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2015:08

Rheological properties of the Bentonite Buffer

Main Review Phase

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SSM perspektiv

Bakgrund

Strålsäkerhetsmyndigheten (SSM) granskar Svensk Kärnbränslehantering AB:s (SKB) ansökningar enligt lagen (1984:3) om kärnteknisk verksamhet om uppförande, innehav och drift av ett slutförvar för använt kärnbränsle och av en inkapslingsanläggning. Som en del i granskningen ger SSM konsulter uppdrag för att inhämta information och göra expertbedömningar i avgränsade frågor. I SSM:s Technical note-serie rapporteras resultaten från dessa konsultuppdrag..

Projektets syfte

Det övergripande syftet med projektet är att ta fram synpunkter på SKB:s säkerhetsanalys SR-Site för den långsiktiga strålsäkerheten för det planerade slutförvaret i Forsmark. Denna rapport granskar och utvärderar SKB:s redovisning av de reologiska och geomekaniska egenskaperna hos buffertbentonit, både vid hög och låg densite.

Författarens sammanfattning

Reologiska egenskaper hos bentonit vid hög densitet

Egenskaperna hos bentonit vid hög densitet är oerhört viktiga. Det verkar så att egenskaperna har varit i viss mån väl utforskade och förstådda. Ytterligare utredningar kring svällning av bentoniten skulle ändå vara välkomna. Det som verkar saknas är en omfattande konstitutiv modell som kan beskriva alla olika aspekter av buffertens beteende. En sådan modell bör utvecklas och det är dessutom nödvändigt att verifiera modellen mot ett antal väl definierade och lämpliga elementära tester. Först efter detta kan man sedan fokusera på de simuleringarna av komplexa scenarier för prototypförsöket.

Reologiska egenskaper hos bentonit vid mycket låg densitet och en extremt hög vattenkvot

Försök för att bestämma hållfasthets- och flödesegenskaperna för gel och sol av bentonitkolloid är svåra att genomföra i laboratoriet eftersom det uppmätta motståndet är extremt låg. Lovvärda laboratorietester har utförts av SKB för att bestämma dessa egenskaper och resultaten har lagt grunden till att förstå beteendet av gel och sol av bentonitkolloid.

Emellertid är egenskaperna hos sådana kolloider inte väl kända och ytterligare undersökningar är absolut nödvändiga, särskilt som denna kunskap är avgörande för att bedöma risken för kemisk erosion av bufferten med utspätt vatten.

Antagen geometri för eroderad volym av buffert
Den antagna geometrin för eroderade volymen av bufferten i figur 4-2 i SKB TR-10-66 togs fram utan några konkreta stödjande argument. En bättre förståelse skulle förmodligen kunna erhållas om stödjande FEM simuleringar utförs. Däremot konstaterades att den minsta exponerade arean på kapselns yta leder till den allvarligaste korrosion samt att tidpunkten för erosion att nå kapseln inte inkluderas i analysen, blir geometrin av eroderade volymen mindre viktig. Den viktigaste frågan är om erosionen av den omfattning som behövs faktiskt kan förekomma.

Projektinformation
Kontaktperson på SSM: Jinsong Liu
Diarienummer:SSM2011-3396
Aktivitetsnummer: 3030012-4082

SSM perspective

Background

The Swedish Radiation Safety Authority (SSM) reviews the Swedish Nuclear Fuel Company's (SKB) applications under the Act on Nuclear Activities (SFS 1984:3) for the construction and operation of a repository for spent nuclear fuel and for an encapsulation facility. As part of the review, SSM commissions consultants to carry out work in order to obtain information and provide expert opinion on specific issues. The results from the consultants' tasks are reported in SSM's Technical Note series.

Objectives of the project

The general objective of the project is to provide review comments on SKB's postclosure safety analysis, SR-Site, for the proposed repository at Forsmark. This technical note reviews SKB:s reporting of the rheological and geomechanical properties of buffer bentonite, both at high and low densities.

