R-11-26

Final report of experiments with rock blocks interacting hydraulically with smectitic pellet fills

Roland Pusch, Sweco Infrastructure AB
Gunnar Ramqvist, EL-Tekno AB
Mikael Hedin, ÅF

November 2010

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

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

ISSN 1402-3091
SKB R-11-26
ID 1251371

Final report of experiments with rock blocks interacting hydraulically with smectitic pellet fills

Roland Pusch, Sweco Infrastructure AB
Gunnar Ramqvist, EL-Tekno AB
Mikael Hedin, ÅF

November 2010

This report is a result of a joint project between SKB and Posiva.

Abstract

The report describes the outcome of the work within the the project **“ SU5 08.20 Impact of water inflow in deposition tunnels ”. Project decision SKBdoc id 1178871 Version 3.0.**

Two activity plans have been used for the field work: AP TD SU50820-09-014 and AP TD SU 50820-09-031.

A problem in backfilling of KBS-3V tunnels with smectitic pellets surrounding highly compacted clay blocks is that water entering the fill have a very substantial effect on the manner in which water moves into or through a pellet-filled region in the period immediately following pellet placement. Channels will be formed that lead much water to the sloping front of the fill in the course of placing it. This can soften the fill and turn it into mud where the water is discharged as demonstrated by large-scale tests. The nature of such channels was investigated in the present study that comprised experiments with rock blocks equipped with nozzles for injecting water into contacting pellet fills at constant flow rates. The purpose was to identify the basic mechanisms in the first phase of hydration of pellet fills and to find out if there is a threshold flow rate for “piping”. The question if channelling at breakthrough takes place along the contact with the confinement, as indicated by preceding tests with steel and plexiglass instead of rock, was in focus.

The wetting process can be described as follows:

- independently of the inflow rate from a single spot the water pressure rises in conjunction with successive tightening of the pellet fill around the spot and will ultimately cause breakthrough of water in the form of a channel directed towards the part of the fill that offers least resistance, which is represented by the free surface like the slope of the fill being placed, or by the uppermost part of the fill in the tunnel,
- the inflow rate determines the rate of formation and growth of channels and breakthrough can take place after several hours or even days if the inflow rate is low and the distance to less dense parts of the filling or a free boundary is small but can otherwise be quick. The rate of backfilling will hence determine whether “piping” and softening will take place,
- uniform “diffusive”- type wetting takes place if the capacity of the pellet fill to sorb water from a “wet spot” is higher than the inflow rate, a threshold value is probably about 0.1 l/min. For high inflow rates or when the degree of water saturation of the fill around the inflow spot has become high, the water pressure will rise and “piping” occur,
- pellets brought in contact with initially water saturated rock hydrate immediately and thereby form a tight skin that seals off the inflow spot from the surrounding fill, causing further wetting to take place by migration of water more or less perpendicularly to the rock surface with the possible exception of cases with very high inflow rates,
- once “piping” has occurred all water in the vicinity of the channel is directed to it, which means that the flow can be high and transform the pellet fill to soft mud where discharge from the fill takes place.

While the mechanisms of water entering a fill from separate local spots in contacting rock are well understood, prediction of the entire wetting process of a larger pellet volume requires consideration of the interactive function of several inflow spots, representing single or networks of rock fractures. Experiments with pellet fills on a larger scale with simultaneous inflow from a number of fractures would provide further information on the wetting process. Such a test is outlined in the report.

Sammanfattning

Ett problem med återfyllning av tunnlar enligt KBS-3V-konceptet med smektitiska pellets som omger pressade lerblock är att vatten som tränger in i fyllningen kan skapa kanaler som kan leda mycket vatten till den lutande fronten på fyllningen som appliceras. Det kan ge flyttillstånd som visats vid tidigare tester i stor skala. Vid den här rapporterade undersökningen användes bergblock med borrat hål för att injektera vatten i anslutande pelletfyllning med konstant flöde. Syftet var att se om det finns något tröskelvärde hos flödet som ger ”piping” och om kanalbildning vid genombrott sker i kontakten med berg eller i fyllningen som tidigare tester med stål och plexiglas i stället för stenmaterial visat.

Bevätningsprocessen kan beskrivas på följande sätt:

- oberoende av inflödeshastigheten från en enskild punkt stiger vattentrycket successivt i samband med att pellets som omger punkten tätar och ger till slut upphov till en kanal som utvecklas mot den del av fyllningen som ger minst strömningsmotstånd, tex den fria ytan hos fyllningen som anbringas, eller där motståndet mot förskjutning är minst såsom närmast tunneltaket,
- inflödeshastigheten bestämmer hur snabbt kanaler bildas och vidareutvecklas och genombrott kan ske efter timmar eller dagar om inflödet är lågt och avståndet till fyllning med låg densitet långt men kan annars ske snabbt,
- jämn, “diffusionslik” bevätning sker om fyllningens kapacitet att ta upp vatten är större än inflödet från berget, det kan finnas ett tröskelvärde av ca 0.1 l/min. Vid högre inflöde eller när tätningseffekten hos fyllningen runt inflödespunkten blivit hög stiger trycket och snabb ”piping” kommer att ske,
- pellets som kommer i kontakt med vattenmättat berg beväts snabbt och bildar ett tätt “skinn” som isolerar inflödespunkten och orsakar att vattenvandringen äger rum mer eller mindre vinkelrätt från bergytan, möjligen med undantag för fallet med starkt inflöde,
- när “piping” har inträffat strömmar allt vatten i kanalens omgivning till densamma vilket innebär att flödet kan bli högt och omvandla fyllningen till lös mudd vid utflöde från fyllningen.

Medan mekanismerna hos vattenupptagningen i pelletfyllningen från enskilda vattenförande punkter i berget är kända kräver prediktion av bevätningen av en större pelletvolym att man tar samverkan av flera inflödespunkter i en enskild eller i ett nätverk av bergsprickor i beaktande. Experiment med pelletfyllning i större skala med samtidigt inflöde från flera sprickor skulle ge bättre besked om bevätningsprocessen. Ett sådant experiment skisseras i rapporten.

Contents

1 Scope

The project was planned to give information on how water from rock fractures enters the pellet fill of KBS-3V tunnels in the earliest stage of hydration (Figure 1-1). A primary question was if transport of water from a fracture takes place along the contact between the pellet fill and the rock or if it has the form of perpendicular penetration into the interior of the pellet fill. A second question was if the mechanisms of water transport through a pellet fill from an inflow spot can change in the course of permeation e.g. from relatively uniform migration to concentrated flow leading to channelling. Both issues were investigated experimentally leading to conceptual models of water migration in fillings of smectite-rich pellets.

The study was organized as follows:

- arrangement of tests with 1) horizontally placed rock slabs with boreholes for wetting overlying pellet fill, and 2) vertically oriented slabs with boreholes for wetting of pellet fills "shotcreted" on them,
- testing by flowing water through the holes in the slabs and further through the pellet fills followed by excavation and sampling of the fill for determining the water content distribution and identifying flow paths,
- formulation of a conceptual microstructural model for inflow of water from rock fractures into clay pellet fills,
- outlining of rock structure model for describing the distribution of inflow spots in tunnels and the quantity of inflowing water per spot.

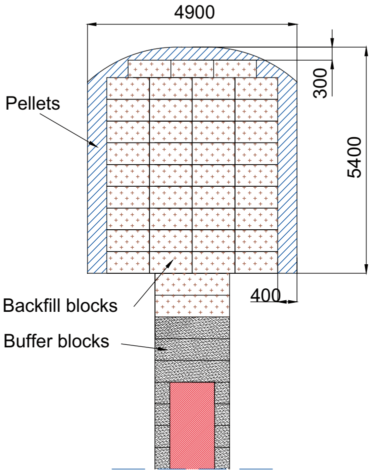


***Figure 1-1**. Schematic section of KBS-3V deposition tunnel. The dimensions are approximate.*

2 Rock Block Experiments

2.1 Test arrangement

A series of experiments using rock blocks with water supply holes drilled through them and then placed in contact with smectite pellet fills have been completed. These tests examined the behaviour of these mock-ups under a variety of water inflow rates and determined the flow paths resulting from rock contact with smectite pellets. The arrangement for horizontally oriented rock/pellet contact is illustrated in Figure 2-1, which indicates that evaluation of the experiments was made by taking numerous samples at three levels in the fill for determining the water content. A corresponding arrangement for vertically oriented contact is illustrated in Figure 2-2. The pellets were poured in the same fashion in all tests for creating conditions that are typical of a KBS-3V repository.

The inflow tube of stainless steel had 6 mm diameter and did not reach above the rock surface. In one of the tests (V4) with vertically oriented rock/pellet contact the pellet fill clay block wall was replaced by a wooden support.

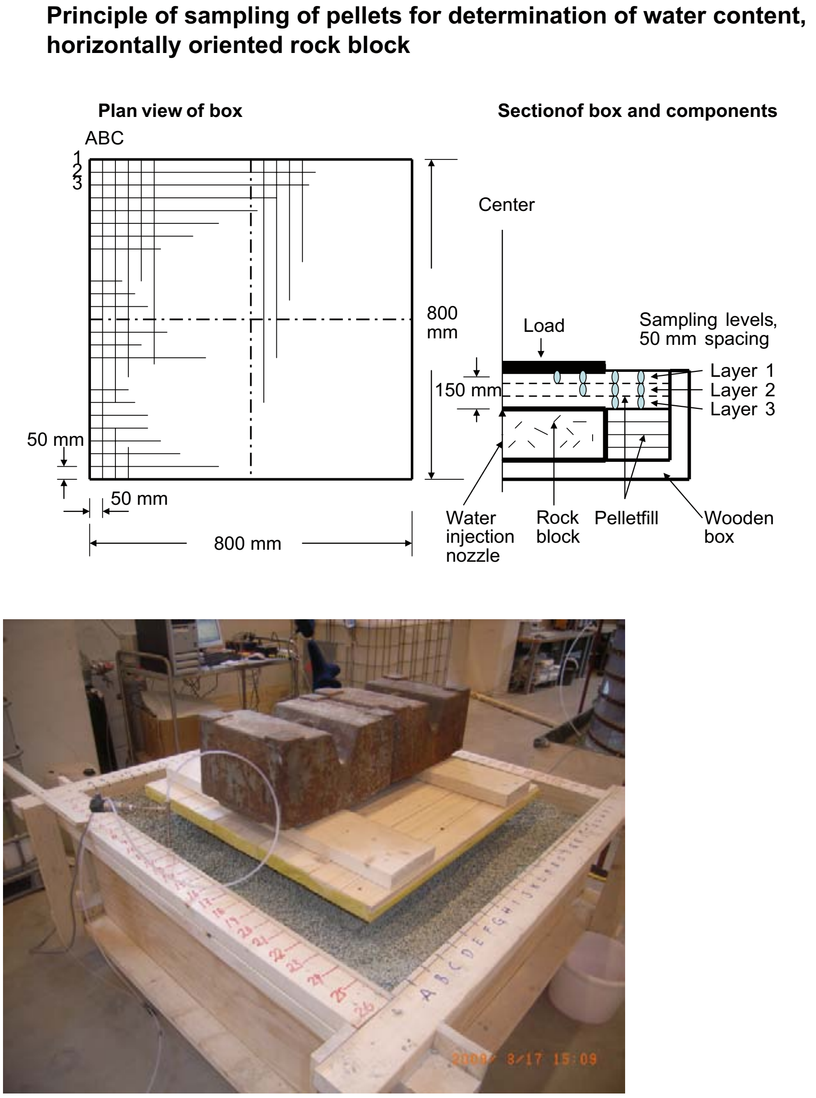
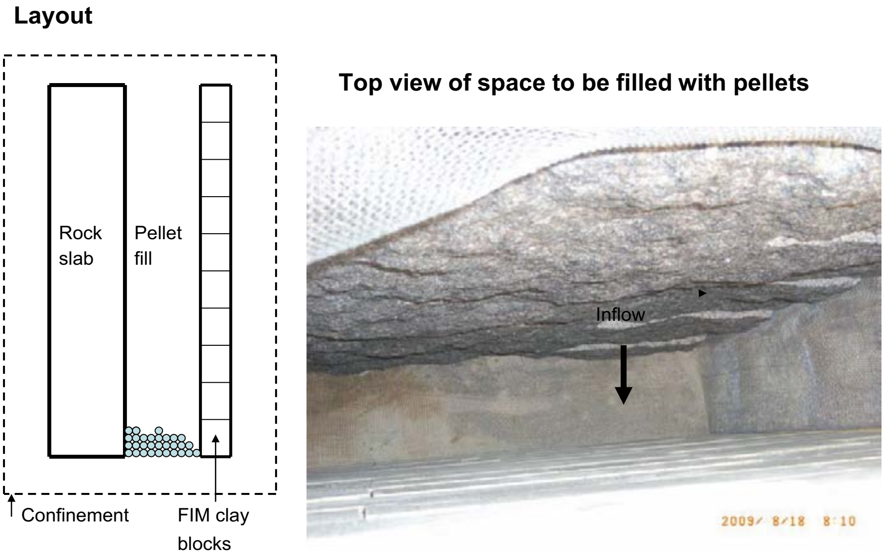


Figure 2-1. *Arrangement for studying wetting of pellet fills. Water is pumped from a hole drilled through the rock block located under the fill that is covered by the wooden plate. Notice the coordinate system for describing the position of the samples taken.*



Layout

Top view of space to be filled with pellets

Figure 2-2. View of the space between rock and block wall to be filled with pellets in all tests except one (V4). In test V4 the pellets were confined by a net supported by a wooden construction.

Sampling of the pellet fill was made by pushing a cylindrical tube to about 5 cm depth and immediately weighing and drying the contents at 105°C for 24 hours following the usual geotechnical procedure for determining the water content[1].

2.2 Materials

CEBOGEL QSE pellets are produced as short cylindrical rods by Cebo Holland BV Company, and imported from Isle of Milos, Greece. The mineralogy and chemistry of Milos bentonite is presented (Appendix 1) the smectite (montmorillonite) was about 90%. The pellets were rod-shaped with a length and diameter of 10–15, and 6 mm, respectively.

The rock blocks were slabs obtained from a granite quarry at Flivik, north of Äspö. The blocks had an edge length of about 800×1,000 mm and a thickness of 150–200 mm. The surfaces were not cleaned or machined and hence represent normally blasted tunnel walls. The blocks were stored under water for about 2 weeks before placement in the large box, which was filled with Äspö water up to a level just below the upper surface of the block. Such water was used also for the injection tests.

2.3 Test program

Ten tests lasting from less than one hour to 1.5 days were made with different inflow rates that were selected to represent actual conditions as specified in Table 2-1:

Table 2-1. Test program.

Test No	Inflow rate, l/min	Duration, hours	Notes
H1	0.005	31	Horizontal
H2	0.01	7	Horizontal
H3	0.05	2	Horizontal
H4	0.10	1	Horizontal
H5	0.20	1	Horizontal
H6	0.50	< 1	Horizontal

---

[1] Weighing before and after the drying gave the mass of water. The water content is expressed as the ratio of water mass and mass of dried soil.

Test No	Inflow rate, l/min	Duration, hours	Notes
V1	0.005	31	Vertical pellets confined by clay blocks
V2	0.10	< 1	Vertical pellets confined by clay blocks
V3	0.10	1	Vertical pellats confined by clay blocks
V4	0.10	2	Vertical pellets in net supported by a wooden construction.

