Master thesis

Development of a blasting area and blasting tests with concrete blocks in half scale to research different fragmentation phenomena

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Declaration of authorship

„I declare in lieu of oath that this thesis is entirely my own work except where otherwise indicated. The presence of quoted or paraphrased material has been clearly signaled and all sources have been referred. The thesis has not been submitted for a degree at any other institution and has not been published yet."

Erhard Maierhofer

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A special thanks to my mother, my father, Elfie, Marie-Madeleine and all my friends, who like me as I am. Also, I want to thank Prof. Moser, Prof. Ouchterlony and Dr. Bauer who supported me technically in this work. Furthermore thanks to all employees of the department who have been very supportive, especially Mr. Wölfler and Mr. Tscharf, who helped me a lot in carrying out the work.

Abstract

To assess preceding blasting works better, a new blasting project at the “Styrian Erzberg” was realized by the University of Leoben. The goal of this work was to get a better understanding of the comminution of concrete blocks through blasting in laboratory scale and half scale. For this reason, a blasting area was established, which allows blasting of concrete blocks in half scale, collecting the resulting excavated material without secondary mechanical crushing and subjecting it to a variety of analysis. A blasting enclosure was built consisting of steel uprights, a wire mesh fence and multiple layers of blasting mats. The following tests attempted to achieve a "good" blasting result, by varying the geometrical factors like burden, spacing, drill hole diameter and amount of explosives. Before that, the material properties of the concrete blocks in half scale were analyzed, by means of test explosions of concrete blocks in laboratory scale, which consisted of the same concrete mixture. For this purpose, cubes with varying edge lengths were detonated and a sieve analysis was carried out. In the subsequent experiments half scale concrete blocks with a size of 2 m^3 were blasted. The burden and spacing was varied and the excavated material was subjected to sieve and graphical analysis. As result of the work sieving curves were established for each experiment. Further, the influence of the geometry in the half scale tests was studied. In these first tests it could be seen that there is a good relation between energy input and fragmentation. For further blasting tests, smaller test blocks which are in a solid bond to the blast site, are recommended.

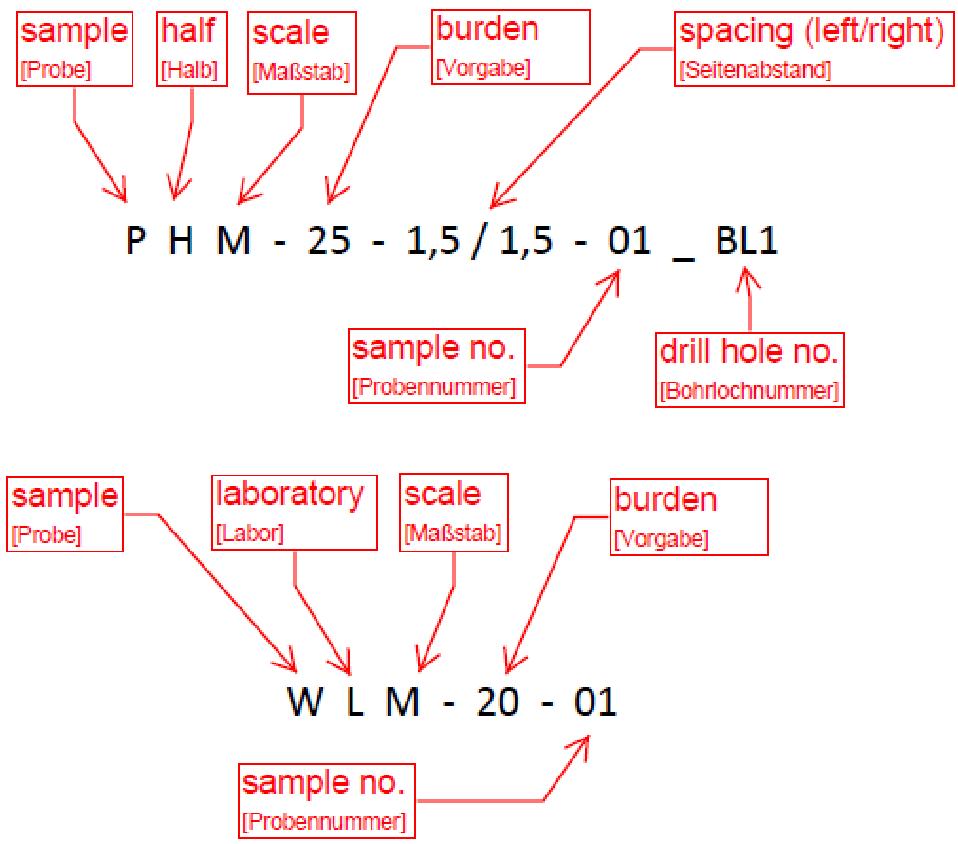
Zusammenfassung

Um vorhergegangene Sprengarbeiten besser beurteilen zu können, wurde vom Lehrstuhl für Bergbaukunde an der Montanuniversität Leoben, ein neues Sprengprojekt auf dem “Steirischen Erzberg” realisiert. Das Ziel dieser Arbeit war es, ein besseres Verständnis der Zerkleinerung von Betonblöcken im Labor- & Halbmaßstab zu erhalten. Aus diesem Grund wurde eine Strengstelle errichtet, mit der man Betonblöcke im Halbmaßstab sprengt und das Ausbruchsmaterial ohne sekundäre mechanische Nachzerkleinerung aufsammelt, um es diversen Analysen unterziehen zu können. Zu diesem Zweck wurde eine Sprengeinhausung bestehend aus Stahlstehern, Maschendrahtzaun und mehreren Lagen einer Sprengmatte errichtet. Bei den nachfolgenden Tests wurde versucht, ein “gutes” Sprengergebnis, mit variierenden geometrischen Faktoren wie Vorgabe, Seitenabstand, Bohrlochdurchmesser und Sprengstoffmenge, zu erzielen. Des Weiteren wurden im Vorfeld die Materialeigenschaften der Betonblöcke im Halbmaßstab mit Hilfe von Probesprengungen im Labormaßstab untersucht, welche aus der gleichen Betonrezeptur bestanden. Dazu wurden Betonwürfel mit unterschiedlichen Kantenlängen gesprengt und eine Siebanalyse durchgeführt. Bei den nachfolgenden Experimenten im Halbmaßstab wurden Betonblöcke mit einer Größe von 2 m³ mit verschiedenen Vorgaben und Seitenabständen gesprengt und das Ausbruchsmaterial wurde einer Siebanalyse und einer graphischen Auswertung unterzogen. Als Ergebnis der Arbeit wurden bei jedem Versuch im Labormaßstab und Halbmaßstab die einzelnen Siebkurven dargestellt. Es hat sich gezeigt, dass ein guter Zusammenhang zwischen aufgewendeter Energie und Zerkleinerung besteht. Weiteres wurde noch der Einfluss der Geometrie bei den Versuchen im Halbmaßstab untersucht. Für weitere Sprengarbeiten kann empfolen werden, kleinere Testblöcke die in einem festen Verbund mit der Sprengstelle stehen, zu verwenden.

List of abbreviations

PETN	Nitropenta
VOD	Velocity of detonation
WLM	Sample laboratory scale (Würfel Labormaßstab)
PHM	Sample half scale (Proben Halbmaßstab)

Detailed explanation of the sample names:



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1 Objective

In the year 2010 the Chair of Mining Engineering at the University of Leoben decided to build a blasting area (see figure 4) on the “Styrian Erzberg”. In this project six blocks in half scale (see figure 2) and nine cubes in laboratory scale (shown in figure 1) with three different edge lengths were blasted. In the half scale tests, concrete blocks with 2 m³ were blasted with different borehole diameters, different burdens and different spacings. After blasting the concrete blocks, a screen analysis and a graphical evaluation were carried out. The objective of this thesis is to describe the conducted work and analysis in detail. For detailed concept, see chapter 2.

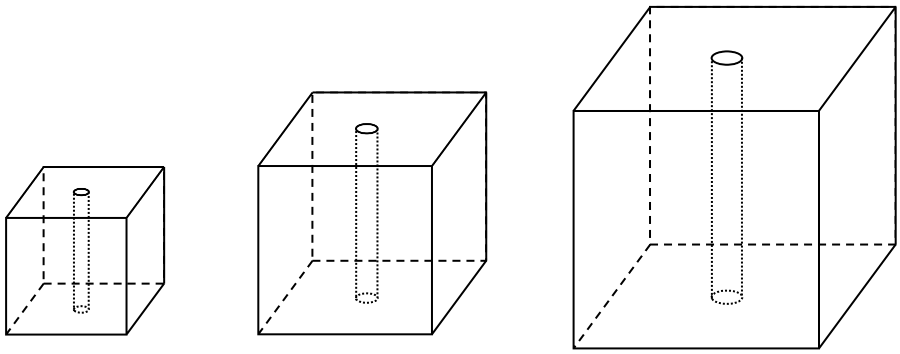


Figure 1: Laboratory scale test

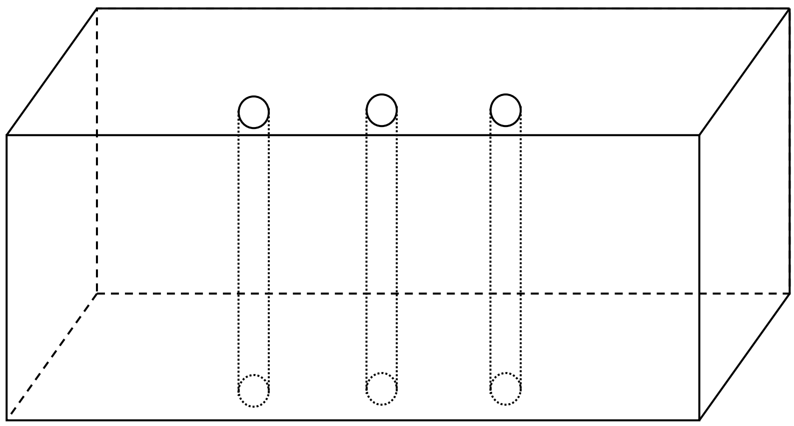


Figure 2: Half scale test

2 Concept of the blasting area

The concept of the blasting area comprised the following points:

- Fly rock safety
- Be able to collect the excavated material
- Longevity of the blasting area
- Easy handling of the blasting area
- Maximum block dimensions: 2 m width / 1 m height / 1 m depth

The planning and the construction job of the blasting site were outsourced to an engineering consultant.

The planning office of Dipl.-Ing. Michael Judmayer created the plan of the blasting site, which was built by the company “Swietelsky”.

The construction started in June of 2010 and was at the beginning supervised by Alexander Tscharf.

2.1 Technical data of the blasting area

In the construction more than 70 m³ concrete with almost 6000 kg reinforcing steel were used (see table 1 and 2 for exact details).

The rear wall was fixed with anchor rods to an existing older concrete wall which is in direct contact to the in situ rock (shown in figure 3).

This connection to the rock should allow a good wave transmission of the blast wave in the back wall.

Component	Volume	Structural steel 550	
	m^3	kg	kg / m^3
Foundation	63,00	3850,39	61,12
Walls	9,75	2611,06	267,80

Table 1: Used material

Component	Concrete Construction	Surface
Concrete quality	C30/37/XM3	C8/10/X0
Steel grade	Structural steel 550	
Concrete cover	3,5 cm	
Component: Concrete construction blasting area		
Plan Content: Formwork and Reinforcement		
Scale:	Plan Number:	Issue Date:
1:25	1049-01	2010-05-18

Table 2: Quality statement

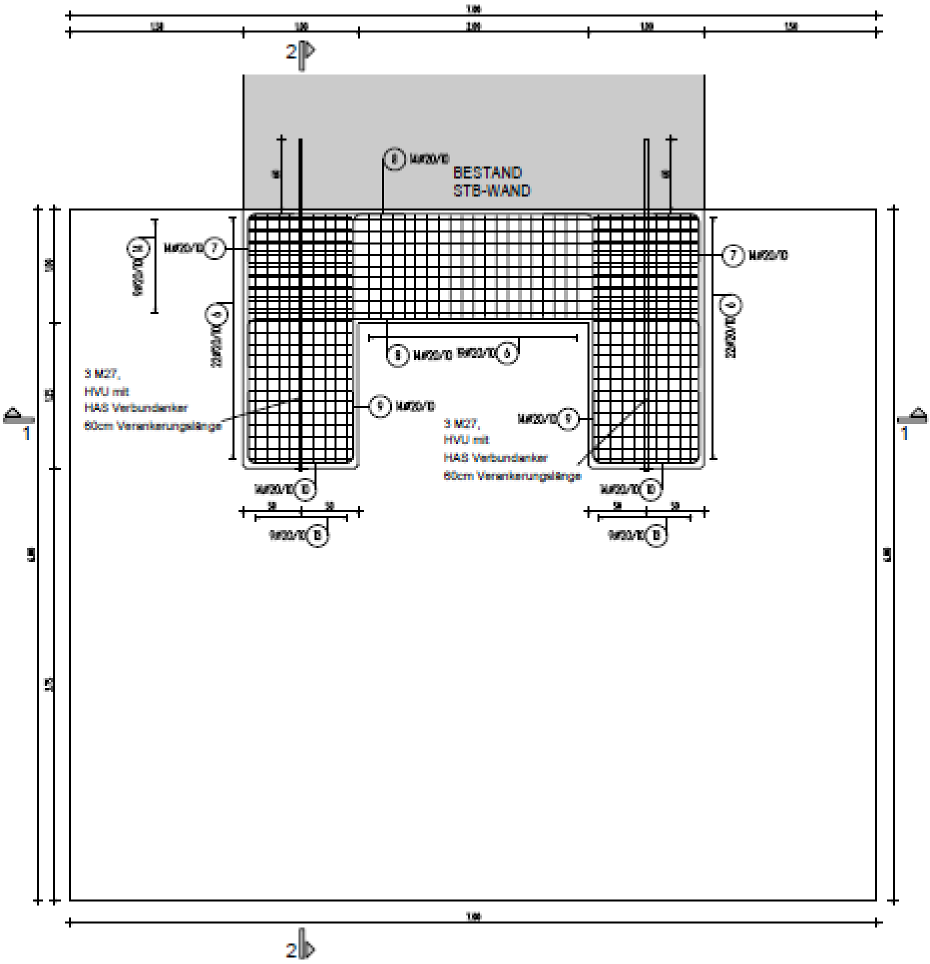


Figure 3: Top view

Figure 4: Blasting area

2.2 Technical requirements

After the construction, a significant number of requirements for the blasting area had to be fulfilled.

Firstly, the enclosure (see chapter 2.4) should be designed in a way that there is no fly rock possible and furthermore it should be constructed in a way that a person can easily pick up the blasted material. This housing should be constructed to protect the blast site against weather and to make it easy, to collect the excaved material. For a better pick up on the floor, the floor was sealed (see figure 7).

Secondly, the 2 m³ concrete block should be in good contact with the existing blasting area during the blast, but easily removable afterwards. For this purpose, a clamping device was designed to clamp the block right back (see figure 5 and 6). The clamping was produced by the company "Maschinen-Service-Erzberg" under the direction of Mr. Helmut Lagelstorfer.

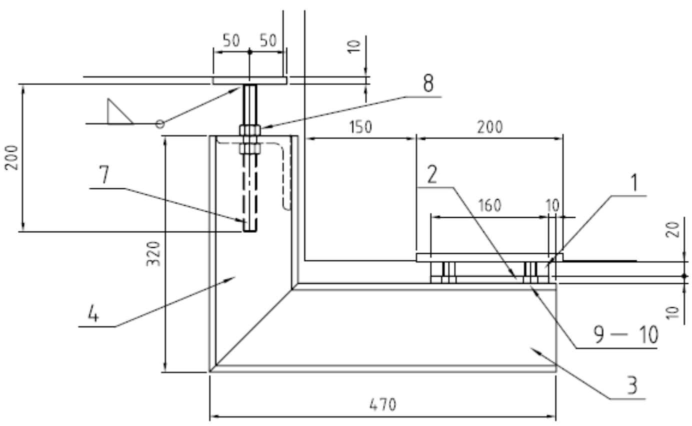


Figure 5: Plan of clamped support

Figure 6: Clamped support

Important note: The clamping was only used for the first two tests.

Figure 7: Seal on the floor

2.3 Block confinement with a good wave transmission

First the idea was, to lift the test block into the blasting area and set it in concrete for optimal transmission. But if the test block is set in concrete, the following work would be very difficult.

After a lengthy search of the ultimate filling material, “children's playing sand” was selected because of its material properties and because of its good results in seismic tests. The test to measure the transit time of the sand and of the concrete samples was carried out at the “Institute of Geophysics”, with great support of the employees.

At the Institute of Geophysics, a core sample with the dimensions l = 70 mm and Ø = 25 mm was used for the tests. The result of the tests was the p-wave velocity.

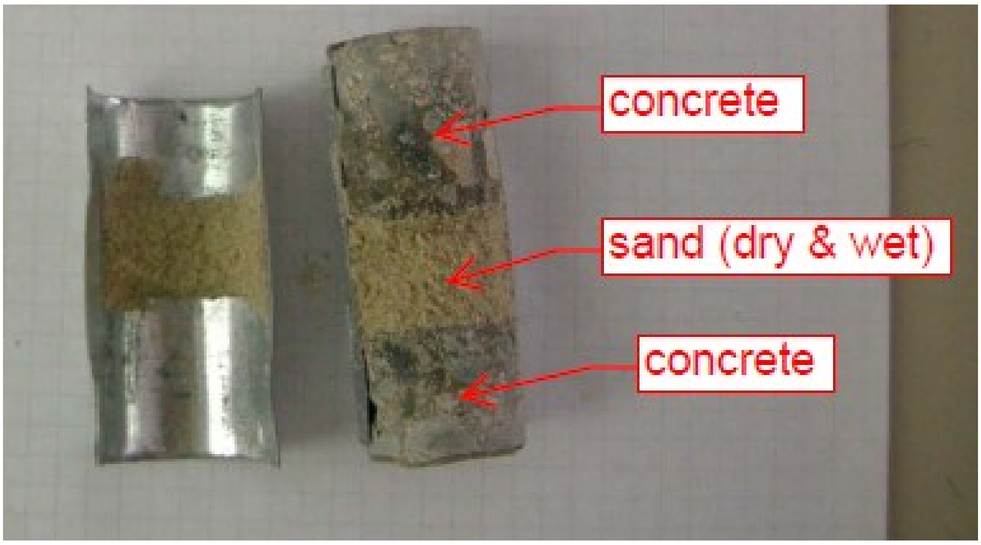


Figure 8: P-wave velocity test sample

The graph (see figure 9) shows a pulse sent in the longitudinal direction of the test core sample (see figure 8). When the amplitude of the core sample passes the visible length, the P-wave velocity can be calculated (see table 4).

$$v_p = \frac{l}{t - t_0}$$

v_p	pressure wave velocity	[m/s]
l	drill core length	[m]
t	wave duration	[s]
t_0	Delay time = 3,2 * 10^{-7} sec.	[s]

Table 3: Shortcut, description and unit of the velocity formula

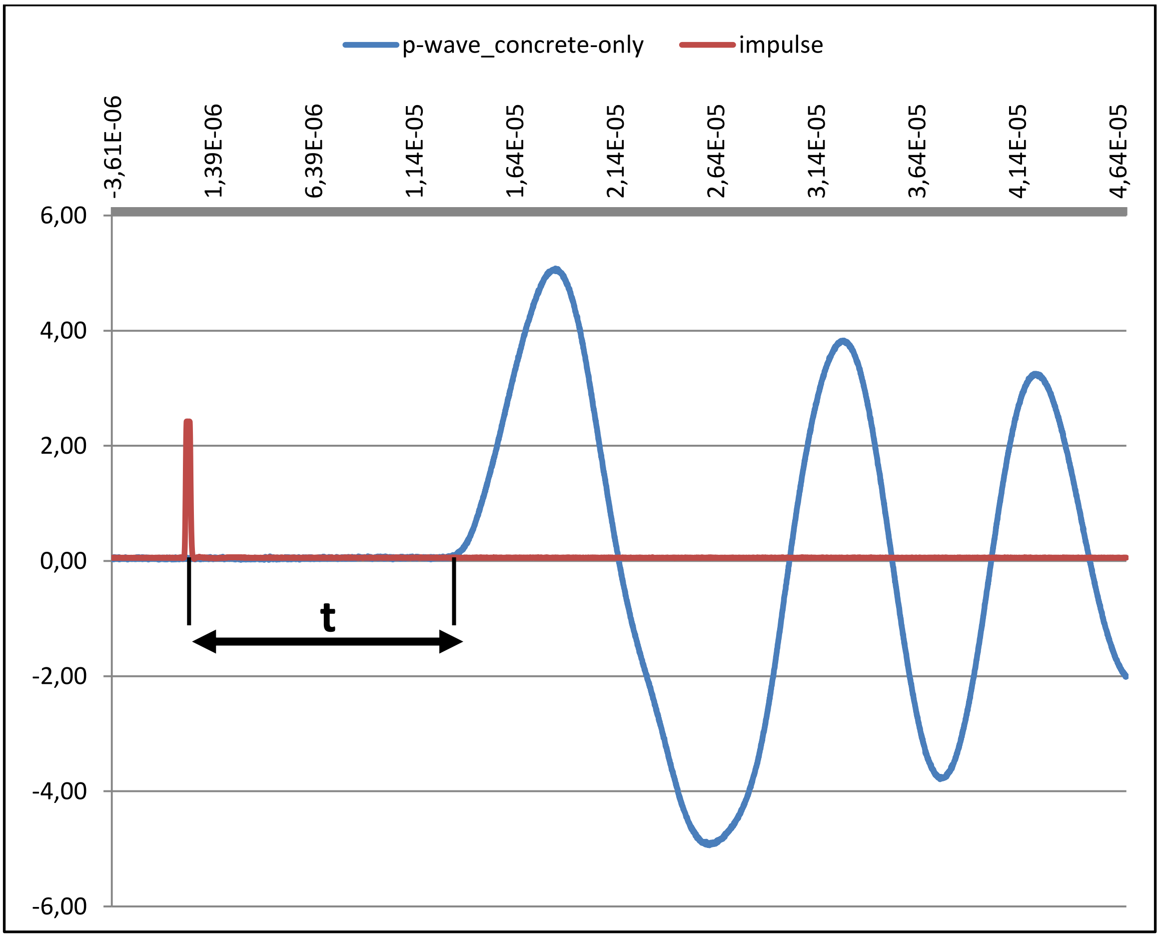


Figure 9: P-wave velocity of concrete

The result of the graphical analysis was the following data.

sample	sample length [m]	p-wave velocity [m/s]
concrete-sample only	0,070	4601,53
sand-sample only	0,062	689,77
concrete-sand-concrete-sample (dry)	0,071	3944,44
concrete-sand-concrete-sample (wet)	0,066	4024,39

Table 4: Calculated p-wave data

After testing the sand properties it was decided to be a good filling material. Then the sand was put before the gap, swept with a broom into the gap and compacted with a wooden board by hand (see following figure).

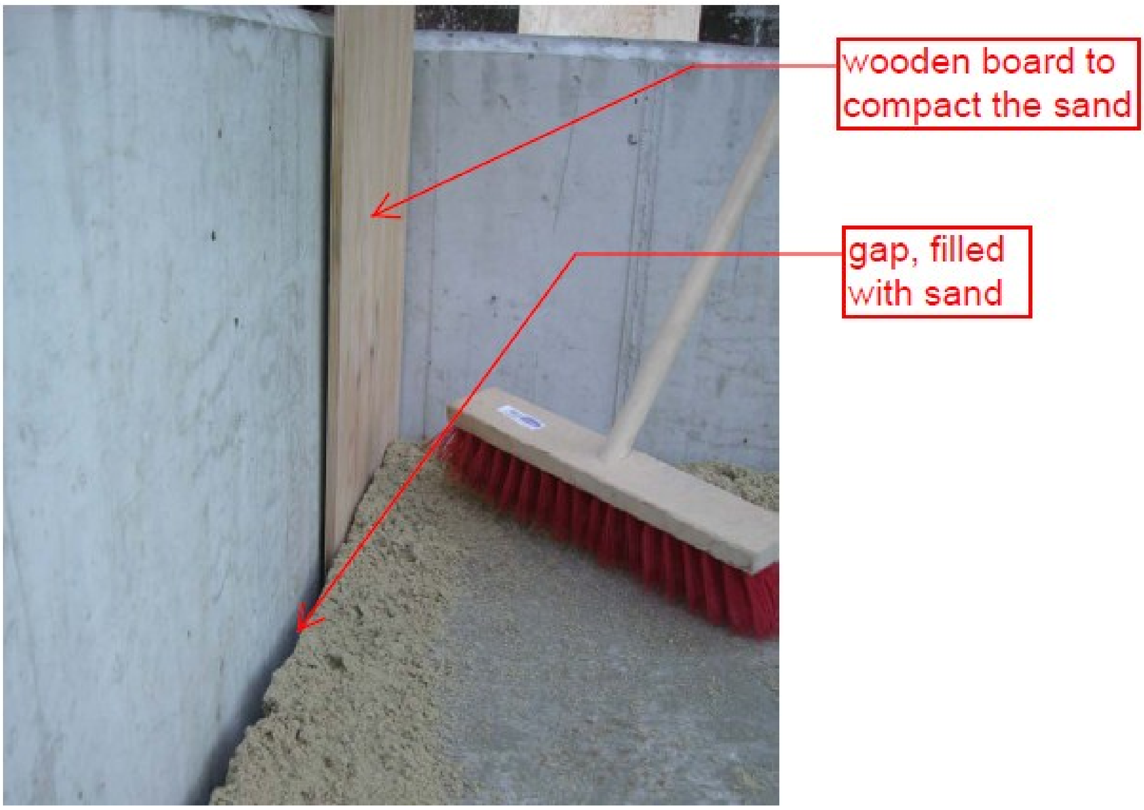


Figure 10: Introduction of the fill material

After the tests with the p-wave velocity, experiments at the “Chair of Mining Engineering” were conducted, to check, if the wave transmission is good enough, for the upcoming blasting tests.

The test set included two concrete blocks and dry sand as a filler material between them. By a hammer strike on the first concrete cube, a seismic wave was generated, which propagates through the sand into the second concrete cube. Two geophones were used for the measurement. The first measurement (Acceleration sensor 1; sensitivity 100 mV/g) was taken after the first concrete cube and the second (Acceleration sensor 2; sensitivity 1000 mV/g) after the second concrete cube.

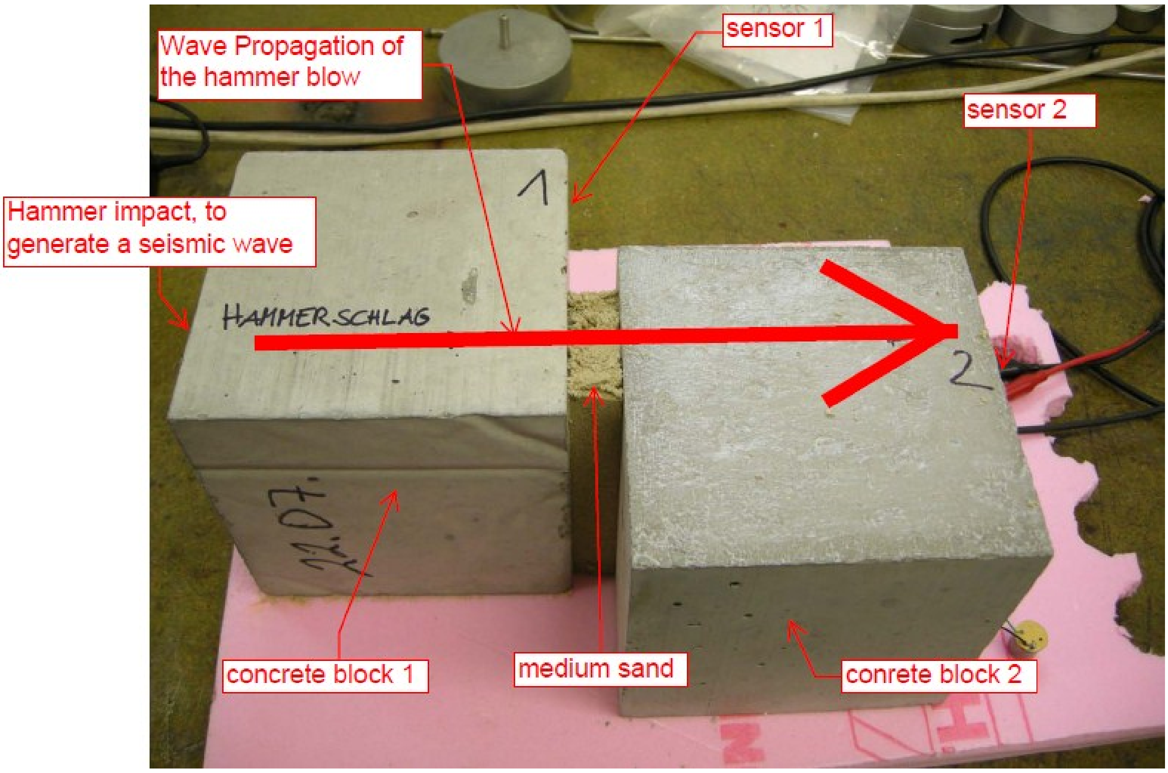


Figure 11: P-wave velocity test construction

As a result of this measurement, two curves could be seen on the oscilloscope (shown in figure 12). There were two different geophones used with varying accuracy. Via graphics, it could be demonstrated that up to 70 % of the blasting wave can go through the backfill material. After that, the blasting wave will run through the built blasting site in the massive rocks.

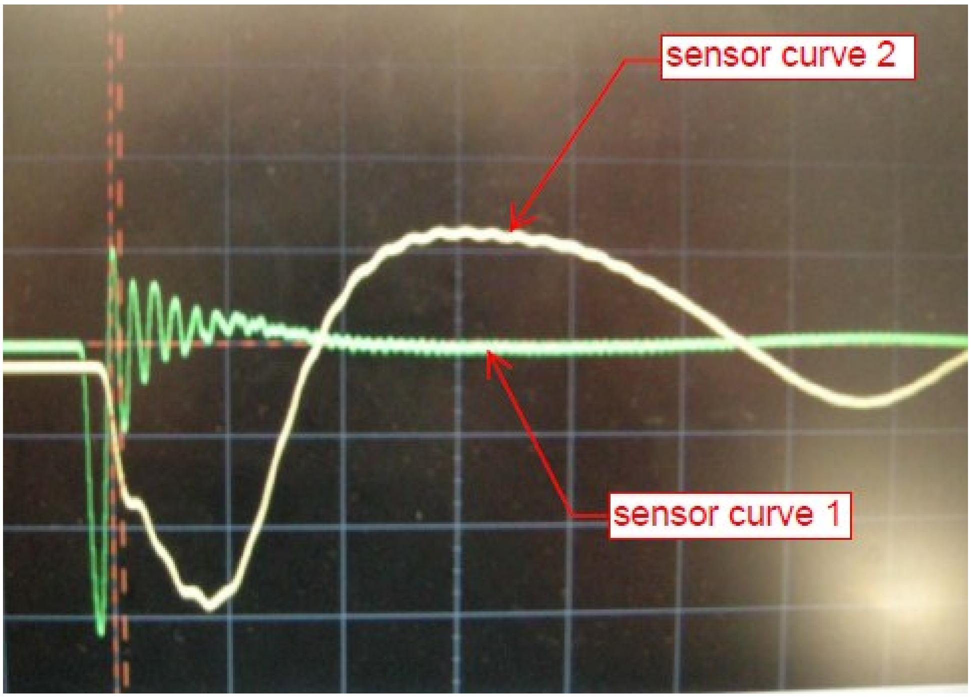


Figure 12: Oscilloscope curves

2.4 Explosion-proof enclosure

A condition for the blasting site was that no fly rock should occur. Also, a further secondary crushing due to an impact should be avoided. For this particular case, an enclosure with several layers of blasting mats was realized.

On the concrete foundation five steel uprights were installed (see figure 13), which were fixed with a steel cable in three different heights to the walls of the blasting area. Between the upper and lower steel cable around the uprights a mesh wire fence was installed (see figure 14). Depending on the specific amount of explosives, several layers of blasting mats were hung over the fence (see figure 15). As a cover, another blasting mat was used. This blasting mat was placed over the blast site and the ends were fixed with elastic rubber ropes (see figure 16).

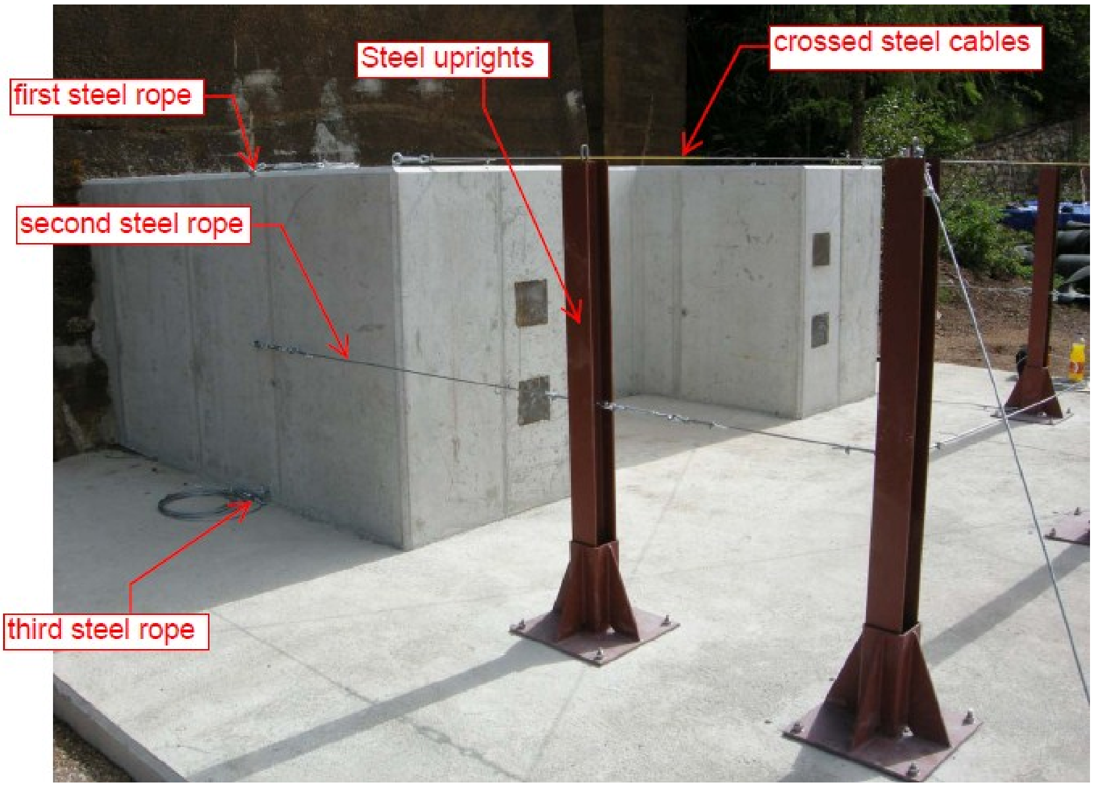


Figure 13: Blasting area under construction

Figure 14: Effect of the wire mesh fence

Figure 15: Multiple layers of the blasting mats

Figure 16: Blasting site during the explosion

3 Material characteristics and aggregate description

In all previous blasting tests, concrete blocks with a finer cement mixture were used. Since the concrete blasting tests now were conducted on a larger scale, this fine concrete mixture was not applied. The main problem was the transport of the concrete blocks from the production site of the company Luiki to the blasting site at Erzberg, without breaking. For this reason Luiki developed a new concrete recipe for this application.

The new concrete with the name *"C30/37/B2/SB/GK11"* includes the aggregates Tieber 0/4, Wurzenberg 0/3, Wurzenberg 4/8 and Wurzenberg 8/12 (see following tables and figures).

component	mass-%
CEM II 42,5 N	14,47
water	7,10
Tieber 0/4	19,62
Wurzenberg 0/3	16,47
Wurzenberg 4/8	4,68
Wurzenberg 8/12	37,66

Table 5: Recipe of the concrete "C30/37/B2/SB/GK11"

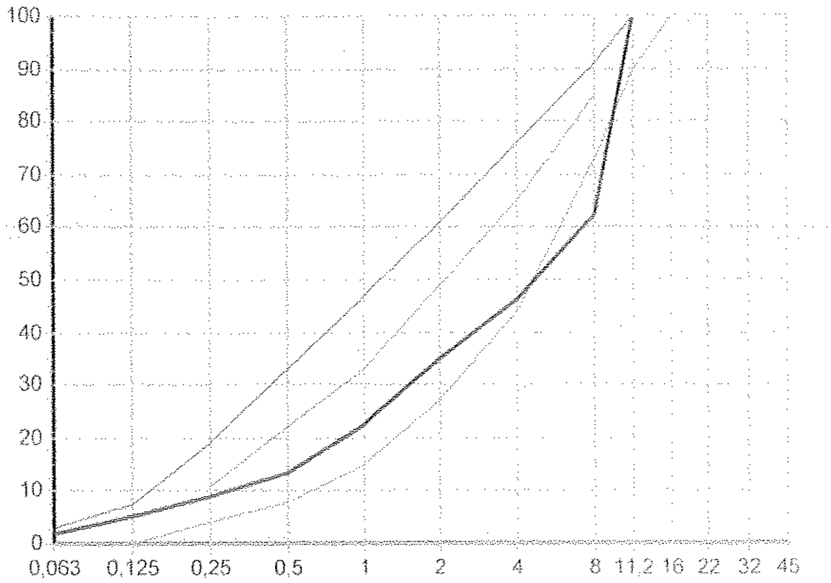


Figure 17: Sieving curve made by Luiki

To control the sieving curve from Luiki (see previous figure), all individual concrete aggregates were sieved and finally calculated from the complete recipe formula, and displayed (see tables below).

concrete formula	[%]	
Tieber 0/4	25,0	0,25
0/3 Wurzenberg	21,0	0,21
4/8 Wurzenberg	6,0	0,06
8/12 Wurzenberg	48,0	0,48
	100,0	

Table 6: Recipe Formula

cumulative curve / LUIKI formula				
screen size	total mass	total residue	total passing	total local inclination
[mm]	[%]	[%]	[%]	[-]
20	0,00%	0,00%	100,00%	
14	0,00%	0,00%	100,00%	0,000000
12,5	0,18%	0,18%	99,82%	0,015759
10	13,26%	13,43%	86,57%	0,638524
6,3	32,16%	45,60%	54,40%	1,005218
4	4,71%	50,30%	49,70%	0,199121
2	12,84%	63,14%	36,86%	0,431372
1	12,65%	75,80%	24,20%	0,606813
0,5	9,54%	85,34%	14,66%	0,723046
0,25	5,33%	90,67%	9,33%	0,652495
0,125	3,32%	93,99%	6,01%	0,634386
0,1	0,90%	94,90%	5,10%	0,731301
0,063	1,71%	96,60%	3,40%	0,880516
<0,063	3,40%	100,00%	0,00%	
	100,00%			

Table 7: Calculated sum curve

Finally, a cumulative sieving curve and a cumulative local inclination curve were drawn from the individual aggregates (see black dashed line in figures 18 and 19).

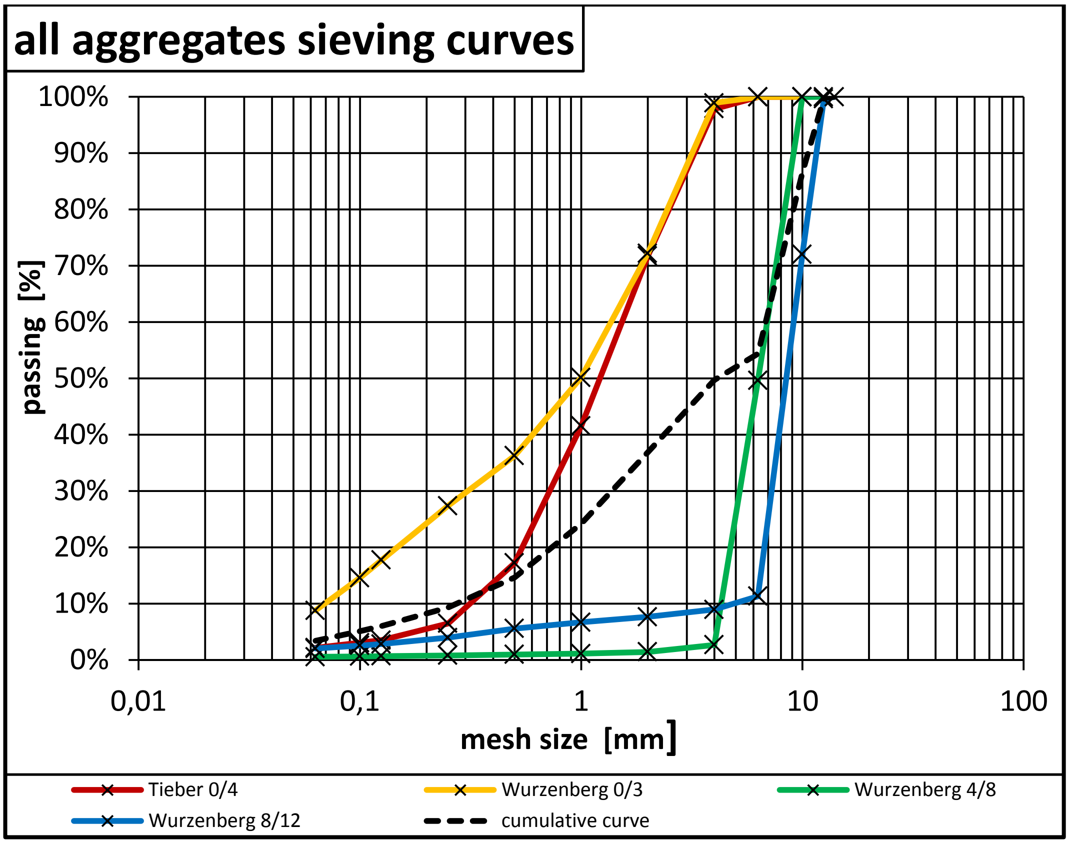


Figure 18: Sieving curve of the aggregates and cumulative curve

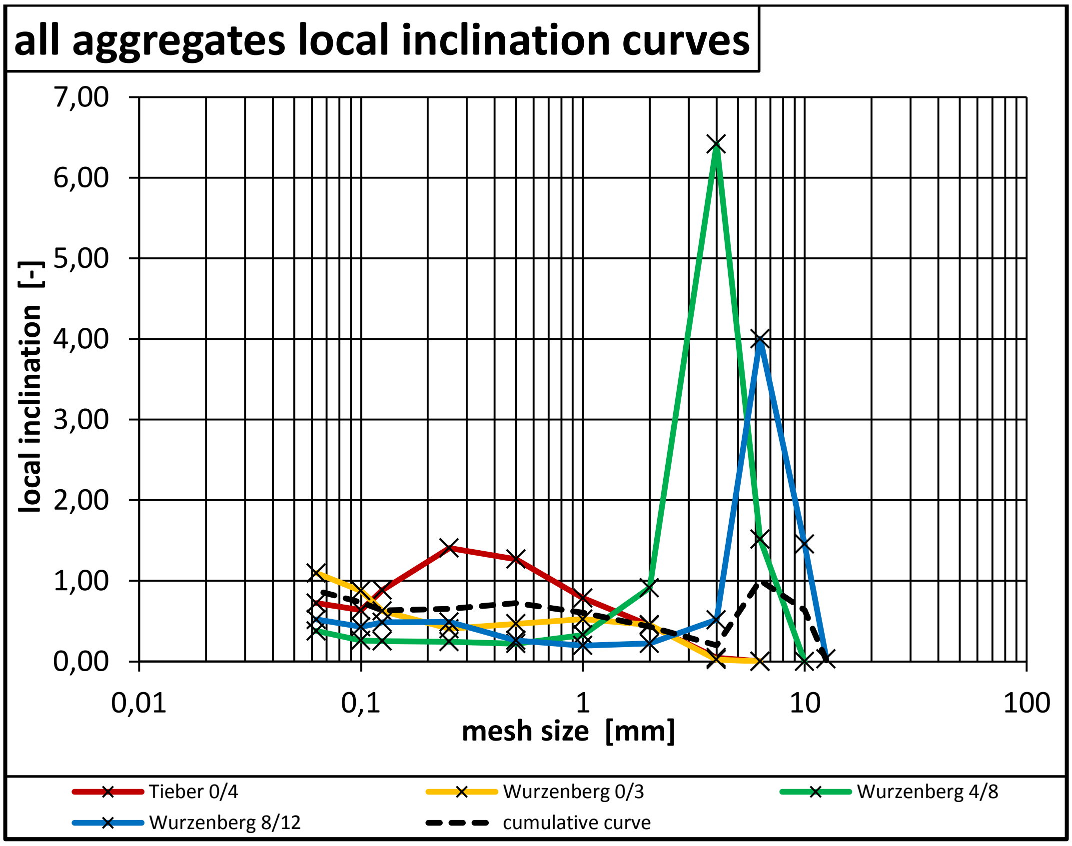


Figure 19: Individual local inclination and cumulative local inclination

3.1 Construction of the laboratory scale concrete blocks

The cube samples were produced by the company Luiki in Leoben and mixed with a maximum batch quantity of 1 m³ concrete according to the recipe. Then they were filled into the manufactured formwork and compacted by using vibration equipment (see figures 20 and 21).
Further test cubes were made with an edge length of 150 mm for various experiments and for compressive strength tests.

Figure 20: Formworks for the samples in laboratory scale

Figure 21: Formworks while filled and compacted

3.2 Construction of the half scale concrete blocks

The large concrete blocks for the tests in the half scale were also produced by the company Luiki in Leoben. Again, the batch quantity of the concrete mixer was limited to 1 m³. Therefore the production needed at least two fillings. The fillings were treated with vibrating rods and compacted.

To lift the large blocks, a ball-head anchor was cast into the center of the concrete blocks (see figure 23).

Figure 22: Formworks for the samples in half scale

Figure 23: Ball-head anchor and lift system

3.3 Strength tests with different sample age

Another test to characterize the material properties is the uniaxial compression test. In these experiments, the pressure modulus, two deformation moduli and the mechanical work of destruction were measured (see figure 24).

The experiments were carried out at the University of Leoben. Furthermore, it should be noted that the pressure tests with the concrete samples are not equivalent to the original compression tests of concrete, because the samples were stored outdoors (no underwater storage of the concrete samples).

Because the first samples were blasted after 14 days, two pressure tests were performed. The first samples were tested after 14 days and the second samples at the age of 28 days.

The pressure testing of the samples at 28 days were made to check the manufacturer's instructions.

All pressure experiment samples were 10 cm long and made with a diameter of 10 cm of core drilling. These are taken from the test cubes made with the dimensions of 150 mm x 150 mm x 150 mm. The tests were done deformation-controlled with a rate of increase of 0,5 mm/min. The transverse strain was not included, but the elongation was measured with an electronic axial extensometer.

In the following, all results are presented by using tables and the average is calculated (see tables 8 and 9).

For full details of the compression tests see the Annex.

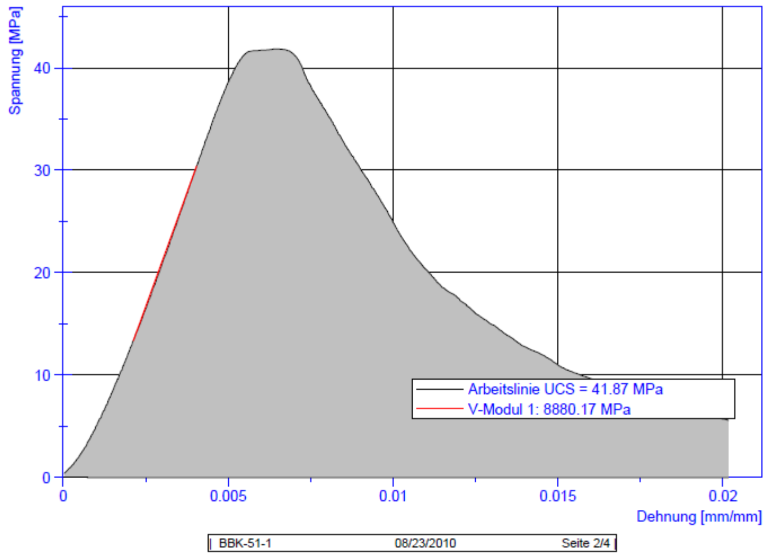


Figure 24: Stress / Strain chart

	BBK-55-1	BBK-55-2	average value
UCS [MPa]	48,92	47,78	48,35
E-module [MPa]	27124,27	38744,14	32934,21
V-module 1 [Mpa]	24664,8	34345,3	29505,05
V-module 2 [MPa]	24608,97	33474,02	29041,50
Destruction work [kJ/m³]	141,56	112,55	127,06
Diameter [mm]	98,34	98,31	98,33
Height [mm]	99,38	98,12	98,75
Mass [g]	1821,81	1811,03	1816,42
Density [g/cm³]	2,41	2,43	2,42

Table 8: Strength test samples [14 days]

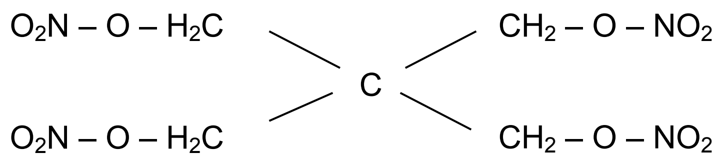
	BBK-51-1	BBK-51-2	BBK-51-3	BBK-51-4	average value
UCS [MPa]	41,87	47,4	49,47	46,13	47,67
E-module [MPa]	-	32597,06	32735,03	34005,42	33112,50
V-module 1 [Mpa]	-	27153,3	30021,4	28946,98	28707,23
V-module 2 [MPa]	-	20325,81	16766,27	18307,85	18466,64
Destruction work [kJ/m³]	392,76	240,77	399,41	190,98	277,05
Diameter [mm]	99	99,08	99	99	99,03
Height [mm]	99,9	99,3	97,4	101	99,23
Mass [g]	1868,34	1866,03	1818,03	1897,73	1860,60
Density [g/cm³]	2,43	2,44	2,42	2,44	2,43

Table 9: Strength test samples [28 days]

4 Explosives

4.1 Description of the explosives

PETN structure formula:



[1]

gross formula: $C_5H_8N_4O_{12}$ [1]

Nitropenta (PETN) was exclusively used as explosives in all tests.

In the laboratory scale tests, loose PETN and PETN cord [20 g/m] was used. The requested amount was determined via scale and the nitropenta bulk was placed in the drill-hole and compacted evenly with a wooden stick. To ignite the loose PETN, a detonating cord [12 g/m] was used in combination with a non-electric detonator.

In the half-scale tests PETN cord with 20 g/m and 40 g/m was used. For the ignition of the explosive, non-electric detonators were used (for more details see the following tables).

4.2 Choice / calculation of specific charge

For the calculation of the specific charge in the laboratory scale (see table 10), the sample mass and the amount of explosive were used. The calculation of these samples does not relate to an outbreak angle, but the complete damage of the cube.

		$m_{example}$ [g]	drill hole diameter [mm]	explosive type	specific explosive consumption [g/t]	explosive charge [g]	loading density cord : [g/m] bulk : [g/cm³]
Samples after explosion	WLM-20-01	19503,50	5,00	PETN bulk	199,96	3,90	1,10
	WLM-20-03	19238,80	8,00	PETN cord	207,91	4,00	20,00
	WLM-30-01	65439,80	5,20	PETN bulk	91,69	6,00	1,10
	WLM-30-02	65569,80	8,00	PETN bulk	251,64	16,50	1,22
	WLM-30-03	65739,40	8,00	PETN cord	91,27	6,00	20,00
	WLM-30-04-Kontrollprobe	65942,80	8,00	PETN cord	90,99	6,00	20,00
	WLM-40-01	155373,20	5,00	PETN bulk	55,35	8,60	1,26
	WLM-40-02	156313,20	7,90	PETN bulk	141,38	22,10	1,13
	WLM-40-03	156214,90	8,00	PETN cord	51,21	8,00	20,00

Table 10: Explosives calculation at laboratory scale

In the half-scale calculation a breakout angle of 90 ° was chosen. Below are two tables, one before (table 11) and another after the blasting (table 12). You can clearly see that there is a large difference in the specific amount of charge before and after the explosion as the breakout angle was bigger than 90°. Therefore all further calculations were made based on the specific charge amount after the detonation.

		Burden [m]	$M_{explosive}$ BL 1 [g]	$M_{explosive}$ BL 2 [g]	$M_{explosive}$ BL 3 [g]	specific explosive consumption BL 1 [g/t]	specific explosive consumption BL 2 [g/t]	specific explosive consumption BL 3 [g/t]
Samples calculation	PHM-25-1,2/1,2-01	0,2500	19,00	-------	-------	125,62	-------	-------
	PHM-19-1,2/1,2-02	0,1900	19,00	-------	-------	217,49	-------	-------
	PHM-15-1,2/1,2-03	0,1500	19,00	19,00	17,00	348,94	290,79	260,18
	PHM-10-1,2/1,5-04	0,1000	19,00	-------	-------	785,12	-------	-------
	PHM-12-1,2/1,5-05	0,1200	38,00	-------	-------	1090,45	-------	-------
	PHM-06-1,2/1,5-06	0,0600	38,00	-------	-------	4361,80	-------	-------

Table 11: Explosives calculation; half scale; before blasting

		Burden [m]	$M_{explosive}$ BL 1 [g]	$M_{explosive}$ BL 2 [g]	$M_{explosive}$ BL 3 [g]	specific explosive consumption BL 1 [g/t]	specific explosive consumption BL 2 [g/t]	specific explosive consumption BL 3 [g/t]
Samples after explosion	PHM-25-1,2/1,2-01	0,2500	19,00	-------	-------	592,59	-------	-------
	PHM-19-1,2/1,2-02	0,1900	19,00	-------	-------	498,70	-------	-------
	PHM-15-1,2/1,2-03	0,1500	19,00	19,00	17,00	95,89	661,42	614,14
	PHM-10-1,2/1,5-04	0,1000	19,00	-------	-------	174,00	-------	-------
	PHM-12-1,2/1,5-05	0,1200	38,00	-------	-------	275,12	-------	-------
	PHM-06-1,2/1,5-06	0,0600	38,00	-------	-------	1.234,37	-------	-------

Table 12: Explosives calculation; half scale; after blasting

4.3 VOD measurement

An important point in the experiments were VOD measurements, carried out to make sure that there will be no major errors in the measurements on a laboratory scale.

To perform these measurements, at both ends of the detonating cord a fine wire was wrapped around, which sends a signal to the oscilloscope and each constitutes a line. If now the detonating cord explodes the wrapped cable is stopped during the explosion of the detonating cord and stops the signal at the oscilloscope.

The detonation front spreads to the other wrapped end of the detonating cord, and interupts the second signal on the oscilloscope. The elapsed time between these interuptions can be used to calculate the velocity when the path length is known. The calculated velocities are shown in Tables 13 and 14.

Date:	22.09.2010	20 $^g/_m$ detonating cord					
experimental number:		1	2	3	4		average value
length:	[mm]	1000	1000	1000	700		925
time:	[sec]	135	135	136	94,4		125,1
VOD:	[$^m/_s$]	7407,40741	7407,40741	7352,94118	7415,25424		7395,75256

Table 13: VOD with a 20 g/m blasting cord

Date:	17.11.2010	40 $^g/_m$ detonating cord				
experimental number:		1	2	3		average value
length:	[mm]	1000	1000	1000		1000
time:	[sec]	143,2	143,6	142,8		143,2
VOD:	[$^m/_s$]	6983,24022	6963,7883	7002,80112		6983,27655

Table 14: VOD with a 40 g/m blasting cord

5 Laboratory scale blasting tests

Before the blocks were blasted in half scale, a series of tests at laboratory scale were made to test the new material properties. The aim was to study the effect of changing parameters. All tests at the laboratory scale were carried out in the blasting chamber of the Styrian Erzberg. The lightweight blocks were lifted manually into the blasting chamber and the heavy blocks were placed by crane into the blasting chamber. The explosion chamber is made of concrete rings with a diameter of 2.5 m and a height of approximately 2 m. The interior of the chamber is lined with conveyor belts so that the blasted material can be picked up better. During the explosive experiments, a lid is placed on the chamber to avoid fly rock.

Every single experiment on a laboratory scale was documented photographically.

Illustrations are shown in figure 25 to figure 27.

Figure 25: Blasting chamber

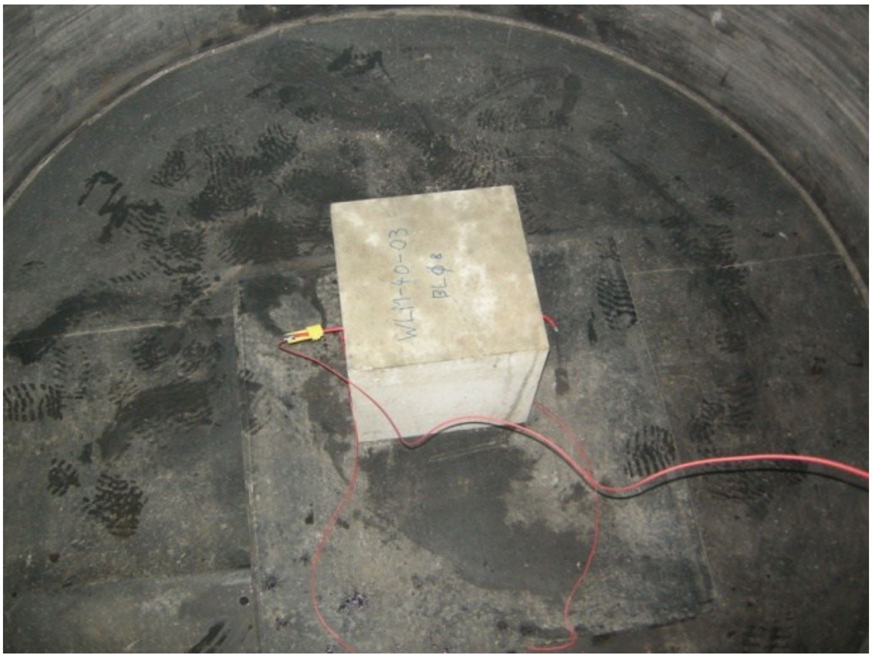


Figure 26: WLM-40-03 test block; before blasting

Figure 27: WLM-40-03 test block; after blasting

5.1 Laboratory scale sample preparation

As mentioned concrete cubes with various edge lengths were used for testing. For the blasting, the specimens were centrally drilled with holes of 5 mm and 8 mm. Drillholes with 5 mm diameter were filled with loose PETN (see figure 28), compacted with a wooden stick and blasted. The 8 mm holes were stuffed with a detonating cord and blasted. To determine the deviation of the drill holes, all samples were drilled through and measured afterwards.

Figure 28: Sample preparation

5.2 Laboratory scale experimental procedure

There were nine cubes with three different edge lengths blasted. In the first series 5 mm holes were drilled, filled with loose PETN and blasted. In the second test series 8 mm holes were drilled, filled with loose PETN and also blasted. In the third test series 8 mm holes were drilled, filled with a 20 g/m detonating cord, and blasted in the next step. The following table shows which explosives were used for the samples and what the specific charge was.

Sample	Nr.:	edge length	drill diameter	mass PETN bulk	mass PETN cord	specific charge
		[mm]	[mm]	[g]	[g]	[g/t]
WLM-20	- 01	200	5	3,9	-------	199,96
	- 03	200	8	-------	4	207,91
WLM-30	- 01	300	5	6	-------	91,69
	- 02	300	8	16,5	-------	251,64
	- 03	300	8	-------	6	91,27
	- 04	300	8	-------	6	90,99
WLM-40	- 01	400	5	8,6	-------	55,35
	- 02	400	8	22,1	-------	141,38
	- 03	400	8	-------	8	51,21

Table 15: Samples laboratory scale

5.3 Laboratory scale VOD measurement

In the tests at laboratory scale, the VOD was supposed to be measured. In two samples this was not possible, because they were not drilled through. In the remaining samples, the VOD was recorded and it turned out that the detonating cord detonated much faster than loose PETN. The reason for this was the different density during the compaction of the loose PETN.

As seen in chapter 4.3, a VOD measurement was also done, but in this case without confinement. It is to be noted that almost no difference can be seen if the detonating cord is in confinement or not.

Sample	Nr.:	length	time	VOD	explosive type
		[mm]	[µs]	[m/s]	[---]
WLM-20	- 01	210,0	41,6	5048,08	PETN bulk
	- 03	200,0	27,2	7352,94	PETN cord
WLM-30	- 01	310,0	58,0	5344,83	PETN bulk
	- 02	300,0	49,4	6072,87	PETN bulk
	- 03	300,0	41,6	7211,54	PETN cord
	- 04	-------	-------	-------	-------
WLM-40	- 01	-------	-------	-------	-------
	- 02	400,0	66,4	6024,10	PETN bulk
	- 03	400,0	55,8	7168,46	PETN cord

Table 16: VOD measurements in laboratory scale

6 Half scale blasting tests

The half scale tests were done in the newly constructed blasting site at the Styrian Erzberg (see figure 29 and 30) on the level Elias. The 2 m³ concrete blocks were manufactured by Luiki and were brought directly to the blasting site. The company "Radlingmaier" was asked to lift the concrete blocks inside the existing blasting site and to lift the blocks out of the blasting site after the blasting tests. Sometimes the blocks were also lifted in the blasting site by the Erzberg employees.

