MENARD
SUSTAINABLE TECHNOLOGY

CARBON FOOTPRINT OF GROUND IMPROVEMENT METHODS – A CASE HISTORY

Kenny Yee & Ooi Teik Aun

CARBON FOOTPRINT OF GROUND IMPROVEMENT METHODS

- Sustainability
- A Case History
- Conclusion

WHAT IS SUSTAINABILITY ?

Dictionaries provide more than 10 meanings for "**sustain**" – "maintain", "support", "endure", "provide", etc.

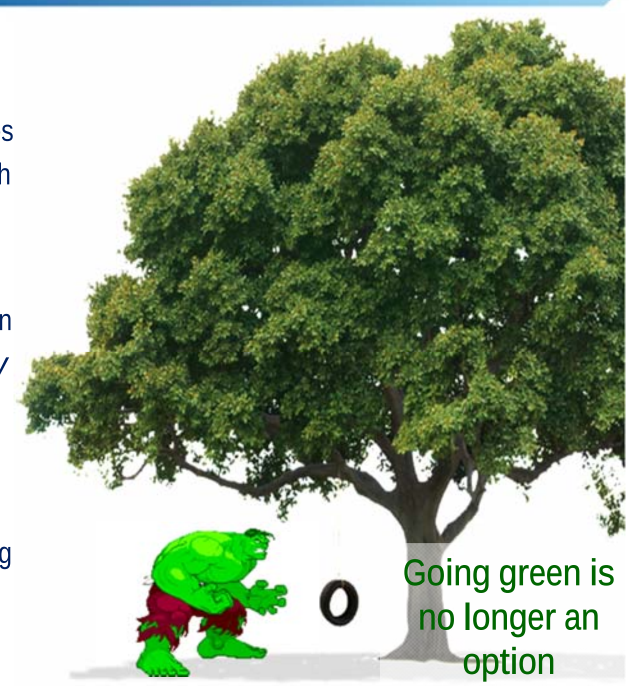
The word **sustain** is derived from the Latin *sustinere* (*tenere* **–** to hold; *sus* **–** up): sustain **– to hold up**

Since 1980s, sustainability has been used more in the sense of ***human sustainability*** on planet Earth.

- ***Sustainable Development*** is a pattern of ***resource use*** that aims to meet human needs while ***preserving the environment*** so that these needs can be met not only in the present, but also for ***generations to come***.

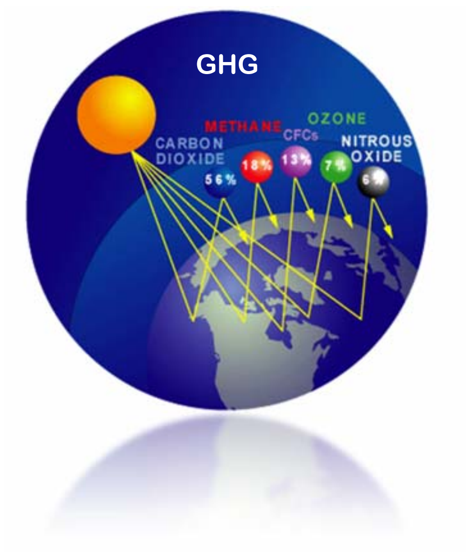
SUSTAINABLE CONSTRUCTION

- *Sustainable Construction:*
  For geotechnical engineers **–** to improve foundation designs and construction processes that ***hold up*** the structures to be built on it with ***less materials*** (minimize wastages), ***less energy*** usage and generate ***less*** CO_2.
- May not be able to achieve zero-energy design but the move towards a ***low carbon economy*** of recycling and alternative low-carbon construction processes using ***low-carbon technology***.
  - ⇨ Necessary for ***carbon footprint*** accounting
  - ⇨ Necessary for CO_2 ***emission*** audit for construction projects.