Clay blocks in tests V1–V3 were made of dense clay (Dixon et al. 2008a). The blocks did not interact hydraulically with the pellets.

2.4 Results

2.4.1 H-tests

Test H1

The evolution of the recorded pressure at the inflow spot is shown in Figure 2-3. The pressure increased initially to 45 kPa after 6 hours and then dropped instantly to nil indicating sudden penetration of water into the fill. A second rise to 50 kPa took place after another 3 h followed by a second drop to about 12 kPa, indicating a second event of this type. A third rise to 45 kPa 15 hours after start was followed by a pressure drop 20 kPa. Outflow to the nearest rim, implying first vertical flow through the 150 mm pellet fill followed by horizontal flow, could be observed after 31 hours. This long period of time is explained by the very low inflow rate (0.005 l/min).

The fact that the test was terminated when water appeared at the rim, i.e. the stage of earliest percolation, means that significant erosion had not yet taken place.

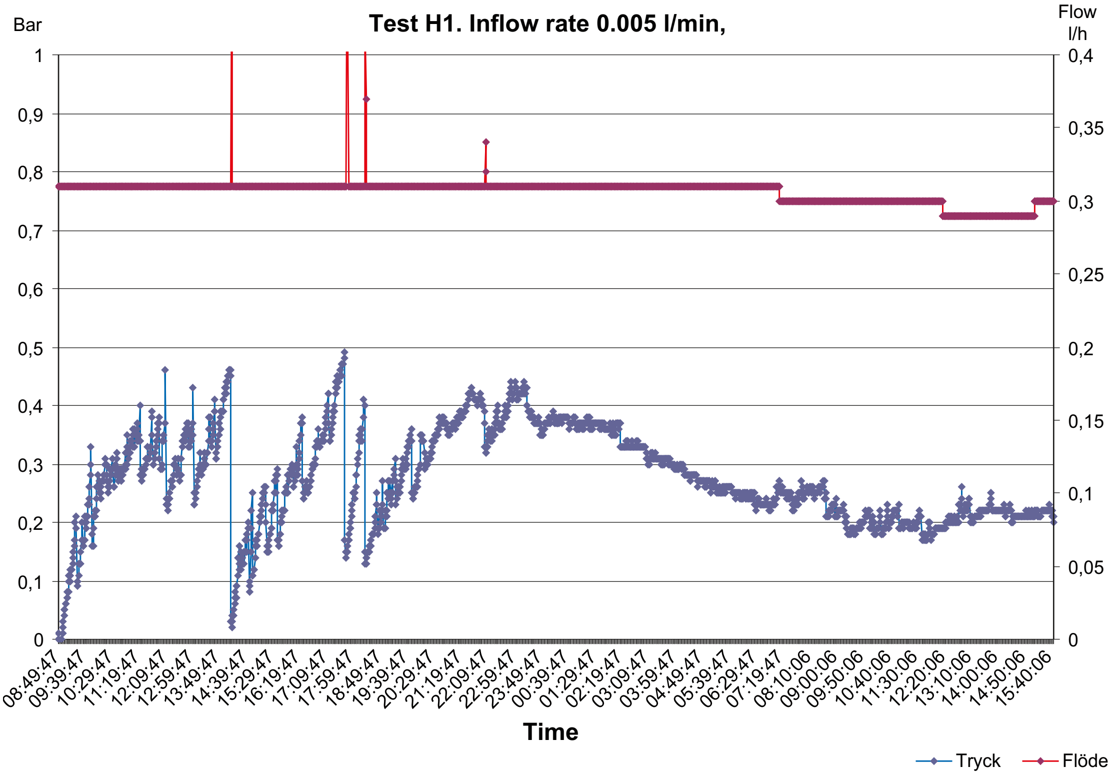


Figure 2-3. *Recorded pressure and flow at the inflow spot in Test H1 as a function of time*[2].

---

[2] SKB's plotting code for this type of recording expresses pressure in terms of *bar*.

The distribution of the water content at the termination of the test is illustrated by Figure 2-4. It shows the position of curves for the water contents 30, 50 and 70%, the lowest representing slight wetting, the intermediate value indicating significant wetting, and the highest showing substantial wetting. The fact that the test was terminated when water appeared at the rim, i.e. the stage of earliest percolation, means that significant erosion had not yet taken place.

Test H2

The evolution of the recorded pressure at the inflow spot is shown in Figure 2-5. The pressure increased initially to about 7 kPa and reached to about 25 kPa after 3 hours after which it dropped to around 10 kPa and then increased to 20 kPa with a peak at 45 kPa. After a few minutes it dropped instantly to nil indicating sudden penetration of water into the fill. The fact that the test was terminated when water appeared at the rim, i.e. the stage of earliest percolation, means that significant erosion had not yet taken place.

The distribution of the water content at the termination of the test is illustrated by Figure 2-6. It shows the position of curves for the water contents 30, 50 and 70% and resembles very much those of test H1 by showing to the formation of a plume and an ultimately formed central channel created in conjunction with breakthrough that caused the loss of pressure.

Test H3

The evolution of the recorded pressure at the inflow spot is shown in Figure 2-7. No pressure was recorded until 15 minutes after injecting water and then varied between nil and 2 kPa in the subsequent 10 minutes after which it dropped, indicating limited local penetration of water into the fill. The pressure then rose again and stayed in the interval 0.9 to 1.8 kPa for about half an hour after which it quickly dropped to nil, indicating breakthrough and formation of a major channel. The fact that the test was terminated when water appeared at the rim, i.e. the stage of earliest percolation, means that significant erosion had not yet taken place.

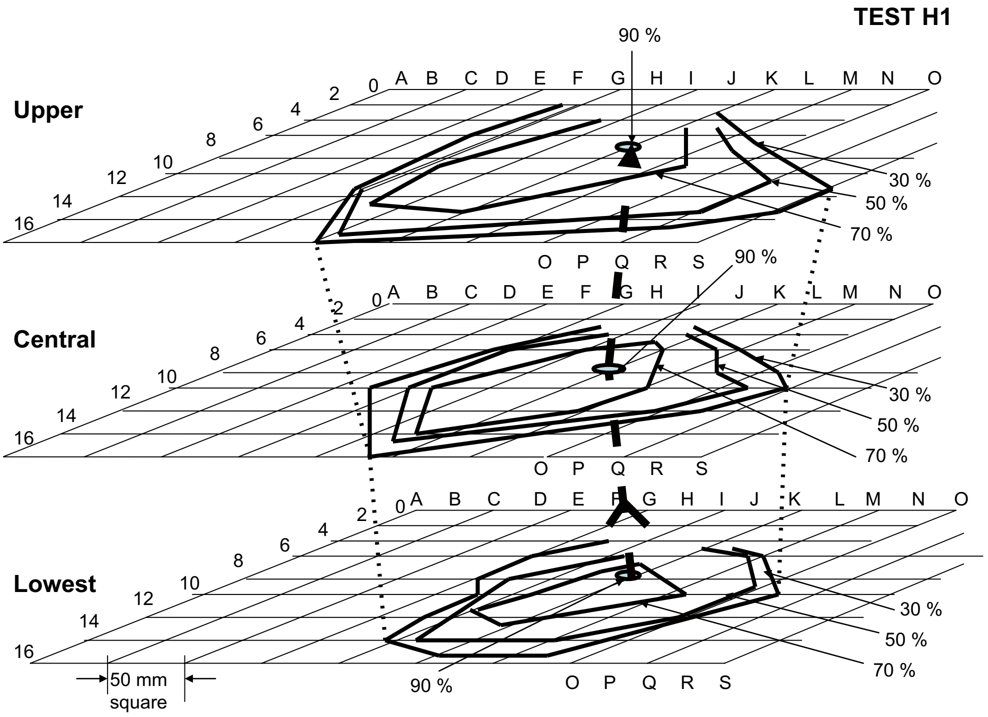


Figure 2-4. Distribution of the water content in the three layers at an inflow rate of 0.005 l/min. The water uptake formed a plume that widened upwards and ultimately gave a channel through which all water flowed, eroding the pellet fill.

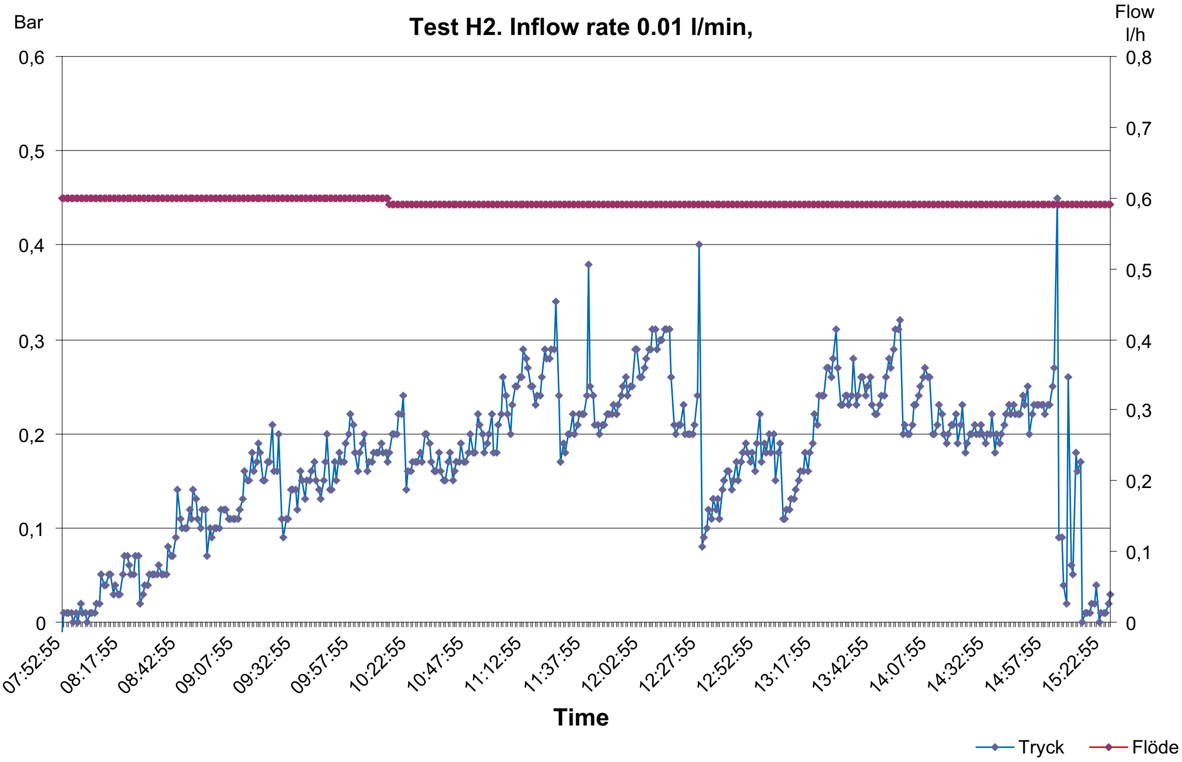


Figure 2-5. Recorded pressure and flow at the inflow spot in Test H2 as a function of time.

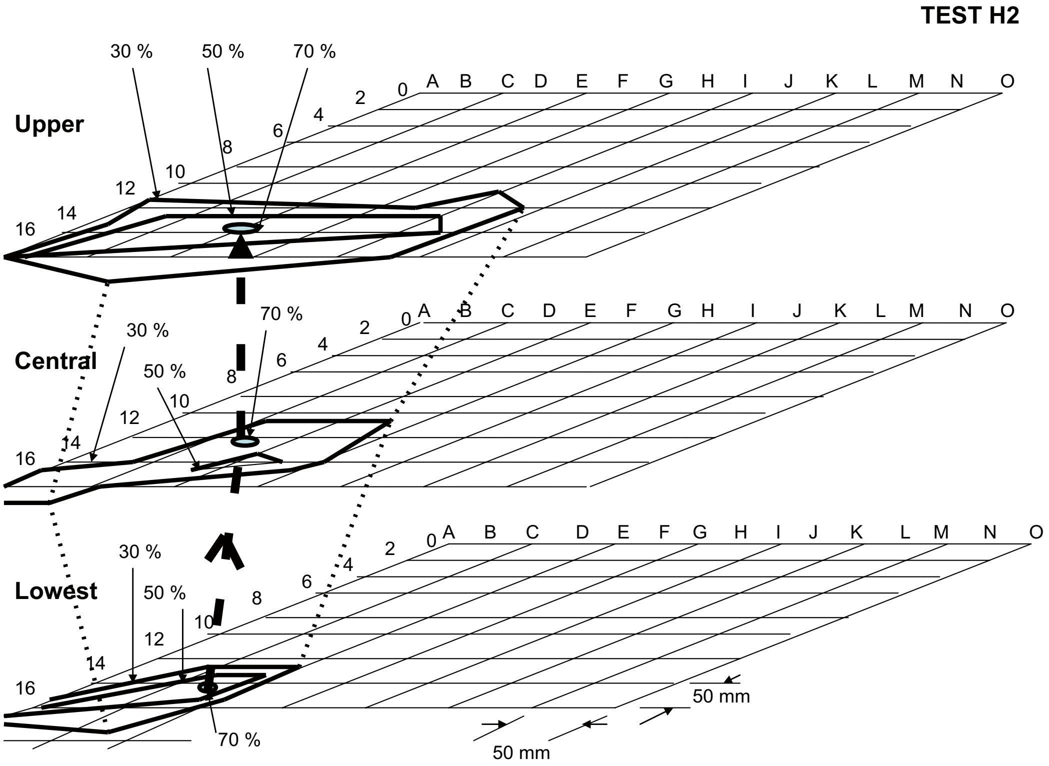


Figure 2-6. Distribution of the water content in the three layers at an inflow rate of 0.01 l/min. The water uptake formed a plume that widened upwards and ultimately gave a channel through which all water flowed, eroding the pellet fill.

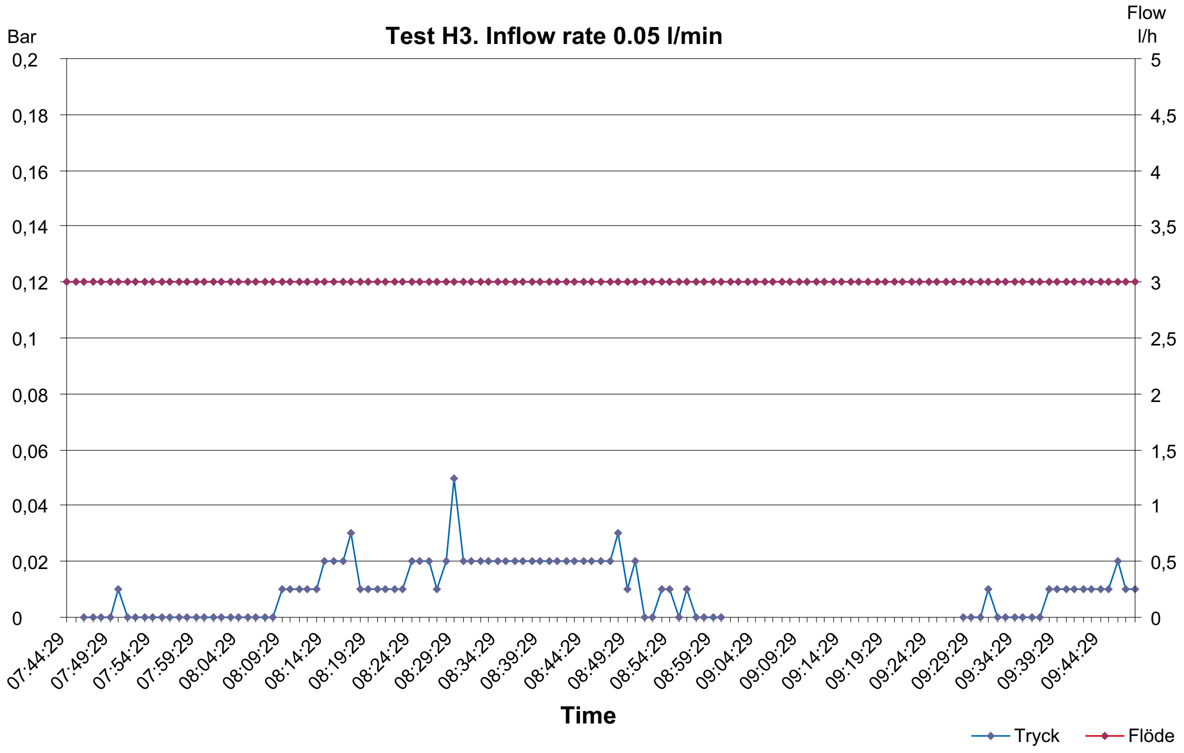


Figure 2-7. *Recorded pressure and flow at the inflow spot in Test H3 as a function of time.*

The distribution of the water content at the termination of the test is illustrated by Figure 2-8. It shows the position of curves for the water contents 30, 50 and 70% and resembles very much tests H1 and H2 by showing the formation of a wet plume and an ultimately formed central channel, created in conjunction with the breakthrough that caused the ultimate loss of pressure.

