




GEOTECHNICAL INSTRUMENTATION WORKSHOP

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Menara PJD, JKR Headquarters, 26-27 October 2010



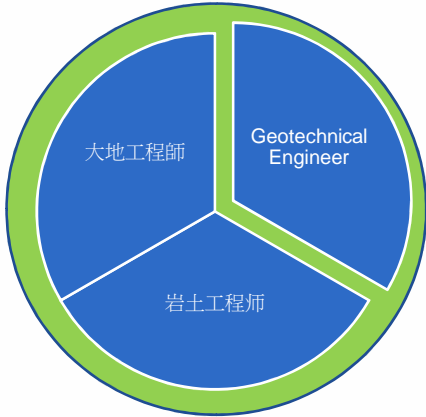
Course Outline

- 1 Planning, Specification & Contractual Arrangement
- 2 Site Monitoring
- 3 Data Processing / Analysis, Interpretation & Actions
- 4 Common Problems, Applications & Lesson Leant from Case Study



Geotechnical Engineer

Civil Engineer



大地工程師
Geotechnical Engineer
岩土工程師

- Geotechnical engineer in Malaysia is ambiguously regarded as "Geologist" in the public perception.
- Geotechnical engineer is a qualified civil engineer registered with **Board of Engineers Malaysia** as either graduate engineer or professional engineer having relevant and competent experience in geotechnical works
 - ability to plan ground investigation & characterise ground conditions for engineering processes
 - identify & assess the potential geo-hazards and the possible ground borne interaction to proposed structures
 - offer feasible engineering design solutions to ensure safety & satisfactory performance of the end product of the engineering works including its surrounding

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Why appoint Geotechnical Engineer?

- **Why Geotechnical Engineer?**
- Geotechnical engineer as an underwriter for risk assessment.
- **GI as tools for Geotechnical Engineer**
- It is regard as necessary, but not a rewarding expense. (Uncertainty, sufficiently accurate design options for Cost & Benefit study)
- **What Risk in Ground & its Consequence ?**
- Ground Variability & Geo-hazards.
- Financial Viability & Cost Overrun (Construction & Operation).

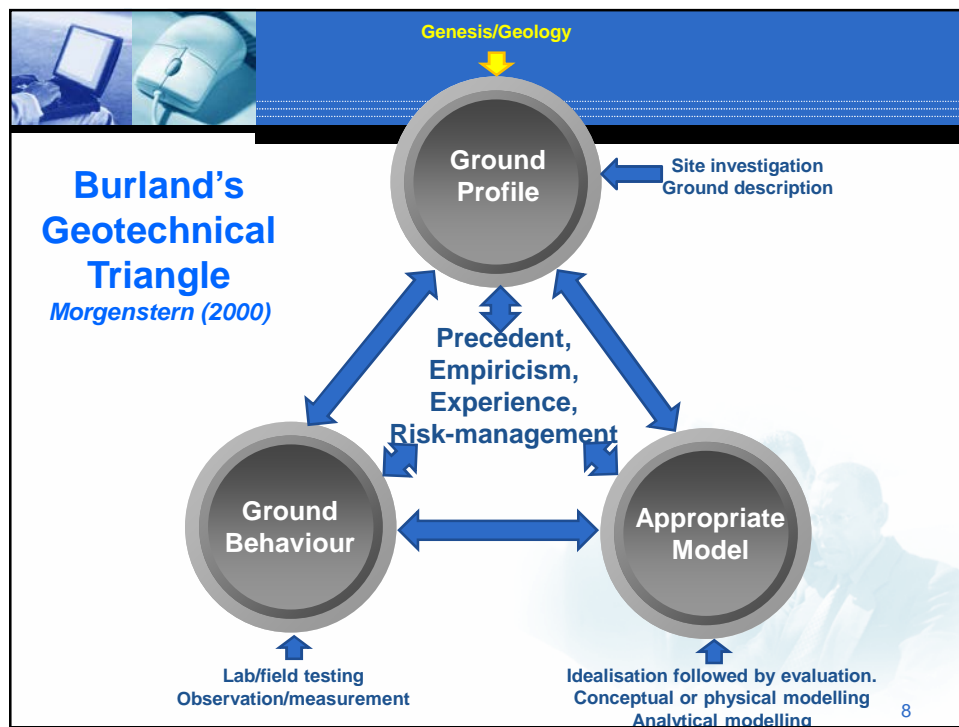
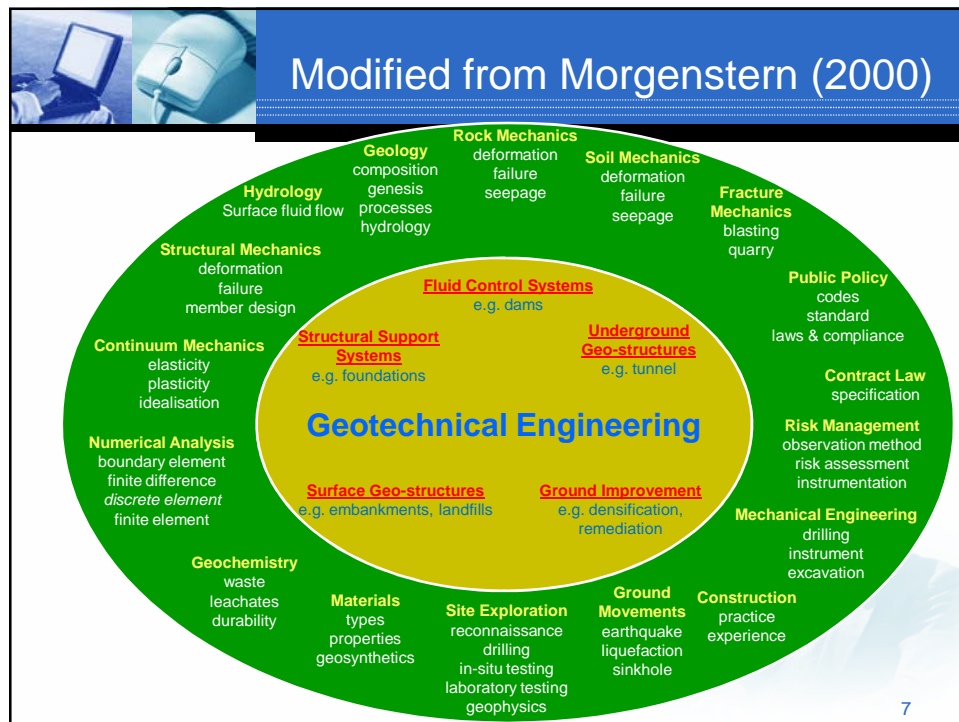





"My design saves the cost of a site investigation ..."

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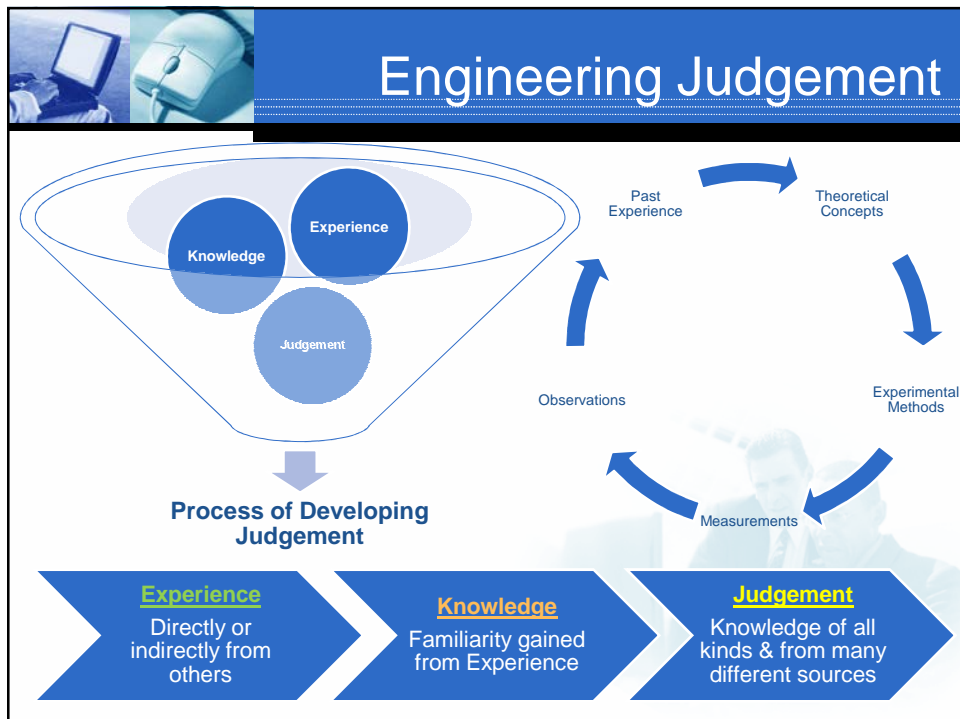


