INSTRUMENTATION for TUNNELS

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With assistance from
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AGS JAN 2006

Tunnel Deformations

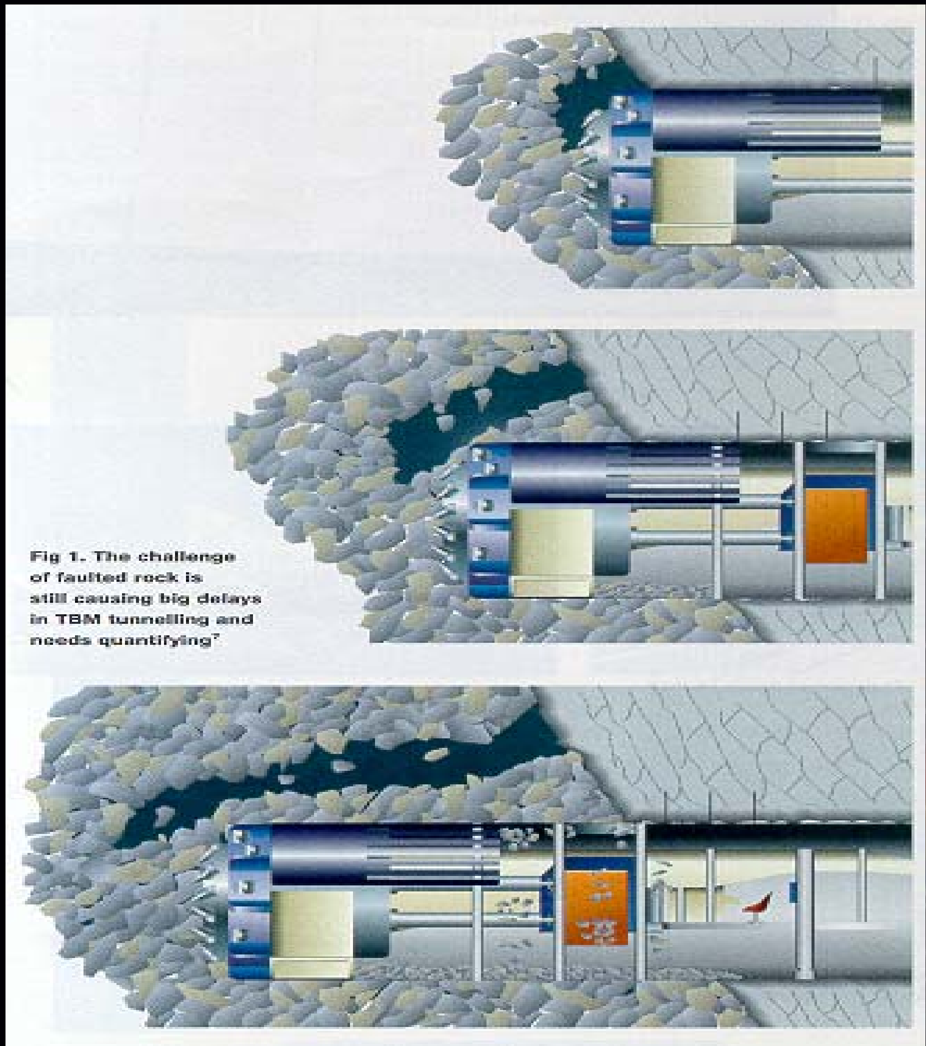
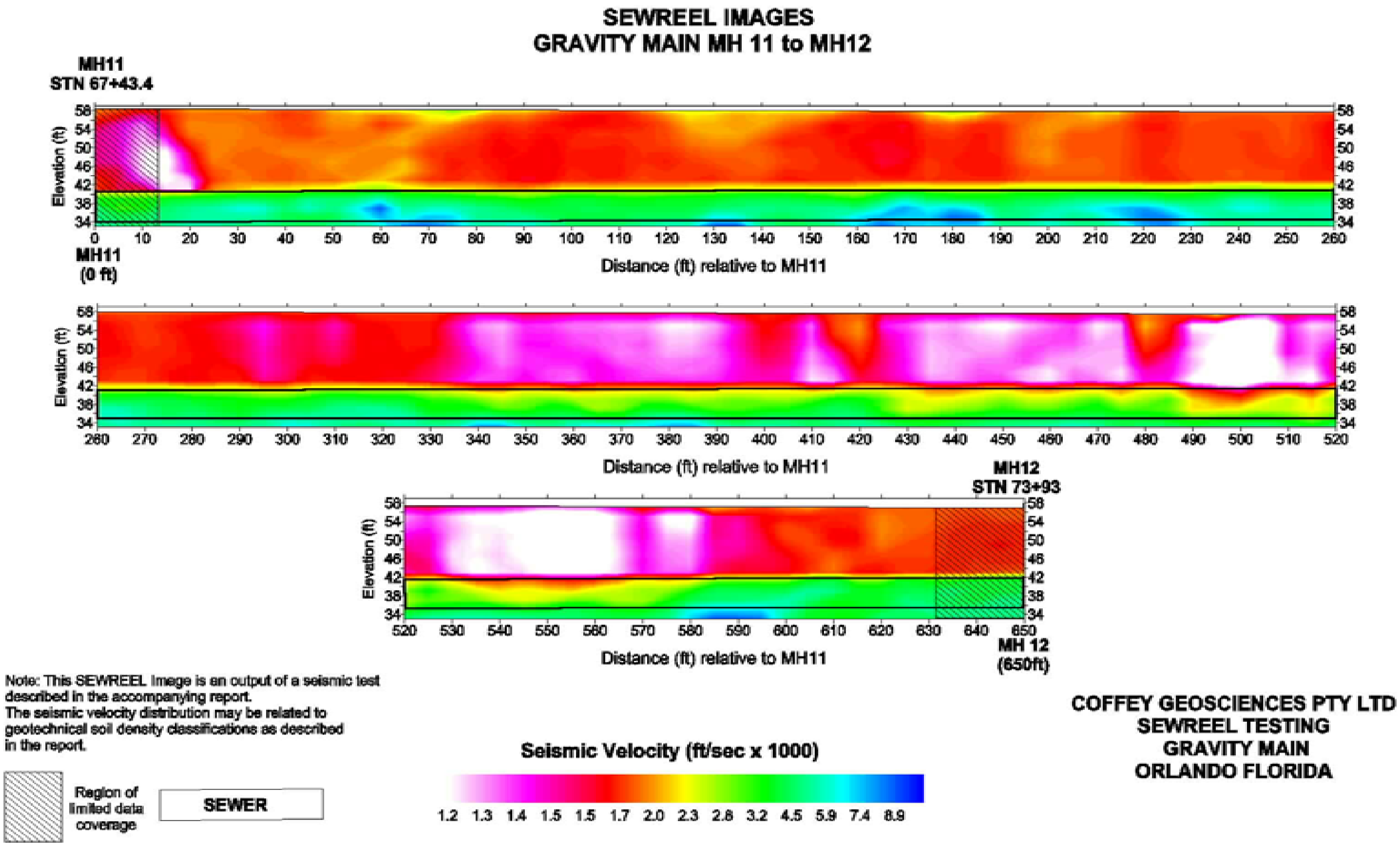