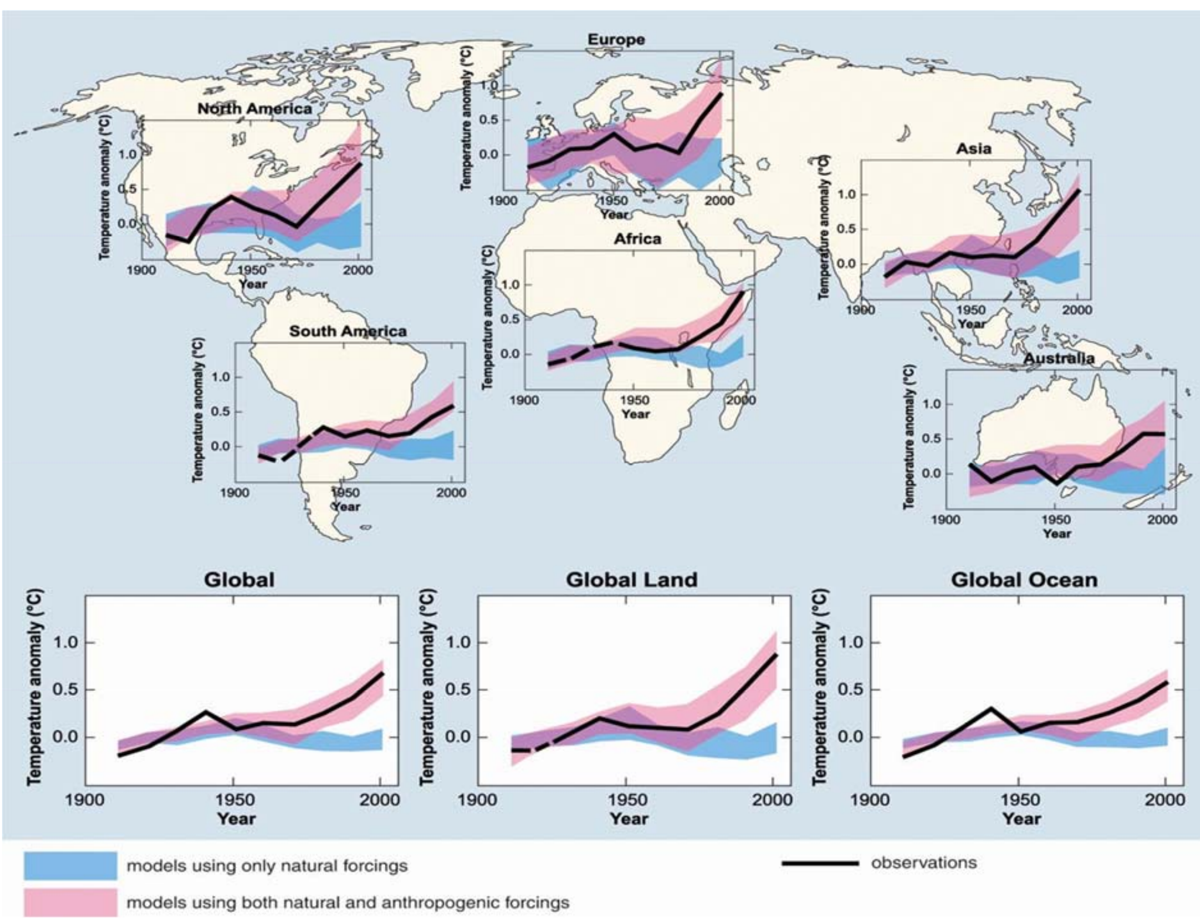


CARBON FOOTPRINT

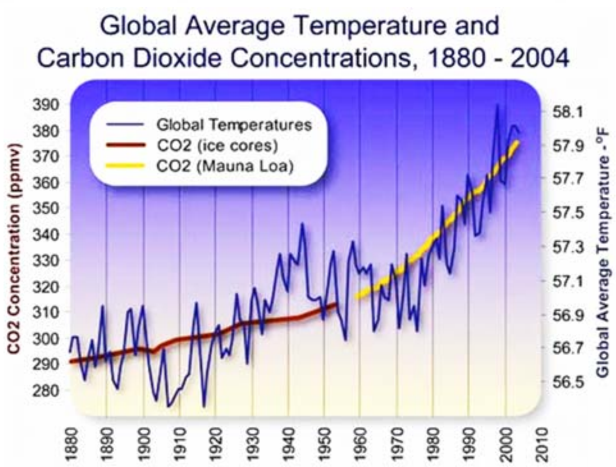
A carbon footprint is an estimation of ***emissions*** of CO_2 and other greenhouse gases (*GHG*) associated with a particular activity which has an impact on the environment in particular ***climate change***.

