Inflow Handling During the Emplacement of the Backfill in the KBS-3 Concept – 14238

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ABSTRACT

The KBS-3 concept for the disposal of spent nuclear fuel (SNF) was developed in Sweden by SKB, and is also planned to be used in Finland by Posiva. In this concept the SNF is placed into deposition tunnels excavated at the depth of 400-700 m in crystalline bedrock. The SNF is encapsulated in copper canisters, placed in vertical deposition holes and surrounded with a buffer consisting of densely compacted, high quality bentonite. After the canisters and the buffer material have been installed, the deposition tunnels are backfilled with bentonite blocks and pellets.

The conditions placed on the method developed and tested during the project are that it shall remain functional as long as the deposition tunnel is open. The method's adverse effect on the long term safety of the repository should also be minimal.

The research project was divided into three parts:

1. Laboratory-scale tests.
2. Half-scale steel tunnel tests.
3. Fastening tests.

The purpose of the laboratory-scale tests was to verify the intended function of the geotextile fabrics to redistribute inflow water between the rock and the bentonite pellets. Based on the results of the laboratory-scale tests, a conventional polypropylene geotextile was used in the half-scale steel tunnel tests.

Three tests were done in the half- scale steel tunnel mockup:

- Reference test 0.25 l/min inflow, without geotextile.
- First test with geotextile: 0.25 l/min inflow.
- Second test with geotextile: 0.5 l/min inflow.

Tested fastening methods were: express nails; two different types of adhesives; and concrete.

INTRODUCTION

The KBS-3 concept (Figure 1) for the disposal of spent nuclear fuel (SNF) developed in Sweden by SKB is also planned to be used in Finland by Posiva. In this concept the SNF is placed in deposition tunnels excavated at the depth of 400-700 m in crystalline bedrock, although in both the SKB and the Posiva case the depth is 400-450m. The SNF is encapsulated in copper canisters, placed in vertical deposition holes and surrounded with a buffer consisting of high quality bentonite. After the canisters and the buffer material have been installed, the deposition tunnels are backfilled with bentonite blocks and pellets. The advantages of bentonite are its, swelling pressure, low water conductivity and its long-term chemical and mechanical stability.

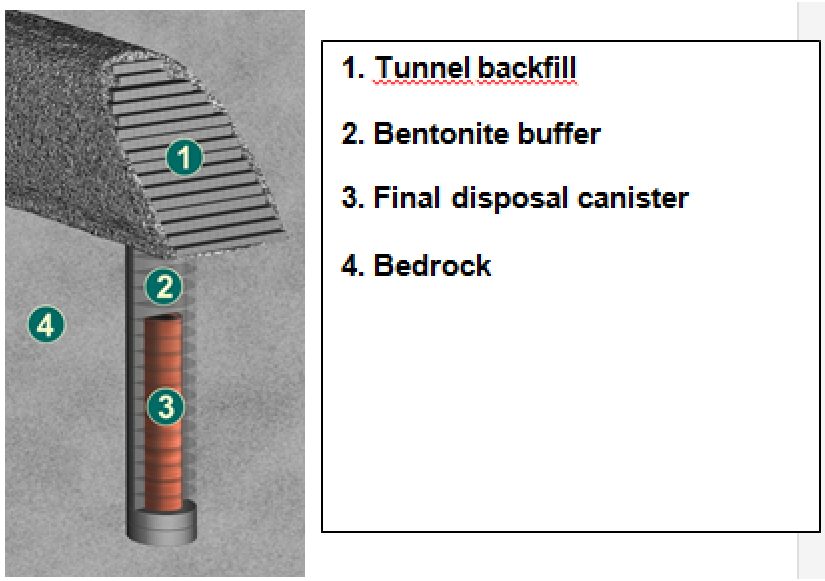

Fig. 1. KBS-3V concept schematic picture (Posiva).

