

A 3D visualization of a tunnel system. The tunnel is represented by a large red pipe-like structure that curves through a landscape. The landscape includes green hills, a body of water, and a road. The tunnel is shown in a cutaway view, revealing internal instrumentation. Numerous vertical lines of different colors (yellow, purple, red) are shown extending from the tunnel's surface into the surrounding terrain, representing various sensors or monitoring points. The background shows a detailed 3D model of the environment, including a dam and surrounding vegetation.

# **INSTRUMENTATION for TUNNELS**

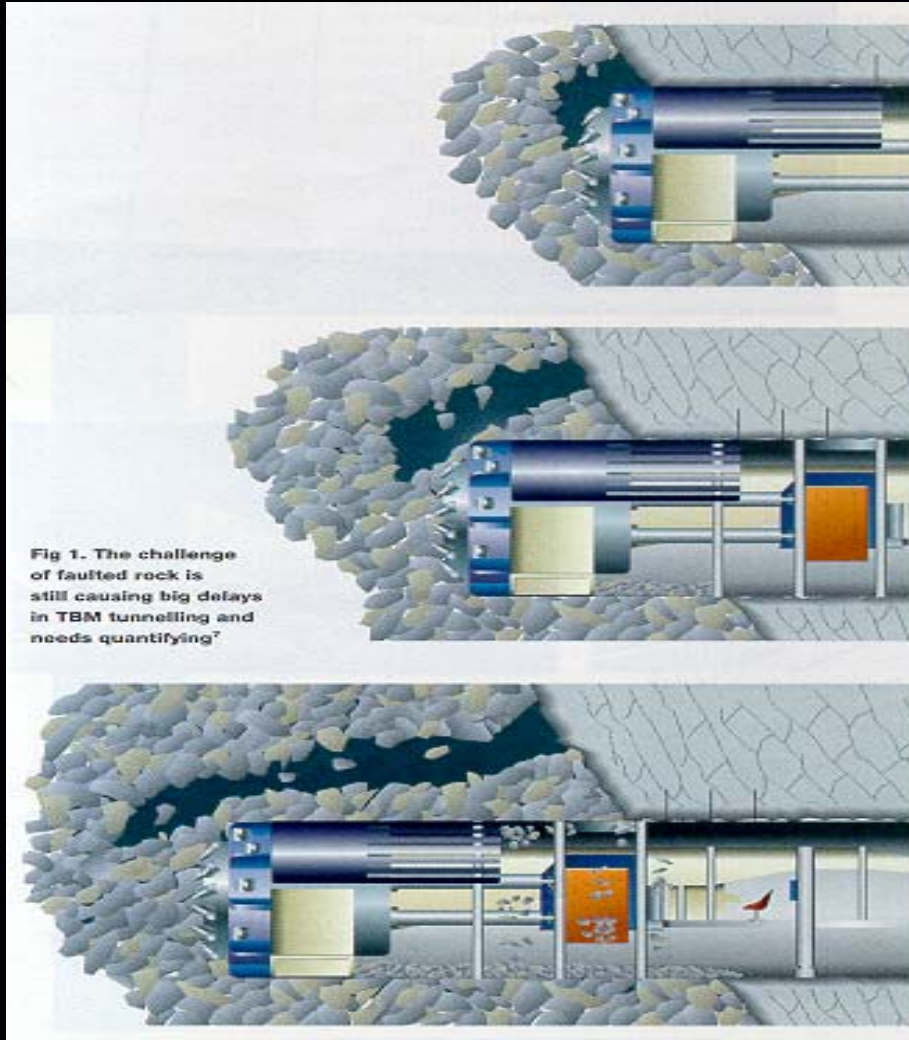
**Angus Maxwell  
Maxwell Geosystems Ltd**

**With assistance from  
Tim Barwell RST (HK)**

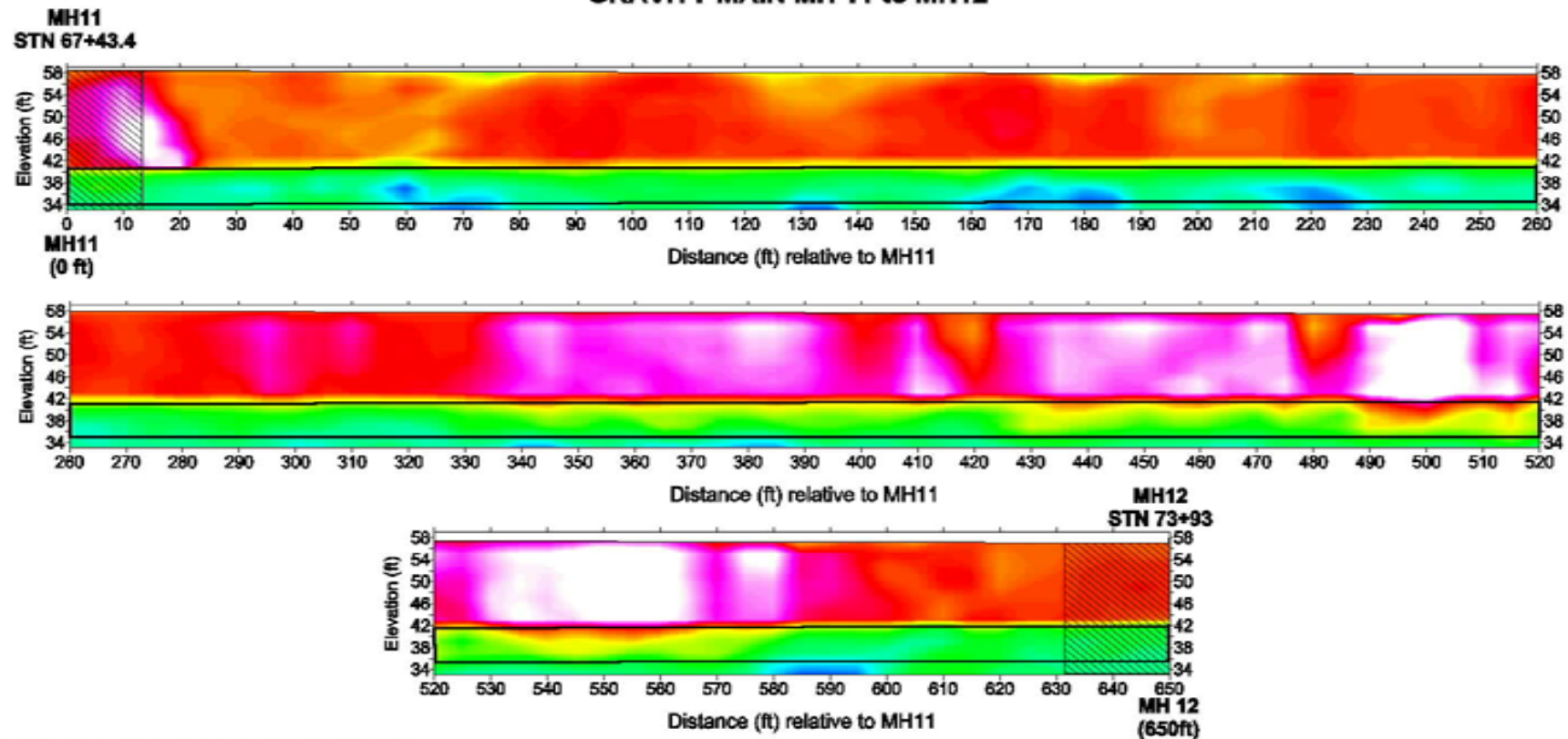
**AGS JAN 2006**



# Tunnel Deformations



## SEWREEL IMAGES GRAVITY MAIN MH 11 to MH12



Note: This SEWREEL Image is an output of a seismic test described in the accompanying report. The seismic velocity distribution may be related to geotechnical soil density classifications as described in the report.