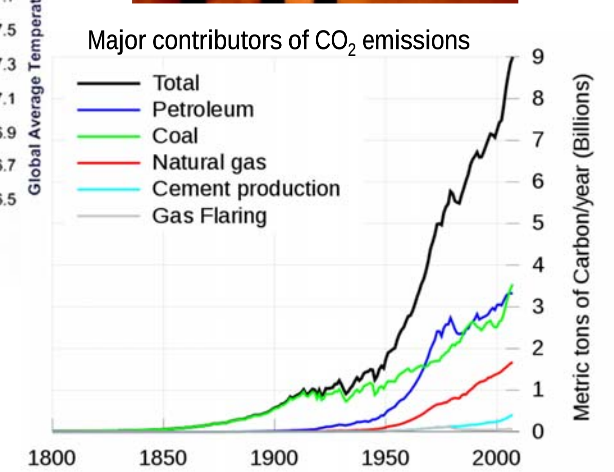


- It is measured in tons (or kg) of CO_2 equivalent.



CO_2 AND GLOBAL WARMING





STEPS TAKEN IN MALAYSIA

Energy, Green Technology and Water Ministry – to promote green technology to reduce the country's carbon footprint and damage to the environment.

The Government's effort to develop ***green technology*** could be seen from two aspects:

1. To create or develop green technology that are environmentally friendly and practical - ***innovation***
2. To promote the ***application*** of green technology in both work processes and daily practices (e.g. *Green Building Index, GBI*).
   - *GBI* was developed by the Malaysian Institute of Architects (PAM) and Association of Consulting Engineers Malaysia (ACEM) based on (i) energy efficiency; (ii) indoor environmental quality; (iii) sustainable site planning; (iv) management, materials and resources used; (v) water usage efficiency and (vi) innovation.

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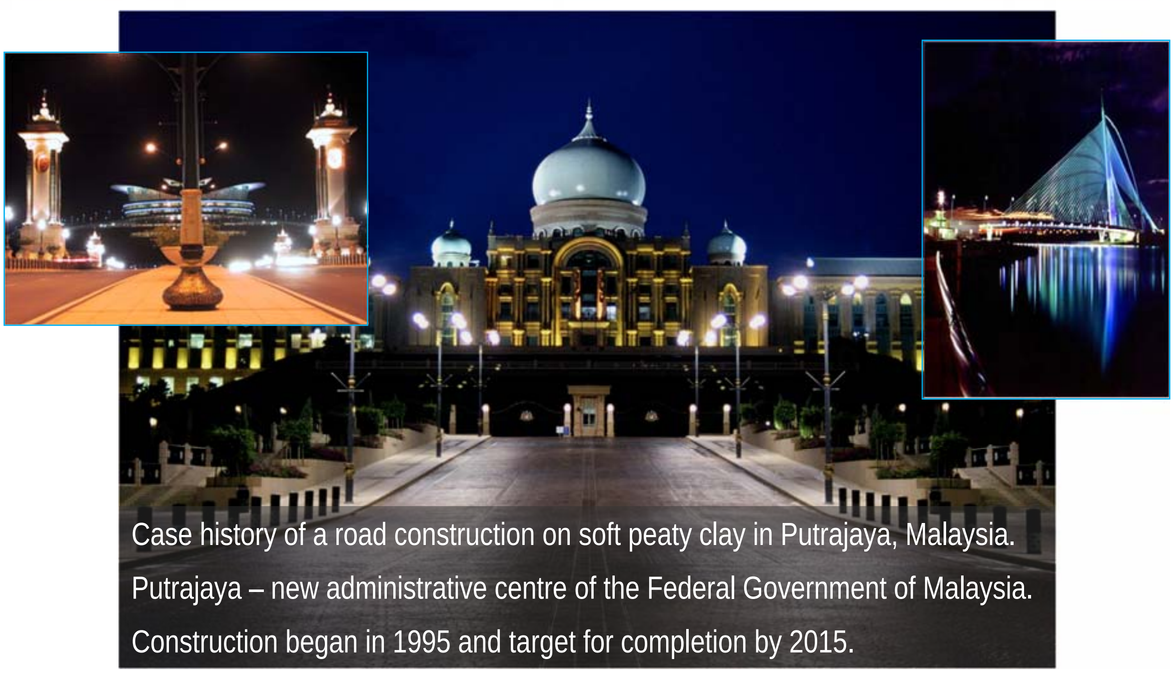
CASE HISTORY IN PUTRAJAYA



Case history of a road construction on soft peaty clay in Putrajaya, Malaysia.

