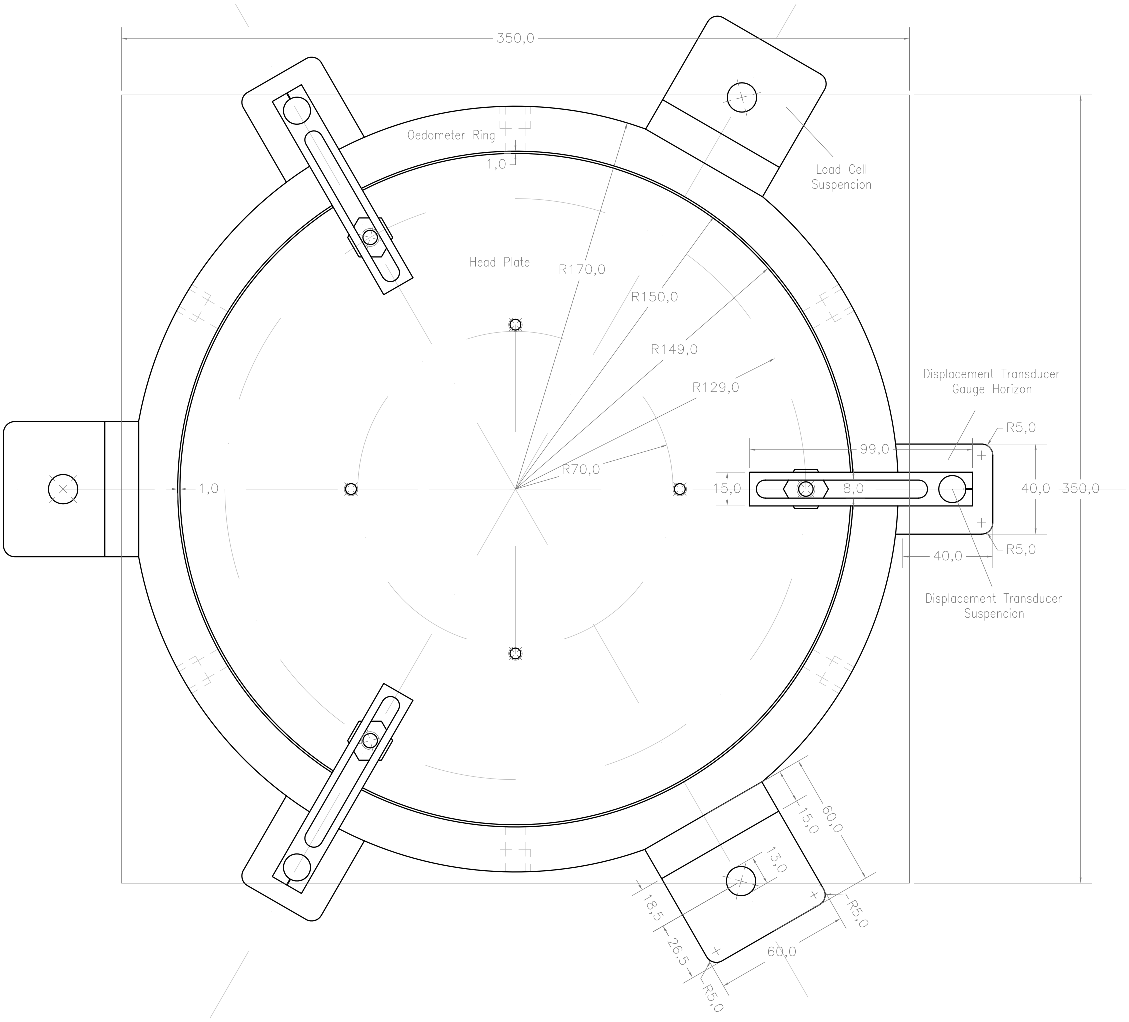


Figure 2.4: Plan View

Description	**Shortcut**	**Dimension**	**DIN 18135 [1]**
Inner Ring Diameter	$d_{\mathrm{OR,i}}$	300 mm	$3 \times h_0$
Outer Ring Diameter	$d_{\mathrm{OR,o}}$	340 mm	
Ring Height	h_{OR}	180 mm	$\geq 5 \times D_{\mathrm{max}}$
Ring Area	A_{OR}	0,071 mm^2	
Filter Plate Diameter	d_{FP}	298 mm	$< d_{\mathrm{OR,i}}$
Large Oedometer Mass	m_{OE}	100 kg	
Maximum Specimen Height	h_0	100 mm	$5 \times D_{\mathrm{max}}$
Maximum Grain Size	D_{max}	20 mm	

Table 2.1: Large Oedometer Dimensions.

2.3 Components

The detailed design drawings of all components are found in the appendix B on page 53.

2.3.1 Large Oedometer Ring

The *large oedometer ring* (figure 2.5) is a cylindrical 20 mm thick steel pipe with an inner radius ($d_{\mathrm{OR,i}}$) of 300 mm, an outer radius ($d_{\mathrm{OR,o}}$) of 340 mm, and a height (h_{OR}) of 180 mm. It can contain specimens with a height from 60 mm to 100 mm. A cross section and a plan view of the ring are given in figure 2.6 and 2.7.

The ring has six outlet ports in three different layers, which accounts for varying the sample height. The outlet ports are equipped with 2/2-*way-mini-ball valves* for controlling the drainage conditions. Three surfaces shifted by 120° (100 × 63,6 mm) are milled out on the top of the ring for mounting the *plunger suspensions* (see figure 2.20, p. 22) to measure the friction force losses.

The ring is made of a pre-hardened high tensile tool steel, denominated as DIN 40CrMnMo-7 (WNr. 1.2311), which was double-hardened. The inner surface is polished to minimize friction between wall surface and specimen.

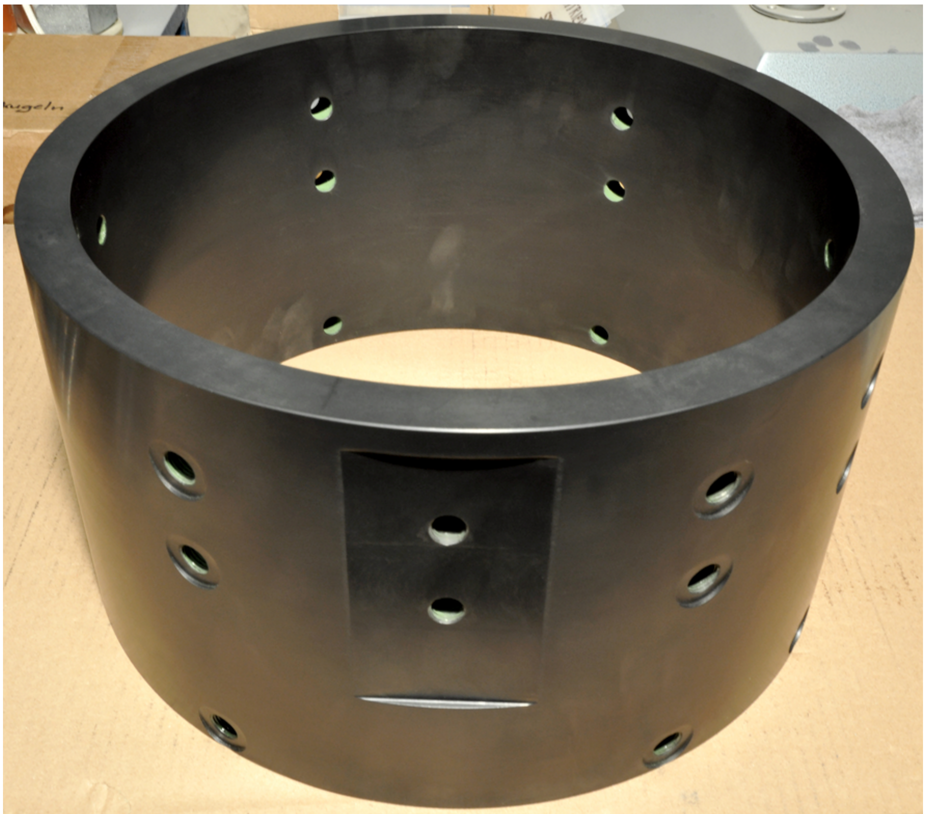


Figure 2.5: Large Oedometer Ring

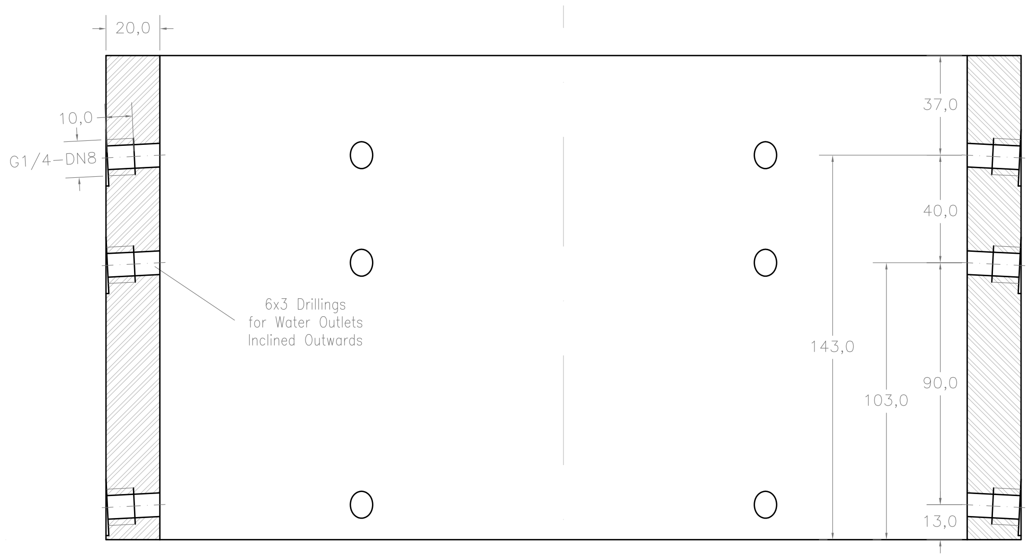


Figure 2.6: Ring Cross Section

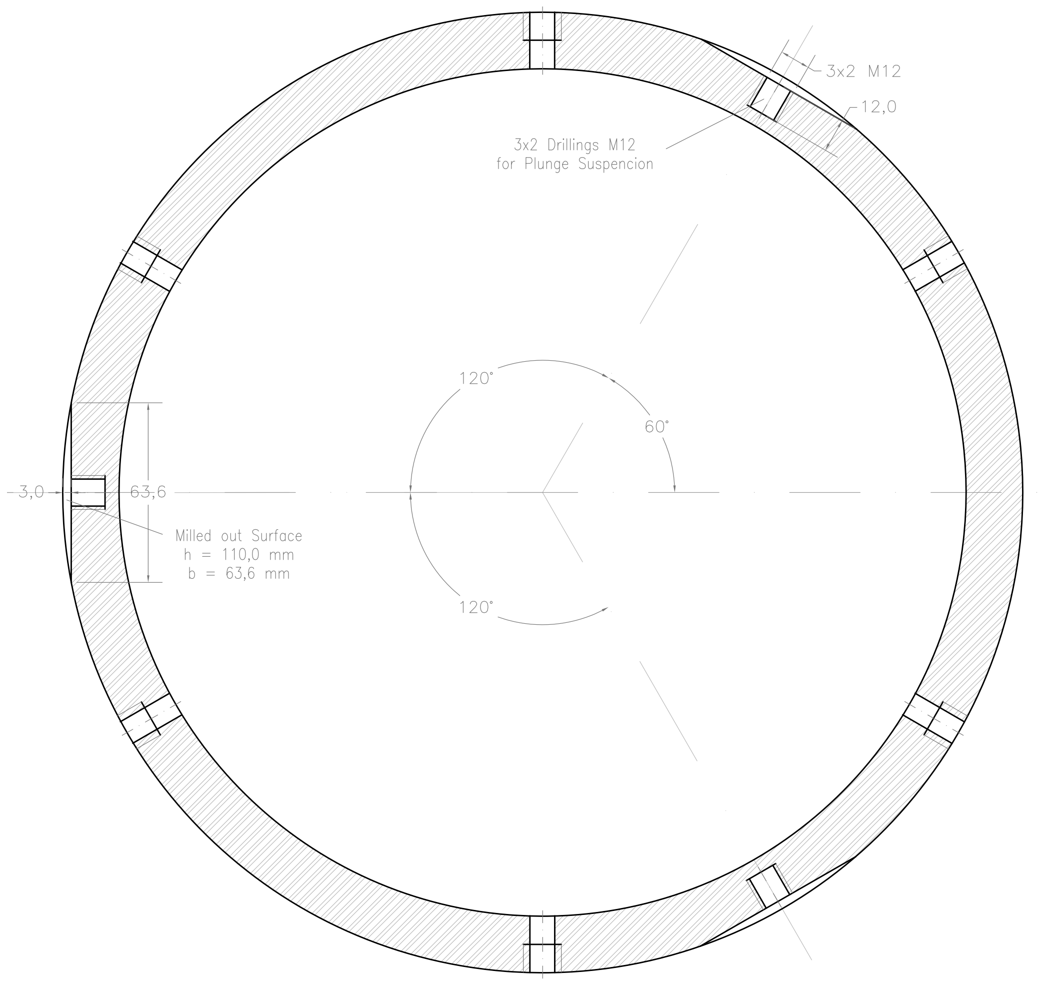


Figure 2.7: Ring Plan View

The wall thickness of the ring was chosen to be 20 mm in order to ensure constrained stress conditions. The *large oedometer ring* was designed to withstand a vertical stress (σ_v') up to 28,3 MPa, assuming a load of 2 MN on a specimen area of 0,071 mm^2. With an assumed coefficient of earth pressure at rest (k_0) of 0,5 a radial stress (σ_r') of 14,1 MPa can be determined. A radial deformation (u) of the ring under this stress can be calculated with the following formula (2.1) after *Worch* in *Düsterloh* [9].

$$u = -\frac{\sigma_r}{E_{\text{Steel}}} \cdot \frac{r_{\text{OR,i}}^2}{r_{\text{OR,o}}^2 - r_{\text{OR,i}}^2} \cdot \left[(1-\nu) + (1+\nu) \cdot \left(\frac{r_{\text{OR,o}}}{r}\right)^2\right] \cdot r \tag{2.1}$$

with:
$\sigma_r = 14{,}1\,\text{MPa}$
$E_{\text{Steel}} = 210.000\,\text{MPa}$
$\nu_{\text{Steel}} = 0{,}285$
$r_{\text{OR,i}} = 0{,}15\,\text{m}$
$r_{\text{OR,o}} = 0{,}17\,\text{m}$
$r = r_{\text{OR,i}} = 0{,}15\,\text{m}$

$$u = 0{,}084\,\text{mm}$$

Therefore the value does not exceed the value given by the *E DIN-18135* standard [see 1, p. 14] of $0,0003 \times d_0 = 0{,}09\,\text{mm}$.

2.3.2 Base Plate

The circular *base plate* (figure 2.8 and 2.9) has a diameter of 340 mm and a thickness of 15 mm. At the edge of the upper side of the plate an annulus of 20 mm thickness and 5 mm height is milled off to ensure a proper alignment of the oedometer ring.
At three points, shifted by 120°, the border has tap holes for mounting the *displacement transducer gauge horizons* (see figure 2.19, p. 21). The plate is positioned directly over the load actuator. Underneath the plate four grub-screws can be mounted for centering the whole oedometer. The plate consists of a molded tool steel (WNr. 1.2312) denominated DIN 40CrMnMoS-8.6.

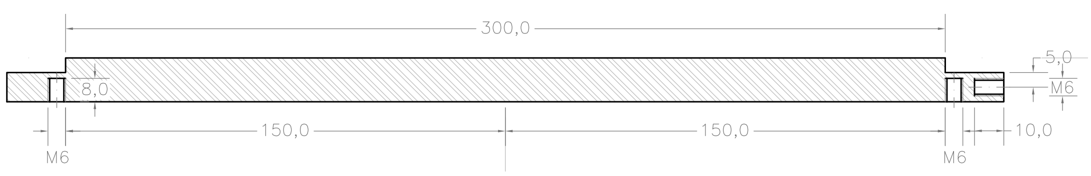


Figure 2.8: Base Plate Cross Section

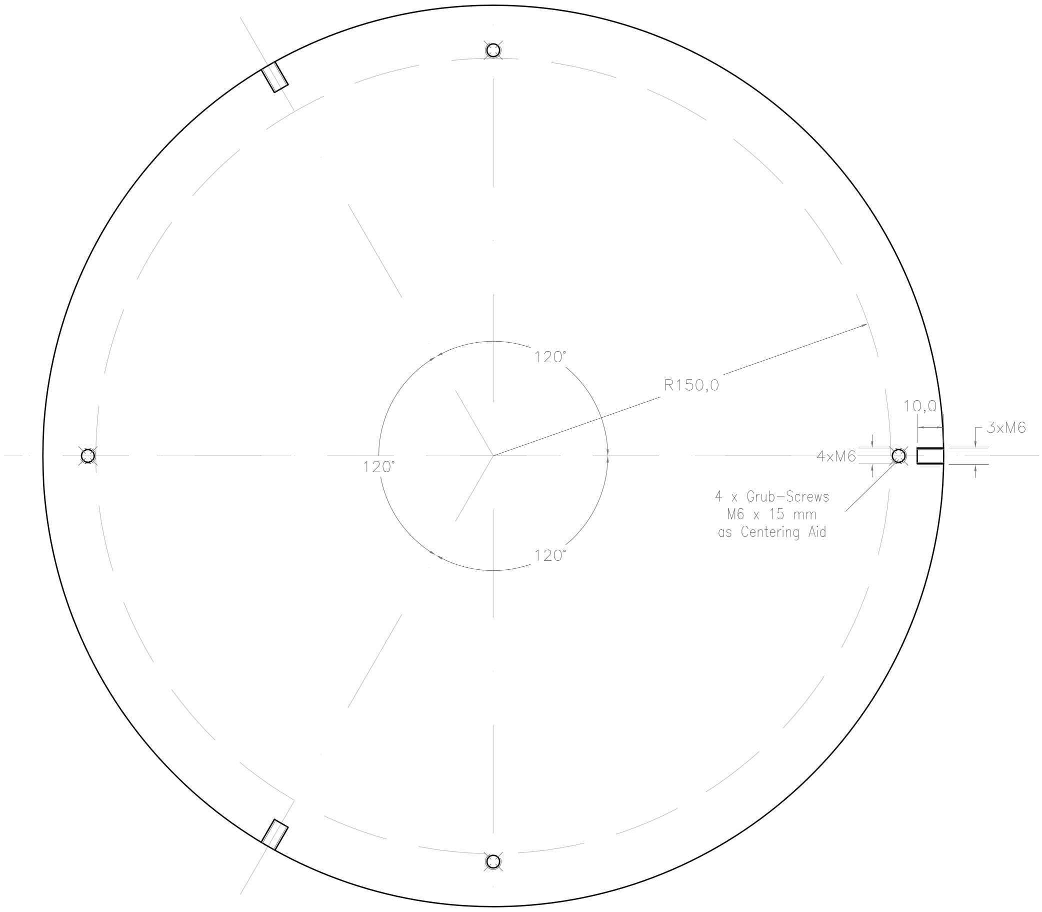


Figure 2.9: Base Plate Plan View

2.3.3 Filter Plate

The *filter plate* (figure 2.10) consists of a 10 mm thick porous *filter head plate*, a 9 mm thick *filter plate boarder*, a 4 mm thick *filter base plate*, and 462 *steel balls* with a diameter of 10 mm. The steel plates are fixed by six countersunk screws. The plate has a diameter of 298 mm and a height of 23 mm. Between *filter plate* and the *oedometer ring* internal wall surface, a gap of 1 mm is left to prevent friction.

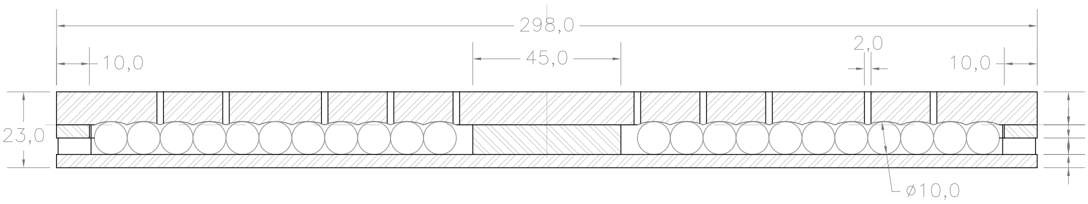


Figure 2.10: Filter Plate Cross Section

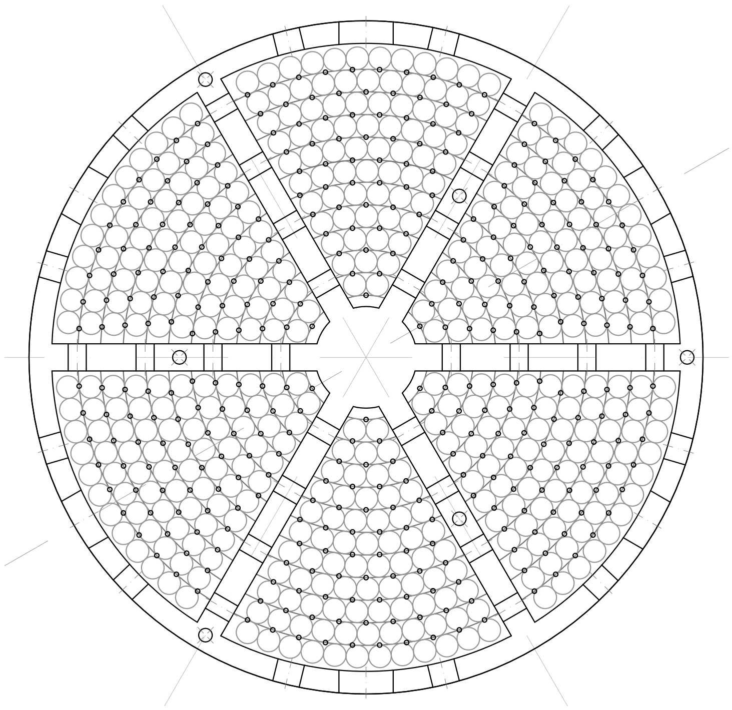
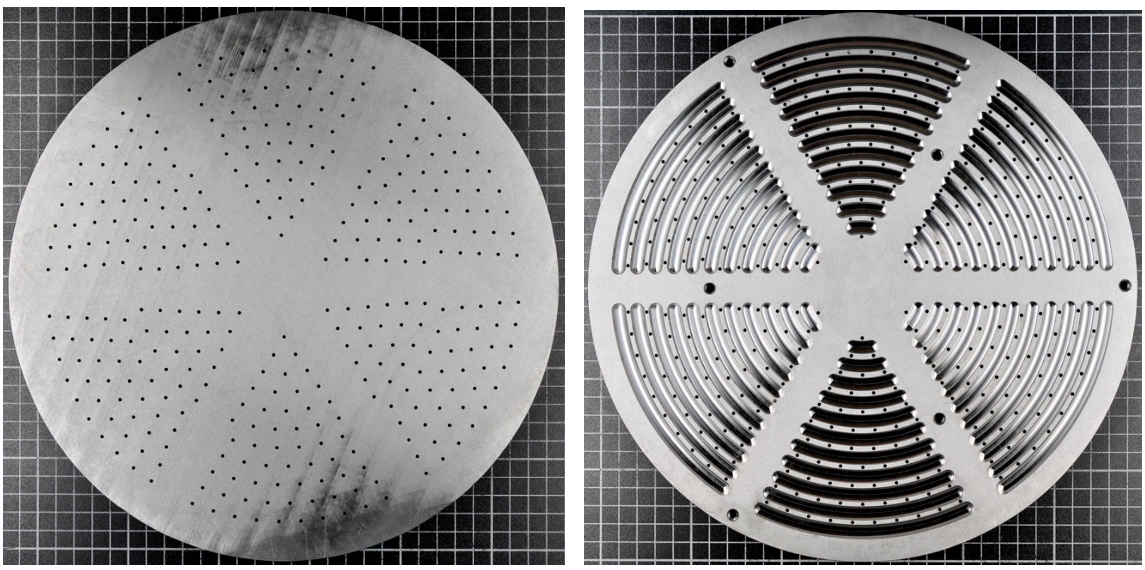


Figure 2.11: Filter Plate Plan View

The *filter head plate* (figure 2.12) is a perforated steel plate made by a plastic mould steel (ferritic-martensitic, hardenable M333 ISOPLAST) denominated X28Cr13 +N. The 366 drillings have a diameter of 2 mm. The inner side of the plate is subdivided into six parts and each part has 11 layers of milling groves which are 1 mm deep and 13 mm wide.



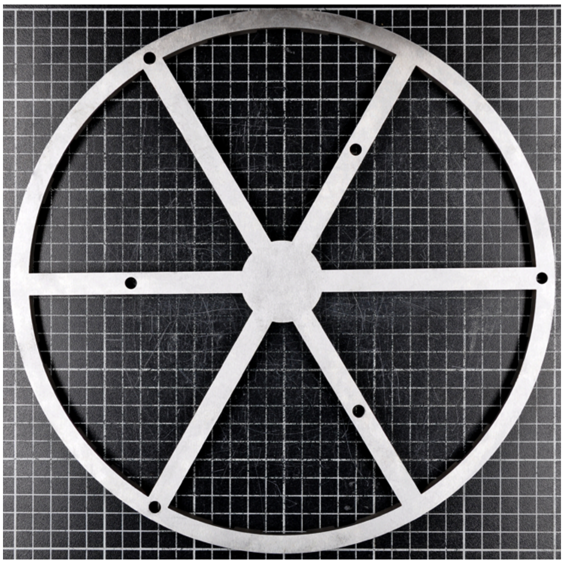
(a) External Side **(b)** Internal Side

Figure 2.12: Filter Head Plate

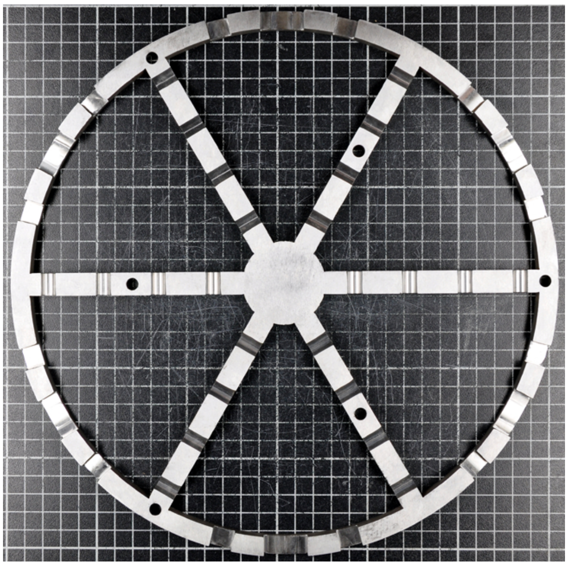
The *filter plate border* is a 10 mm wide curb with a star shaped inlay made by a wear resistant steel (WNr. 1.8715 ,DILLIDUR 400 V) denominated DIN 17 MnCr 5 3. The inlay is composed of a central cylinder with a diameter of 45 mm wherefrom six 12 mm wide and 117,2 mm long arms connect the curb. Each steel arm has four horizontal drillings which facilitate the water to circulate between the segments. On every segment the curb has three outlet parts. Figure 2.13 shows both sides of the filter plate border.

The *filter base plate* is made by a tool steel with a high surface hardness, denominated DIN X155CrVMo12-1 (WNr. 1.2379), and has six drillings for the countersunk screws to fix the entire *filter plate*.

The *steel balls* are sandwiched between the *filter head plate* and the *filter base plate* to a quadratic sphere packing with a maximum density of 78,5 %. Every segment contains 77 balls and is confined laterally by the *filter plate border*. Figure 2.11 (p. 16) and figure 2.14 (p. 18) show the steel ball packing and the drilling disposition.



(a) Upper Side



(b) Lower Side

Figure 2.13: Filter Plate Border

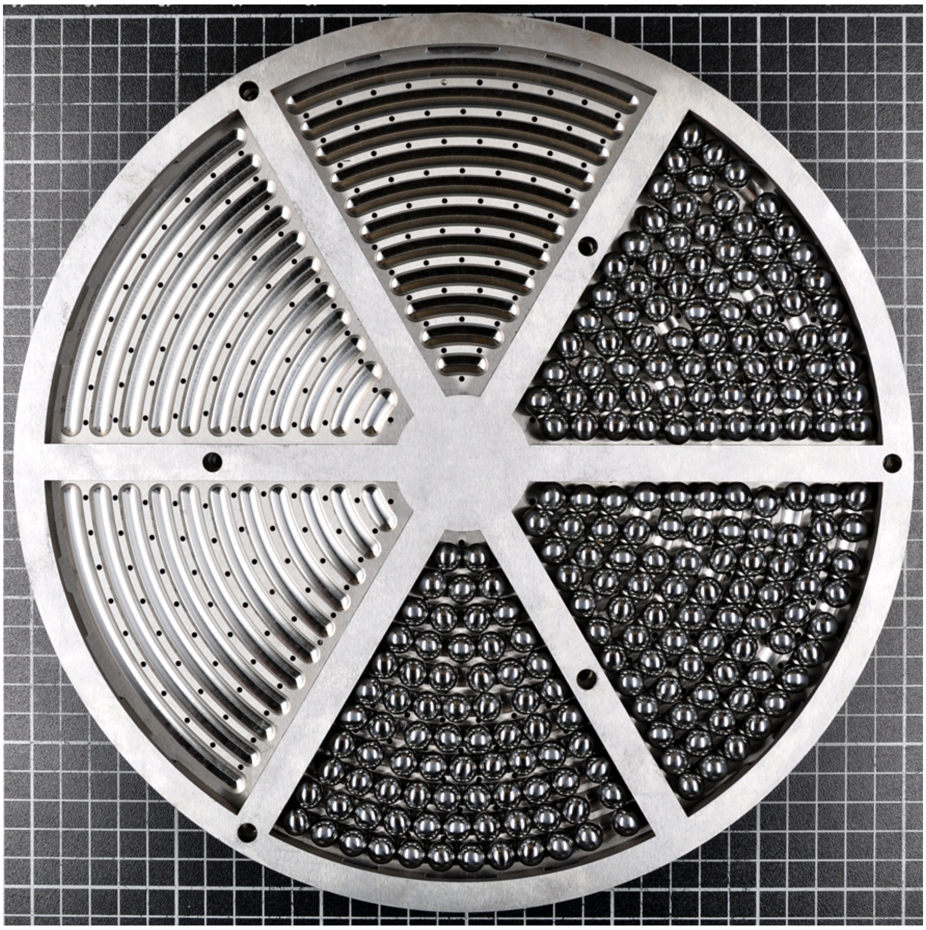


Figure 2.14: Steel Ball Packing

2.3.4 Head Plate

The *head plate* (figure 2.17) with the *displacement transducer suspensions* is the measurement reference for the *displacement transducer gauge horizon* and distributes the load uniformly to the specimen. The *head plate* has a diameter of 298 mm and a height of 30 mm (figure 2.15 and 2.16).

A gap of 1 mm is left between the *head plate* and the *oedometer ring* in order to prevent contact between those two parts in case of a vertical skew of the plate during loading. Four grub screws, mounted on top of the plate, provide a centering aid for the *steel cylinders* and the load cell.

The *head plate* consists of a molded tool steel (WNr. 1.2312) denominated DIN 40CrMnMoS-8.6.

The *displacement transducer suspensions* are horizontally moveable and enable a simple height adjustment and a force-fitted fixture of the displacement transducers.

