Chemical grouting in the soils of Hong Kong

Nick Shirlaw

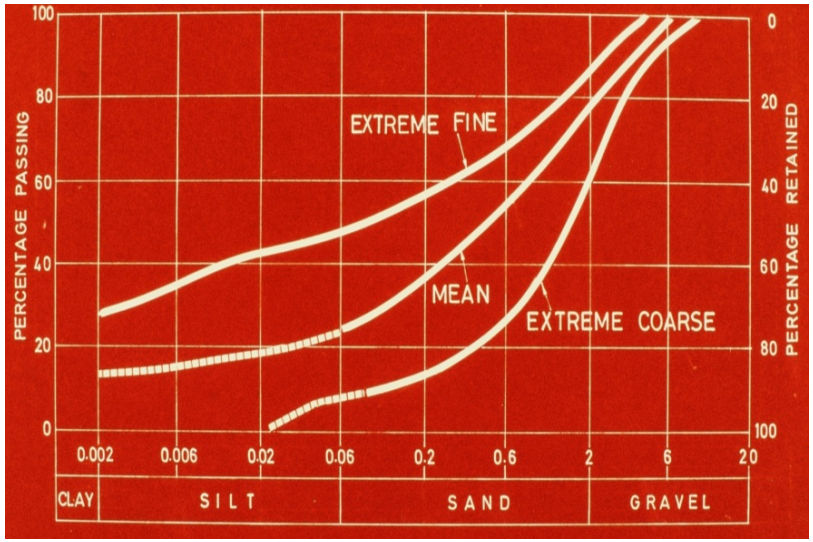
Golder Associates

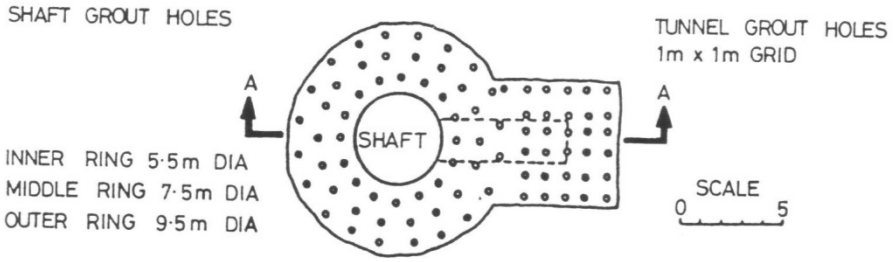
Grouting trial

- EN 12715, ‘Execution of special geotechnical work – grouting’. Clause 5.3.1 of the standard states that:
- *“Field grouting trials are executed in order to define or validate a grouting method. Field grouting trials should be considered as part of the initial site investigation. They should be conducted during the final design phase, or as part of the construction phase if they did not form part of the site investigation. They should be executed where initial investigations and local or comparable experience is insufficient to support or justify the effectiveness of the grouting project. The trials should provide information on borehole spacing, grouting pressure and grout take and types.’*

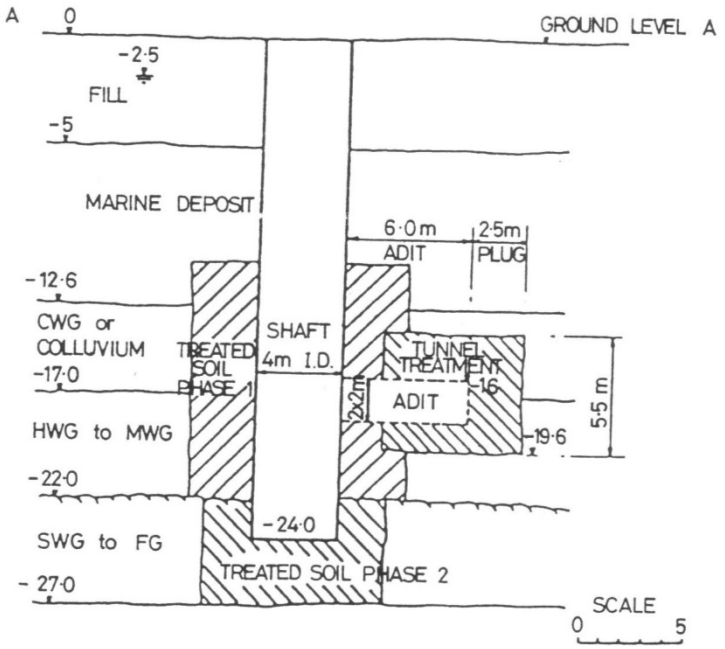
Preliminary trial, Hong Kong

- Trial tunnels and chemical grouting carried out in 1973/1974, prior to MIS construction, to demonstrate effectiveness of use of compressed air or chemical grouting for tunnelling in cdg





