P-11-48

Tests for evaluation of pellets as foundation bed material KBP1003 – ÅSKAR

Anna Johnsson, ES-Konsult AB

December 2011

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00

ISSN 1651-4416
SKB P-11-48

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1 Introduction

The reference design for the backfill of deposition tunnels, described in SKB (2010), include bentonite blocks, bentonite pellets and a foundation bed of bentonite pellets or granulate. The tunnel floor needs to be flat and have sufficient bearing capacity to make it possible to stack the backfill blocks according to the reference design. To achieve a flat foundation the tunnel floor will be covered with a bed of pellets or granulate made of bentonite clay. The bed can be either compacted or non-compacted.

Bed tests have been performed as a part of the project KBP1003 DP1 Design, which is a subproject of KBP1003 ÅSKAR. The main objectives for KBP1003 DP1 is to define all requirements for the backfill and its production and installation prior to start of the large scale tests, based on given perquisites.

KBP1003 is based on the reference design for the backfill of deposition tunnels which was developed in 2010 (SKB 2010). The concept for installation and block design has been further developed during the project. A new dimension of the backfill blocks has been developed; the chosen dimension makes it possible to gain overlapping joints between the blocks by block stacking. The further developed concept is hereinafter referred to as the ÅSKAR-concept.

The purpose of the performed bed tests was to define the bed requirements in the backfill installation to enable stable stacking of backfill blocks. The tests included stacking of blocks on different bed materials, on blasted and wire sawn floor, with and without concurrent water inflow.

The bed tests was subdivided into four main parts:

- block stacking on different bed compositions
- block stacking on bed during water inflow
- block stacking in a realistic test tunnel
- block stacking on the upper part of the deposition hole and bevel.

1.1 Test site

1.1.1 Bentonite Laboratory

The main parts of the tests were performed in the Bentonite Laboratory at Äspö, URL. The temperature in the Bentonite Laboratory is app. 19°C and the relative humidity varies between 40 and 70% depending on the outdoor conditions.

Tests in the Bentonite Laboratory were set up on an even concrete floor which was assumed to be comparable to a wire sawn tunnel floor.

1.1.2 M-tunnel

Tests in the M-tunnel were mainly performed to verify the ÅSKAR-concept under conditions similar to the ones in the planned deposition tunnels. The “M-tunnel” is a cavity with an uneven blasted floor with a bottom area of 13 m^2. The “M-tunnel” is situated 700 m into a blasted tunnel, – 97 m underground. It is a small natural water inflow in the M-tunnel, so the test was set up on a partly wet tunnel floor. The temperature in the tunnel was app. 12°C and the relative humidity app. 98% during the performed tests.

1.1.3 Foundation bed material

Two types of bed materials of bentonite were used MX-80 and IBECO RWC-BF.

The MX-80 material delivered in 2010-01 was roller compacted and pillow shaped (16×16×5 mm) with a water content (m_w/m_s) of 11.3%. The dry density of the bulk material was 0.881 g/cm^3.

The IBECO RWC-BF material delivered in 2010 was extruded and cylindrical shaped with a diameter of 6 mm and a length of 6–22 mm with a water content of 16.2%. The dry density of the bulk material was 0.925 g/cm^3.

1.1.4 Water for simulated inflow

A simulated water inflow was created in the Bentonite Laboratory using a pump leading water through a geo textile. The geo textile was used to simulate a crack on the tunnel floor. The inflowing water was tap water with 1% total dissolved salts (50% NaCl and 50% KaCl).

2 Performed tests

2.1 Block stacking on different bed compositions

The purpose of the tests was:

- To evaluate the ÅSKAR-concept of stacking on a non compacted bed.
- To study the feasibility of using pellets as bed material with sufficient stability in the block stack.

2.1.1 Method

The tests were performed in the Bentonite Laboratory. The tests were set up within a wooden frame with dimensions (L×W×H) 3,000×3,000×200 mm placed on an even concrete floor with 1% inclination, see Figure 2-1. The wooden frame was filled with leveled, but not compacted, bed material. A number of concrete blocks were thereafter stacked on the foundation bed according to the geometry in Figure 2-2. A ballast of steel weights was used to simulate the load from a full stack resting on the lower layers. For every new installed layer the upper surface was measured at measure points according to measure points in Annex 1. The placement of bed material and concrete blocks was done manually with the help of a beam crane.

The test was performed four times. Test 1 and 2 was carried out with stacking geometry according to Figure 2-2. Measurement of the settlings was performed after each layer and after the ballast placed.

The stacking geometry was adjusted for the remaining tests, due to suspicions that the blocks achieved different ballast pressure depending on the position of the block. The adjusted stacking geometry is shown in Figure 2-3. In the adjusted method the blocks were placed one after another in the same order as planned in the ÅSKAR-concept. A spreading layer of pellets was used to achieve a uniform ballast pressure on the blocks. Measurement of the settlings was performed after placement of all the blocks and after each third of the ballast placed. For further details, see Table 2-1.

Figure 2-1. *Test setting in the Bentonite Laboratory.*

Figure 2-2. Stacking method used in test 1–2.

