

DEMONSTRATION OF GAP FILL MATERIAL DELIVERY TECHNOLOGY TO BACKFILL PLACEMENT ROOM VOIDS

M. Mielcarek¹ and K. Birch¹

¹ Nuclear Waste Management Organization, Toronto, Ontario, Canada
mmielcarek@nwmco.ca, kbirch@nwmco.ca

Abstract

The placement rooms for long term used fuel storage in the deep geological repository are to be excavated using drill and blast techniques. The rooms are approximately 3.2 m wide and 2.2 m tall to fit one Buffer Box wide, stacked 2 high through the length of the room. Due to the undulating wall profile, the resulting distance between the rock and the Buffer Boxes is expected to range from 100 to 250 mm. The resulting void must be backfilled with Gap Fill Material (GFM) to achieve the required dry density of the bentonite engineered barrier. The GFM is compacted bentonite that is granulated to a specific particle size distribution to efficiently fill the void. The as-placed GFM must meet a minimum dry density requirement of 1410 kg/m³.

The method currently being tested by the NWMO to place the GFM is by screw conveyor. Initial bench testing was conducted using commercially available equipment to test GFM delivery into a 1 m x 1m x 0.15 m test box. Bench testing with an alternate, GFM-like material achieved equivalent as-placed dry-densities that exceeded the 1410 kg/m³ requirement.

A custom screw conveyor system has been specifically designed and fabricated to test and develop the process for filling the void in a simulated, full size room section. The system is capable of moving the screw conveyor vertically up the walls of the room and horizontally across the top of the buffer boxes. The screw conveyor is designed to withstand a 225 kg axial force to push the GFM into the void and fill all the wall surface irregularities to achieve the required dry density of 1410 kg/m³.

Keywords: Bentonite, Screw conveyor, Gap Fill Material

1. Introduction

The rectangular shaped placement rooms for long term used fuel storage in the deep geological repository will be excavated using drill and blast techniques. In drill and blast methods, the perimeter blast holes are drilled at a slight angle into the rock wall, and as a result, there is a slight variation or undulation in the cross-section dimensions along the length of the excavation. The resulting maximum cross-section dimensions are often referred to as the lookouts and are usually present at the end of each blast round. Due to the wall profile, the resulting distance between the rock and the Buffer Boxes is expected to range from 100 to 250 mm. The resulting void must be backfilled with Gap Fill Material (GFM) to achieve the required dry density. The GFM is compacted bentonite that is granulated to a specific particle size distribution to efficiently fill the void. The as-placed GFM must meet a dry density requirement of 1410 kg/m³.

NAGRA, which is the Swiss technical competence centre for deep geological disposal of radioactive fuel, have developed a bentonite based backfilling material for their placement concept. NAGRA refers to this as a highly compacted granulated bentonite mixture (GBM) which involves granulating and blending highly compacted bentonite pellets. The result is a blend of material with particle sizes ranging from a maximum size of roughly 8 mm to less than 10% finer than 75 µm. NAGRA uses a screw conveyor system to deliver and place the GBM material in their placement tunnel concept and have demonstrated that an as-placed dry density exceeding 1410 kg/m³ is achievable. NAGRA's void space is significantly larger and their screw conveyor design can't be used in the NWMO placement room concept.

The objective of this work is to develop a screw conveyor specification and a method of delivering NWMO GFM to the narrow void between the Buffer Box and the Placement Room walls (surrounding rock) and achieve a minimum as-placed dry density greater than 1410 kg/m³.

2. Background

2.1 Bentonite Dry Density

The bentonite buffer serves multiple roles. The buffer swells and fills any remaining void space and as a result provides support to the surrounding rock and container. Its low permeability inhibits porewater flow to and from the container and its sorption properties inhibit radionuclide movement in the event of container breach. The bentonite also transfers heat from the container to the surrounding rock. Perhaps most importantly, a water activity of <0.96 is required to suppress microbial activity and mobility. To meet this water activity requirement, an average weighted minimum buffer dry density of 1600 kg/m³ is required for groundwater with salinity of less than 100 g/L [2]. The buffer which consists of 100% bentonite materials, includes both the GFM and the Highly Compacted Bentonite.