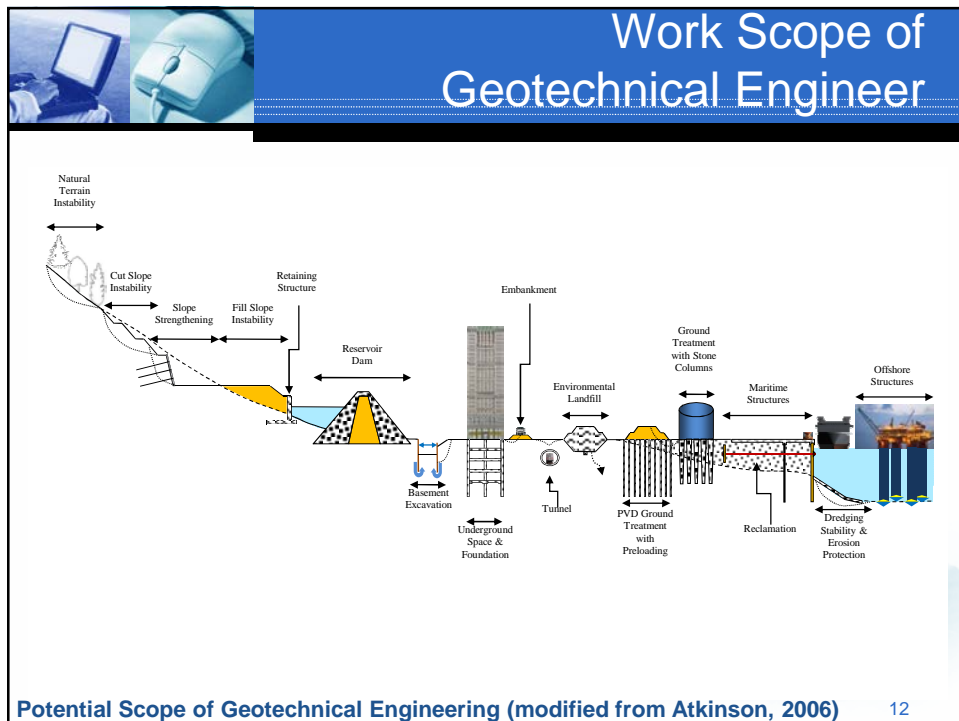
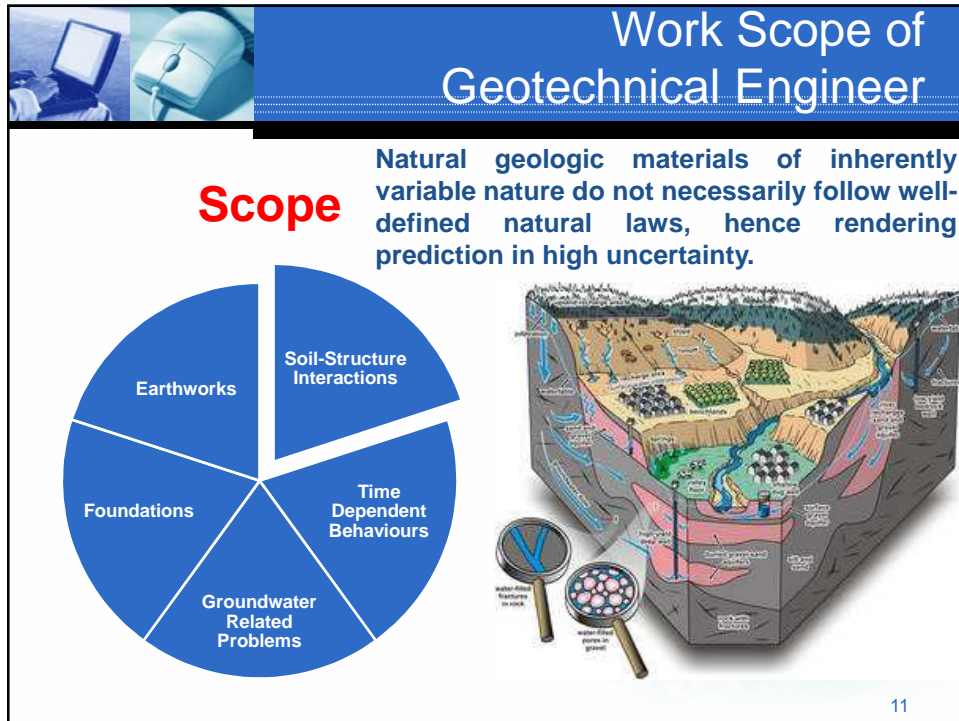




Engineering Judgement

- **Definition** : The operation of the mind, involving “**comparison**” and “**discrimination**” by which knowledge of values and relations is mentally formulated. (*Webster’s New Collegiate Dictionary*)
- **Recognition** : **Engineering judgement** as an acceptable engineering practice



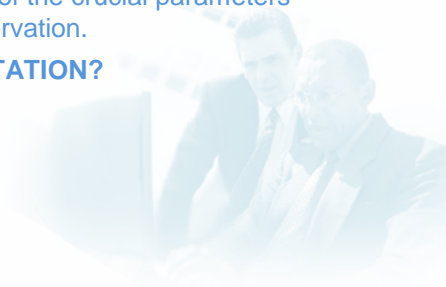




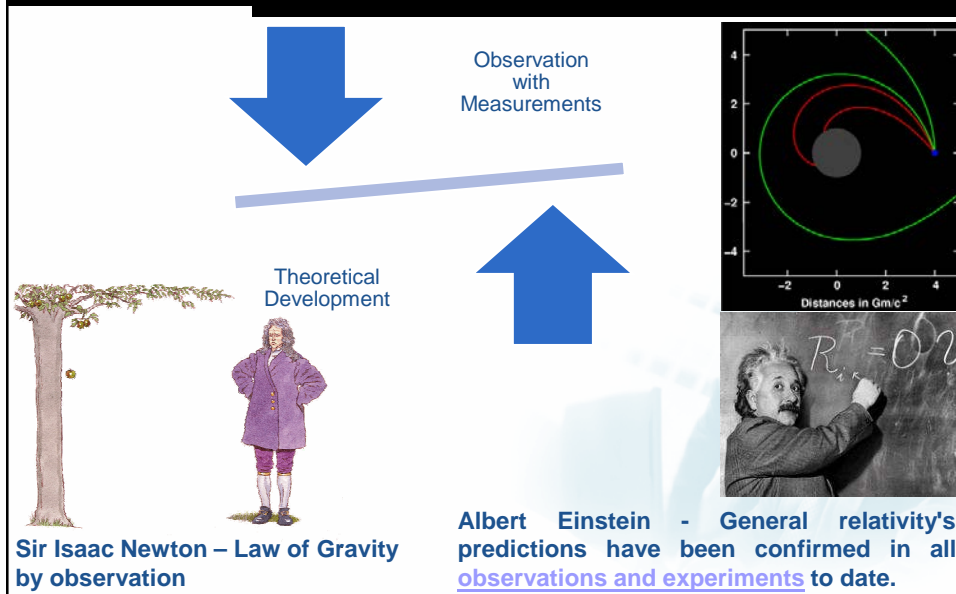
Why Instrumentation?

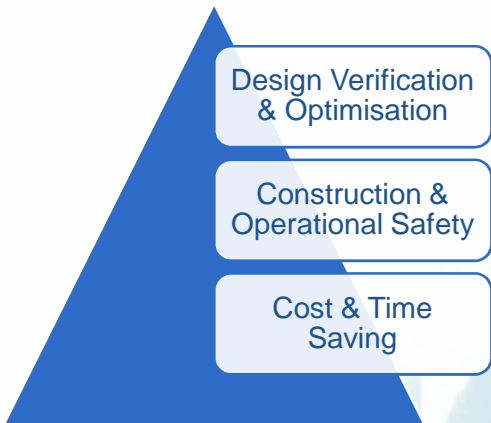
It is a useful tool to supplement what we can not identify trend of behaviours & quantify the changes of the crucial parameters affecting the behaviours in the observation.

WHY DO WE NEED INSTRUMENTATION?



Theory .vs. Observation

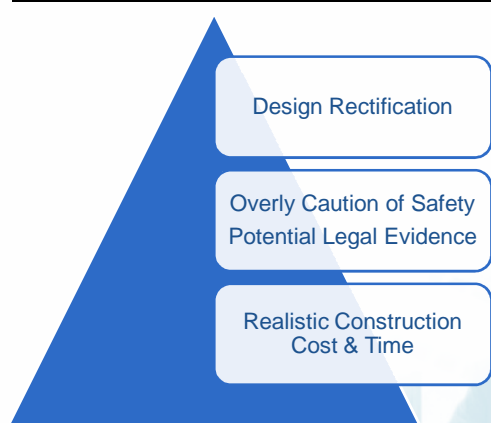




Benefits of Instrumentation

- Design Verification & Optimisation
- Construction & Operational Safety
- Cost & Time Saving

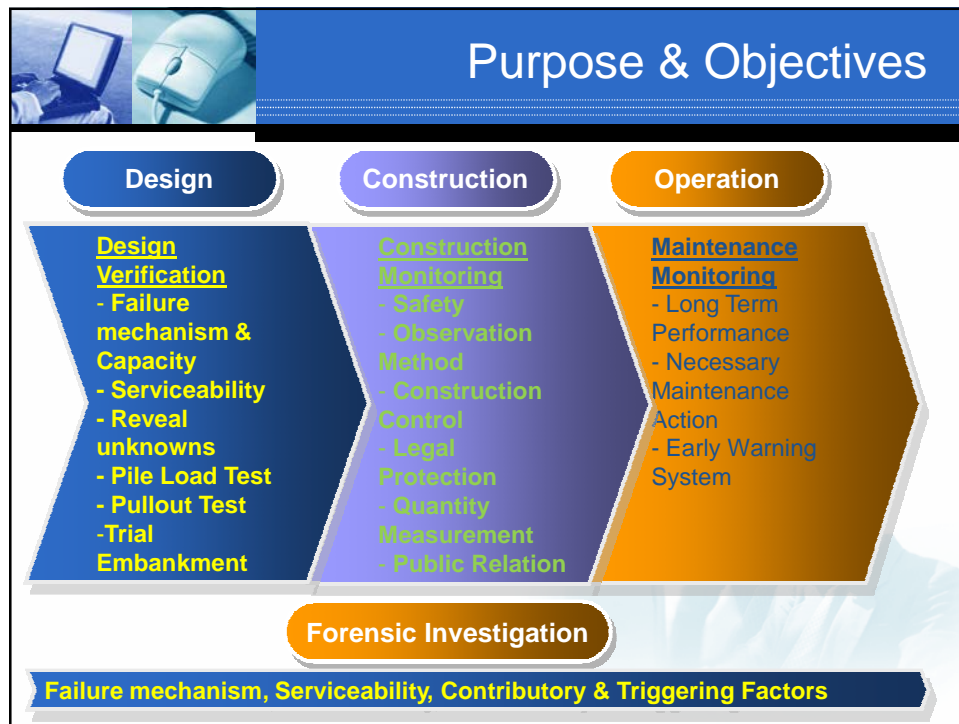
If you can not get high quality and reliable data, then better don't initiate any instrumentation scheme because it will create more problems than being advantageous.

