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# Interface shear behaviour of tunnel backfill materials in a deep-rock nuclear waste repository in Finland

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**Abstract**

The need for environmental protection and safety in facilities dedicated for the final safe disposal of spent nuclear fuel is paramount. Highly engineered multi-barriers are widely used in such waste containment facilities in order to provide a tight seal for the waste they contain. In Finland, several research studies have been conducted to investigate the feasibility of the final safe disposal of spent nuclear fuel in crystalline bedrock by incorporating the KBS-3V multi-barrier repository concept. As the saturation of the tunnels in a repository progresses, the pre-compressed bentonite buffer may swell and generate very high swelling pressure in the range of 7–15 MPa. Such high swelling pressure can cause the upheaval and the compression of the tunnel backfill that would eventually decrease the density of the buffer. For various reasons, the current KBS-3V design suggests that the saturated density of the buffer should be maintained within a narrow range of 1950–2050 kg/m$^3$ at all times. As the swelling of the buffer directly influences the saturated density of the buffer, it must be controlled by designing a tunnel backfill that possesses an adequate amount of interface shear strength to sustain any additional pressure that is exerted by the swelling of the buffer. This study presents the findings of a series of direct shear box tests conducted on various tunnel backfill interfaces. Additionally, different types of rock profiles were also tested with the selected backfill materials. Based on the results, it was observed that the interface shear behaviour of different backfill-rock interfaces varied significantly with the surface roughness of the rock, while clay blocks resulted in similar shear behaviour with all the backfill materials.
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*Keywords:* Multi-barrier; Interface shear; Tunnel backfill; Bentonite; Nuclear waste; KBS-3V

## 1. Introduction

Nuclear waste management has become more challenging with the rapidly increasing global demand for nuclear energy; and hence, the final safe disposal of spent nuclear fuel has attracted increasing attention in recent years. Facilities for the final disposal of spent nuclear fuel require highly engineered disposal techniques, which often incorporate multi-barriers in order to protect the environment over the long-term. In Finland, research studies are being carried out to investigate the feasibility of the final safe disposal of spent nuclear fuel in crystalline bedrock at a depth of approximately 420 m below the ground level by incorporating the KBS-3V (*"KärnBränsleSäkerhet"* referred to as "nuclear safety") concept, (SKB, 1998; Posiva, 2010).

The multi-barrier system is often comprised of several individual barriers; it isolates the waste from organic nature by providing a tight final seal (Miller et al., 2000; Sinnathamby et al., 2014). These multi-barrier systems are designed in such a way that the failure of a single barrier does not jeopardise the performance of the entire barrier system. One of the key elements of the multi-barrier system in the KBS-3V concept is the backfill of disposal tunnels. According to the current

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**Notations**

| | |
|---|---|
| $R_a$ | average roughness parameter |
| $c$ | cohesion |
| $e_0$ | initial void ratio |
| $w$ | water content |
| $w_0$ | initial water content |
| $\rho$ | density |
| $\rho_d$ | dry density |
| $\rho_s$ | density of solids |
| $\rho_w$ | density of water |
| $\phi$ | interface friction angle |

KBS-3V proposals, the backfill of disposal tunnels consists of three major components, namely, block backfill (pre-compressed bentonite blocks) that fills the majority of the tunnel volume, foundation bed material (bentonite granules or a mixture of crushed rock and bentonite granules) that is placed between the floor of the tunnel and the block backfill, and pellet filling (bentonite pellets) sprayed around the block backfill (Hansen et al., 2010) (Fig. 1a).