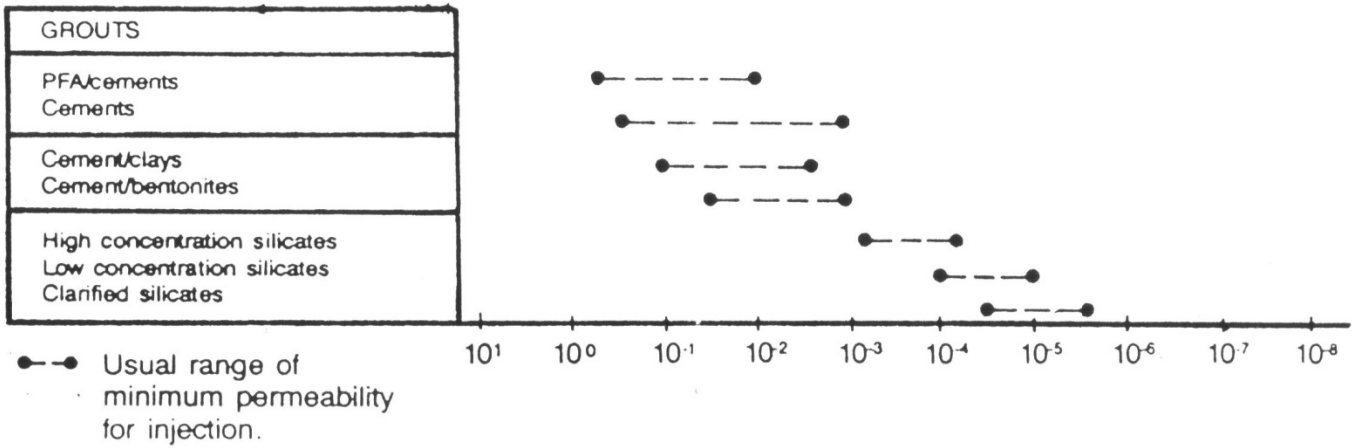
PLAN VIEW SHOWING GROUTHOLE ARRANGEMENT

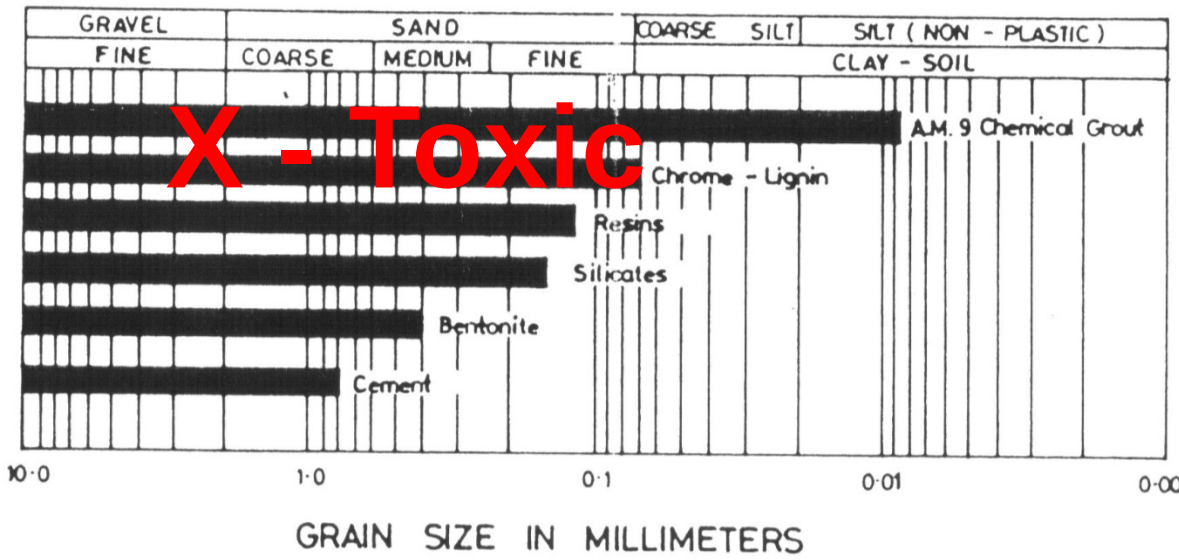


Concern over high fines content of cdg – typically over 20%

Golder Associates

Injection of grouts into soils





Limited by viscosity, practical pumping rate

Limited by grain size of suspended particles

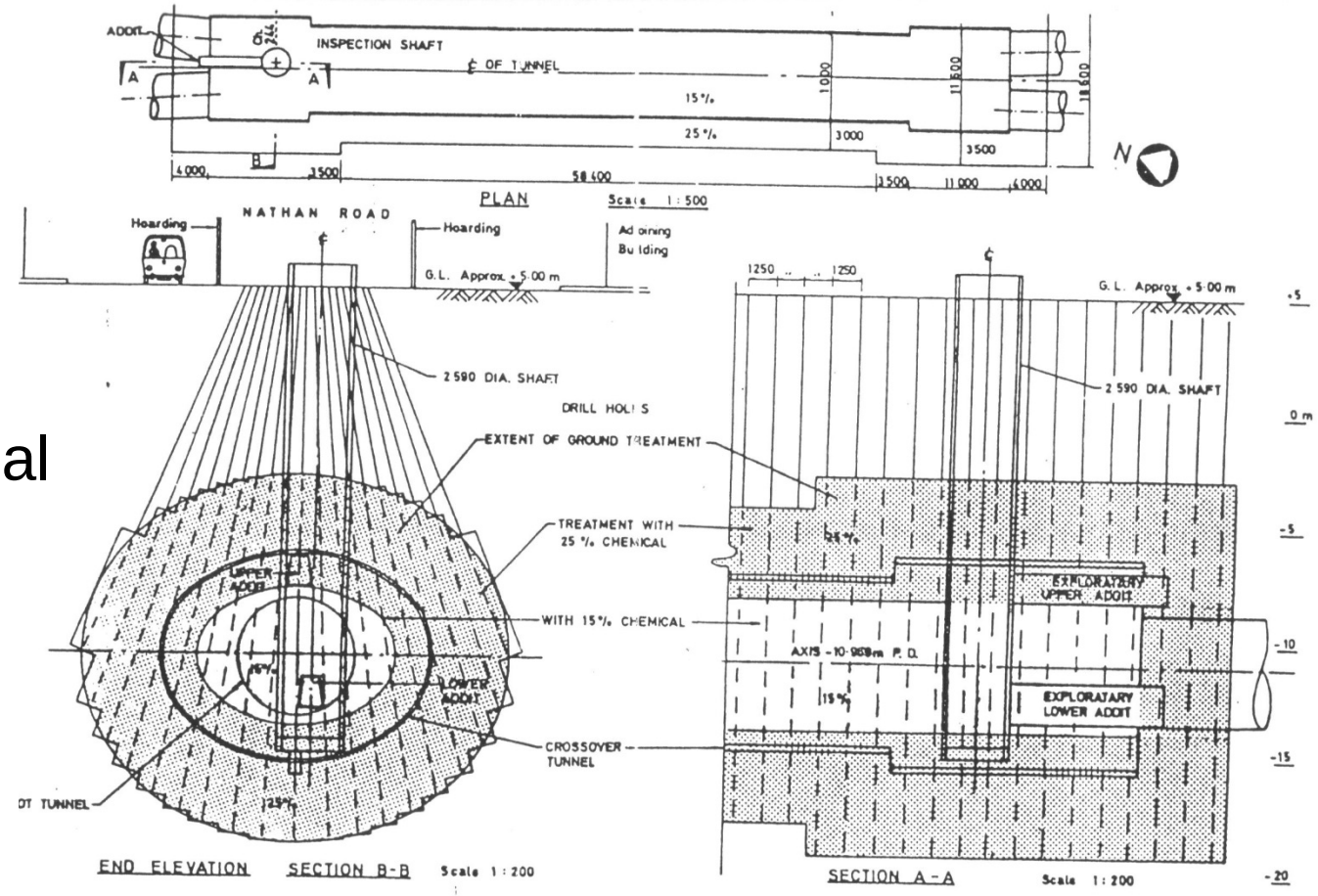
Examples from MIS, Tsuen Wan and Island Lines