Figure 29: PHM-10-03 test block; before blasting

Figure 30: PHM-10-03 test block; after blasting

6.1 Half scale experimental procedure

First, a borehole was drilled with a defined burden. A template was used in combination with a small rock drillbit, which avoided any deviation. After some centimeter drilling, the next larger drillbit was used for drilling more accurately. After the first hole was drilled, the concrete block was lifted into the blasting site. The gap between the block and the blasting area was filled with sand, compacted with a wooden board and covered with a sealing strip to ensure that no sand comes out during the blasting procedure. Thus, a good wave transmission in the rocks was possible. First, all three holes of a block were drilled, but it was waived for reasons of cracking to the adjacent drill holes for the other blocks. The required other holes were drilled in the clamped block of the blasting site, in case they were ever needed.

6.2 Half scale sample preparation

All the experiments in the half scale were exclusively blasted with detonating cord. In the first four tests, a 20 g/m detonating cord was used and in the other two tests, a 40 g/m detonating cord was used. The detonating cord was oiled with WD-40 for a better fitting in the drill hole. The whole procedure took place in the clamped concrete block. In the picture below you can see a ready prepared test sample with a 20 g/m detonating cord.

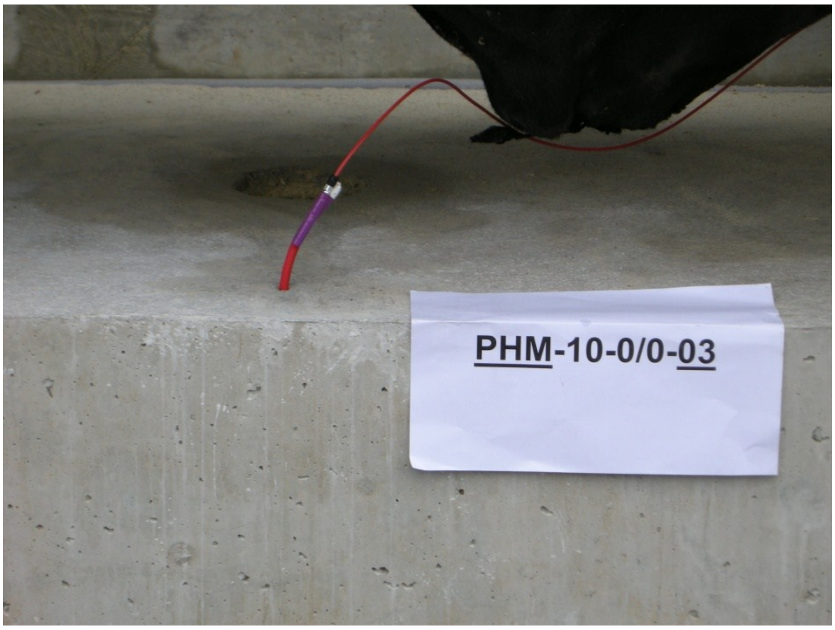


Figure 31: Preparation with a detonating cord

After the detonation cord was inserted into the borehole, the blasting site was carefully covered with blasting mats and the test was conducted. After the blasting procedure the blasting cracks were marked with a pen, in order to identify the cracks in the subsequent photographic documentation better (as can be seen in figure 32).

Figure 32: Tracing the blasting cracks

After all broken out material was carefully collected for further analysis, the sand was scraped out. As a scraping tool small metal rods with hooks at the end were used. The test sample was lifted out of the blasting site by using a crane, and a new trial could be done after cleaning the blasting site.

Due to the cracks in the concrete block, caused by the explosive pressure, the blocks sometimes broke during the lift out and had to be crushed at the blast site. By mounting of hooks (see figure 33) to each block, the pieces could be lifted.

Figure 33: Elevated crushed samples from the blasting site

6.3 Half scale VOD measurement

There were no VOD measurements done during the half scale tests.

It was considered to install some accelerometers in the blasting area, but this was not realized for reasons of time at that stage of the tests.

6.4 Angle and crack analysis

Since the breakout angle was very flat, and not 90° like the calculated one, an angle was drawn and measured in every picture of the concrete specimens, to show the flat angle in the evaluation. On both sides of the blasted edge lines, lines were drawn, as if you were creating a tangent line. Between the distances of the two tangent lines, the angle was documented (see figure 34).

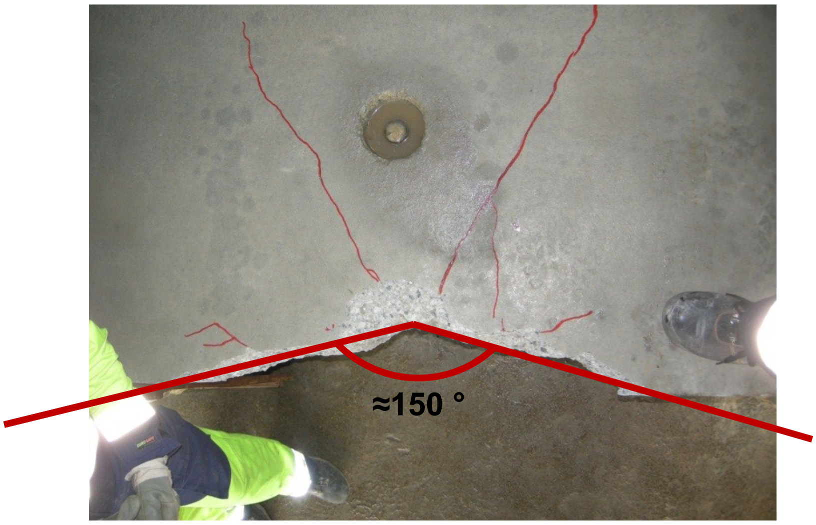


Figure 34: Outbreak angle of PHM-05

Since it almost always came to a crack in the direction of the ball-head anchor, it can be seen as a weakness of the system. As shown in the table below, the number of cracks and the breakout angles were documented.

Sample no.	Breakout angel [°]	Number of cracks [--]
PHM-01	≈ 150	7
PHM-02	≈ 150	6-7
PHM-03	2 x ≈ 65	6-7
PHM-04	≈ 145	3
PHM-05	≈ 150	5-6
PHM-06	≈ 145	2

Table 17: Angle and crack data

6.5 BlastMetriX analysis

An attempt was made to present the graphical analysis using BlastMetriX (see figure 35). This program is used in quarries, to get a 3D image of a blastsite. With this method, two separate images from different perspectives are illustrated in one image. This allows a three-dimensional viewing of the image. The pictures were taken with a SLR camera, in a lateral distance of about 1/5 to 1/8 of the samples distance. Then the 3D pictures were created on the computer using the BlastMetrix 3D software.

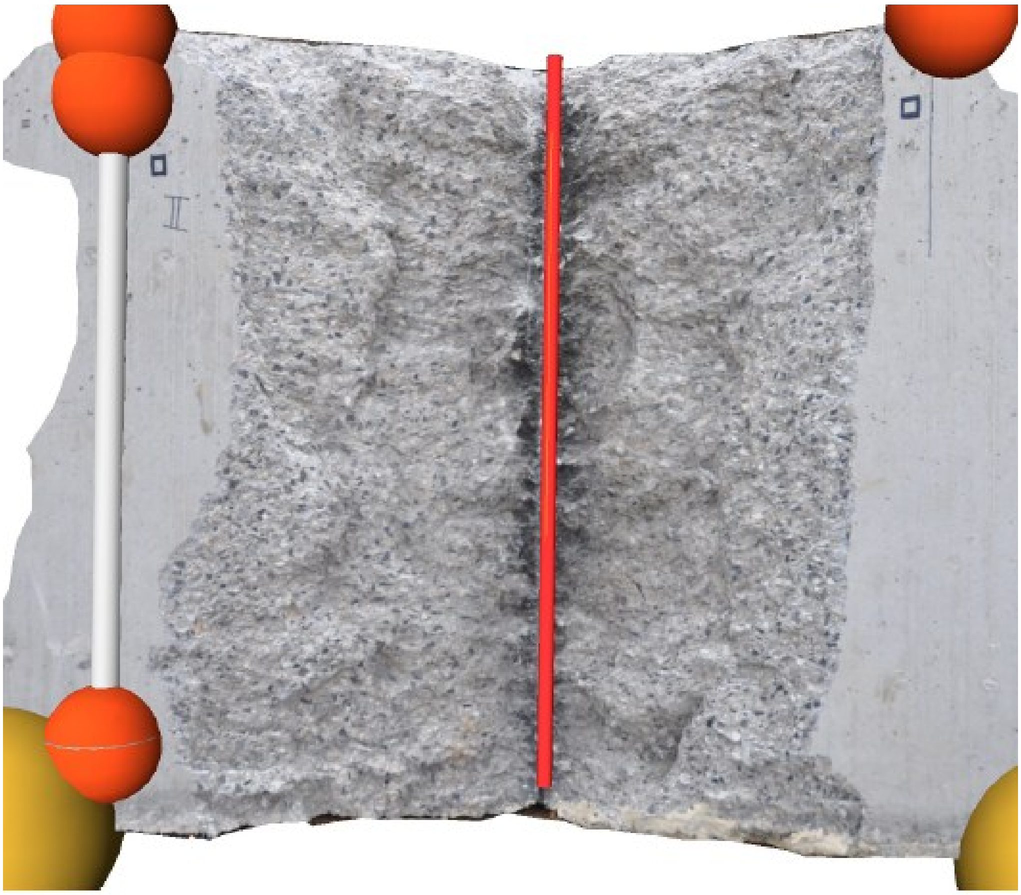


Figure 35: 3D image of the the test sample; PHM-05

The program furthermore creates a top view of the model, drill hole details and a cross-section of the drill hole direction (see figure 36 and 37 and table 18).

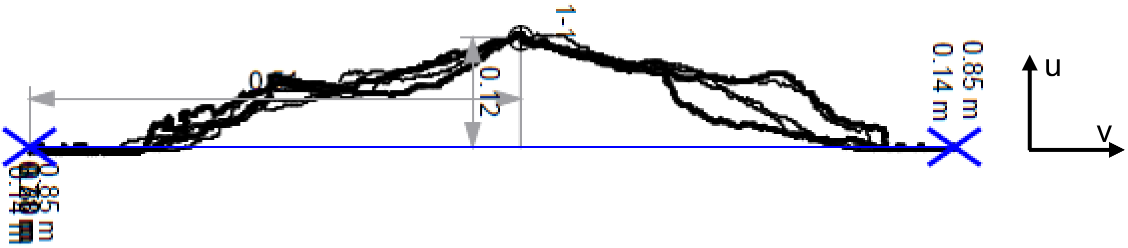


Figure 36: Top view of the 3D model in scale 1:10; PHM-05

designation	u	v	alpha	inclination	length
[-]	[m]	[m]	[deg]	[deg]	[m]
1-1	**0,54**	**0,12**	**90,10**	**1,00**	**0,95**

Table 18: Borehole details, PHM-05

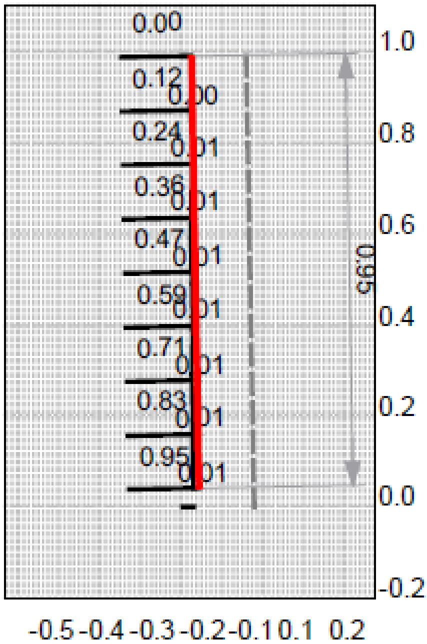


Figure 37: Cross-section of the drill hole direction in scale 1:10; PHM-05

6.6 Influence of the geometric ratios

The energy input is the main factor of the fragmentation in the laboratory scale experiments. Therefore, various k-values were shown as a function of the specific charge, to see the effect of the energy input. The graph shows the changing of the k-values, by increasing the energy input (see figure 38 and table 19).

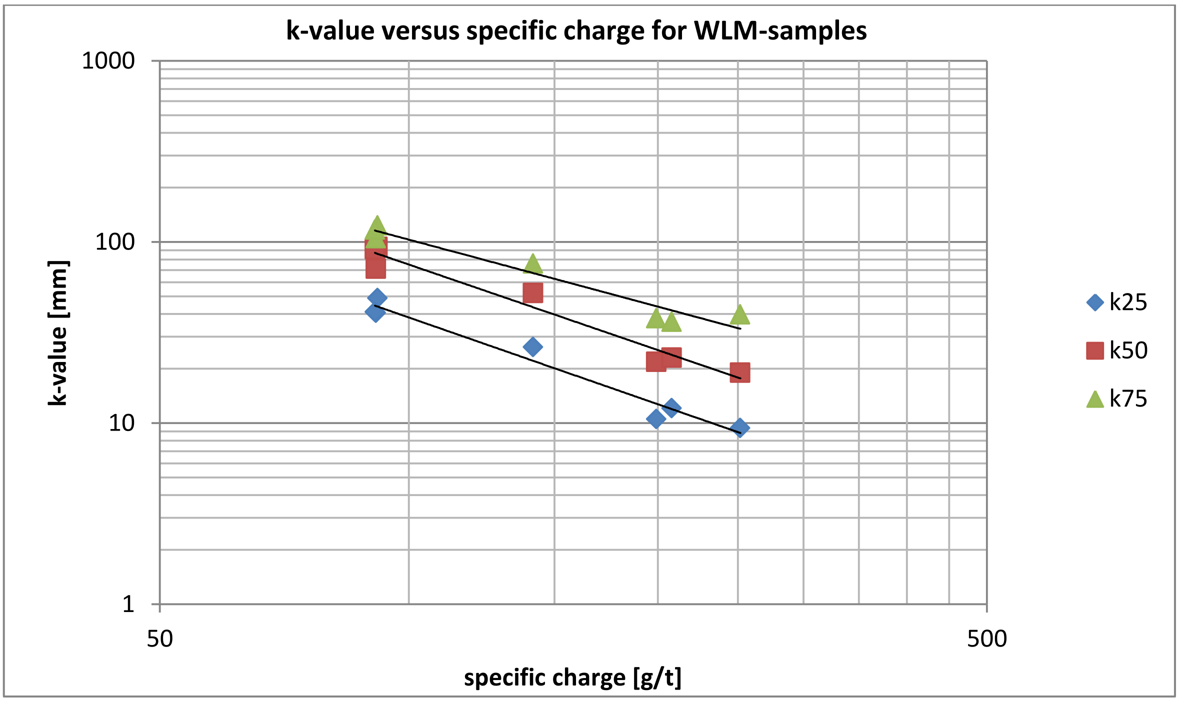


Figure 38: K-values versus specific charge; laboratory tests

		WLM-20-01	WLM-20-03	WLM-30-01	WLM-30-02	WLM-30-03	WLM-30-04	WLM-40-02
k_25	[mm]	10,5	12,1	49,0	9,4	40,7	41,1	26,2
k_50	[mm]	21,8	22,9	93,7	19,0	71,2	91,5	52,3
k_75	[mm]	38,0	36,3	123,6	39,7	105,0	116,9	76,1
specific charge	[g/t]	199,3	207,9	91,7	251,6	91,3	91,0	141,4

Table 19: K-values; laboratory tests

The same was done for the half-scale tests, in which case the specific charge was not the only parameter. In this case, the reduction of the burden leads to an increase of energy input. A rise of the k-values was also observed when the energy input rises. But in this case, a presentation of a diagram is not meaningful, because the data of the specific charge after the blasting is not an independent parameter. For the determination of the diagram, the values of the specific charge should relate to data before the blasting was done (input) and not the values after the blasting (output).

The use of these later calculated values would be misleading, because these values are "output data" obtained by the actual breakage mass values.

		PHM-01-BL1	PHM-02-BL1	PHM-03-BL1	PHM-03-BL2	PHM-03-BL3	PHM-04-BL1	PHM-05-BL1	PHM-06-BL1
k_25	[mm]	36,3	32,1	-------	9,6	9,7	39,9	18,9	5,1
k_50	[mm]	82,0	71,1	-------	27,3	38,1	79,4	59,3	13,7
k_75	[mm]	121,4	107,0	-------	72,4	-------	-------	105,4	76,4
specific charge	[g/t]	592,6	498,7	95,9	661,4	614,1	174	275,1	1234,4
1/q	[dm^3/g]	0,70	0,83	4,31	0,62	0,67	2,37	1,50	0,33
burden	[mm]	250	190	150	150	150	100	120	60

Table 20: K-values versus burden; half scale tests

Another display format is the various k-values (output) against the burden (input).

Since the energy input at smaller burdens becomes greater, the various k-values were plotted versus burden (see figure 39 and table 20). Thus, the burden for the same amount of explosives is a powerful geometric factor that must be considered.

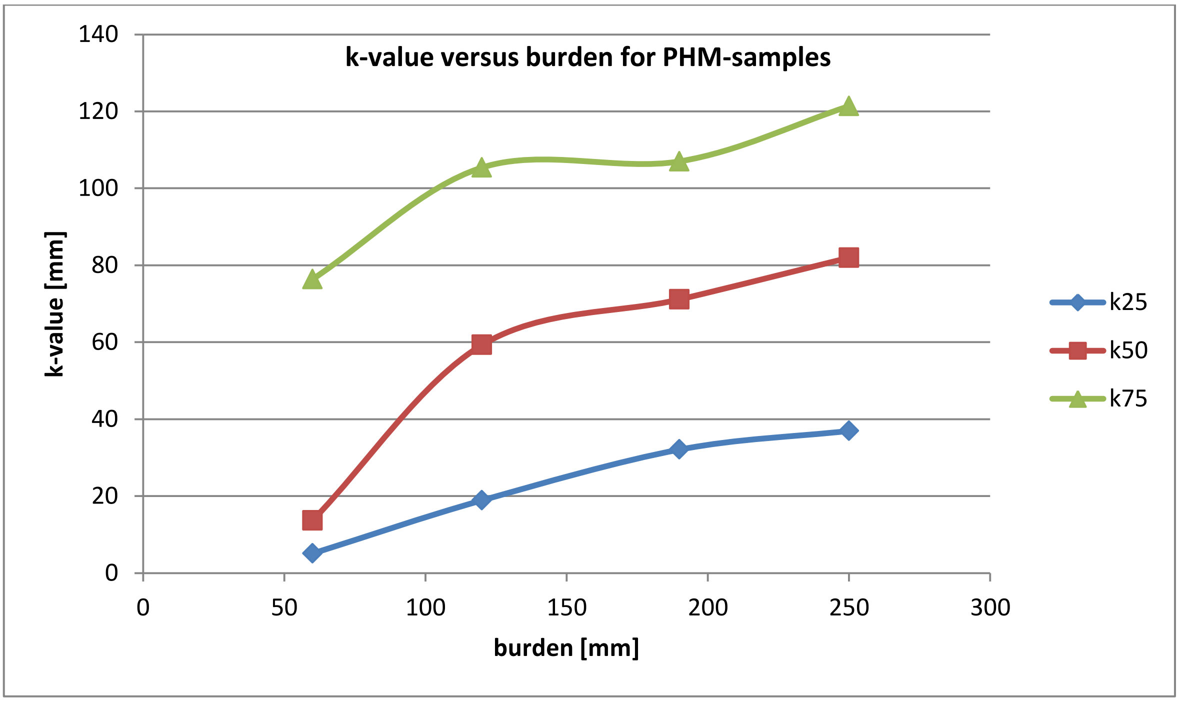


Figure 39: K-values versus burden; half scale tests

Furthermore, the volume versus the burden is illustrated (see figure 40 and table 20).

Since the half-scale tests were loaded with different types of detonating cords (20 g/m and 40 g/m), the volumes were divided by the amount of explosives and the reciprocal value was illustrated. This allows a uniform representation, despite different amounts of explosive.

Therefore, 1/q versus the burden is illustrated.

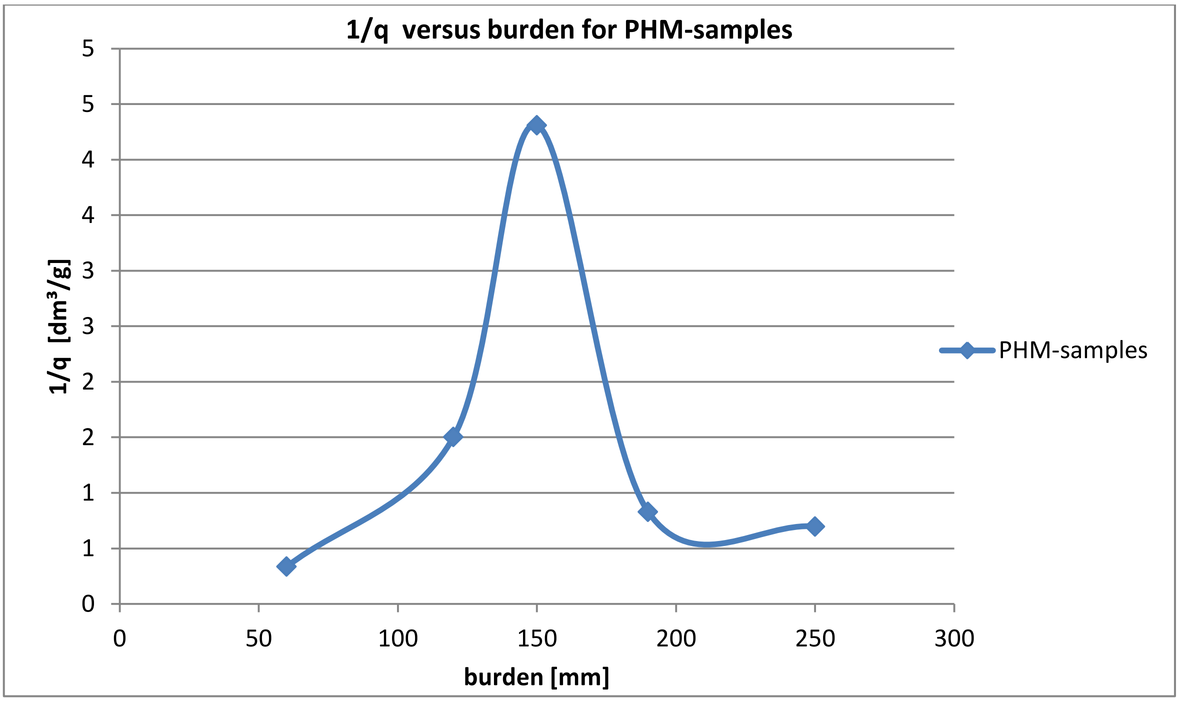


Figure 40: 1/q versus burden; half scale tests

After each test in half scale, a very flat breakout angle was observed. For this purpose, the angle is plotted versus the burden (see figure 41 and table 24).

In the figure below, only the last three results of the half scale test series are illustrated, because in the first two tests the burden was not thrown. The third test is also not illustrated, because there were two more shots in the block, unlike the other blocks. Thus, the first 3 trials are not comparable with the last 3 trials.

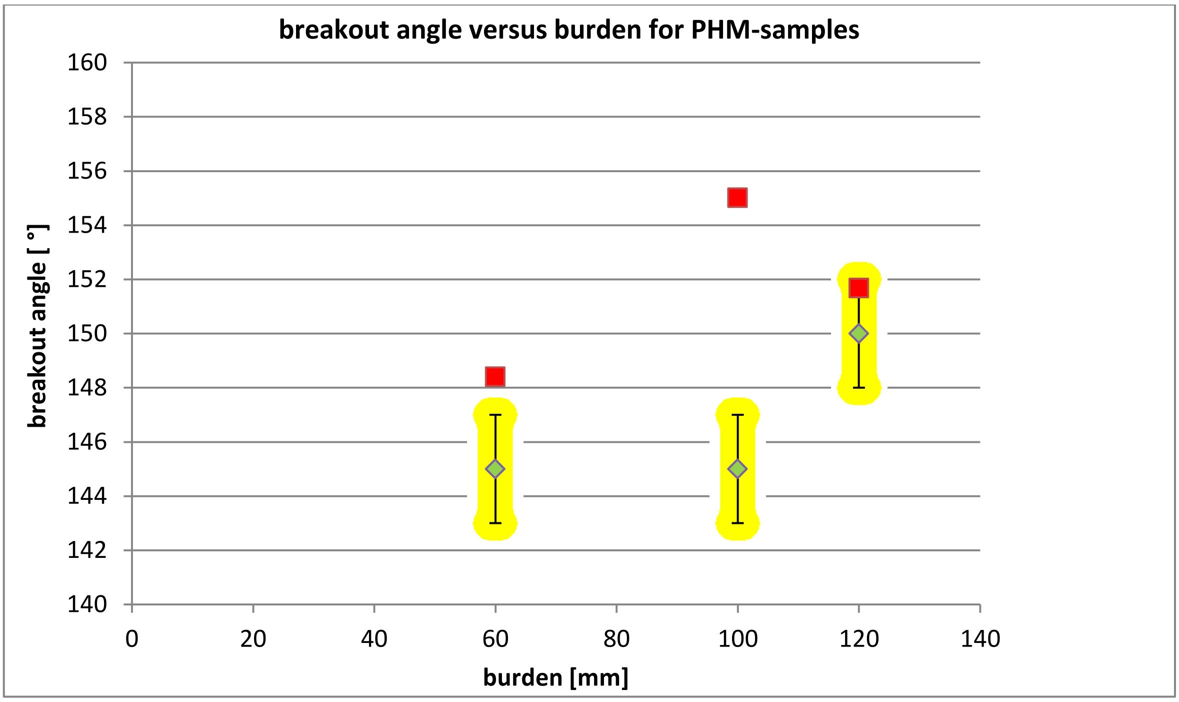


Figure 41: Breakout angle versus burden; half scale tests

If the breakout angle is known the volume can be calculated by the following equation.

$$V = H * B^2 * \tan\frac{\Theta}{2}$$

V	volume of fragmented concrete	[m³]
H	height of the block	[m]
B	burden	[m]
Θ	breakout angle (measured)	[°]

Table 21: Abbreviation, description, units of the "volume" formula

In table 24, the calculated volume and the breakout volume (determined over the collected mass), are compared.

By using the formula of the volume, an adoption of a triangular outbreak shape, the width of the breakout front and the burden, the breakout angle is calculated.

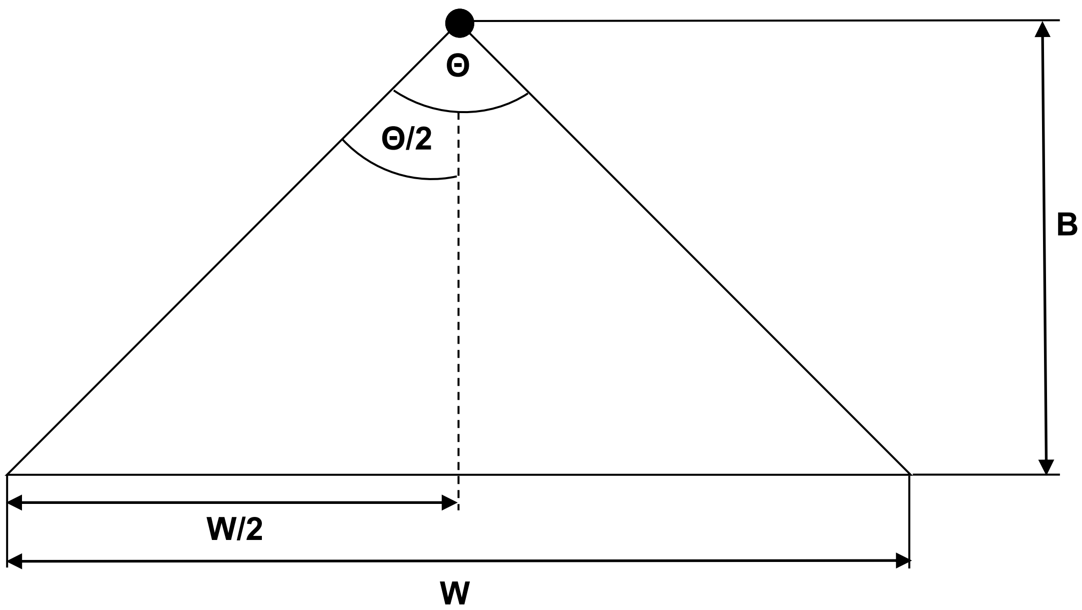


Figure 42: Breakout assumption

The assumption in the calculation was that the drill hole is in the tip of the triangle (see figure 42).

The width of the breakout front is calculated by the following equation.

$$V = \frac{m}{\rho} = \frac{W * B * H}{2}$$

$$W = \frac{2 * m}{\rho * B * H}$$

V	volume of fragmented concrete	[m³]
m	mass of fragmented conrete	[kg]
ρ	Density of concrete	[kg/m³]
B	burden	[m]
H	height of the block	[m]

Table 22: Abbreviation, description, units of the "width" formula

The breakout angle is calculated by the following equation.

$$\Theta = 2 * \arctan\left(\frac{W}{2 * B}\right)$$

Θ	breakout angle	[°]
W	width oft the breakout front	[m]
B	burden	[m]

Table 23: Abbreviation, description, units of the "breakout angle" formula

The calculated values of the breakout front and of the outbreak angle are in the table below.

		PHM-01-BL1	PHM-02-BL1	PHM-03-BL1	PHM-04-BL1	PHM-05-BL1	PHM-06-BL1
burden	[mm]	250	190	150	100	120	60
$volume_{calculate}$	[dm³]	233,25	134,73	-------	31,72	53,74	11,42
$volume_{breakout}$	[dm³]	13,25	15,74	81,88	45,12	57,08	12,72
deviation	[%]	1661	756	-------	-30	-6	-10
$weight_{calculated}$	[kg]	564,47	326,04	-------	76,75	130,05	27,63
$weight_{breakout}$	[kg]	32,06	38,10	198,14	109,19	138,12	30,79
deviation	[%]	1661	756	-------	-30	-6	-10
breakout $front_{calculated}$	[mm]	106	166	1092	902	951	424
breakout $front_{measured}$	[mm]	-------	-------	-------	985	608	508
deviation	[%]	-------	-------	-------	-8	56	-17
breakout $angle_{calculated}$	[°]	24	47	149	155	152	148
breakout $angle_{measured}$	[°]	150 ± 2	150 ± 2	-------	145 ± 2	150 ± 2	145 ± 2
deviation	[%]	-84	-69	-------	7	1	2

Table 24: Breakout angle versus burden; half scale tests

Please note:

Since the measured breakout angle was determined through drawing of the tangents, a deviation of ± 2 ° was specified.

All suggestions to chapter 6.6 were taken from [2].

7 Sieving analysis

In order to describe the fragmentation properties more effectively, the blasted material was carefully collected and subjected to a sieving analysis.

As evaluation, the particle size distribution curve, the local inclinations curve, the k_{25}, the k_{50} and the k_{75} value were calculated for each sample and displayed graphically (as example see the test sample PHM-04 in table 25 and 26 and figure 43 and 44 on the next page; all other diagrams can be found in the appendix).

	sample name:	PHM-10-1,2/1,5-04				
	feeding mass:	**109193,0**	[g]	Other:	**2,1**	[g]
	specific charge:	**785,12**	[g/t]	Loss	**173,4**	[g]
	screen size [mm]	mass [g]	mass [%]	residue [%]	passing [%]	local inclination
Department standard	125	32178,0	29,52%	29,52%	70,48%	
	100	10454,0	9,59%	39,11%	60,89%	0,655364
	80	11482,0	10,53%	49,64%	50,36%	0,851029
	63	10588,0	9,71%	59,35%	40,65%	0,896818
	50	10847,0	9,95%	69,30%	30,70%	1,214693
	40	6159,0	5,65%	74,95%	25,05%	0,911387
	31,5	4340,0	3,98%	78,93%	21,07%	0,724459
	25	3850,0	3,53%	82,46%	17,54%	0,793809
	20	2772,9	2,54%	85,01%	14,99%	0,702188
	14	4024,0	3,69%	88,70%	11,30%	0,792276
	12,5	965,5	0,89%	89,58%	10,42%	0,719958
	10	2364,9	2,17%	91,75%	8,25%	1,046347
	6,3	3295,0	3,02%	94,77%	5,23%	0,987766
	4	1886,9	1,73%	96,50%	3,50%	0,885553
	2	1763,1	1,62%	98,12%	1,88%	0,896253
	<2	2047,2	1,88%	100,00%	0,00%	
	TOTAL:	**109017,5**	100,00%			

Table 25: Calculation of PHM-04

k25	screen size [mm]	passing [%]	**k50**	screen size [mm]	passing [%]
P1	31,5	21,07%	P1	63	40,65%
P2	40	25,05%	P2	80	50,36%
Δ k	8,5		Δ k	17	
Δ D		3,98%	Δ D		9,71%
Δ T	3,93%		Δ T	9,35%	
Δ g	8,39		Δ g	16,37	
k25	39,89	25,00%	k50	79,37	50,00%

Table 26: K-value calculation of PHM-04

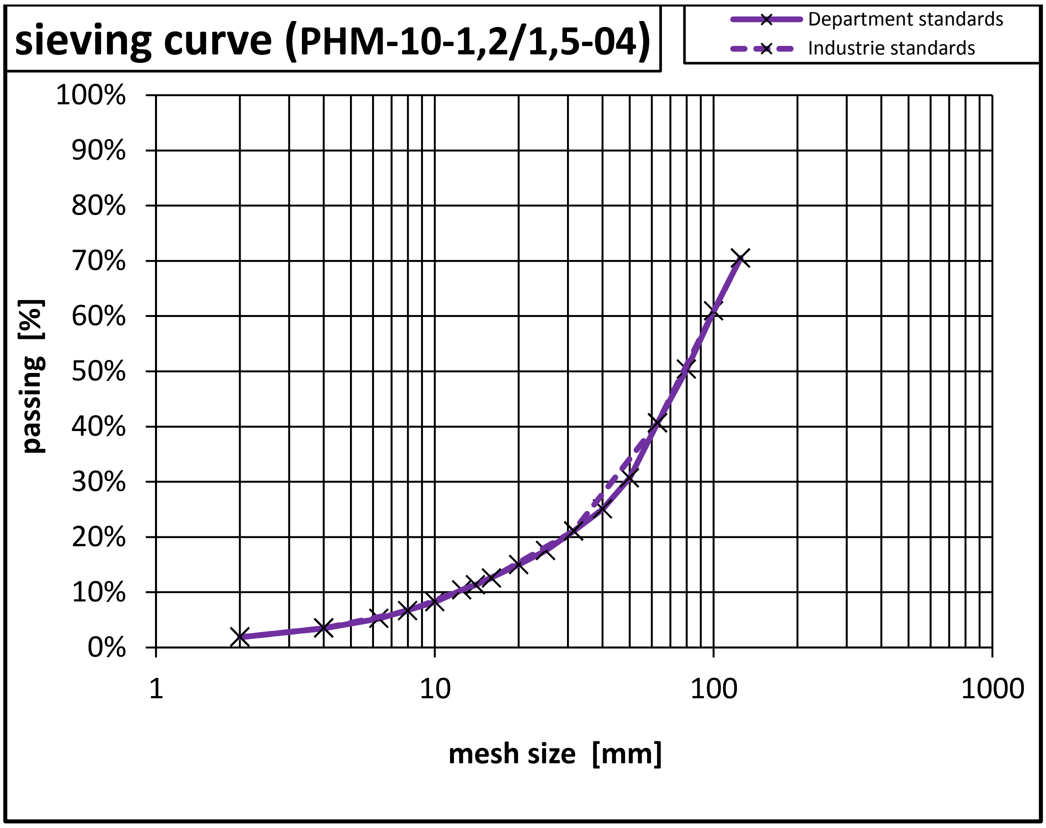


Figure 43: Sieving curve from PHM-04

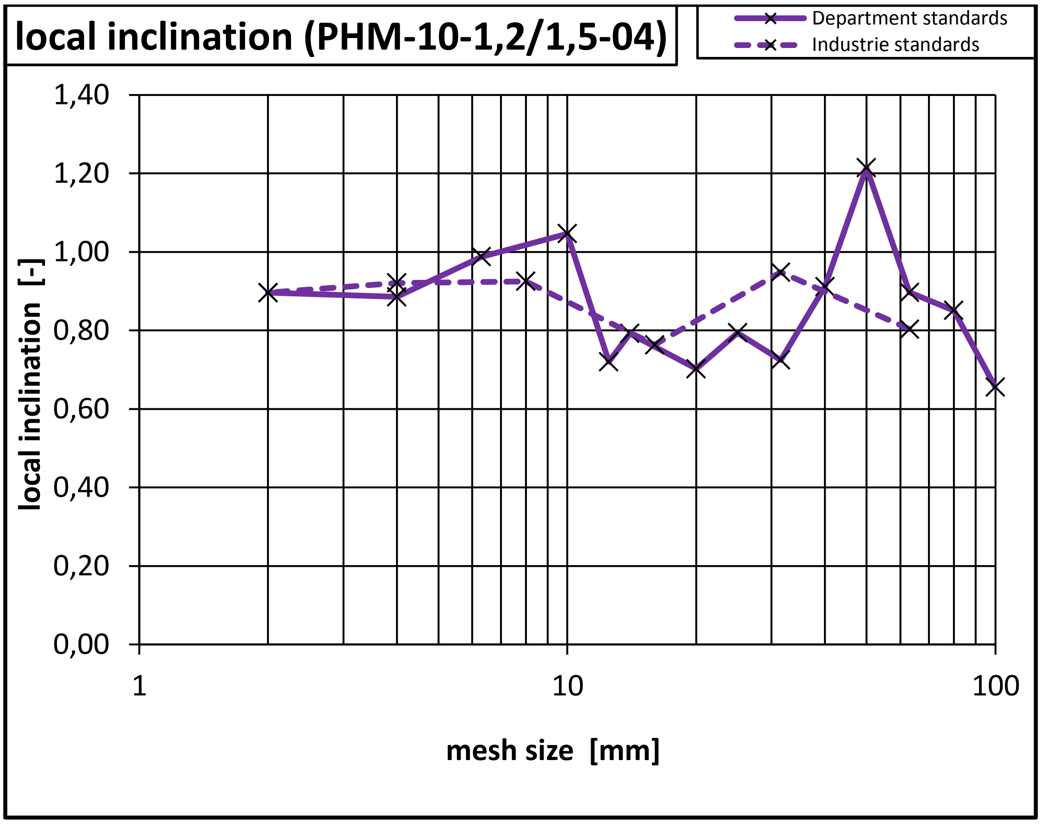


Figure 44: Local inclination from PHM-04

7.1 Sieving specification

For screening, a screening guide was published by the University of Leoben, which has been followed. Since the screening steps at the University are more accurate than the usual screening steps in the processing, both of the curves are shown in this work. The screening step of the University of Leoben is declared in this work as "Department standard" (see table 27) and the usual screening step is declared as the "Industry standard" (see table 28).

When sieving the large mesh sizes (> 125 mm to 10 mm) each piece of the blasted material was sampled by hand through the mesh.

Department standard	>125	mm
	100	mm
	80	mm
	63	mm
	50	mm
	40	mm
	31,5	mm
	25	mm
	20	mm
	14	mm
	12,5	mm
	10	mm
	6,3	mm
	4	mm
	2	mm
	1	mm
	0,5	mm
	0,25	mm
	0,125	mm
	0,1	mm
	0,063	mm
	<0,063	mm

Table 27: Sieving steps of the department

All screening steps with the mesh sizes from 10 mm down to 0.063 mm were screened by hand. The reason for this was the breaking of the aggregates from the concrete pieces which did not allow to use an automatic sieving tower.

Industry standard	>125	mm
	63	mm
	31,5	mm
	16	mm
	8	mm
	4	mm
	2	mm
	1	mm
	0,5	mm
	0,25	mm
	0,125	mm
	0,063	mm
	<0,063	mm

Table 28: Sieving steps of the industry

When it was noticed, that the aggregates would break, the sieving process was stopped.

Some samples were split before the next screening step, if enough material was available. There is a rule that states that the optimal feeding in gram corresponds to the mesh size in microns.

It should be noted that the samples in the half scale tests were only sieved down to a mesh size of two millimeters. One reason for this was the dirt and the dust at the Erzberg mine. Another reason is the filling material sand, which has a particle size of two millimeters.

7.2 Calculation of particle size distribution

For the graphical analysis the GGS distribution (Gates-Gaudin-Schuhmann) was selected.

The passing is calculated as follows:

$$D = 100 * (\frac{k}{k_{max}})^n$$

D	passing	[%]
k	particle size	[mm]
k_{max}	maximum particle size	[mm]
n	GGS exponent	[-]

Table 29: Abbreviation, description, units of the "passing" formula

The GGS exponent is calculated as follows:

$$n = \frac{\log(\frac{D_o}{D_u})}{\log(\frac{k_o}{k_u})}$$

D_o	passing value; upper grain class	[%]
D_u	passing value; lower grain class	[%]
k_o	particle size; upper grain class	[mm]
k_u	particle size; lower grain class	[mm]
n	GGS exponent	[-]

Table 30: Abbreviation, description, units of the "GGS exponent" formula

The graphical difference in the cumulative curve between the "Department standard" and the "Industry standard" is relatively low (see figure below).

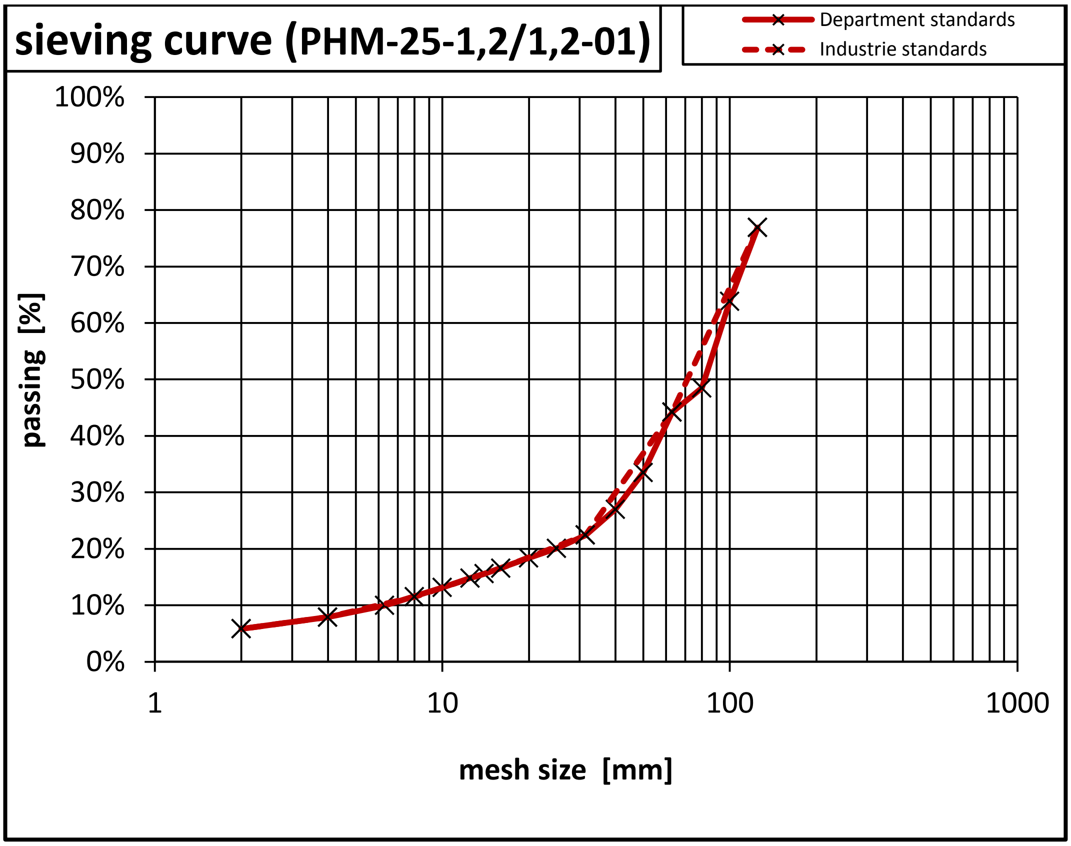


Figure 45: Sieving curve calculated; PHM-01

7.3 Calculation of the local inclination

Another point was the calculation and the illustration of the local inclination (see figure 46) and the conversion of the screening results from the "Department standard" to the "Industry standard" by determining the GGS components. The calculation was performed, as it has been done by Grasedieck A. in his doctoral thesis [3].

Calculation of n:

$$n = \frac{\log(\frac{D_o}{D_u})}{\log(\frac{k_o}{k_u})}$$

Interpolation calculation:

$$D_o = \frac{D_u}{(\frac{k_u}{k_o})^n}$$

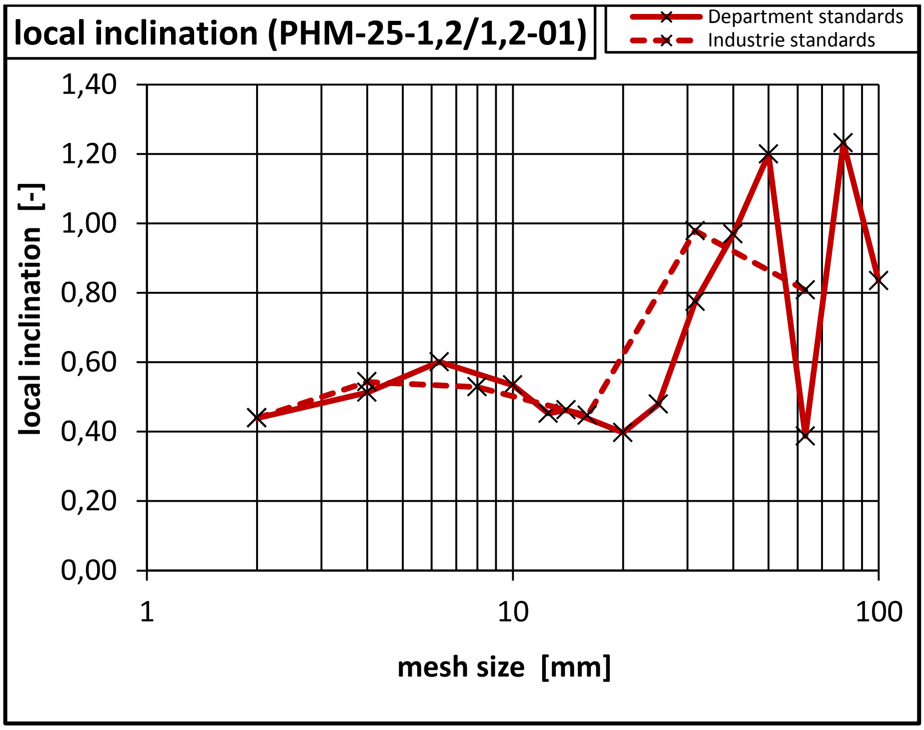


Figure 46: Local inclination calculated; PHM-01

Important note: The respective n-value in the entire work always refers to the lower k-value.

Here the calculation steps explained step by step:

sample name:	PHM-25-1,2/1,2-01				
feeding mass:	32062,9	[g]	Other:	2	[g]
spezific charge:	125,62	[g/t]	Loss	78,8	[g]
screen size [mm]	mass [g]	mass [%]	residue [%]	passing [%]	local inclination
125	7388,0	23,10%	23,10%	76,90%	
100	4180,0	13,07%	36,17%	63,83%	0,834802
80	4906,0	15,34%	51,51%	48,49%	1,231778
63	1370,6	4,29%	55,80%	44,20%	0,387337
50	3423,0	10,70%	66,50%	33,50%	1,199562
40	2083,2	6,51%	73,01%	26,99%	0,968896
31,5	1458,0	4,56%	77,57%	22,43%	0,774532
25	751,4	2,35%	79,92%	20,08%	0,478780
20	544,8	1,70%	81,62%	18,38%	0,397280
14	893,8	2,79%	84,42%	15,58%	0,462525
12,5	249,3	0,78%	85,20%	14,80%	0,452858
10	531,9	1,66%	86,86%	13,14%	0,534123
6,3	1018,8	3,19%	90,05%	9,95%	0,600963
4	661,8	2,07%	92,12%	7,88%	0,513069
2	661,8	2,07%	94,19%	5,81%	0,439212
<2	1859,7	5,81%	100,00%	0,00%	
TOTAL	31982,1	100,00%			

(Rows 125 to <2: Department standard)

$$n = \frac{\log(\frac{D_o}{D_u})}{\log(\frac{k_o}{k_u})} = \frac{\log(\frac{48,49}{44,20})}{\log(\frac{80}{63})} = 0,387337$$

$$D_o = \frac{D_u}{(\frac{k_u}{k_o})^n} = \frac{15,58}{(\frac{14}{16})^{0,462525}} = 16,57$$

Industry standard:

screen size [mm]	passing [%]	local inclination
125	76,90%	
63	44,20%	0,808074571
31,5	22,43%	0,978818151
16	16,57%	0,446578653
8	11,49%	0,528560848
4	7,88%	0,543361543
2	5,81%	0,439212315

Table 31: Calculation of "n" and "Interpolation"

7.4 Calculation of the k values

More specifically, the k-values at 25 %, 50 % and 75 % of the passing, for the test series in half scale and laboratory scale, were calculated. For this calculation, a linear inerpolation was performed to calculate the required values.

$$k_{50} = k_u + \frac{k_o - k_u}{D_o - D_u} * (D_{50\%} - D_u)$$

With this formula, the k_{25}, and the k_{75} value can be calculated in the same way.

k_u	particle size over 50 %	[mm]
k_o	particle size under 50 %	[mm]
D_o	passing over 50 %	[%]
D_u	passing under 50 %	[%]
$D_{50\%}$	passing = 50 %	[%]

Table 32: Abbreviation, description, units of the "k_{50}" formula

		WLM-20-01	WLM-20-03	WLM-30-01	WLM-30-02	WLM-30-03	WLM-30-04	WLM-40-01	WLM-40-02	WLM-40-03
k_25	[mm]	10,52	12,11	49,01	9,41	40,68	41,13	-------	26,24	-------
k_50	[mm]	21,77	22,94	93,74	18,96	71,17	91,45	-------	52,35	-------
k_75	[mm]	37,97	36,27	123,57	39,73	105,01	116,94	-------	76,15	-------
spec. charge	g/t]	199,26	207,91	91,69	251,64	91,27	90,99	55,35	141,38	51,21

Table 33: K-values at laboratory scale

		PHM-01-BL1	PHM-02-BL1	PHM-03-BL1	PHM-03-BL2	PHM-03-BL3	PHM-04-BL1	PHM-05-BL1	PHM-06-BL1
k_25	[mm]	36,29	32,10	-------	9,56	9,70	39,89	18,90	5,08
k_50	[mm]	81,97	71,13	-------	27,35	38,06	79,37	59,29	13,67
k_75	[mm]	121,37	107,01	-------	72,37	-------	-------	105,40	76,38
spec. charge	[g/t]	592,59	498,70	95,89	661,42	614,14	174,00	275,12	1234,37

Table 34: K-values at half scale

8 Presentation of the results

For the aggregates, the task was to check whether the specified range of grain sizes is correct. It could be seen that in each grain class oversized grain material was present. For results see figure 49 and figure 50.

The result of the laboratory scale tests was a particle size distribution curve and a local inclination curve. At the WLM samples, three different sizes of cubes were blasted and only the amount of explosives should be changed. Thus, the amount of explosives should be the crucial parameter for the crushing behavior. For results see figure 50 and figure 51.

The tests in half scale showed that three parameters are responsible for the crushing behavior. The amount of explosive, the burden and the spacing. Except for test sample PHM-03, no more than one hole was blasted in the same sample. The result of the half scale tests was a particle size distribution curve and a local inclination curve. Also a graphical analysis was carried out. Furthermore the influence of geometric relationships was discussed. For results see figure 52 and figure 53.

8.1 Aggregate results

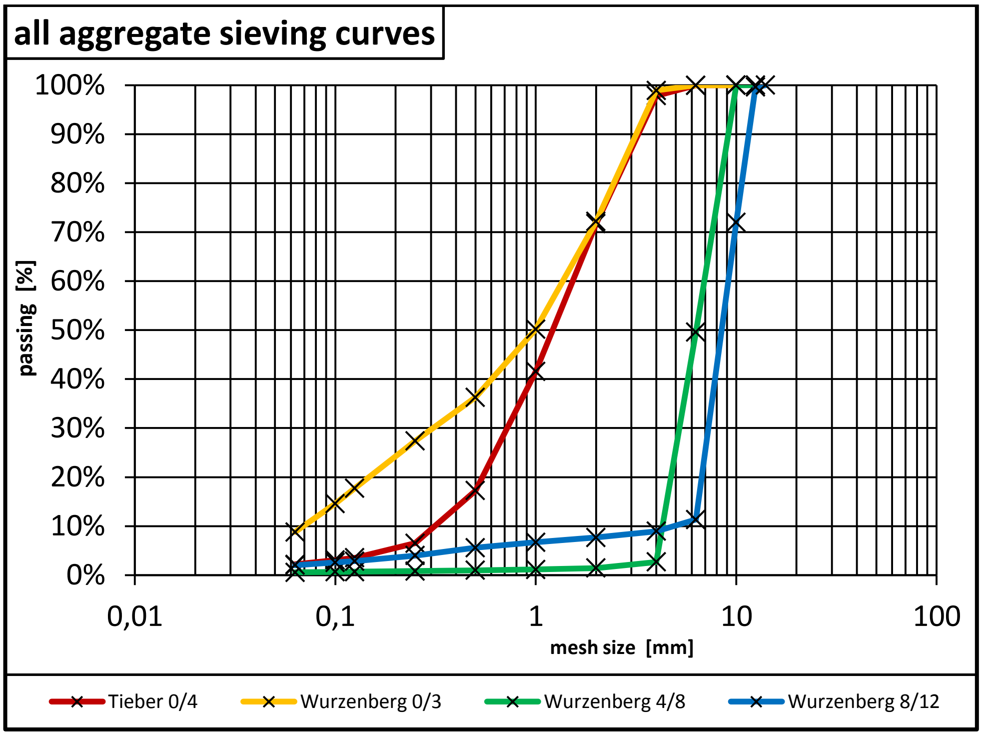


Figure 47: All aggregate sieving curves

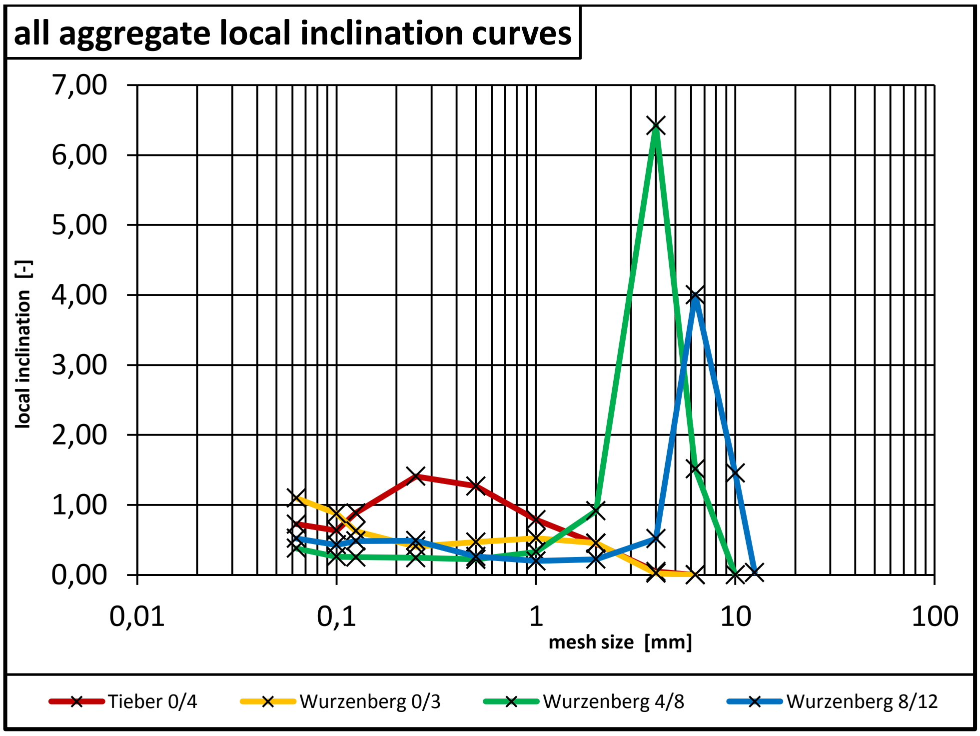


Figure 48: All aggregate local inclination curves

8.2 Laboratory scale results

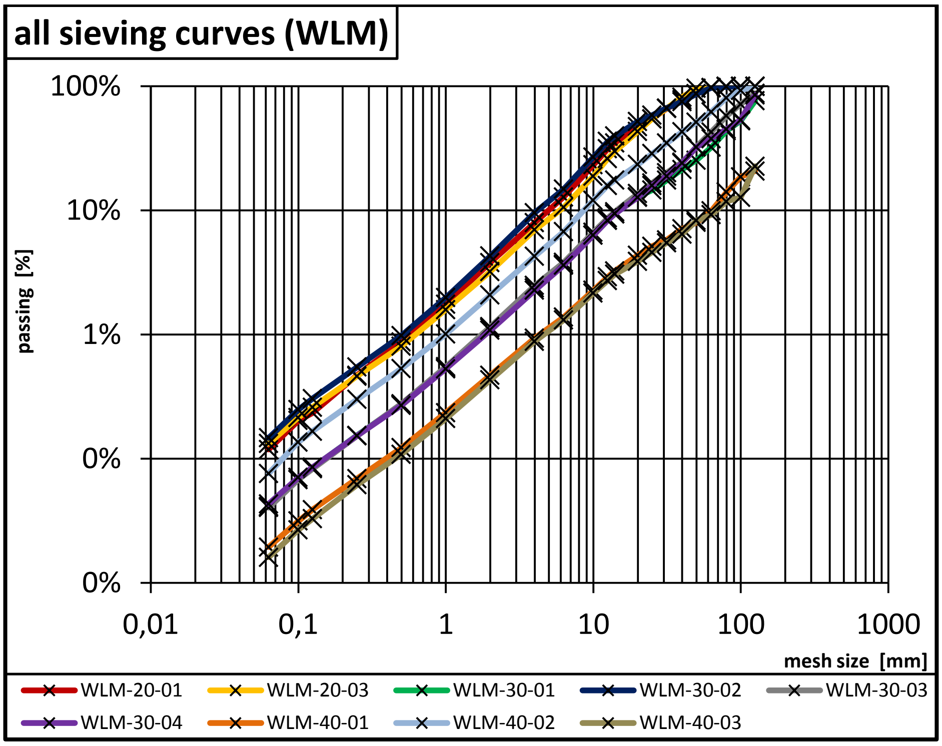


Figure 49: All WLM sieving curves

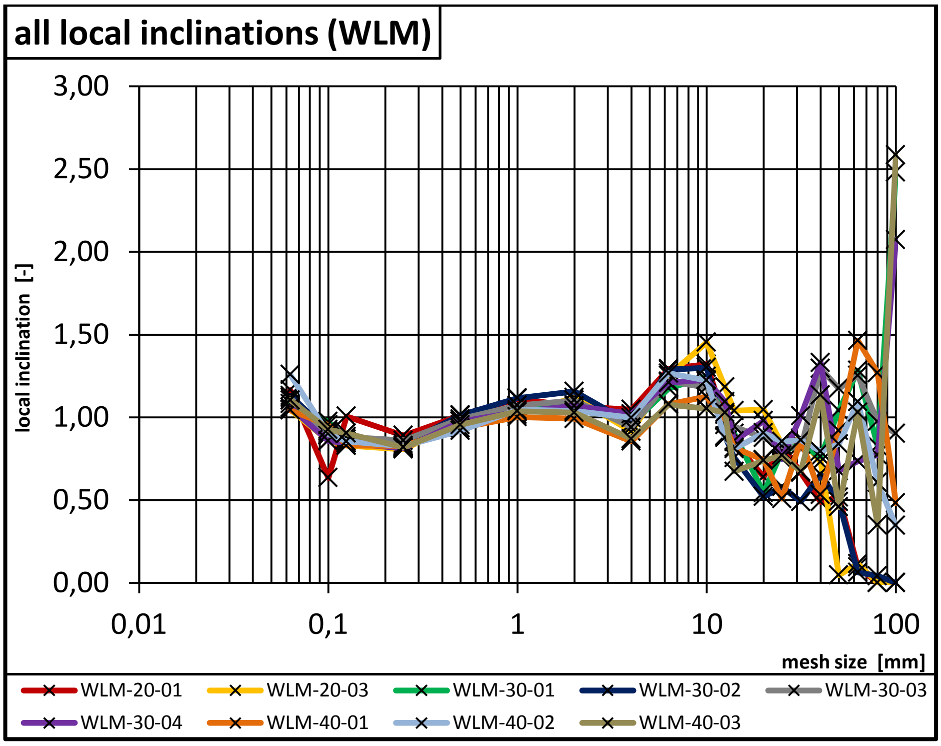


Figure 50: All WLM local inclinations curves

8.3 Half scale results

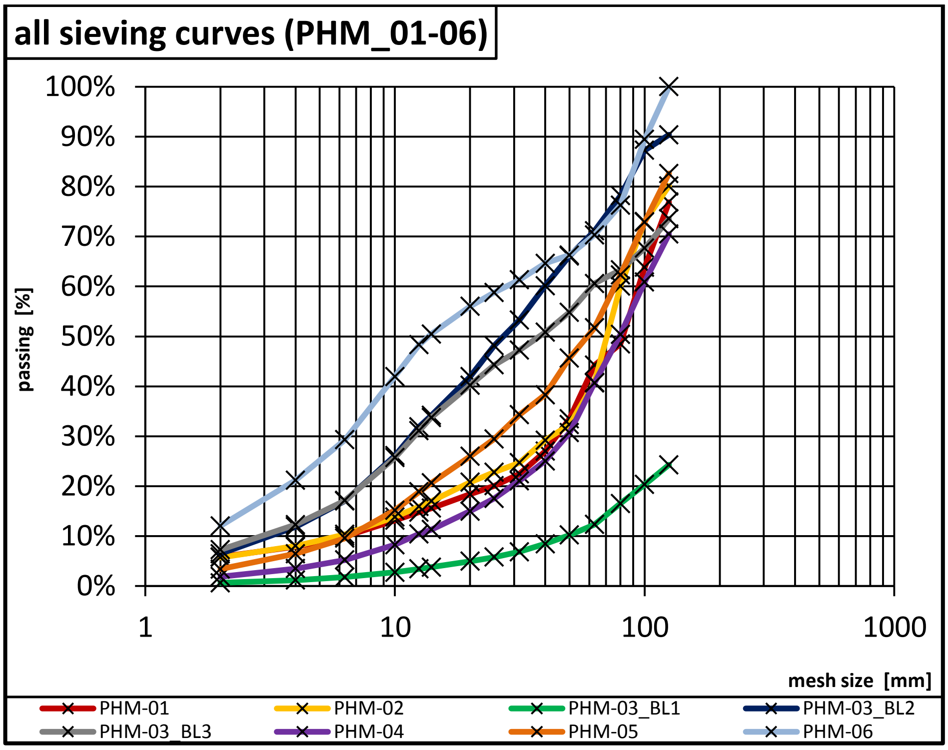


Figure 51: All PHM sieving curves

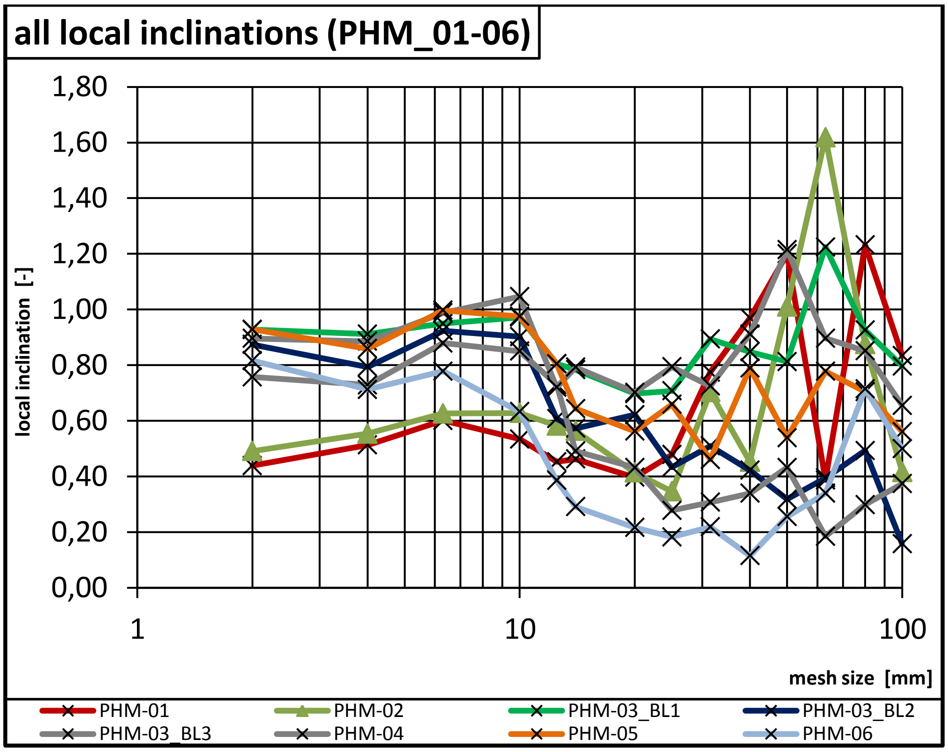


Figure 52: All PHM local inclinations curves

9 Discussion of the results

9.1 The aggregate results

The aggregates had a little oversized grain in the individual grain classes. In general, it was noted that the aggregates in this test series were much bigger than at the last blasting tests that were performed by Grasedieck A. [3].

