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PLANS FOR SOLVING THE EMPLACEMENT PROBLEM SITUATIONS FOR KBS-3V EMPLACEMENT WORK AND GAP FILLING

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Contents

1 INTRODUCTION

The report describes development of methods for the management and recovery of broken buffer blocks, gap filling and other exceptional situations, from a vertical deposition hole during KBS-3V buffer block emplacement work and gap filling.

The final disposal facility to store the spent nuclear fuel produced in Finland will be located in Olkiluoto, at a depth of approximately -420 metres. At this level there is also demonstration tunnels used to test the final disposal techniques under repository conditions.

The main aim of the work described in this document is to test the feasibility of various methods for the removal of damaged buffer components could be accomplished such that the other already emplaced parts are not damaged. In addition to primary goal of recovering damaged bentonite blocks at their emplacement humidity, removal of bentonite blocks that have reacted with water (simulating a wet borehole) had to be demonstrated.

The machinery developed to remove damaged buffer components consists of a bentonite block lifter device mounted on a frame, a device for water jet cutting damaged blocks and a suction device to remove block and pellet fragments or materials from the deposition hole.

2 FEASIBILITY STUDIES

Error handling in buffer installation can involve a wide range of situations. They could include such things as dealing with a water filled deposition hole, to a hole and buffer contaminated by oil leaking from deposition tunnel backfilling machinery, through to mechanical failure of the buffer during or post-placement in the deposition hole. As a result, some limitations to project scope were identified in the LUCOEX WP5 LOT3 work description and further limitations to LOT3 were identified while completing the work in LOT2 (buffer quality assurance) and LOT1 (buffer emplacement).

As noted the scope of LOT3 needed to be revised and narrowed and this occurred the feasibility assessment phase of problem handling methods and equipment. Some problem descriptions and subsequent technical demands led to very complex remediation/recovery handling equipment of high cost and high technological risk associated with them. In evaluation of the options for remedial activities, these demands and situations were re-assessed with the intent to achieve realistic, practical and technically robust design(s) that could perform the task of dealing with installation upset situations while ensuring both worker and long term safety in deposition tunnels.

In the likely range of situations that could be encountered in the process of installation of the buffer there are several situations that could be expected to occur. Below is a listing of the types of items/materials that the installation/remediation equipment should be able to remove from the deposition hole:

- Irregularly shaped bentonite clods
- Gravel like small bentonite pieces
- Bentonite pellets
- Bentonite dust
- Slurry from bentonite/bentonite water interaction
- Small rocks
- Rubber moisture protection shield and pieces of it
- Complete bentonite blocks
- Broken bentonite blocks
- Machine parts, nuts, bolts, pins
- Contaminated bentonite blocks
- Water

The above-listed items and situations are used as the basis for development of approaches and equipment for dealing with complications to the buffer installation process.

2.1 Problem handling before canister installation

If installation of buffer blocks fails before the canister has been installed, there is no radiologically-impacted material in the deposition hole. Although there may be a canister in an adjacent borehole, the distance and shielding provided by several metres of intact rock means that there is no radiological hazard to the operators of the crew undertaking clean-out of the affected deposition hole. There would of course be continuous radiation monitoring of the area throughout the time that clean-up is occurring. In this case the fastest, most accurate, and safest solution is for human operators to enter the deposition hole (or its vicinity) to complete cleaning.
Depending on the condition of the materials to be recovered and factors such as water inflow to the deposition hole there will be different equipment and approaches needed to complete clean-up. In the

most commonly anticipated condition in Posiva's repository (dry deposition holes), some equipment will be needed to break the bentonite blocks and to lift block pieces and pellets from the deposition hole. These tools are simply heavy hammer drill, vacuum cleaner (industrial cleaning truck) and screw lifter or anchor for bentonite clods that needs to be developed to gain maximum grip from bentonite blocks.

As humans are operating in the deposition hole, in addition to the normal safety regulations, the following points need attention before starting the dismantling work:

- Safety of the human workers (safety harness, helmet etc.)
- Safety regulations on lifting weights
- Safety regulations on lifting orders when lifting bentonite using screw attachment
- Safety regulations on working depths (cm level below bentonite top level)
- Safety regulations on tunnel operations during the cleaning work
- Presence of a radiological monitoring system if there are nearby deposition holes that already contain spent fuel canisters.

In the best-case situation, damaged blocks that are still mainly in one piece and have a sufficient top surface area shall be removed using a suction lifter. Posiva's existing vacuum lifter can be used for 800mm high bentonite block removal from deposition hole when an adapter plate is installed on the BIM gripper (Fig. 1 and Fig. 2). Ring segment removal will probably not be possible with the standard lifting and moving procedure as space between legs and gripper is limited.

With vacuum lifter following items can be removed from the deposition hole in error situations:

- Complete bentonite blocks
- Broken bentonite blocks
- Chemically contaminated blocks

If use of the suction lifter is not possible then human workers can enter the deposition hole to clean down to the lifting surface of the first complete bentonite block that has an upper surface that remains unharmed. Smaller block pieces could be removed using through bolt expansion anchors. This method was tested to verify if the anchor can be used to lift a bentonite piece several meters down in the deposition hole.

Once the broken materials have been cleaned out of the deposition hole and a clean and intact upper surface of an underlying block is identified then the vacuum lifter can be utilized and complete and rapid buffer dismantling with a vacuum lifter can occur. This will be particularly useful in a case where a complete ring block has fallen on top of previously installed blocks.

In a situation where there has been a block installation failure or subsequent unanticipated water influx has compromised the deposition hole's content there are a couple of potential responses. These include:

- Excavation of wet materials through use of hydro-excavation (see section 2.2.6 and 2.3) or other technique and then re-installation of buffer,
- Abandonment of the deposition hole, buffer recovery may or may not be undertaken depending on the situation.

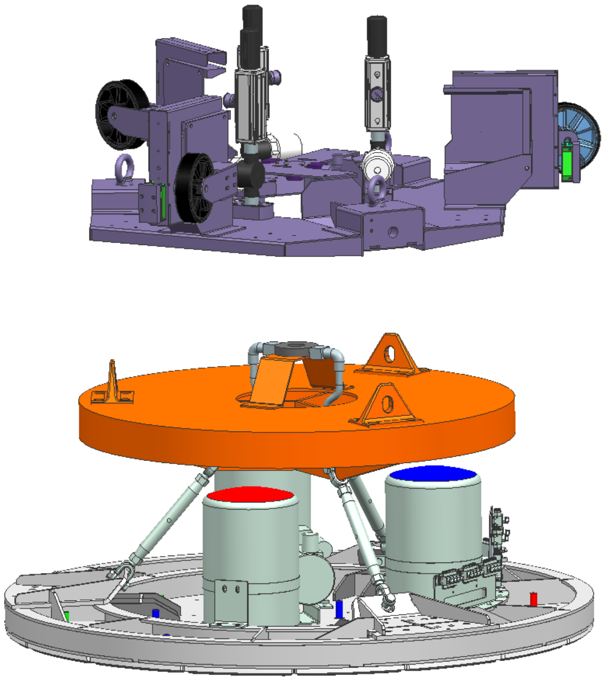

Fig. 1.Posiva's test vacuum lifter with BIM adapter plate (orange part).

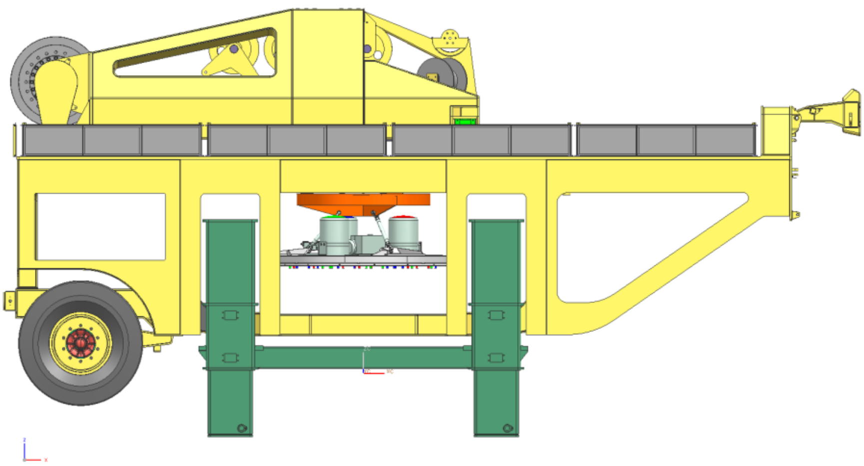

Fig. 2. Posiva's test vacuum lifter in BIM gripper.

2.2 Problem handling after canister installation

Problem handling, including recovery of a damaged buffer segment or the need to recover a canister after its installation (e.g. as a result of excessive water inflow not identified or occurring subsequent to canister installation) has two additional and serious challenges compared to what is needed to recover buffer before canister installation. First, the work has to be performed remotely because of the radiation from the canister. Second, extra care has to be taken not to damage the installed canister.

Several methods of handling broken or damaged blocks were considered and evaluated (Sections 2.2.1-2.2.6).