Putrajaya – new administrative centre of the Federal Government of Malaysia.

Construction began in 1995 and target for completion by 2015.

THE NEEDS FOR GROUND IMPROVEMENT

The needs arises when the existing ground is unable to adequately ***sustain*** the load that is to be applied as assessed by the design criteria:

- *Bearing capacity* and *stability*
- *Total settlement* and the *rate of settlement*

ORIGINAL PROPOSAL

Original (Exhibited) Design:

To remove and replace unsuitable materials to depth up to 5 - 6m.

Constraints:

Construction difficulties with high GWT, instability of working platform, large quantity of excavation.

Lack of suitable dumping ground and borrows pits (> 20 km away); high cost of imported fill.

ENVIRONMENTAL IMPACTS

Fuel consumption of on-site plant and equipment and transportation of unsuitable and suitable fill to and from borrows pits and dumping sites (approx. 1,412,800 liters) → equiv. 3,815 tons of CO_2 emission.

Alternative *Sustainable Construction* technique is needed i.e. a solution that uses less energy and resources at a rate that does not compromise the natural environment.

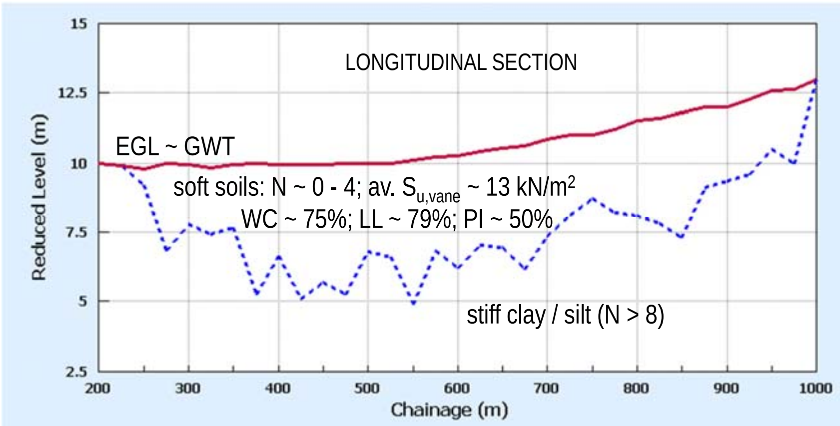
PROJECT DESCRIPTION

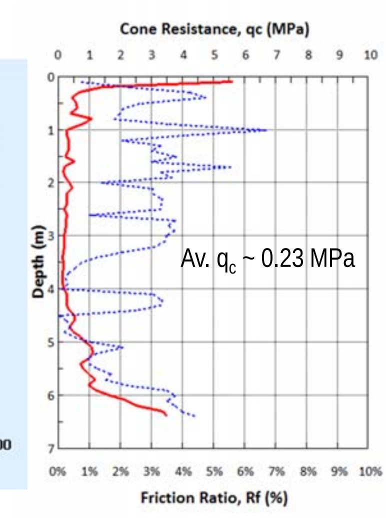
Background

- 11.6 km primary distributor road with 3-lane dual carriageway.
- Height of road embankment varies from 5m to 16m.
- Construction period from Oct. 2001 – Nov. 2002 (from foundation to laying of pavement).
- Turnkey design-built ground improvement works to performance specifications and sustainability requirement.

GROUND CONDITIONS

- Upper 5m soft clay / silt with intrusions of peat (up to 2m thick).
- GWT at about 0.3m below surface.