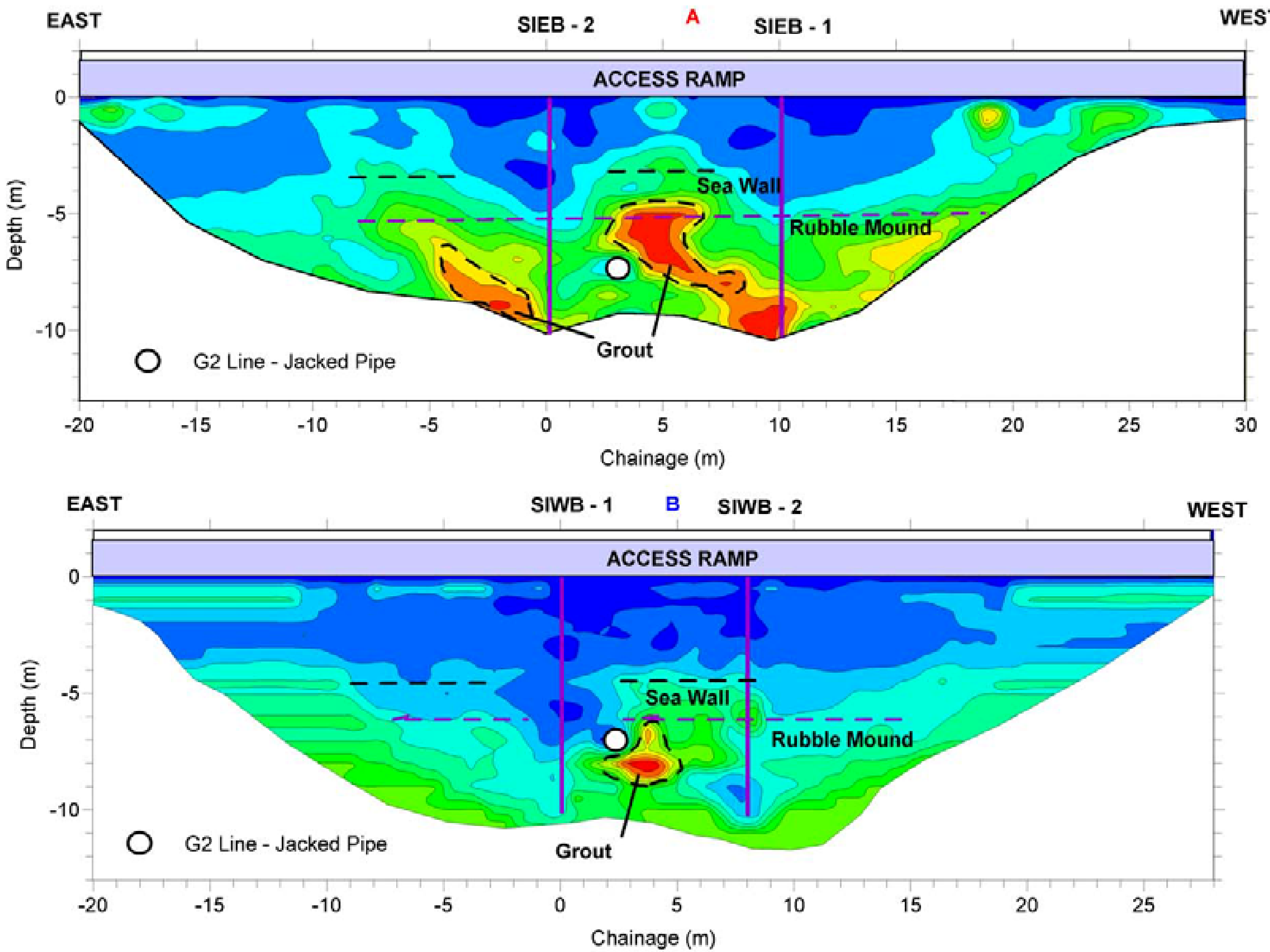
Fig 1. The challenge of faulted rock is still causing big delays in TBM tunnelling and needs quantifying[7]