This paper describes a research project regarding the use of geotextiles for redistribution of inflowing water during the installation of backfill. The objective of the research was to develop a technically feasible method to distribute inflow water more evenly in the backfill. This will allow more rapid saturation of the bentonite backfill and increase the flexibility of the backfill installation timing in case of a machine failure.

Background

The main alternative for the backfill design considered by both SKB and Posiva includes emplacement of pre-compacted blocks into most of the tunnel volume together with bentonite pellets that are filling up the spaces between blocks and tunnel walls. Pellets will also be placed on the tunnel floor in the SKB concept, while Posiva is planning for an in situ compacted flooring layer, in order to even out the rough rock surface and thereby provide a suitable surface upon which the backfill blocks can be piled. The installation of such a backfill system includes a lot of challenges e.g. advanced technical solutions are needed for an automation of block transports, piling of blocks, emplacement of pellets etc. One of the main issues identified is how the water inflow to the tunnels should be handled during emplacement. Depending on the flow rates and how the inflow points are distributed in the tunnel, the inflowing water may affect the stability of the backfill installation and also cause erosion of the backfill.

Earlier tests performed at different scales, e.g. [1 - 3], have shown that the bentonite pellet filling has the potential to store a large quantity of water. Tests have also been made in order to optimize this property of the pellet filling. Furthermore, the tests have shown that even if the storing capacity of the pellet filling is large, there still will be large pellet volumes that will remain dry during the time immediately following backfill placement and so not provide water storage volume during this period. Several alternatives have been proposed to improve early water storage in the pellet fill and the idea showing greatest promise is to distribute the inflowing water over a larger contact area by use of geotextiles.

Other possible methods to collect or redistribute inflowing water were considered, such as glass and steel pipes to lead water out of the backfill, and other fabric materials such as basalt fiber and Kevlar. However, all of the other possibilities were discarded because of high price and low availability or potentially adverse long term safety effects.

MATERIALS AND METHODS

Two different bentonites were used. In the short tests like these the bentonite material is not significant factor. Different types of bentonite materials used in the tests are shown in Table I.

TABLE I. Clay materials used in the tests.

Clay material	Laboratory scale tests	Steel tunnel tests
IBECO RWC BF pellets	Extruded, 6 mm diameter	-
Asha NW BFL-L blocks	-	Used
Asha NW BFL-L pellets	-	Extruded, 6 mm diameter

Laboratory Scale Tests

The aim with the laboratory tests was to test three preselected geotextile materials and to evaluate their function as a water distributor before testing at larger scale. The geotextile types were:

1. A typical polypropylene geotextile, *Fibertex F-1000M/Fibertex F-1000M White.*
2. A "thin" glass fiber geotextile.
3. An Insulation type glass fiber textile, *Needle mat AF800-6.*

The test equipment used consists of a Plexiglass tube which can be filled with pellets, see photo provided in Figure 2. In both ends perforated steel plates are mounted in order to keep the pellets in position but still allow water to leak out. At the mid height it is possible to apply a water flow on the wall. The tests can be performed with the pure pellet filling but it is also possible to place a piece of geotextile over the inflow point. The Plexiglass makes it possible to study the wetting behaviour from the outside of the tube. Tests have been performed both with vertical standing tubes, simulating a wall inflow, but also with horizontal laying tubes simulating the case with ceiling inflows.

The tests were performed by applying a constant flow at the inflow point. The water pressure needed in order to keep the water flow constant was measured during the test time. In addition, the wetting front of the pellet filling was studied from the outside. Photos were taken at predetermined intervals.

Fig. 2. Picture showing the test equipment used in order to study the function of geotextiles as water distributer.