Summary by the author

Rheological properties for bentonite at high densities

The properties of bentonite at high densities are extremely important and it appears as it has been to a certain extent well researched and understood, although further investigations regarding swelling of the bentonite would be welcome. What, however, seems to be missing is a comprehensive constitutive model capturing all the different aspects of the buffer behaviour. Such a model should be developed and then it is necessary to benchmark the model against a number of well-defined and suitable element tests in order to evaluate the merits of the model. Not until then should the simulations of complex scenarios for the prototype be given proper attention.

Rheological properties for bentonite at very low densities and extremely high water radios

Testing of strength and flow properties of gels and sols are difficult to make in the laboratory as the measured resistance is extremely low. Commendable laboratory testing has been carried out in order to determine those properties and the results form a first base for understanding the behaviour of bentonite gels and sols.

However, the properties of such colloids is not well known and further investigations are imperative, especially as this knowledge is crucial for evaluating the risk for erosion under fresh water conditions.

Assumption of the geometry of buffer erosion

The assumed geometry of the eroded volume in Fig 4-2 in SKB TR-10-66 is assumed without any concrete supporting arguments. A better understanding could probably be obtained if supporting FEM simulations were carried out. On the other hand it was concluded that the smallest exposed area leads to the most severe corrosion and as the time for the erosion to reach the canister is not explicitly included in the analysis, it is not that important how the geometry of the eroded volume is. The dominating question is whether erosion of such an extent as needed actually can occur.

Project information

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Contents

1. Introduction

The review task is labelled *Rheological Properties of Bentonite Buffer*. Sometimes the term Geomechanical Properties is also included. For clarity a brief discussion and definition of the term Rheological Properties are given below. Thereby it is also stated how the term Rheological Properties is interpreted in this review task.

The common understanding is that rheological properties relate to flow properties of matter, mainly in the liquid state. But within the area of strength of materials rheological properties also include fairly soft solids undergoing deformation defined as plastic flow, in contrast to elastic deformation. In modern modelling of soil behaviour complex constitutive models are used which are able to describe and catch all types of responses to a change in stresses. So for very dilute states of the bentonite, e.g. semi-fluid state, gel and sol, classical models for flow properties are used, while for bentonite in a solid state the rheological properties are described by more complex constitutive models. This is probably what the term geomechanical properties refer to.

This technical note is not aimed at being a complete description of the area of Rheological properties, but merely a response to the questions raised by SSM. These were:

- Are SKB's reporting of the rheological and geomechanical properties of bentonite buffer scientifically sound for high-density sodium- and calcium bentonite?
- Is SKB's assumption of the geometry of buffer erosion in SKB TR-10-66, Section 4.3.3 reasonable from the point of view of the rheological and geomechanical properties of the buffer at low density?

Under the first heading, quite some effort is devoted to the phenomenon of homogenisation, even if that was not explicitly indicated in the review task.

It should also be pointed out that the report summarizes the author's assessment of the questions raised by SSM.

2. Rheological and geomechanical properties for bentonite buffer of high density.

The important parameters of the buffer at high densities are primarily

- Swelling pressure
- Constraint modulus
- Hydraulic conductivity
- Suction, Retention properties
- Resistance to shear, shear strength

The *swelling pressure* is important from several aspects, as it constitutes the main capability of the bentonite to e.g. homogenize, seal possible gaps after installation or created by erosion, support the canister regarding settlement as well as shear.

The *constraint modulus* is for example extremely important for the protection of the canister during earth quake induced shear.

One of the key parameters when it comes to prevent/delay spreading of radionuclides is the *hydraulic conductivity*. This parameter is sensitive to changes in density.

Suction during unsaturated conditions, often referred to as the retention properties is extremely important when it comes to saturation and homogenisation of the buffer.

The *shear strength* is important in many respects as it greatly influences friction between the bentonite and the canister and bentonite and the bedrock and thereby affects the homogenisation process. It is also one of the governing parameters when analysing canister sinking. The shear strength also has implications on the extent of the swelling of bentonite into an aperture.

All these parameters, and probably some more, influence the process of homogenisation, which is one of the main tasks within this review. This chapter is organized so that first the above mentioned parameters are briefly discussed, one by one, and then homogenisation of the buffer is discussed as a synthesis problem.

