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Compaction of full size blocks of bentonite for the KBS-3 concept

Initial tests for evaluating the technique

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December 1999

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Keywords: clay, compaction, blocks of bentonite, compaction, pressure, compaction technique

Abstract

In this report, tests with uniaxial compaction of large blocks of bentonite (MX-80) are described. The parameters varied in the tests were the block shape, the maximum compaction pressure and the water content of the bentonite. After compaction the density, water ratio and tensile strength were measured in several locations in the blocks. The blocks were also examined with respect to damages and cracks.

Besides the test with the compaction device several other pieces of equipment were tested for the mixing of the bentonite with water, filling of the form with bentonite and lifting of the blocks.

The tests of the equipment turned out well. Furthermore the density of the compacted bentonite was in parity with the expected. The compacted blocks had grooves and flanges in order to facilitate the emplacement of the blocks. Unacceptable damages and cracks close to the flanges were observed on the blocks with low water ratio. As a consequence of these damages it is recommended that the form is modified so that blocks with plane surfaces can be made.

Sammanfattning

Föreliggande rapport beskriver försök där stora block av MX-80 har kompakterats enaxligt. I försöken varierades blockens form, kompakteringsspänningen och vattenkvoten. Efter kompaktering bestämdes vattenkvot, densitet och böjdraghållfastheten på prover tagna från blocken. Blocken undersöktes också med avseende på förekomst av sprickor och andra skador.

Förutom försöken med kompakteringsutrustningen testades också övrig utrustning som behövs vid produktion av stora bentonitblock. Exempel på sådan utrustning är blandare i vilken bentonit blandas med vatten, utrustning för att fylla formen med bentonit samt utrustning för att lyfta stora block.

Resultaten från de utförda testerna visar att den använda utrustningen fungerade som planerat. Vidare uppnåddes de förväntade densiteterna på blocken. Blocken hade för att underlätta inplaceringen i deponeringshål urspamingar och falsar. På många av blocken med låg vattenkvot uppkom oacceptabla sprickor och skador i anslutning till dessa falsar. Som följd av detta rekommenderas att formen modifieras så att släta block utan urspamingar och falsar kan göras.

Contents

1 Background

The Swedish KBS3 concept for disposal of nuclear waste implies that the bentonite barrier around the waste canister is installed in the form of blocks of highly compacted bentonite. Techniques for manufacturing of blocks of highly compacted bentonite have been studied and developed in an ongoing project. There are two main techniques for compacting blocks of bentonite; isostatic compaction and uniaxial compaction. The bentonite barrier can consist of several small blocks, which are manageable by hand, or large blocks, which require special tools to be handled. If isostatic compaction is used, it is convenient to make as large blocks as possible, while uniaxial compaction technique can be used both for large and small blocks. This project deals with development and testing of a technique for uniaxial compaction of large blocks.

Blocks with a diameter of about 1000 mm and a height of about 450 mm were compacted in previous tests. The blocks weighed about 600 kg. These tests were successful, and it was decided to manufacture a full-size form. This form can be used for compacting both cylindrical and ring shaped blocks with maximum diameters of 1650 mm.

The form will in the first place be used for the blocks needed in the Prototype Repository and the Canister Retrieval Test. A schematic drawing of a canister hole with bentonite blocks is shown in Figure 1-1. The figure shows that the total amount of blocks in one deposition hole is 10 ring-shaped blocks and 4 cylindrical blocks. The total weight of the bentonite needed for one deposition hole is about 22 tons. The form will be used for production of bentonite blocks for 8 deposition holes, i.e. 100 blocks. The initial water ratio of the bentonite blocks has not been finally decided yet. For blocks with water ratio larger than 10% (the water ratio of bentonite at equilibrium with an indoor climate), water must be added to the bentonite in a mixer. The large amount of planned manufactured blocks requires, beside the form, other equipment as a mixer, filling equipment and a lifting device.

This report describes the initial tests of the form and the other equipment. In the tests MX-80 bentonite was used.

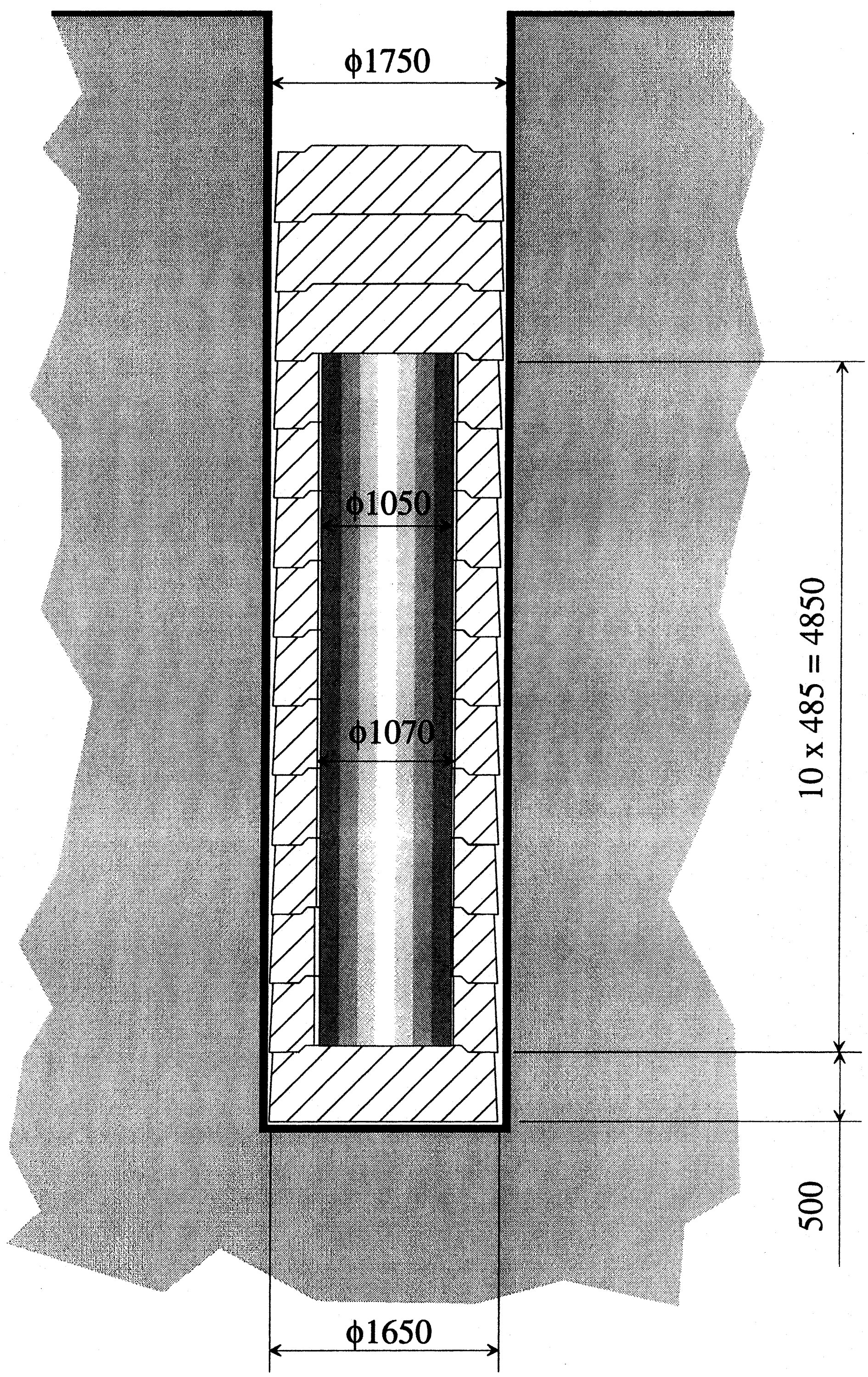

Figure 1-1. *A schematic drawing of a deposition hole with bentonite blocks and canister.*

2 Objectives

The major objective of the tests is to develop a technique for compacting bentonite blocks for the planned field tests at Äspö. This can be summarised as follows:

- To find a suitable technique for mixing large volumes of bentonite with water.
- To find suitable techniques for transportation and storage of mixed bentonite.
- To develop the technique for uniaxial compaction of large blocks of bentonite, both ring-shaped and cylindrical.
- To investigate whether the blocks will function as planned both during installation (can the blocks be handled without breaking, can the blocks be placed as planned in a deposition hole) and as a barrier (have the blocks sufficient density, are the blocks homogeneous).
- To find suitable techniques for transportation and storage of compacted blocks.

3 Mixing of Bentonite

The mixing of the bentonite was performed at Hackman-Rörstrand in Lidköping using a mixer used for mixing clays for porcelain ware. The mixer, see Figure 3-1, is an Erich mixer with a built-in weighing-machine. The maximum batch that could be handled by the mixer was about 1.5 tons. In order to avoid bentonite contamination of the factory, special transportation tubes for the bentonite had to be installed. Furthermore, the mixer was outfitted with special devices for emptying the bentonite in Big-Bags. The necessary modifications of the mixer were constructed and manufactured by Ulrich Balzar at Ulrich Balzar AB and by personnel at Hackman Rörstrand.

The bentonite, of type MX-80, was filled in a silo placed above the mixer and then transported to the mixer. About 1 ton of bentonite was mixed in each batch. A small sample was taken from the bentonite filled in the mixer and the initial water content was determined. Using the initial water content and the total amount of bentonite as input, the amount of water needed in order to get final water content of 17% was calculated. After mixing the bentonite was filled in Big-Bags and a sample was taken in order to determine the final water content. A total number of 11 batches were mixed. The results from the determination of the water ratios are plotted in Figure 3-3. The figure shows that the average water ratio was 16.4% which was somewhat lower than the required water content of 17%. This can be explained by the fact that the amount of bentonite coming from the silo into the mixer and the amount of water added to the bentonite was manually controlled in these tests. However, the mixing station is equipped with devices for automatically weighing of both bentonite and water. The water ratio would probably have varied less if these devices were used.

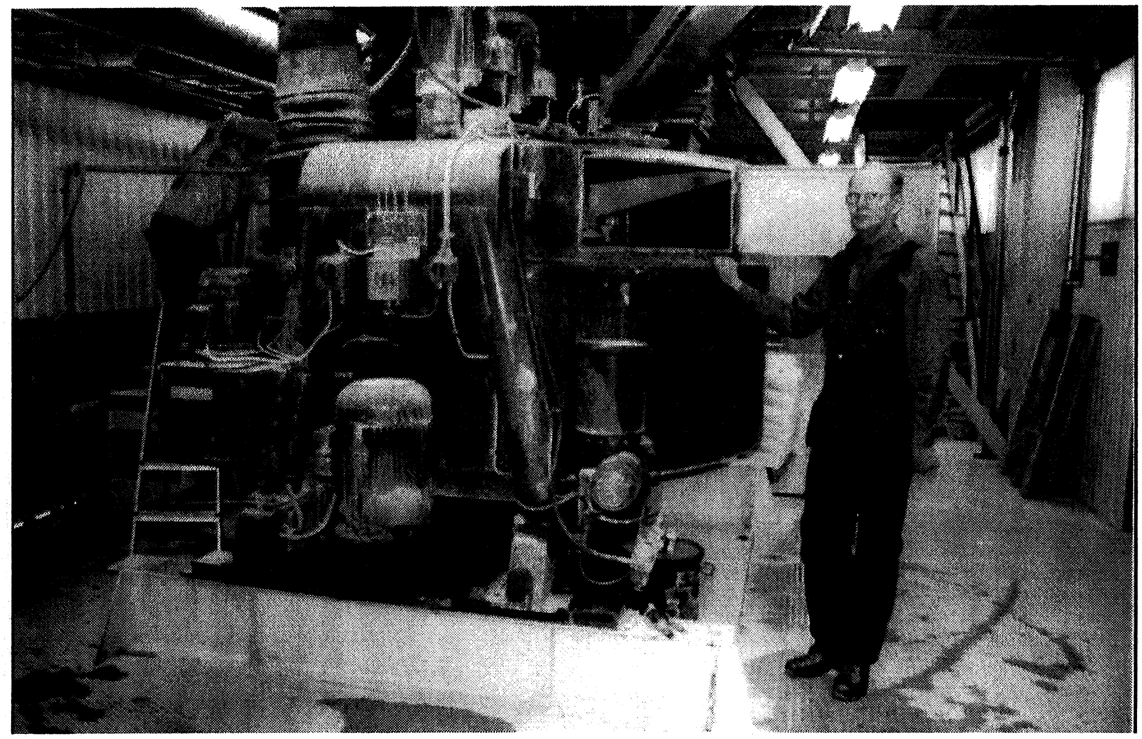

__Figure 3-1.__ The Eirich mixer used at Hackman-Rörstrand

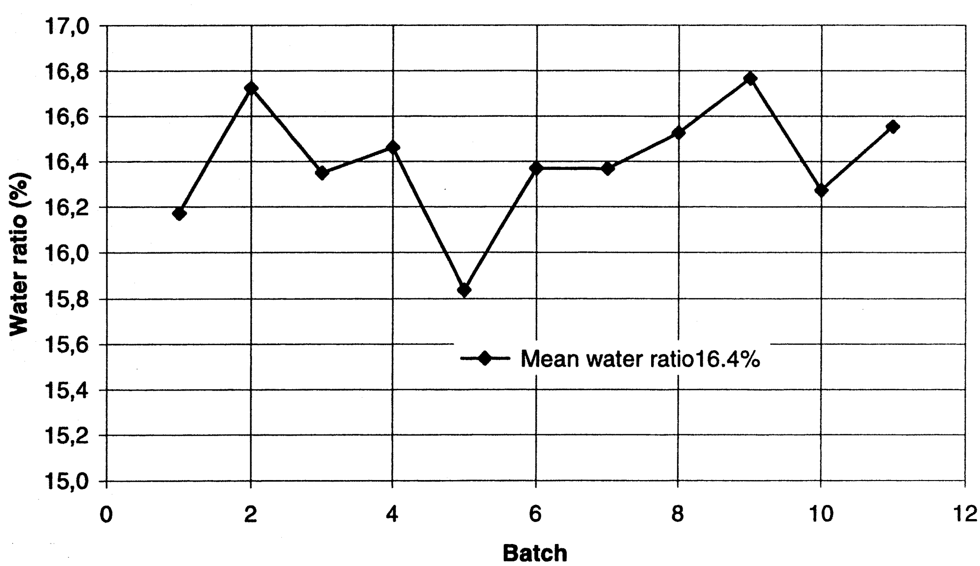

__Figure 3-2.__ Results from the measurement of the water ratio for 11 batches of mixed bentonite (MX-80).

4 Equipment Used in the Tests

4.1 General

The mixed bentonite was transported in Big-Bags to HYDROWELD AB:s plant in Ystad where the press is situated. The bentonite was filled into a silo, which is part of the filling equipment. The exact weight of bentonite was then poured into the form, which was inserted into the press with a subsequent compaction of the bentonite. After compaction the block was removed from the form and placed on a pallet using the specially designed lifting equipment and then wrapped in plastic.

4.2 Filling Equipment

Ulrich Balzar at Ulrich Balzar AB and personnel at MOLITEKNIK AB SKAR designed and manufactured the filling equipment. The equipment is shown in Figure 4-1. It consists of a silo where the bentonite is filled from the Big-Bags and a worm conveyor that transports the bentonite from the bottom of the silo through the filling tube and into the form. A filter and a fan has been installed in order to dispose of most of the dust occurring both during the filling of the silo but also during the filling of the form. A vibrator is installed in the bottom of the silo, which facilitates the emptying of the silo and minimises the risk of the bentonite getting stuck. An electronic weighing-machine integrated in the equipment makes it possible to portion the bentonite into the form automatically and very accurately.

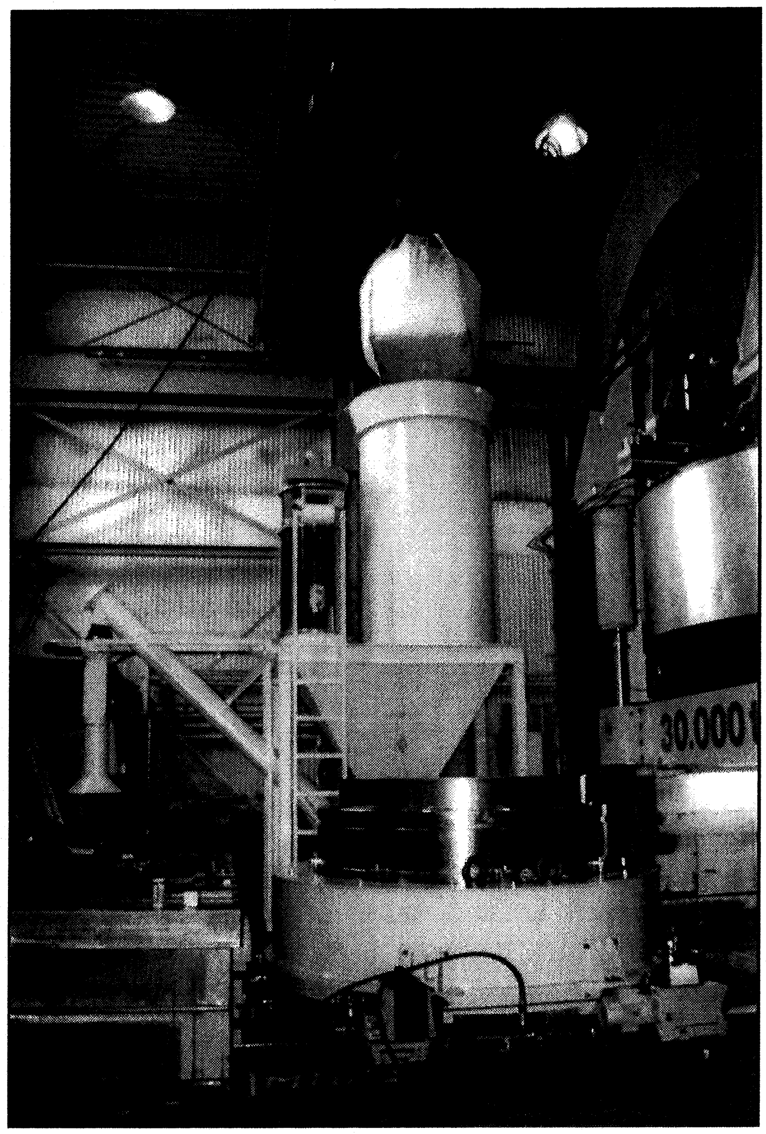

Figure 4-1. The filling equipment.