Estimated that 100 million litres of grout was injected to aid tunnelling and station construction on the three lines

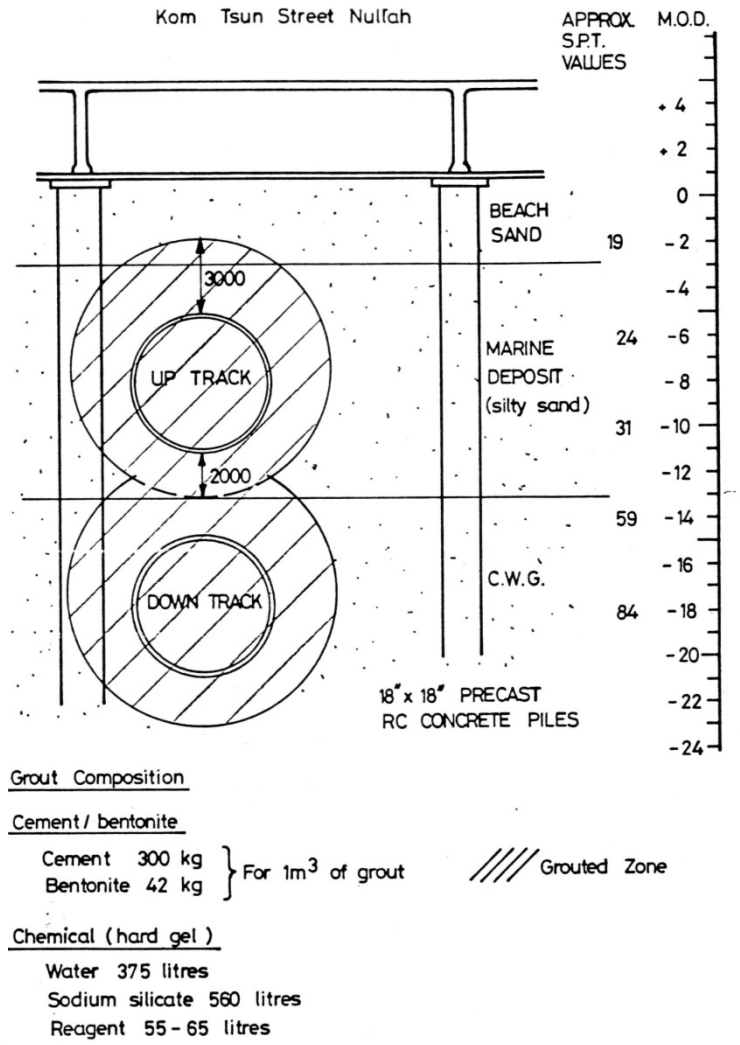
Golder Associates

Use of chemical grouting, MIS

High level, elliptical cross-over, North Nathan Road, in cdg



Tunnelling under Butterfly Valley nullah



Tsuen Wan extension, grouting in marine deposits, cdg

Note use of high viscosity silicate Grout

Drilling from within Nullah

Tunnelling and ground treatment – Island Line

	Number of cases	Tunnel length (m)	Comments
Ground treatment only	42	1,323.9	
GT + dewatering	3	161.5	
GT + reduced compressed air	7	186.1	
GT + full compressed air	10	455.9	For building protection
Total	60	2,127.4	

Golder Associates

Typical procedures used

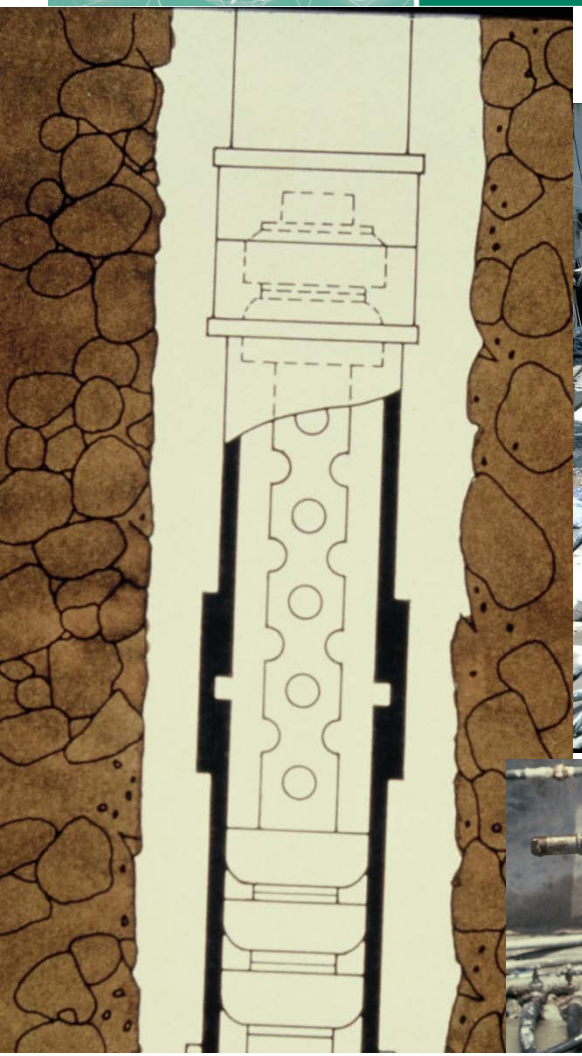
- Mainly grouting through Tubes-a-manchette (TaMs), but not always
- Two phase grouting – first phase of cement-bentonite, second of sodium silicate/chemical reagent
- Initial quantities, as % of ground to be treated:

Soil type	C/B	Silicate/ reagent
Marine	10	35
Alluvium & Colluvium	10	40
cdg	5	25

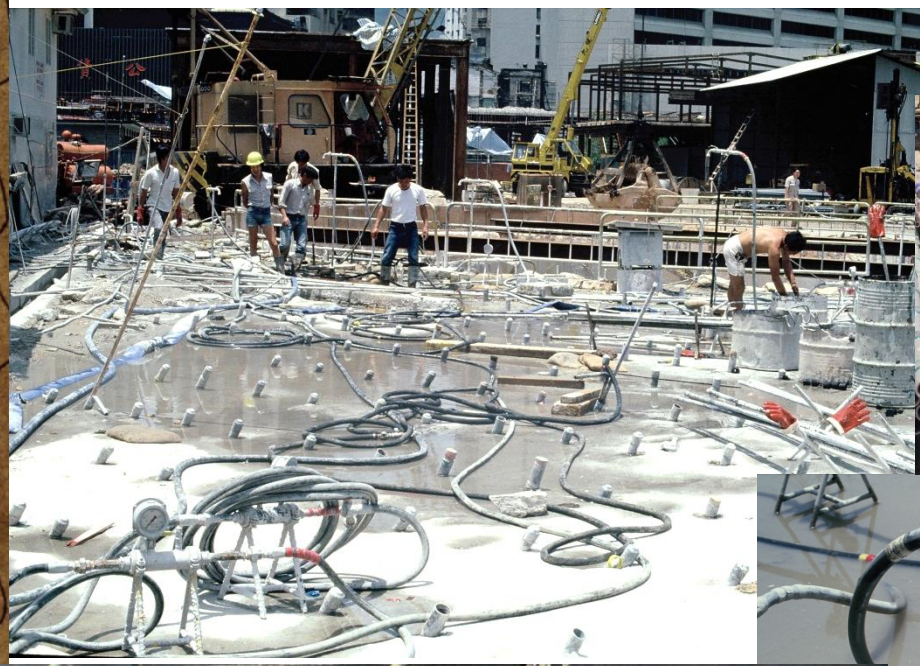
- Maximum pressure generally 25 bars (not a target, just a limit)
- Regrouting for low pressures (typically <5 bar, but dependent on depth)
- Injection rates: 2 to 8 l/minute for the silicate grout
- Low viscosity silicate for cdg (typically 250l of silicate per m^3)
- High viscosity silicate for marine & alluvial sand (400 to 450l of silicate/m^3)