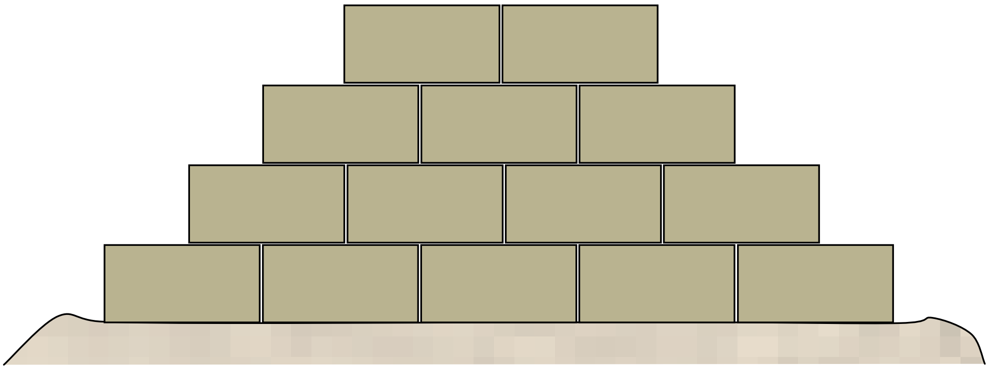


Figure 2-3. Stacking method used in test 3–10.

Table 2-1. Test details for test 1–4.

	Test 1	Test 2	Test 3	Test 4
Bed material	854 kg IBECO.	1,720 kg IBECO.	1,773 kg IBECO.	1,955 kg MX-80 pillows
Bed thickness	100 mm	200 mm	200 mm	200 mm
Nr of blocks	88	88	64	64
Load spreading layer of IBECO pellets	–	–	45×1,500×1,500 mm	45×1,500×1,500 mm
Bottom layer	16 blocks	16 blocks	20 blocks	20 blocks
Ballast	3,068 kg.	3,068 kg	15,466 kg (4,881 + 4,894 +5,691 kg)	15,466 kg (4,881 + 4,894 +5,691 kg)
Total weight (ballast + blocks)	32,150 kg	32,150 kg	33,066 kg	33,066 kg

In test 1 and 2 IBECO RWC-BF was used as bed material, with 100 and 200 mm bed thickness respectively. The bed thickness should be 100 mm according to the reference design (SKB 2010). With a blasted tunnel floor the floor has to be leveled out with bed material and thereafter filled up with 100 mm bed material, which gives a maximum bed material depth of approximately 200 mm. Since the settlings observed with 200 mm bed thickness in test 2 were acceptable a bed thickness of 200 mm was used for the subsequent tests. Test 3 and 4 was performed with IBECO RWC-BF and MX-80 respectively as bed material.

The work was carried out in accordance with the activity plan AP TD KBP1003-10-037. The activity plan is one of SKB's internal controlling dokument.

2.1.2 Results

The blocks could be stacked according to the reference design in all of the tests. The block stack was stable during all of the tests and no problems with placement of the blocks due to instability were obtained. No significant gaps between the blocks were seen. The measured settlings in the foundation bed are shown in Figure 2-4 to Figure 2-7.

Comparison of test 2 and 3 shows that the stacking method used in test 3 gives somewhat more evenly distributed settlings and hence was the stacking method according to Figure 2-3 used in the subsequent test.

The settlings in test 3 with IBECO RWC-BF as bed material were more evenly distributed and in addition smaller than the settlings in test 4 with MX-80 pillows.

All of the tests indicate that additional settlings of the bed over time are small, since there was only a slightly increase of the settling level during the first three days.

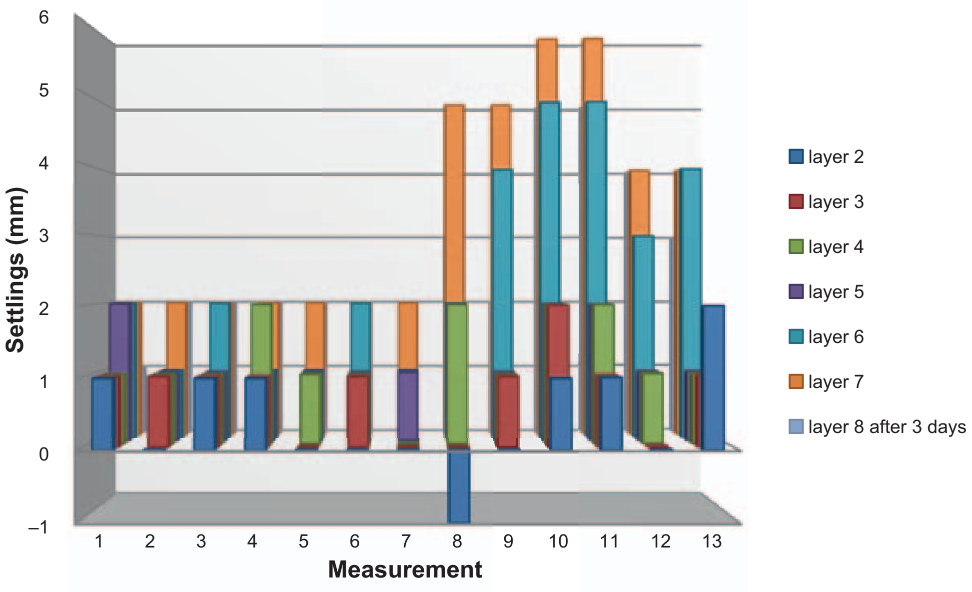


Figure 2-4. Measured settlings of IBECO RWC-BF pellet bed at different measure points (see annex 1) in test 1, with 100 mm bed thickness.