Test H4

The evolution of the recorded pressure at the inflow spot is shown in Figure 2-9. No pressure was caused in the first 45 minutes but a small peak representing about 1 kPa then appeared for slightly more than 10 minutes. This indicates that the water uptake took place at approximately the same rate as inflow.

The distribution of the water content at the termination of the test is illustrated by Figure 2-10. It shows the position of curves for the water contents 30, 50 and 70% and resembles the preceding tests with respect to the formation of a plume and an ultimately formed central channel. The fact that almost no pressure was recorded can be explained if the migration was not dominated by flow but by slow diffusive uptake controlled by the high suction power of the pellet fill. The channel may have had the form of a wet zone and not being related to sudden water breakthrough since the pressure stayed very low throughout the test. Longer testing time may have led to a second pressure rise because of the successive tightening of the pellet fill near the inflow spot and along the channel.

The photo in Figure 2-10 shows the appearance of the upper surface with discharge of water with Methylene Blue tracer (2 g per litre) from the steep channel meandering from there on the surface.

Test H5

The evolution of the recorded pressure at the inflow spot is shown in Figure 2-11. It resembled the pressure history of test H2 but gave somewhat lower values and a couple of pressure drops that indicated quick, intermittent penetration of water. The pressure increased initially to about 4 kPa after a few minutes and fell slowly to about 2 kPa after half an hour followed by a quick and distinct loss of pressure, indicating breakthrough and formation of a major channel.

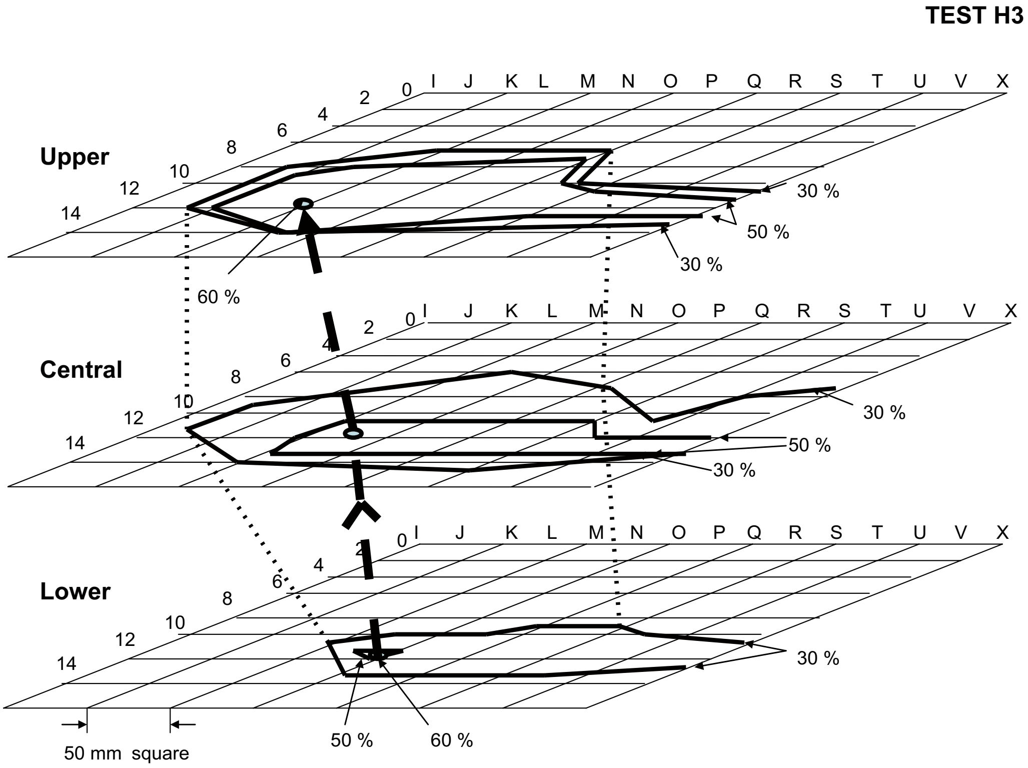


Figure 2-8. Distribution of the water content in the three layers at an inflow rate of 0.05 1 l/min. The water uptake formed a plume that widened upwards and ultimately gave a channel through which all water flowed, eroding the pellet fill.

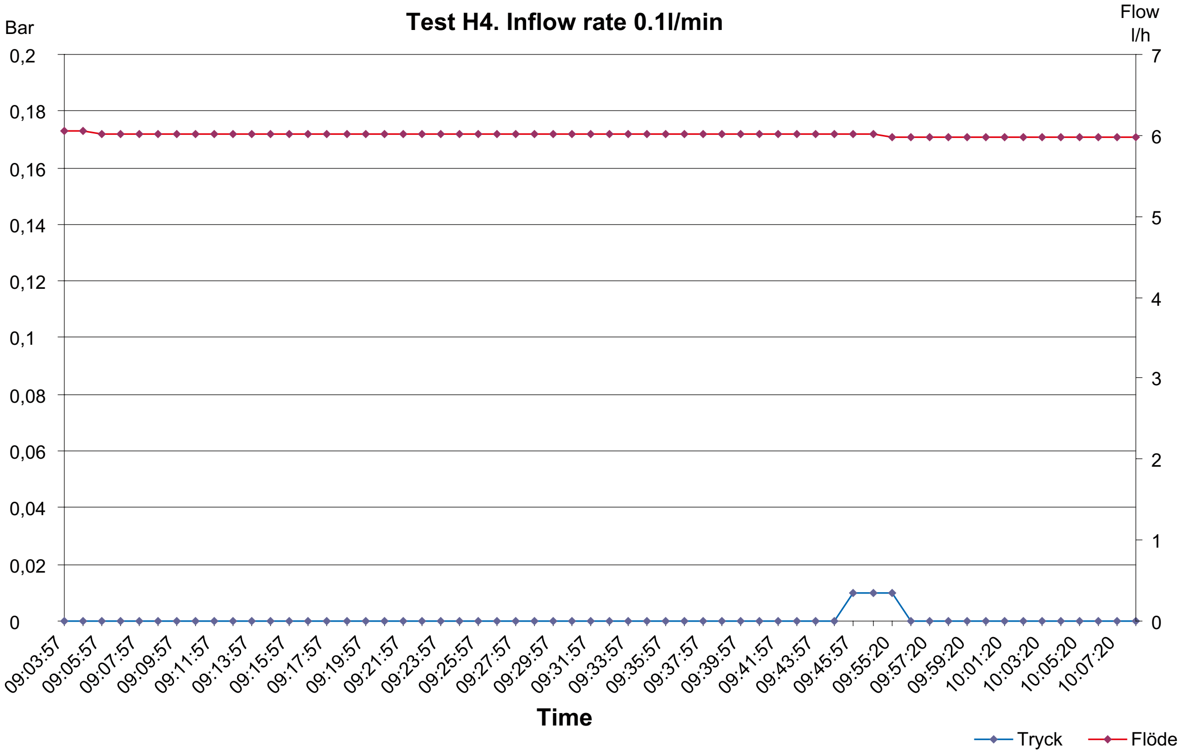


Figure 2-9. Recorded pressure and flow at the inflow spot in Test H4 as a function of time.

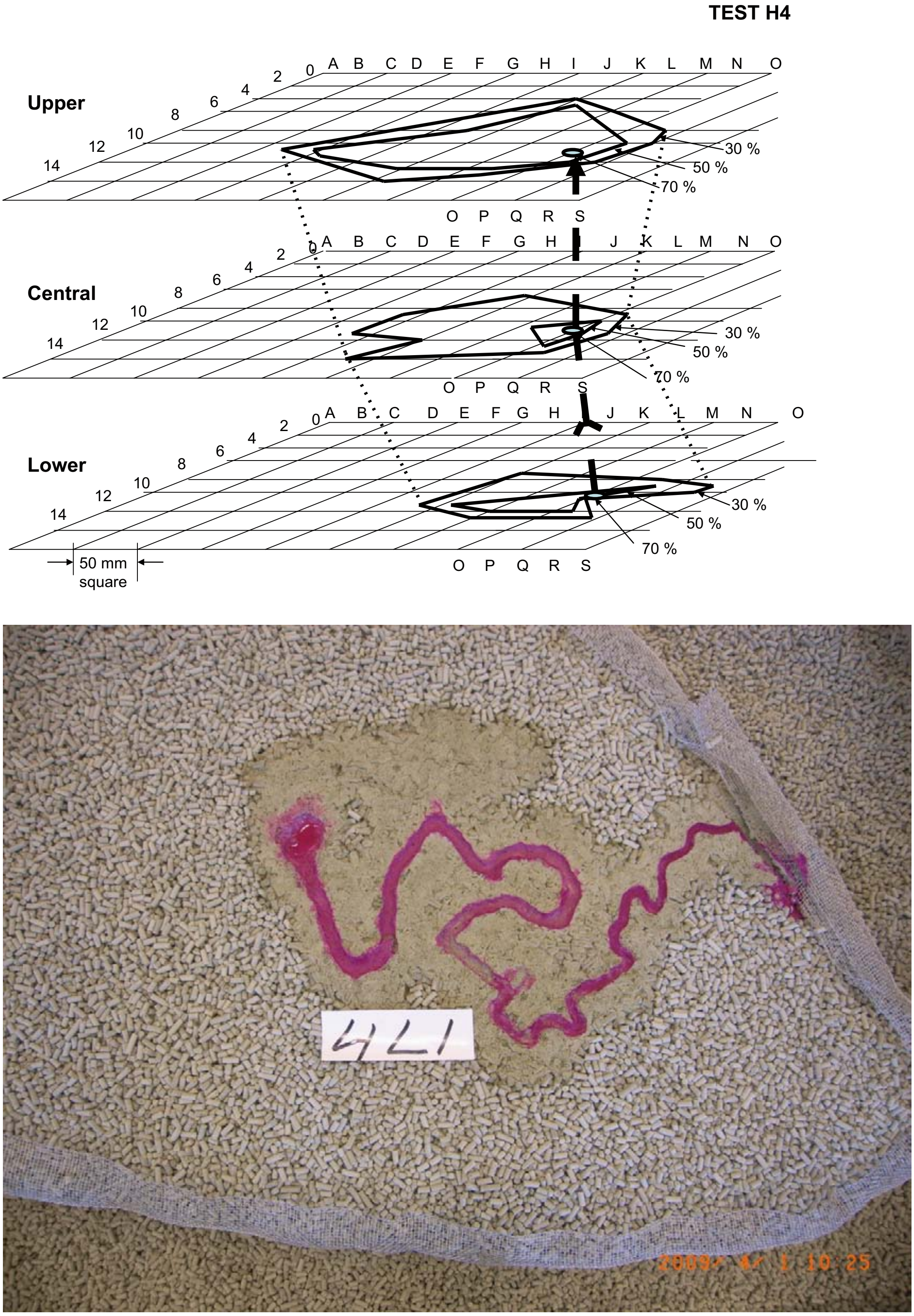


Figure 2-10. Migration of the water content in the three layers in test H4 with an inflow rate of 0.1 l/min. Upper: Distribution of the water content indicating formation of a plume that widened upwards and ultimately gave a channel through which all water flowed, eroding the pellet fill. Lower: Photo of upper surface with meandering water expelled from the steep channel (Photo by Hedin).

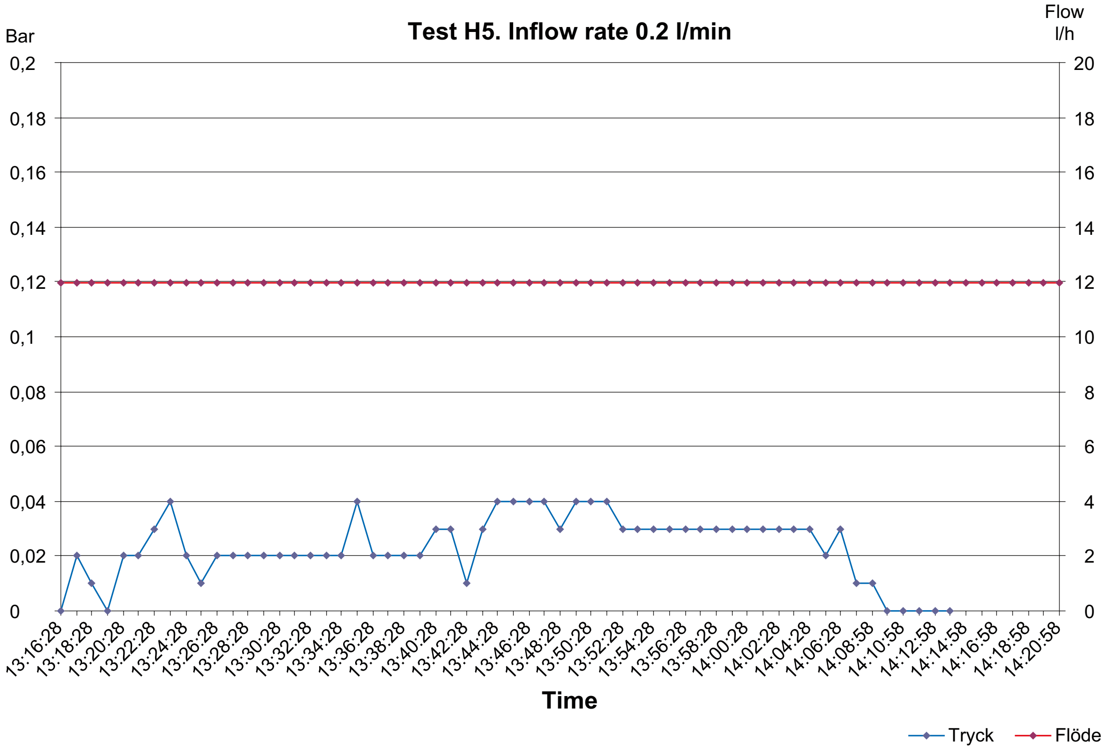


Figure 2-11. Recorded pressure and flow at the inflow spot in Test H5 as a function of time.