Steel Tunnel Tests

The objective of the ½-scale steel tunnel tests was to verify and demonstrate the functionality of the inflow handling system. The functionality of the geotextiles was tested in laboratory scale, before the ½-scale tests started. Since the ½-scale steel tunnel tests are time consuming (4-5 weeks/test) and therefore more expensive, only the most suitable components from the laboratory scale were tested. Due to the poor availability of the glass fiber based geotextiles and the desire to finish the tests before the end of the year 2012, the polypropylene geotextile was selected for the ½-scale steel tunnel tests

The test tunnel in the Äspö bentonite laboratory is made of steel. Its nominal cross section is 7.1 m^2, and the usable length for the tests is 4 m. The tunnel walls are not able to withstand the full swelling pressure of the fully backfilled tunnel. Therefore, instead of backfill in the centre of the tunnel, there was a wooden framework designed to deform and fail mechanically, if the swelling pressures become too high. The wooden frame was covered with a bentonite geotextile mat to control the movement of any water that penetrated both the pellet and block materials. The blocks were mounted two layers deep (300 mm thickness) against the inner frame. The gap between the blocks and the wall (about 150 mm) was filled with bentonite pellets.

The water used in the tests had 1% salinity (TDS 10 g/l), half of the salt in the water is Ca^{2+} and the other half is in Na^+. The purpose of using this mixture was to mimic the salt content in the repository conditions at the time of its operation.

The salt was mixed into fresh water in big tanks. Special metering pumps were used in order to pump water at a determined flow rate into the selected inflow point on the wall of the steel tunnel, see Figure 3. In the tests, only one inflow point was used (the red dot in Figure 3). The geotextile was placed over the inflow point and then the whole way up to the roof and down into the other side of the tunnel. This design made it possible to study how well the inflowing water can be distributed also to the other side by the geotextile.

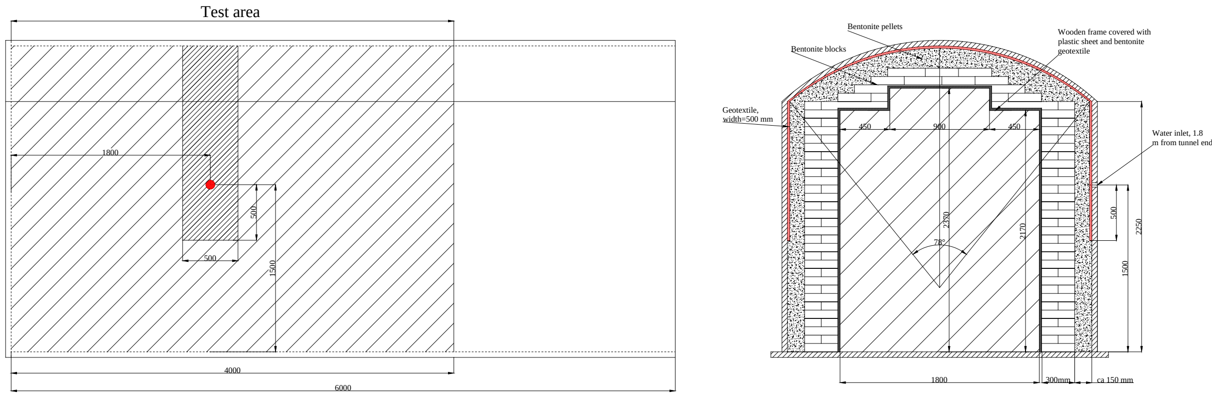

Fig. 3. Schematic of the ½-scale steel test tunnel.[2]

In order to evaluate the water storing capacity, the difference between the inflow and outflow water volume was measured. Also the time to the first outflow was recorded. These are the simplest and most reliable measurements to determine the functionality of the geotextile.

During the dismantling of the test, samples were taken according to the chart in Figure 4, at 600 mm intervals. Pictures were also taken at 600 mm intervals in order to create visual records of the tests. One example of the sampling can be seen in Figure 5. The water content of the samples was measured by use of a standard laboratory oven, drying the samples at 105 °C for 24 hours (h).

Fig. 4. The sampling chart in the ½-scale steel tunnel test.