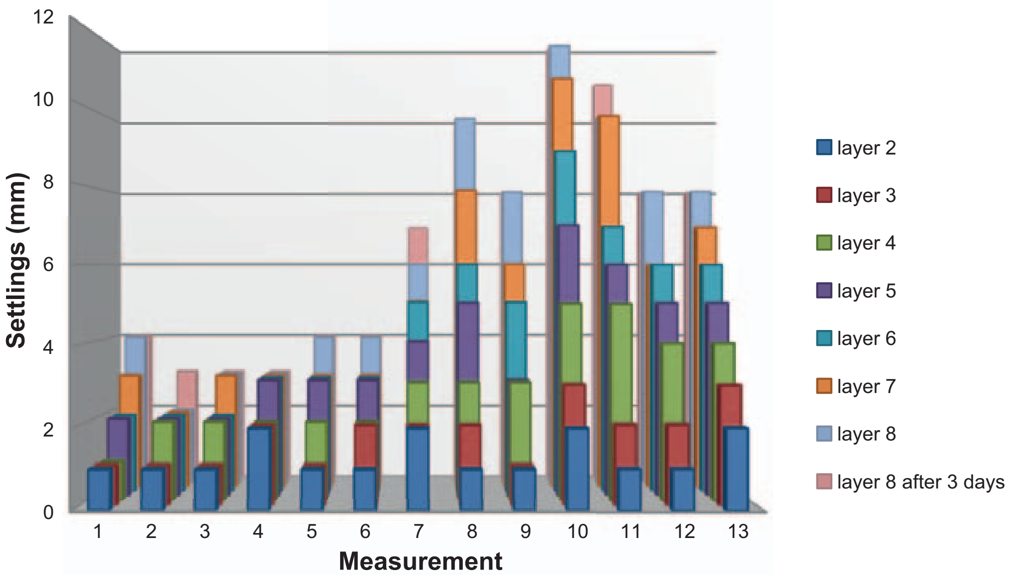


Figure 2-5. Measured settlings of IBECO RWC-BF pellet bed at different measure points (see annex 1) in test 2, with 200 mm bed thickness.

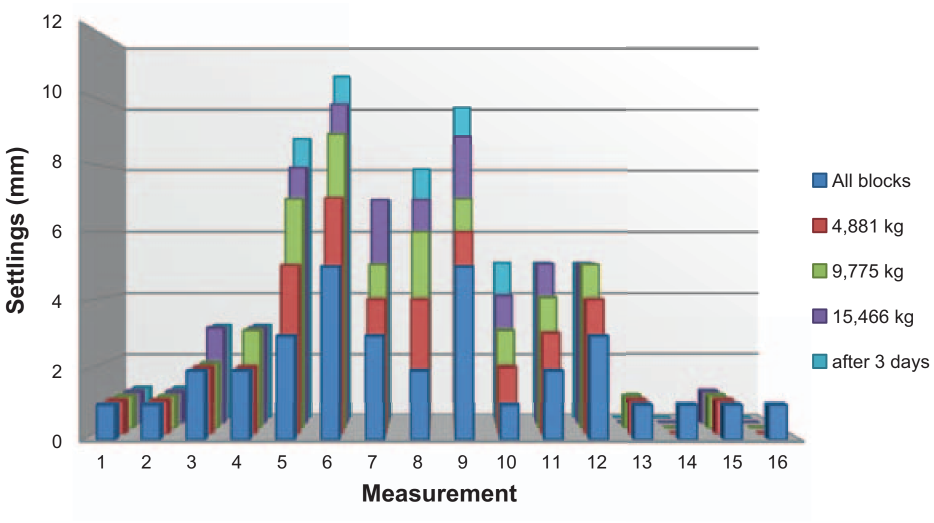


Figure 2-6. *Measured settlings of IBECO RWC-BF pellet bed at different measure points (see annex 1) in test 3.*

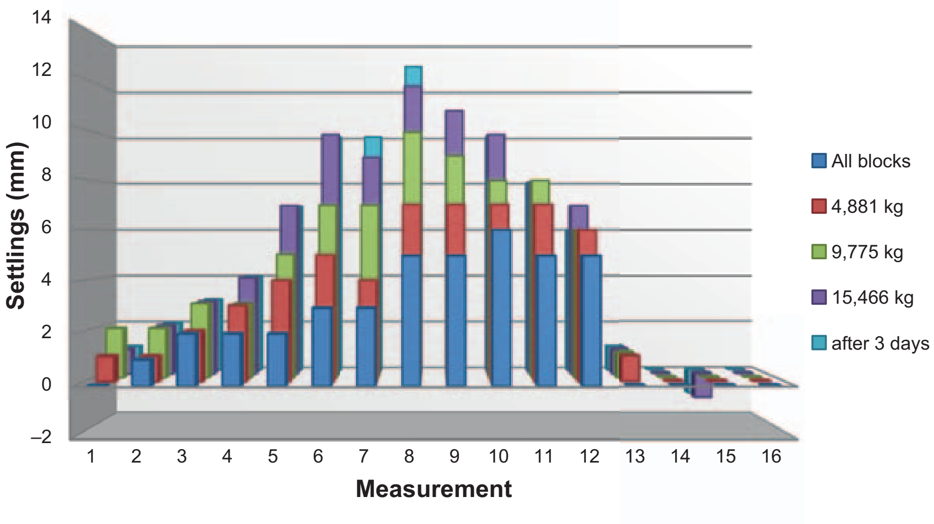


Figure 2-7. *Measured settlings of the MX-80 bed at different measure points (see annex 1) in test 4.*

2.2 Block stacking on bed during water inflow

The purpose of the test was to study how the bed and the stability of the block stack were affected by different rates of inflowing water.

2.2.1 Method

Two tests with different water inflows were performed. The choice of stacking geometry and bed material was based upon the prior tests, hence stacking geometry according to Figure 2-3 was chosen and IBECO RWC-BF pellets was used as bed material.

The tests were performed under controlled conditions with the same test arrangement as described in section 2.1.1. A simulated crack with water inflow was created using a geo textile which was placed on the floor within the wooden frame. The water inflow was started prior to pellets filling of the bed and was shut of when the block stack was completed. The water inflow was set to 6 l/h in test 5 and 60 l/h in test 6. For further details, see Table 2-2.

The front of the wooden frame was removed in test 6 to examine if it was possible to stack close to a pellet front.

