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En experimentell studie för mätning Av inträngningsförmåga av injekteringsmedel, förbättring av spridning av bruket, och utvärdering av RTGC-teorin

An experimental study to measure grout penetrability, improve the grout spread, and evaluate the real time grouting control theory

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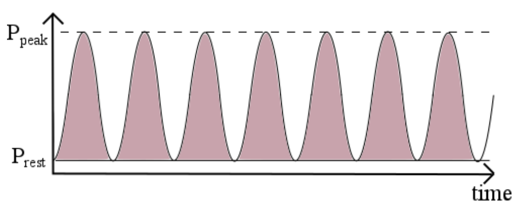
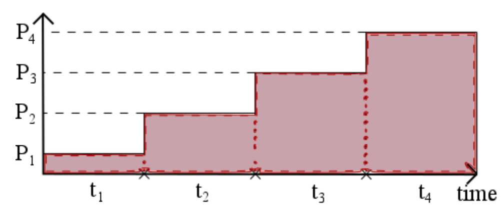
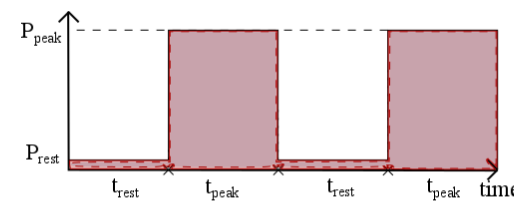


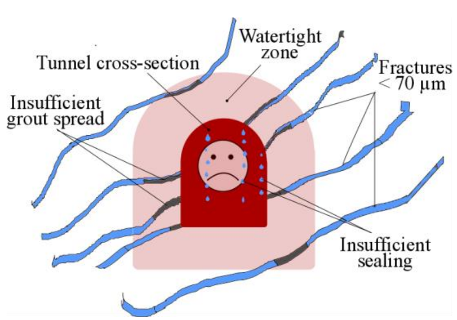
High-frequency
Oscillating pressure

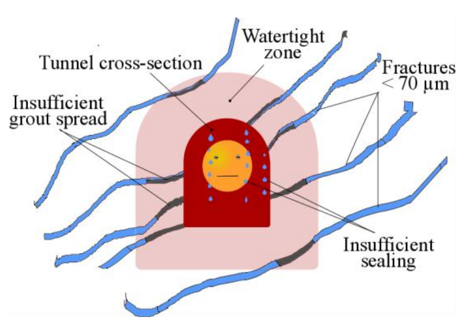


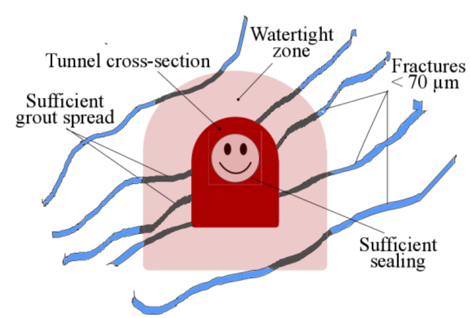
Stepwise
Static pressure increments



Low-frequency
Rectangular pressure impulse







Introduction

Water ingress into the underground facilities causes increase in time & costs of the projects, environmental issues such as lowering the groundwater tables, settlement of the structures, and destruction of vegetation. It can be hazardous to human life, e.g., falling icicles in tunnels. It shortens the life cycle of the projects and raises the maintenance costs.

To obtain the required sealing, sufficient spread of grout in surrounding fractures is required. To achieve sufficient grout spread, chemical grouts provide satisfactory spread with considerable sealing efficiency. But in several occasions, they showed severely hazardous environmental issues. Cement-based grouts are cheaper with less environmental issues, but filtration of the cement particles that restricts the grout spread is an obstacle. This PhD study is therefore dedicated to investigate the grout penetrability/filtration properties in fractured hard rock in four parts with following objectives:

A. *Which of the existing test methodologies developed to measure grout penetrability are more reliable and how?*

B. *How can grout penetrability be measured more realistically?*

C. *How can the grout spread be improved effectively using dynamic pressure impulses?*

D. *Is it feasible to employ the RTGC theory to predict the grout spread in an artificial fracture with variable aperture?*

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Part (A): Measurement of Grout Penetrability
The Existing Methodologies

