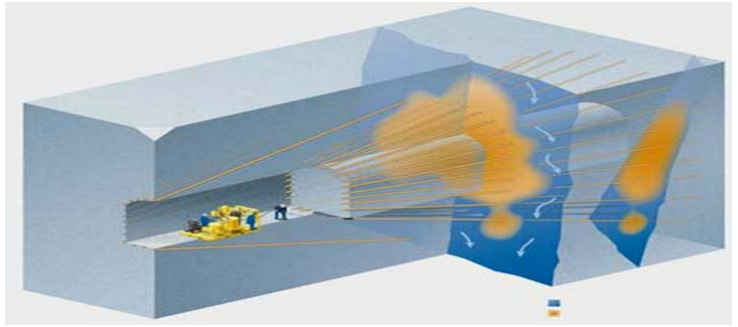
GROUTING DESIGN DURING CONSTRUCTION PHASE IN A CLIENT PERSPECTIVE

Thomas Dalmalm, Swedish Transport Administration

CONTENT - CLIENT PERSPECTIVE

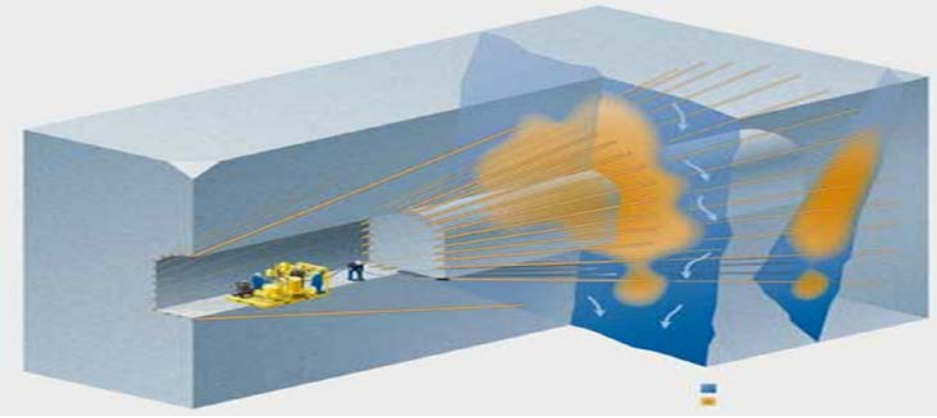


- Grouting concepts
- Grout properties
- Pricing
- Responsibility
- Contracts for grouting

TRAFIKVERKET

Grouting concepts

- stop criteria's



- Flow
  The rock fractures are filled up enough when the flow is less than a certain value during a time period, E.g. less the when 2l/min during 5 minute
- Volume
  The rock fractures are filled up enough when predicted volume is reached,
  E.g. 500 litre
- GIN
  Grouting intensity number, GIN=P*V, the combination of pressure and volume sums up to fulfil the stop criteria

- Thickening
  Decrease the grout w/c ratio during grouting in combination with a flow criteria

- RTGC (Time), for a specified aperture the time for achieving a grouted zone around the tunnel can be calculated. The method limits the excess use of grout.
  A development is needed to get the method on-line on the grouting rig for decision making.

South Link Stockholm 1998-2004

- Grouting chapter is named “Bergförstärkning genom injektering”
- PhD thesis, Swedenborg 2001, Grouting is No rock support
- Pressure 2,5 MPa above groundwater pressure.
- Stop criteria: Flow low less than 2 l/m, during 5 min

Properties	Grout based on microcement	Grout based on groutcement
Yield value (Pa)	≤ 1.0	3 - 8
Marshtime (s)	≤38	≤60
Filtration stability (ml) 75, 125	≥250	≥50
Water separation (%)	≤1	≤1
Volume change (%)	≤2	≤2
Setting time (h)	≤15	≤10
Shear strength, 4h (kPa)	≥0.2	≥0.5
Shear strength, 12 h (kPa)	≥20	≥30

Waterloss (LU)	w/c ratio	cement (Kg)
< 1,0	2	100
	1	200
	0,8	400
	0,5	+
> 1,0	1	200
	0,8	400
	0,5	+

Palmqvist

Löttingetunneln, Stockholm 2004-2006

- Grouting classes are based on Lugeon values
- Pressure 2-6 MPa above groundwater
- Grout volumes was calculated for each typical rock mass
- Stop criteria: Flow low less than 1 l/m, during 2 min
- Overlap minimum 4 m

Waterloss (LU)	grout holes	special
>10	65 holes	Double fans
10 ≥ Vfl > 4	65 holes	
4 ≥ Vfl > 1	35 holes	
1 ≤ Vfl	25 holes	

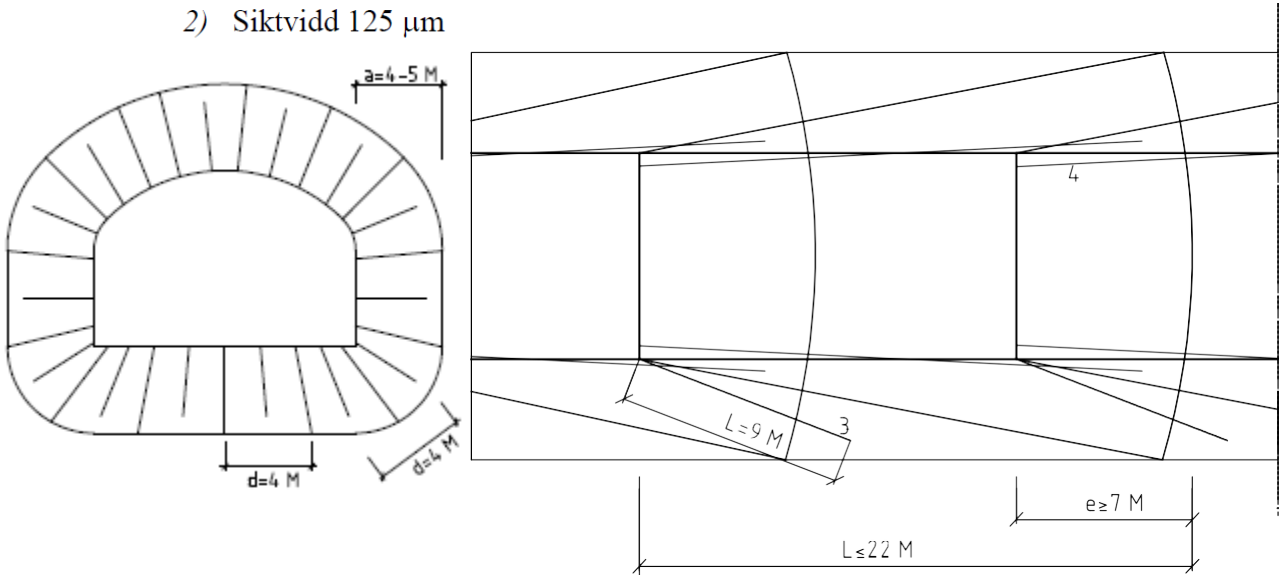
Grout type	Volume [liters]
Start	100
Sealing	150
Stopp	64

North Link, Stockholm 2006-2014

- Pressure 2.3-3.0 MPa above groundwater
- Grout 1 with: 40kg/drillmeter and thereafter grout 2 with 30 kg/drillmeter
- Hole spacing 2 m (4+4)
- Stop criteria: Flow low less than 1 l/m, during 2 min
- MWD was successfully used as a tool to analyse the rock mass for grouting and rock support
- Overlap 7m

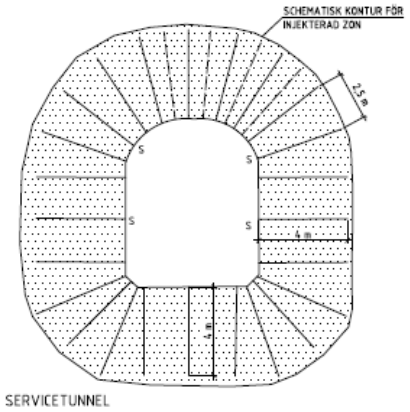
	Bruksb. I	Bruksb.II
Cementtyp	Injekterings-cement vct 0,8	Injekterings-cement vct 0,6
Kornstorlek (µm)[1)]	≤ 30	≤ 30
Marshtid (s)	≤ 41	≤ 60
Filtrerings-stabilitet (ml)	≥ 200[2)]	≥ 200[2)]
Vattenseparation (%)	≤ 4,5	≤ 2