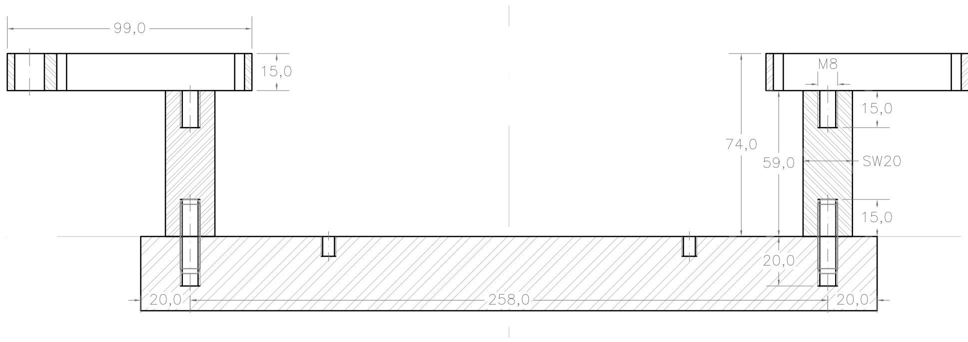


Figure 2.15: Head Plate Cross Section

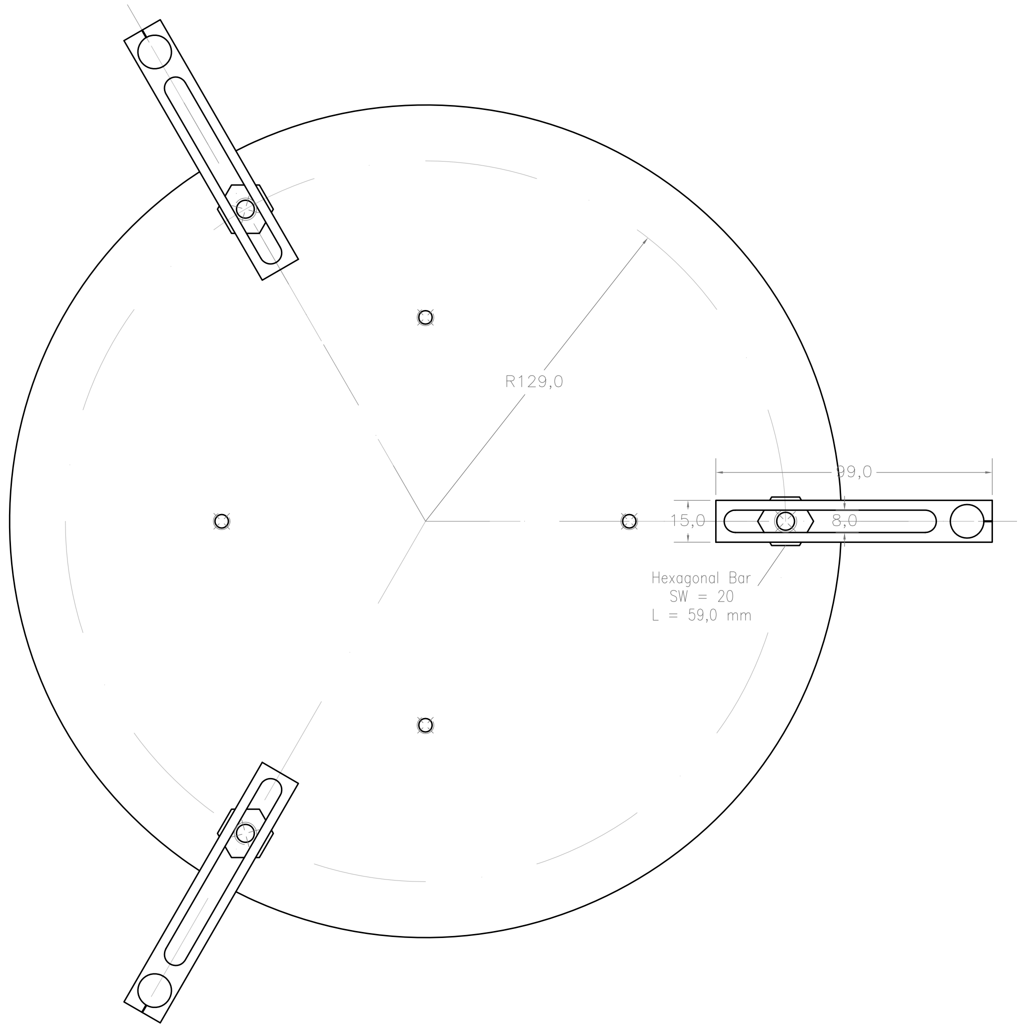


Figure 2.16: Head Plate Plan View

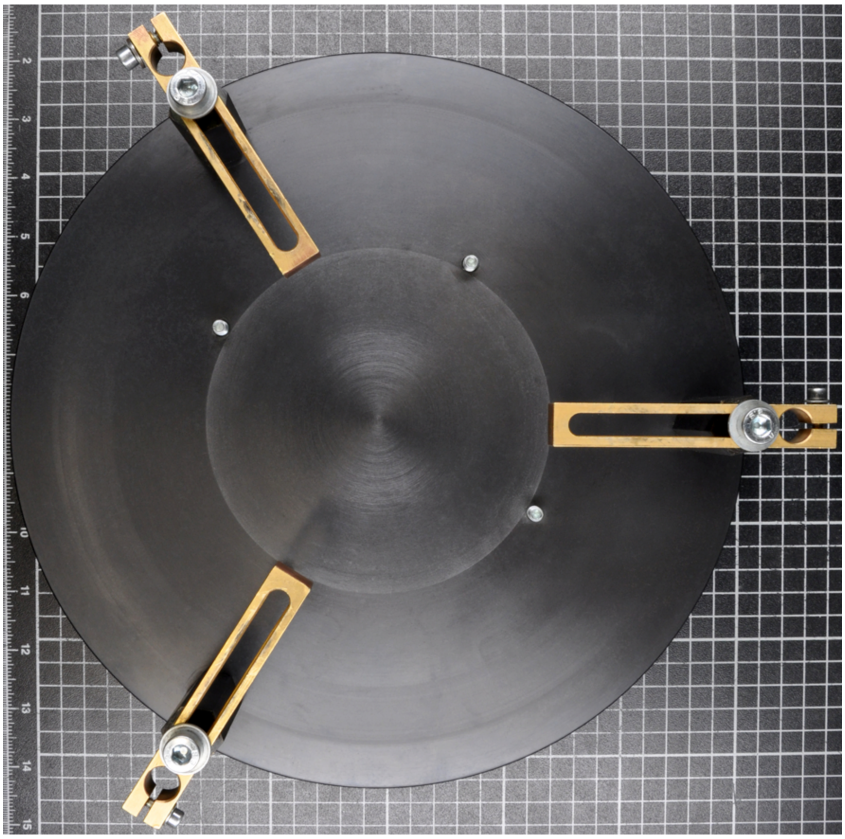


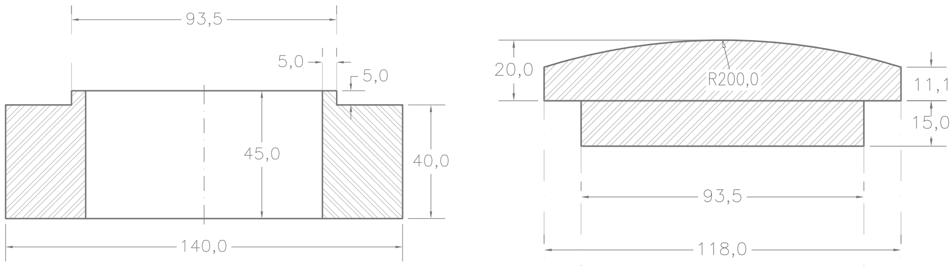
Figure 2.17: Head Plate

2.3.5 Related Equipment

Several minor components are required for completing the *large oedometer* set-up. A comprehensive list of all components is given in appendix A on page 47.

Quadratic *spacers* are used as an aid for a proper alignment of the *oedometer cell* and the *head plate*. The *spacers* are removed after completion of the set-up.
Three *steel plates* with a diameter of 298 mm and a height of 20 mm are used for the calibration set-up (see section 5.1, p. 34) instead of the specimen. One *steel plate* is also needed in the *floating ring configuration* (RS) (see section 4.2, p. 29) to compensate the clearance between the first layer of outlets and the lower *filter plate*.

The clearance between *head plate* and loading actuator is equipped with *steel cylinders* (figure 2.18a) (20 or 40 mm, according to the sample height) as filling elements and as pedestal for the load cell. A 20 mm high *spherical cap* (figure 2.18b) is mounted on the top of the load cell to apply the load centrically to the base frame.



(a) Steel Cylinder **(b)** Spherical Cap

Figure 2.18: Fill Elements

Displacement transducer gauge horizons (figure 2.19) have an L-shaped geometry and are screwed to the *base plate*. To achieve a smooth surface *small glass plates* (40×40 mm) are bonded on top.

Figure 2.19: Displacement Transducer Gauge Horizon

In *floating ring configuration (RS)* (see section 4.2, p. 29) the oedometer is situated on three load cells. Therefore a *suspension ring* is mounted on the loading cylinder of the compression test machine. At the outer surface of the *oedometer ring* three *plunger suspensions* (figure 2.20) with three *plungers*, consisting of a threaded rod with a hex nut with flange, are added. The *oedometer ring* sits only on the specimen and on the load cells, which are dimensioned to carry 10 % of the nominal load of approximately 50 kN each.

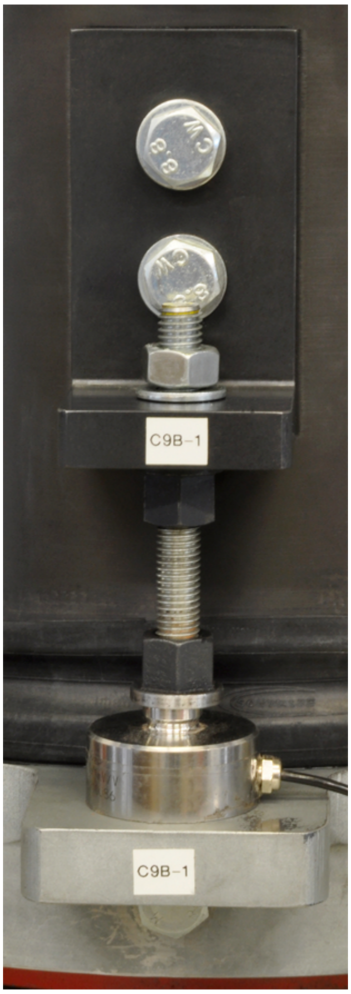


Figure 2.20: Plunger Suspension

3 Instrumentation

This chapter describes the used load and displacement measurement devices as well as the data acquisition system. All devices have been calibrated accurately before use.

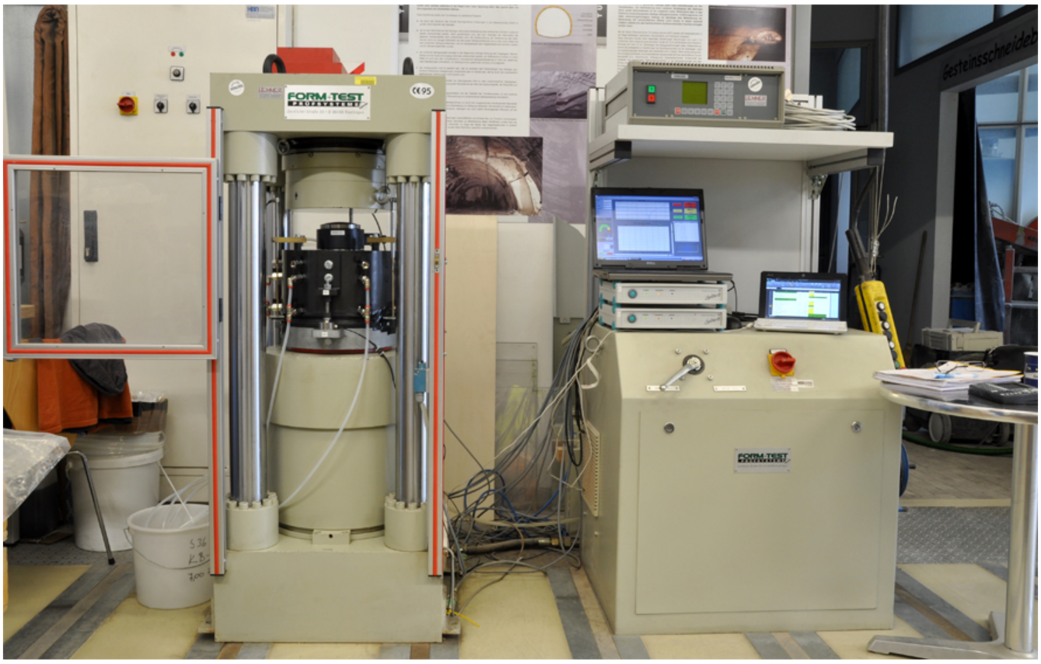


Figure 3.1: Large Oedometer Test

3.1 Load Device

The load device consists of a compression test machine by *Form+Test Prüfsysteme GmbH* (figure 3.1) with a maximum pressure nominal load of 3.000 kN. The load is transmitted by a hydraulic loading actuator which is situated at the base of the compression test machine. The maximum actuator way is 100 mm and the accuracy of the machine is 2 %. The base and head cylinder have a diameter of 300 mm. The clearance dimensions are 350 × 350 mm on the base and 320 mm in height. The machine is controlled by a test controlling software which allows an incremental loading of the specimen. The pressure measurement is carried out by a diaphragm gauge, measuring the engine oil pressure.

3.2 Measurement Instrumentation

3.2.1 Displacement Transducers

Three *inductive displacement transducers*, type HBM WA-20, are used to measure the vertical displacements of the specimen. The maximum nominal displacement is 20 mm, the linearity deviation[1] is ±0,2 % to ±0,1 %, and the nominal sensitivity[2] is 80 mV/V. The *displacement transducers* are clamped on the *displacement transducer suspensions* on the *head plate* and the reference data is set on the *displacement transducer gauge horizons* on the *base plate*. To bypass the high difference between the two reference points a 140 mm long extension has been added to the displacement sensor.

3.2.2 Load Cell for Axial Force

The load transmitted by the compression test machine to the specimen is measured by a toroidal *load cell*, type GEFRAN CTC-1000, with a nominal load of 1.000 kN and an accuracy of 0,5 %. The maximum amount of applicable load on the specimen is therefore determined by the load cell. A *spherical cap* is inserted in the top opening for a centrical load initiation.

3.2.3 Load Cell for Friction Force

To measure the friction forces between *oedometer ring* wall surface and specimen, already described in section 2.3.5 (p. 20), three *load cells*, type HBM C9B, are used. The nominal load is 50 kN and the accuracy is 0,5 %. The small size of these cells (46 mm in diameter and 28 mm in height) is a great advantage in constricted space conditions. The cells are screwed on the *suspension ring flaps* and each loaded by a *plunger* connected to the ring.

3.2.4 Strain Gauges

Three *strain gauges*, type HBM DMS 1-LY11-6/120, are bonded on three different levels on the *oedometer ring* to control and measure lateral displacements. The maximum resolution of the strain gauges is 0,0001 ‰ with a nominal resistance value of 120 Ohm. With the three measured values a vertical stress profile at the analyzed levels in the ring can be depicted, a specimen's *Poisson's ratio* and a *Young's modulus* of the specimen can be calculated.

[1] Greatest deviation between start and end point.
[2] Nominal output signal at nominal displacement with output unloaded.

3.3 Data Acquisition System

The data acquisition system consists of two *measuring amplifiers*, type HBM Spider8, and a laptop computer. Ten synchronized channels with A/D converter are used by the measurement chain and supply up to 9.600 measurements per second from each channel with a resolution of 16 bit. The software *HBM catman 4.5* and a specially written program manage all data handling. The program interface is shown in figure 3.2.

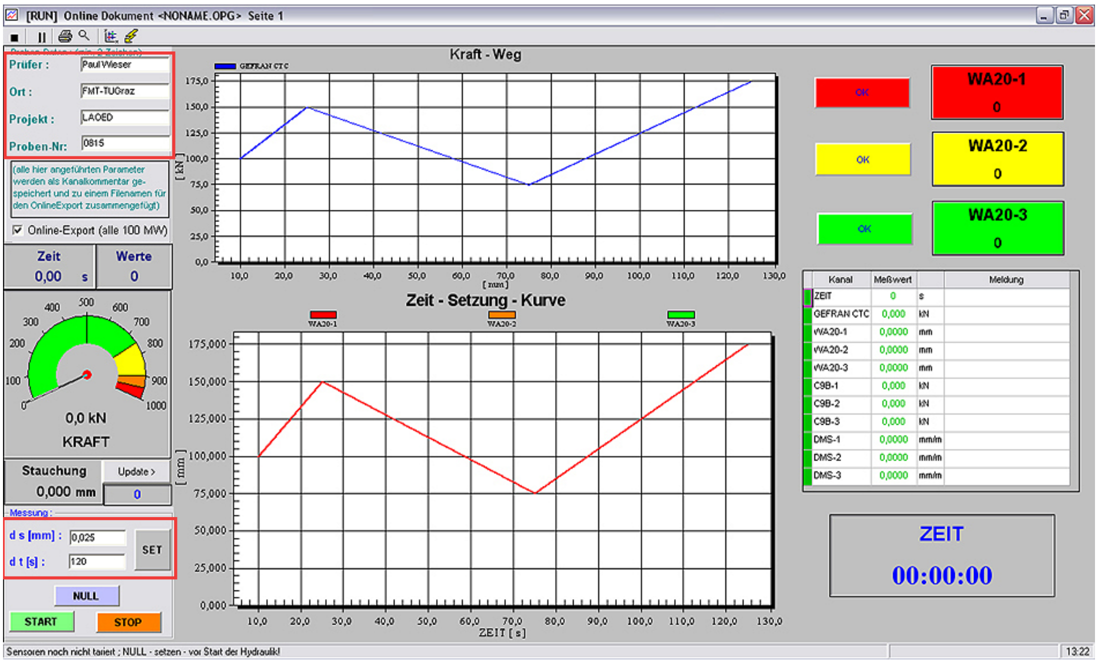


Figure 3.2: Measuring Program Interface

After inserting all required data in the specified fields, such as operator name, place, project name, and sample number, the measuring logging interval has to be chosen in the fields *ds* and *dt*. The first field, *ds* [mm], is the trigger for saving the measured data in a selected displacement interval. It means that if the displacement variation, as an average value of the three displacement transducers, exceeds the specified value (in figure 3.2 as 0,025 mm) data will be saved on a *.bin* file. If this is not the case, the second field *dt* [s] gives the saving rate and data is saved no matter if there is a displacement variation or not. This is an easy way to keep track of the huge amount of data collected in the entire test period and to chose how many data the system should save in the desired intervals. A modification of these two parameters is also possible during testing. First the data have to be entered and then pressing the *SET* button will update the saving rate.
Pressing the *NULL* button tares the measurement devices. This procedure is obligatory otherwise it is not possible to start a new measurement. The *START* and *STOP* button starts and stops the measurement process, respectively. The *Update* button updates the

graphic charts which show the displacement vs. force (figure 3.2 above) and displacement vs. time charts (figure 3.2 below). At the end of the *large oedometer test* all data will be saved on a *.bin* file for further processing.

Every single measurement device is controlled by the program and in case of an excess of the nominal range an alarm is shown. A maximum tilting of 10 mm of the *head plate* gives also an alert on the screen and the test procedure must be stopped. If an alarm is given a manual stop of the compression test machine is required. Because of the independency of the load device and the data acquisition system an automatic shut down is not provided.

4 Test Set-Up

The *large oedometer* test set-up has to be carried out in defined stages in order to provide a fast and accurate assembly to prevent the specimen from drying out. For this purpose an installation manual, in which every single move is described step by step, has been written.

4.1 Specimen Preparation

The *large oedometer test* was mainly developed for performing tests on disturbed samples of fault rocks, taken from drilling core samples exemplarily shown in figure 4.1.

Figure 4.1: Core Samples

At sample delivery a denomination and description and a classification of the sample material should be done. The depth of recovery (h_{z}) has to be denoted to estimate the effective overburden pressure ($\sigma^{'}_{\mathrm{v},0}$). The unit weight of particles (γ_{s}) has to be determined with a *pycnometer*.
In case of a large quantity of sample material a granulometric analysis for granular soils and consistency limits for cohesive soils should be performed. If the maximum grain size ($D_{\max}$) is less or equal to 12 mm an initial specimen height (h_0) of 60 mm (P_{60}) ought to be selected. If the maximum grain size is between 12 and 20 mm the initial specimen height has to be between 60 and 100 mm (P_{100}).

$$D_{\max} \leq 12\,\mathrm{mm} \longrightarrow P_{60} \tag{4.1}$$

$$12\,\mathrm{mm} < D_{\max} \leq 20\,\mathrm{mm} \longrightarrow P_{60} - P_{100} \tag{4.2}$$

After the determination of the above mentioned parameters the required sample mass ($m_{0,\mathrm{as}}$) can be calculated with equation (4.5). For a first raw estimation the unit weight of soil (γ) can be assumed between 20 and 25 kN/m^3. The sample can be put in a large bowl (figure 4.2) before filling into the *large oedometer*.
If the degree of saturation (S_r) has to be changed the sample should be watered with the water collected at the sampling point or water with similar chemism [see 1, p. 18]. The initial water content (w_0) has to be determined.

$$A_0 = \frac{d_0^2 \cdot \pi}{4} \tag{4.3}$$

$$V_0 = A_0 \cdot h_0 \tag{4.4}$$

$$m_{0,\mathrm{as}} = \left(\frac{\gamma}{g}\right) \cdot V_0 \tag{4.5}$$

Figure 4.2: Bowl with Sample

4.2 Large Oedometer and Specimen Assembly

The process of assembling all components and the specimen to start a *large oedometer test* is described as a chronological listing of all necessary actions on the next pages.
Two ring configurations for different specimen heights are possible (see figures 4.3 to 4.6):

1. In the *fixed ring configuration (RF)* the ring directly rests on the *base plate*. In this configuration it is not possible to determine the friction force between the sample and the oedometer ring surface. This fixed ring configuration was used for calibration issues and for determining the system stiffness of the large oedometer.

2. In this thesis the *floating ring configuration (RS)* describes the configuration in which the ring is kept in position by friction between specimen and ring wall surface. By utilizing three load cells, described in section 3.2.3 on page 24, one can determine the friction force. This configuration is the standard configuration used in the performed tests. This denomination is used in this thesis to describe a configuration where the ring hangs on the specimen by friction, which can be measured through *plungers* on three load cells.

Filter Plates Assembly

The first action consists of assembling the *filter plates* to ensure drained conditions during the compression test. Two *filter plates* are needed. The components of both plates must not be mixed up and should be stored separately.

The *filter head plate* is positioned with the milling grooves on top. For the *lower filter plate* the *filter plate border* is placed with the openings upwards on the *filter head plate*. For the *upper filter plate* the openings shall be downwards (see figure 2.14 on page 18). The resulting segments have to be filled by *steel balls*. It is import to pay attention to fill the exact quantity of steel balls per segment (see table 4.1).

The *filter base plate* functions as closure head. Six countersunk screws fix the entire *filter plate* as a unity.

Parts	Steel Balls
1 Segment	77
1× Filter Plate	462
2× Filter Plates	924

Table 4.1: Steel Ball Quantity.

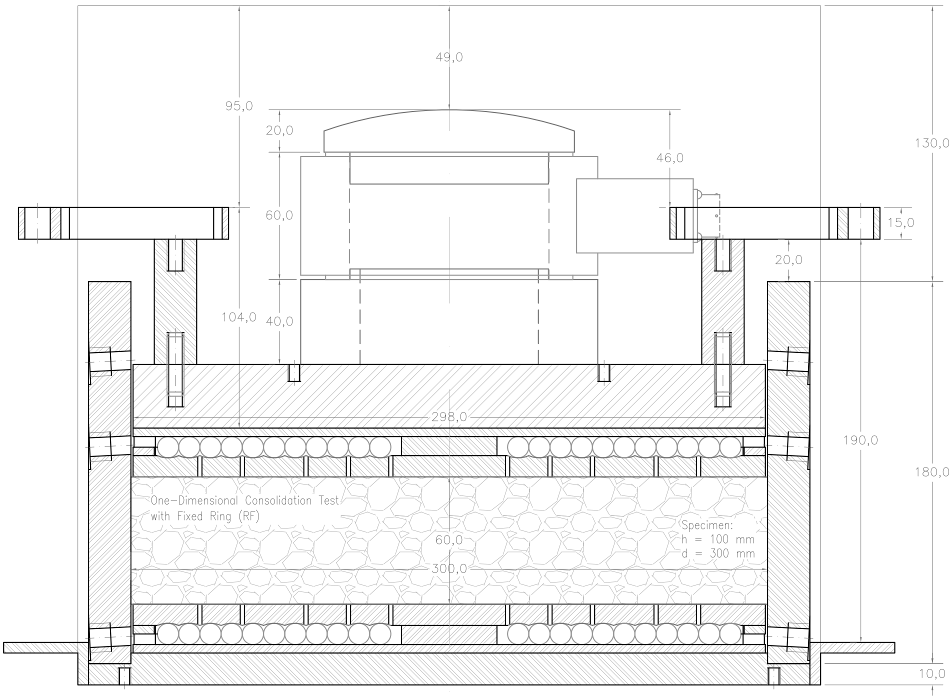


Figure 4.3: Fixed Ring Configuration with a Specimen Height of 60 mm (P_{60}, RF)

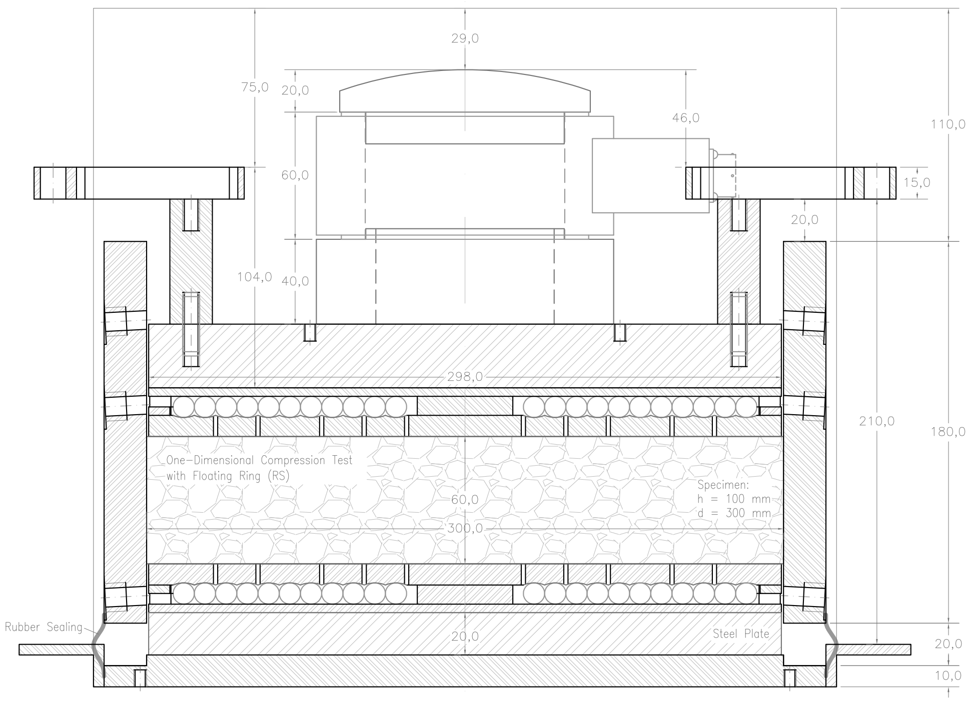


Figure 4.4: Floating Ring Configuration with a Specimen Height of 60 mm (P_{60}, RS)

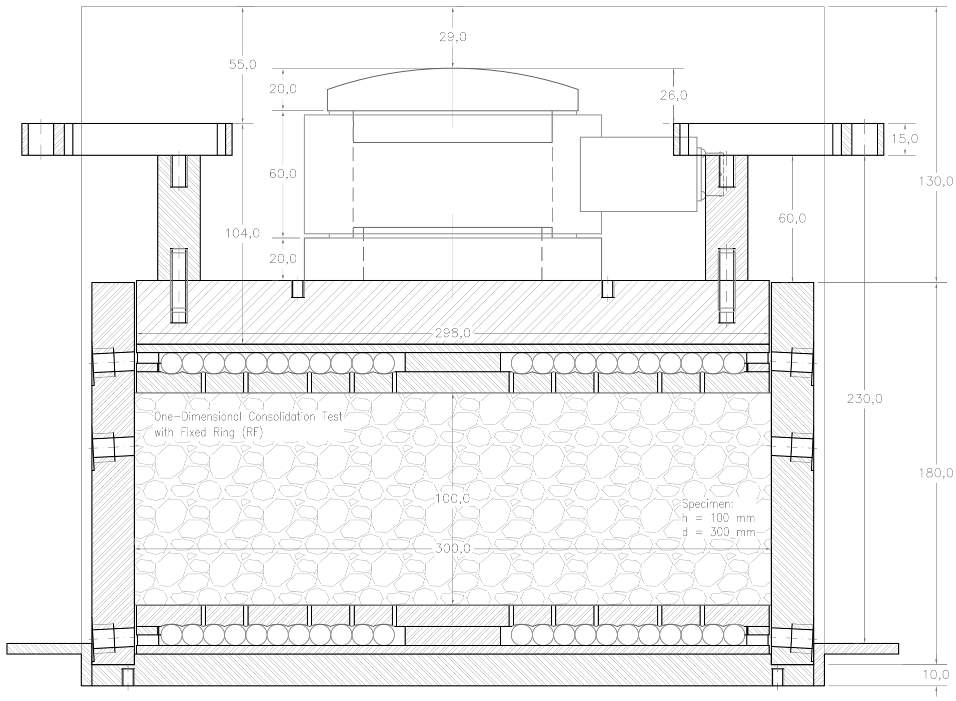


Figure 4.5: Fixed Ring Configuration with a Specimen Height of 100 mm (P_{100}, RF)

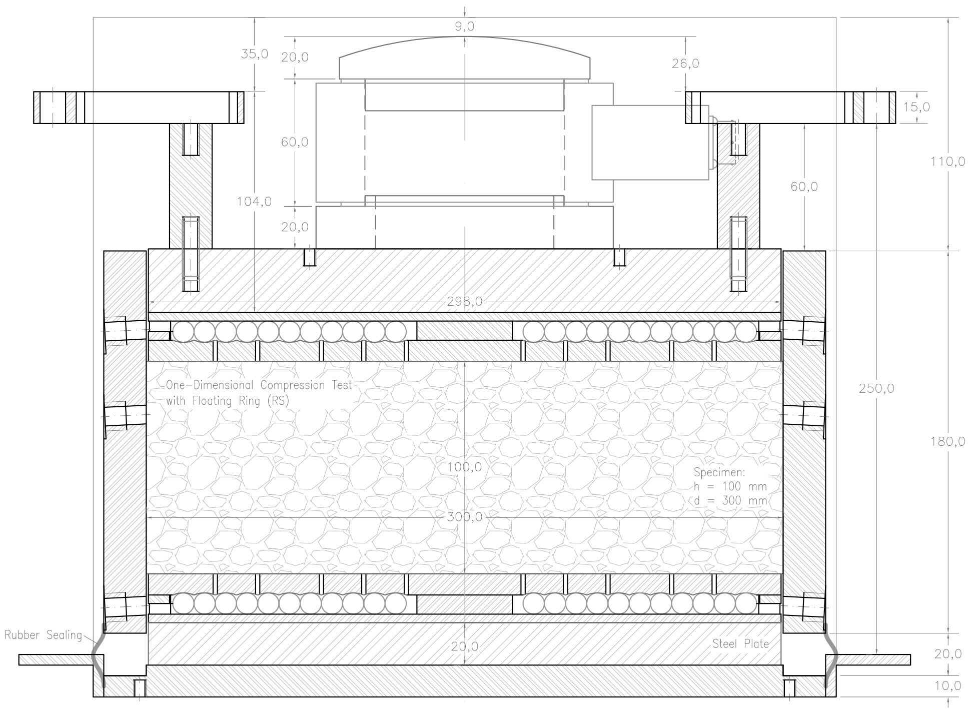


Figure 4.6: Floating Ring Configuration with a Specimen Height of 100 mm (P_{100}, RS)

Large Oedometer Assembly (RS)

Due to the restricted dimensions of the compression test machine one part of the oedometer has to be assembled outside the machine while the measurement instrumentation is set-up in the final test position of the oedometer.

The *large oedometer* is assembled on a mobile lifting table for an easy handling of the apparatus. Above the *base plate*, which is the bottommost part, a 20 mm *steel plate* (for the *floating ring configuration*) and the *lower filter plate* are placed. On the cavity in the margins of the *base plate*, three quadratic *spacers* are installed to hold the ring on balance at the defined level. The *oedometer ring* has to be greased with a thin layer of lubricant and if a P_{100} configuration is chosen, the outlet ports in the middle should be closed with a sealing tape. If a P_{60} configuration is chosen this outlet ports remain open. Then the ring is positioned on the three *spacers*. Two layers of moistened *geotextile* in a circular shape with a diameter of 300 mm are placed on the *lower filter plate*. The distance between upper edge of the *oedometer ring* and the *geotextile* surface has to be measured at four different points. The average height is then $h_{\mathrm{av},1}$.

Specimen Assembly

The *oedometer ring* is stepwise filled in layers of 20 mm until the desired height is reached (figure 4.7b). The sample quantity is weighed by a precision balance. Every layer is compacted with a *Proctor hammer* to the specified density. Uniform and reproducible assembly conditions have to be chosen [see 1, p. 15]. With an even and sharp plate the specimen surface has to be leveled. The sum of the weighed sample material is the initial specimen mass (m_0).

(a) Assembly **(b)** Specimen Top Edge

Figure 4.7: Specimen Assembly

On top of the specimen two layers of moistened *geotextile* (circular shape with a diameter of 300 mm) and the *upper filter plate* are placed. After some time has elapsed the *filter plate* and the *geotextile* are removed and the distance from the upper edge of the *oedometer ring* and the specimen surface is measured at four different points. The average height (average value of the four measured distances) is denoted as $h_{\mathrm{av},2}$. After measuring, the *geotextile* and the *filter plate* are returned back on the specimen. The initial height (h_0) of the specimen is calculated by the following equation:

$$h_0 = h_{\mathrm{av},1} - h_{\mathrm{av},2} \tag{4.6}$$

The *head plate*, with the three *displacement transducer suspensions* and one *steel cylinder*, is arranged on three *spacers* on the ring, ensuring that no contact between *filter plate* and *head plate* can occur. This measure guarantees that no load is applied on the specimen before starting the test procedure.