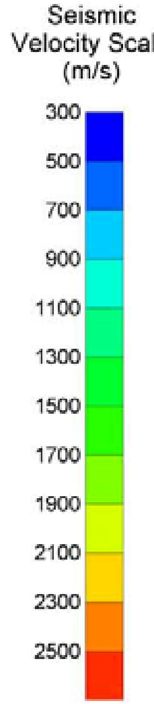
Heterogenous Ground 1



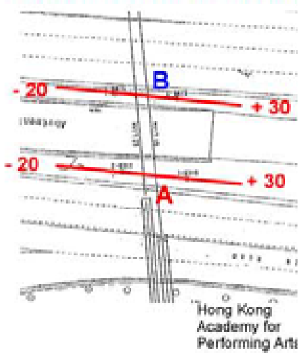
Heterogenous Ground 2

SEISMIC IMAGE

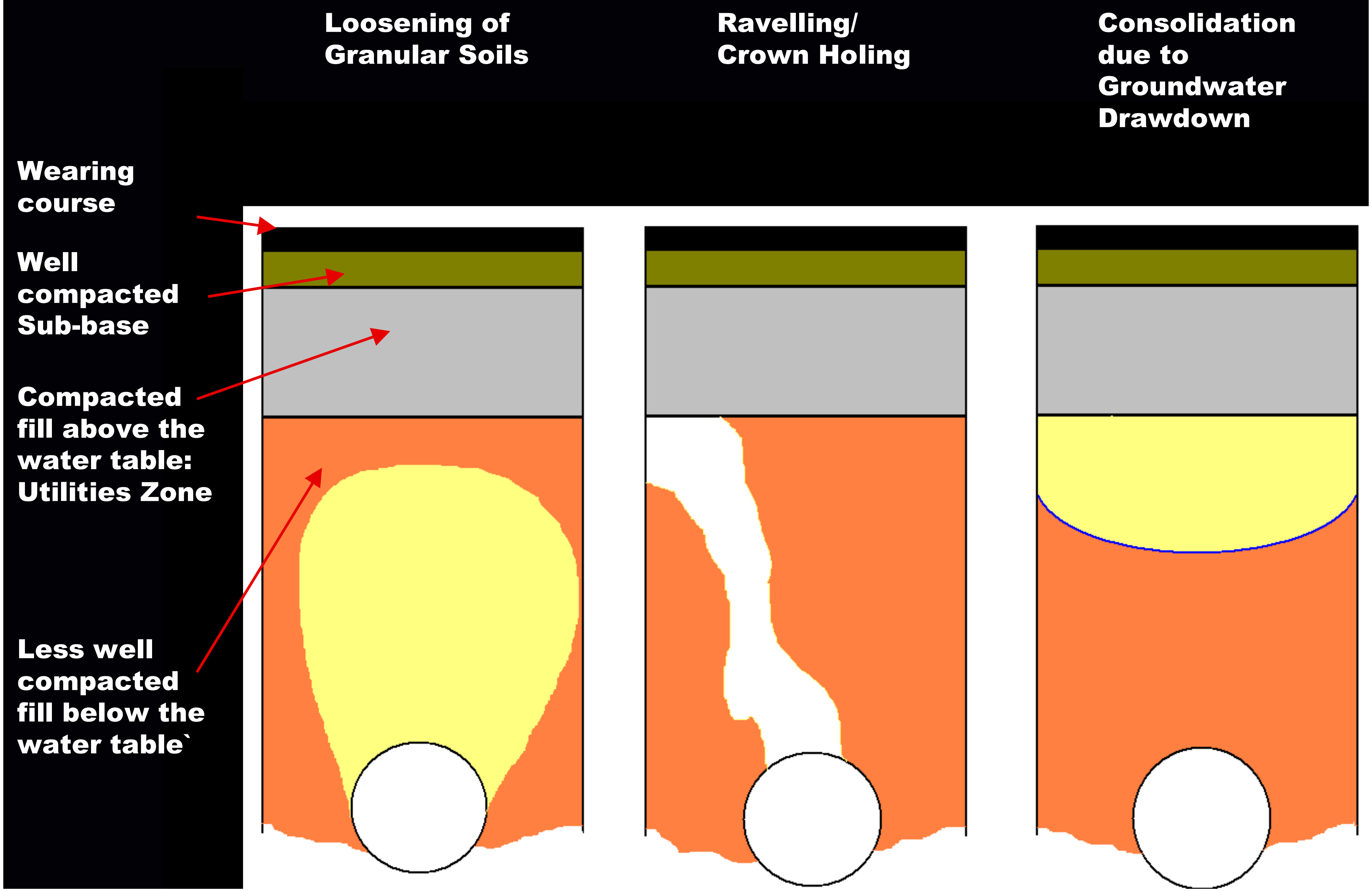


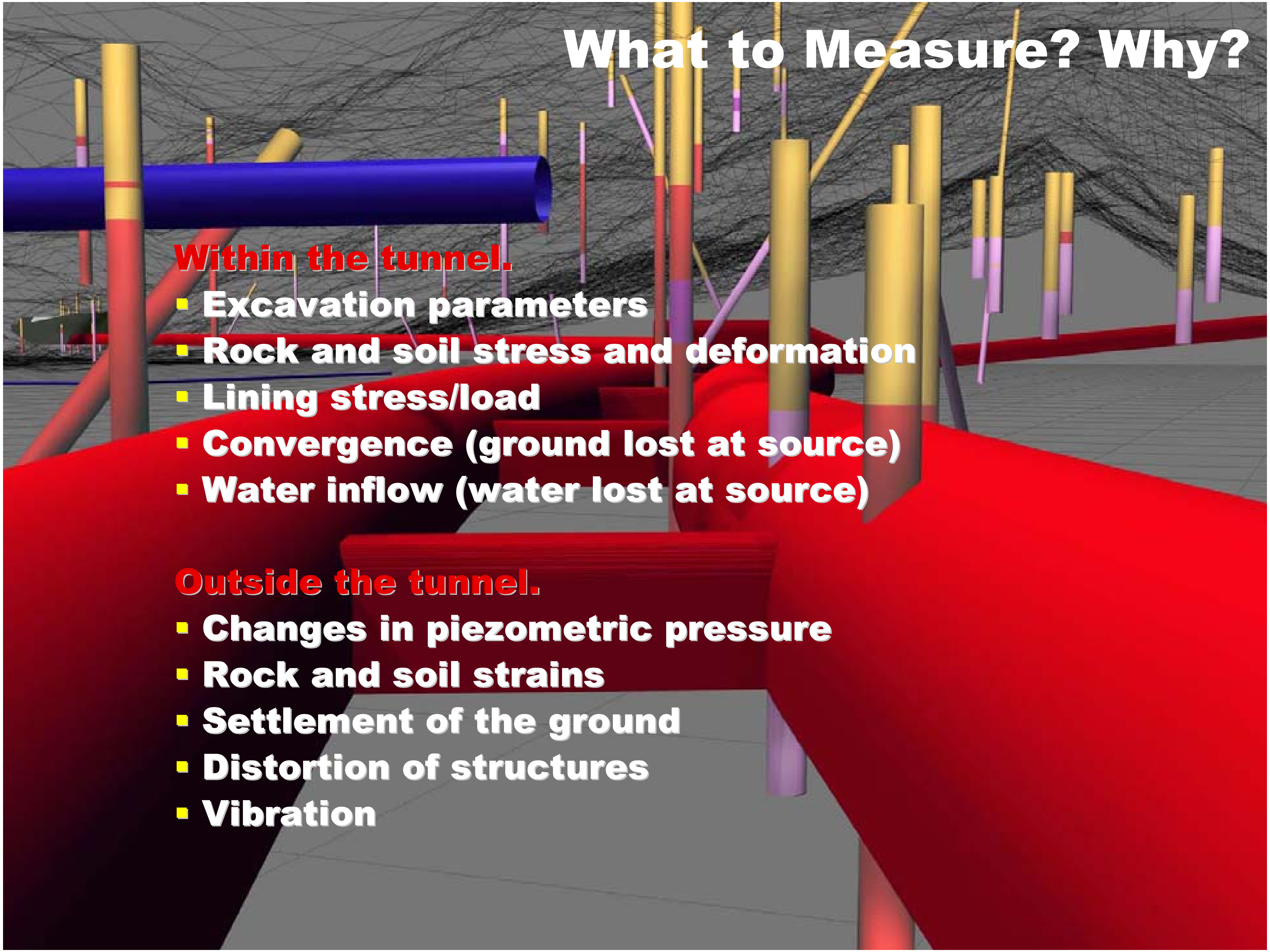


SEISMIC SCAN LOCATI



Ground Movement Modes





What to Measure? Why?

Within the tunnel.

- Excavation parameters
- Rock and soil stress and deformation
- Lining stress/load
- Convergence (ground lost at source)
- Water inflow (water lost at source)

Outside the tunnel.

- Changes in piezometric pressure
- Rock and soil strains
- Settlement of the ground
- Distortion of structures
- Vibration

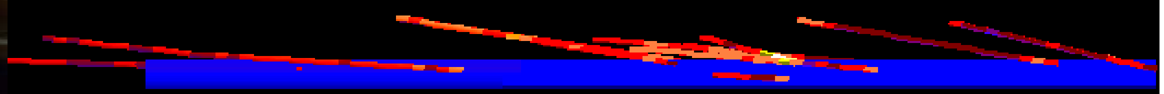
Excavation Parameters?

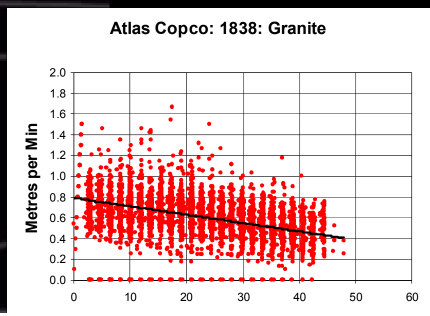
Soft Ground TBM Tunnels (assume expanded segmental linings).

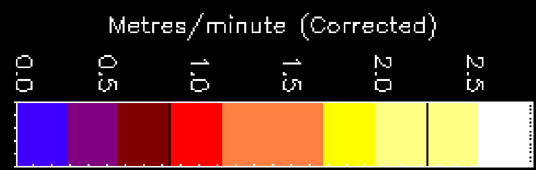
- Face pressure (EPBM)
- Slurry pressure (slurry machine)
- Revs/torque
- Attitude
- Progress
- Screw volume
- Cut diameter vs ring diameter
- Water inflow (water lost at source)

Rock TBMs.

- Face pressure/revs
- Attitude
- Progress
- Disk wear
- Probe parameters



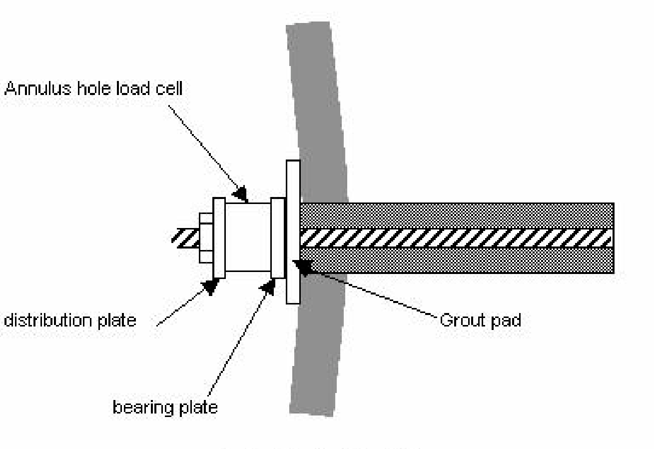




Rock and Soil Stress

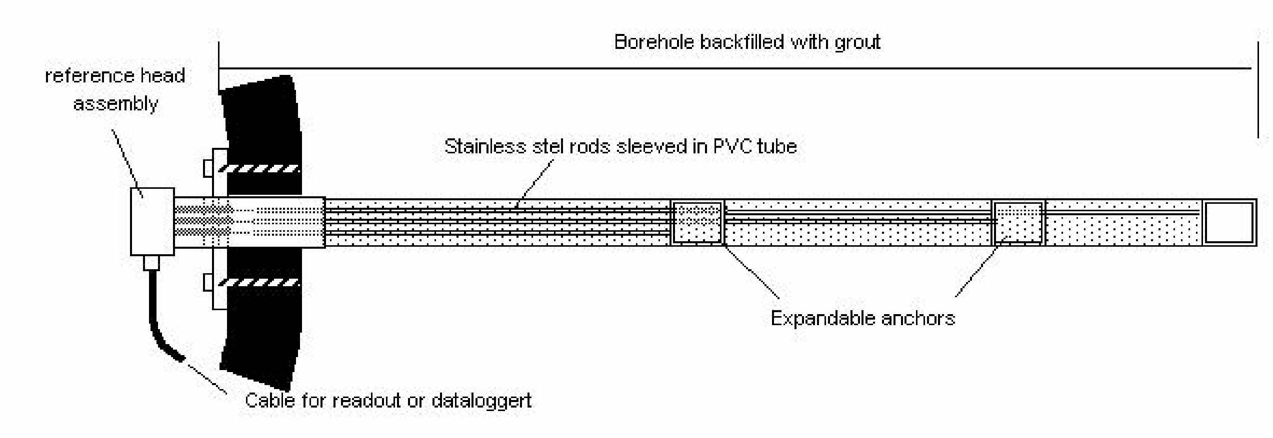
Within the tunnel.