2.1. SKB's presentation

The rheological properties of bentonite buffer have been researched for several decades. Extensive testing programs have been carried out in the laboratory and also some semi-full scale tests have been done, not only in Sweden but also internationally. Elaborate measuring techniques have facilitated logging of e.g. pressure, suction and deformation in order to obtain detailed information on the progression of the tests.

2.1.1. Swelling Pressure

The swelling pressure has been investigated in numerous laboratory tests and also in some half scale tests. The effect of mainly, the density, degree of saturation, pore water chemistry (different ions and ion concentration) and temperature on the swelling pressure have been thoroughly investigated and reported. Thereby the swelling pressure and its dependency of these parameters can fairly accurately be predicted.

2.1.2. Constraint Modulus

The constraint modulus has been determined in the laboratory for a number of element tests. This parameter is closely linked to the swelling pressure and is to a certain extent dependent of the same parameters. Important to note, and somewhat more difficult to model, is the hysteresis effect as a result of the loading and unloading. But this can also to a certain degree of accuracy be modelled.

2.1.3. Hydraulic Conductivity

The hydraulic conductivity has also been extensively researched, in the laboratory, mainly on an element scale. As the parameter is a key parameter as a safety indicator, SKB claims that that it is well understood. In these reports ample data are given for how the hydraulic conductivity varies with density, degree of saturation, chemistry of the pore fluid etc. It is evident that the hydraulic conductivity decreases with increasing density, decreasing degree of saturation, and that certain ions in the pore fluid results in an increase in the hydraulic conductivity. The macro structure also has a great influence on the hydraulic conductivity and this is further treated in the section on homogenisation.

2.1.4. Suction, Retention properties

When the bentonite is only partly saturated, negative pore pressures develop in the soil. This is mainly due to the small meniscus of water formed in the pores. The negative pore pressures can be numerically very large, often several MPa. When water becomes available at a boundary, flow occurs due to the large gradients and the degree of saturation increases gradually until the bentonite becomes saturated. The hydraulic conductivity also increases as the degree of saturation increases, primarily because the area where flow can occur increases.

In the case where the bentonite is constrained by rigid boundaries, the swelling pressure will gradually increase as the degree of saturation increases.

On the other hand, if the bentonite is not constrained at its boundaries it will instead absorb large amounts of water and swell freely, and expand tremendously as the degree of saturation gradually increases. Also these processes are affected by ion concentration and type in the absorbed water.

2.1.5. Shear Strength

The shear strength has been determined in the laboratory by means of triaxial tests, and is mainly expressed in terms of the strength parameters friction angle and cohesion. Thereby the shear strength variation with stress can be estimated, for example by means of Mohr/Coulomb's failure criteria.

2.1.6. Homogenisation and Constitutive Models

As the bentonite buffer is placed around the canister at a very dense state, with low water content and far from saturated, the process of wetting and homogenisation is extremely important for the buffer in order to fulfil its safety conditions. The properties discussed in section 2.1.1 – 2.1.5 above are all important parameters when it comes to understanding the process and being able to model the complicated phenomenon of homogenisation, which indeed requires a sound understanding of the above mentioned parameters.

In report TR-10-11, chapters 5, 6 and 8 are devoted to the issue of homogenisation and different scenarios are investigated, while chapters 3 and 4 discuss and model the time scale and moisture redistribution or the process of gradual saturation. Different scenarios of up to three missing blocks of buffer are analysed and modelled through FEM in mainly ABACUS. The results indicate that even such an improbable event eventually will lead to a closure of the canister and to a fairly homogenous buffer.

Comparison with actual test results from the Canister Retrieval Test (CRT) shows fairly good agreement between the moister distributions predicted by the FEM modelling and results actually measured after the completion of the test and reported from the CRT, although some deviations are evident.

In a more recent report, TR-12-02, some test results are reported, where the homogenisation process for a swelling element has been the main focus. Different test set up have been used, allowing a cylindrical bentonite sample to swell either in vertical or radial direction (outwards or inwards). Measurements were made of the change in swelling pressure and final moisture distribution over the sample.

