NICOLL HIGHWAY COLLAPSE

Courtesy: N.Prebaharan

Introduction

- On 20th April 2004 (3:30 pm) a 30m deep excavation in marine clay adjacent to Nicoll Highway (in Singapore) collapsed, resulting in the tragic loss of four lives.
- A Committee of Inquiry (CoI) was set up to ascertain the cause and circumstances of the incident.
- Evidence was given by 173 witnesses of fact and 20 experts.
- The Committee found out two main reasons for the failure:
  - Wrong design of the connection between the struts and walers
  - Wrong computer analysis used for the design of the retaining system
- Lessons learnt and the follow up actions taken will be discussed in this presentation.

Location


Nicoll Highway
site
1 km
KALLANG BASIN
BOULEVARD
NICOLL HIGHWAY
DHOBY GHAUT
MUSEUM
CONVENTION CENTRE
MILLENIA
CITY HALL MRT STATION
BUGIS MRT STATION
NATIONAL STADIUM
KALLANG FIELDS
STADIUM WALK
STADIUM CRESCENT
JALAN BENAN KAPAL
GEYLANG RIVER
REPUBLIC AVENUE
REPUBLIC BOULEVARD
RAFFLES BOULEVARD
RAFFLES AVENUE
EAST COAST PARKWAY
BEACH ROAD
NORTH BRIDGE ROAD
VICTORIA STREET
ORCHARD ROAD
FORT CANNING ROAD
PENANG ROAD
MIDDLE ROAD
KALLANG ROAD
NICOLL HIGHWAY
HILL STREET
STAMFORD ROAD
TEMASEK BOULEVARD
TEMASEK AVENUE
OPHIR ROAD
ROCHOR ROAD
SULTAN PLAZA
RAFFLES HOSPITAL
SUNTEC CITY
MARINA SQUARE
MARINA BAY FRONT
RAFFLES CITY
ST ANDREW'S CATHEDRAL
SINGAPORE CRICKET CLUB
ESPLANADE PARK
FORT CANNING PARK
NATIONAL MUSEUM OF SINGAPORE
SINGAPORE ART MUSEUM
ASIAN CIVILISATIONS MUSEUM
NATIONAL LIBRARY
SINGAPORE INDOOR STADIUM
KALLANG THEATRE
LEISURE PARK
KALLANG PRATICE TRACK
THE RITZ-CARLTON MILLENIA
ORCHID RESTAURANT