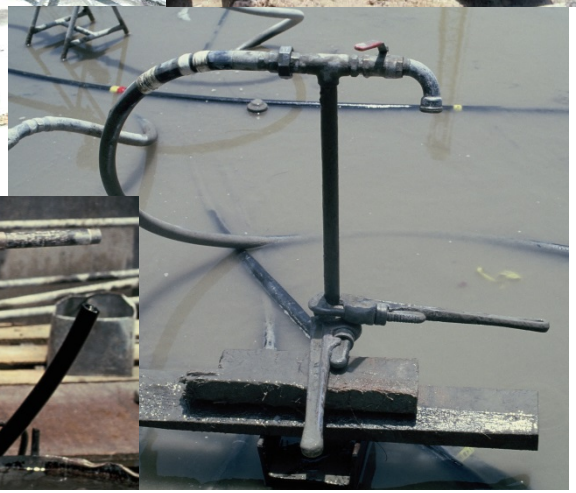
Golder Associates

TaMs

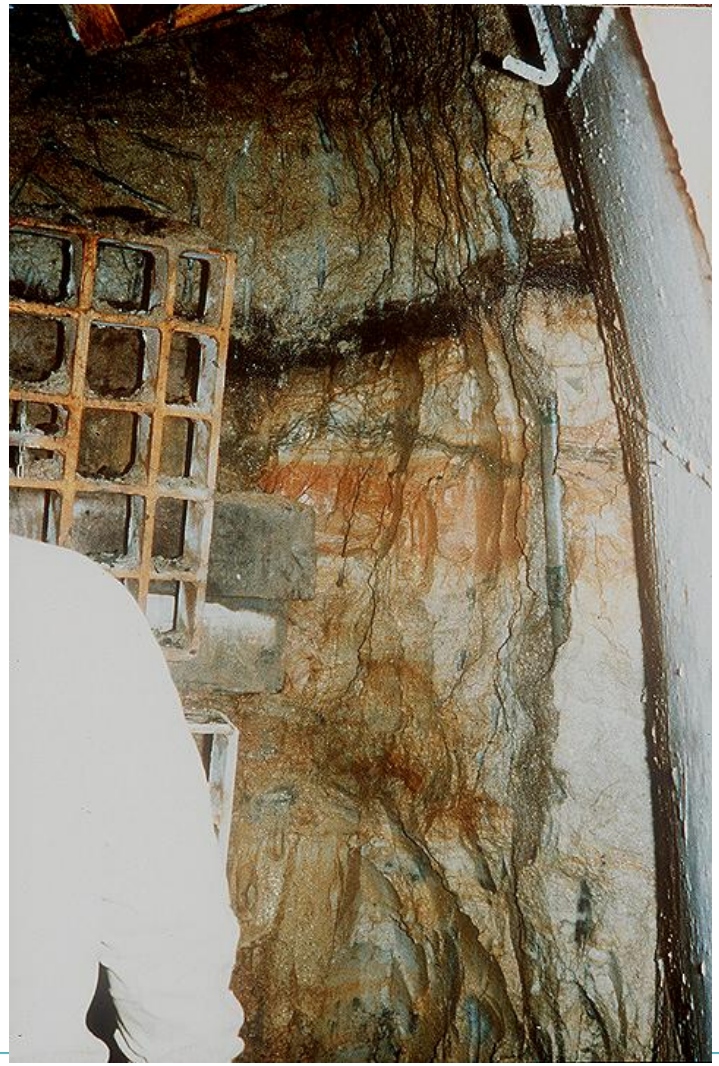


Spacing: average 1.2m centres





TaM



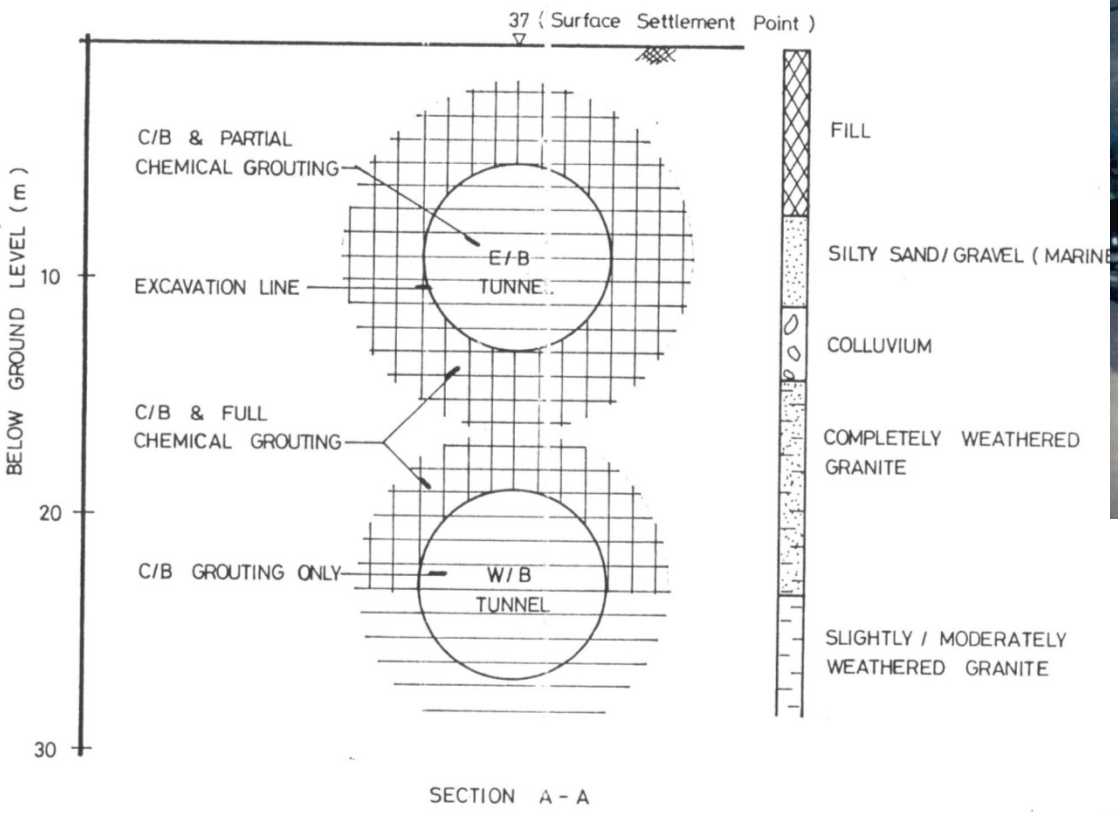
TaMs allow regrouting with the same or different grouts

Do not change the fundamental behaviour of grouts in soil

Should not be used for grouting in rock

Central Station extension tunnels

Upper tunnel 5m below Des Voeux Road, Central, in Fill, marine sand, colluvium



SCL driven tunnels

Driven with 0.4 to 0.6 bar Compressed air (balancing at crown)

Wanchai Station tunnel

Shield drive in marine deposits, colluvium

Treated colluvium

First 39m in free air, remaining 212m in compressed air

Golder Associates

Tin Hau – initial drive

Alluvium and cdg

Shield driven with 0.9 bars of compressed air (balance at crown)