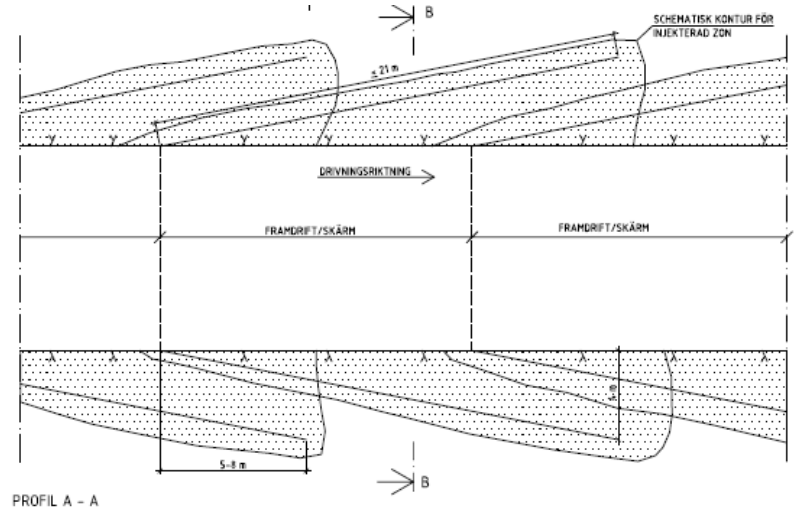
1) Vid 95 % passerande mängd
2) Siktvidd 125 µm



Citytbanan, Stockholm 2009-2017

- Probe holes (4)
- Pressure 0.5-2.0 MPa above groundwater
- Hole spacing 2,5 m or 1,5 m (3+3)
- Stop criteria: 40 min grouting or 500 litre (21 m hole length)
- Mix 1: w/c ratio 0.8 grout cement
- Mix 2: w/c ratio 0.8 micro fine cement
- Mix 3: silica sol
- Overlap 5-8 m





Citybanan - One concept for grouting

1. One subproject followed the concept ~100%
2. One subproject partly changed concept 70%
3. One subproject argued that the concept didn´t work 0%

Compliance	
100 %	recent work with similar concept
70 %	no recent work similar concept, but good grouting experience
0 %	no recent work, minor grouting experience and a contractor who had low prices on grouting

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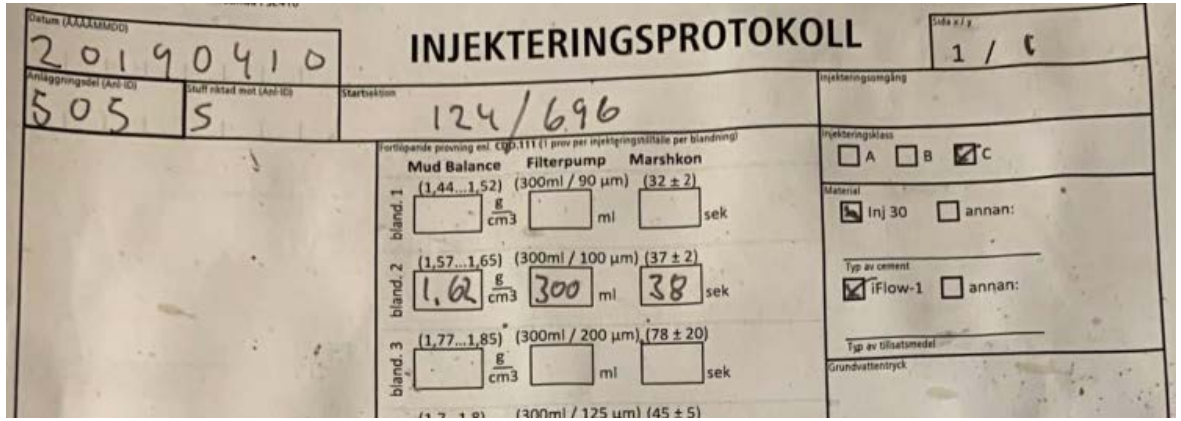
Grout protocoll and real grout properties



INJEKTERINGSPROTOKOLL

Datum (ÅÅÅÅMMDD): 20190410

Sida x / y: 1 / 1

Anläggningsdel (Anl-ID): 505

Stuff riktad mot (Anl-ID): S

Startsektion: 124/696

Injekteringsomgång:

Fortlöpande provning enl. CDP.111 (1 prov per injekteringsställe per blandning)

	Mud Balance	Filterpump	Marshkon
	(1,44…1,52)	(300ml / 90 µm)	(32 ± 2)
bland. 1	g/cm3	ml	sek
	(1,57…1,65)	(300ml / 100 µm)	(37 ± 2)
bland. 2	1,62 g/cm3	300 ml	38 sek
	(1,77…1,85)	(300ml / 200 µm)	(78 ± 20)
bland. 3	g/cm3	ml	sek
	(1,7…1,8)	(300ml / 125 µm)	(45 ± 5)

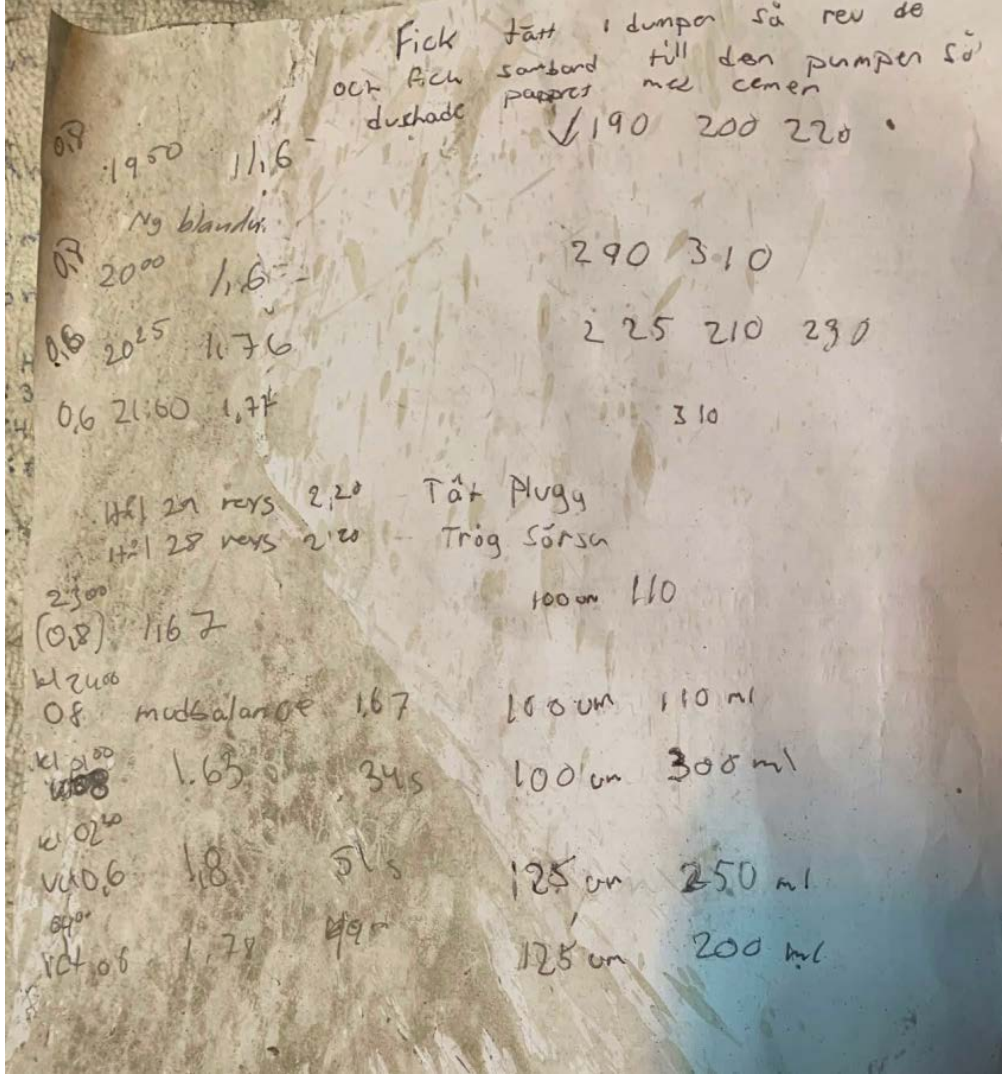
Injekteringsklass: ☐ A ☐ B ☑ C

Material: ☒ Inj 30 ☐ annan:

Typ av cement: ☒ iFlow-1 ☐ annan:

Typ av tillsatsmedel:

Grundvattentryck:



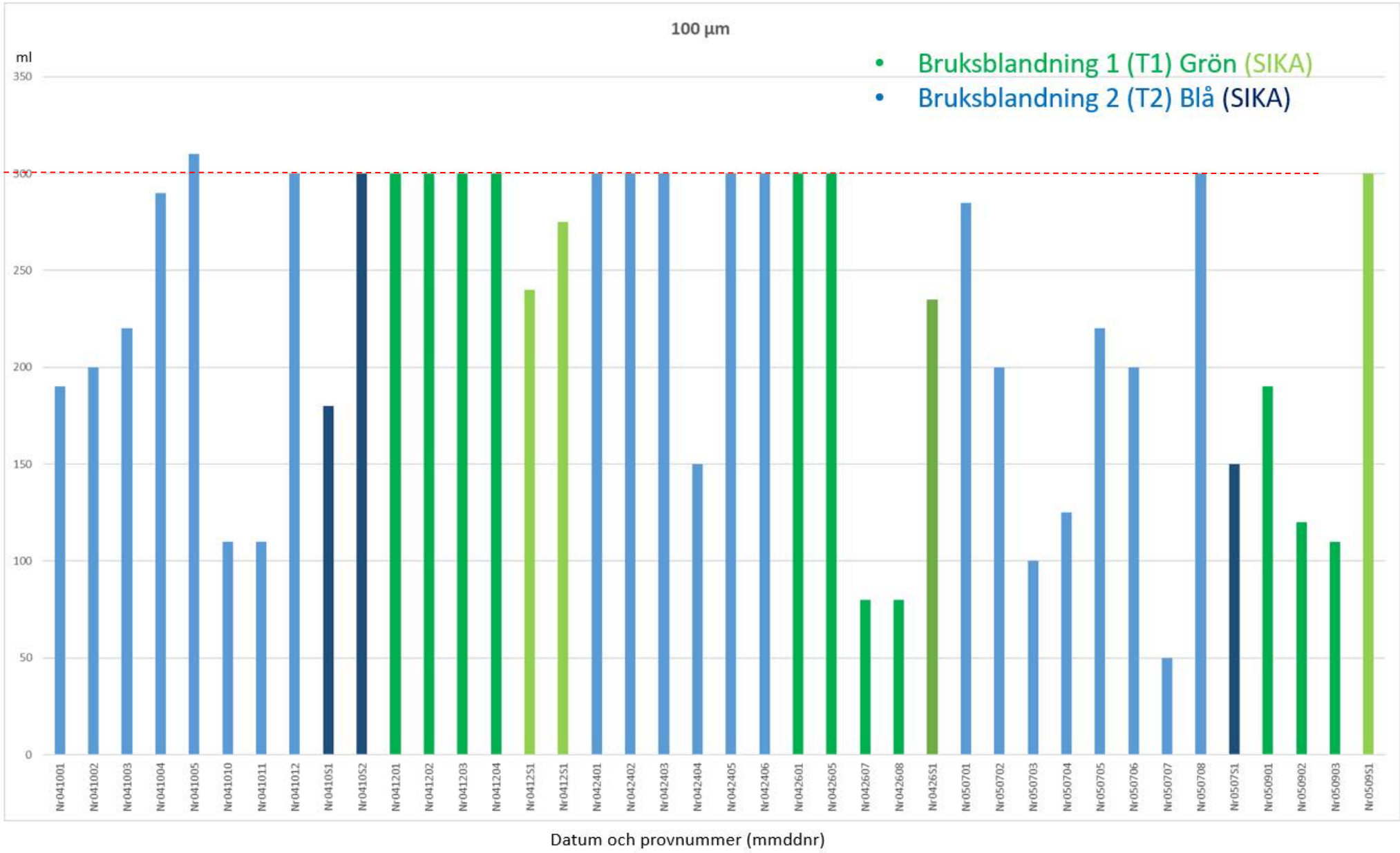
190, 200, 220, 290, 310, 230, 225, 210, 230, 100, 300, 125, 250, 125, 300

TRAFIKVERKET

Filterpump test

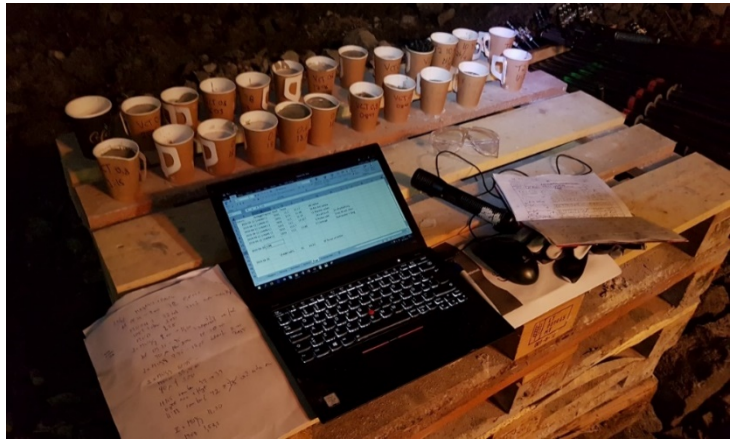
In laboratory 100% pass 75 µm filter

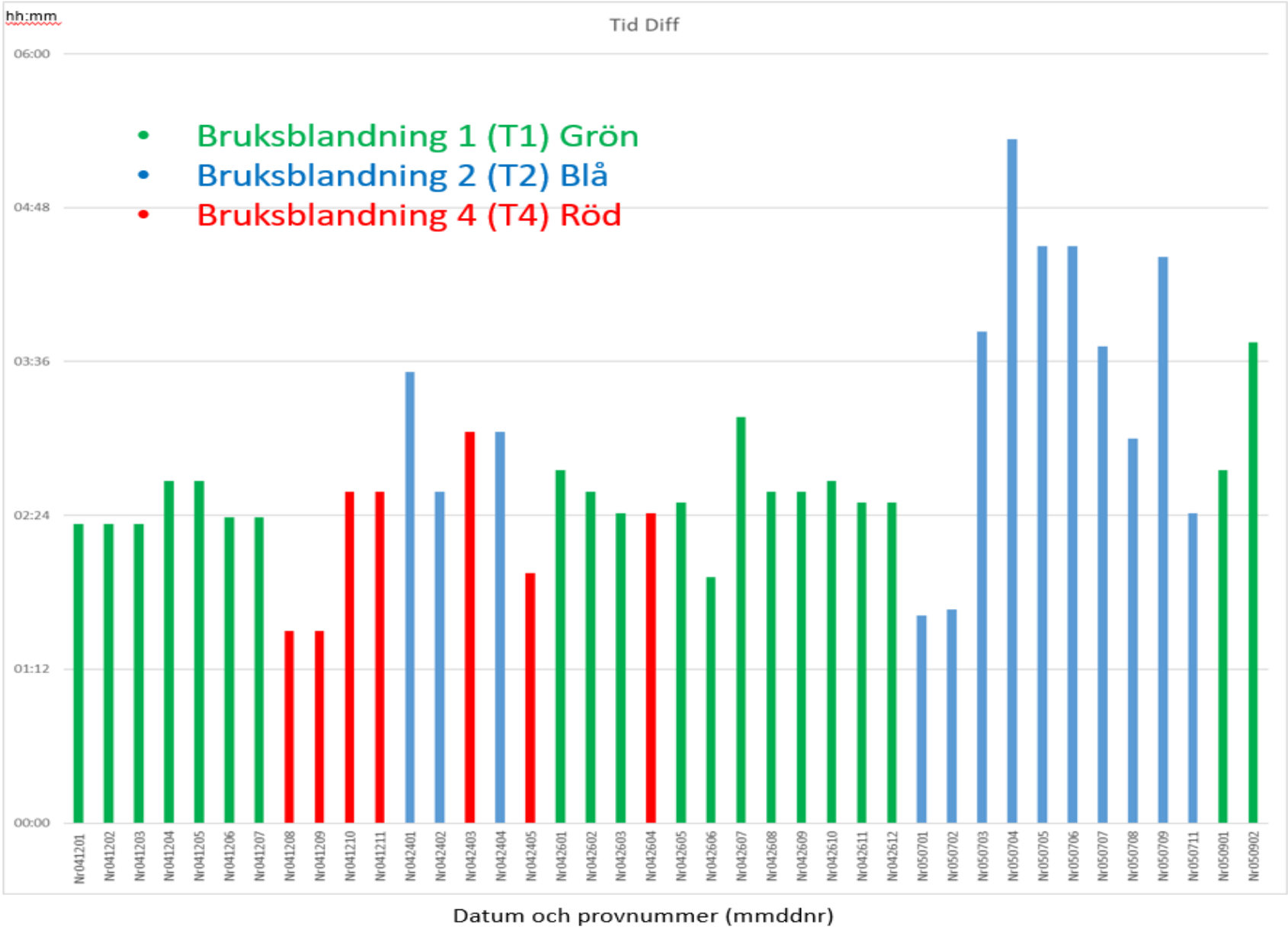
In field only 30% of the mixes pass 100 µm filter



TRAFIKVERKET

Cup test





TRAFIKVERKET

Mixing of grout

1	Water	Cement	mixing 120s	Superplastizicer	mixing 30s	accelerator	mixing 30s
2	Water	Cement	mixing 30s	Superplastizicer	mixing 30s	accelerator	mixing 180s
3	Water	Cement	mixing 30s	Superp. Acc.	mixing 120s		
4	Water	Cement		Superplastizicer	mixing 180s		
5	Water	Cement		Superplastizicer	mixing 240s		

- During design stage the efforts of finding a grout concept is extensive
- During bidding the contractor far to often have low experience on how to the produce the different grouting concepts
- The cement producers, from time to time, have as well limited knowledge of to mix the different recipes
- The mixing order considerable affect the grout properties