4.3 Form

A form was constructed which made it is possible to compact both ring-shaped and cylindrical bentonite blocks with the full size diameter for a deposition hole. Figures 4-2 and 4-3 show drawings of the form. Finn Jonsson at Finn Jonsson Engineering made the design of the form that was manufactured at KOCKUMS INDUSTRIER AB and at HERRSTRÖMS MEKANISKA AB. The form has a maximum inner diameter of 1650 mm and a height of about 1100 mm. After compaction the blocks have a height of about 500 mm. The form consists of three main parts; a bottom plate (No 5 in Figure 4-2), a cylinder consisting of one lower part which can withstand a high radial pressure (No 1) and one thin upper part (No 2), and a piston consisting of three steel plates (No 3 and 4). The piston is divided into three parts due to the limited height available in the press.

The lower-most part of the cylinder is conical in order to prevent damages on the blocks during removal from the cylinder. The lower part of the cylinder wall is inclined about 1.4° to the distance 500 mm from the bottom plate. There are filter stones (No 25) both in the piston and in the bottom plate. A vacuum pump can be connected to the filter stones and the compaction can be made at vacuum. In order to retain the vacuum during the compaction there are O-rings both in the piston (No 37) and in the bottom plate (No 40). There are both an upper (No 6) and a lower sealing ring (No 7) in the form. No further guiding of the piston was used. When ring-shaped blocks are compacted, an inner cylinder (No 28 in Figure 4-3) is placed on the bottom plate centric to the outer cylinder and a piston with a centric hole is used (No 23 and 27). Figure 4-2 and 4-3 show that the blocks after compaction have grooves and flanges in order to facilitate the emplacement of the blocks.

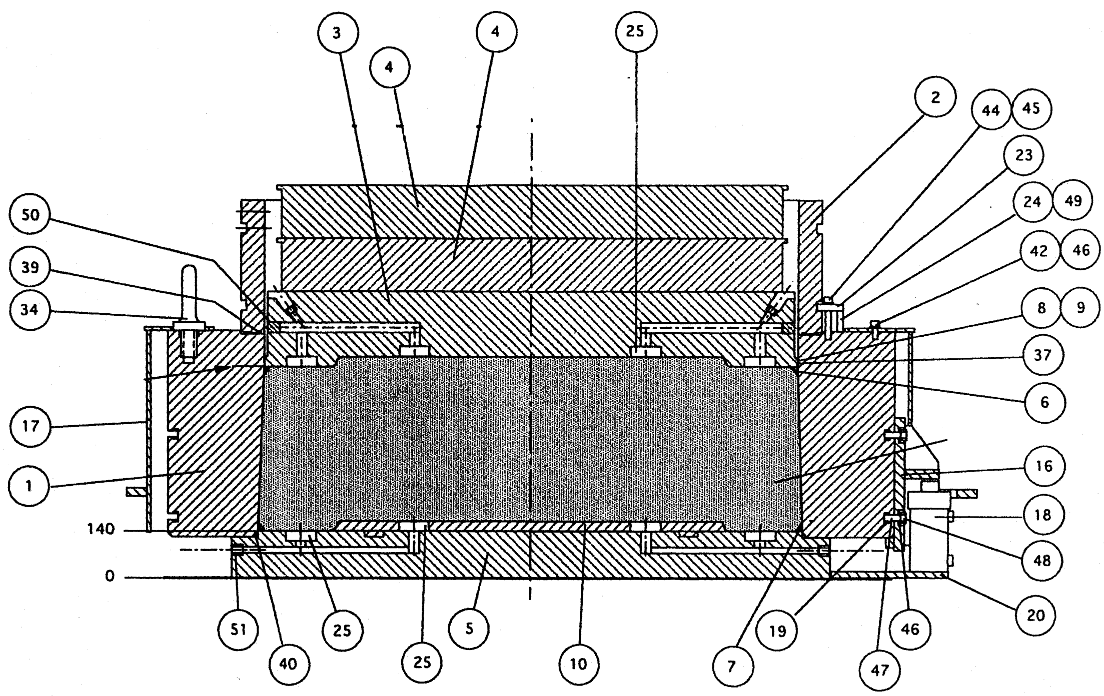

Figure 4-2. *The form used for compacting cylindrical blocks (after completed compaction).*

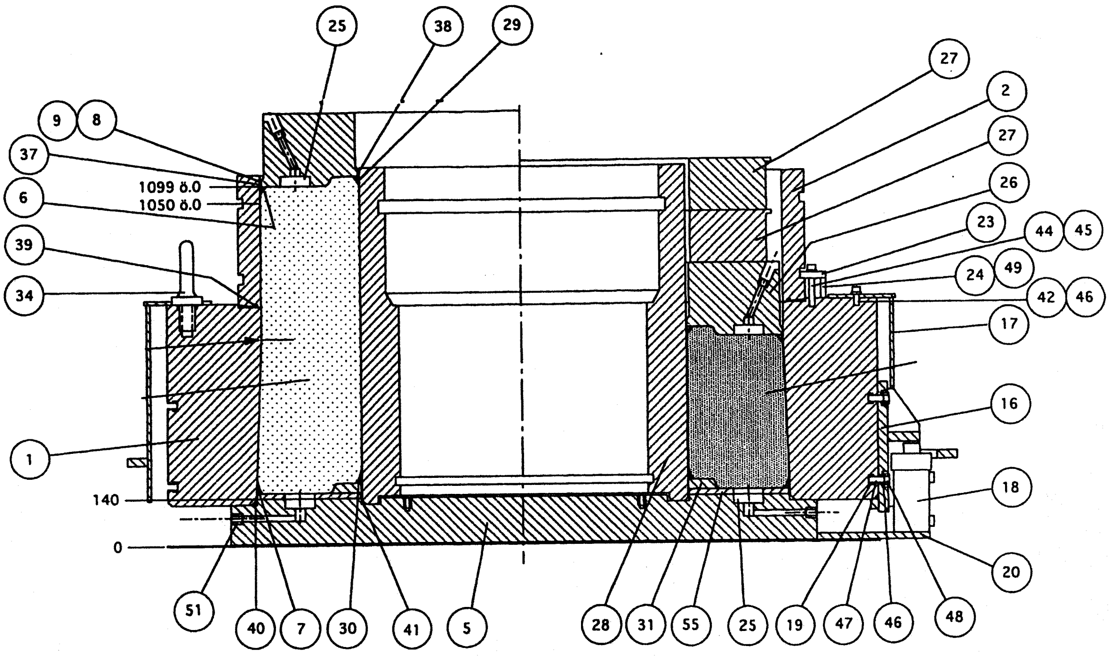

Figure 4-3. The form used for compacting ring-shaped blocks. The left part of the figure shows the situation before compaction while the right part shows the situation after compaction.

4.4 Lifting Equipment

The lifting equipment with a maximum lifting capacity of 2300 kg was designed by CARLHAG AB and Ulrich Balzar at Ulrich Balzar AB. CARLHAG AB also manufactured the equipment. It is free of electrical components and consists of a frame (see Figure 4-4) on which 43 suction cups are mounted and a compressor with the capacity to create a pressure of 6 bars and a maximum flow of 1260 litres/minute. By placing the equipment on the top of the block and connecting it to the compressor with tubes, vacuum can be obtained in the suction cups. Since the leakage of air through the bentonite block is very small it is possible to lift the block with the equipment hanging in an overhead crane (se Figure 4-5). The equipment can be used both for lifting cylindrical and ring-shaped blocks. A console is integrated in the equipment (the grey case placed on the frame in Figure 4-4) on which there is an indication when enough vacuum is reached in the cups for lifting a block. If air leaks through the suction cups or through the block, this will also be indicated on the console. All the suction cups are not connected to the same tube, which means that a leakage in one cup is not creating a drop of vacuum in the whole system. If there is an indication of drop in vacuum, there is normally time for placing the block on the ground before it falls.

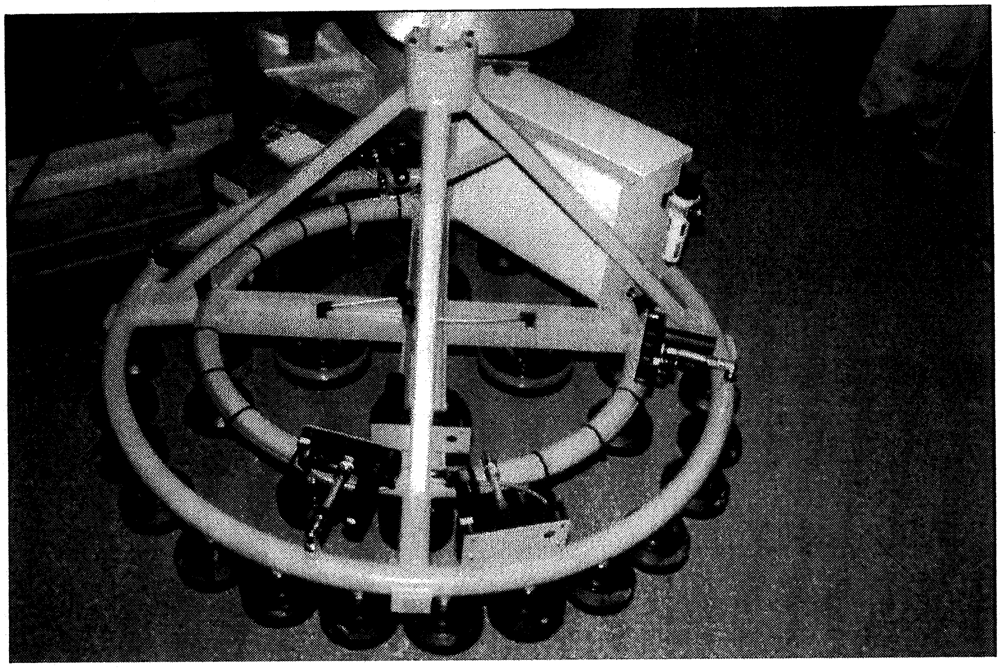

Figure 4-4. *The lifting equipment with its 43 suction cups.*

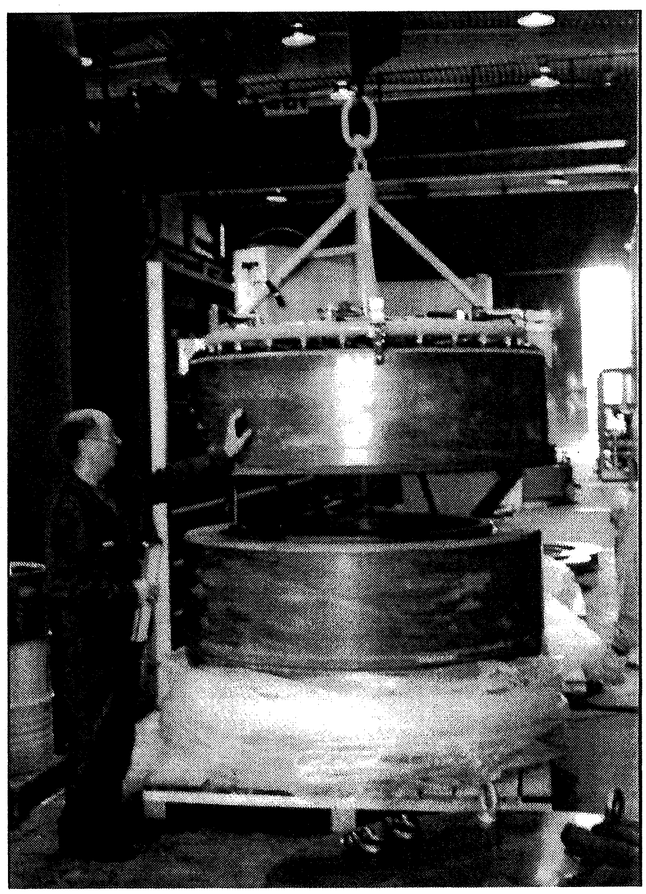

Figure 4-5. *The lifting equipment hanging from an overhead crane when a ring-shaped block is placed on top of another block.*

5 Block Compaction

5.1 Compaction Sequence

Altogether 11 blocks, 5 cylindrical and 6 ring-shaped, were compacted (see Table 5-1). MX-80 was used in all tests. The following parameters were varied; the block shape, the maximum compaction pressure and the water content of the bentonite. The time during which maximum load acted on the blocks was about 10 minutes, except in one test were the maximum load was allowed to act for about 4 hours. The purpose with this test was to investigate the effect of the time at maximum load on the properties of the compacted blocks. Laboratory tests on samples taken from the blocks indicate that there is some influence of the resting time (see Section 6). The compaction of each block was made in the following sequence.

- The form was mounted outside the press and lubricated with MOLYKOTE BR 2 plus®, which is a molybdenum-based lubricant for lubricating at high pressure.

- The silo was filled with bentonite and the form was filled through the filling tube with the exact weight of bentonite settled beforehand.

- The first piston was placed on the top of the bentonite in the form and the form was placed in the press. The tubes from the filters were connected to a vacuum pump and air was evacuated from the bentonite in the form. The evacuation was retained through the whole compaction sequence. The bentonite was then compacted with the press as far as possible. Then the second piston was placed on the top of the first piston and the compaction continued. The same procedure was repeated for the third piston. The total time for the compaction was about 10 minutes. The maximum load was then left on the piston for another 10 minutes (hold time 10 minutes). A picture of the press is shown in Figure 5-1. The maximum load capacity of the press is about 30.000 tons.

- The decompression of the block took about 10 minutes. The form with bentonite and the pistons were then lifted with jackets. Steel plates were placed between the form and the bottom plate whereupon the block was pushed out of the form with the press.

- The form and the block were then removed from the press and the ring and pistons lifted off the block. With the lifting equipment the block was placed on a pallet and then wrapped in plastic.

- Samples were taken at different locations in the blocks. These locations are shown in Figure 5-2. The water ratio and the density were measured. The tensile strength of these samples was also measured by use of a beam test. The results from the tests are described in Section 6.

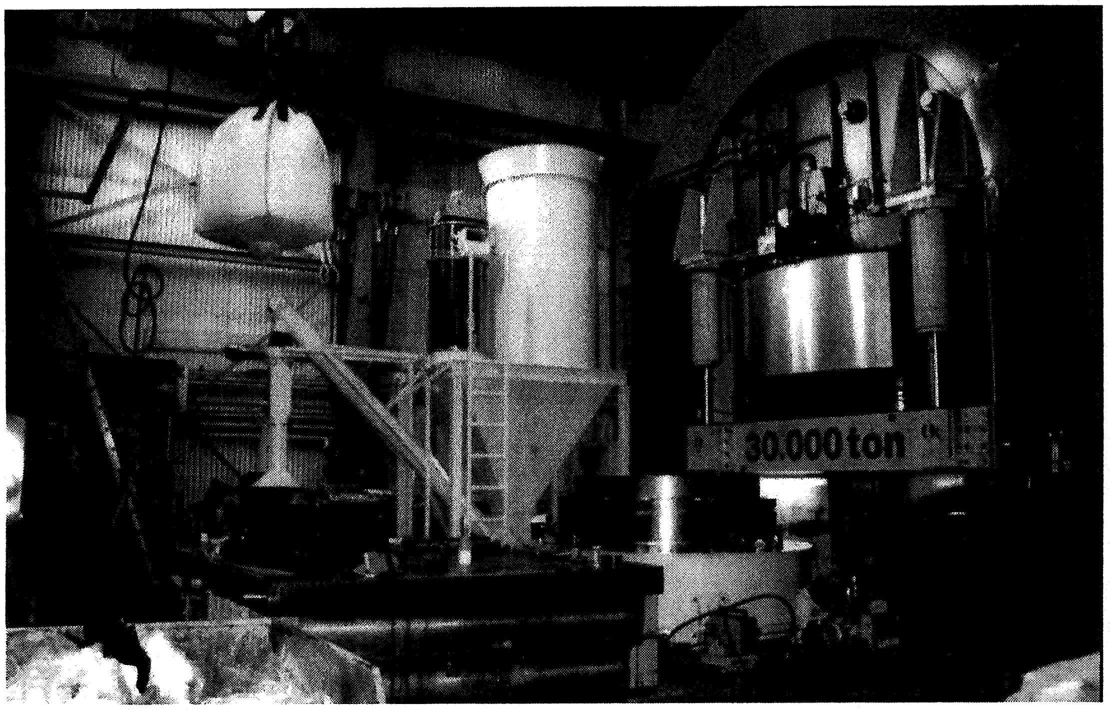

Figure 5-1. The press and the form together with the filling equipment

TABLE 5-1. The test program.