The work was carried out in accordance with the activity plan AP TD KBP1003-10-055.

Table 2-2. Test details for test 5 and 6.

	Test 5	Test 6
Water inflow	6 l/h	60 l/h
Bed material	1,740 kg IBECO.	App. 1,700 kg IBECO.
Bed thickness	200 mm	200 mm
Nr of blocks	64	64
Load spreading layer of IBECO pellets	45×1,500×1,500 mm	45×1,500×1,500 mm
Bottom layer	20 blocks	20 blocks
Ballast	15,466 kg (4,881 + 4,894 + 5,691 kg)	15,466 kg (4,881 + 4,894 + 5,691 kg)
Total weight (ballast + blocks)	33,066 kg	33,066 kg

2.2.2 Results

The block stack was stable during the both tests and no significant gaps between the blocks were obtained. The removed front of the wooden frame did not affect the stability of the blocks or the block stacking.

The inflowing water was mostly absorbed by the pellets around the simulated crack. The water was also pushed up to the sides of the block stack where it was absorbed by the pellets, see Figure 2-8. After a third of the ballast placed in test 6 the inflowing water was pressed out from the pellet bed at the water inlet, where it was absorbed by the pellets close to the inlet.

The measured settlings in the foundation bed are shown in Figures 2-9 and 2-10.

The settlings of the pellets bed in test 5 were somewhat larger than in the comparable test without water inflow, test 3. The settlings in test 6 with the higher water inflow were twice as large in average as the settlings in test 5.

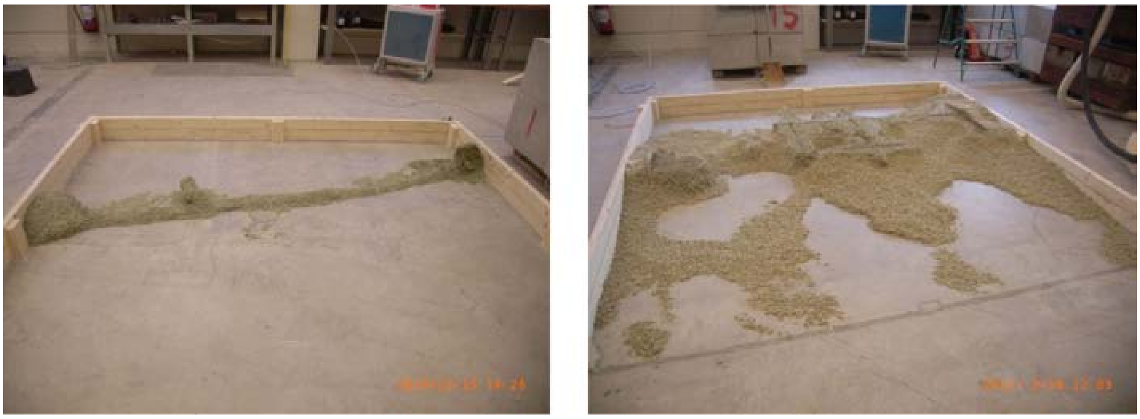


Figure 2-8. *The remaining pellets after the block stack and dry pellets removed. Left, test 5 and right test 6.*

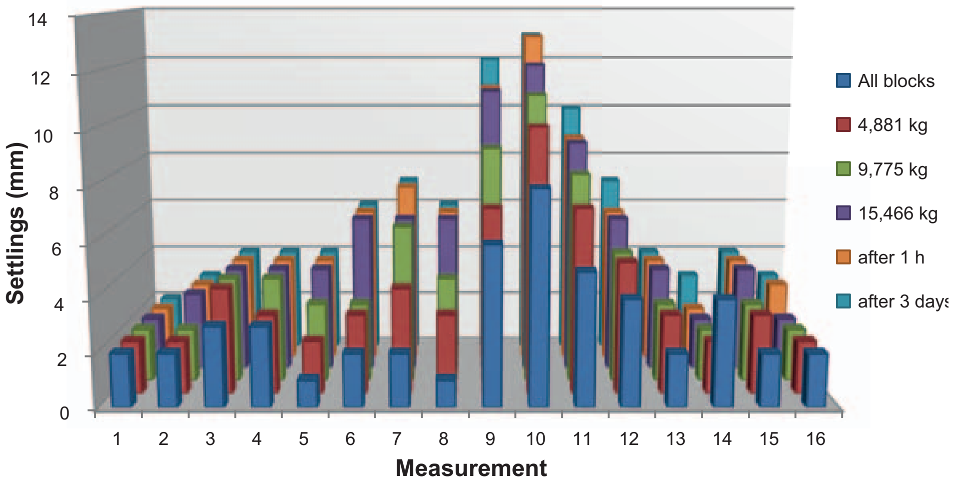


Figure 2-9. Measured settlings of the pellet bed at different measure points (see annex 1) in test 5 with a water inflow of 6 l/h.