2.2.1 Screw lifter

A screw lifter is a mechanical lifter that would be attached to Posiva's bentonite buffer installation machine (BIM) with multiple self-tapping coarse threads (Fig. 3). The Lifter would be lowered into contact with the broken bentonite block and each of the screws would be turned to grip the bentonite block parts. This method would allow bigger broken bentonite parts to be lifted from a deposition hole with one lift. The Screw lifter would be able to handle full bentonite blocks, broken bentonite blocks and possibly bigger bentonite clods, but not materials like smaller bentonite pieces, soft segments or slurry. For these smaller pieces and pellets a suction cleaner etc. would be needed.

Concept pros:

- Relatively reliable when correct thread type and hole size has been found
- If screws can be lowered individually, recovery of highly damaged blocks via lifting can be accomplished as screws can grip bentonite clods better than a vacuum lifter
- Method is robust; no need to worry about dust in pumps etc.

Concept cons:

- Hard to control, visibility under screwset is very limited, instrumentation for screws penetration to bentonite hard to engineer. These cause unreliable operation.
- Extremely complex mechanics is needed if advantage over vacuum gripper is wanted.
- Needs possibly long test and re-engineering phase for screws and control to achieve reliable operation.
- Lifting reliability highly dependent on screw penetration and mass, bentonite fragments with small top surface area and high mass may not be possible to lift or may come loose to fall back into the deposition hole, impacting on the underlying bentonite blocks or canister.

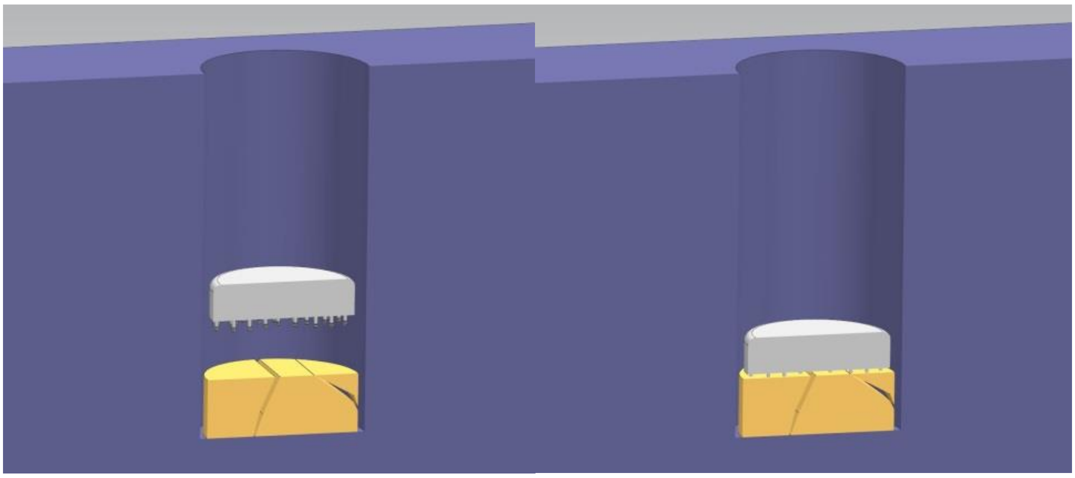

Fig. 3. Screw lifter in deposition hole with broken bentonite block. Lifter approaching (left) and attached to broken block (right).

2.2.2 Grinder with suction cleaner

A bentonite grinder is a grinding machine that reduces damaged bentonite block(s) to small gravel like pieces or dust and an integrated suction cleaner takes away this material. Grinder and suction cleaner combination can be used to remove all kinds of objects and has the ability to remove water and slurry (depending on suction head design). The risk of damaging underlying previously undamaged bentonite blocks and spent fuel canister below the segment to be removed is present, but this risk can be minimized with depth measurements being used to limit the movement of the cutter.

- Grinder was studied for potential integration with deposition hole bottom levelling machine.
- Grinder was found to be not practical. It would require extensive modifications to levelling machine design in order to protect it from the dust and sludge generated during the removal of bentonite parts. It would also require a relatively even surface for its operation to be effective using the levelling machine, limiting the number of situations where it could be used. The levelling machine is also designed to grind just millimetres if rock at a time, not to move many cm in a short time, making the process very slow without extensive re-engineering of this machine.

2.2.3 Surface conforming vacuum lifter

Surface conforming vacuum lifter is a lifter attached to BIM with container top type of vacuum lifter which can move a little bit in vertical and lateral directions as well as tolerating some tilting of the lifter head. All vacuum lifter pads would be instrumented with under pressure sensors and in case of pressure loss every pad could be closed with magnetic valve. Surface conforming vacuum lifter could be used with full blocks and broken/cracked bentonite blocks. Installation of a suction cleaner and possibly some other tools for use of breaking up bigger clods is needed with this tool.

Concept pros:

- Relatively easy remote operations, lifter has a grip if several suction pads can be under pressurized
- BIM can provide power and pressure/under pressure to the equipment
- Blocks and big block parts with undamaged block top can be removed without risk of damaging block or canister below

Concept cons:

- Blocks and canister still have a risk of damage if clods can’t be removed and maybe some breaking equipment needs to be used.
- Added complexity because of surface conforming function compared to normal vacuum lifter
- Horizontal forces on suction pads if lifter has to conform angles before lifting
- High amount of instrumentation and valves
- Danger of dust from broken bentonite in ejectors and pipes causing blocking
- Only relative large and nicely broken bentonite pieces can be lifted
- Risk of fragments coming loose during lifting, and subsequently falling back to strike underlying materials or the canister.

2.2.4 Concrete demolition machine (remote operated)

Remote controlled demolition machine is a tracked vehicle with excavator boom and diesel or electric motor used mainly for demolishing buildings and for operation in hazardous and dangerous spaces. Demolition machines are also used for remote controlled operations in nuclear applications. In buffer, block installation problem handling, several tools would need to be included in this type of equipment, e.g. gripper scabbler and suction cleaner, all equipped with video cameras. It was found that the company Brokk manufactures demolition machines big enough and with sufficient to clean out a deposition hole down to a canister's top surface (Fig. 4). A Brokk model 330 machine brochure is presented in Appendix 2 and Brokk attachments brochure is presented in Appendix 3.

Concept pros

- Commercially available, contractors available for testing purposes
- Compact design, suitable for tunnel operations
- Operator can see machine and boom quite near, good understanding of movements
- Large assortment of tools available, normal excavator tools can be also fitted
- Using a suction cleaner or mechanical grabble can allow small and medium sized pieces be removed and totally disturbed big bentonite blocks can be ground to gravel like fragments and removed with suction cleaner
- BROKK machines fit between the frame of BIM, so light operations can be done even with BIM positioned above deposition hole, short distance remote controlling enables good line of sight to possible collisions between BIM and demolition machine.

Concept cons

- Limited visibility to deposition hole with manual operation still needs trained operator
- Risk of harming bentonite blocks and canister below when using scabbler

Fig. 4. BROKK 330 demolition machine with scabbler breaking concrete structure.

2.2.5 Robot with various tools

As a universal cleaning tool for removing different kinds of blocks and foreign objects from deposition hole a downwards oriented robots were also studied (Fig. 5). The Robot would be installed upside down and attached to BIM gripper and then lowered into the deposition hole with the gripper. Gripper pads would be used to avoid gripper and robot swinging.

Such a robot would be equipped with various tools that could be used for breaking up bigger bentonite segments, a grinding and vacuum lifter could then be used to remove the rubble. Alternatively, lifting surfaces could be contacted and using a vacuum lifter and/or mechanical gripper objects could be removed from the deposition hole. Additionally a rubble collecting bin and a tool changer cabinet would be needed within the deposition hole.

Robot size for such an installation is very limited and full bentonite block lifting with a robot is impossible. As the block recovery task to be done differs in all cases and hence automation for robot handling of such varying situations and geometries cannot at present be engineered with reasonable effort. With these complications, only direct human operation of robot is a possible option. Linear controls would be needed to enable reasonable remote operation.

Concept pros:

- Universal tool especially for small objects in deposition tunnel
- Can be used for various tasks for buffer emplacement, for example helping clear pellet blocking problems
- No significant harm for blocks and canister below when used by professional user

Concept cons

- Highly complex design and operation, engineering amount versus product capabilities not in reasonable relation
- Limited capacity, approx. 200kg is maximum handled load
- Limited capacity causes need of breaking up larger pieces, which makes task different for every time robot is used and so requires well trained personnel
- Limited space for robots, needs engineering to avoid harmful collisions with deposition hole wall

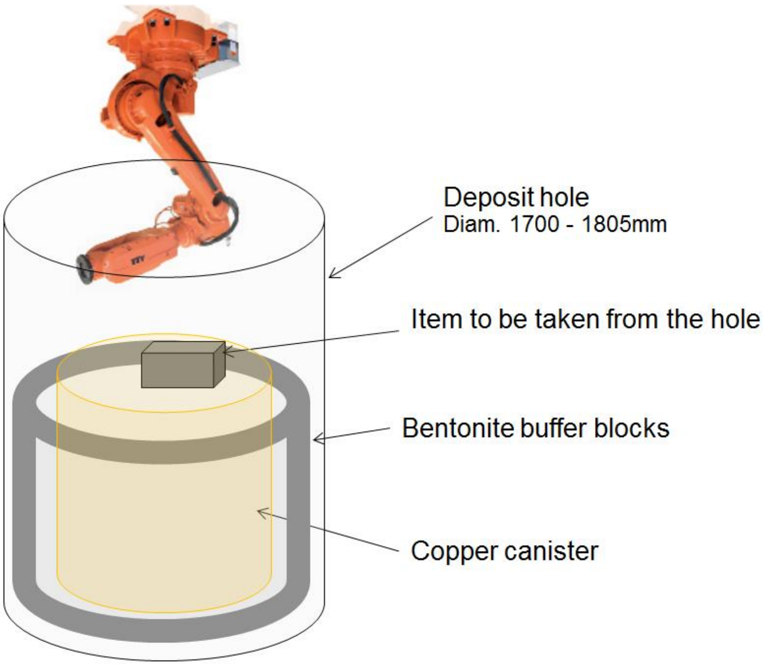

Fig. 5. ABB IRB6620 industrial robot in deposition hole.