It should also be noted, that during the screening process, the individual grains were separated from the matrix. This separation is probably due to the high explosion pressure, in which these micro-cracks were formed.

9.2 The WLM results

At the laboratory scale it is clear that by increasing the amount of explosive, the grading curve moves up. This is because in fact only one parameter has been changed, and this is the specific amount of explosive.

9.3 The PHM results

At the test experiments in the half scale, three drill holes should be blasted per block, but due to the flat breakout angle, this was, except for PHM-03, not possible. Furthermore the problem with the clamping device and the backfill material is not fully known yet, because the blasting reflections are not precisely known. It was also noticed that, when the concrete block was pushed back too much with the clamping device, the blasting cracks were significantly affected. For a more detailed analysis, the breakout angle and the number of cracks were identified for each block and documented.

10 Conclusions

The aggregates of the concrete that were used in all these test trials had in each grain class a little oversize, but the manufacturer's specifications were generally correct.

At the tests on a laboratory scale and for all other test series, which were done before, the statement is true, that if the energy input becomes greater, the fragmentation gets finer.

At the tests in half scale six attempts were made. The distribution curves on the half scale tests were not very meaningful, because there was a big difference between the expected breakout volume and the actual breakout volume. There were also big differences in the breakout angle and in the breakout front. Also the phenomenon of a flat angle was observed. This is perhaps due to the fact that only one single drill hole was blasted. So the main focus was placed on a graphical analysis and the construction of the blasting site itself. For the graphical analysis the k-value, 1/q and the breakout angle were plotted against the burden and the breackout angle and the breakout front was back calculated with the actual values.

It may be noted, that no calculations of the existing reflections were made.

It also raises the question whether the correct backfill material was used. Instead of the existing fill material concrete could be used for the backfill.

Due to the high cost of the 2 m concrete blocks, smaller and cheaper concrete blocks could be used for further tests. Also a uniform photographic documentation should be made.

11 Bibliography

[1] Miklautsch A.: Experimental investigation of the blast fragmentation behavior of rocks and concrete, Diplomarbeit, University of Leoben, Chair of Mining Engineering and Mineral Economics, 2002

[2] Dr. Agne Rustan, Sen. Lecturer V.S. Vutukuri, Msc Torbjörn Naarttijärvi: First International Symposium on ROCK FRAGMENTATION BY BLASTING, Luleå, Sweden, August, 1983
The influence from specific charge, geometric scale and physical properties of homogenous rock on fragmentation.

[3] Grasedieck A.: Die natürliche Bruchcharakteristik (NBC) von Gesteinen in der Sprengtechnik, Dissertation, University of Leoben, Chair of Mining Engineering and Mineral Economics, 2006

12 List of figures

13 List of tables

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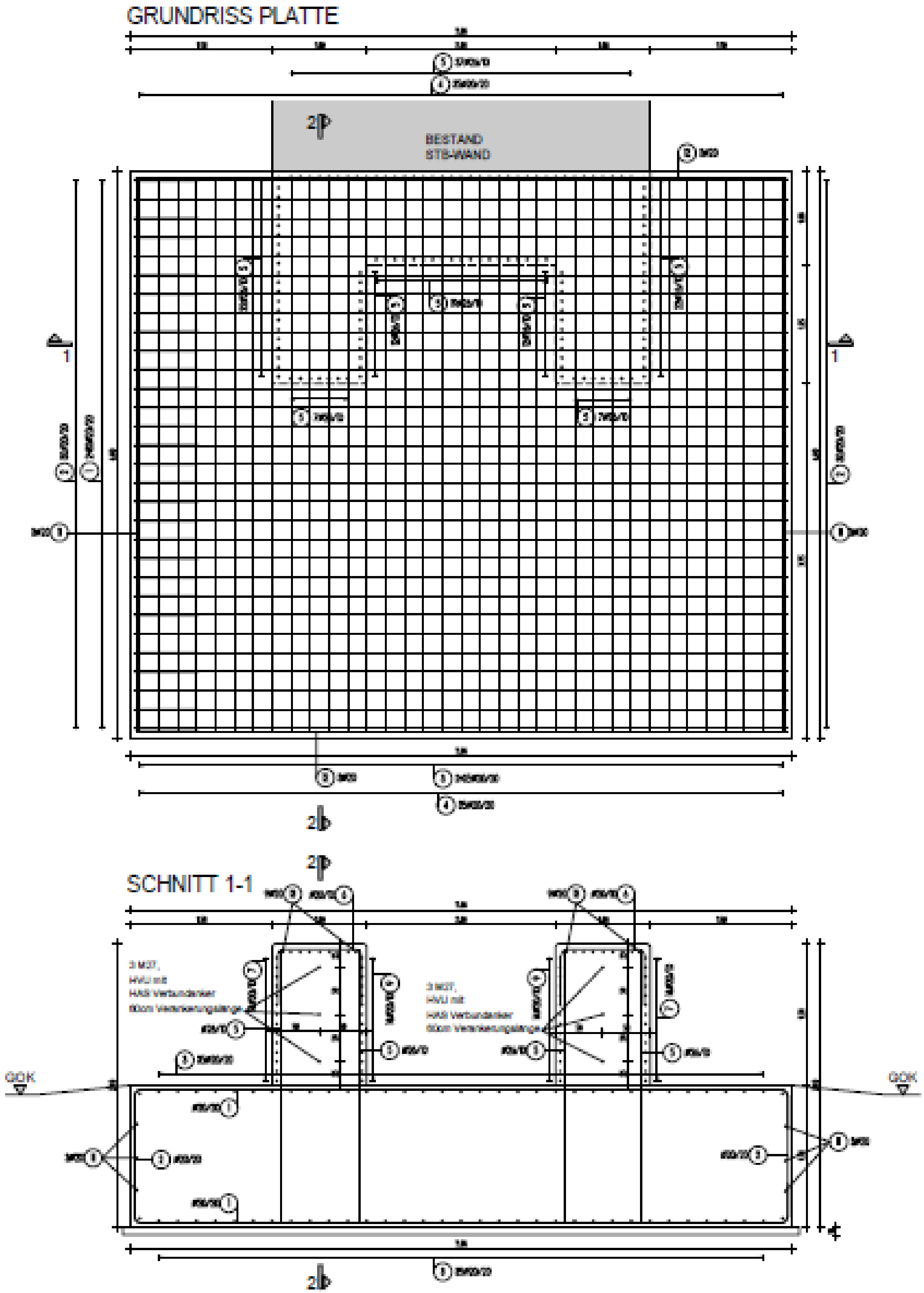
Annex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STB-WAND
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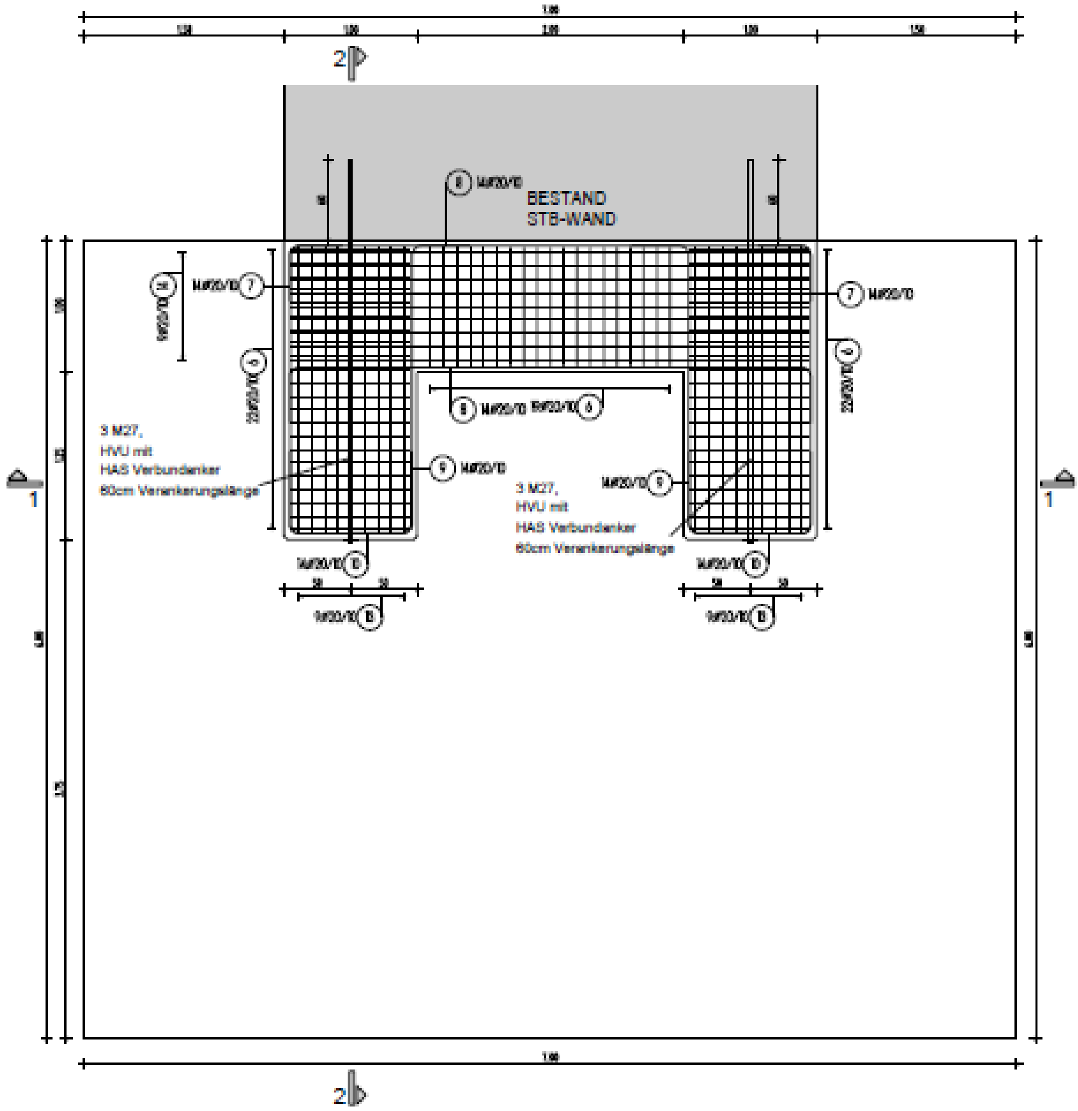
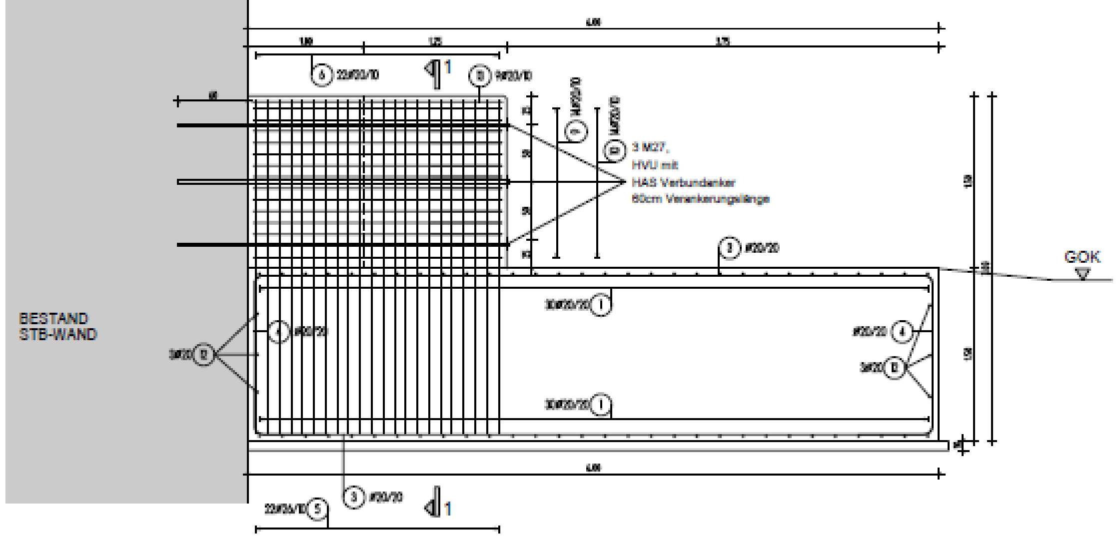
HAS Verbundanker
60cm Verankerungslänge
GOK
GOK

DRAUFSICHT



SCHNITT 2-2



Stabliste - Biegeformen

Pos.	Stck	ø [mm]	Einzel Länge [m]	Bemaßte Biegeform (unmaßstäblich)	Gesamt Länge [m]	Masse [kg]
1	60	20	7.80		468.00	1155.96
2	60	20	2.80		168.00	414.96
3	70	20	6.70		469.00	1158.43
4	70	20	2.70		189.00	466.83
5	138	26	2.90		400.20	1668.83
6	63	20	2.10		132.30	326.78
7	28	20	3.00		84.00	207.48
8	28	20	4.80		134.40	331.97
9	27	20	3.09		83.43	206.07
10	28	20	2.20		61.60	152.15
11	6	20	5.90		35.40	87.44
12	6	20	6.90		41.40	102.26
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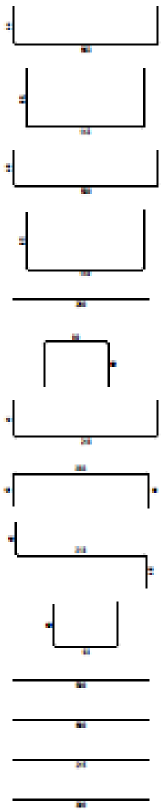
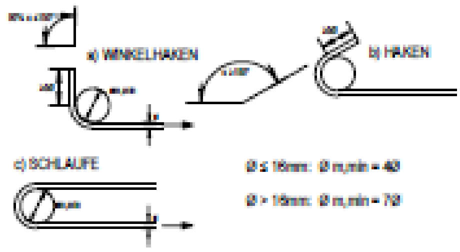
14	9	20	3.90		35.10	86.70



Gesamtmasse [kg] : 6461.45

BIEGEANWEISUNG LAUT EUROCODE 2

WINKELHAKEN, HAKEN, SCHLAUFEN, BÜGEL



KRÜMMUNGEN VON SCHRÄGSTÄBEN UND ANDEREN STÄBEN

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C 20/25	33Ø	25Ø	22Ø	20Ø	20Ø
C 25/30	28Ø	20Ø	20Ø	20Ø	20Ø
C 30/37	22Ø	20Ø	20Ø	20Ø	20Ø
C 35/45	20Ø	20Ø	20Ø	20Ø	20Ø
und höher	20Ø	20Ø	20Ø	20Ø	20Ø

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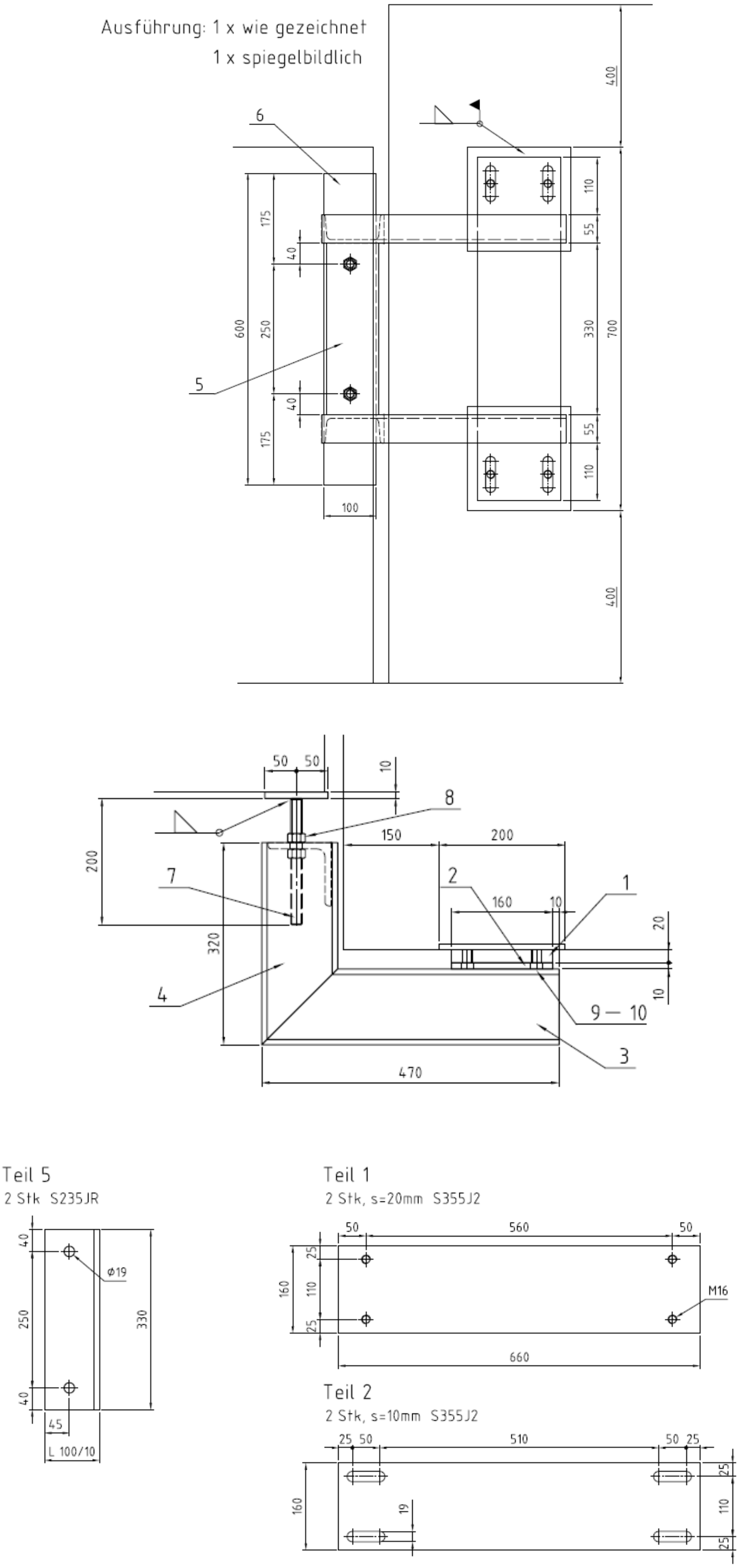
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7
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320
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9 — 10
10
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470
Teil 5
2 Stk S235JR
40
ϕ19
250
330
40
45
L 100/10
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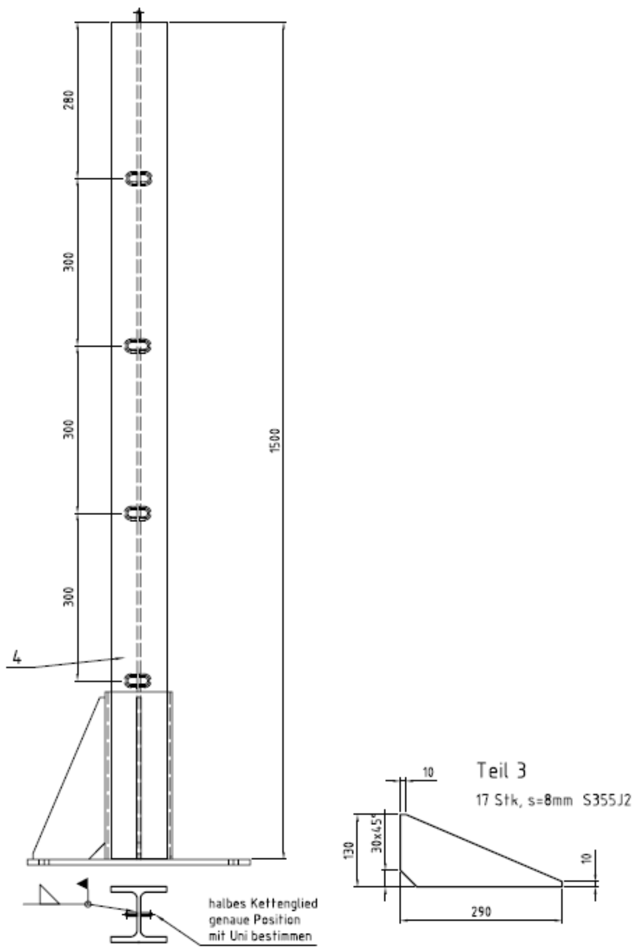
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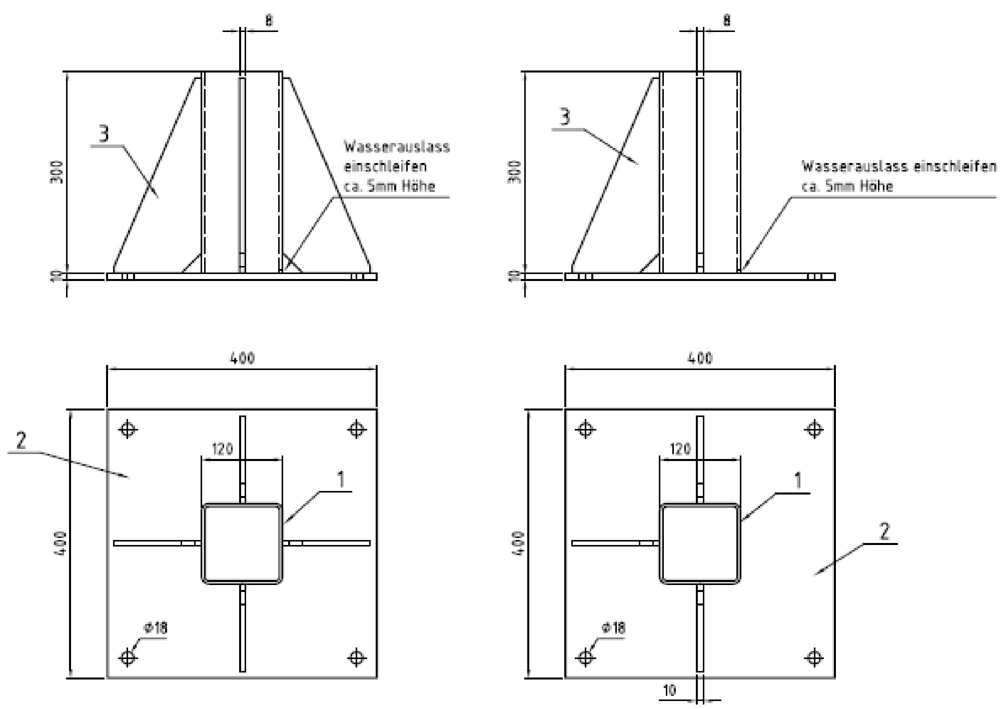
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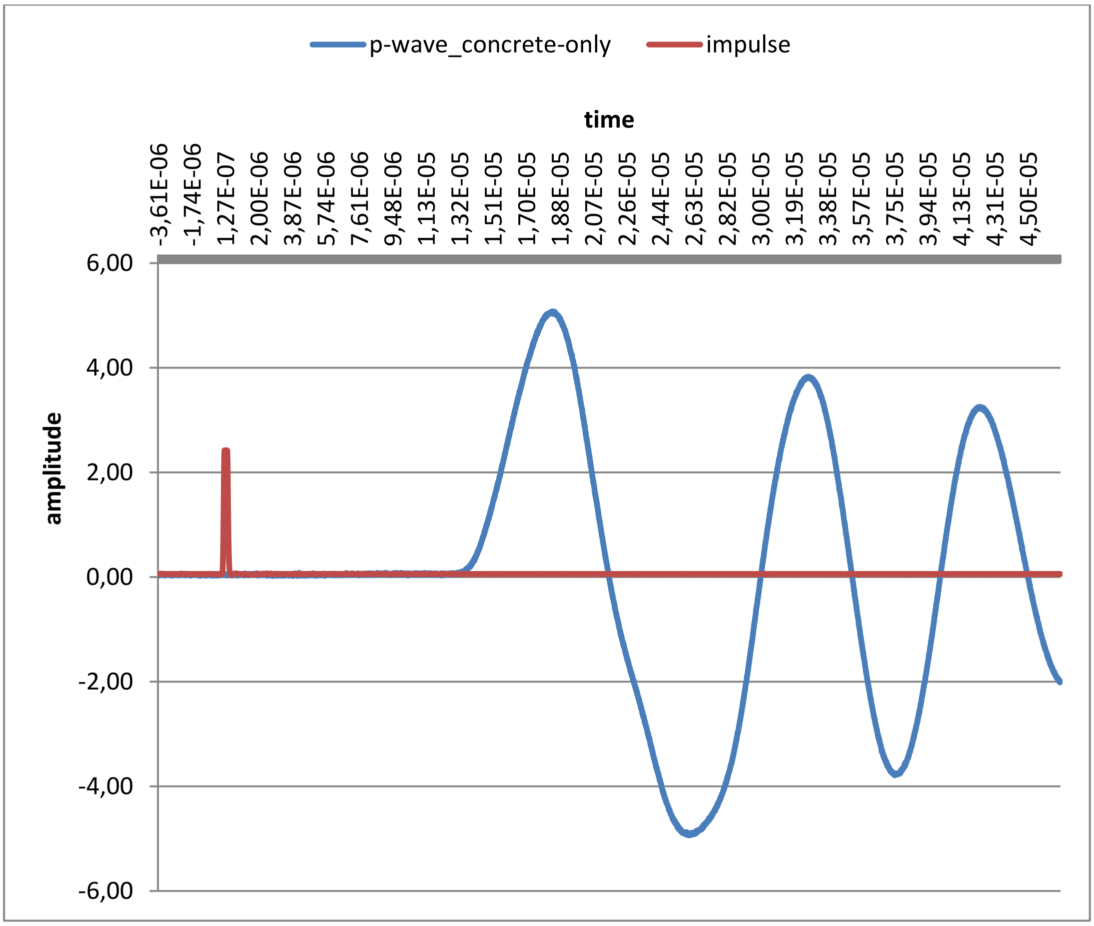
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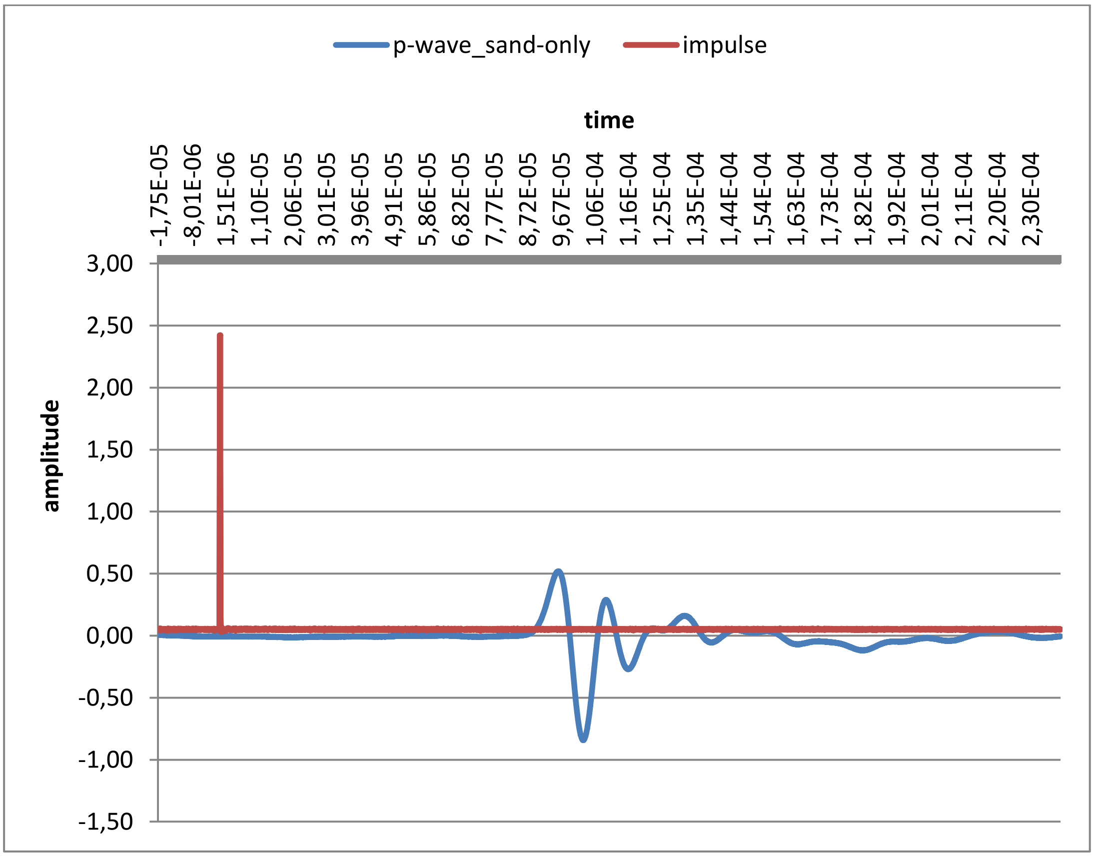
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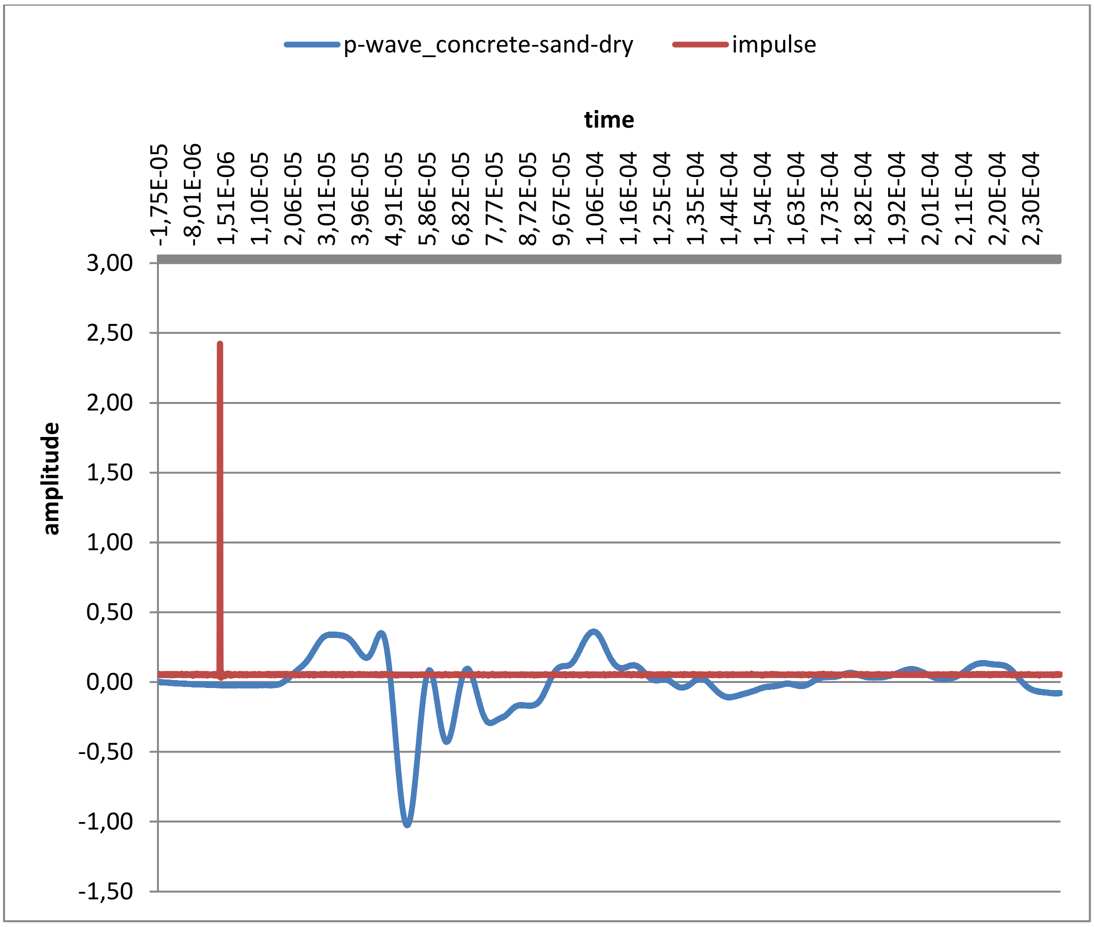
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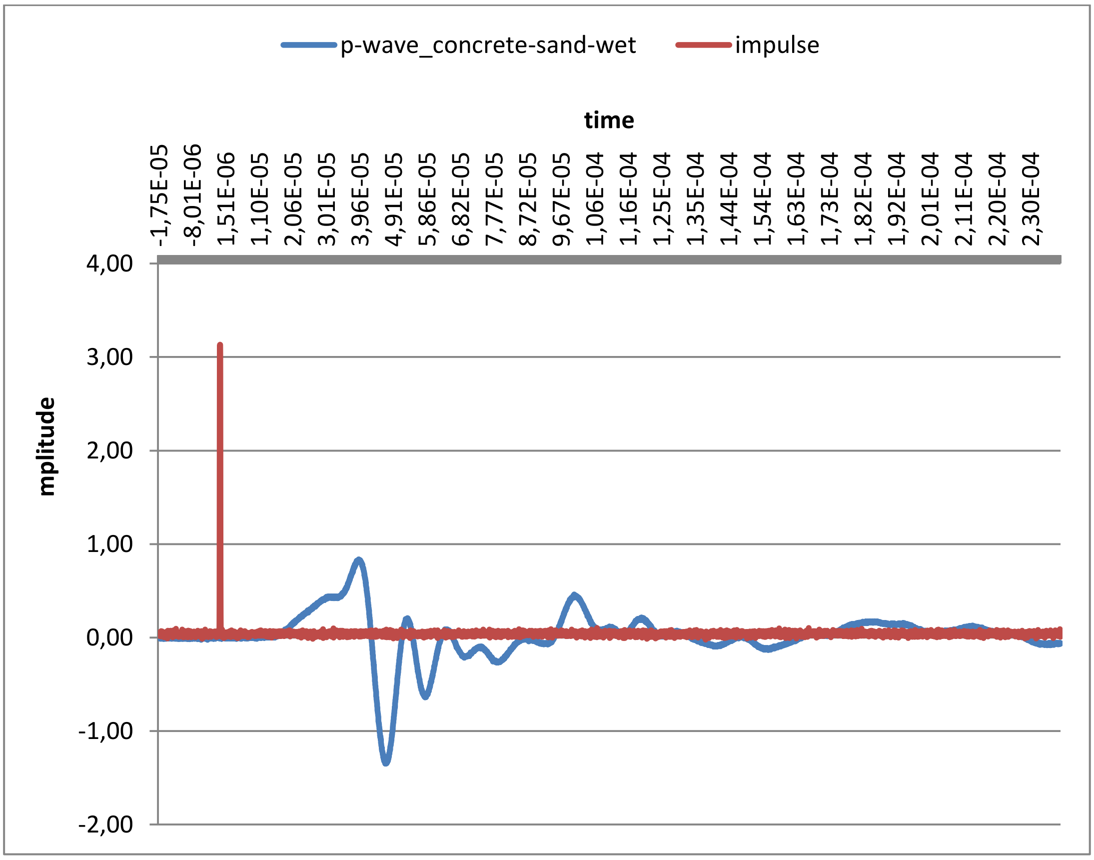
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	form:	granular	
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	> 125	0,00	100,00%
	125/100	0,00	100,00%
	100/80	0,00	100,00%
	80/63	0,00	100,00%
	63/50	0,00	100,00%
	50/40	0,00	100,00%
	40/31,5	0,00	100,00%
	31,5/25	0,00	100,00%
	25/20	0,00	100,00%
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	14/12,5	0,00	100,00%
	12,5/10	0,00	100,00%
	10/6,3	0,70	99,98%
	6,3/4	79,80	97,87%
	4/2	986,94	71,73%
	2/1	1139,30	41,55%
	1/0,5	917,88	17,24%
	0,5/0.25	405,39	6,50%
	0,25/0,125	112,56	3,52%
	0,125/0,1	17,56	3,05%
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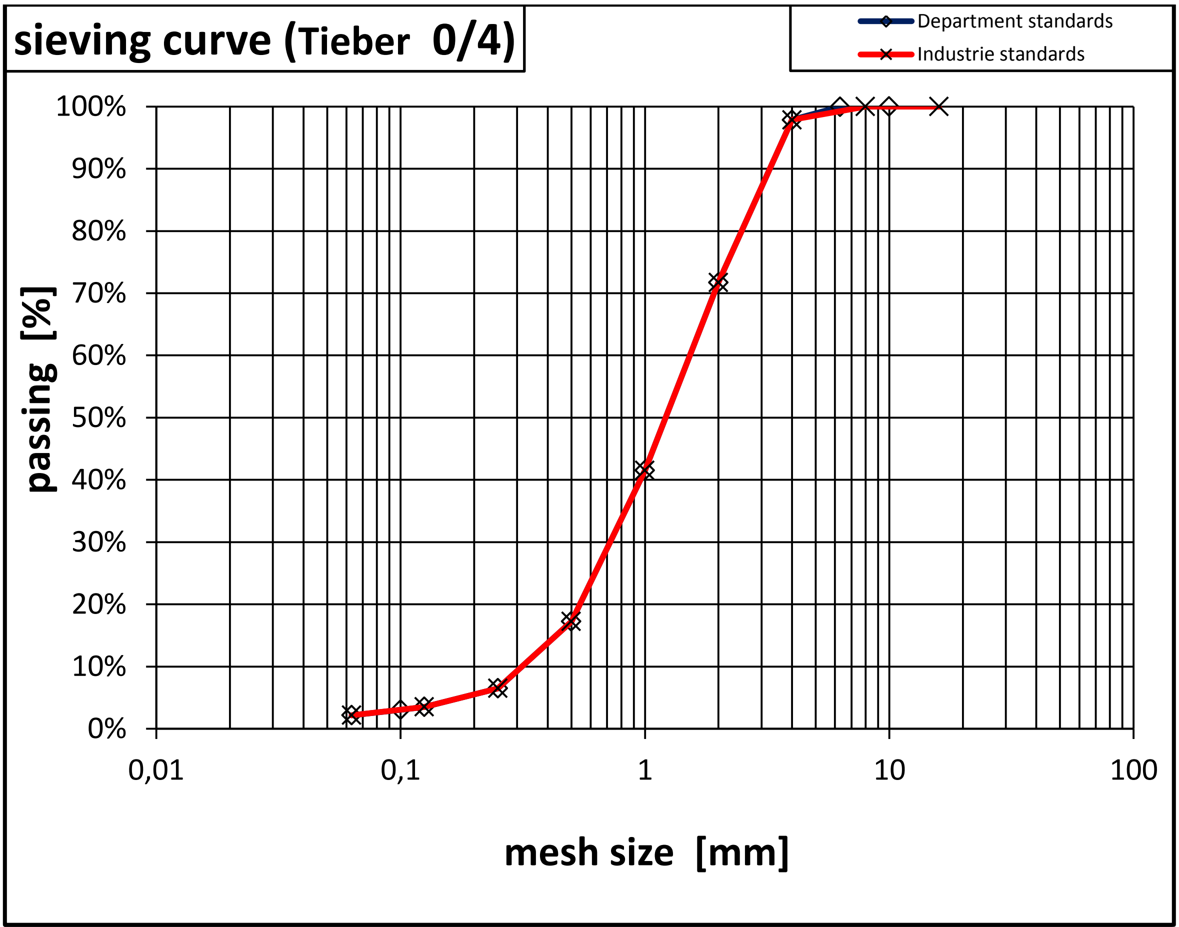
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Industrie standards
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80%
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60%
50%
40%
30%
20%
10%
0%
passing [%]
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0,1
1
10
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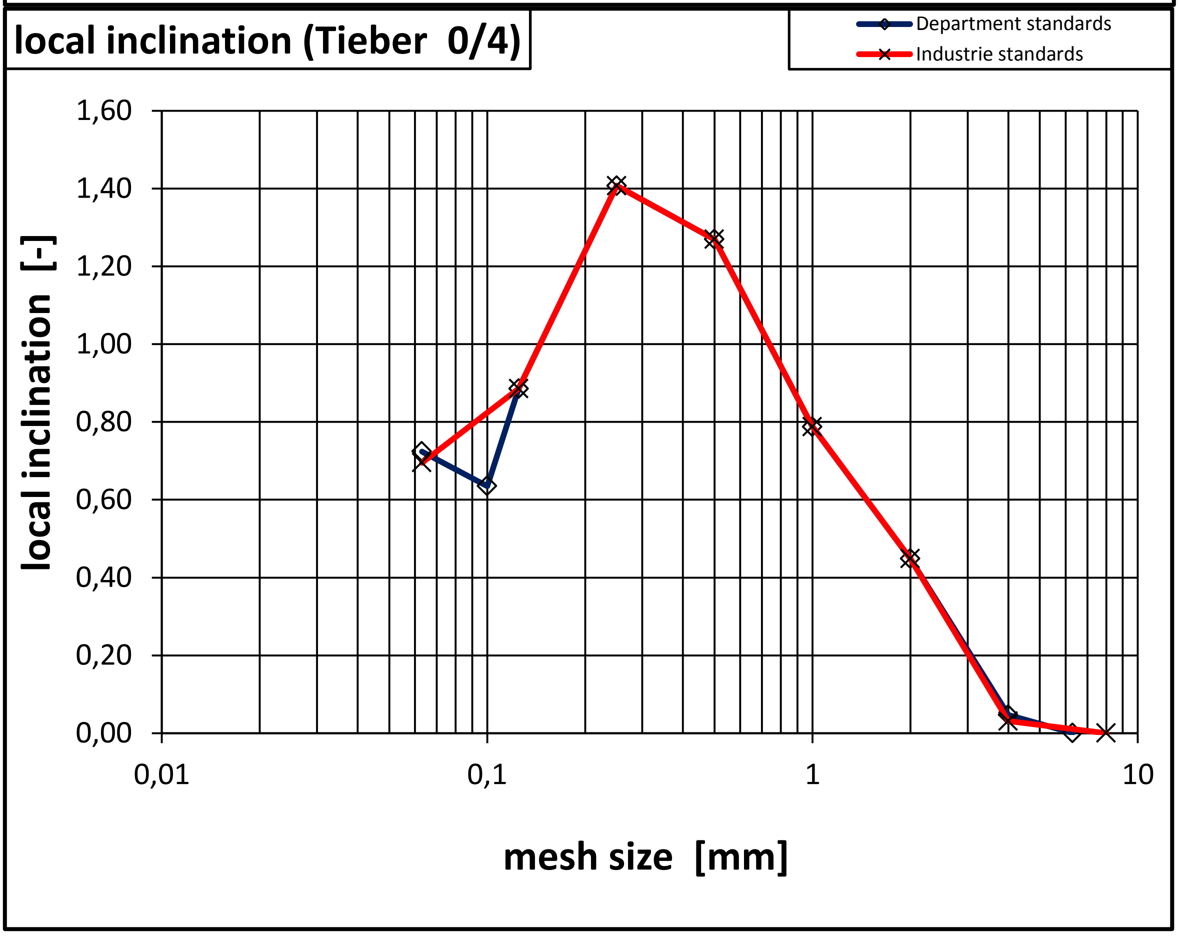
mesh size [mm]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Department standards
Industrie standards
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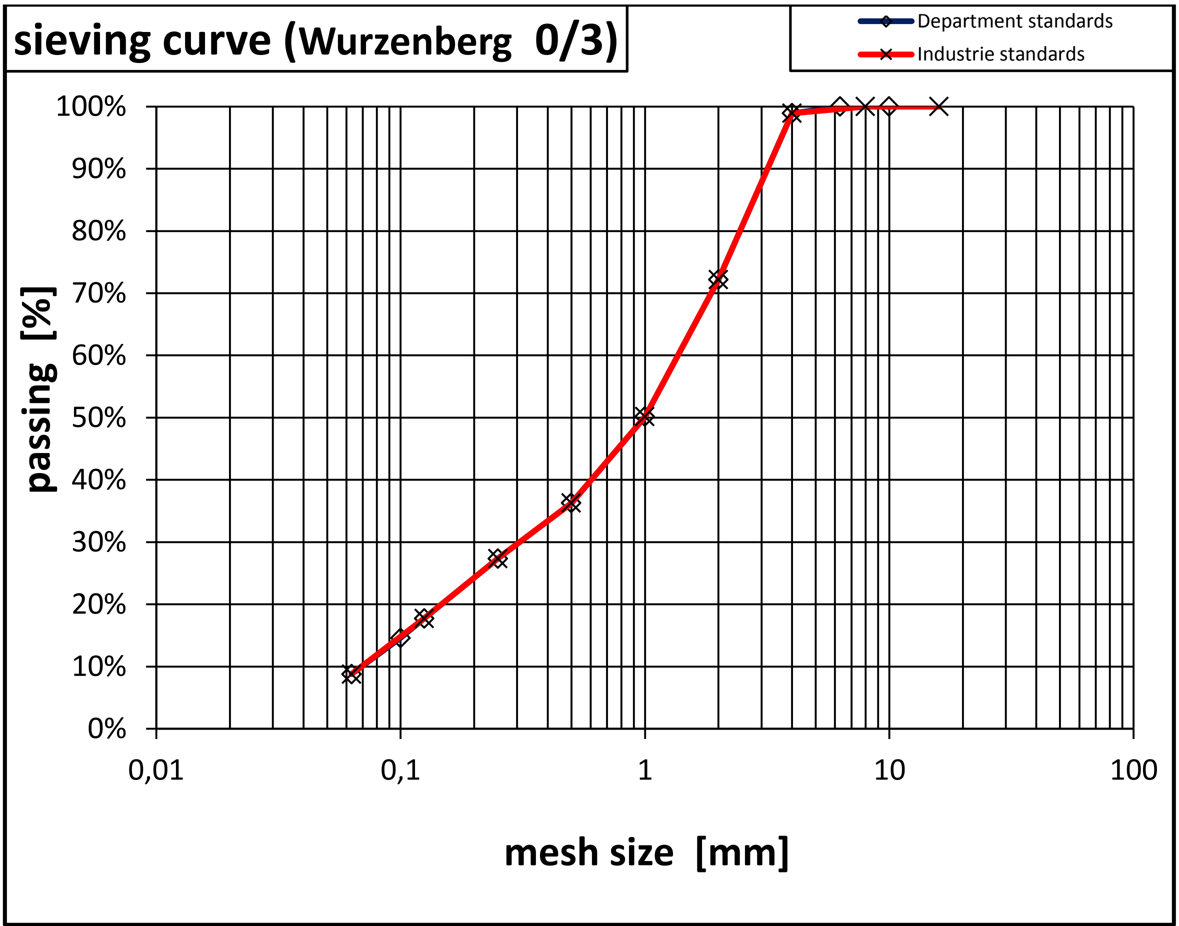
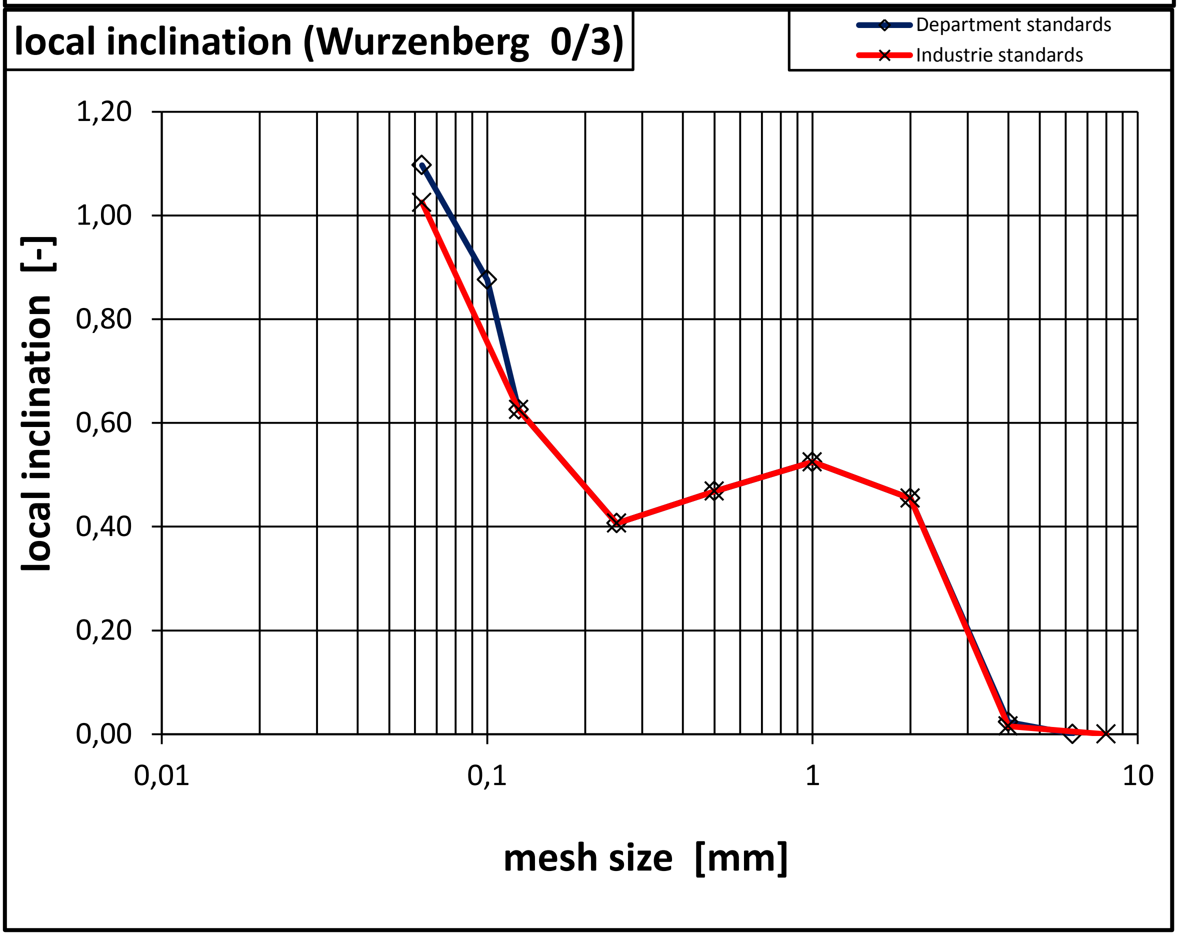
10
mesh size [mm]

SAMPLE	sample Nr.:	**Wurzenberg 0/3**	
	sieving date:	03.08.2010	
	material:	concrete aggregate	
	form:	granular	
SCREENING	feeding mass	6150,90	[g]
	screening loss	72,90	[g]
	screensize [mm]	mass [g]	passing [%]
	> 125	0,00	100,00%
	125/100	0,00	100,00%
	100/80	0,00	100,00%
	80/63	0,00	100,00%
	63/50	0,00	100,00%
	50/40	0,00	100,00%
	40/31,5	0,00	100,00%
	31,5/25	0,00	100,00%
	25/20	0,00	100,00%
	20/14	0,00	100,00%
	14/12,5	0,00	100,00%
	12,5/10	0,00	100,00%
	10/6,3	0,70	99,99%
	6,3/4	63,10	98,93%
	4/2	1587,42	72,18%
	2/1	1306,35	50,17%
	1/0,5	825,29	36,27%
	0,5/0.25	528,61	27,36%
	0,25/0,125	571,42	17,74%
	0,125/0,1	186,98	14,59%
	0,1/0,063	344,25	8,79%
	< 0,063	521,62	0,00%
	TOTAL	5935,74	[g]

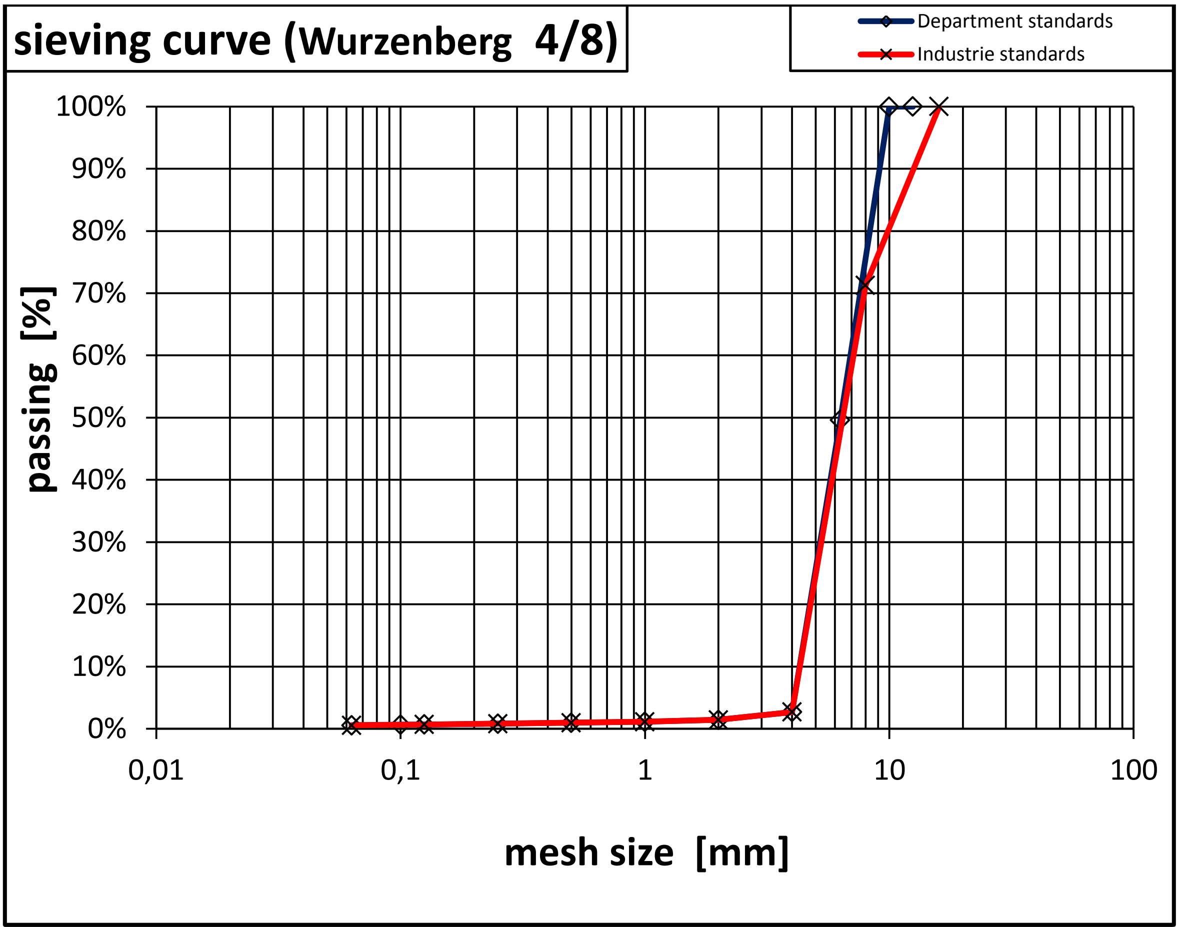


sieving curve (Wurzenberg 0/3)
Department standards
Industrie standards
passing [%]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0,01
0,1
1
10
100
mesh size [mm]