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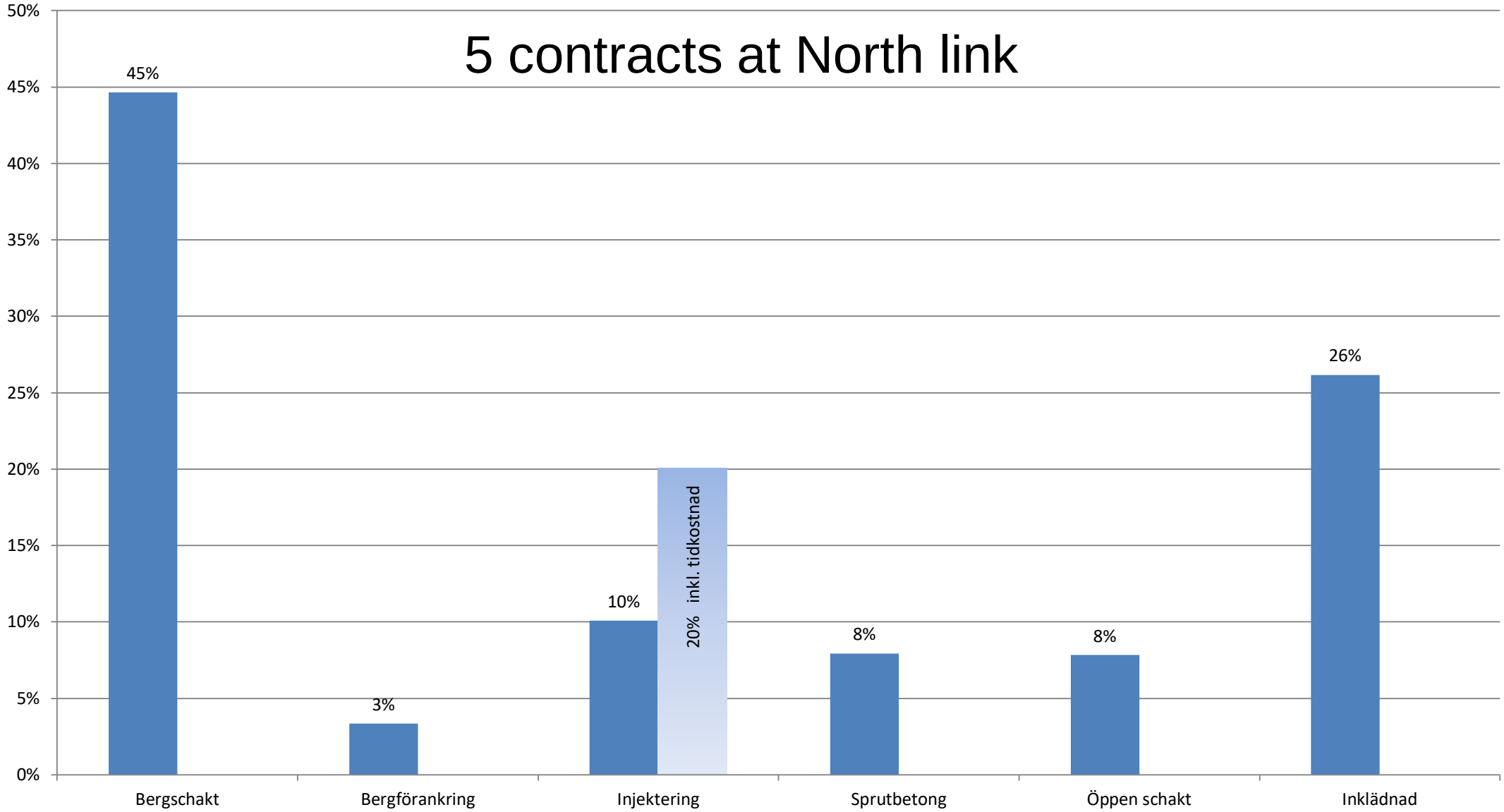
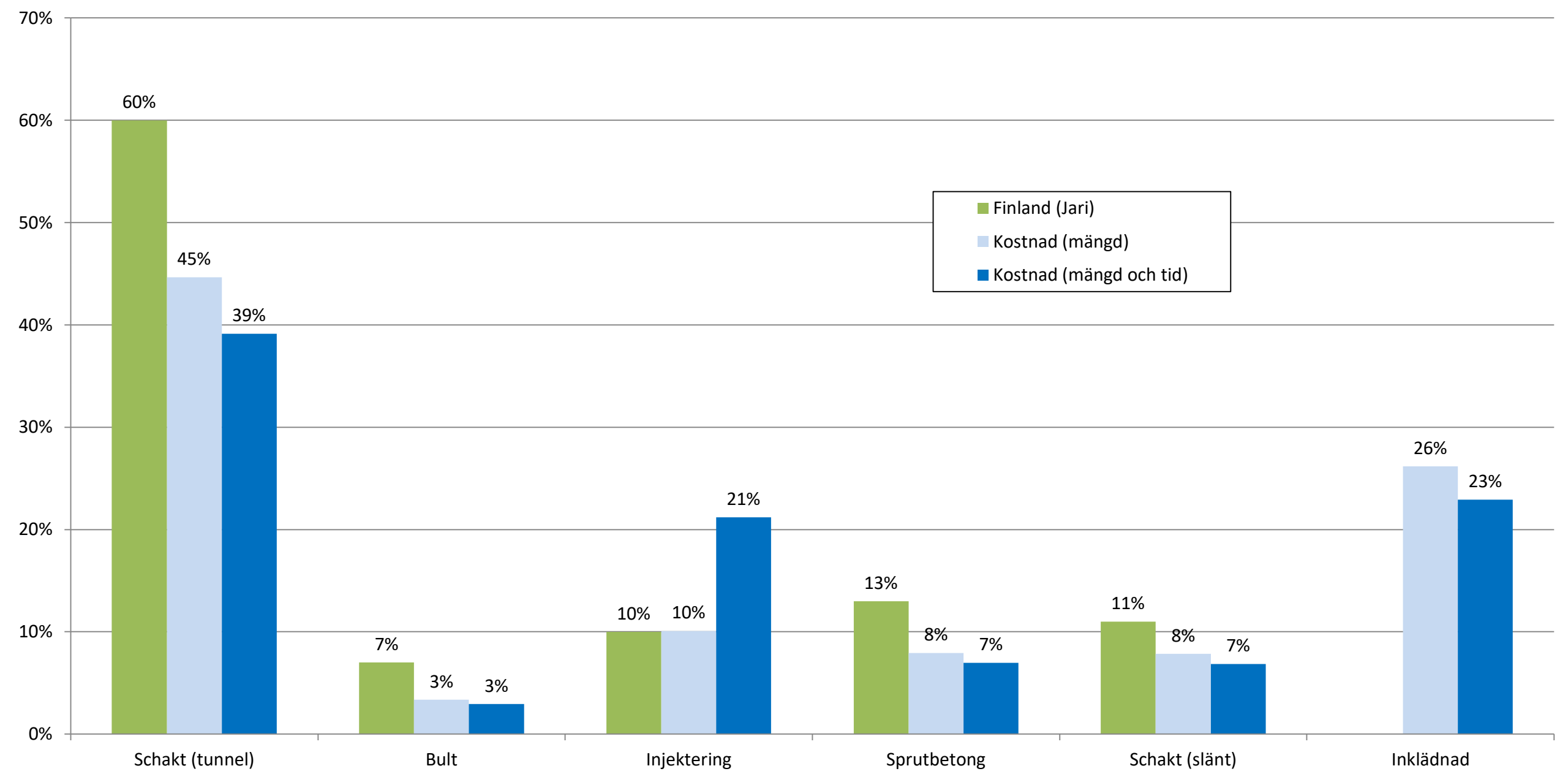

5 contracts at North link
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
45%
3%
10%
20% inkl. tidkostnad
8%
8%
26%
Bergschakt
Bergförankring
Injektering
Sprutbetong
Öppen schakt
Inklädnad


70%
60%
50%
40%
30%
20%
10%
0%
60%
45%
39%
7%
3%
3%
10%
10%
21%
13%
8%
7%
11%
8%
7%
26%
23%
Finland (Jari)
Kostnad (mängd)
Kostnad (mängd och tid)
Schakt (tunnel)
Bult
Injektering
Sprutbetong
Schakt (slänt)
Inklädnad