2.2 Placement Concept

The NWMO placement concept is illustrated in Figure 1. The current placement room is an approximately 275 to 325 meter long, dead ended tunnel with a rectangular cross-section. The room cross section is based on access requirements for placement equipment and the Buffer Boxes. The Used Fuel Containers (inside Buffer Boxes) are first placed at the closed end of the room and are stacked two high. The room is filled in a retreating manner until the required number of buffer boxes have been placed (Figure 2).

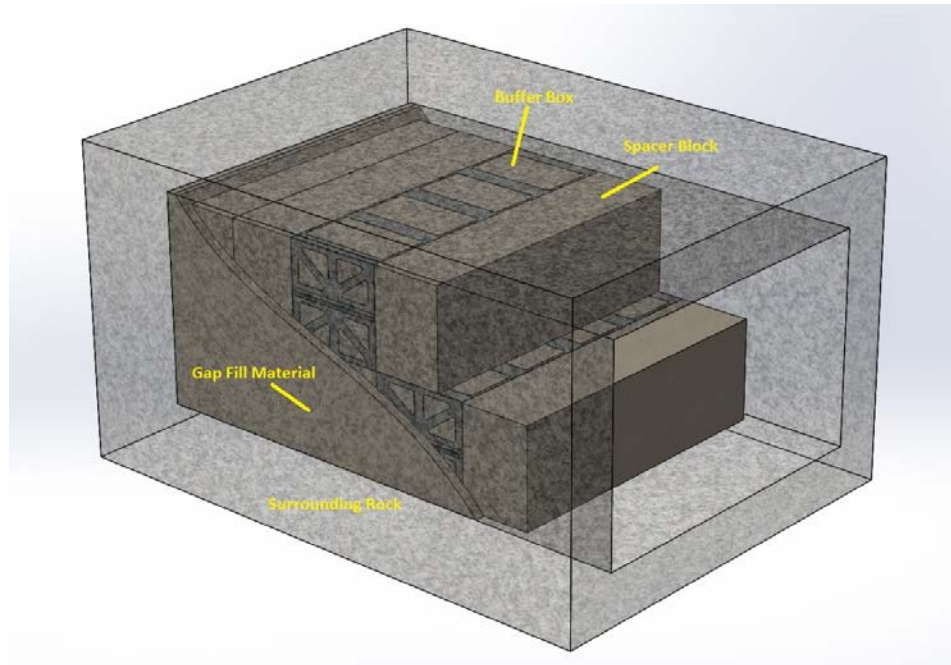


Figure 1 Placement Room Concept

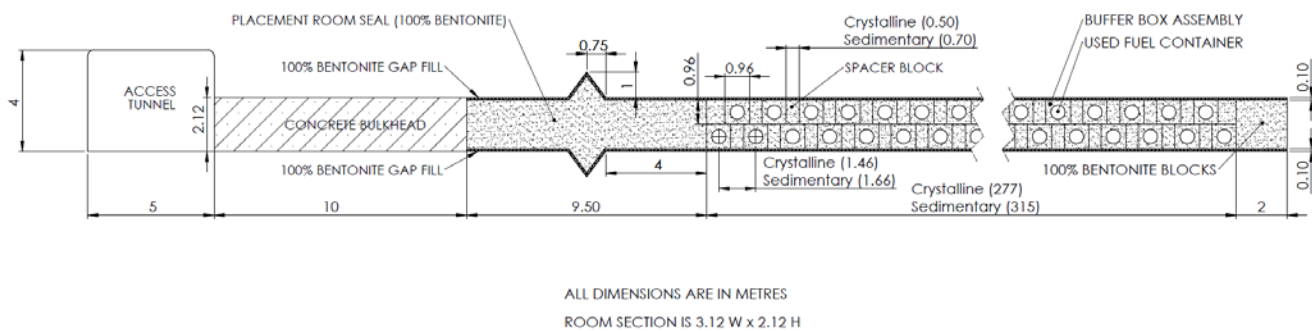


Figure 2 Placement Room Layout

The nature of the rock excavation combined with the need to maintain space for equipment movement necessitates a void space between the Buffer Box and the surrounding rock of the room. The minimum void width is 100 mm. The void must be filled for the length of the placement room.