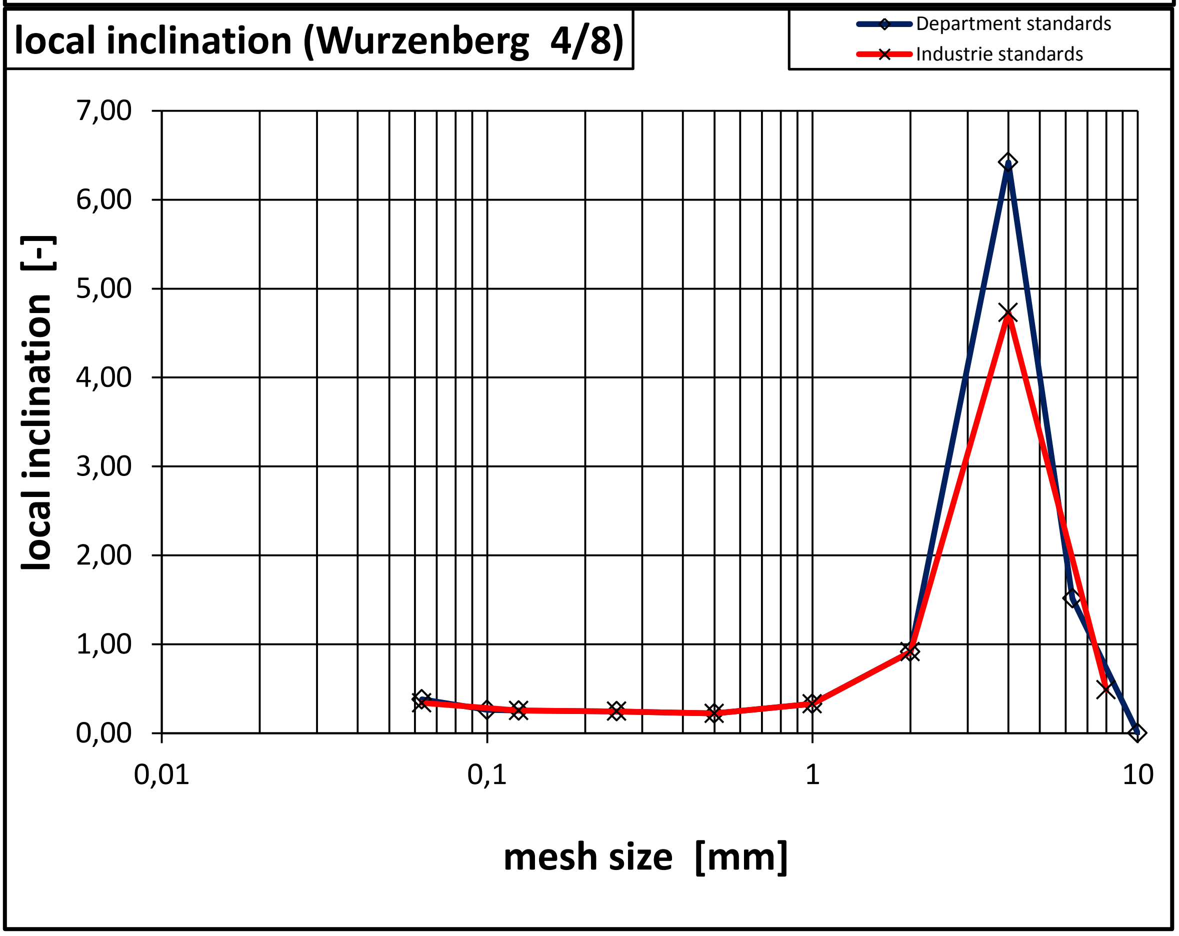


local inclination (Wurzenberg 0/3)
Department standards
Industrie standards
local inclination [-]
1,20
1,00
0,80
0,60
0,40
0,20
0,00
0,01
0,1
1
10
mesh size [mm]

SAMPLE			
	sample Nr.:	**Wurzenberg 4/8**	
	sieving date:	21.07.2010	
	material:	concrete aggregate	
	form:	granular	
SCREENING	feeding mass	8000,00	[g]
	screening loss	51,20	[g]
	screensize [mm]	mass [g]	passing [%]
	> 125	0,00	100,00%
	125/100	0,00	100,00%
	100/80	0,00	100,00%
	80/63	0,00	100,00%
	63/50	0,00	100,00%
	50/40	0,00	100,00%
	40/31,5	0,00	100,00%
	31,5/25	0,00	100,00%
	25/20	0,00	100,00%
	20/14	0,00	100,00%
	14/12,5	0,00	100,00%
	12,5/10	2,30	99,97%
	10/6,3	4001,90	49,63%
	6,3/4	3731,20	2,68%
	4/2	100,10	1,43%
	2/1	23,10	1,13%
	1/0,5	12,80	0,97%
	0,5/0.25	12,10	0,82%
	0,25/0,125	10,50	0,69%
	0,125/0,1	3,10	0,65%
	0,1/0,063	8,30	0,55%
	< 0,063	43,40	0,00%
	TOTAL	7948,80	[g]

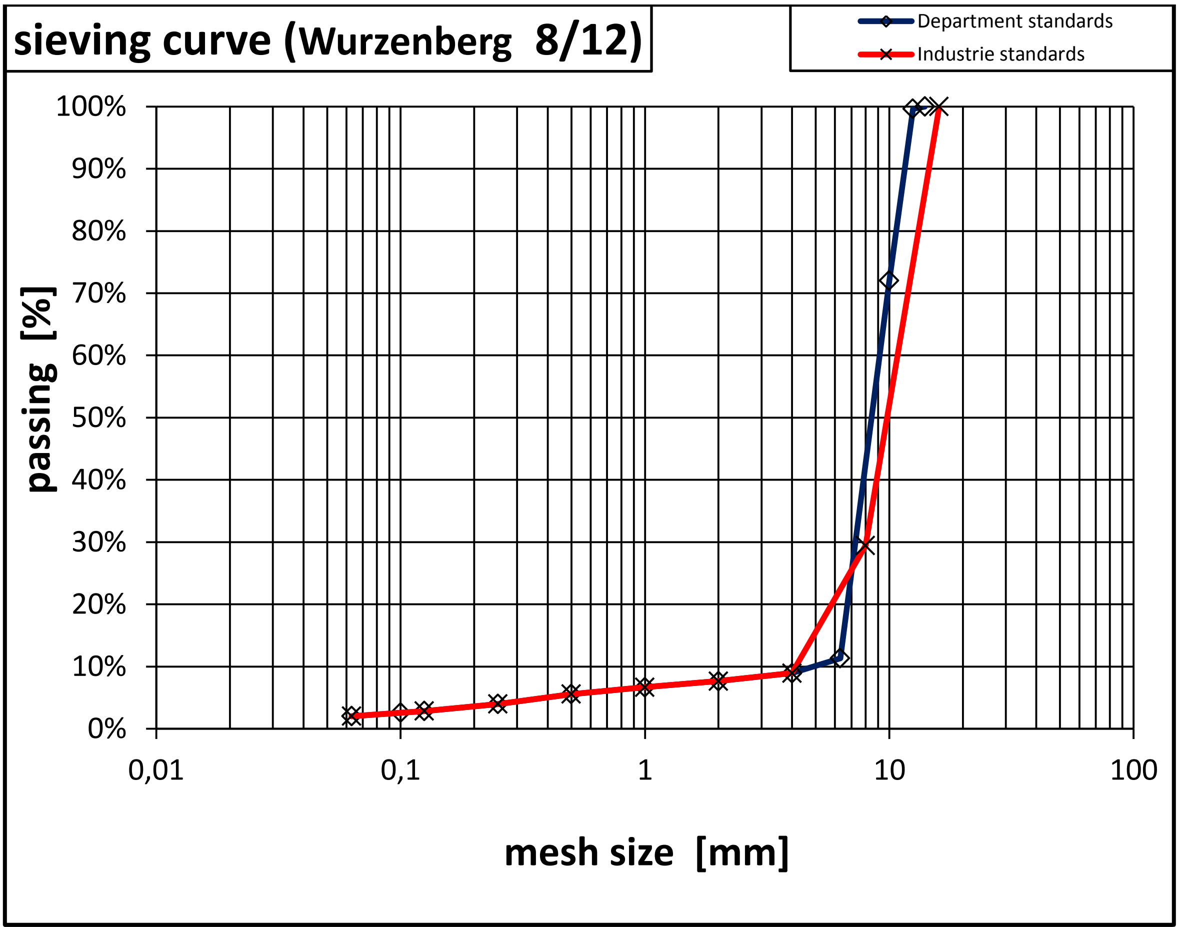


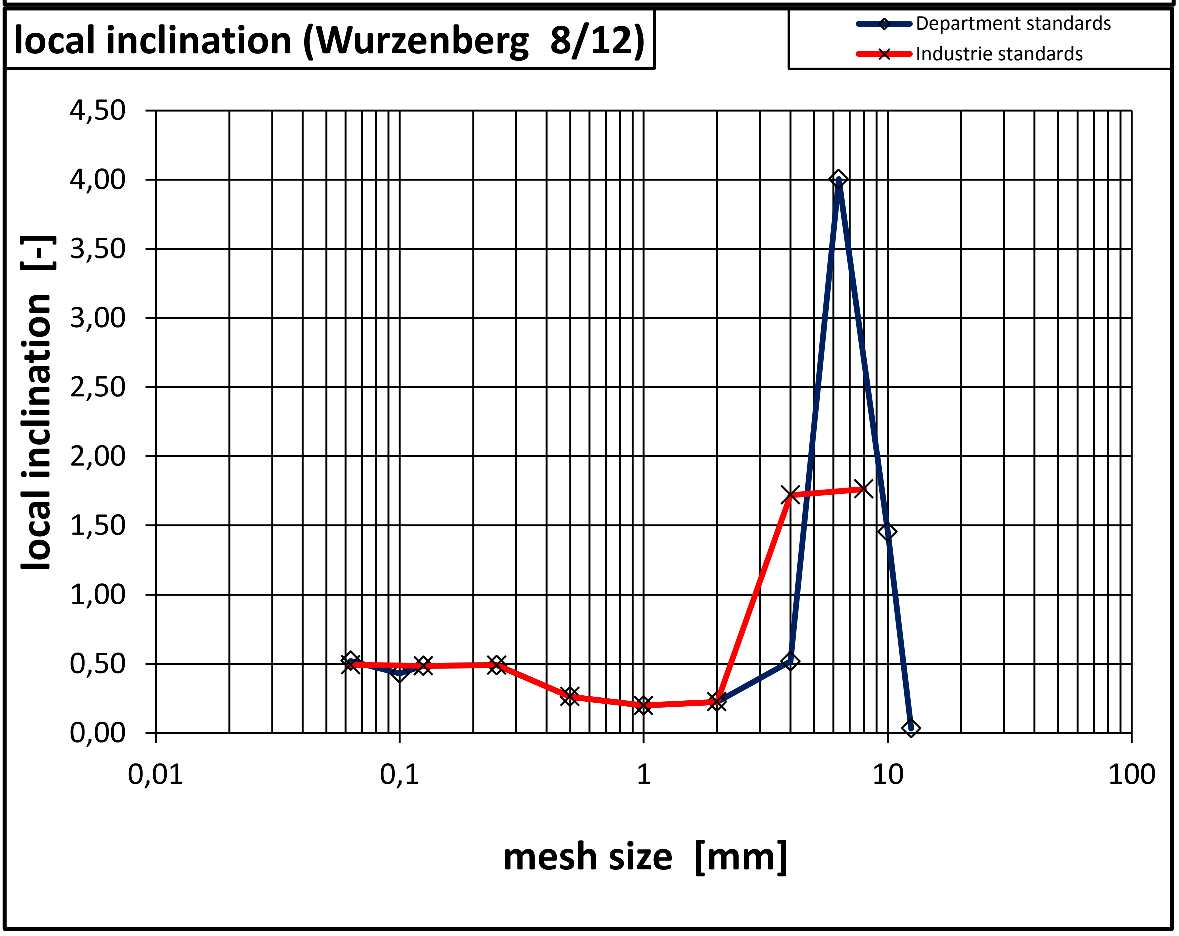
sieving curve (Wurzenberg 4/8)
Department standards
Industrie standards
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
passing [%]
0,01
0,1
1
10
100
mesh size [mm]



local inclination (Wurzenberg 4/8)
Department standards
Industrie standards
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
local inclination [-]
0,01
0,1
1
10
mesh size [mm]

SAMPLE	sample Nr.:	**Wurzenberg 8/12**	
	sieving date:	19.07.2010	
	material:	concrete aggregate	
	form:	granular	
SCREENING	feeding mass	14000,00	[g]
	screening loss	79,60	[g]
	screensize [mm]	mass [g]	passing [%]
	> 125	0,00	100,00%
	125/100	0,00	100,00%
	100/80	0,00	100,00%
	80/63	0,00	100,00%
	63/50	0,00	100,00%
	50/40	0,00	100,00%
	40/31,5	0,00	100,00%
	31,5/25	0,00	100,00%
	25/20	0,00	100,00%
	20/14	0,00	100,00%
	14/12,5	51,60	99,63%
	12,5/10	3832,90	72,02%
	10/6,3	8424,65	11,32%
	6,3/4	328,78	8,95%
	4/2	178,62	7,67%
	2/1	136,22	6,69%
	1/0,5	153,89	5,58%
	0,5/0.25	222,79	3,97%
	0,25/0,125	157,19	2,84%
	0,125/0,1	36,03	2,58%
	0,1/0,063	76,57	2,03%
	< 0,063	281,49	0,00%
	TOTAL	13880,72	[g]


sieving curve (Wurzenberg 8/12)
Department standards
Industrie standards
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
passing [%]
0,01
0,1
1
10
100
mesh size [mm]


local inclination (Wurzenberg 8/12)
Department standards
Industrie standards
4,50
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
local inclination [-]
0,01
0,1
1
10
100
mesh size [mm]

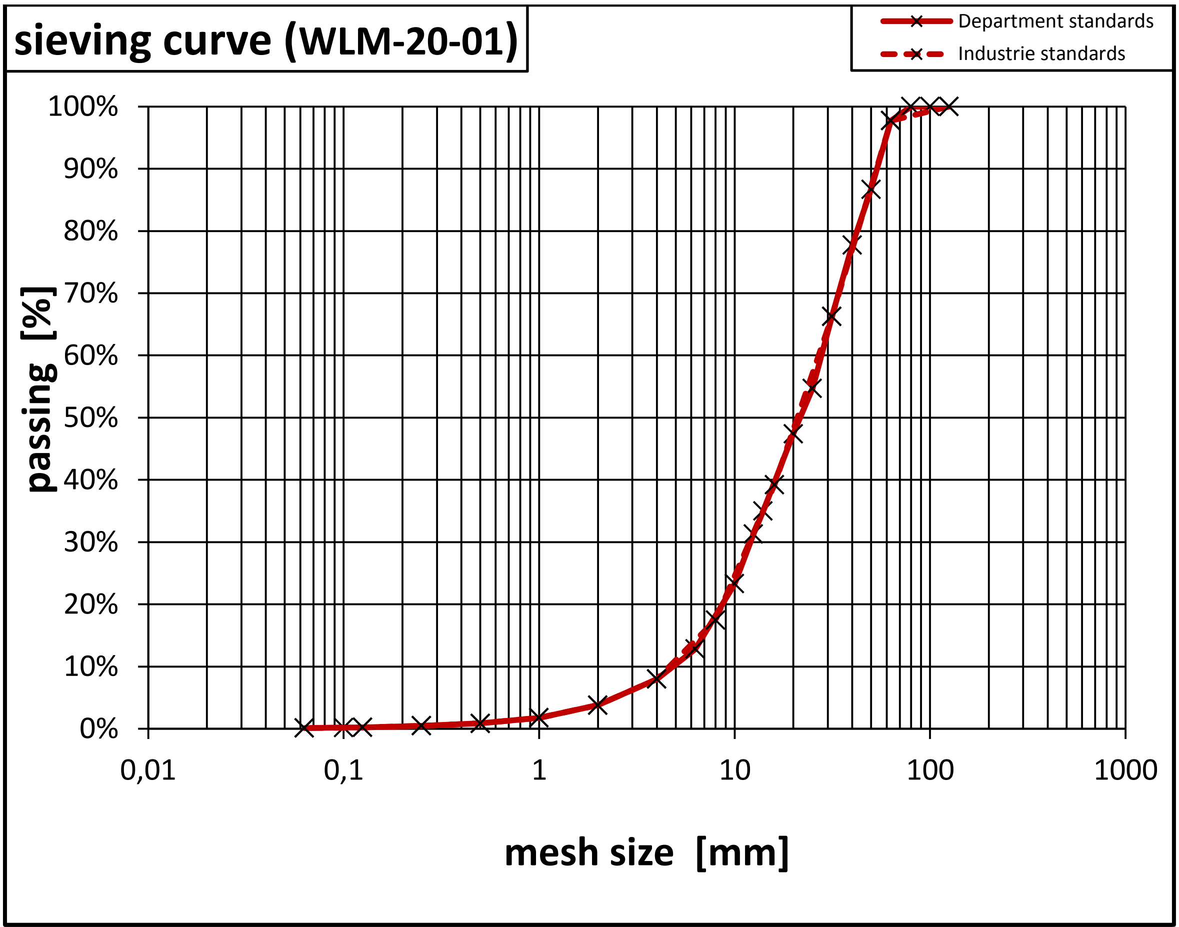
WLM-20-01

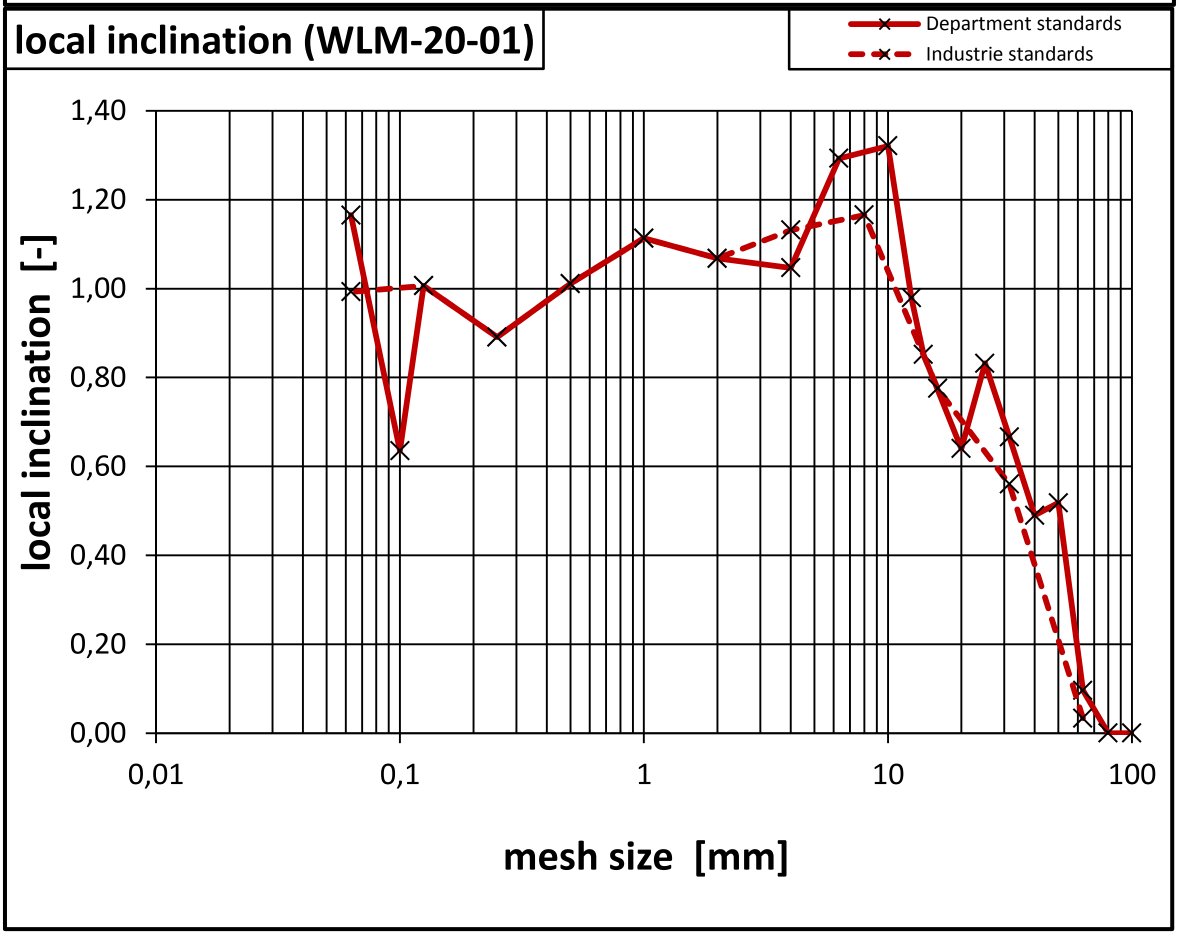
feeding mass	19503,5	[g]
other mass	22,8	[g]
screening loss	111,00	[g]

BLOCK	sample ID	blasting date	29.07.2010	
		sieving date	04.08.2010	
		material	concrete	
	geometry	form	cube	
		X:	200,50	[mm]
		Y:	200,00	[mm]
		Z:	200,00	[mm]
		volume	0,008020	[m³]
		weight	19	[kg]
		density	2,43	[g/m³]
BLASTING	initiation	NONEL		
	explosive	PETN bulk	type: -------	[g/m]
			length: -------	[m]
			charge mass: 3,90	[g]
			spezific charge: 199,96	[g/t]
	VOD	length	210,00	[mm]
		time	41,60	[µs]
		VOD	5048,08	[m/s]
	geometry	diameter	5	[mm]
		length	-------	[mm]

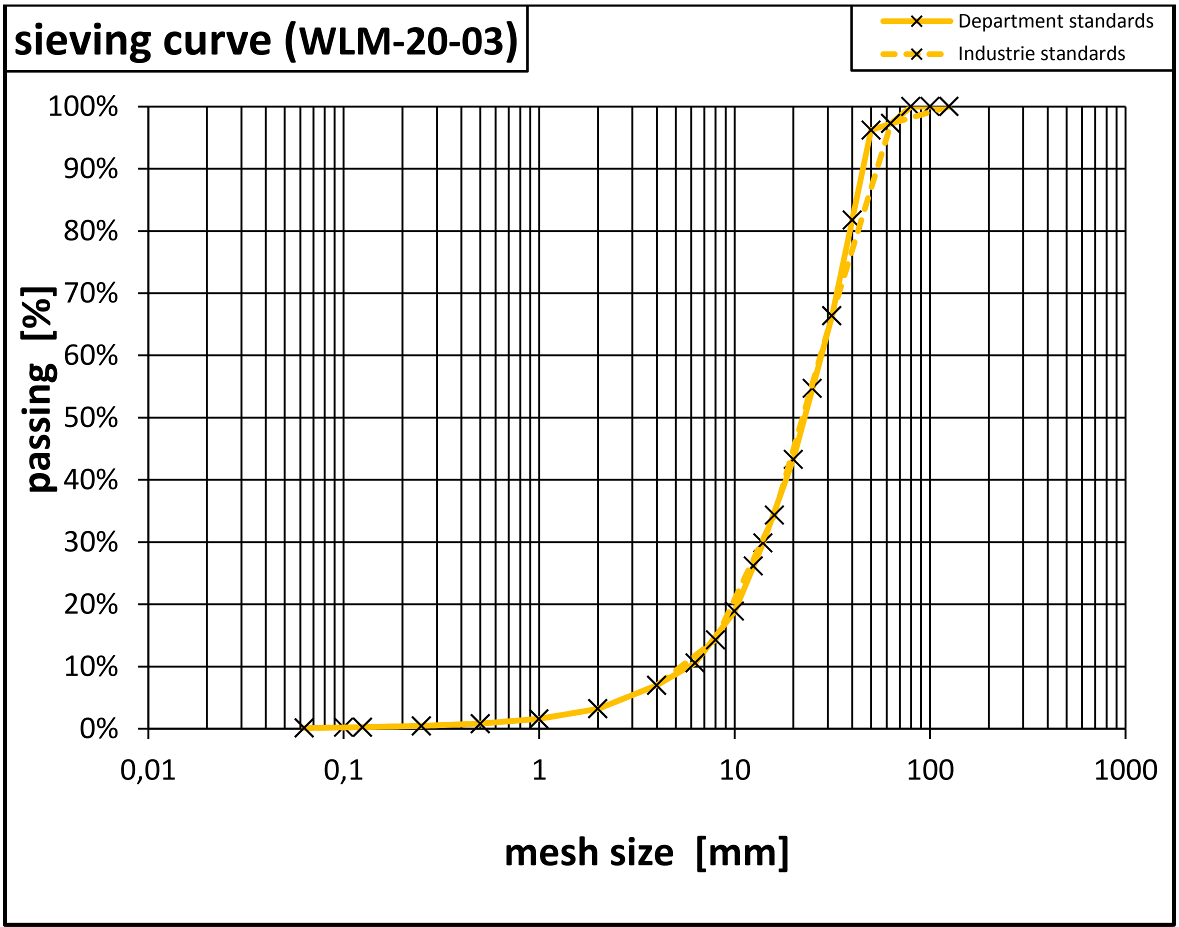
SCREENING

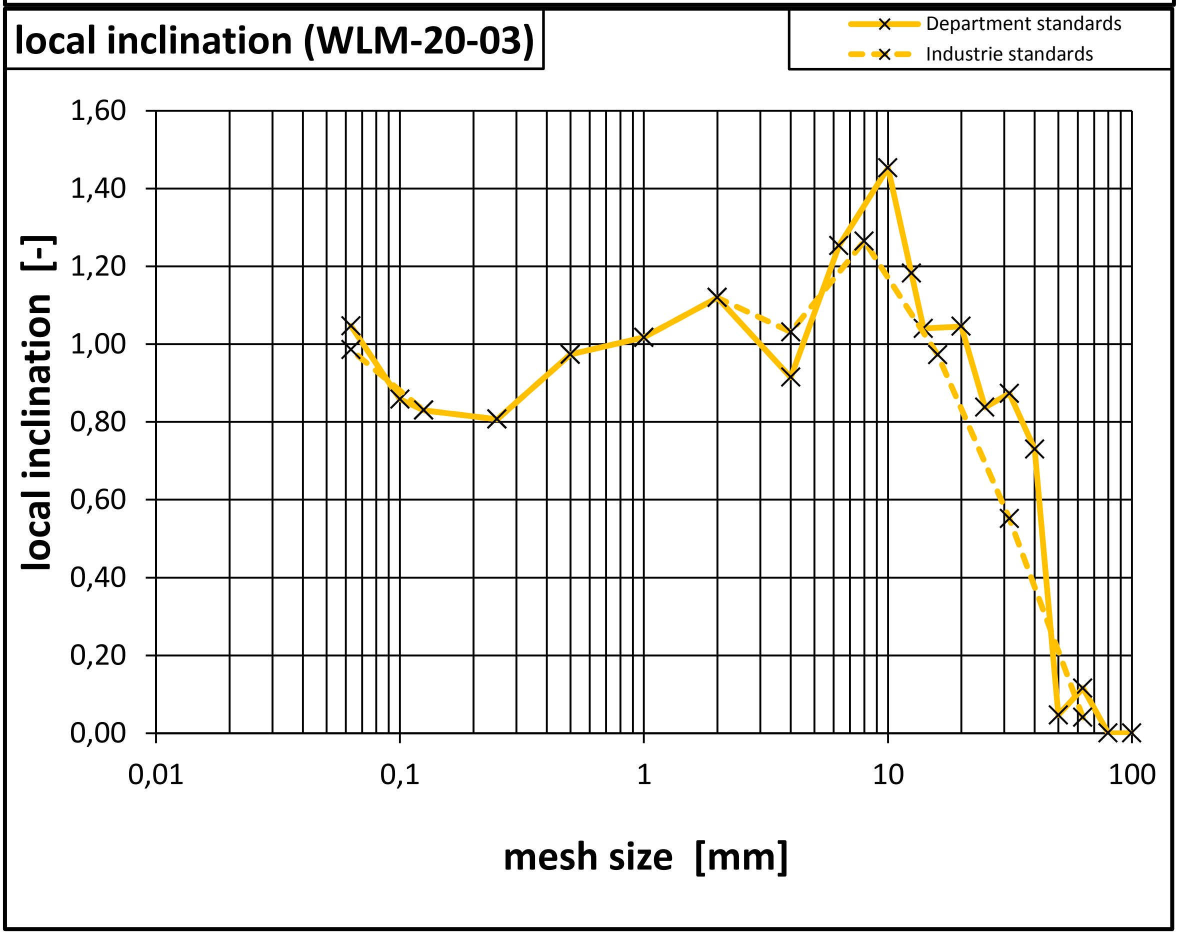
screensize [mm]	mass [g]	passing [%]
>125	0,0	100,00%
125/100	0,0	100,00%
100/80	0,0	100,00%
80/63	439,2	97,73%
63/50	2135,0	86,71%
50/40	1739,1	77,73%
40/31,5	2215,5	66,29%
31,5/25	2245,6	54,70%
25/20	1409,7	47,42%
20/14	2406,5	35,00%
14/12,5	712,0	31,32%
12,5/10	1548,8	23,33%
10/6,3	2031,9	12,84%
6,3/4	940,8	7,98%
4/2	808,4	3,81%
2/1	396,4	1,76%
1/0,5	171,7	0,87%
0,5/0,250	77,9	0,47%
0,250/0,125	45,8	0,23%
0,125/0,100	6,0	0,20%
0,100/0,063	16,4	0,12%
<0,063	23,0	0,00%
TOTAL	19369,70	[g]


sieving curve (WLM-20-01)
Department standards
Industrie standards
passing [%]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0,01
0,1
1
10
100
1000
mesh size [mm]


local inclination (WLM-20-01)
Department standards
Industrie standards
local inclination [-]
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
0,01
0,1
1
10
100
mesh size [mm]

WLM-20-03				feeding mass	19238,8	[g]	screensize [mm]	mass [g]	passing [%]
				other mass	15,1	[g]	>125	0,0	100,00%
				screening loss	44,80	[g]	125/100	0,0	100,00%
							100/80	0,0	100,00%
BLOCK	sample ID	blasting date	29.07.2010			SCREENING	80/63	523,1	97,27%
		sieving date	10.08.2010				63/50	200,0	96,23%
		material	concrete				50/40	2775,1	81,76%
	geometry	form	cube				40/31,5	2952,7	66,36%
		X:	200,00		[mm]		31,5/25	2239,5	54,69%
		Y:	200,50		[mm]		25/20	2182,7	43,31%
		Z:	190,00		[mm]		20/14	2574,5	29,88%
		volume	0,007619		[m³]		14/12,5	718,7	26,14%
		weight	19		[kg]		12,5/10	1388,3	18,90%
		density	2,53		[g/m³]		10/6,3	1593,1	10,59%
BLASTING	initiation	NONEL					6,3/4	690,6	6,99%
	explosive	PETN cord	type	20	[g/m]		4/2	723,7	3,22%
			length	0,2	[m]		2/1	312,1	1,59%
			charge mass	4,00	[g]		1/0,5	149,6	0,81%
			spezific charge	207,91	[g/t]		0,5/0,250	66,5	0,46%
	VOD	length	200,00		[mm]		0,250/0,125	38,8	0,26%
		time	27,20		[µs]		0,125/0,100	8,7	0,21%
		VOD	7352,94		[m/s]		0,100/0,063	15,8	0,13%
	geometry	diameter	8		[mm]		<0,063	25,4	0,00%
		length	-------		[mm]		TOTAL	19178,90	[g]


sieving curve (WLM-20-03)
Department standards
Industrie standards
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
passing [%]
0,01
0,1
1
10
100
1000
mesh size [mm]


local inclination (WLM-20-03)
Department standards
Industrie standards
1,60
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
local inclination [-]
0,01
0,1
1
10
100
mesh size [mm]

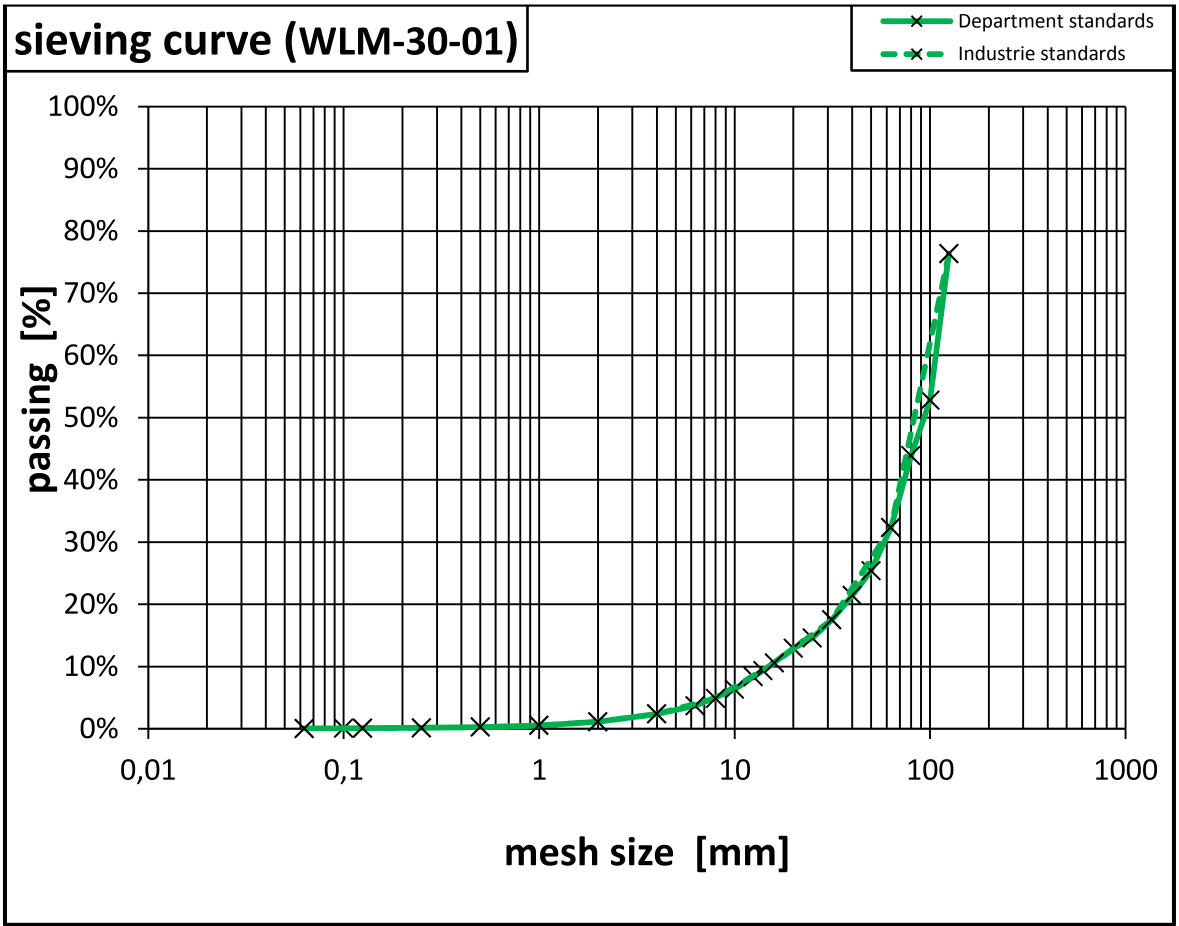
WLM-30-01

feeding mass	65439,8	[g]
other mass	24,9	[g]
screening loss	67,90	[g]

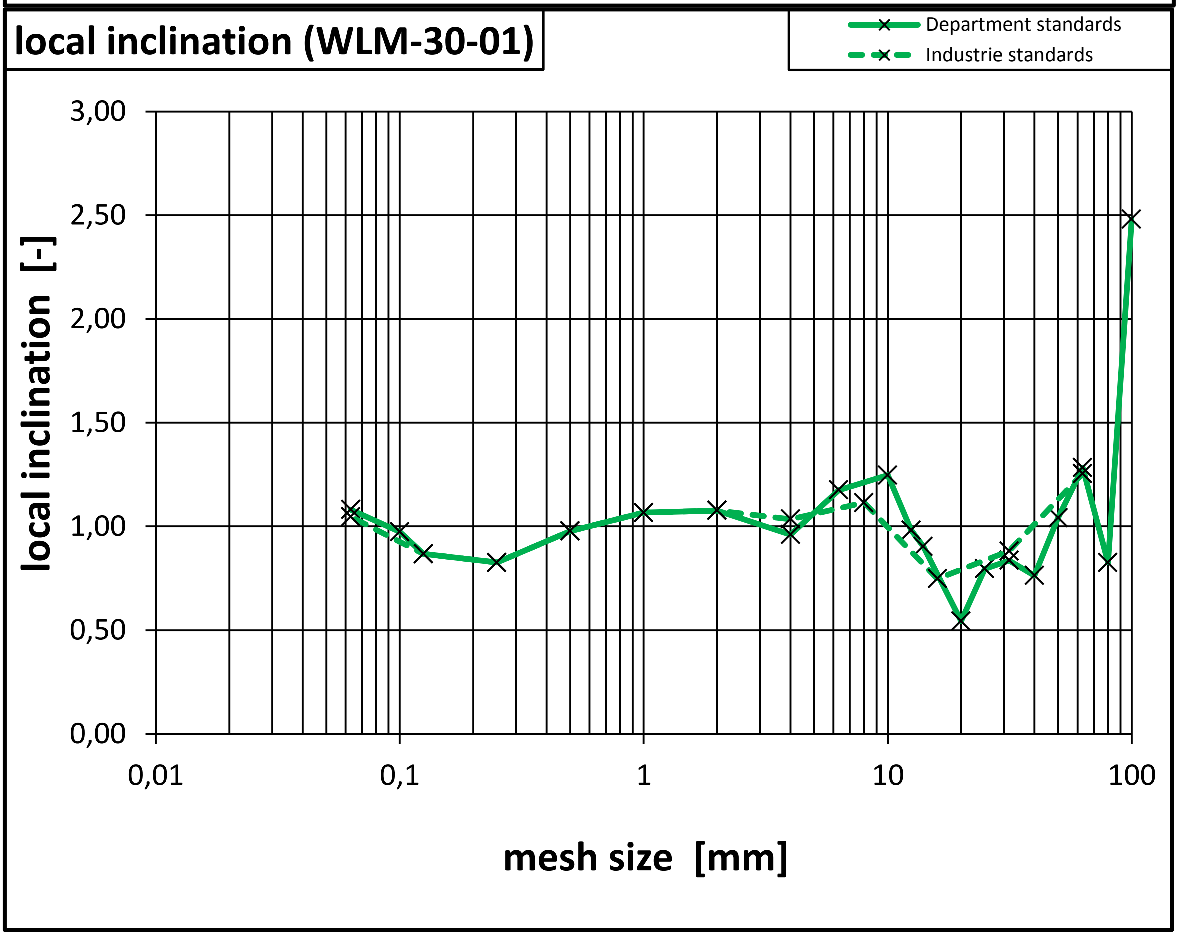
BLOCK	sample ID	blasting date		29.07.2010	
		sieving date		11.08.2010	
		material		concrete	
	geometry	form		cube	
		X:		300,50	[mm]
		Y:		300,50	[mm]
		Z:		290,00	[mm]
		volume		0,026187	[m³]
		weight		65	[kg]
		density		2,50	[g/m³]
BLASTING	initiation	NONEL			
	explosive	**PETN bulk**	type	------	[g]
			length	-------	[g/t]
			charge mass	6,00	[m]
			spezific charge	91,69	[g]
	VOD	length		310,00	[mm]
		time		58,00	[µs]
		VOD		5344,83	[m/s]
	geometry	diameter		5,2	[mm]
		length		-------	[mm]

SCREENING

screensize [mm]	mass [g]	passing [%]
>125	15455,0	76,35%
125/100	15400,0	52,78%
100/80	5807,1	43,90%
80/63	7572,4	32,31%
63/50	4518,2	25,39%
50/40	2600,0	21,42%
40/31,5	2534,2	17,54%
31,5/25	1925,2	14,59%
25/20	1090,1	12,92%
20/14	2326,0	9,36%
14/12,5	644,3	8,38%
12,5/10	1329,7	6,34%
10/6,3	1736,5	3,69%
6,3/4	851,9	2,38%
4/2	818,3	1,13%
2/1	385,7	0,54%
1/0,5	173,5	0,27%
0,5/0,250	78,0	0,15%
0,250/0,125	45,6	0,08%
0,125/0,100	10,8	0,07%
0,100/0,063	17,5	0,04%
<0,063	27,0	0,00%
TOTAL	65347,00	[g]



sieving curve (WLM-30-01)
Department standards
Industrie standards
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
passing [%]
0,01
0,1
1
10
100
1000
mesh size [mm]



local inclination (WLM-30-01)
Department standards
Industrie standards
3,00
2,50
2,00
1,50
1,00
0,50
0,00
local inclination [-]
0,01
0,1
1
10
100
mesh size [mm]

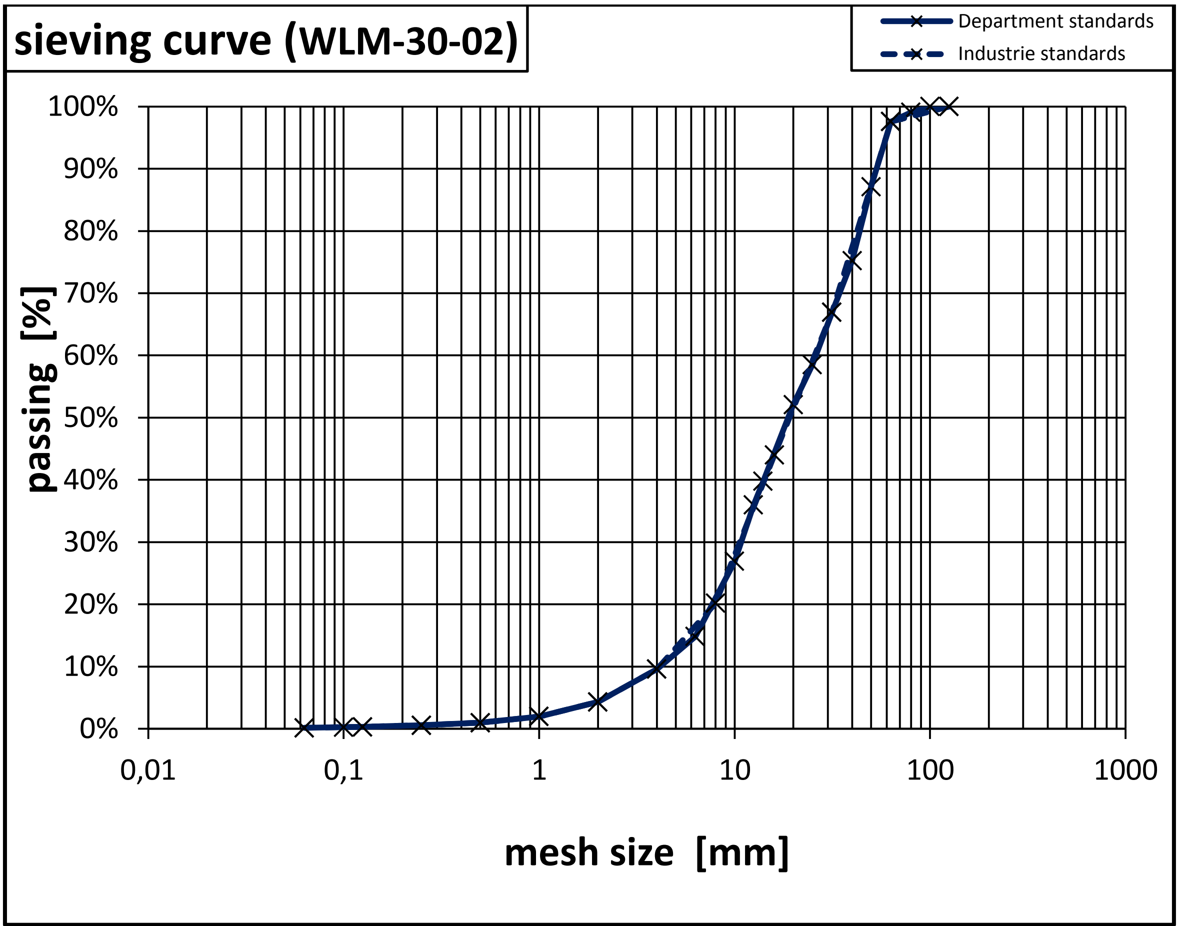
WLM-30-02

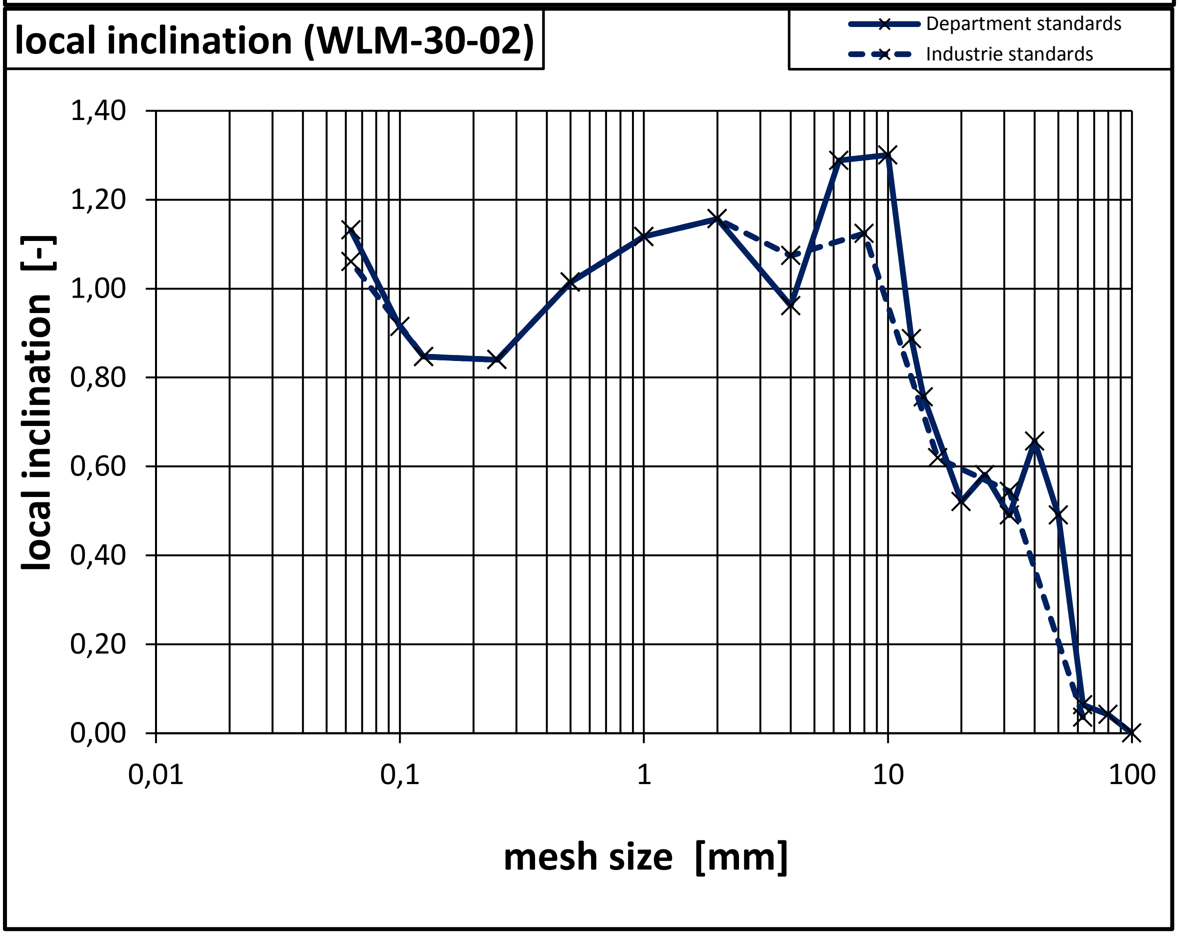
feeding mass	65569,8	[g]
other mass	12,7	[g]
screening loss	480,50	[g]

BLOCK	sample ID	blasting date	30.07.2010		
		sieving date	12.08.2010-17.08.2010		
		material	concrete		
	geometry	form	cube		
		X:	300,00		[mm]
		Y:	300,00		[mm]
		Z:	300,50		[mm]
		volume	0,027045		[m³]
		weight	65		[kg]
		density	2,42		[g/m³]
BLASTING	initiation	NONEL			
	explosive	PETN bulk	type	------	[g]
			length	-------	[g/t]
			charge mass	16,50	[m]
			spezific charge	251,64	[g]
	VOD	length	300,00		[mm]
		time	49,40		[µs]
		VOD	6072,87		[m/s]
	geometry	diameter	8		[mm]
		length	-------		[mm]

SCREENING

screensize [mm]	mass [g]	passing [%]
>125	0,0	100,00%
125/100	0,0	100,00%
100/80	602,3	99,07%
80/63	967,7	97,58%
63/50	6782,8	87,12%
50/40	7696,5	75,26%
40/31,5	5392,5	66,95%
31,5/25	5453,8	58,54%
25/20	4161,9	52,12%
20/14	7985,0	39,82%
14/12,5	2467,1	36,01%
12,5/10	5883,8	26,94%
10/6,3	7839,8	14,86%
6,3/4	3410,5	9,60%
4/2	3434,2	4,31%
2/1	1505,0	1,99%
1/0,5	650,4	0,98%
0,5/0,250	281,5	0,55%
0,250/0,125	158,1	0,31%
0,125/0,100	36,6	0,25%
0,100/0,063	65,8	0,15%
<0,063	95,8	0,00%
TOTAL	64870,93	[g]


sieving curve (WLM-30-02)
Department standards
Industrie standards
passing [%]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0,01
0,1
1
10
100
1000
mesh size [mm]


local inclination (WLM-30-02)
Department standards
Industrie standards
local inclination [-]
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
0,01
0,1
1
10
100
mesh size [mm]

WLM-30-03

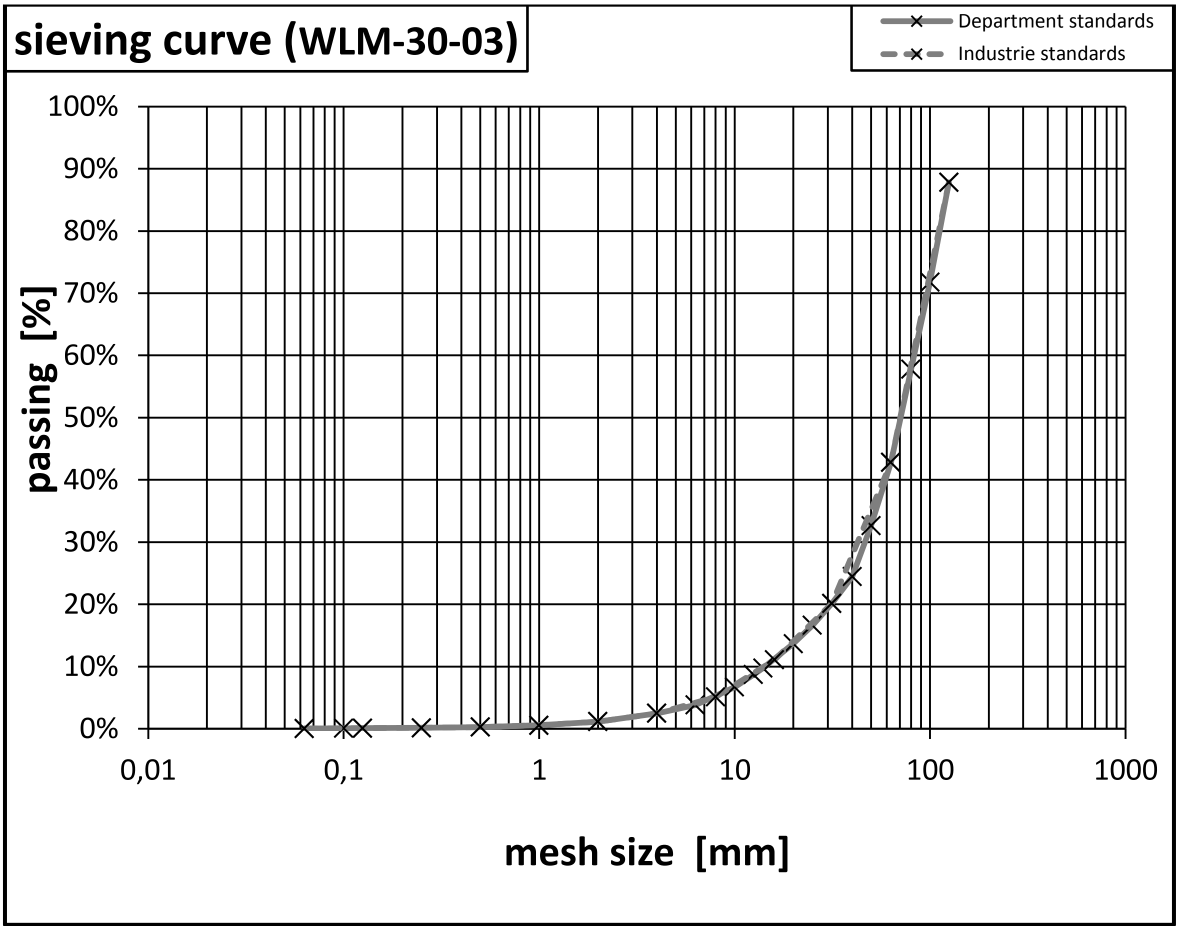
feeding mass	65739,4	[g]		
other mass	18,3	[g]		
screening loss	75,50	[g]		

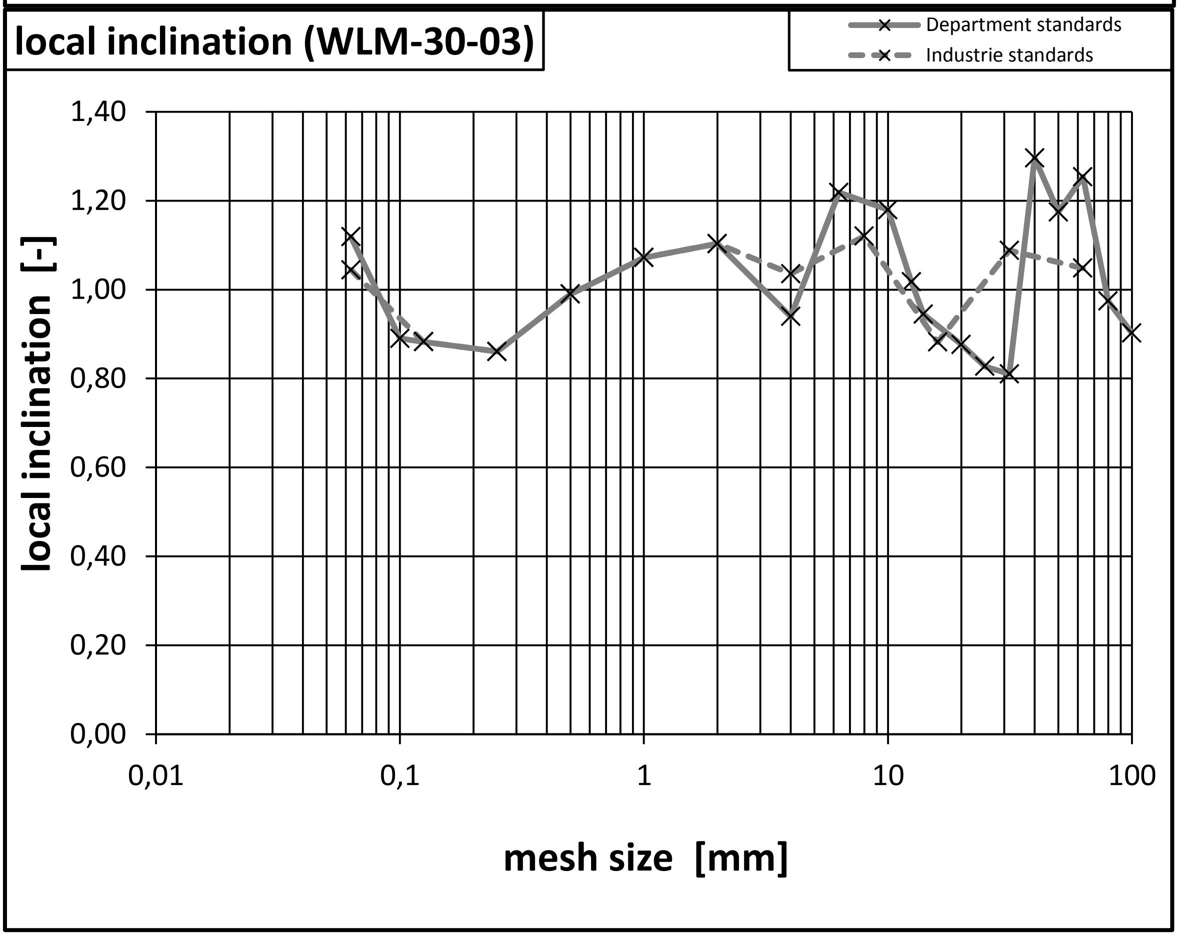
BLOCK				
sample ID	blasting date	29.07.2010		
	sieving date	17.08.2010-19.08.2010		
	material	concrete		
geometry	form	cube		
	X:	-------	[mm]	
	Y:	-------	[mm]	
	Z:	-------	[mm]	
	volume	-------	[m³]	
	weight	65	[kg]	
	density	-------	[g/m³]	

BLASTING				
initiation	NONEL			
explosive	PETN bulk	type	20	[g/m]
		length	0,3	[m]
		charge mass	6,00	[g]
		spezific charge	91,27	[g/t]
VOD	length	300,00	[mm]	
	time	41,60	[µs]	
	VOD	7211,54	[m/s]	
geometry	diameter	8	[mm]	
	length	-------	[mm]	

SCREENING

screensize [mm]	mass [g]	passing [%]
>125	8006,4	87,80%
125/100	10509,4	71,79%
100/80	9207,4	57,77%
80/63	9813,1	42,82%
63/50	6681,9	32,64%
50/40	5381,1	24,44%
40/31,5	2823,1	20,14%
31,5/25	2300,8	16,64%
25/20	1940,1	13,68%
20/14	2568,4	9,77%
14/12,5	698,4	8,71%
12,5/10	1322,7	6,69%
10/6,3	1890,9	3,81%
6,3/4	869,1	2,49%
4/2	872,7	1,16%
2/1	398,5	0,55%
1/0,5	179,5	0,28%
0,5/0,250	81,8	0,15%
0,250/0,125	45,9	0,08%
0,125/0,100	9,8	0,07%
0,100/0,063	18,0	0,04%
<0,063	26,6	0,00%
TOTAL	65645,60	[g]


sieving curve (WLM-30-03)
Department standards
Industrie standards
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
passing [%]
0,01
0,1
1
10
100
1000
mesh size [mm]

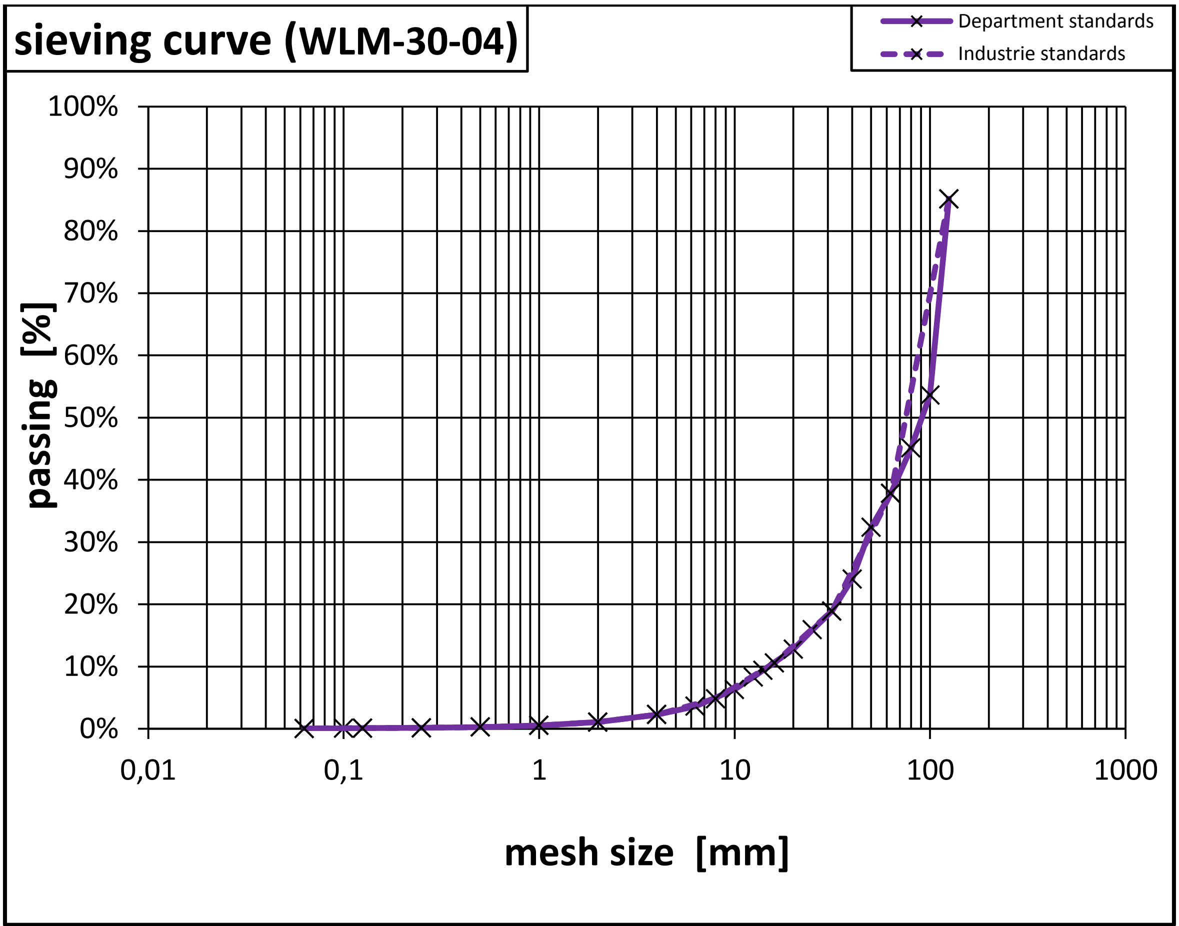

local inclination (WLM-30-03)
Department standards
Industrie standards
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
local inclination [-]
0,01
0,1
1
10
100
mesh size [mm]