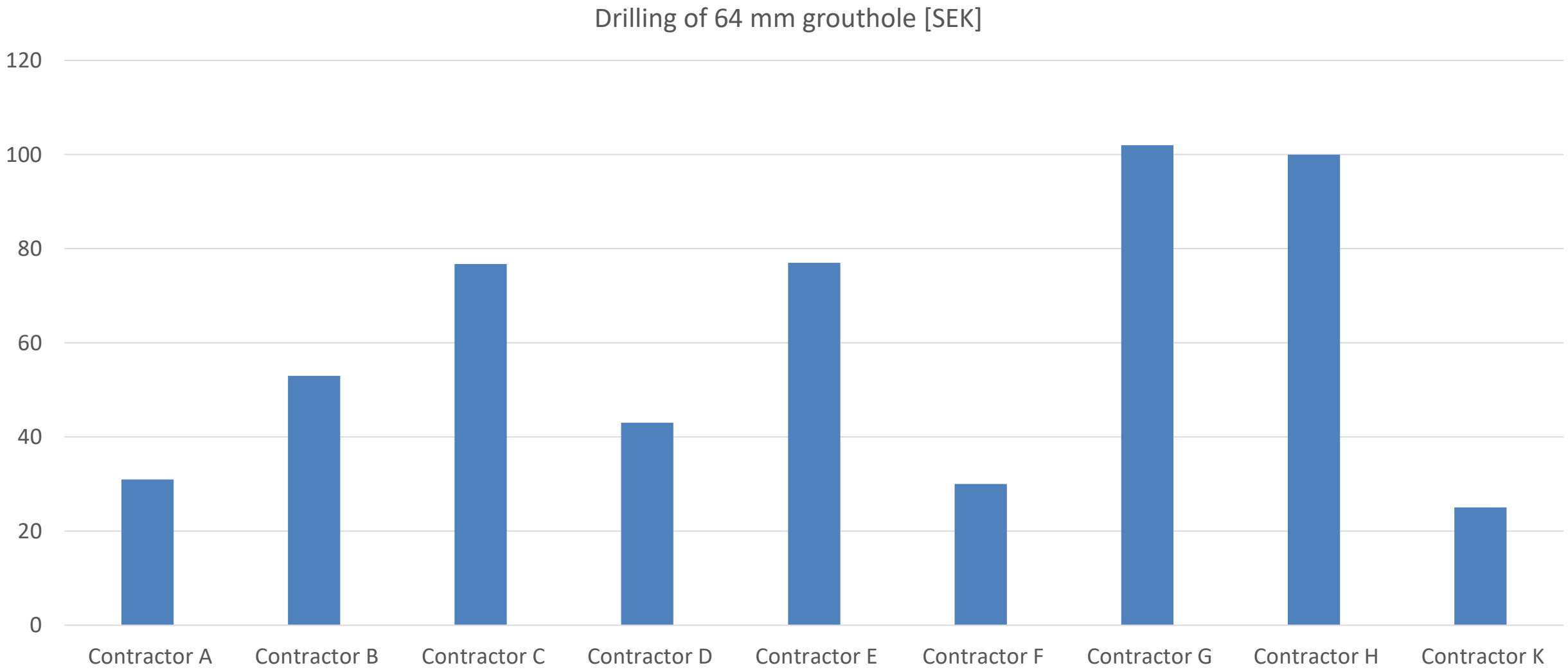
Comparison of two access tunnels at the South Link project - Both tunnels costed app. 10 million SEK

	Arena				Arla	
	Predicted	Measured			Predicted	Measured
Hole volume(litre)	32000	53046			33600	40780
Grout volume = Hole volume (0 hål)	-	44 %			-	27 %
Grout take(litre)	-	225			-	367

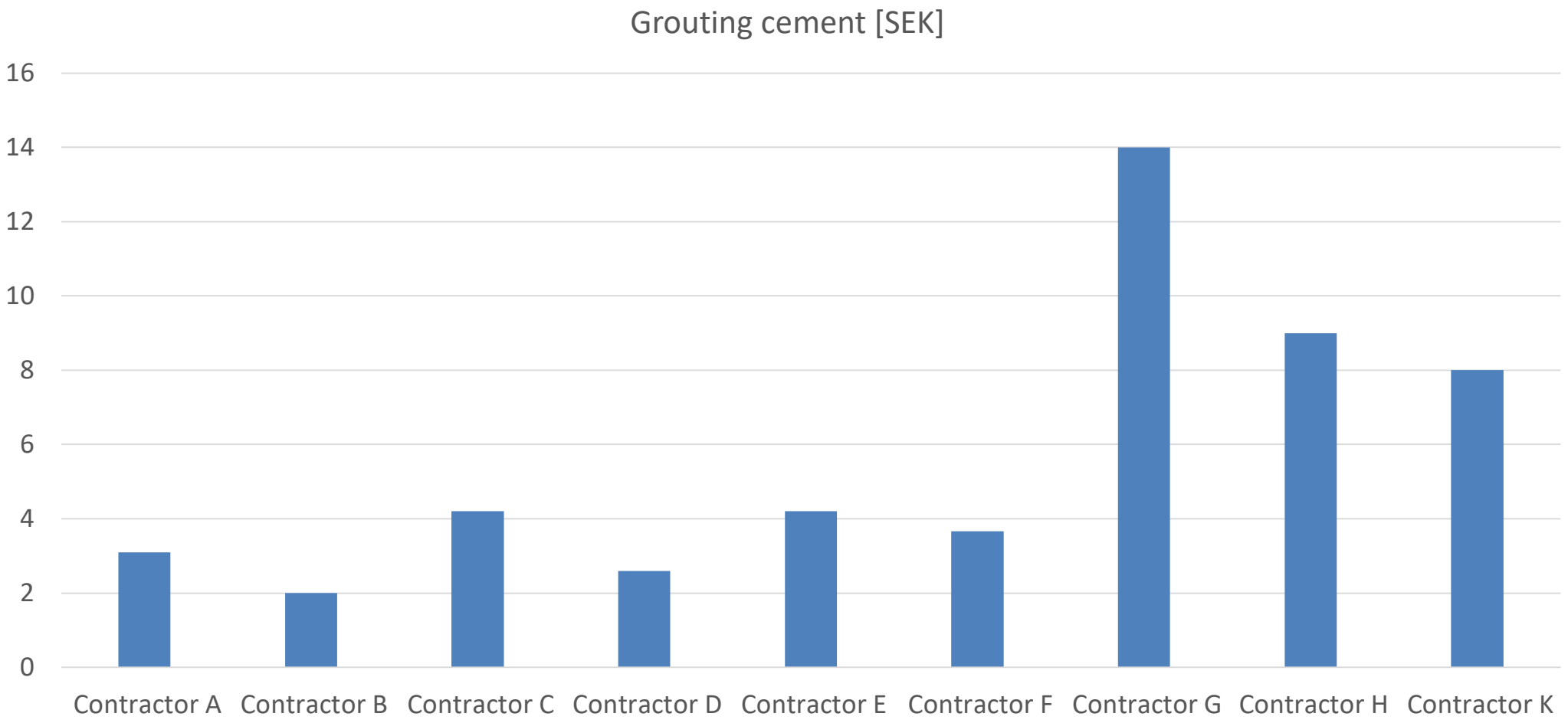
Bill of quantities and prices

	unit	Arena [SEK]	Arla [SEK]
Grout hole	no	1650	325
Drilling	m	98	60
Grout cement	kg	3,6	6
Micro cement	kg	6	9

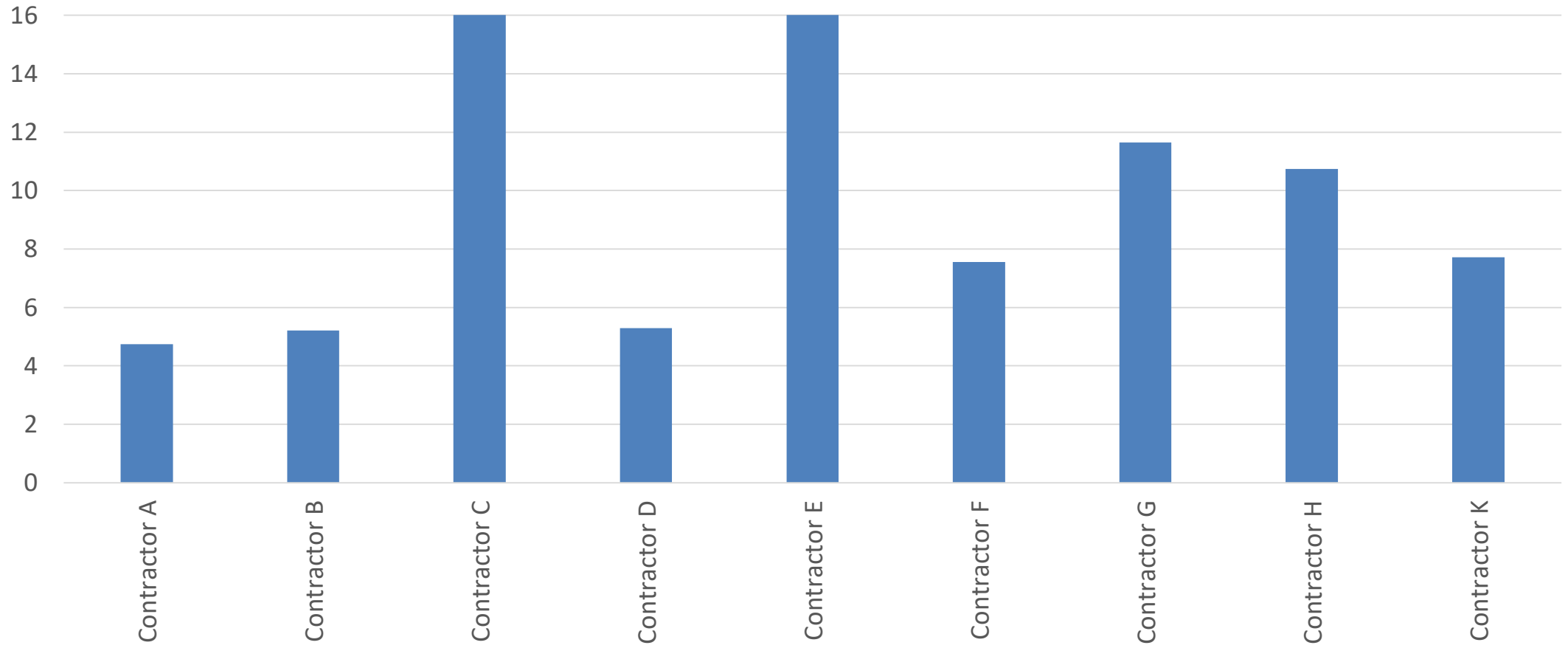
Pricing of grouting



Pricing of grouting



Grouting of 1061 meter tunnel [million SEK]



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Who is responsible?