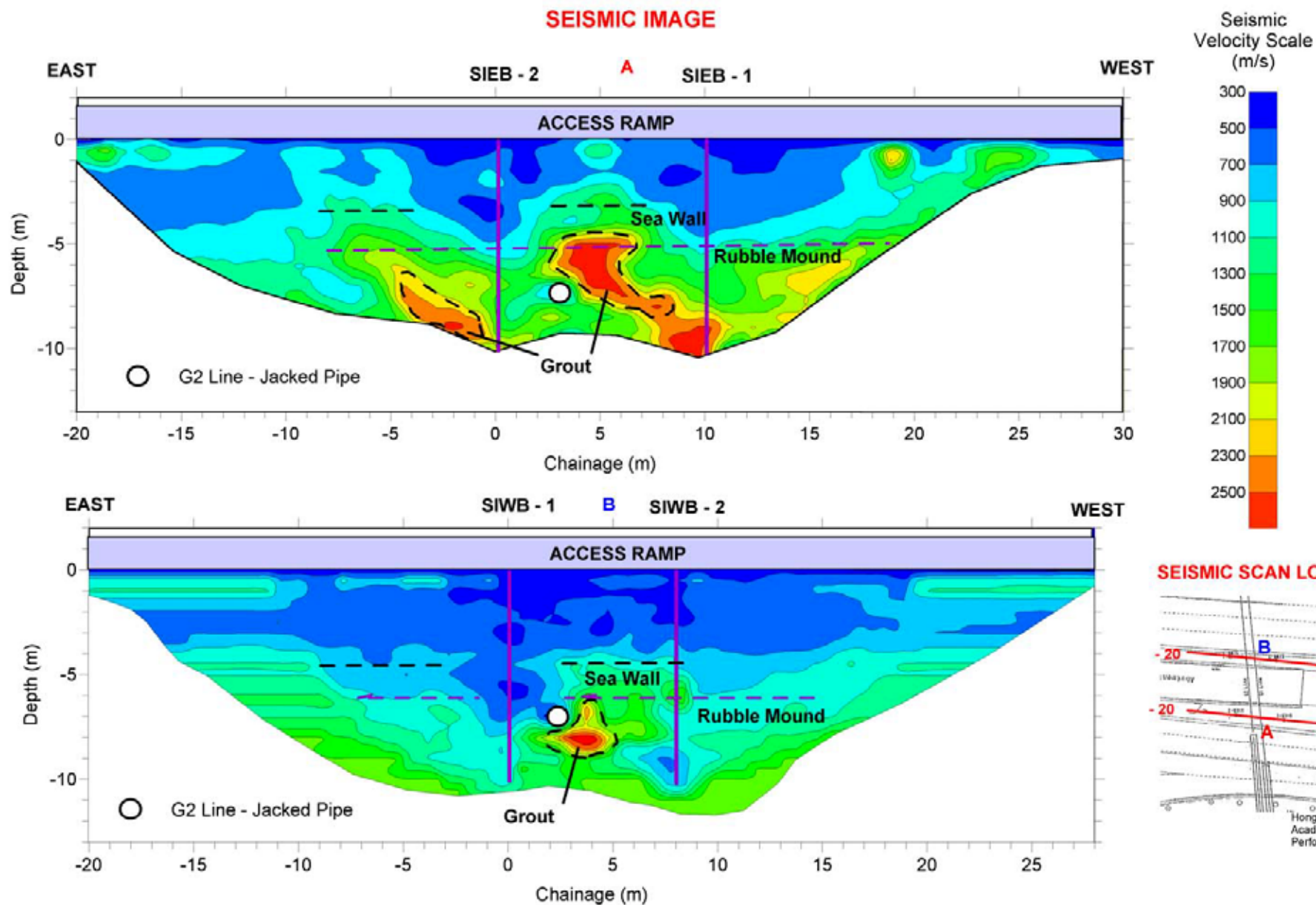
Region of limited data coverage

SEWER

COFFEY GEOSCIENCES PTY LTD  
SEWREEL TESTING  
GRAVITY MAIN  
ORLANDO FLORIDA



# Heterogenous Ground 2



# Ground Movement Modes

**Loosening of  
Granular Soils**

**Ravelling/  
Crown Holing**

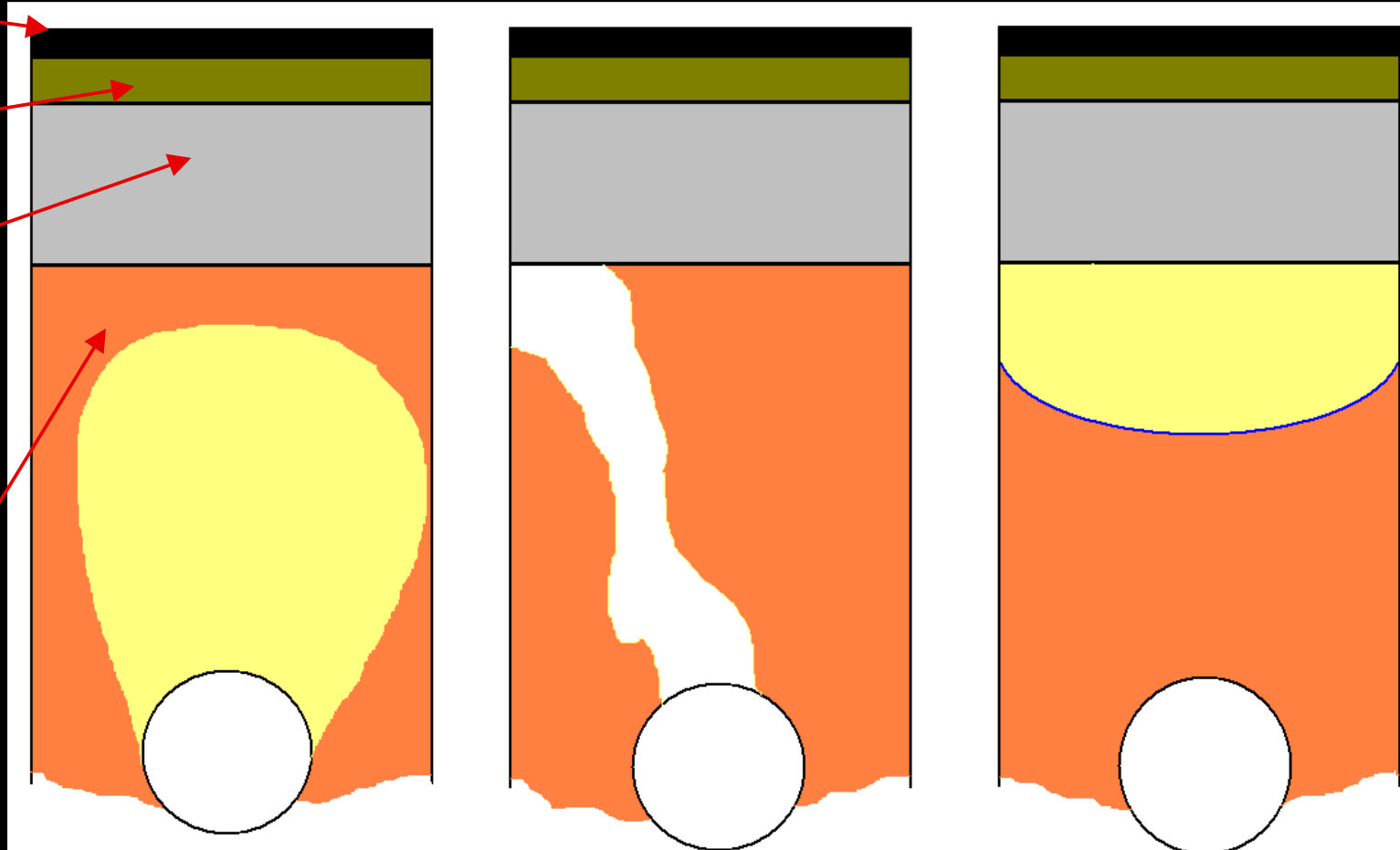
**Consolidation  
due to  
Groundwater  
Drawdown**

