STIFTELSEN BERGTEKNISK FORSKNING
ROCK ENGINEERING RESEARCH FOUNDATION

Utveckling av dynamisk injektering
Etapp 1

Development of dynamic grouting
Stage 1

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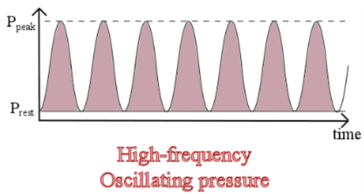
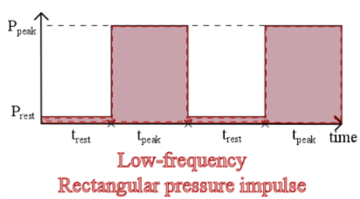
Introduction

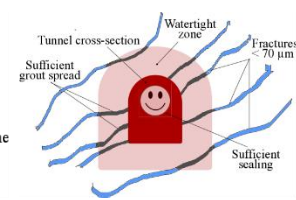
Since 1985, several researchers have been working on use of high-frequency oscillating pressure to improve the grout spread by virtue of reducing the grout apparent viscosity. Despite their promising results, use of dynamic pressure impulses has not yet been established as a common method in grouting practice, due to the limited efficiency and quick dissipation of the oscillation along a fracture.

To solve these issues, in a recent study, the authors introduced a low-frequency rectangular pressure impulse to better control the filtration by successive erosion of the produced filter cakes at a fracture constriction. This was obtained by continuous variation in the flow pattern in consecutive cycles caused by the pressure change. The results showed significant improvement (up to 11 times) in the total volume of grout take in 30-43 µm apertures in the experiments using a short slot. Afterwards, the dissipation of the pressure impulses was studied in a considerably longer artificial fracture (i.e. varying aperture long slot-VALS). The results revealed that the remaining amplitudes of the pressure impulses at 2.0 and 2.7 m distances from the source were as large as 46% and 25% of the initial applied amplitude, respectively. However, due to some limitations, it was not possible to quantify the improvement in the volume of grout passed through the apertures < 70 µm. Accordingly, none of the previous studies were sufficiently comprehensive for drawing the conclusions that dynamic pressure impulses effectively improve the grout spread in grouting operations.

Issues of significance were nevertheless how quickly the dynamic pressure impulses dissipate from the source along a fracture and how much the dynamic pressure impulses can improve the corresponding grout spread in fractures < 70 µm.







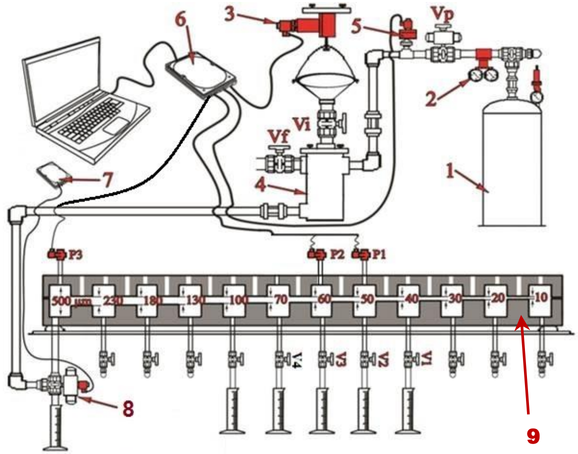
Objectives/Outline

- Main objectives:
  - To examine to what extent dynamic pressure impulses can improve the grout spread in micro-fractures < 70 µm.
  - To study how quickly the dynamic pressure impulses dissipate from the source to the grout front along an artificial fracture with variable aperture.

- Outline:
  - Step 1:
    Evaluation of influence of rectangular pressure impulse using Varying Aperture Long Slot (VALS) in a close system with pressurized gas as pressure source
  - Step 2:
    Evaluation of influence of rectangular pressure impulse using VALS in an open system with a screw pump as pressure source

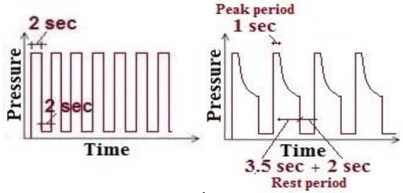
Step 1.
Evaluation of dynamic impulses using VALS with pressurized gas