No.	Water ratio	Shape	Maxi. Comp.stress (MPa)	Hold time	Location of samples	Number of samples
1	0.093	Cylindr.	50	10 min	See Fig 4-6 a	15
2	0.093	Cylindr.	100	10 min	See Fig 4-6 a	15
3	0.093	Ring	100	10 min	See Fig 4-6 b	25
4	0.093	Ring	100	10 min	No samples taken	-
5	0.164	Cylindr.	50	10 min	See Fig 4-6 a	15
6	0.164	Cylindr.	ca 65	10 min	See Fig 4-6 a	15
7	0.164	Ring	100	10 min	See Fig 4-6 b	25
8	0.164	Ring	100	10 min	No samples taken	-
9	0.164	Cylindr.	100	10 min	See Fig 4-6 a	15
10	0.093	Ring	100	10 min	No samples taken	-
11	0.093	Ring	100	4 hours	See Fig 4-6 b	25

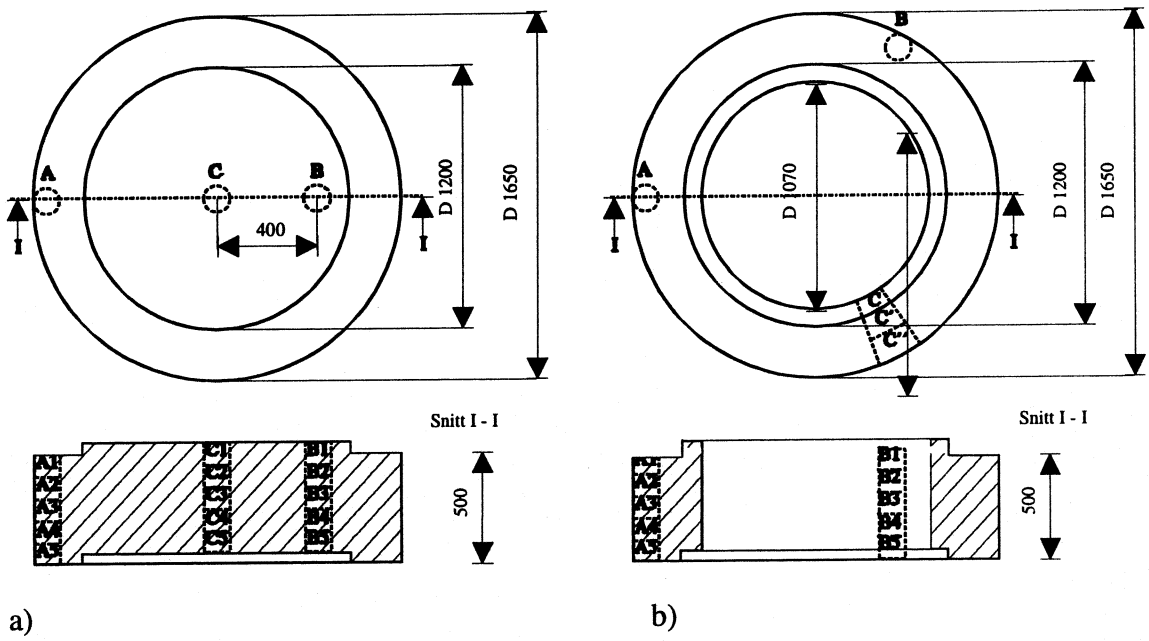

Figure 5-2. *Location of samples taken in a) cylindrical block and b) ring-shaped block*

5.2 Handling of the Blocks

After compaction the blocks were placed on a pallet by use of the lifting equipment described in Section 4.4. Preceding tests with the equipment showed that it was very important to have the required air pressure and amount of air-flow from the compressor. Although the compressor had the required performance, there were some initial difficulties to achieve the necessary vacuum in the suction cups in order to be able to lift the blocks in a safe way. During the lifting tests it was found that these difficulties were caused by air pressure loss due to long and narrow tubes coming from the compressor. By using tubes with a larger section area the problem was solved.

In order to minimise the desiccation of the blocks during storage they were wrapped in a plastic bag before they were placed on a pallet (see Figure 5-3). The plastic bag was then sealed with a strong tape.

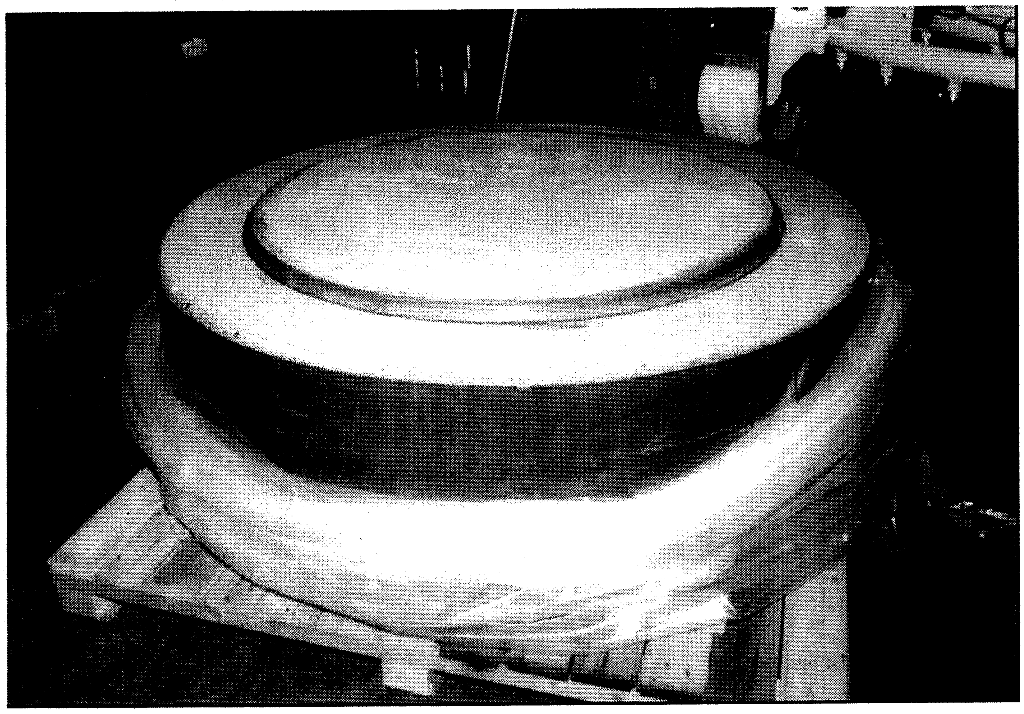

Figure 5-3. A cylindrical block partly wrapped in plastic and placed on a pallet.

As mentioned before the blocks had grooves and flanges in order to facilitate the emplacement. To find out if the blocks were functioning as planned, three blocks were put together in a stack (see Figure 4-5). Two ring-shaped blocks were placed on a cylindrical block. After emplacement 1 mm gaps between the blocks were observed. The reason for these gaps was that the bottom surfaces of the blocks were not plane. The difference in height between the centre part and the periphery of a cylindrical block was estimated to about 2 mm. The dome-shaped surface of the block is probably created during deloading. Decreasing load results in elastic swelling of the block. Due to the friction between the form and the block this is smaller for the peripheral parts of the block, hence the difference in height.

5.3 Damages on the Blocks

After compaction the blocks were examined with respect to damages and cracks. The observed damages and cracks can roughly be divided in the following groups:

1. Damages which are assumed to be caused by "mistakes" at the compaction and at the removal of the block from the form.

2. Crack and damages with very small extension both in depth, width and length.

3. Cracks and damages observed at the grooves of the blocks

4. Cracks at the top of the blocks (see Figure 5-4)

The first type of damage was observed on the lower part of Block 3. The damage occurred when the block was removed from the form. Block 10 also had damages caused by mistakes at the compaction. In this case the upper sealing rings (see section 4.3) had not been used at the compaction.

Most of the blocks have the second type of damages. They are assumed to have no effect on the possibility to handle the blocks.

The third kind of damage was observed on all blocks with low water ratio. The damage was caused during removal of the piston from the top of the blocks after extraction from the form. The blocks are at this stage free to expand radial, except for the upper part, where the piston prevents expansion. This causes large stresses close to the flanges, which the compacted bentonite cannot withstand. The reason why these damages only are observed on the blocks with low water ratio, is that the elastic swelling increases with decreasing water ratio for the compacted bentonite (see Johannesson et al 1995). The damages are considered so comprehensive that they affect the possibility to handle and place the blocks in a deposition hole.

The fourth type of damage was very apparent on Block 9. The crack had a width of 2 mm and a depth into the block of about 50 mm. The length of the crack around the circumference was about 2 m. Although this type of cracks was not so apparent on the rest of the blocks it is most likely that it can be found in most of them. Previously performed investigations and FEM calculations indicate that the cracks are due to the large elastic swelling of the block during the reloading in combination with the conical form. These damages are not considered to affect the handling and the possibility to place the blocks in a deposition hole.

An investigation of the blocks with respect to damages and cracks is also described in Pusch 1998.

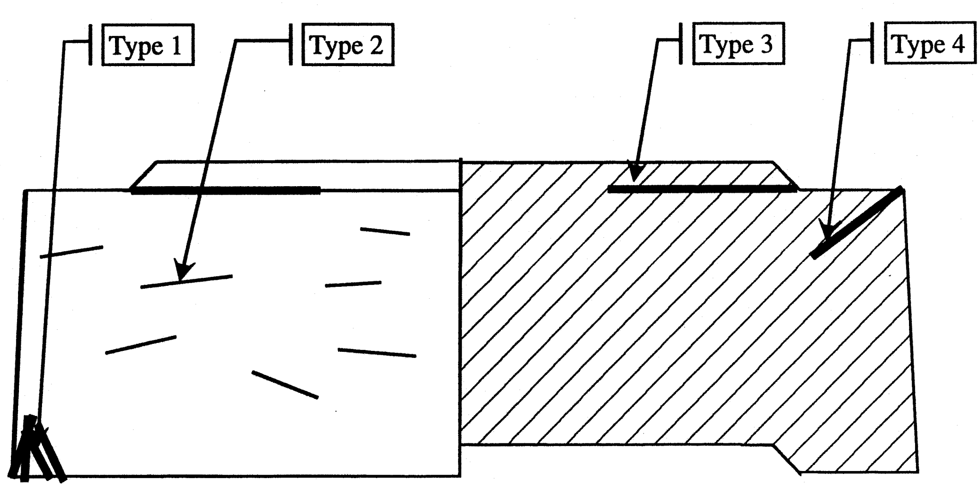

Figure 5-4. *A schematic drawing of the different type of cracks and damages observed on the block surface (left) and in the block interior (right).*

6 Results From the Laboratory Tests

6.1 General

The locations of the samples taken from the two types of blocks were shown in Figure 4-6. The water ratio (w) and the density (ρ) are determined for each sample. From these parameters the degree of saturation (S_r), the void ratio and the density at saturation (ρ_m) can be calculated by using the following eqns.

$$S_r = \frac{w \cdot \rho \cdot \rho_s}{[\rho_s \cdot [w+1] - \rho] \cdot \rho_w} \qquad (5\text{-}1)$$

$$e = \frac{\rho_s - \rho}{\rho - \rho_w \cdot S_r} \qquad (5\text{-}2)$$

$$\rho_m = \frac{\rho_s + \rho_w \cdot e}{1+e} \qquad (5\text{-}3)$$

where ρ_w is the density of the pore water and ρ_s is the density of the solid particles of the soil. In this report ρ_w and ρ_s are assumed to be 1.00 and 2.78 g/cm^3 respectively.

The tensile strength is also determined for each sample. Small beams with 10x20x35 mm^3 (axbxc in Figure 6-1) are sawn from the samples and the tensile strength is determined by applying a load in the centre of the beam supported in both ends. This type of test is described more in detail in Johannesson et al 1995. The tensile stress and the tensile strain during the test can be calculated with the following equations

$$\sigma_t = \frac{6Qc}{4ba^2} \qquad (5\text{-}4)$$

$$\varepsilon_f = \frac{a\omega 6}{c^2} \qquad (5\text{-}5)$$

where

Q = vertical force
a = sample height
b = sample width
c = sample length
ω = the vertical displacement at the force

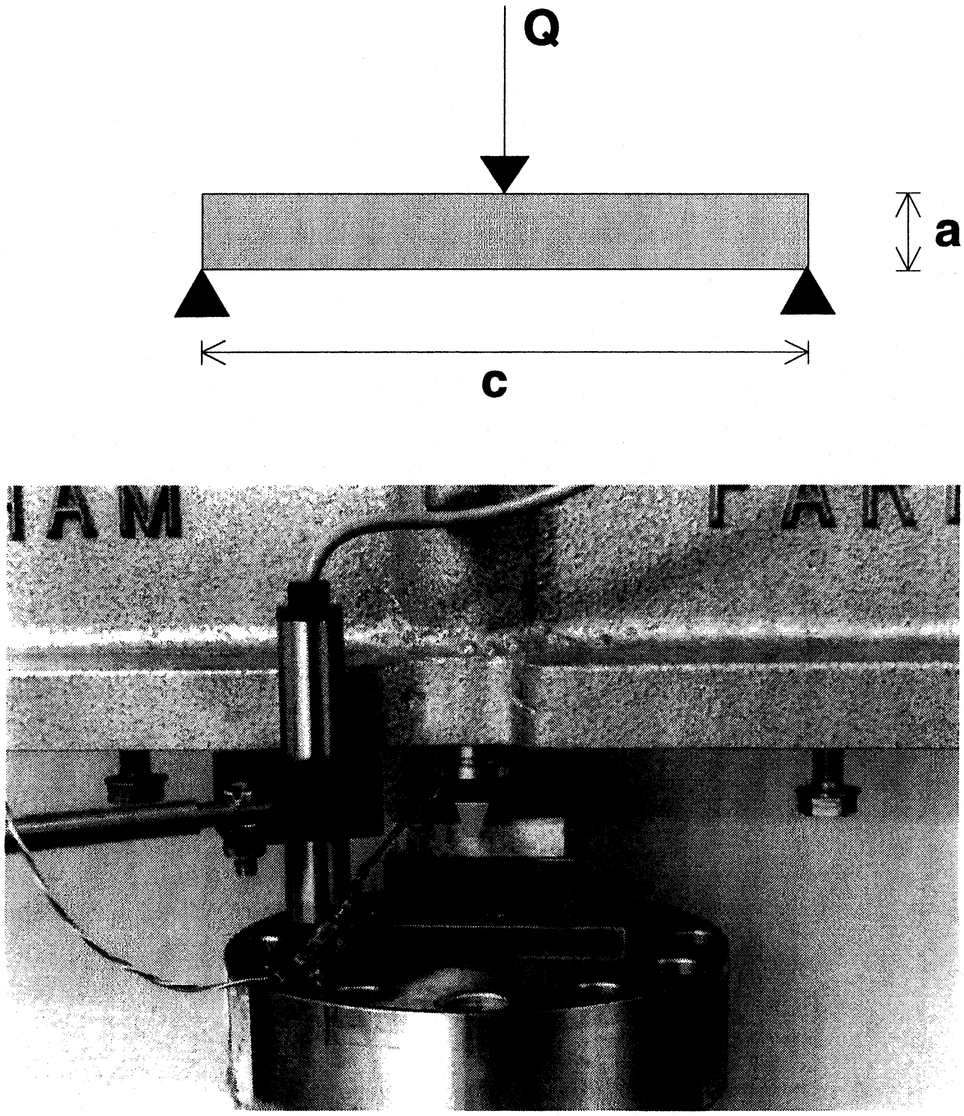

Figure 6-1. *Test arrangement for determination of the tensile strength.*

6.2 Density and Water Ratio

As described in section 5.1, the water ratio and the density were measured at several locations in the blocks. With these parameters the void ratio, the degree of saturation and the density at saturation were calculated with Eqns. 5-1 to 5-3. The density and the void ratio for all the investigated blocks are plotted in APPENDIX I. The void ratios of three ring-shaped blocks are plotted as functions of the distance from the top of the blocks in Figure 6-2. The figure shows that the variation of the void ratio within the blocks is rather small. In Table 6-1 the mean and standard deviation of both the density and water ratio of the blocks are shown. The table also shows the degree of saturation, void ratio and density at saturation. These parameters are calculated with the mean values of the water ratio and the density of the blocks. The void ratios for the compacted blocks are compared with the void ratio for blocks of smaller sizes in Figure 6-3. The figure and Table 6-1 indicate the following:

- The void ratio of the ring shaped and the cylindrical blocks are similar at the same compaction pressure.
- The void ratio of the blocks is a function of the compaction pressure. At low water ratio, the difference in void ratio between the two compaction stresses, 50 and 100 MPa, is more significant.
- The maximum degree of saturation, about 84%, is reached at the highest water ratio.
- The scatter in the density distribution in the blocks seems to be rather independent of both the shape (ring and cylindrical) and the water ratio, see Table 6-1. The largest difference between the maximum and minimum density in a block compacted with 100 MPa was 0.06 g/cm^3, which is about 3% of the average density.
- There is a small indication that the density increases with the time the maximum compaction pressure is allowed to rest (hold time). Block No 11, with average water ratio of 9.3%, was compacted with a hold time of 4 hours. The average density of the block was 2.14 g/cm^3, while block 3 with similar water ratio (9.1%) but compacted with only 10 minutes of hold time reached an average density of 2.11 g/cm^3.
- The void ratio of the larger blocks is similar to the void ratio of the smaller blocks, see Figure 6-3.