**Wearing  
course**

**Well  
compacted  
Sub-base**

**Compacted  
fill above the  
water table:  
Utilities Zone**

**Less well  
compacted  
fill below the  
water table`**



# What to Measure? Why?

A 3D visualization of a tunnel excavation. The tunnel is represented by a large red volume. The surrounding ground is shown in grey. Numerous vertical and horizontal pipes and sensors are visible, colored in yellow, blue, and red. The background shows a complex network of lines representing the ground's internal structure.

## **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?

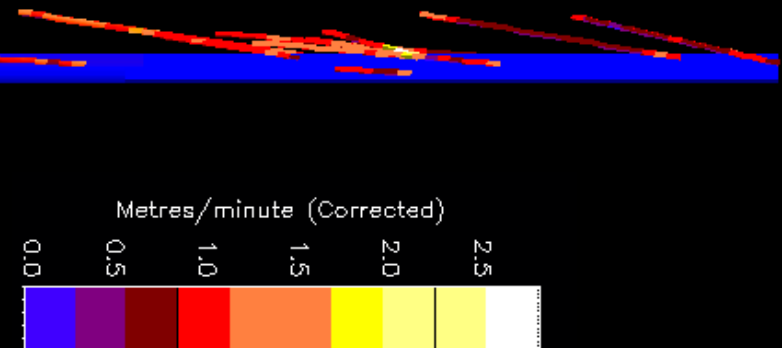
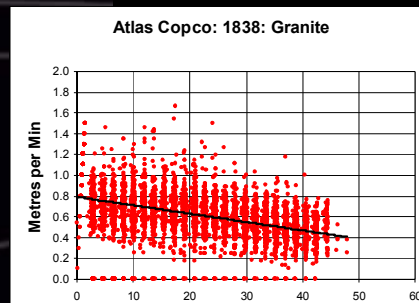
## Soft Ground TBM Tunnels (assume expanded segmental linings).

- 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.

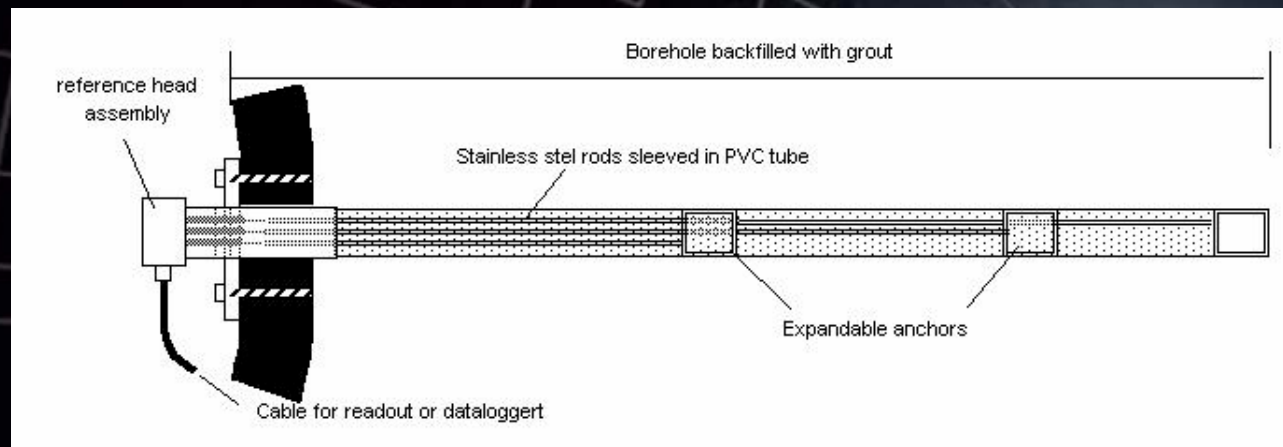
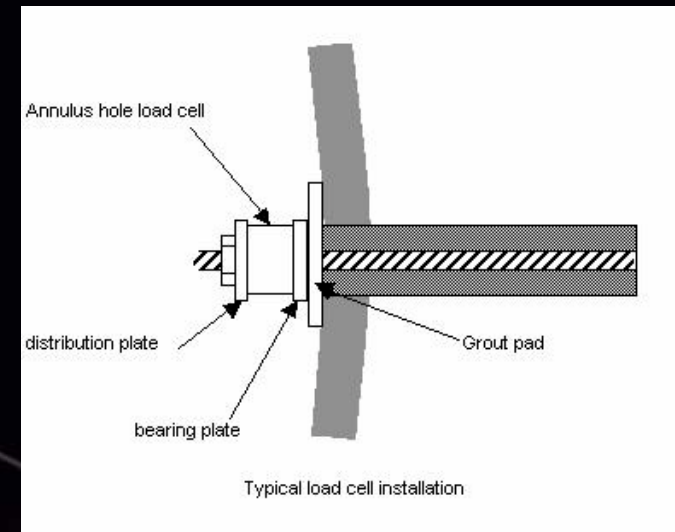
- Face pressure/revs
- Attitude
- Progress
- Disk wear
- Probe parameters