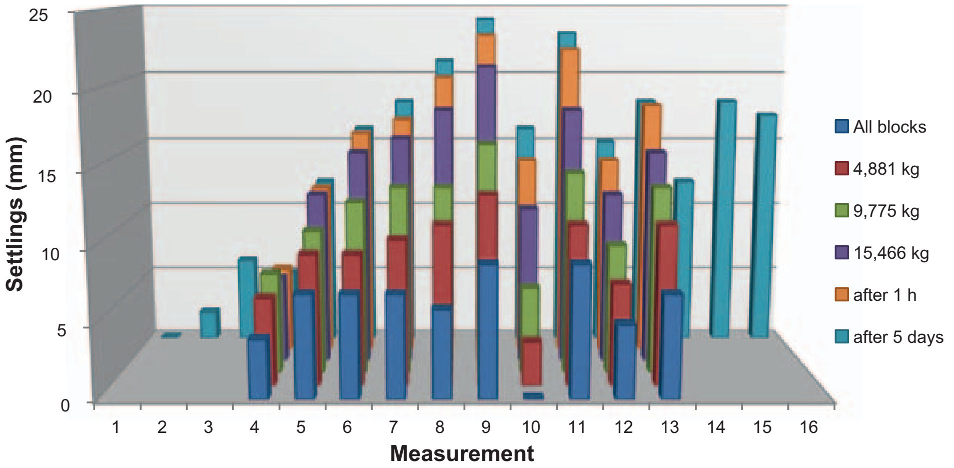


Figure 2-10. Measured settlings of the pellet bed at different measure points (see annex 1) in test 6, with a water inflow of 60 l/h. It was not possible to measure the settlings in point 1–3 and 14–16 with the blocks stacked since the measurement points were inaccessible.

2.3 Block stacking in a test tunnel

Two tests were performed in the M-tunnel. The purpose of the test was mainly to verify the ÅSKAR-concept in a situation similar to the planned deposition tunnels. Since the tunnel floor in the M-tunnel is blasted and uneven the affection on the bed by a blasted tunnel floor was studied as well.

2.3.1 Method

The tests were set up directly on the tunnel floor, see Figure 2-11. The tunnel floor was first leveled up with bed material which resulted in a pellet depth of app. 90 mm at the shallowest parts and 500 mm at the deepest parts. Concrete blocks and steel weights were thereafter placed in the same way as in the prior tests, described in section 2.1.1.

The choice of stacking geometry and bed material was based upon prior test results and hence IBECO RWC-BF pellets was used as bed material and the block was stacked according to the geometry showed in Figure 2-3 and with the bed thickness shown in Annex 2. Two replicate tests, test 7 and 8 were performed, for further details, see Table 2-3.

The work was carried out in accordance with the activity plan AP TD KBP1003-10-55.

Figure 2-11. The test arrangement in the M-tunnel.

Table 2-3. Test details for test 7 and 8.

	Test 7	Test 8
Water inflow	2,7 l/h	2,7 l/h
Bed material	App. 23,000 kg IBECO.	App. 23,000 kg IBECO.
Bed thickness	See annex 2	See annex 2
Nr of blocks	64	64
Load spreading layer of IBECO pellets	45×1,500×1,500 mm	45×1,500×1,500 mm
Bottom layer	20 blocks	20 blocks
Ballast	15,466 kg (4,881 + 4,894 + 5,691 kg)	15,466 kg (4,881 + 4,894 + 5,691 kg)
Total weight (ballast + blocks)	33,066 kg	33,066 kg

2.3.2 Results

Neither the inflowing water nor the uneven tunnel floor affected the stability of the block stack. The blocks could be stacked according to the reference method, no problems with gaps between the blocks or instability in the block stack were obtained. The measured settlings in the foundation bed are shown in Figures 2-12 and 2-13.

The settlings in the both tests were of the same magnitude. For both test 7 and 8 the settlings increased between the time of completion of the block stack and five days after completion of the block stack.

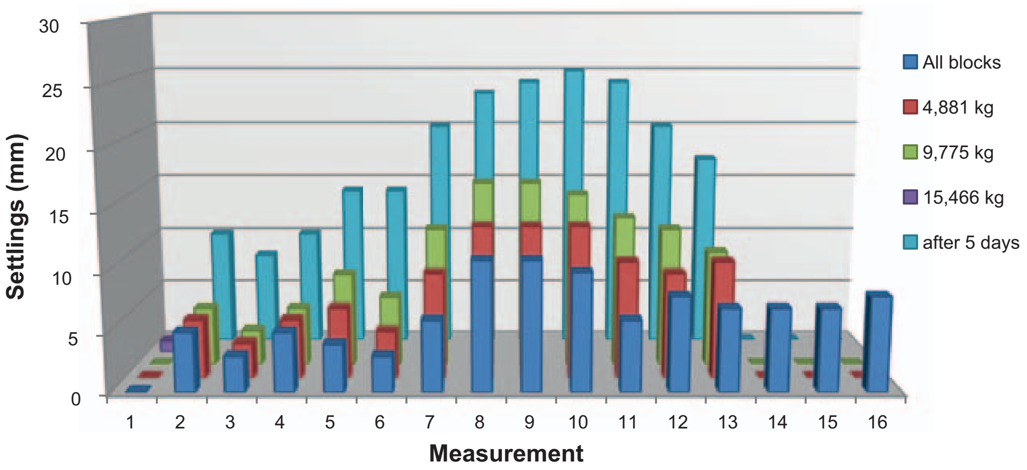


Figure 2-12. Measured settlings of the pellet bed at different measure points (see annex 1) in test 7. It was not possible to measure in point 1 and 14–16 after the first part of the ballast placed, since the measurement points were unavailable.