3. Gap Fill Material

NAGRA have developed a bentonite based material for their placement concept that can be adopted as a GFM in the NWMO concept. GFM is produced by reducing the moisture content of as-delivered MX-80 bentonite to 2-3% and then running it through a roll compactor to increase dry density before milling the compacted material to achieve the desired particle distribution for optimum packing efficiency.

4. Bench Testing

The steps in the testing program were designed to simulate the filling of the gap in a smooth annulus representative of the width of gap expected in the emplacement room. The test configuration, consisting of the screw conveyor and frame, is shown in the photograph in Figure 3. The screw conveyor is inserted through the portal and into the test frame so the outlet is positioned at the far wall.

For this study, limestone screenings were used to simulate the bentonite-based GFM. The limestone screenings had a particle size distribution that was similar to that of GFM. The limestone screenings are placed in the hopper of the screw conveyor and the screw conveyor is turned on. As the screw conveyor discharges GFM into the gap, the test frame is rolled back along a track to simulate the withdrawal of the screw conveyor from the gap. Once a layer is filled, the frame is lowered roughly 100 to 200 mm, the frame is moved forward, and the overlying GFM layer placement is repeated.



Figure 3 Photograph of utility screw conveyor and small scale test frame

The placement trials are varied by burying the screw conveyor outlet in the deposited GFM a specified depth in an effort to compact the as-placed material. By inserting the screw conveyor outlet into the GFM, the GFM being discharged will compact the previously placed material, thereby increasing the as-placed density within the gap. For these initial trials, the screw conveyor outlet depths, as measured from the top of the casing, were 0, 50 and roughly 100 mm. When the screw conveyor is buried, the screw conveyor will force out the GFM, so that a mound forms above top of outlet. As an aside, in the NAGRA placement concept, the screw conveyor outlets are buried in the previously placed Gap Fill and backed out as the backfill pressure exceeds a set point.

The bulk density of the as-placed limestone screenings is then determined by measuring the volume of the screenings in the frame, and removing and weighing the screenings. For comparison purposes, trials were also conducted where the screenings were dropped from the top of the box, and from the bottom lip of the outlet and onto the layer below. In select trials, the volume of GFM was re-measured after the

filled test frame was vibrated. In these tests a rubber mallet was used to induce vibrations into the box in an effort to densify the GFM.

4.1 Observations

4.1.1 Limestone Screenings Characteristics

Particle size (ASTM C136), and a standard Proctor (ASTM D698-12) analyses were carried out on samples of the limestone screenings used to simulate the GFM in the bench scale GFM placement trials. These tests were carried out to compare the limestone screenings properties with the NAGRA Gap Fill material. Proctor tests are a laboratory method of determining the optimal moisture content at which a given soil type will become most dense and achieve its maximum dry density. A standard Proctor test was carried out on the limestone screenings and the Standard Proctor Maximum Dry Density (SPMDD) was found to be 2225 kg/m³ at an optimal moisture content of 7%.

4.1.2 Particle Size Distribution Curves on Gap Fill Material and Limestone Screenings

The grainsize distribution curves for three samples of the limestone screenings, a sample of the NAGRA Gap Fill material, and MX-80 are compared to a municipal specification for limestone screenings as shown in Figure 4. Each of the four GFM type samples meets the limestone screenings specifications. In comparison, the MX-80 consists of sand sized particles and is more uniform with respect to its particle size. The limestone screenings consist of well-graded angular crushed particles that provide a readily compactable material. The NAGRA gap fill material has been prepared with a similar intention.