The distribution of the water content at the termination of the test is illustrated by Figure 2-12. It shows the position of curves for the water contents 30, 50 and 70% and is different from the preceding tests. Thus, water had moved in different directions in the respective layers and in an asymmetric fashion at the lowest level, i.e. at the rock/pellet contact. Two channels seem to have been created. One of them could not be identified with certainty at this level but both appear in the two upper layers. The fact that the water created the upward directed channels shows that flow along the rock/pellet contact did not dominate.

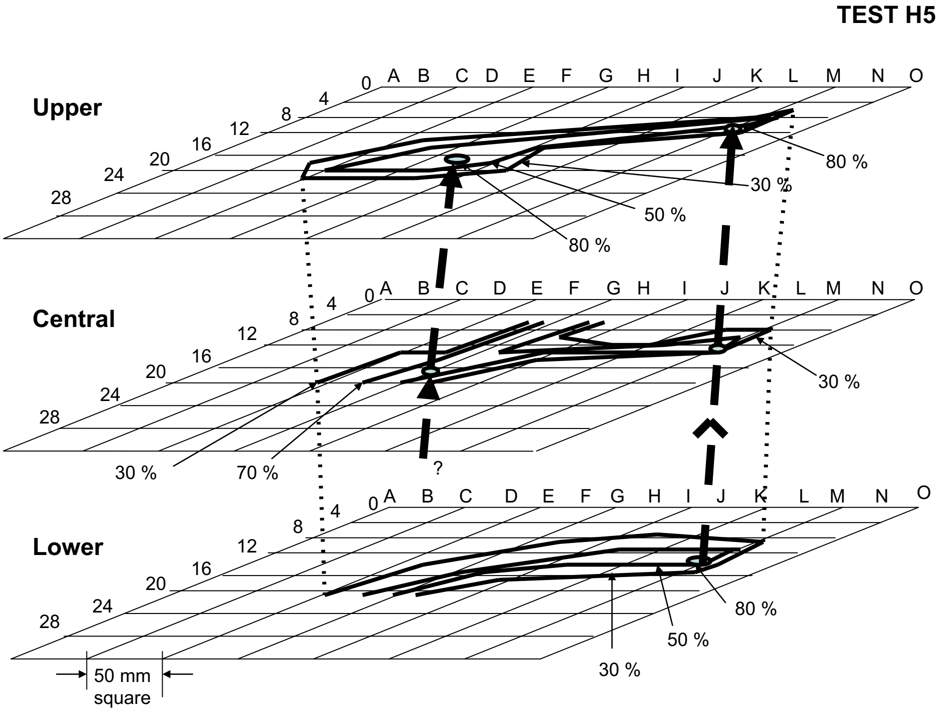


Figure 2-12. Distribution of the water content in the three layers at an inflow rate of 0.2 l/min. Water moved in different directions uptake formed a plume that widened upwards and ultimately gave a channel through which all water flowed, eroding the pellet fill.

As for the preceding tests it is probable that breakthrough of channel-transported water to the uppermost level caused the ultimate loss of pressure. The fact that the test was terminated when water appeared at the rim, i.e. the stage of earliest percolation, means that significant erosion had not yet taken place.

Test H6

No pressure related to resistance to water injection was observed, indicating quick penetration and discharge of water in test H6 with an inflow of water of 0.5 l/min. Figure 2-13 shows the position of curves with the water contents 30, 50 and 70% and indicates that the wetting process was similar to that in test H5. Water appears to have moved initially along the rock/pellet contact but soon found least resistance to vertical movement creating two channels very quickly. Early breakthrough of channel-transported water to the uppermost level explains why no pressure was recorded. The fact that the test was terminated when water appeared at the rim, i.e. the stage of earliest percolation, means that significant erosion had not yet taken place.

2.4.2 V-tests

The test arrangement did not offer a possibility to observe outflow of water in the course of the experiments, in which the evolution of pressure was of main interest. The experience from the H-tests suggested that major processes at injection take place in the first 8 hours, which was taken as total testing time except for test V1 which ran for 31 hours.

Test V1

No resistance to water injection in the form of pressure generation was observed., This can be explained if the migration was not dominated by flow but by slow diffusive uptake controlled by the high suction power of the pellet fill in test V1 with an inflow of water of 0.005 l/min. Figure 2-14 shows the position of curves for the water contents 30, 50 and 70%. Level 1 is the top and increasing numbers represent successively deeper levels. The wetting process was different from that in most of the tests with horizontally oriented rock/fill contact in the sense that water appears to have spread symmetrically from the inflow spot at the rock/pellet contact and continued to form a horizontally oriented "converted" plume with smaller diameter at increasing distance from the inflow spot.

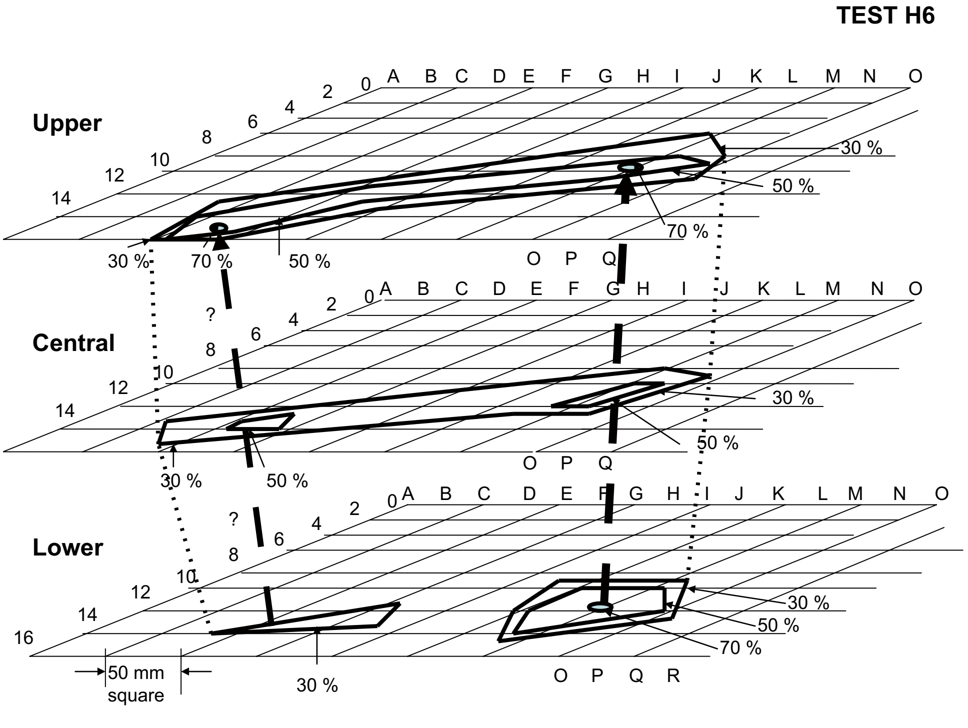


Figure 2-13. Distribution of the water content in the three layers at an inflow rate of 0.5 l/min. Water moved in different directions but the wetting still formed a plume that widened upwards and ultimately gave a channel through which all water flowed, eroding the pellet fill.

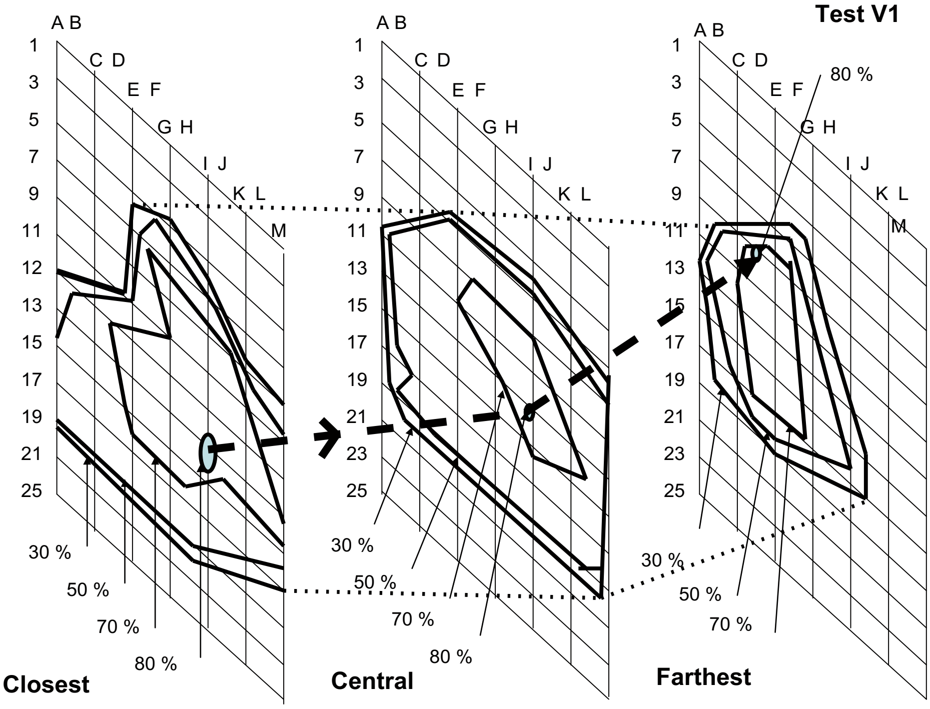


Figure 2-14. Distribution of the water content at three vertical planes with 50 mm spacing in test V1 with a water inflow of 0.005 l/min. The channel may have had the form of a wet zone at the farthest plane located about 150 mm from the rock surface.

At the largest distance from the rock the channel may have had the form of a wet zone. There was obviously no dominant trend of water to migrate downwards at the rock/pellet contact or in the fill, indicating that gravity did not control the wetting process.

Test V2

No pressure was generated and one estimates from the V1 and V2 tests that spotwise inflow on the order of 0.005 to 0.1 l/min may represent an upper value for avoiding early channelling, i.e. "piping".

The distribution of the water content at the termination of the test is illustrated by Figure 2-15. It shows the position of curves for the water contents 30, 50 and 70%. Level 1 is the top and increasing numbers represent successively deeper levels. The wetting process was similar to that of test V1 except that the horizontally oriented "converted" plume was narrower and that its central part, containing the ultimately formed discharge channel, was somewhat less well developed. Also, the maximum water content in the channel area was somewhat lower than in test V1.

Test V3

The evolution of the recorded pressure at the inflow spot is shown in Figure 2-16. The pressure rose to 4 kPa after a few minutes, dropped to a few kPa in minute and rose again to 13 kPa after which it dropped a second time and then went up to about 9 kPa. This pressure caused quick penetration of water and loss of the pressure that appeared again about 15 minutes after test start. It reached up to 7 kPa and stayed in the interval 7–17 kPa until about 1.5 hours after test start when it finally dropped to a low value indicating breakthrough through a major channel.

The distribution of the water content at the termination of the test is illustrated by Figure 2-17. It shows the position of curves with the water contents 30, 50 and 70% and resembles the one for test V2 with the exception that water had tended to move upwards but still led to formation of a horizontal channel to the outer vertical boundary. The correlation between pressure and nature of water movement is not obvious but it is believed that the irregular pressure increase in the first half hour was associated with an initial flow of water upwards and that the horizontal channel began to grow subsequently and finally reached the outer boundary causing the ultimate pressure drop.

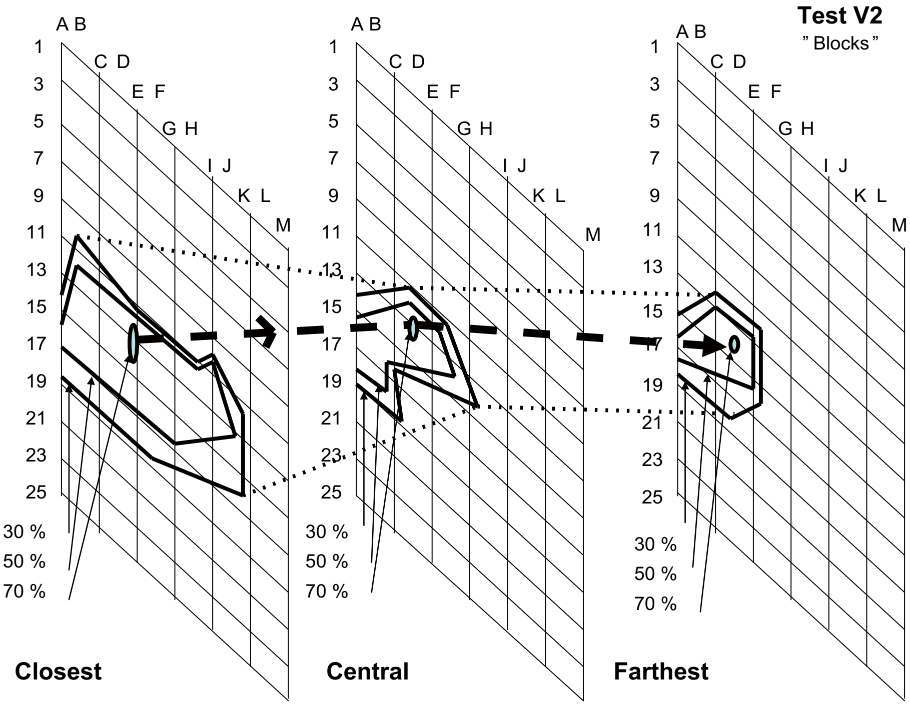


Figure 2-15. Distribution of the water content at three vertical planes with 50 mm spacing in test V2 with a water inflow of 0.1 l/min. The channel may have had the form of a wet zone at the farthest plane located about 150 mm from the rock surface.

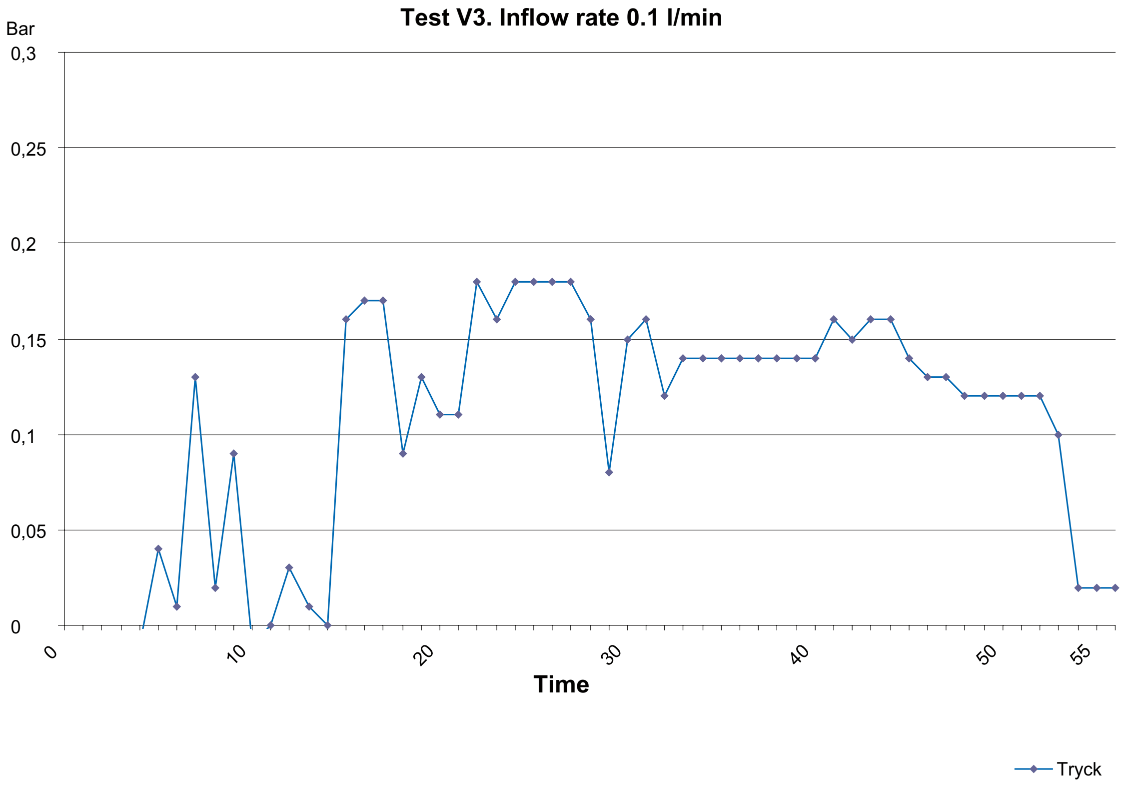


Figure 2-16. Recorded pressure at the inflow spot in Test V3. Time in minutes.