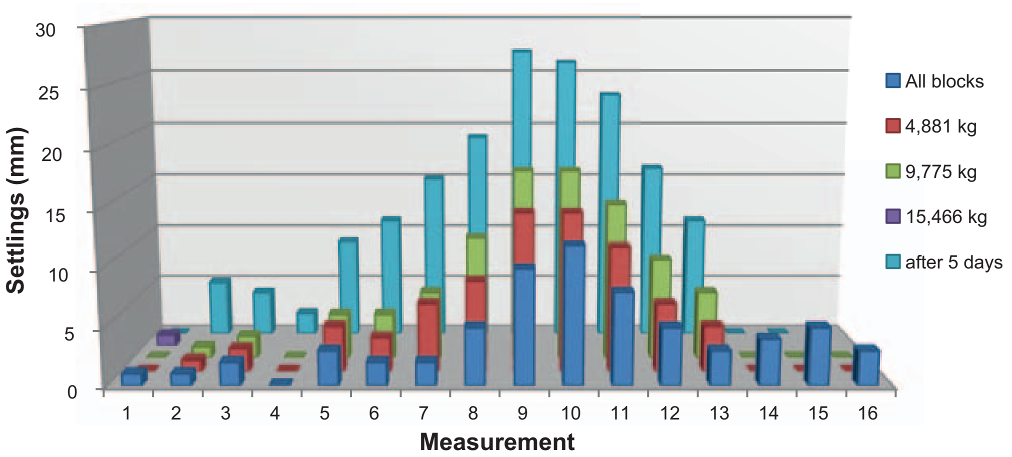


Figure 2-13. Measured settlings of the pellet bed at different measure points (see annex 1) in test 8. It was not possible to measure in point 1 and 14–16 after the first part of the ballast placed, since the measurement points were inaccessible.

2.4 Block stacking on the upper part of the deposition hole and bevel

The purpose of the test was to study how the bed and the block stack were affected by stacking over a deposition hole, with and without concurrent water inflow.

2.4.1 Method

The tests were performed in the Bentonite Laboratory.

The tests were set up on an even concrete tunnel floor of full width according to the reference design (4,200 mm), with 1% inclination. The upper part of a deposition hole (with buffer blocks) and the bevel were build of concrete, in full scale, see Figure 2-14. As in the prior tests, section 2.1.1, the floor was covered with leveled pellets within a wooden frame. The pellets bed had an app. maximum depth of 450 mm on the bevel and a minimum of 150 mm over the buffer blocks. A number of concrete blocks were stacked on the foundation bed according to the pattern in Figure 2-3. A ballast of steel weights was used to achieve the load corresponding to the right number of bentonite blocks

Figure 2-14. The upper part of a deposition hole with buffer block and bevel was modelled with concrete in full scale.

according to the ÅSKAR-concept. For every new installed layer the upper surface was measured. Every measure point was measured again during the dismantling of the block stack. The placement of bed material and concrete blocks was done manually.

Test 10 was performed with a simulated water inflow, which was created using a geo textile in the same way as described in section 2.2.1. The water inflow was set to 60 l/h. For further details, see Table 2-4.

The work was carried out in accordance with the activity plan AP TD KBP1003-11-032.

Table 2-4. The test arrangement for test 9 and 10.

	Test 9	Test 10
Water inflow	–	60 l/h
Bed material	5,035 kg IBECO.	5,010 kg IBECO.
Bed thickness	150–450 mm	150–450 mm
Nr of blocks	112	112
Load spreading layer of IBECO pellets	–	–
Bottom layer	32 blocks	32 blocks
Ballast	25,400 kg (14,400 kg + 11,000 kg)	25,400 kg (14,400 kg + 11,000 kg)

2.4.2 Results

The blocks could be stacked according to the reference method, no problems with gaps between the blocks or instability in the block stack occurred.

The largest settlings were observed in the bevel, where the pellets depth was deepest. This caused a compaction of the block stack over the bevel, which rather increased the stability of the block stack than decreased it.

The measured settlings in the pellet bed are shown in Figures 2-15 and 2-16.