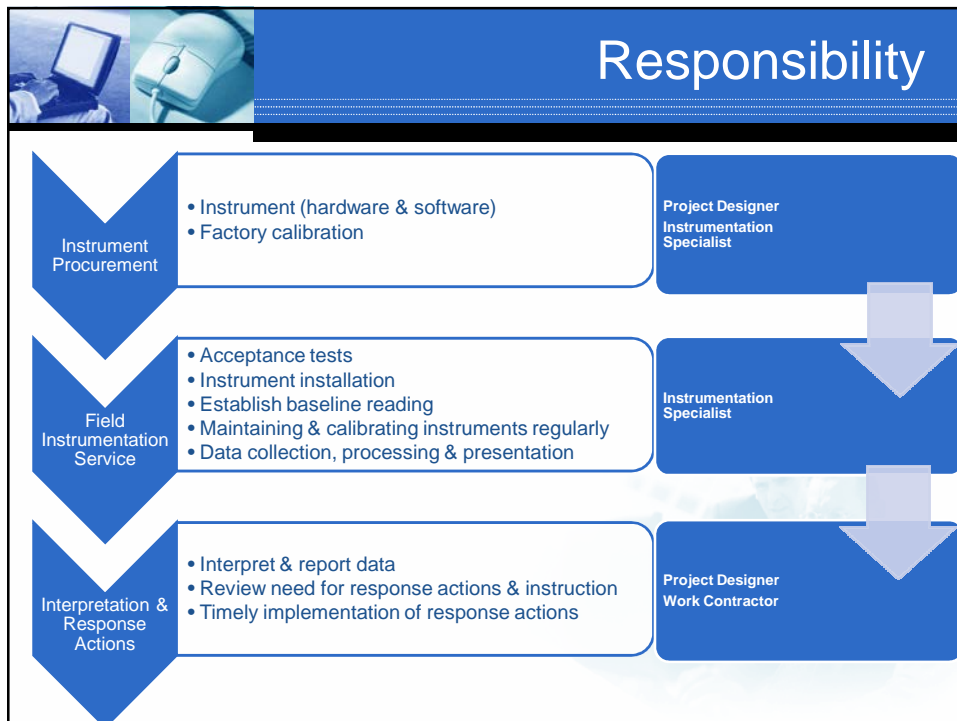
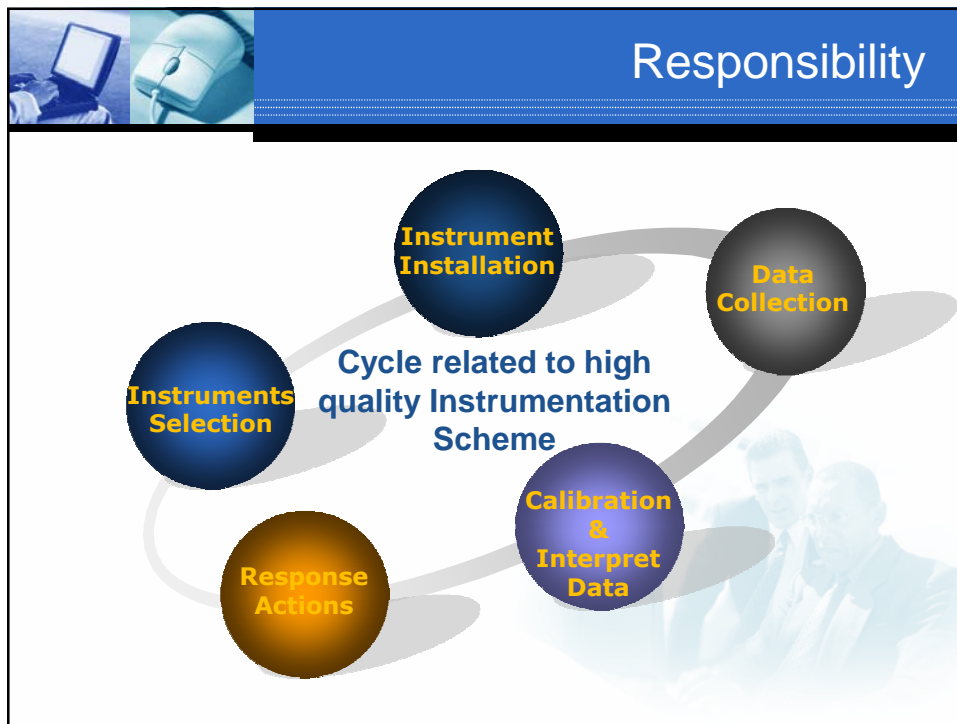


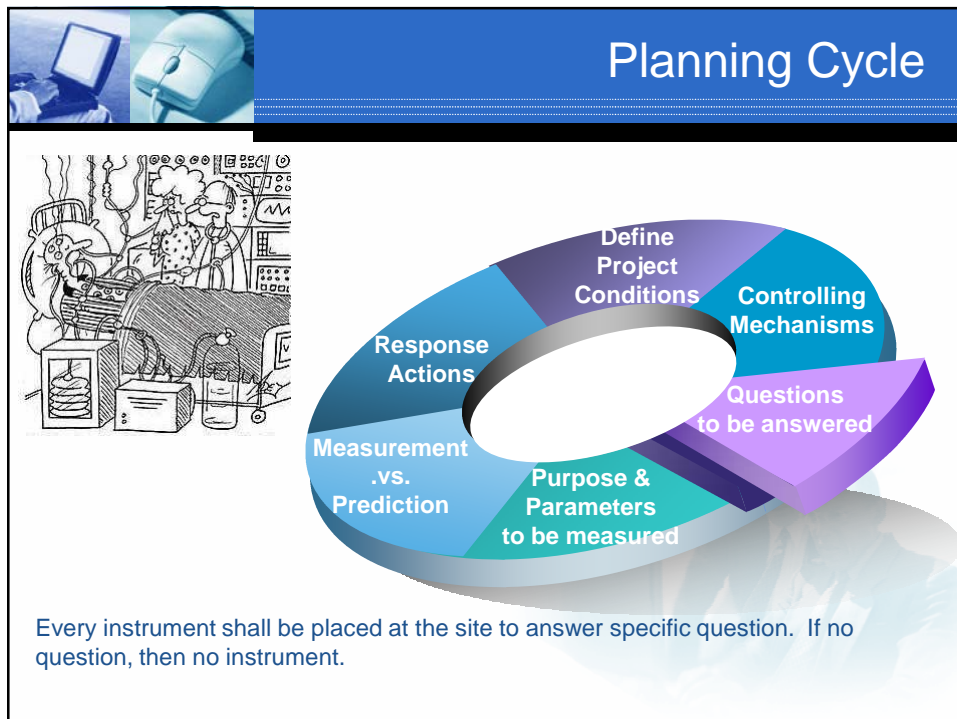
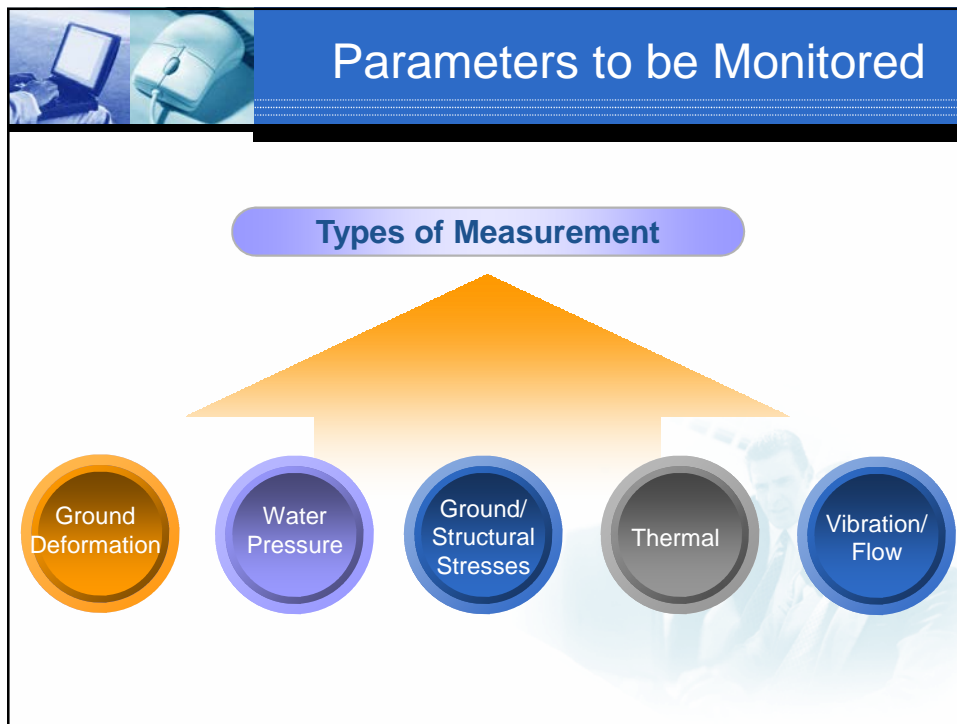
Pitfalls of Instrumentation

- Design Rectification
- Overly Caution of Safety
Potential Legal Evidence
- Realistic Construction
Cost & Time

In some cases, instrumentation results may reveal the shortcomings or negligence in the design of the project designer and also those by the work contractor.