2.2.6 Hydrodemolition device

A hydrodemolition machine (often referred to as a waterjet), breaks the bentonite into small pieces using a very high water pressure and has an attached vacuum suction to remove bentonite fragments.

If the whole buffer is to be removed from a deposition hole with recovery of an uncompromised canister already installed, carefully controlled hydrodemolition is an option that could be used without compromising the radiation safety of the canister. This option has numerous potential advantages associated with it and so was the subject of an extensive evaluation and demonstration study, presented in Section 2.3.

2.3 Summary of examined methodologies and identification of activities chosen for further evaluation.

2.3.1 Evaluation of Options examined

A number of potential methods to recover damaged buffer materials from deposition boreholes were briefly presented in Sections 2.1 and 2.2. In a situation where there are not radiological issues (no canister in borehole), recovery/removal of buffer components is relatively straight-forward and can be accomplished through use of vacuum lifter if damage is slight or with conventional manual means.

In a situation where there is a canister present in the borehole then recover becomes more complicated. Evaluation of 6 technical options identified the following.

- If damage to the block is minor, vacuum lifter used to install the block(s) may be useable to remove the subject material.

- If damage to the block is substantial and vacuum lifter is not a viable option then a more intrusive method must be used.

In a situation where the lifter cannot be used to remove the block(s) or materials from the deposition hole, then potentially viable options for use in recovering the buffer from the borehole are more limited. Of the options examined in Section 2.2, the use of hydrodemolition technology seems to hold the post potential for successful application. As a result, a series of preliminary field trials were undertaken and these are described in Section 2.3.2.

2.3.2 Preliminary field trials of hydrodemolition method

As noted above, hydrodemolition has been identified as a very promising option for handling problem situations during the buffer installation, allowing for buffer block removal after installation in a deposition hole. Tests were arranged to initially assess the suitability of this method to break down bentonite and evaluate its potential for use via remote control.

Detailed scope of this initial screening test was to:

- see how hydrodemolition breaks bentonite blocks,
- is generated waste suitable for removal with high capacity vacuum truck and
- how much rubble is flying off from the demolished bentonite.

Testing

Trials involving hydrodemolition of bentonite blocks of the size, density and composition that would be used as buffer were undertaken using two commercially available devices. Two bentonite blocks (Minelco Ca bentonite and MX-80 bentonite) were used for this test and Fig. 6 shows one of these blocks being cut.

The first device was a unit with max operating capacity of about 1000bar water pressure and 200l/min flow. Testing was actually done at 700bar and significantly lower water flow as tests were made with human operators rather than mounted on heavy equipment and operated remotely. This unit was successful in cutting the buffer block up, however due to its much higher water supply, it generated a substantial amount of flying fragments and mud.

The second device examined had a pump capable of supplying 3000bar of pressure and 28l/min, tests were made with 2600bar and 26l/min. With the lower water supply and higher operating pressure, this unit broke up the bentonite mass more effectively. The effective cutting depth with this unit was about 15cm, and also caused significant cracks to develop in the bentonite blocks.


Fig. 6. Preliminary hydrodemolition test.

Summary
Based on the results obtained in these preliminary field trials, hydrodemolition is likely suitable for breaking bentonite up in a deposition hole. It is recognized that remote controlled operations will need to be designed so that flying debris does not cause problems for operators or machinery. Also flying debris needs to be handled in such a way that it does not cause problems in the deposition tunnel, especially if tunnel backfilling has already occurred close to the problem area. It should be remembered that this concept's application is focussed on a situation where the issue in the deposition hole is the buffer, not the canister. It is assumed that the canister is undamaged and sound, hence contamination of the buffer is not an issue.

With the promising preliminary field trial results, a machine concept was developed that included combined suction pipe and water pressure hose lines and that further testing was warranted. In order to undertaken this further testing the conceptual design was tested with a simplified component arrangement and without the remote control option, to verify its viability in a deposition hole. This is presented in Chapter 3.

3 DESIGN OF HYDRODEMOLITION DEVICE

Following the promising results of the preliminary test (section 2.3), a full-scale hydrodemolition test device was designed. As this is still a trial, more complex components such as the remote control instrumentation were not included but could be added at a future date if needed. Mechanical 3D-modelling and 2D-drafting was done using Siemens PLM Software NX. ANSYS engineering simulation program was used for structural analysis of the lifter frame.

3.1 Waterjet Demolition Carrier (WDC)

3.1.1 General description

The waterjet demolition carrier (Fig. 7) consists of a lifter frame (1), suction and pressure pipe unit (2), transfer frame (3), electrical chain lifter (4), foot control pedal (5) and connecting hoses (6). Table 1 and Figure 8 provide the technical specifications and dimensions of the resultant device.

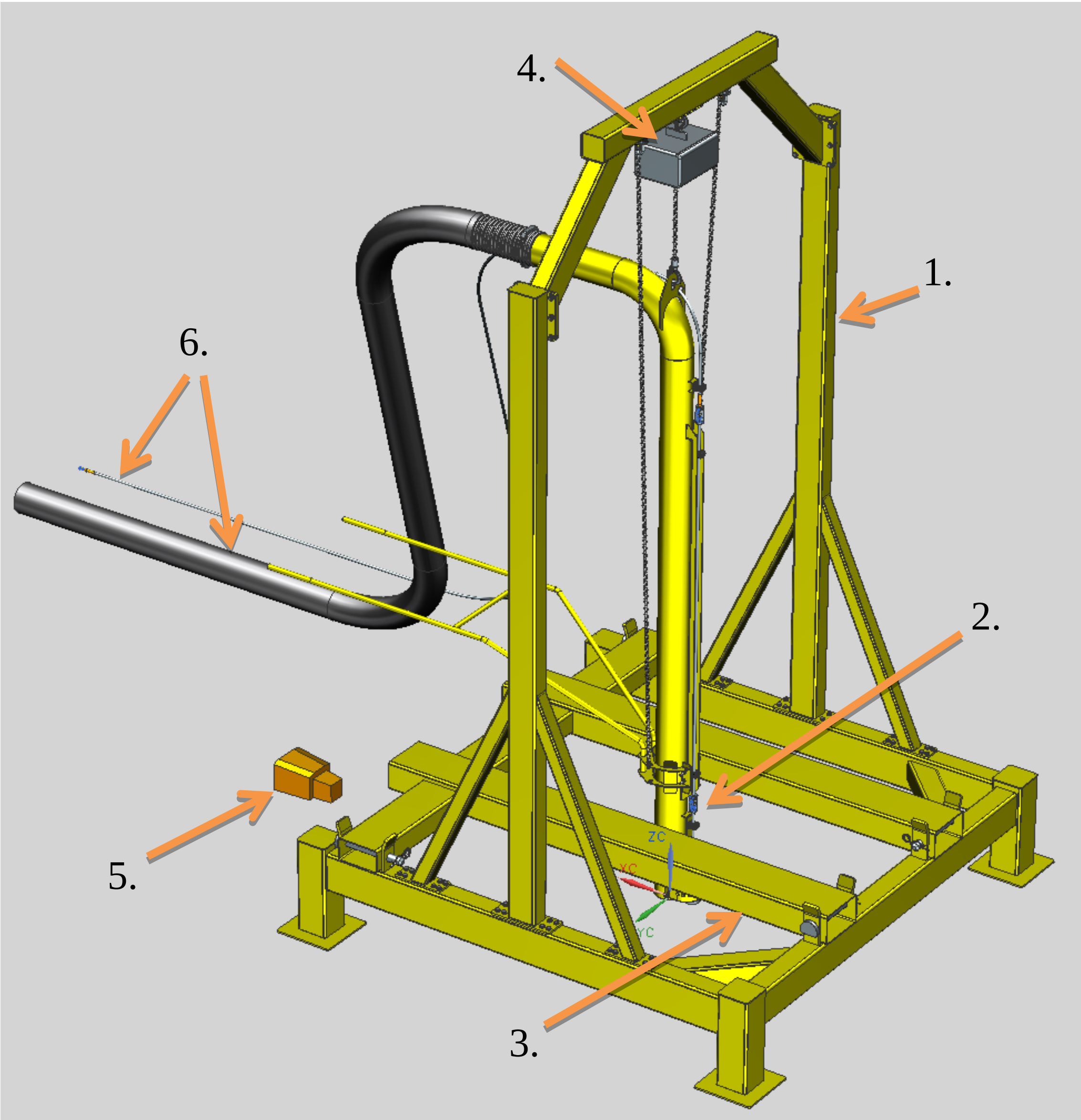

Fig. 7. WDC structure.