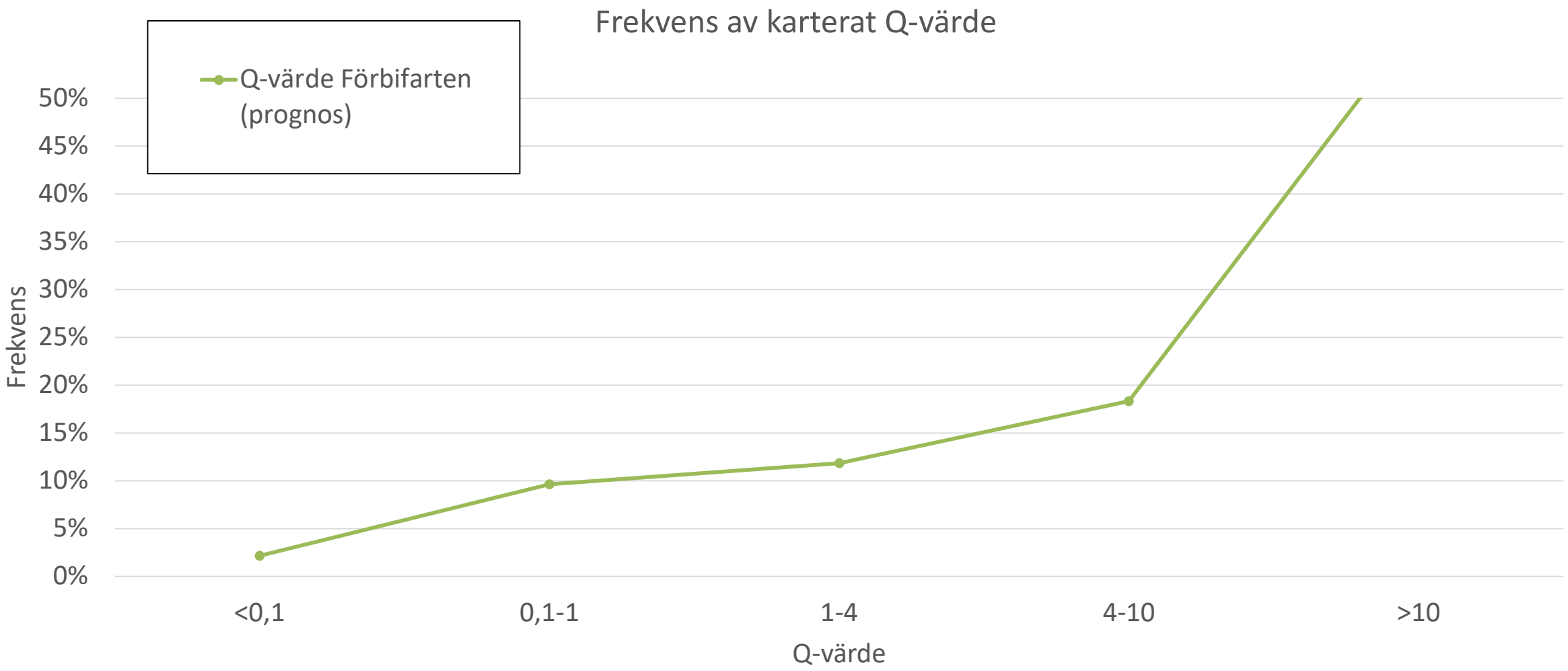
Designers responsibility in EUR

Country	Small projects	Large projects
Sweden	0, 5 m EUR	0, 5 m EUR
Switzerland	30 m EUR	1000 m EUR

- The contractor is responsible for the performance, but takes rarely responsibility for the grouting result
- The designer is responsible for the grouting design. The execution of the grouting works is not always according to the design
- The grout design is valid for the predicted geology, the geology is rarely as predict

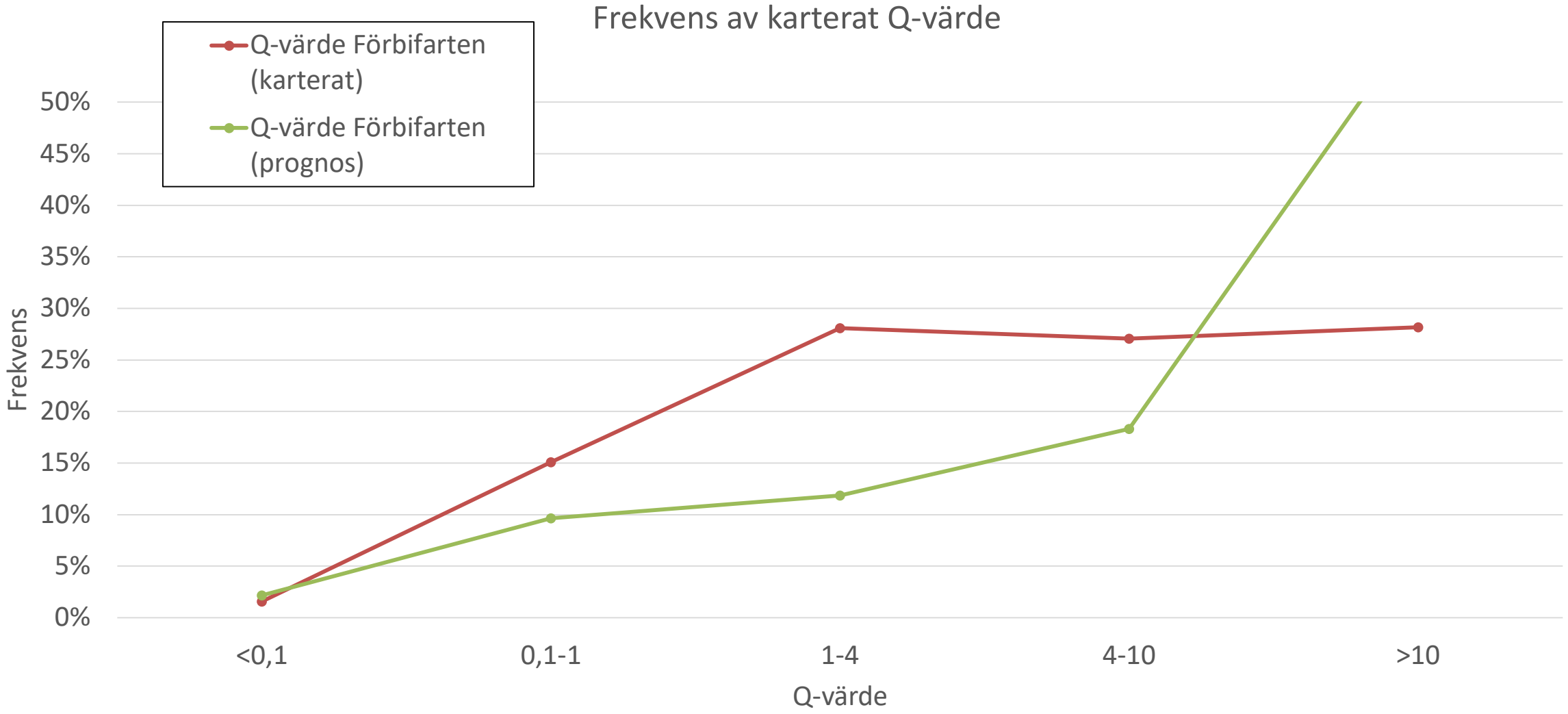
Who takes responsibility?