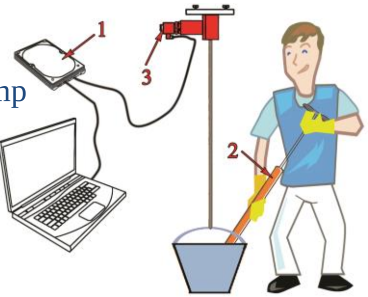
Objective

- ❑ ***Which of the existing test methodologies are more reliable and how?***

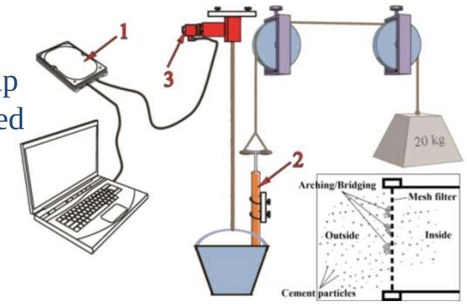
Test setups

T1
Regular Filter pump
Manualy operated
Volume: 0.3 l
Pressure: < 0.5 bar
Mesh geometry
Volume of passed grout

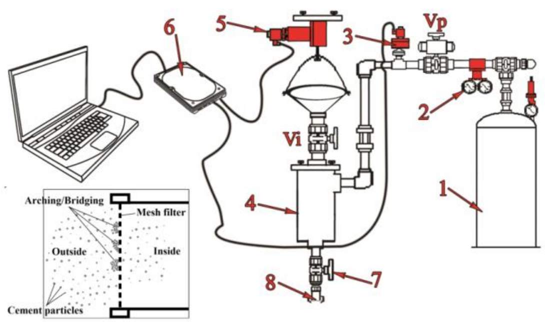
T2
Modified Filter pump
Manualy operated
Volume: 0.3 l
Pressure: < 0.5 bar
Mesh geometry
W-T measurement



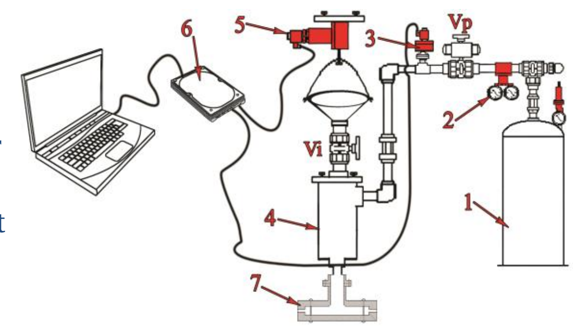
T3
Modified Filter pump
Mechanicaly operated
Volume: 0.3 l
Pressure: 1 bar
Mesh geometry
W-T measurement



T4
Modified Penetrability meter
Volume: 2.6 l
Pressure: 1 bar
Mesh geometry
W-T measurement



T5
Short slot
Volume: 2.6 l
Pressure: 1-15 bar
Slot geometry
W-T measurement



Conclusions

- ✓ ***Diversity in the applied pressure, grout volume, evaluation method, and constriction geometry were found as the main origins of uncertainty/contradiction in the results of the grout penetrability measurement.***
- ✓ ***Use of Filter pump & Penetrability meter is no longer recommended to evaluate grout penetrability, but Filter pump can still be used for quality control of cement and mixing process.***
- ✓ ***Accordingly among the three methods, use of Short slot is considered to be more reliable due to more realistic geometry, test condition, and evaluation method.***