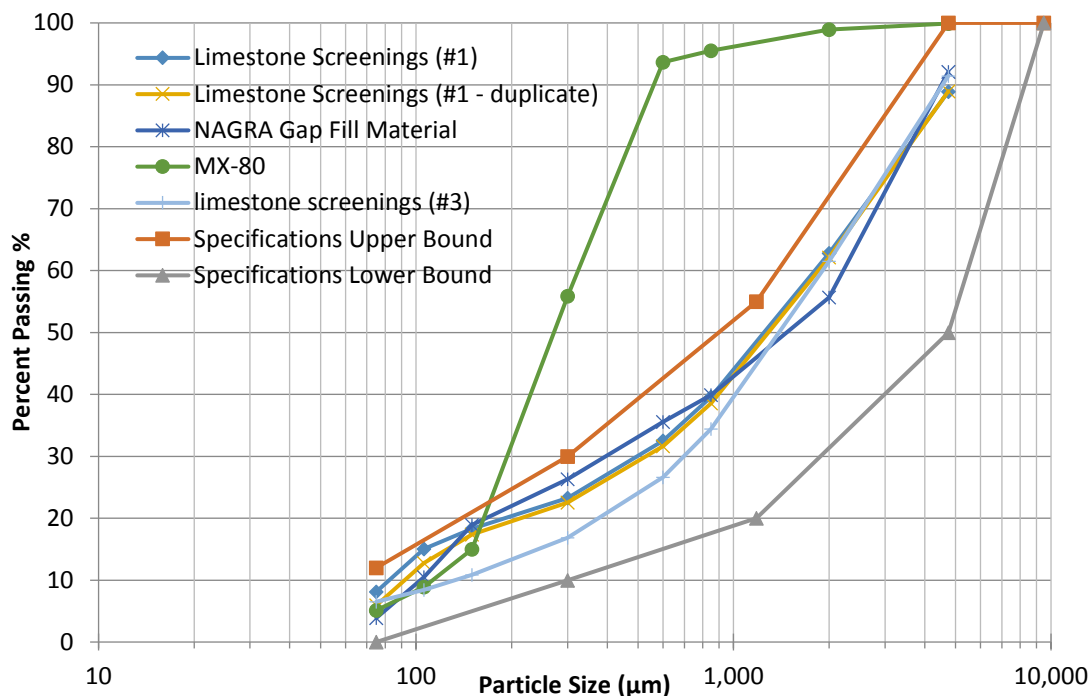


Figure 4 Particle Size Analyses on Limestone Screenings, NAGRA Gap Fill Materials and MX-80

4.1.3 Small Scale Gap Fill Placement Trials

A total of 18 screw conveyor trials were completed using the utility screw conveyor and the flexible shaft less screw conveyor. The utility screw conveyor was used in 14 of the trials, and the flexible shaft less screw conveyor was used in the remainder. For the shaft less flexible screw conveyor, the screw conveyor

could not consistently deliver the GFM from the screw conveyor casing into the as-placed GFM, and as a result the number of tests were limited, since the GFM could only be discharged when there was no obstructions covering the screw conveyor outlet. Other conditions were also varied, including the number of layers and the depth of burial of the screw conveyor outlet into the placed material.

The NWMO GFM dry density was categorized into “as-placed” (light compaction) or “enhanced” (moderate compaction). To reflect the nature of the compaction during the placement trial. Each of the eight tests where the test frame was struck with the rubber mallet inducing a vibratory shock, or where the screw conveyor outlet was inserted into the already placed limestone screenings was designated as “enhanced” compaction. In some trials the screw conveyor casing was observed to vibrate due to the inferred grinding of particles by the screw conveyor. These vibrations were observed to induce settlement of the limestone screenings within the test frame.

Once the tests were completed, the height of the GFM within the test frame was measured to determine the as-placed volume. No bowing of the test frame was observed. The GFM was then removed from the test frame and weighed. Given that the moisture content of the limestone screenings was 0.13%, the dry density was then computed. A conservative bentonite moisture content of 4 % was assumed. For calculation purposes, it is assumed that the GFM pellet specific gravity density will be roughly 0.77 of the specific gravity of the limestone particles based on bulk specific gravity test results (ASTM D 1188).

4.1.4 Gap Fill Test Results

The dry density of the limestone screenings was compared with the burial depth of the screw conveyor outlet as shown in Figure 5. The plot also compares results where the GFM was “as placed” or placed under “enhanced” conditions. “As placed” includes the tests where there was no resistance to the GFM being discharged from the screw conveyor outlet, or where no apparent vibrations occurred during placement. For enhanced compaction, the screw conveyor outlet was buried during placement so as to provide some compaction effort to the GFM, or the test frame was vibrated by the screw conveyor or by tapping the exterior of the test frame.