2.2. Motivation of the assessment

In this section some comments are made regarding the properties treated in each sub-section above. The overall dominating questions, that of modelling the combined effect of all the different phenomena or parameters, are dealt with in subsection 2.2.6 Homogenisation and Constitutive Models.

2.2.1. Swelling

In general the results are comprehensive and logical. The influence of the suction parameters on the swelling properties have been extensively researched and fairly well understood. Different boundary conditions have been used and tested.

A drawback with the presentation of the results is that the swelling pressure is mostly presented as a unique property and graphs are given for how it will change with changes in e.g. density, chemistry of the pore water etc.

In reality the swelling pressure depends strongly on the stress history of the sample and is not necessarily isotropic in its nature. Also its history in terms of wetting and drying is important. That means that loading/unloading changes in principle stresses and directions and drying/wetting needs to be further investigated. This knowledge is crucial when designing/developing a constitutive model for implementation in a FEM simulation.

2.2.2. Constraint Modulus

Also here the results are comprehensive and logical, although more details are needed. However, in further testing and development, as suggested in the previous section on swelling, this information on constraint modulus will most probably be possible to withdraw from these data.

2.2.3. Hydraulic Conductivity

The hydraulic conductivity is the physical parameter showing the greatest span in terms of size. It spans over several orders of magnitude for bentonite with moderate changes in densities and degrees of saturation. For saturated conditions it is fair to say that the hydraulic conductivity is well known. For unsaturated buffer the uncertainty is greater. The parameter is extremely important when modelling the saturation process.

2.2.4. Suction and Retention properties

Suction and Retention properties are closely linked to the hydraulic conductivity and are also important when studying the saturation process but is of limit interest once the buffer is saturated.

It is extremely difficult to measure in the laboratory, especially under low degrees of saturation. It seems, however, as the results presented constitutes a good enough base for predicting the saturation process, and as the task treated in this review task mainly concerns the post saturation conditions, suction has very little influence.

2.2.5. Shear strength

A limited number of tests, mainly triaxial test, have been performed and the strength has been evaluated. The failure envelope is not linear and therefor it is important to evaluate the strength parameters, when the Mohr/Coulomb failure criterion is used, for the stress range at hand.

The knowledge regarding strength parameters for bentonite with high densities are probably sufficient. However, no tests have been reported where the friction between bentonite and other material such as bedrock or copper is investigated.

2.2.6. Homogenisation and Constitutive Model

First it should be stated that the problem of wetting, swelling and homogenisation of the bentonite buffer is a complicated process and it is extremely difficult to capture all aspects of it in a constitutive model. Before evaluating a test like the CRT, it is important to benchmark the model by comparing its prediction with swelling tests for well-defined element tests. This was not systematically done for the model used when analysing the CRT. Still the same model was used for modelling the homogenisation of the buffer where a few blocks of buffer were missing. The merit of these results is thus limited or could even be questionable.

Thus it is imperative to develop a FEM model which is comprehensive enough to include all the phenomena discussed above. Then it should be used to predict the test results from where the properties discussed in subsection 2.2.1 – 2.2.5 above were evaluated. Not until then, if the results are acceptable, should further modelling of scenarios which cannot very well be physically tested, be modelled and the so made predictions can form a base for evaluation of those scenarios.

In TR-12-02 very well defined element testing has been reported and they constitute a good base for benchmarking of the FEM models used. This will be interesting and shall probably require further model development and testing. The swelling process is indeed complicated and phenomenon like friction along sides, time for completion of swelling, creep, hysteresis effects, dilatancy of the material and strength-induced anisotropy must be accounted for, or at least evaluated.

2.3. The Consultants' assessment

Deformation properties (swelling a constraint modulus), hydraulic properties (hydraulic conductivity and retention properties) and strength properties have been fairly extensively tested in the laboratory. The influence of a number of different parameters on those properties has also been tested and the results are indeed comprehensive.