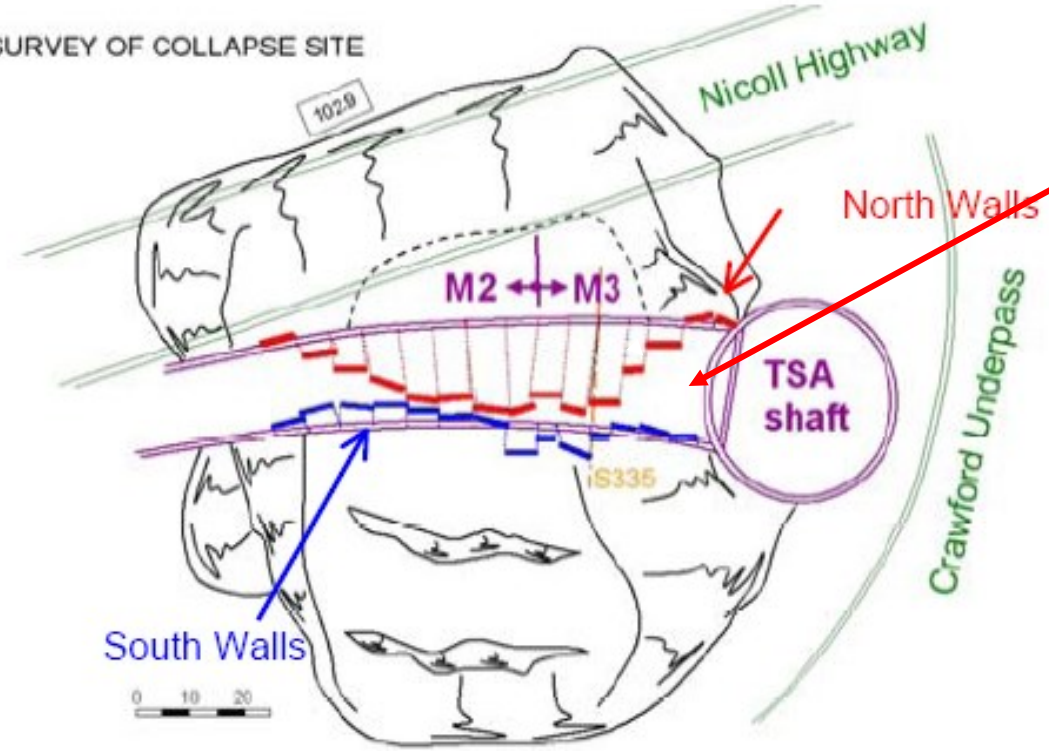
Location

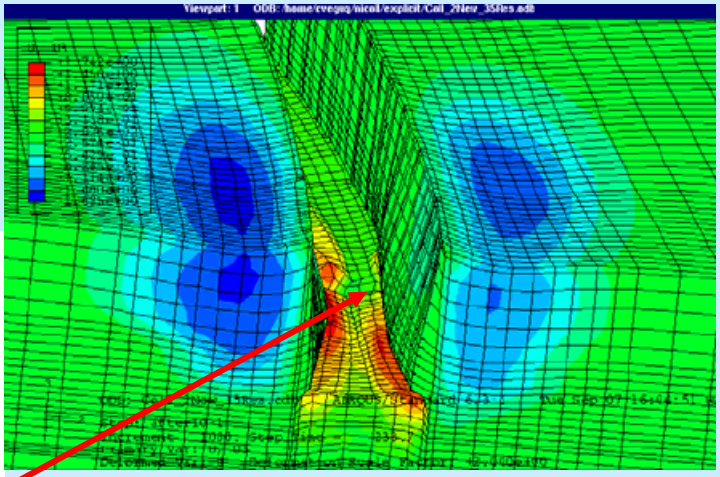
Three Days Before the Collapse

TSA Shaft (35 m dia & 33 m deep)

After Collapse……

Problems with the curved alignment





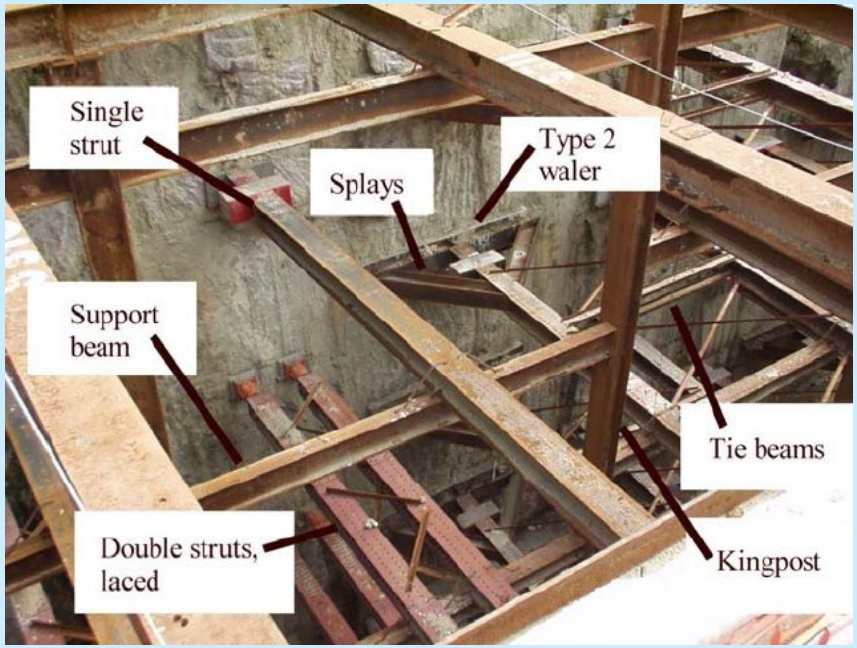
Deformation of mesh just before collapse, 3-D FEM