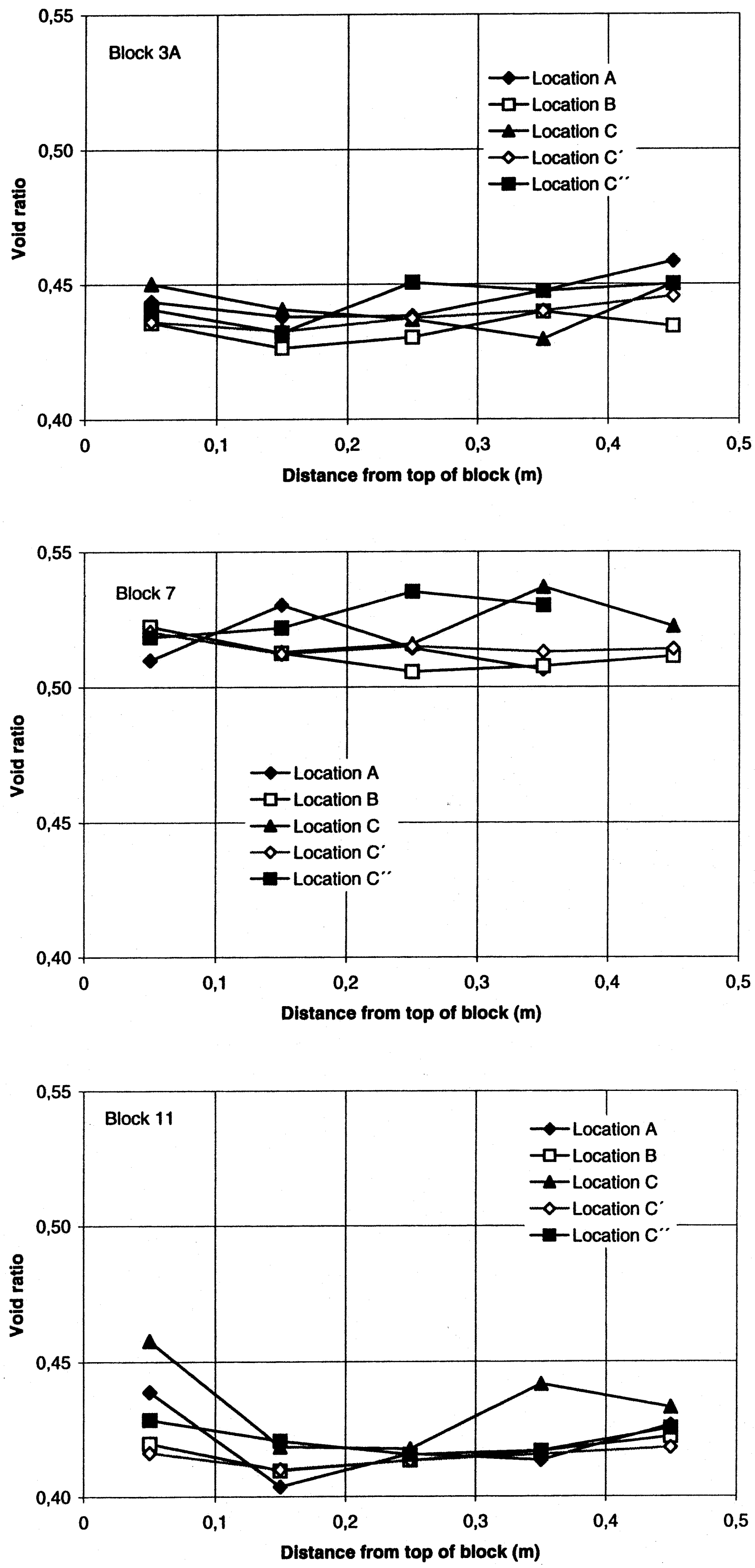

Figure 6-2. *Void ratio plotted as function of distance from top of three ring-shaped blocks. The locations of the taken samples are shown in Figure 5-1.*

TABLE 6-1. Results from laboratory tests performed on the compacted blocks.

No.	Form	Comp.stress (MPa)	Time at Max. stress	Number of samples	w_{mean} (%)	St.dev w (%)	ρ_{mean} (g/cm^3)	St.dev ρ (g/cm^3)	ρ_{max}-ρ_{min} g/cm^3)	S_r	e	ρ_m (g/cm^3)
1	Cylinder	50	10 min	15	9,0	0,1	1,99	0,015	0,06	0,475	0,524	2,17
2	Cylinder	100	10 min	15	9,1	0,1	2,10	0,013	0,05	0,567	0,448	2,23
3	Ring	100	10 min	25	9,1	0,2	2,11	0,012	0,04	0,577	0,440	2,24
4	Ring	100	10 min									
5	Cylinder	50	10 min	15	15,9	0,4	2,03	0,006	0,02	0,756	0,584	2,12
6	Cylinder	ca 65	10 min	2	16,1		2,05		0,01	0,775	0,576	2,13
7	Ring	100	10 min	25	15,6	0,3	2,12	0,010	0,03	0,840	0,518	2,17
8	Ring	100	10 min									
9	Cylinder	100	10 min	15	16,2	0,2	2,11	0,005	0,01	0,846	0,534	2,16
10	Ring	100	10 min									
11	Ring	100	4 hours	25	9,3	0,3	2,14	0,014	0,06	0,611	0,421	2,25

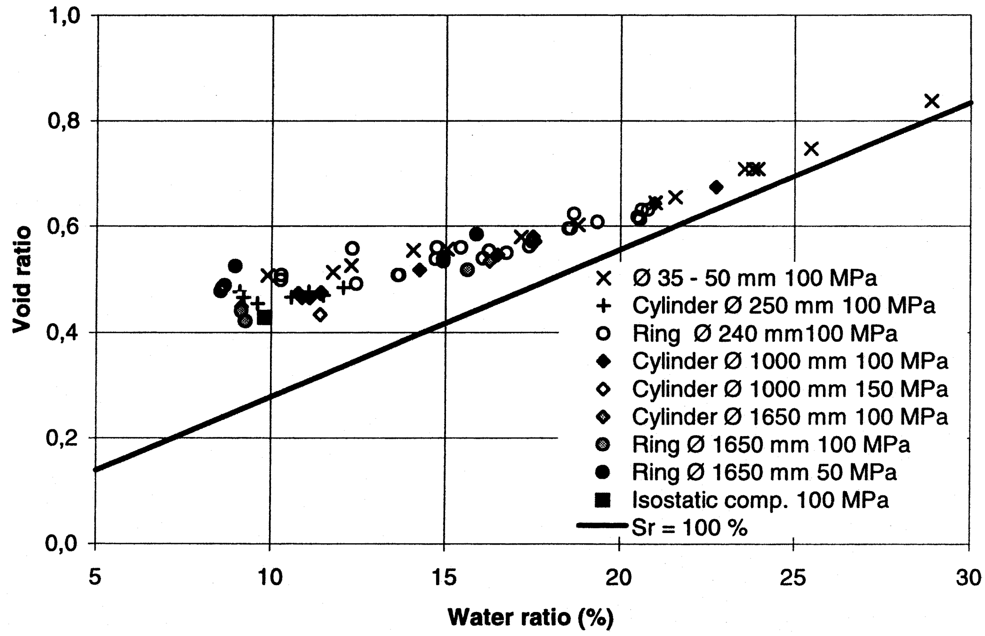

Figure 6-3. *Compilation of compaction results. Void ratio as a function of water ratio for blocks with different sizes.*

6.3 Tensile Strength

As described in section 5.1, the tensile strength was measured at several locations within the blocks with a so-called beam test (see section 6-1). The tensile stress and the tensile strain during the tests were calculated with Eqn. 6-4 and Eqn. 6-5. The tensile stress as function of the tensile strain for all tests is plotted in APPENDIX II. The mean and standard deviation of both the tensile strength and the strain at failure of the blocks are shown in Table 6-2. In Figure 6-5 is the tensile strength as function of the void ratio for the large blocks plotted. In Figure 6-4 is the uniaxial blocks compared with isostatic compacted blocks. Figure 6-4 to 6-5 and Table 5-2 indicate the following:

- The tensile strength is, as expected, increasing with decreasing void ratio (increasing dry density), see Figure 6-4.
- The tensile strength seams to increase when the time at maximum load is increasing (cf. Block 11 and Block 3)
- Figure 6-5 is indicating that the tensile strength is similar for uniaxial and isostatic compacted blocks

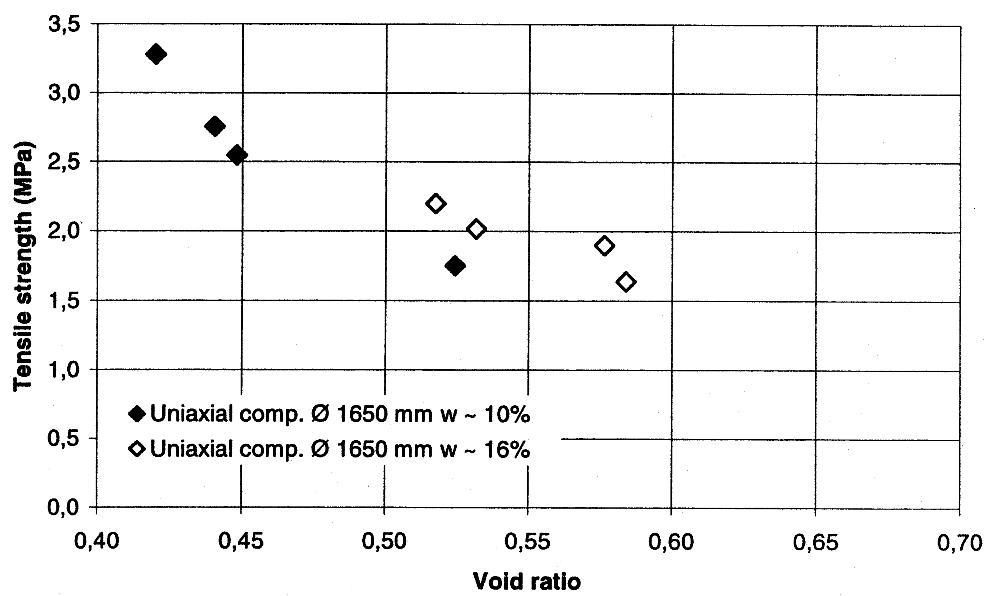

Figure 6-4. *Compilation of tensile strength measurements. Tensile strength as a function of void ratio for uniaxial compacted blocks.*

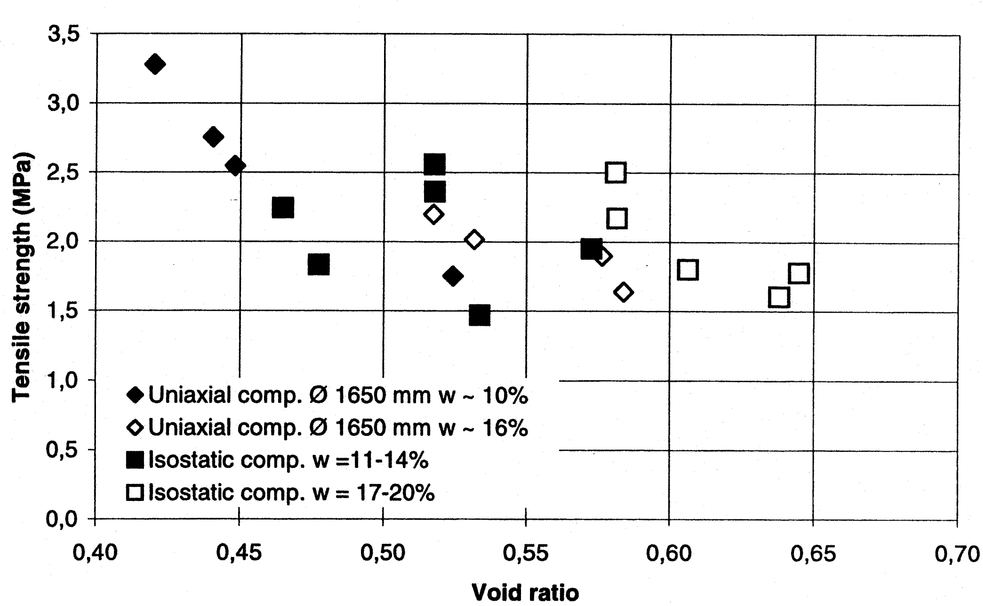

Figure 6-5. *Compilation of tensile strength measurements. Tensile strength as a function of void ratio for blocks with different sizes and compaction technique.*

TABLE 6-2. Results from the measurements of the tensile strength of the compacted blocks.

No.	Form	Comp.stress (MPa)	Time at Max. stress	Number of samples	w_{mean} (%)	ρ_{mean} (g/cm^3)	e	$\varepsilon_{f,mean}$ (%)	St.dev $\varepsilon_{f,mean}$ (%)	$\sigma_{f,mean}$ (MPa)	St.dev $\sigma_{f,mean}$ (MPa)	$\sigma_{f,max}$-$\sigma_{f,min}$ (MPa)
1	Cylinder	50	10 min	15	9,0	1,99	0,524	0,76	0,15	1,75	0,314	0,88
2	Cylinder	100	10 min	15	9,1	2,10	0,448	0,89	0,14	2,55	0,405	1,31
3	Ring	100	10 min	25	9,1	2,11	0,440	0,87	0,22	2,76	0,549	2,03
4	Ring	100	10 min									
5	Cylinder	50	10 min	15	15,9	2,03	0,584	0,71	0,12	1,64	0,304	1,05
6	Cylinder	~65	10 min	2	16,1	2,05	0,576					
7	Ring	100	10 min	25	15,6	2,12	0,518	0,80	0,18	2,20	0,446	1,69
8	Ring	100	10 min									
9	Cylinder	100	10 min	15	16,2	2,11	0,534	0,77	0,11	2,02	0,237	0,79
10	Ring	100	10 min									
11	Ring	100	4 hours	25	9,3	2,14	0,421	1,02	0,49	3,28	0,578	2,42

7 Conclusions and Discussion

Although there are only a few performed tests with the new form, the following conclusions can be drawn:

- The Eirich mixer used for the mixing functioned well. If the integrated system for portioning both water and bentonite can be used, the final intended water content can probably be achieved with higher accuracy than in these tests.
- The filling equipment also functioned very well. The equipment will be modified in order to minimise the amount of dust during filling of the silo and the form. Furthermore, the weighing, that is machine integrated with the equipment, will be recalibrated before the next tests.
- The form functioned as planned. No large problems were observed during compaction and removal of the block from the form.
- The blocks were homogeneous and had the expected densities in accordance with to previously performed tests.
- The densities for both ring-shaped and cylindrical blocks were similar. Previous performed tests indicated a somewhat lower density for ring-shaped blocks than for corresponding cylindrical blocks.
- The damages of the flanges on the blocks with low water ratio were so comprehensive that the possibility to handle and place the blocks in a deposition hole in a safe way may be affected. If the form is to be used for compaction of blocks with low water ratio, it should be modified.
- Other observed damages on the blocks were assumed to have no affect on the possibility to handle the blocks in the way planned.
- The lifting equipment functioned as planned after modification of the tube dimensions.

References

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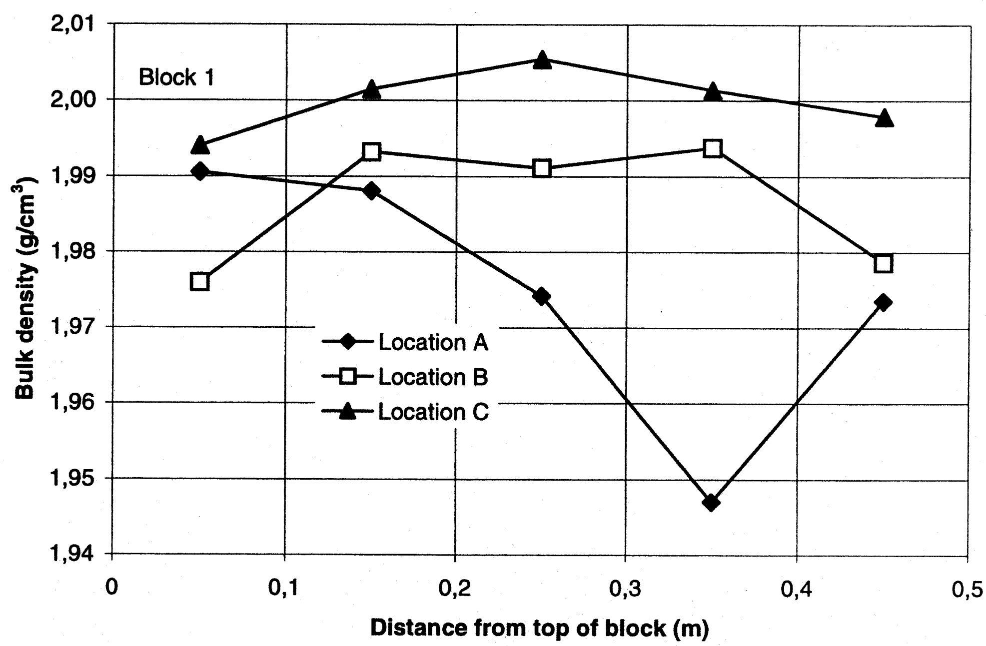
Sjöblom, R, Balzar, U, Johannesson, L, Karlsson, S, Nord, S, 1998. Isostatic compaction of bentonite blocks. Exploratory investigations. SKB PR D-98-05.