- Pressuremeter (soils and weak rocks)
- Load cells on bolts (passive)
- Jack tests on bolts (active)
- Rod Extensometers
- Door stopper tests
- Flat jack tests
- Overcoring
- Convergence (ground lost at source)



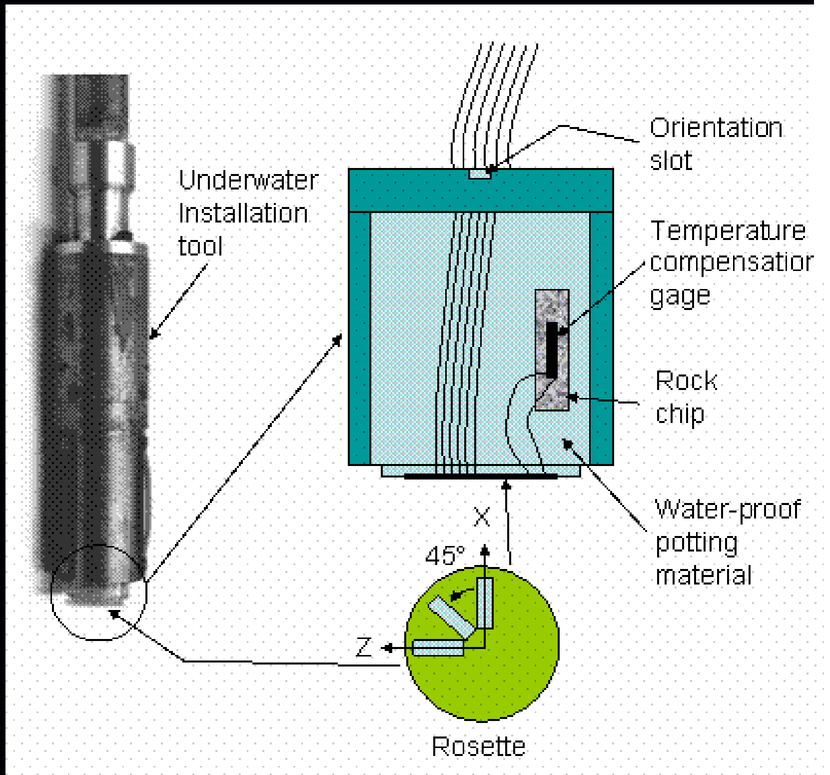
Typical load cell installation

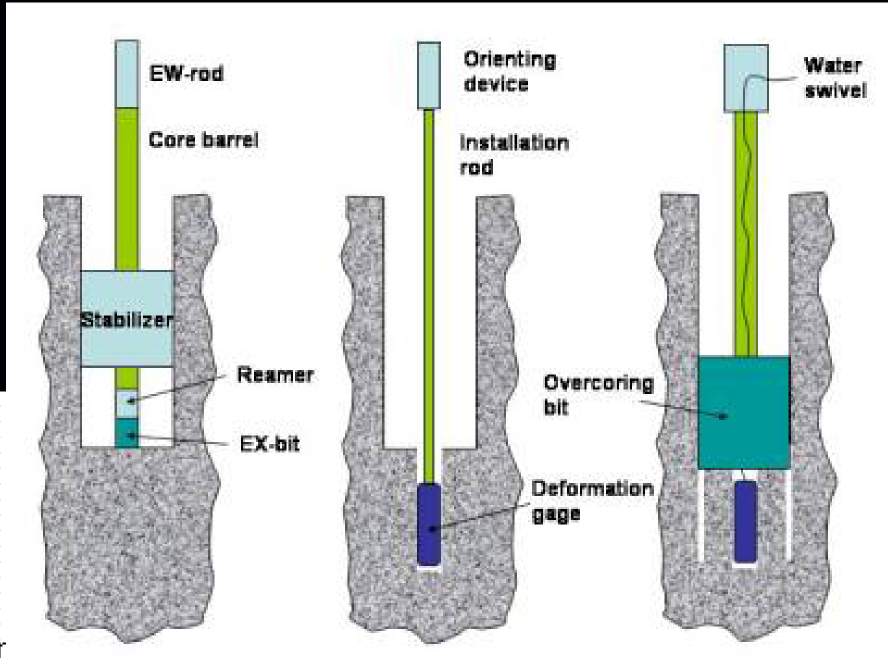
Range of groutable anchors



Rock and Soil Stress

Door stopper



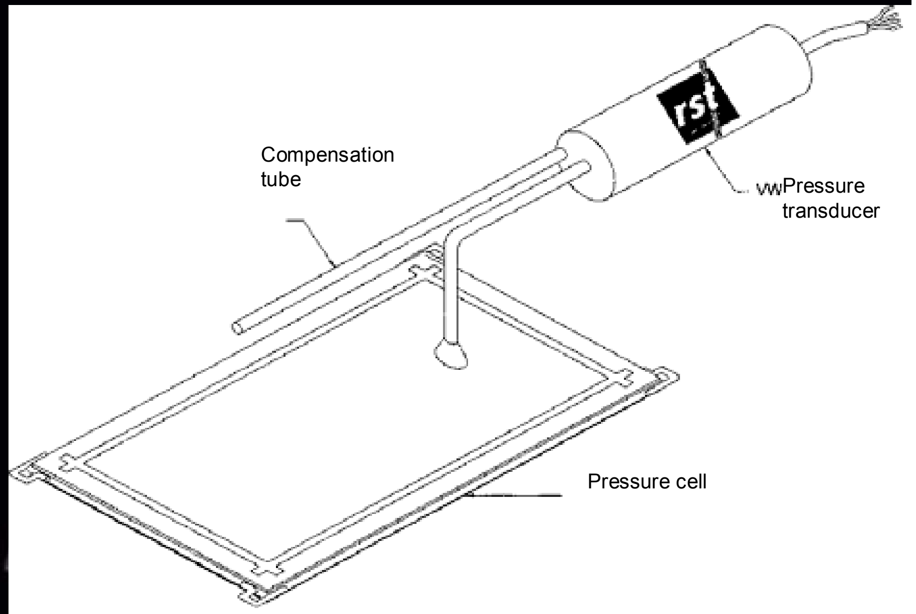


Universal Measurement Guage

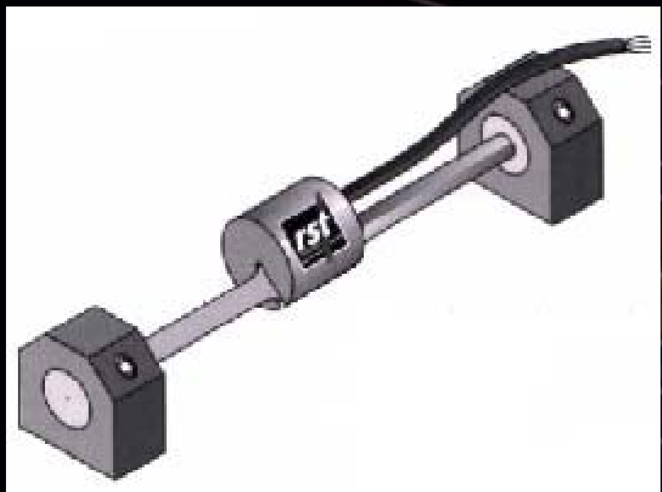
Lining Stresses and Load

Within the tunnel.

- Concrete load pressure cells
- Strain gauges
- Water pressure transducers
- Convergence



Load pressure cell



Vibrating wire attachment type strain gauge

Convergence

TBM Tunnels

- Indirect methods (comparison of cut vs lining dimension)
- Problem for soft ground. Over-excavation at the face?

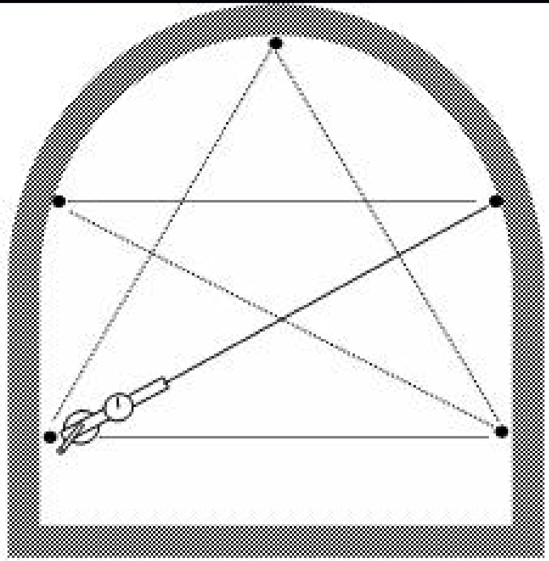
NATM and Drill and Blast Tunnels

- Tape extensometer/survey
- In situ convergence arrays (Bassett)

Movement of lining or adjacent tunnels

- As for NATM

Typical open loop profiler installation



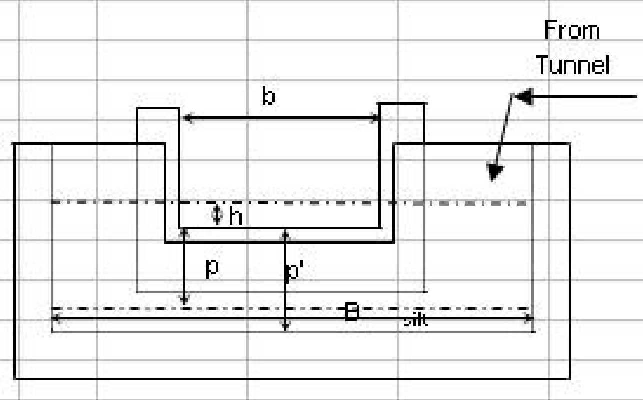
Typical reference anchor arrangement

Water Inflow

Within the tunnel.