Measurement Instrumentation Assembly

A *suspension ring* has to be fixed on the actuator of the compression test machine. The *large oedometer* is then carefully shifted in a central position into the compression test machine. The three small load cells are screwed on the flaps of the *suspension ring*. Then the three *plunger suspensions* with *plungers* are mounted on the ring. The *oedometer ring* is now supported by the *plungers* and the load cells and the *spacers* can be removed. The clearance of 20 mm between *oedometer ring* and *base plate* has to be sealed with a adhesive tape. The *displacement transducer gauge horizons* can now be screwed on the *base plate*. The *2/2-way-mini-ball valves* are connected with polyurethane-plastic hoses and then fixed on the outlet ports at the ring.

Load cell and *spherical cap* are placed on the *steel cylinder* on the *head plate*. The three displacement transducers are pitched on the *displacement transducer suspensions*. All measurement devices are now connected to the *measuring amplifiers*. At this point the *head plate* is carefully lowered to the *upper filter plate* and the *spacers* can be removed. The displacement transducers are adjusted to contact the *displacement transducer horizons*. The dead load on the specimen due to the dead load of the *upper filter plate*, the *head plate*, the filling elements, and the measurement instrumentation is approximately 337 N, which equals a stress of 4,8 kPa.

The *oedometer test* begins after starting the measuring amplifiers, the measuring software, and the compression test machine. The *2/2-way-mini-ball valves* are opened to enable drainage.

5 Test Procedure

5.1 Calibration

The *large oedometer* calibration is an important task in order to achieve precise test results. When the calibration correction determined exceeds 5 % of the measured specimen deformation and when filter paper disks or geotextile are used, the measured axial displacements must be corrected [see 3, p. 4].

The inner diameter of the *oedometer ring* ($d_{\mathrm{OR,i}}$) is defined as the average value of two perpendicularly measured values of the diameter with an accuracy of 0,05 mm [see 2, p. 10]. The inner diameter of the ring is equal to the specimen diameter (d_0) if the specimen contacts the ring and no intermediate layers are used. To record the deformations of the apparatus and the inner system stiffness the *large oedometer* has to be set-up with *steel plates* instead of the specimen as shown in figure 5.1. The three *steel plates* have a height of 60 mm and are positioned between the two *filter plates* each with two moistening layers of *geotextile*. The *filter plates* and the *steel plates* are 2 mm smaller in diameter than the ring. The *large oedometer* is repeatedly loaded and unloaded and the deformations are recorded continuously. Every load stage should be held for 5 min in which the moisture is squeezed out from the *geotextile*. Table 5.1 and figure 5.2 illustrate the loading and unloading stages.

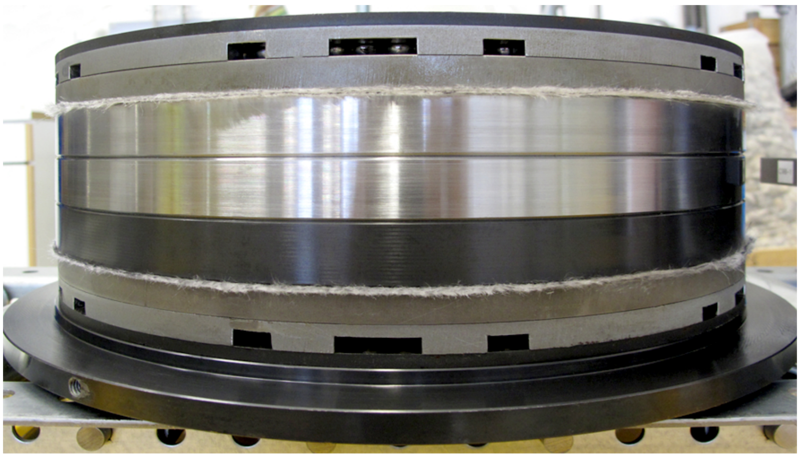


Figure 5.1: Calibration Set-Up

Load Level	**Axial Force** [kN]	**Axial Stress** [kPa]	**Holding Period** [min]
0	12	173	5
1	100	1.434	5
2	200	2.867	5
3	300	4.301	5
4	450	6.452	5
5	10	143	5
6	450	6.452	5
7	550	7.886	5
8	710	10.180	5
9	350	5.018	5
10	710	10.180	5
11	800	11.470	5
12	908	13.019	5
13	450	6.452	5
14	908	13.019	5
15	10	143	5
16	0	0	5

Table 5.1: Loading and Unloading Stages for Determination of the System Stiffness

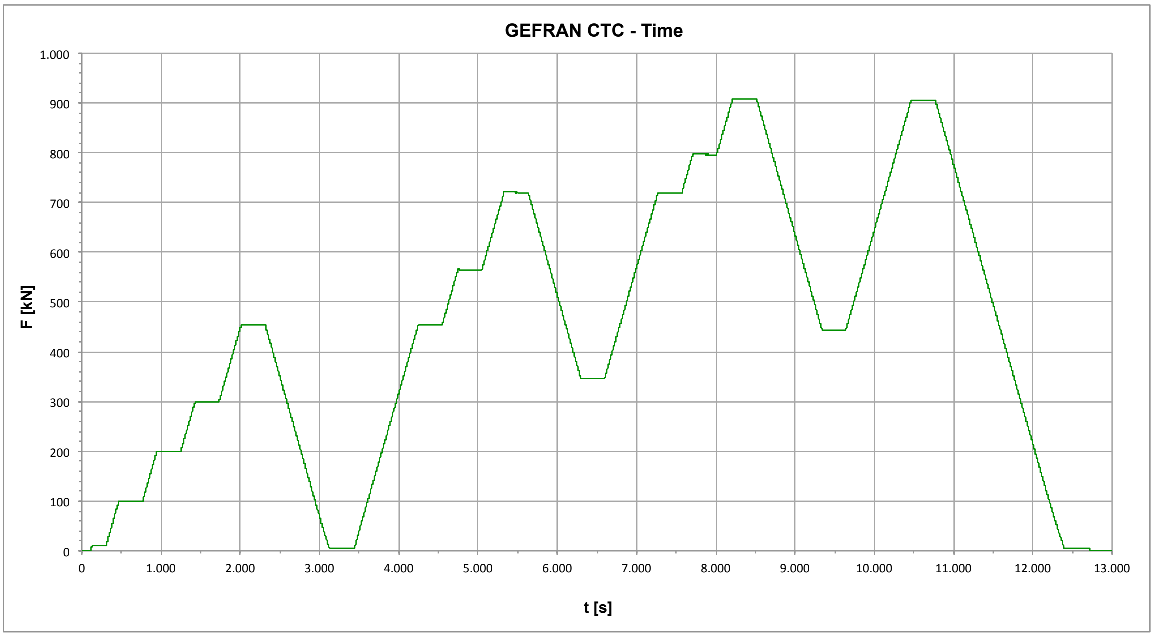


Figure 5.2: Force-Time Chart for Determination of the System Stiffness

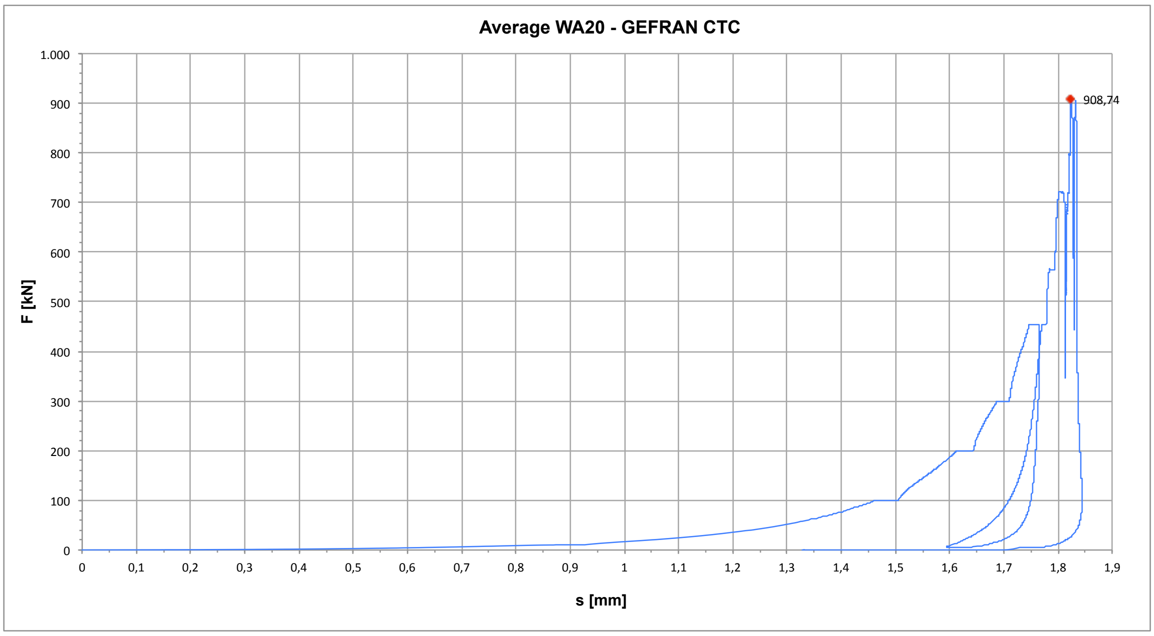


Figure 5.3: Displacements-Force Chart for Determination of the System Stiffness

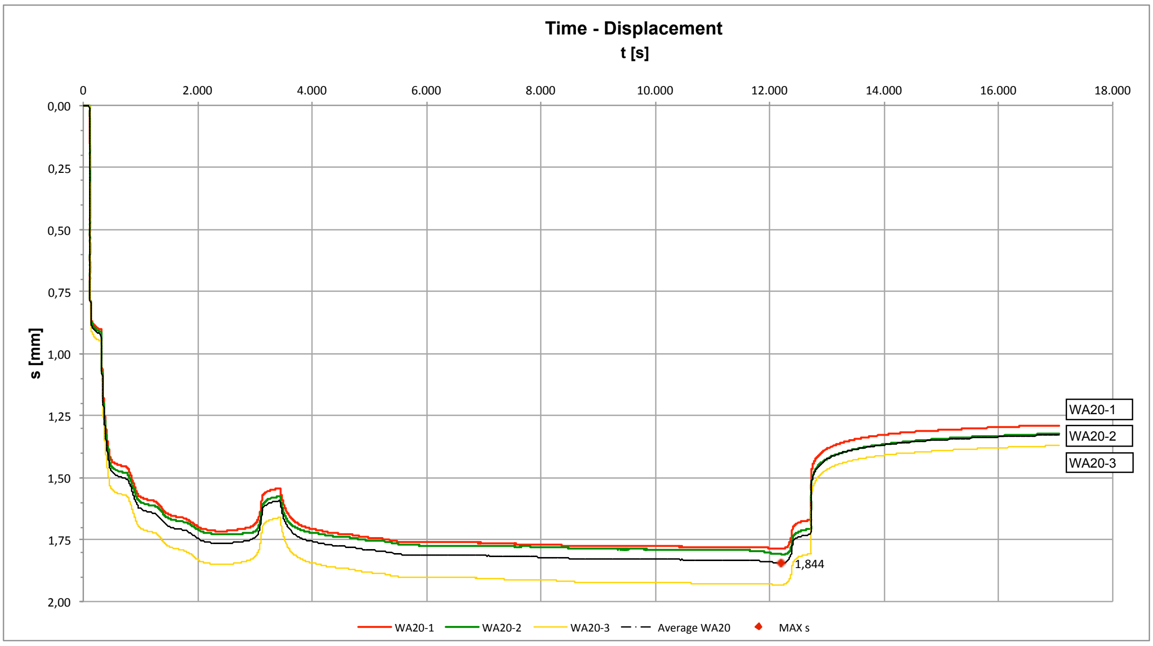


Figure 5.4: Time-Displacements Chart for Determination of the System Stiffness

Figure 5.3 and figure 5.4 show the results of the system stiffness determination in a force-displacement and a time-displacement chart, respectively. The starting points of each loading and unloading cycle were detected from the recorded load step data series for a subsequent filtering of data. In order to have a mathematical representation of the load-displacement relationship of the system stiffness, a function fitting the point series was required. The function, shown in equation (5.1) was found as almost perfectly fitting the load-displacement behavior.

$$s_\mathrm{c} = \frac{1}{a + \frac{b}{\sqrt{F_\mathrm{v}}}} \tag{5.1}$$

with:
$a = 0,46825397$
$b = 2,2195769$
F_v = Axial Force
s_c = Correction Inner System Stiffness

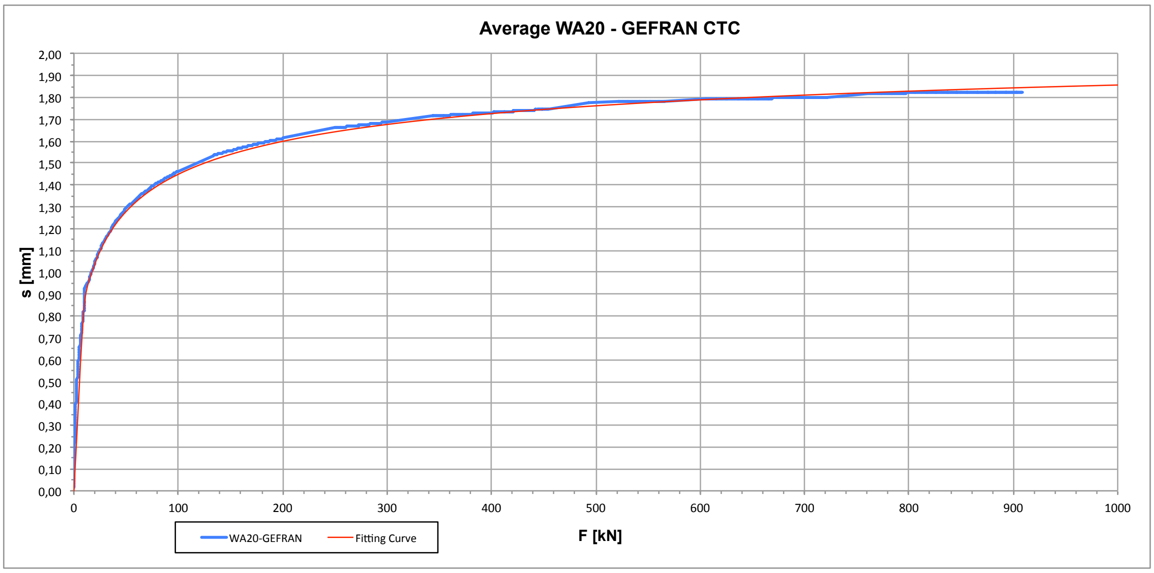


Figure 5.5: Fitting Curve on Adjusted System Stiffness

5.2 Load Levels

The sequence of loading and unloading cycles and the magnitude of load steps is determined for every sample, based on the effective overburden pressure state of the sampling point ($\sigma'_{\mathrm{v},0}$). The maximum applicable load is 1 MN which corresponds to a stress of 14,15 MPa. The seating load after starting the machine, in which the hydraulic loading actuator contacts the oedometer, is approximately 173 kPa. Table 5.2 lists the dead load of each component on the specimen.

Components	**Mass** [kg]	**Force** [kN]	**Stress** [kPa]
Spherical Cap	2,132	0,021	0,296
Load Cell GEFRAN CTC	2,282	0,022	0,317
Steel Cylinder 20 mm	1,585	0,015	0,220
Steel Cylinder 40 mm	3,133	0,031	0,435
Head Plate + Components	17,420	0,171	2,418
Displacement Transducers	0,064	0,002	0,027
Start-Up Load	1.223,240	12,000	169,765

Table 5.2: Dead Load of Single Components

The dead load for P_{60} specimens is:

$$\sigma^{'}_{\mathrm{z,P60}} = 3,492 + 169,765 = 173{,}257\,\mathrm{kPa}$$

The dead load for P_{100} specimens is:

$$\sigma^{'}_{\mathrm{z,P100}} = 3,277 + 169,765 = 173{,}042\,\mathrm{kPa}$$

The dead load is left for 15 min on the specimen. The load is increased with a velocity of 0,5 kN/s to certain load steps and kept constant until the displacement rates become almost zero. The load steps are defined as fractions of the effective overburden pressure.

Once the effective overburden pressure ($\sigma^{'}_{\mathrm{v,0}}$) is reached, an unload-reload cycle by halving the pressure, should be imposed on the specimen. Further unload-reload cycles are conducted on $1,5 \times \sigma^{'}_{\mathrm{v,0}}$. The loading sequence is stopped after reaching an axial pressure of $2,0 \times \sigma^{'}_{\mathrm{v,0}}$ or at the maximum applicable pressure of 14,15 MPa.

6 Evaluation and Illustration of Test Results

Eleven *large oedometer Tests* were performed at the laboratory of the *Institute for Rock Mechanics and Tunnelling* to test the functionality of the new apparatus. All tests were conducted in the *floating ring configuration (RS)* on disturbed samples with different degrees of saturation (S_r). The fault rock material derives from core samples of the *Koralm Railway Project (A)* and the *Semmering Railway Project (A)*. All sample materials tested are listed in table 6.1.

Material	Sample Identification	Specimen Status	Initial Water Content	Depth of Recovery
Sand	UK4	moist	0,115	-
Sand	UK4	dry	0,000	-
Sand	UK4	moist	0,170	-
Sand	UK4	saturated	0,283	-
Gravel	8-16	moist	0,002	-
Fault Rock	KB-UT 4.1u 3,0–4,0 m	moist	0,084	241 m
Fault Rock	KB-UT 4.2u 2,0–3,0 m	moist	0,079	240 m
Fault Rock	KB-UT 2.1o 1,7–2,8 m	saturated	0,211	240 m
Fault Rock	KB-UT 19/11 75,0–76,0 m	moist	0,081	76 m
Fault Rock	KB-UT 3.2o 4,0–4,7 m	moist	0,115	240 m
Fault Rock	KB-UT 4.2o 1,2–2,0 m	moist	0,077	242 m

Table 6.1: List of Tested Samples

6.1 Evaluation

The recorded data is converted to an MS Excel file format and for post-processing treatment. A data evaluation sheet was coded in MS Excel to compute all necessary values and to display the associated diagrams. All formulas used are presented in this section in the next pages.

Before the specimen is assembled in the *large oedometer* the initial liquid water content (w_0) has to be determined. The specimen water mass (m_{SP}) is calculated by subtracting the dry specimen mass ($m_{\mathrm{SP,d}}$) after desiccation from the moist specimen mass (equation (6.1)). The initial water content is derived with equation (6.2).

$$m_{\mathrm{SP,w}} = m_{\mathrm{SP}} - m_{\mathrm{SP,d}} \tag{6.1}$$

$$w_0 = \frac{m_{\mathrm{SP,w}}}{m_{\mathrm{SP,d}}} \tag{6.2}$$

With the initial specimen mass (m_0) and the acceleration of gravity ($g = 9{,}817\,\mathrm{m/s^2}$) the initial specimen weight is calculated with equation (6.3). The unit weight of soil (γ) (equation (6.4)) and the unit weight of dry soil (γ_{d}) (equation (6.5)) are defined as followed.

$$W_0 = m_0 \cdot g \tag{6.3}$$

$$\gamma = \frac{W_0}{V_0} \tag{6.4}$$

$$\gamma_{\mathrm{d}} = \left(\frac{1}{1 + w_0}\right) \cdot \gamma \tag{6.5}$$

The initial void ratio (e_0) and the initial porosity (n_0) are given as

$$e_0 = \left(\frac{\gamma_{\mathrm{s}}}{\gamma_{\mathrm{d}}}\right) - 1 \tag{6.6}$$

$$n_0 = \frac{e_0}{1 + e_0} \tag{6.7}$$

With the unit weight of water at 10 °C ($\gamma_{\mathrm{w}} = 9{,}804\,\mathrm{kN/m^3}$) and the above calculated parameters, the initial degree of saturation ($S_{\mathrm{r},0}$) is

$$S_{\mathrm{r},0} = \frac{w_0 \cdot \gamma_{\mathrm{s}}}{e_0 \cdot \gamma_{\mathrm{w}}} \tag{6.8}$$

The sum of the three *load cells HBM C9B* is the friction force (F_{R}) between specimen and *oedometer ring* wall surface. Values up to 15 % of the axial force have been measured.

The effective axial force (F_v) is the difference between axial force measured by the *load cell GEFRAN CTC-1000* ($F_{v,LC}$) and friction force as shown in equation (6.9). The effective axial stress ($\sigma'_{v,i}$) is calculated with equation (6.10).

$$F_v = F_{LC} - F_R \tag{6.9}$$

$$\sigma'_{v,i} = \frac{F_{v,i}}{A_0} \tag{6.10}$$

The measured values of the three *displacement transducers HBM WA-20* have to be averaged ($\overline{s}$) and adjusted by the inner system stiffness correction (s_c) (see equation (5.1), p. 37) to calculate the effective compression (s) as shown in equation (6.11). The system stiffness correction is only applied in loading stages. The reason therefore lies in the high amount of plastic, irreversible deformations the *geotextiles* feature. On unloading-reloading cycles the average displacements ($\overline{s}$) are corrected with the maximum value of the inner system stiffness correction (s_c) of the previous load stage.

$$s = \overline{s} - s_c \tag{6.11}$$

Then the axial strain (ϵ_a) and the void ratio (e) are computed as followed

$$\epsilon_a = \frac{s}{h_0} \tag{6.12}$$

$$e = e_0 - \epsilon_a \cdot (1 + e_0) \tag{6.13}$$

An e/ϵ_a-σ'_v diagram (see figure 6.3, p. 43) and an e/ϵ_a-log(σ'_v) diagram (see figure 6.4, p. 44) are plotted with the above calculated parameters.
The constrained modulus (E_s), also known as oedometer modulus, can be obtained for a certain stress interval on the ϵ_a-log(σ'_v) diagram as tangent modulus ($E_{s,tan}$), shown in figure 6.1 or as secant modulus ($E_{s,sec}$) as shown in figure 6.2. The calculation of these moduli is given as

$$E_{s,tan} = \frac{d\sigma'_{v,i}}{d\epsilon_{a,i}} \tag{6.14}$$

$$E_{s,sec} = \frac{\Delta\sigma'_{v,i}}{\Delta\epsilon_{a,i}} \tag{6.15}$$

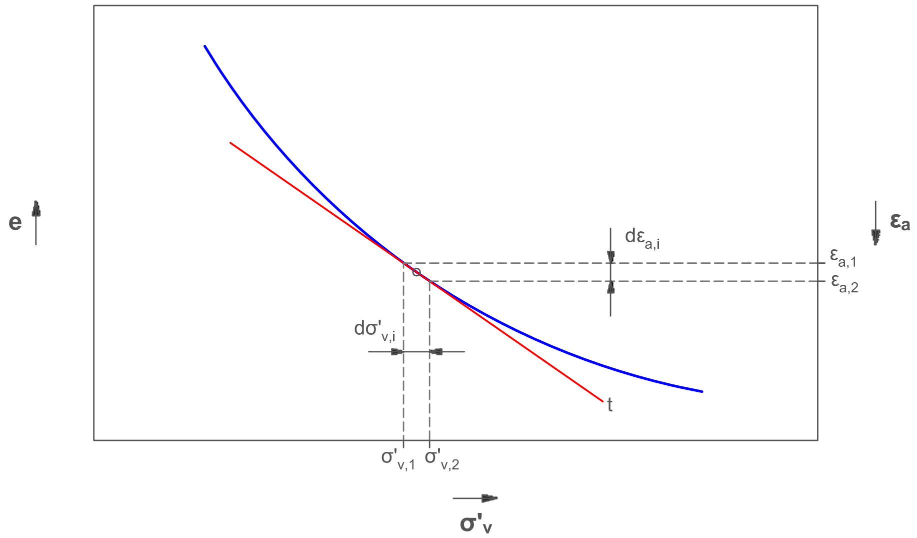


Figure 6.1: Determination of a Constrained Tangent Modulus

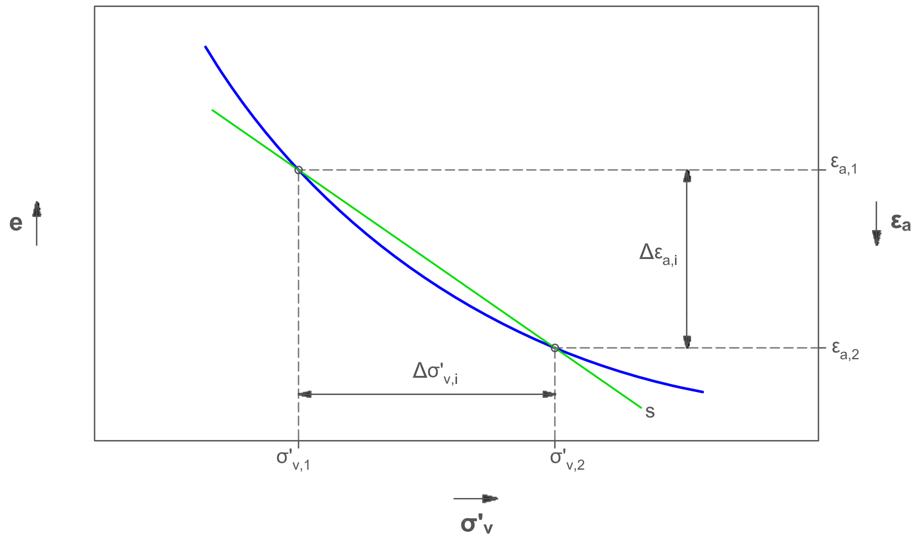


Figure 6.2: Determination of a Constrained Secant Modulus

The representative value of the circumferential strain (ϵ_{c}), measured by the three strain gauges, is multiplied with the outer perimeter of the *oedometer ring* (U_{o}) (equation (6.16)) to achieve the circumferential displacements (Δu_{c}), hence the radial displacements (Δu_{r}) are calculated (equation (6.17)).

$$\Delta u_{\mathrm{c}} = \epsilon_{\mathrm{c}} \cdot U_{\mathrm{o}} \tag{6.16}$$

$$\Delta u_{\mathrm{r}} = \frac{\Delta u_{\mathrm{c}}}{2 \cdot \pi} \tag{6.17}$$

With the radial displacements (Δu_{r}), the Young's modulus of steel ($E_{\mathrm{Steel}} = 210.000\,\mathrm{MPa}$), and the inner ($r_{\mathrm{i}}$) and outer radius ($r_{\mathrm{o}}$) of the *Oedometer Ring*, the radial stress (σ_{r}) can be calculated (equation (6.18)). The *Poisson's ratio* (ν) and subsequently the *Young's modulus* (E) of the specimen can be computed with equation (6.19) and (6.20).

$$\sigma_{\mathrm{r}} = \Delta u_{\mathrm{r}} \cdot E_{\mathrm{Steel}} \cdot \frac{r_{\mathrm{o}}^2 - r_{\mathrm{i}}^2}{2 \cdot r_{\mathrm{i}}^2 \cdot r_{\mathrm{o}}} \tag{6.18}$$

$$\nu = \frac{\sigma_{\mathrm{r}}}{\sigma'_{\mathrm{v,i}} + \sigma_{\mathrm{r}}} \tag{6.19}$$

$$E = \frac{\sigma'_{\mathrm{v,i}}}{\epsilon_{\mathrm{a}}} - \frac{2 \cdot \nu \cdot \sigma_{\mathrm{r}}}{\epsilon_{\mathrm{a}}} \tag{6.20}$$

6.2 Illustration

In order to determine the stress dependent constrained moduli (E_{s}) on chosen stress and strain intervals, an e/ϵ_{a}-σ'_{v} diagram, illustrated in figure 6.3, and an e/ϵ_{a}-log(σ'_{v}) diagram, illustrated in figure 6.4, are plotted. The interval selection should be chosen for the calculation of the secant modulus ($E_{\mathrm{s,sec}}$) (equation (6.15)) for loading and unloading moduli for various cycles.

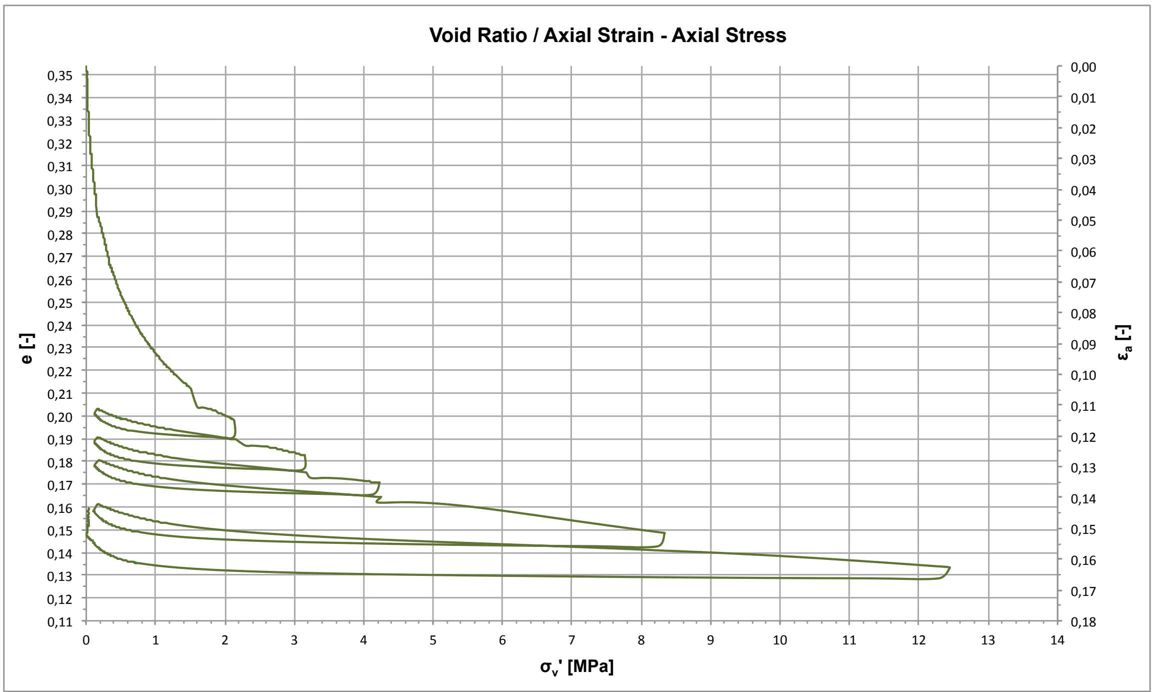


Figure 6.3: Void Ratio-Strain-Stress Chart

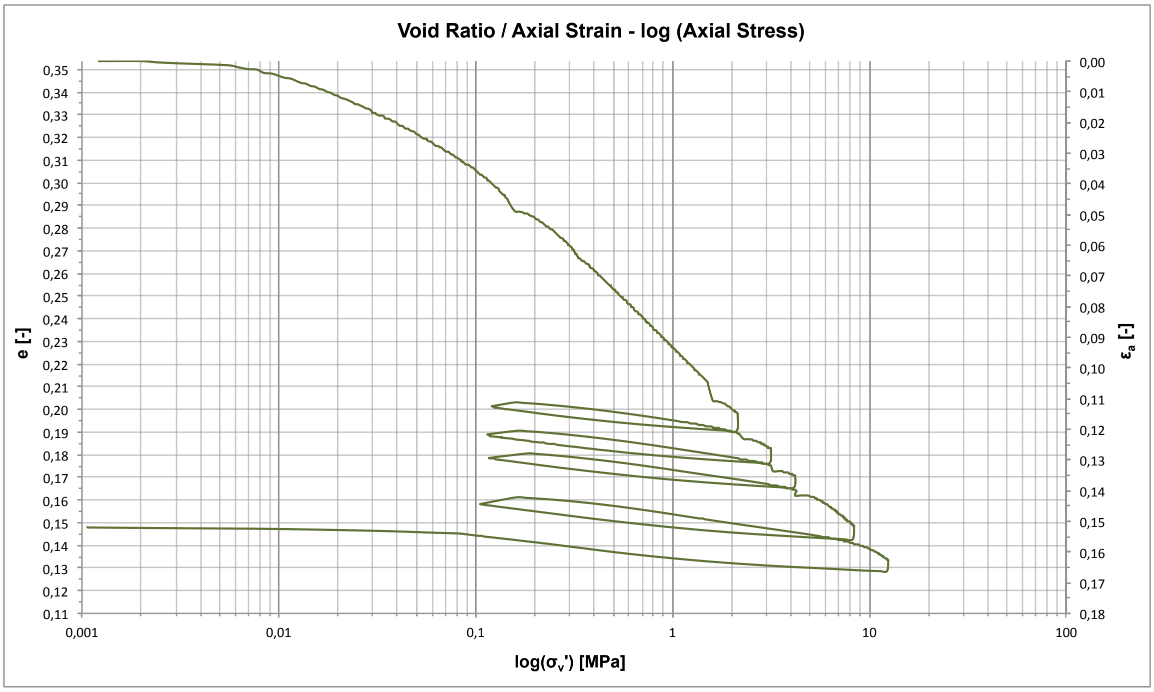


Figure 6.4: Void Ratio-Strain-Stress (log) Chart

7 Conclusions

After giving a brief state-of-the-art review in section 1.1 (p. 2) all aspects of different *large oedometer* designs and set-ups have been taken into consideration and the problem stated in section 1.2 (p. 5) has been solved: as shown in chapter 2 to 6, a *large oedometer* has been designed and manufactured to determine elastic parameters of fault rocks at the *Institute for Rock Mechanics and Tunnelling* of *Graz University of Technology*. An adequate test procedure was developed as shown in chapter 4 to 6 and disadvantages of previous testing methods have been eliminated.