Project Conditions

- **Construction Control** : modify or improve the initial construction sequence or/and method.
- **Remedy** : strengthen the stability, reduce the negative impacts, repair the damage or distresses
- **Notice** : serving notice to project owner, insurance, neighbouring owners, local authorities

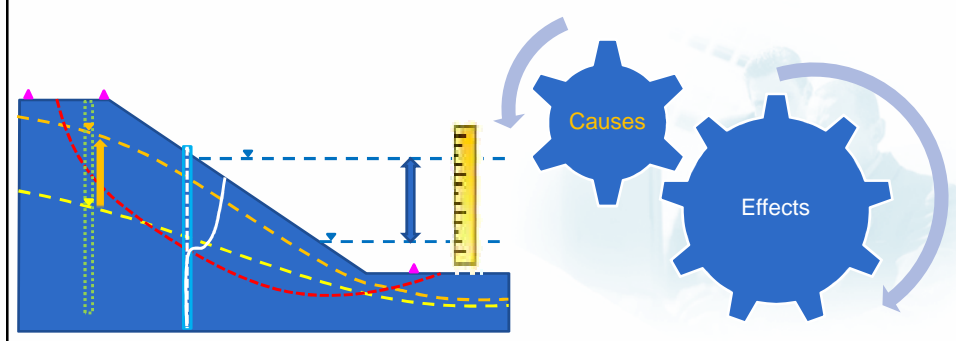


Questions to be answered

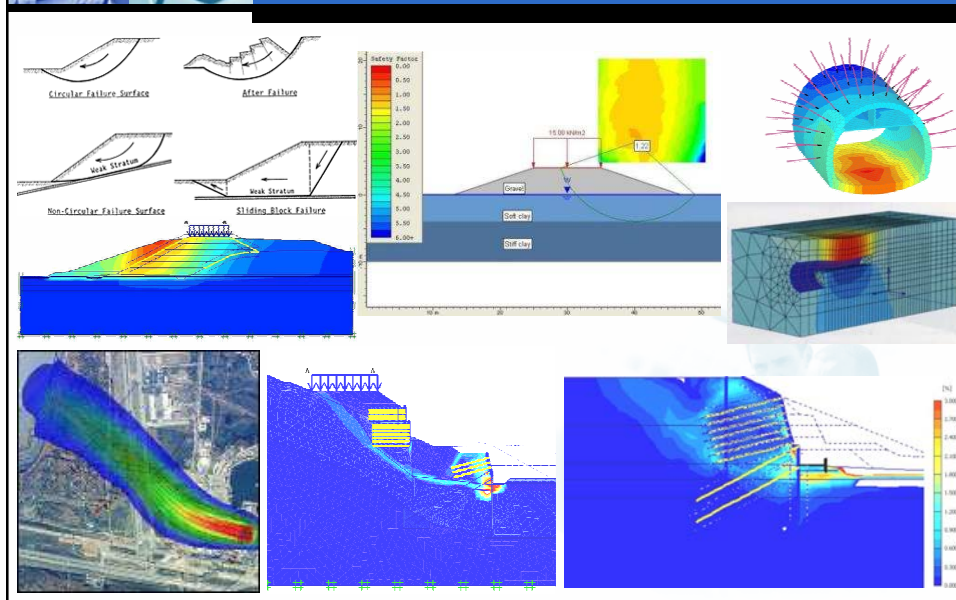
- **Any Questions related to Performance of the Concerned System**
 - **Deformation of Ground or Structures**
 - **Stress or Strain in Ground or Structure**
 - **Water Pressure Distribution, Flow and Changes**
 - **Thermal, Vibration, Tidal Effects**
 - **Location and magnitude of changes**

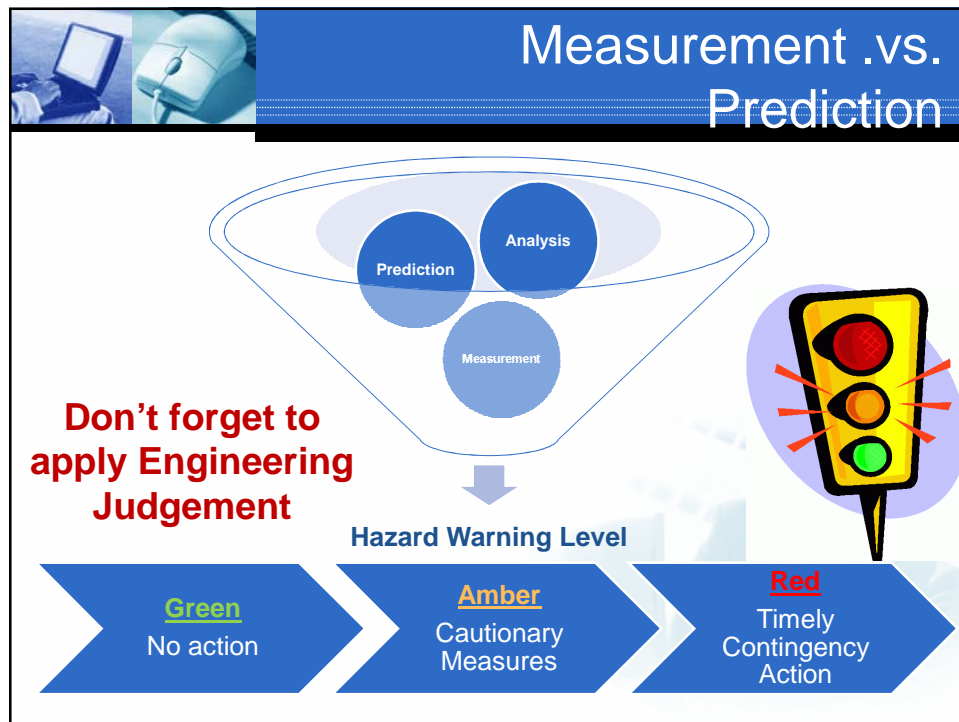
What does instrument measure & response?

- Measurement can be either performed on the changes of **CAUSES** (difficult to pick up the changes) or **EFFECTS** (usually too late for response actions).
- Most instruments provide point measurement with dependence on localised characteristics, hence may not represent the problem in larger scale, unless large number of point measurement instruments are installed.



Controlling Mechanisms





Dilemma of Instrumentation

1 : Doc, can you guarantee I have 100% fix of all my problems?

2 : Well, do you want me to open up everything, big or small one, to check for fixing.

3 : Doc, his credit card limit is up to RM50,000 only.

Specification

Clear

Over-specified

- High price
- Inadequate budget with expectation of omission of requirements
- Inexperienced site staffing

Concise

Project-specific

- Measurement range
- Duration of service

Complete

Under Owner

- Sufficient baseline data
- Avoid price slaughter in subcontracting

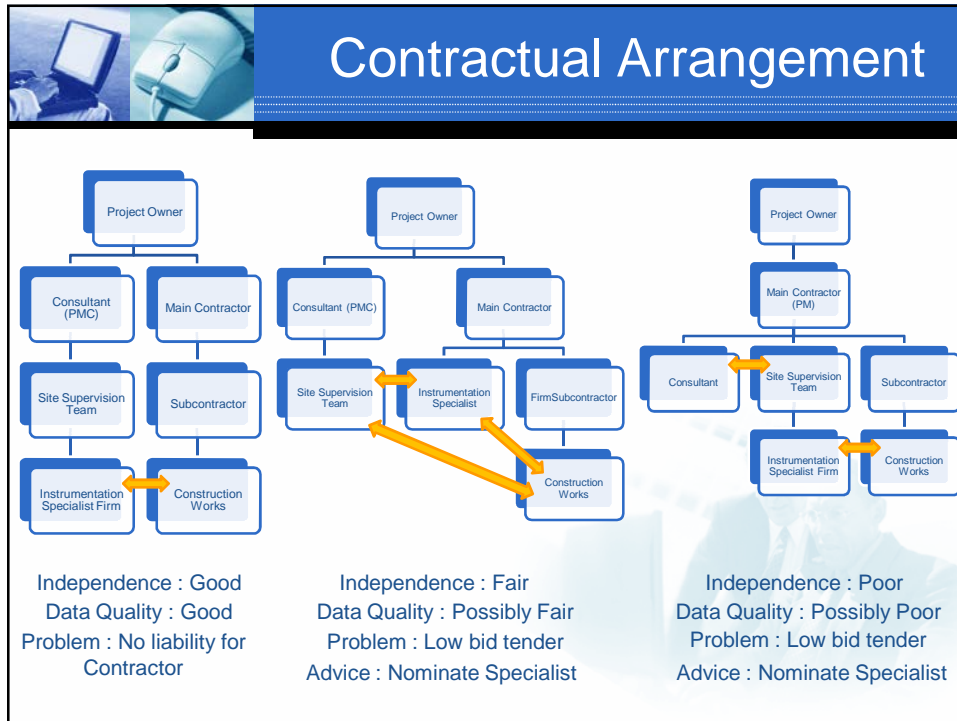
Correct

-Prescriptive

Owner accept liability, but better control

-Performance

Innovation, no bias, clear liability, competitive, but difficult to evaluate



Procurement Approach

- **Professional Service**
- **Lowest Bid Tender**
- **Independence**

We're underfunded, but we manage!