- V-notch weir
- Impeller flow-meter
- Magflow
- Pump counters

- Difficulties?



Front Elevation of Weir Plate as set in Outflow of Surface Settlement Tank

p' = depth to base of tank (1.462m)

measurements taken to top of silt at 1.022m below weir crest

Kinfsvater-Carter Formula for Standard Weir is:-

$$Q = C_e\, 2/3\, (2g_n)^{0.5}\, b_e\, h_e^{3/2}$$

Where	Q	is	Volume rate of flow in m^3/sec.		
	b	is	measured width of the notch, in metres		
	B	is	width of the approach channel, in metres		
	b/B	=	0.7/3.013	=	0.2323
	Ce	is	Coefficient of discharge (from chart of h/p)		
	h	is	measured head in metres		
	h_e	=	$h + k_h$	k_h	= 0.001
	b_e	=	$b + k_b$	k_b	= 0.00245
	g_n	is	acceleration due to gravity in m/sec^2		
	p	is	height of the crest relative to the silt level, in metres		

Piezometric Pressure

Outside the tunnel.

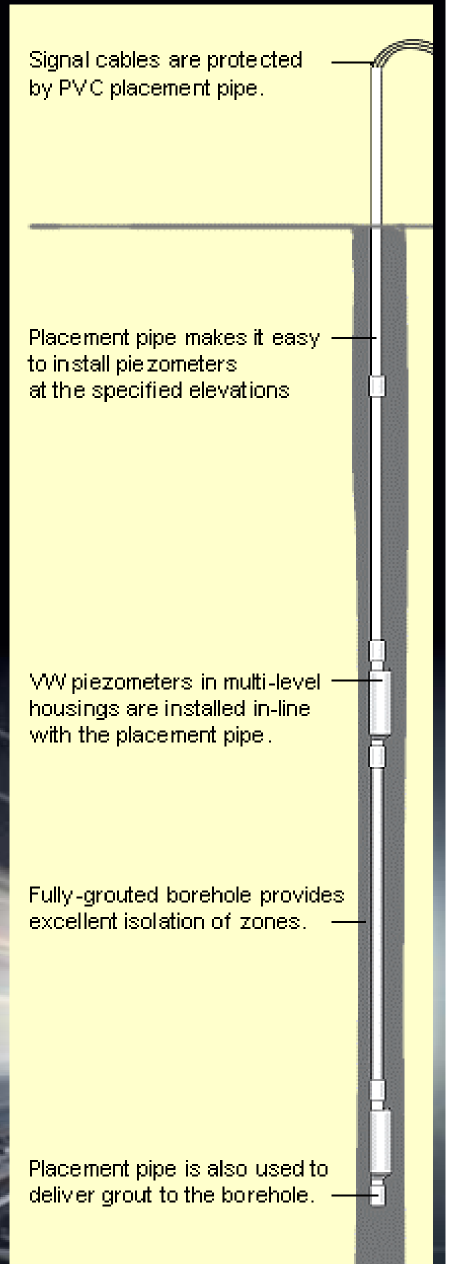
- Standpipes (water level)
- Casagrande
  - Pinger
  - Diver
- Pneumatic
- Vibrating wire
- Pressure transducer

- Difficulties?

Multi level vibrating wire

Pneumatic (rare)

Pressure transducer



Rock and Soil Strains

From the surface

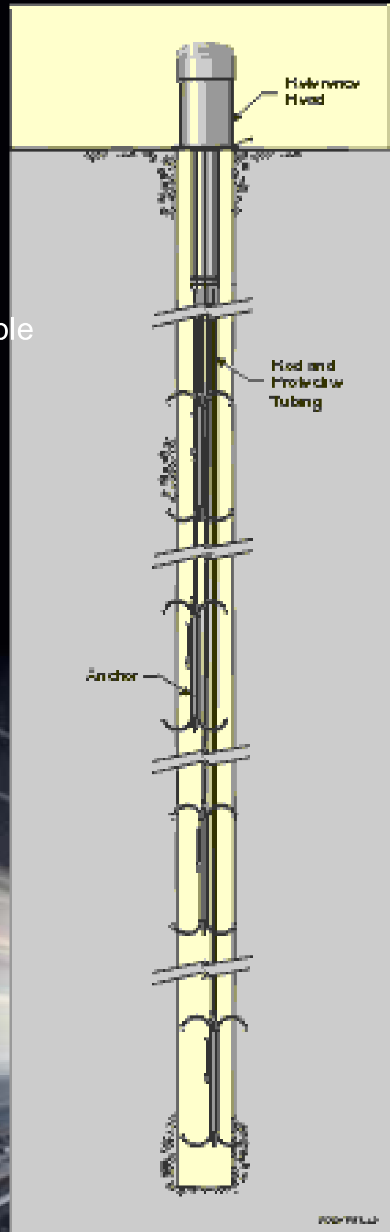
- **Magnetic Extensometers**
  - **Referencing issues**
- **Rod Extensometers**
- **Inclinometers**

- **Difficulties?**

Rod Extensometer Head Assemble

Inclinometer probe

Extensometer magnets and plates.