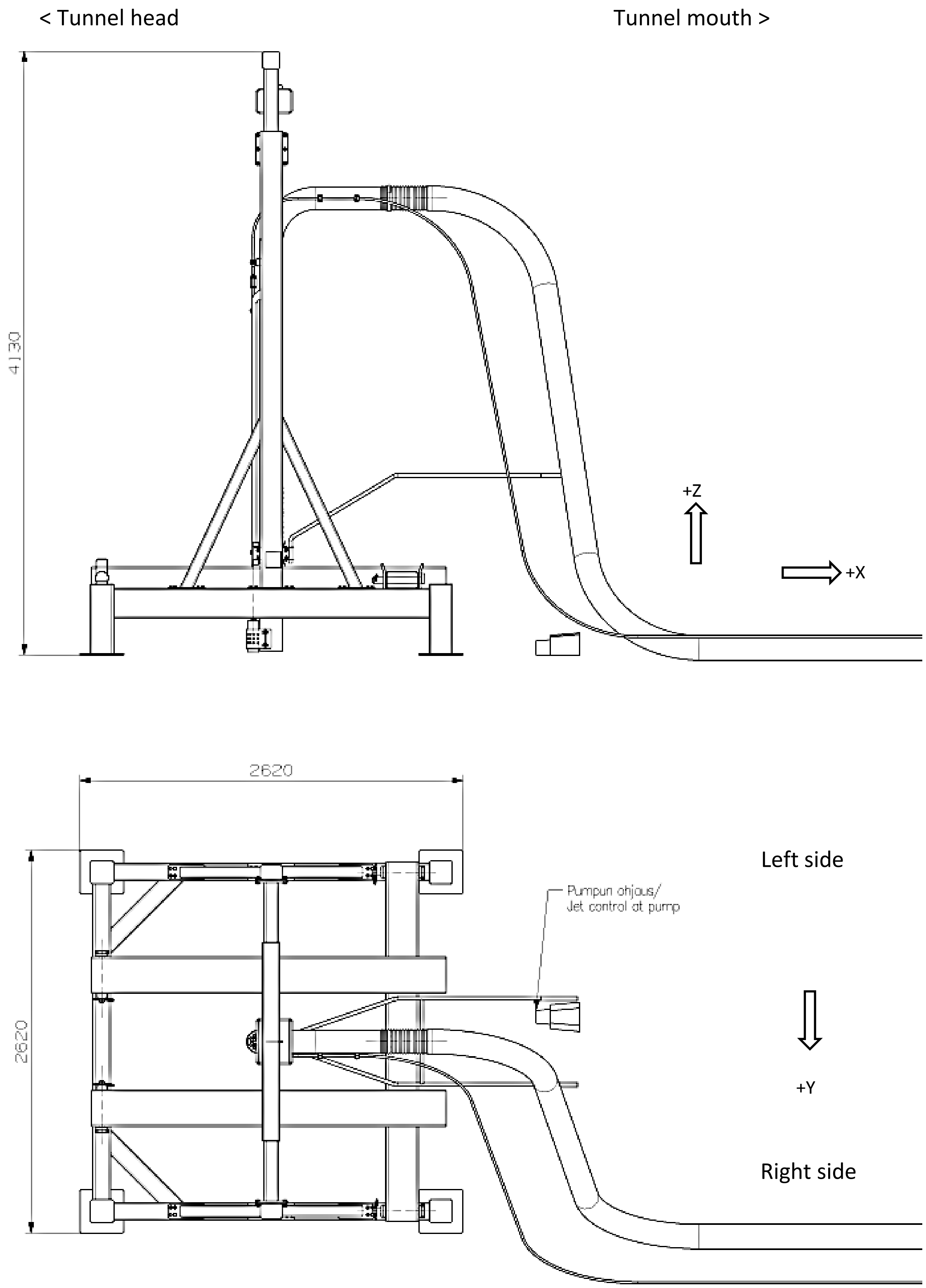

Fig. 8. Main dimensions of the WDC

Table 1. *WDC technical specification.*

Weight	approx. 1000 kg	
Length	2620 mm	does not include hoses
Width	2620 mm	
Height	4130 mm	
Power requirements	Electrical P=2,30 kW Water pressure max. 3000 bar[1)] Suction vacuum[2)]	[1)]from external pump [2)]from suction lorry or similar
Electrical feed	400 VAC 10A 50 Hz 3~	connection to tunnel network
Operators	1	
Lifter load rating	1600 kg	
Lifter vertical (Z) movement	12000 mm	

3.1.2 Lifter unit

The lifter unit frame, shown in Fig. 7 is a welded steel construction onto which the rest of the equipment is attached.

A chain lifter of 1600 kg lifting capacity is attached to the top beam of the frame and this allows for support and adjustment of the hoses associated with the water jet and suction device (Fig. 7).

On the bottom part of the frame, a removable transfer frame (Fig. 7) is attached with four large pins. Transfer frame has two lifting fork locations and is detached for operation.

3.1.3 Pressure and suction assembly

The pressure and suction assembly has a high pressure rotating nozzle at the base of the suction tube. High pressure water is fed from an externally-located pump to the nozzle and this impact of this water on the block surface is used to breakup/cut the bentonite. The mixture of bentonite pieces and sludge resulting from this cutting is drawn into the suction tube and is routed to the suction lorry.

This assembly can be operated manually when attached to the lifter unit, or it can be fixed to the boom of an excavator for machine operation.

4 MANUFACTURING OF WATER DEMOLITION CARRIER (WDC)

The water demolition carrier was manufactured by Hollming Works Oy in Pori, Finland.

The manufacturing was very straight forward as there were only few purchase components and the steel work was simple.

The WDC was finished in autumn 2014.

5 TESTING

Preliminary test to study the potential use of hydrodemolition on bentonite blocks (10.1.2014) was performed using commercial equipment, as described in chapter 2.3.

Testing was planned as follows:

- Ground level tests of lifting bentonite block parts using three types of fixing anchors.
- Ground level testing of hydrodemolition device.
- Underground testing in ONKALO, lifting bentonite block parts using fixing anchor type that was proven most suitable in ground level test.
- Underground testing of hydrodemolition device in ONKALO.

Testing of tension and shear force of different fixing anchors in bentonite blocks was tested in Tampere University of Technology (Appendix 1).

5.1 Problem handling tests: above-ground trials

Above-ground testing consisted of an anchor comparison test and a hydrodemolition test using the WDC.

5.1.1 Anchor tests

Anchor test was performed in December 2014. Three anchor types were chosen for testing, based on the results from pull and shear tests made in Tampere University of Technology during June and July, 2013, where five types of anchors were used (see Appendix 1).

Four different size bentonite block pieces and a ring block were used to simulate broken blocks to be removed from a deposition hole. These fragments weighed 20, 50 and 90 kg. The weight of the ring block test-lifted was 1130 kg. Anchors were attached manually to the bentonite pieces and lifted using the WDC lifter frame and chain host (Fig. 9).

Fig. 9. WDC lifter frame during test.

Types of anchors used were:

- Universal facade plug Sormat S-UF 10x100 HEX MG
- PFG expansion bolt Sormat SB 8-30
- Safety bolt Liebig B M8-12/55/40

Test results show that the facade plug was sufficient for pieces up to 50 kg weight. However the two-phase installation of the plug may be too complicated for an automated installation. Façade plug use was not tested with ring block, as it would require an impractical number of plugs.

The PFG expansion bolt was sufficient for lifting the 90 kg piece. Three PFG bolts were installed into the ring block, but failed to lift the block as one bolt slipped out of the bore hole.

The safety bolt tested was found to be sufficient for use with all pieces. The ring block was lifted successfully using three bolts on top surface (axial pull on bolts), as well as three bolts on the inside surface (radial shear on bolts).

With all anchor types it was very easy to crack the bentonite during anchor installation, resulting in the need to relocate the bold. At this stage no device for anchor installation was developed, but manual tools were used.

5.1.2 WDC hydrodemolition tests

WDC hydrodemolition tests were performed in December, 2014.

The test was performed outdoors, in a 1 metre deep well constructed for the test (Fig. 10). A concrete well ring of 2 m diameter was dug into the ground. A canister copper lid was placed in the bottom, and on top of it was placed a damaged bentonite block (Fig. 10).

Fig. 11 shows the test in progress. The pressure system was connected to a 3000 bar and 28 l/min unit mounted in a lorry and the suction pipe was attached to a suction lorry.

The first test revealed that the rotating RD Flex 3000 water pressure nozzle used was not appropriate for use in cutting and breaking bentonite blocks. The cutting was very slow and the sludge splashes extensive (Fig 12). The suction system was easily clogged if additional water feed was not present, which could prove problematic in an underground environment. The operation of the device was physically demanding.

The water jet aimed directly at the canister copper lid caused some polishing (Fig. 12) and it was possible to feel a slight edge with finger where the jet had been active for a prolonged period. This indicates that this recovery process could require that canisters recovered as the result of a buffer-only issue could be compromised, requiring that the spent fuel be removed and installed in a new canister.

Fig. 10. Test setup.

Fig. 11. WDC hydrodemolition test.

Fig. 12. Damage from water jet on copper cover.

5.2 Testing in ONKALO

Using the results of the surface tests to assist in planning for underground testing at ONKALO, underground testing consisted of an anchor lift test using the WDC lifter and a hydrodemolition test using the WDC pressure and suction pipe unit attached to an excavator were completed.

5.2.1 Anchor tests

The anchor test in ONKALO was performed on 19.5.2015.