WLM-30-04

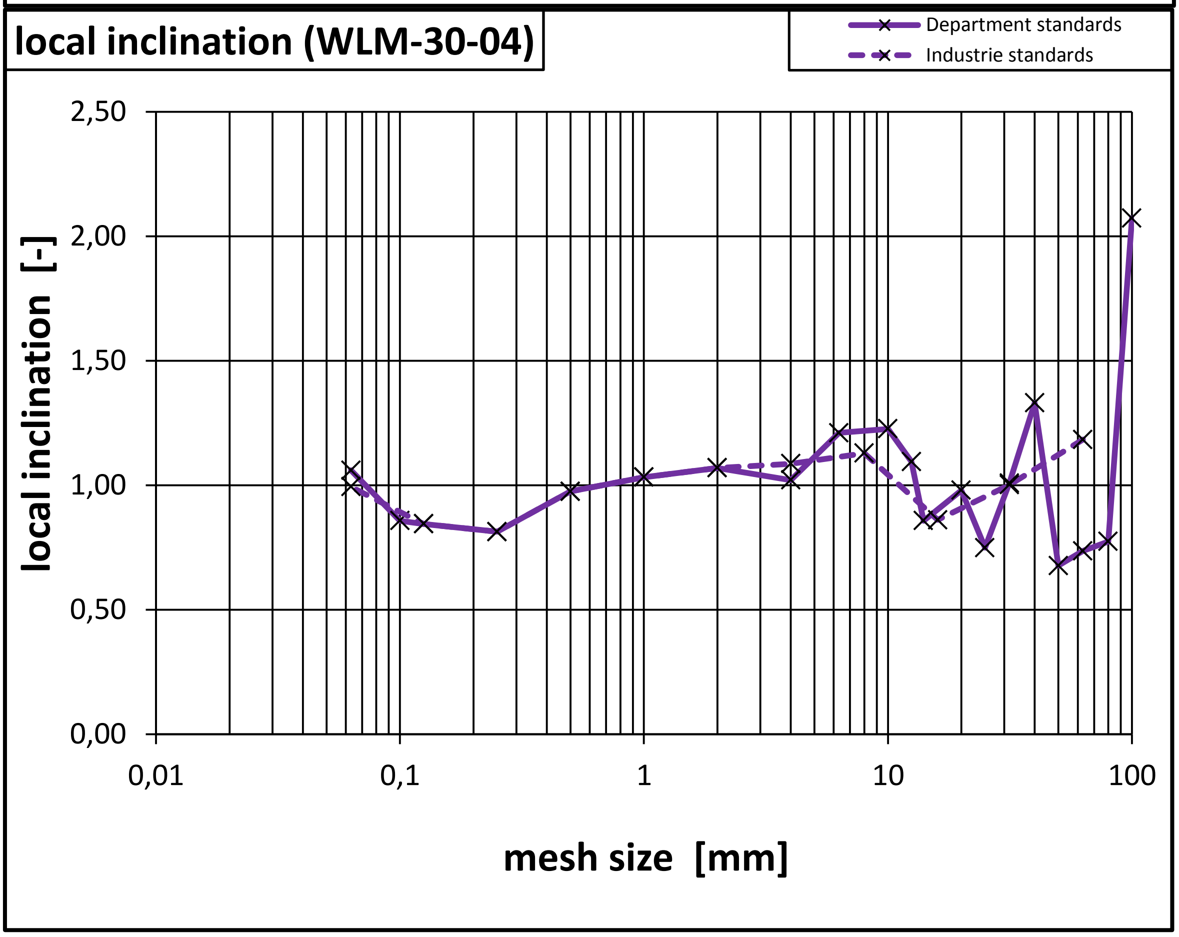
		feeding mass	65942,8	[g]
		other mass	16,4	[g]
		screening loss	53,00	[g]
BLOCK	sample ID	blasting date	22.09.2010	
BLOCK	sample ID	sieving date	25.10.2010	
BLOCK	sample ID	material	concrete	
BLOCK	geometry	form	cube	
BLOCK	geometry	X:	300,00	[mm]
BLOCK	geometry	Y:	300,00	[mm]
BLOCK	geometry	Z:	300,00	[mm]
BLOCK	geometry	volume	0,027000	[m^3]
BLOCK	geometry	weight	65	[kg]
BLOCK	geometry	density	2,44	[g/m^3]
BLASTING	initiation		NONEL	
BLASTING	explosive (PETN cord)	type	20	[g/m]
BLASTING	explosive (PETN cord)	length	0,3	[m]
BLASTING	explosive (PETN cord)	charge mass	6,00	[g]
BLASTING	explosive (PETN cord)	spezific charge	90,99	[g/t]
BLASTING	VOD	length	-------	[mm]
BLASTING	VOD	time	-------	[µs]
BLASTING	VOD	VOD	-------	[m/s]
BLASTING	geometry	diameter	8	[mm]
BLASTING	geometry	length	-------	[mm]

SCREENING

screensize [mm]	mass [g]	passing [%]
>125	9771,0	85,17%
125/100	20772,0	53,63%
100/80	5601,0	45,13%
80/63	4792,0	37,86%
63/50	3611,0	32,37%
50/40	5477,0	24,06%
40/31,5	3393,2	18,91%
31,5/25	1979,2	15,90%
25/20	2057,3	12,78%
20/14	2218,2	9,41%
14/12,5	723,3	8,32%
12,5/10	1311,3	6,33%
10/6,3	1784,8	3,62%
6,3/4	883,8	2,27%
4/2	784,2	1,08%
2/1	365,0	0,53%
1/0,5	171,5	0,27%
0,5/0,250	76,5	0,15%
0,250/0,125	44,8	0,09%
0,125/0,100	9,8	0,07%
0,100/0,063	18,0	0,04%
<0,063	28,5	0,00%
TOTAL	65873,40	[g]



sieving curve (WLM-30-04)
Department standards
Industrie standards
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
passing [%]
0,01
0,1
1
10
100
1000
mesh size [mm]



local inclination (WLM-30-04)
Department standards
Industrie standards
2,50
2,00
1,50
1,00
0,50
0,00
local inclination [-]
0,01
0,1
1
10
100
mesh size [mm]

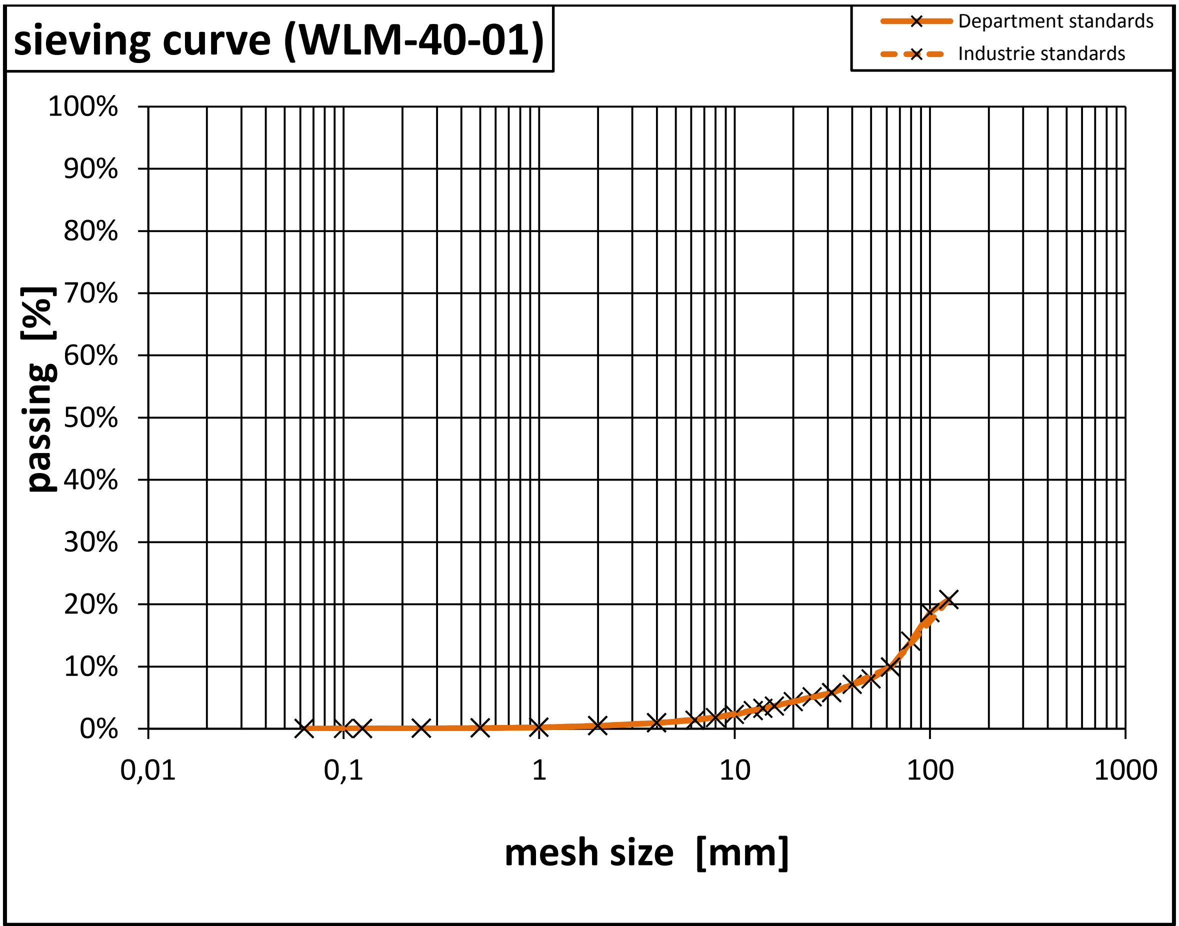
WLM-40-01

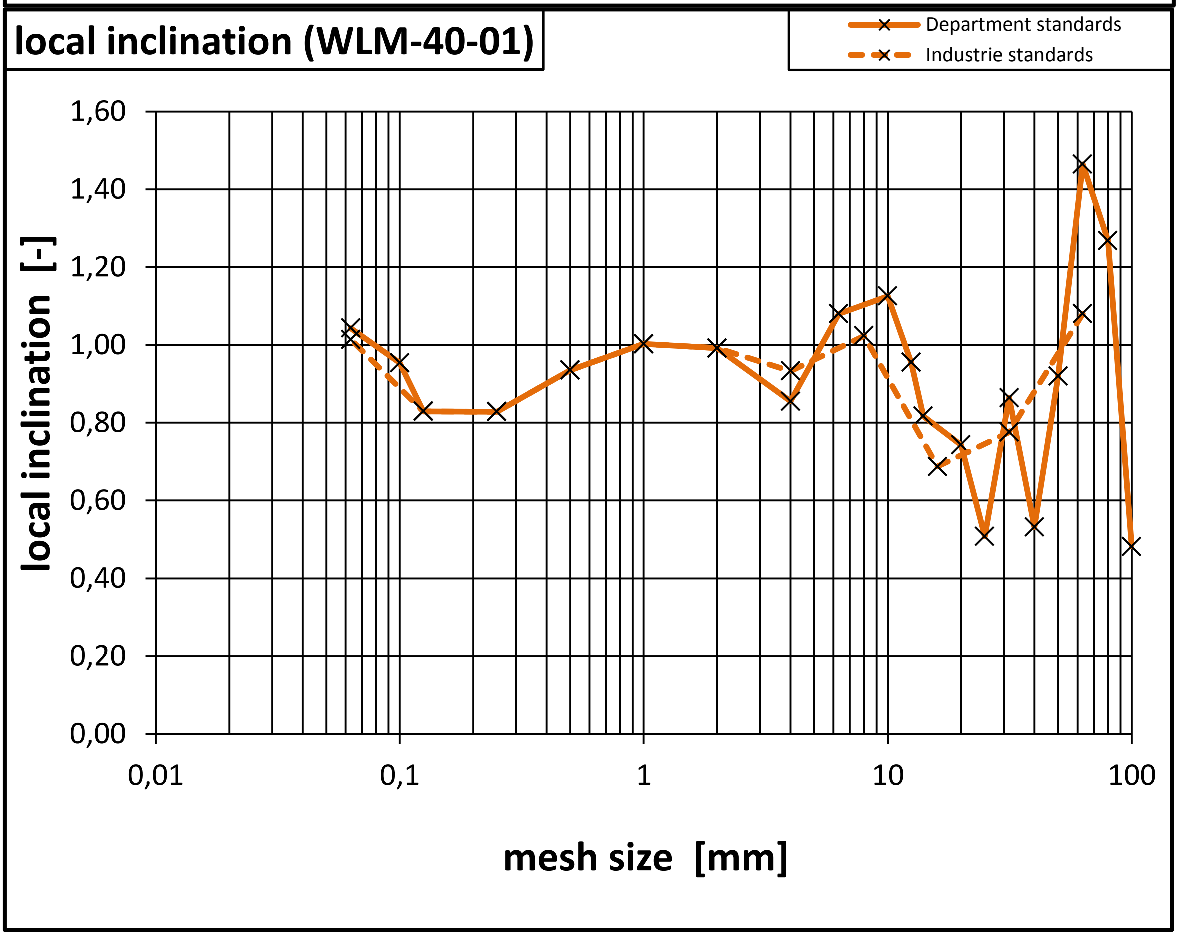
feeding mass	155373,2	[g]
other mass	17,8	[g]
screening loss	61,40	[g]

BLOCK	sample ID	blasting date		29.07.2010	
		sieving date		20.08.2010	
		material		concrete	
	geometry	form		cube	
		X:		400,00	[mm]
		Y:		400,00	[mm]
		Z:		397,00	[mm]
		volume		0,063520	[m³]
		weight		155	[kg]
		density		2,45	[g/m³]
BLASTING	initiation	NONEL			
	explosive	PETN bulk	type	-------	[g/m]
			length	-------	[m]
			charge mass	8,60	[g]
			spezific charge	55,35	[g/t]
	VOD	length		-------	[mm]
		time		-------	[µs]
		VOD		-------	[m/s]
	geometry	diameter		5	[mm]
		length		-------	[mm]

SCREENING

screensize [mm]	mass [g]	passing [%]
>125	123028,0	20,78%
125/100	3288,4	18,66%
100/80	7141,8	14,06%
80/63	6444,9	9,91%
63/50	2947,1	8,01%
50/40	1392,8	7,12%
40/31,5	2061,8	5,79%
31,5/25	995,6	5,15%
25/20	1221,2	4,36%
20/14	1712,0	3,26%
14/12,5	519,1	2,92%
12,5/10	1008,4	2,27%
10/6,3	1388,1	1,38%
6,3/4	690,4	0,94%
4/2	723,0	0,47%
2/1	366,3	0,24%
1/0,5	174,2	0,12%
0,5/0,250	83,4	0,07%
0,250/0,125	47,0	0,04%
0,125/0,100	11,6	0,03%
0,100/0,063	18,7	0,02%
<0,063	30,2	0,00%
TOTAL	155294,00	[g]


sieving curve (WLM-40-01)
Department standards
Industrie standards
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
passing [%]
0,01
0,1
1
10
100
1000
mesh size [mm]


local inclination (WLM-40-01)
Department standards
Industrie standards
1,60
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
local inclination [-]
0,01
0,1
1
10
100
mesh size [mm]

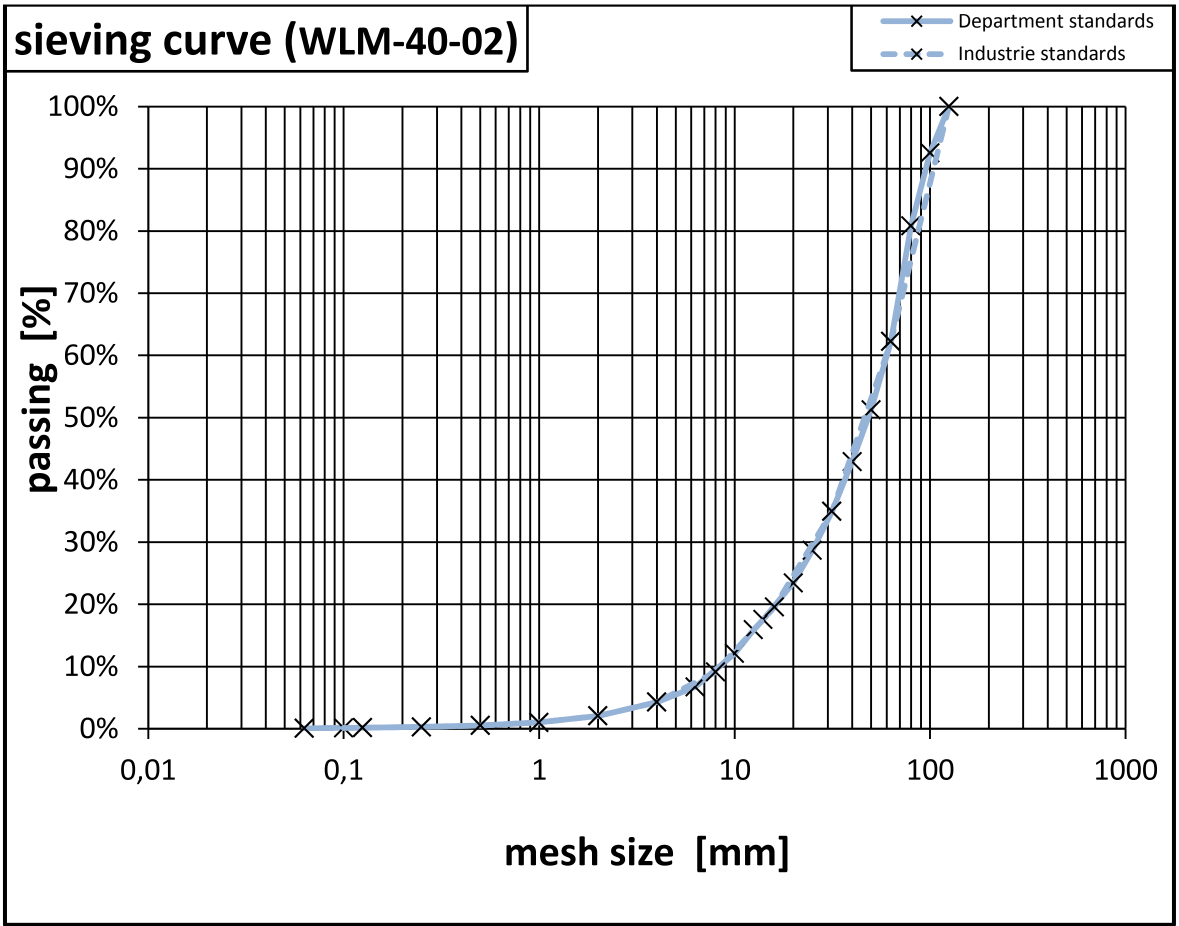
WLM-40-02

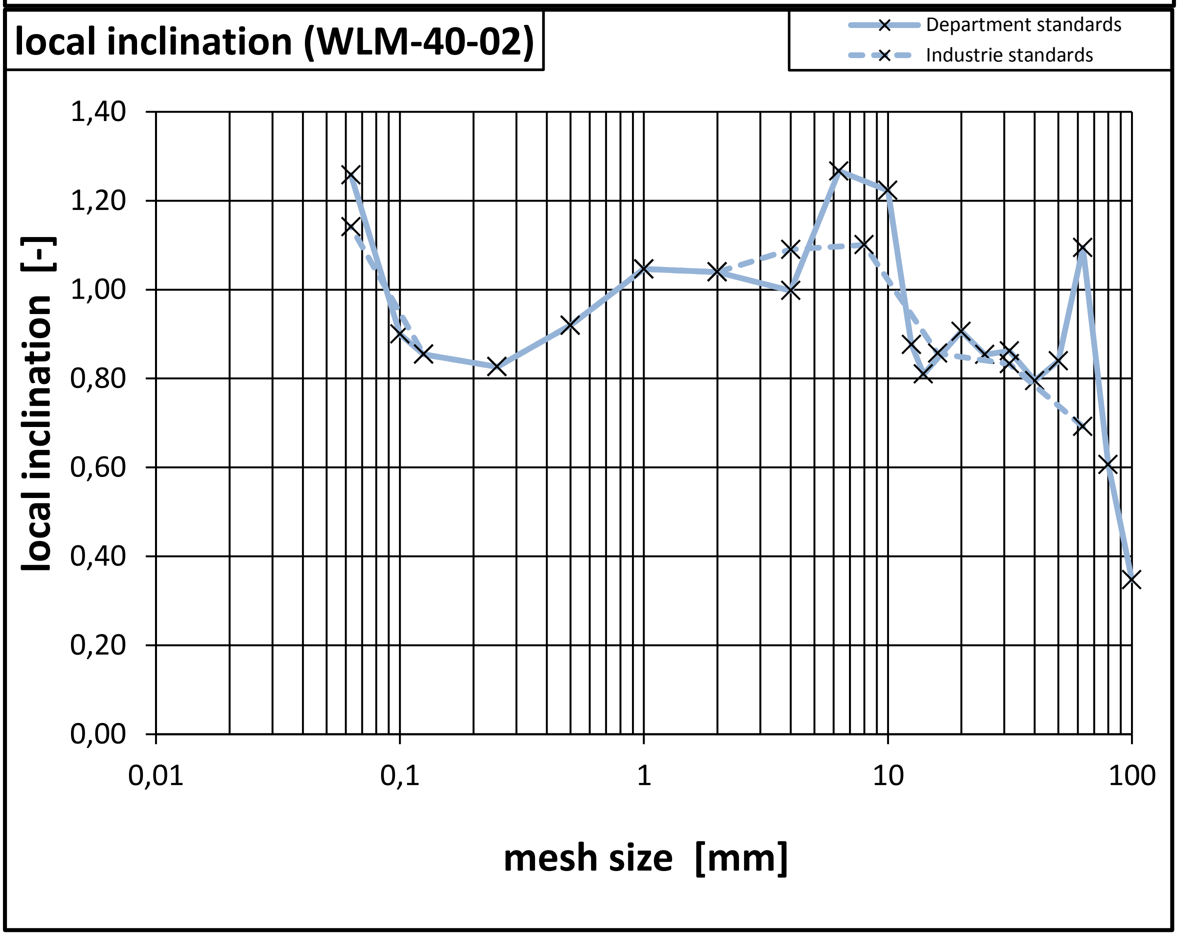
feeding mass	156313,2	[g]
other mass	17,8	[g]
screening loss	617,00	[g]

BLOCK	sample ID	blasting date	30.07.2010		
		sieving date	26.082010-30.08.2010		
		material	concrete		
	geometry	form	cube		
		X:	400,00		[mm]
		Y:	401,00		[mm]
		Z:	400,00		[mm]
		volume	0,064160		[m³]
		weight	155		[kg]
		density	2,44		[g/m³]
BLASTING	initiation	NONEL			
	explosive	PETN bulk	type	-------	[g/m]
			length	-------	[m]
			charge mass	22,10	[g]
			spezific charge	141,38	[g/t]
	VOD	length	400,00		[mm]
		time	66,40		[µs]
		VOD	6024,10		[m/s]
	geometry	diameter	7,9		[mm]
		length	-------		[mm]

SCREENING

screensize [mm]	mass [g]	passing [%]
>125	0,0	100,00%
125/100	11589,3	92,03%
100/80	18223,8	79,51%
80/63	28931,6	59,62%
63/50	17081,0	47,88%
50/40	12967,2	38,97%
40/31,5	12436,6	30,42%
31,5/25	9736,4	23,73%
25/20	8172,1	23,44%
20/14	9147,6	17,56%
14/12,5	2583,0	15,90%
12,5/10	5909,5	12,10%
10/6,3	8342,0	6,74%
6,3/4	3821,8	4,28%
4/2	3423,5	2,08%
2/1	1673,0	1,01%
1/0,5	740,1	0,53%
0,5/0,250	362,0	0,30%
0,250/0,125	209,3	0,17%
0,125/0,100	47,1	0,14%
0,100/0,063	93,4	0,08%
<0,063	118,5	0,00%
TOTAL	155608,86	[g]


sieving curve (WLM-40-02)
Department standards
Industrie standards
passing [%]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0,01
0,1
1
10
100
1000
mesh size [mm]


local inclination (WLM-40-02)
Department standards
Industrie standards
local inclination [-]
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
0,01
0,1
1
10
100
mesh size [mm]

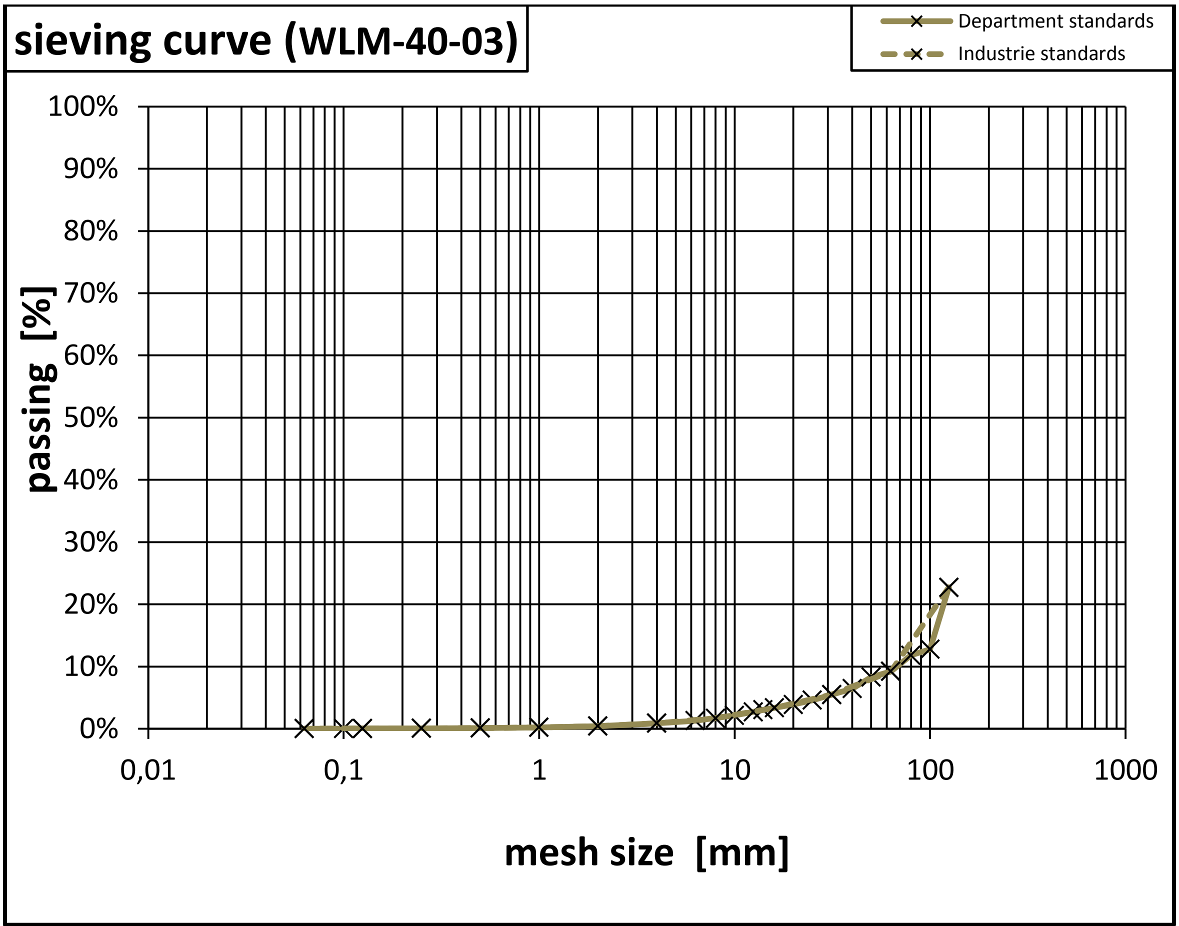
WLM-40-03

feeding mass	156214,9	[g]	
other mass	18,1	[g]	
screening loss	63,10	[g]	

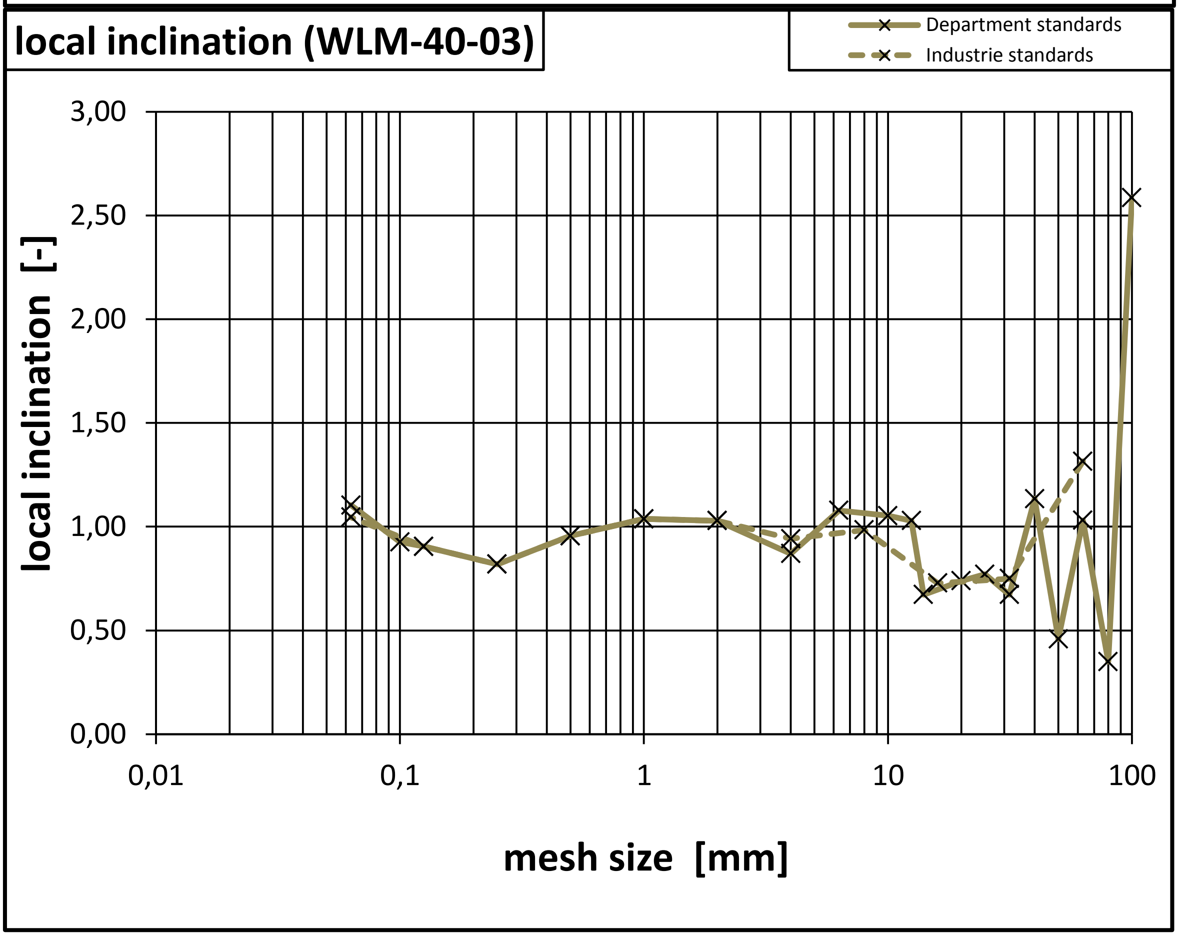
BLOCK	sample ID	blasting date	29.07.2010		
		sieving date	25.08.2010-26.08.2010		
		material	concrete		
	geometry	form	cube		
		X:	400,00		[mm]
		Y:	400,00		[mm]
		Z:	400,00		[mm]
		volume	0,064000		[m³]
		weight	155		[kg]
		density	2,44		[g/m³]
BLASTING	initiation	NONEL			
	explosive	PETN cord	type	20	[g/m]
			length	0,4	[m]
			charge mass	8,00	[g]
			spezific charge	51,21	[g/t]
	VOD	length	400,00		[mm]
		time	55,80		[µs]
		VOD	7168,46		[m/s]
	geometry	diameter	8		[mm]
		length	-------		[mm]

SCREENING

screensize [mm]	mass [g]	passing [%]
>125	120642,2	22,73%
125/100	15557,2	12,77%
100/80	1495,9	11,81%
80/63	4023,8	9,23%
63/50	1450,2	8,30%
50/40	2899,1	6,45%
40/31,5	1493,7	5,49%
31,5/25	1397,5	4,59%
25/20	1090,7	3,90%
20/14	1297,8	3,07%
14/12,5	526,8	2,73%
12,5/10	891,5	2,16%
10/6,3	1321,4	1,31%
6,3/4	667,9	0,88%
4/2	702,6	0,43%
2/1	346,3	0,21%
1/0,5	159,4	0,11%
0,5/0,250	73,5	0,06%
0,250/0,125	44,8	0,03%
0,125/0,100	9,6	0,03%
0,100/0,063	16,7	0,02%
<0,063	25,1	0,00%
TOTAL	156133,70	[g]

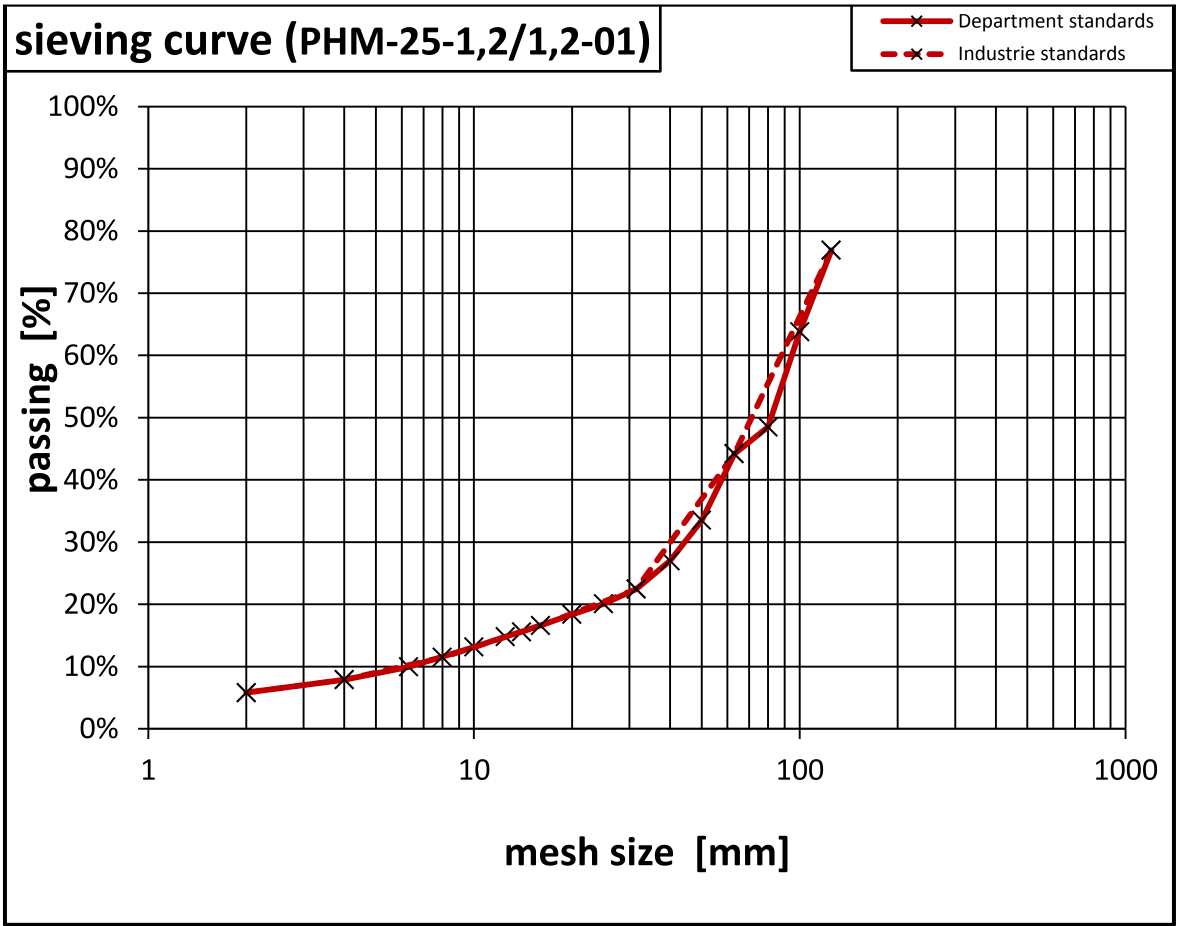


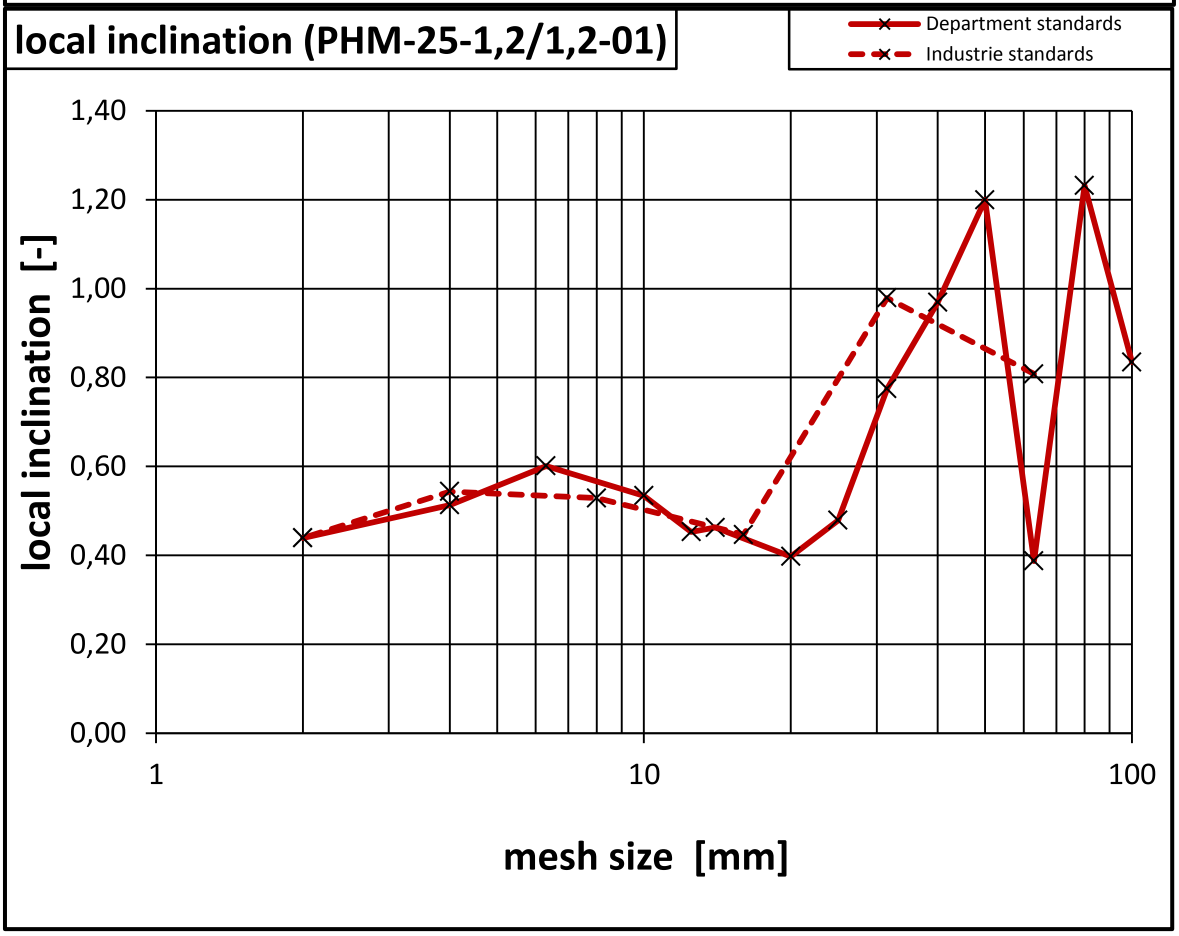
sieving curve (WLM-40-03)
Department standards
Industrie standards
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
passing [%]
0,01
0,1
1
10
100
1000
mesh size [mm]



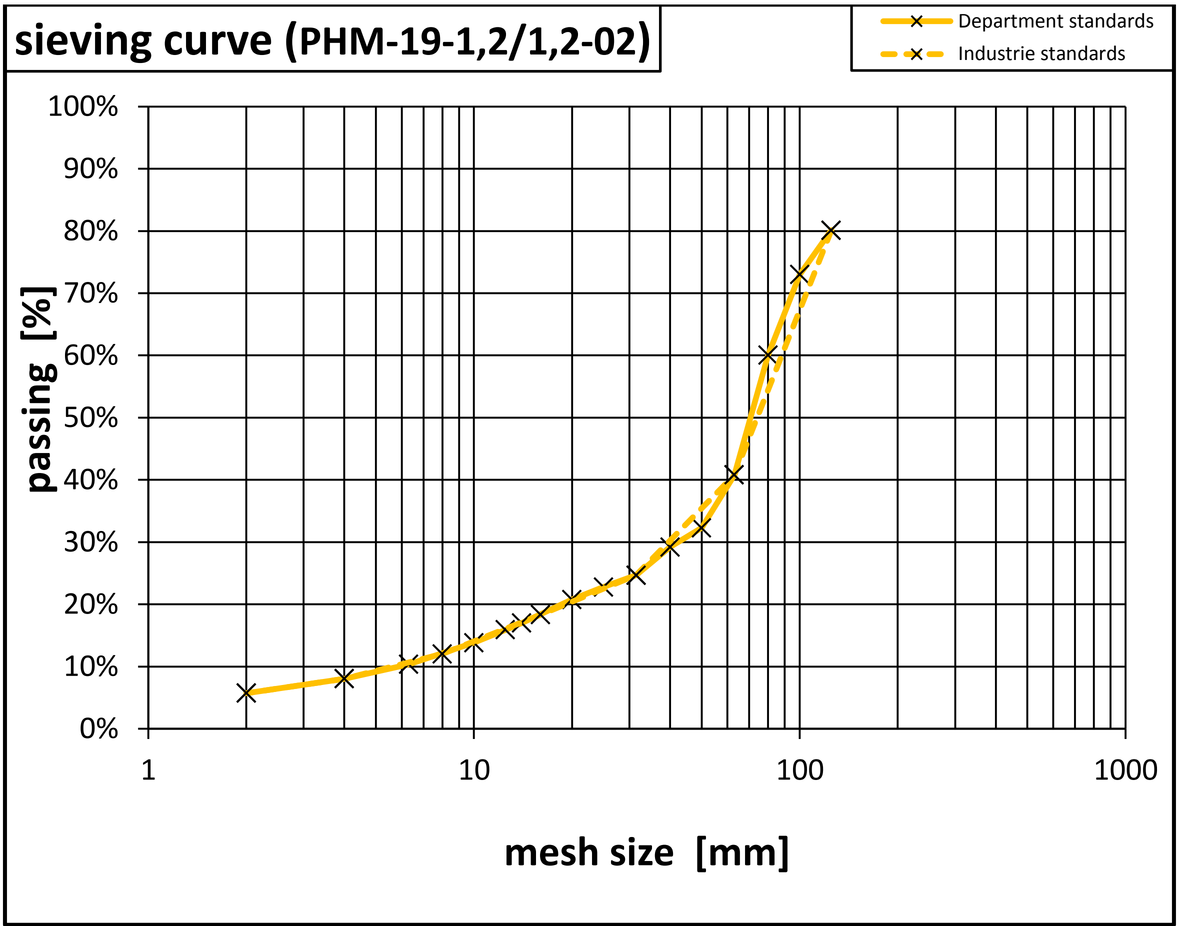
local inclination (WLM-40-03)
Department standards
Industrie standards
3,00
2,50
2,00
1,50
1,00
0,50
0,00
local inclination [-]
0,01
0,1
1
10
100
mesh size [mm]

BLOCK	sample ID	sample Nr.:	**PHM-25-1,2/1,2-01**			SCREENING	feeding mass	32062,90	[g]
		blasting date:	22.09.2010				other mass	2	[g]
		sieving date:	16.12.2010				screening loss	78,80	[g]
		material:	concrete						
		form:	cuboid				screensize [mm]	mass [g]	passing [%]
	geometry	X:	1000		[mm]		>125	7388,00	76,90%
		Y:	1960		[mm]		125/100	4180,00	63,83%
		Z:	1000		[mm]		100/80	4906,00	48,49%
		volume:	1,96		[m³]		80/63	1370,60	44,20%
		weight	4743,2		[kg]		63/50	3423,00	33,50%
		density:	2,42		[g/m³]		50/40	2083,20	26,99%
BLASTING	initiation	NONEL					40/31,5	1458,00	22,43%
	explosive	PETN	detonating cord		[20 g/m]		31,5/25	751,40	20,08%
			BL1	19	[g]		25/20	544,80	18,38%
			BL2	-------	[g]		20/14	893,80	15,58%
			BL3	-------	[g]		14/12,5	249,30	14,80%
			overall:	19	[g]		12,5/10	531,90	13,14%
	specific charge	BL1	592,59	[g/t]			10/6,3	1018,80	9,95%
		BL2	-------	[g/t]			6,3/4	661,80	7,88%
		BL3	-------	[g/t]			4/2	661,80	5,81%
	geometry	diameter	8		[mm]		2/1	1859,70	0,00%
		length	total length		-------		TOTAL	31982,10	[g]

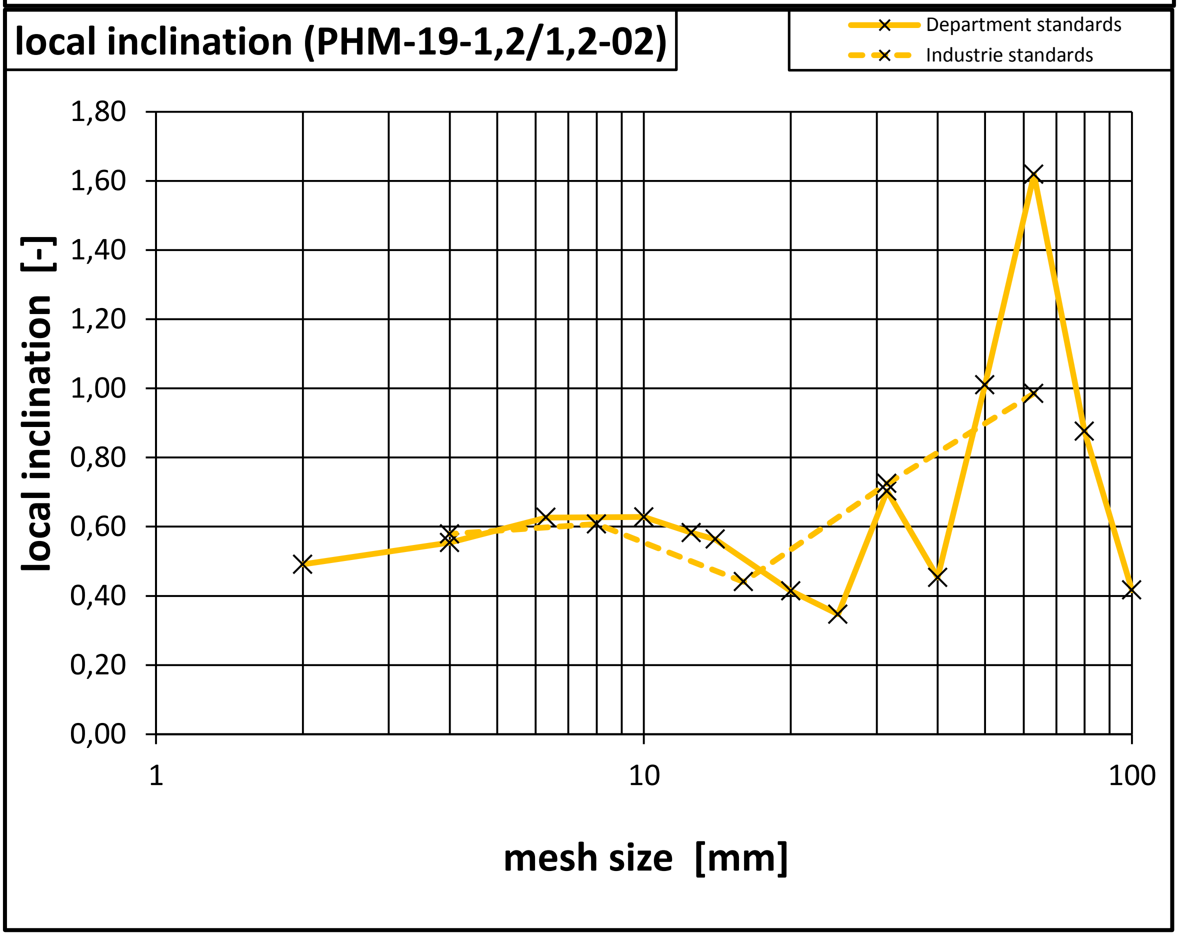

sieving curve (PHM-25-1,2/1,2-01)
Department standards
Industrie standards
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
passing [%]
1
10
100
1000
mesh size [mm]


local inclination (PHM-25-1,2/1,2-01)
Department standards
Industrie standards
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
local inclination [-]
1
10
100
mesh size [mm]

BLOCK	sample ID	sample Nr.:	**PHM-19-1,2/1,2-02**		SCREENING	feeding mass	38099,30	[g]
		blasting date:	28.09.2010			other mass	3,2	[g]
		sieving date:	17.12.2010			screening loss	82,40	[g]
		material:	concrete					
		form:	cuboid			screensize [mm]	mass [g]	passing [%]
	geometry	X:	1000	[mm]		>125	7560,00	80,11%
		Y:	1960	[mm]		125/100	2701,20	73,01%
		Z:	1000	[mm]		100/80	4925,00	60,05%
		volume:	1,96	[m³]		80/63	7321,00	40,79%
		weight	4743,2	[kg]		63/50	3229,00	32,30%
		density:	2,42	[g/m³]		50/40	1180,10	29,19%
BLASTING	initiation	NONEL				40/31,5	1714,90	24,68%
	explosive	PETN	detonating cord	[20 g/m]		31,5/25	721,90	22,78%
			BL1 19	[g]		25/20	764,60	20,77%
			BL2 -------	[g]		20/14	1438,40	16,99%
			BL3 -------	[g]		14/12,5	412,70	15,90%
			overall: 19	[g]		12,5/10	790,40	13,82%
	specific charge	BL1	498,70	[g/t]		10/6,3	1320,90	10,35%
		BL2	-------	[g/t]		6,3/4	875,20	8,05%
		BL3	-------	[g/t]		4/2	882,50	5,72%
	geometry	diameter	8	[mm]		2/1	2175,90	0,00%
		length	total length	-------		TOTAL	38013,70	[g]

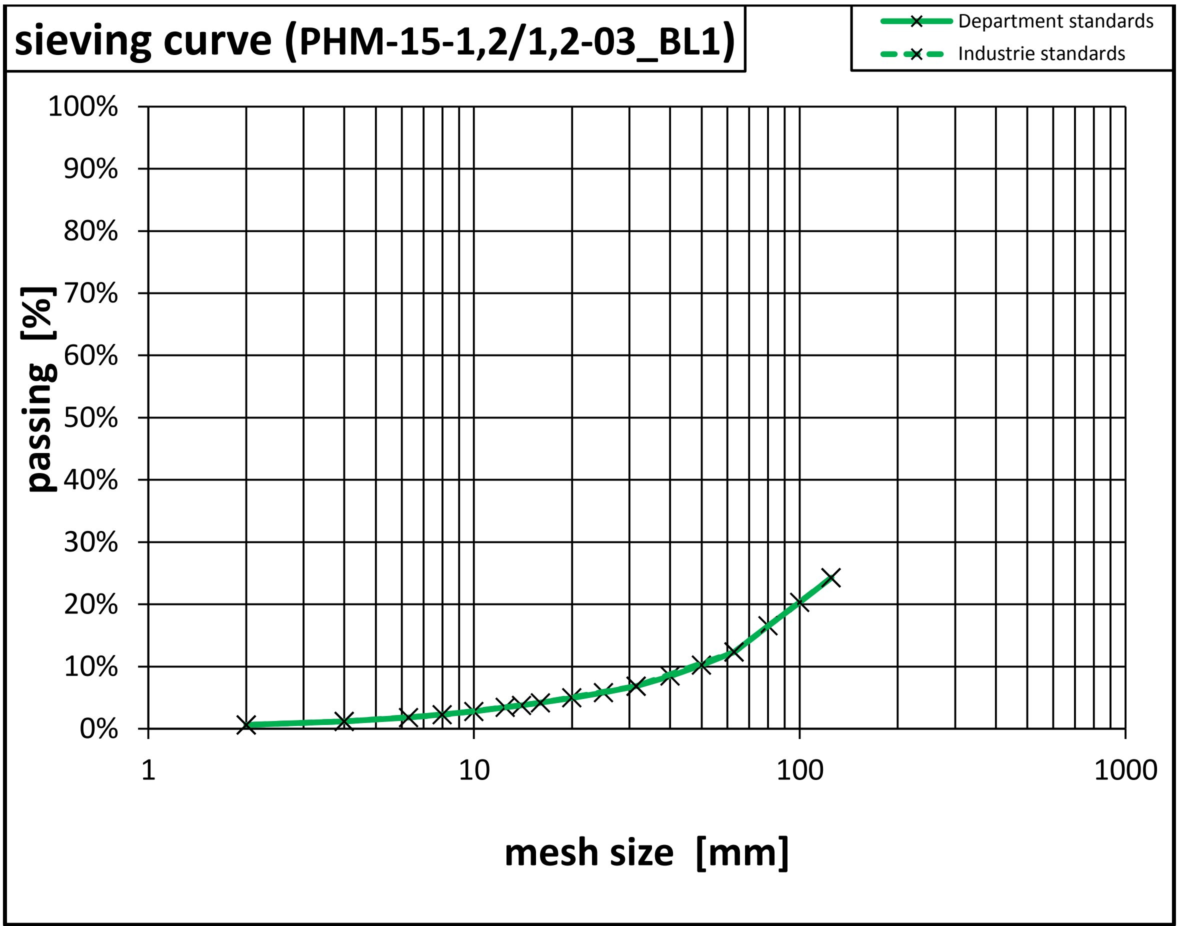


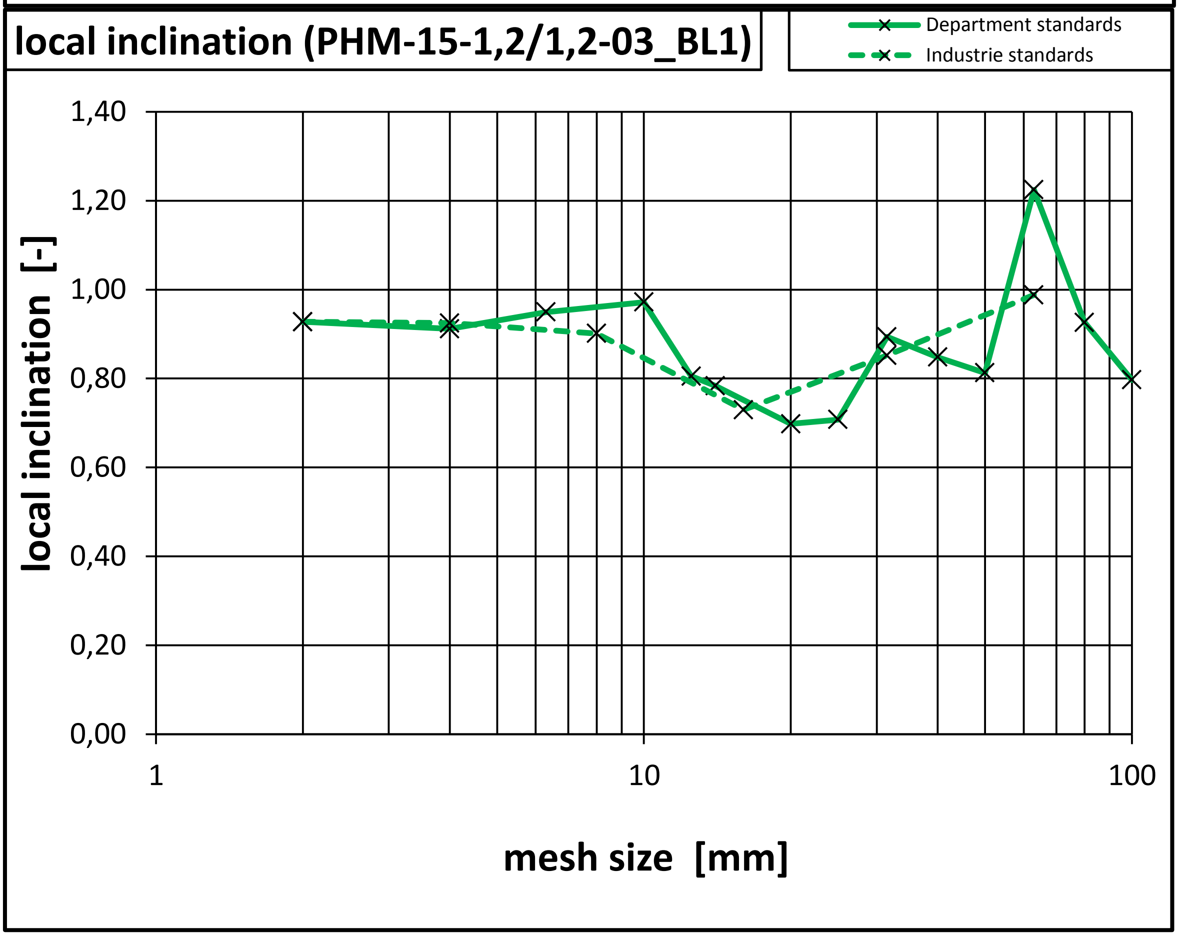
sieving curve (PHM-19-1,2/1,2-02)
Department standards
Industrie standards
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
passing [%]
1
10
100
1000
mesh size [mm]



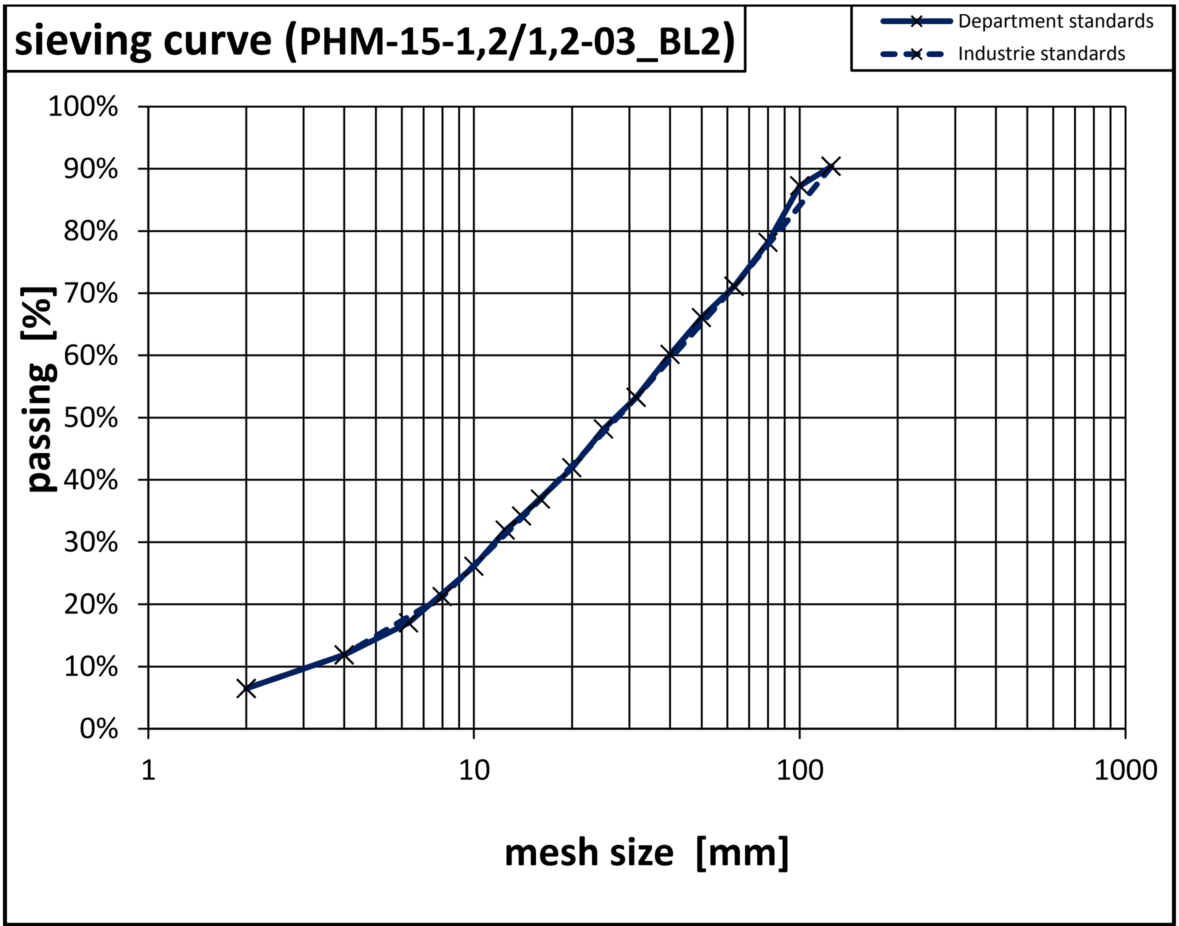
local inclination (PHM-19-1,2/1,2-02)
Department standards
Industrie standards
1,80
1,60
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
local inclination [-]
1
10
100
mesh size [mm]