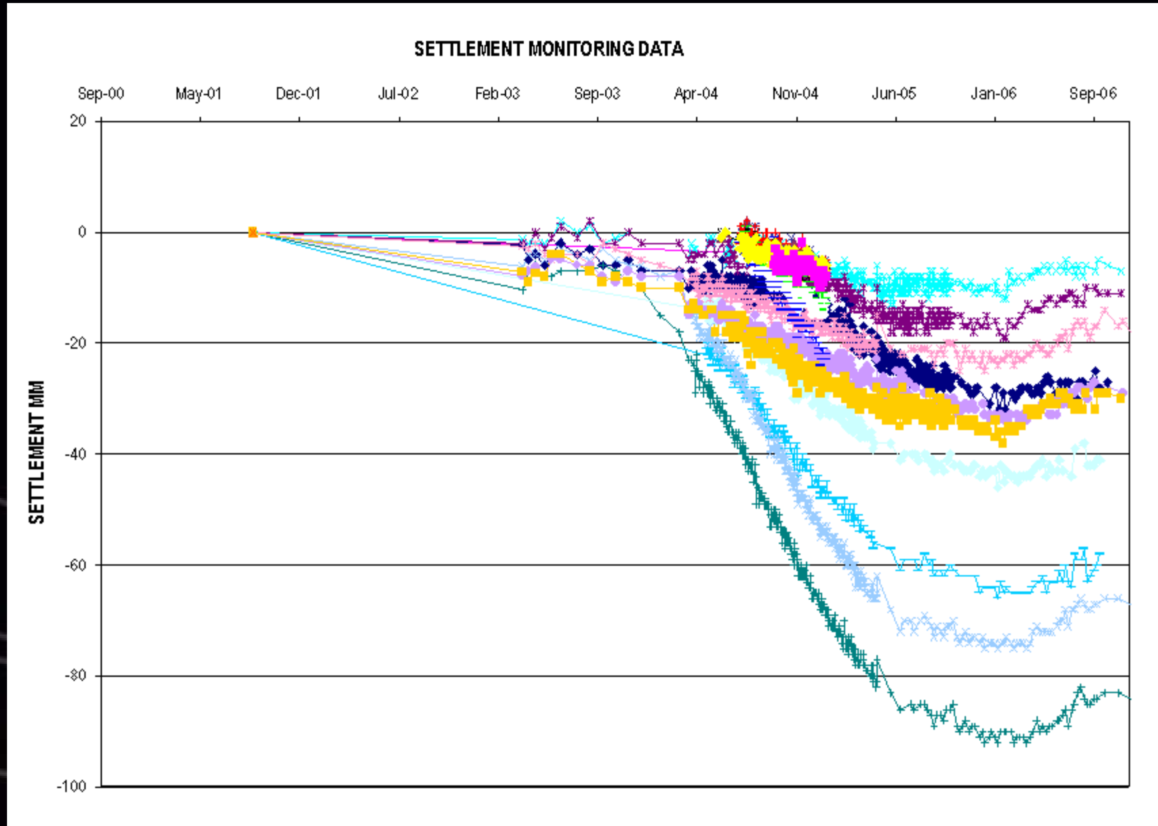


Rod Extensometers in Borehole

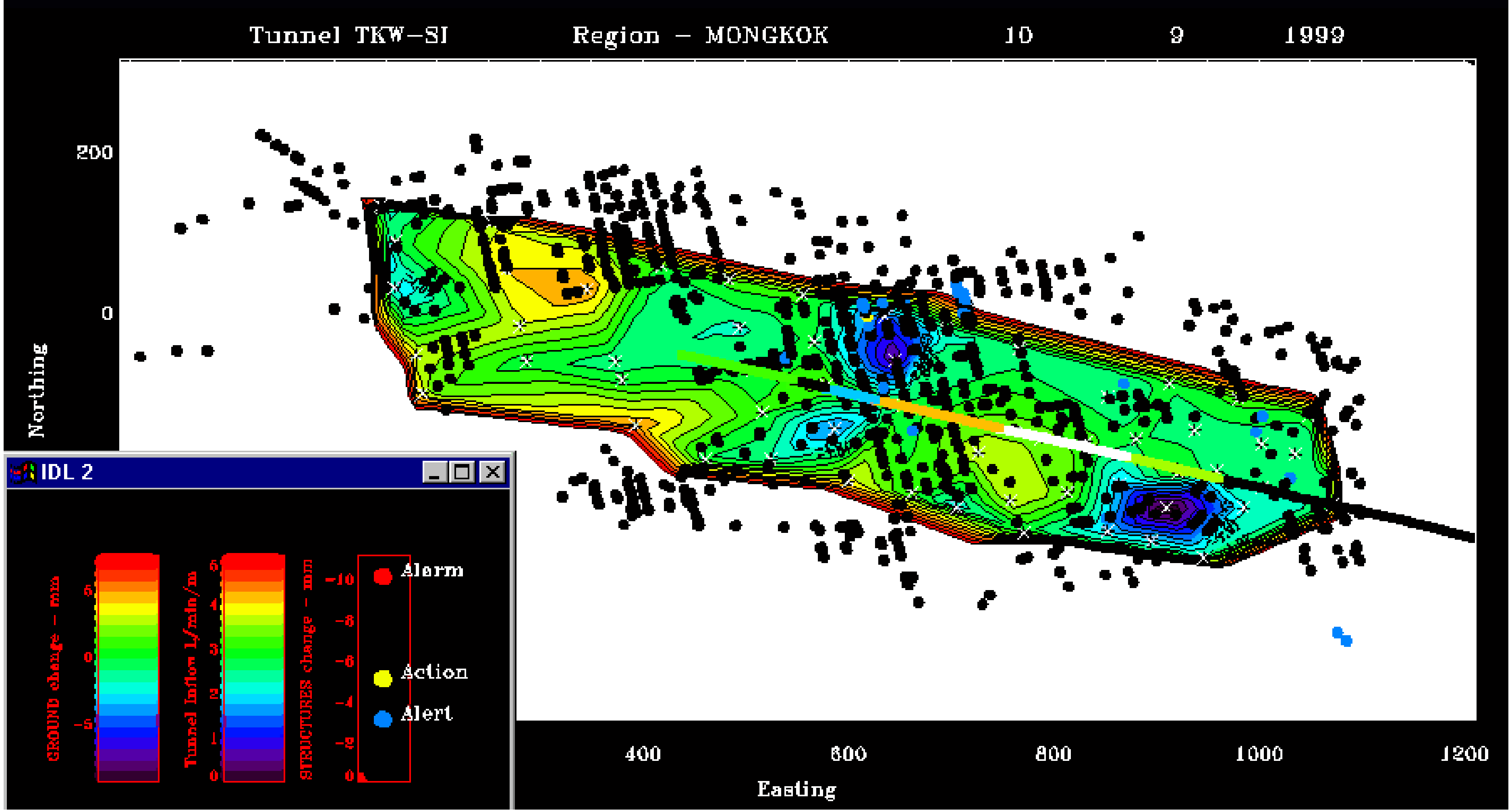
Ground Settlement

At the surface

- Survey
  - Settlement arrays
  - Benchmarks
  - Accuracy
  - Frequency
  - Revision
- Utility monitoring
  - Pipes
  - Cables

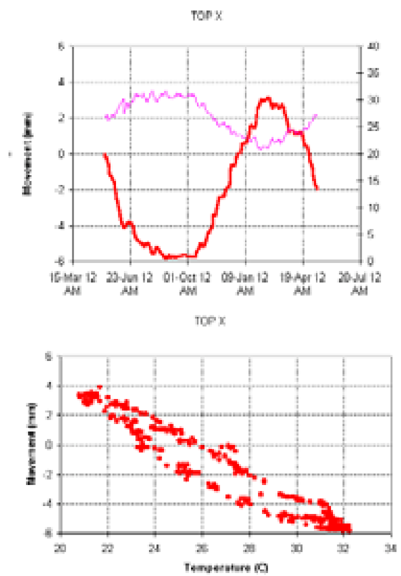


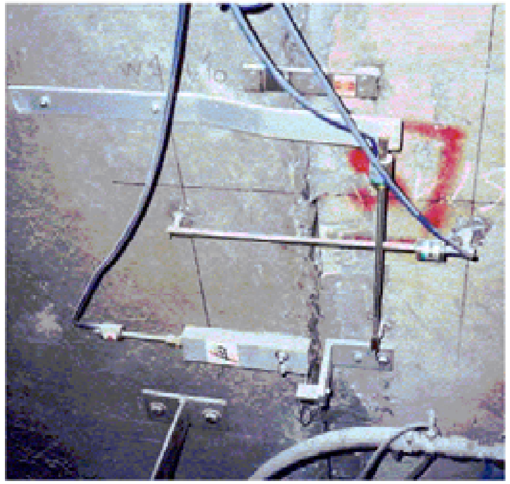
Example: Settlement Monitoring Mong Kok

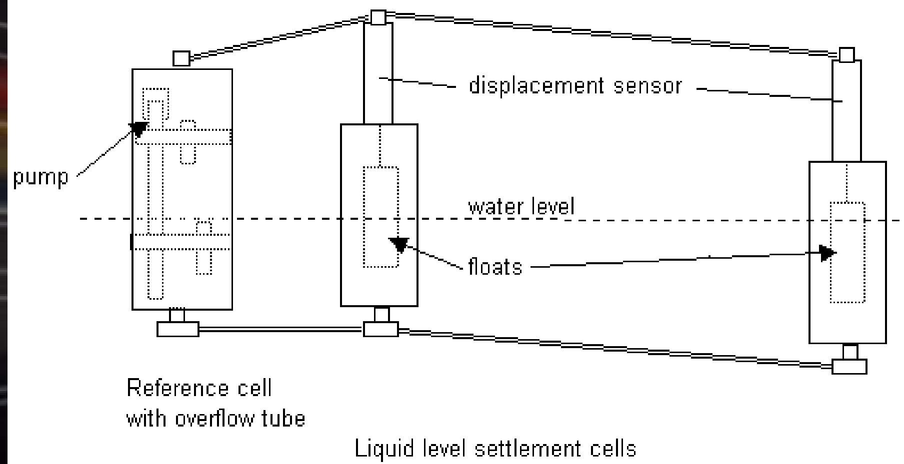


Structure Monitoring

- Survey points
- Crack meters
  - Grid type “tell tale”
  - Demec
  - VW type
- Tiltmeters
  - servo accelerometer type (portable/fixed)
  - VW type
  - Electrolytic
- ADMS systems
- Liquid level systems
- Bassett Convegence Systems
- Laser systems



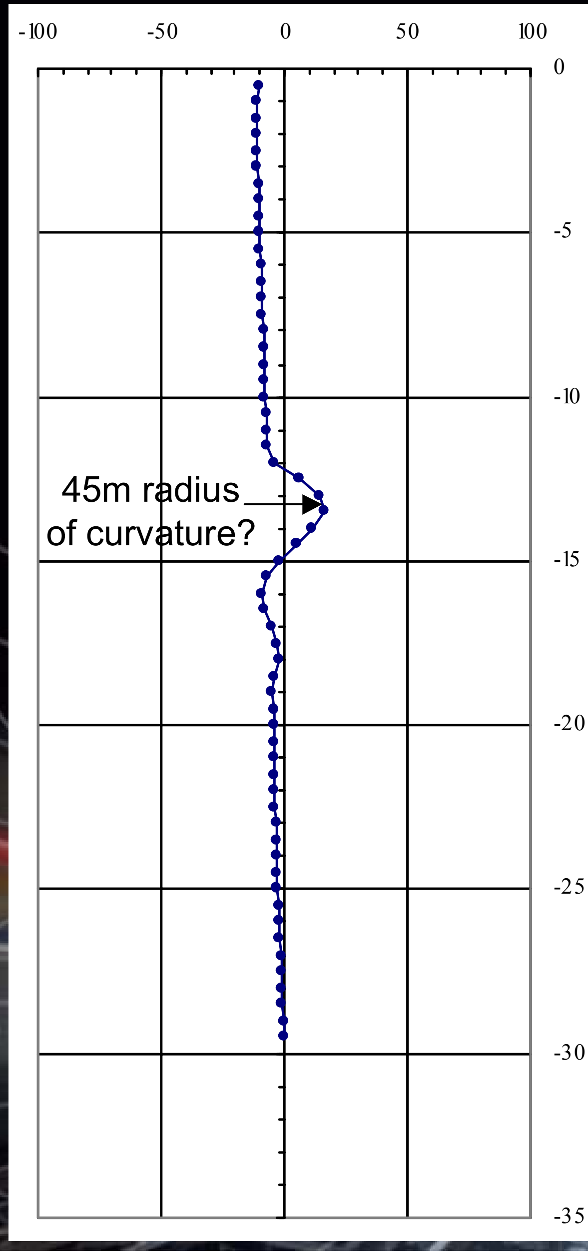




Distortion

Derived Parameters

- Differential Settlement
- Hog Sag
- Angular deviation/bending moment
- Out of tolerance (linings)
- Shear



