Technical Report

TR-06-12

Consequences of upwards swelling from a wet deposition hole into a dry tunnel with backfill made of blocks

A preliminary study

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August 2006

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Abstract

Earlier calculations of the mechanical interaction between the buffer and field compacted backfill show that the buffer swells upwards and compress the backfill 5–20 cm with large influence of the backfill composition and density. The compression properties of such a backfill are rather independent by the degree of wetting, so the results are not affected by the sequence of wetting.

For a concept with a backfill made of highly compacted large blocks the properties are however quite different depending on if the blocks have been water saturated or are completely unwetted. In order to study the consequences of h ow a wet deposition hole interact mechanically with the backfill in a completely dry tunnel a number of simple calculations have been done.

The calculations have been done with the assumption that only a cylinder with the same diameter as the deposition hole has taken part since the lateral support is small due to the pellets filled slots at the rock walls.

The upwards swelling of the buffer has been calculated as a function of the displacement of the upper surface in the same way as earlier. The compression of the backfill has been estimated as the sum of the compression of the backfill blocks and the pellets filled slot at the roof and the compression of the horizontal slots between the blocks.

The calculations yielded an estimated upwards swelling of about 8 cm. The results must though be considered preliminary since the assumptions and calculation methods are uncertain and call for supplementary tests and calculations.

Sammanfattning

Tidigare beräkningar av mekanisk samverkan mellan buffert och in situ packad återfyllnad visar att bufferten sväller uppåt och komprimerar återfyllningen 5–20 cm varvid inverkan av densitet och återfyllnadens sammansättning är stor. Kompressionsegenskaperna hos denna återfyllning är tämligen oberoende av bevätningsgraden varför resultaten inte påverkas av i vilken ordning bevätningen sker.

För ett koncept med en återfyllning av inplacerade stora block är emellertid egenskaperna helt olika beroende på om blocken vattenmättats eller är helt obevätta. För att studera konsekvenserna av hur bufferten i ett blött deponeringshål samverkar mekaniskt med återfyllningen i en helt torr tunnel har några enkla beräkningar gjorts.

Vid beräkningarna har konservativt antagits att endast en cylinder av återfyllningen med samma diameter som deponeringshålet medverkat eftersom sidostödet är litet pga de pelletsfyllda spalterna vid bergväggarna.

Uppsvällningen av bufferten har beräknats som funktion av överytans förskjutning på samma sätt som tidigare. Kompressionen av återfyllningen har uppskattats som summan av återfyllningsblockens och pelletsspaltens kompression samt hoptryckningen av de horisontella spalterna mellan blocken.

Beräkningarna gav en uppskattad uppsvällning av ca 8 cm. Osäkerheter i antaganden och beräkningar gör dock att resultaten måste anses preliminära och att kompletterande tester och beräkningar behöver göras.

Contents

1 Introduction

When the bentonite buffer is water saturated it swells and exerts a swelling pressure on the surroundings. Since the swelling pressure and the swelling capacity are very high the overlying backfill that fills a deposition tunnel will be compressed by the swelling buffer. In the case of a backfill made of field compacted bentonite/ballast mixture the upwards swelling is expected to be 5–20 cm with large influence of the backfill composition and density. If the backfill is made of pre-compacted blocks, the upwards swelling will be less, due to the higher density and high swelling pressure of the blocks. Those swelling calculations were made with the assumption that the backfill is water saturated.

However, if the wetting of the deposition hole is faster than the wetting of the backfill the upwards swelling may be more complicated and difficult to calculate. In the case of in situ compacted backfill the difference is rather small but if the backfill is made of blocks and pellets there are both opens slots and loose pellets fillings that may be compressed. In addition the staples of blocks may be instable and the blocks may be crushed or sheared to failure.

This study is a first estimation of the consequences of an extreme scenario with a very wet deposition hole and a tunnel that is so dry that the backfill will be insignificantly wetted after completed saturation of the buffer.