Test setup

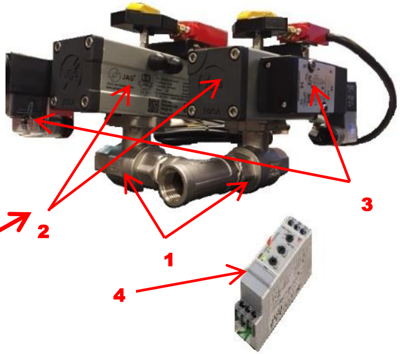


1. Gas tank
2. Pressure regulator
3. Weight sensor
4. Grout tank
5. Pressure sensor
6. DAQ
7. 3 coupled asymmetrical recycler timers
8. 2 two-way ball-valves with pneomatic actuators, and solenoid valves
9. VALS

Peak/Rest period



1. 2 s/2 s
2. 1 s/5.5 s



1. Ball-valves, 2. Pneomatic actuators, 3. Solenoid valves, 4. Asymmetrical recycler timer

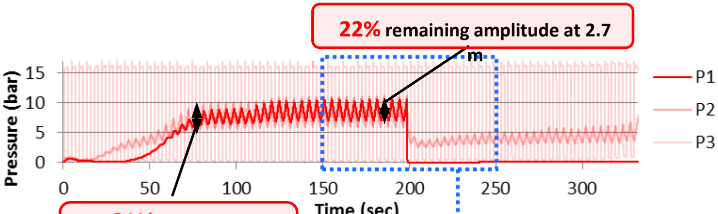
Step 1.
Evaluation of dynamic impulses using VALS with pressurized gas

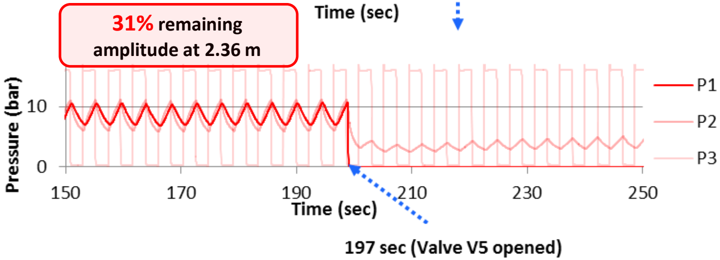
Results

The improvement on grout spread obtained using dynamic impulses (1s/5.5s) compared to static pressure in apertures < 70 µm

Test group	Test No.	Peak/Rest period [sec]	Weight of the passed grout [g] V1 (40 µm)	V2 (50 µm)	V3 (60 µm)	V4 (70 µm)	Average (40-70) µm	Improvement of grout spread in apertures < 70 µm
C (Static)	1	-	84	60	0	0	102	-
	2	-	0	0	44	16		
D (Dynamic)	1	1 s/5.5 s	0	120	880	-	1020	10.0
	2	1 s/5.5 s	0	76	964	-		

Development of dynamic impulses along the VALS registered by P1, P2 and P3 (2s/2s peak/rest period)





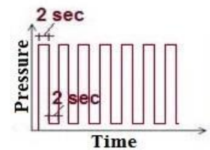
Comments

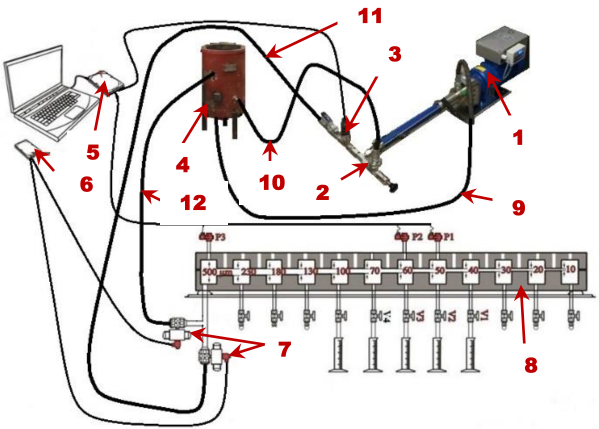
The pressure sourse in step 1 was pressurized gas in a closed system. Even though the setup used to provide dynamic impulses was much better than the previous setups, yet there was considerable loss of grout from the pressure release valve in each cycle. That was to provide quick drop of pressure during the rest period in each cycle. To prevent that, use of a screw pump (as pressure sourse) and an open grout container with a bypass was considered as the test setup in Step 2.