The presented *large oedometer* constitutes an important new apparatus in rock mechanics laboratories and yields a valuable contribution for a proper geomechanical characterization. High stress levels (up to 28,3 MPa) can be applied on large specimens (d=300 mm, h=60 to 100 mm) with a higher grain size diameter (20 mm), than in a standard oedometer. The *oedometer ring* was designed to adopt a *fixed* set-up (RF) for faster and easy *oedometer tests* and a *floating* set-up (RS) for more precise results. The friction force between specimen and *oedometer ring* can be measured in order to achieve accurate values of the effective load acting on the specimen. Not only stress dependent *constrained moduli* (E_s) but also *Young's moduli* (E) can be determined by measuring the lateral displacements and calculating a *Poisson's ratio* (ν).

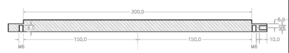
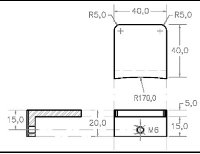
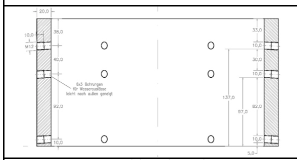
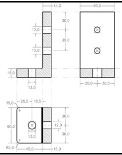
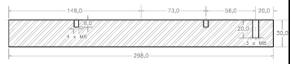
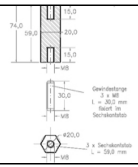
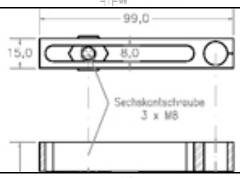
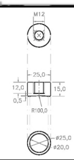
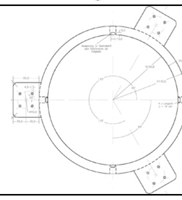
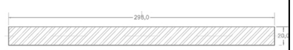
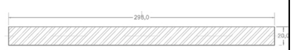
For a future work some aspects have to be taken into consideration:

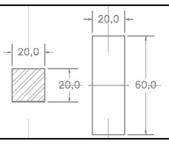
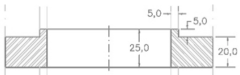
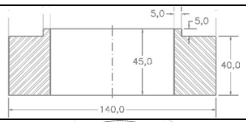
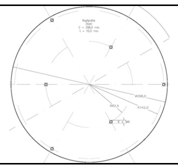
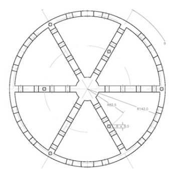
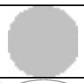
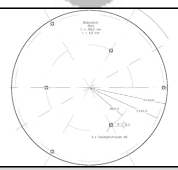
1. A better specimen preparation concept has to be developed in order to minimize the degree of disturbance. New sampling methods with such a large diameter to match with the *large oedometer* size are expensive and only achievable with a high energy input. For this reason a standardized testing procedure for *large oedometers* should be developed.

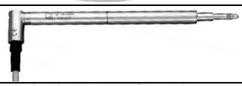
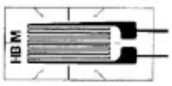
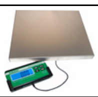
2. The evaluation of the test results has to be standardized. The selection of the stress intervals for the calculation of loading and unloading moduli for various cycles has to be more precise in order to define targeted intervals, otherwise the spread of the calculated moduli is too large. A future project at the *Institute for Rock Mechanics and Tunnelling* will take account of this matter and different methods will be considered and compared.

The new *large oedometer* has certainly overcome the disadvantages of previous testing methods and is a valuable apparatus for determining stress dependent elastic moduli on fault rocks.

A Bill of Materials

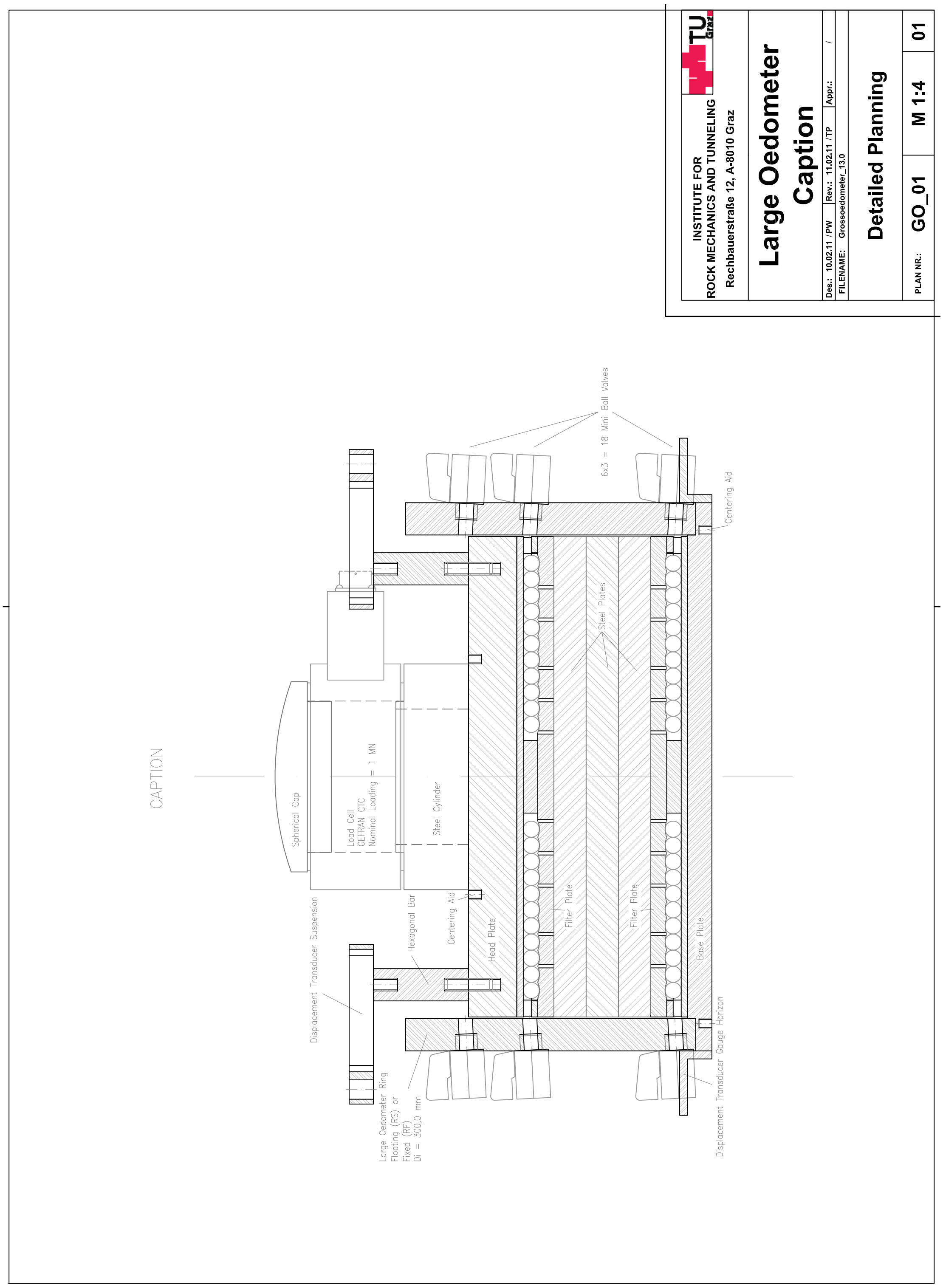
DRAWINGS	DESCRIPTION	DIMENSIONS	QUANTITY	MATERIAL
	Base Plate	D_i = 300,0 mm D_o = 340,0 mm H = 15,0 mm m = 9,858 kg	1	1.2312
	Displacement Transducer Gauge Horizon	l = 40,0 mm w = 40,0 mm h = 20,0 mm t = 5,0 mm m = 0,081 kg	3	1.2312
/	Small Glass Plate	l = 35,0 mm w = 35,0 mm h = 5 mm	3	Glass
	Consolidation Ring	D_i = 300,0 mm D_o = 340,0 mm H = 180,0 mm t = 20,0 mm m = 28,174kg	1	1.2311
	Plunger Suspension	l = 60,0 mm w = 60,0 mm h = 110,0 mm t = 15,0 mm m = 1,045 kg	3	1.2312
	Head Plate	D = 298,0 mm H = 30,0 mm m = 16,670 kg	1	1.2312
	Hexagonal Bar	WS = 20 d = 21,0 mm h = 59,0 mm m = 0,147 kg	3	C45E
	Displacement Transducer Suspension	l = 99,0 mm w = 15,0 mm h = 15,0 mm m = 0,103 kg	3	n.s.
	Plunger: Hex Nut with Flange and Threaded Rod	d = 25,0 mm h = 18,0 mm R = 100,0 mm m = 0,162 kg	3	8.8
	Suspension Ring	D_i = 301,0 mm t = 20,0 mm Ears: l = 60,0 mm w = 80,0 mm t = 20,0 mm m = 11,050 kg	1	S355J2+N
	Steel Plate	D = 298,0 mm H = 20,0 mm m = 10,858 kg	1	1.2312
	Steel Plate	D = 298,0 mm H = 19,4 mm m = 10,590 kg	2	S355J2+N

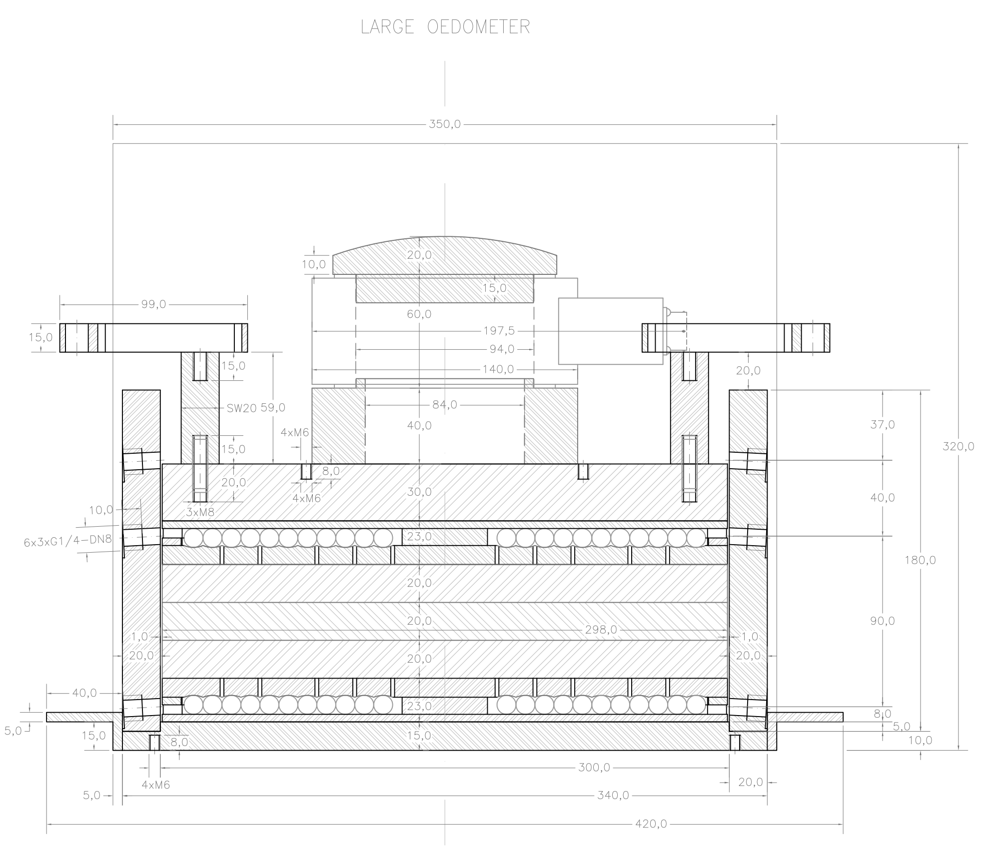
	Spacer	l = 20,0 mm w = 20,0 mm h = 60,0 mm m = 0,186 kg	6	S355J2+N
	Spherical Cap	R = 200,0 mm D_o = 118,0 mm D_i = 93,5 mm h = 35,0 mm m = 2,132 kg	1	S355J2+N
	Steel Cylinder	D_o = 140,0 mm D_i = 93,5 mm h = 20,0 mm m = 1,585 kg	1	S355J2+N
	Steel Cylinder	D_o = 140,0 mm D_i = 93,5 mm h = 40,0 mm m = 3,133 kg	1	S355J2+N
	Filter Head Plate	D = 298,0 mm H = 10,0 mm m = 5,123 kg	2	M333 ISOPLAST
	Filter Plate Border	D = 298,0 mm H = 9,0 mm t = 10,0 mm Star: d = 45,0 mm l = 117,2 mm t = 12,0 mm m = 1,163 kg	2	DILLIDUR 400
	Steel Balls	d = 10,0 mm m = 0,004 kg	924	100Cr6
	Filter Base Plate	D = 298,0 mm H = 4,0 mm m = 2,199 kg	2	1.2379
/	Grub-Screws	M6 x 15mm	4	8.8
/	Grub-Screws	M6 x 10mm	4	8.8
/	Hexagonal Screws	M6 x 15mm	3	8.8
/	Hexagonal Screws	M12 x 27mm	6	8.8
/	Hexagonal Screws	M12 x 35mm	4	8.8
/	Hexagonal Nut	M12	6	8.8
/	Washers	M12	6	8.8
/	Threaded Rod	M12 x 100mm	3	8.8
/	Countersunk Screw	M4 x 26mm	12	8.8
/	Hexagonal Screws	M8 x 25mm	3	8.8
/	Threaded Rod	M8 x 30mm	3	8.8
/	Countersunk Screws	M6 x 20mm	12	8.8 A2
/	Ring Screws	M6 x 20mm	3	8.8

	Load Cell GEFRAN CTC	Nominal Loading: 1.000 kN m = 2,284 kg	1	Stainless Steel
	Load Cell HBM C9B	Nominal Loading: 50 kN m = 0,260 kg	3	Stainless Steel
	Displacement Transducer HBM WA20	Measuring Range: 0...20 mm m = 0,064 kg	3	Stainless Steel
	Strain Gauge HBM DMS Series Y	LY41-20/120	3	n.s.
	Measuring Amplifier HBM Spider8	10 TF Module SR55 (15-pin Socket)	2	n.s.
	Weighing Platform RAUCH TCS-150kg	G_{max} = 150.000 g Reading Prec.: 10 g	1	Stainless Steel
	Precision Balance Mettler Toledo PM16-K	G_{max} = 16.000 g Reading Prec.: 0,1 g σ = 0,05 g Linearity: ±0,2g	1	Stainless Steel
/	Adapter Cable KAB 133A	From Sub-D-Socket Bu (15-pin) to MS Socket (7-pin)	3	n.s.
	2/2-Way-Mini-Ball Valve	G1/4 DN8	18	Chromed Brass
	Angled Screw Coupling	G1/4 DN8 Hose D_o 8 mm	6	Nickel - Plated Brass
	Male Branch Tee	G1/4 DN8 Hose D_o 8 mm	12	Nickel - Plated Brass
	Polyurethane – Plastic Hose	D_a = 8,0 mm D_i = 6,0 mm	10 m	H-PU
	Geotextile TenCate Polyfelt TS 810	k = $2{,}2 \times 10^{-3}$ m/s $D_{Opening}$ = 0,12 mm t = 0,9 mm m = 115 g/m^2	4 x 10 m	PP
/	Geotextile Circle	d = 300 mm	4	PP
/	Sealing Tape	w = 25 mm l = 1.070 mm	1	Rubber
/	Rust Preventive Oil	Koch & Stiedl Mobilarma MT	1	n.s.
/	Lubricant	WD 40	1	n.s.
	Bucket	V_{min} = 6,0 l	2	Plastic

TOOLS

B Large Oedometer Drawings


INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz
TU Graz
Large Oedometer
Caption
Des.: 10.02.11 /PW
Rev.: 11.02.11 /TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: GO_01
M 1:4
01
CAPTION
6x3 = 18 Mini-Ball Valves
Centering Aid
Steel Plates
Spherical Cap
Load Cell
GEFRAN CTC
Nominal Loading = 1 MN
Steel Cylinder
Displacement Transducer Suspension
Hexagonal Bar
Centering Aid
Head Plate
Filter Plate
Filter Plate
Base Plate
Displacement Transducer Gauge Horizon
Large Oedometer Ring
Floating (RS) or
Fixed (RF)
Di = 300,0 mm



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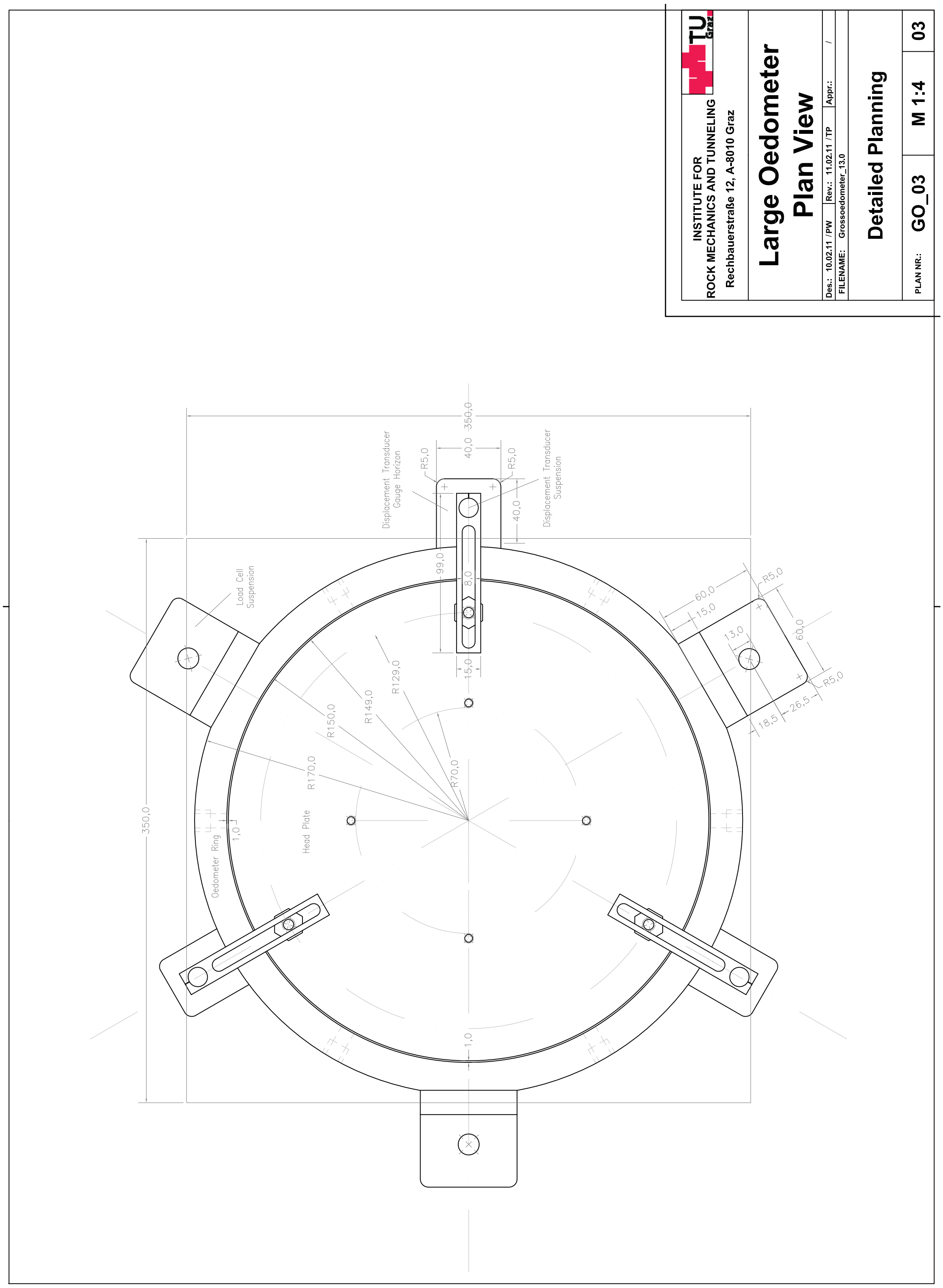
TU Graz

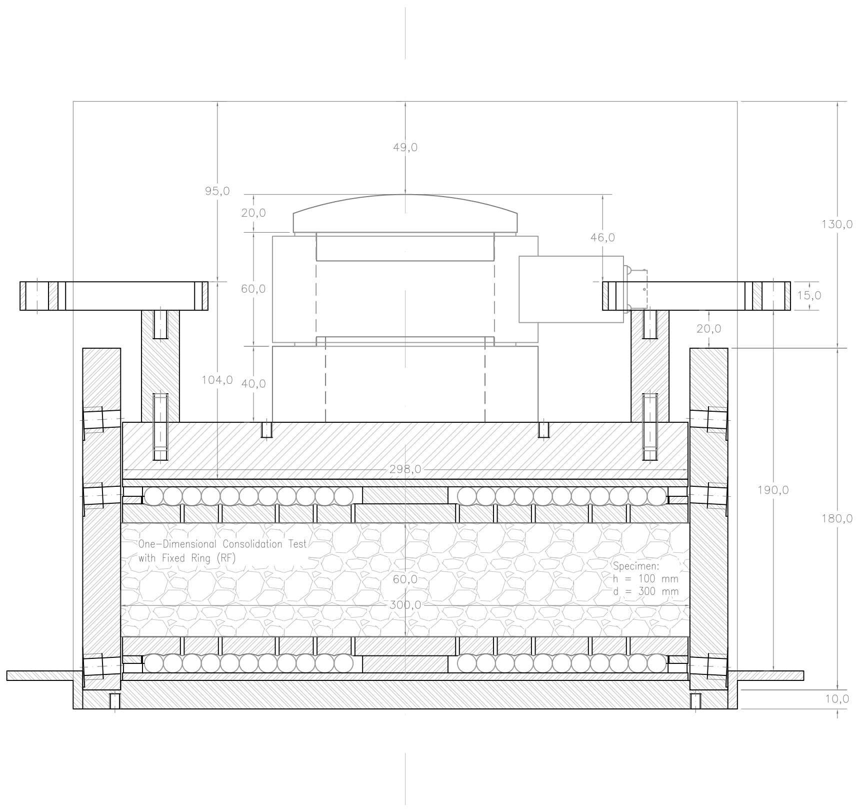
Large Oedometer Cross Section

Des.: 10.02.11 /PW	Rev.: 11.02.11 /TP	Appr.: /
FILENAME: Grossoedometer_13.0		

Detailed Planning

PLAN NR.:	GO_02	M 1:4	02


INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz
TU Graz
Large Oedometer
Plan View
Des.: 10.02.11 /PW
Rev.: 11.02.11 /TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: GO_03
M 1:4
03
Displacement Transducer Gauge Horizon
Displacement Transducer Suspension
Load Cell Suspension
Oedometer Ring
Head Plate
350,0
40,0
R5,0
99,0
8,0
15,0
60,0
13,0
18,5
26,5
R129,0
R149,0
R150,0
R170,0
R70,0
1,0



INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz

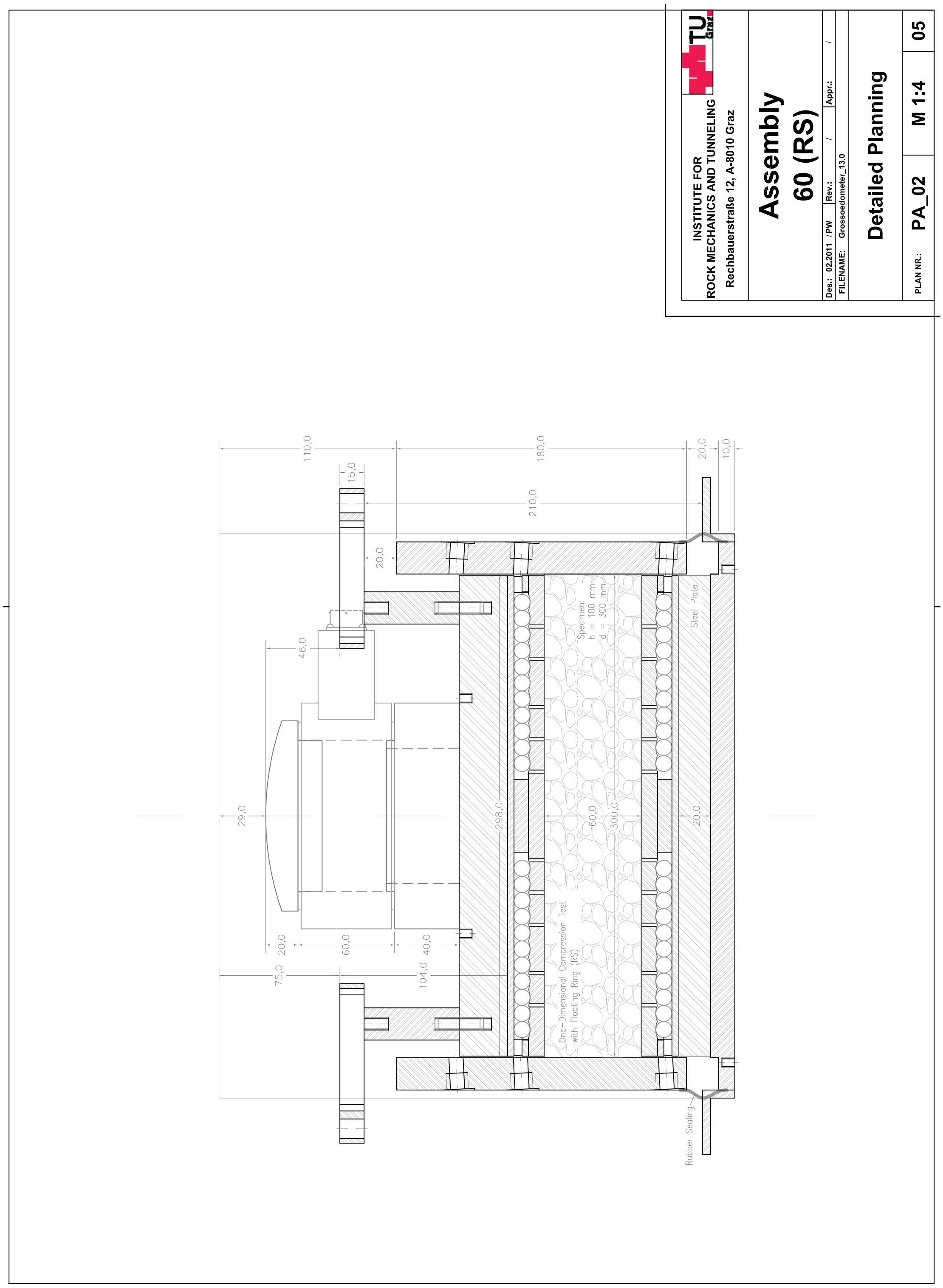
Assembly
60 (RF)

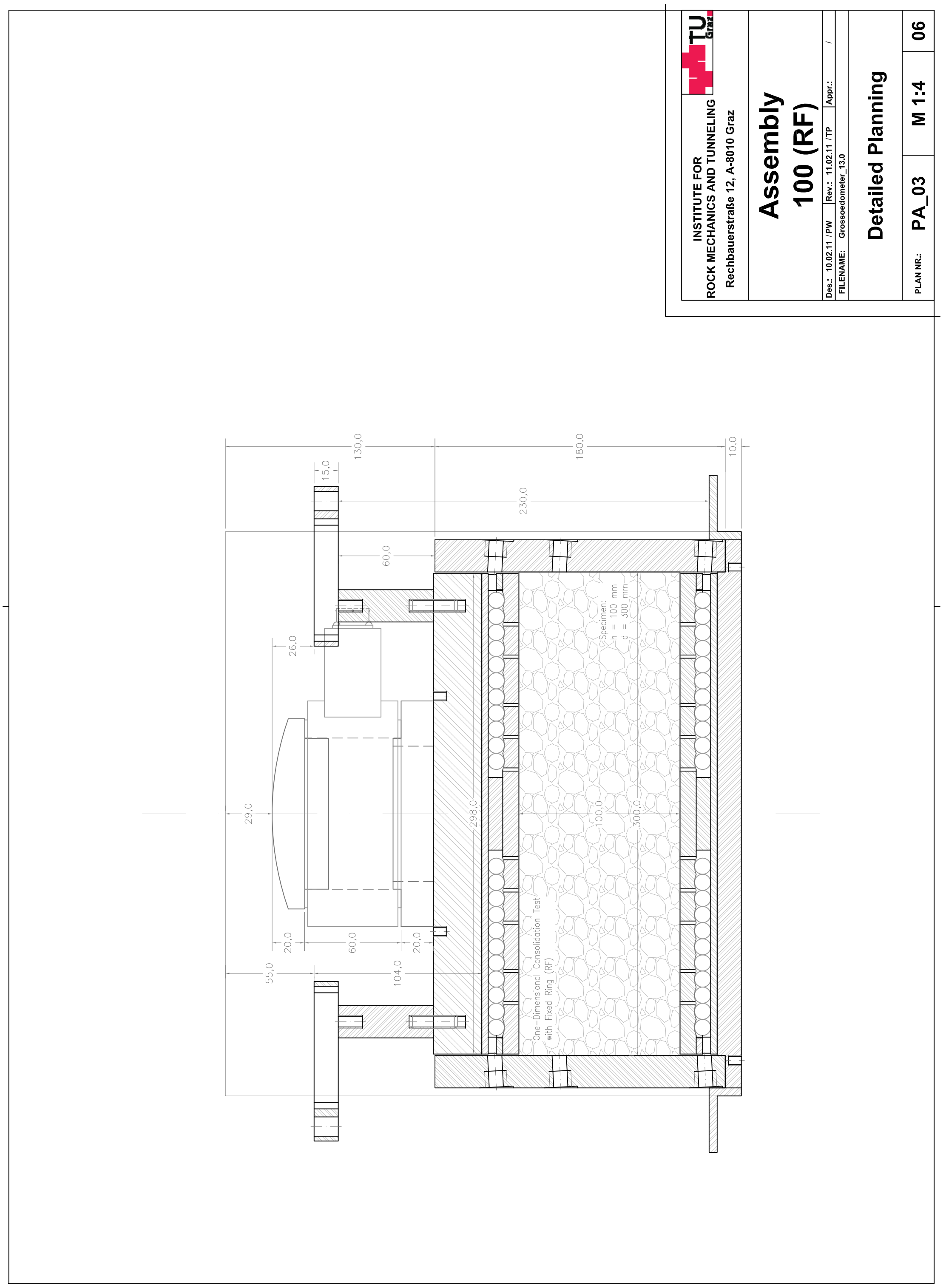
Des.: 10.02.11 /PW	Rev.: 11.02.11 /TP	Appr.: /