PERFORMANCE CRITERIA

Design Criteria (MHA/PWD):

1. Total settlement within the ***first 7 years*** of service shall not exceed ***10%*** of the sum of the total theoretical primary settlement and secondary settlement, the later being assessed for a period of 20 years.
2. Settlement within the ***first 7 years*** of service shall nowhere exceeds ***40cm***.
3. In ***areas of transition*** between piled approach embankments and general low embankments, differential settlement within the ***first 7 years*** of service shall not exceed ***10cm*** within a length of ***50m***. In areas remote from structures and transition zones, differential settlement shall not exceed 1***0cm*** within a length of ***100m***.
4. ***Factor of safety*** > 1.3 during construction.

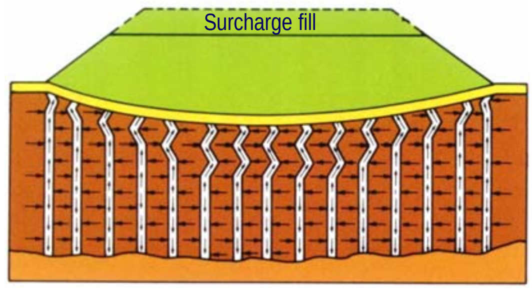
CONCEPTUAL DESIGN

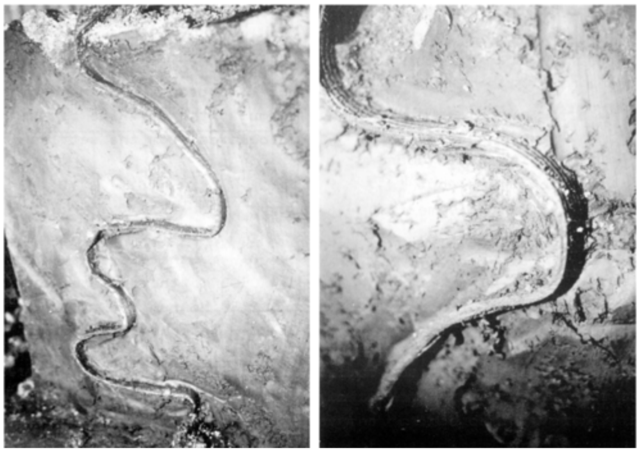
1. The performance criteria can be achieved by ***limiting*** the ***post construction settlement***. (to ***accelerate*** the consolidation process – min. settlement after the 12-mth construction period).
2. Rate of consolidation is affected by (a) the available ***drainage facilities;*** and (b) the ***rate of filling*** of embankment.
3. Required ***drainage facilities*** can be provided by Prefabricated Vertical Drains (*PVD*).
4. To increase the rate of embankment filling, the ***bearing capacity*** and ***stability*** need to be improved. Dynamic Replacement (*DR*) columns are used to provide support to the embankment so that the required rate of filling of embankment can be achieved.
5. DR columns are also ***large diameter PVDs***.
6. Treatment area is about 102,000m^2. Ground improvement work was limited to ***6 months***.

VERTICAL DRAINS FOR CONSOLIDATION

INFLUENCE OF VERTICAL DRAINS

Vertical drains *do not* provide *structural* support or increase bearing capacity
→ they buckle under soil consolidation.



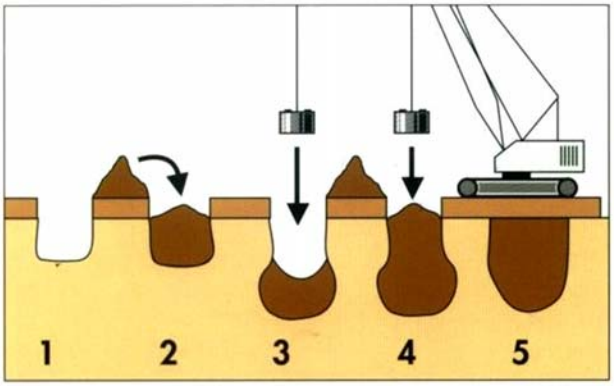


For sites with stability problem, the soft soil will *initially* have the *same strength with* or *without* vertical drains installed.
⇒ Ground *reinforcement* to provide stability.

DYNAMIC REPLACEMENT FOR REINFORCEMENT

Replacement of existing soft soils with *granular* fill (sand, stone, aggregate, rock) in the form of columns by means of *heavy impacts*.