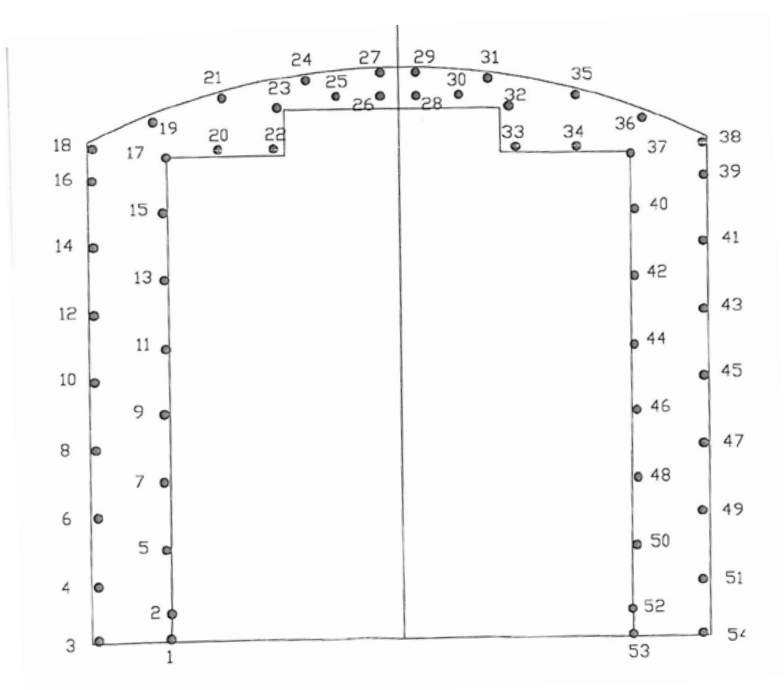

Fig. 5. Picture of the sampling during, the test 2.

In total three tests were performed in this scale (Table II). The construction of the test setup takes approximately one week and the dismantling and sampling takes a time. The actual test duration for each of the tests was two to three days.

The monitoring data collection started when the water inflow started and was stopped when the water inflow stopped. After observation of the first outflow at the front of the chamber, the test was continued until the outflow and inflow rates were roughly the same.

Small changes were made to the third test based on practical reasons (the dust generation during the pellet spraying) and on the results from the previous test (moving the geotextile 20 cm backward). Due to the excessive dust generation in the first two tests, the pellets were sieved and the small particles were removed for the last test.

The first test was a reference test performed without geotextile and with a water inflow of 0.25 l/min. In the second test a geotextile was added but the water inflow was the same as in the reference. In the third test the water inflow rate was increased to 0.5 l/min.

TABLE II. The test matrix for the ½-scale steel tunnel tests.

	Geotextile	**Number of inflow nozzles**	**Inflow rate [l/min]**
1. Reference test	no	1	0,25
2.	yes	1	0,25
3.	yes	1	0.5

Fastening Tests

The fastening of the geotextile onto wet rock surface was tested in the Loviisa low and intermediate level waste repository, which is excavated into crystalline rock to 110 meters depth. The location was chosen for its accessibility for Fortum's employees, as well due to its suitable dusty and wet rock surfaces.

The methods tested in the project were designed to be suitable also regarding the fact that some materials have to be left in the deposition tunnels. At this point of testing, only the functionality of the fastening methods has been tested.

The cleaning and preparing of the rock surface was kept at its minimum. The rock surfaces were naturally wet, and no artificial wetting was used.

The primary objective was to fasten one meter wide and 1-3 meters long sheets of geotextile to the rock wall.

TABLE III Test matrix for the fastening tests.

Fastening method	Plastic geotextile	Insulation type glass fiber fabric
Express nails	July 2012	May 2013
Glue type 1	November 2012	no
Glue type 2	November 2012	no
Concrete paste	no	May 2013

RESULTS

Laboratory Scale Test Results

The tests completed show very clearly, as can be seen in Figure 6, that all the tested geotextiles distributed inflowing water well. In the reference test there is a water pressure build up, but in the tests with geotextile the water can flow without any resistance which means that the water can be distributed over a larger area without any risk for forming a piping channel or a water filled pocket. There was no obvious difference between the tested geotextiles regarding this property. However, due to poor mechanical strength, the thin glass fiber geotextile cannot be recommended for use in larger scale applications.