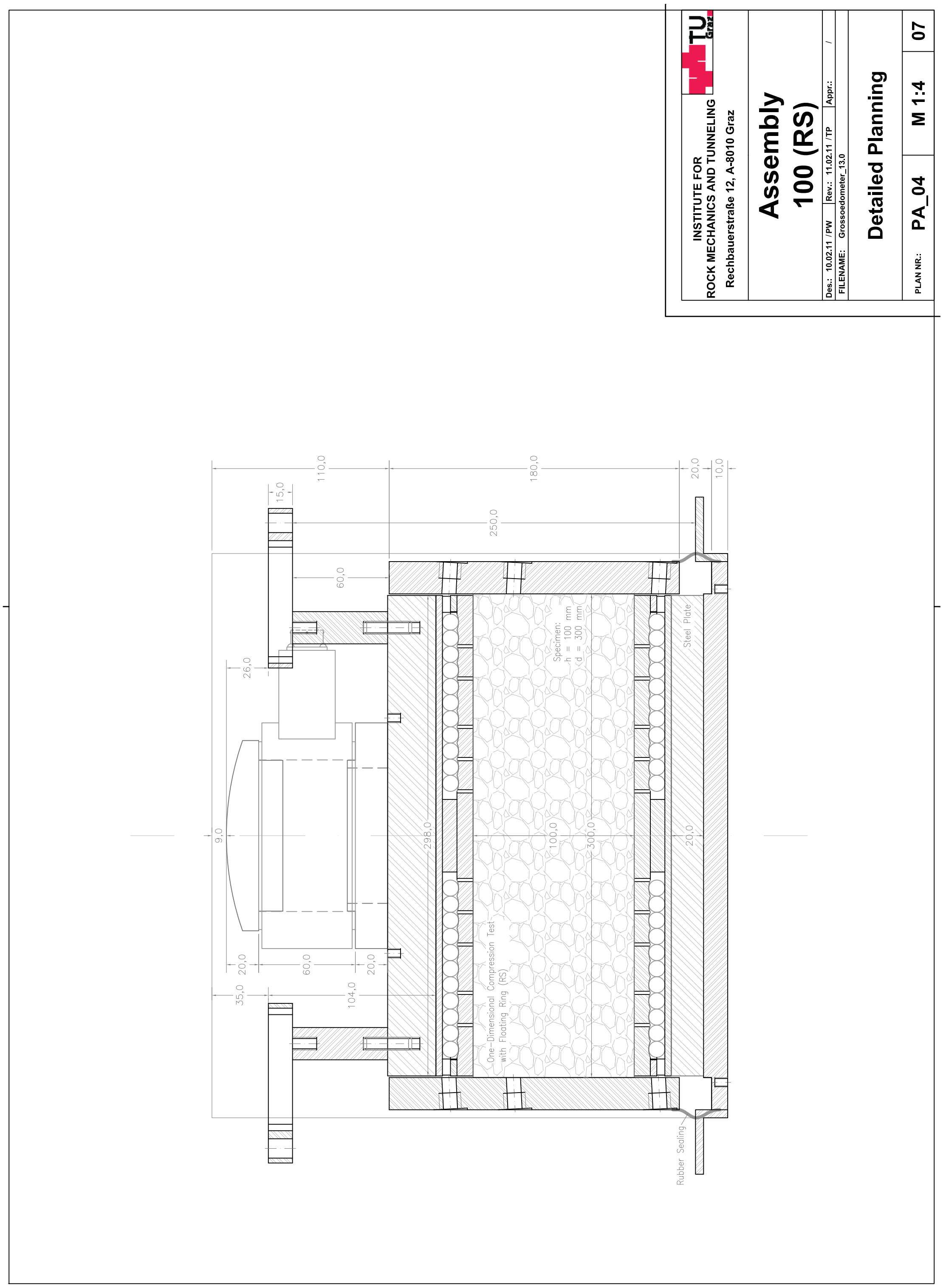
FILENAME: Grossoedometer_13.0

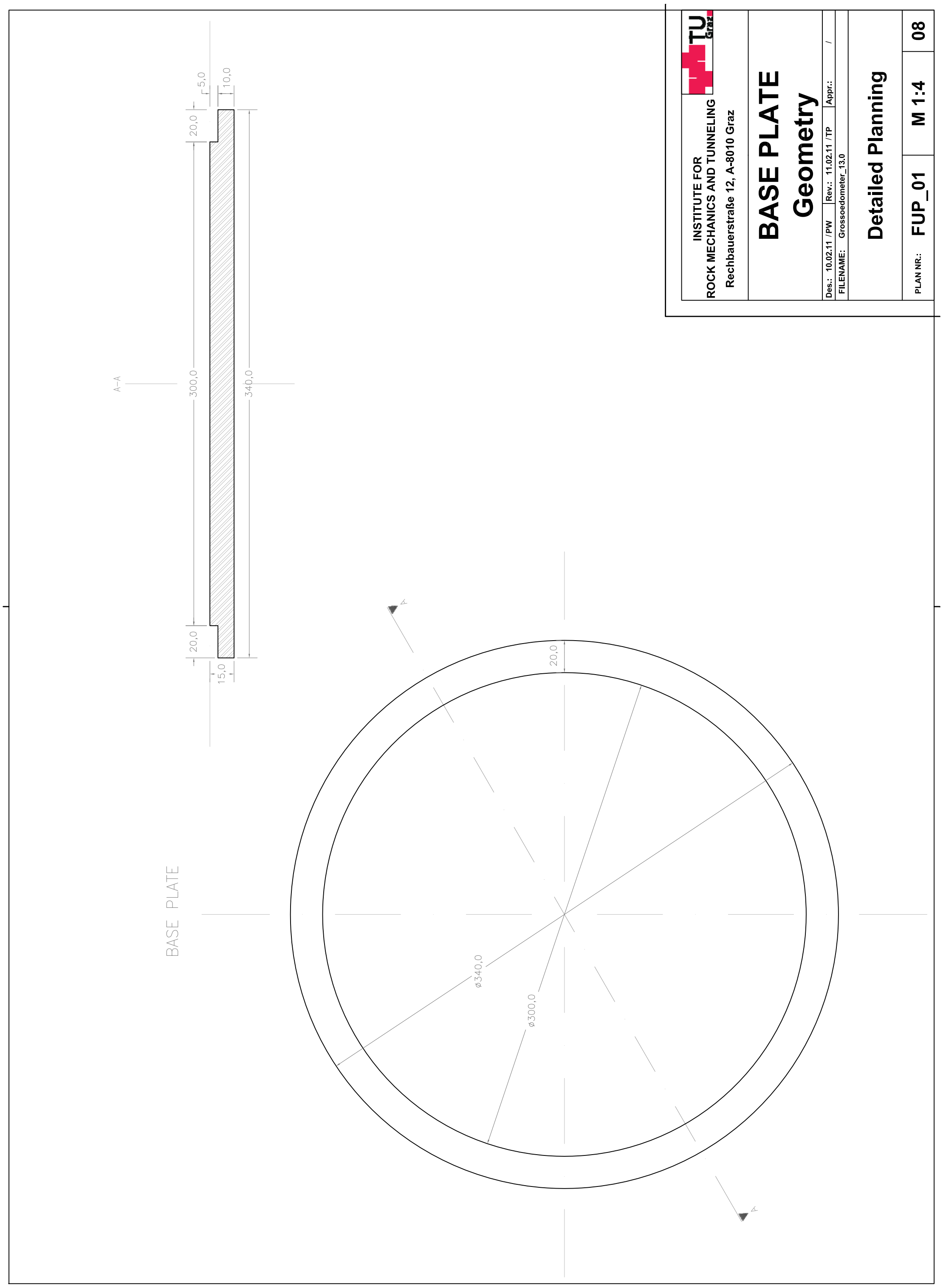
Detailed Planning

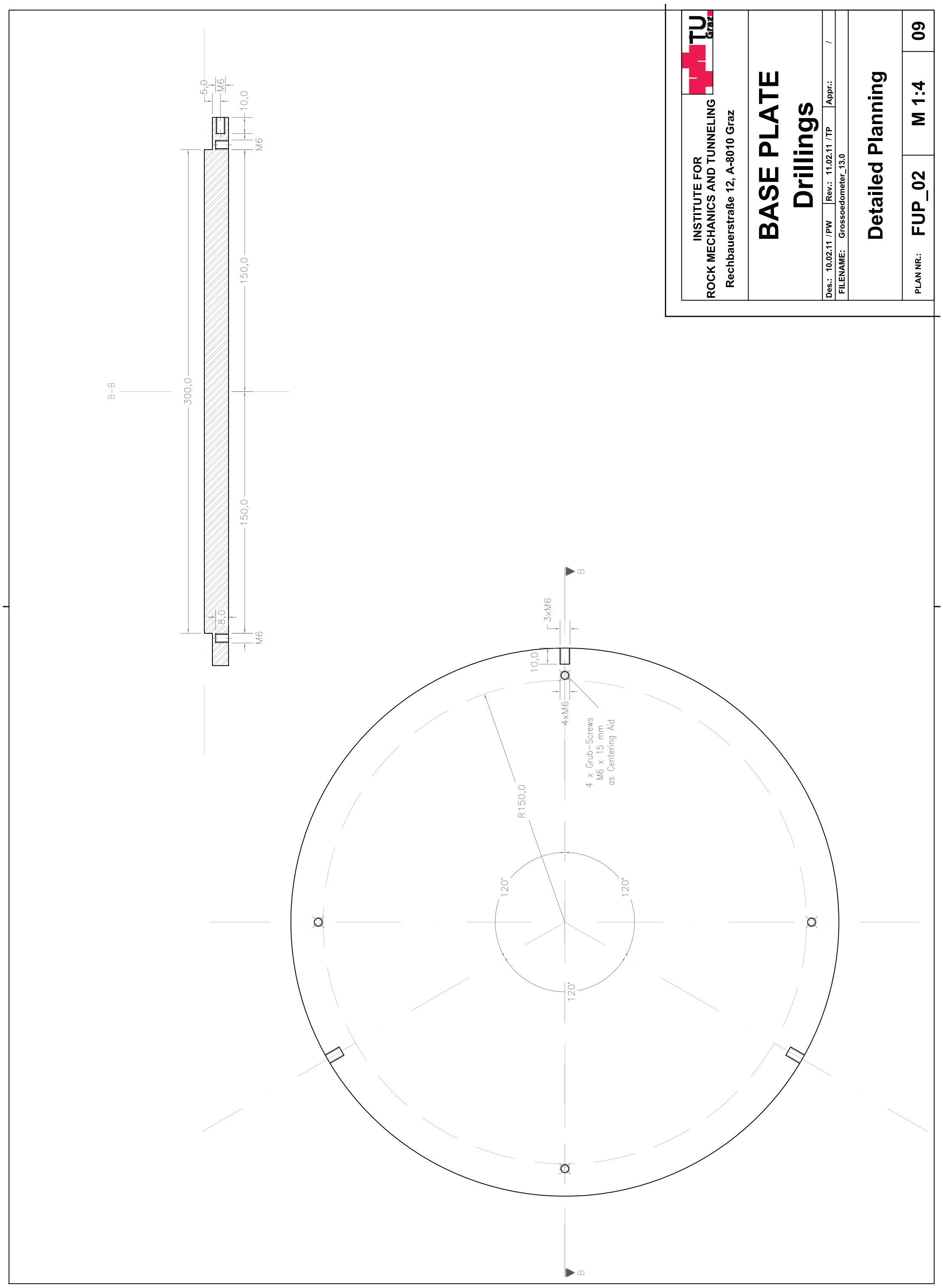
PLAN NR.:	PA_01	M 1:4	04

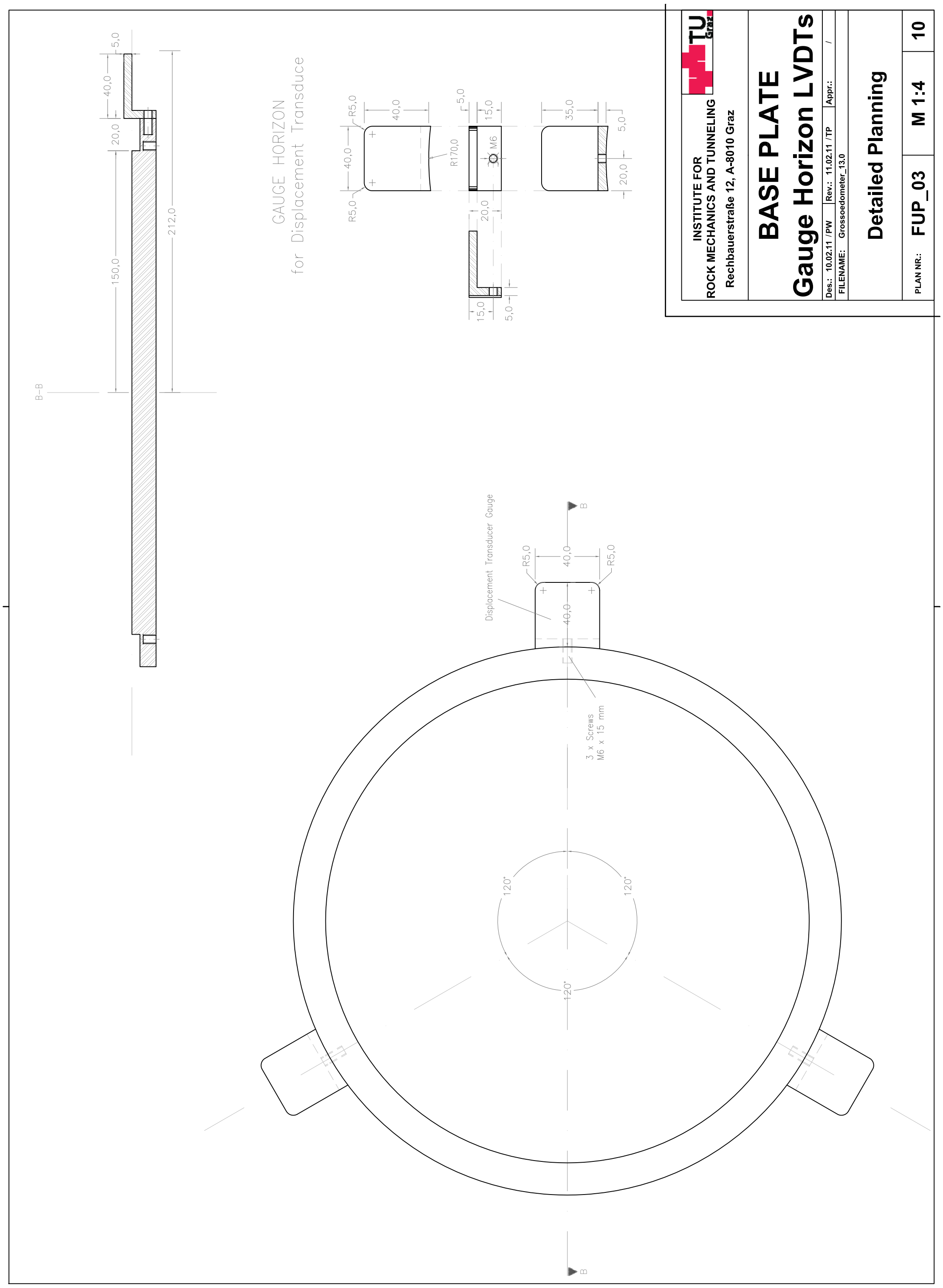

INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz
TU Graz
Assembly
60 (RS)
Des.: 02.2011 /PW
Rev.: /
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: PA_02
M 1:4
05
Specimen:
h = 100 mm
d = 300 mm
One-Dimensional Compression Test
with Floating Ring (RS)
Steel Plate
Rubber Sealing

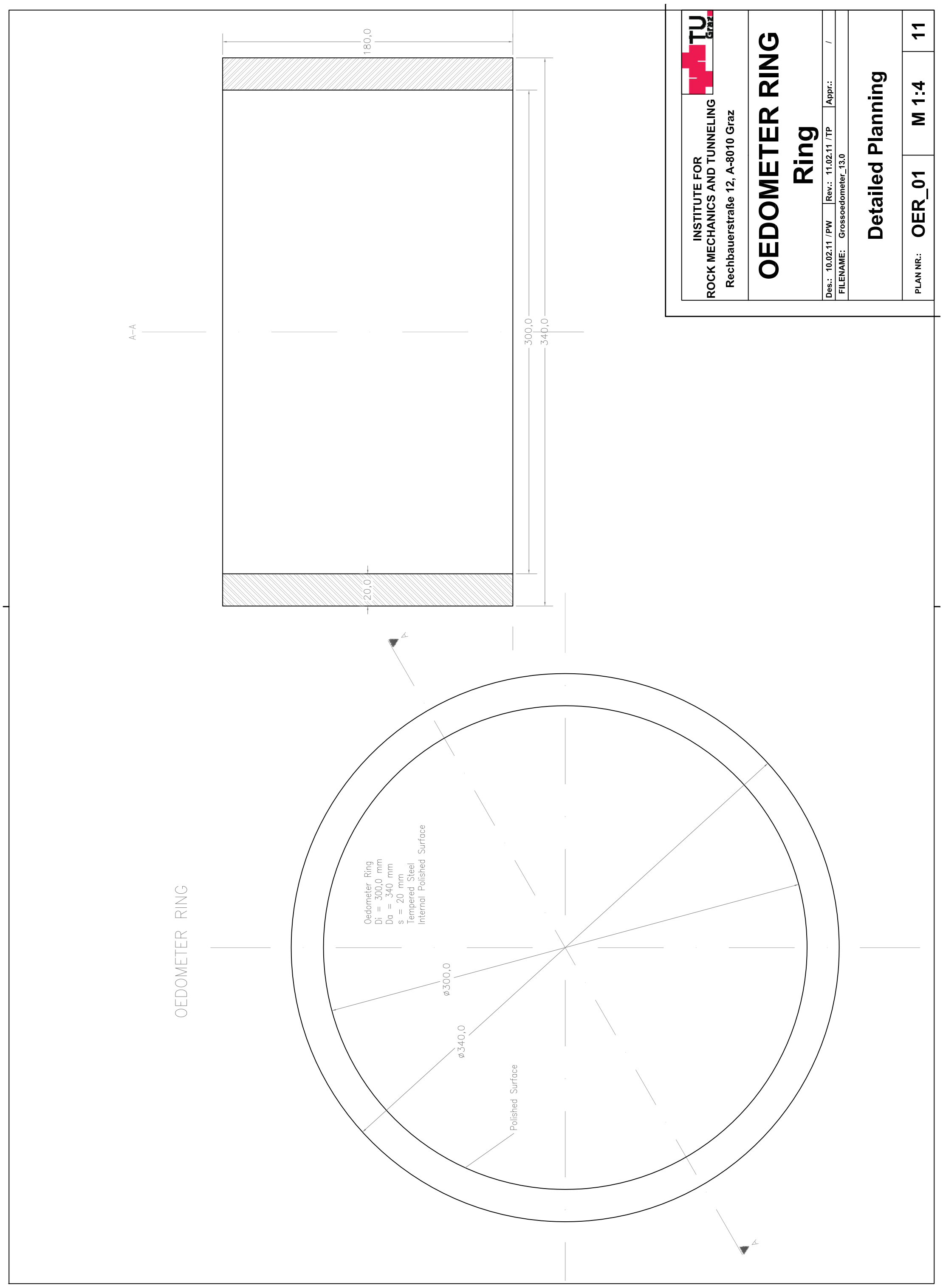

INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz
TU Graz
Assembly
100 (RF)
Des.: 10.02.11 /PW
Rev.: 11.02.11 /TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: PA_03
M 1:4
06
130,0
180,0
10,0
15,0
230,0
60,0
26,0
29,0
298,0
100,0
300,0
Specimen:
h = 100 mm
d = 300 mm
20,0
60,0
20,0
55,0
104,0
One-Dimensional Consolidation Test
with Fixed Ring (RF)


INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz
TU Graz
Assembly
100 (RS)
Des.: 10.02.11 /PW
Rev.: 11.02.11 /TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: PA_04
M 1:4
07
Steel Plate
Specimen:
h = 100 mm
d = 300 mm
One-Dimensional Compression Test
with Floating Ring (RS)
Rubber Sealing
110,0
180,0
20,0
10,0
15,0
250,0
60,0
26,0
9,0
298,0
100,0
300,0
20,0
20,0
60,0
20,0
35,0
104,0

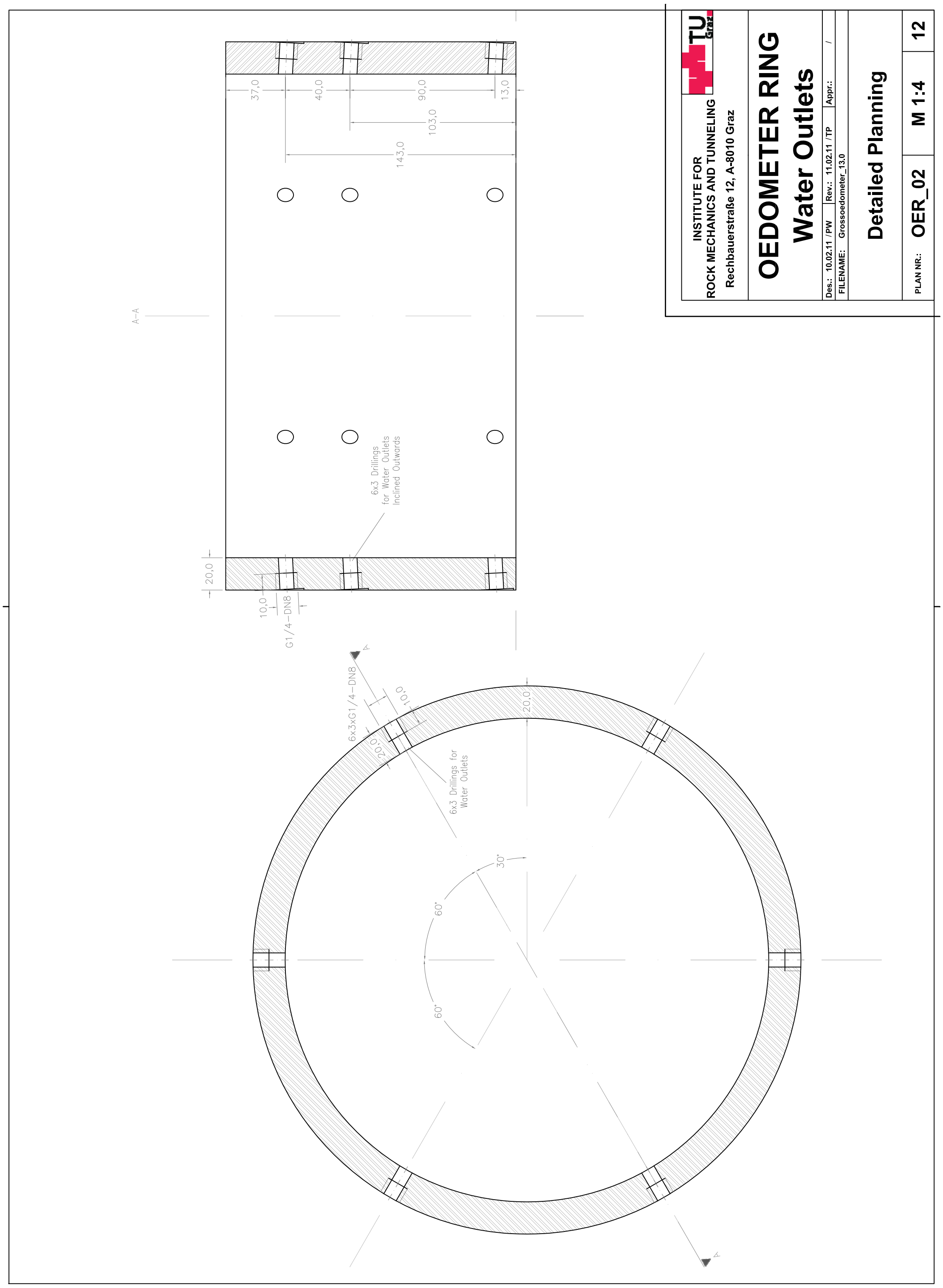

INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz
BASE PLATE
Geometry
Des.: 10.02.11 /PW
Rev.: 11.02.11 /TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: FUP_01
M 1:4
08
A-A
20,0
5,0
10,0
300,0
340,0
20,0
15,0
BASE PLATE
20,0
ø340,0
ø300,0

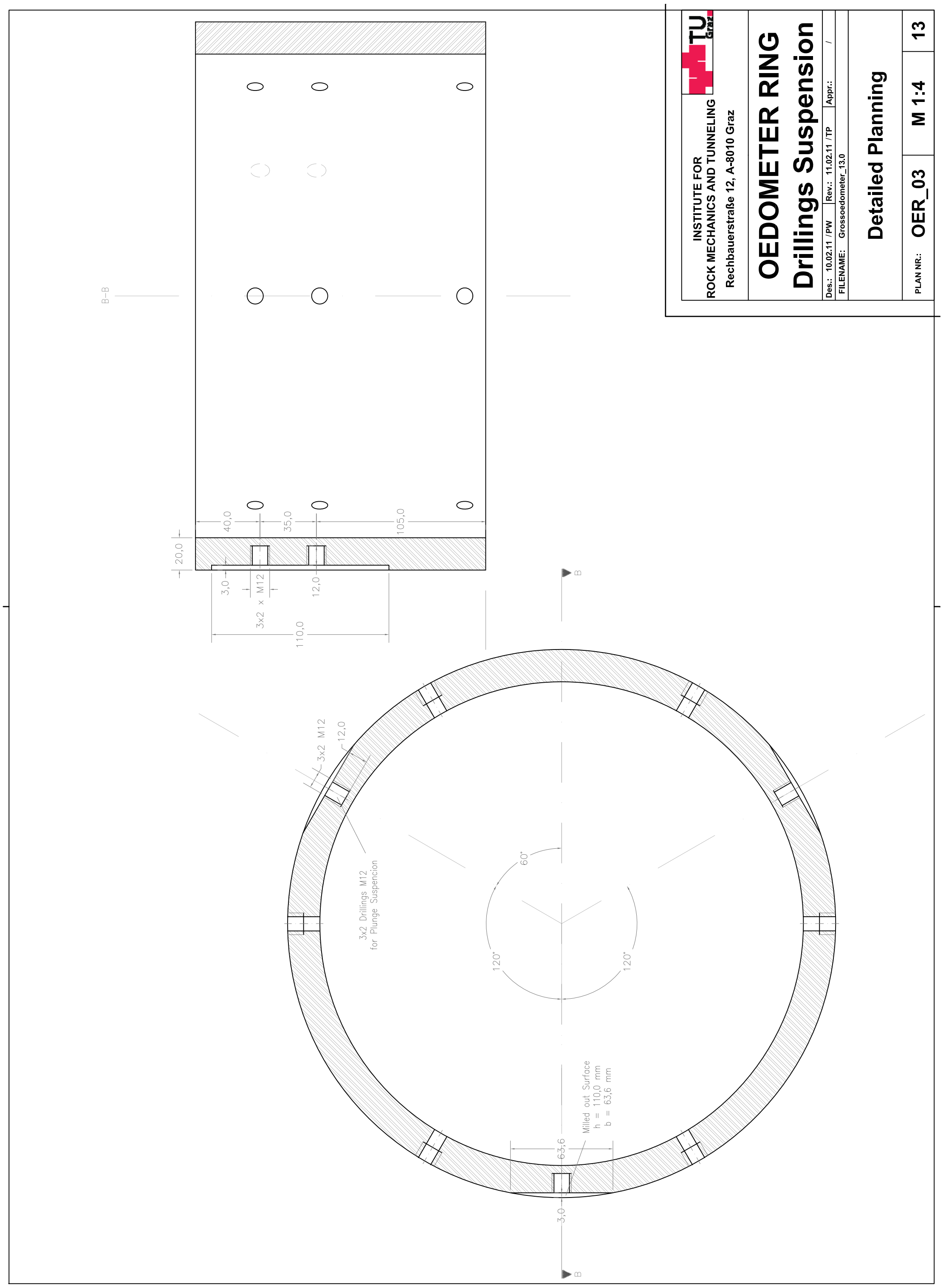

INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz
TU Graz
BASE PLATE
Drillings
Des.: 10.02.11 /PW
Rev.: 11.02.11 /TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: FUP_02
M 1:4
09
B-B
300,0
150,0
150,0
10,0
5,0
8,0
M6
3xM6
4xM6
R150,0
120°
120°
120°
4 x Grub-Screws
M6 x 15 mm
as Centering Aid
B

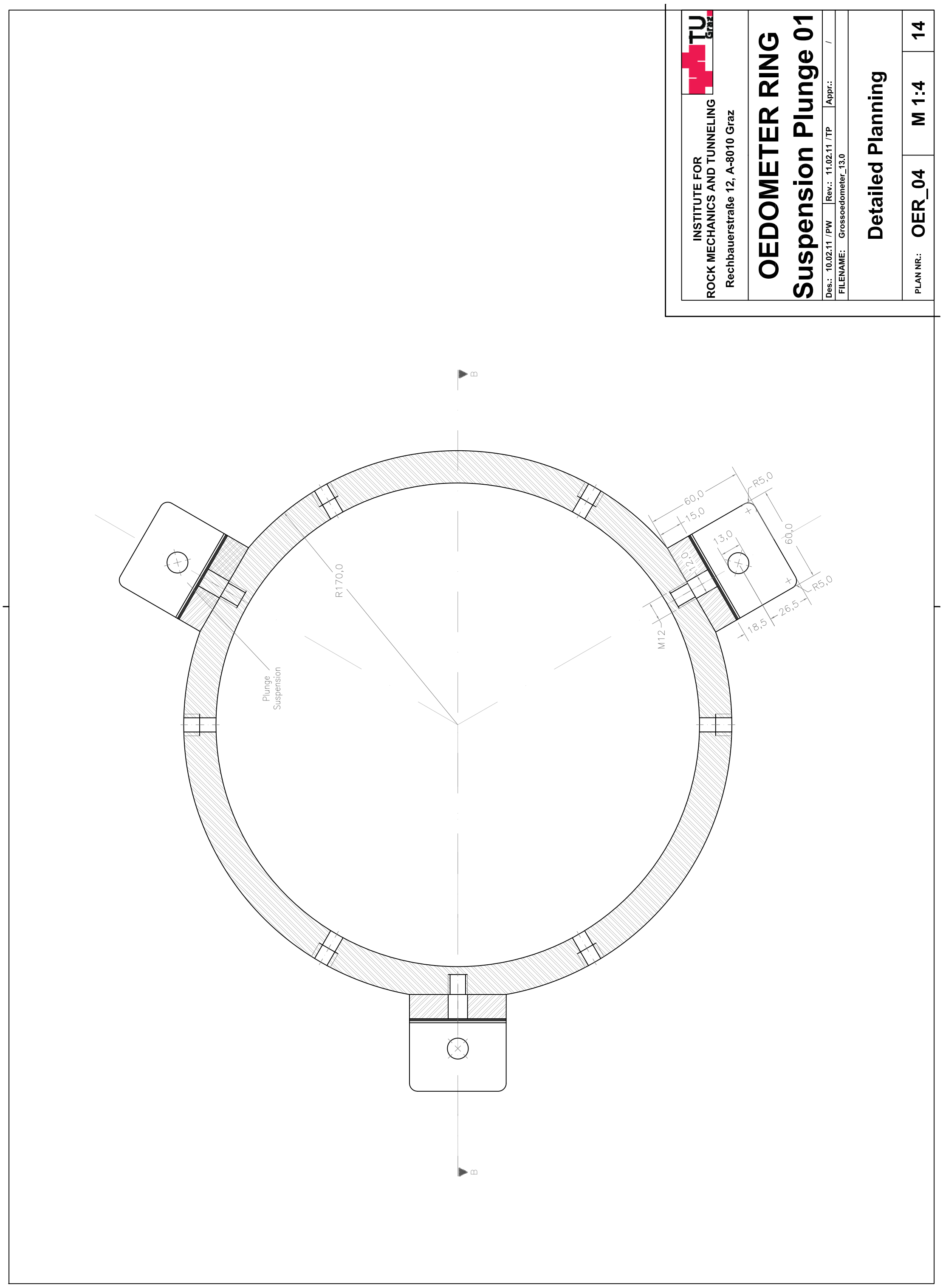

INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz
TU Graz
BASE PLATE
Gauge Horizon LVDTs
Des.: 10.02.11 /PW
Rev.: 11.02.11 /TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: FUP_03
M 1:4
10
GAUGE HORIZON
for Displacement Transduce
Displacement Transducer Gauge
3 x Screws
M6 x 15 mm
B-B
120°
R5,0
40,0
R170,0
M6
212,0
150,0
20,0
35,0
15,0
5,0