The challenging step from interpreted results from testing to prediction of integrated behaviour of the prototype, such as the evolution of saturation and swelling of the buffer in the prototype, requires further development of a complicated constitutive model.

In order to verify the accuracy of such a model a number of benchmarking tests and exercises are needed. To some extent this has been done, but more tests, as those reported in TR-12-02, should probably be carried out.

It does not appear as if a comprehensive enough constitutive model has been developed. Once this mature constitutive model is developed and implemented in the FEM code, a number of benchmarking simulations must be presented. Once that is done reliable simulations of the different scenarios can form the basis for consideration whether the criteria for the buffer is sufficiently fulfilled.

3. Rheological and geomechanical properties for bentonite buffer of low density.

The buffer is installed around the canister at a high density and will hopefully remain in that condition. However, if the buffer is exposed to erosion, it can swell and its density will gradually decrease. If erosion continuous over long time and the buffer expands out into an aperture in the surrounding bedrock, erosion might under very specific conditions lead to very low densities of the buffer. The buffer will then gradually change from a solid to a gel and possibly a sol or even liquid where single particles are suspended. Due to this process the properties of the buffer at very low densities will be of interest.

3.1. SKB’s presentation

The rheology of bentonite suspensions at very high water ratios are mainly reported in TR-09-34, chapter 3 Rheology. The bentonite behaviour is classified in mainly two categories, namely viscosity and stress-strain relation, the latter referring to somewhat stiffer suspensions. Also thixotropy is treated to a certain extent. These different characteristics and the models used for describing them are briefly discussed below.

A majority of the tests have been performed on MX-80 and WyNa, although some tests were also made on Ca-bentonites. Tests were made on bentonite mixed with pure water and water with different ion concentration, mainly NaCl.

3.1.1. Shear Strength

The shear strength or the stress-strain behaviour is determined by means of the laboratory vane test. The so determined strength is dependent on a number of parameters and these have to a certain extent been documented.

The effect of the *shear rate* has been investigated over a fairly large range and as expected a logical increase of shear resistance with increasing shear rate has been documented.

A large number of different suspensions have also been tested. Water ratios varying from 0 to 300 were used and ion concentrations varying from 0 to 100 mM NaCl were tested. Ample results are given.

It is concluded when the strength is larger than 1 Pa, the behaviour is best described by means of a stress-strain relation.

3.1.2. Flow Models

A large number of rheology tests (viscosity tests) are also reported with varying water ratios and ion concentrations for mainly MX-80 and WyNa. A fairly simple, but frequently used, viscometer was utilized for the laboratory test. Based on the results, different flow models were suggested and parameters for these models were evaluated.

3.1.3. Thixotropy

Most suspension show thixotropy and thus get ‘stiffer’ the longer the resting period is. For a sol at rest the viscosity increase with time, or may even transform to a non-Newtonian sol or even a gel. The shear strength for a gel also increases with resting time. This time concept complicates the modelling of the gels and sols, but is often neglected and thus the assumptions are on the safe side.

3.1.4. Models for describing bentonite behaviour at high water ratios

It is claimed, based on the results from the rheological tests presented in TR-09-34, that the rheological properties of

- a gel is best modelled by a stress/strain relation
- a semi-fluid (sol) should be modelled as a Non-Newtonian fluid with viscosity, preferably a Power law.
- a fluid is modelled as a Newtonian fluid with viscosity
- water is modelled with the viscosity of water.

A number of diagrams show how the strength varies with different parameters and also how the model parameters for non-Newtonian and Newtonian depend on water ratios and ion concentration. This means that by using different models the basic behaviour can be fairly well mimicked and predictions can be made. A phase diagram for bentonite defines the type of behaviour as a function of ion concentration and water ratio.

Regarding thixotropy, the time dependency of the properties with the resting period, it is stated that it complicates the modelling of the rheological properties of the gels and sols. On the other hand it is claimed that, as the resting time in the prototype is much longer than in the laboratory tests the viscosities and strengths based on laboratory tests are on the safe side and therefor there is no risk for overestimation of these properties, rather the opposite.