APPENDIX I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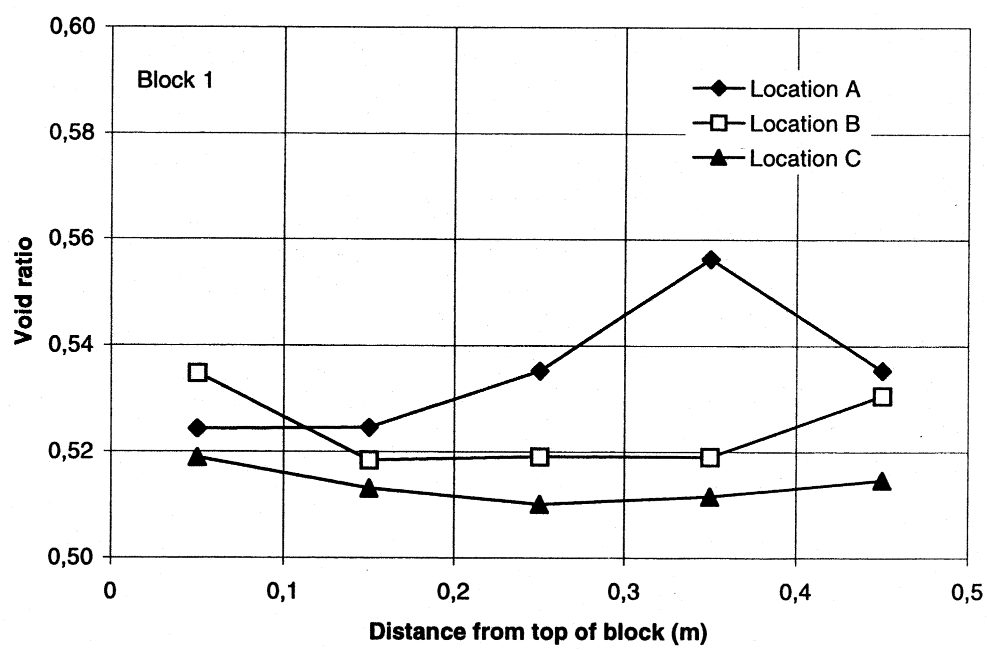
Distance from top of block (m)
Location A
Location B
Location C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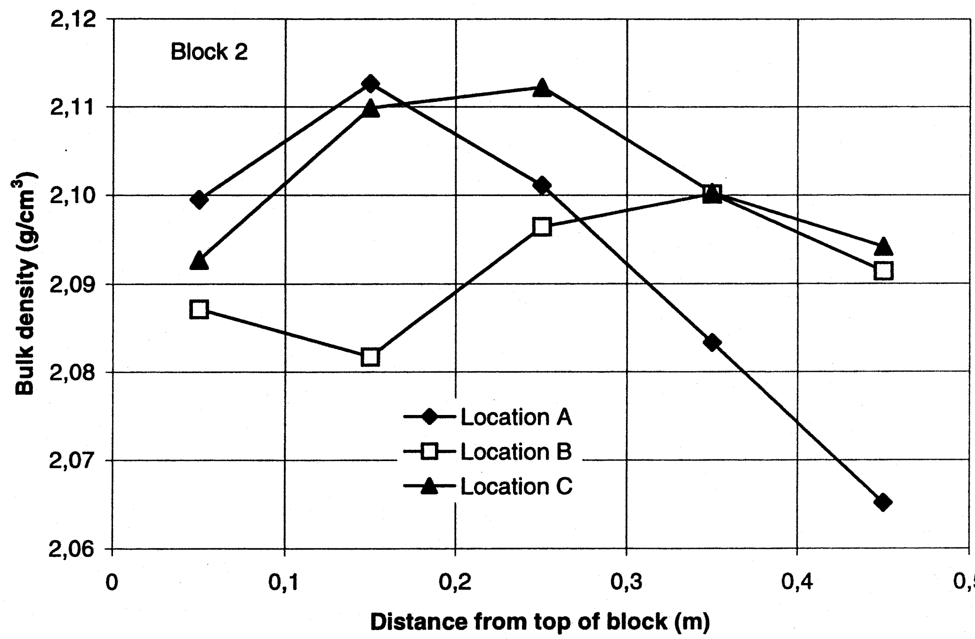
Distance from top of block (m)
Location A
Location B
Location C

APPENDIX I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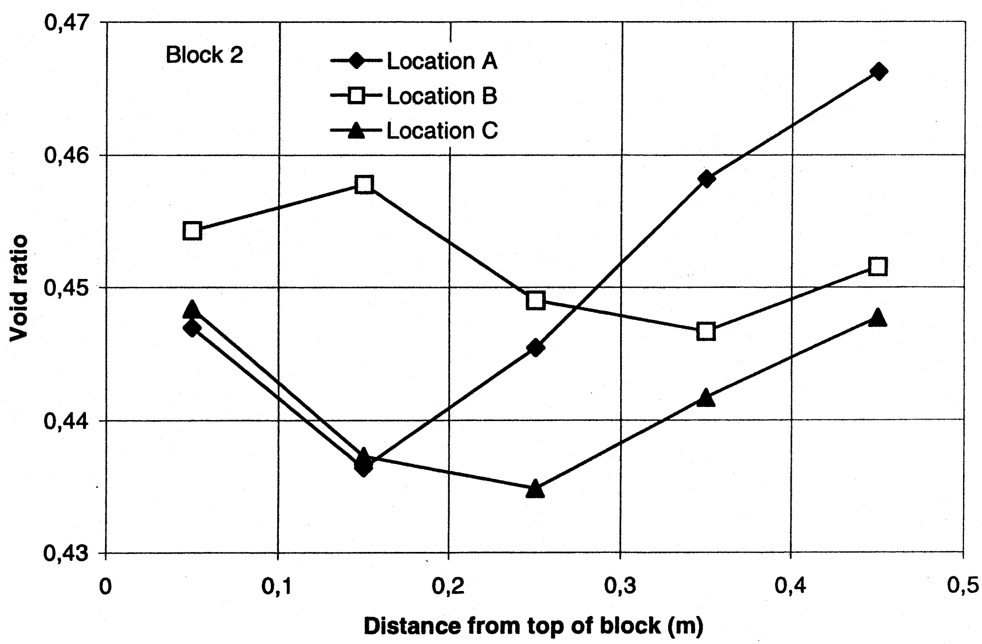
Distance from top of block (m)
Location A
Location B
Location C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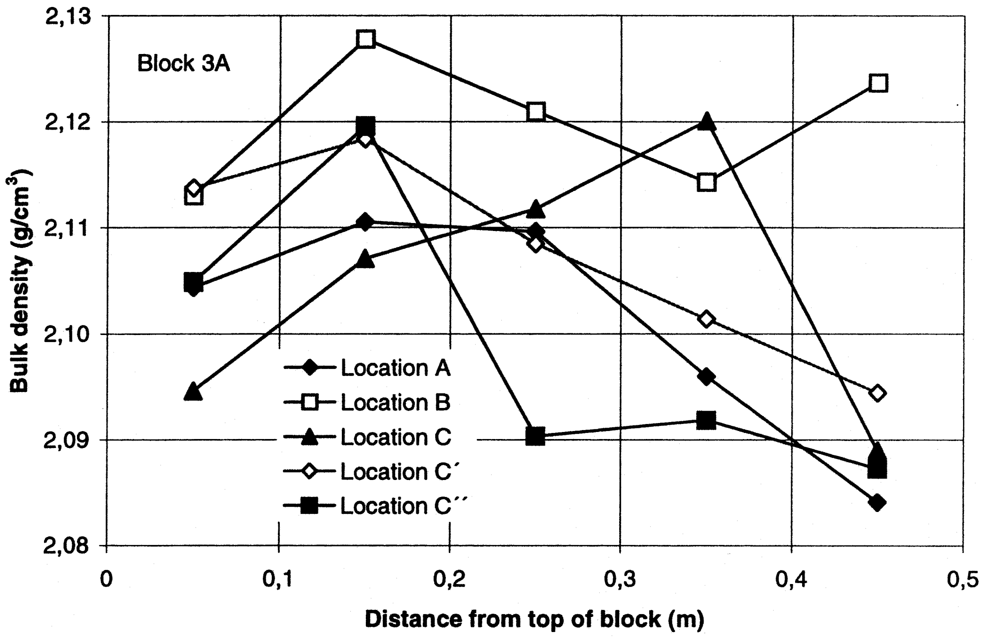
Location A
Location B
Location C

APPENDIX I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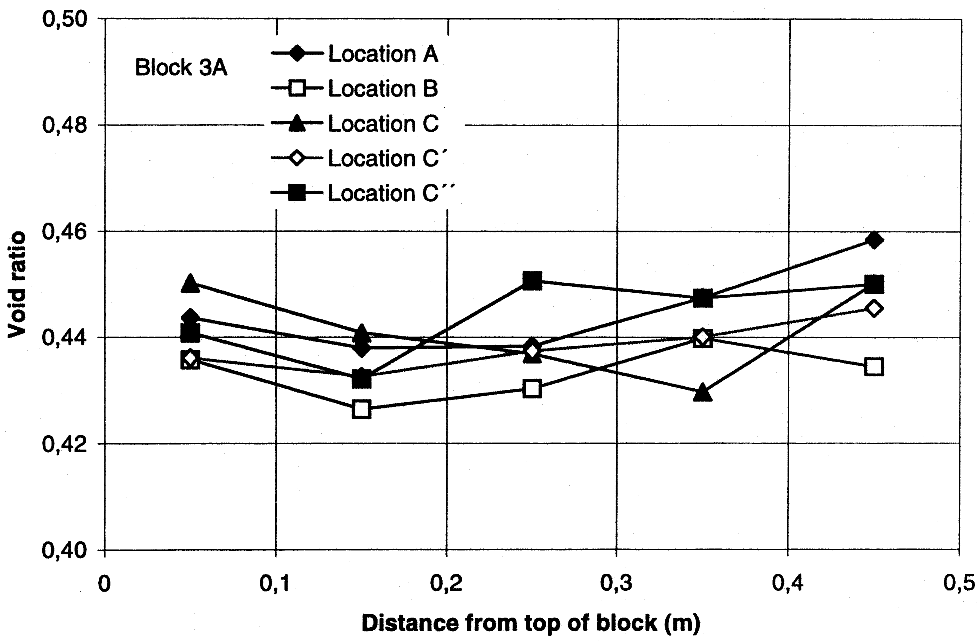
Location B
Location C
Location C´
Location C´´
Distance from top of block (m)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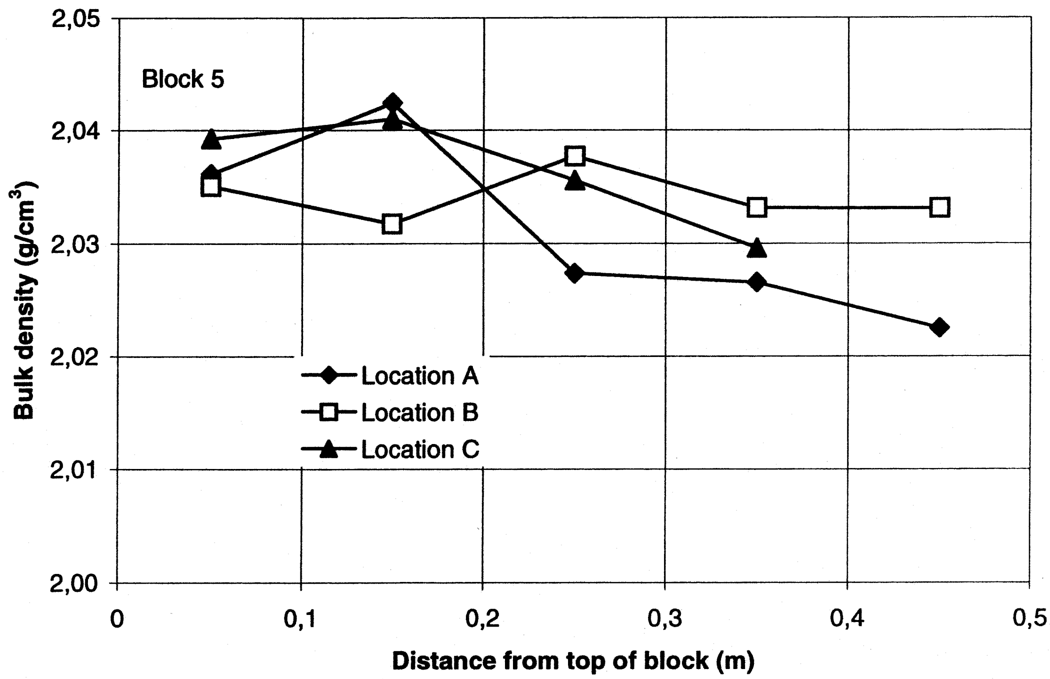
Location B
Location C
Location C´
Location C´´
Distance from top of block (m)

APPENDIX I



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2,03
2,02
2,01
2,00
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Location C
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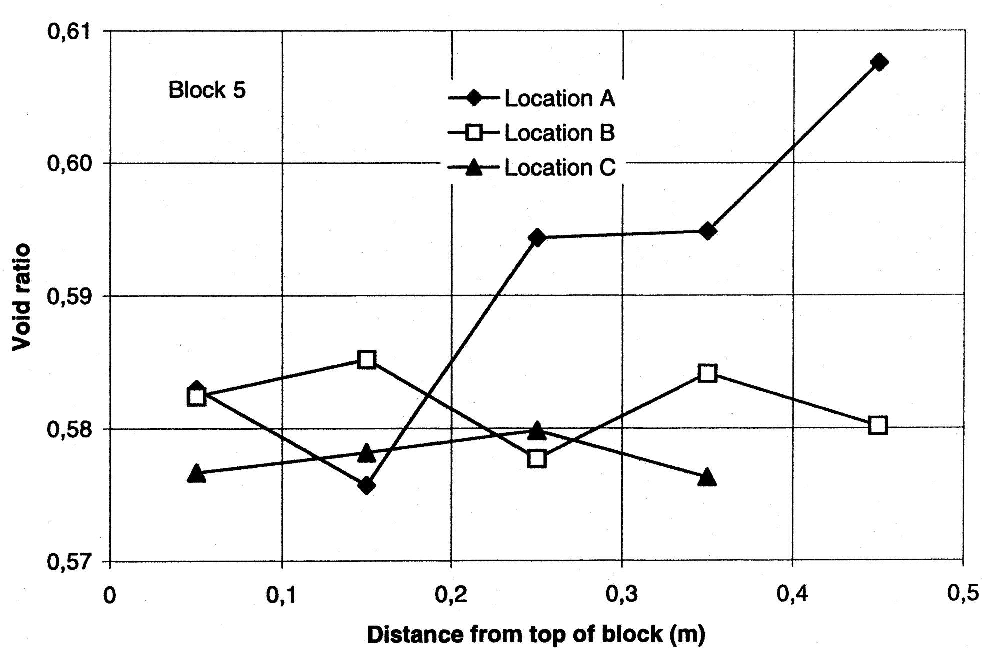
Distance from top of block (m)



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0,58
0,57
Block 5
Void ratio
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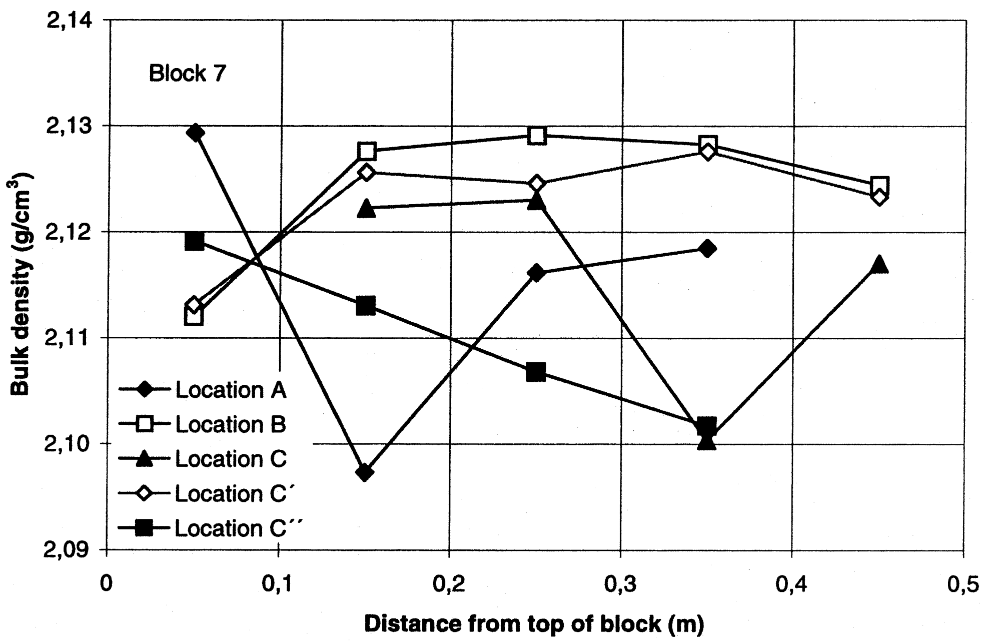
0,2
0,3
0,4
0,5
Distance from top of block (m)