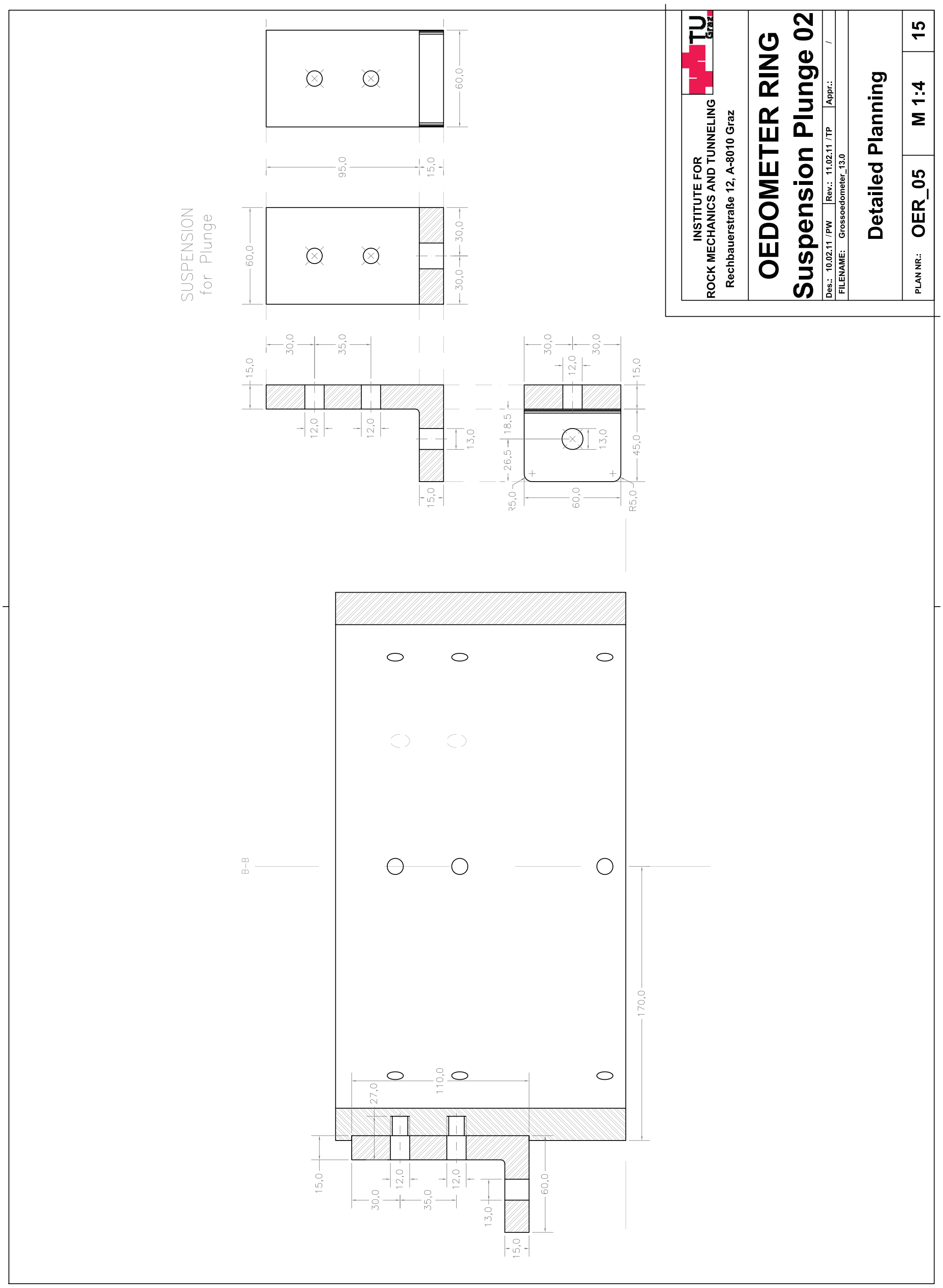


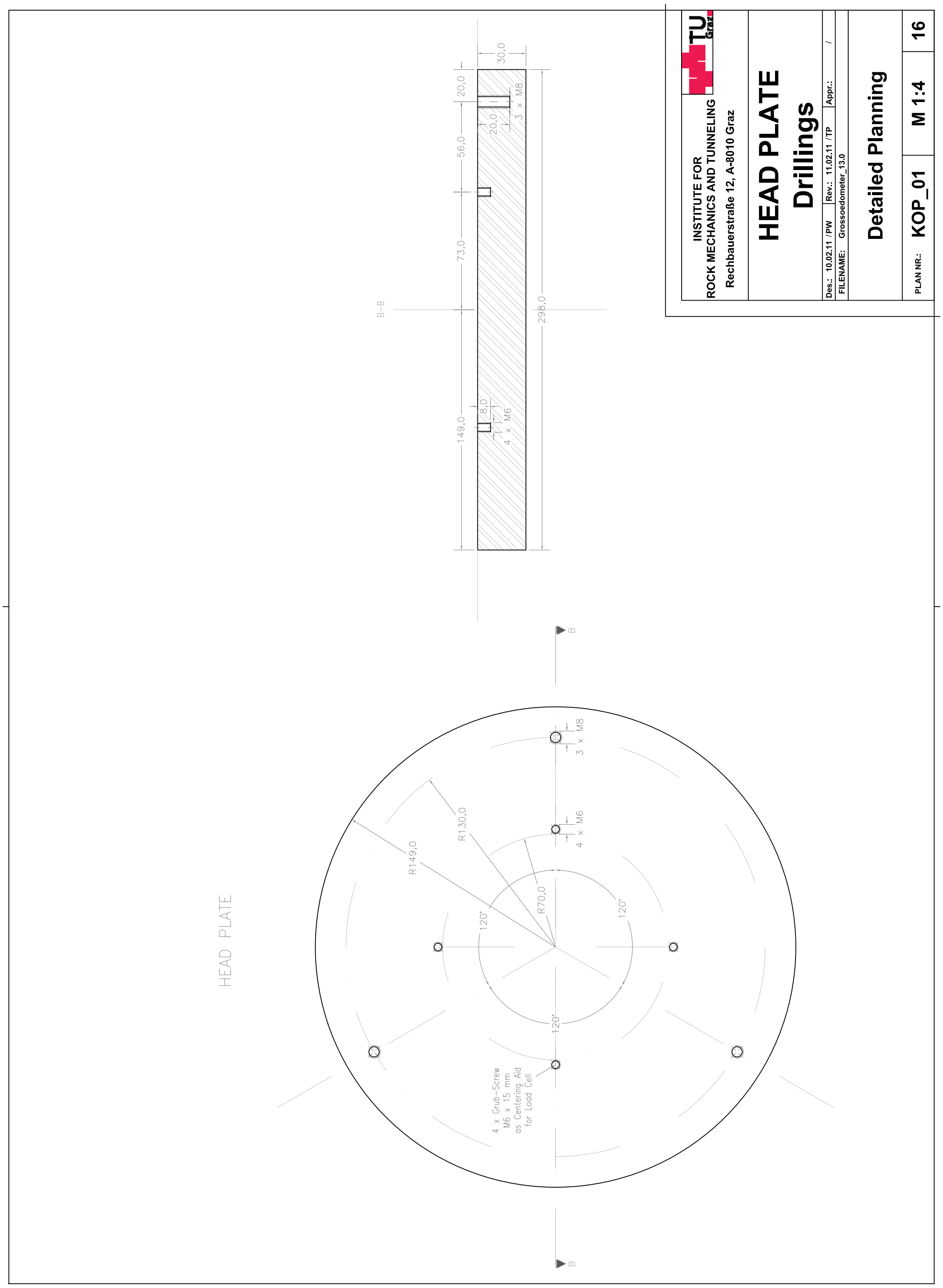
180,0
A–A
300,0
340,0
20,0
A
OEDOMETER RING
Oedometer Ring
Di = 300,0 mm
Da = 340 mm
s = 20 mm
Tempered Steel
Internal Polished Surface
ø300,0
ø340,0
Polished Surface
INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz
TU Graz
OEDOMETER RING
Ring
Des.: 10.02.11 /PW
Rev.: 11.02.11 /TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: OER_01
M 1:4
11

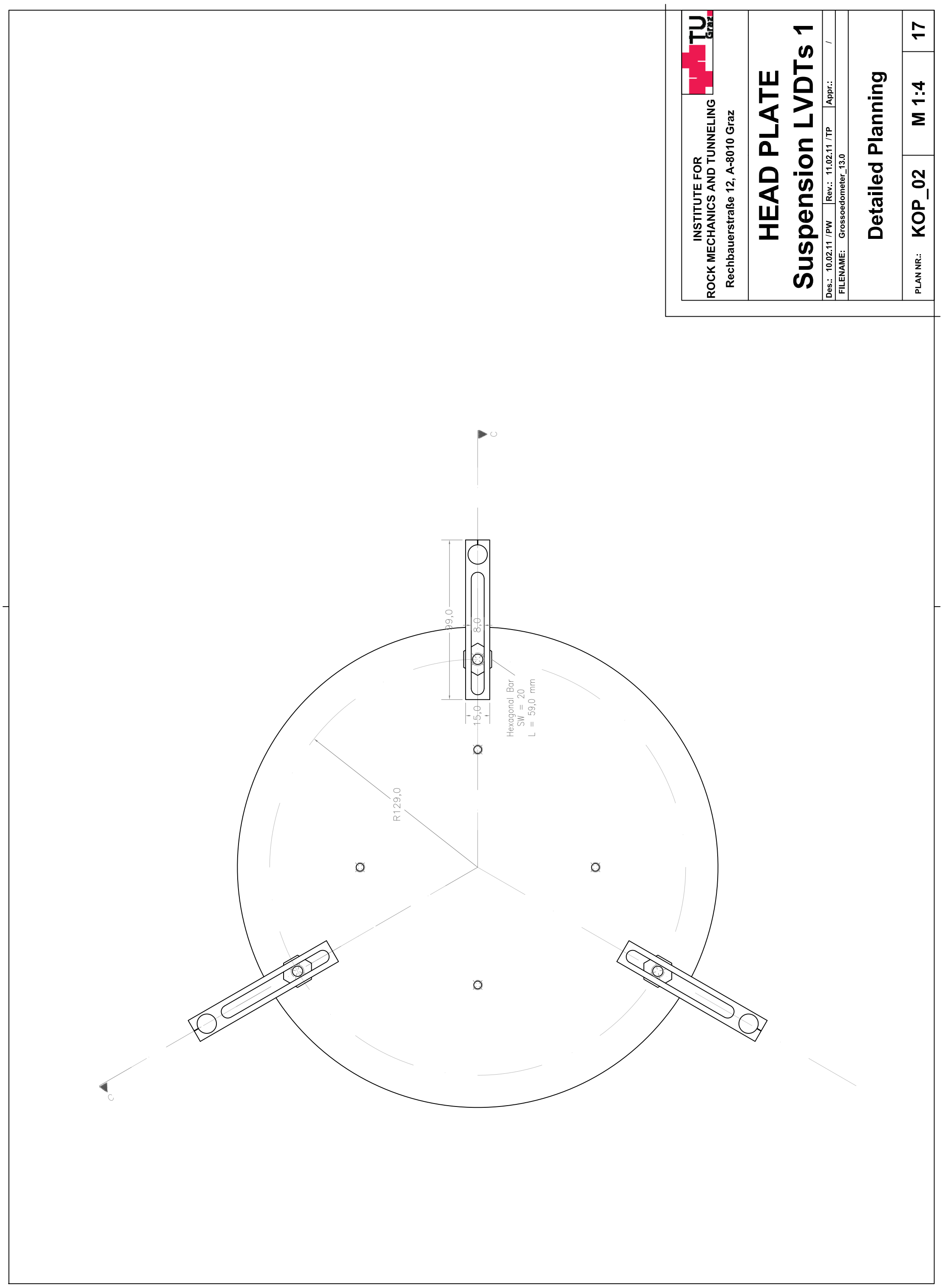

INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz
TU Graz
OEDOMETER RING
Water Outlets
Des.: 10.02.11 /PW
Rev.: 11.02.11 /TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: OER_02
M 1:4
12
A-A
37,0
40,0
90,0
13,0
103,0
143,0
6x3 Drillings for Water Outlets Inclined Outwards
20,0
10,0
G1/4-DN8
6x3xG1/4-DN8
6x3 Drillings for Water Outlets
30°
60°
60°

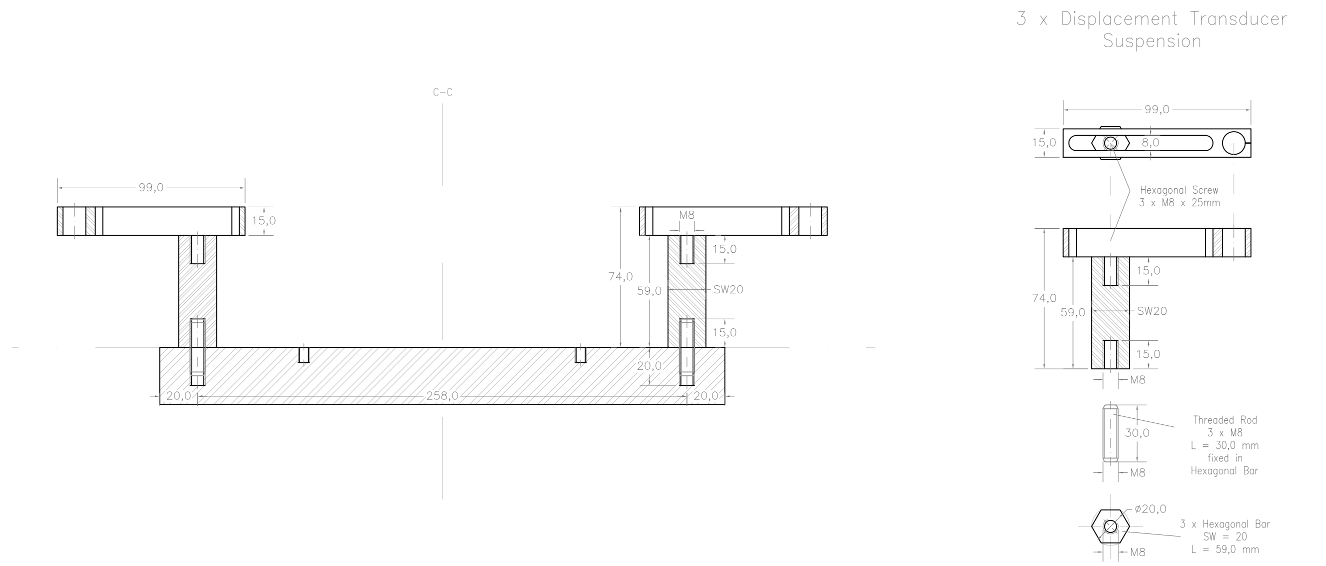

INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz
TU Graz
OEDOMETER RING
Drillings Suspension
Des.: 10.02.11 /PW
Rev.: 11.02.11 /TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: OER_03
M 1:4
13
B–B
40,0
35,0
105,0
20,0
3,0
3x2 x M12
12,0
110,0
B
3x2 M12
12,0
3x2 Drillings M12
for Plunge Suspencion
60°
120°
120°
Milled out Surface
h = 110,0 mm
b = 63,6 mm
63,6
3,0


INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz
TU Graz
OEDOMETER RING
Suspension Plunge 01
Des.: 10.02.11 /PW
Rev.: 11.02.11 /TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: OER_04
M 1:4
14
R170,0
Plunge Suspension
M12
60,0
15,0
R5,0
13,0
12,0
60,0
18,5
26,5
R5,0
B
B


INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz
TU Graz
OEDOMETER RING
Suspension Plunge 02
Des.: 10.02.11 / PW
Rev.: 11.02.11 / TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: OER_05
M 1:4
15
SUSPENSION for Plunge
B–B
95,0
15,0
60,0
30,0
35,0
12,0
13,0
18,5
26,5
45,0
R5,0
170,0
110,0
27,0


INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz
TU Graz
HEAD PLATE
Drillings
Des.: 10.02.11 /PW
Rev.: 11.02.11 /TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: KOP_01
M 1:4
16
B-B
20,0
56,0
73,0
149,0
298,0
30,0
20,0
3 x M8
8,0
4 x M6
HEAD PLATE
R149,0
R130,0
R70,0
120°
120°
120°
3 x M8
4 x M6
4 x Grub-Screw
M6 x 15 mm
as Centering Aid
for Load Cell
B
B


INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz
TU Graz
HEAD PLATE
Suspension LVDTs 1
Des.: 10.02.11 / PW
Rev.: 11.02.11 / TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: KOP_02
M 1:4
17
89,0
8,0
15,0
Hexagonal Bar
SW = 20
L = 59,0 mm
R129,0
C
C



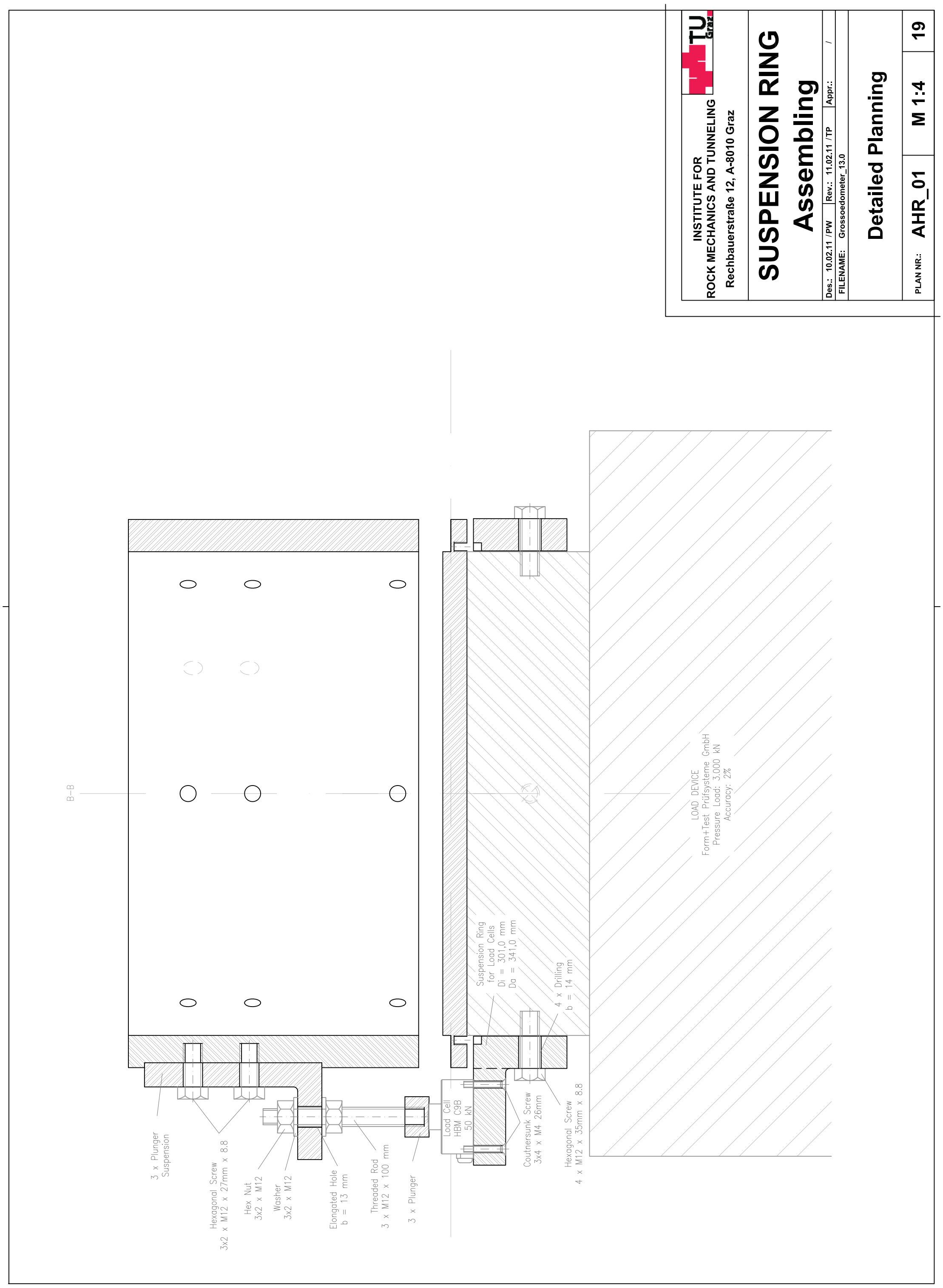
INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz

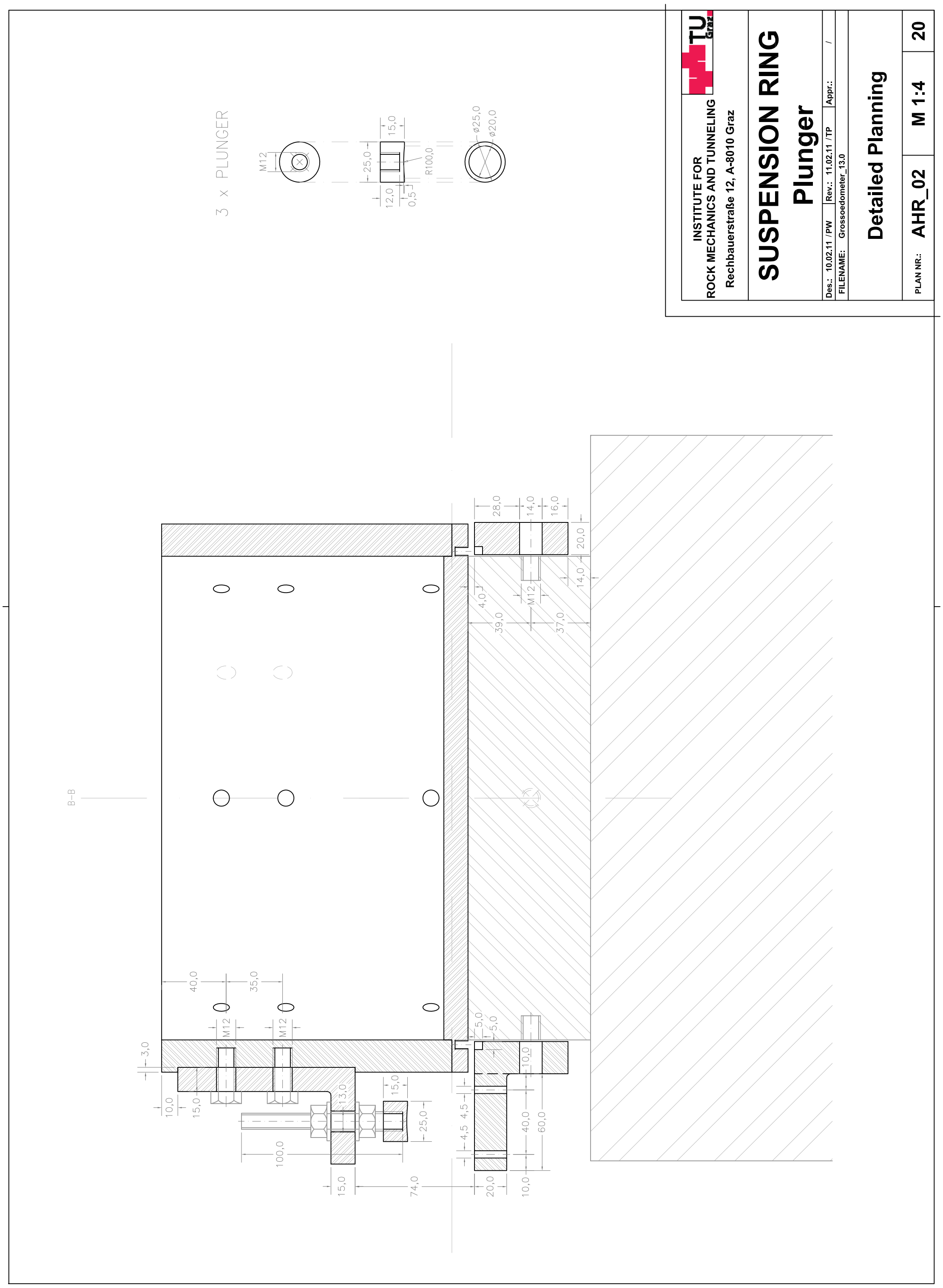
HEAD PLATE
Suspension LVDTs 2

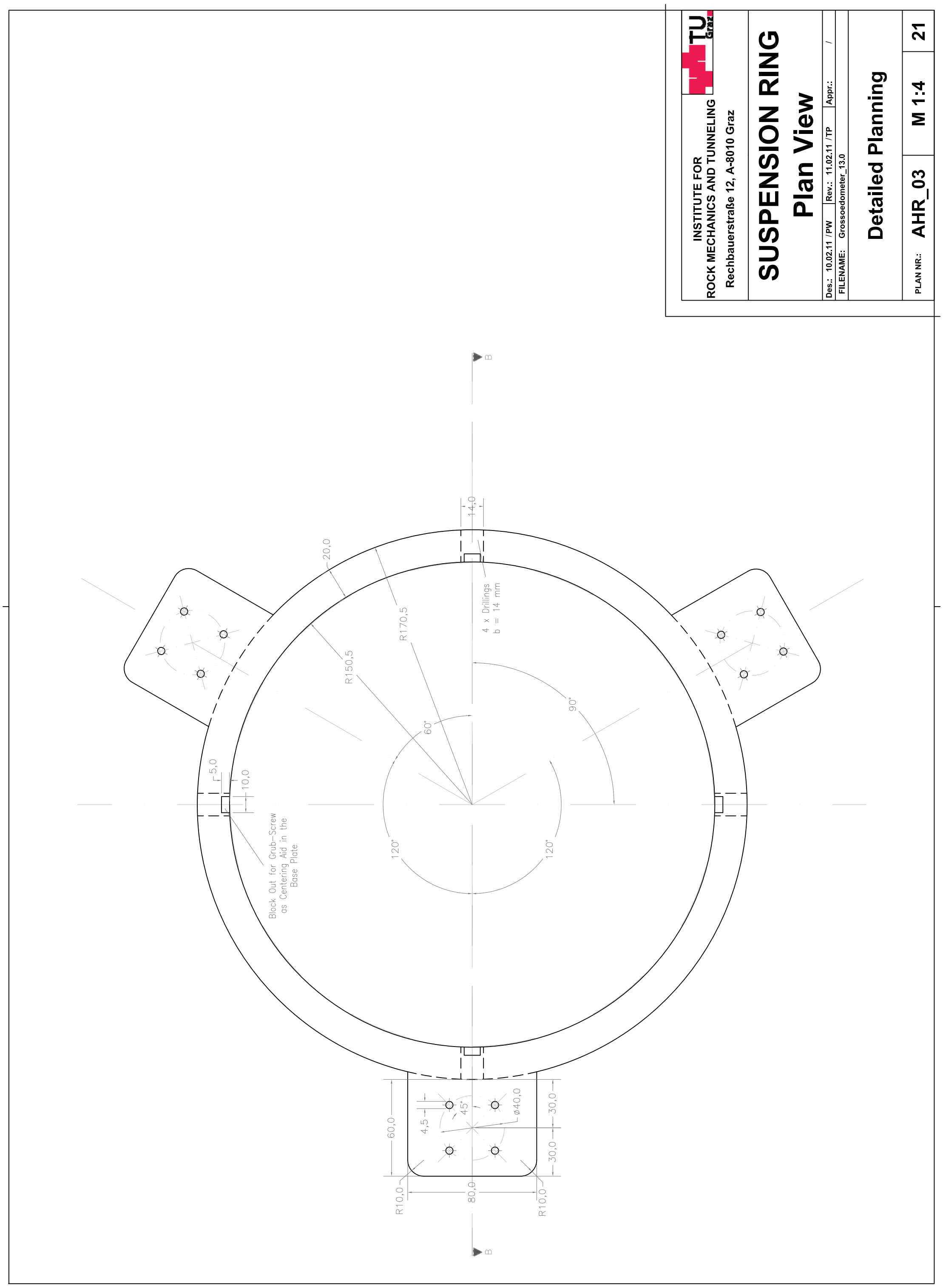
Des.: 10.02.11 /PW	Rev.: 11.02.11 /TP	Appr.: /
FILENAME: Grossoedometer_13.0		

Detailed Planning

PLAN NR.: KOP_03	M 1:4	18


INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz
TU Graz
SUSPENSION RING
Assembling
Des.: 10.02.11 /PW
Rev.: 11.02.11 /TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: AHR_01
M 1:4
19
B-B
LOAD DEVICE
Form+Test Prüfsysteme GmbH
Pressure Load: 3.000 kN
Accuracy: 2%
Suspension Ring
for Load Cells
Di = 301,0 mm
Da = 341,0 mm
4 x Drilling
b = 14 mm
3 x Plunger
Suspension
Hexagonal Screw
3x2 x M12 x 27mm x 8.8
Hex Nut
3x2 x M12
Washer
3x2 x M12
Elongated Hole
b = 13 mm
Threaded Rod
3 x M12 x 100 mm
3 x Plunger
Load Cell
HBM C9B
50 kN
Coutnersunk Screw
3x4 x M4 26mm
Hexagonal Screw
4 x M12 x 35mm x 8.8


INSTITUTE FOR
ROCK MECHANICS AND TUNNELING
Rechbauerstraße 12, A-8010 Graz
TU Graz
SUSPENSION RING
Plunger
Des.: 10.02.11 / PW
Rev.: 11.02.11 / TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: AHR_02
M 1:4
20
3 x PLUNGER
B-B


INSTITUTE FOR
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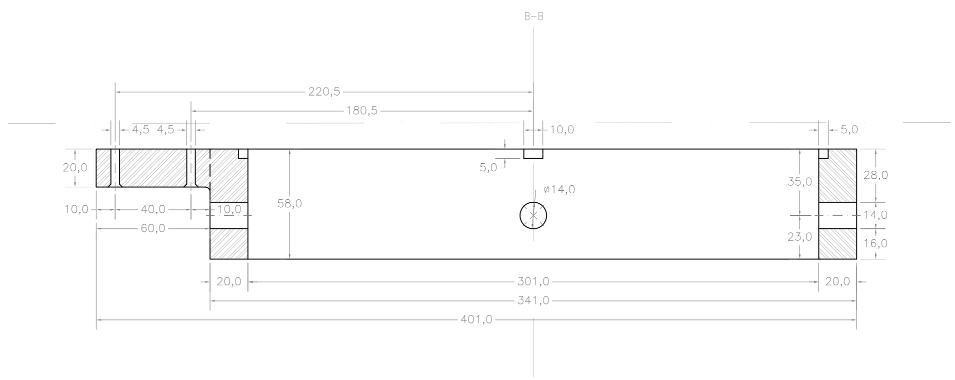
Rechbauerstraße 12, A-8010 Graz
TU Graz
SUSPENSION RING
Plan View
Des.: 10.02.11 / PW
Rev.: 11.02.11 / TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: AHR_03
M 1:4
21
B
14,0
20,0
4 x Drillings
b = 14 mm
R170,5
R150,5
60°
90°
5,0
10,0
120°
120°
Block Out for Grub-Screw
as Centering Aid in the
Base Plate
60,0
4,5
45°
ø40,0
30,0
30,0
R10,0
80,0
R10,0
B



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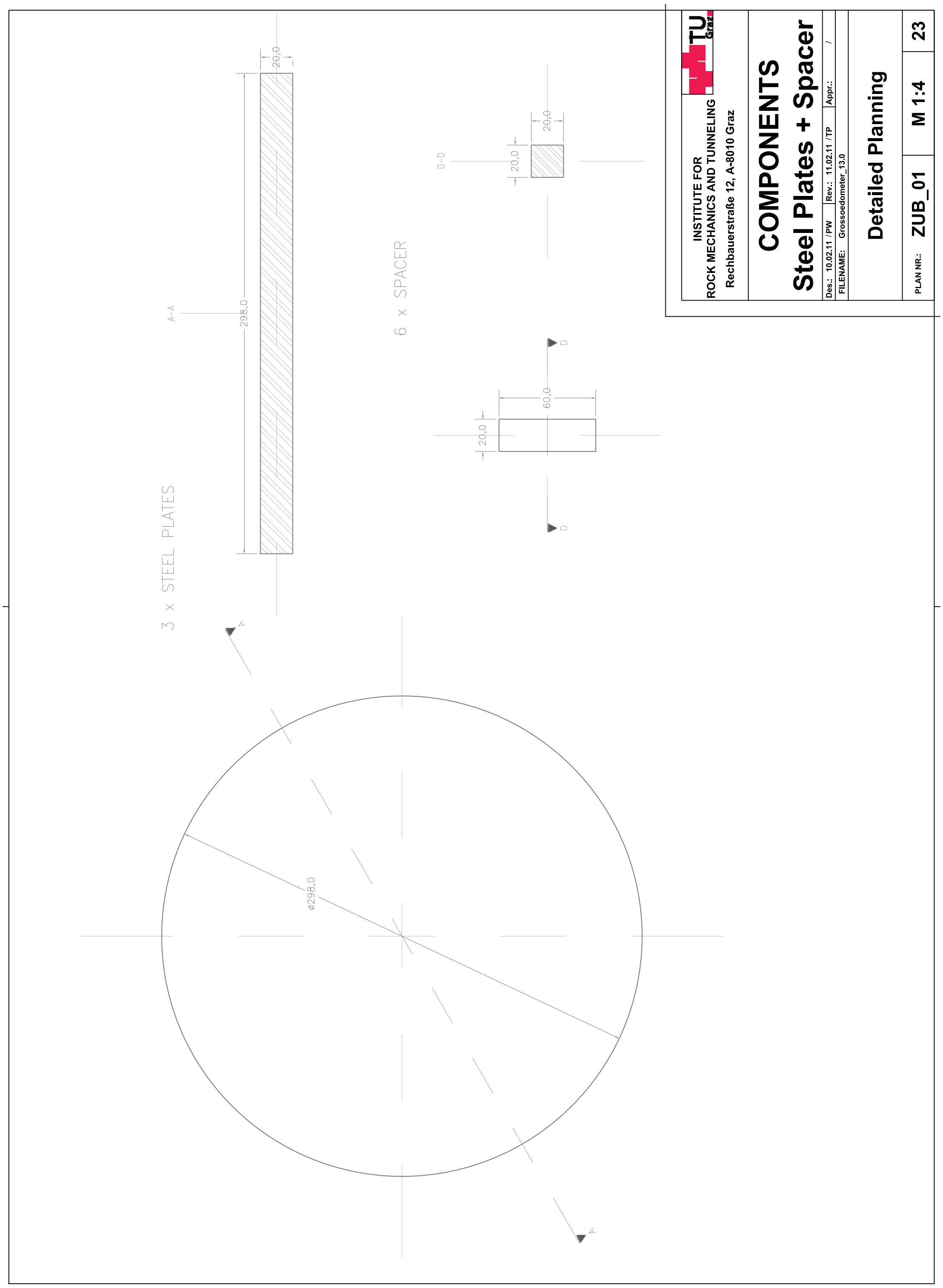
SUSPENSION RING
Cross Section