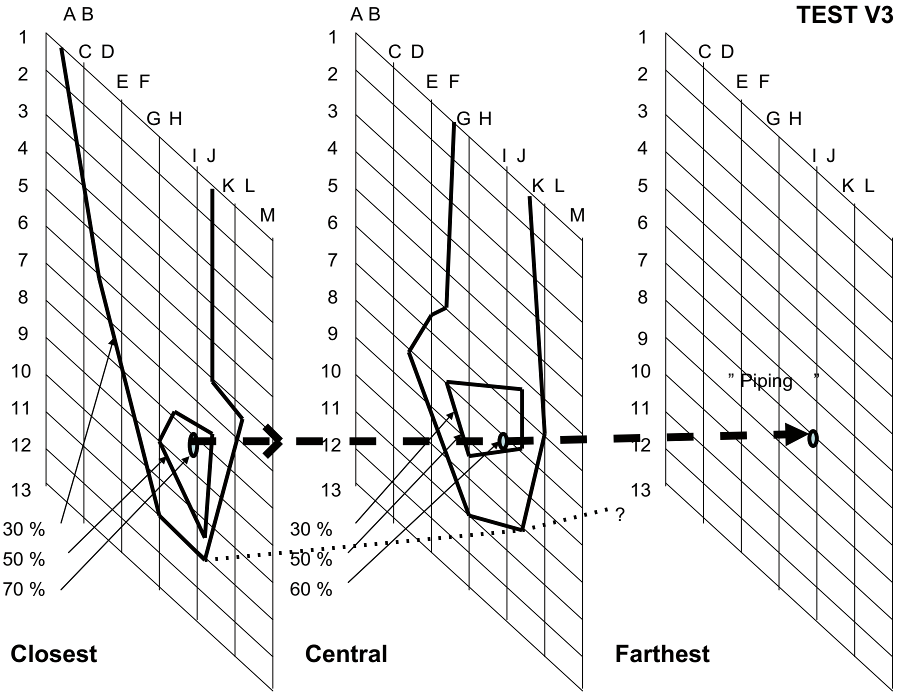


***Figure 2-17.** Distribution of the water content at three vertical planes with 50 mm spacing in test V3 with a water inflow of 0.1 l/min. Water moved upwards without creating a visible outflow spot, causing slight wetting of the pellet fill (maximum 50% water content). A channel proceeded horizontally from the rock surface to the central plane and further off in the form of distinct flow path ("piping").*

Test V4

The evolution of the recorded pressure at the inflow spot is shown in Figure 2-18. The pressure evolution was similar to that in test V3 but the pressure rose to a higher level, about 31.5 kPa and dropped linearly with time to about 10 kPa 1.5 hours after test start. A quick drop to a few kPa followed, indicating breakthrough through a major channel.

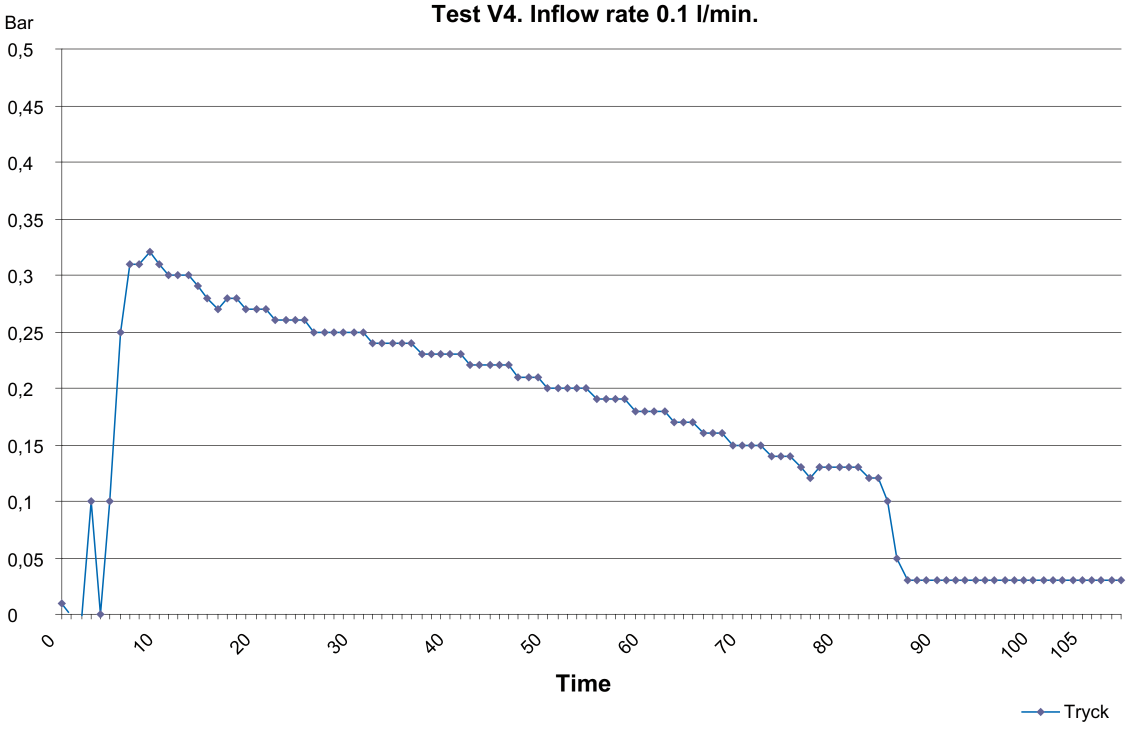


***Figure 2-18.** Recorded pressure in test V4. Time in minutes.*

The distribution of the water content at the termination of the test is illustrated by Figure 2-19. The pellet fill was contained in a net supported by a wooden construction, which may have implied a possibility of slight lateral displacement, while in all other V-tests the pellet fill was confined between the rock slab and a wall of clay blocks. The figure shows the position of curves with the water contents 30, 50 and 70% and resembles the one for test V2 with the exception that water had tended to move both upwards and downwards, which can have been caused by such displacement. As in the other tests a horizontal channel to the outer vertical boundary was finally created. The correlation between pressure and nature of water movement is weaker than for test V3, but the irregular pressure pattern in the first minutes may have been associated with an initial flow of water upwards and downwards in the pellet fill parallel to the formation of a major horizontal channel that grew and finally reached the outer boundary causing the ultimate pressure drop.

2.4.3 Comments and discussion of the flow tests

The experiments gave important information on the wetting process of smectitic pellet fillings caused by water inflow from single spots in water saturated rock. The major findings were:

- None of the tests indicated channel flow and breakthrough of water along the rock/pellet contact.
- Inflow rates below and up to 0.1 l/min caused slow successive wetting of the fill close to the inflow spots and ultimately formation of channels oriented perpendicularly to the rock surface leading to discharge associated with erosion.
- Inflow rates higher than 0.1 l/min led to early formation of channels oriented perpendicularly to the rock surface leading to discharge associated with erosion.
- Tests with horizontally oriented rock/pellet contact ultimately gave water migration to the nearest edge of the box but the dominant water transport was through vertically oriented channels.
- Tests with vertically oriented rock/pellet contacts gave upward directed water transport towards the free upper surface of the fill but the dominant water transport was through horizontally oriented channels.

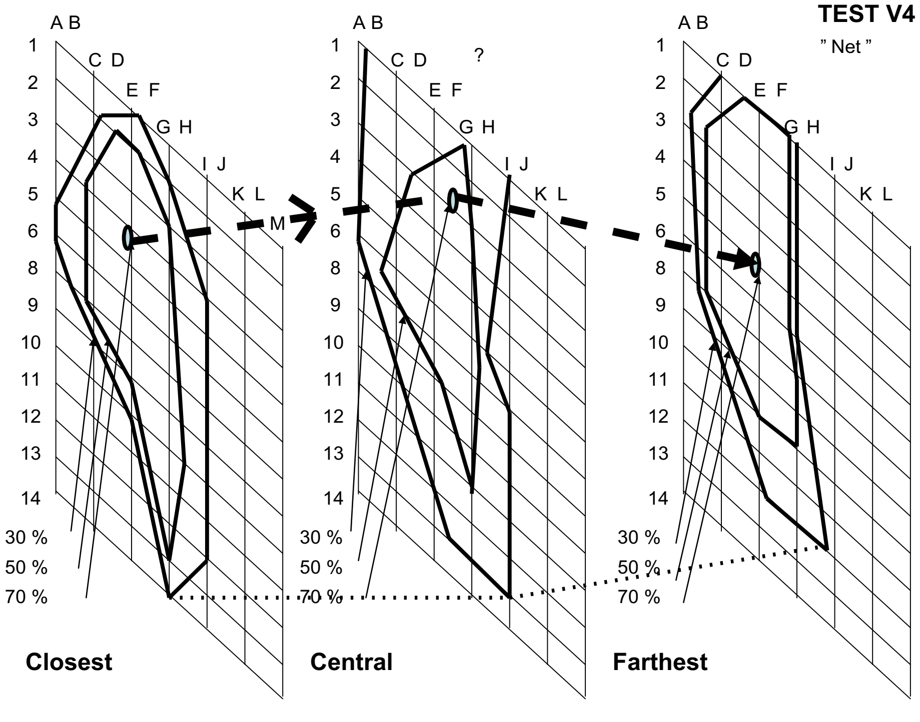


Figure 2-19. Distribution of the water content at three vertical planes with 50 mm spacing in test V4 with a water inflow of 0.1 l/min and the pellet fill confined in fiber net supported by a wooden construction. Water moved upwards and ultimately created a visible outflow spot but the water content determination indicates that the major water transport had the form of a horizontal channel extending from the rock surface to the central plane and further off to the outer boundary.

A first conclusion from the experiments is that the successive tightening of the pellet fill around the inflow spot will generate a rising water pressure that will ultimately cause breakthrough of water in the form of a channel directed towards the part of the fill that offers least resistance. It represents a free surface like the slope of the fill in the KBS-3V case, or a part where displacement of the fill can take place with least resistance e.g. the uppermost part of the fill in the KBS-3V case. This process takes place independently of the inflow rate but is believed to be slower and lead to higher pressure if it is low.

A second conclusion is that the tightening of the fill around the inflow spot is supported and speeded up if the rock is water saturated, thereby reducing the risk of early formation of channels along the rock/fill contact. This phenomenon was observed in the large-scale BACLO tests with steel tunnels at the Äspö laboratory and associated experiments (Dixon et al. 2008a, b). A third conclusion is that the water pressure at the inflow spot can be low for two reasons: 1) the water uptake is so slow that water is sucked up by the fill quicker than it enters from the inflow spot, 2) the water forms a breakthrough channel so quickly that water is discharged from it without resistance. An obvious consequence of the various processes is that the rate of backfilling of pellets determines whether channelling, i.e. “piping”, and erosion will take place.

Taking all the results into consideration it is believed that the number and spacing of water inlets over a given rock surface must be an important parameter. Thus, the character and location of inflow spots, all appearing in fractures, are believed to have great impact on the wetting process and on the risk of build-up of critically high pressures. We will examine this matter in the subsequent chapter from engineering points of view and take it as a basis of outlining ways of modelling the wetting process on full scale.

3 Water conduction in rock

3.1 Structural categorization

For our purpose a categorization scheme for discontinuities like faults, fractures and fissures is helpful and we will use the one in Table 3-1. Most of the discontinuities of 3rd and higher orders, i.e. finer weaknesses, cannot be seen until construction of the repository is occurring and one can identify those of 3rd, 4th, 5th 6th orders. Consideration of the hydraulic interaction of smectitic pellet fills and rock primarily concerns the three last mentioned features.

Table 3-1. Categorization scheme for rock discontinuities[3] (Pusch 1995).

Geometry				**Characteristic properties**		
Order	Length, m	Spacing, m	Width, m	Hydraulic conductivity	Gouge content	Shear strength
Low-order (conductivity and strength refer to the resp. discontinuity as a whole)						
1st	> E4	> E3	> E2	Very high to medium	High	Very low
2nd	E3–E4	E2–E3	E1–E2	High to medium	High to medium	Low
3rd	E2–E3	E1–E2	E0–E1	Medium	Medium to low	Medium to high
High-order (conductivity and strength refer to bulk rock with no discontinuities of lower order)						
4th	E1–E2	E0–E1	< E-2	Low to medium	Very low	Medium to high
5th	E0–E1	E-1 to E0	< E-3	Low	None	High
6th	E-1 to E0	E-2 to E-1	< E-4	Very low	None	Very high
7th	< E-1	< E-2	< E-5	None	None	Very high

E denotes the log scale exponent, i.e. E4=10,000, E1=10, E-2=0.01 etc.

A generalized structural model that contains low-and high-order discontinuities is shown in Figure 3-1. One recognizes a major discontinuity (1st order) that can represent the weaknesses in which big rivers have eroded valleys to large depths, a few 2nd – and 3rd-order fracture zones, and a system of more or less interacting 4th order fractures. In the little block with 5 to 50 m edge length, 5th order discontinuities form a sub-system in the network of those of 4th order. Geometrically, the various discontinuities form fractal-like patterns but the different categories have quite different mechanical and hydraulic properties. A long tunnel or drift excavated in common rock can be located so that 1st and 2nd order discontinuities – larger fracture zones – can be avoided while it is virtually impossible to avoid intersection by those of 3rd order. 4th order features, i.e. discrete water-bearing fractures, will intersect such openings with a frequency of one per 2–20 m tunnel length and are the ones that give off sufficiently much water to the pellet fills to cause piping and erosion. Smaller ones, i.e. those of 5th and higher orders have limited persistence and carry some but small amounts of water. The smallest ones provide water by capillary action that keeps the rock surface moist at normal ventilation. At effective ventilation these little fissures desiccate, which makes the rock surface look dry. Their hydraulic performance was a key issue in the present study.

---

[3] A structural feature identified in nature is termed according to what can be observed and quantified and that it may well be a component of a structural component of lower order, i.e. a larger structural element.