It is also concluded that Ca-bentonites seems to form a stable sediment for fairly high water ratios and that these bentonites do not constitute a problem, primarily because they are unable to form colloids.

3.2. Motivation of the Assessment

Two types of tests have been used and the influence of water ratio and ion concentration on the strength and viscosity has been tested. A large number of tests have certainly been made, but still, considering the importance of the issue, far more testing is needed.

3.2.1. Shear Strength

It deserves to be pointed out that the vane strength testing method is a geotechnical testing method developed for determining the shear strength of soils and it has been extensively used, but usually for strengths in the order of kPa. Here strengths down to a few Pa and even fractions of a Pa are reported. Still, the results seem very logical and it appears as if the laboratory routines and precision are very good and commendable. Questions can, however, be risen regarding the accuracy of the method and it is recommended that a systematic comparisons with some other strength test is made, possibly the viscometer where ample data are available. The merits of an oscillating test could also lessen the uncertainty.

3.2.2. Flow Models

A number of influencing factors have been investigated and parameters for a few different flow models have been evaluated. Also here the results seem to be of good quality and logical, indicating a high quality of the laboratory work. Again the accuracy of the tests has not been quite verified.

3.2.3. General Model

In order to model the behaviour of a bentonite suspension at high water ratios and how it will expand into a fracture and possibly be eroded, a constitutive model is required, a model that describes and handles all the different phases of the bentonite. It is questionable if it is enough to be able to describe the behaviour by means of a few different, fairly simple models. No comprehensive model has been suggested.

The phase diagram and thus the understanding of the material in a colloid state are extremely complicated. In TR-09-34 this question is mentioned but not treated in any depth. It is imperative to expand this area of research.

3.3. The Consultant’s assessment

A large number of experiments have been carried out in order to determine the properties of bentonite at very high water ratios. Different models were suggested for describing the behaviour, but no model was presented that encompassed the full range of behaviour. Such a model might be necessary to capture and analyse the phenomenon of bentonite swelling out into a fracture and possibly being gradually eroded.

The properties of the dilute buffer is schematically defined by the above mentioned phase diagram, which in turn is decisive for whether erosion will occur or not. The behaviour and properties of such a colloid is not at all well-known and further investigations of the properties of such colloids are imperative.

4. Assumption of the geometry of buffer erosion

Assumptions regarding the three dimensional geometry of an eroded volume of bentonite buffer is important, not so much for the time of erosion, but for the size of the area of the canister exposed to fresh water and thus exposed to corrosion.

4.1. SKB's presentation

SKB has in a scenario of buffer erosion made a number of assumptions as presented in Section 4.3.3 in TR-10-66 regarding the geometrical factors. SKB assumes that erosion can take place, probably as predicted by Neretniks et.al. (2009) and remove large amounts of the buffer bentonite. Furthermore it is assumed or postulated that a cavity is formed in the buffer and that it has the shape of a semi-circular cross section. It is also stated that the smaller the exposed area of the canister is, the more severe is the corrosion, and it is also pointed out that all the assumptions are made very pessimistically.

Then the amount of corrosion is estimated and, in spite of all the pessimistic assumptions, SKB arrives at the conclusion that very limited corrosion will occur, at the most a few millimetres. Even for the most extreme assumptions one or at the most two canisters could be expected to fail.

4.2. Motivation of the assessment

It might seem unnecessary to spend further efforts on the issue, if the consequences, even under the pessimistic assumptions made according to SKB, are so minor. However, a few issues deserve some comments. Neretniks' et.al. model, based on a theoretical derivation and some limited empirical test data, has not been verified through any experimental data in aperture tests, but it is hard to believe that the model in anyway would under predict the erosion rate. So, in summary, the assumptions made are indeed pessimistic.

The geometry of the eroded volume is assumed without any concrete backup facts or references. It is simply discussed and stated that this is how they believe or assume it will happen. On the other hand, the most critical scenario is when a very small area of the canister is exposed and therefor the geometry is maybe not that crucial.