Step 2.
Evaluation of dynamic impulses using VALS with screw pump

Test setup

Peak/Rest period





1. Screw pump
2. Pressure control valve
3. Pressure sensor
4. Grout tank
5. DAQ system
6. Asymmetrical recycler timers
7. Two-way ball-valves with pneomatic actuators, and solenoid valves
8. VALS
9. Inlet from 4 to 1
10. Bypass from 2 to 4
11. Outlet from 1 to 8
12. Backflow from 8 to 4

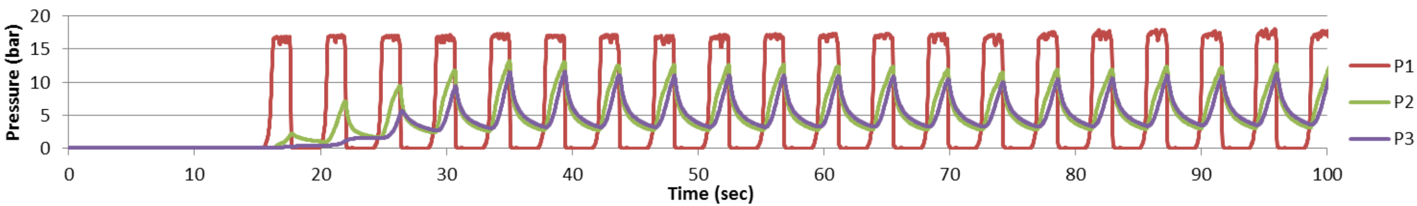
Step 2.
Evaluation of dynamic impulses using VALS with screw pump

Results

The improvement on grout spread obtained using dynamic impulses at 2s/2s & 1s/5.5s compared to static pressure (gas and pump driven) in apertures < 70 µm

Test group	Pressure source	Test No.	Peak/Rest period [sec]	Weight of the passed grout [g] V1 (40 µm)	V2 (50 µm)	V3 (60 µm)	V4 (70 µm)	Average (40-70) µm	Improvement of grout spread in apertures < 70 µm	Improvement of grout spread in apertures < 70 µm
C (Static)	Gas (Step 2b)	1	-	84	60	0	0	102	-	
		2	-	0	0	44	16			
D (Dynamic)		1	1 s/5.5 s	0	120	880	-	1020	10.0	
		2	1 s/5.5 s	0	76	964	-			
C (Static)	Pump (Step 3)	1	-	-	64	290	16	491	-	
		2	-	-	60	532	20			
D (Dynamic)		1	2 s/2 s	-	206	344	0	825	1.68	8.09
		2	2 s/2 s	-	192	908	0			

Test D1-Pressure-time variation at 0.0, 2.36, and 2.7 m from the slot's beginning registered by P1, P2, and P3 between 0-100 sec.



Conclusions/Future studies

Concluding remaks:

1. Considerable improvement of the grout spread is possible to obtain in apertures < 70 µm in VALS using dynamic pressure impulses compared to the static pressure condition.
2. Considerable amplitudes of the dynamic impulses have remained after 2.36 and 2.7 m from the slot's begining.
3. Use of dynamic pressure impulse can be a more effective alternative than static pressure to improve the grout spread in apertures < 70 µm in the projects with high sealing demands. This should however be further examined in the field in the next stage of the project.

Suggestion for future studies:

To improve the existing grouting technique and increase the efficiency of rock grouting, our future work focuses on further development and implementation of dynamic grouting in the field-scale. This would be a supplementary study to maximize the efficiency of the new technique and adapt our lab-scale knowledge from the previous stages to the field application. The aim is to demonstrate the associated economic, environmental, and sustainability advantages of the method to the stakeholders as a better alternative, especially in projects with higher sealing demands such as in nuclear/toxic waste repositories to build a safer environment for the next generations.

Accordingly, a distributer unit is first developed and tested in the lab to change the static pressure of a regular grouting pump to a programmable dynamic pressure. It also supplies multiple boreholes in sequence in order to improve the grout spread and reduce the grouting time simultaneously. The efficiency of the developed technique can be then demonstrated in Äspö hard rock laboratory.