Sai Wan Ho Station tunnel

Marine, alluvial and colluvial deposits, and cdg

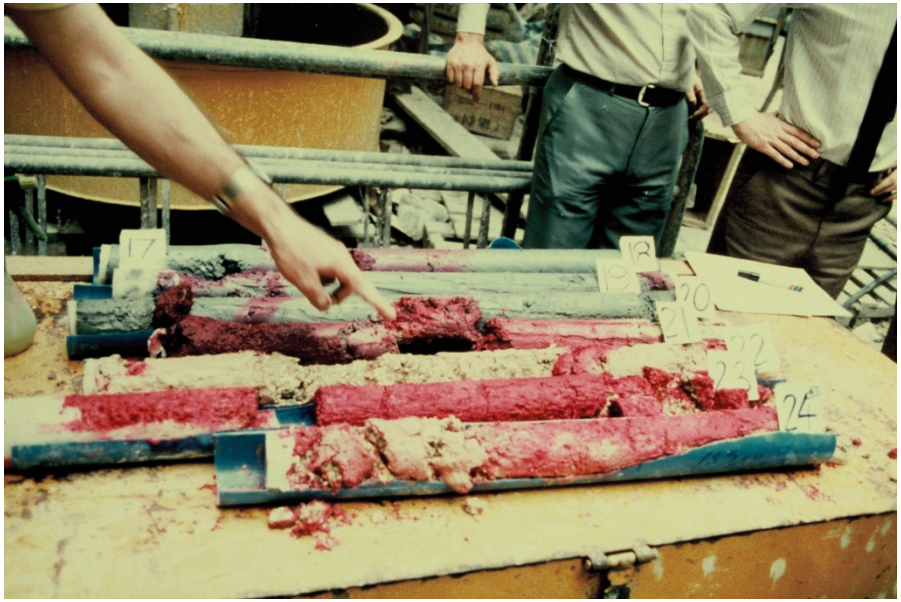
Ribs and lagging in free air

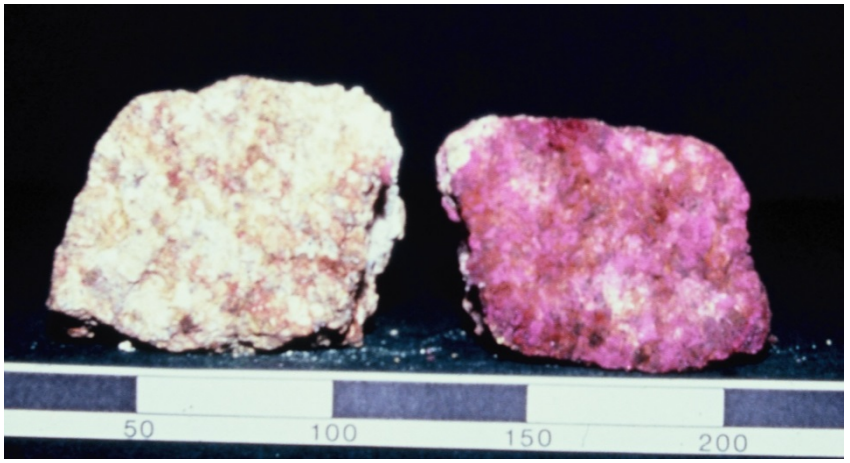
Golder Associates

Observed behaviour of grout

- Cement/bentonite
  - Generally does not permeate Hong Kong soils (except loose, coarse beach sand, some fill)
  - Generally apparent as fractures in the soil
  - Process of injection under pressure squeezes out 85% of the mix water (pressure filtration), so volume of fissures only 25% of volume of grout injected
- Silicate/reagent
  - Permeates marine and alluvial sands readily
  - Generally permeates cdg, but not consistently
  - Some failures of treatment (SWH tunnel, three caissons) due to use of low viscosity silicate grout in medium/coarse alluvial and marine sands

Grouting in cdg





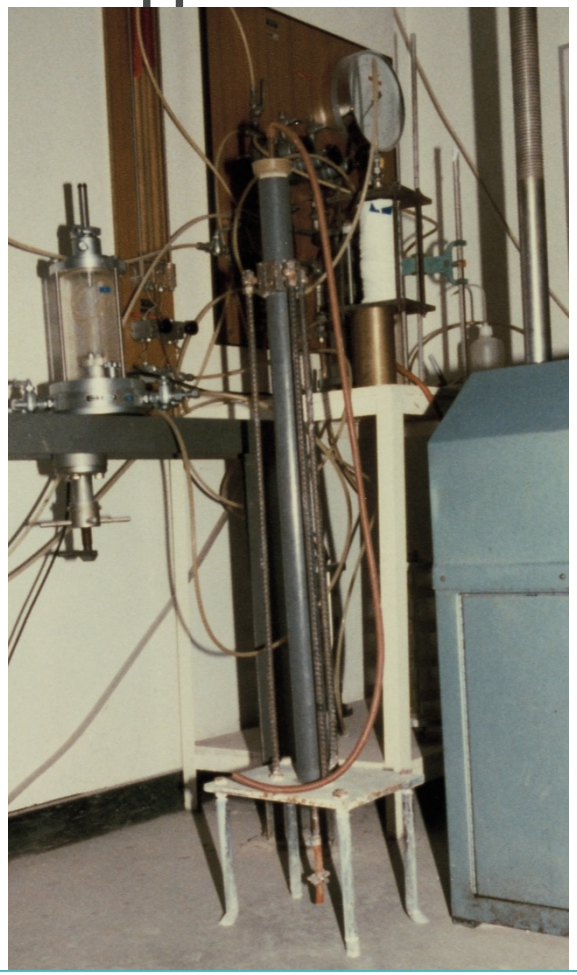
43 out of 56 samples (77%) showed good permeation of silicate grout (Bruce and Shirlaw 1985)

Structure of cdg means fines are agglomerated. Grading curve with dispersants not indicative of permeability