2 Presumptions

The geometry of the tunnel is according the Simpevarp Plant Description 4.9 m wide and 5.4 m high as shown in Figure 2-1. The tunnel is assumed to be filled with blocks with 0.5 m height and 1.0 m width. A slot of 0.4 m is left between the backfill blocks and the rock walls and a slot of 0.3 m is left between the backfill blocks and the roof and filled with bentonite pellets.

The deposition hole is filled with bentonite blocks up to 1.0 m from the floor. The upper end is assumed to be filled with two 0.5 m high blocks made of the same material as the backfill. The upper block is fitted to the diameter of the deposition hole in order to avoid water piping from the deposition hole.

The buffer and the pellets are made of MX-80 while the backfill blocks probably will be made of another type of swelling clay like Friedland clay or Asaphura bentonite. The properties of blocks made of the latter clay types are not known, so the properties of MX-80 are assumed to be valid also for the backfill blocks.

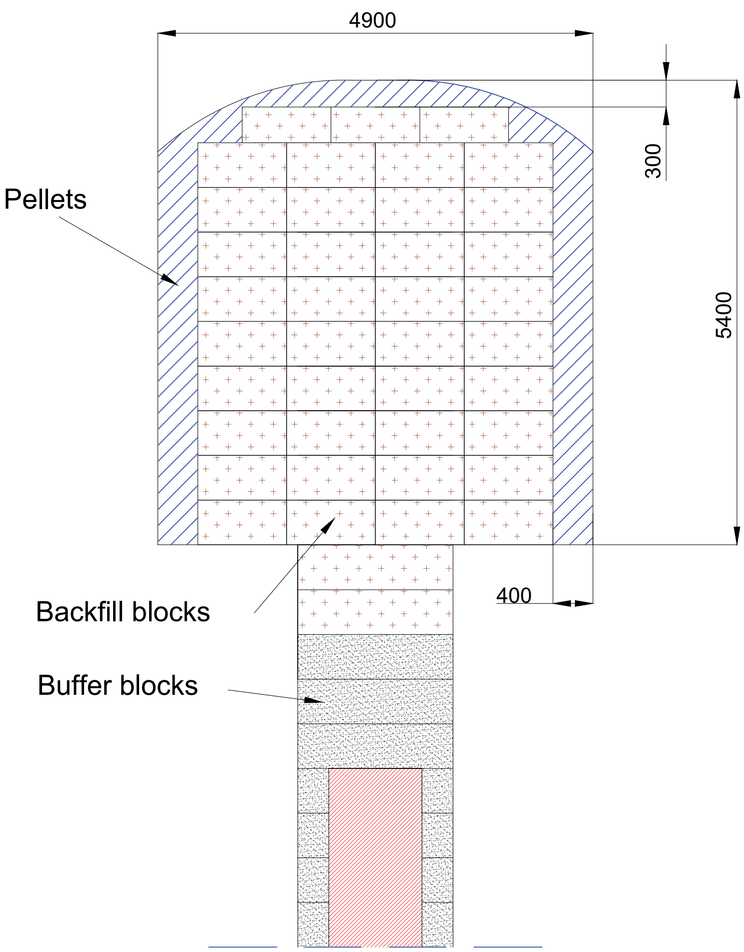

Figure 2-1. *Geometry of tunnel backfilled with blocks and pellets.*

3 Properties

The mechanical properties of the separate components need to be defined.

Backfill blocks

The following properties of MX-80 blocks with a bulk density of 2,100 kg/m^3 and a water ratio of 10% have been measured (see /1/ and /2/):

E = 500 MPa

ν = 0.2

$(\sigma_1 – \sigma_3)_f$ = 8 MPa

where

E = Young's modulus

ν = Poisson's ratio

$(\sigma_1 – \sigma_3)_f$ = Deviator stress at failure derived from uniaxial compression tests

Pellets

The compression properties of pellets filling is controlled by the strength of the individual pellet and the pore space available between the pellets. So far only preliminary tests with low pressure have been performed. The results from these tests indicate that pellets filling with an initial dry density of about 1,100 kg/m^3 will be compressed to a dry density of 1,500–1,600 kg/m^3 at the pressure 8 MPa /3/.