Des.: 10.02.11 /PW	Rev.: 11.02.11 /TP	Appr.: /
FILENAME: Grossoedometer_13.0		

Detailed Planning

PLAN NR.: AHR_04	M 1:4	22


3 x STEEL PLATES
A-A
298,0
20,0
ø298,0
6 x SPACER
D-D
20,0
20,0
60,0
20,0
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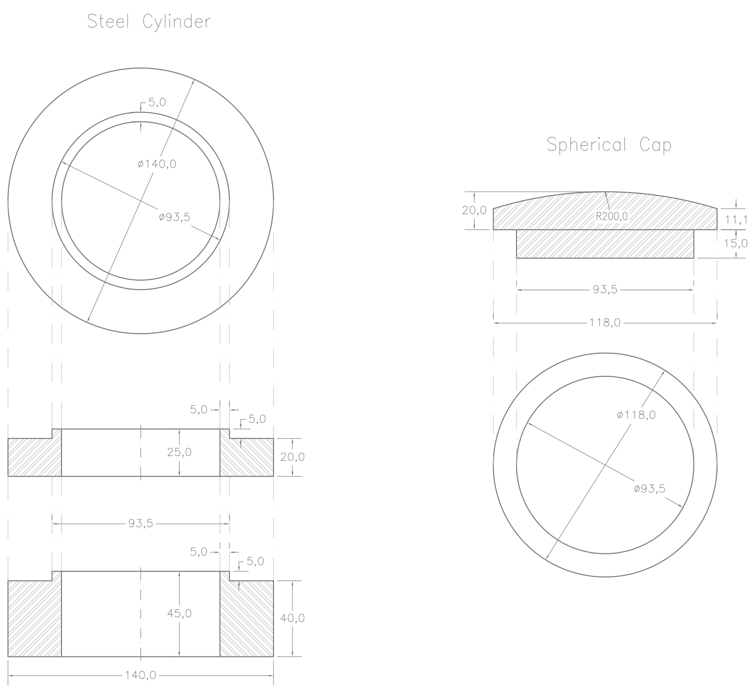
COMPONENTS
Steel Plates + Spacer
Des.: 10.02.11 / PW
Rev.: 11.02.11 / TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: ZUB_01
M 1:4
23



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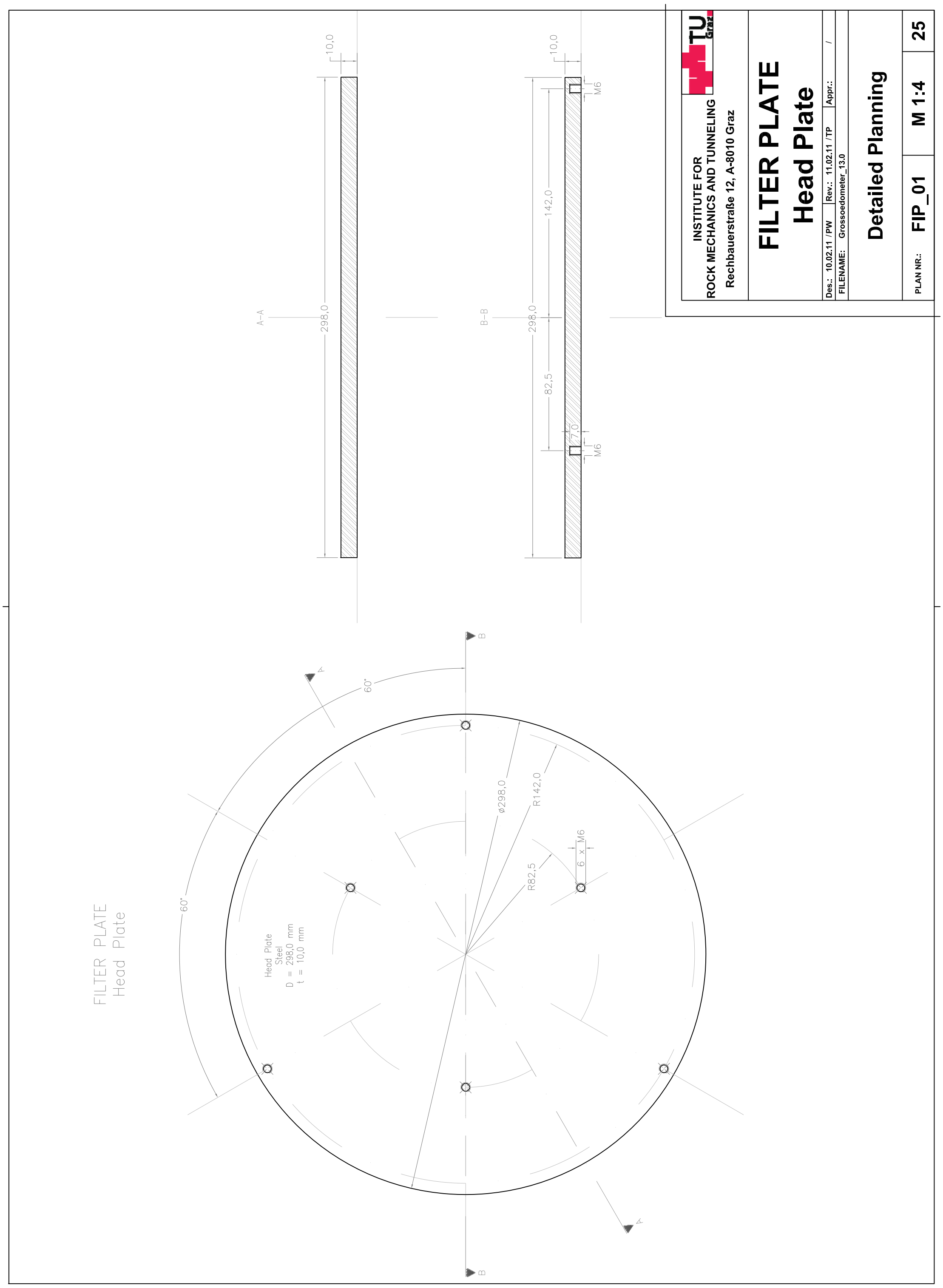
COMPONENTS
Cylinder + Cap

Des.: 10.02.11 /PW	Rev.: 11.02.11 /TP	Appr.: /

FILENAME: Grossoedometer_13.0

Detailed Planning

PLAN NR.:	ZUB_02	M 1:4	24


INSTITUTE FOR
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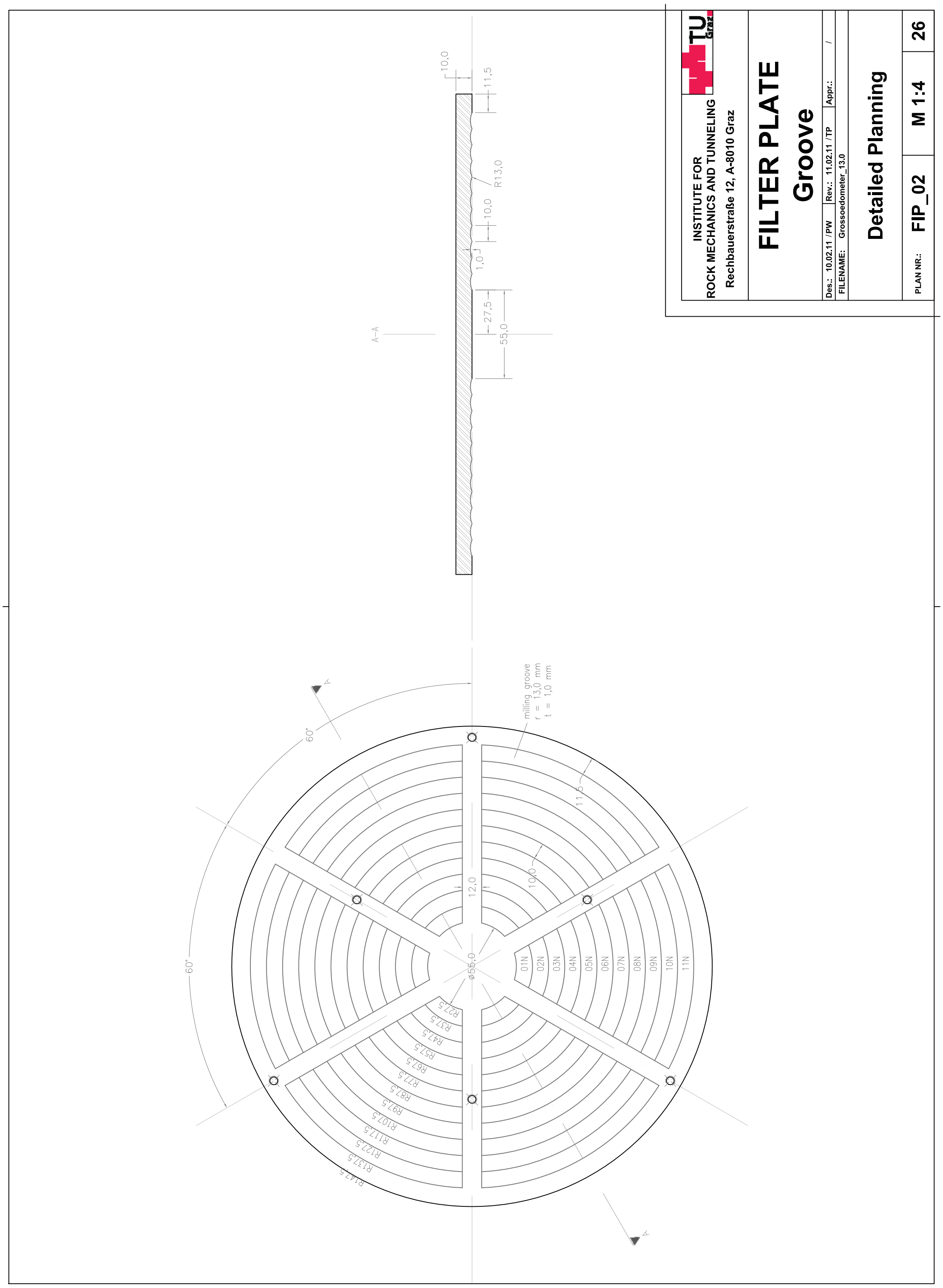
Rechbauerstraße 12, A-8010 Graz
TU Graz
FILTER PLATE
Head Plate
Des.: 10.02.11 / PW
Rev.: 11.02.11 / TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: FIP_01
M 1:4
25
A–A
B–B
298,0
10,0
142,0
82,5
7,0
M6
ø298,0
R142,0
R82,5
6 x M6
60°
FILTER PLATE
Head Plate
Head Plate
Steel
D = 298,0 mm
t = 10,0 mm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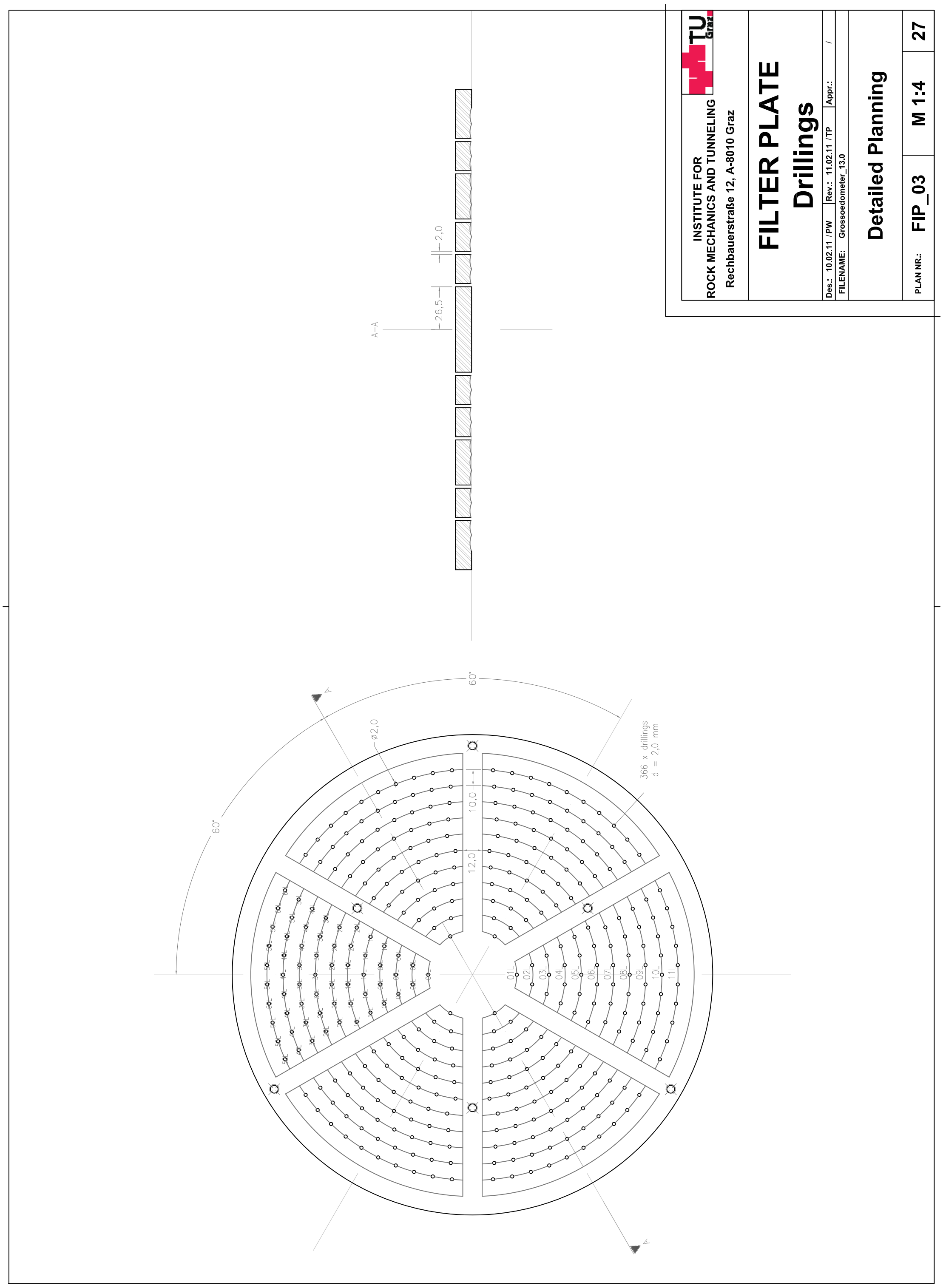
Rechbauerstraße 12, A-8010 Graz
FILTER PLATE
Groove
Des.: 10.02.11 /PW
Rev.: 11.02.11 /TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: FIP_02
M 1:4
26
A-A
milling groove
r = 13,0 mm
t = 1,0 mm
60°
Ø55,0
01N
02N
03N
04N
05N
06N
07N
08N
09N
10N
11N
R27,5
R37,5
R47,5
R57,5
R67,5
R77,5
R87,5
R97,5
R107,5
R117,5
R127,5
R137,5
R142,5
12,0
10,0
11,0
11,5
R13,0
1,0
27,5
55,0


INSTITUTE FOR
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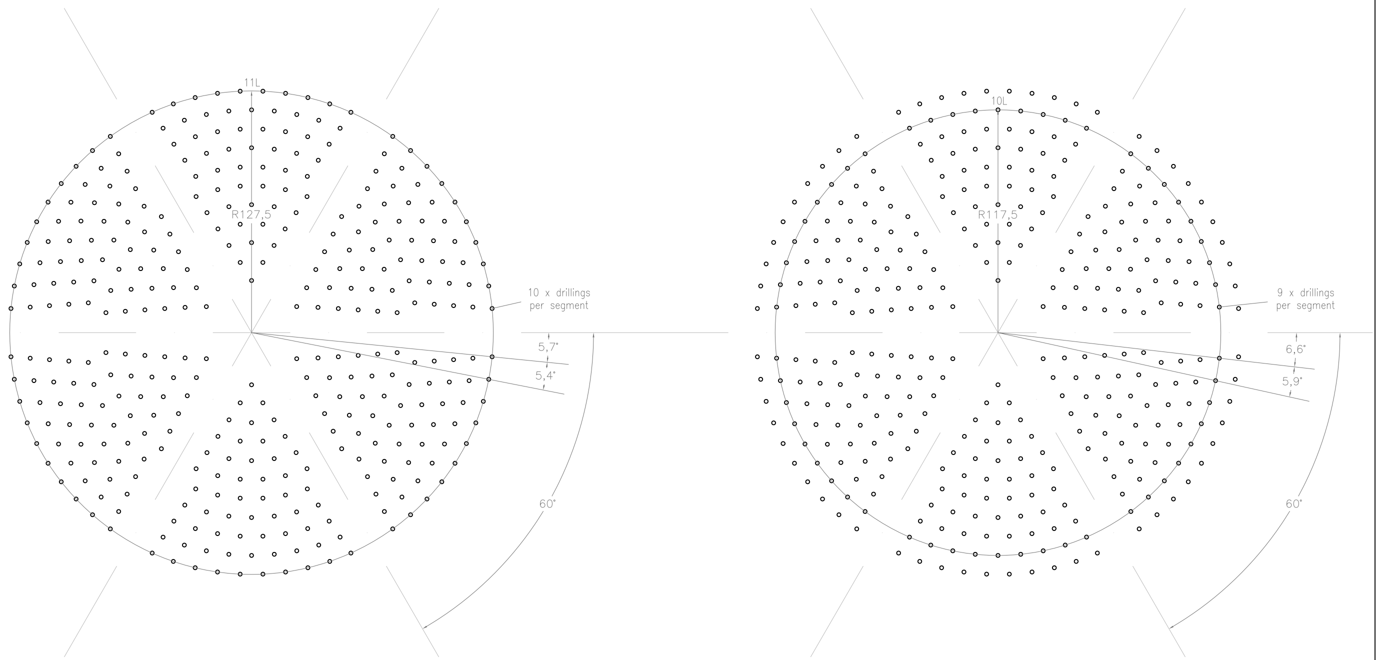
Rechbauerstraße 12, A-8010 Graz
TU Graz
FILTER PLATE
Drillings
Des.: 10.02.11 / PW
Rev.: 11.02.11 / TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: FIP_03
M 1:4
27
A–A
26,5
2,0
60°
60°
ø2,0
10,0
12,0
366 x drillings
d = 2,0 mm
01
02
03
04
05
06
07
08
09
10
11



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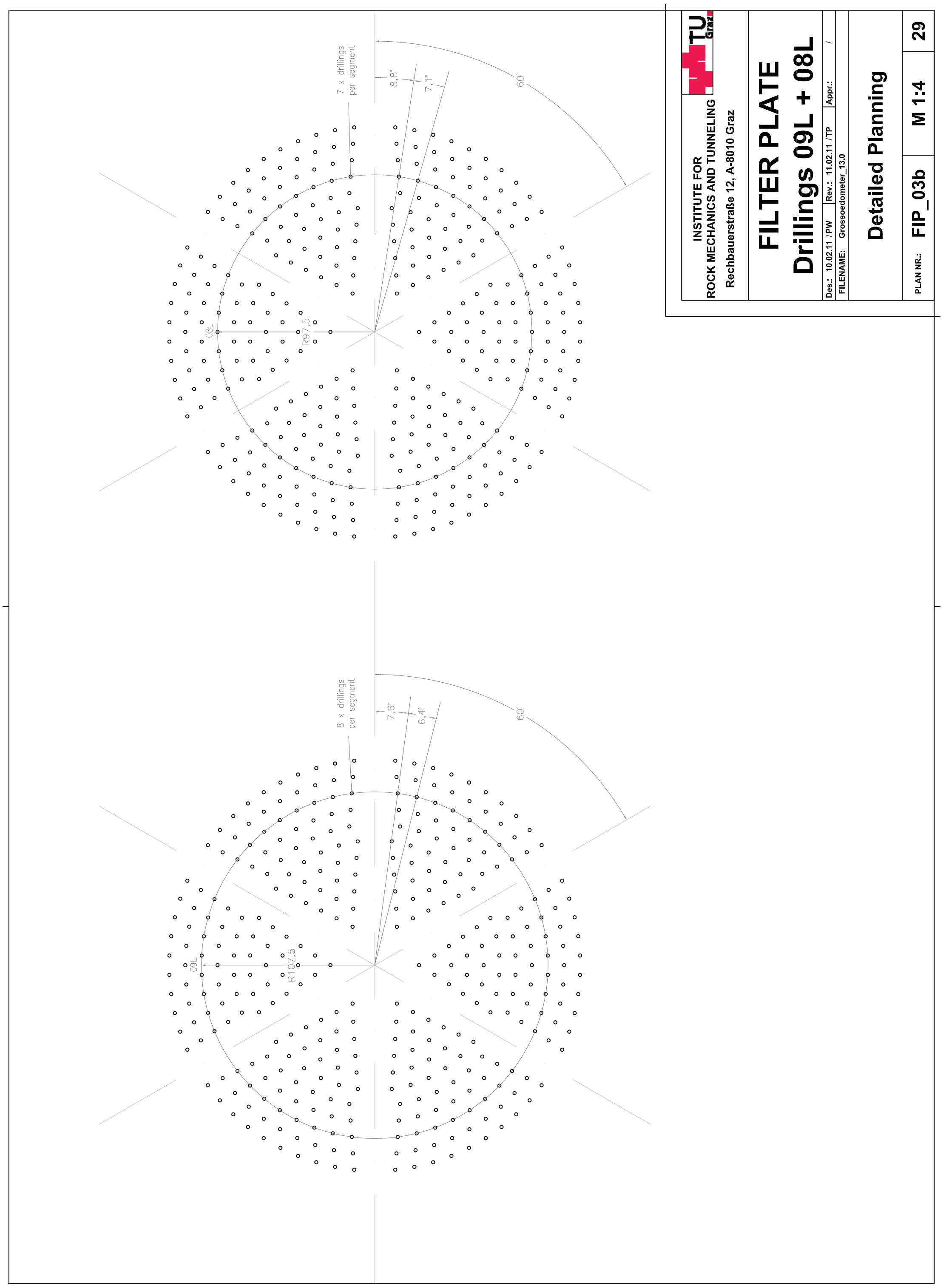
FILTER PLATE
Drillings 11L + 10L

Des.: 10.02.11 /PW	Rev.: 11.02.11 /TP	Appr.: /

FILENAME: Grossoedometer_13.0

Detailed Planning

PLAN NR.:	FIP_03a	M 1:4	28


7 x drillings per segment
8,8°
7,1°
60°
08L
R97,5
8 x drillings per segment
7,6°
6,4°
60°
09L
R107,5
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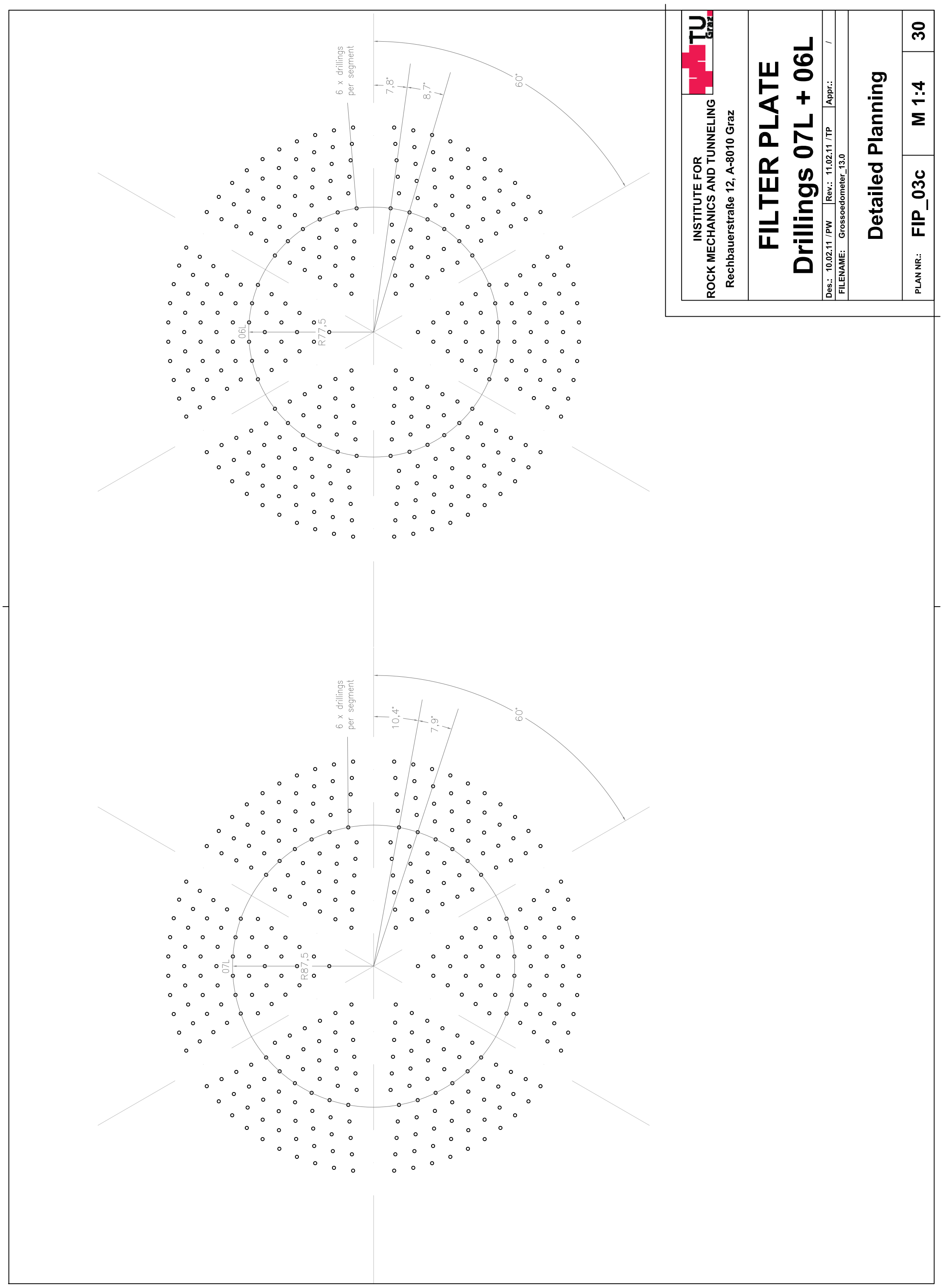
TU Graz
FILTER PLATE
Drillings 09L + 08L
Des.: 10.02.11 / PW
Rev.: 11.02.11 / TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: FIP_03b
M 1:4
29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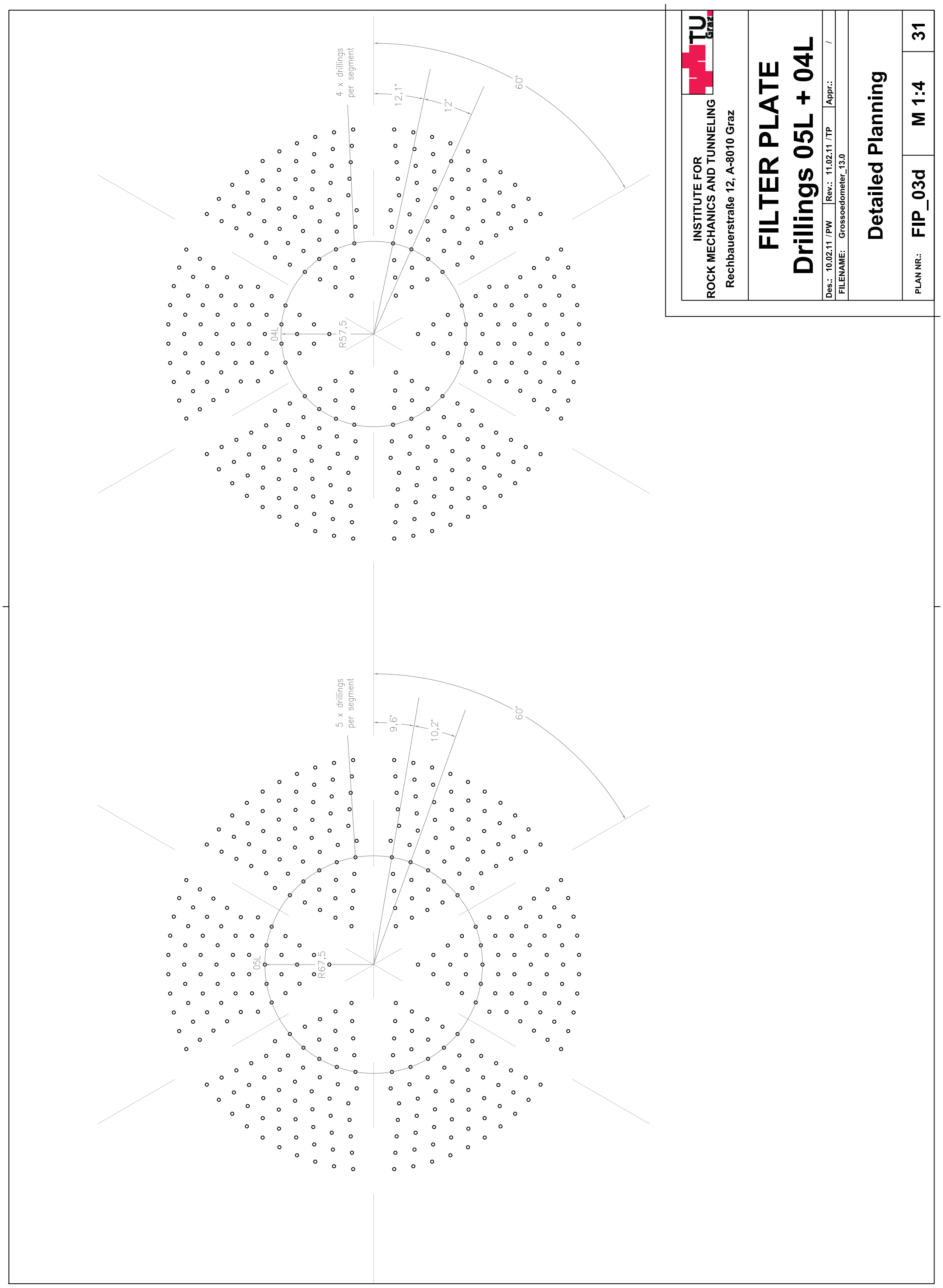
Rechbauerstraße 12, A-8010 Graz
TU Graz
FILTER PLATE
Drillings 07L + 06L
Des.: 10.02.11 /PW
Rev.: 11.02.11 /TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: FIP_03c
M 1:4
30
6 x drillings per segment
7,8°
8,7°
60°
06L
R77,5
6 x drillings per segment
10,4°
7,9°
60°
07L
R87,5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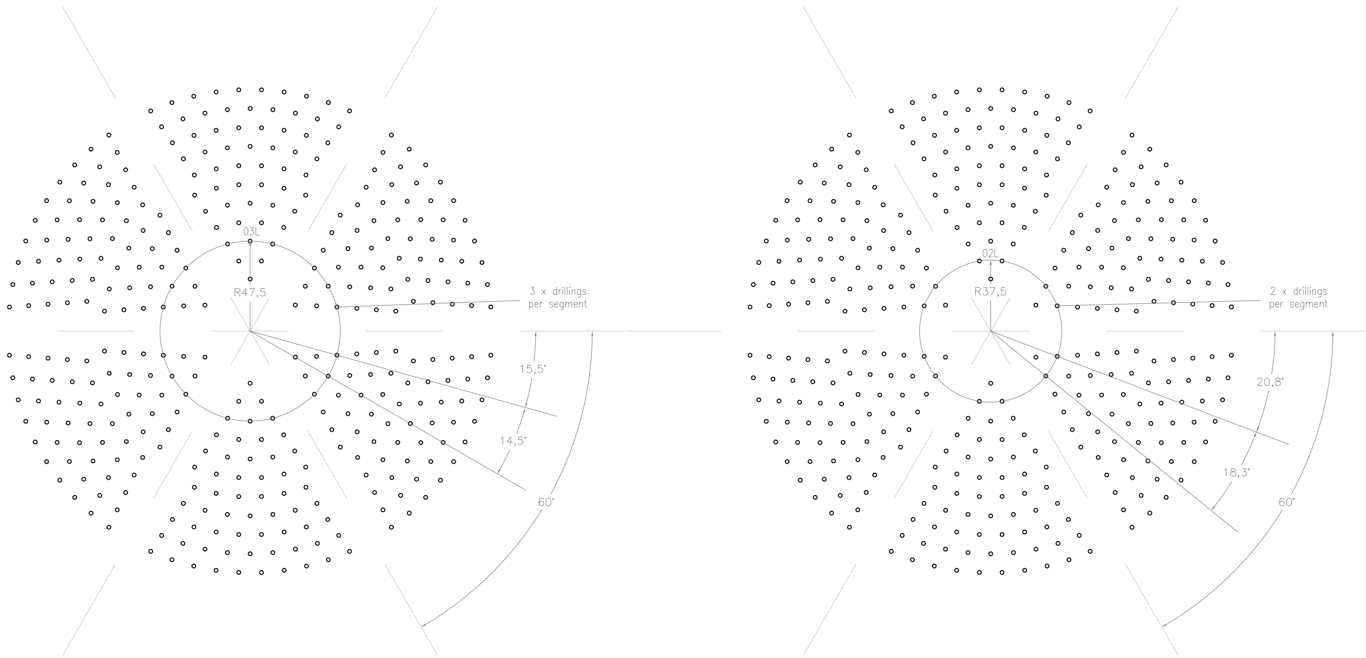
Rechbauerstraße 12, A-8010 Graz
FILTER PLATE
Drillings 05L + 04L
Des.: 10.02.11 / PW
Rev.: 11.02.11 / TP
Appr.:
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: FIP_03d
M 1:4
31
4 x drillings per segment
12,1°
12°
60°
04L
R57,5
5 x drillings per segment
9,6°
10,2°
60°
05L
R67,5