Part (B): Measurement of Grout Penetrability
New Method

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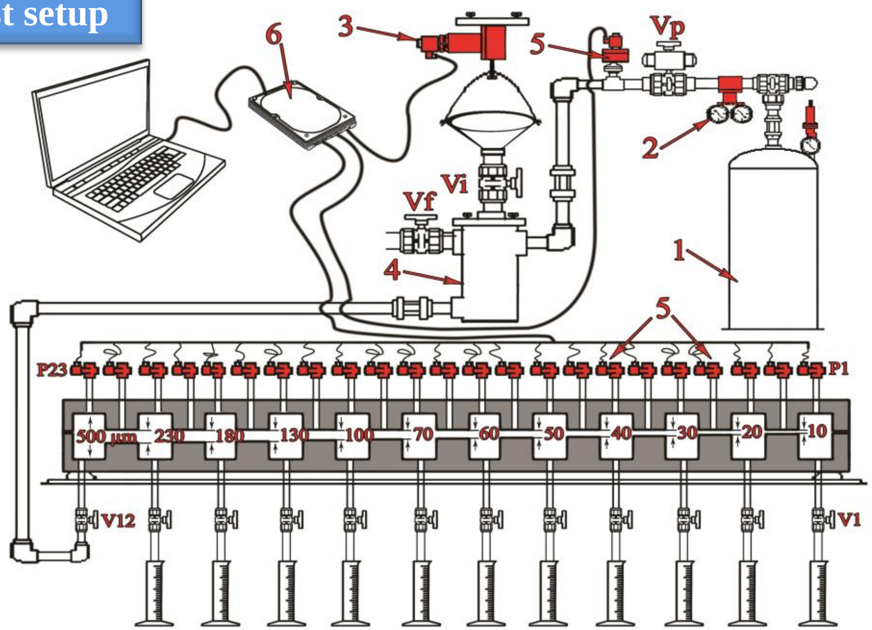
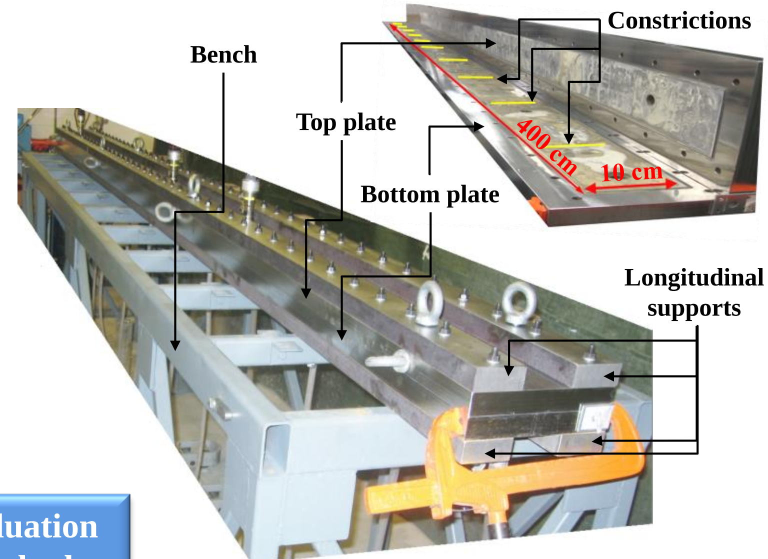
Objective

- *How can grout penetrability be measured more realistically?*

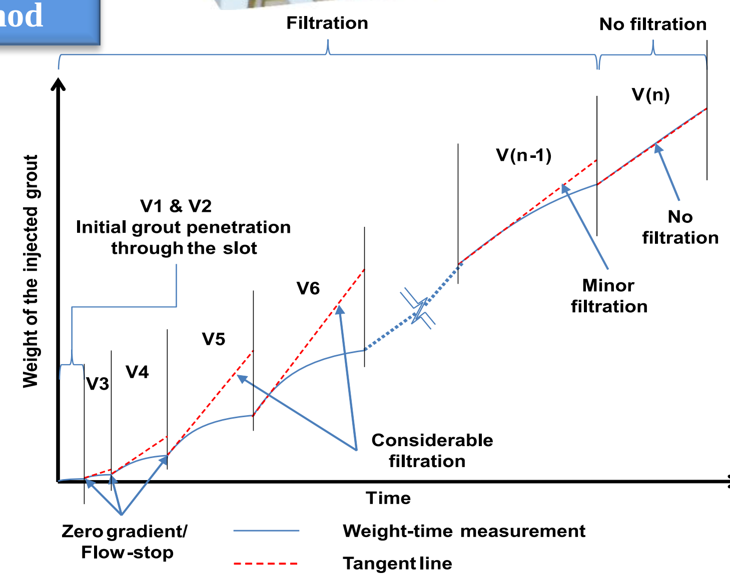
Test setup



Schematic depiction of the test apparatus: (1) gas container, (2) pressure regulator, (3) load cell, (4) grout tank, (5) pressure transducers, (6) DAQ



Evaluation method



Conclusion

✓ *The study showed the potential of the method to investigate the fundamental behavior of rock grouting at varying parameters with satisfactory repeatability at both static and dynamic pressure conditions.*