Slots between blocks

The backfill blocks will be stapled probably with some overlapping like a brick work. Since the blocks cannot be made with precise heights there will be slots between the blocks. How wide these slots will be is not known but an average aperture of 4 mm corresponding to 0.8% difference in height is a qualified guess.

4 Simplified calculation of the backfill compression

A simplified and probably conservative calculation is to assume that the entire force is taken only by the blocks located above the deposition hole and that there is no lateral stress distribution. The motivation for such an approach is that there are vertical slots between the blocks and that there is a large pellets filled slot on both sides of the block staple, which will allow horizontal deformations and prevent lateral stress propagation.

The total vertical displacement of the backfill will with this assumption be the sum of

1) the vertical elastic deformation of the blocks,

2) the compression of the pellets filling above the blocks and

3) the closing of the horizontal gaps between the blocks.

In the first calculation the swelling pressure from the buffer is assumed to be unaffected by the swelling and by the friction between the deposition hole wall and the bentonite yielding a total swelling pressure at the buffer/backfill interface of about 7 MPa.

Elastic deformation of the backfill blocks

The height of the block staple is h = 6.1 m including the two backfill blocks in the upper part of the deposition hole. The total compression δ_b will be

$\delta_b = h\sigma/E = 6.1 \cdot 7.0/500 = 0.085$ m

Compression of the pellets at the roof

The dry density of the pellets filling will be about ρ_{di} = 1,100 kg/m^3. Assuming that the pellets filling will be compressed to the dry density ρ_{dc} = 1,550 kg/m^3 at the pressure 7 MPa yields a total compression δ_p of:

$\delta_p = \mathrm{h} \cdot (1 - \rho_{di/}\rho_{dc})$

$\delta_p = 0.3 \cdot (1 - 1{,}100/1{,}550) = 0.087$ m

Deformation of slots between blocks

Maximum 4 mm slots caused by differences in heights of the backfill blocks are expected. Since such slots occur over a limited part of the horizontal joints, due to the overlapping brick work, they will only partially be closed. It is conservatively assumed here that the entire slot apertures will be closed. Altogether there are 9 such joints (see Figure 2-1), which yields the following total displacement:

$\delta_s = a_{s1} \cdot N = 0.036$ m

where

$a_{s1} \cdot$ = aperture of one slot

N = number of slots

Total displacement

The total displacement will thus be

$\delta = \delta_b + \delta_p + \delta_s = 0.208$ m

However, these calculations are done with the assumption that there is no friction between the rock and the buffer that reduces the swelling pressure at the buffer/backfill interface. If the friction angle 10 degrees is applied and the compression of the backfill is assumed to be proportional to the pressure from the buffer, the upwards displacement and the swelling pressure at the buffer/backfill interface will be less than half. The evaluation is done according to a model where the swelling of the buffer and the compression of the backfill are plotted in the same diagram and the actual displacement corresponds to the intersection between the curves as described in /4/ (see Figure 4-1).

The resulting upwards swelling is thus according to this simplified calculation estimated to be

$\delta \sim 8$ cm

and the maximum deviatoric stress in the backfill column

$(\sigma_1 - \sigma_3) \sim 3.0$ MPa,

which both are acceptable.