Vibration/acceleration

Tolerance (ppv and m/s^2)

- Laser Lithography/MRI scanners
- Single event (eg blasting)
- Continuous eg. TBM

Types

- Seismograph (Instantel Blastmate)
- Piezoelectric

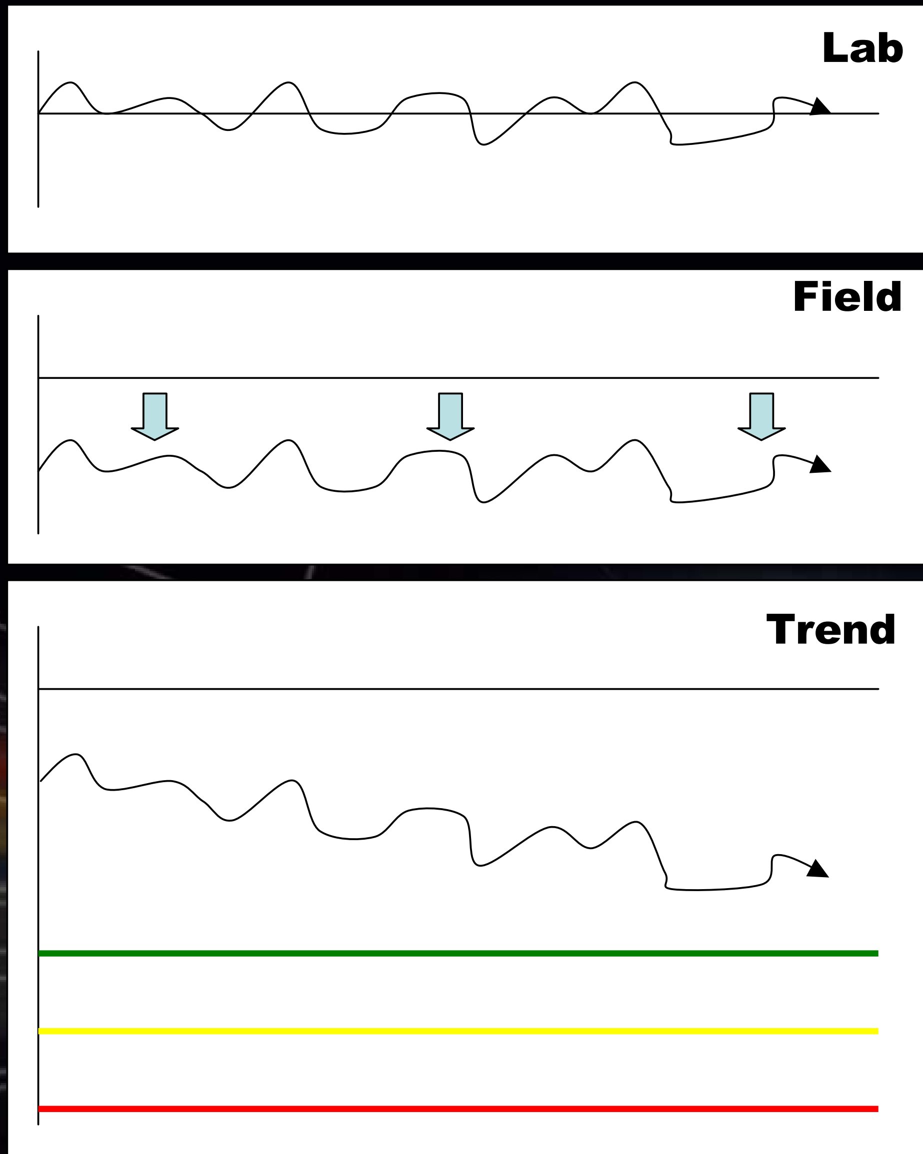
Trigger Levels

Accuracy Sensitivity
- From Lab

Sensitivity in the field
- Function of background fluctuation

Trend
- On going change in reading

Magnitude
- Alert: Check design
- Action/Alarm: Protect safety/third party interests
- Must relate to design – example piezos.



Example

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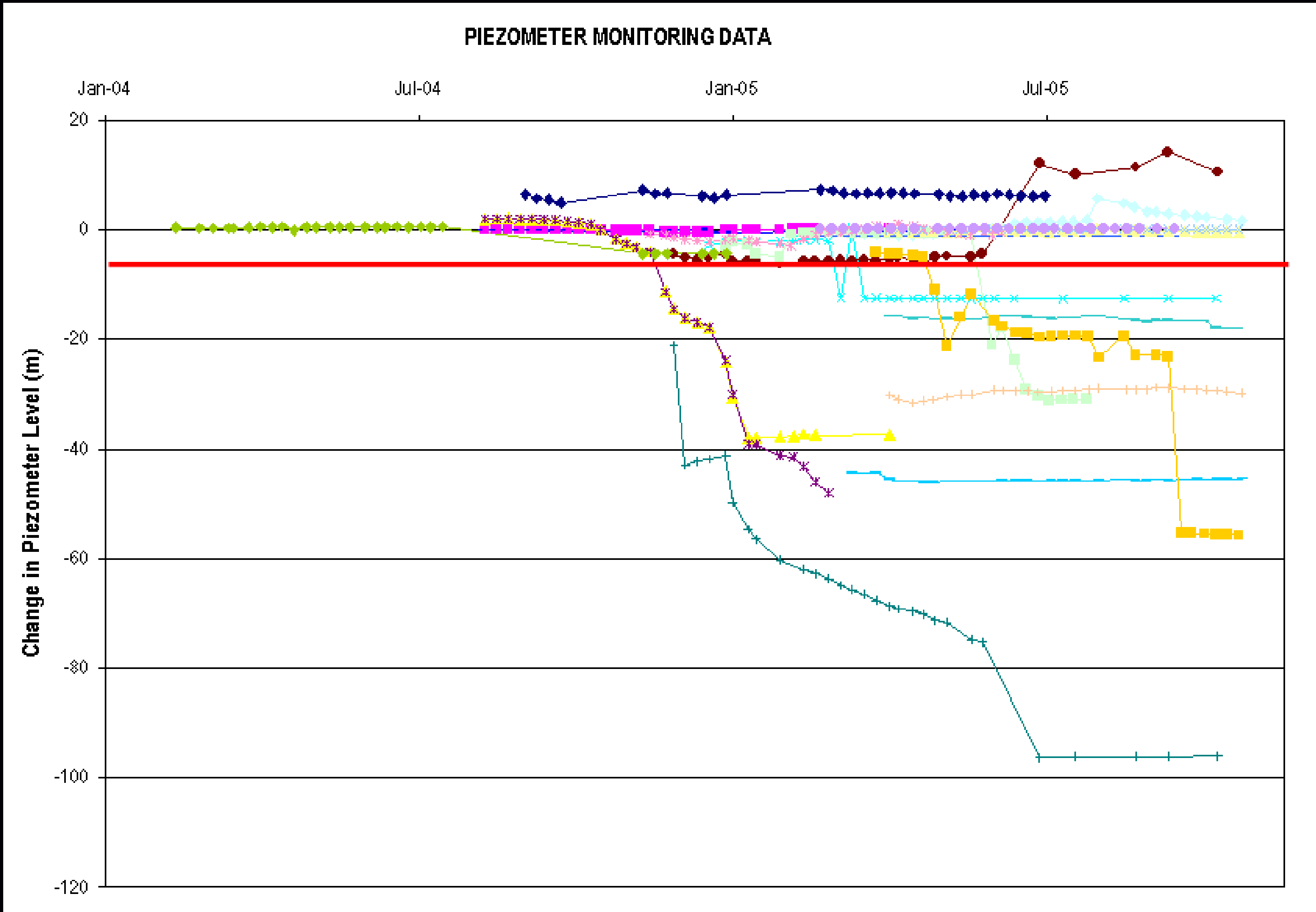


