Latest rock grouting technologies under sea water in Nordic countries and Japan

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Abstract

In Japan, the coastal region is discussed to be a more suitable for the geological disposal in the council held by ANRE. However, the engineering technology has not been fully studied to apply the repository to this region. Regarding the engineering technology, the rock grouting has been recently studied as one of the most significant technologies. Although the cement has not been reported to be affected by saline water, the latest grouting material called colloidal silica grout (CSG or silica sol in Sweden), which has become a mandatory material to seal narrow rock fractures in great depth, is known to be sensitive to salinity. It is a durable liquid grout with a gelling property by mixing a salt accelerator. Its mechanism affected by sea water is unclear and its grouting methodology in such condition is not yet established either.

Therefore, a research project on grouting under sea water was established, as a part of the public offered project by ANRE, in order to enhance existing rock grouting technology for disposal tunnels under sea water. During this project, we studied on the latest grouting technologies for geological disposal in Nordic countries and Japan by article survey and a workshop held in Finland in January 2017.

As a result, it was found that the approaches for countermeasures in grouting under sea water were different between Japan, Sweden and Finland, which are based respectively on mixing method, design method, and controlling method. It seems that the best solution against this problem is in the near future to establish a hybrid and optimal grouting methodology under sea water by combining each country's developed technology. As for the Japanese project, it was discovered significant to develop a generic mixing method under sea water.

1. Introduction

In Japan, the coastal region is discussed to be a more suitable for the geological disposal (see, Fig. 1) in the aspect of transportation, in the council held by Agency for Natural Resources and Energy (ANRE), Ministry of Economy, Trade and Industry (METI). However, the engineering technology for the disposal or safety assessment has not been fully studied for the purpose of applying the repository to this region.

With regard to the engineering technology, the rock grouting for the geological disposal has been recently studied as one of the most significant engineering technologies. The latest grouting material "colloidal silica", which is composed of activated silica colloid, came to be an essential candidate to considerably reduce water ingress into the tunnels in the deep underground. Although the cement grout has not been reported to be affected by saline water, this rather new material is known to be sensitive to salintiy due to its gelling property by the salt accelerator. The mechanism of its affection by sea water is unclear and the grouting methodology in such condition is not yet established either.

Therefore, a research project on "characterisation of colloidal silica grout under sea water" was established, as a part of the public offered project by ANRE, METI to enhance the existing rock grouting technology for disposal tunnels in Japan.

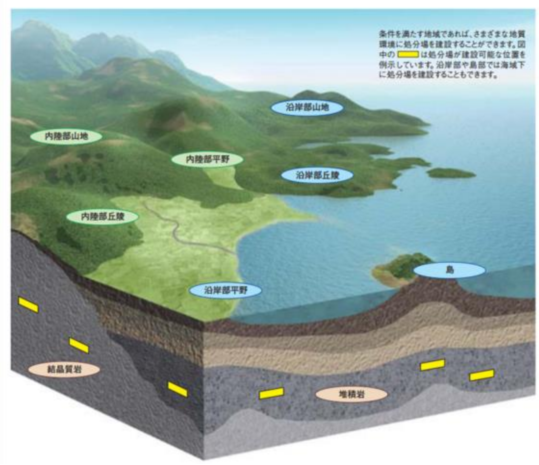


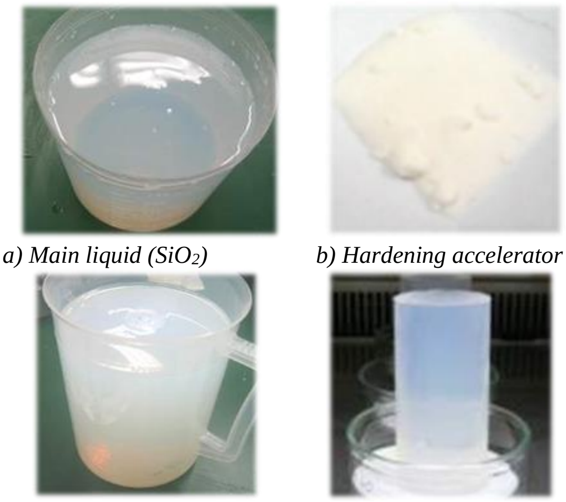
Fig.1: Schematic view of feasible region of the geological repository [1]. The geographical region varies from inner to coastal region and the yellow parts indicate the ideal candidates for the geological disposal.