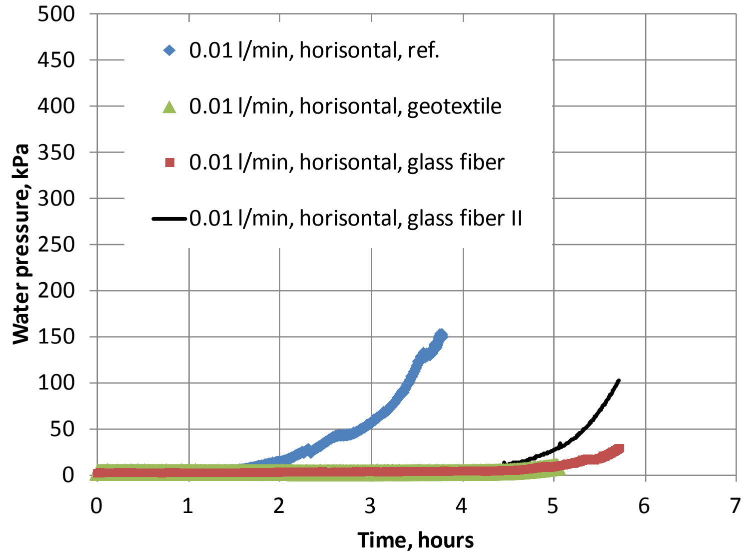

Fig. 6. Water pressure plotted versus time for the four tests performed with a flow rate of 0.01 l/min and in horizontal direction.

Steel Tunnel Test Results

As can be seen from Table III, the water storing capacity is increased significantly from the reference test. However, the changes of test setup to the last test makes direct comparison problematic. The sieving out of the small clay particles for the last test may have an impact to the water storing capacity and needs to be studied further. Alternatively, it is possible that the geotextile functions better with higher inflow rates when it spreads the inflow to larger area and the presence of fine-grained material is not important with respect to water storage.

TABLE III. The water storage capacity in the steel tunnel tests

Test	**Inflow rate [l/min]**	**water pressure before outflow [kPa]**	**outflow time [h]**	**water fed [liters]**
1. reference test	0.25	45	30,4	460
2.	0.25	105	39,5	588
3.	0.5	155	53,3	1600

Comparing figures 7 through 9 clearly illustrates the capability of the geotextile to spread inflow to the other side of the tunnel. In every test with or without geotextile, the outflow point is roughly in the same spot in the tunnel roof. This is presumably caused by the tunnel dimensions in conjunction to the test setup geometry, and it can't be concluded to happen in repository conditions.