CONSTRUCTION OF DR COLUMNS



1. Pre-excavation of column print
2. Fill with granular materials (fines < 5%)
3. Pounding to form a compacted “plug”
4. Further filling of granular materials
5. Increase pounding with more energy to form column to ground level.

DR SAND AND DR STONE COLUMNS

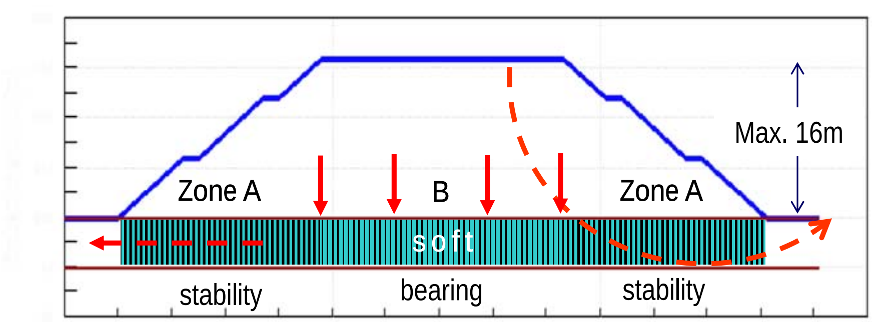
CHARACTERISTICS OF DR COLUMNS

Amount backfill per column ~ 25 - 35m^3

Typical "average" diameter ~ 2.5 – 3.2m

FIELD IMPLEMENTATION

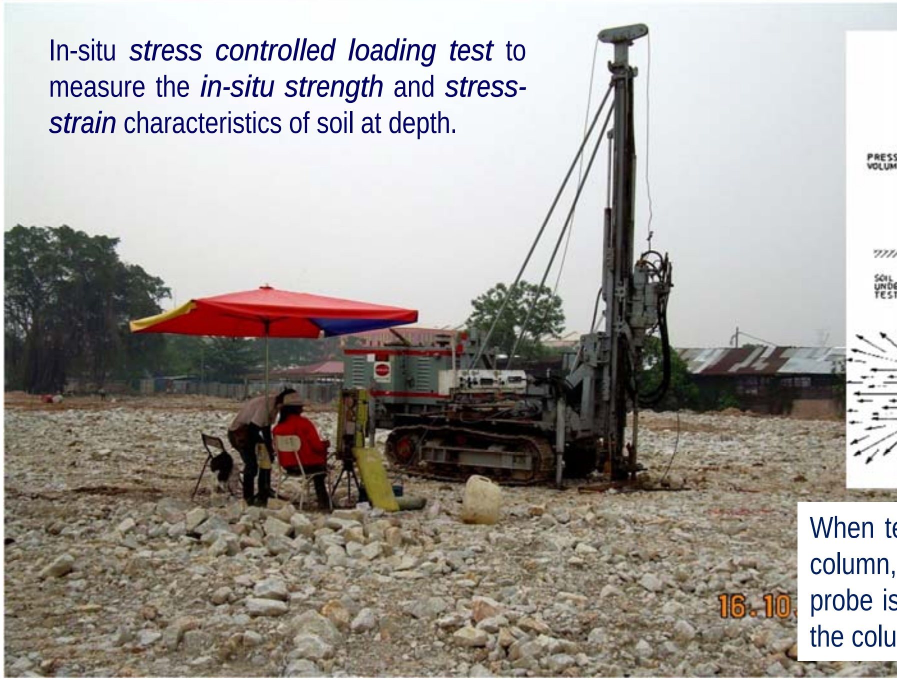
- *Corset* effect at sloping edges (zone A) are provided for ***stability*** during construction.
- *Visual inspection* at DR columns to identify ***peat intrusion*** (> 0.5m thick, use 150mm stones instead of sand; > 1.5m thick, additional 600 ton.m compaction energy on stones followed by PMT)