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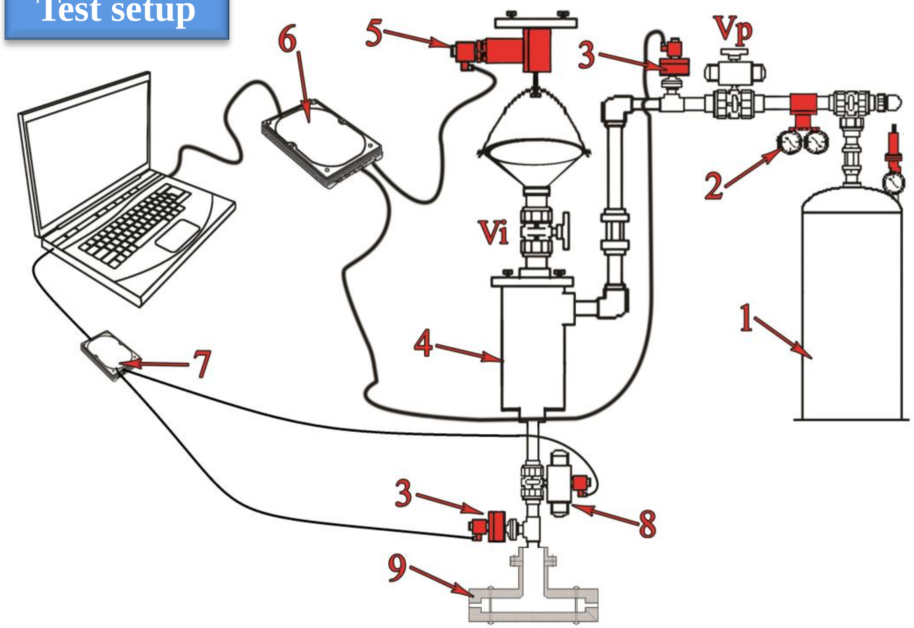
Part (C1): Improvement of Grout Spread Dynamic Grouting

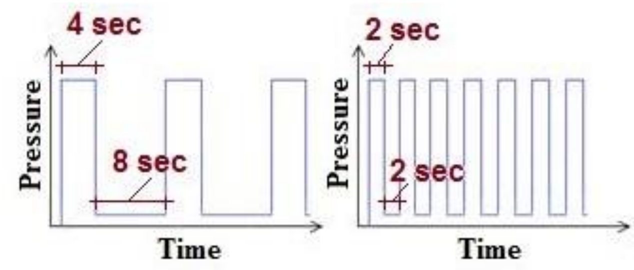
Objective

- ❑ ***How can the grout spread be improved effectively using dynamic pressure impulses?***

Test setup

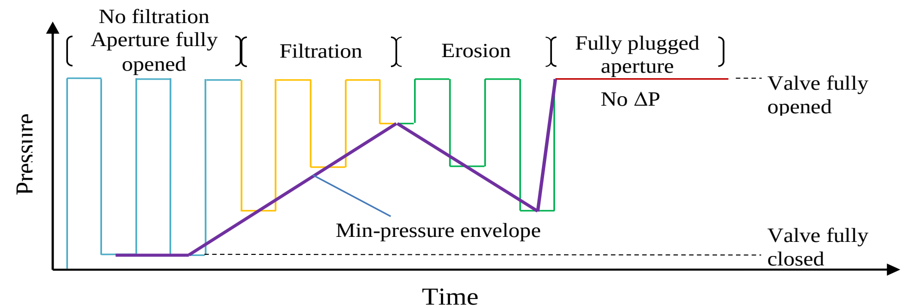


Applied pressures



Evaluation methods

- ❑ **Total weight of passed grout**
- ❑ **Cycle mean flow rate ($CMFR = {}^{V}/_{T}$)**
- ❑ **Min-pressure envelope**



Mechanism of action

- ❑ **Erosion of the produced filter cakes due to change of flow pattern**

Conclusions

- ✓ **The low frequency rectangular pressure impulse showed a substantial control on filtration and improved the grout spread within parallel plates with constrictions ≤ 70 µm.**
- ✓ **The results obtained from 2 s/2 s peak/rest period were much better than 4 s/8 s.**