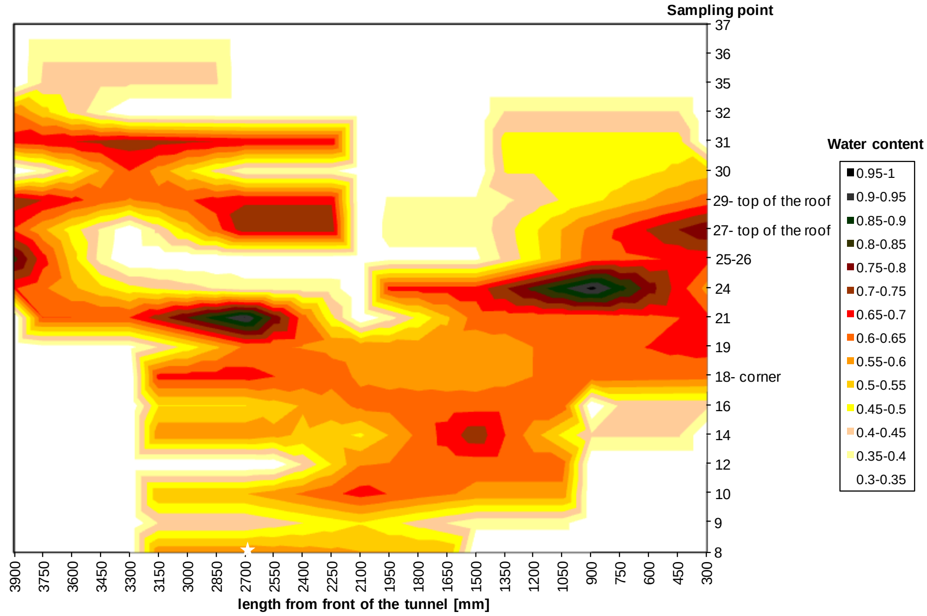

Fig. 7. Wetting pattern of the pellet filling in the reference test. The star marks the place of the inflow point.

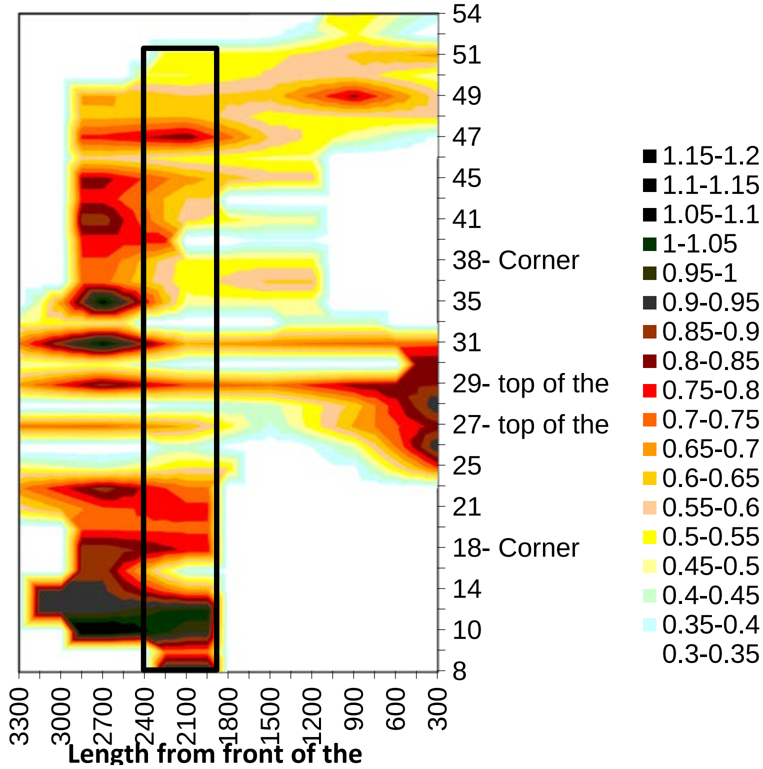

Fig. 8. Wetting pattern of the pellet filling in Test 2 (with geotextile). The star marks the place of the inflow point. The black rectangle roughly illustrates the position of the geotextile.