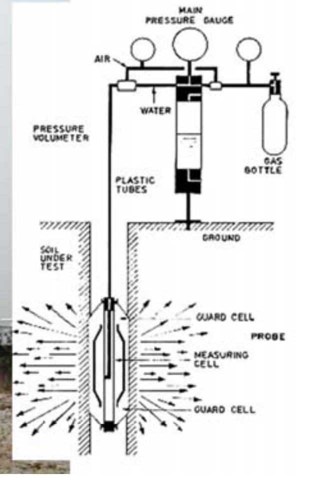


Zone	Location	DR col. backfill	DR col. diameter	DR col. spacing	Replacement ratio	PVD spacing
A	Below slope	Sand and Stones	2.5m	4.5m	24%	1.3m
B	Below crest	Sand	2.5m	5.5m	16%	1.37m

QA/QC WITH PRESSUREMETER TEST

In-situ ***stress controlled loading test*** to measure the ***in-situ strength*** and ***stress-strain*** characteristics of soil at depth.





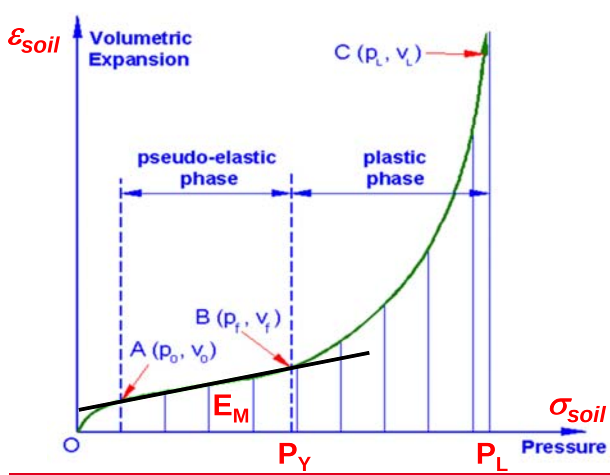
When tested inside the granular column, the expanding PMT probe is similar to the bulging of the column when loaded.

STRESS-STRAIN CURVE OF PMT

From the PMT curve (in-situ stress-strain curve):

1. ***Limit Pressure (P_L):*** $P_L = 5.5c_u$; $P_L = 2.5*2^{(\phi-24/4)}$ Ref: Menard (1975)
2. ***Menard Pressuremeter Modulus (E_M)***

   ($E_{oed} = E_M/\alpha$ where *α = 2/3 for clay; 1/2 for silt; 1/3 for sand and 1/4 for stones*)



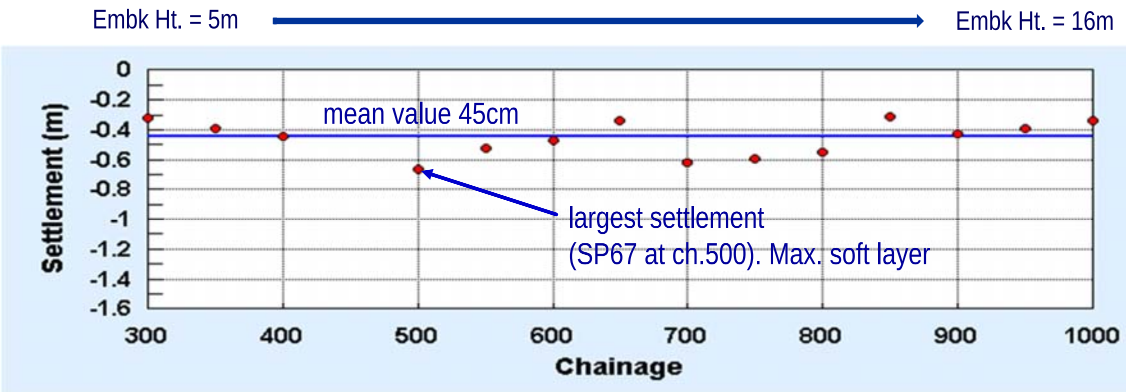
With the same test, PMT measures a ***failure parameter*** (P_L) for bearing capacity calculation and a ***deformation parameter*** (E_M) for assessment of settlements / deformation.