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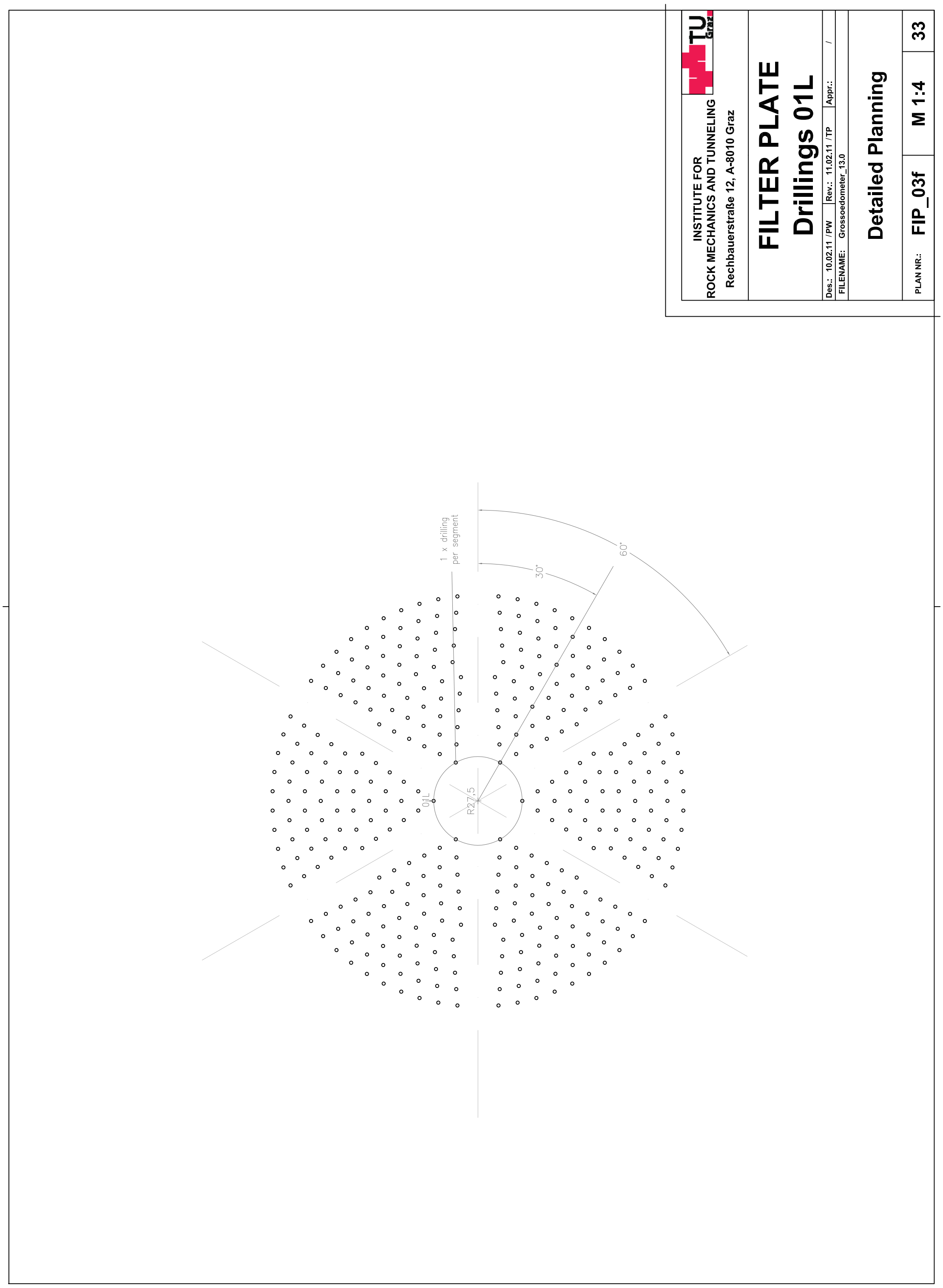
FILTER PLATE
Drillings 03L + 02L

Des.: 10.02.11 /PW	Rev.: 11.02.11 /TP	Appr.: /

FILENAME: Grossoedometer_13.0

Detailed Planning

PLAN NR.:	FIP_03e	M 1:4	32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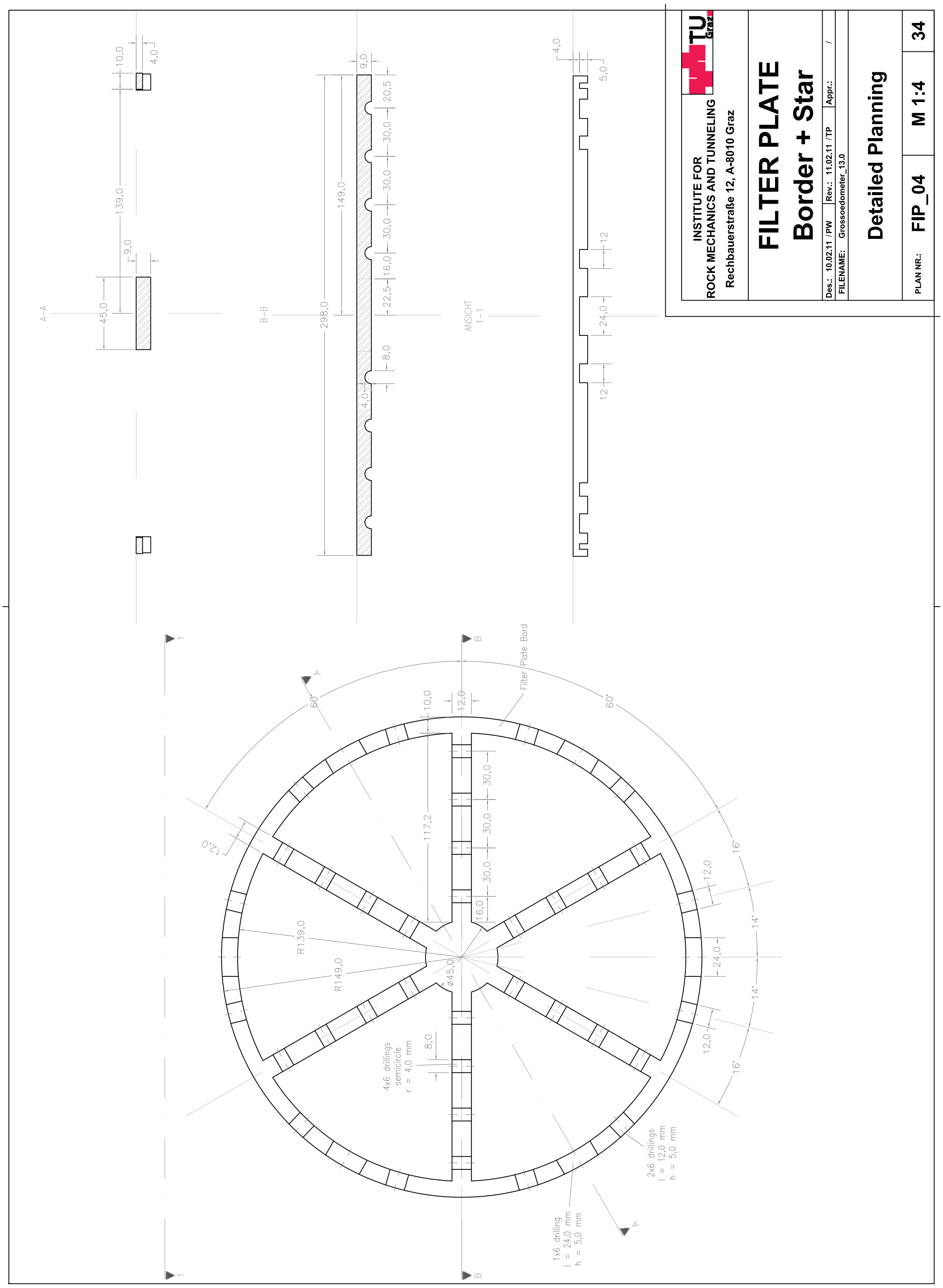
FILTER PLATE
Drillings 01L
Des.: 10.02.11 / PW
Rev.: 11.02.11 / TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: FIP_03f
M 1:4
33
1 x drilling per segment
30°
60°
R27.5
01L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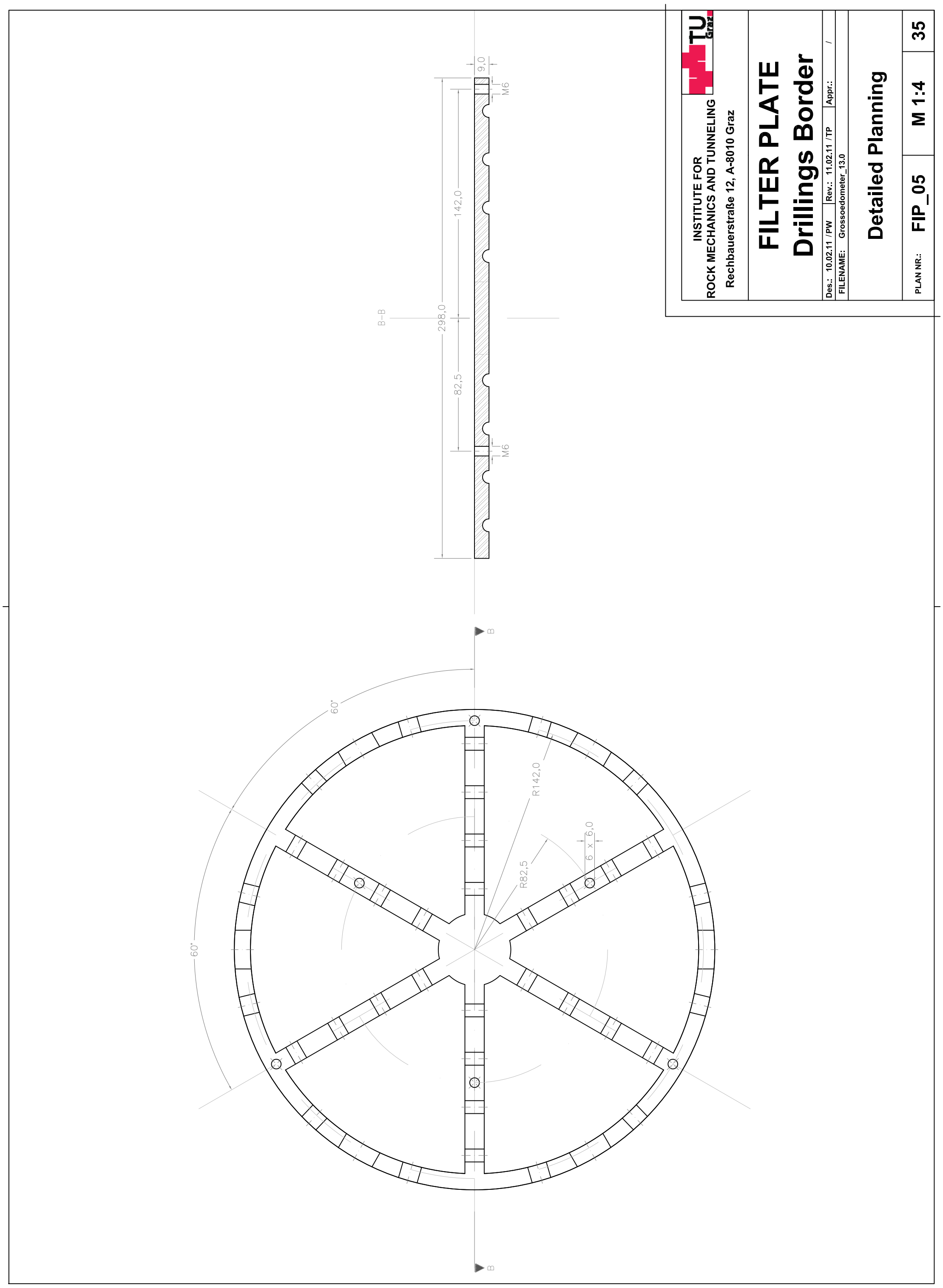
FILTER PLATE
Border + Star
Des.: 10.02.11 / PW
Rev.: 11.02.11 / TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: FIP_04
M 1:4
34
A-A
B-B
ANSICHT 1-1
Filter Plate Bord
R139,0
R149,0
ø45,0
4x6 drillings semicircle r = 4,0 mm
2x6 drillings l = 12,0 mm h = 5,0 mm
1x6 drilling l = 24,0 mm h = 5,0 mm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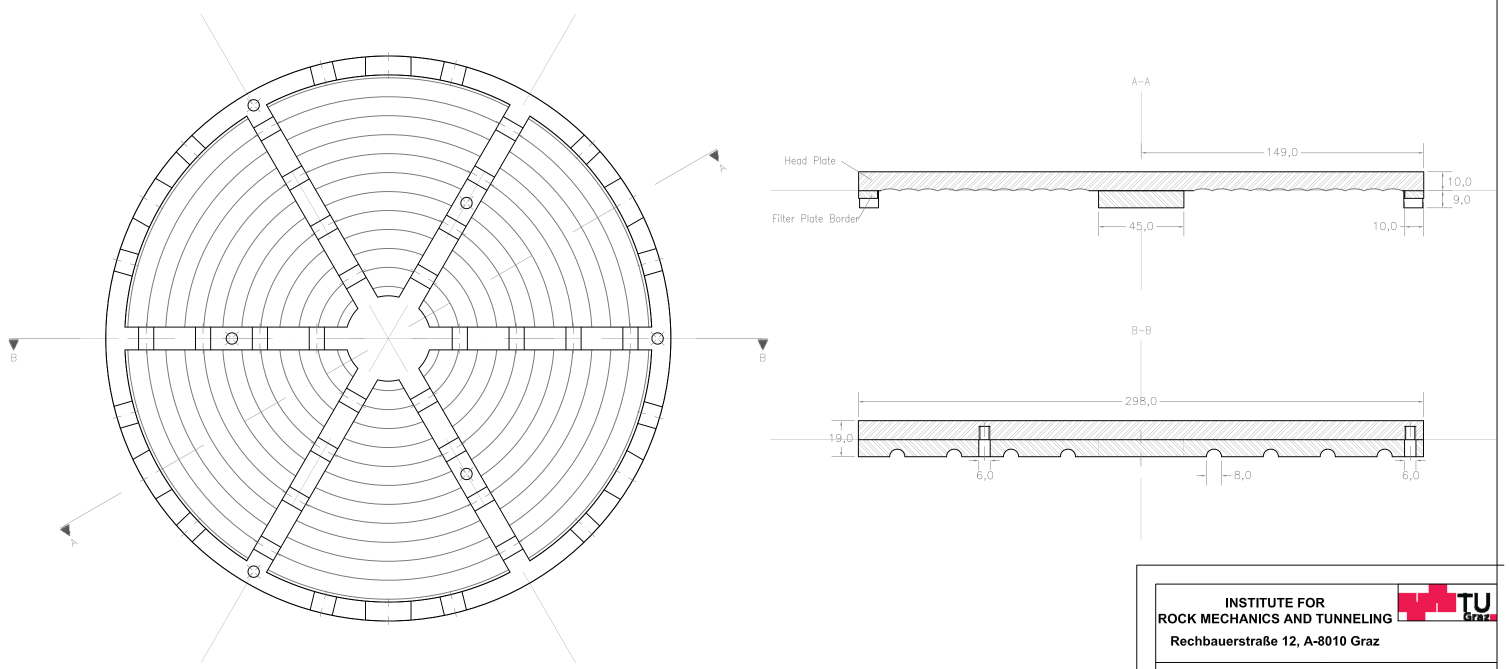
FILTER PLATE
Drillings Border
Des.: 10.02.11 / PW
Rev.: 11.02.11 / TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: FIP_05
M 1:4
35
B-B
298,0
142,0
82,5
9,0
M6
M6
60°
60°
R142,0
R82,5
6 x 6,0
B
B



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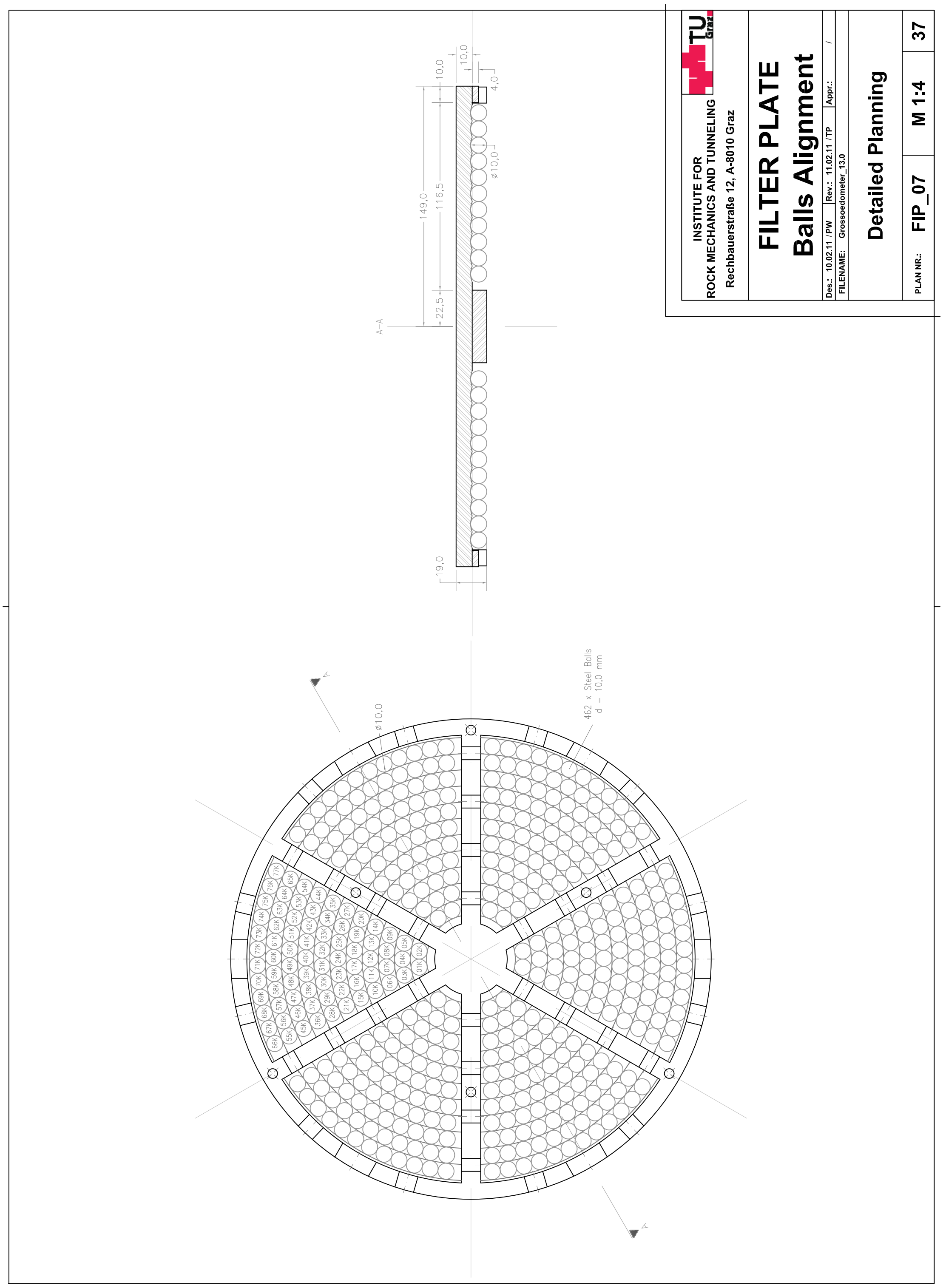
FILTER PLATE **Head Plate + Border**		
Des.: 10.02.11 /PW	Rev.: 11.02.11 /TP	Appr.: /
FILENAME: Grossoedometer_13.0		
Detailed Planning		
PLAN NR.: **FIP_06**	**M 1:4**	**36**



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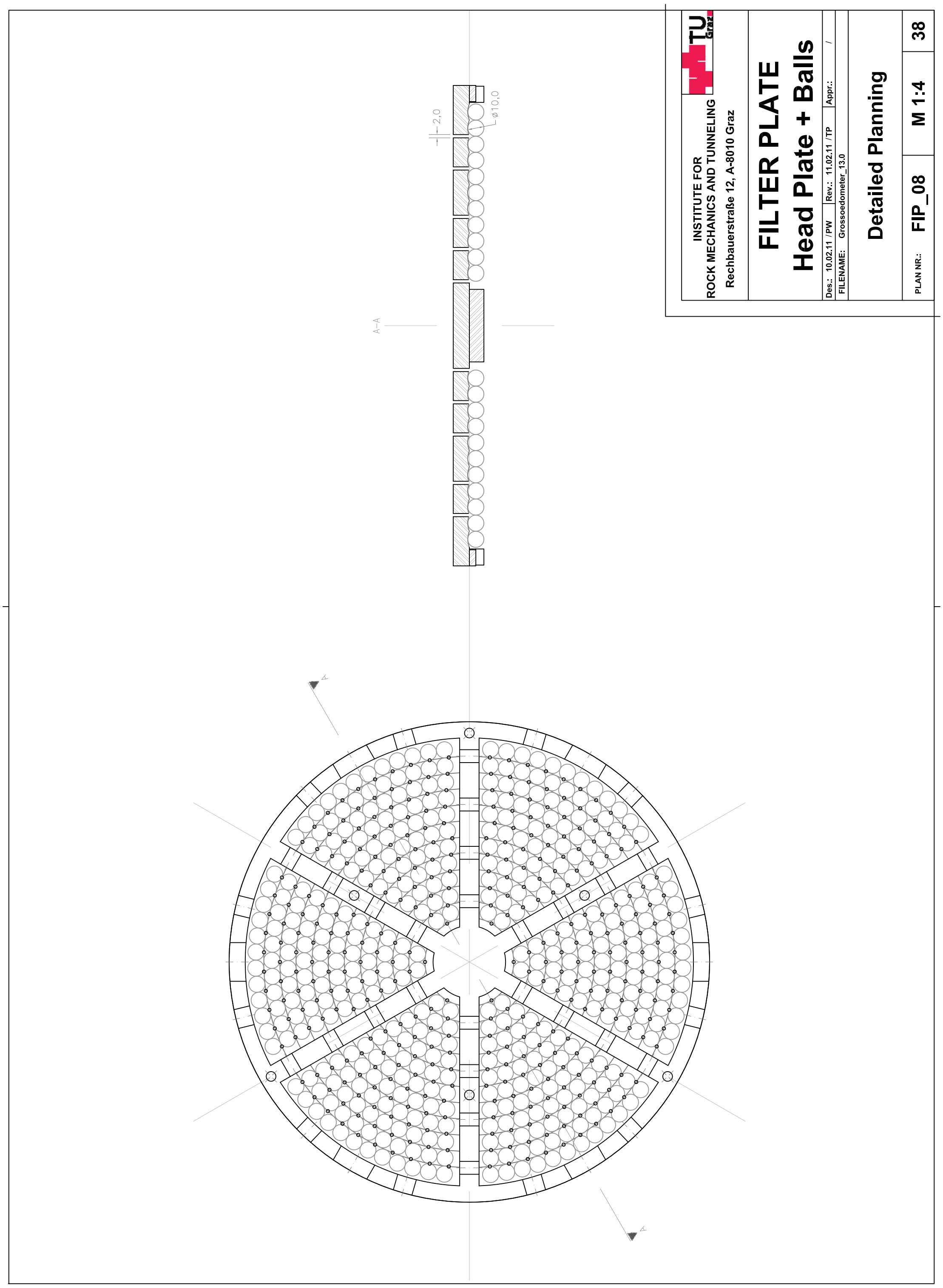
FILTER PLATE
Balls Alignment
Des.: 10.02.11 /PW
Rev.: 11.02.11 /TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: FIP_07
M 1:4
37
A–A
462 x Steel Balls
d = 10,0 mm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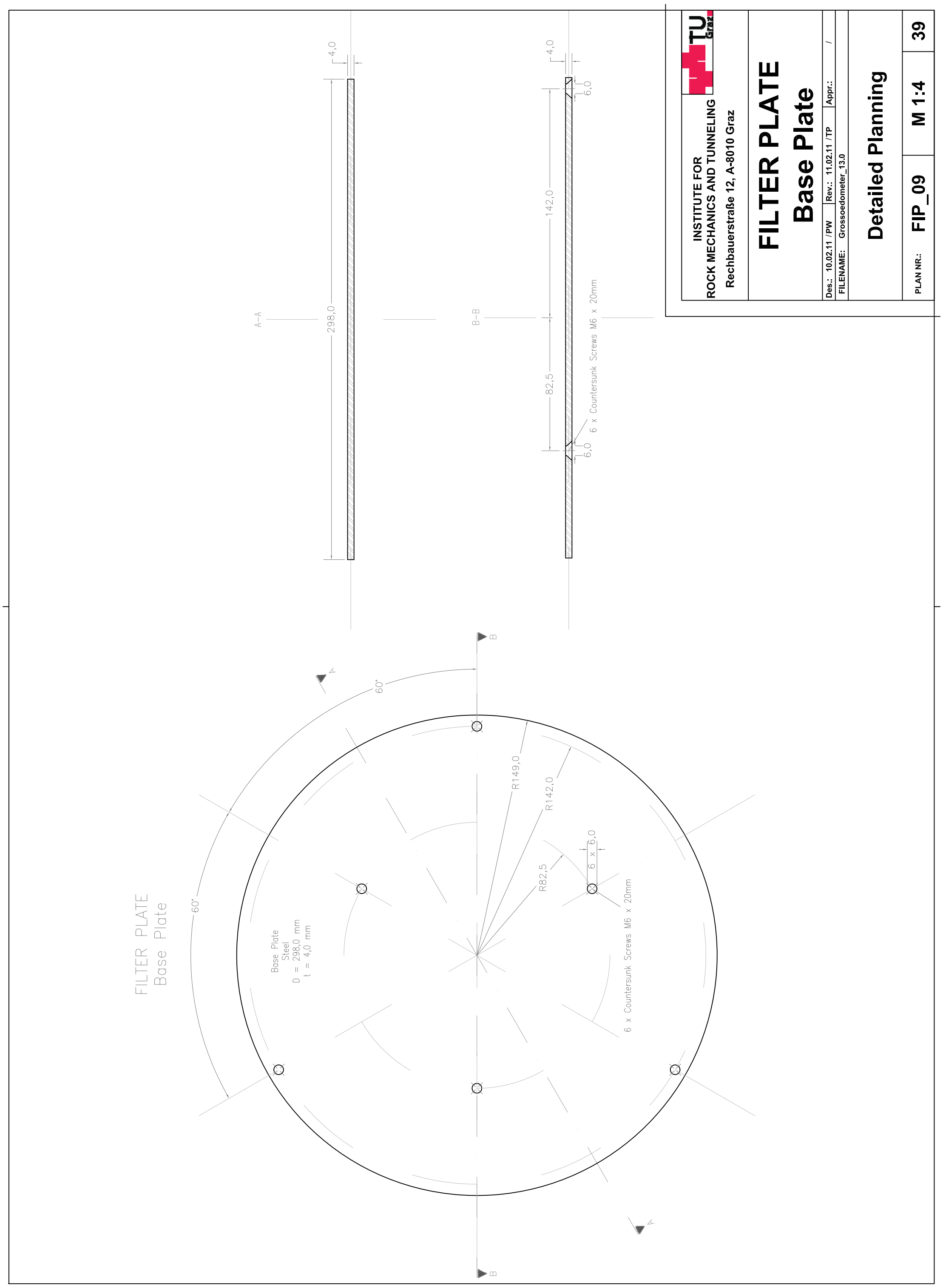
TU Graz
FILTER PLATE
Head Plate + Balls
Des.: 10.02.11 / PW
Rev.: 11.02.11 / TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: FIP_08
M 1:4
38
2,0
ø10,0
A–A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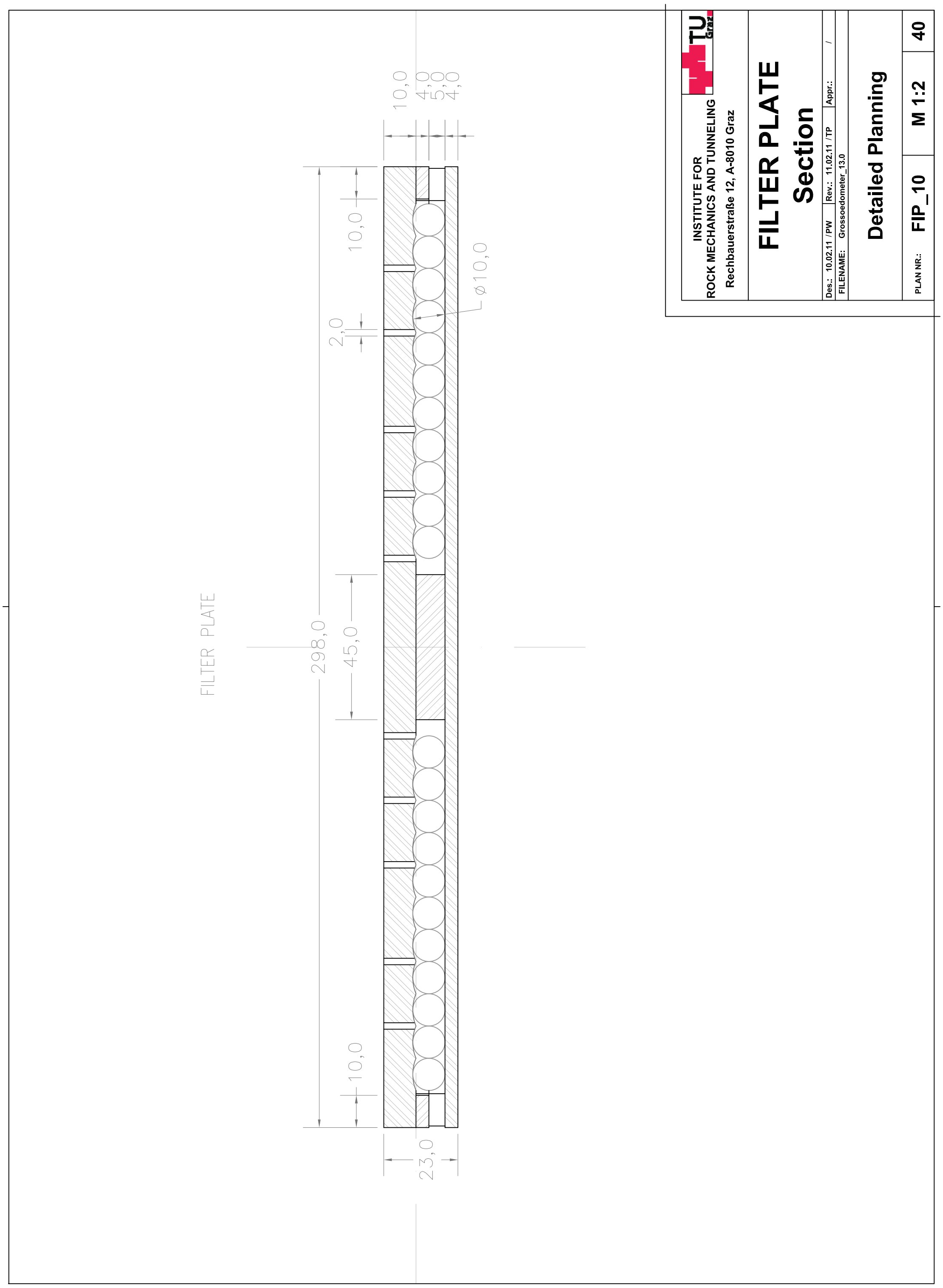
FILTER PLATE
Base Plate
Des.: 10.02.11 / PW
Rev.: 11.02.11 / TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: FIP_09
M 1:4
39
A–A
298,0
4,0
B–B
142,0
82,5
6,0
6 x Countersunk Screws M6 x 20mm
FILTER PLATE
Base Plate
Base Plate
Steel
D = 298,0 mm
t = 4,0 mm
60°
R149,0
R142,0
R82,5
6 x 6,0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TU Graz
FILTER PLATE
Section
Des.: 10.02.11 / PW
Rev.: 11.02.11 / TP
Appr.: /
FILENAME: Grossoedometer_13.0
Detailed Planning
PLAN NR.: FIP_10
M 1:2
40
FILTER PLATE
10,0
4,0
5,0
4,0
10,0
2,0
⌀10,0
298,0
45,0
10,0
23,0

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