APPENDIX I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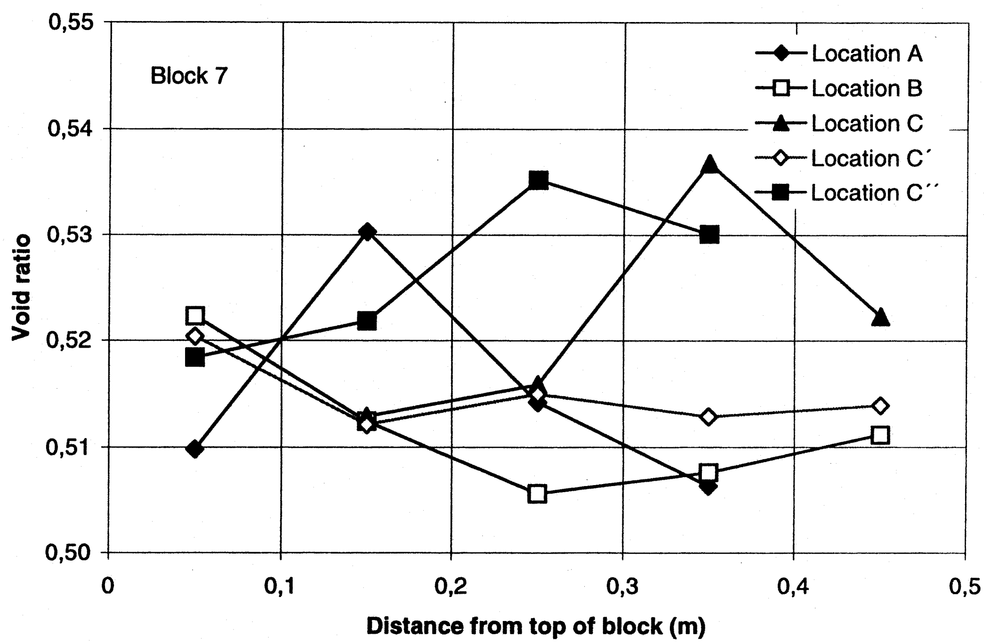
0,5
Distance from top of block (m)
Location A
Location B
Location C
Location C´
Location C´´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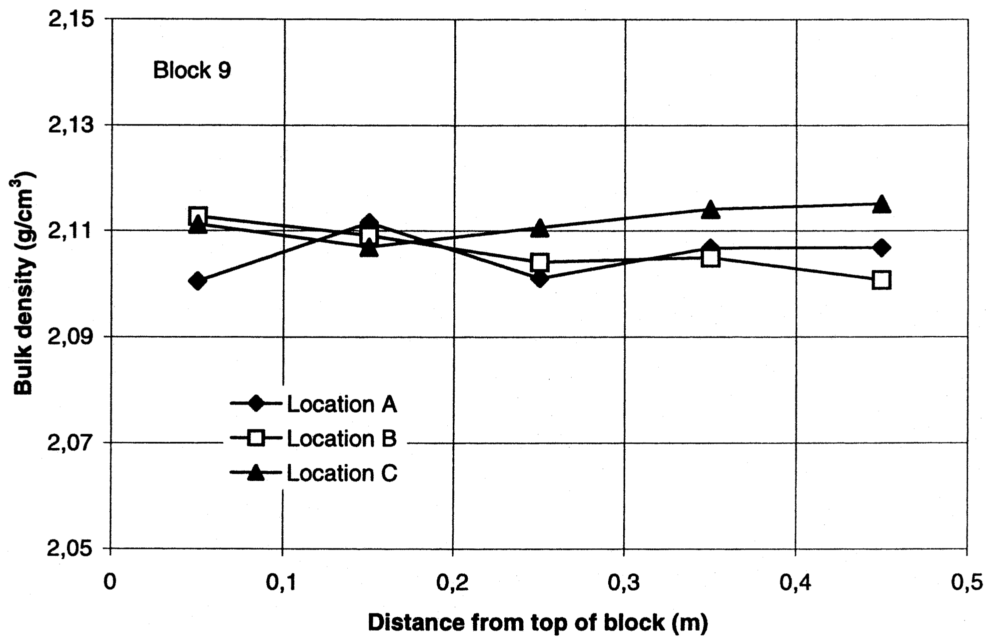
Distance from top of block (m)
Location A
Location B
Location C
Location C´
Location C´´

APPENDIX I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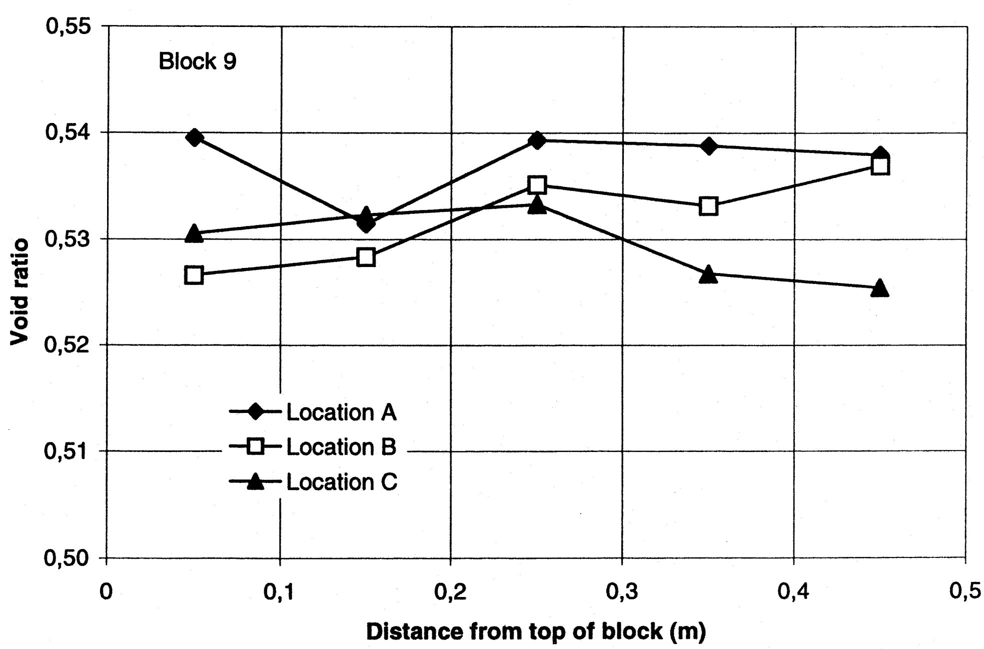
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0,51
0,50
Block 9
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Location C
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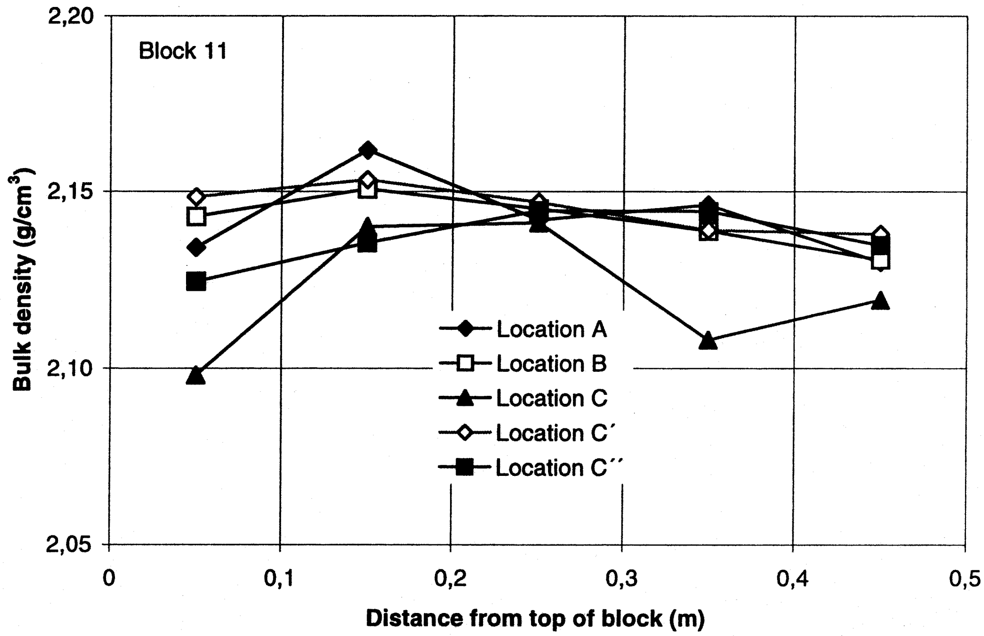
Distance from top of block (m)

APPENDIX I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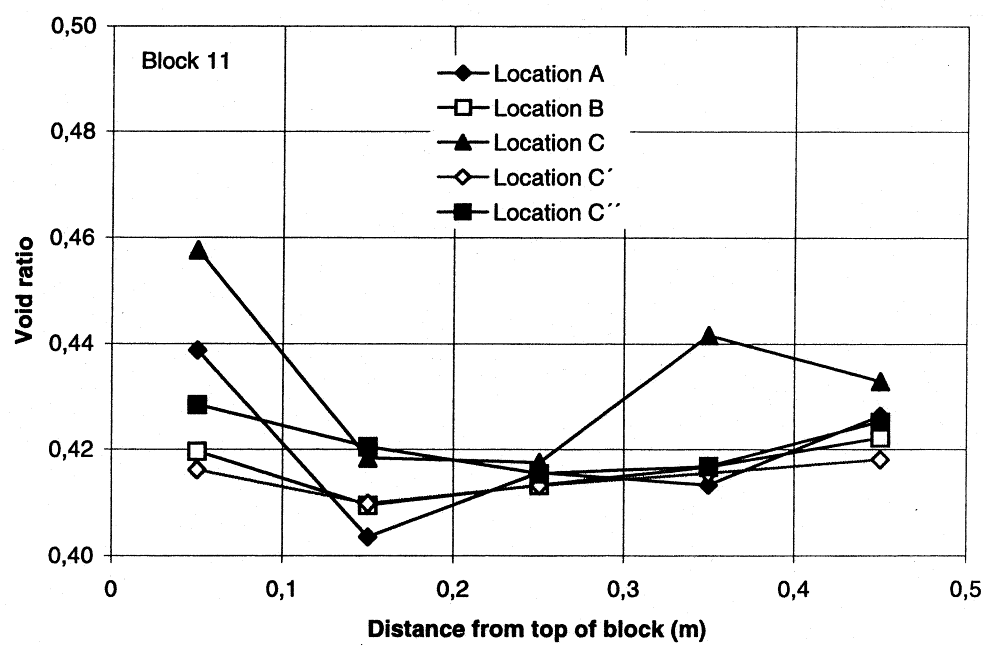
Distance from top of block (m)
Location A
Location B
Location C
Location C´
Location C´´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0,2
0,3
0,4
0,5
Distance from top of block (m)
Location A
Location B
Location C
Location C´
Location C´´

APPENDIX I:8

Thank You For Filling Out This Form

Thank you for taking the time to fill out our feedback form.Below is what you submitted to support@cec488.com on Tue Nov 30 10:28:59 EST 1999

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subject = Internet Request

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recipient = support@cec488.com

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name = Dear Sirs, We need to upgrade the software (function library, device driver etc) to make it possible to use our PC<>488 ISA card on an Windows NT PC. Our card is equipped with a NEC 7210 controller. By the way, when we try to download software from your site we need a username and a password??? Regards Mats Collin

---

Name = Mats Collin

Company = Clay Technology

Address = IDEON Research Center

Address 2 = Ole Römers väg 12 D

City = Lund

State = Skåne

Zip = 22370

Country = Sweden

Telephone = +46 46 286 25 78

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how = Internet

ContactRequested = Please forward to sales, contact requested

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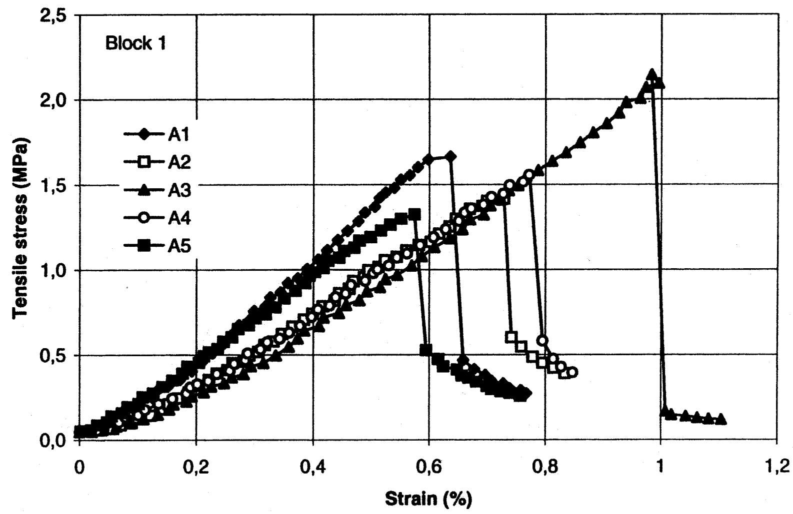
Submit = Submit Comments

APPENDIX II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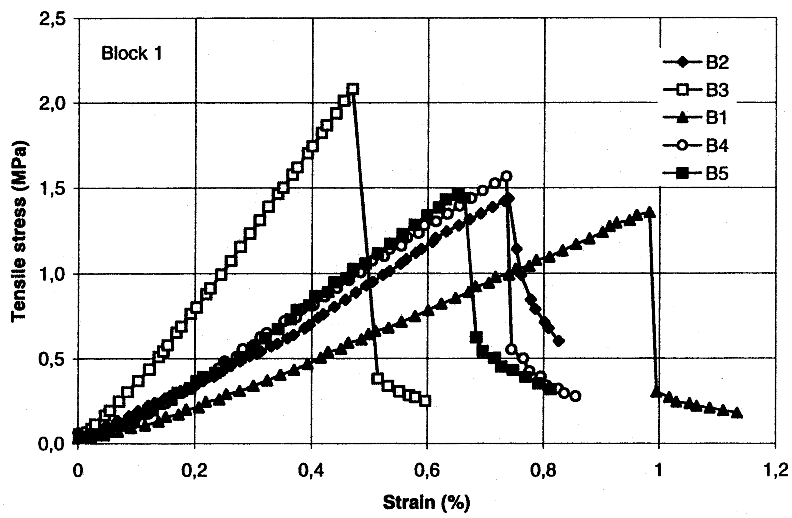
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Strain (%)
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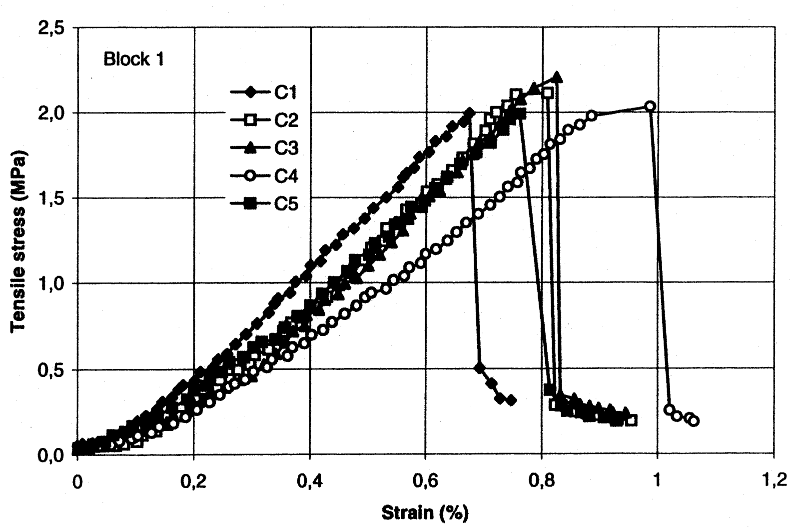
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Strain (%)
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1
1,2