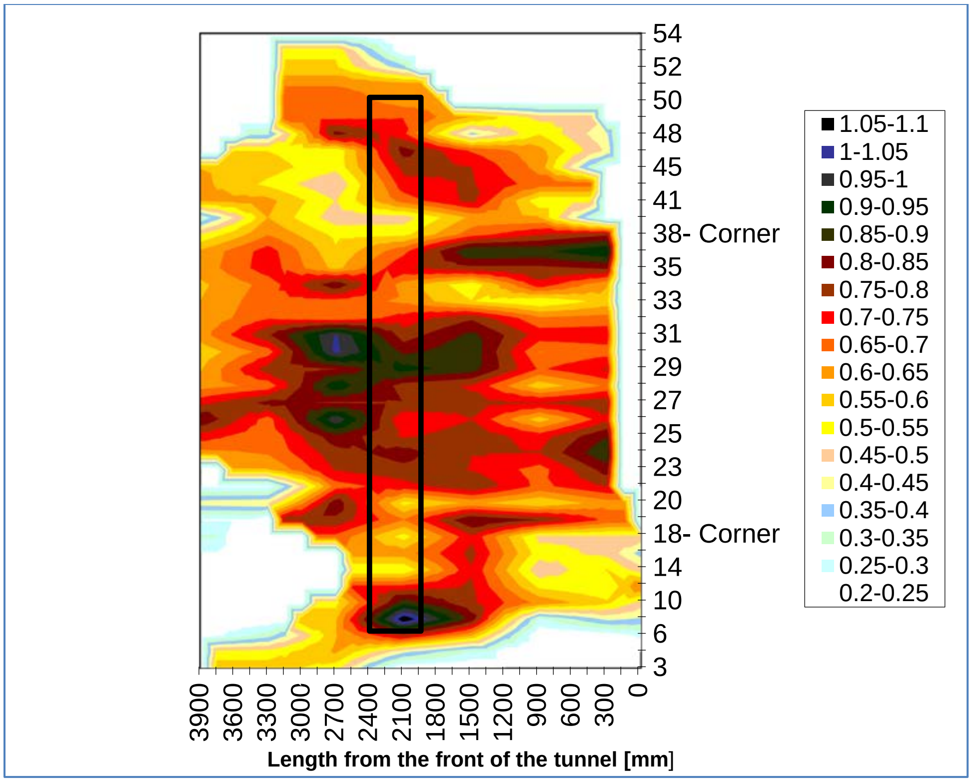

Fig. 9. Wetting pattern of the pellet filling in the Test 3. The star marks the place of the inflow point. The black rectangle roughly illustrates the position of the geotextile.

Fastening Test Results

Express nails were easy and fast to use for geotextile installation, and produced strong bonding between the polypropylene geotextile and the rock surface. Express nails are hollow metallic nails designed to be used on hard surfaces such as rock and concrete. In the case of the glass fiber fabric, larger washers than 16 mm which were used in the tests are required. Out of the tested methods, express nails were clearly the best option for fastening of the geotextile.

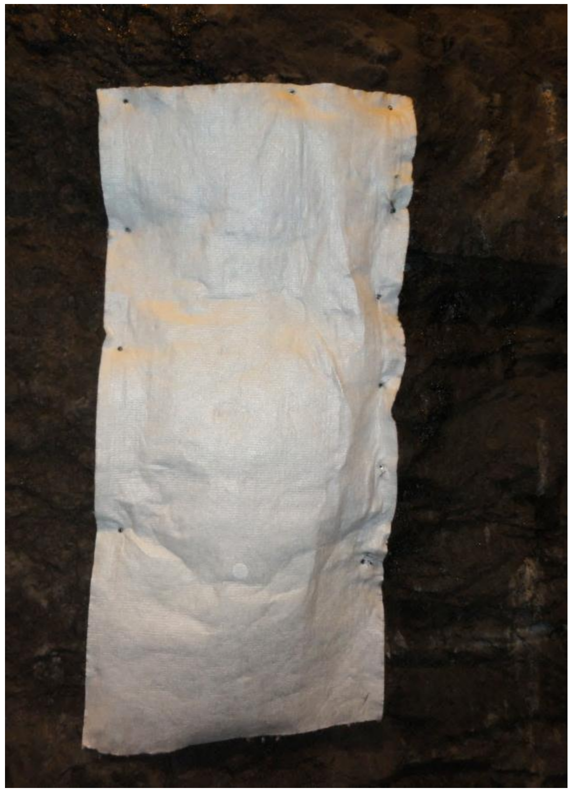

Fig. 10. The glass fiber fabric nailed onto the rock.

Gluing was attempted with two different types of glues (two component epoxy glue and MS-polymer glue). Because the surface was wet and dusty, the glue did not achieve very good adhesion between the fabric and the rock surface. If the rock had been cleaned and dried, the result may have been very different, but this is not practical or even possible in repository condition and therefore was not attempted. Furthermore, the acceptability of glues due to their organic content is considered to be questionable from the long term safety point of view. Hence, no more effort was put on the gluing alternative in the tests.