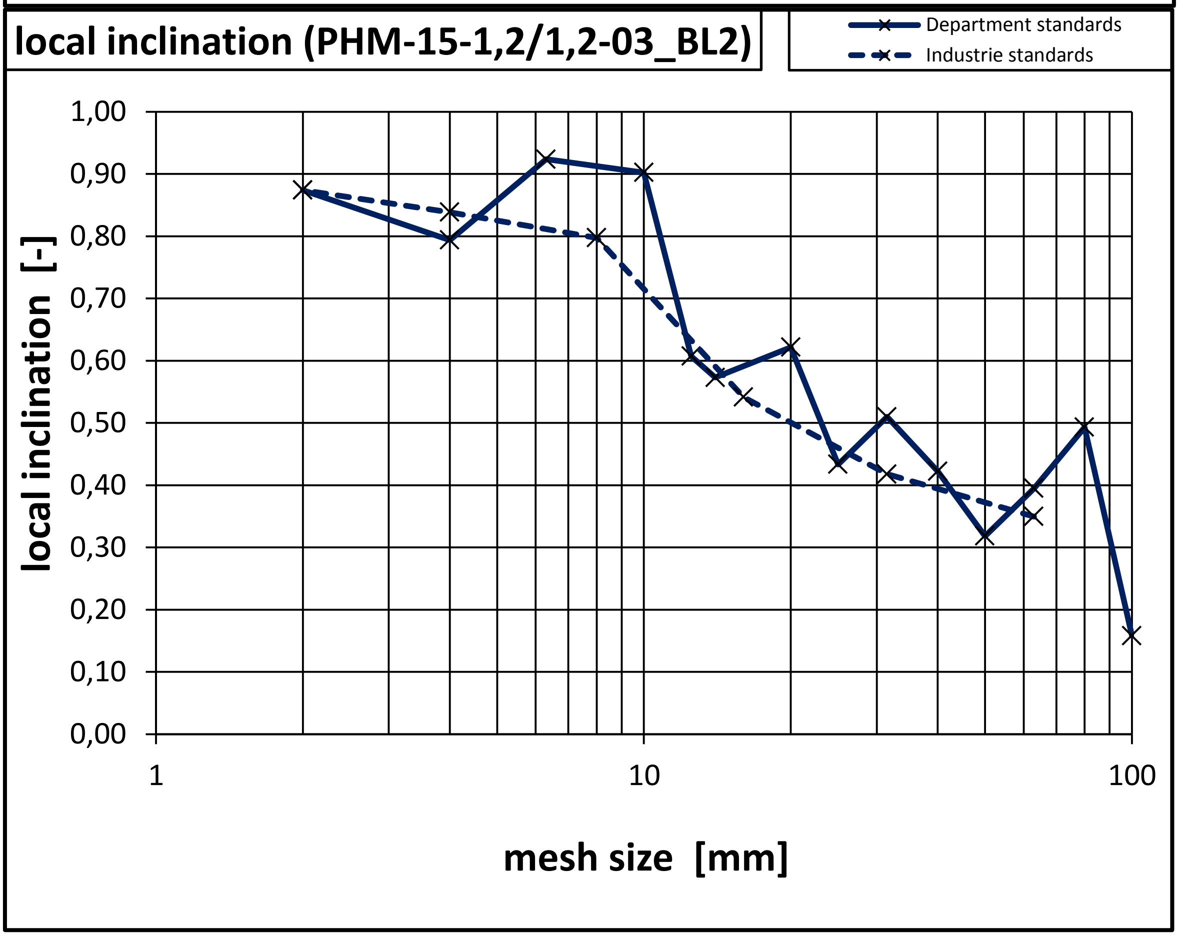
BLOCK	sample ID	sample Nr.:	**PHM-15-1,2/1,2-03-BL1**			SCREENING	feeding mass	198144,30	[g]
		blasting date:	06.10.2010				other mass	3	[g]
		sieving date:	20.12.2010-21.10.2010				screening loss	96,70	[g]
		material:	concrete						
		form:	cuboid				screensize [mm]	mass [g]	passing [%]
	geometry	X:	1000		[mm]		>125	149976,70	24,27%
		Y:	1960		[mm]		125/100	7830,00	20,32%
		Z:	1000		[mm]		100/80	7513,00	16,52%
		volume:	1,96		[m³]		80/63	8300,00	12,33%
		weight	4743,2		[kg]		63/50	4182,00	10,22%
		density:	2,42		[g/m³]		50/40	3490,00	8,46%
BLASTING	initiation	NONEL					40/31,5	3220,00	6,83%
	explosive	PETN	detonating cord		[20 g/m]		31,5/25	2041,30	5,80%
			BL1	19	[g]		25/20	1657,30	4,97%
			BL2	-------	[g]		20/14	2397,70	3,76%
			BL3	-------	[g]		14/12,5	648,50	3,43%
			overall:	19	[g]		12,5/10	1323,30	2,76%
	specific charge	BL1	95,89	[g/t]			10/6,3	1940,90	1,78%
		BL2	-------	[g/t]			6,3/4	1194,90	1,18%
		BL3	-------	[g/t]			4/2	1104,40	0,62%
	geometry	diameter	8		[mm]		2/1	1224,60	0,00%
		length	950		[mm]		TOTAL	198044,60	[g]


sieving curve (PHM-15-1,2/1,2-03_BL1)
Department standards
Industrie standards
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
passing [%]
1
10
100
1000
mesh size [mm]


local inclination (PHM-15-1,2/1,2-03_BL1)
Department standards
Industrie standards
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
local inclination [-]
1
10
100
mesh size [mm]

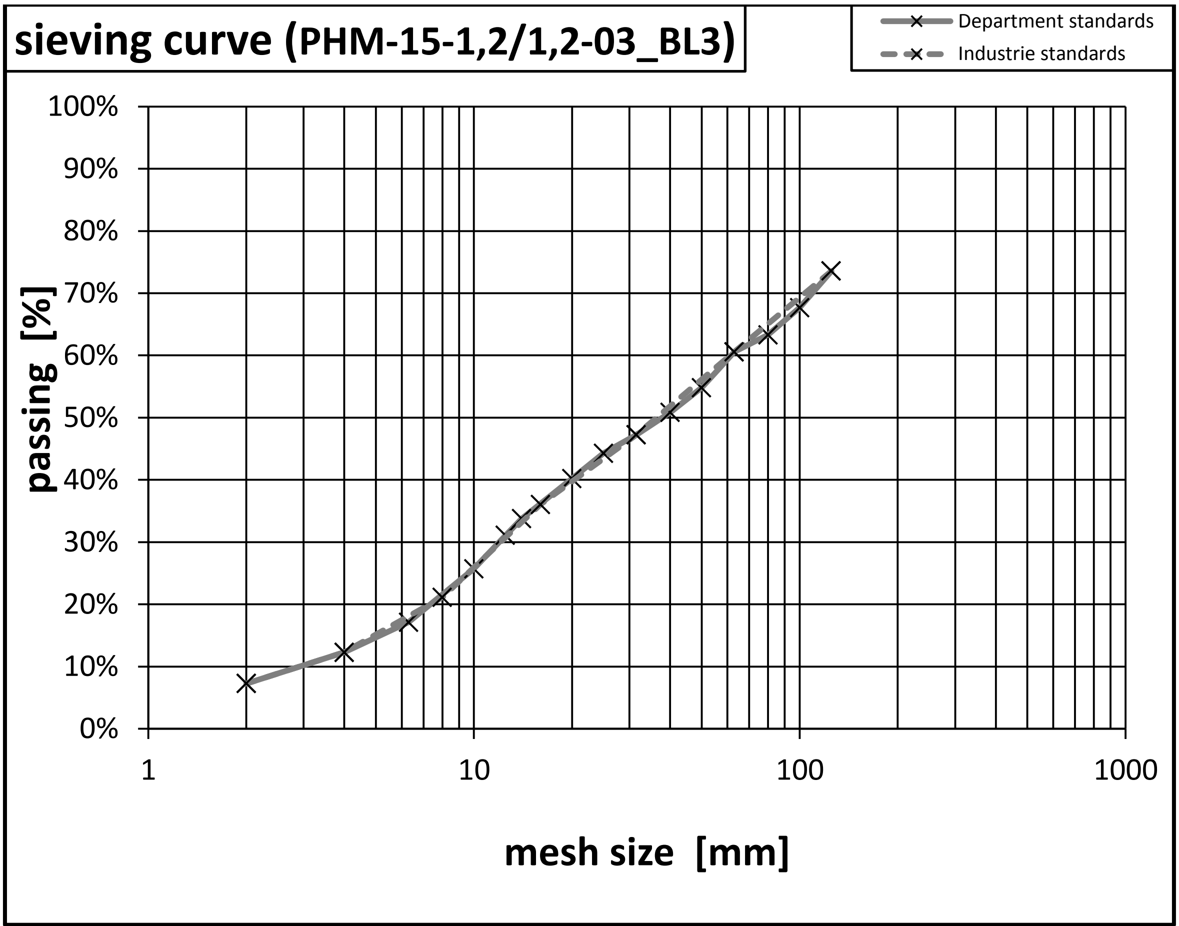
BLOCK	sample ID	sample Nr.:	**PHM-15-1,2/1,2-03-BL2**		SCREENING	feeding mass	28726,20	[g]
		blasting date:	06.10.2010			other mass	6,7	[g]
		sieving date:	22.12.2010			screening loss	185,90	[g]
		material:	concrete					
		form:	cuboid			screensize [mm]	mass [g]	passing [%]
	geometry	X:	1000	[mm]		>125	2744,20	90,38%
		Y:	1960	[mm]		125/100	893,60	87,25%
		Z:	1000	[mm]		100/80	2593,90	78,16%
		volume:	1,96	[m³]		80/63	2008,10	71,12%
		weight	4743,2	[kg]		63/50	1438,60	66,08%
		density:	2,42	[g/m³]		50/40	1696,10	60,14%
BLASTING	initiation	NONEL				40/31,5	1967,60	53,24%
	explosive	PETN	detonating cord	[20 g/m]		31,5/25	1447,90	48,17%
			BL1 -------	[g]		25/20	1780,40	41,93%
			BL2 19	[g]		20/14	2211,00	34,18%
			BL3 -------	[g]		14/12,5	648,60	31,90%
			overall: 19	[g]		12,5/10	1660,50	26,09%
	specific charge	BL1	-------	[g/t]		10/6,3	2585,80	17,02%
		BL2	661,42	[g/t]		6,3/4	1470,50	11,87%
		BL3	-------	[g/t]		4/2	1538,90	6,48%
	geometry	diameter	8	[mm]		2/1	1847,90	0,00%
		length	total length	-------		TOTAL	28533,60	[g]


sieving curve (PHM-15-1,2/1,2-03_BL2)
Department standards
Industrie standards
passing [%]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
10
100
1000
mesh size [mm]

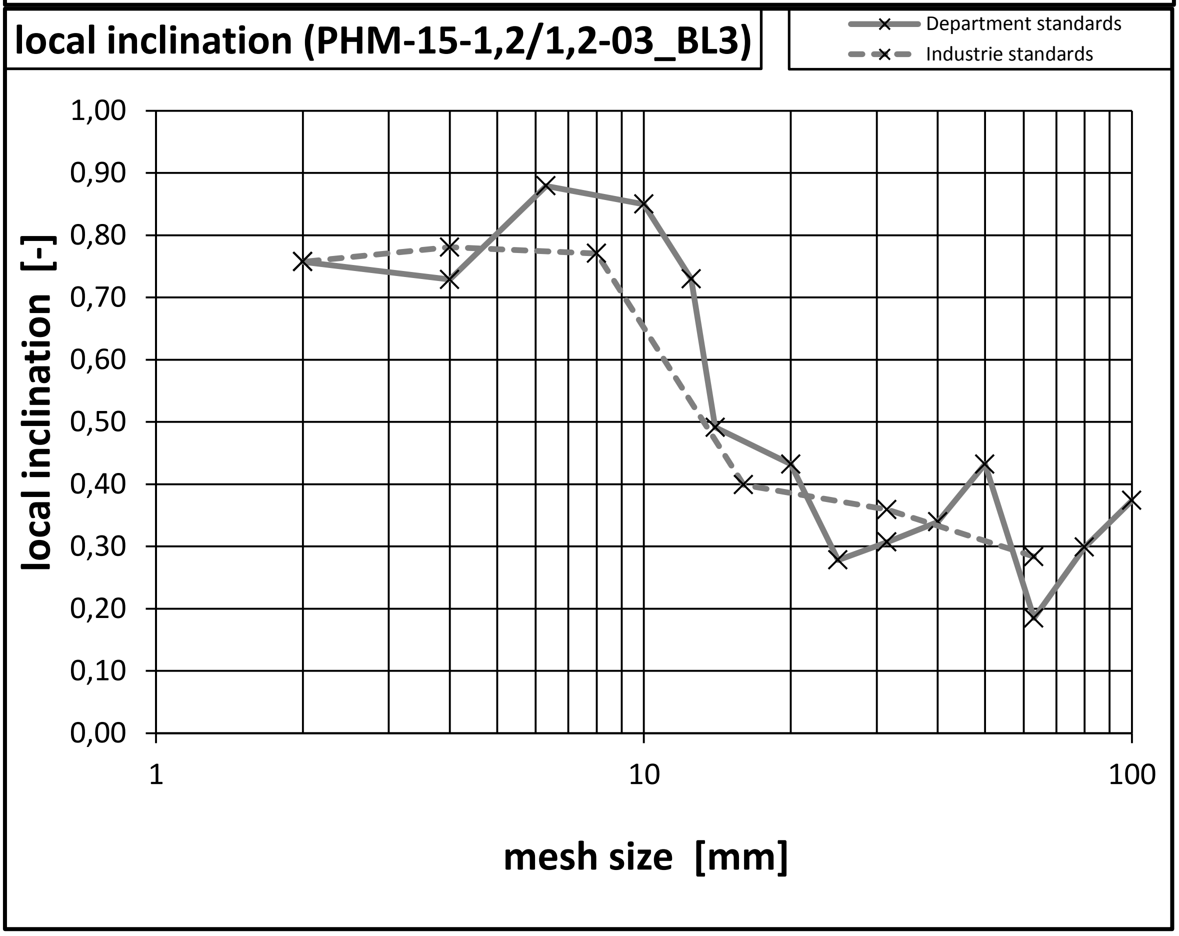

local inclination (PHM-15-1,2/1,2-03_BL2)
Department standards
Industrie standards
local inclination [-]
1,00
0,90
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
1
10
100
mesh size [mm]

BLOCK	sample ID	sample Nr.:	**PHM-15-1,2/1,2-03-BL3**			
		blasting date:	06.10.2010			
		sieving date:	10.01.2011			
		material:	concrete			
		form:	cuboid			
	geometry	X:	1000		[mm]	
		Y:	1960		[mm]	
		Z:	1000		[mm]	
		volume:	1,96		[m³]	
		weight	4743,2		[kg]	
		density:	2,42		[g/m³]	
BLASTING	initiation	NONEL				
	explosive	PETN	detonating cord		[20 g/m]	
			BL1	-------	[g]	
			BL2	-------	[g]	
			BL3	17	[g]	
			overall:	17	[g]	
	specific charge	BL1	-------	[g/t]		
		BL2	-------	[g/t]		
		BL3	614,14	[g/t]		
	geometry	diameter	8		[mm]	
		length	total length		-------	

SCREENING			
	feeding mass	27681,00	[g]
	other mass	2,5	[g]
	screening loss	56,60	[g]
	screensize [mm]	mass [g]	passing [%]
	>125	7303,00	73,56%
	125/100	1626,20	67,67%
	100/80	1205,20	63,31%
	80/63	755,40	60,58%
	63/50	1590,10	54,82%
	50/40	1104,30	50,82%
	40/31,5	992,90	47,23%
	31,5/25	812,10	44,29%
	25/20	1124,40	40,22%
	20/14	1785,10	33,75%
	14/12,5	740,00	31,07%
	12,5/10	1482,80	25,71%
	10/6,3	2370,60	17,12%
	6,3/4	1333,20	12,30%
	4/2	1387,20	7,27%
	2/1	2009,40	0,00%
	TOTAL	27621,90	[g]



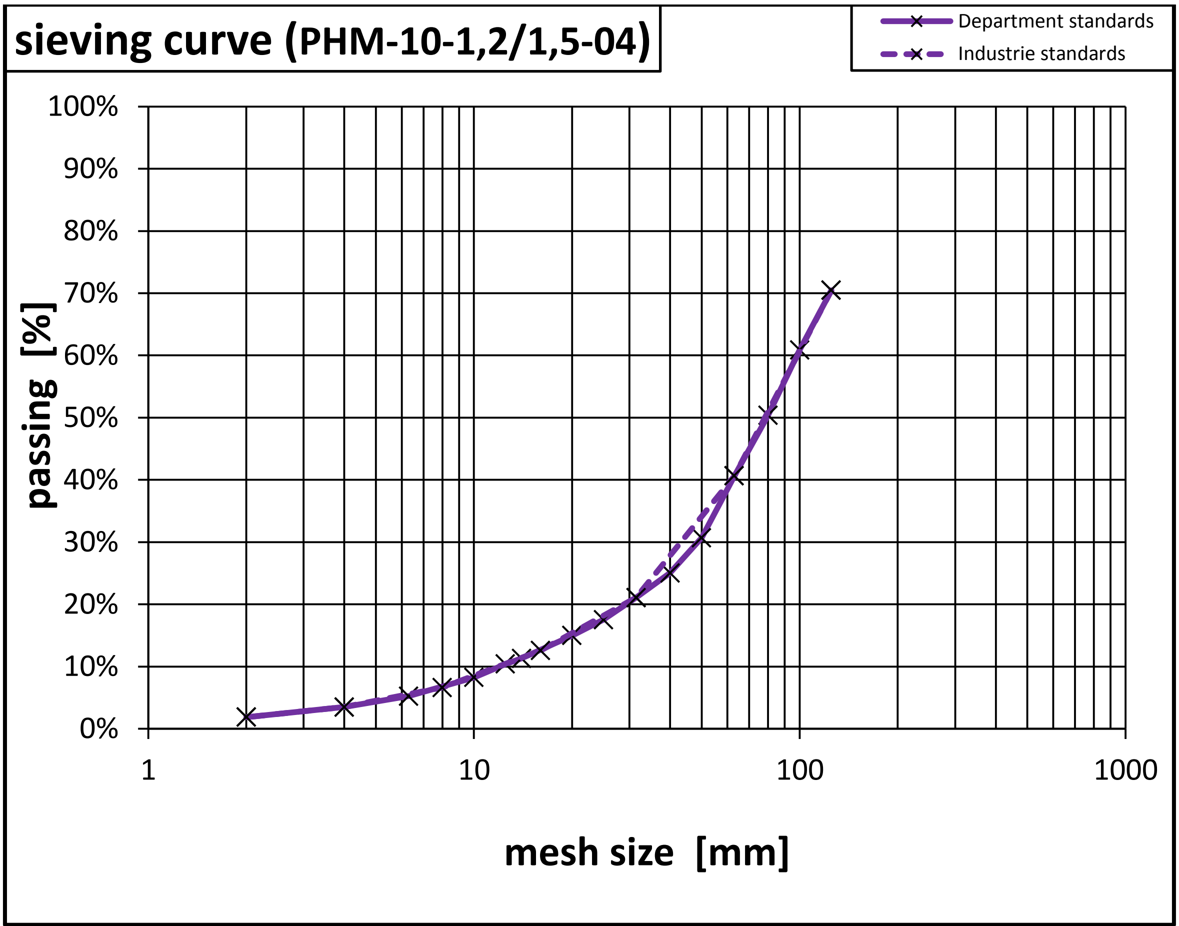
sieving curve (PHM-15-1,2/1,2-03_BL3)
Department standards
Industrie standards
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
passing [%]
1
10
100
1000
mesh size [mm]

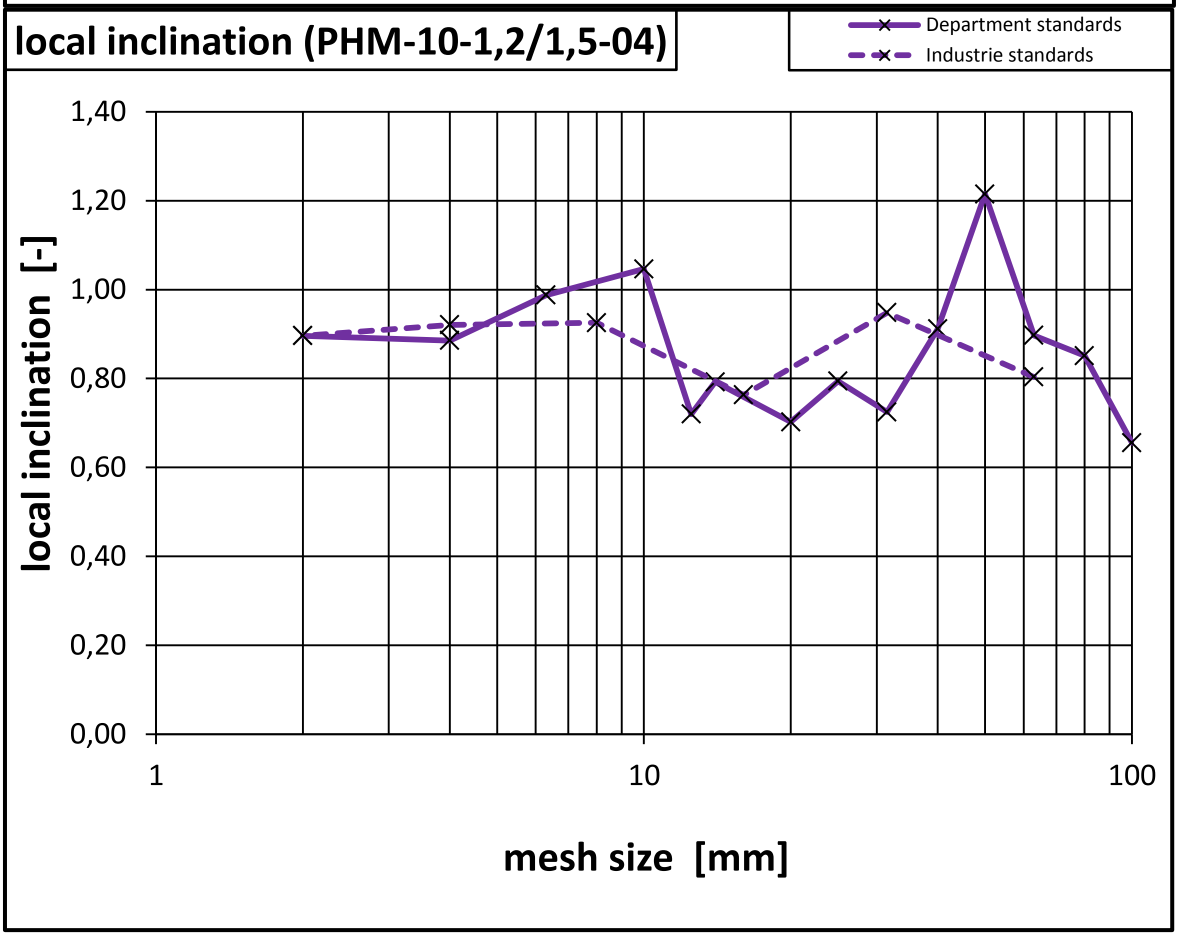


local inclination (PHM-15-1,2/1,2-03_BL3)
Department standards
Industrie standards
1,00
0,90
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
local inclination [-]
1
10
100
mesh size [mm]

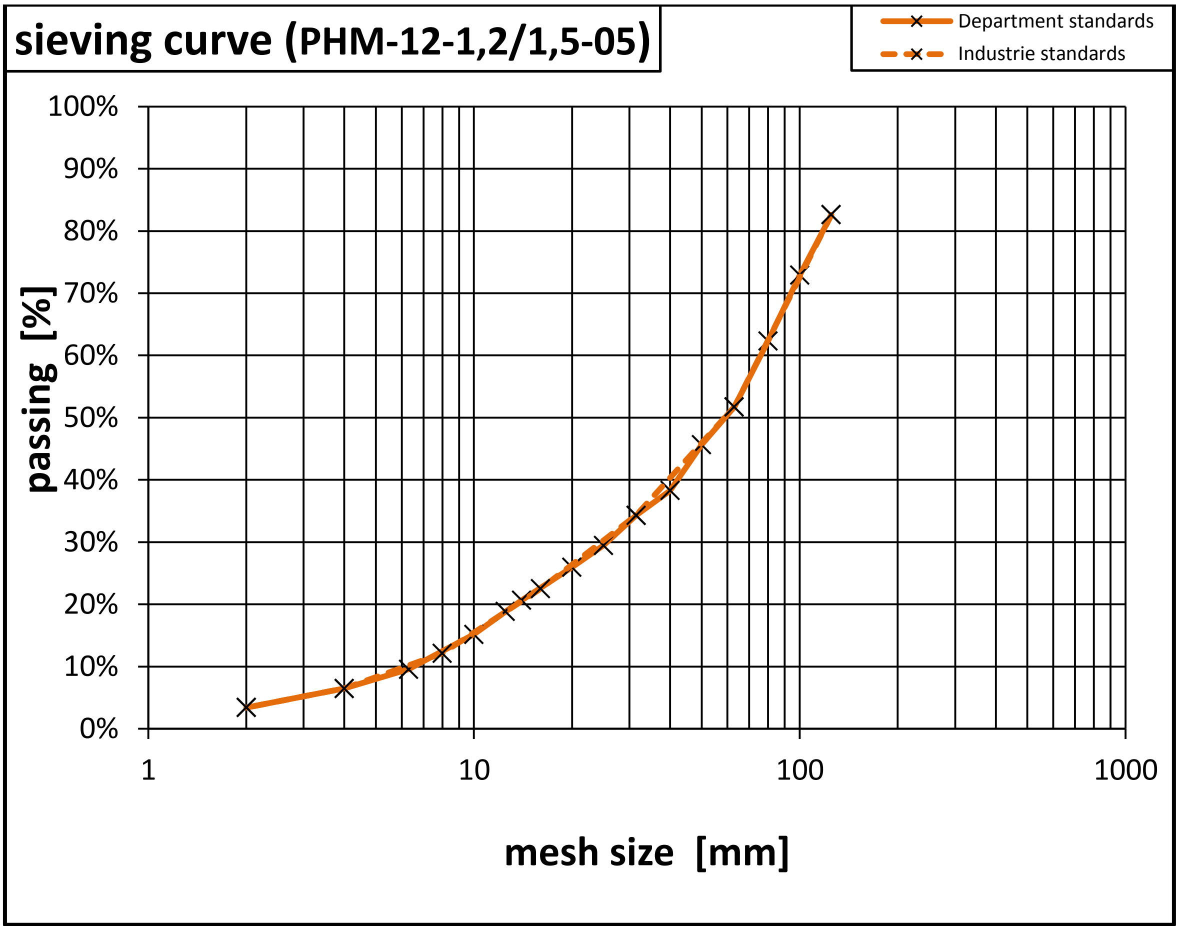
BLOCK	sample ID	sample Nr.:	**PHM-10-1,2/1,5-04**		
		blasting date:	28.10.2010		
		sieving date:	11.01.2011		
		material:	concrete		
		form:	cuboid		
	geometry	X:	1002		[mm]
		Y:	1960		[mm]
		Z:	1002		[mm]
		volume:	1,97		[m³]
		weight	4762,2		[kg]
		density:	2,42		[g/m³]
BLASTING	initiation	NONEL			
	explosive	PETN	detonating cord		[20 g/m]
			BL1	19	[g]
			BL2	-------	[g]
			BL3	-------	[g]
			overall:	19	[g]
	specific charge	BL1	174,00	[g/t]	
		BL2	-------	[g/t]	
		BL3	-------	[g/t]	
	geometry	diameter	8		[mm]
		length	total length		-------

SCREENING			
	feeding mass	109193,00	[g]
	other mass	2,1	[g]
	screening loss	173,40	[g]
	screensize [mm]	mass [g]	passing [%]
	>125	32178,00	70,48%
	125/100	10454,00	60,89%
	100/80	11482,00	50,36%
	80/63	10588,00	40,65%
	63/50	10847,00	30,70%
	50/40	6159,00	25,05%
	40/31,5	4340,00	21,07%
	31,5/25	3850,00	17,54%
	25/20	2772,90	14,99%
	20/14	4024,00	11,30%
	14/12,5	965,50	10,42%
	12,5/10	2364,90	8,25%
	10/6,3	3295,00	5,23%
	6,3/4	1886,90	3,50%
	4/2	1763,10	1,88%
	2/1	2047,20	0,00%
	TOTAL	109017,50	[g]

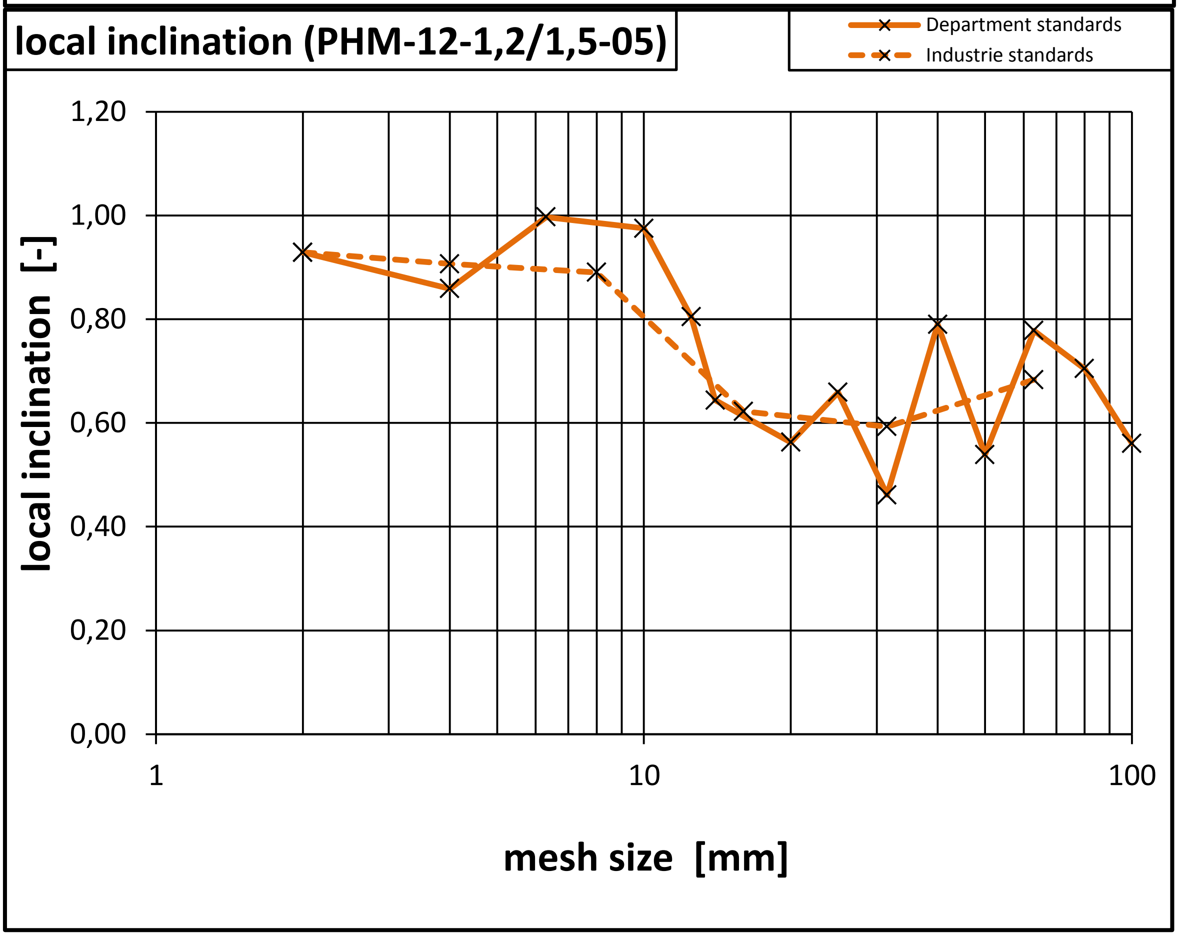

sieving curve (PHM-10-1,2/1,5-04)
Department standards
Industrie standards
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
passing [%]
1
10
100
1000
mesh size [mm]


local inclination (PHM-10-1,2/1,5-04)
Department standards
Industrie standards
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
local inclination [-]
1
10
100
mesh size [mm]

BLOCK	sample ID	sample Nr.:	**PHM-12-1,2/1,5-05**			SCREENING	feeding mass	138123,30	[g]
		blasting date:	12.11.2010				other mass	12,8	[g]
		sieving date:	14.01.2011				screening loss	494,00	[g]
		material:	concrete						
		form:	cuboid				screensize [mm]	mass [g]	passing [%]
	geometry	X:	1000		[mm]		>125	23923,00	82,62%
		Y:	1958		[mm]		125/100	13370,00	72,90%
		Z:	1004		[mm]		100/80	14598,00	62,29%
		volume:	1,97		[m³]		80/63	14538,00	51,73%
		weight	4757,3		[kg]		63/50	8338,00	45,67%
		density:	2,42		[g/m³]		50/40	10157,00	38,29%
BLASTING	initiation	NONEL					40/31,5	5496,00	34,30%
	explosive	PETN	detonating cord		[40 g/m]		31,5/25	6667,00	29,45%
			BL1	38	[g]		25/20	4782,00	25,98%
			BL2	-------	[g]		20/14	7333,50	20,65%
			BL3	-------	[g]		14/12,5	2476,00	18,85%
			overall:	38	[g]		12,5/10	5072,00	15,16%
	specific charge	BL1	275,12	[g/t]			10/6,3	7702,00	9,57%
		BL2	-------	[g/t]			6,3/4	4253,00	6,48%
		BL3	-------	[g/t]			4/2	4230,00	3,40%
	geometry	diameter	10		[mm]		2/1	4681,00	0,00%
		length	total length		-------		TOTAL	137616,50	[g]



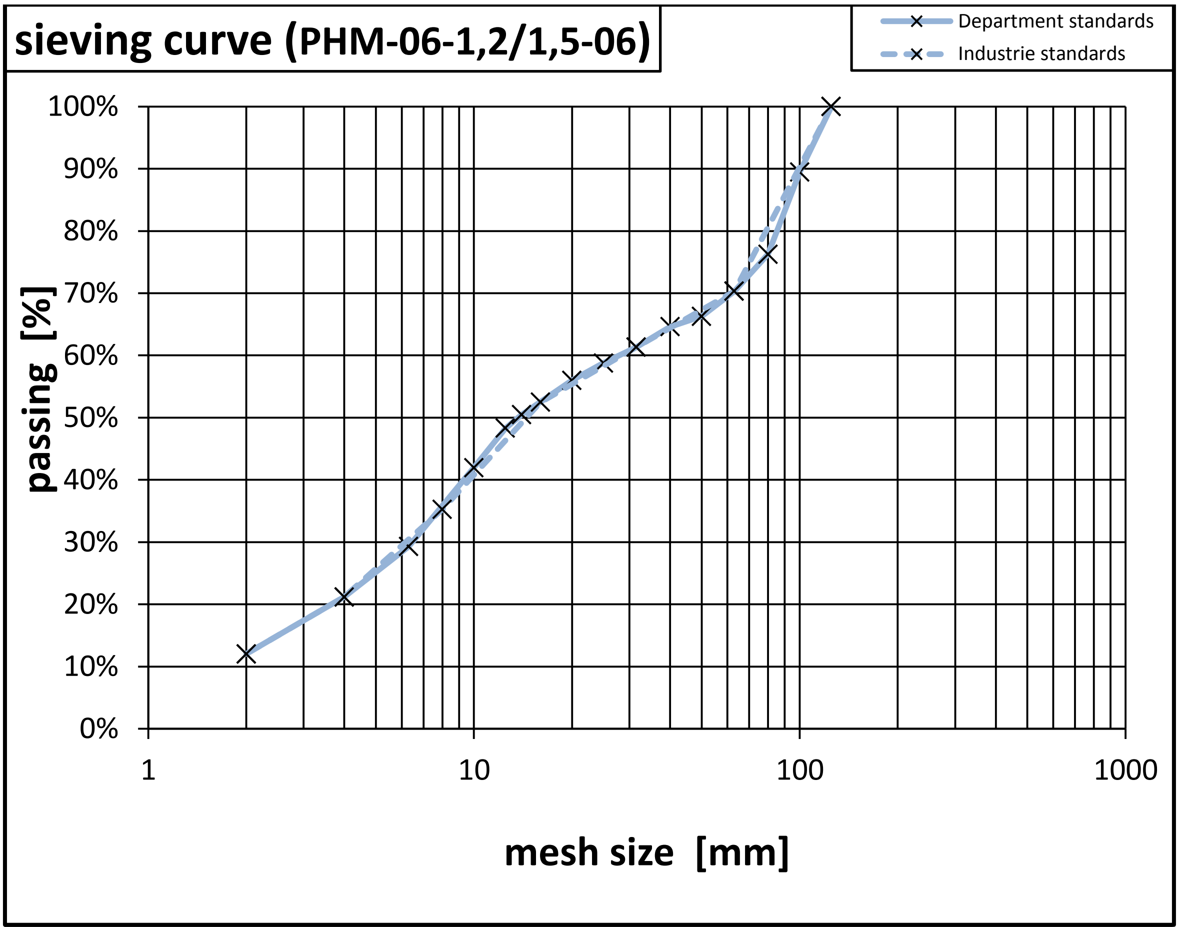
sieving curve (PHM-12-1,2/1,5-05)
Department standards
Industrie standards
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
passing [%]
1
10
100
1000
mesh size [mm]



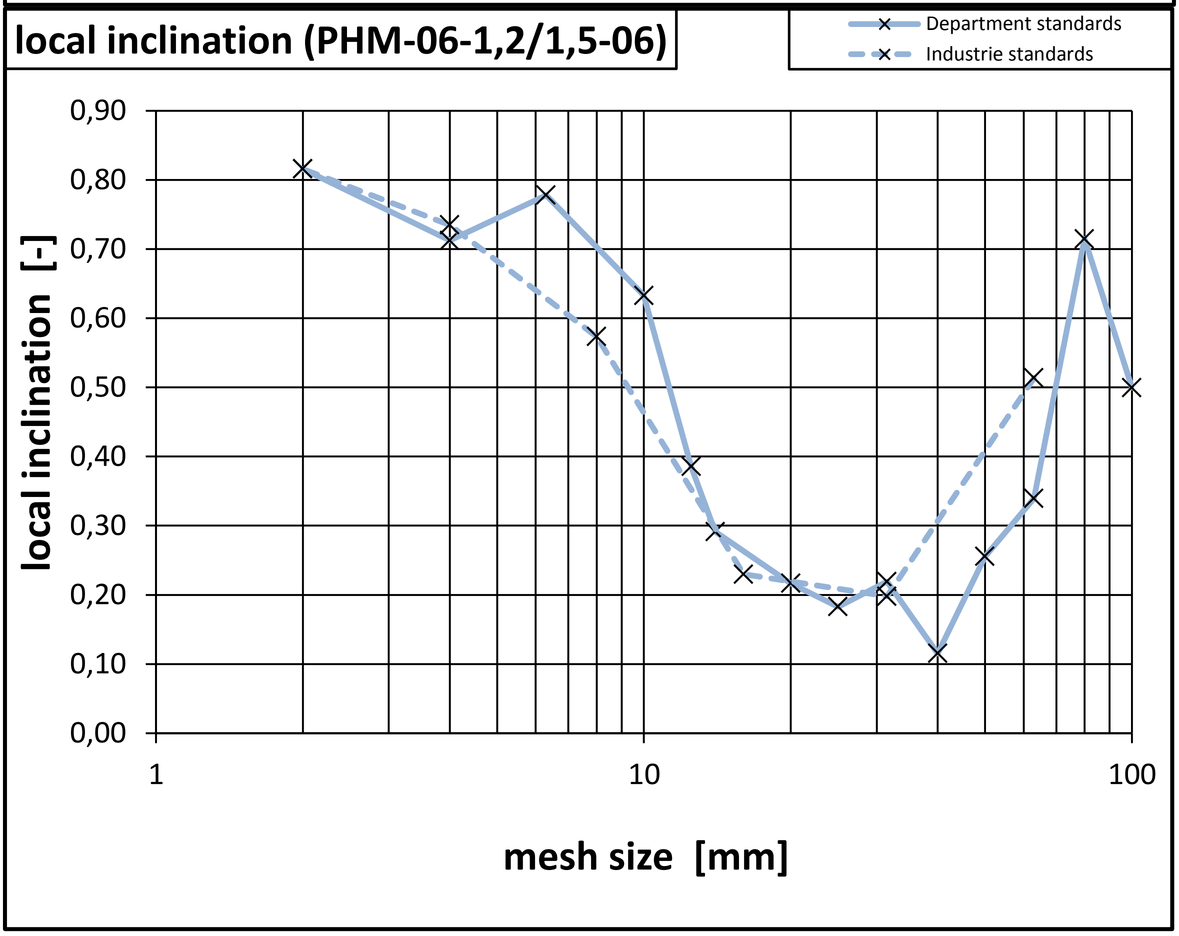
local inclination (PHM-12-1,2/1,5-05)
Department standards
Industrie standards
1,20
1,00
0,80
0,60
0,40
0,20
0,00
local inclination [-]
1
10
100
mesh size [mm]

BLOCK	sample ID	sample Nr.:	**PHM-06-1,2/1,5-06**	
		blasting date:	19.11.2010	
		sieving date:	09.12.2010-10.12.2010	
		material:	concrete	
		form:	cuboid	
	geometry	X:	1002	[mm]
		Y:	1958	[mm]
		Z:	1002	[mm]
		volume:	1,97	[m³]
		weight	4757,3	[kg]
		density:	2,42	[g/m³]
BLASTING	initiation	NONEL		
	explosive	PETN	detonating cord	[40 g/m]
			BL1 38	[g]
			BL2 -------	[g]
			BL3 -------	[g]
			overall: 38	[g]
	specific charge	BL1	1234,37	[g/t]
		BL2	-------	[g/t]
		BL3	-------	[g/t]
	geometry	diameter	10	[mm]
		length	total length	-------

SCREENING			
feeding mass	30785,00	[g]
other mass	18,3	[g]
screening loss	142,00	[g]
screensize [mm]	mass [g]	passing [%]
>125	0,00	100,00%
125/100	3230,40	89,45%
100/80	4038,20	76,27%
80/63	1818,80	70,33%
63/50	1234,50	66,30%
50/40	515,20	64,61%
40/31,5	1008,80	61,32%
31,5/25	776,50	58,78%
25/20	849,30	56,01%
20/14	1693,30	50,48%
14/12,5	660,70	48,32%
12,5/10	1949,00	41,96%
10/6,3	3879,70	29,29%
6,3/4	2479,90	21,19%
4/2	2803,40	12,04%
2/1	3687,00	0,00%
TOTAL	30624,70	[g]



sieving curve (PHM-06-1,2/1,5-06)
Department standards
Industrie standards
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
passing [%]
1
10
100
1000
mesh size [mm]



local inclination (PHM-06-1,2/1,5-06)
Department standards
Industrie standards
0,90
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
local inclination [-]
1
10
100
mesh size [mm]

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Materialanalyse BBK-55-1

Verantwortlicher Prüfer: Wolfgang Hohl

Auftraggeber:	LBBK	Prüfdatum:	03.11.2010
Eingangsdatum:	27.10.2010	Masse:	1821.81 [g]
Entnahmeort:	Betonwerk Luiki	Höhe (L):	99.38 [mm]
Herstellungsdatum:	20.10.2010	Durchmesser (D):	98.34 [mm]
Materialart:	Beton	Dichte:	2.41 [g/cm³]
Maximale Prueflast:	371.55 kN	Probenfläche:	7595 [mm²]
Wassergehalt:	Nicht bestimmt [%]	Volumen:	754791 [mm³]
Probenkennung extern:	Nicht bekannt	L/D:	1.01 [-]
Projektbezeichnung:	Forschung allgemein	Probenlagerung:	unbekannt

Prüfparameter:	UCS	V-Modul	E-Modul	Poissonzahl	Zerstörungsarbeit
Bestimmt:	X	X	X	-	X

Prüfmaschinensteuerung

Aufnahme der Laengsdehnung durch: Elektronische Axialextensometer
Aufnahme der Querdehnung durch: Keine Messung
Steuerungsart: Verformungskontrolliert
Steuerungsrate: 0.5 mm/min
Anmerkungen: Keine Anmerkungen

Probenbeschreibung

Keine Anmerkungen

Parameter	Wert [MPa]	Unterspannung [MPa]	Unterspannung/ Bruchspannung	Oberspannung [MPa]	Oberspannung/ Bruchspannung
Einaxiale Druckfestigkeit	48.92				
V-Modul 1	24664.8	6.08	12.43 %	18.31	37.43 %
E-Modul 1	27124.27	0.39	0.8 %	20.79	42.5 %
V-Modul 2	24608.97	4.48	9.16 %	30.82	63 %
E-Modul 2	0	0	0 %	0	0 %
V-Modul Mittelwert	24636.885				
E-Modul Mittelwert	27124.27				
Poissonzahl [-]	0				
Zerstörungsarbeit [kJ/m³]	141.56				

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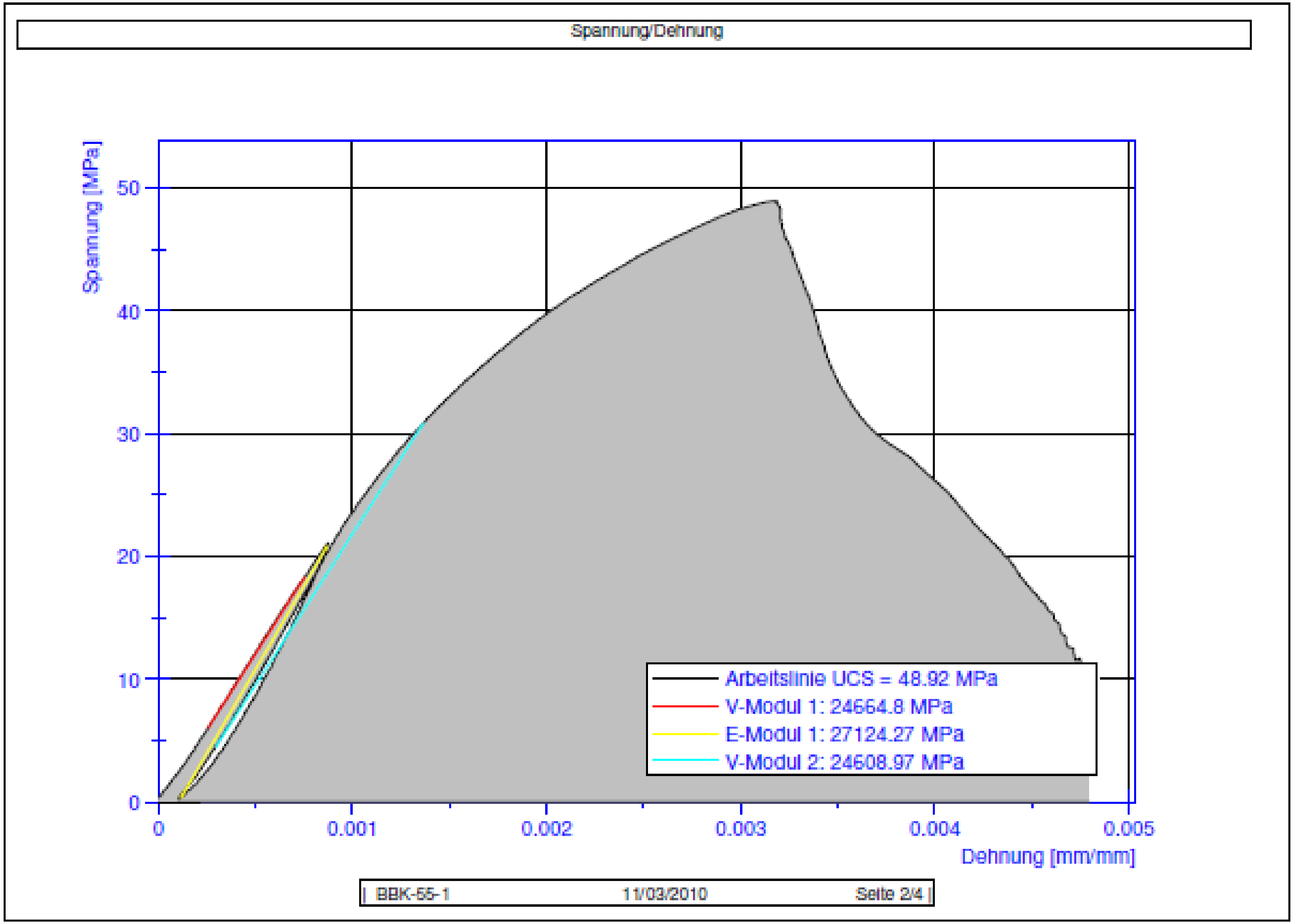
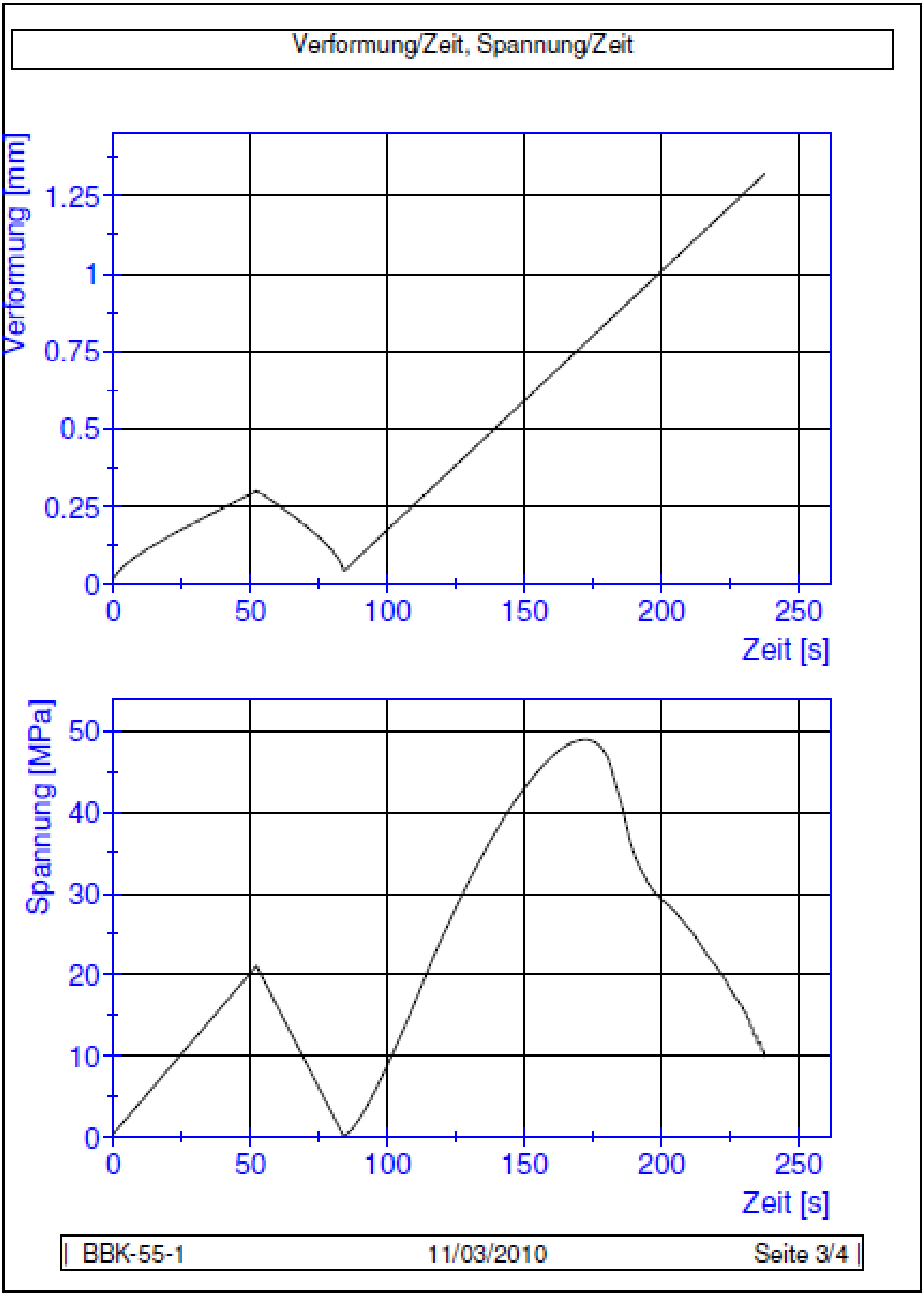
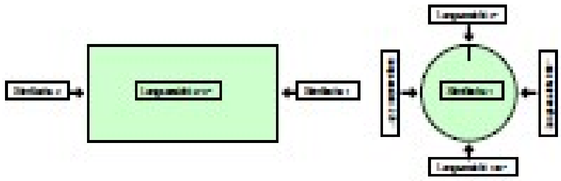


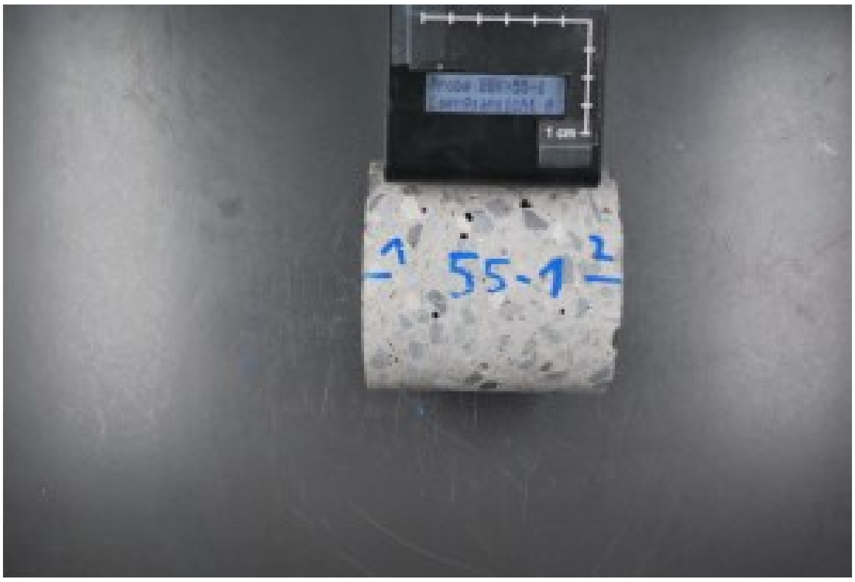
Spannung/Dehnung
Spannung [MPa]
0
10
20
30
40
50
0
0.001
0.002
0.003
0.004
0.005
Dehnung [mm/mm]
Arbeitslinie UCS = 48.92 MPa
V-Modul 1: 24664.8 MPa
E-Modul 1: 27124.27 MPa
V-Modul 2: 24608.97 MPa
| BBK-55-1
11/03/2010
Seite 2/4 |


Verformung/Zeit, Spannung/Zeit
Verformung [mm]
1.25
1
0.75
0.5
0.25
0
0
50
100
150
200
250
Zeit [s]
Spannung [MPa]
50
40
30
20
10
0
0
50
100
150
200
250
Zeit [s]
| BBK-55-1
11/03/2010
Seite 3/4 |

Fotodokumentation



Längsansicht 0°



Stirnfläche 1

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Materialanalyse BBK-55-2

Verantwortlicher Prüfer: Wolfgang Hohl

Auftraggeber:	LBBK	Prüfdatum:	03.11.2010
Eingangsdatum:	27.10.2010	Masse:	1811.03 [g]
Entnahmeort:	Betonwerk Luiki	Höhe (L):	98.12 [mm]
Herstellungsdatum:	20.10.2010	Durchmesser (D):	98.31 [mm]
Materialart:	Beton	Dichte:	2.43 [g/cm³]
Maximale Prueflast:	362.7 kN	Probenfläche:	7591 [mm²]
Wassergehalt:	Nicht bestimmt [%]	Volumen:	744829 [mm³]
Probenkennung extern:	Nicht bekannt	L/D:	1 [-]
Projektbezeichnung:	Forschung allgemein	Probenlagerung:	unbekannt

Prüfparameter:	UCS	V-Modul	E-Modul	Poissonzahl	Zerstörungsarbeit
Bestimmt:	X	X	X	-	X

Prüfmaschinensteuerung

Aufnahme der Laengsdehnung durch: Elektronische Axialextensometer
Aufnahme der Querdehnung durch: Keine Messung
Steuerungsart: Verformungskontrolliert
Steuerungsrate: 0.5 mm/min
Anmerkungen: Keine Anmerkungen

Probenbeschreibung

Keine Anmerkungen

Parameter	Wert [MPa]	Unterspannung [MPa]	Unterspannung/ Bruchspannung	Oberspannung [MPa]	Oberspannung/ Bruchspannung
Einaxiale Druckfestigkeit	47.78				
V-Modul 1	34345.3	3.96	8.29 %	17.39	36.4 %
E-Modul 1	38744.14	1.71	3.58 %	20.82	43.57 %
V-Modul 2	33474.02	3.43	7.18 %	31.09	65.07 %
E-Modul 2	0	0	0 %	0	0 %
V-Modul Mittelwert	33909.66				
E-Modul Mittelwert	38744.14				
Poissonzahl [-]	0				
Zerstörungsarbeit [kJ/m³]	112.55				