Thankyou

Function of Depth

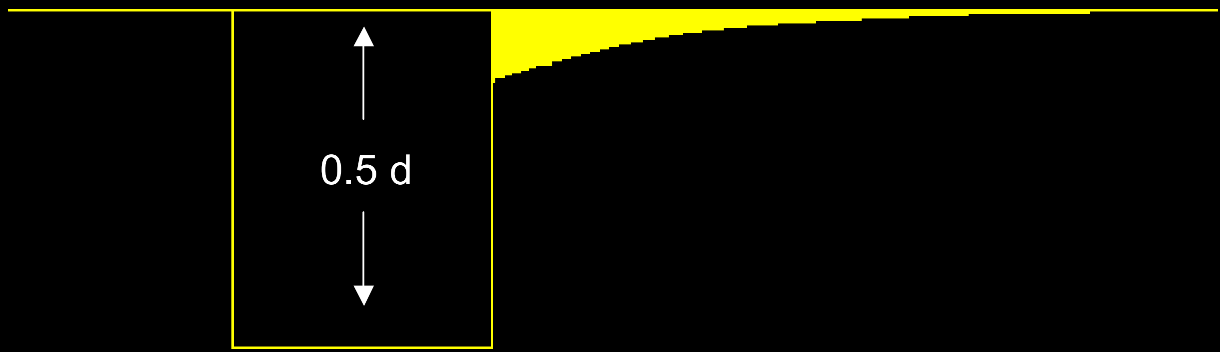
d = Final Depth of Excavation

0.5d

Alert = 7 mm

Action=15mm

Alarm=25mm

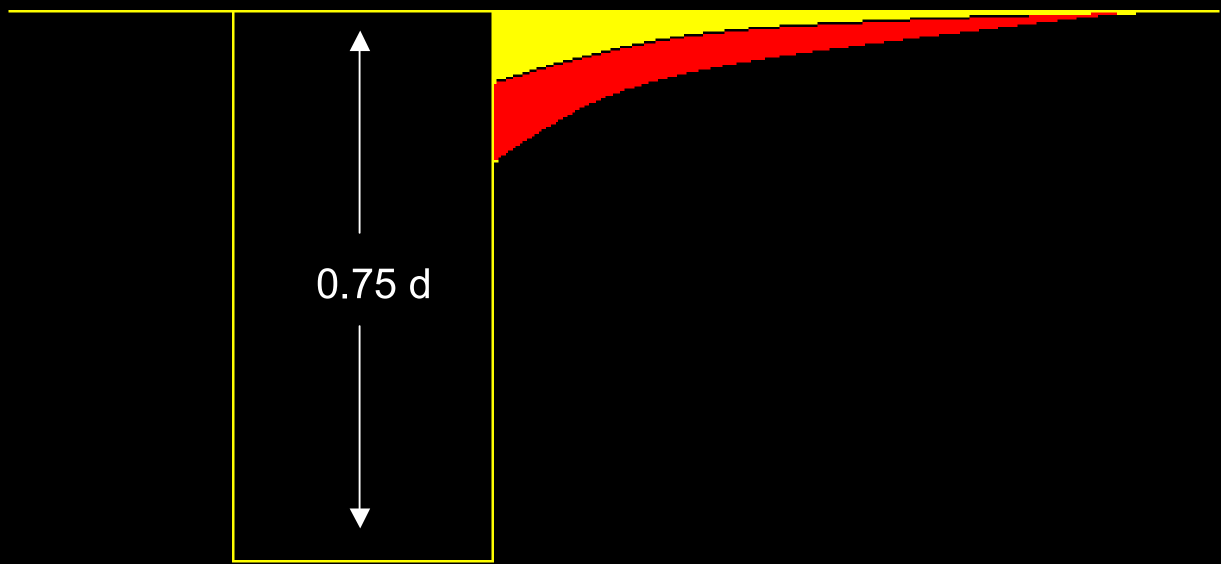


0.75d

Alert = 15 mm

Action=25mm

Alarm=40mm



Function of Distance

d = Final Depth of Excavation

0.5d

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Action=25mm

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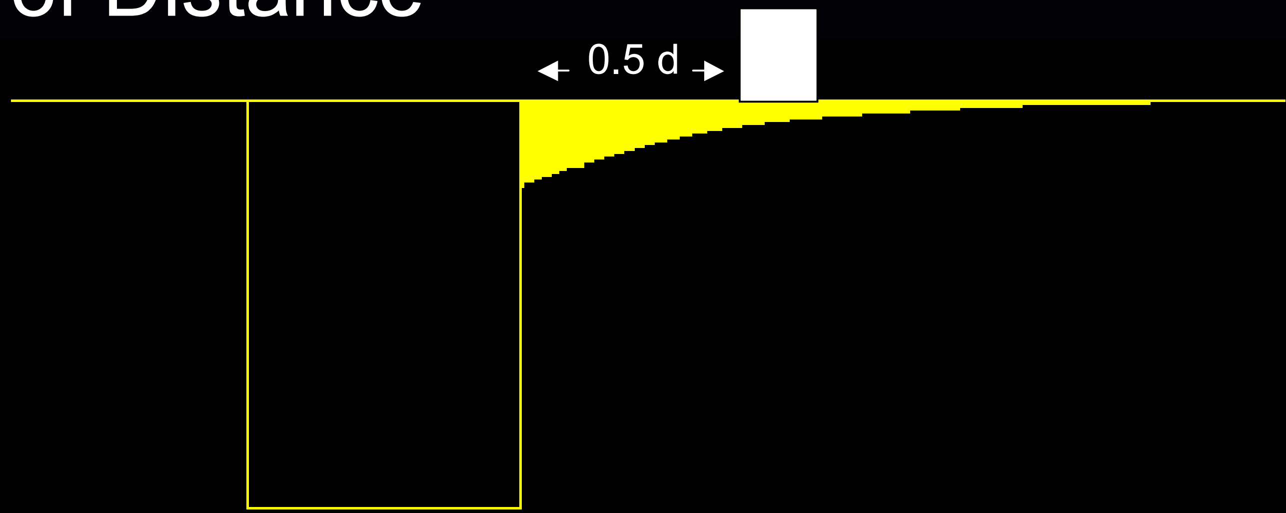
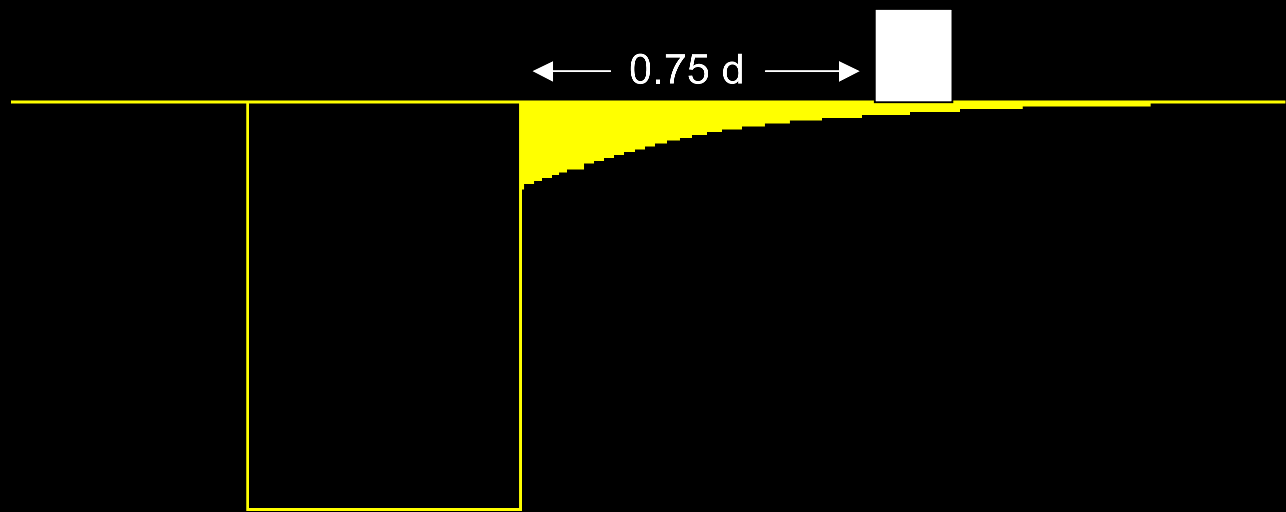


0.75d

Alert = 7mm

Action=15mm

Alarm=25mm



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