If the assumed volume of buffer shall be eroded, swelling will occur in the surrounding buffer which in turn will affect the density of the buffer and that safety indicator will be violated, probably long before the corrosion of the canister starts. No FEM calculations are presented that would illustrate how much buffer needs to be eroded in order to create the cavity assumed, nor is any time span for such a scenario given. In another report, SKB TR-10-11, it was shown that even if two or even three bentonite blocks were missing, the cavity would eventually be closed, under the assumption though that further loss of bentonite was restricted. A similar calculation for the case presented here would be enlightening. This would probably reveal some further aspects on how the geometry of the assumed cavity would develop with time.

4.3. The Consultants' assessment

The assumed geometry of the eroded volume in Fig 4-2 in SKB TR-10-66 is assumed without any concrete supporting arguments. A better understanding could probably be obtained if supporting FEM simulations were carried out. On the other hand it was concluded that the smallest exposed area leads to the most severe corrosion and as the time for the erosion to reach the canister is not explicitly included in the analysis, it may not be that important how the geometry of the eroded volume is. The dominating question is whether erosion of such an extent as needed actually can occur. This issue has been discussed in detail in the previous chapter, and again it should be pointed out that further investigation regarding the properties of these colloids should be undertaken.

5. The Consultant's overall assessment

5.1. Rheological properties for bentonite at high densities

The properties of bentonite at high densities are extremely important and it appears as it has been to a certain extent well researched and understood, although further investigations regarding swelling of the bentonite would be welcome. What, however, seems to be missing is a comprehensive constitutive model capturing all the different aspects of the buffer behaviour. Such a model should be developed and then it is necessary to benchmark the model against a number of well-defined and suitable element tests in order to evaluate the merits of the model. Not until then should the simulations of complex scenarios for the prototype be given proper attention.

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Testing of strength and flow properties of gels and sols are difficult to make in the laboratory as the measured resistance is extremely low. Commendable laboratory testing has been carried out in order to determine those properties and the results form a first base for understanding the behaviour of bentonite gels and sols.

However, the properties of such colloids is not well known and further investigations are imperative, especially as this knowledge is crucial for evaluating the risk for erosion under fresh water conditions.

5.3. Assumption of the geometry of buffer erosion

The assumed geometry of the eroded volume in Fig 4-2 in SKB TR-10-66 is assumed without any concrete supporting arguments. A better understanding could probably be obtained if supporting FEM simulations were carried out. On the other hand it was concluded that the smallest exposed area leads to the most severe corrosion and as the time for the erosion to reach the canister is not explicitly included in the analysis, it is not that important how the geometry of the eroded volume is. The dominating question is whether erosion of such an extent as needed actually can occur.

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SSM2011-2426-130 1371890 - Svar till SSM på begäran om komplettering rörande buffert och återfyllning under driften av slutförvarsanläggningen.

Coverage of SKB reports

Table 1

Reviewed report	Reviewed sections	Comments
SKB TR-09-34	Chapter 3	
SKB TR-10-11	Chapter 5, 6, 8	
SKB TR-10-66	Section 4.3.3	
SKB TR-12-02	Full report	

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The Swedish Radiation Safety Authority has a comprehensive responsibility to ensure that society is safe from the effects of radiation. The Authority works to achieve radiation safety in a number of areas: nuclear power, medical care as well as commercial products and services. The Authority also works to achieve protection from natural radiation and to increase the level of radiation safety internationally.

The Swedish Radiation Safety Authority works proactively and preventively to protect people and the environment from the harmful effects of radiation, now and in the future. The Authority issues regulations and supervises compliance, while also supporting research, providing training and information, and issuing advice. Often, activities involving radiation require licences issued by the Authority. The Swedish Radiation Safety Authority maintains emergency preparedness around the clock with the aim of limiting the aftermath of radiation accidents and the unintentional spreading of radioactive substances. The Authority participates in international co-operation in order to promote radiation safety and finances projects aiming to raise the level of radiation safety in certain Eastern European countries.

The Authority reports to the Ministry of the Environment and has around 315 employees with competencies in the fields of engineering, natural and behavioural sciences, law, economics and communications. We have received quality, environmental and working environment certification.

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