2. Colloidal silica, a fruitful grout for repository

Rock grouting is one of the best construction methods to reduce water ingress into the tunnels in deep underground during the excavation. In cases of tunnels for the geological repository, it had been assumed to be hard to seal the rock mass only by the existing rock grouting method. This is due to narrower rock fractures must be sealed under higher water pressure in deeper underground of repository tunnels than of ordinary tunnels. It is also necessary to consider the effect of the grout component on the engineered and the natural barriers, which means that a low alkaline grout is favourable.

Therefore, it has been studied and developed to sophisticate the existing rock grouting technologies. Firstly, it was performed in Sweden and Finland (e.g., [2] [3]), and then in Japan for a last decade (e.g., [4]). During the development of such technologies in each country, a durable liquid-type colloidal silica grout (CSG or called "silica sol" in Sweden) has become one of most fruitful candidates for the future disposal sites (e.g., [5] or [6]) owing to its property with low pH and the capability of sealing narrow rock fractures that cement cannot penetrate. Therefore, it has a potential to reduce more water inflow than a cement grout. The main component is the liquid of amorphous particles of SiO_2 with diameters of 10-20 nm. When the main liquid is mixed with an inorganic salt of a hardening accelerator, the silica particles start to aggregate to form a durable gel, see Fig. 2.

Fig. 3 shows a summary of R&D and application on the CSG between Japan, Sweden and Finland [7]. This material was originally invented in Japan more than 20 years ago, mainly for the stabilization of soils as permanent structures in civil engineering. It has now been applied for more than 1200 sites for such ground improvement purpose in Japan [8].



a) Main liquid (SiO_2) *b) Hardening accelerator*

c) After mixture before gelling *d) Hardened homo-gel*

Fig. 2: Photos of the durable liquid-type colloidal silica grout (CSG) in Japan.