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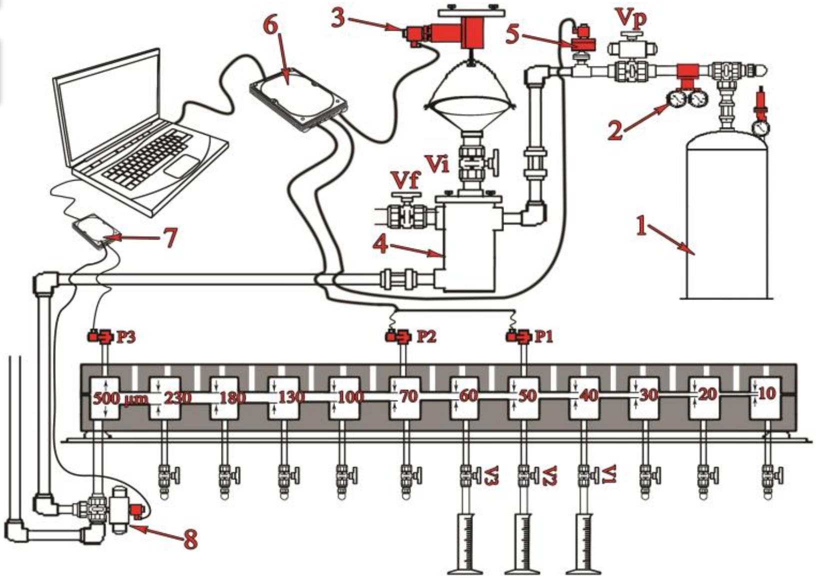
Part (C2): Improvement of Grout Spread Dynamic Grouting

Objective

❑ ***How is the dissipation of pressure-impulses along a longer artificial fracture?***

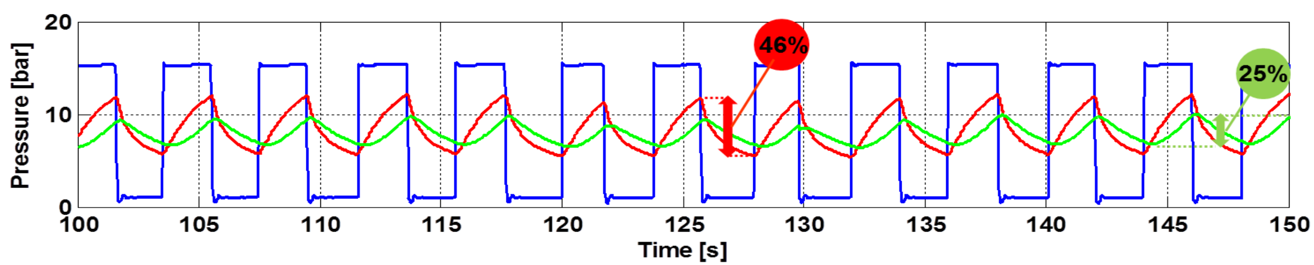
Test setup



Combination of Part B + Part C1

- **P1: At 2.7 m, before 40 µm aperture**
- **P2: At 2.0 m, before 60 µm aperture**
- **P3: At 0.0 m before 230 µm aperture**
- **Applied Pressure: 15 bar**
- **Peak/Rest Period: 2S/2S**

Results



Conclusions

✓ **By applying a low-frequency rectangular pressure-impulse in VALS, the remaining amplitudes of the pressure impulses after 2.0 and 2.7 m, were 46% and 25% of the initial applied amplitudes.**

✓ **The study showed the potential of the method on improvement of grout spread in fractured hard rock specially in fractures <70 µm.**

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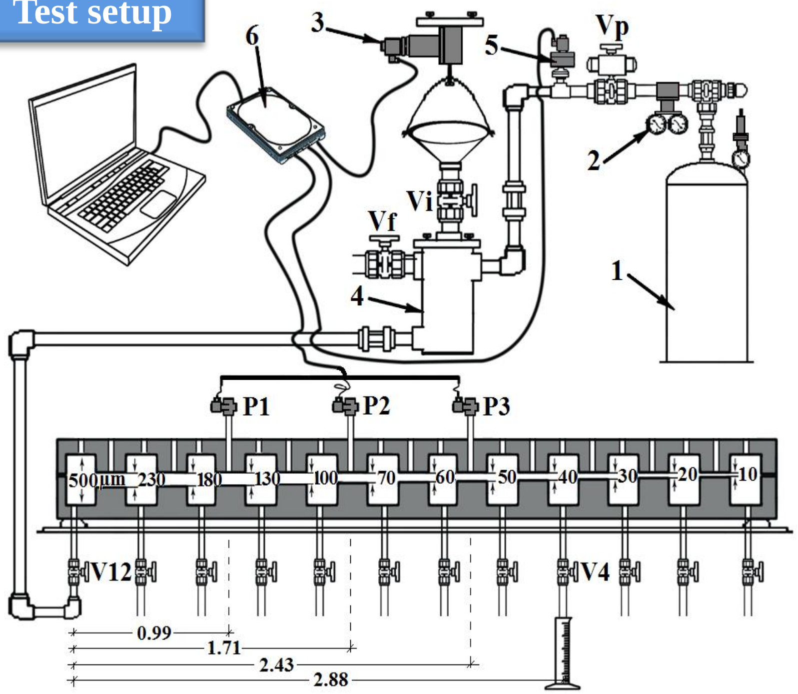
Part (D); Evaluation of the RTGC theory