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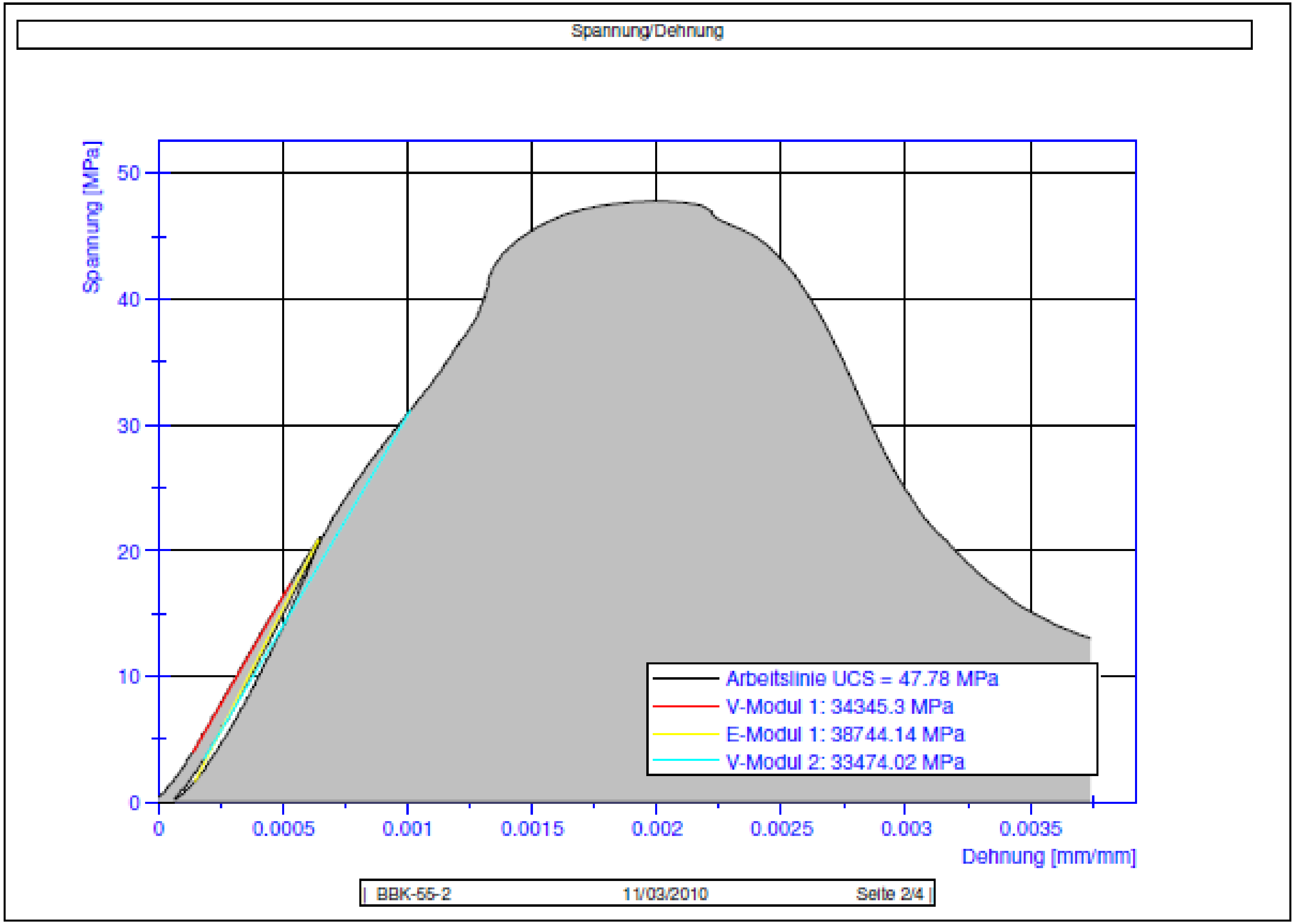
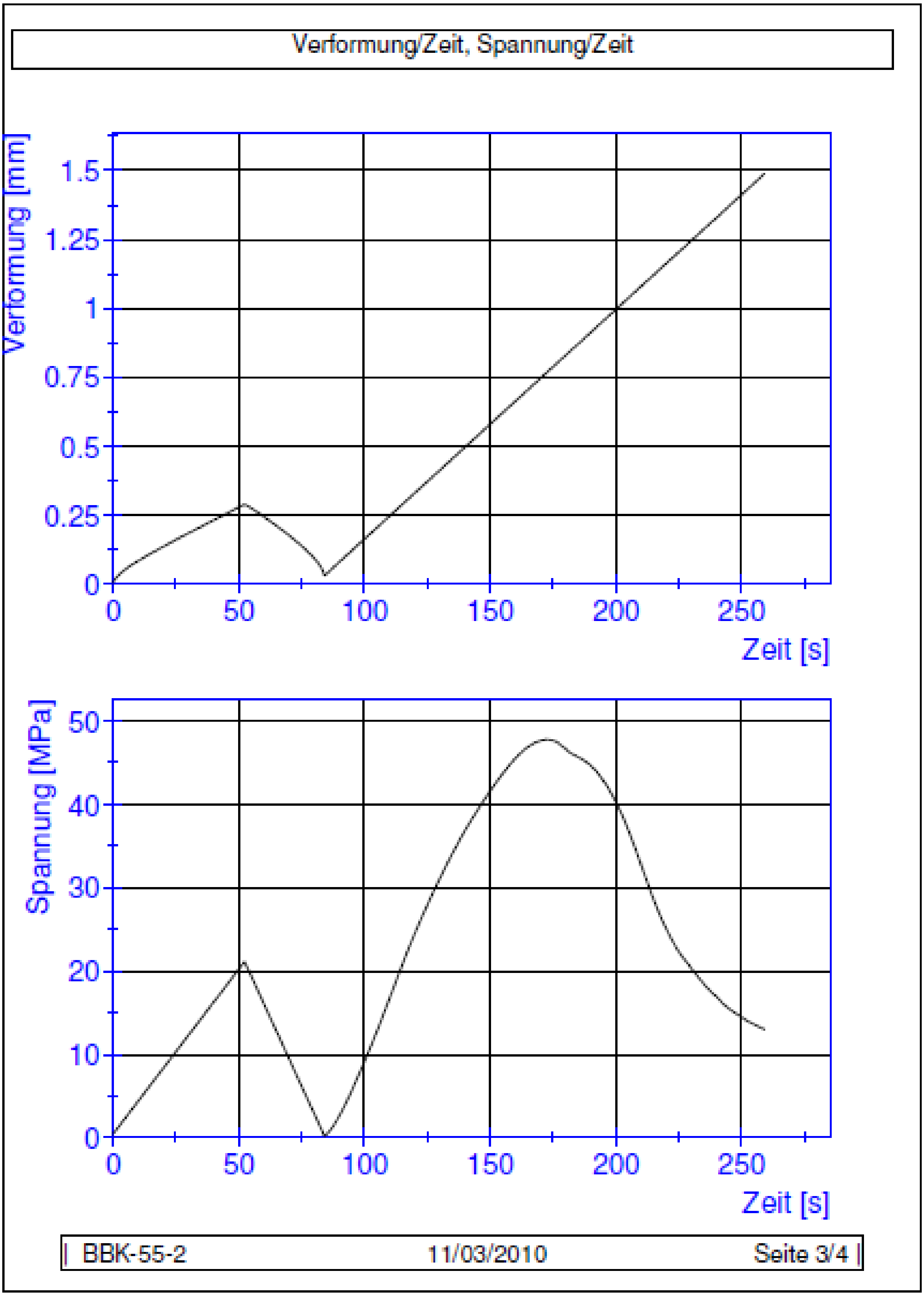
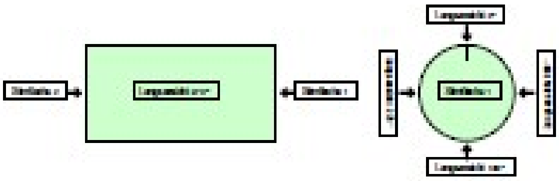
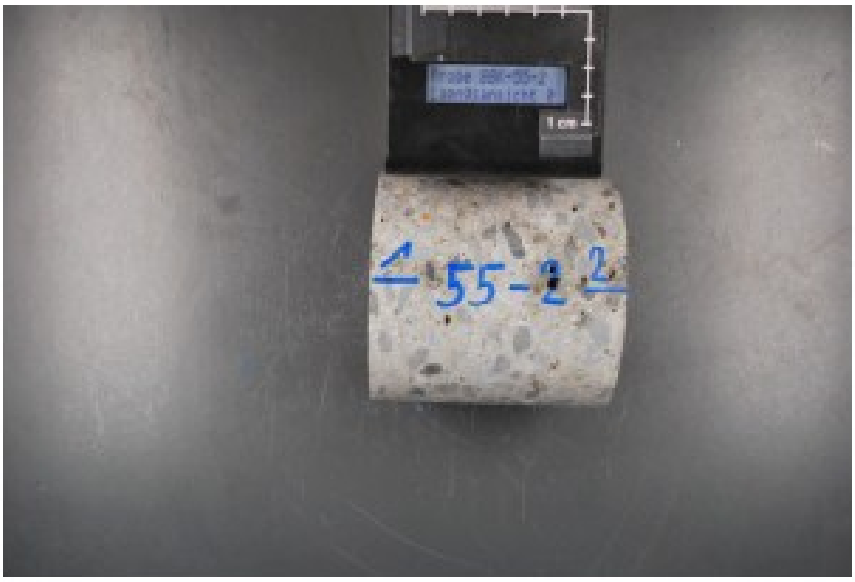

Spannung/Dehnung
Spannung [MPa]
50
40
30
20
10
0
0
0.0005
0.001
0.0015
0.002
0.0025
0.003
0.0035
Dehnung [mm/mm]
Arbeitslinie UCS = 47.78 MPa
V-Modul 1: 34345.3 MPa
E-Modul 1: 38744.14 MPa
V-Modul 2: 33474.02 MPa
| BBK-55-2
11/03/2010
Seite 2/4 |


Verformung/Zeit, Spannung/Zeit
Verformung [mm]
1.5
1.25
1
0.75
0.5
0.25
0
0
50
100
150
200
250
Zeit [s]
Spannung [MPa]
50
40
30
20
10
0
0
50
100
150
200
250
Zeit [s]
| BBK-55-2
11/03/2010
Seite 3/4 |

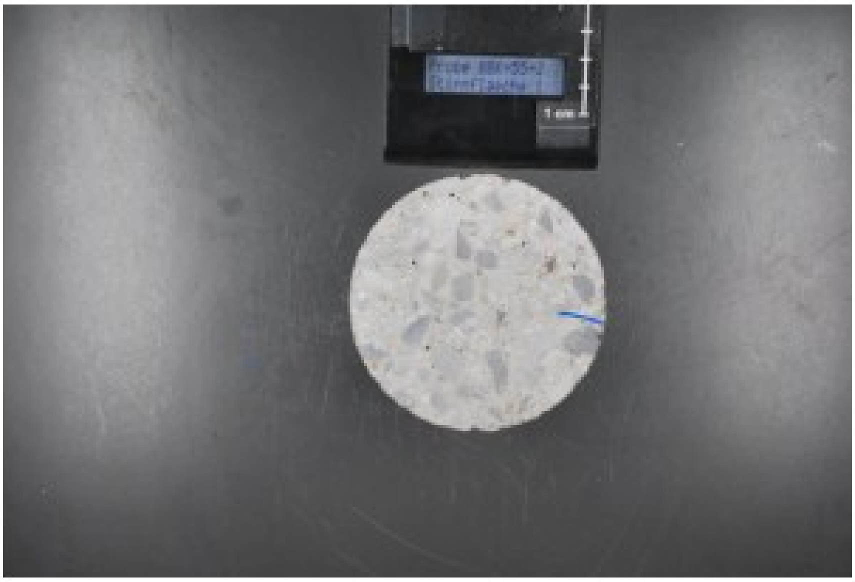
Fotodokumentation



Längsansicht 0°



Stirnfläche 1



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Materialanalyse BBK-51-1

Verantwortlicher Prüfer: Wolfgang Hohl

Auftraggeber:	LBBK	Prüfdatum:	23.08.2010
Eingangsdatum:	23.08.2010	Masse:	1868.34 [g]
Entnahmeort:	Unbekannt	Höhe (L):	99.9 [mm]
Herstellungsdatum:	23.08.2010	Durchmesser (D):	99 [mm]
Materialart:	Beton	Dichte:	2.43 [g/cm³]
Maximale Prueflast:	322.28 kN	Probenfläche:	7698 [mm²]
Wassergehalt:	Nicht bestimmt [%]	Volumen:	769030 [mm³]
Probenkennung extern:	Nicht bekannt	L/D:	1.01 [-]
Projektbezeichnung:	Forschung allgemein	Probenlagerung:	trocken

Prüfparameter:	UCS	V-Modul	E-Modul	Poissonzahl	Zerstörungsarbeit
Bestimmt:	X	-	-	-	X

Prüfmaschinensteuerung

Aufnahme der Laengsdehnung durch: Druckkolbenweg
Aufnahme der Querdehnung durch: Keine Messung
Steuerungsart: Verformungskontrolliert
Steuerungsrate: 0.5 mm/min
Anmerkungen: Keine Anmerkungen

Probenbeschreibung

Keine Anmerkungen

Parameter	Wert [MPa]	Unterspannung [MPa]	Unterspannung/ Bruchspannung	Oberspannung [MPa]	Oberspannung/ Bruchspannung
Einaxiale Druckfestigkeit	41.87				
V-Modul 1	8880.17	13.38	31.96 %	30.4	72.61 %
E-Modul 1	0	0	0 %	0	0 %
V-Modul 2	0	0	0 %	0	0 %
E-Modul 2	0	0	0 %	0	0 %
V-Modul Mittelwert	8880.17				
E-Modul Mittelwert	0				
Poissonzahl [-]	0				
Zerstörungsarbeit [kJ/m³]	392.76				

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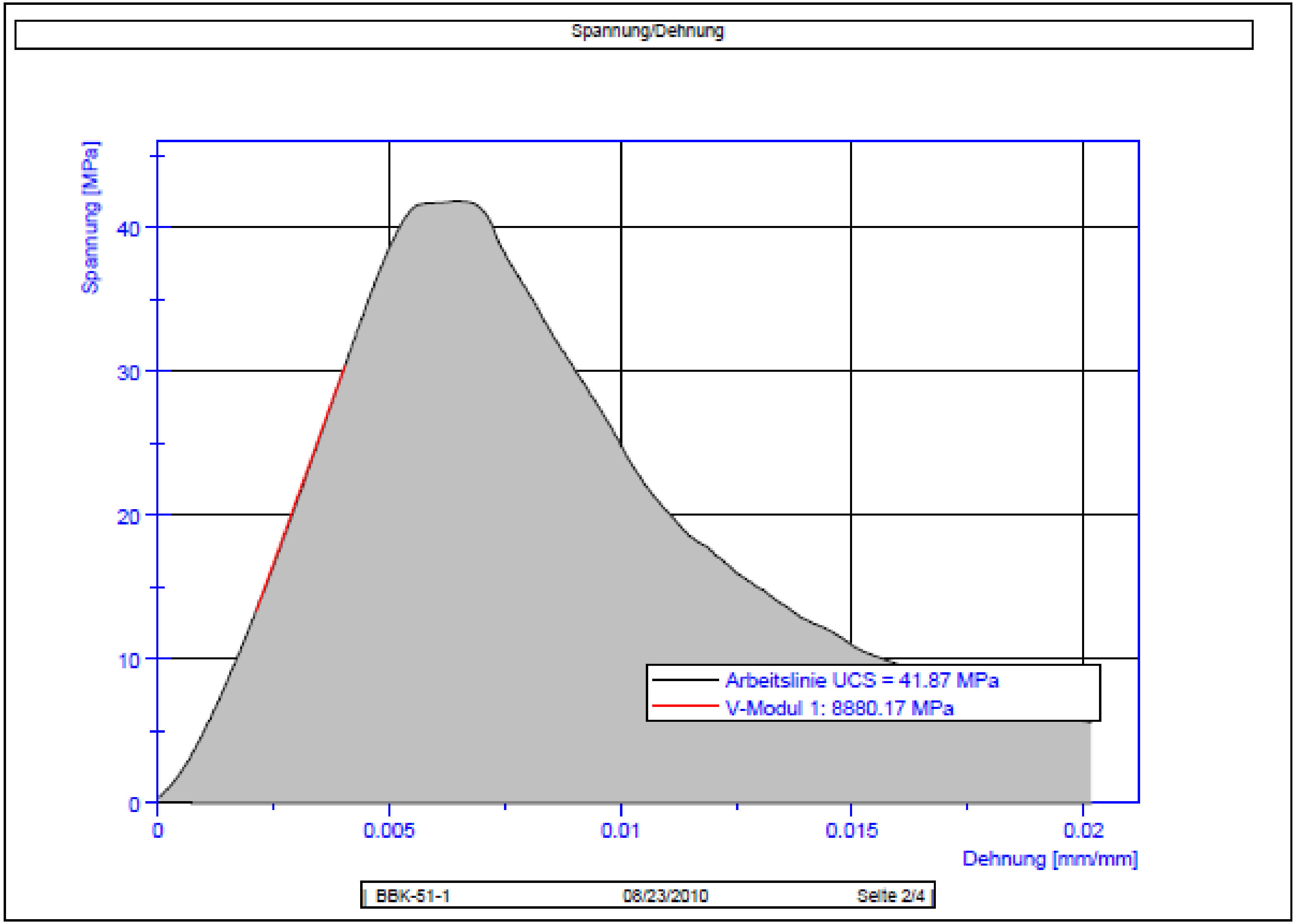
Spannung/Dehnung
Spannung [MPa]
40
30
20
10
0
0
0.005
0.01
0.015
0.02
Dehnung [mm/mm]
Arbeitslinie UCS = 41.87 MPa
V-Modul 1: 8880.17 MPa
BBK-51-1
08/23/2010
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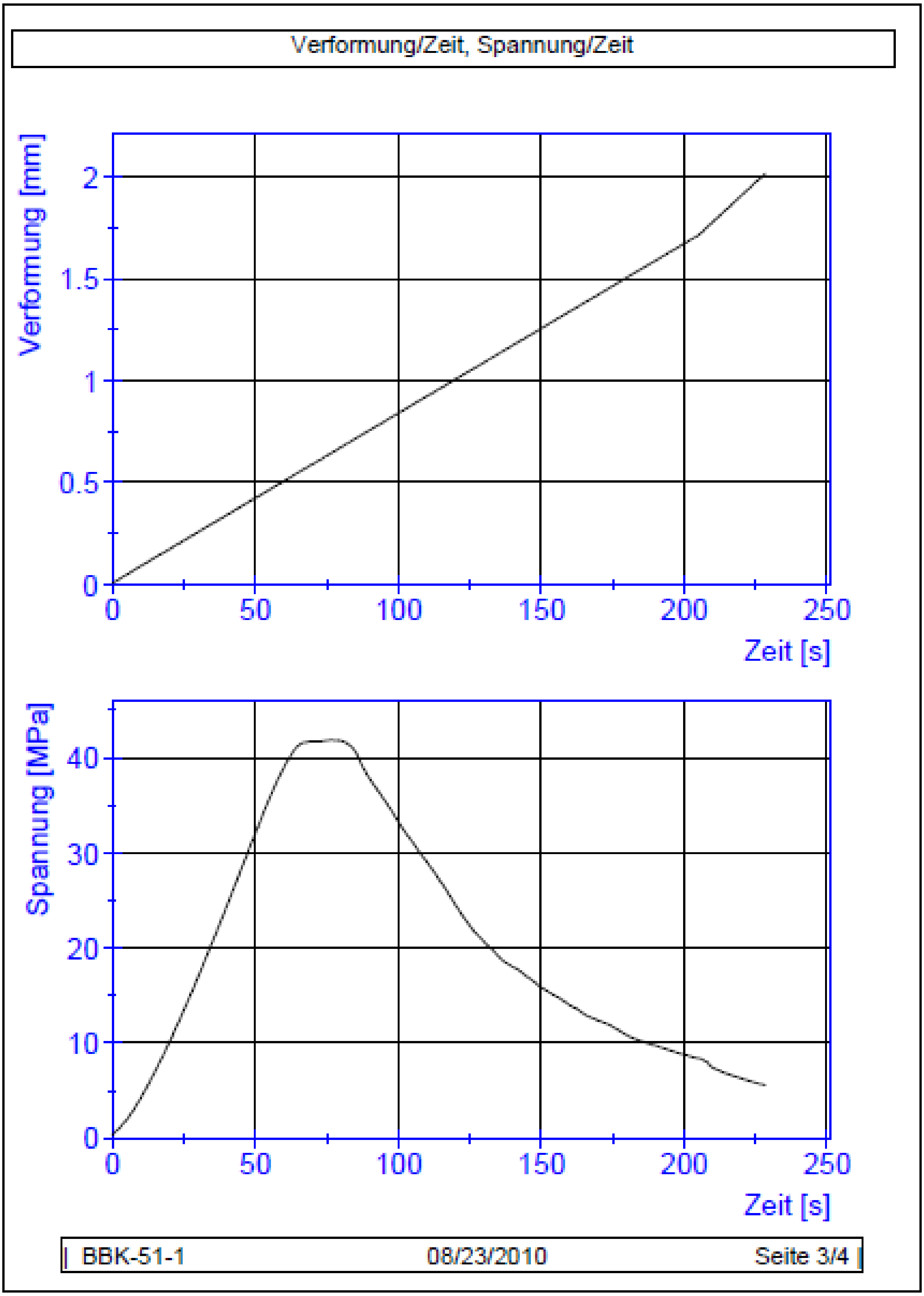
Verformung/Zeit, Spannung/Zeit
Verformung [mm]
2
1.5
1
0.5
0
0
50
100
150
200
250
Zeit [s]
Spannung [MPa]
40
30
20
10
0
0
50
100
150
200
250
Zeit [s]
| BBK-51-1
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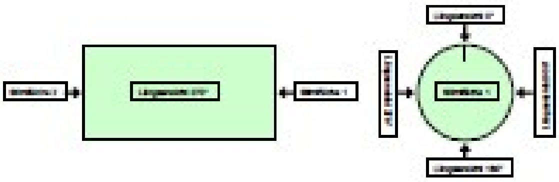
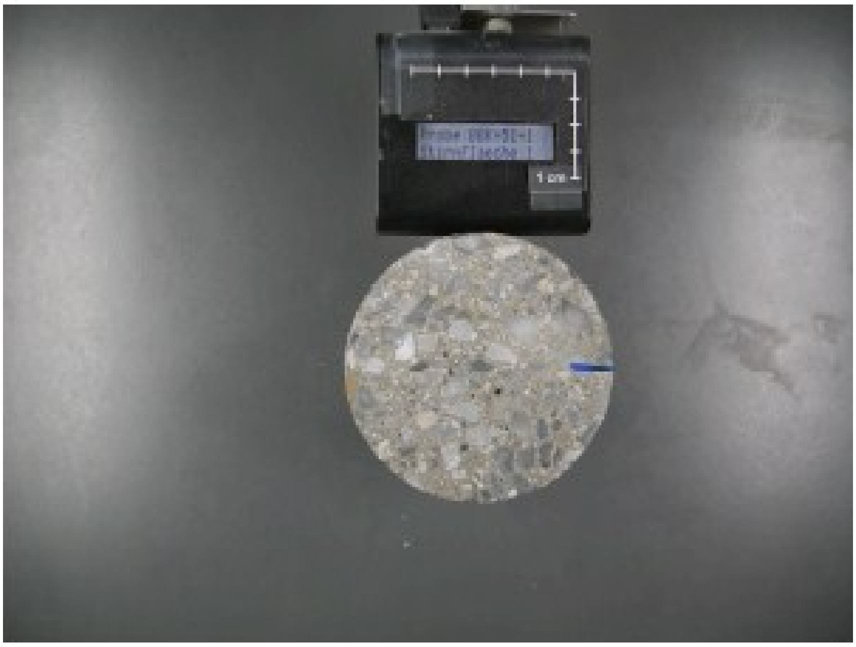
Fotodokumentation



Längsansicht 0°

Stirnfläche 1



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Materialanalyse BBK-51-2

Verantwortlicher Prüfer: Wolfgang Hohl

Auftraggeber:	LBBK	Prüfdatum:	23.08.2010
Eingangsdatum:	23.08.2010	Masse:	1866.03 [g]
Entnahmeort:	Unbekannt	Höhe (L):	99.3 [mm]
Herstellungsdatum:	23.08.2010	Durchmesser (D):	99.08 [mm]
Materialart:	Beton	Dichte:	2.44 [g/cm³]
Maximale Prueflast:	365.49 kN	Probenfläche:	7710 [mm²]
Wassergehalt:	Nicht bestimmt [%]	Volumen:	765603 [mm³]
Probenkennung extern:	Nicht bekannt	L/D:	1 [-]
Projektbezeichnung:	Forschung allgemein	Probenlagerung:	trocken

Prüfparameter:	UCS	V-Modul	E-Modul	Poissonzahl	Zerstörungsarbeit
Bestimmt:	X	X	X	-	X

Prüfmaschinensteuerung

Aufnahme der Laengsdehnung durch: Elektronische Axialextensometer
Aufnahme der Querdehnung durch: Keine Messung
Steuerungsart: Verformungskontrolliert
Steuerungsrate: 0.5 mm/min
Anmerkungen: Keine Anmerkungen

Probenbeschreibung

Keine Anmerkungen

Parameter	Wert [MPa]	Unterspannung [MPa]	Unterspannung/ Bruchspannung	Oberspannung [MPa]	Oberspannung/ Bruchspannung
Einaxiale Druckfestigkeit	47.4				
V-Modul 1	27153.3	4.02	8.48 %	17.12	36.12 %
E-Modul 1	32597.06	3.37	7.11 %	20.74	43.76 %
V-Modul 2	20325.01	22.10	46.79 %	30.07	65.13 %
E-Modul 2	0	0	0 %	0	0 %
V-Modul Mittelwert	23739.555				
E-Modul Mittelwert	32597.06				
Poissonzahl [-]	0				
Zerstörungsarbeit [kJ/m³]	240.77				

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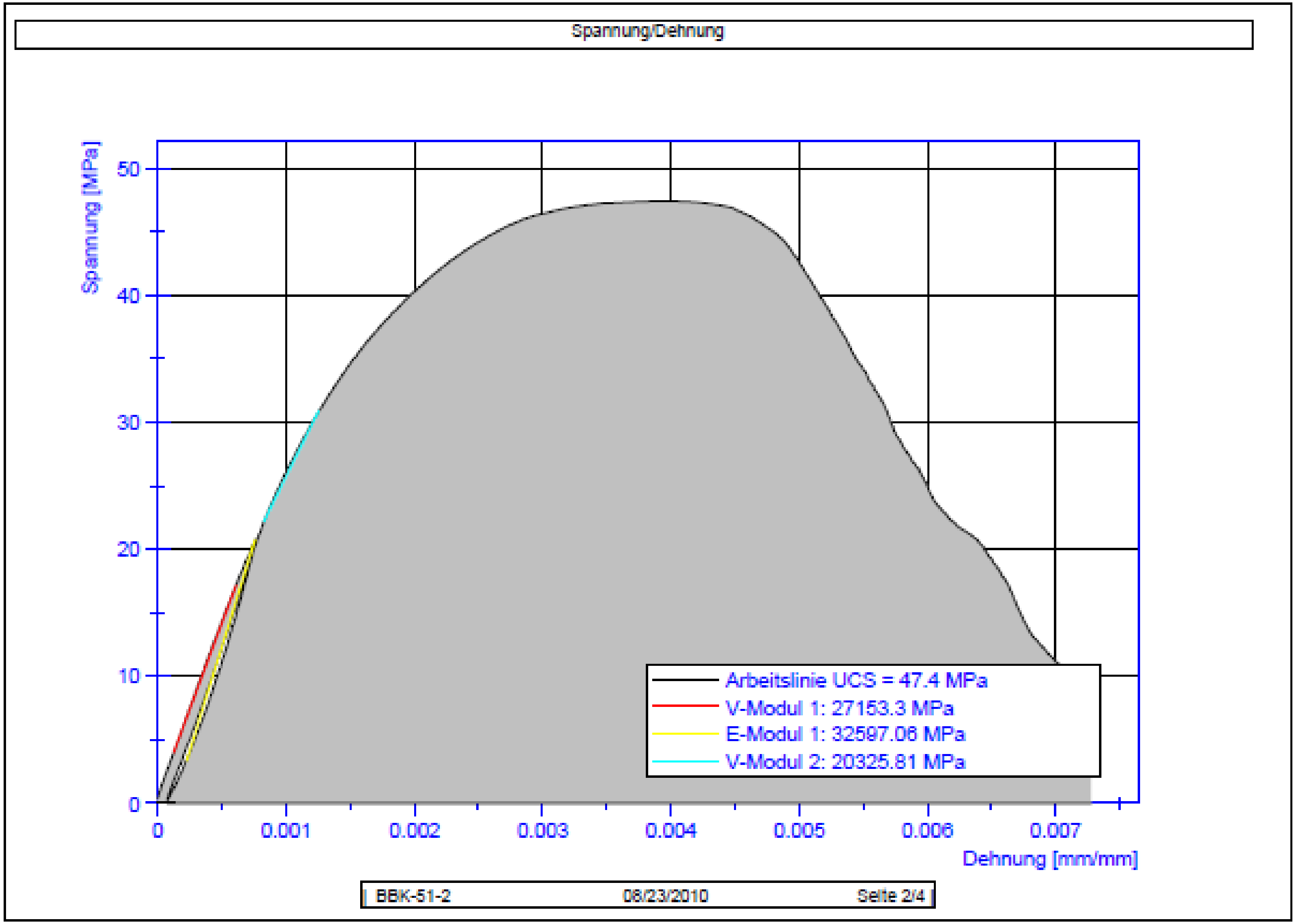

Spannung/Dehnung
Spannung [MPa]
50
40
30
20
10
0
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
Dehnung [mm/mm]
Arbeitslinie UCS = 47.4 MPa
V-Modul 1: 27153.3 MPa
E-Modul 1: 32597.06 MPa
V-Modul 2: 20325.81 MPa
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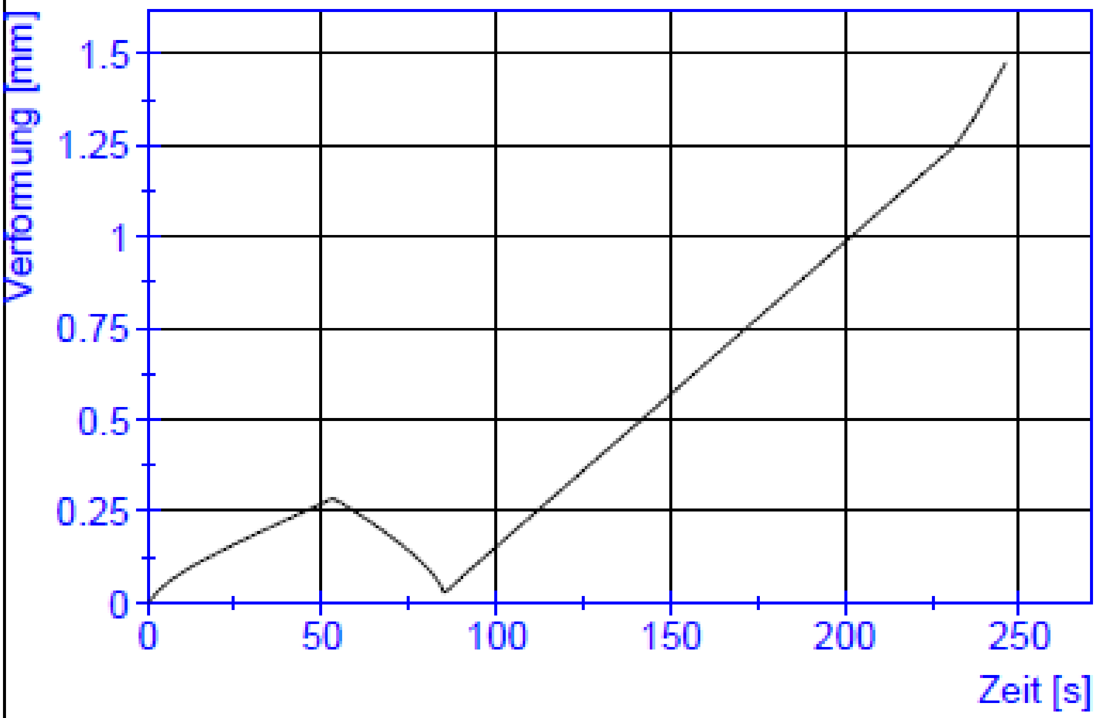
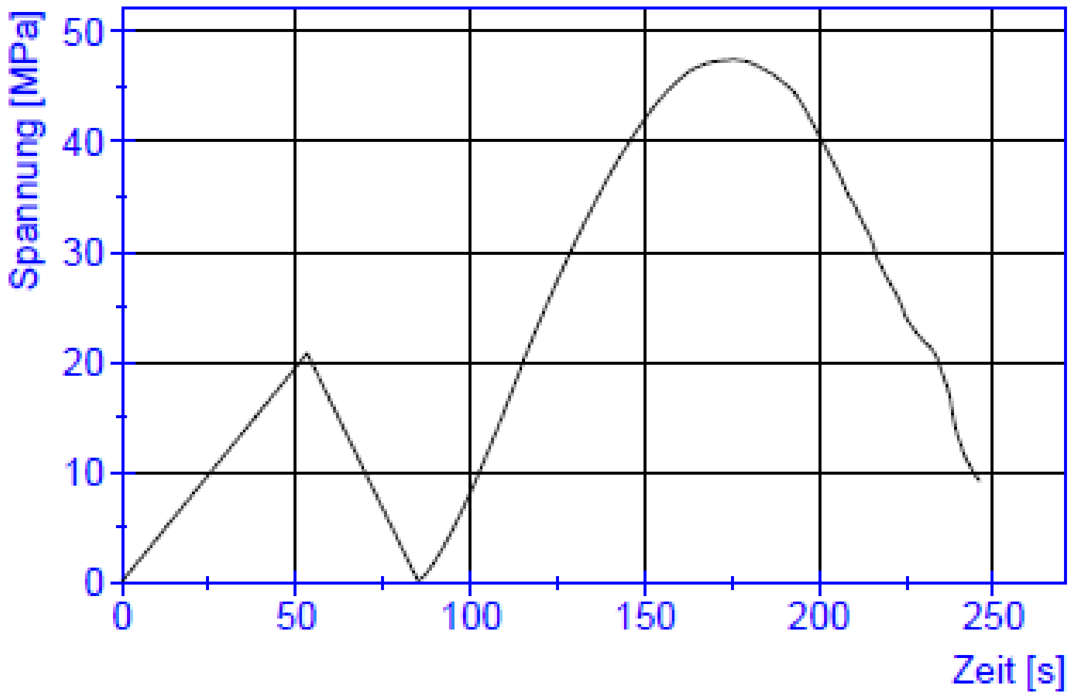
Verformung/Zeit, Spannung/Zeit





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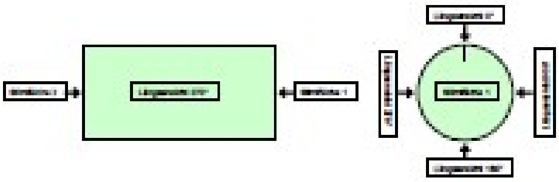
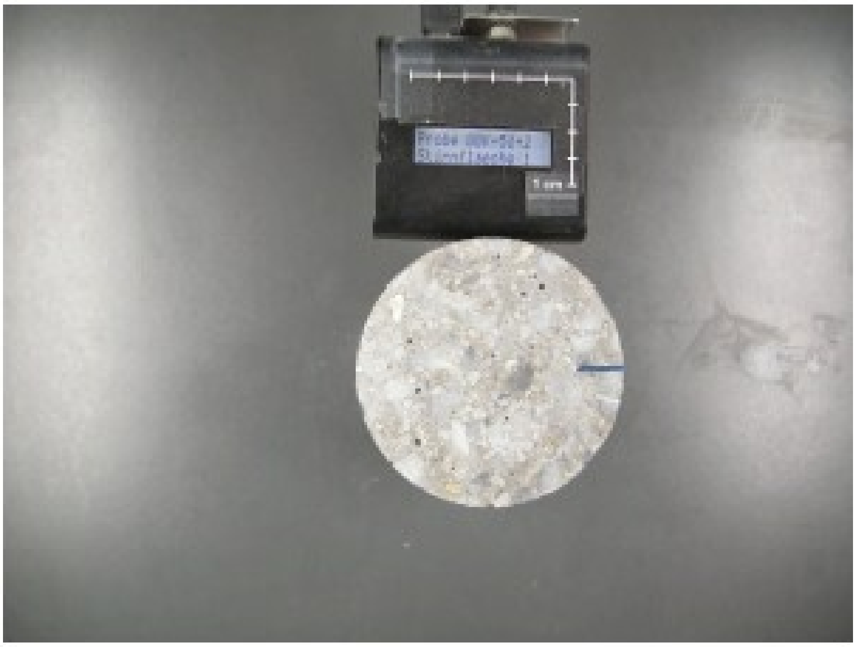
Fotodokumentation



Längsansicht 0°

Stirnfläche 1



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Materialanalyse BBK-51-3

Verantwortlicher Prüfer: Wolfgang Hohl

Auftraggeber:	LBBK	Prüfdatum:	23.08.2010
Eingangsdatum:	23.08.2010	Masse:	1818.03 [g]
Entnahmeort:	Unbekannt	Höhe (L):	97.4 [mm]
Herstellungsdatum:	23.08.2010	Durchmesser (D):	99 [mm]
Materialart:	Beton	Dichte:	2.42 [g/cm³]
Maximale Prueflast:	380.78 kN	Probenfläche:	7698 [mm²]
Wassergehalt:	Nicht bestimmt [%]	Volumen:	749785 [mm³]
Probenkennung extern:	Nicht bekannt	L/D:	0.98 [-]
Projektbezeichnung:	Forschung allgemein	Probenlagerung:	trocken

Prüfparameter:	UCS	V-Modul	E-Modul	Poissonzahl	Zerstörungsarbeit
Bestimmt:	X	X	X	-	X

Prüfmaschinensteuerung

Aufnahme der Laengsdehnung durch: Elektronische Axialextensometer
Aufnahme der Querdehnung durch: Keine Messung
Steuerungsart: Verformungskontrolliert
Steuerungsrate: 0.5 mm/min
Anmerkungen: Keine Anmerkungen

Probenbeschreibung

Keine Anmerkungen

Parameter	Wert [MPa]	Unterspannung [MPa]	Unterspannung/ Bruchspannung	Oberspannung [MPa]	Oberspannung/ Bruchspannung
Einaxiale Druckfestigkeit	49.47				
V-Modul 1	30021.4	4.55	9.2 %	14.68	29.67 %
E-Modul 1	32735.03	2.99	6.04 %	17.54	35.46 %
V-Modul 2	10700.27	23.30	47.20 %	43.07	87.00 %
E-Modul 2	0	0	0 %	0	0 %
V-Modul Mittelwert	23393.835				
E-Modul Mittelwert	32735.03				
Poissonzahl [-]	0				
Zerstörungsarbeit [kJ/m³]	399.41				

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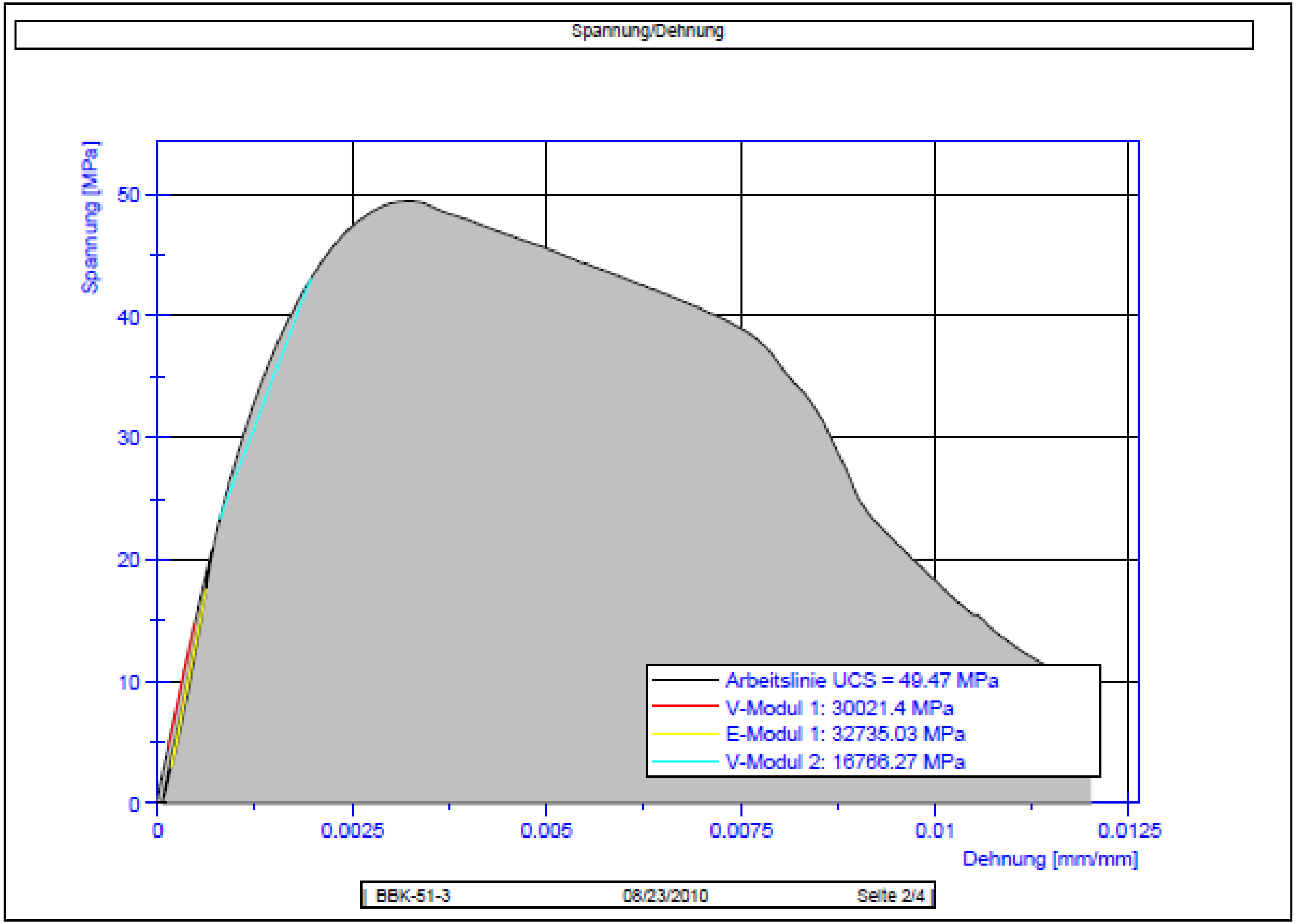
Spannung/Dehnung
Spannung [MPa]
50
40
30
20
10
0
0
0.0025
0.005
0.0075
0.01
0.0125
Dehnung [mm/mm]
Arbeitslinie UCS = 49.47 MPa
V-Modul 1: 30021.4 MPa
E-Modul 1: 32735.03 MPa
V-Modul 2: 16766.27 MPa
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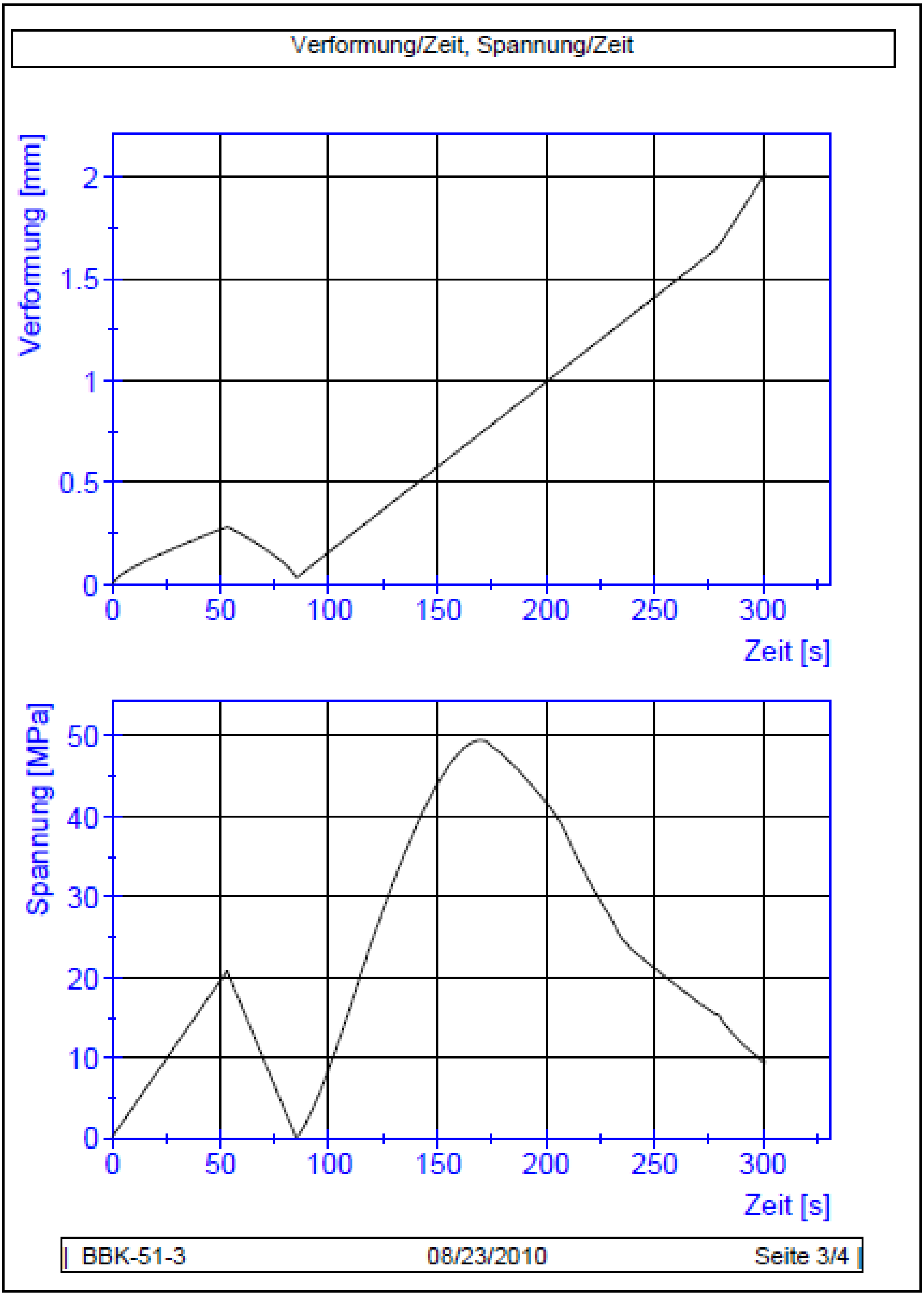
Verformung/Zeit, Spannung/Zeit
Verformung [mm]
2
1.5
1
0.5
0
0
50
100
150
200
250
300
Zeit [s]
Spannung [MPa]
50
40
30
20
10
0
0
50
100
150
200
250
300
Zeit [s]
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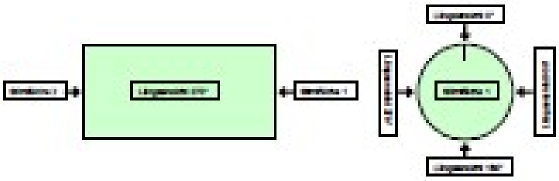
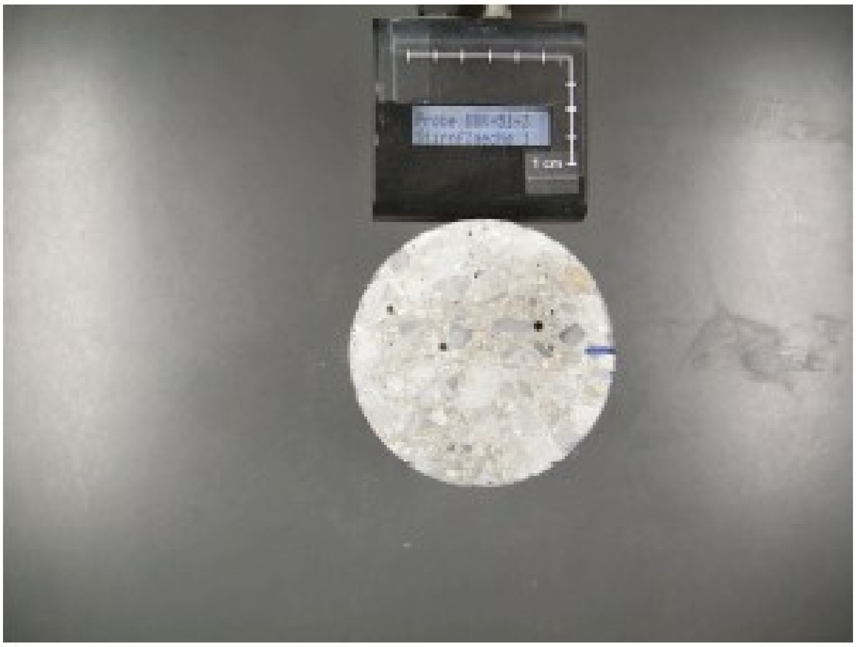
Fotodokumentation



Längsansicht 0°

Stirnfläche 1



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Materialanalyse BBK-51-4

Verantwortlicher Prüfer: Wolfgang Hohl

Auftraggeber:	LBBK	Prüfdatum:	23.08.2010
Eingangsdatum:	23.08.2010	Masse:	1897.73 [g]
Entnahmeort:	Unbekannt	Höhe (L):	101 [mm]
Herstellungsdatum:	23.08.2010	Durchmesser (D):	99 [mm]
Materialart:	Beton	Dichte:	2.44 [g/cm³]
Maximale Prueflast:	355.09 kN	Probenfläche:	7698 [mm²]
Wassergehalt:	Nicht bestimmt [%]	Volumen:	777498 [mm³]
Probenkennung extern:	Nicht bekannt	L/D:	1.02 [-]
Projektbezeichnung:	Forschung allgemein	Probenlagerung:	trocken

Prüfparameter:	UCS	V-Modul	E-Modul	Poissonzahl	Zerstörungsarbeit
Bestimmt:	X	X	X	-	X

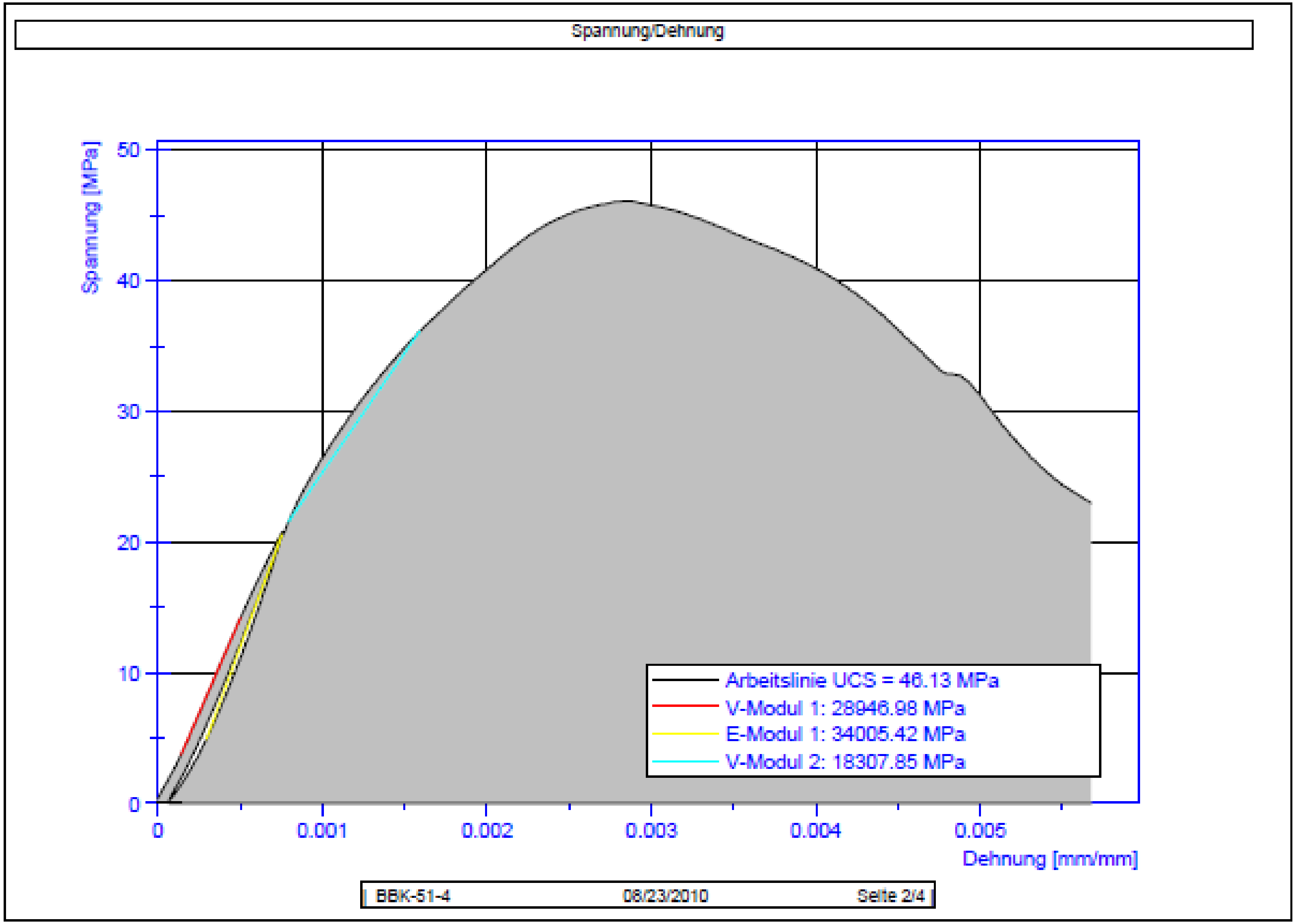
Prüfmaschinensteuerung

Aufnahme der Laengsdehnung durch:		Elektronische Axialextensometer
Aufnahme der Querdehnung durch:		Keine Messung
Steuerungsart:	Verformungskontrolliert	
Steuerungsrate:	0.5 mm/min	
Anmerkungen:	Keine Anmerkungen	

Probenbeschreibung

Keine Anmerkungen

Parameter	Wert [MPa]	Unterspannung [MPa]	Unterspannung/ Bruchspannung	Oberspannung [MPa]	Oberspannung/ Bruchspannung
Einaxiale Druckfestigkeit	46.13				
V-Modul 1	28946.98	3.77	8.17 %	14.16	30.7 %
E-Modul 1	34006.42	4.93	10.69 %	20.52	44.48 %
V-Modul 2	10307.85	21.57	40.70 %	30.12	70.3 %
E-Modul 2	0	0	0 %	0	0 %
V-Modul Mittelwert	23627.415				
E-Modul Mittelwert	34006.42				
Poissonzahl [-]	0				
Zerstörungsarbeit [kJ/m³]	190.98				


Spannung/Dehnung
Spannung [MPa]
50
40
30
20
10
0
0
0.001
0.002
0.003
0.004
0.005
Dehnung [mm/mm]
Arbeitslinie UCS = 46.13 MPa
V-Modul 1: 28946.98 MPa
E-Modul 1: 34005.42 MPa
V-Modul 2: 18307.85 MPa
| BBK-51-4
08/23/2010
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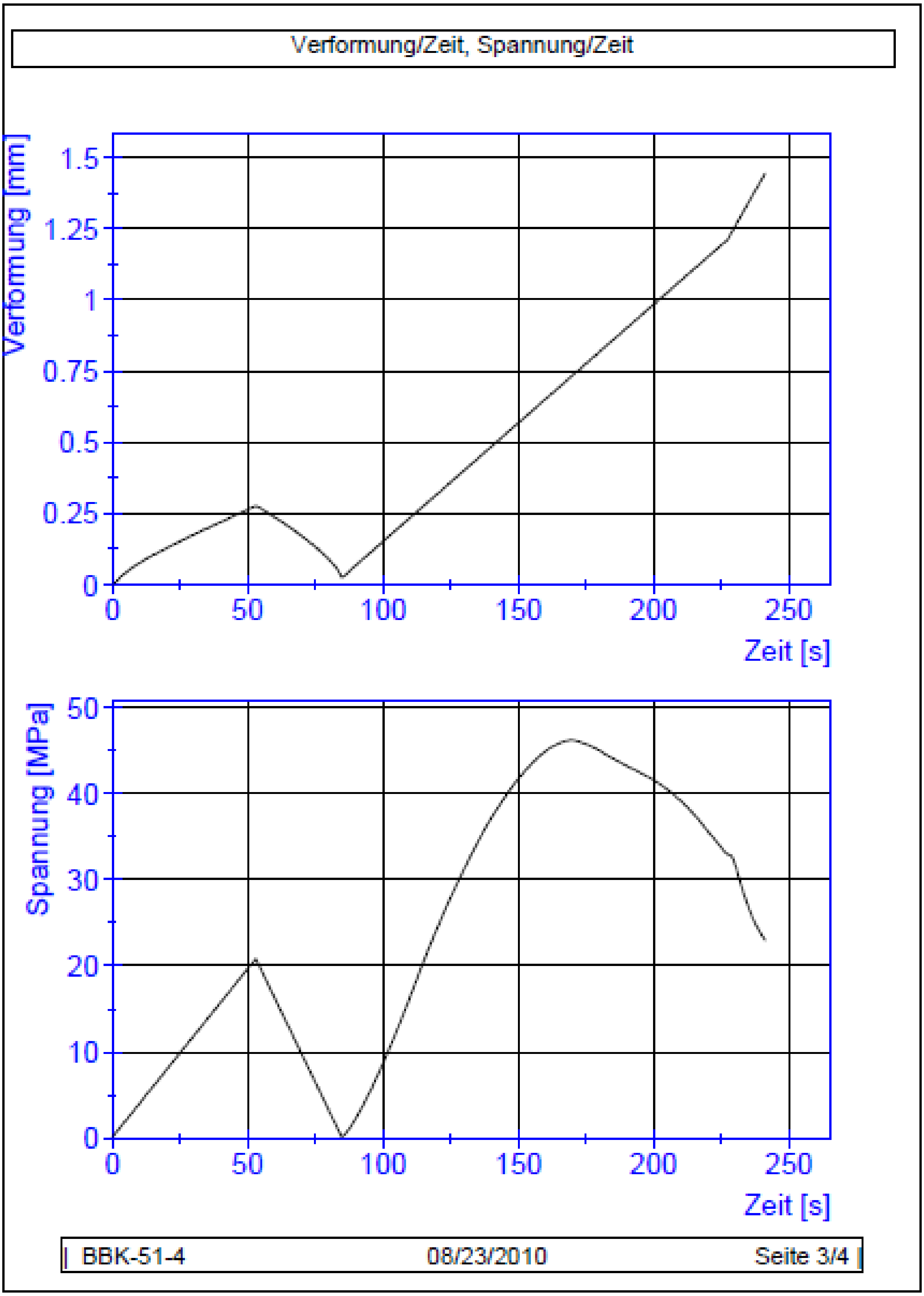
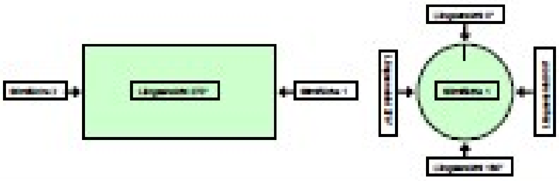
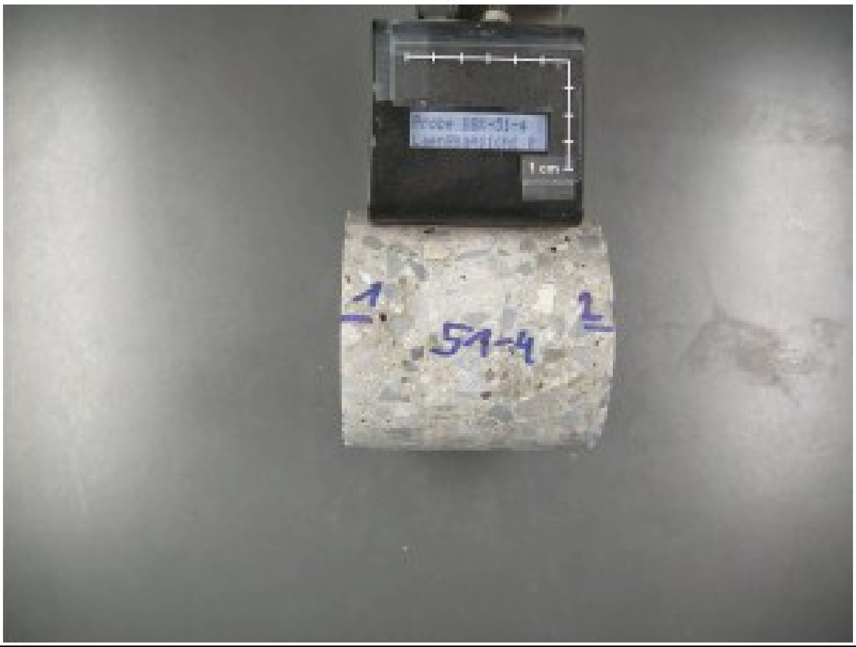

Verformung/Zeit, Spannung/Zeit
Verformung [mm]
1.5
1.25
1
0.75
0.5
0.25
0
0
50
100
150
200
250
Zeit [s]
Spannung [MPa]
50
40
30
20
10
0
0
50
100
150
200
250
Zeit [s]
BBK-51-4
08/23/2010
Seite 3/4

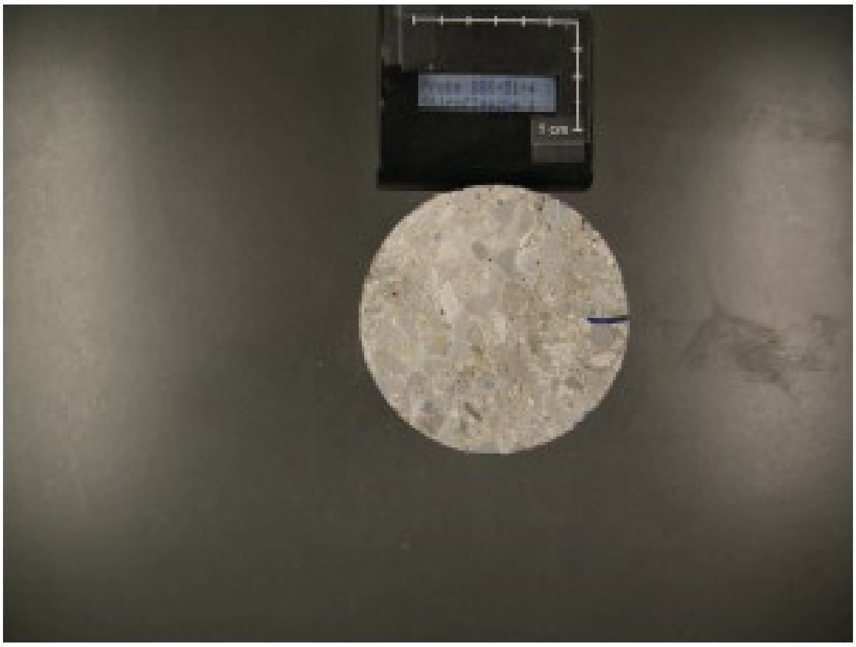
Fotodokumentation



Längsansicht 0°



Stirnfläche 1



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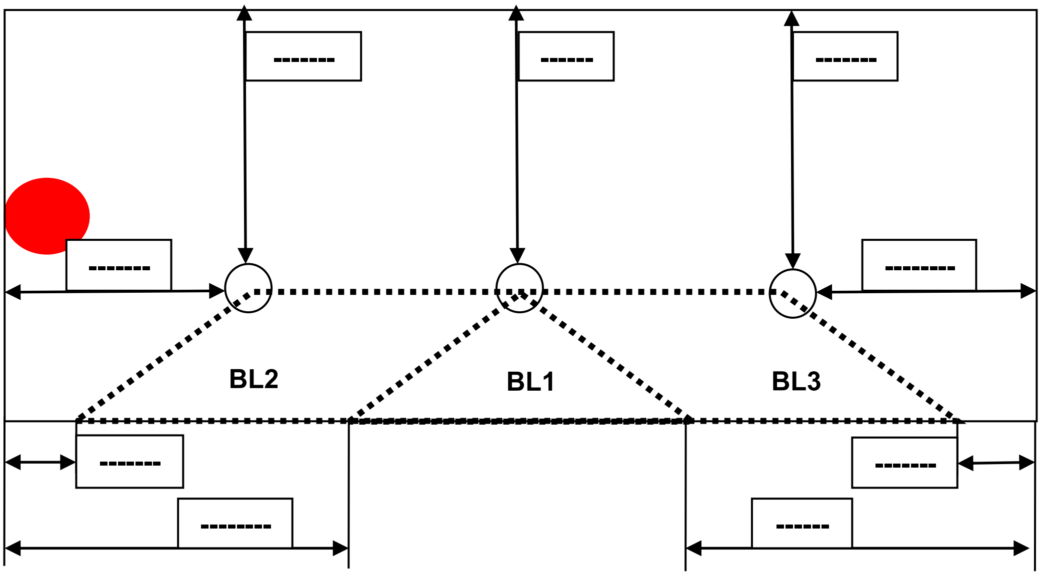
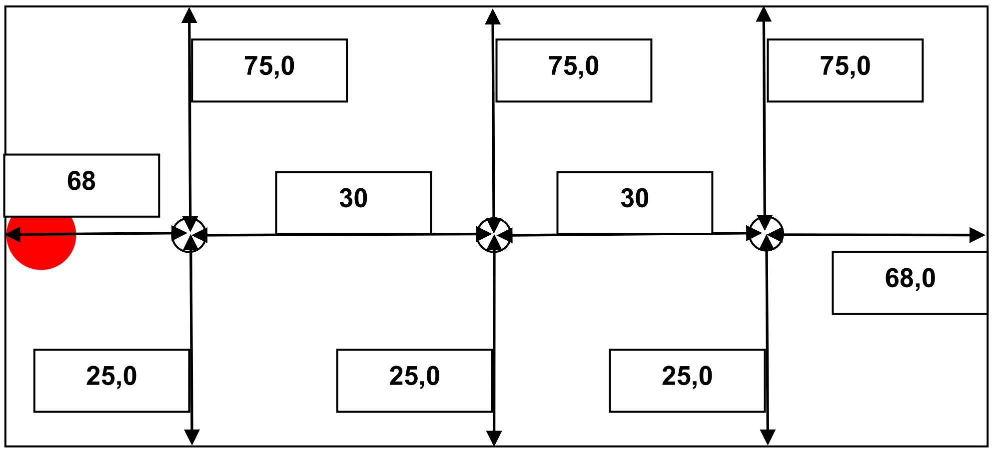
PHM-25-1,2/1,2**-01**