Predicted geology Stockholm Bypass



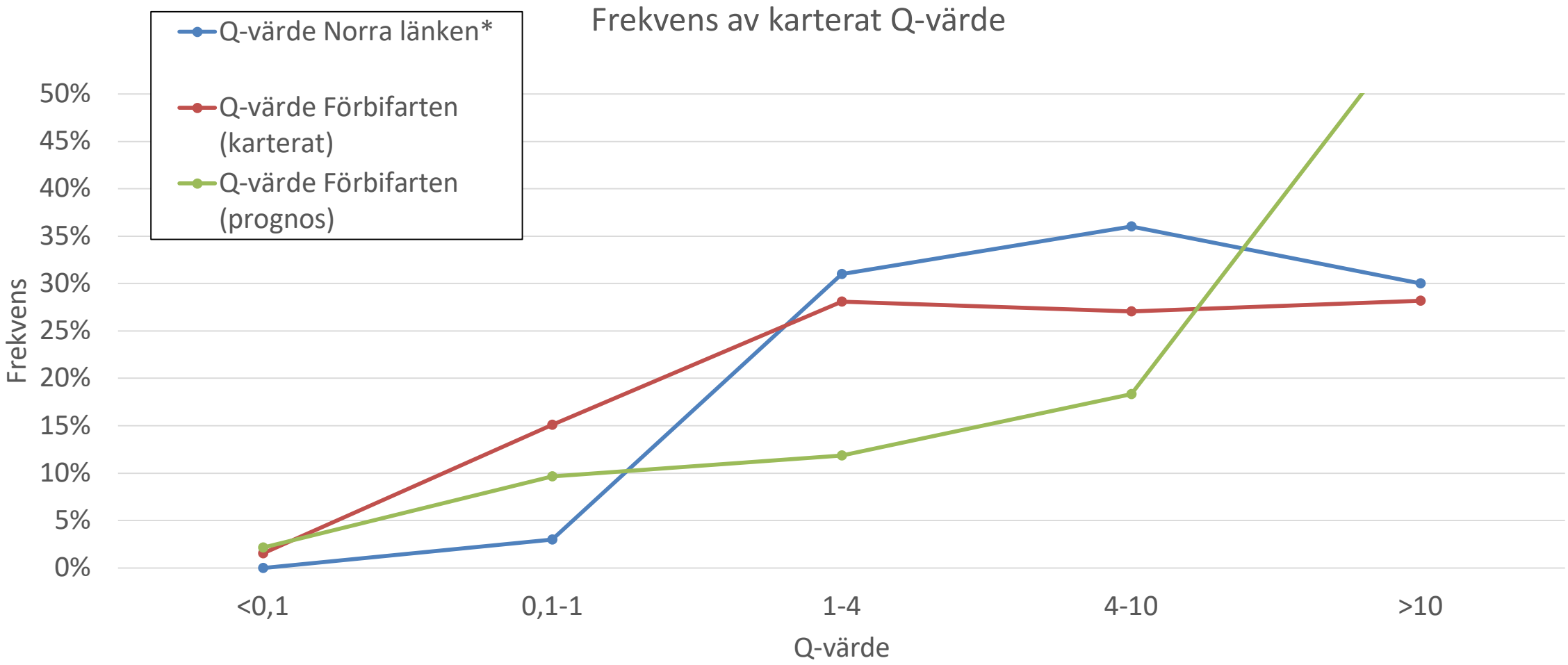
TRAFIKVERKET

Predicted and surveyed geology Stockholm Bypass



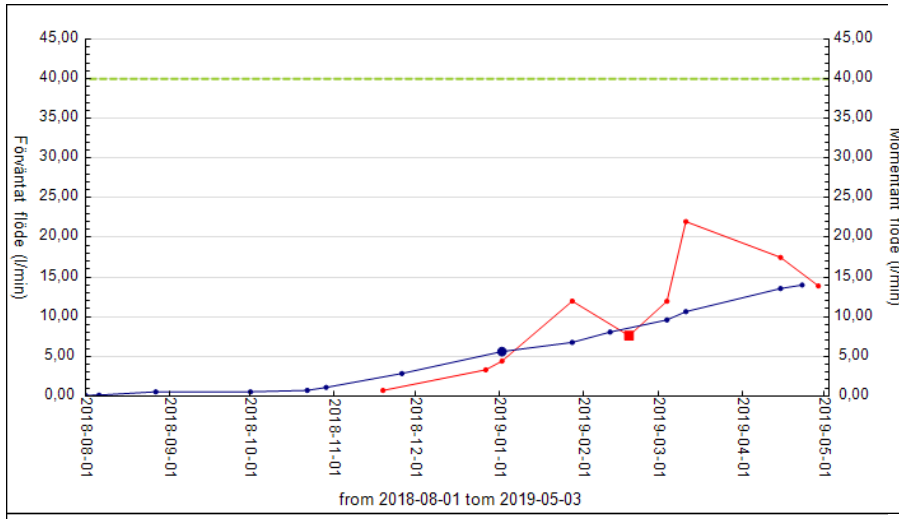
TRAFIKVERKET

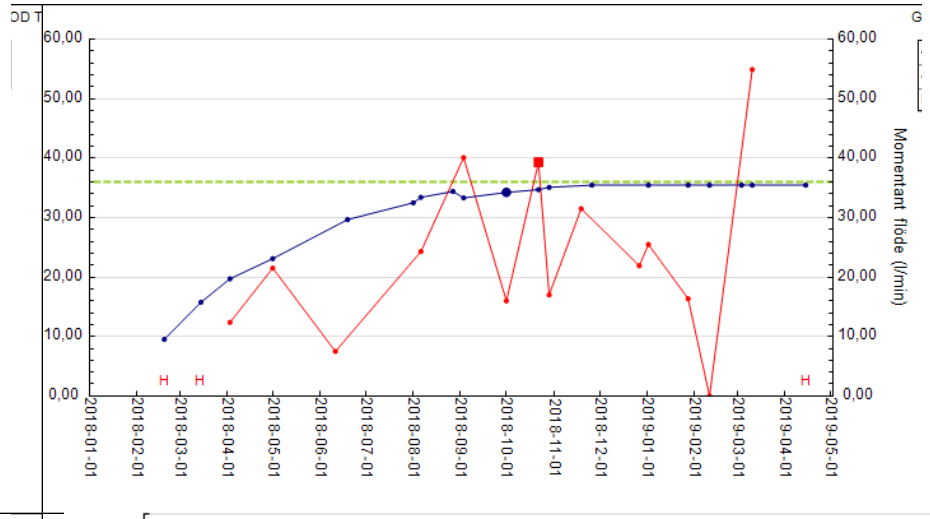
Predicted and surveyed geology Stockholm Bypass versus Northlink