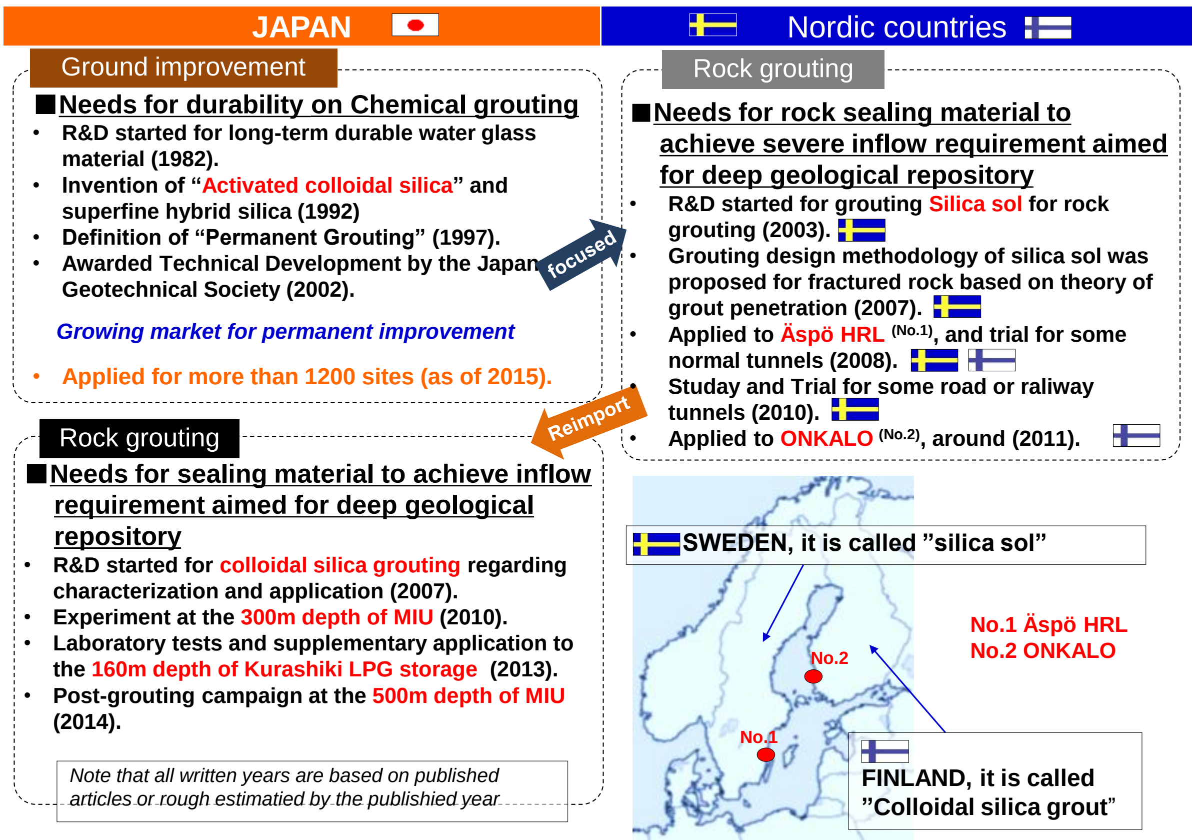


Fig. 3: Summary of R&D and application on colloidal silica grout (CSG) between Japan, Sweden, and Finland, referred from [7] (in Japanese) and translated to English by authors. It is remarkable that the CSG was firstly invented in Japan and applied for the rock grouting in Nordic countries and then "reimported" to Japan as for rock grouting in this field.

As for a grouting material for hard rock, the European CSG was firstly studied in Sweden by Chalmers University of Technology (e.g., [9] or [10]). The rock grouting theory and strategy with this material has been developed and applied to some recent projects in Sweden (e.g., [5]) and the guide to grouting with the CSG was published by BeFo, Rock Engineering Research Foundation in Sweden [11].

Around the same time, JAEA started studying on this grout as a new and fruitful material for grouting tunnels in hard rock (e.g., [6]). For the first time in Japan in great depth, the CSG was applied to an in-situ post-grouting test at 300m depth of Mizunami Underground Research Laboratory (MIU) [12]. Then, it was carried out that comparison study on applying the material between this test and a Swedish project [13]. Based on these experiences, the CSG were applied to the post- grouting campaigns at 500m depth of MIU with catching up Swedish design philosophy [14] , [15].

3. Applications on the CSG under saline water

During the project shown in the introduction, we have investigated the articles regarding latest grouting technologies and especially for CSG, in the aspect of its application under the sea or salty ground water, among Nordic countries and Japan. Here, some of the significant findings are shown as follows.

3.1. Kurashiki National LPG Stockpiling Base, Japan

The CSG has been practically and supplementary applied to the construction of the Kurashiki National LPG Stockpiling Base in Japan [16]. The site is located in the coastal region with saline groundwater. It was applied to seal the fine fractures in order to control the pressure drop of groundwater and to restrict the ingress of water. Before its application, it was meticulously tested to obtain its basic properties and to find the mixtures applicable to the site. Fig. 4 shows an example of "turbidity check test". The grout was slowly poured into the locally collected groundwater and checked if the grout turns white at once or not. This silica grout, which is weakly alkaline, was controlled to be less sensitive to sea salt by adjusting its pH between neutral or weakly acidic. This was performed by adding an acidic pH adjuster.

a) No turbidity, applicable b) Turbidity, not applicable

Fig. 4: Turbidity check tests on sea water. It was performed during the grouting works at the Kurashiki LPG.