Good Practices

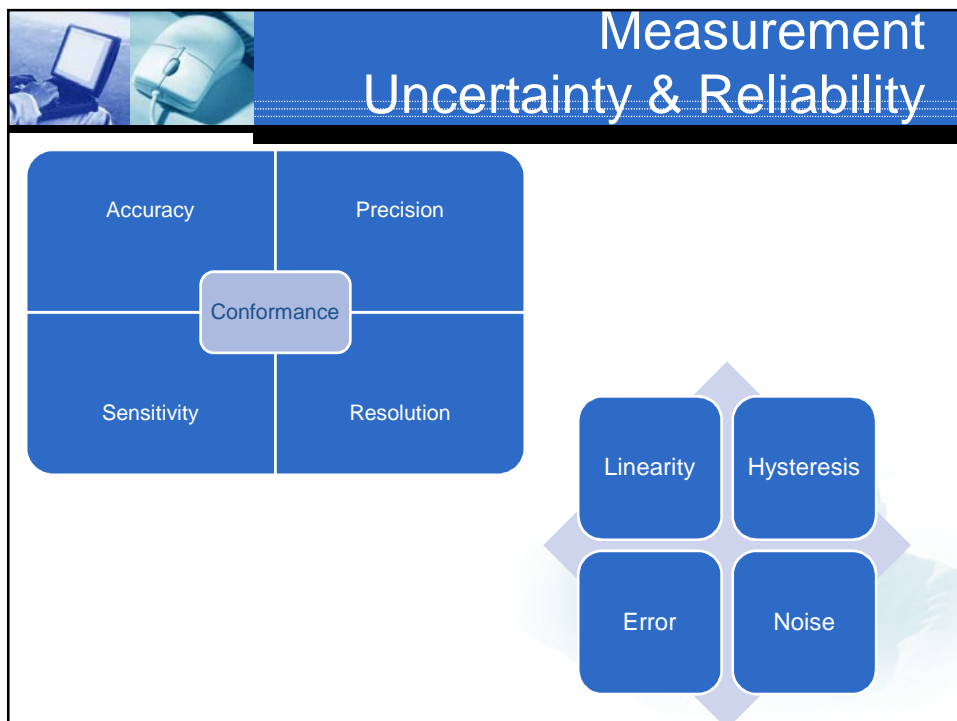
- **Instrument Life-Cycle Costs** : Calibration, installation, taking readings, maintenance, data management & interpretation, and decommissioning.
- **Partnership to Instrument Manufacturers/Suppliers**



Good Practices

- **Good QA/QC of Personnel Training, Equipments, Data Management**
- **Dedicated Team & Equipment for Project**
- **Measures of Instrument Protection**
- **Duplicate Instruments for Data Redundancy**





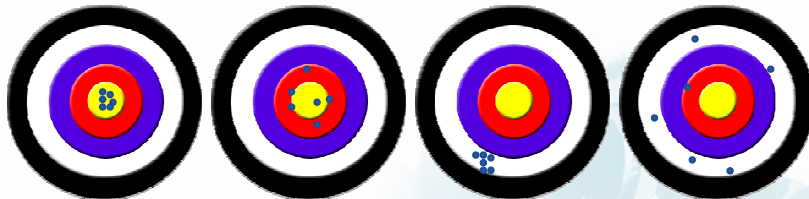
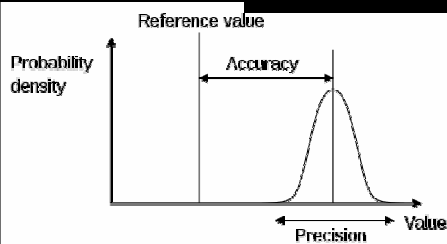


Conformance

- Good conformance of instrument and installation procedures are necessary for measurement of good accuracy.
- Beware of any changes of properties related to parameters to be measured due to presence of instrument



Accuracy & Precision



Accuracy	High	High	Low	Low
Precision	High	Low	High	Low
Acceptance	Good	Fair	Systematic Error	Bad

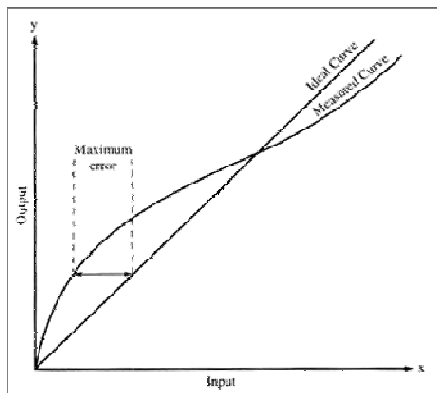


Measurement Deviation

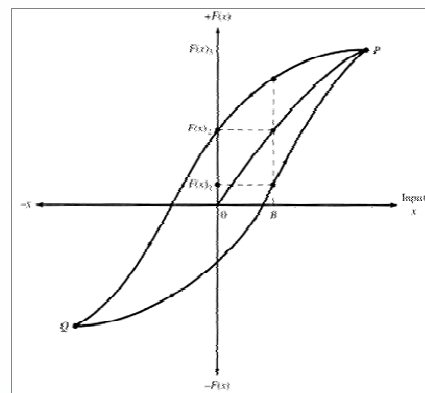
- **Resolution** : the degree to which the smallest change it can detect in the quantity that it is measuring.
- **Sensitivity** : the smallest absolute amount of change that can be detected by a measurement, usually defined as the ratio between output signal and measured property
- **Linearity** : The amount of error change throughout an instrument's measurement range. Linearity is also the amount of deviation from an instrument's ideal straight-line performance.
- **Hysteresis** : an error caused by when the measured property reverses direction, but there is some finite lag in time for the sensor to respond, creating a different offset error in one direction than in the other
- **Noise** : Random measurement variations by external factors




Linearity & Hysteresis




Non Linearity



Hysteresis



Types of Errors & Corrective Measures		
Type of Error	Sources	Corrective Actions
Gross Error	Human mistakes	Care, checking & training
Systematic Error	Calibration, hysteresis & non-linearity	Periodic recalibration
Conformance Error	Instrument design & installation	Appropriate instrument, improve installation procedures
Environmental Error	Weather, temperature, vibration & corrosion	Apply correction with recorded environmental changes & conditioning instrument to ambient environment
Observation Error	Variation between observers	Training & automatised data acquisition
Sampling Error	Inherent variability & sampling technique	Sufficient instruments
Random Error	Noise, friction & environmental effect	Statistical analysis on multiple readings





Course Outline	
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Parameters to be Measured

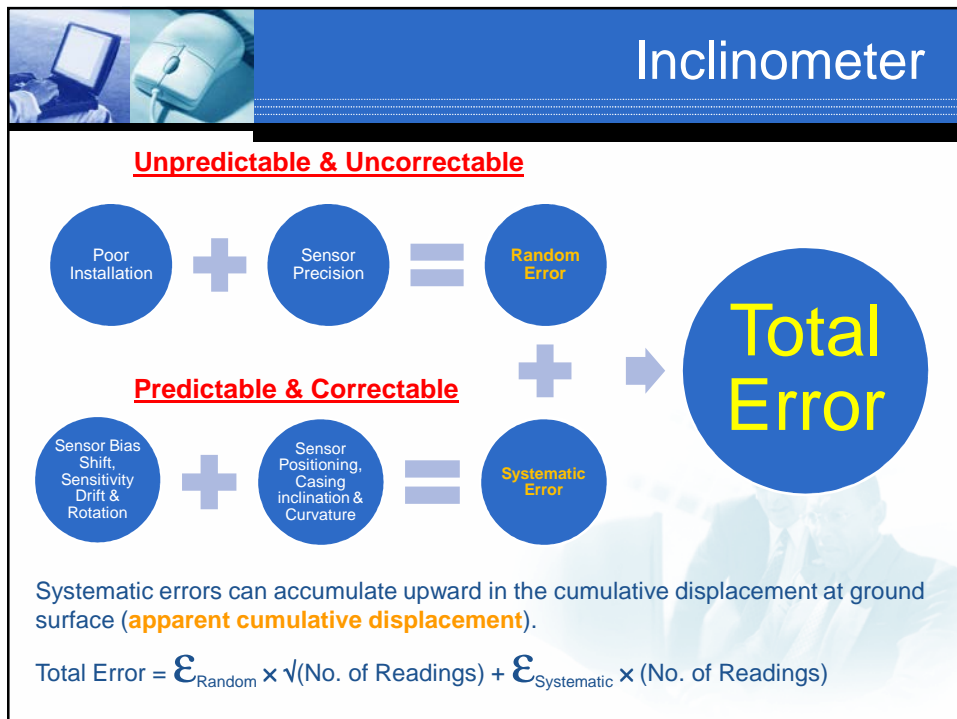
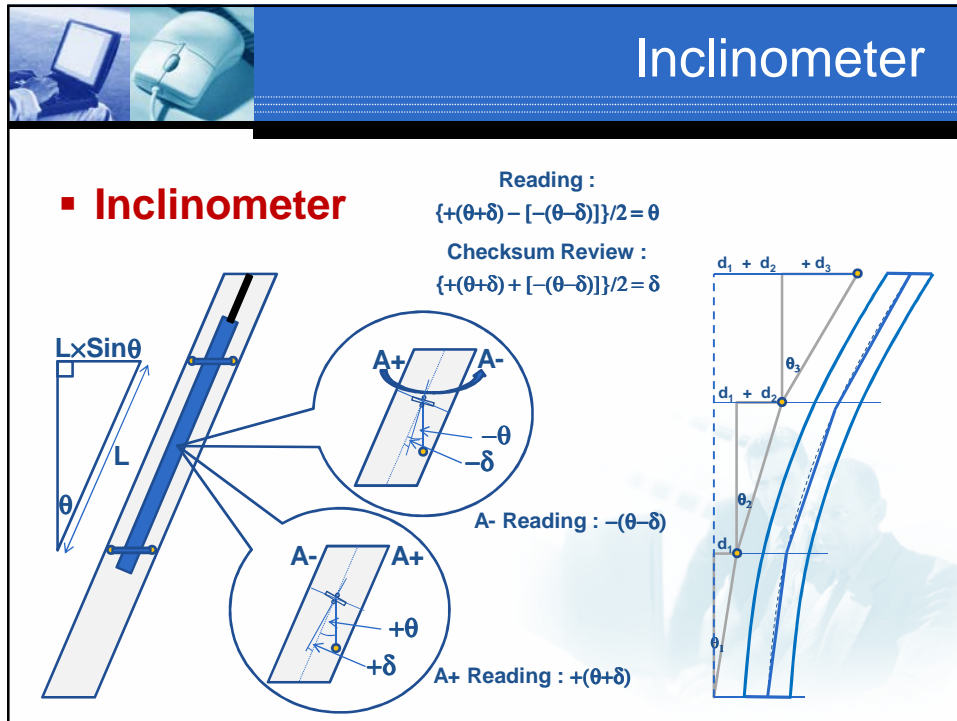
- **Deformation/Movement**
 - Inclinometer
 - Extensometer
 - Ground Movement Marker
 - Tiltmeter
 - Crackmeter
- **Water/Earth Pressure**
 - Piezometer, Observation Well
 - Earth Pressure Cell