During the lifetime of a repository, the backfill and the buffer will undergo saturation due to groundwater seepage into the tunnels through the fractures in the host rock. Fig. 1b shows a worst-case scenario in which the buffer first starts to become saturated due the presence of a fracture in the deposition hole (the tunnel backfill is relatively dry at this stage). As the buffer material contains swelling clay minerals, the saturation will cause the buffer to swell. Since lateral expansion is limited inside the deposition hole, the swelling will predominately result in the subsequent upheaval of the buffer. When the backfill is dry (i.e., no counter-swelling pressure created by the tunnel backfill at this stage against the swelling of the buffer), the swelling buffer can cause upward deformation in the tunnel backfill (Fig. 1c). If the upheaval of the tunnel backfill exceeds a certain limit, it will lead to a substantial decrease in buffer density. According to the current KBS-3V proposals, the saturated density of the buffer directly above the canister should not be allowed to decrease below 1950 kg/m$^3$ at any time, in order to protect the copper canisters from corrosion, by preventing microbial activities. An upper bound has also been proposed for the saturated buffer density of 2050 kg/m$^3$, in order to protect the copper canisters from possible rock movements and to keep the swelling pressure of the bentonite buffer below 10 MPa. This prevents the host rock from possible damage caused by the excessive swelling of the buffer (Juvankoski and Marcos, 2010). From this worst-case scenario, it can be understood that the backfill should be designed in order to sustain any forces created by the swelling

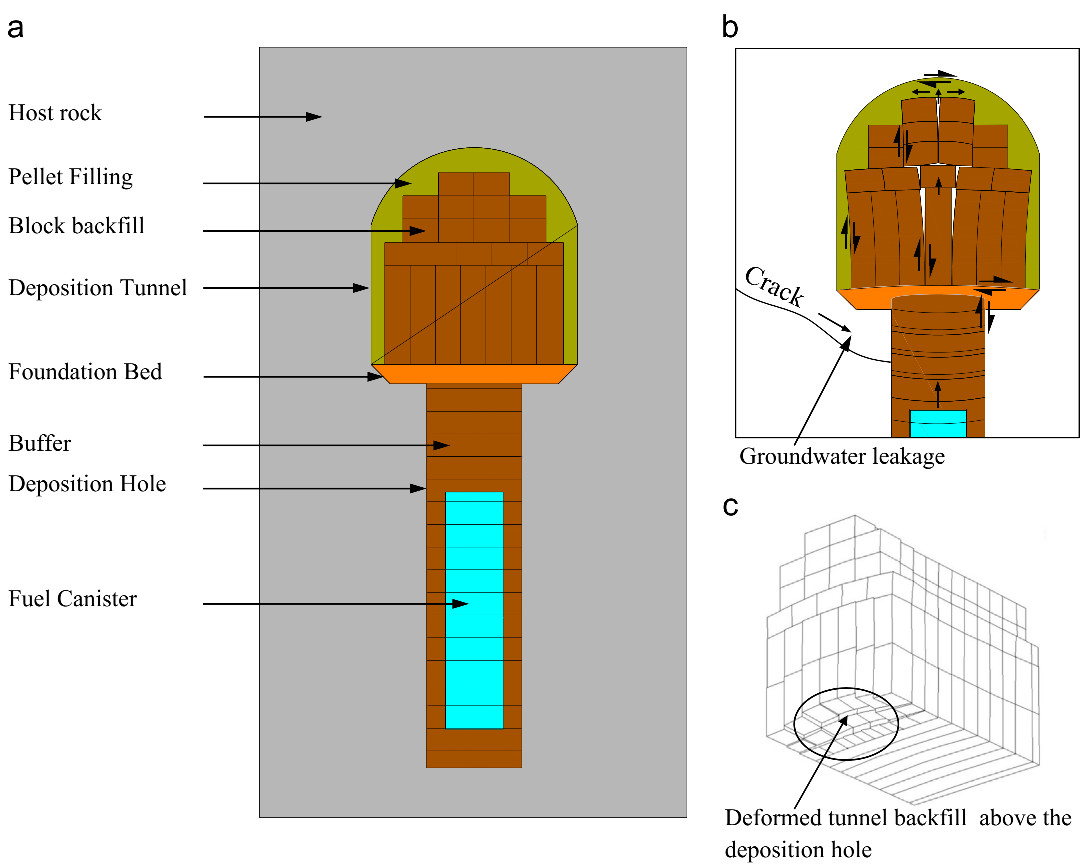


Fig. 1. (a) Schematic of KBS-3V concept, (b) swelling of buffer into tunnel backfill and upheaval of backfill caused by groundwater leakage through rock fractures and (c) deformation of tunnel backfill directly above deposition hole (in 3D) (after Leoni, 2012).

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