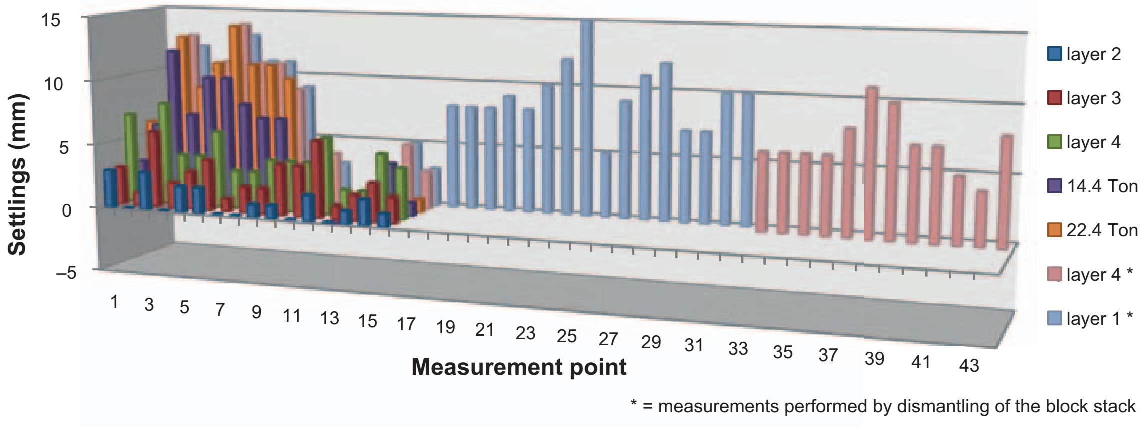


__Figure 2-15.__ Measured settlings of the pellet bed over the deposition hole at different measure point, test 9.

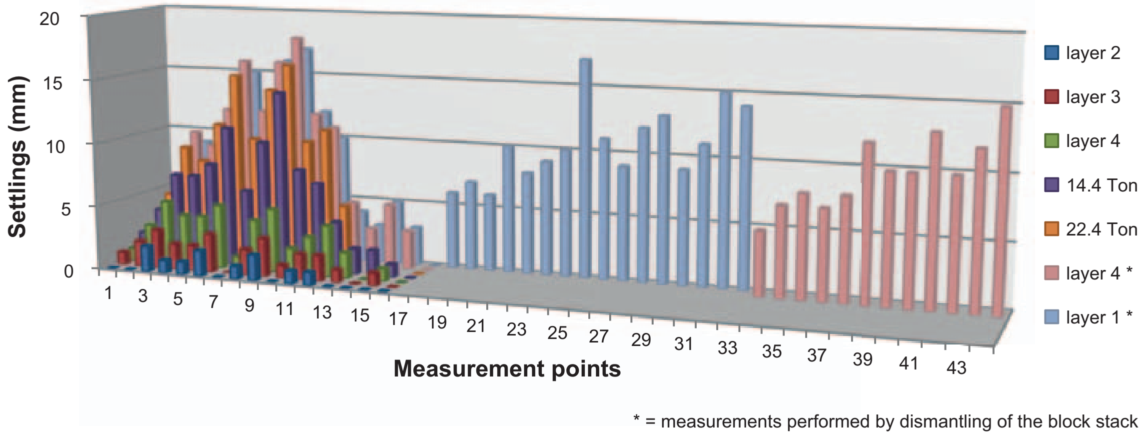


__Figure 2-16.__ Measured settlings of the pellet bed, over the deposition hole with a simulated water inflow, at different measure point, test 10.

3 Limitations of the test settings

Concrete blocks were used instead of bentonite blocks since they are easier to handle and the main focus was to study the foundation bed rather than the blocks. In addition earlier performed tests on the foundation bed showed that test results are independent of the block material (Wimelius and Pusch 2008). One difference between concrete and bentonite is that concrete does not absorb water to the same extent as bentonite. This was not a big issue in the performed tests since the foundation bed was only wetted through at some spots and most of the water was collected on the sides around the block stack.

The length of the block stack in the tests was only 2.3 m, which corresponds to the first 2.3 m of the block stack in the deposition tunnel. In the deposition tunnel the block stack, except the first part of it, will always have support from the blocks behind.

The pellets, blocks and ballast were handled manually, which takes much longer time than the planned installation in deposition tunnels.

4 Discussion

The block stack was stable and stacking was performed in all tests without any problems. The tests show that the stacking geometry is very stable and not sensitive when it comes to foundation material and compaction of the foundation bed. The block stack was stable on both the blasted and wire sawn floor. The stability of the stack is caused by the stacking geometry with overlapping joints; every newly placed block locks the underlying ones.

The inclination of the tunnel floor in the deposition tunnel is 1% according to Wimelius and Pusch (2008). This was modeled in the tests performed in the Bentonite Laboratory and no movements "downhill" of the foundation bed or the block stack were obtained. This indicates that the inclination in the planned deposition tunnels is no problem for stacking according to the ÅSKAR-concept.

The thickness of the bed seems to affect the level of the settlings. Larger settlings were achieved with 200 mm pellets bed compared with 100 mm, in the first tests performed. The tests performed in the M-tunnel and the upper part of the deposition hole indicates the same thing. The largest settlings were achieved in the same spots as the largest pellets depth was located.

Comparing test 5 and 6 gives that larger water inflow results in larger settlings, especially over time. The time aspect is important, larger settlings over time are allowed since the front of the block stack and the stacking will probably not be affected by settlings in the block stack several meters further into the tunnel.

No continued settlings after placement of the blocks and ballast were obtained for the tests performed in the Bentonite Laboratory. The settlings of the bed in the tests performed in the M-tunnel increased with app. 5–10 mm between installed block stack and removal of the stack 5 days later. The cause of the continued settlings could possibly be the continued natural water flow or the fact that the pellets bed was thicker and more uneven in depth than in the laboratory tests. The settlings in both test 7 and 8 were also somewhat larger than in test 5 with comparable water inflow.

The test results show that the settlings are relatively evenly distributed over the bed area, when the thickness of the bed is uniform. Blocks adjacent to each other have settlings of the same magnitude. This is a positive result since it is the relative settlings between block that is of interest, hence no problem with the stack stability will occur as long as the settlings are of same magnitude.

Uneven settlings could cause a problem for the robot to stack according to stacking geometry. The largest observed settlings were approximately 25 mm (registered in test 8), corresponding to 5% of the block width, which gives an angle change in the block position of maximum 5%. An angle difference between two blocks could possibly cause a problem for the robot to stack the blocks according to the stacking pattern, but it is unlikely that an angle of 5% is of significance. Gaps between blocks across tunnel does not affect the total block filling degree of the tunnel as long as the robot can follow the stacking pattern. On the contrary, settlings which cause gaps along the tunnel affect the block filling degree. None of the settlings observed in the tests caused any gaps affecting the block filling degree.

For all tests larger settlings was observed in measure position 8–11, which corresponds to the right side/front corner of the block stack. It is possible that the ballast pushed the block stack forwards and caused the larger settlings.

Comparing test 3 and 4 gives that the settlings when using IBECO RWC-BF as bed material were smaller and more evenly distributed than in test 4 with MX-80 pillows. This indicates that extruded pellets are better suited as bed materials than roller compacted pillows. But the settlings for the MX-80 pillows are still acceptable.

The tests performed in the M-tunnel indicate that the ÅSKAR-concept is applicable for backfill of the deposition tunnels. This will be further studied in full scale testes.

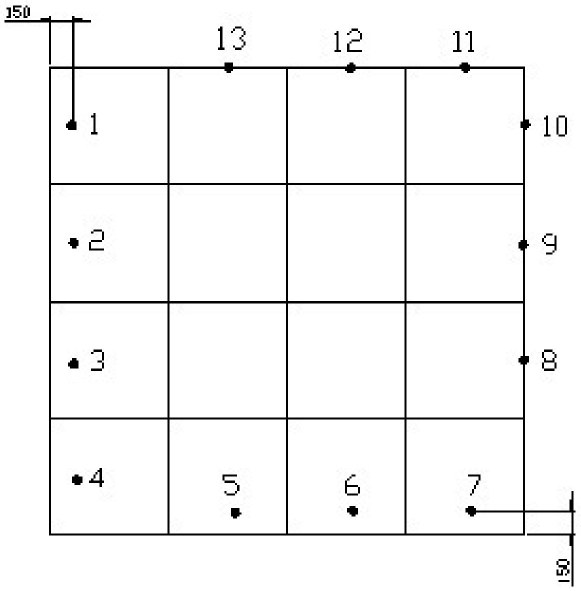
References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.se/publications.