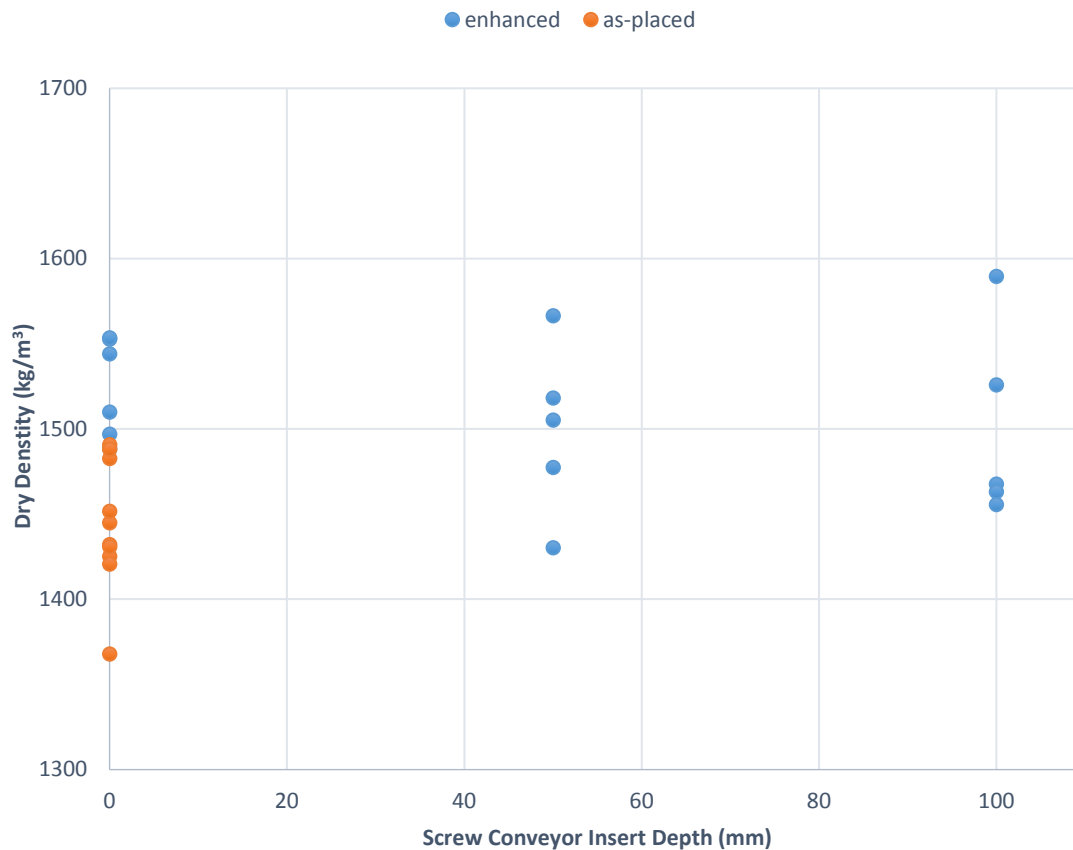


Figure 5 Equivalent As-placed Dry Density as a Function of Screw Conveyor Insert Depth

From all the tests conducted the equivalent as-placed dry densities as determined from the screw conveyor trials ranged from 1368 kg/m³ to 1589 kg/m³. In the 10 results deemed to be reflective of light compaction the average as-placed equivalent dry density was 1443 kg/m³, this compares with the 16 results deemed to be reflective of a moderate compaction where the average was 1509 kg/m³. In eight of these 16 tests, the test frame was tapped with a rubber mallet for roughly 2 to 3 minutes and these vibrations appeared to increase the average equivalent GFM dry density from 1461 to 1526 kg/m³. In the tests where the screw conveyor outlet was inserted 100 mm into the already placed Gap Fill Material, the equivalent GFM dry densities were found to range from 1456 to 1525 kg/m³. Dust generation was significantly less when the screw conveyor was buried into the as-placed GFM. An attempt was also made to insert the utility screw conveyor casing into the placed GFM a distance of greater than 100 mm, but the screw conveyor motor stalled, and therefore the depth of insert was limited to 100 mm.