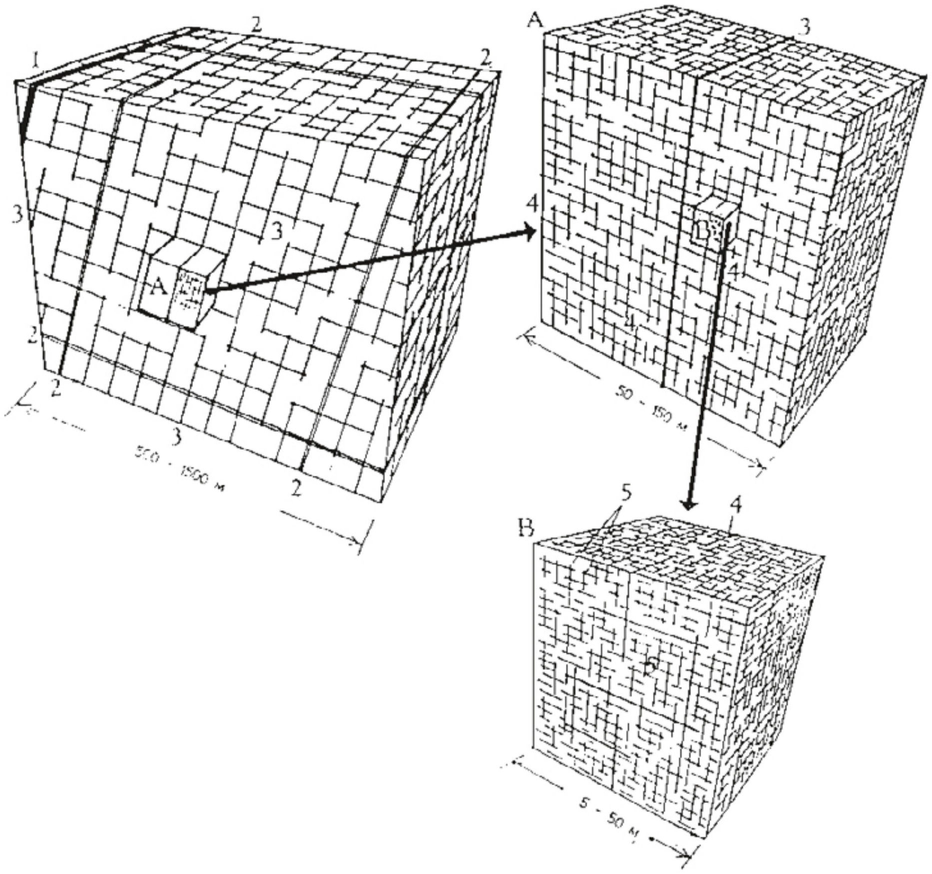


Figure 3-1. *Generalized rock structure model for crystalline rock. 1) Very large permeable fracture zone representing 1st order discontinuities, 2) Major fracture zones representing 2nd order discontinuities, 3) Minor fracture zones representing 3rd order discontinuities, 4) Persistent permeable fractures representing 4th order discontinuities, 5) Minor fractures representing 5th order discontinuities. 6th and 7th order discontinuities are represented in large to very large numbers between those of 5th order (Pusch 2008).*

3.2 Nature of "wet spots" in rock walls

3.2.1 Inflow from fractures

We will distinguish here between structural features that dominate water inflow in KBS-3V tunnels and drifts and those that bring in little water, predominantly by capillary effects. Those of 4th order type (Figure 3-2) commonly represent discrete straight planar features although they have commonly a complex nature. The actual spacing varies and comprehensive experience from grouting projects have consistently demonstrated that sealing of a permeable fracture or parts thereof directs inflowing water to not yet sealed features that are hydraulically interacting with the sealed ones. The detailed geometry of the water-bearing fractures is therefore not of importance with the exception of a special case namely inflow spots represented by crossings of water-bearing fractures (Figure 3-3).

3.2.2 Migration from the crystal matrix

The structural features that provide a sufficient amount of water to keep the rock surface moist in normally ventilated tunnels and drifts are those termed 5th and 6th order discontinuities here. The former are easily activated by blasting and dominate the EDZ while the latter, the finer ones, form a stable network that is responsible for gas penetration, ion migration and capillary transport of water (Pusch 2008). Figure 3-4 shows examples of the latter indicating that they have a persistence of a few tens of millimetres and apertures ranging from a few micrometers to a few tens of micrometers. They play a major role in cutting and treating rock in the stone industry.

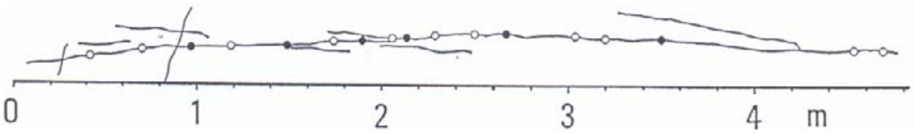


Figure 3-2. *Typical appearance of discrete water-bearing fracture of 4th order. It is slightly winding and contains bifurcations and splay fractures.*

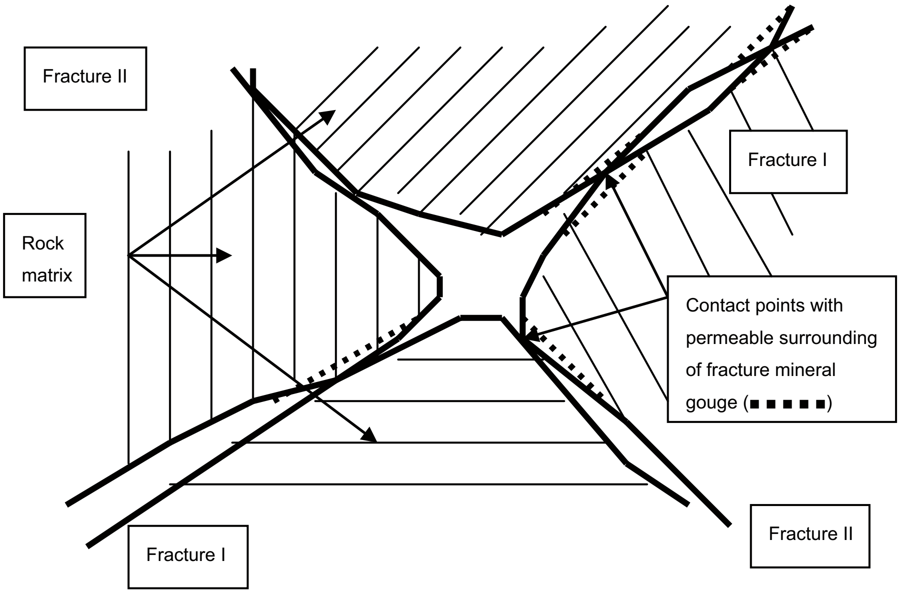
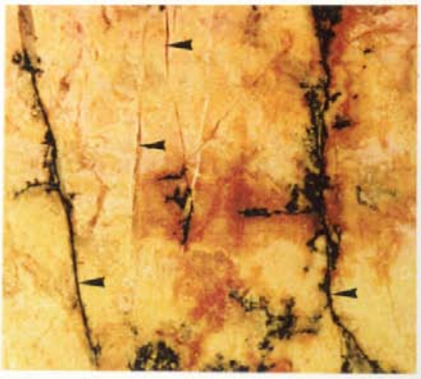
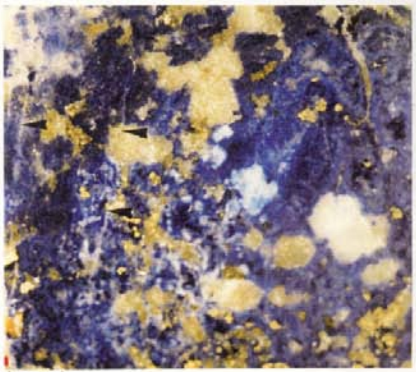


Figure 3-3. *Crossing of fractures with contact points and open space around them.*



Rhodonite



Lazurite

Pegmatite

Figure 3-4. *Examples of discontinuities of 6th order. They are embryonic "dislocations" serving as effective ion diffusion paths and are responsible for the hydraulic and gas conductivities of the crystal matrix (Pusch 2008).*

3.3 Distribution of “wet spots” in rock walls

The complexity of the rock structure is obvious from any attempt to work out detailed physical models but the traditional plots of discontinuities using Schmidt net graphics gives evidence of preferred orientation of major sets of discontinuities. Comparison of plottings of the orientation of 4th order discontinuities and of those of 5th order of the same crystalline rock mass indicates that the latter are more randomly distributed and oriented than the firstmentioned (Pusch 1995). This trend is even more obvious for smaller features suggesting that the rock can be generalized as a porous medium with 5th and higher order discontinuities representing transport paths on the microscopic scale that is superimposed by a system of more or less regularly grouped and oriented plane discontinuities of 4th order containing rows of inflow spots. This yields a wet spot pattern of the type shown in Figure 3-5 showing wet spots along 4th order discontinuities, particularly where they intersect, and wet spots in the form of capillary apertures along 5th and 6th order discontinuities. The latter two categories make up the “porous medium” while the 4th order discontinuities have visible inflow spots.

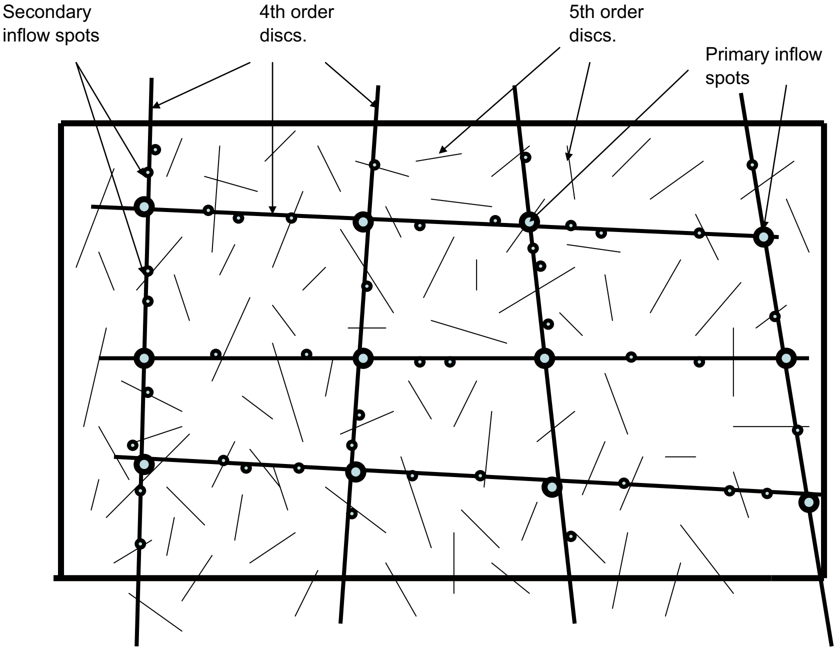


***Figure 3-5.** Schematic picture of a rock surface with visible inflow (“primary” inflow spots) in 4th order discontinuities, and 5th order discontinuities representing secondary inflow spots that dominate the EDZ. 6th order discontinuities form a tight network in the entire area and provide water by capillary action.*

4 Conceptual model of the wetting of smectitic pellet fills

4.1 Mechanisms

4.1.1 The two issues

We will consider two conditions for wetting of smectitic pellet fills here: 1) water migration from rock fractures representing 4th order discontinuities and 2) water uptake from the fine capillaries represented by 5th and 6th order discontinuities, which keep the rock surface moist in normally or poorly ventilated tunnels and drifts.

4.1.2 Water migration along the contact of rock and pellet fill

The rock matrix contains numerous fine fissures and voids that contribute very little to the overall hydraulic conductivity of the rock but lets water through to an extent that is concluded to be important for the wetting of the pellet fill. The conditions at the rock/pellet contact can either be that the rock surface is dry because of effective ventilation or kept moist, which have different impacts on the wetting of the pellet fill. Thus, early wetting of the pellets around the inflow spot may make them hydrate and seal off the contact (Figure 4-1) while dry pellets offer easy channelling along the rock/pellet contact. The matter is discussed in the subsequent chapter referring to the outcome of performed tests.

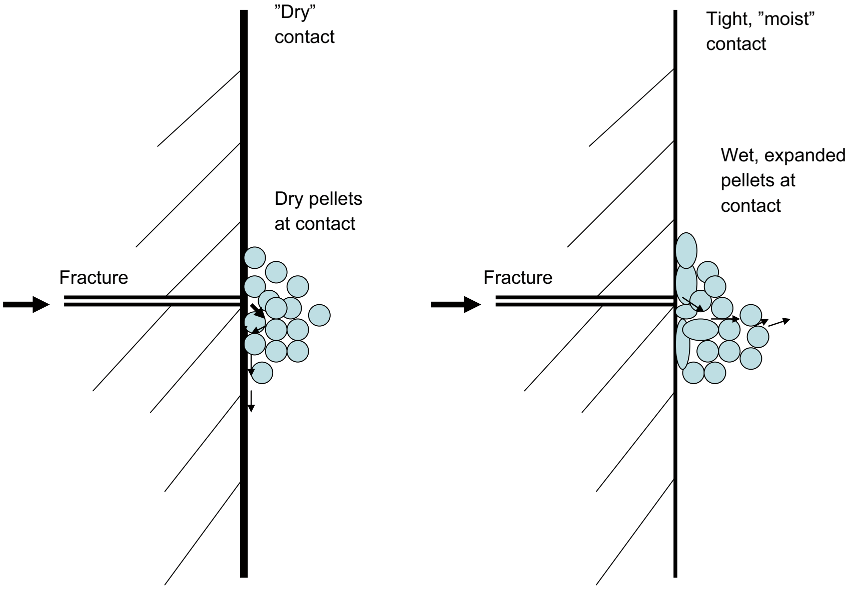


Figure 4-1. *Water inflow from a water-bearing 4th order fracture of at a “dry” pellet/rock contact (left), and at a moist contact where wetted pellets create a tight skin directing inflowing water into the fill in the normal direction (right).*

4.1.3 Water migration from inflow spots into pellet fills

The case considered here is a backfill consisting of a block masonry isolated from the rock by a pellet filling (Figure 1-1) that becomes hydrated by water entering the fill spot-wise from water-bearing fractures of 4th order. Simplifying the microstructure of the pellet fill to consist of regularly stacked cylinders in contact with each other the following conceptual model of wetting by inflowing water is proposed:

- Water entering the fill follows the path that offers least flow resistance.
- The driving force for continued penetration is threefold: a) water pressure, b) gravity, c) capillary suction.
- For low pressures the wetting of the contacting pellet fill is controlled by capillary suction yielding surface diffusion along the pellet surfaces, associated with expansion of the pellets and release of minute particle aggregates that form clay gels that tighten the voids between the pellets. When the degree of saturation rises the pressure also goes up.
- For higher water pressure the wetting is dominated by inflow through a channel that widens if the water pressure is high enough to overcome the pressure acting between the pellets. Almost all water flows in the wide channel under the influence of gravity causing downward migration of the water.

Figure 4-2 shows the case with very low pressure. The water produces a small hydraulic wedge that stagnates by being blocked by the expanding pellets around it. Many more small wedges are formed in different directions and they all soon stop growing because of the tightness of the expanding pellets surrounding them. The water pressure is thereby raised, which makes the wedge with least resistance develop and propagate as indicated in Figure 4-3. One can therefore expect that the high-pressure case evolves independently of the inflow rate.

Figure 4-3 shows the case with high water pressure generating a propagating hydraulic wedge that displaces pellets and wets them by which they expand and form a tube-like channel that continues to propagate if the inflow is high enough to maintain a sufficiently high pressure at its tip. Gravity will tend to direct the channels downwards leading penetrating water to the lowest part of the sloping front of the pellet fill. Wetting of the pellets confining the channel takes place by diffusive migration of water, which makes the channel walls successively tighter. This means that all water entering from an inflow spot is forced through one main channel that becomes eroded and widened. It will not self-heal until the water pressure at its tip has dropped below the critical value for driving the channel forwards.