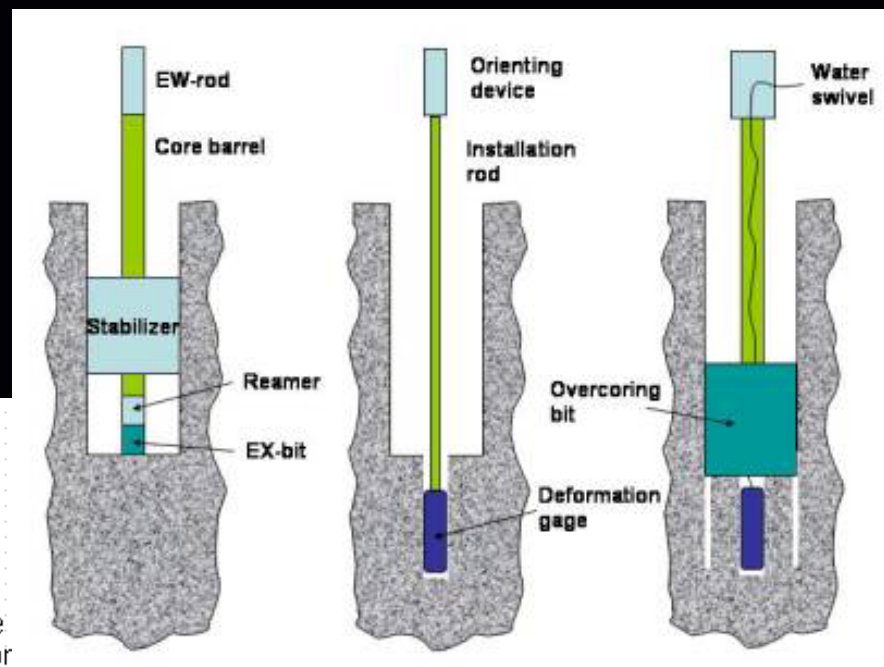
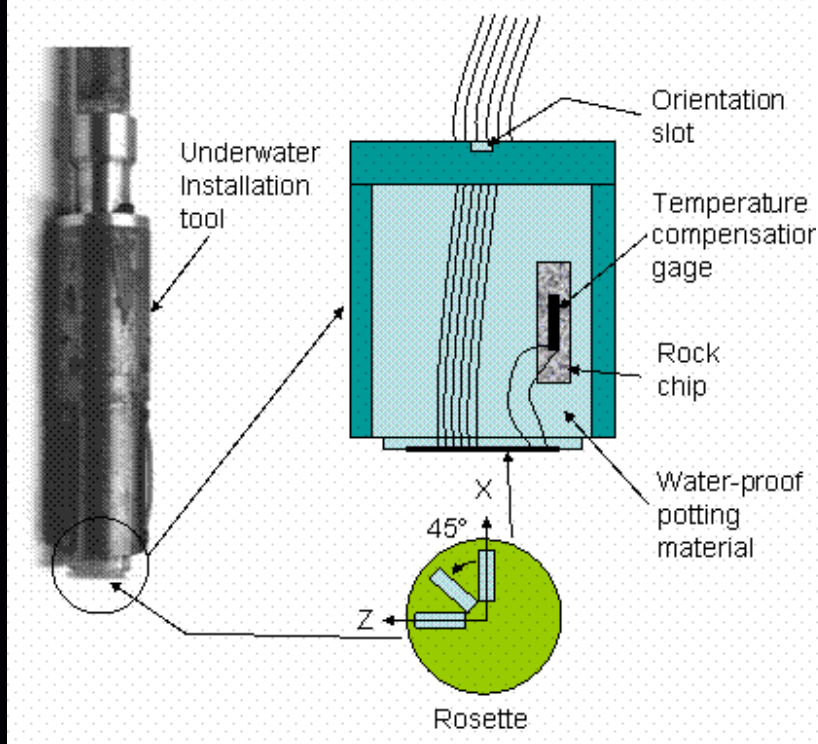
## Within the tunnel.

- 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)





## Door stopper



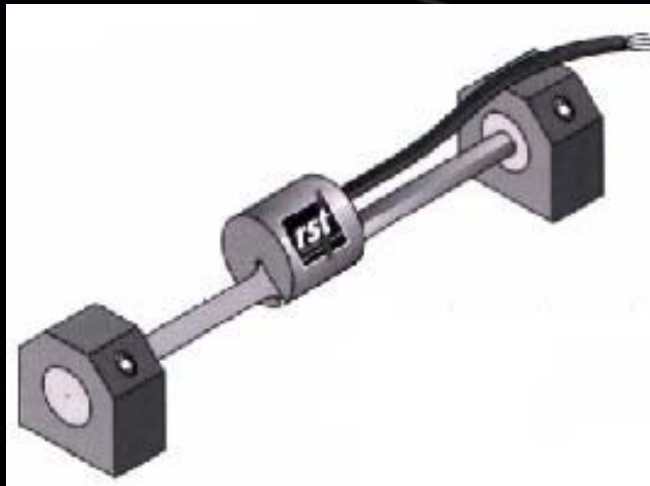
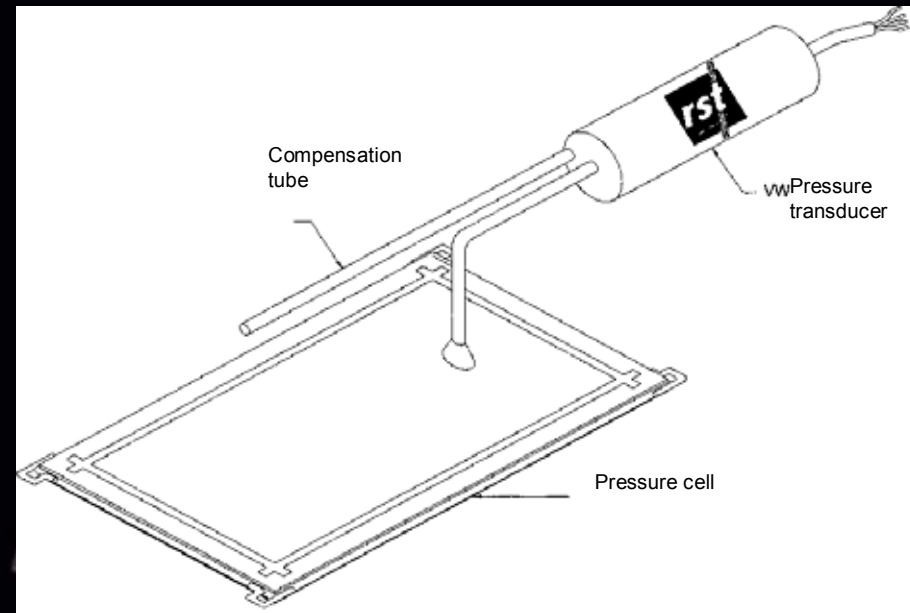
## Universal Measurement Guage



# Lining Stresses and Load

## **Within the tunnel.**

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



Vibrating wire attachment type strain gauge

Load pressure cell



## TBM Tunnels

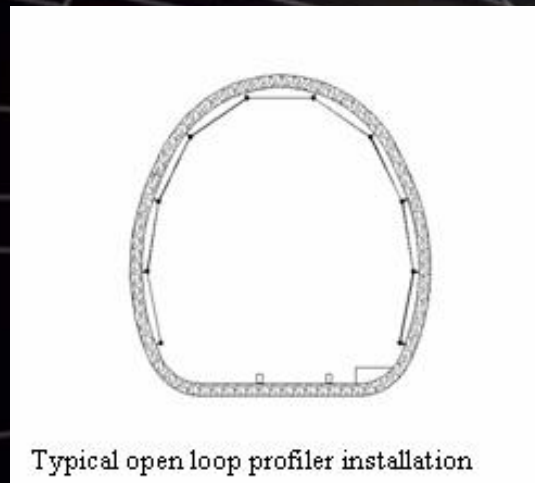
- Indirect methods (comparison of cut vs lining dimension)
- Problem for soft ground. Over-excavation at the face?