The results shown in Figure 5 suggest there is a benefit in either vibrating the GFM during placement or by inserting the screw conveyor outlet into the as-placed GFM in order to provide additional compact. This is consistent with NAGRA's observations using their larger diameter screw conveyors. It is acknowledged that there is a comparatively wide range of results, and this is likely due to the qualitative nature of the vibrations applied to the test frame.

Based on these trials, it is apparent the particle size distribution of a crushed, angular particle can be optimized to produce a material for placement to the required dry density with minimal compaction. A revised NWMO GFM particle size distribution is warranted to better reflect the particle size distribution of the limestone screenings and the NAGRA GFM. This revision is presented as Column 3 in Table 2.

Table 2 Current and proposed GFM particle size distribution envelope

(1) Particle Size (mm)	(2) Limestone Screenings Specifications Cumulative Weight Passing	(3) Proposed Revised GFM Cumulative Weight Percent Passing Specifications
8.0	100	100
4.75	50-100	70-100
1.18	20-55	30-55
0.3	10-30	10-30
0.075	0 -12	0 -12

4.1.5 Bench Testing Conclusions

Eighteen placement trials were carried out using the 100 mm diameter utility screw conveyor and the 75 mm diameter flexible shaft less screw conveyor. The screw conveyor outlet was either placed into the already placed GFM, or the GFM was dropped into the frame from the end of the screw conveyor. During several of these trials unintended vibrations also increased the as-placed densities. In several tests, the test frame was tapped with a rubber mallet to further assess the impact of additional vibrations.

Based on the results of these small scale gap fill placement trials the following conclusions can be made:

- The shaft less screw conveyor is not suitable for placement of the GFM, as the screw compresses and the particles bind in the screw conveyor casing prior to discharge;
- The depth of insert of the utility screw conveyor into the placed GFM was limited to less than 100 mm, anything greater resulted in the screw conveyor motor stalling.
- It would be apparent in almost all cases, that the as-placed dry density of the GFM would meet design requirements, under the assumption that the individual Gap Fill particles have a dry density of roughly 2100 kg/m³, and the particle size distribution of the GFM is similar to the particle size distribution of the limestone screenings used for these demonstration trials.
- It is also apparent that applying vibrations to the GFM and inserting the screw conveyor outlet into the as-placed GFM improves the bulk density of the material.

5. Custom Screw Conveyor

Based on the initial bench test trials, the NWMO contracted Solutions Novika of La Pocatière, Quebec to design a custom screw conveyor and travel system specifically for the void dimensions in the NWMO placement room concept. It is important to note that this screw conveyor is to be used to develop the placement methodology and the power and torque requirements. This system is not a prototype for

operating with the dimensional constraints of the placement room. Testing is scheduled to start in the spring of 2016.

The custom screw conveyor system is designed to conduct testing in a mock-up section of the NWMO room concept. The mock-up room section represents the approximate height of the room, half of the width and 4 meters of depth (Figure 6).