The WDC lifter frame was placed on the test deposition hole in ONKALO Demonstration Tunnel 1. A bentonite ring block weighing 1300 kg was cut vertically into two pieces. The cutting did cause some unintentional cracking of the ring block (Fig. 13).

The smaller piece was 1/3 of the whole ring. On the top surface of each piece, holes of 12 mm diameter were drilled and three Liebig B M8-12/55/40 anchors were attached while the bentonite was still on tunnel floor level. The pallet with bentonite pieces on it was taken into the tunnel having the test deposition hole and the pallet and pieces were lowered into the deposition hole. The anchors were attached using lifting chains to the WDC lifter.

The smaller bentonite ring part was first lifted from the hole successfully (Fig. 154 and Fig. 15). All anchors remained attached despite some intentional abuse using the lifter to raise and lower the block in the deposition hole.

The bigger bentonite part was then attached to the lifter (Fig. 16). When lifting was initiated, two of three anchors were pulled out of the bentonite and the remaining anchor lifted just a fragment of the previously intact segment (Fig. 17).

The part of larger bentonite block remaining in the hole after the failed lifting attempt was lifted out of the hole on the pallet and three anchors were attached to the outer side surface (Fig. 18). When lifting the remainder of the bentonite block following the new anchor installations, it broke into several pieces, and test was ended (Fig. 19).

From these lifting trials it would appear that using these types of mechanical anchors to remove broken bentonite block parts is of limited applicability. Only in specific cases, where the bentonite still retains its strength at near manufacturing values is it possible to use anchors. If there has been exposure to humidity or severe mechanical shocks, there is a very high chance that this method is not suitable.

Fig. 13. Bentonite ring after cutting, showing some cracks.

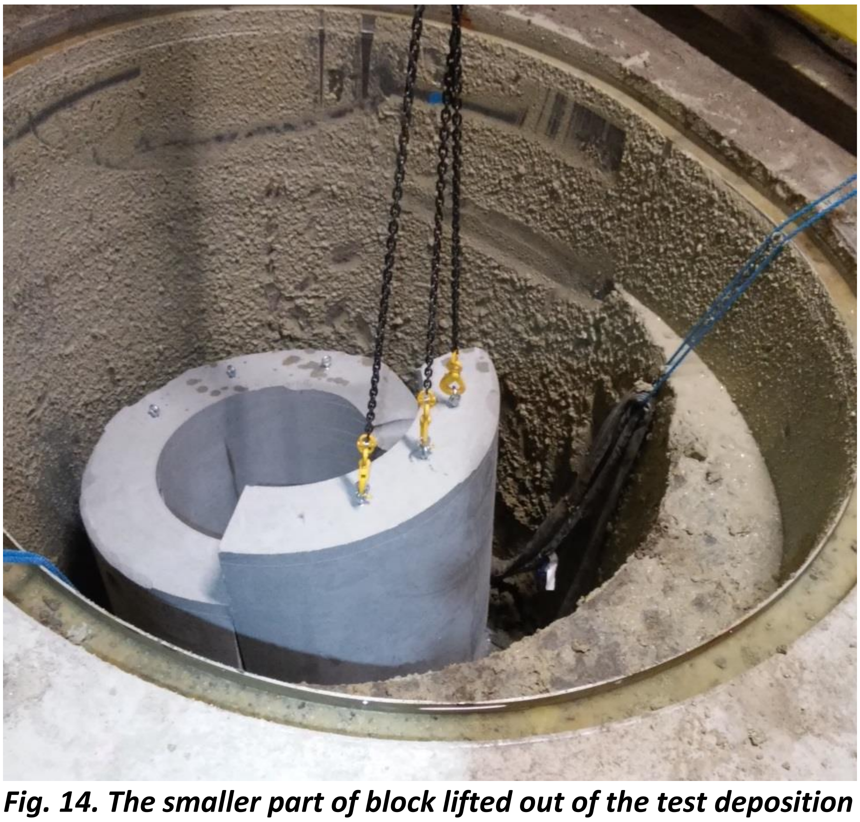

Fig. 14. The smaller part of block lifted out of the test deposition hole.

Fig. 15. The smaller part of block lifted out of the test deposition hole.

Fig. 16. Anchors attached to large ring block part.

Fig. 17. Failure to lift the large ring block part.

Fig. 18. Anchors attached to side of the block part.

Fig. 19. Block part after the last lifting attempt.

5.2.2 Hydrodemolition test in ONKALO

The hydrodemolition test in ONKALO Demonstration Tunnel 1 was performed on 13.5.2015.

The test deposition hole was fitted with a spacer platform structure, leaving a 2 m deep hole (Fig. 20).
On top of this platform was a solid bentonite block (Fig. 21).

The pressure and suction pipe assembly was attached to an excavator boom (Fig. 22), and then connected to a high pressure pump lorry and a suction lorry.

The excavator was driven to the test deposition hole and the pressure and suction pipe was lowered into the hole. The water pressure and suction were initiated and the operator inside excavator cabin started to move the pipe assembly over the bentonite block. The operator had a display with view from a camera attached to excavator boom, enabling him to see the progress of the work.

The progress was checked after the first 10 minutes (Fig. 23), then again after 20 minutes of operation (Fig. 24).

The test was stopped after 30 minutes of hydrodemolition operation. The bentonite block was removed almost fully, and only some loose parts remained (Fig. 25).

The mist from the high pressure water was far less than expected (based on the ground level test) and the splashes of bentonite sludge remained almost fully inside the test deposition hole.

The tested block was smaller in diameter than the reference blocks, but somewhat taller. Its volume is approximately 80% of a 800 mm high solid block, which is the largest volume reference block. It was estimated that the test block would have been fully removed within a total hydrodemolition operation time of 45 minutes. This would mean that any standard size block could be removed within an hour.

In conclusion, hydrodemolition is a plausible method for removing bentonite from deposition hole.

Fig. 20. Platform structure in test deposition hole.

Fig. 21. Bentonite block before test.

Fig. 22. The pressure and suction pipe assembly attached to an excavator

Fig. 23. Bentonite block after 10 minutes of hydrodemolition.

Fig. 24. Bentonite block after 20 minutes of hydrodemolition.

Fig. 25. Bentonite block after 30 minutes of hydrodemolition.

6 SUMMARY

6.1 Problem handling before canister installation

If installation of buffer blocks fails before canister has been installed, the fastest, most accurate and simplest solution is to use a human operator in the hole for cleaning. Some equipment will be needed to break the bentonite blocks and to lift block pieces and pellets from the deposition hole. Suggested tools are a heavy hammer drill and vacuum cleaner (industrial cleaning truck).

The use of screws or anchors on bentonite is questionable based on the tests performed.

A human worker can clean the broken bentonite block so that lifting surface of the first complete bentonite block remains unharmed. This enables complete buffer dismantling with vacuum lifter in minimum time also in case of complete ring block has fallen on top of previously installed blocks.

Damaged blocks that are still mainly in one piece and have a sufficient top surface area could be removed using a suction lifter. Posiva’s existing vacuum lifter can be used for 800mm high bentonite block removal from deposition hole, when installed with adapter plate to the bentonite installation machine (BIM) gripper. Ring segment removal will probably not be possible with standard lifting and moving procedure as space between legs and gripper is limited.

With a vacuum lifter the following items can be removed from the deposition hole in error situations:

- Complete bentonite blocks
- Broken bentonite blocks
- Contaminated blocks

6.2 Problem handling after canister installation

Hydrodemolition is a plausible method for removing bentonite from deposition hole. It can be used in all problem solving cases involving bentonite removal from deposition hole.

It can be utilized manually before the canister is installed, or by remote control after canister installation, provided that the canister is not physically compromised.

For production use it would be relatively easy to design different pressure and suction nozzle variations for operation on bentonite buffer between canister and host rock. Mechanically limiting the water jet direction to avoid copper canister damage would not be technically challenging.

The major drawback using hydrodemolition is that the whole buffer and the canister need to be removed and reinstalled. Due to introduction of water into the deposition hole, it is not possible to design a hydrodemolition system that would leave underlying bentonite usable. The testing of buffer installation has revealed that even a small particle on bentonite block top surface can disrupt the installation of the next block. Removing bentonite parts accurately enough with other methods studied would be very time consuming, if practical at all.

For incidents involving other materials entering the deposition hole, a simple vacuum suction can remove almost all particles in centimetre size range. If the foreign material in the borehole is ferrous (e.g. stray bolt or fitting from machines), and not in close proximity to the canister then a small suspended magnet could be used to lift and remove it. Larger items would need a remote operated gripper device of similar concept to the BROKK demolition machine.

7 ACKNOWLEDGEMENT

The LUCOEX-project has received funding from the European Union's EUROATOM-research program (FP7) under grant agreement 269905 –LUCOEX.

8 APPENDICES

Appendix 1: Slides from the report: Rantala J., Mattila T., 2013. Testing of tension and shear forces of fixing tools (Bentoniittilohkojen tartuntaelinten veto- ja leikkauskokeet) Research report TRT/2219/2013 Tampere technical university

Appendix 2. BROKK 330 technical data

Appendix 3. BROKK attachments

Appendix 1.