## NATM and Drill and Blast Tunnels

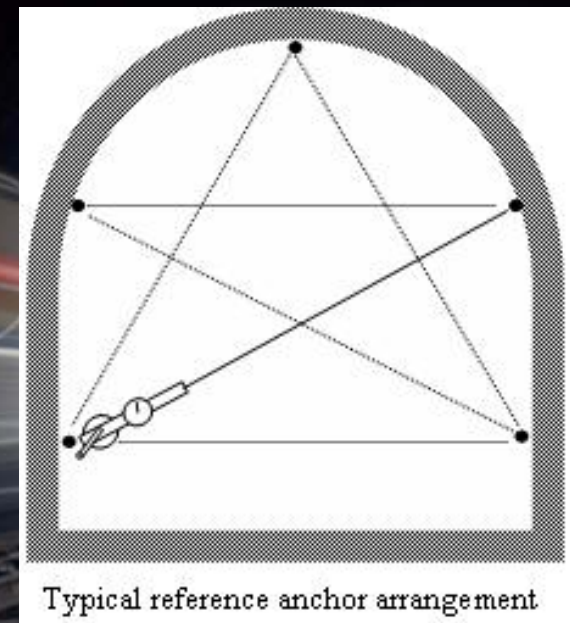
- Tape extensometer/survey
- In situ convergence arrays (Bassett)

## Movement of lining or adjacent tunnels

- As for NATM



Typical open loop profiler installation



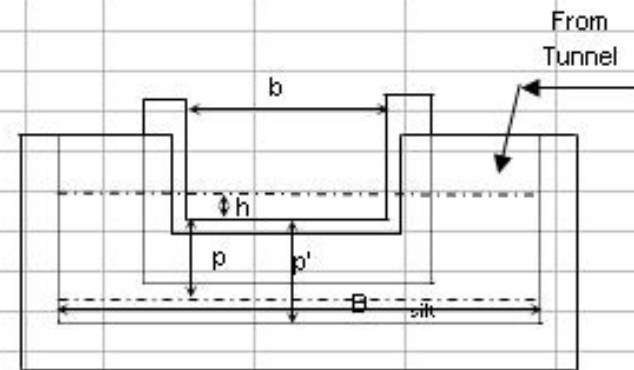
Typical reference anchor arrangement



## 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:-

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

Where	Q	is	Volume rate of flow in m <sup>3</sup> /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
	C <sub>e</sub>	is	Coefficient of discharge (from chart of h/p)
	h	is	measured head in metres
	h <sub>e</sub>	=	h + k <sub>h</sub> k <sub>h</sub> = 0.001
	b <sub>e</sub>	=	b + k <sub>b</sub> k <sub>b</sub> = 0.00245
	g <sub>n</sub>	is	acceleration due to gravity in m/sec <sup>2</sup>
	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

Signal cables are protected by PVC placement pipe.

Placement pipe makes it easy to install piezometers at the specified elevations

VW piezometers in multi-level housings are installed in-line with the placement pipe.

Fully-grouted borehole provides excellent isolation of zones.

Placement pipe is also used to deliver grout to the borehole.

# Rock and Soil Strains

## From the surface

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



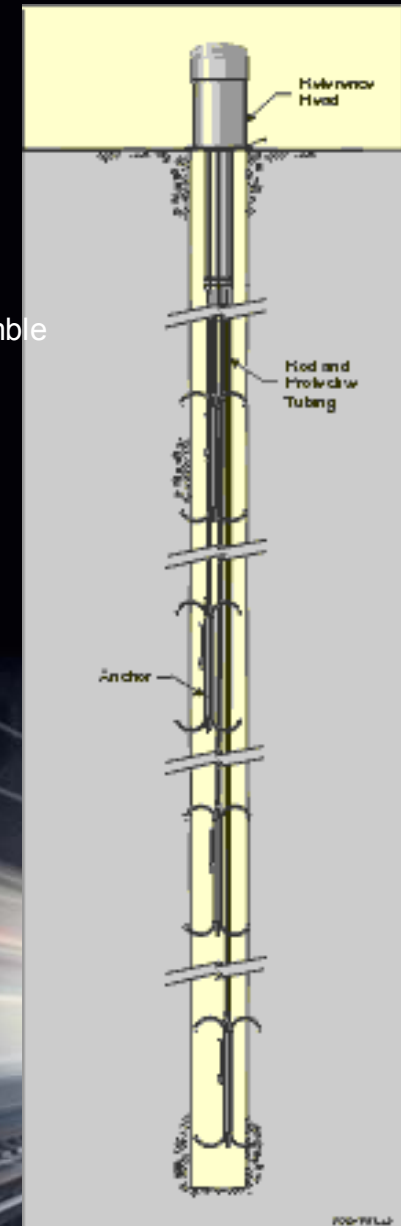
Rod Extensometer Head Assembly



Inclinometer probe



Extensometer magnets and plates.