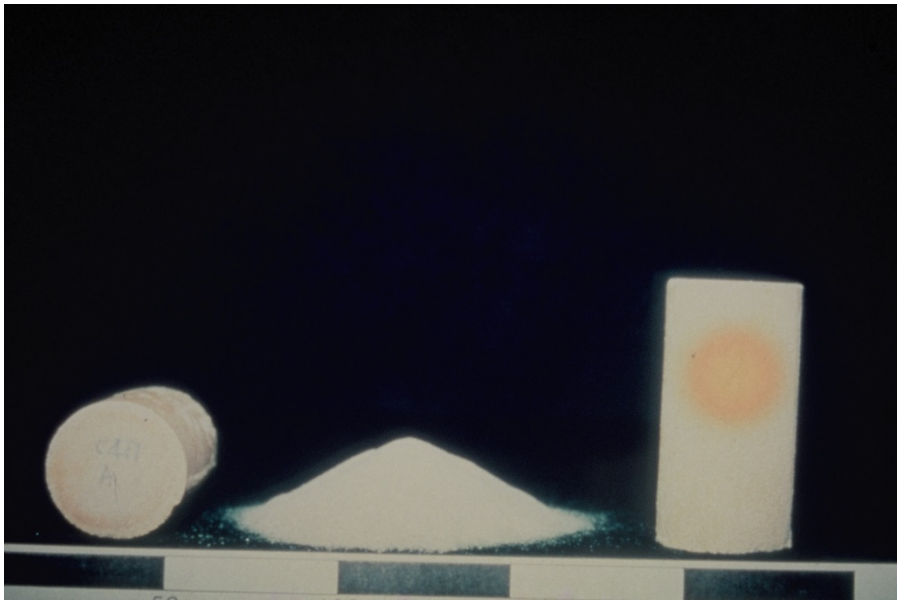
Golder Associates

Laboratory testing – MTR laboratory

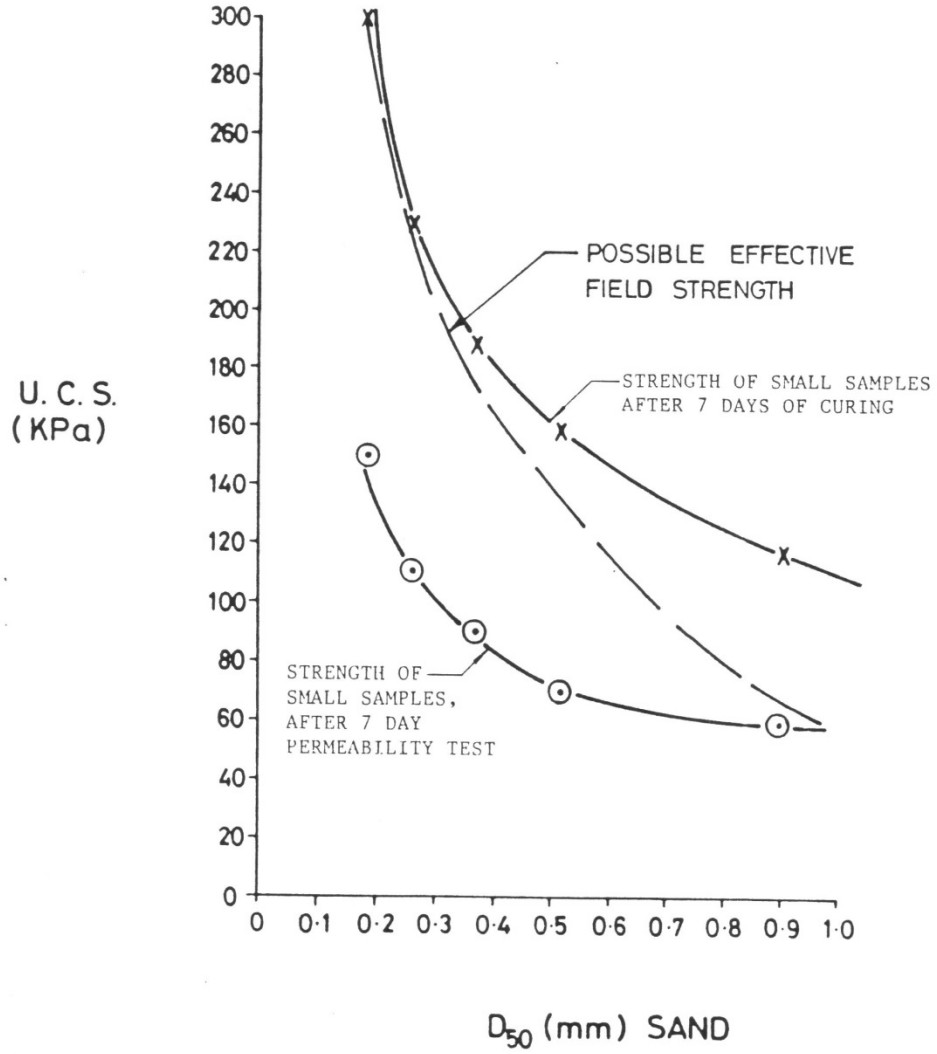
Infusion apparatus



Grouted samples of fine sand



Effect of grain size, seepage on strength of grouted sand



Current grouts

- C/B and sodium silicate grouts still widely used
- Reagents for silicate grout
  - 1980s grouting used mainly diester reagents, some inorganic reagents also used
  - Now appears to be reversion to older reagents, like bicarbonates
- Practice often poor
- Cement can be used to gel the silicate ('L.W.' grout) – but the cement will not permeate most of the soils, and is removed by pressure filtration. The Sodium Silicate then either will not gel or forms very weak, reversible gel.
- LW can be used as a pre-treatment in soil/old sea walls, containing voids and cavities; also useful for initial sealing of major leaks, recompaction of disturbed ground. But is NOT a chemical grout
- Alternatives – trials in 2013 showed microfine and ultrafine cement grouts generally did not permeate cdg

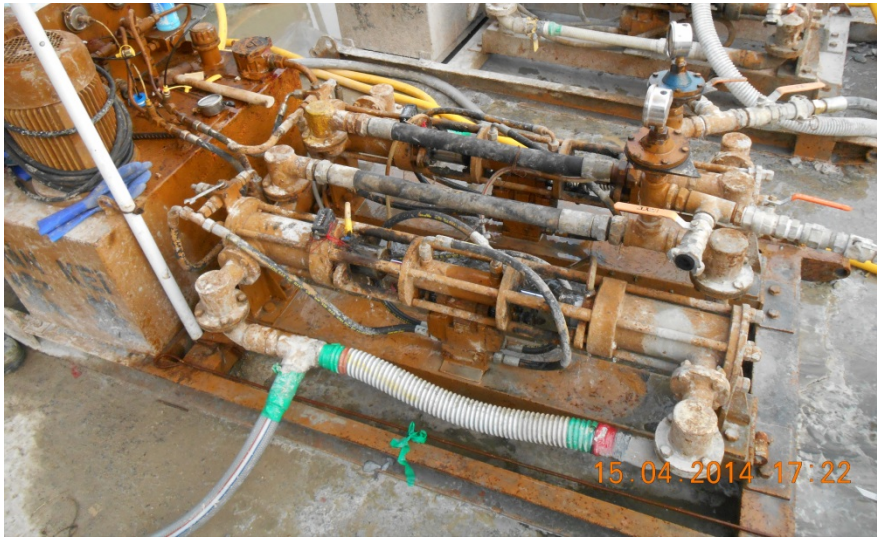
Golder Associates

Changes in practice since Island Line????