TESTING OF FIXING TOOLS

- Testing of tension and shear force of different fixing accessories in bentonite blocks has tested in Tampere University.
- Test blocks used in the tests

  - Material MX-80
  - L x W x H: 400 x 300 x 250 mm3
  - Isostatically pressed
    43 MPa, dry density 1742 kg/m3

Blocks	Vaterc ratio (weight-%)
1	16,5
2	16,7
3	16,2
4	17,1

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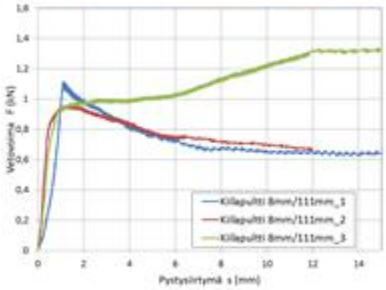
Appendix 1.

TESTING OF TROUGH BOLT (1)

- FBN 8/50, D8 – 85/111 MM, AXIAL FORCE



Koe	Murtovoima F_{max} (kN)	Murtosiirtymä s_{murto} (mm)	$F_{keskiarvo}$ (kN)	Keskihajonta s_x (kN)	Koelohko
1	1,11	1,1	1,14	0,20	1
2	0,96	1,19			1
3	1,36	11,8			1

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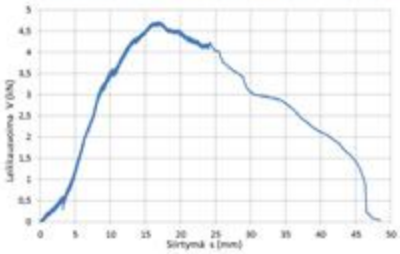
TESTING OF TROUGH BOLT (1)

- FBN 8/50, D8 – 85/111 MM, SHEAR FORCE



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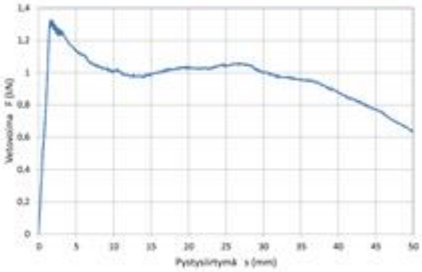
Appendix 1.

TESTING OF TROUGH BOLT (2)

- D10 – 75/92 MM, AXIAL FORCE



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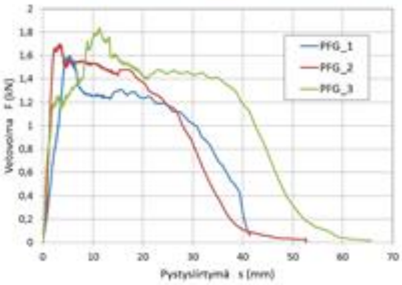
Appendix 1.

TESTING OF TROUGH BOLT (3)

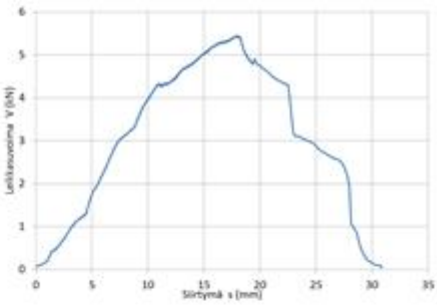
- PFG 8/85 (12.5 - 65 MM) AXIAL FORCE



Koe	Murtovoima F_{max} (kN)	Murtosiirtymä s_{murto} (mm)	$F_{keskiarvo}$ (kN)	Keskihajonta s_x (kN)	Koelohko
1	1,59	4,5	1,71	0,119	2
2	1,69	2,6			2
3	1,83	10,8			2

TESTING OF TROUGH BOLT (3)

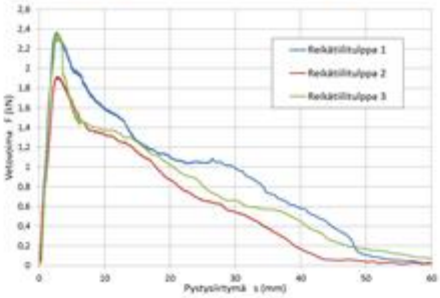
- PFG D8 – 85 (12.5 - 65 MM) SHEAR FORCE

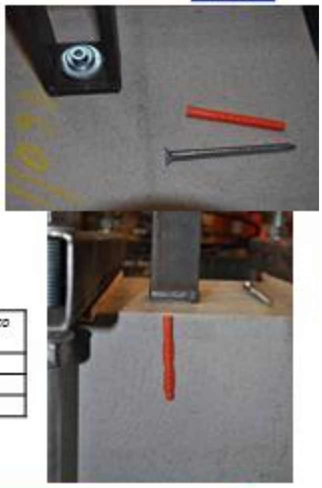


Appendix 1.

TESTING OF PLASTIC PLUG (4)

- Plastic plug HD82 – 7/105 (9 – 85 MM) AXIAL FORCE





Koe	Murtovoima F_{max} (kN)	Murtosiirtymä s_{murto} (mm)	$F_{keskiarvo}$ (kN)	Keskihajonta s_x (kN)	Koelohko
1	2,36	2,0	2,20	0,25	2
2	1,91	2,4			2
3	2,33	2,5			2

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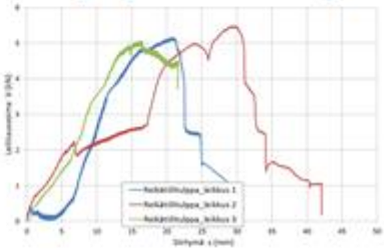
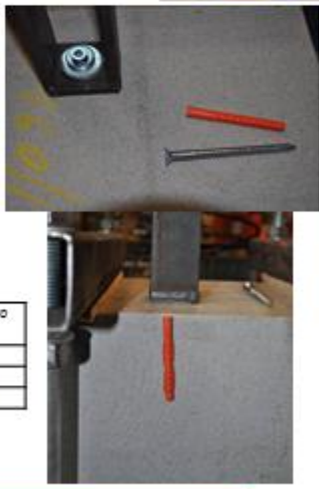
TESTING OF PLASTIC PLUG (4)

- Plastic plug HD82 – 7/105 (9 – 85 MM) SHEAR FORCE





Koe	Murtovoima V_{max} (kN)	Murtosiirtymä s_{murto} (mm)	$V_{keskiarvo}$ (kN)	Keskihajonta s_x (kN)	Koelohko
1	5,14	20,8	5,22	0,225	1
2	5,48	29,3			1
3	5,05	15,9			2

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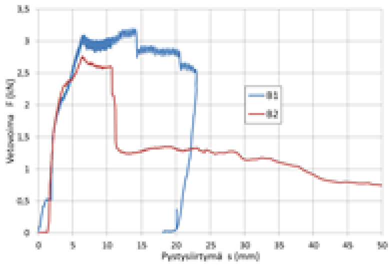
Appendix 1.

TESTING OF HEAVY TROUGH BOLT (5)

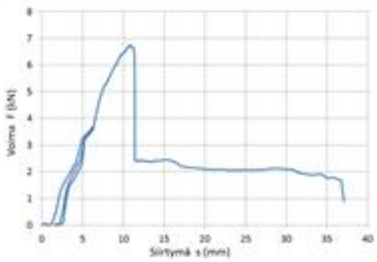
- PGF D12 – 112 MM (11 - 98 MM) AXIAL FORCE



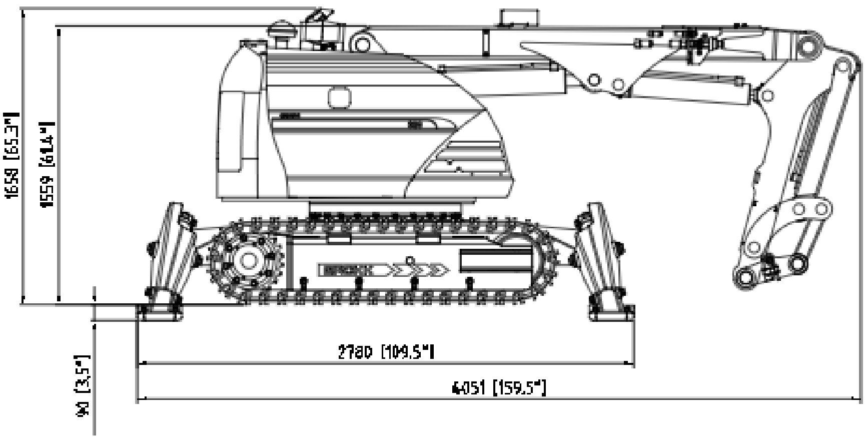
Koe	*Murtovoima F_{max} (kN)*	*Murtosiirtymä s_{murto} (mm)*	*$F_{keskiarvo}$ (kN)*	*Keskihajonta s_x (kN)*	*Koelohko*
1	3,19	13,5			3
2	2,76	6,1	2,97	0,096	4

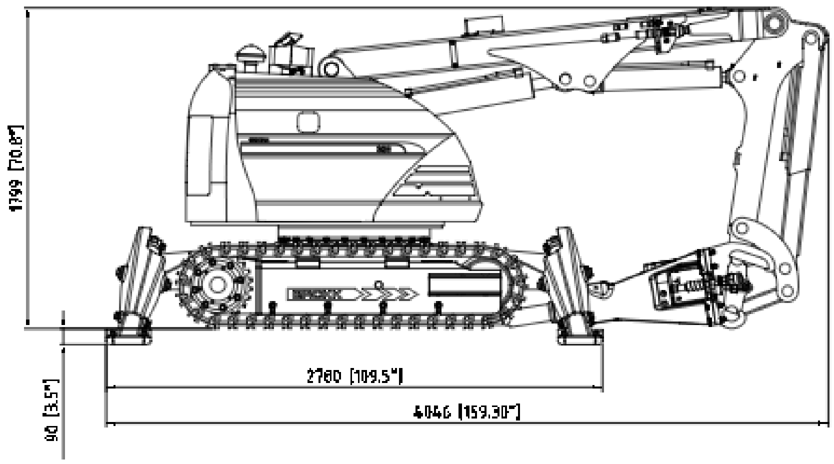
TESTING OF HEAVY TROUGH BOLT (5)