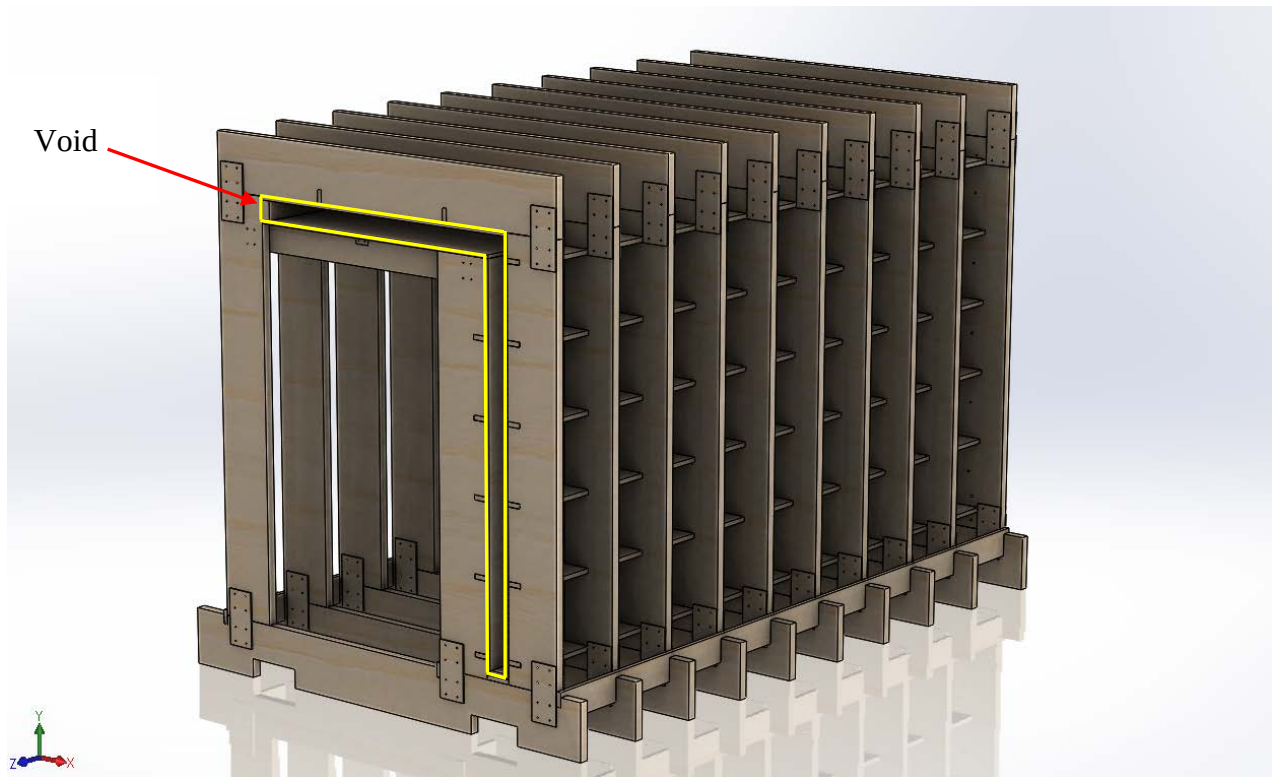


Figure 6 Mock-up Half Room Section

The custom screw conveyor sits on a track system and lift table that can move the screw conveyor within the yellow highlighted area in Figure 6 and can reach the full 4 m length into the mock-up and can be retracted all the way out.

The screw conveyor tube is 90 mm in diameter and powered by a 2 HP Nord Gear, worm type, gear motor with an output speed of 174 rpm and an output torque of 70 Nm. The gear motor is connected to the screw via chain and sprockets at a nominal ratio of 2:1. This ratio is adjustable for test purposes. The entire system is designed to withstand an axial force at the tip of the screw in excess of 225 kg_F to ensure sufficient packing density of the GFM. The prototype is also outfitted with a vibrator on the screw tube to help densify the GFM as it is placed. The prototype is shown in Figure 7.



Figure 7 Novika Prototype Screw Conveyor

6. Conclusion

Based on the small scale trials in a 1 m by 1 m by 0.15 m box, it is apparent that bentonite based Gap Fill Material with a particle size distribution similar to that of standard limestone screenings, and with a chip dry density of roughly 2050 kg/m³, will exceed the minimum dry density of 1410 kg/m³, particularly, if a moderate compactive effort is made to the as-placed material.

Given the success of the small scale trials, a prototype screw conveyor capable of placing Gap Fill Material into a 100 mm gap in a full scale placement room has been fabricated. The prototype Screw conveyor will be used to demonstrate that an as-placed dry density of 1410 kg/m³ is achievable and to further refine the requirements for a pre-production prototype screw conveyor system to back fill GFM within the geometric constraints of the placement room.

7. References

- [1] Kotler, S., B. Garitte, H. Weber, and H. Müller. 2015. Emplacement Report LUCOEX – WP2. Deliverable (D-N°:D2.5). Grant Agreement: 269905)
- [2] Stroes-Gascoyne, S., C.J. Hamon, P. Maak and S. Russell. 2010. The effects of the physical properties of highly compacted smectitic clay (bentonite) on the culturability of indigenous microorganisms. *Appl. Clay Sci.* 47:155-162.