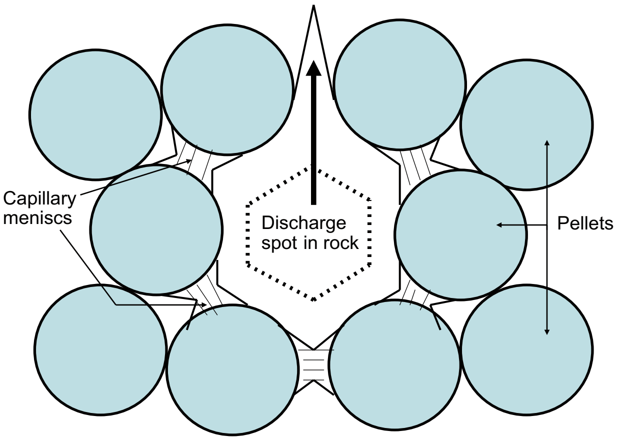


Figure 4-2. First phase of wetting of the pellet fill at low water pressure.

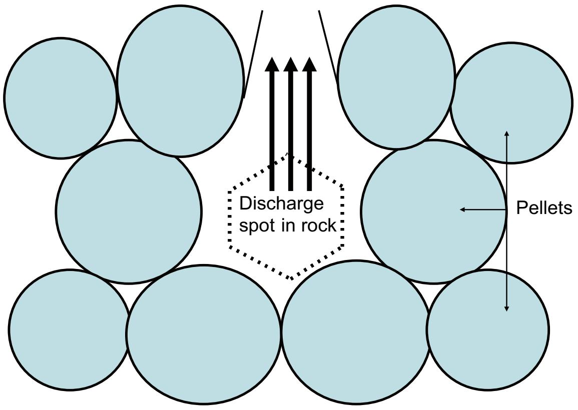


Figure 4-3. *First phase of wetting of the pellet fill at high water pressure.*

One can roughly estimate the critical water pressure for forming a large channel by displacing pellets in the surrounding non-saturated fill. Thus, in vertical direction of the tunnel in Figure 1-1, the pressure must exceed the "effective" pellet pressure $h \text{x} \rho_p$, where h the height of the pellet fill above the inflow spot, and ρ_p the density[4] of the fill. The latter is about 1,000 kg/m^3 and since h is 0 at the roof and 5 m at the floor of the tunnel, the water pressure required to create a wide channel would be about zero at the roof and 50 kPa at the floor. The channel would tend to be oriented upwards, where the resistance to displace pellets is lowest and since the pellet fill will initially not be in contact with the tunnel roof, upward displacement of the fill is most probable and hence also upward growth of the wide channel. However, two conditions can change this: 1) where the distance from the inflow spot to the free slope of the pellet fill is shorter than the distance between the spot and the roof or the block masonry, the channel will turn and be directed towards the slope surface or into the block masonry; 2) gravity will tend to make water in the wide channel flow downwards, directing the channel in the same way.

---

[4] The density of the pellet fill with its original water content, which can be in the interval 8–15%.

5 Implementation of the conceptual model on performed tests

5.1 Cases considered

One concludes from the description of rock structure that the rock matrix contains numerous fine fissures that contribute very little to the overall hydraulic conductivity of the rock but let water through to an extent that may be important for the wetting of the pellet fill. The major part of the inflow is through the primary and secondary inflow spots at crossings of 4th order discontinuities and along them. It can have the form of penetration into the pellet fill normal to the rock/pellet contact or along this contact. Experiments that simulate the conditions in a dry KBS-3V tunnel have been performed in the BACLO project at the Äspö laboratory and they therefore make up one case to be considered. Another case is represented by the tests dealing with the wetting of pellet fills in contact with water saturated rock described in this report.

5.2 BACLO experiments

The ½-tunnel scale BACLO experiments described by Dixon et al. (2008b) were made for investigating the impact of inflowing water on backfill consisting of masonries of compacted blocks of Friedland clay surrounded by blown-in pellets according to the design principle shown in Figure 1-1[5]. The rock was simulated by a 5 m long tunnel segment made of steel with nozzles installed at different points for letting water in. The outcome of the experiments, which involved injection of Äspö water at constant rates ranging between 0.1 and 2.5 l/min, was that wetting was initially through channelling along the steel/pellet contact from where water migrated in different directions into the pellet fills. Channelling leading to breakthrough and outflow at the free surface of the sloping pellet fill occurred in a few hours for the highest inflow rates and in a few days for the lowest. The general trend of water migration in pellet fills was as illustrated in Figure 5-1.

5.3 Bench-scale tests

Tests by small scale simulation of the KBS-3V case with pellets filled in a plexiglass box with a height of about 1 meter and considerably smaller width and with nozzles installed at different points have indicated the same general trend of water migration as in the BACLO experiments[6]. The use of plexiglass means that the hydraulic interaction of rock and pellet fill could not be simulated and it is hence concluded that the surrounding rock and its microstructure can have a very substantial effect on the manner in which water moves into or through a pellet-filled region in the period immediately following pellet placement.

---

[5] *(SKB-08-132).*

[6] *(SKB R-09-52).*

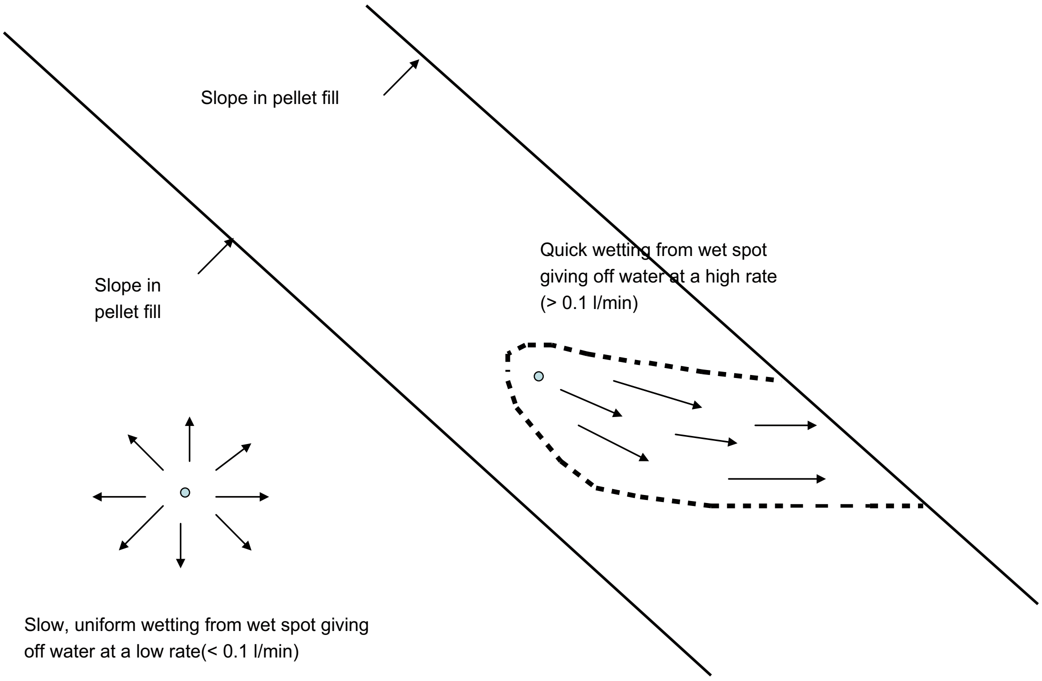


Figure 5-1. *Interpretation of bench-scale experiments implying early wetting at spot-wise inflow in a pellet fill placed from left to right with the moving front represented by the two inclined lines. Left: Uniform diffusive wetting of the pellet fill for inflow rates < 0.1 l/min. Right: Rapid wetting by quick inflow and channel formation.*

5.4 Rock/pellet experiments

The results from the rock/pellet experiments described in the present report agree very well with the proposed conceptual model by showing that:

- pellets in contact with initially water saturated rock hydrate immediately and thereby form a tight skin that seals off the inflow spot from the surrounding fill and causes further wetting to take place by migration of water more or less perpendicularly to the rock surface with the possible exception of cases with very high inflow rates,
- once “piping” has occurred, the majority of the water entering the tunnel in the vicinity of the channel is directed to it, which means that the channelled flow can be high. This also means that subsequent material erosion can result in substantial loss of the density of the pellet filled region,
- the successive tightening of the pellet fill around the inflow spot will generate a rising water pressure that ultimately causes breakthrough of water in the from of a channel. It is directed towards the part of the fill that offers least resistance, represented by a free surface like the slope of the fill in the KBS-3V case (Figure 5-1), or a part where displacement of the fill can take place with least resistance e.g. the uppermost part of the fill in the KBS-3V case. This process takes place independently of the inflow rate but is slower and leads to higher pressure if it is low.

6 Conclusions

Backfilling of blasted tunnels in a KBS-3V repository can be made under "dry" (ventilated) or "moist" conditions. Real conditions implying moist rock and simulated in the rock/pellet tests described in the present report imply tightening of the contact between rock and pellet fill and penetration of water from discrete significantly water-bearing fractures more or less perpendicularly to the rock surface into the pellet fill. The successively increased water pressure creates channels that become oriented towards existing nearby free surfaces or low density parts of the fill. For KBS-3V it would represent the conditions in Figure 7-1. The practical consequence of this is that the rate of backfilling, i.e. the speed with which the slope is moved forward, determines the risk of piping and erosion.

The processes can be summarized as follows:

- Uniform "diffusive"- type wetting takes place if the capacity of the pellet fill to sorb water from a fracture is higher than the inflow rate. Test H4 did not give piping for an inflow rate of 0.1 l/min while V2, V3 and V4 showed initiation of piping at this inflow rate. This value appears to indicate the conditions for piping in the earliest hydration phase but the successive pressure rize by continued inflow will, however, create channelling.
- At high inflow or when the degree of water saturation of the fill around the inflow spot has become high, the water pressure will rise and a channel is formed that will widen due to the rising water pressure and become a major flow path ("piping"). It will appear irrespective of the inflow rate and irrespective of whether the backfilling has advanced far form the inflow spot or not. For the case with the pellet backfill confined between tunnel plugs, inflow of water will still create systems of finger-like channels leading to non-homogeneous conditions. However, for the KBS-3V case the successive water saturation of the block masonry will make it expand and consolidate the pellet fill by which the homogeneity will be substantially increased.
- For the case with a free slope of the pellet fill the time for breakthrough will be long, i.e. days, for small inflow rates (< 0.1 l/min) and short, i.e. hours, for higher inflows.

In practice, water will enter the fills from several points depending on the build-up of pressures and flow in the respective rock discontinuities. Understanding, modelling and prediction of the wetting of fills by water entering from a larger rock surface, as a tunnel wall, needs full scale testing for providing information that is needed for modelling the hydro/structural constitution of the rock and the distribution of inflowing water of the type indicated in Figure 3-5. A first attempt to relate the inflow spot frequency to the average hydraulic conductivity of virgin and blasted rock with one hundred times more spots in 2D is shown in Table 6-1 for a circular tunnel with 5 m diameter, demonstrating that the dispersion of inflowing water in blasted tunnels gives much lower inflow rate per spot compared to TBM tunnels. Taking an inflow of 0.1 l/min to be sufficiently low to make pellet backfilling possible it would work for blasted tunnels in virgin rock with a conductivity of E-8 m/s while it would not be possible for a TBM tunnel (10 l/min).

The integrated wetting over a larger rock surface also requires that the hydraulic function of the block masonries in the tunnels is taken into consideration since water migration from the rock into the fill will imply that the channels reach the block assemblies and cause redistribution of water by the suction and expansion of the blocks. This will greatly affect the maturation of the pellet and block fills and the homogeneity of these components.

Table 6-1. Calculated inflow per inflow spot (channel) assuming a hydraulic gradient of 100.

Average *K* of virgin rock, m/s	Inflow in tunnel per meter tunnel length, l/m,min	Number of channels per meter tunnel length in virgin rock	Inflow in tunnel per channel, l/min	Inflow in blasted tunnel per channel in EDZ, l/min
E-11	0.01	1	0.01	0.0001
E-11	0.01	5	0.002	0.00002
E-11	0.01	10	0.001	0.00001
E-10	0.1	1	0.1	0.001
E-10	0.1	5	0.02	0.0002
E-10	0.1	10	0.01	0.0001
E-9	1.0	1	1	0.01
E-9	1.0	5	0.2	0.002
E-9	1.0	10	0.1	0.001
E-8	10	1	10	0.1
E-8	10	5	2	0.02
E-8	10	10	1	0.01
E-7	100	1	100	1
E-7	100	5	20	0.2
E-7	100	10	10	0.1
E-6	1,000	1	1,000	10
E-6	1,000	5	200	2
E-6	1,000	10	100	1

7 Recommendations

While the mechanisms of water entering the pellet fills from separate local fractures in contacting rock in the blasted tunnels of a KBS-3V repository are largely understood, prediction of the entire wetting process of a larger pellet mass requires consideration of the interactive function of several inflow spots, representing a system of rock fractures. Experiments with simultaneous, equally high inflow in several spots connected by a permeable ribbon for simulating a water-bearing fracture are being conducted in the aforementioned steel tunnel at Äspö for investigating the integrated function of several inflow spots and they will provide further information on the wetting process. However, the conditions in real rock where the impact of channelling along the contact of the confinement and the pellets is considerably smaller according to the outcome of the tests described in this report, must form the basis of any attempt to perform large-scale modelling of the wetting and homogenization of pellet fills.

Conduction of full-scale experiments with pellet/block backfills in blasted or bored tunnels representing 3D conditions for investigating the integrated wetting process will require very long time and cause difficulties in evaluation because of the complex interaction of rock and initially heterogeneous pellet/block backfill. It is therefore recommended that such tests be preceded by a large-scale version of the rock/pellet experiments in 2D with the form indicated in Figure 7-1. Prior to the placement of pellets and blocks the natural inflow of the space to be filled is determined by ventilation or desiccation tests performed by LBL[7] (Gale and Witherspoon 1978). The possible need for sawing and sealing slots normal to the rock surface around the tested rock volume has to be investigated.

No water is added artificially so the wetting of the pellets and blocks is controlled by the hydro/structure of the shallow rock. Instrumentation for recording the water pressure in the rock is arranged but determination of the distribution of the water content and the impact on the homogeneity of the filling by channelling is made in conjunction with comprehensive excavation and sampling at the end of the test.