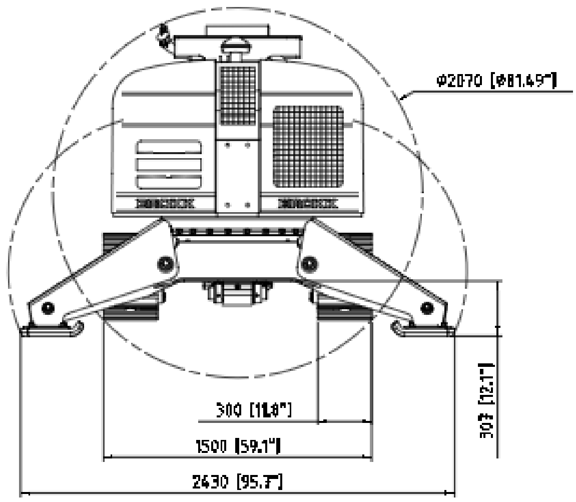
- PGF D12 – 112 MM (11 - 98 MM) SHEAR FORCE



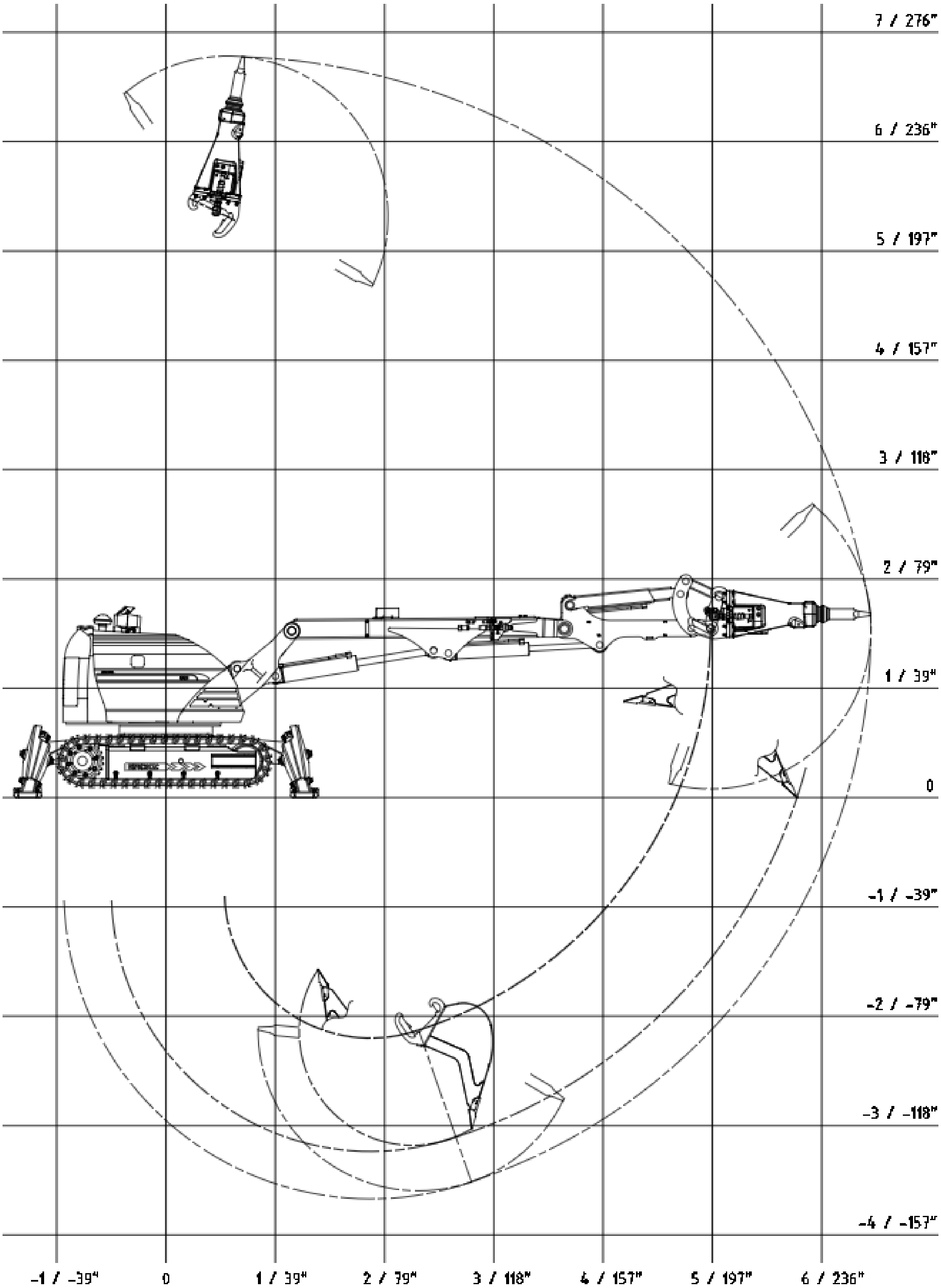
Appendix 2.







Appendix 2.


7 / 276"
6 / 236"
5 / 197"
4 / 157"
3 / 118"
2 / 79"
1 / 39"
0
-1 / -39"
-2 / -79"
-3 / -118"
-4 / -157"
-1 / -39"
0
1 / 39"
2 / 79"
3 / 118"
4 / 157"
5 / 197"
6 / 236"

Appendix 3.

SB302

BREAKERS

	Hitting power*	Blows/min	Weight	Made for
SB 52	101 J/Nm	720 – 1680	60 kg/132 lb	Brokk 50
SB 152	254 J/Nm	780 – 1920	142 kg/315 lb	Brokk 100, 160
SB 202	406 J/Nm	840 – 1800	212 kg/470 lb	Brokk 160, 180
SB 302	610 J/Nm	600 – 1410	310 kg/685 lb	Brokk 260, 330D, 400
SB 452	855 J/Nm	540 – 1260	450 kg/990 lb	Brokk 330D, 400
SB 552	1048 J/Nm	660 – 1140	535 kg/1177 lb	Brokk 400
MB 1000	2033 J/Nm	350 – 750	1295 kg/2850 lb	Brokk 800

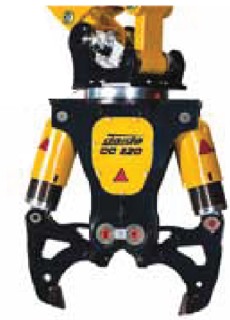
*Actual output, impact energy class (Joule/Nm)

A variety of chisels and tools can be fitted to the breakers. Other breaker brands can also be used on Brokk machines. Contact your local Brokk dealer or Brokk AB for information.

PTA-09

SIDE ANGLING DEVICE

	Angle	Weight	Made for
PTA-04,5	±60°	180 kg/407 lb	SB 152/Brokk 100
PTA-06	±70°	215 kg/473 lb	SB 152/Brokk 160
PTA-07	±70°	330 kg/725 lb	SB 202/Brokk 260
PTA-09	±55°	555 kg/1220 lb	SB 302/Brokk 400



CC520

CONCRETE CRUSHERS**

	Jaw opening	Rebars	Crushing force	Weight	Made for
CC260	250 mm/10 in	Ø20 mm/0,8 in	220 kN/22 t/ 50 Klbf	76 kg/ 160 lb	Brokk 50
CC320	316 mm/12,4 in	Ø20 mm/0,8 in	320 kN/32,6 t/ 792Klbf	150 kg/ 330 lb	Brokk 100
CC420*	420 mm/16,5 in	Ø28 mm/1,1 in	382 kN/38,2 t/ 85 Klbf	265 kg/ 585 lb	Brokk 160
CC520*	540 mm/21,3 in	Ø28 mm/1,1 in	466 kN/48 t/ 105 Klbf	410 kg/ 900 lb	Brokk 260, 330D
CC700*	680 mm/27 in	Ø28 mm/1,1 in	680 kN/69 t/ 162 Klbf	595 kg/ 1,310 lb	Brokk 400, 800

*Option pulverizing pads
**Free rotation

Appendix 3.