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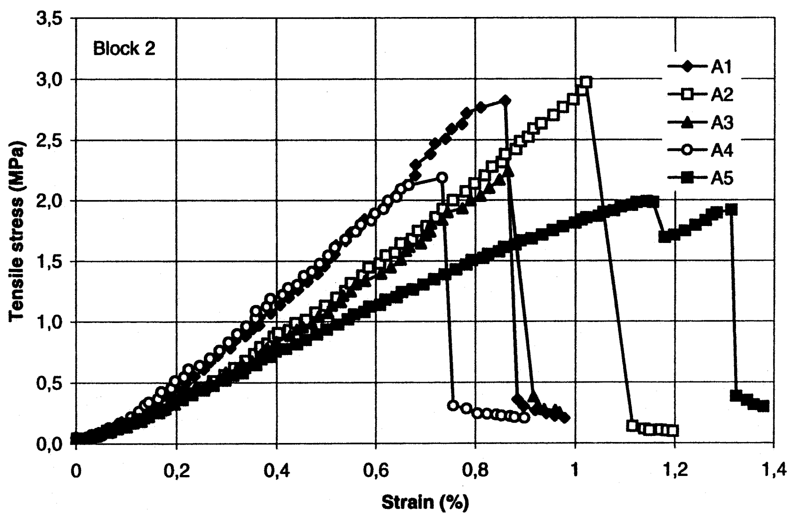
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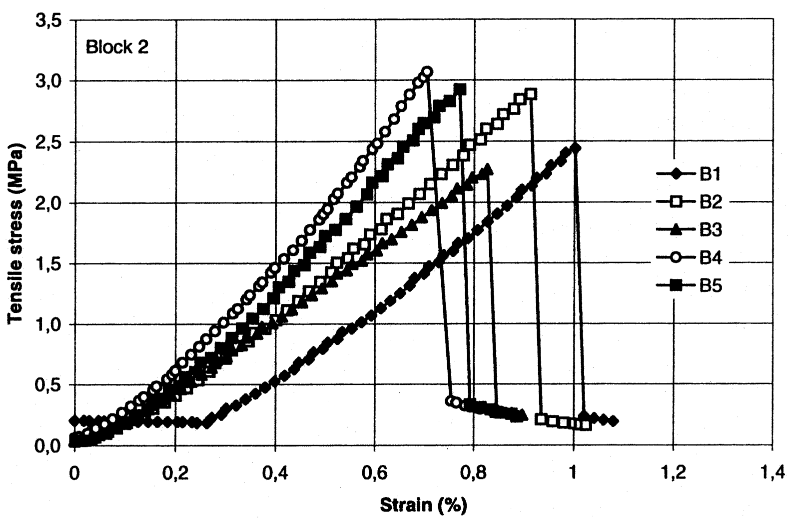
A5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Strain (%)
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B3
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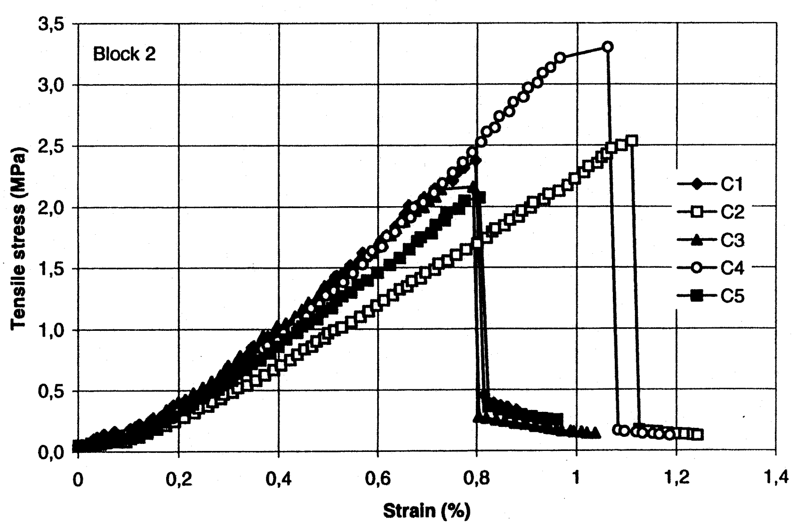
B5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Strain (%)
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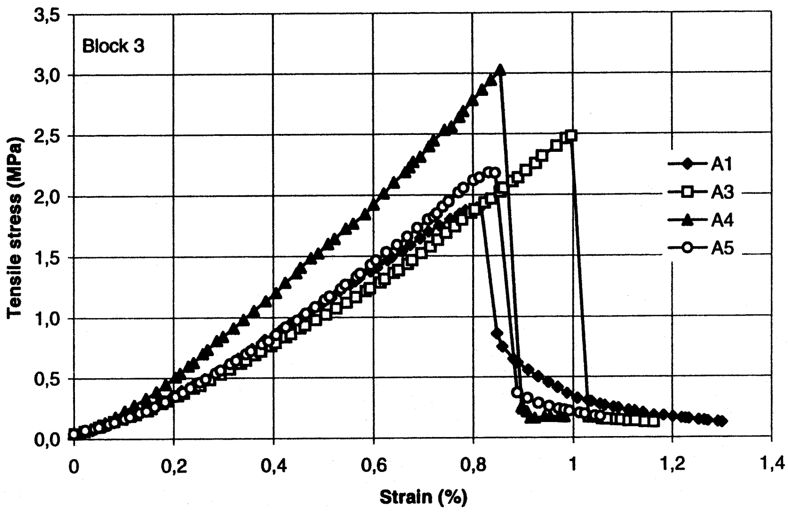
C4
C5

APPENDIX II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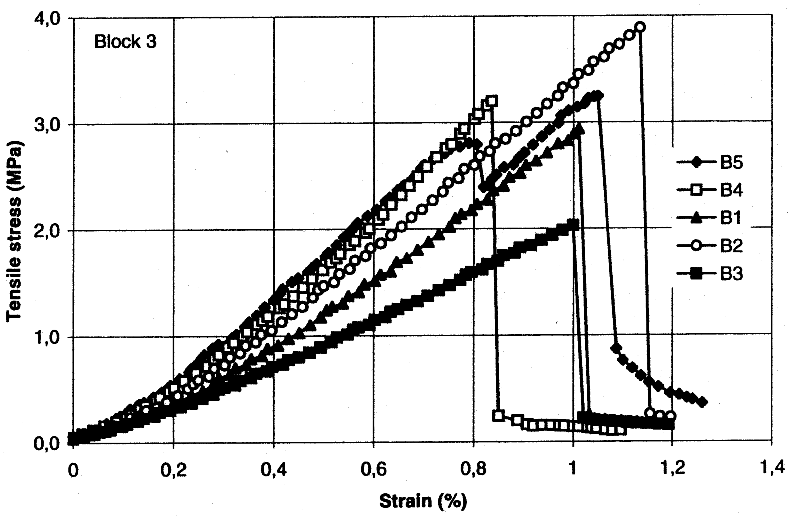
A4
A5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Tensile stress (MPa)
Strain (%)
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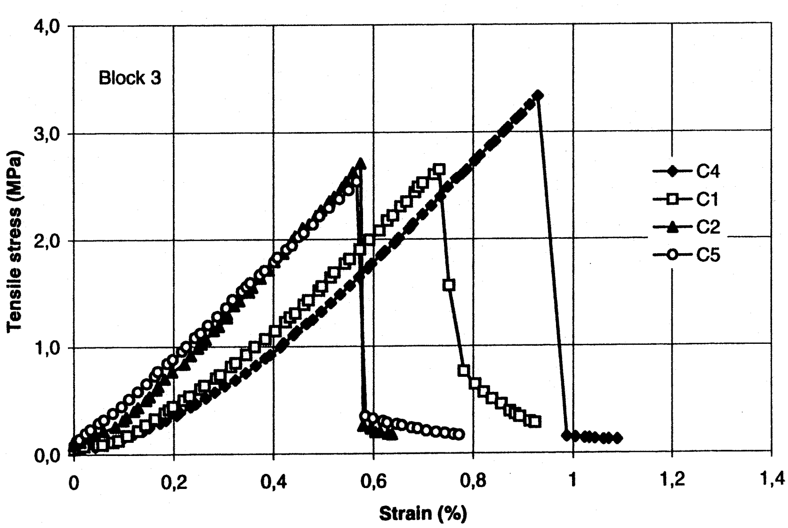
B4
B1
B2
B3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Strain (%)
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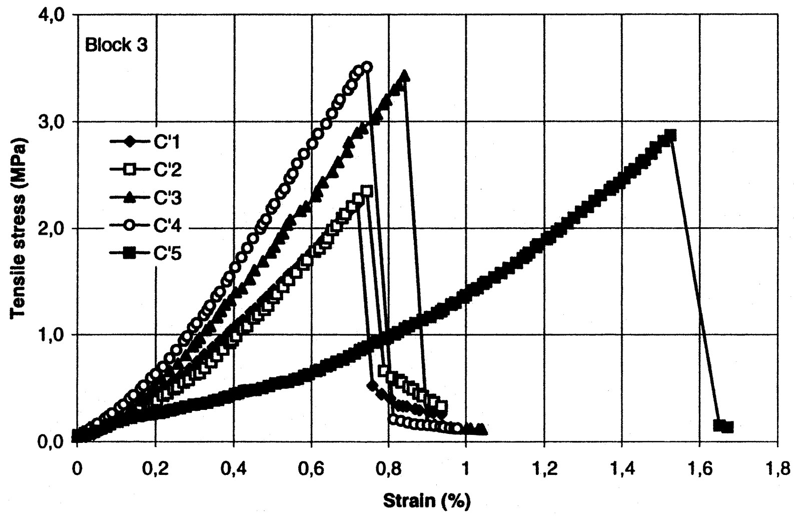
C1
C2
C5

APPENDIX II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C'2
C'3
C'4
C'5
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Strain (%)
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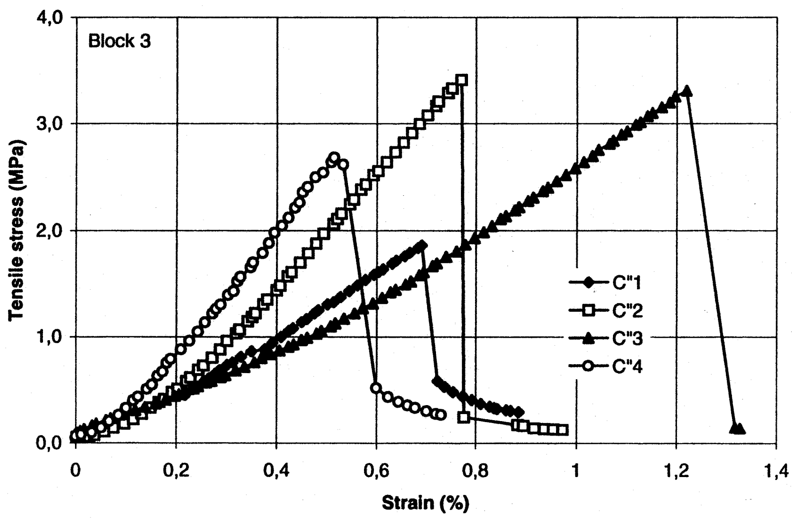
1,4
1,6
1,8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C"2
C"3
C"4
Tensile stress (MPa)
Strain (%)
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0,8
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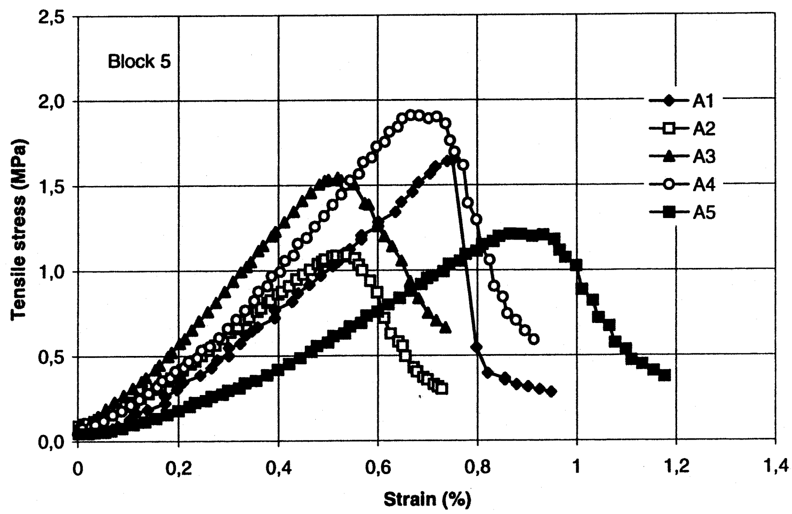
1,2
1,4

APPENDIX II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A2
A3
A4
A5
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0,2
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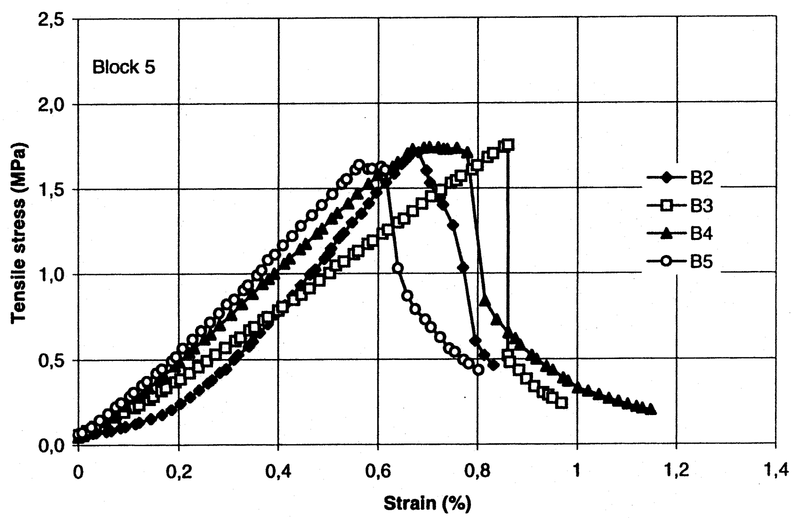
0,6
0,8
1
1,2
1,4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Tensile stress (MPa)
Strain (%)
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B3
B4
B5
2,5
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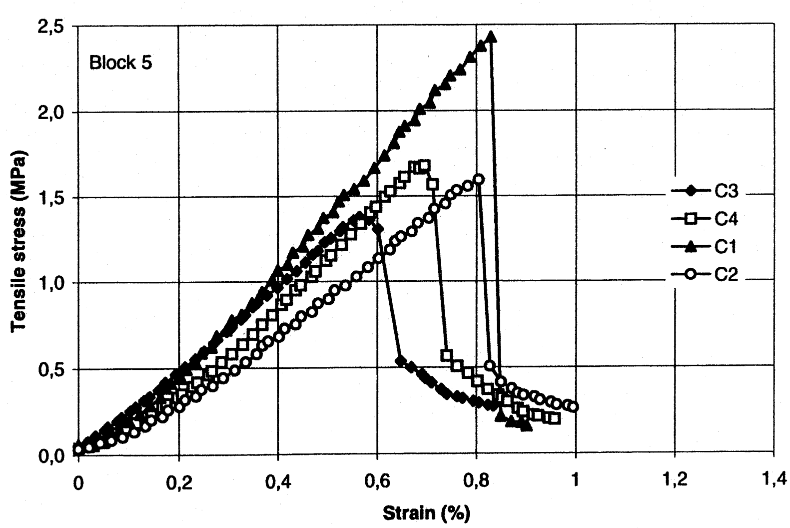
0
0,2
0,4
0,6
0,8
1
1,2
1,4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Strain (%)
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C4
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C2
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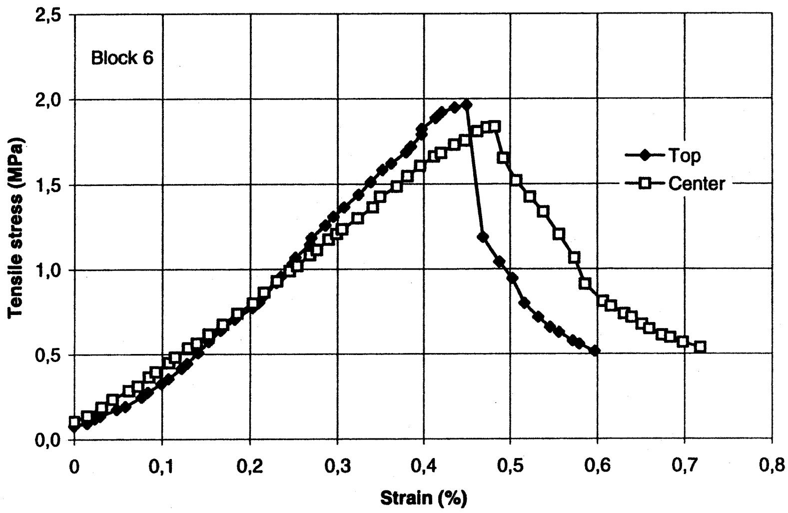
1,2
1,4

APPENDIX II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Top
Center
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0,3
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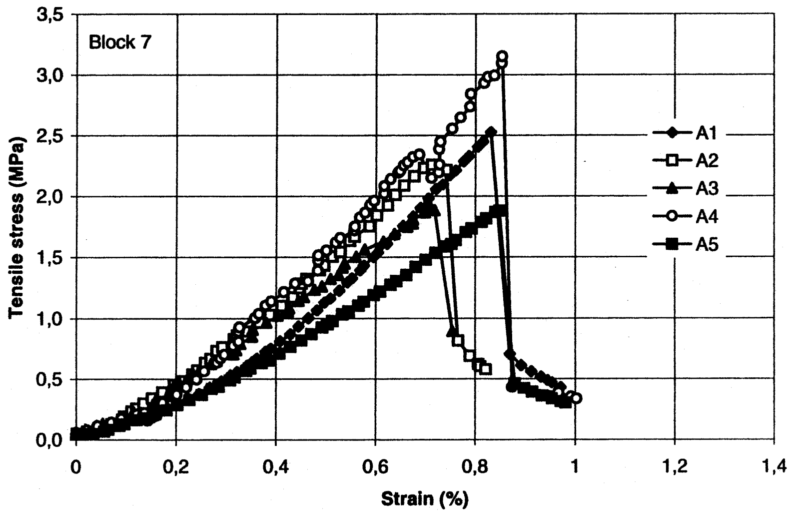
0,5
0,6
0,7
0,8