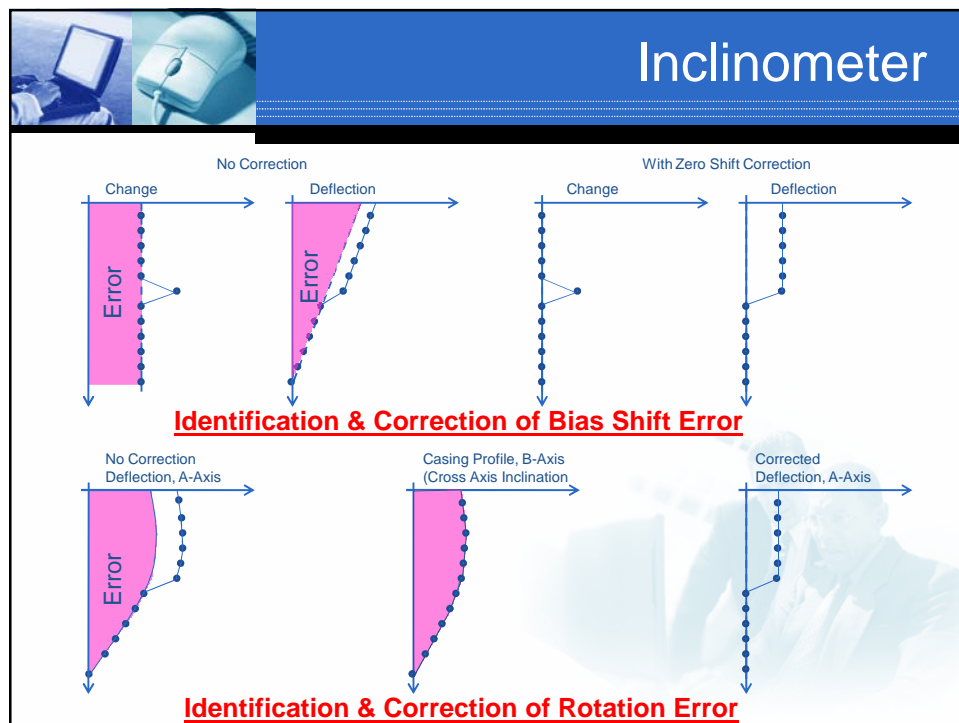
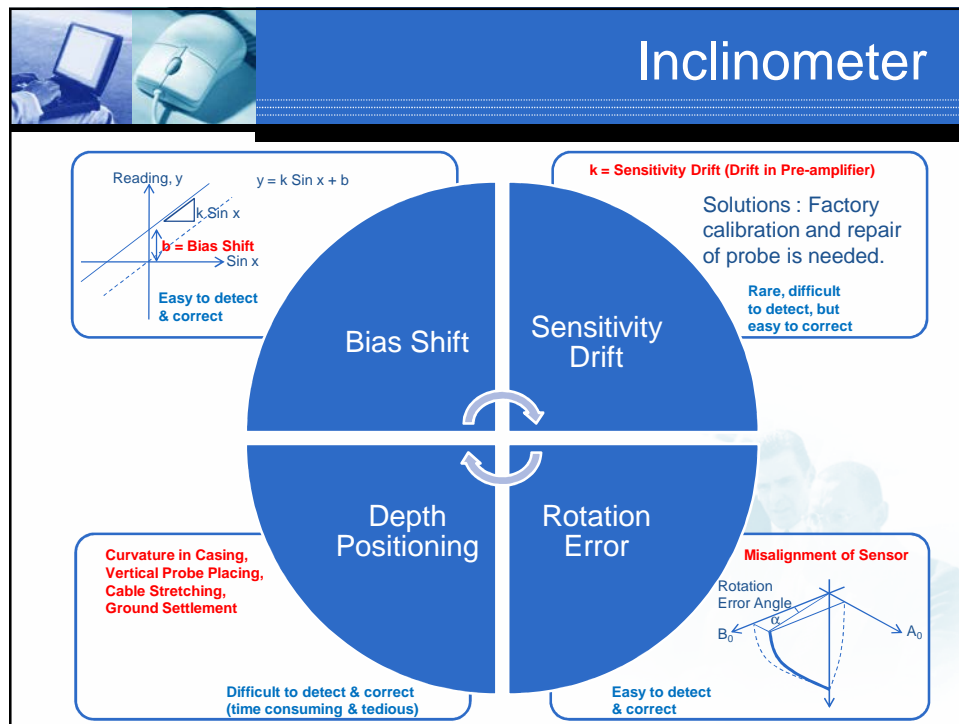


Parameters & Measurement

- **Load/Stress/Strain**
 - Strain Gauges
 - Load Cell
- **Thermal**
 - Thermal Coupler
- **Flow**
 - V-Notch Gauge
- **Vibration**
 - Accelerometer



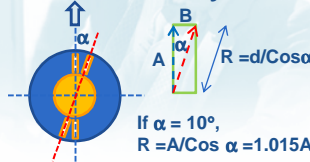






Inclinometer

- **Spiral Probe**
- Twisted casings lead to incorrect magnitude of movement in the A and B directions.
- Application :
 - To check orientation of the inclinometer grooves for necessary correction for direction of resultant movement.
 - Readings show movements in unlikely direction
 - Check installation quality
 - Deep casing installation



Inclinometer

- **Error Detection & Correction :**
 - Double data redundancy with readings taken in diametrical direction
 - 3 to 6m bottom of casing into firm strata for good fixity to provide calibration data
 - Deeper readings have highest potential systematic errors : (a) **Sensor warming up**, (b) **Steepest borehole inclination**, (c) **Further distance from top reference**