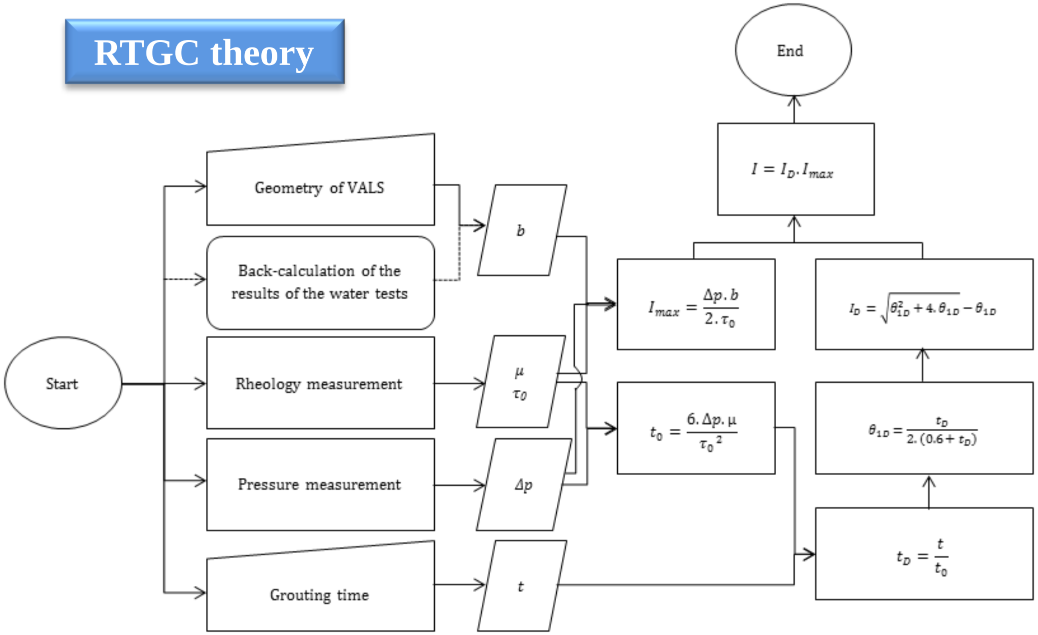
Objective

- *Is it feasible to employ the RTGC theory to predict the grout spread in an artificial fracture with variable apertures?*

Test setup



RTGC theory



Conclusion

✓ **The predictions of grout propagation obtained from the RTGC theory using b_h, the way that the theory was used previously in the early stages of the development, showed relatively good agreement with the experimental results for all the tested materials. However, the predictions using b_{phy}, the way that the theory is nowadays used in field applications, showed considerably faster spread than the experimental results.**

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Limitations
& Suggestion for future works

Limitations

- ✓ Number of test repetitions
- ✓ Geometry
  - Limited width
  - Limited length of each section
  - Limited no. of constrictions
  - Sharp variation of the apertures
  - Surface roughness of the steel plates
  - Distribution/order of the apertures
  - Grout flow in 1D (one-dimensional) flow condition
- ✓ Equipment
  - Limited capacity of the grout tank (2.6 l)
  - Lack of agitating system
  - Limited no. of pressure sensors

Future works

- ✓ Field-scale verification of the efficiency of dynamic grouting in micro fractures < 70 µm in the Äspö hard rock laboratory
- ✓ Development of a standard test methodology for in-line evaluation of grout penetrability properties in rock fractures in grouting units in field.
- ✓ Investigation of the dissipation of low-frequency pressure impulses in VALS using different pressure set-ups and materials