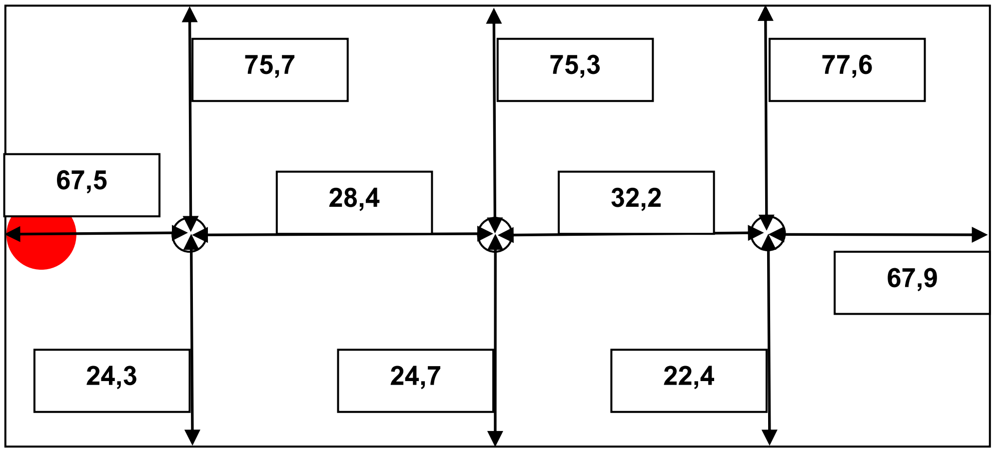
Excavation geometry:



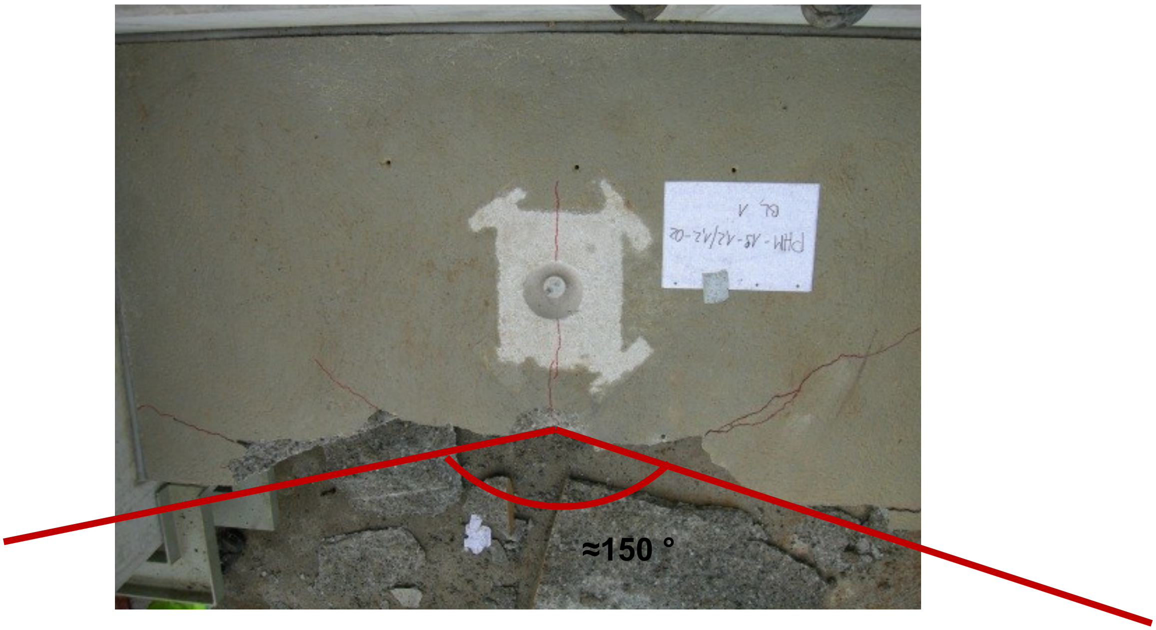
Top hole position:



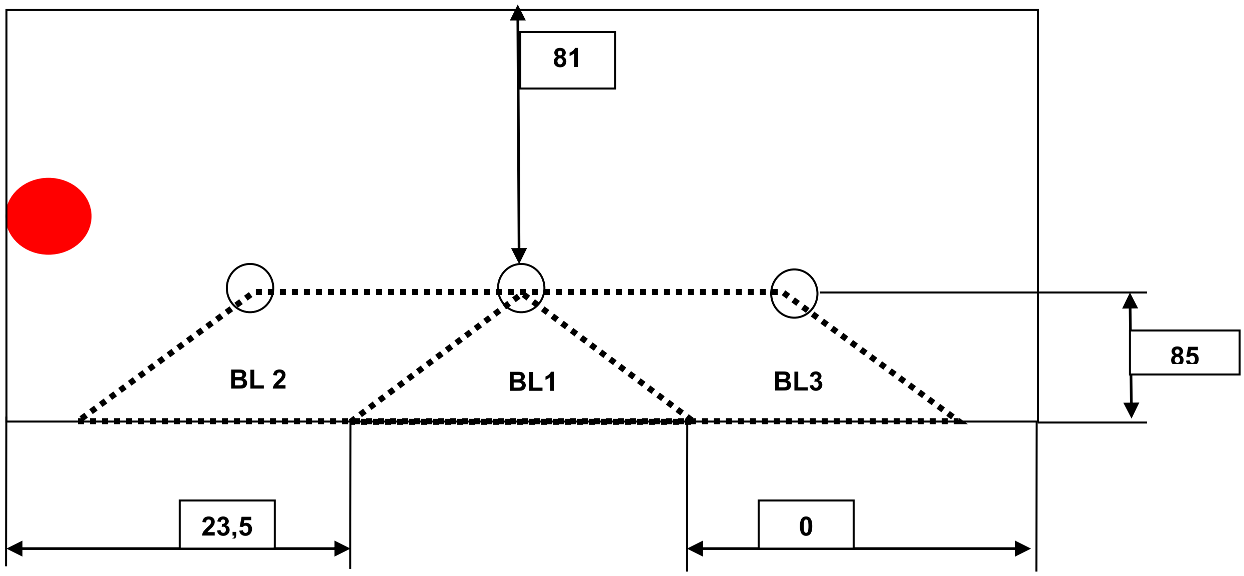
Bottom hole position:



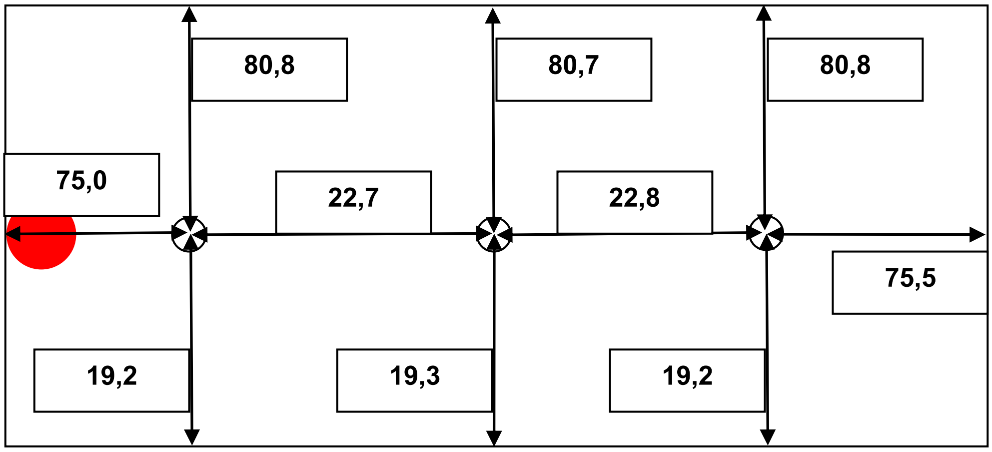
PHM-19-1,2/1,2**-02**



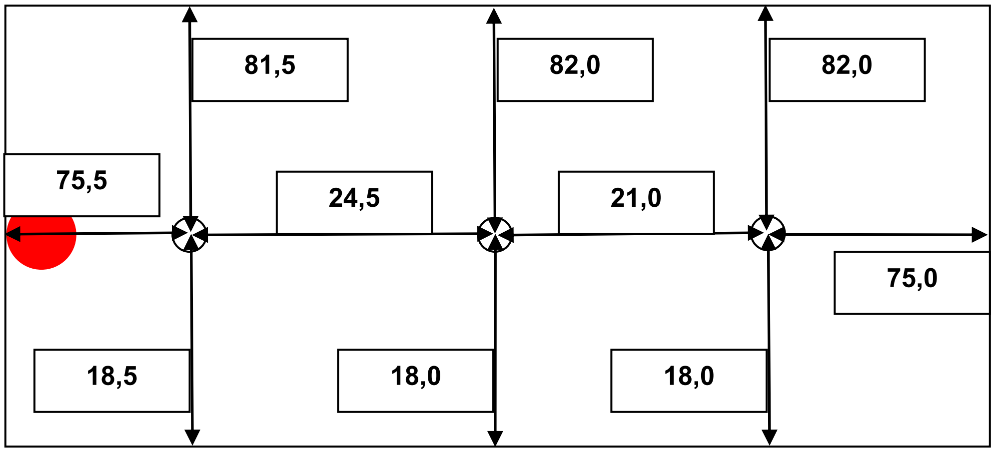
Excavation geometry:



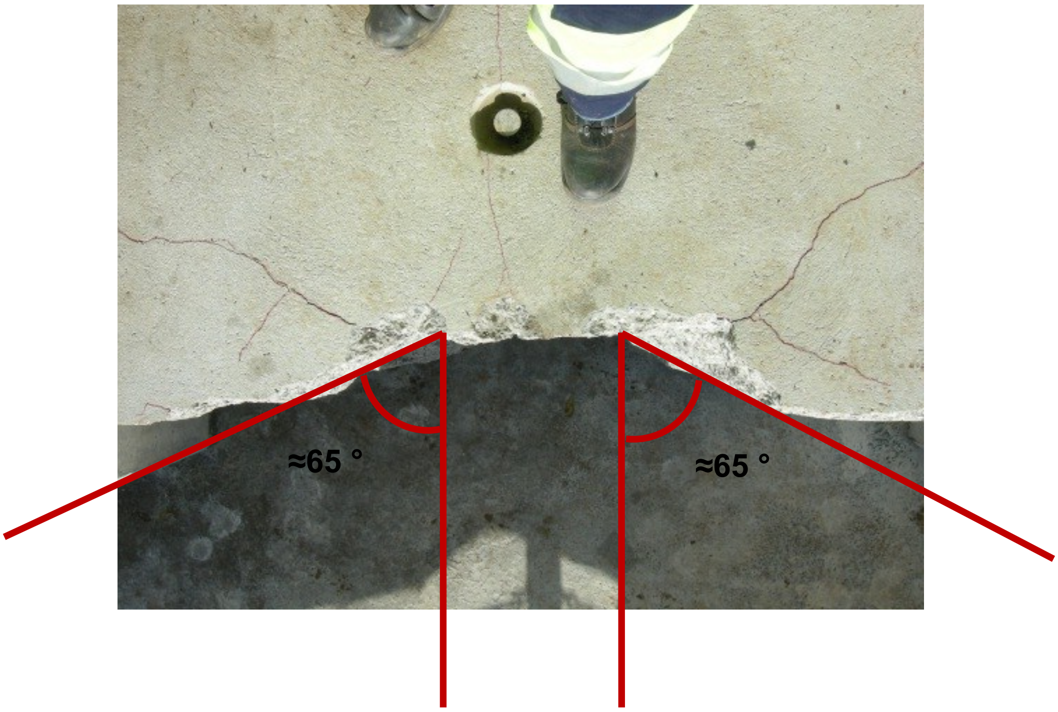
Top hole position:



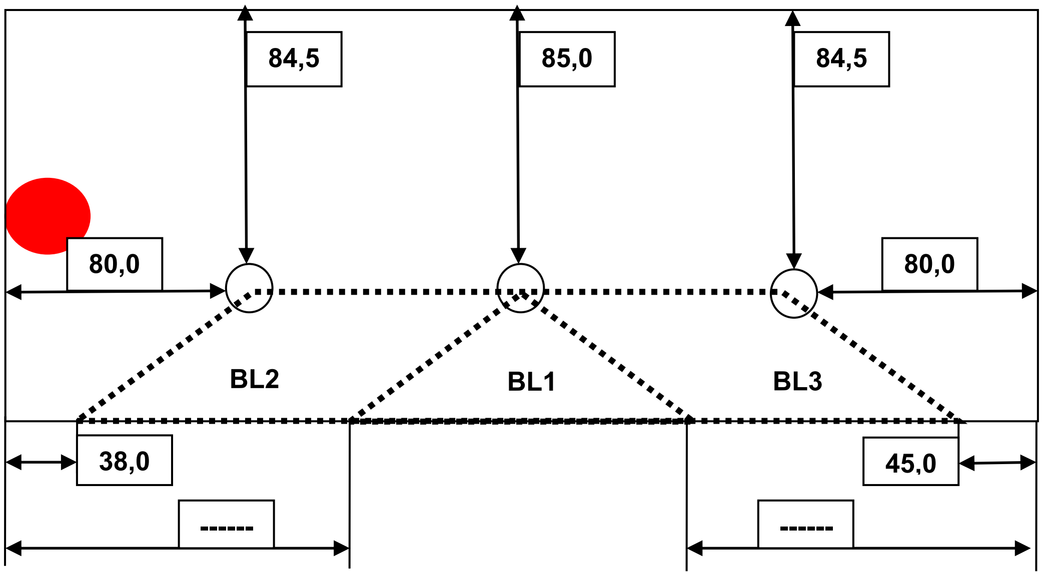
Bottom hole position:



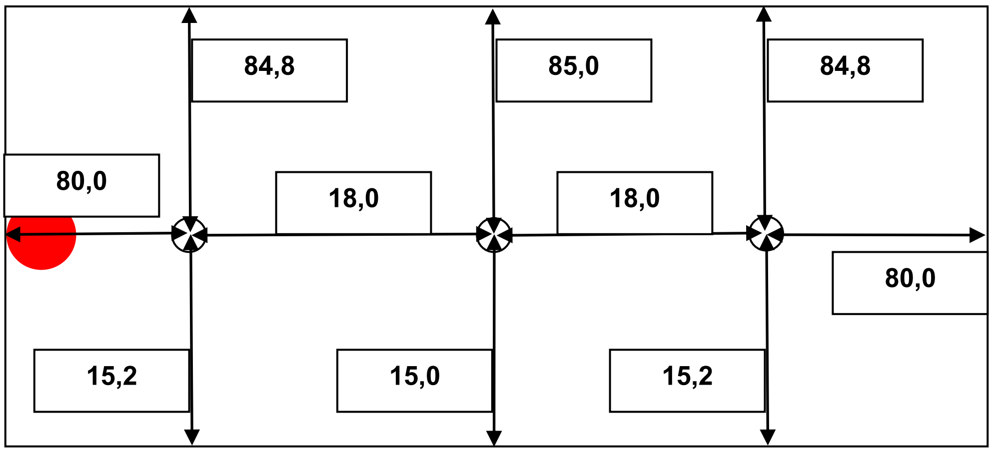
PHM-15-1,2/1,2**-03**


≈65 °
≈65 °

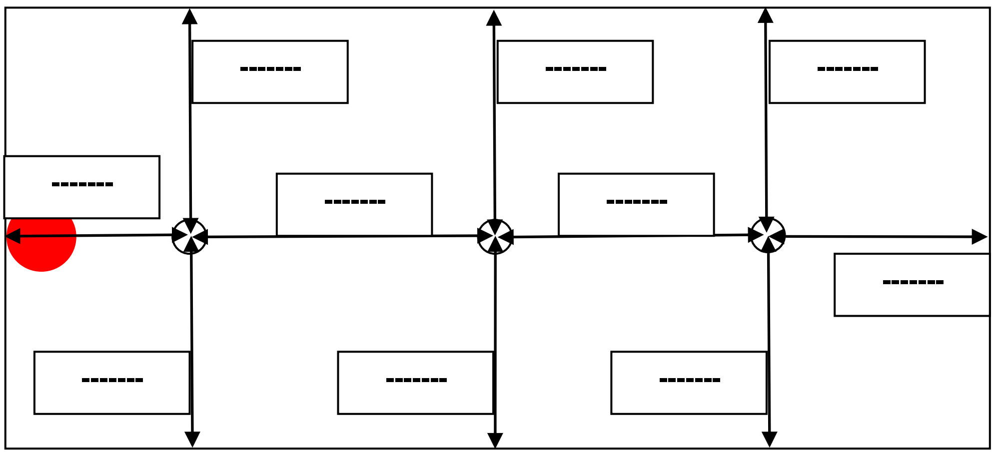
Excavation geometry:



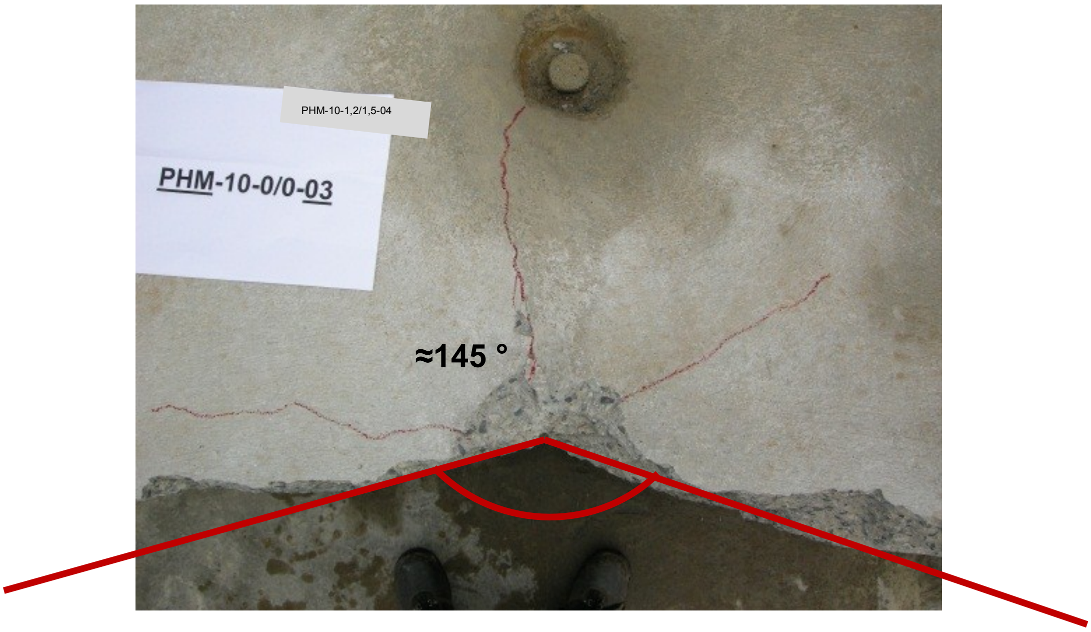
Top hole position:



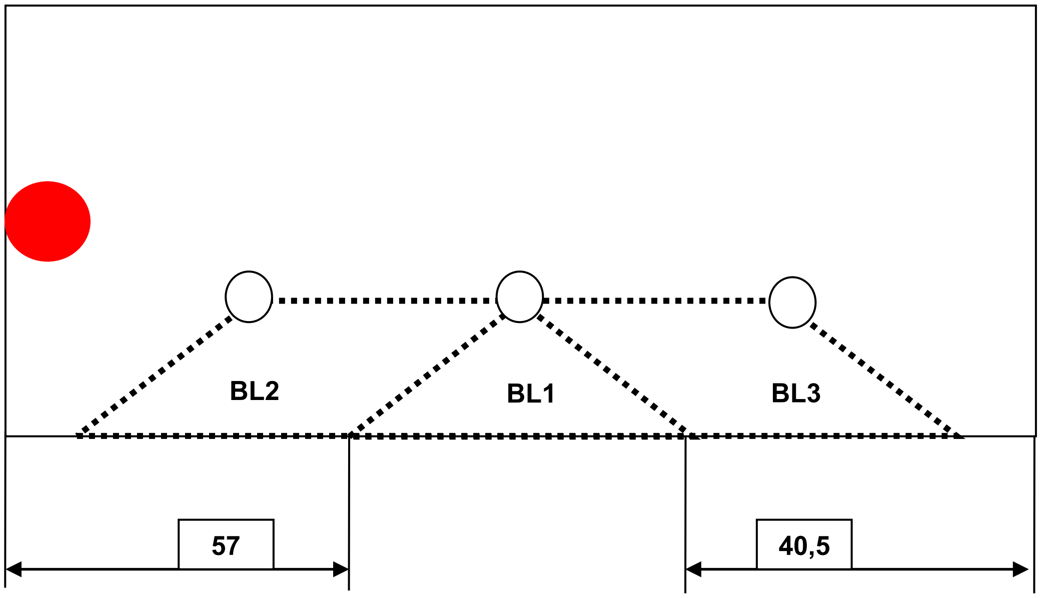
Bottom hole position:



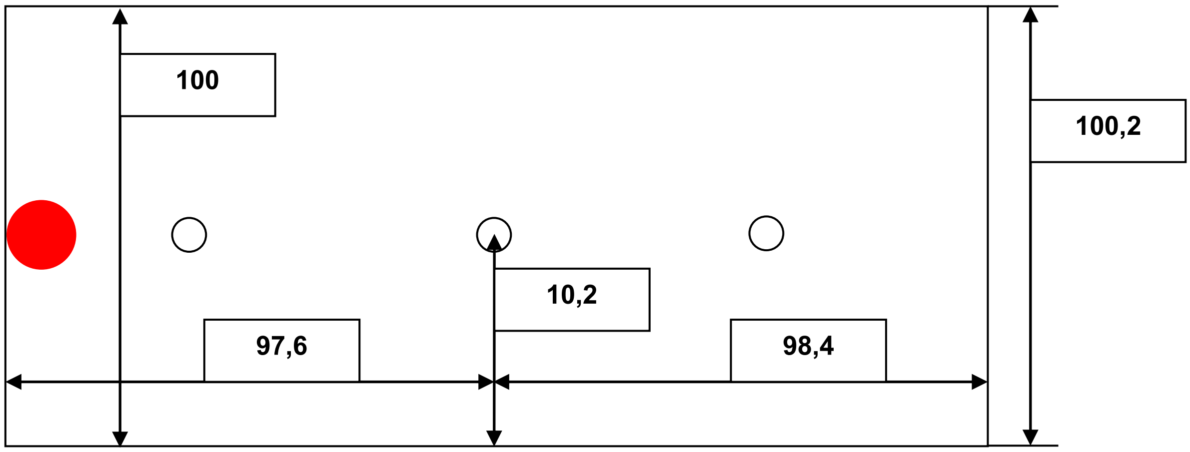
PHM-10-1,2/1,5**-04**



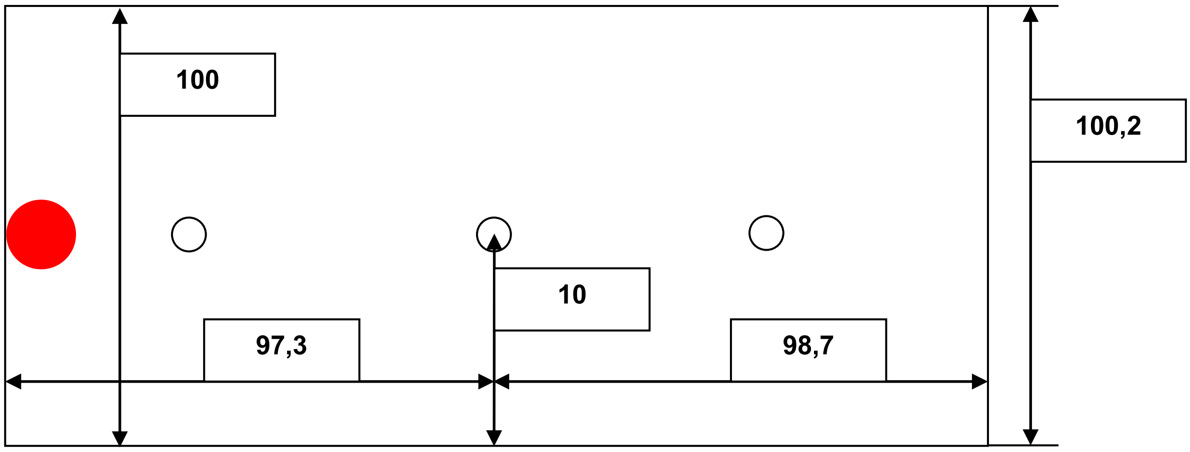
Excavation geometry:



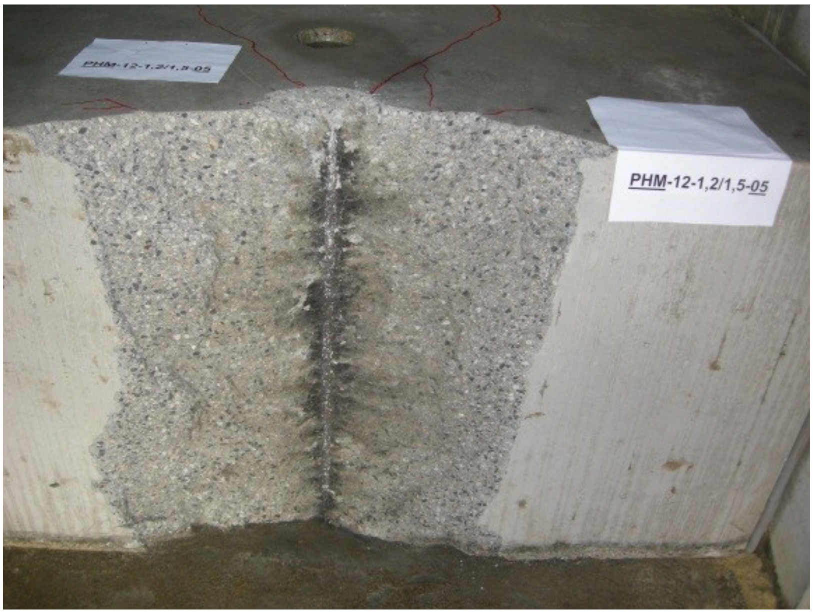
Top hole position:

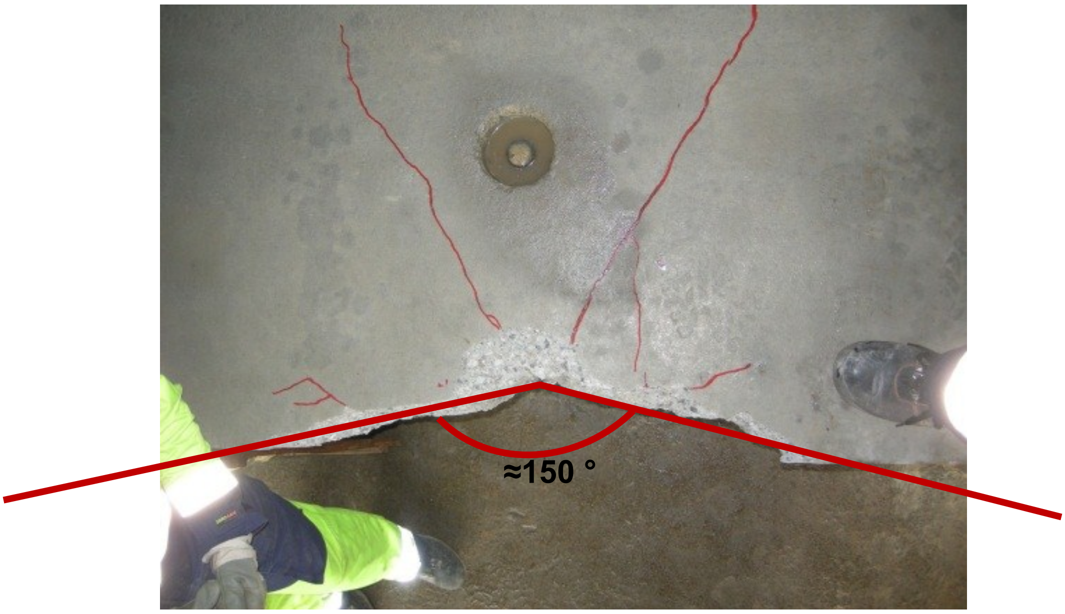


Bottom hole position:

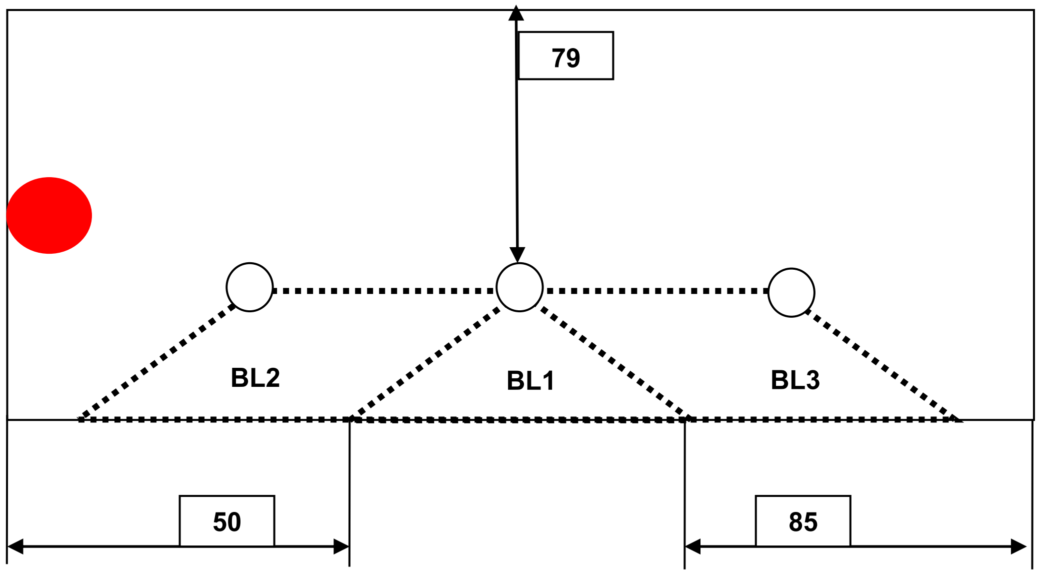


PHM-12-1,2/1,5**-05**

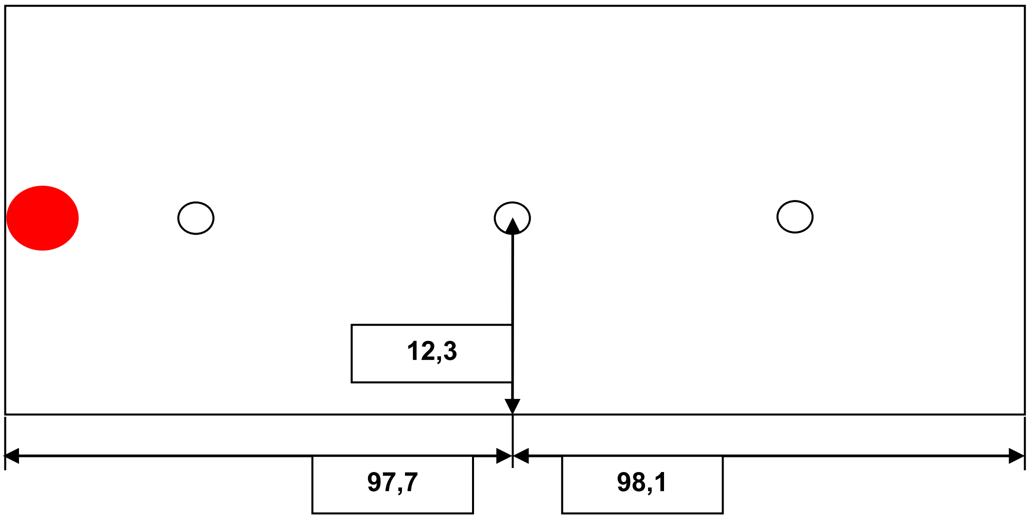




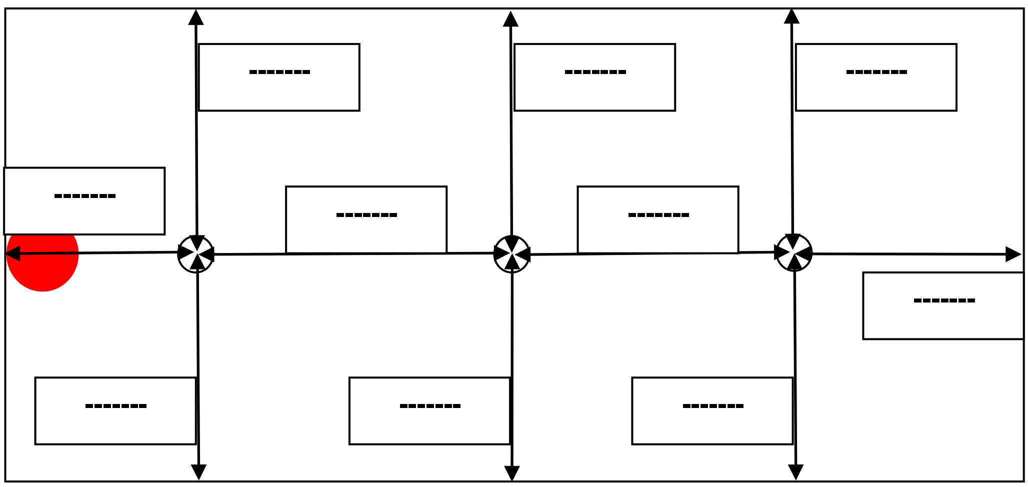
Excavation geometry:



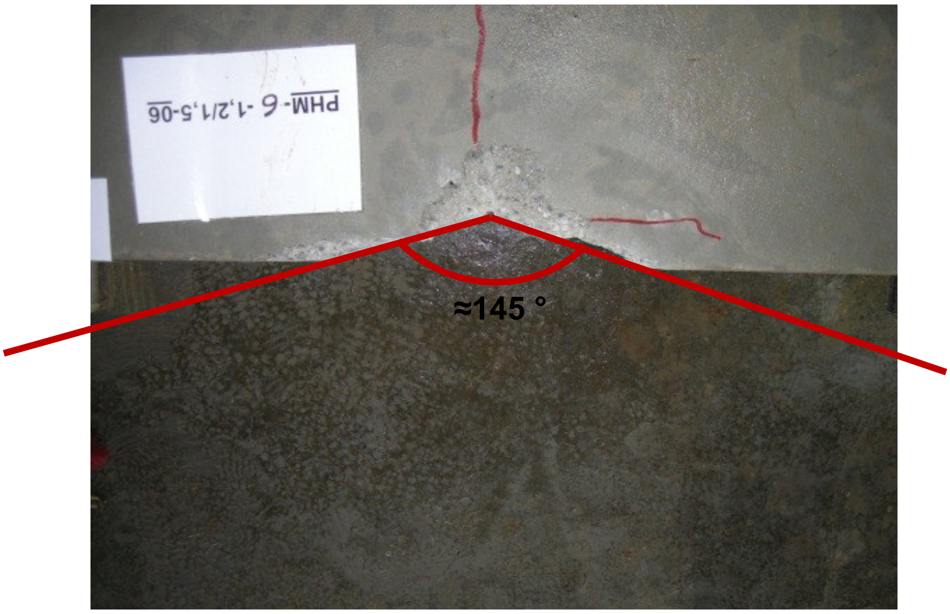
Top hole position:



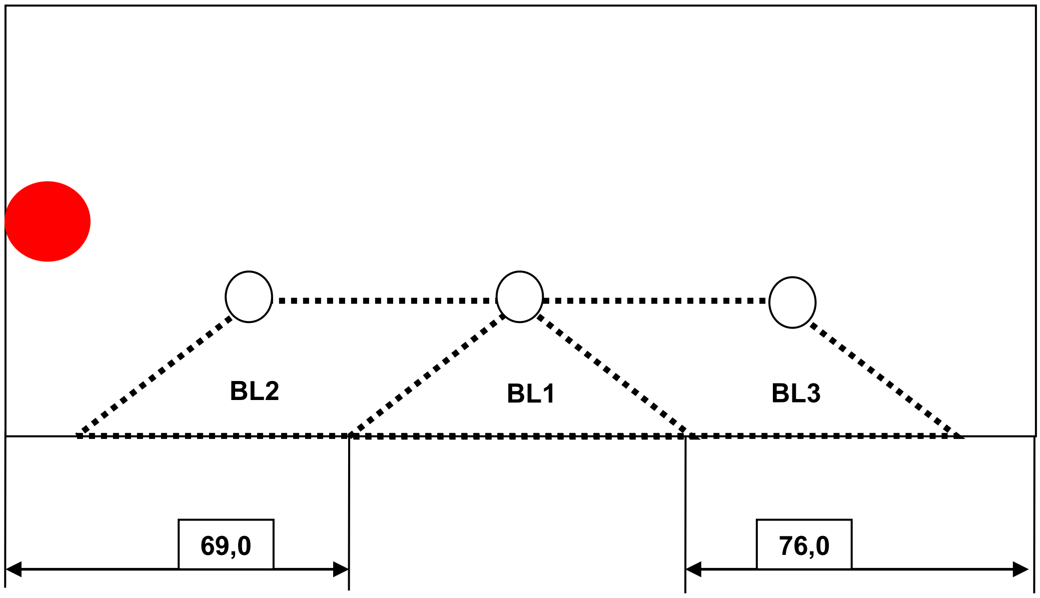
Bottom hole position:



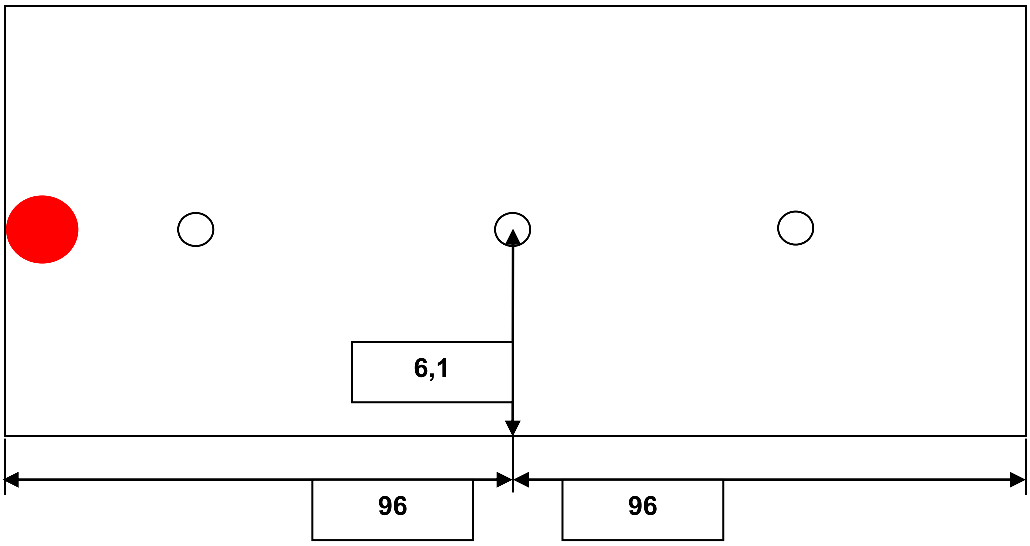
PHM-06-1,2/1,5**-06**



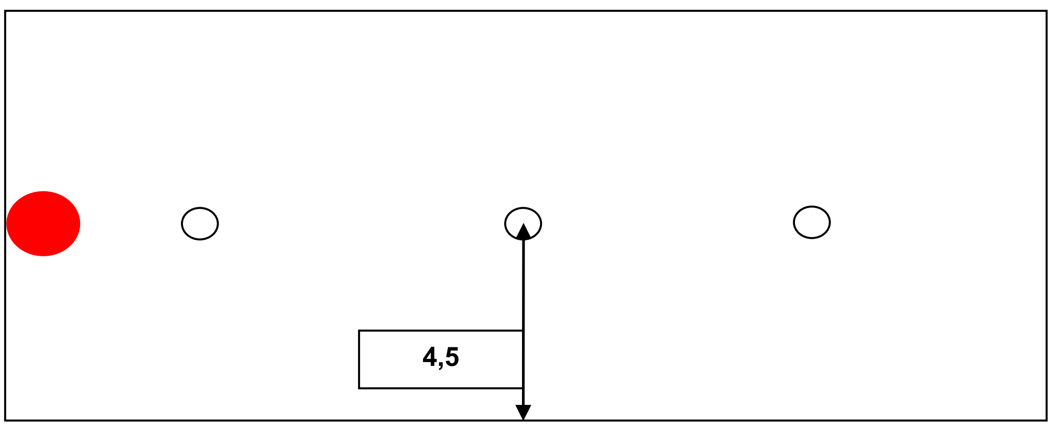
Excavation geometry:



Top hole position:



Bottom hole position:



Erzberg - PHM-05

Übersicht

Einsatzort:	Erzberg
Name der Bruchwand:	Elias
Bezeichnung der Sprenganlage:	PHM-05
Aufnahmezeitpunkt:	26.11.2010 11:13:10
Gesteinsdichte:	2420 kg/m³
3D Bild:	PHM-05.jm3
Sprenganlage:	PHM-05.smb

Anmerkungen:

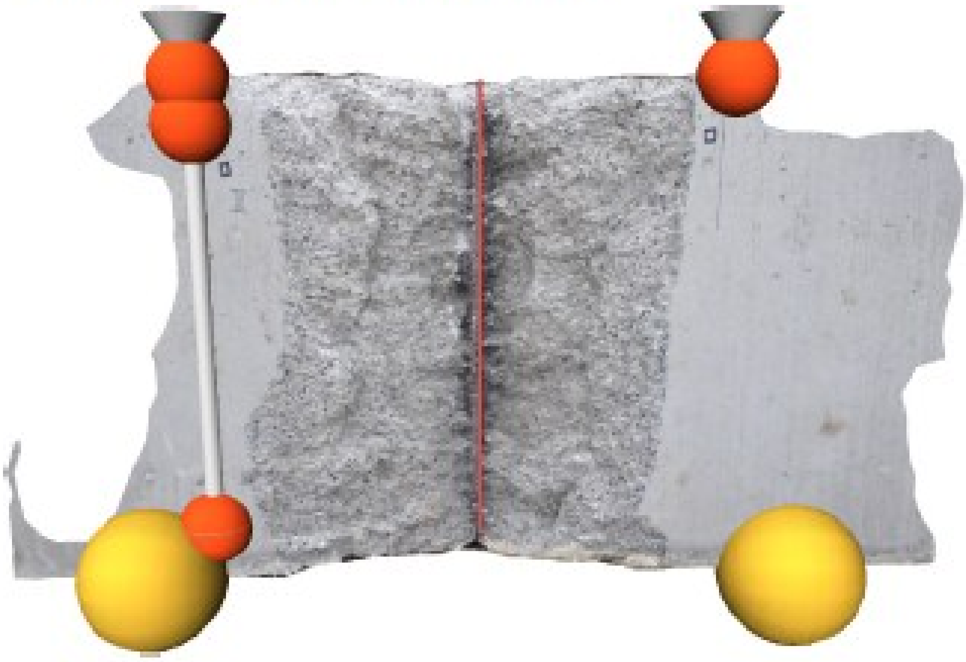
Geometrie der Sprenganlage

Minimale Höhe der Bruchwand:	0.99 m
Mittlere Höhe der Bruchwand:	0.99 m
Maximale Höhe der Bruchwand:	0.99 m
Neigung der Bruchwandebene:	89.66 °
Neigungsrichtung der Bruchwandebene:	n.a.
Abstand zwischen den Begrenzern:	1.02 m
Abstand zwischen den Begrenzungsebenen:	1.02 m
Anzahl an Bohrlöchern:	1
Gesamt-Bohrlochlänge:	0.95 m

Bohrschema

Vorgabe:	0.12 m
Anzahl der Reihen:	1
Reihenversatz:	0.0 m
Seitenabstand:	0.0 m
Bohrlochneigung:	1.00 °

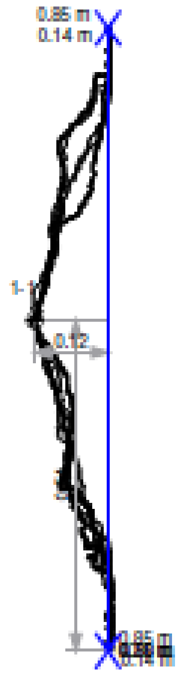
Es wird festgehalten, dass die mit BlastMetriX3D geplante Sprenganlage ausschließlich auf berührungslos gemessenen Informationen der Bruchwand erarbeitet wurde. Die mittels BlastMetriX3D geplante Sprengung ist auf jeden Fall von einem verantwortlichen Sprengbefugten auf Richtigkeit und Durchführbarkeit zu prüfen. Es wird vorausgesetzt, dass sämtlichen rechtlich bindenden Gesetzen, Verordnungen und Richtlinien entsprochen wird. Bei der Umsetzung der geplanten Sprenganlage gilt als vereinbart, dass Sie auf alle allenfalls Ihnen gegen 3G Software & Measurement zustehenden Forderungen zu verzichten.



Datum: 12.05.2011 15:33:00
BlastMetriX3D 3.5 Seite: 1/5

Erzberg - PHM-05

M 1:10



Begrenzer
Referenzlinie
Bohrlochposition
Bohrloch
Bemaßung in [m]

Datum: 12.05.2011 15:33:00
BlastMetrix3D 3.5

Seite: 2/5

Erzberg - PHM-05

Bohrlochdetails

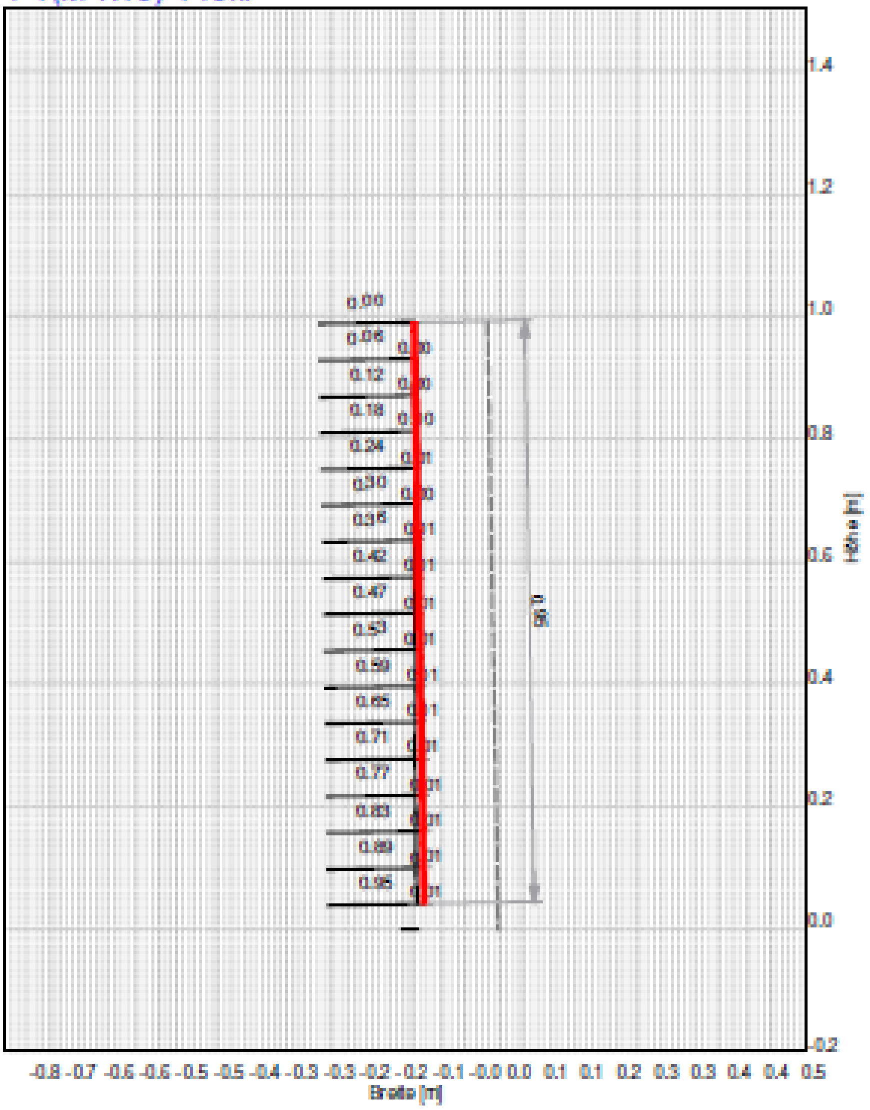
Bezeichnung	u [m]	v [m]	Alpha [deg]	Neigung [deg]	Länge [m]
1-1	0.54	0.12	90.10	1.00	0.95

Datum: 12.05.2011 15:33:00
BlastMetriX3D 3.5

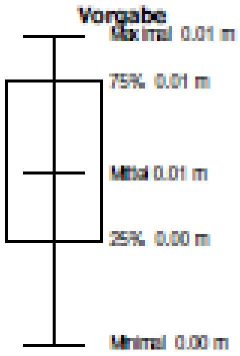
Seite: 3/5

Erzberg - PHM-05

1-1(M 1:10) Profil



Neigung: 1.00 °
Länge: 0.95 m
Durchmesser: 10.00 mm
Fläche: 0.0 m² (vom Profil)



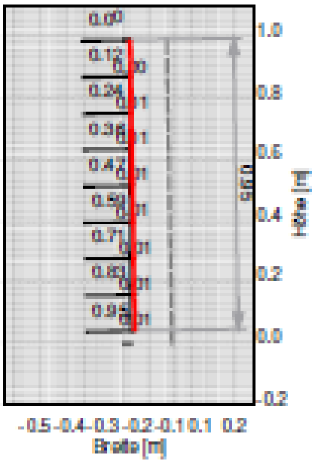
Tiefe | Profil

Datum: 12.05.2011 15:33:00
BlastMetriX3D 3.5

Seite: 4/5

Erzberg - PHM-05

1-1 Profil



Datum: 12.05.2011 15:33:00
BlastMetrix3D 3.5

Seite: 5/5

Erzberg - PHM-06

Übersicht

Einsatzort:	Erzberg
Name der Bruchwand:	Elias
Bezeichnung der Spronganlage:	PHM-06
Aufnahmezeitpunkt:	26.11.2010 11:17:11
Gesteinsdichte:	2420 kg/m³
3D Bild:	PHM-06.jm3
Sprenganlage:	PHM-06.smb

Anmerkungen:

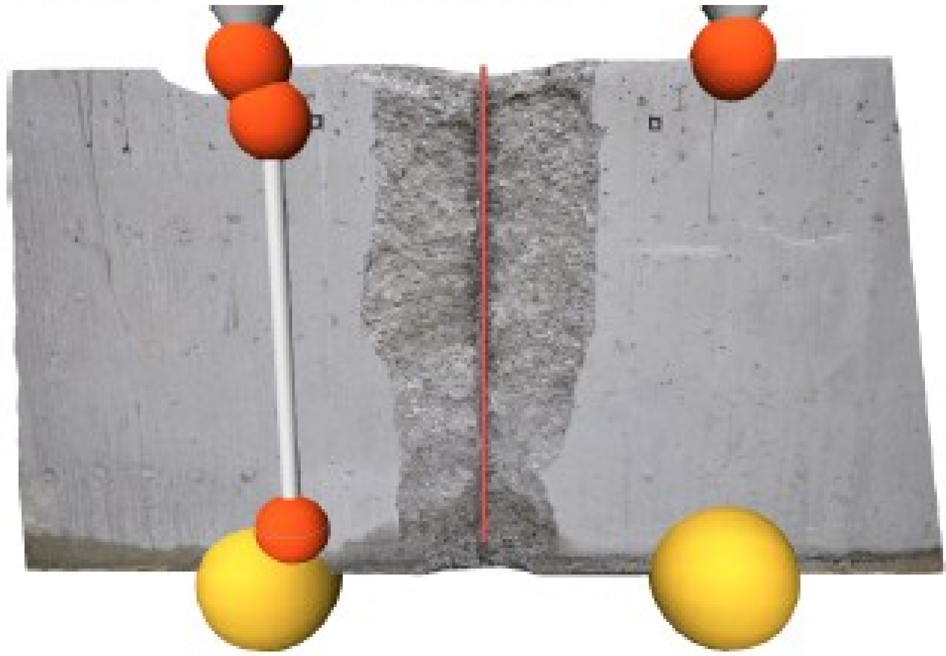
Geometrie der Sprenganlage

Minimale Höhe der Bruchwand:	1.01 m
Mittlere Höhe der Bruchwand:	1.02 m
Maximale Höhe der Bruchwand:	1.03 m
Neigung der Bruchwandebene:	89.83 °
Neigungsrichtung der Bruchwandebene:	n.a.
Abstand zwischen den Begrenzern:	0.87 m
Abstand zwischen den Begrenzungsebenen:	0.87 m
Anzahl an Bohrlöchern:	1
Gesamt-Bohrlochlänge:	0.95 m

Bohrschema

Vorgabe:	0.06 m
Anzahl der Reihen:	1
Reihenversatz:	0.0 m
Seitenabstand:	0.0 m
Bohrlochneigung:	1.70 °

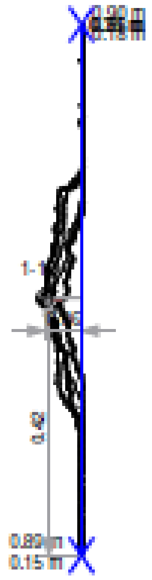
Es wird festgehalten, dass die mit BlastMetriX3D geplante Sprenganlage ausschließlich auf berührungslos gemessenen Informationen der Bruchwand erarbeitet wurde. Die mittels BlastMetriX3D geplante Sprengung ist auf jeden Fall von einem verantwortlichen Sprengbefugten auf Richtigkeit und Durchführbarkeit zu prüfen. Es wird vorausgesetzt, dass sämtlichen rechtlich bindenden Gesetzen, Verordnungen und Richtlinien entsprochen wird. Bei der Umsetzung der geplanten Sprenganlage gilt als vereinbart, dass Sie auf alle allenfalls Ihnen gegen 3G Software & Measurement zustehenden Forderungen zu verzichten.



Datum: 12.05.2011 15:34:12
BlastMetriX3D 3.5 Seite: 1/5

Erzberg - PHM-06

M 1:10



Begrenzer

Referenzlinie

Bohrlochposition

Bohrloch

Bemaßung in [m]

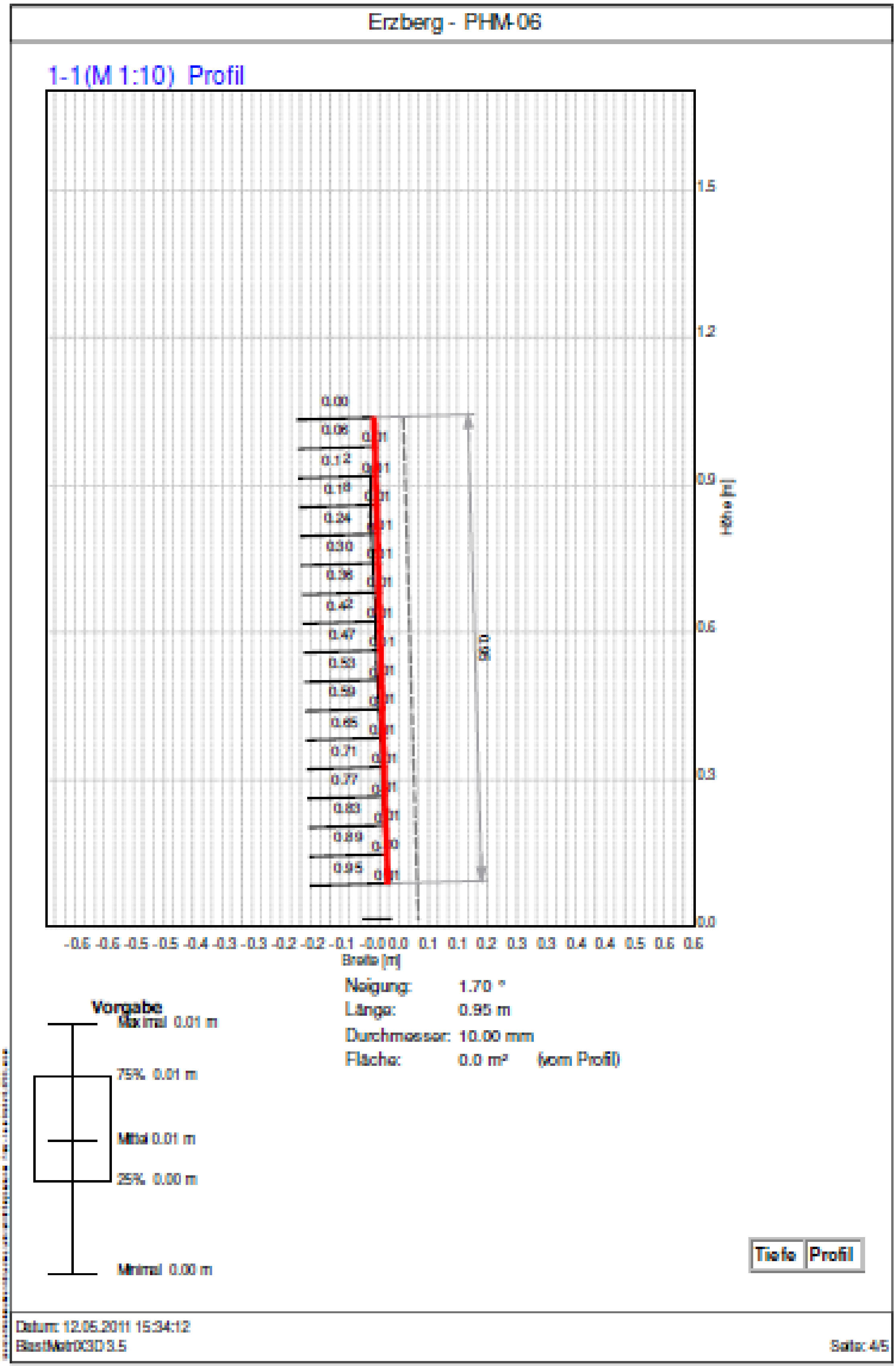
Datum: 12.05.2011 15:34:12

BlastMetriX3D 3.5

Seite: 2/5

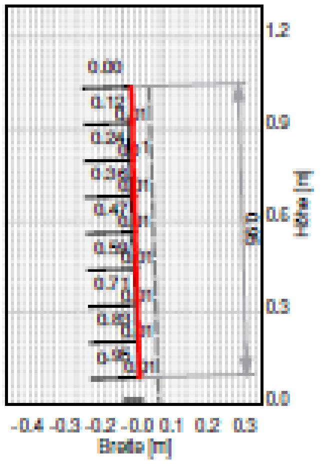
Bohrlochdetails

Bezeichnung	u [m]	v [m]	Alpha [deg]	Neigung [deg]	Länge [m]
1-1	0.42	0.06	89.83	1.70	0.95


Erzberg - PHM-06
1-1(M 1:10) Profil
Höhe [m]
Breite [m]
Neigung: 1.70 °
Länge: 0.95 m
Durchmesser: 10.00 mm
Fläche: 0.0 m² (vom Profil)
Vorgabe
Maximal 0.01 m
75% 0.01 m
Mittel 0.01 m
25% 0.00 m
Minimal 0.00 m
Tiefe
Profil
Datum: 12.05.2011 15:34:12
BlastMetrix3D 3.5
Seite: 4/5

Erzberg - PHM-06

1-1 Profil



Datum: 12.05.2011 15:34:12
BlastMetriX3D 3.5

Seite: 5/5