3.2. ONKALO, Finland

In Nordic countries, especially in ONKALO in Finland, a low-pH cement grout combined with the CSG was applied to seal the tunnels in great depth, and it was firstly applied with an excavation at "demonstration tunnel 2" at 420m depth, see Fig. 5 and Fig 6. It was reported that the ground water in ONKALO contains a lot of calcium ion in solution and the problem in the execution was that this grout reacts aggressively with this calcium ion [17].

Therefore, grouting methods such as "water injection" were invented in ONKALO [19]. By this method, a fresh water is injected before the grouting and thus the groundwater environment is expected to be unsalted. In addition, fine inclusions in the rock fractures are expected to be flushed out, which makes a positive effect to the better penetration.

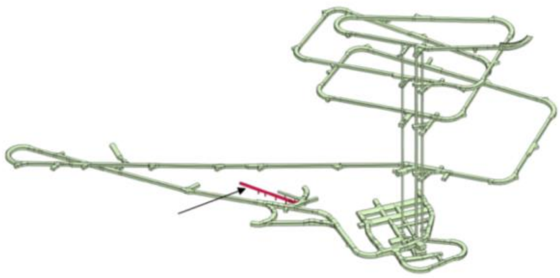


Fig. 5: ONKALO and the demonstration tunnel 2 (red), where the grouting by the CSG was carried out [17].

Fig. 6: A photo of the demonstration tunnel 2 from Posiva Oy's website [18]. It shows a dry condition in the tunnel.

3.3. Äspö HRL, Sweden

In Sweden, a low-pH cement grout combined with the CSG was applied to TASS-tunnel at 450m depth of Äspö HRL see Fig. 7 [5]. Although it was not pointed out about the affection by the groundwater such as saline condition, the more concern was to establish a robust methodology of grouting design in the high ground water pressure of 3.5 MPa or to ensure its durability.

Therefore, related grouting experiments on the "silica sol", which is how this gelling grout is called in Sweden, is still ongoing in Sweden (e.g. [20]).

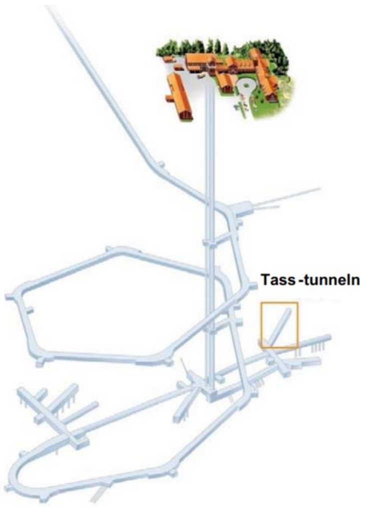


Fig. 7: Äspö HRL and the TASS-tunnel, where the grouting by the CSG was carried out [5].

3.4. Submarine tunnel (by Norwegians), Hong Kong

Norwegians excavated a submarine tunnel called HATS2A under Victoria Harbour in Hong Kong at 150m depth, see Fig. 8 [21]. Remarkably, they applied a microfine cement combined with the CSG to their grouting works in order to attain severe requirement of water ingress into the tunnel. As a result, they succeeded in considerably reducing the water ingress. For example, a fault zone that the ingress expected to be 9200 litres/min per 100m turned out to be 1.0 litres/min, which means a reduction of 99.99%.

It was not pointed out about any problems of this grout affected by sea water in this project.