Inclinometer

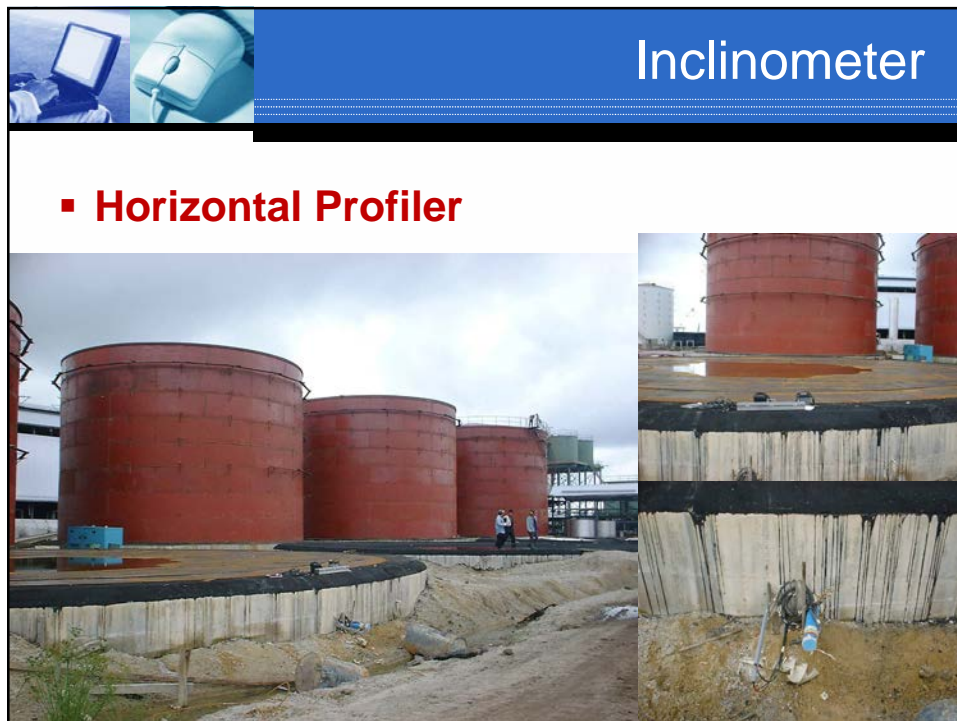
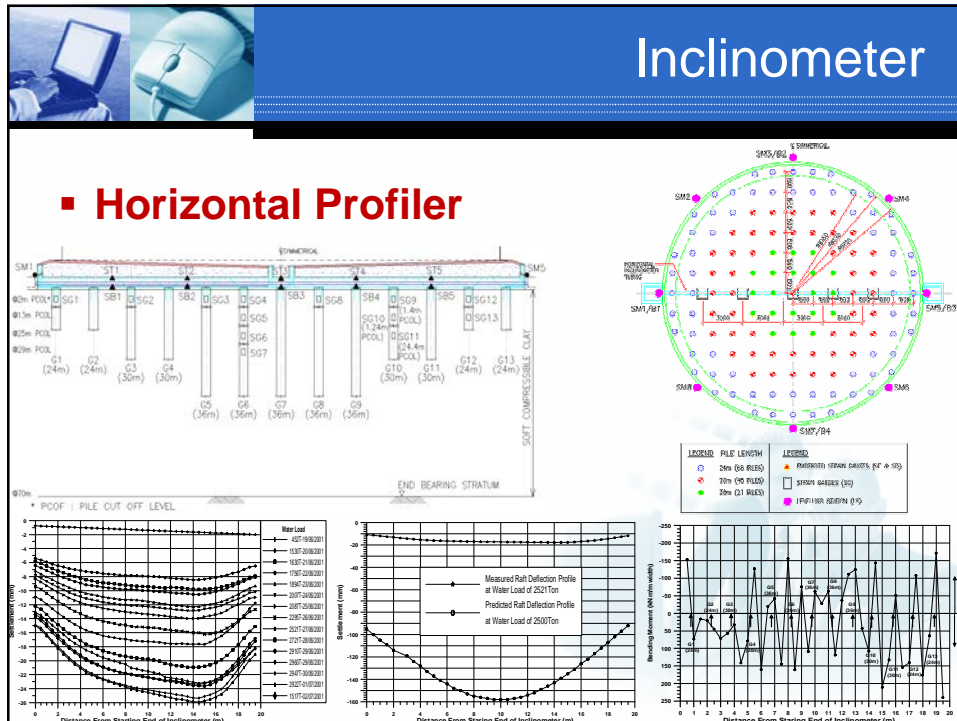
- **Tolerance :** Variation of Checksum < 5 to 10 units of Mean Checksum
- **Correction :**
 - If the large variation is localised to one depth, correction can be performed based on mean of other checksum.
 - If the large variation spreads over the entire dataset, it is better to retake the readings.



Inclinometer

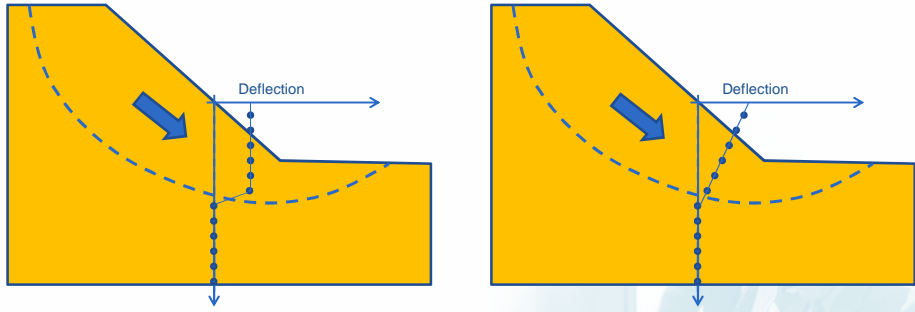
▪ Inclinometer (Vertical)





Data Evaluation

- **Type of Ground Movement**




Developed Shear Zone with Drastic Movement Profile

Creeping Slope with Continuous Movement Profile



Data Presentation

- **Good Practice :**
 - Use of exaggerated horizontal scale shall be avoided because “errors” are magnified & could be misinterpreted.
 - Change plot (incremental deformation) is useful to emphasize the location of deformation zone.



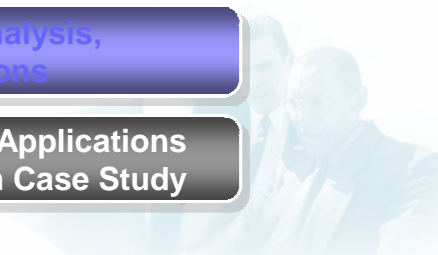
Case Studies

- **Demo 1** – Open Cut Excavations using Jack-In Pipe Anchorage & Soil Nail Anchorage
- **Demo 2** – 8 Cases on Landslides
- **Demo 3** – Piling Foundation
- **Demo 4** – Reinforced Soil Wall with Stone Columns Improvement
- **Demo 5** – Dewatering
- **Demo 6** – Dam



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Myths in Instrumentation

- **Myth No.1** : Instrumentation can prevent bad thing from occurring.
- **Myth No. 2** : Maintenance free instruments are possible.
- **Myth No. 3** : Geotechnical engineer is not needed to review the instrumentation results if threshold and action plan are available (traffic light system).
- **Myth No. 4** : Instrumentation does not require the input from instrumentation specialist.



Myths in Instrumentation

- **Myth No. 5** : Instrumentation can replace engineering judgement. Everything is fine if instrumentation is in place.
- **Myth No.6** : More instruments and data are better.
- **Myth No. 7** : Instrumentation is costly investment, hence is unnecessary if the design is good.



Common Problems

- **Instrument** : Selection of appropriate instrument fit for the purpose.
- **Contract Arrangement** : Interest party for high quality instrumentation data.
- **Data Quality** : Poor quality data will neither reveal the truth of engineering behaviours nor give correct warning.
- **Data Management** : Keeping raw data is essential for future data reprocessing with new interpretative objectives



Common Problems

- **Data Interpretation** : Screening & filtering of problematic data or uninvited events/factors for a distilled content are deliberately needed.
- **Data Presentation** : Data presentation without connection to records of activities at site is a discounted information for decision making.



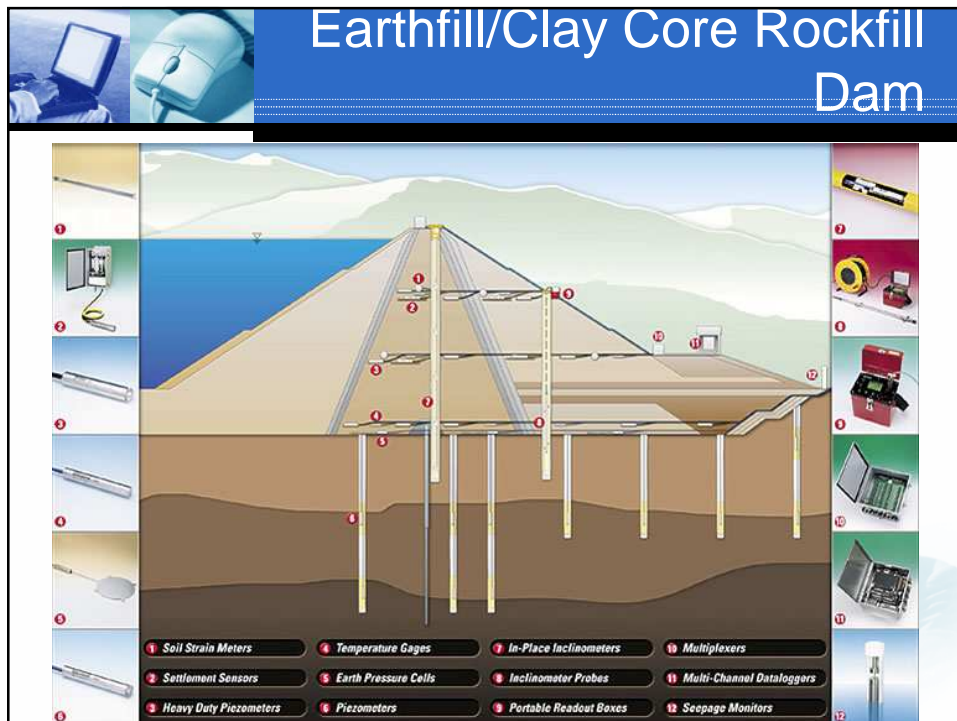
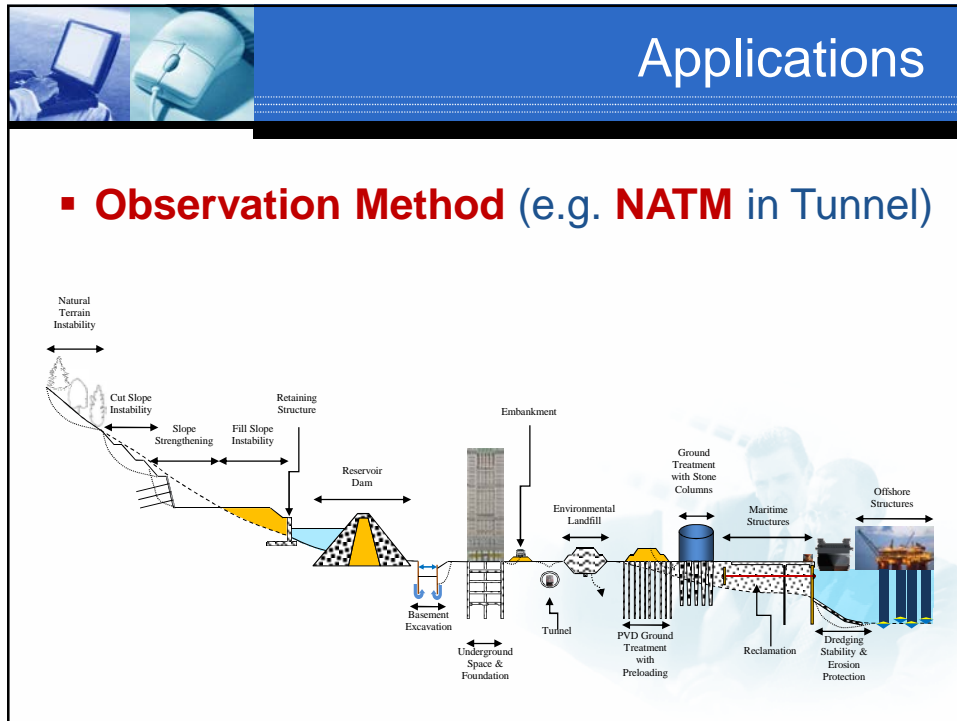
Common Problems