BMS 250

METAL SHEARS*

	Cutting force	Jaw opening	Weight	Made for
HCS6	169 kN/17 t/37 Klbf	320 mm/12,6 in	55 kg/120 lb	Brokk 50, 100
HCS7	312 kN/31 t/69 Klbf	350 mm/13,8 in	123 kg/270 lb	Brokk 100, 160
CC420S	740 kN/75,4 t/166 Klbf	145 mm/5,7 in	310 kg/680 lb	Brokk 160, 260
CC700S	1772 kN/181 t/398 Klbf	271 mm/10,5 in	690 kg/1520 lb	Brokk 400, 800
BMS 100	1020 kN/102 t/225 Klbf	185 mm/7,3 in	385 kg/850 lb	Brokk 160, 260
BMS 140	1380 kN/138 t/304 Klbf	245 mm/9,6 in	645 kg/1420 lb	Brokk 330D, 400
BMS 250	2500 kN/250 t/550 Klbf	395 mm/15,5 in	1205 kg/2650 lb	Brokk 800

*Requires one extra hydraulic function
Rotator with continuous rotation

2501

BUCKETS*

Volume	Width	Weight	Made for
20 l/0,7 cu ft	330 mm/12 in	20 kg/44 lb	Brokk 50
60 l/2,1 cu ft	520 mm/20 in	61 kg/134 lb	Brokk 100
80 l/2,8 cu ft	690 mm/27 in	76 kg/167 lb	Brokk 160
250 l/8,8 cu ft	960 mm/38 in	195 kg/430 lb	Brokk 260, 330D, 400
500 l/17,6 cu ft	1200 mm/47 in	600 kg/1300 lb	Brokk 800

CO5HPX

CLAMSHELL BUCKETS*

	Volume	Opening range	Width	Weight	Made for
CO2H-25	25 l/0,9 cu ft	667 mm/26 in	250 mm/10 in	110 kg/240 lb	Brokk 100
CO3H-35	65 l/2,3 cu ft	879 mm/35 in	350 mm/14 in	175 kg/385 lb	Brokk 160
CO5H-40	115 l/4,1 cu ft	1090 mm/43 in	400 mm/16 in	210 kg/460 lb	Brokk 260
CO5HPX-40	115 l/4,1 cu ft	1112 mm/44 in	400 mm/16 in	340 kg/750 lb	Brokk 330D
CO5HPX-60	170 l/6,1 cu ft	1112 mm/44 in	600 mm/24 in	375 kg/825 lb	Brokk 400
CO8HPX-80	300 l/10,6 cu ft	1250 mm/50 in	800 mm/31 in	580 kg/1275 lb	Brokk 800

*See load diagram for each Brokk machine
Rotator with continuous rotation
Requires one extra hydraulic function

Appendix 3.

A05H-40

KM650

MULTI PURPOSE GRAPPLES*

	Volume	Opening range	Width	Weight	Made for
AO2H-30	35 l/1,2 cu ft	760 mm/30 in	300 mm/12 in	133 kg/295 lb	Brokk 100
AO2H-30	35 l/1,2 cu ft	760 mm/30 in	300 mm/12 in	144 kg/320 lb	Brokk 160
AO3H-40	70 l/2,5 cu ft	1474 mm/58 in	390 mm/15 in	265 kg/585 lb	Brokk 260
AO5H-40	70 l/2,5 cu ft	1474 mm/58 in	390 mm/15 in	320 kg/705 lb	Brokk 330D
AO5HPX-40	100 l/3,6 cu ft	1399 mm/55 in	400 mm/16 in	375 kg/825 lb	Brokk 400
AO9HPX-50	200 l/7,1 cu ft	1695 mm/66 in	500 mm/20 in	675 kg/1490 lb	Brokk 800
Orange Peel Grapple					
KM651-4 180	180 l/6,4 cu ft	1450 mm/57 in	1070 mm/42 in	520 kg/ 1150 lb	Brokk 330D, 400
KM651-4 250	250 l/8,8 cu ft	1550 mm/61 in	1285 mm/51 in	870 kg/ 1920 lb	Brokk 800

*See load diagram for each Brokk machine
Requires one extra hydraulic function
Rotator with continuous rotation

G50

D02H

SORTING & DEMOLITION GRAPPLES*

	Jaw opening	Weight	Made for
G30	300 mm/12 in	42 kg/92 lb	Brokk 50
G50	500 mm/20 in	133 kg/295 lb	Brokk 100
G50	500 mm/20 in	145 kg/320 lb	Brokk 160
D02H-30	792 mm/31 in	133 kg/295 lb	Brokk 100
D02H-30	792 mm/31 in	145 kg/320 lb	Brokk 160
D03HPX-40	975 mm/38 in	310 kg/680 lb	Brokk 260, 330D
D05HPX-50	1135 mm/45 in	375 kg/825 lb	Brokk 400
DO9HPX-60	1400 mm/56 in	595 kg/1310 lb lb	Brokk 800

*See load diagram for each Brokk machine
Requires one extra hydraulic function
Rotator with continuous rotation

Appendix 3.

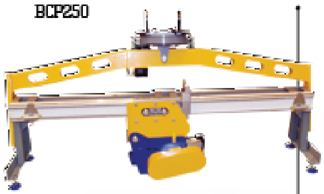
WS 15

SCABBLERS

	Cutting depth**	Width	Weight	Made for
RT 15*	0-10 mm/0-0.4 in	203 mm/8 in	82 kg/180 lb	Brokk 100, 160
ER 50	0-30 mm/0-1.2 in	480 mm/19 in	115 kg/250 lb	Brokk 100, 160
WS15	0-62 mm/0-2.4 in	557 mm/22 in	330 kg/725 lb	Brokk 160, 260, 330D
ER 100	0-65 mm/0-2.6 in	550 mm/22 in	300 kg/660 lb	Brokk 160, 260, 330D
WS30	0-89 mm/0-3.5 in	678 mm/27 in	490 kg/1,075 lb	Brokk 330D, 400
ER 250	0-80 mm/0-3.2 in	620 mm/24 in	520 kg/1,150 lb	Brokk 330D, 400
ER 600	0-100 mm/0-4 in	780 mm/31 in	1,120 kg/2,460 lb	Brokk 800
WS45	0-100 mm/0-4 in	655 mm/26 in	1,070 kg/2350 lb	Brokk 800

*Also available with cover and suction
**Data depending on concrete quality

BCP250



PLB 300

PLANERS

	Cutting depth	Width	Weight	Made for
BCP 250*	0-6 mm/0-0.25 in	265 mm/10.4 in	220 kg/485 lb	Brokk 100, 160
BCP 350*	0-6 mm/0-0.25 in	335 mm/13.2 in	250 kg/550 lb	Brokk 260, 330D, 400
PLB 200**	0-50 mm/0-2 in	200 mm/7.8 in	220 kg/485 lb	Brokk 160, 180
PLB 300*	0-50 mm/0-2 in	300 mm/11.8 in	290 kg/640 lb	Brokk 260, 330D, 400

*Avalible with cover and suction
**Avalible with cover, suction only on special reqeust

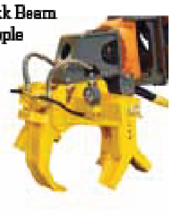
MMB260

DRILLING EQUIPMENT

	Length	Bore depth	Drill diam. (Std)***	Water or airflushing	Weight	Made for
BSD-80** (concrete)	1760 mm/ 70 in	600 mm/23 in* max 2 m/80 in	24-51 mm/ 1.2 - 2 in	0.4 m³/min at 5-16 bar or 10 l/min at 4-16 bar	205 kg/ 450 lb	Brokk 100
MMB260-180**** (concrete and rock)	2900 mm/ 115 in	1600 mm/63 in* max 10 m/395 in	33-76 mm/ 1.3 - 3 in	0.5 m³/min at 5-20 bar or 25 l/min at 4-20 bar	415 kg/ 915 lb	Brokk 160
MMB260-240**** (concrete and rock)	3500 mm/ 138 in	2200 mm/87 in* max 10 m/395 in	33-76 mm/ 1.3 - 3 in	0.5 m³/min at 5-20 bar or 25 l/min at 4-20 bar	432 kg/ 952 lb	Brokk 260, 330D, 400
HEB350-240**** (concrete and rock)	3590 mm/ 141 in	2200 mm/87 in* max 20 m/790 in	41-102 mm/ 1.6 - 4 in	0.5 m³/min at 5-20 bar or 25 l/min at 4-20 bar	760 kg/ 1675 lb	Brokk 400, 800

Appendix 3.

Brokk Beam Grapple



Brokk Shot Crete

TUNNEL AND MINING EQUIPMENT

	Jaw opening	Beam weight*	Weight	Made for
Brokk Beam Grapple**	240 mm/9.5 in	500 kg/1100 lb	320 kg/705 lb	Brokk 260, 330D, 400, 800

	Concrete hose (di)	Gunning pressure	Air pressure	Weight	Made for
Brokk Shot Crete**	45 mm/ 1.77 in	65 bar/ 6.5 mpa	0.1-0.2 m³/ at 3-5 bar	180 kg/400 lb	Brokk 260, 330D, 400, 800

*See load diagram for each Brokk machine
**Requires two extra hydraulic functions

Cut Off Saw

CUT OFF SAW*

	Saw disk diameter**	Cutting depth***	Weight****	Made for
BCS 8	355 or 400 mm/ 14 or 15.75 in	150 or 170 mm/ 5.9 or 6.7 in	70 kg/ 155 lb	Brokk 50
BSC10	355 or 400 mm/ 14 or 15.75 in	150 or 170 mm/ 5.9 or 6.7 in	85 kg/ 190 lb	Brokk 100, 160
BCS 25 *****	600 or 800 mm/ 23.5 or 31.5 in	160 or 260 mm/ 6.3 or 10.2 in	250 kg/ 550 lb	Brokk 160, 260
BCS 35 *****	600 or 800 mm/ 23.5 or 31.5 in	160 or 260 mm/ 6.3 or 10.2 in	260 kg/ 575 lb	Brokk 260, 330D, 400, 800

*Requires one extra hydraulic function
**Different saw disks available depending on material
***With new saw disk
****Depending on machine model
*****Requires drainage hose