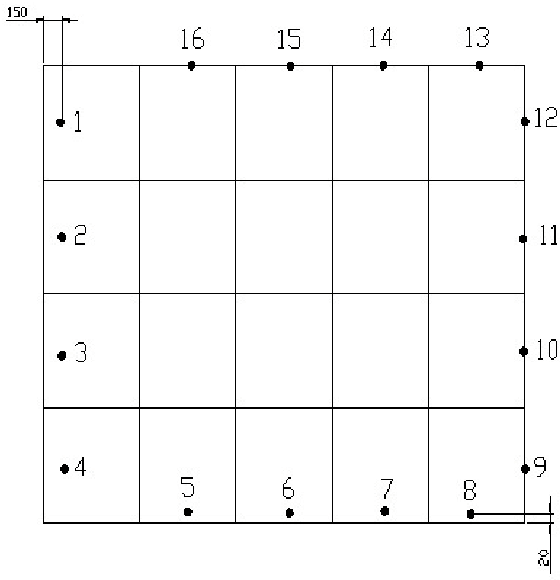
SKB, 2010. Design, production and initial state of the backfill and plug in deposition tunnels. SKB TR-10-16, Svensk Kärnbränslehantering AB.

Wimelius H, Pusch R, 2008. Backfilling of KBS-3V deposition tunnels – possibilities and limitations. SKB R-08-59, Svensk Kärnbränslehantering AB.

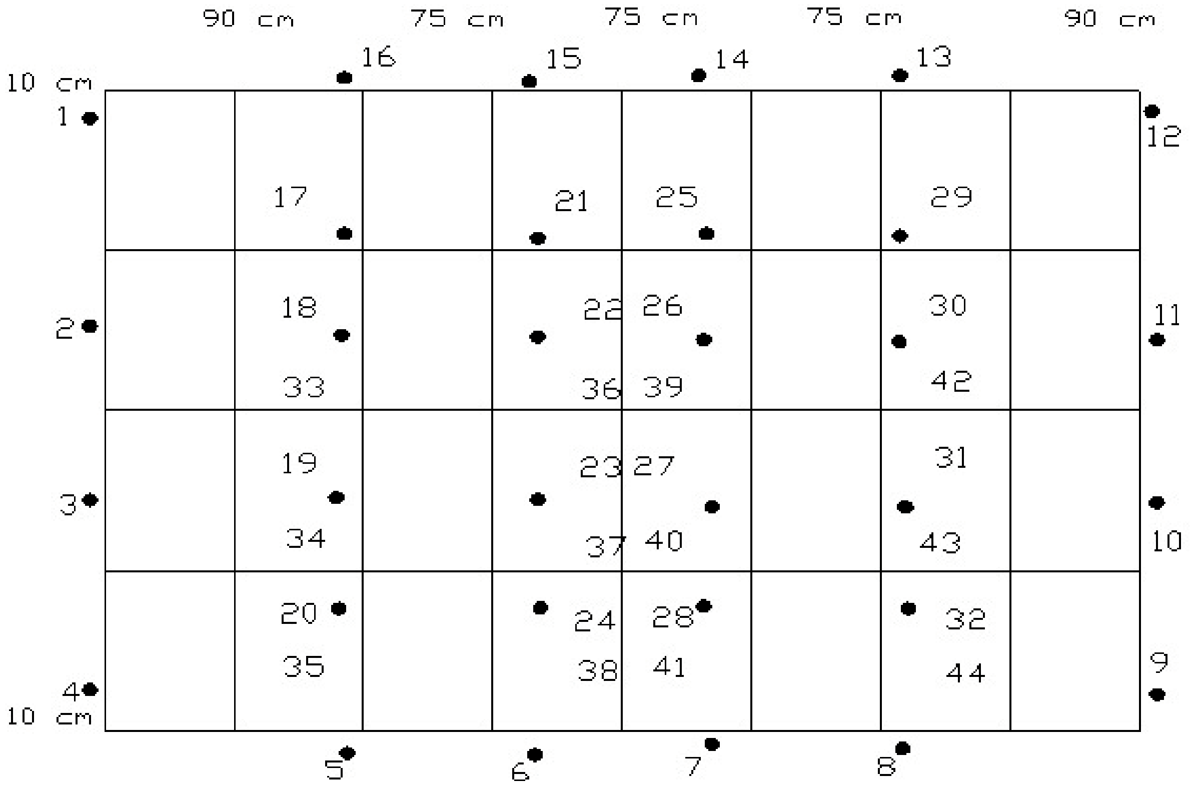
Annex 1 – Measurement positions



Measure position test 1–2



Measure position test 3–8



Measure positions test 9–10. Nr 33–44 is measure points in layer 4 with the same position as measure points 18–35 in layer 1.

Annex 2 – Bed thickness test 7 and 8

Against tunnel wall (m)

Along the tunnel (m)	0.20	0.50	1.00	1.50	2.00	2.50	3.00
0.20	310	340	280	370	390	280	90
0.50	300	300	370	380	310	300	200
1.00	250	240	280	350	350	270	330
1.50	210	170	230	290	310	260	400
2.00	120	130	180	210	260	330	320
2.50	130	90	200	160	200	410	500
3.00	120	230	260	320	180	300	350

Bed thickness (mm)