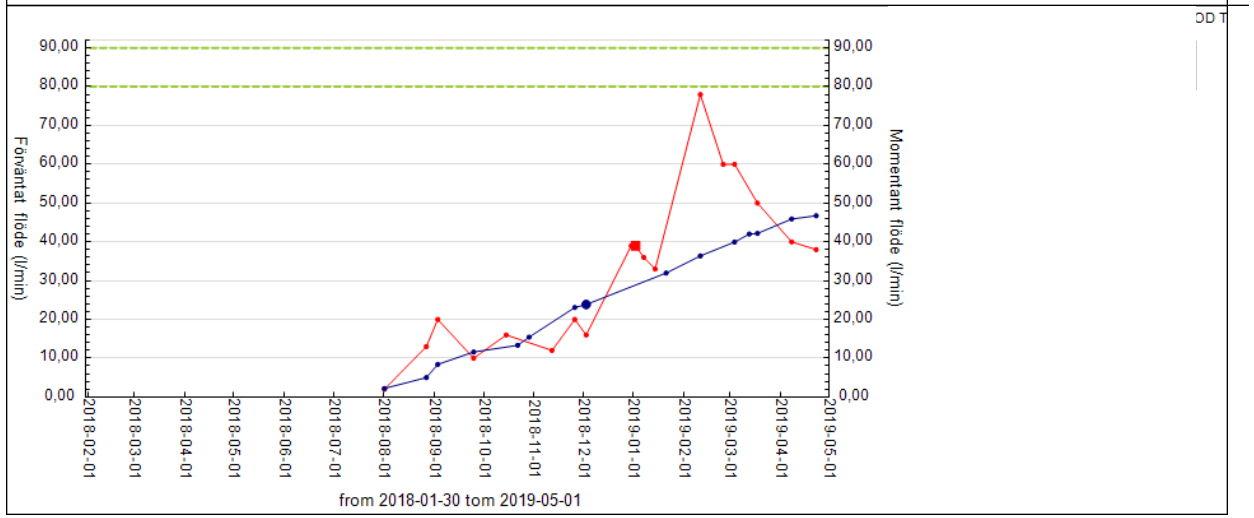


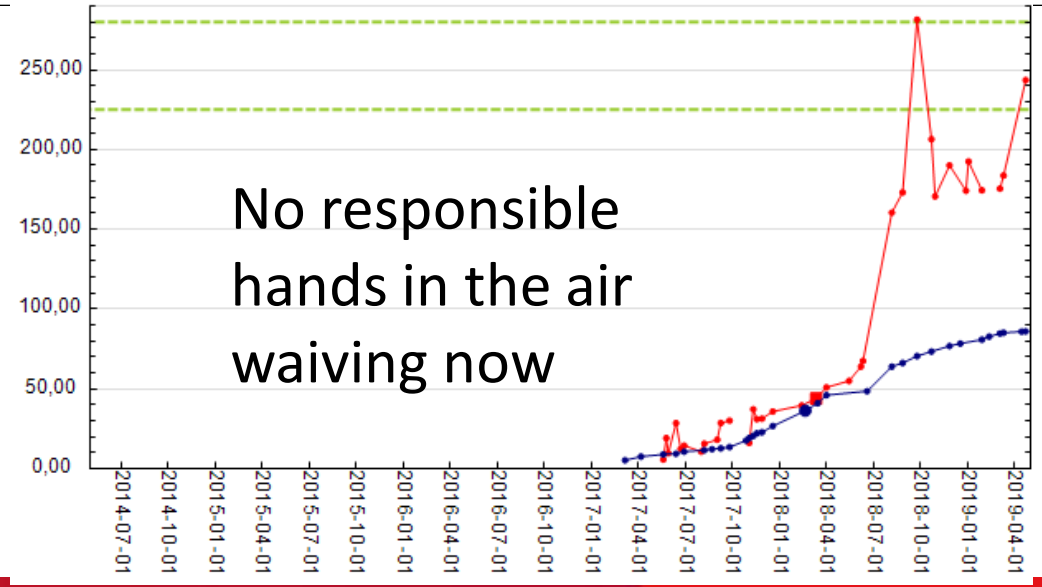
TRAFIKVERKET

Measure water leakage to tunnel









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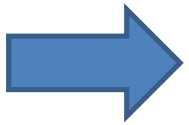
Swedish contract text

- “The employees of both parties must have a strong belief in and be inspired by a co-operation idea. A willingness to achieve the agreed goals and staffed with competent staff from both parties”

- Far too often we look at the issue only from our own perspective
- Far to often the co-operation idea is forgotten
- Far to often we have a superstition on our own legal position

Design Built contract for Grouting

- Grouting is very dependent of the geology
- The geology is difficult to describe for grouting
- The contractor is only responsible for what can be expected
- Grouting result isn`t always as excepted



Grouting on Design & Build contracts is not the best idea

Bill of Quantity contracts for grouting

- In Sweden there is a long tradition of using BoQ contracts for grouting
- Was it better before and why?
- Contractors was Swedish (or Scandinavian), same contractor from project to project
- Grouting prices was higher 10 years ago

Concepts (1/2)

1. **Allocation of risk**. The ground and groundwater related risks should be assigned to the Employer, as the party who will most benefit from the completed project and as the party that can best control these risks.
   The performance related risk arising from expected ground conditions should be assigned to the Contractor.
2. **Disclosure of all available geological and geotechnical information**. All available information should be transmitted to prequalified tenderers, avoiding the use of exculpatory language.
3. **Inclusion of a contractual geotechnical baseline**. A geotechnical contractual baseline should be included that sets out the contractual limits of the conditions anticipated to be encountered during construction, thus providing clear distinctions in the contract documents between expected and unexpected underground conditions.
4. **Inclusion of an "Unforeseeable Physical Conditions" clause**. For the case that actual ground conditions encountered differ from the predicted ones, an "Unforeseeable Physical Conditions" clause should be incorporated in the contract documents to allow relief from the unforeseeable conditions and allow the contractual flexibility to compensate for them.

(From "Motivation for proposing a new Form of Contract for Tunnelling and Underground Works", TG10, 4/4/2015)

Concepts (2/2)

5. **Implementation of a ground classification system and of supporting particular conditions that properly reflect the effort of excavation and stabilization**. The contractual classification of ground conditions should be based on the measures the Contractor has to take in order to excavate and support the ground, so as to minimize claims and disputes.

6. **Time for completion is largely influenced by ground conditions**. For this reason, time adjustment according to actually encountered ground conditions should be regulated in the contract documents.

7. **Provision of a flexible mechanism for remuneration according to ground conditions, foreseen and unforeseen.** A unit price contract payment system for items that are affected by ground and groundwater conditions should be used. The unit price structure should be organized to facilitate the distinction between fixed costs, time-related costs, value-related costs and quantity-related costs.

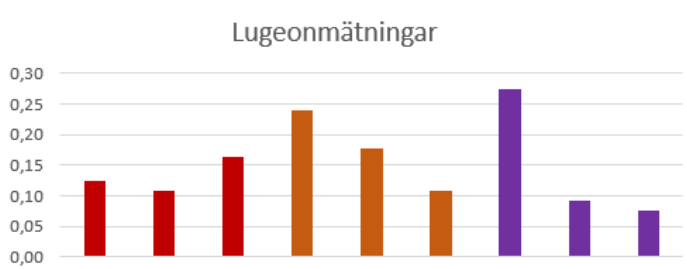
(From "Motivation for proposing a new Form of Contract for Tunnelling and Underground Works", TG10, 4/4/2015)

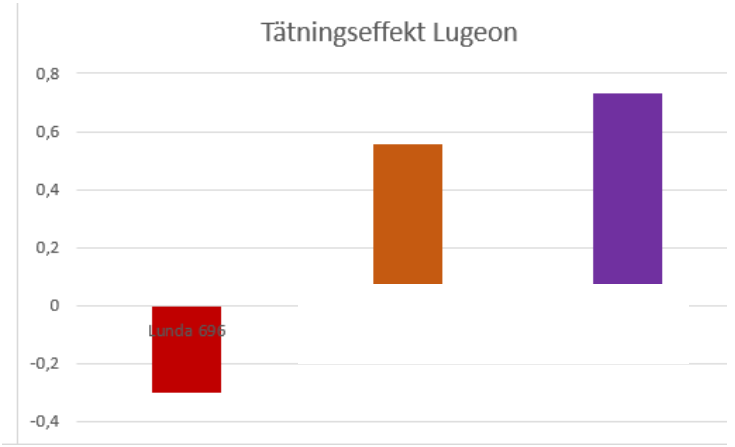
The contract time can both be shorter and longer and the contract can hadle this.

Starting at tunnel job predicted to 24 months, finishing after 12 or 36 months is taken care of by the contract

In the dust bin

- Bill of Quantities contract with 25% volume rule
- Design & Build contract for grouting
- Very low contract prices
- WPT with low accuracy (are the flow below 1-2 litre/minute it is not always possible to measure



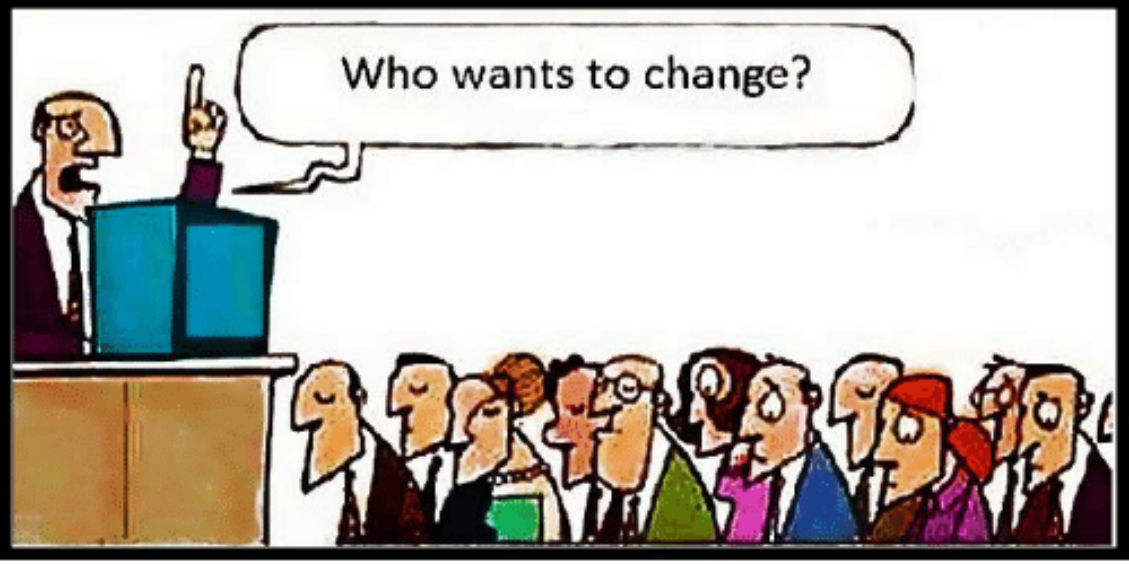


Before grouting, after 1st and 2nd

TRAFIKVERKET

In the Toolbox for grouting

- Grout mixing order instructions from cement producers
- Equal pricing between different activities in the tunnel
- A shared office during construction for contractor, designer and the client to promote co-operation (even in the tunnel)
- Competent personnel inspired by the cooperation idea
- Emerald book contract with incitements



#Anonymous

Thanks for the attention