APPENDIX II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0,5
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Strain (%)
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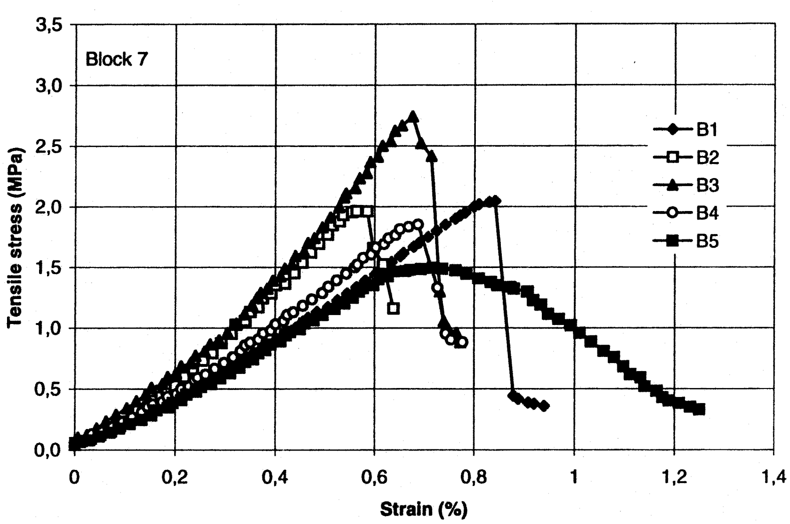
A2
A3
A4
A5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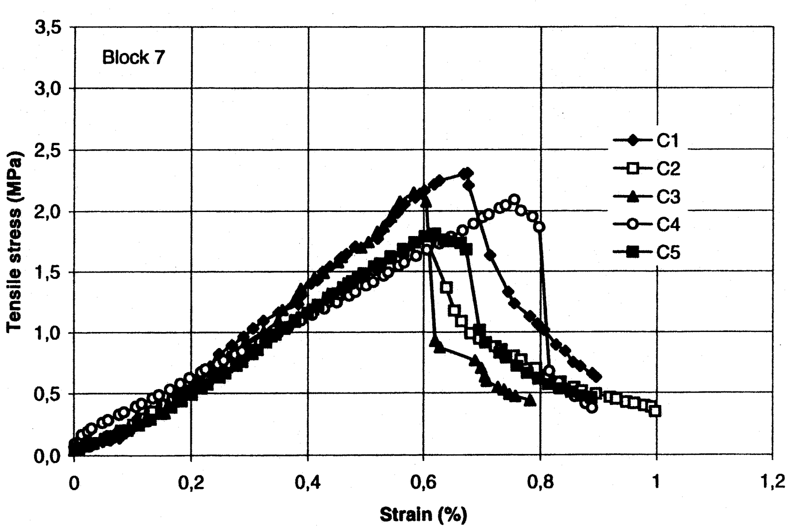
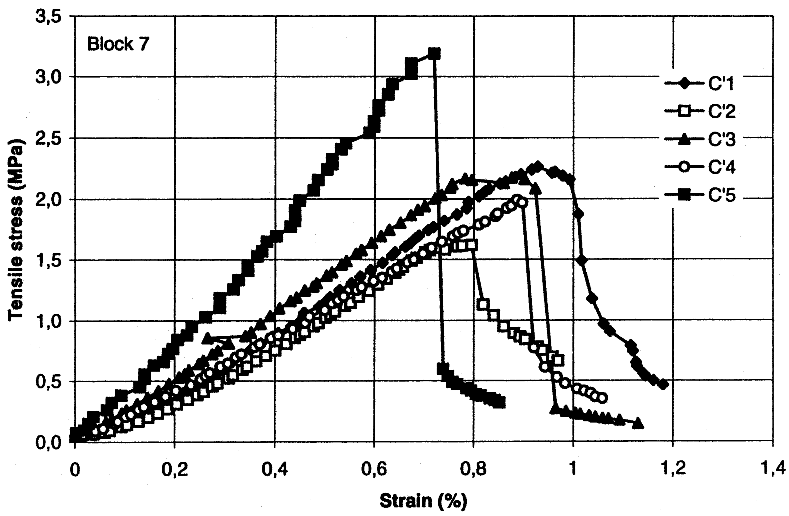
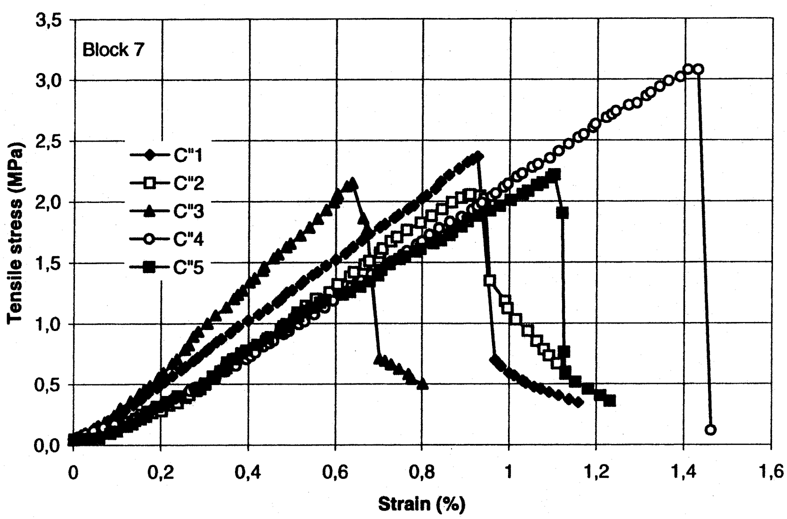
Tensile stress (MPa)
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0
0,2
0,4
0,6
0,8
1
1,2
1,4
Strain (%)
B1
B2
B3
B4
B5

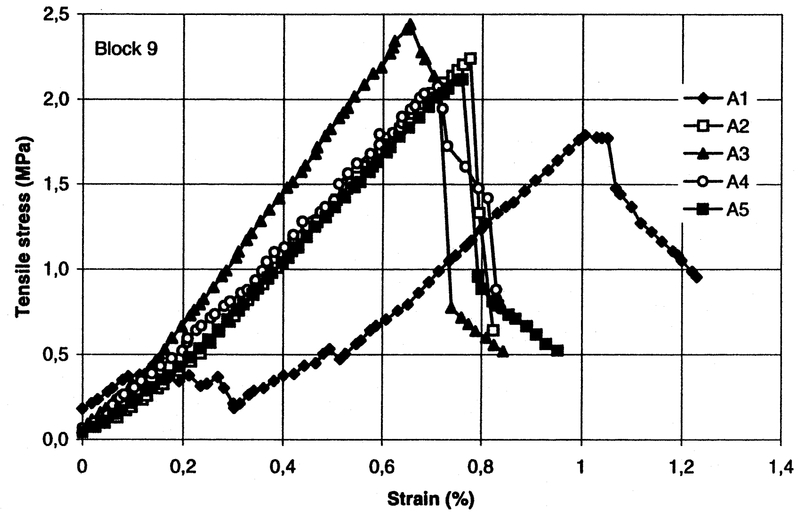

Block 7
Tensile stress (MPa)
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0
0,2
0,4
0,6
0,8
1
1,2
Strain (%)
C1
C2
C3
C4
C5

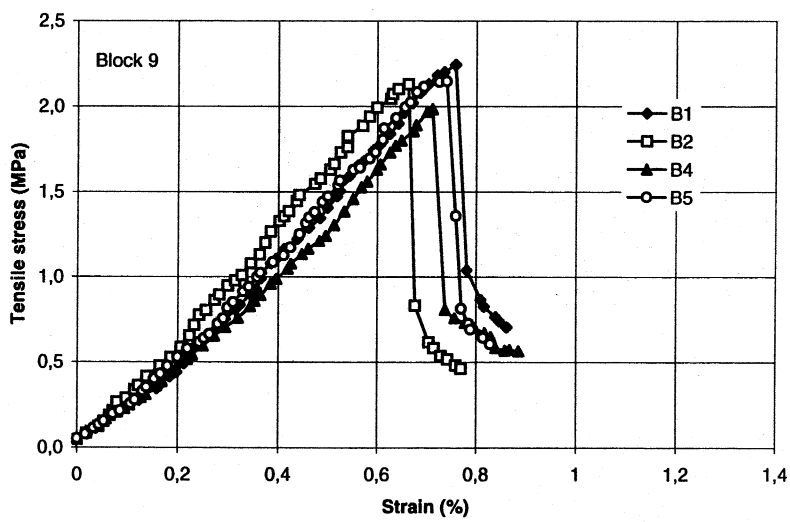
APPENDIX II

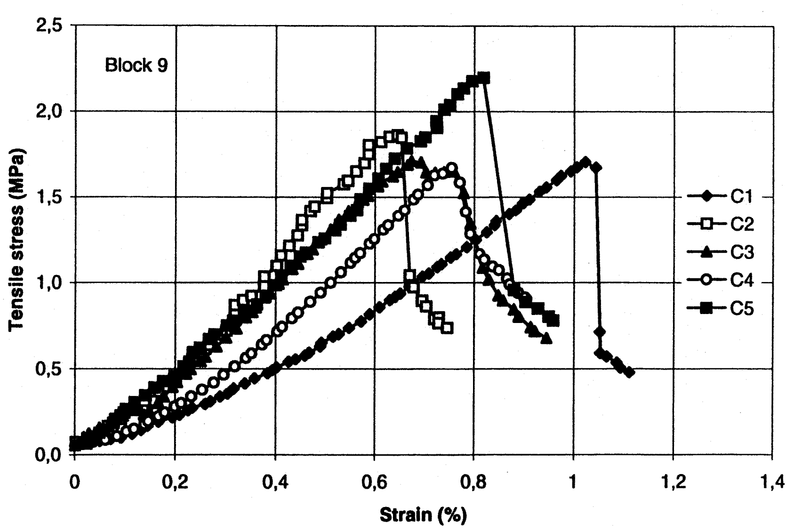

Block 7
Tensile stress (MPa)
Strain (%)
C'1
C'2
C'3
C'4
C'5
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0
0,2
0,4
0,6
0,8
1
1,2
1,4


Block 7
Tensile stress (MPa)
Strain (%)
C"1
C"2
C"3
C"4
C"5
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0
0,2
0,4
0,6
0,8
1
1,2
1,4
1,6

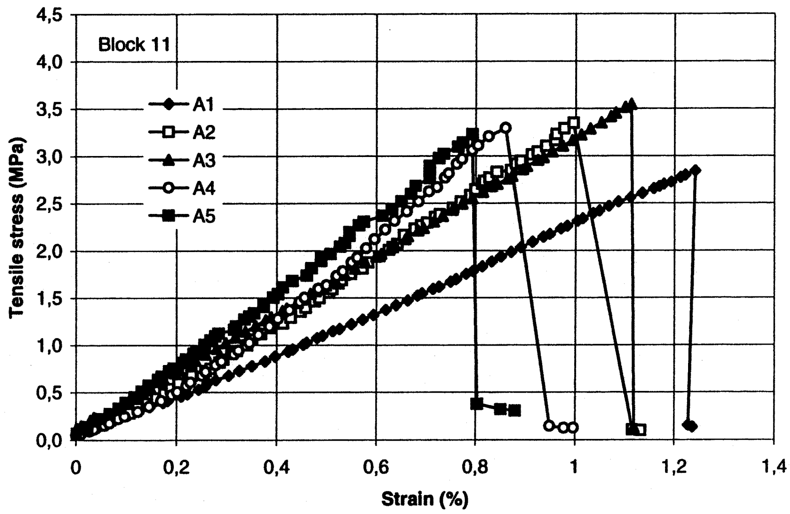
APPENDIX II

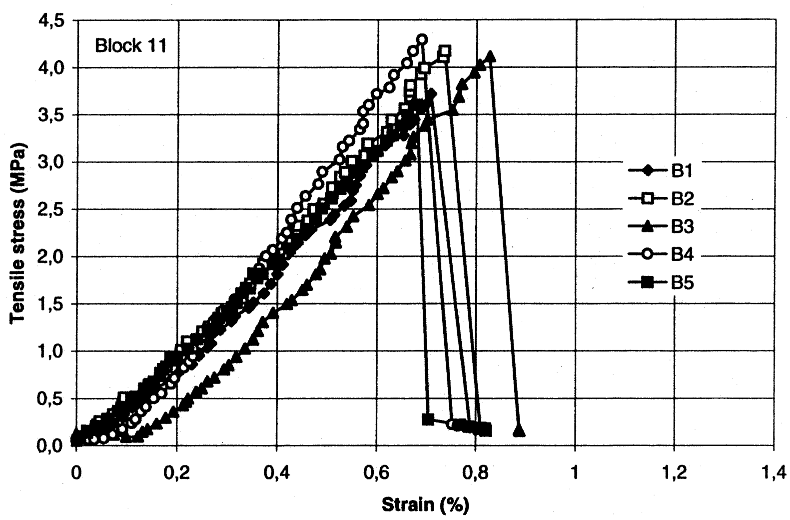

Block 9
2,5
2,0
1,5
1,0
0,5
0,0
Tensile stress (MPa)
0
0,2
0,4
0,6
0,8
1
1,2
1,4
Strain (%)
A1
A2
A3
A4
A5

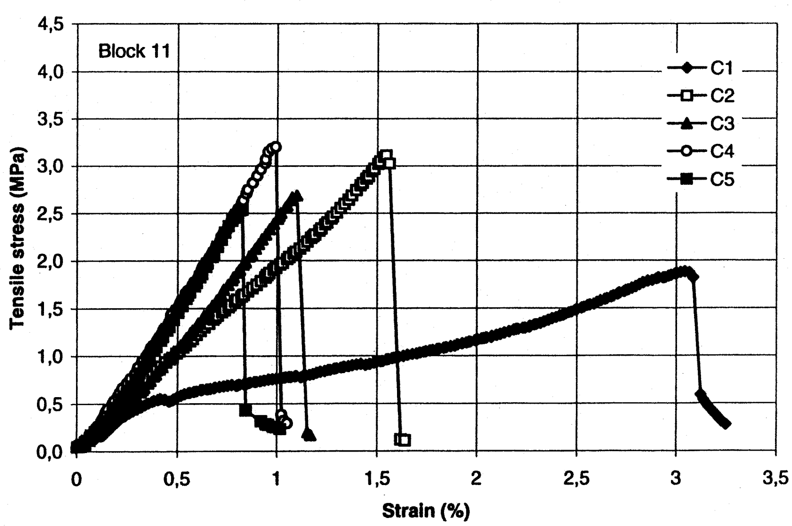

Block 9
2,5
2,0
1,5
1,0
0,5
0,0
Tensile stress (MPa)
0
0,2
0,4
0,6
0,8
1
1,2
1,4
Strain (%)
B1
B2
B4
B5


Block 9
2,5
2,0
1,5
1,0
0,5
0,0
Tensile stress (MPa)
0
0,2
0,4
0,6
0,8
1
1,2
1,4
Strain (%)
C1
C2
C3
C4
C5

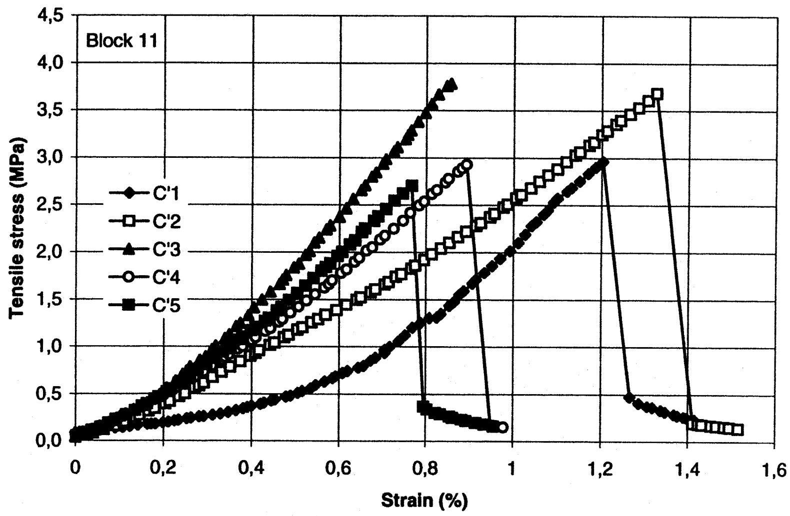
APPENDIX II

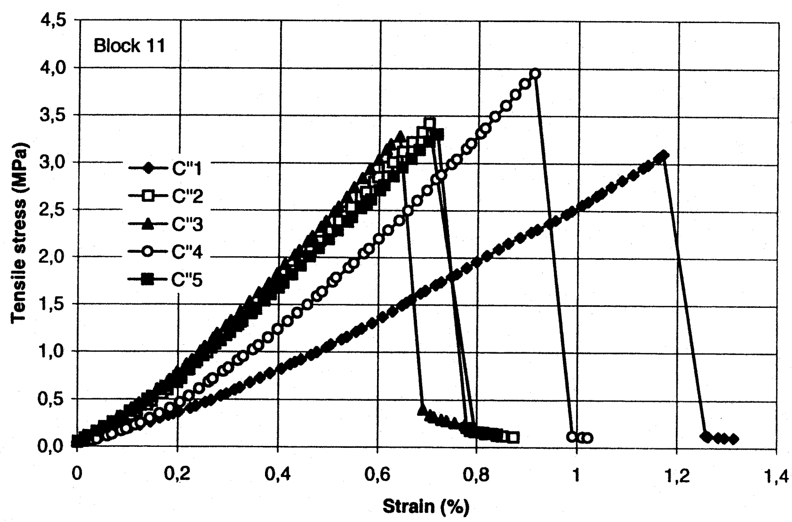

Block 11
A1
A2
A3
A4
A5
Tensile stress (MPa)
Strain (%)
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0
0,2
0,4
0,6
0,8
1
1,2
1,4


Block 11
B1
B2
B3
B4
B5
Tensile stress (MPa)
Strain (%)
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0
0,2
0,4
0,6
0,8
1
1,2
1,4


Block 11
C1
C2
C3
C4
C5
Tensile stress (MPa)
Strain (%)
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0
0,5
1
1,5
2
2,5
3
3,5

APPENDIX II


Block 11
C'1
C'2
C'3
C'4
C'5
Tensile stress (MPa)
Strain (%)
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0
0,2
0,4
0,6
0,8
1
1,2
1,4
1,6


Block 11
C"1
C"2
C"3
C"4
C"5
Tensile stress (MPa)
Strain (%)
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0
0,2
0,4
0,6
0,8
1
1,2
1,4