Concrete paste was also used as a glue. The results were better than with glues, but the amount of concrete used had to be relatively high. The concrete used in this trial takes around 5 hours to achieve some hardening and fastening effect. Due to the large amount needed and long hardening time concrete is not considered to be an optimal material for use in geotextile fastening, although could be used if so desired.

CONCLUSIONS

As shown in the laboratory scale tests, there were no major differences between the three fabrics tested regarding water distribution properties, even if one of those was not designed to function as drainage. Based on the laboratory scale tests the fastening material has only a limited impact on the function of the fabric in a bentonite pellet-fabric system. If so desired, it might be possible to find a better glass fibre fabric more suitable for this application.

The results from the ½-scale steel tunnel test showed increased water storing capacity of the pellet filling when using geotextile as a means of redistributing the inflowing water. The scale of the benefits of using geotextile is uncertain, since the test setup didn't remain identical throughout the tests. The use of geotextile seems at least to increase the water storing capacity of a pellet filling by 30%. More accurately determining the amount of increase of the water storing capacity would require additional testing, as well as studying the effect of sieved pellets on the water storage capacity. The possible additional testing on the effects of the sieved pellets will be done during 2014, although when and how it will be done has not been decided.

Based on the ½-scale steel tunnel test, the geotextile delays the onset of water piping and increases the water storing capacity at least up to the tested 0.5 l/min inflow rate. In a full scale deposition tunnel (SKB or Posiva type) the inflow could be as high as 1 l/min in a 6-m long tunnel section. Since the inflow spots can be in adjacent tunnel sections, the exact inflow rate limit for the geotextile system is not unambiguous. At the points with inflow rates higher than 1 l/min/tunnel section, alternative water handling methods are probably needed.

The pellet type used in the three tests stores water very well. In the reference test it took more than 30 hours before any outflow occurred. It should be considered that this long time to outflow was reached with a rather high inflow (0.25 l/min) and in a test which in terms of the available pellet volume was much smaller than in the full scale test.

The water storing in the test performed with geotextile and with an inflow of 0.25 l/min, increased by about 28 % when compared to the reference test. This is somewhat lower than desired but improvement probably depends on the scale i.e. the distance to the front from the geotextile is limited. Presumably the percentage increase would be greater in full scale.

The water pressure measurements show that the water pressure required before water outflow occurred is higher in the tests that included a geotextile component. This is probably due to the fact that the geotextile is filled with water rather quickly and that the pellets closest to the geotextile get some extra time to swell and seal.

The sieving of the pellets to remove the fines component may have affected the performance of the pellet filling, and therefore jeopardize the comparability to the reference test. The geotextile was also moved 20 cm backwards in order to delay the first outflow. It is also possible that the geotextile system with higher inflow rates works better without the fine particles in the pellet front.

The express nails seemed to be the best alternative in order to fasten the geotextile onto the rock wall. The drilling needed in the installation of these fasteners is minimal and very shallow, and shouldn't cause any major occupational hazards. Due to the difficulties observed in the nailing process with the glass fibre fabric, the diameter of the washer should be significantly increased.

If the steel in the express nails can't be accepted due to long term safety aspects, the material could be changed to some other metal such as copper, titanium or even non-metallic compounds. In that case the nails must be specially manufactured for this purpose. Also plastic fastening pins might be worth considering, since the fastening would be even easier and faster, however plastics might be problematic in the long term safety point of view.

The use of concrete as a glue might be possibility, but it would cause difficulties to the deposition time schedule due to the curing time. Also the amount of concrete used in the fastening test was quite high, lowering the effective area available for the water distribution.

Based on the fastening tests, the express nail methodology is the most promising method for further development. Since none of the tested fastening methods can be accepted in the current state from the long term safety point of view, express nails are most likely to lead to acceptable result with the least amount of effort.

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