- **Review** : Timely review is important to capture indication of distress development & need for instrument maintenance/checking for proper functioning.
- **Loss of Feel** : Sometimes readings given to person who is not taking care of the instruments has no clue to slight variation of the readings, but possible an important indication of adverse effect. (You will not know your baby if you did not take care of him/her.)
- **Threshold Limits** : It is not easy to set a accurate set of threshold limits for multiple parameters controlling the behaviours.
- **Action** : Timely implementation of actions as identified from interpreting instrumentation results.

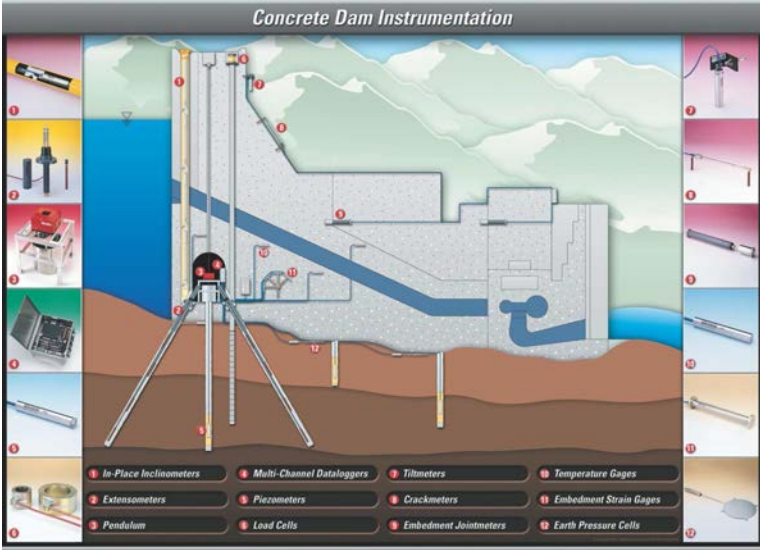


Advices

- **Paradox** :
 - Appearance of apparently unmotivated change are often the first sign of distress
 - Observations of overall phenomenon become more relevant than “spot” occurrence.



Concrete Dam



Concrete Dam Instrumentation

The diagram illustrates the instrumentation of a concrete dam. It shows a cross-section of the dam structure with various sensors and instruments installed. The instruments are numbered 1 through 17, corresponding to the legend below. The legend lists the following instruments:

- 1 In-Place Inclometers
- 2 Extensometers
- 3 Pendulum
- 4 Multi-Channel Dataloggers
- 5 Piezometers
- 6 Load Cells
- 7 Tiltmeters
- 8 Crackmeters
- 9 Embedment Jointmeters
- 10 Temperature Gages
- 11 Embedment Strain Gages
- 12 Earth Pressure Cells

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Tunnel & Underground Excavation

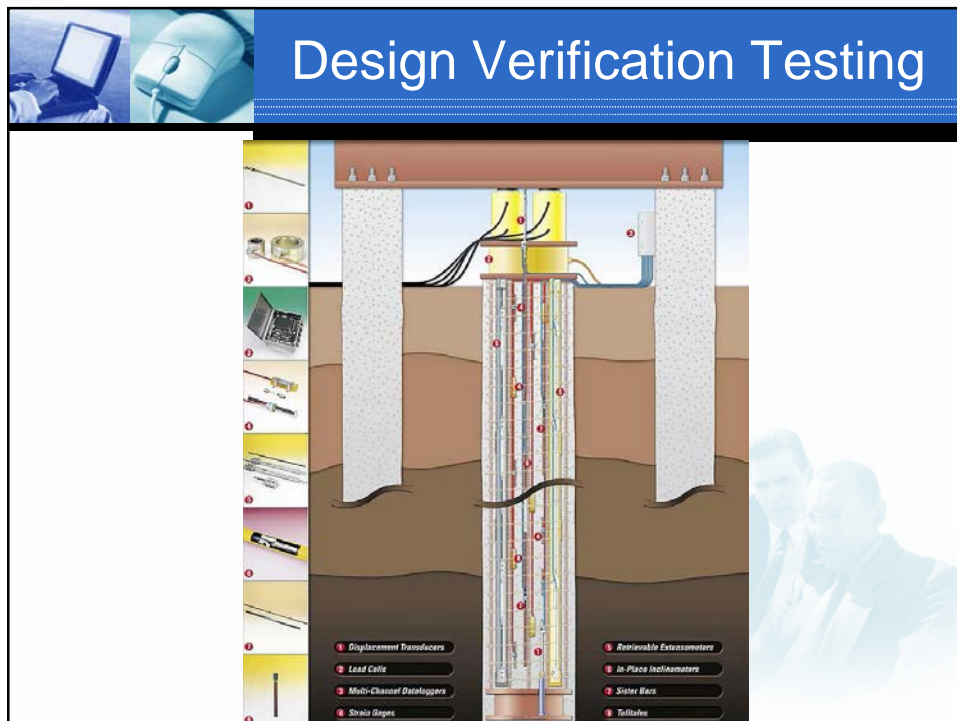
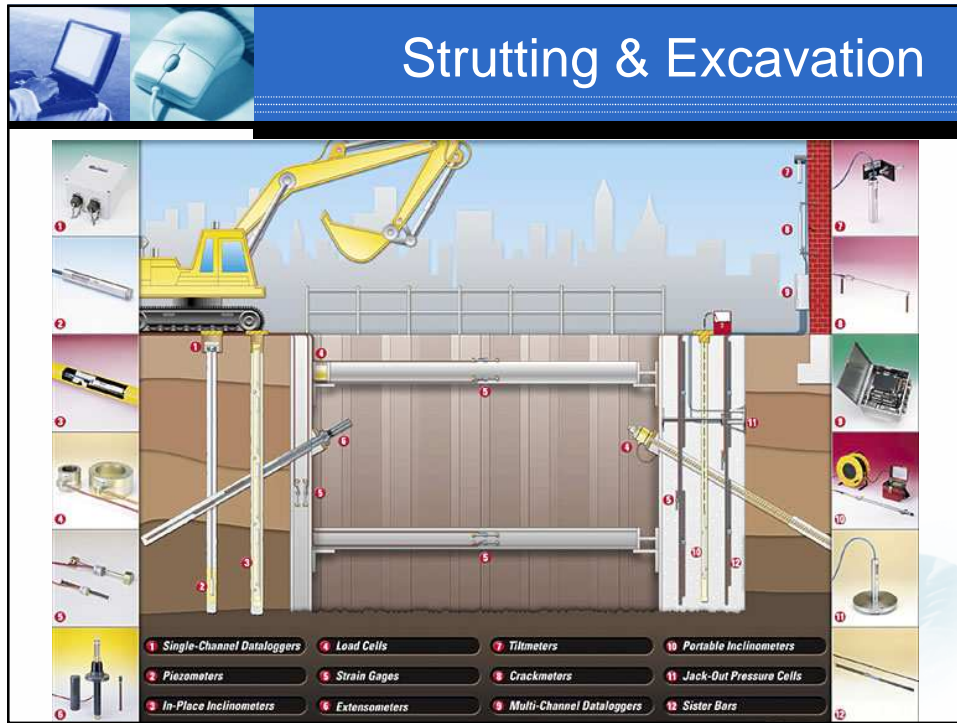


Tunnelling Instrumentation

The diagram illustrates the instrumentation of a tunnel and underground excavation. It shows a cross-section of the tunnel structure with various sensors and instruments installed. The instruments are numbered 1 through 17, corresponding to the legend below. The legend lists the following instruments:

- 1 Single-Channel Dataloggers
- 2 Piezometers
- 3 Extensometers
- 4 Load Cells
- 5 NATM Pressure Cells
- 6 Strain Gages
- 7 Tiltmeters
- 8 Crackmeters
- 9 Multi-Channel Dataloggers
- 10 In-Place Inclometers
- 11 Tape Extensometers
- 12 Convergence Meters

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Case Studies

- **Demo 1** – Open Cut Excavations using Jack-In Pipe Anchorage & Soil Nail Anchorage
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Thank you

Lord Kelvin (1827 - 1907) :

When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of Science, whatever the matter may be.