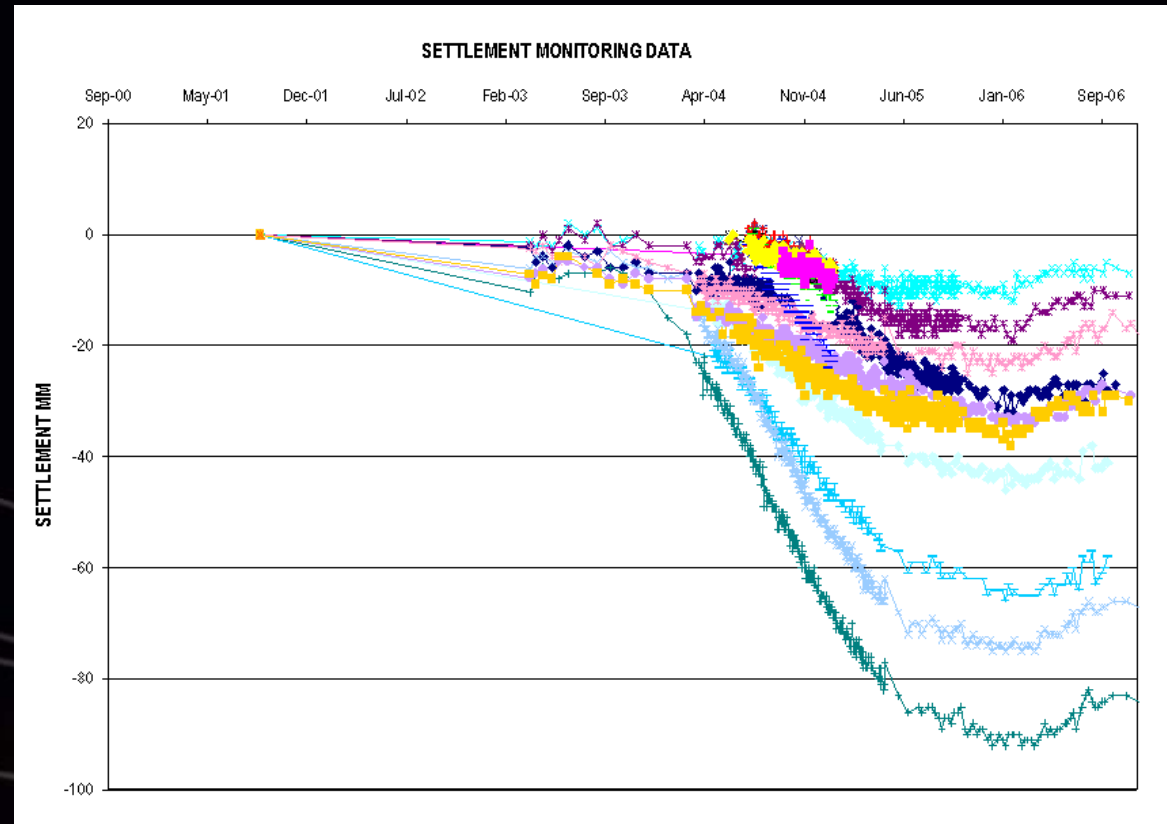


Rod Extensometers in Borehole



## At the surface

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



## Example: Settlement Monitoring Mong Kok

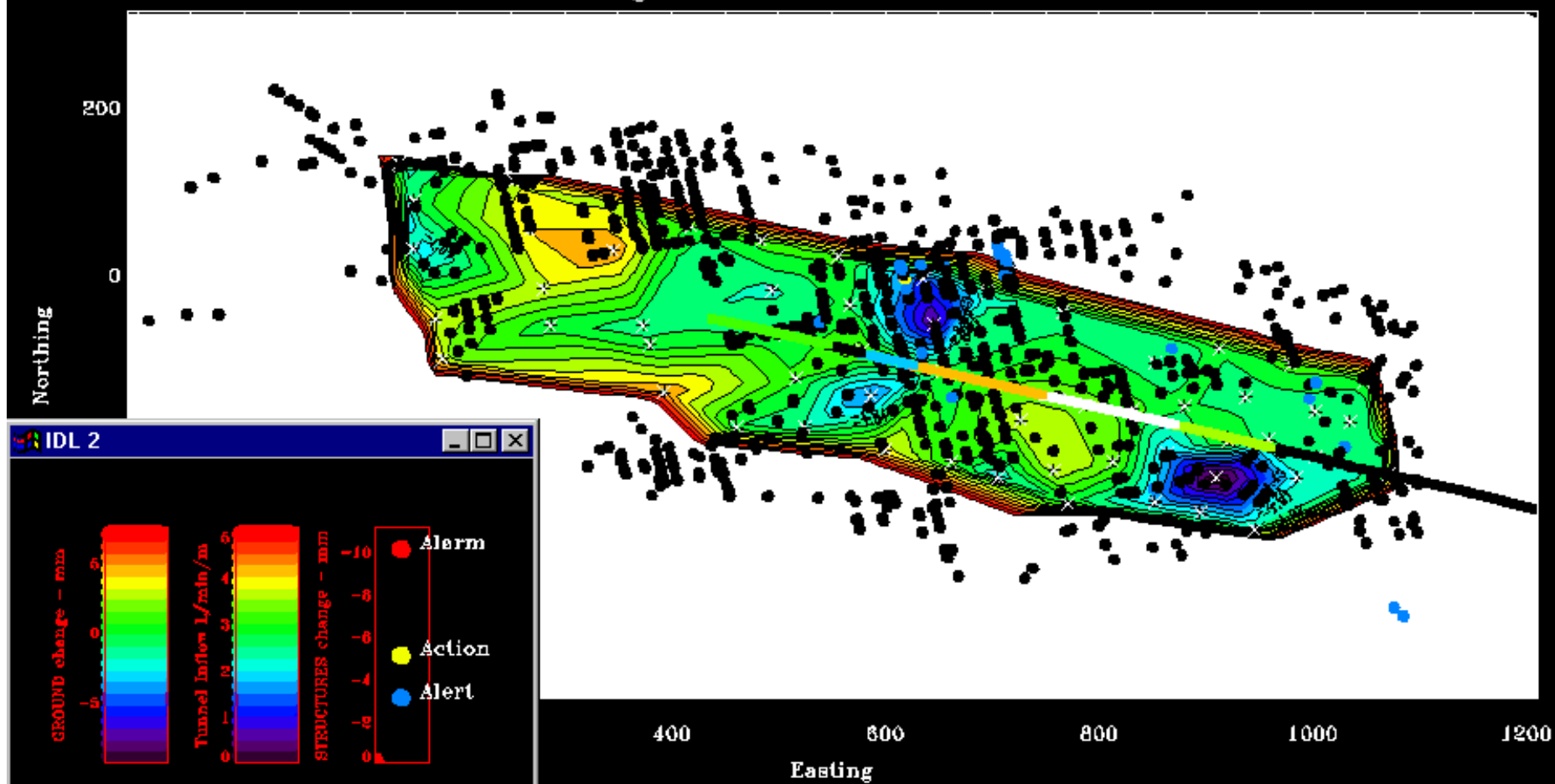
Tunnel TKW-SI

Region - MONGKOK

10

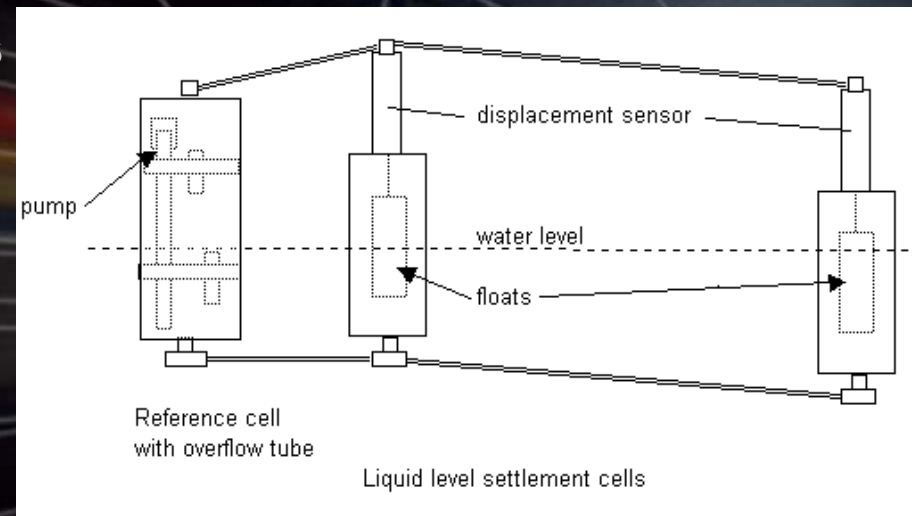
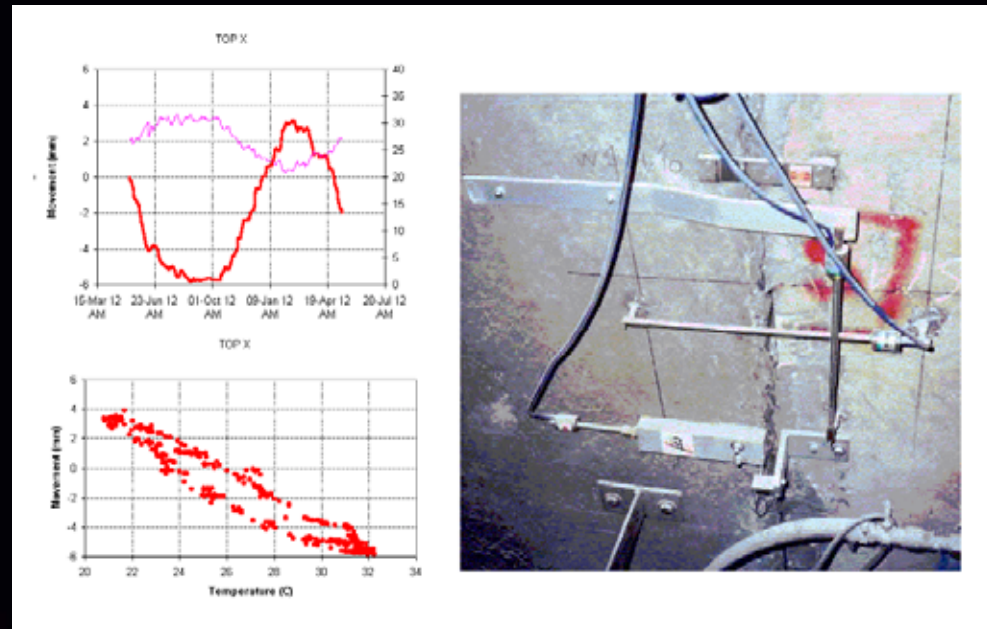
9