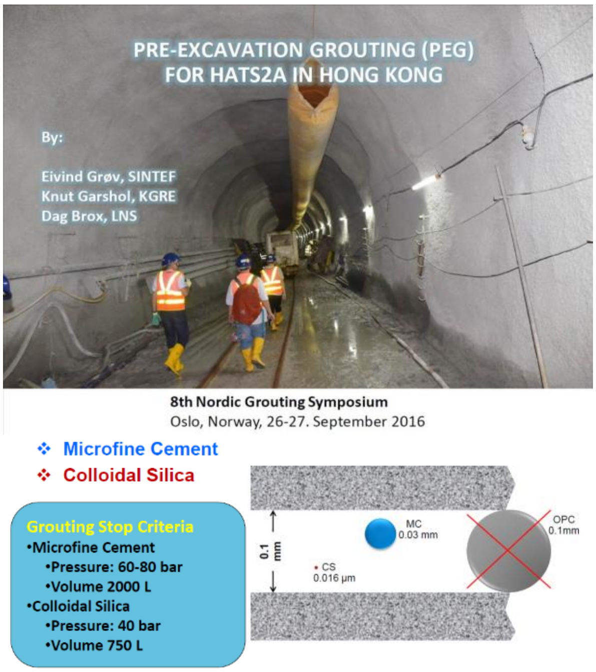


Fig. 8: HATS2A tunnel shown in the above and the applied materials shown in the bottom [21].

4. Grouting workshop in Finland

During this project, we held a *"workshop on colloidal silica grouting in sea water, Helsinki"* in Finland on 26th January 2017, see Fig. 9. The purpose was to exchange information on latest grouting technologies related to geological disposal and especially on the technology of the CSG under sea water, with experts in related fields.

Fig. 9: "Workshop on colloidal silica grouting in sea water, Helsinki" was held on 26th January 2017.

The participants were affiliated with Posiva, Saanio & Riekkola, B+Tech, ROCKPLAN, Chalmers University of Technology, Tyréns, JAEA, and Shimizu Corporation.

During the discussion, a research coordinator in Posiva insisted that Posiva had moved into a phase of the construction of the actual disposal facility and thus Posiva is strictly limiting the ingress of water in the whole underground facility in order to reduce the risk of a rise in fossil water level. Moreover, it was turned out that both the CSG and low-pH cement had become essential materials for Posiva due to the prerequisite to keep the rock mass in deep underground as low alkaline as possible.

We could also obtain the knowledge from Finnish consultants that how they studied on the gelling problems of this material under sea water or calcium rich ground water, and understood how and why they invented the "water injection" method.

On the other hand, from a Swedish expert, it was pointed out that the methods to solve this gelling phenomenon by experiences at construction sites, such as the water injection method were not optimal and better to be avoided. He stressed that the grouting methodology should have been more economical based on more theoretical and experimental approaches.

Regarding the Japanese countermeasure of adjusting the pH of the CSG to lower alkaline, it has been applied to the Kurashiki National LPG stockpiling project as shown above and we were commented as this method might be one of the best approaches against the salty ground water so far. We were advised that it must be needed to sophisticate this mixing method and to confirm the effect on the grout penetration affected by sea water in the rock fractures both by experimental approaches. Moreover, we were advised that the difference in the constituent of sea water must have been focused.

5. Conclusion

Based on the article survey and what we knew from the grouting workshop, we sorted out in each country the ideal direction toward the development of the grouting methodology in the CSG under sea water with an approach to the solution, as follows.

- Japan: Developing and establishing a mixing method of the CSG using the pH adjuster is necessary. The approach to the solution should be based on the experience in the Kurashiki LPG stockpiling project.
- Sweden: Developing more reliable grouting design and ensuring the durability for the CSG is necessary. The approach to the solution should be based on theories and experiments.
- Finland: Developing more economic controlling methods for the CSG at site is necessary. The approach to the solution should be based on the actual grouting works.

As a result, it was found that the approaches for countermeasures in grouting the CSG under sea water were different between Japan, Sweden and Finland. In Japan, it is based on mixing method, in Sweden on design method, and in Finland on controlling method. Therefore, it seems that the best solution against this problem is in the near future to establish a hybrid and optimal grouting methodology under sea water by combining each country's developed grouting technology.

This should be performed by periodically sharing the latest information in each country regarding this field.

As for this Japanese project, it was discovered significant to develop a generic mixing method for the CSG under saline water by referring to a previous experience in the Kurashiki LPG stockpiling project in Japan. We have recently started laboratory tests to establish this method under sea water.

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