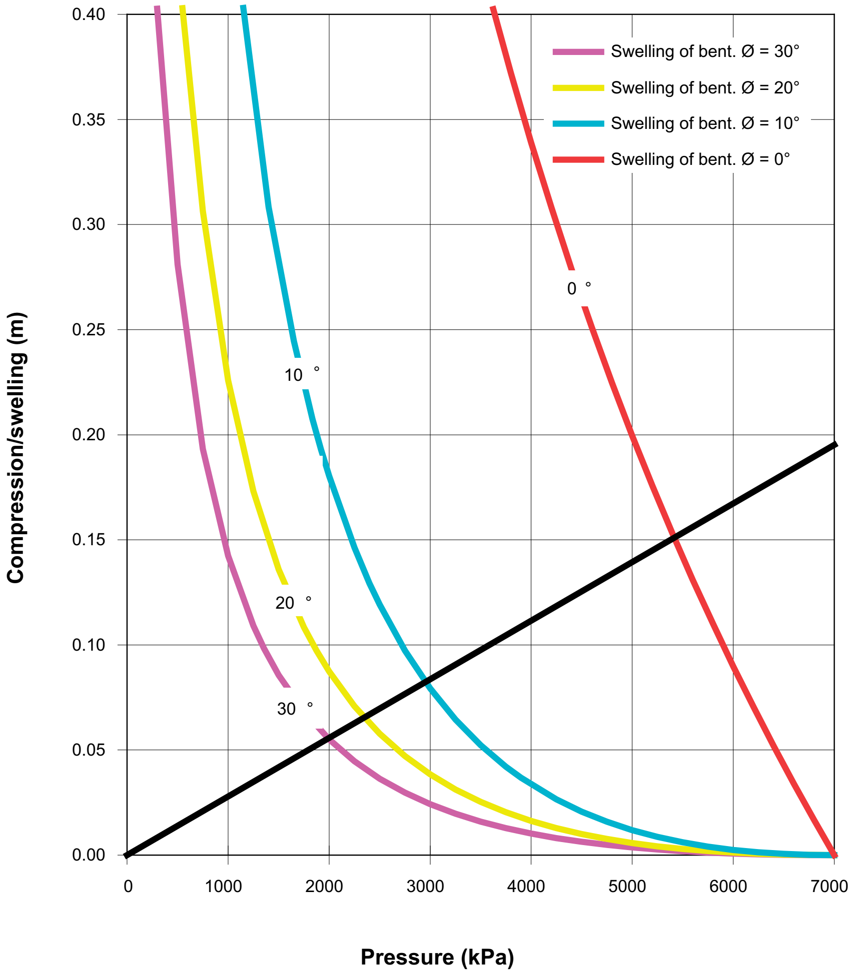

Figure 4-1. *The displacement of the interface between the bentonite buffer and the overlaying back-fill made of blocks and pellets. The coloured lines show the swelling of the buffer at different friction angles and the black line shows the estimated compression of the backfill.*

5 Risk of failure

Since the lateral support from the side blocks and pellets is expected to be low and not accounted for in the calculation the shear stresses in the blocks will be high and must be taken into account by checking the risk of failure of the block column. The column may be compared to a large cylinder with the diameter 1.75 m and the height 5.1 m. Without lateral support the deviatoric stress of this cylinder will be the same as the swelling pressure from the buffer.

The deviatoric strength of the blocks /2/ is at the bulk density 2,100 kg/m^3

$(\sigma_1 - \sigma_3)_f$ = 8 MPa.

The block column will thus be close to failure if friction in the deposition hole is not taken into account while the axial compressive stress from the buffer will be only about 3 MPa and thus far from failure if the friction is considered according to Figure 4-1.

6 Conclusions

With the simplified assumption that the backfill functions as a column with the same diameter as the deposition hole and without lateral support the estimated total upwards displacement will be about 8 cm, which is about the same as for in situ compacted 30/70 backfill. However, there are several uncertainties involved in these calculations, such as the compression properties of the pellets filling, the compression of the slots between the blocks and the structural stability of a block assembly like this. The parameters used are best estimates from present knowledge. The elastic and strength properties of blocks made of the actual materials proposed as backfill should be determined. Also the compression properties of pellets filling and the mechanical properties of slots between bentonite blocks should be investigated in the laboratory. Also the risk of failure needs to be further investigated since the assumption that the package has the same strength as a solid may be questioned.

References

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