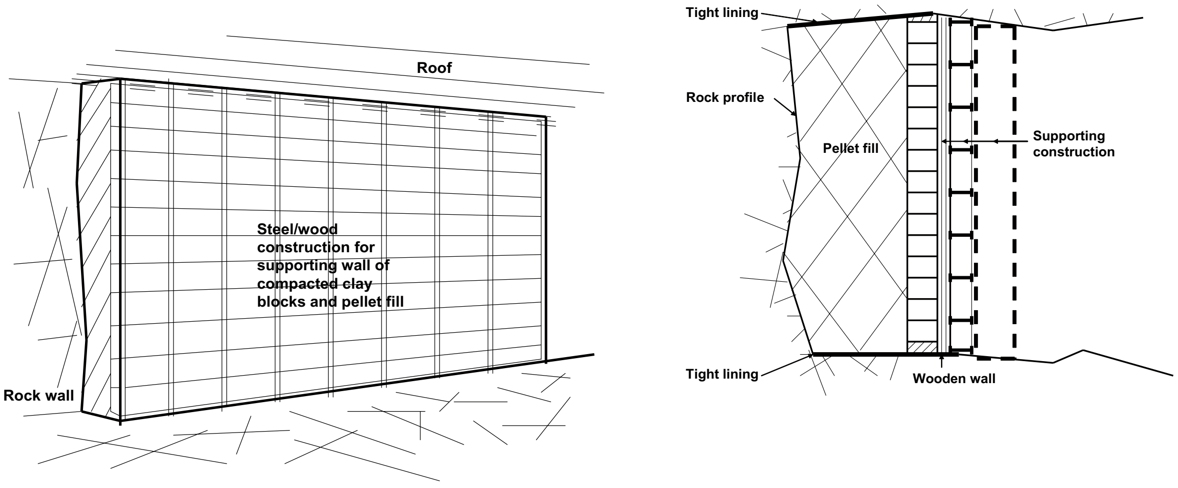


Figure 7-1. Schematic illustration of "2D" test representing a large-scale version of the rock/pellet tests described in the present report.

---

[7] Lawrence Berkeley Laboratory.

References

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

Dixon D, Lundin C, Örtendahl E, Hedin M, Ramqvist, 2008a. Deep repository – engineered barrier systems. Half scale tests to examine water uptake by bentonite pellets in a block-pellet backfill system. SKB R-08-132, Svensk Kärnbränslehantering AB.

Dixon D, Anttila S, Viitanen M, Keto P, 2008b. Tests to determine water uptake behaviour of tunnel backfill. SKB R-08-134, Svensk Kärnbränslehantering AB.

Karnland O, Olsson S, Nilsson U, 2006. Mineralogy and sealing properties of various bentonites and smectite-rich clay minerals. SKB TR-06-30, Svensk Kärnbränslehantering AB.

Pusch R, 1995. Rock mechanics on a geological base. Amsterdam: Elsevier. (Developments in geotechnical engineering 77).

Pusch R, 2008. Geological storage of highly radioactive waste: current concepts and plans for radioactive waste disposal. Berlin: Springer.

Gale J, Witherspoon P A, 1978. An approach to the fracture hydrology at Stripa: preliminary results. Proceedings of the Seminar on in situ heating experiments in geological formations, Ludvika, Sweden, 13–15 September 1978. Paris: OECD, 161–175.

Appendix 1

PM

2012-03-21

Torbjörn Sandén
Ola Karnland
Clay Technology AB

Limited mineralogical investigation of Cebogel QSE

Background

Pellets made of a sodium activated bentonite, Cebogel QSE, have been used in several large scale tests performed at Äspö HRL. In order to check that the material data provided from the manufacturer is correct, see Appendix 1, a limited mineralogical investigation has been made. The following analyses were performed:

- X-ray diffraction analysis.
- Element analysis.
- Exchangeable cation analysis.

X-ray diffraction analysis (XRD)

The mineralogical composition of the material was evaluated from the XRD diffractograms by use of the Siroquant quantitative XRD software. The method is described in detail in /Karnland et al. 2006/. The results from the quantitative analysis are provided in Table 2-1.

Table A1-1. Results from the Siroquant analyses of the Cebogel QSE bentonite.

#	ID	Phase	Weight%	Error of Fit
1	8137	Montmorillonite, (CP)	90	0.9
2	1	Quartz	1.4	0.4
3	37	Cristobalite	0.7	0.1
4	10	Calcite 1	3.6	0.4
5	31	Dolomite	3.1	0.6
6	29	Pyrite	1.1	0.1

Element analyze

The bulk material was analyzed for major elements using standard ICP-AES technique at an ISO 9002 accredited laboratory (Acme Analytical Labs). Loss of ignition (LOI) was determined gravimetrically by ignition to 1,000°C. The results are provided in Table 3-1.

Table A1-2. The chemical composition expressed as weight percent of major oxides of the bulk material.

SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LOI	C	S	Sum
52.3	16.9	5.0	3.8	4.9	3.6	0.6	0.7	0.1	11.7	1.5	0.4	99.8

Exchangeable cations, EC

The composition of extractable cations was determined by exchange against ammonium ions in an alcoholic solution. The method is described in detail in /Karnland et al. 2006/. The investigation included one duplicate. The results are provided in Table 6-1.

Table A1-3. Table showing the distribution of exchangeable ions in the bulk material.

	Ca %	K %	Mg %	Na %
Cebogel 1	5.2	1.8	2.6	90
Cebogel 2	6.2	1.9	2.6	89

Conclusions

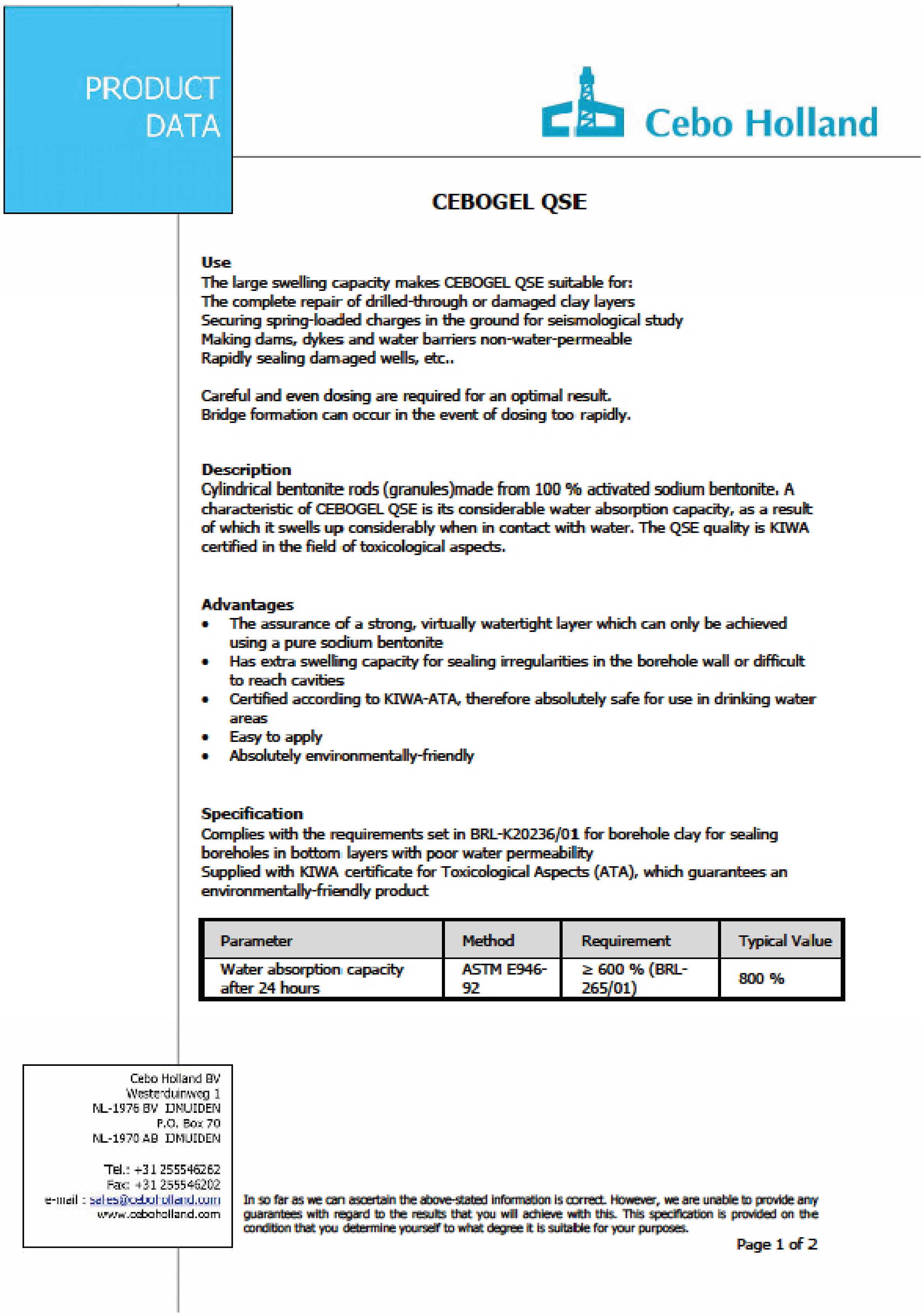
In the manufacturer's data sheet regarding Cebogel QSE, a typical value of the montmorillonite content is declared to be 80%. The results from the performed XRD analyze gives a montmorillonite content of 90% (which is somewhat higher).

The results from the element analysis are typical for a bentonite with high content of montmorillonite.

The high sodium content detected in the EC-analyze, shows that the material is converted to a sodium state, as declared in the data sheet.

The results from the performed analyses are judged to be in fair agreement with the data provided in the data sheet for Cebogel QSE.

Appendix 2



PRODUCT DATA

Cebo Holland

CEBOGEL QSE

Use
The large swelling capacity makes CEBOGEL QSE suitable for:
The complete repair of drilled-through or damaged clay layers
Securing spring-loaded charges in the ground for seismological study
Making dams, dykes and water barriers non-water-permeable
Rapidly sealing damaged wells, etc..

Careful and even dosing are required for an optimal result.
Bridge formation can occur in the event of dosing too rapidly.

Description
Cylindrical bentonite rods (granules)made from 100 % activated sodium bentonite. A characteristic of CEBOGEL QSE is its considerable water absorption capacity, as a result of which it swells up considerably when in contact with water. The QSE quality is KIWA certified in the field of toxicological aspects.

Advantages

- The assurance of a strong, virtually watertight layer which can only be achieved using a pure sodium bentonite
- Has extra swelling capacity for sealing irregularities in the borehole wall or difficult to reach cavities
- Certified according to KIWA-ATA, therefore absolutely safe for use in drinking water areas
- Easy to apply
- Absolutely environmentally-friendly

Specification
Complies with the requirements set in BRL-K20236/01 for borehole clay for sealing boreholes in bottom layers with poor water permeability
Supplied with KIWA certificate for Toxicological Aspects (ATA), which guarantees an environmentally-friendly product

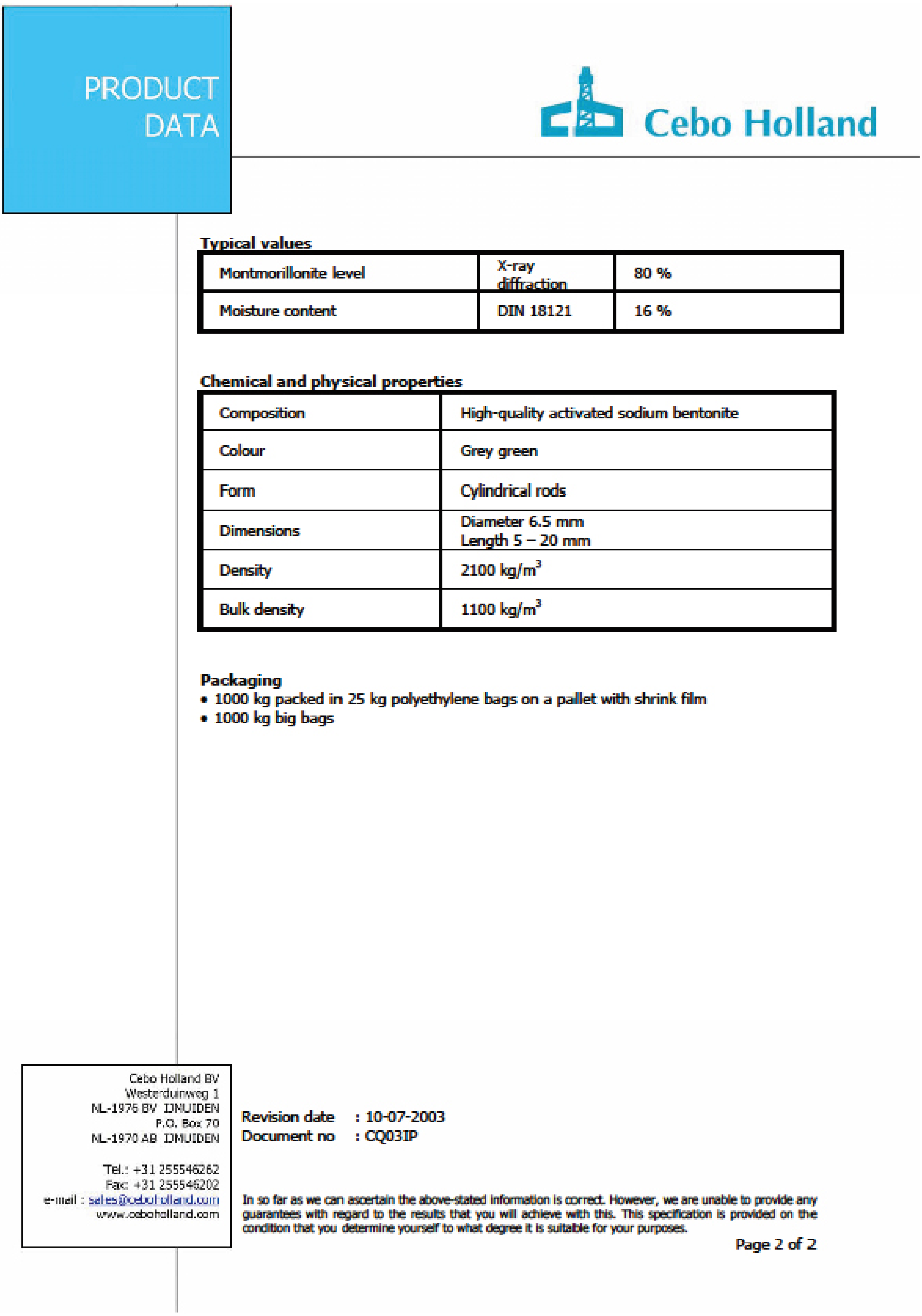
Parameter	Method	Requirement	Typical Value
Water absorption capacity after 24 hours	ASTM E946-92	≥ 600 % (BRL-265/01)	800 %

Cebo Holland BV
Westerduinweg 1
NL-1976 BV IJMUIDEN
P.O. Box 70
NL-1970 AB IJMUIDEN

Tel.: +31 255546262
Fax: +31 255546202
e-mail : sales@ceboholland.com
www.ceboholland.com

In so far as we can ascertain the above-stated information is correct. However, we are unable to provide any guarantees with regard to the results that you will achieve with this. This specification is provided on the condition that you determine yourself to what degree it is suitable for your purposes.

Page 1 of 2



PRODUCT
DATA

Cebo Holland

Typical values

Montmorillonite level	X-ray diffraction	80 %
Moisture content	DIN 18121	16 %

Chemical and physical properties

Composition	High-quality activated sodium bentonite
Colour	Grey green
Form	Cylindrical rods
Dimensions	Diameter 6.5 mm Length 5 – 20 mm
Density	2100 kg/m^3
Bulk density	1100 kg/m^3

Packaging
- 1000 kg packed in 25 kg polyethylene bags on a pallet with shrink film
- 1000 kg big bags

Cebo Holland BV
Westerduinweg 1
NL-1976 BV IJMUIDEN
P.O. Box 70
NL-1970 AB IJMUIDEN

Tel.: +31 255546262
Fax: +31 255546202
e-mail : sales@ceboholland.com
www.ceboholland.com

Revision date : 10-07-2003
Document no : CQ03IP