1999



# Structure Monitoring

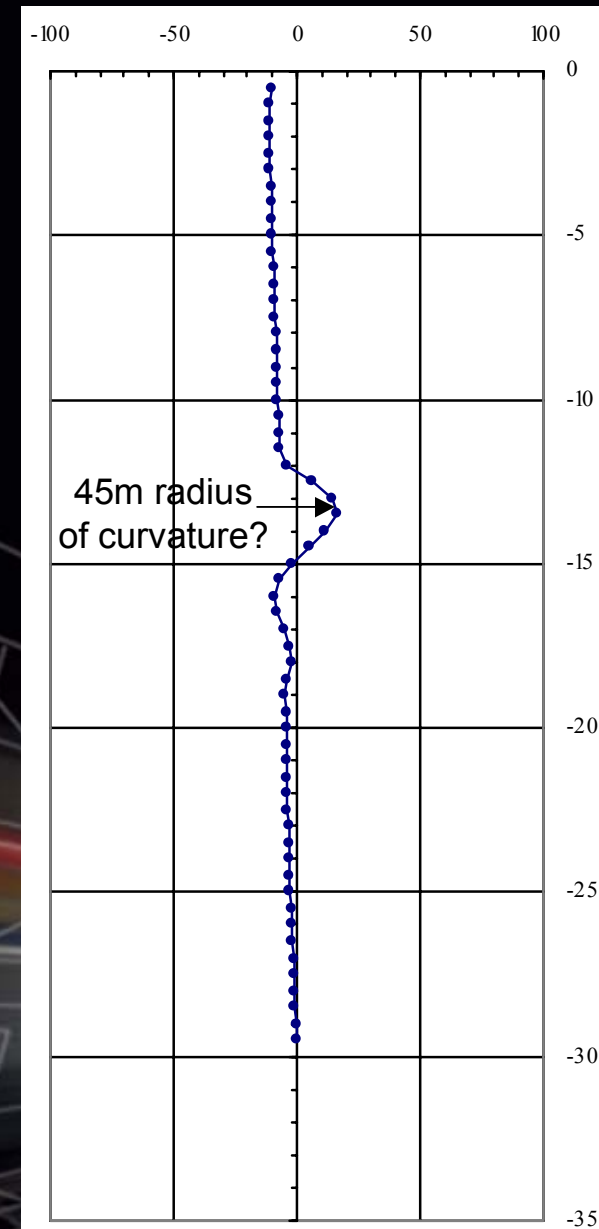
- **Survey points**
- **Crack meters**
  - Grid type “tell tale”
  - Demec
  - VW type
- **Tiltmeters**
  - servo accelerometer type (portable/fixed)
  - VW type
  - Electrolytic
- **ADMS systems**
- **Liquid level systems**
- **Bassett Convegence Systems**
- **Laser systems**





## Derived Parameters

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



## **Tolerance (ppv and m/s<sup>2</sup>)**

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

## **Types**

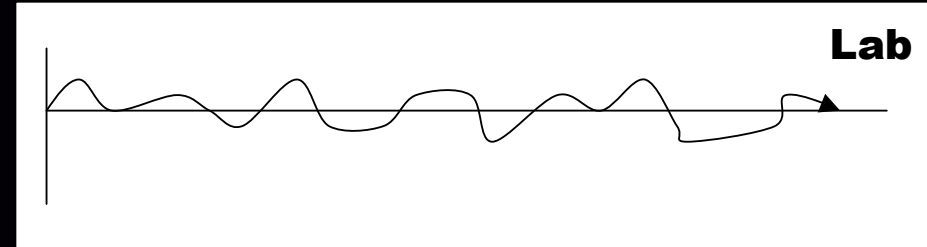
- **Seismograph (Instantel Blastmate)**
- **Piezoelectric**