1983

Automated mixing of small batches
Slave units readily controlled to 2 to 8 l/min

2014

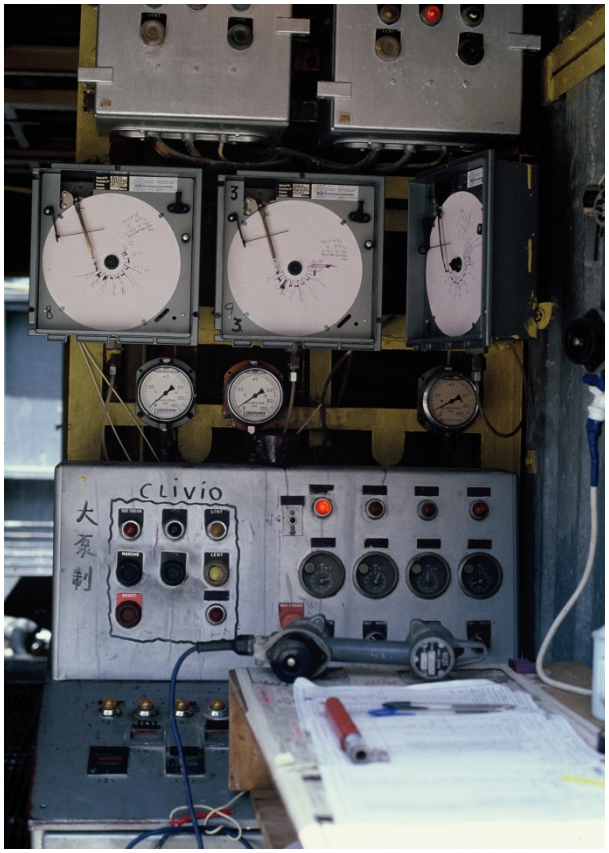


A+B mixes injected through two lines
Manually controlled pumps, difficult to coordinate, difficult to control to below 8 l/min

Golder Associates

Changes in practice since Island Line????

1983

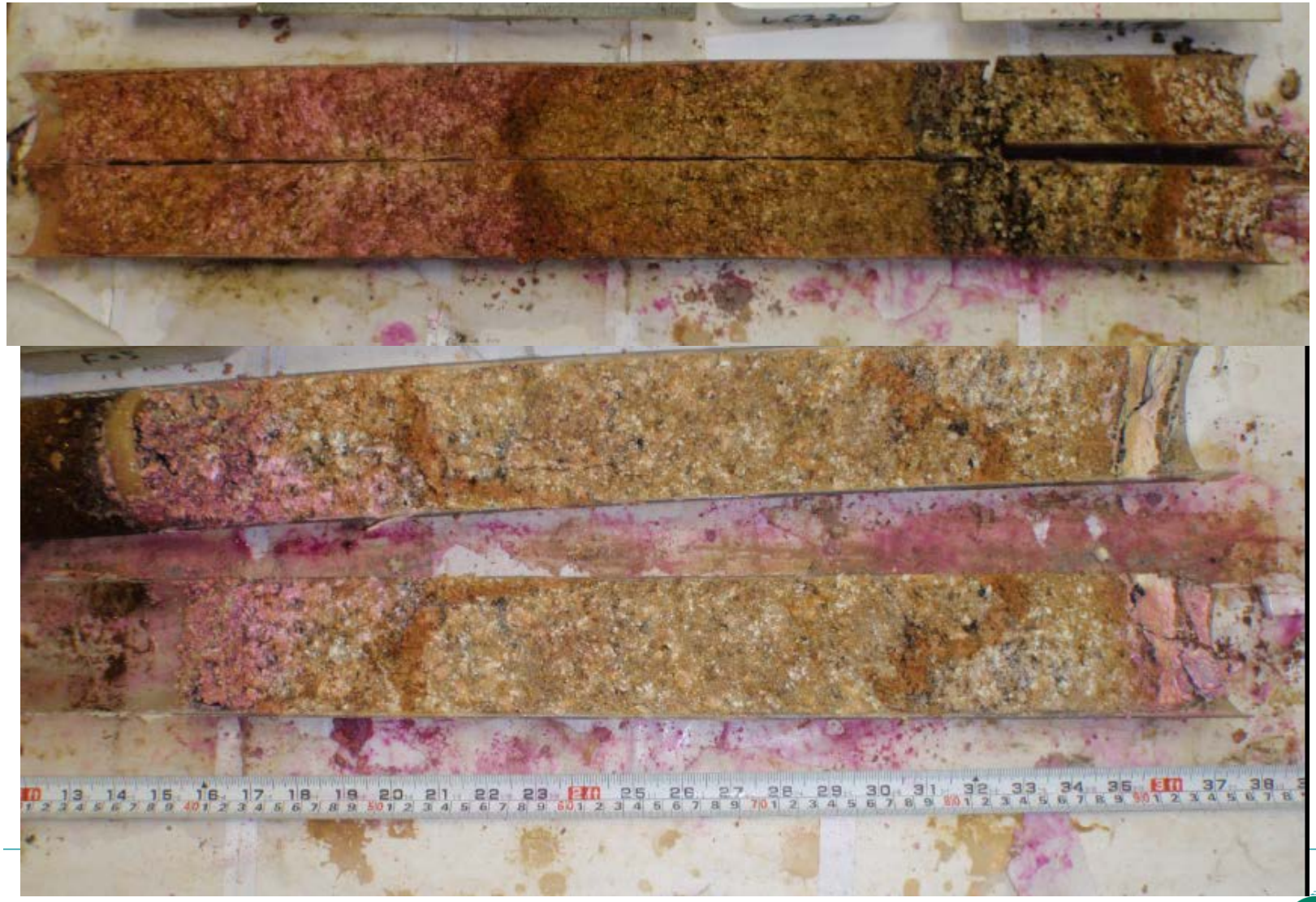


Paper chart recorders for pressure, rate of injection

2014

Manual recording off pressure gauges, stroke counter

Micro-fine cement grout trial (2013) – very limited permeation in cdg



Soil grouting in Hong Kong - Forward to the past?

Current practice often poor relative to what was achieved 30+ years ago

Improvement needed in equipment, procedures, quality control, staff just to get back to general standard of 30 years ago

AND catch up with modern practice, particularly:

- Data-logging of pressure and volume of injection
- Computer display of injection
- Selective use of more modern grouts e.g. colloidal silica, acrylate grouts