$$E_M = (1+v)2V\left(\frac{\Delta p}{\Delta v}\right)$$

$$P_Y = Yield\ Pressure$$

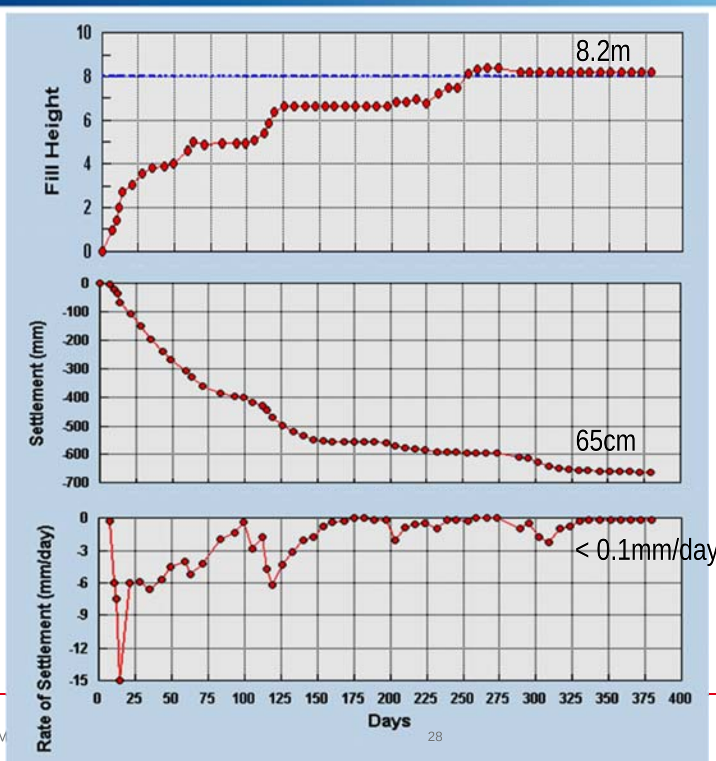
$$P_L = Limit\ Pressure$$

MEASURED SETTLEMENT



- At ch.500, computed settlement using PMT data was 69cm against measured value of 65cm.
- Installed inclinometers to control the rate of embankment filling for stability to maintain $\beta = \delta_h / \delta_v < 0.25$
- Rate of settlement reached < 0.1 mm/day for pavement construction to proceed.

MEASURED SETTLEMENT AT CH.500 (SP67)



OCT 2001 – NOV 2002

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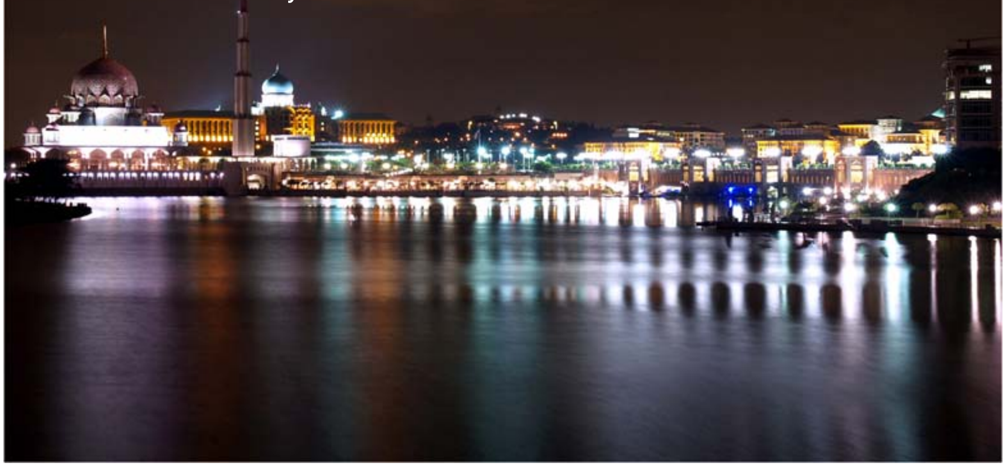
CONCLUSION – COST & TIME BENEFITS

- Alternative solution was cost effective compared with R&R
- Completed within 12-month time schedule:
  - Assisted by increased rate of filling of embankment.
  - Assisted by increased rate of consolidation.



CONCLUSION – ENVIRONMENTAL BENEFITS

- Allowed better use of natural resources and reduced excavation (*sustainable construction*).
- Reduced fuel consumption (*201,950 liters* instead of *1,412,800 liters*) and reduced overall carbon footprint by approximately *3,270 ton* CO_2 (representing an offset for CO_2 emission of about *700 persons* for a year).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