# Trigger Levels

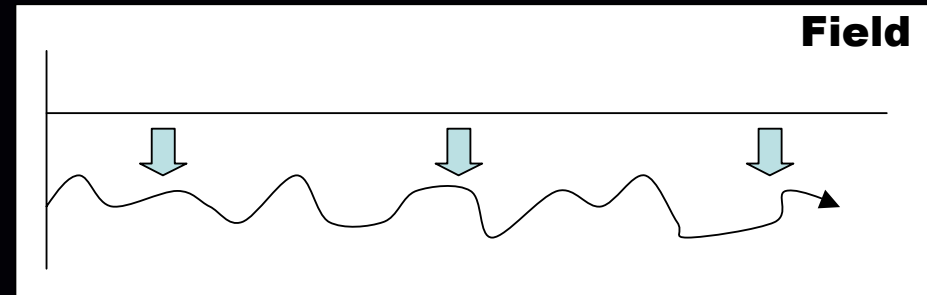
## Accuracy Sensitivity

- From Lab



## Sensitivity in the field

- Function of background fluctuation



## Trend

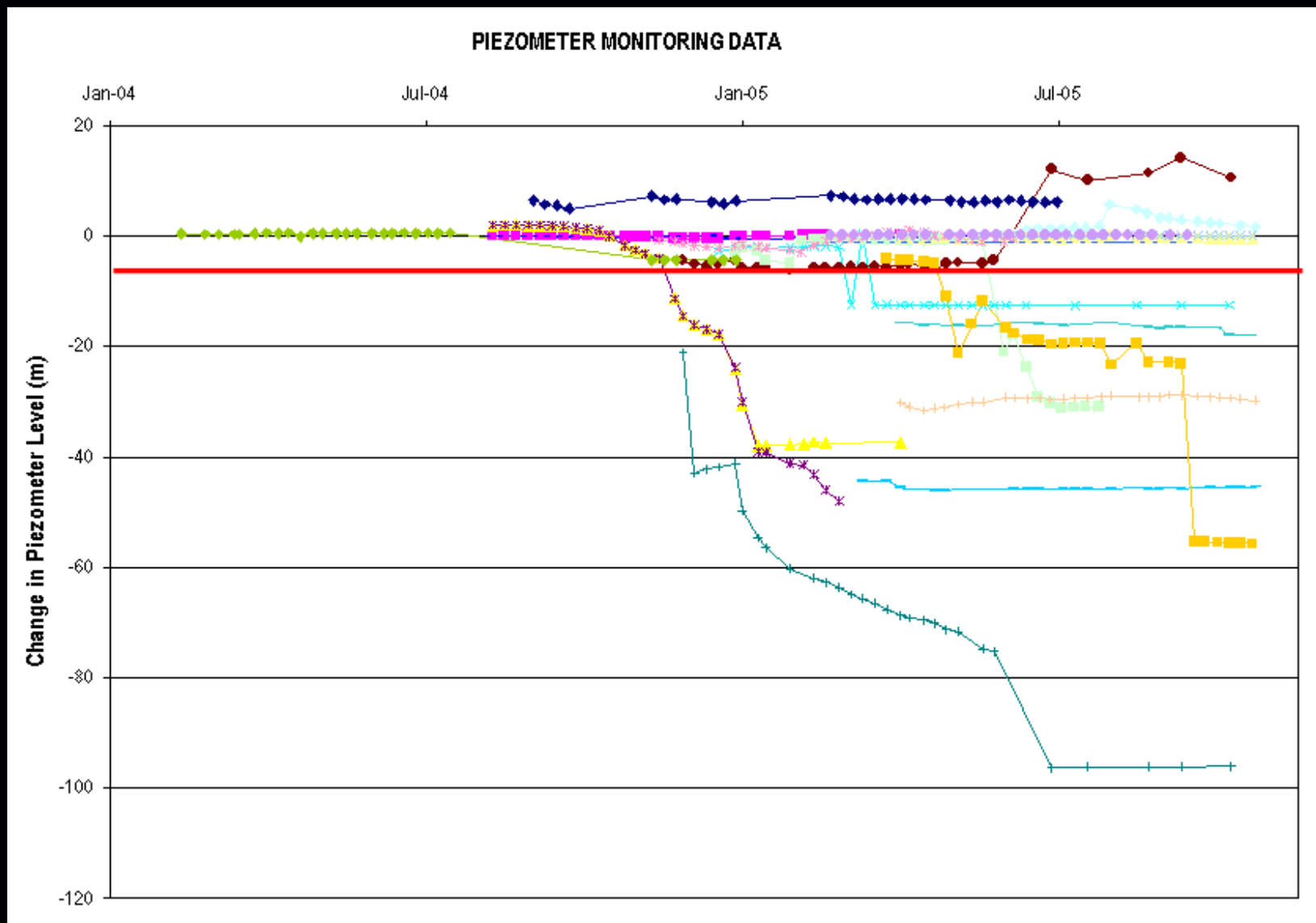
- On going change in reading



## Magnitude

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





**Thankyou**



# Function of Depth

$d$  = Final Depth of Excavation

$0.5d$

Alert = 7 mm

Action=15mm

Alarm=25mm

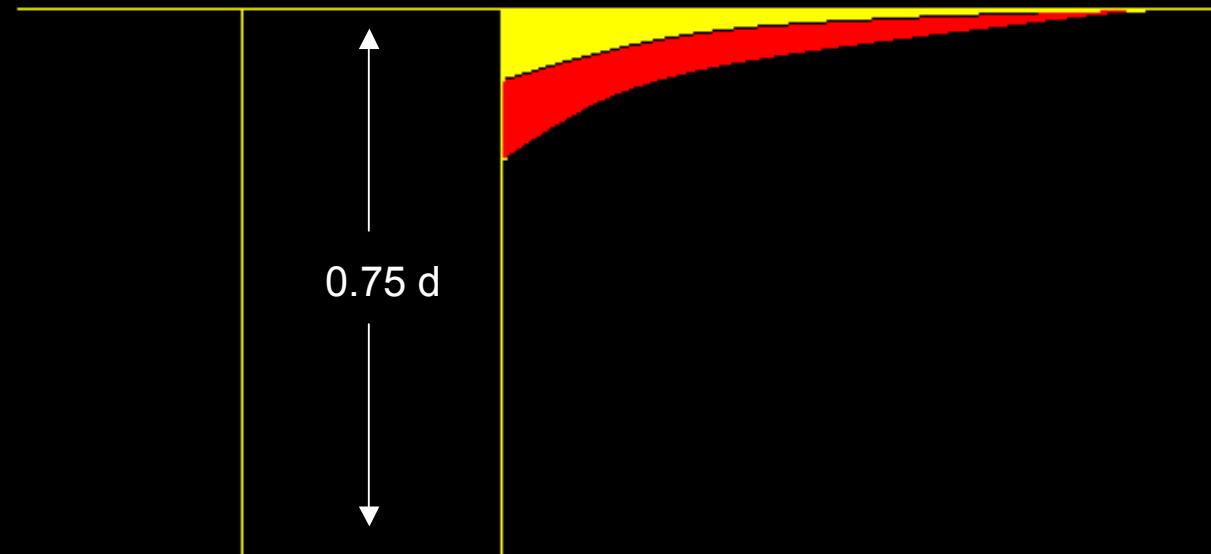


$0.75d$

Alert = 15 mm

Action=25mm

Alarm=40mm





# Function of Distance

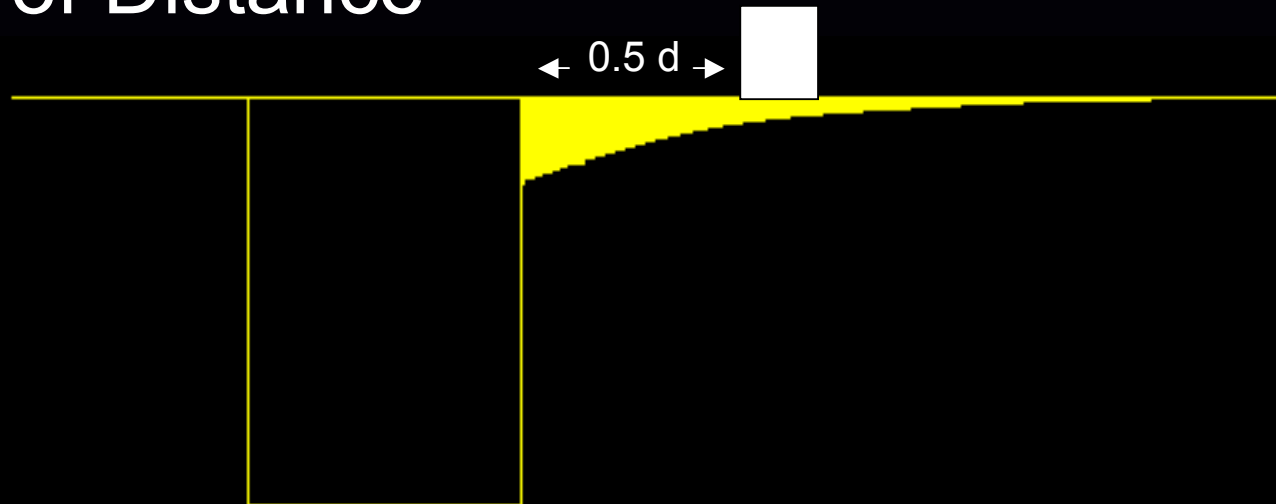
$d$  = Final Depth of Excavation

$0.5d$

Alert = 15mm

Action=25mm

Alarm=40mm



$0.75d$

Alert = 7mm

Action=15mm

Alarm=25mm