3-D FEM model indicated that some joints between the wall panels would open up, if the walers are not continuous

Survey of collapse Site

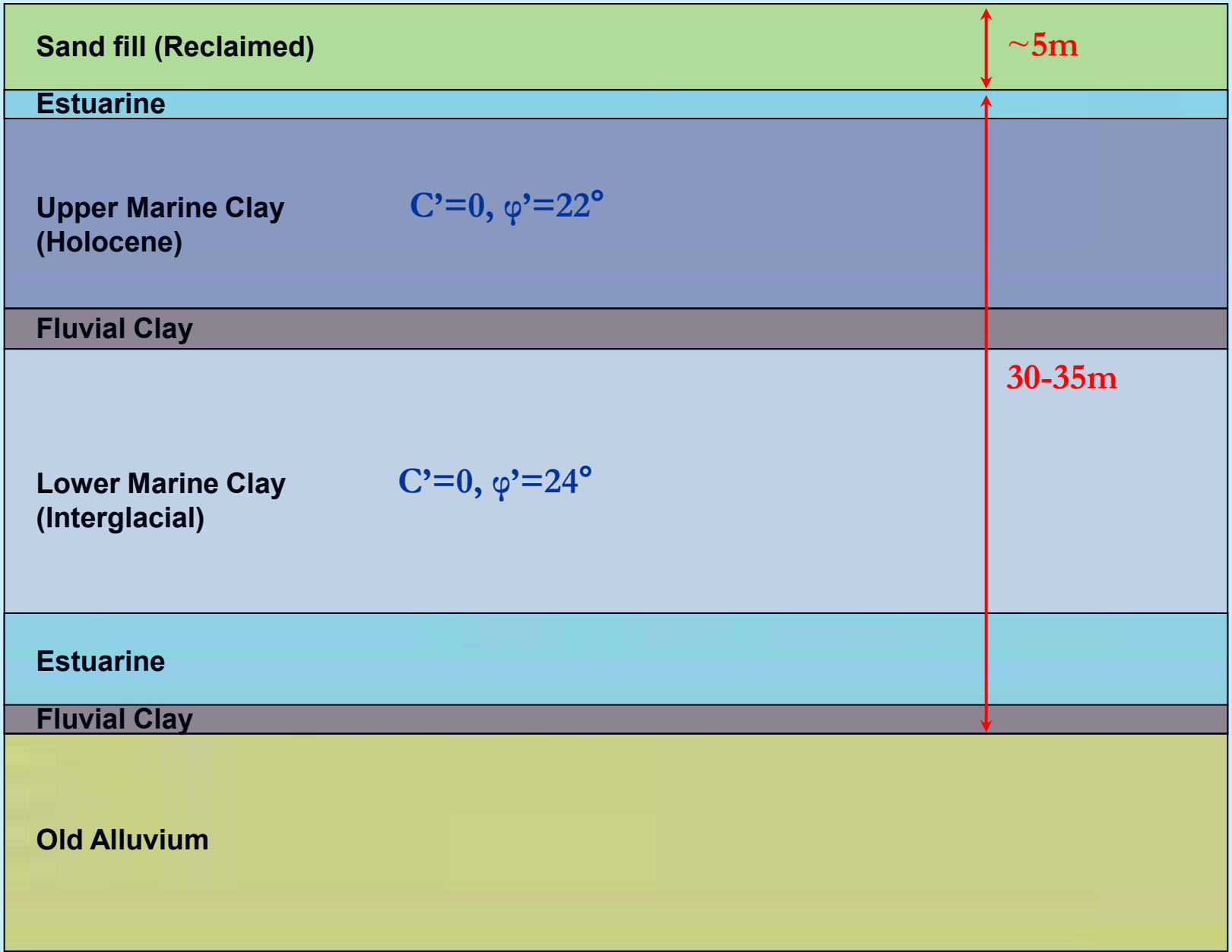
(Diaphragm wall panels moved independently to each other)

Strutting System Used (discontinuous walers)

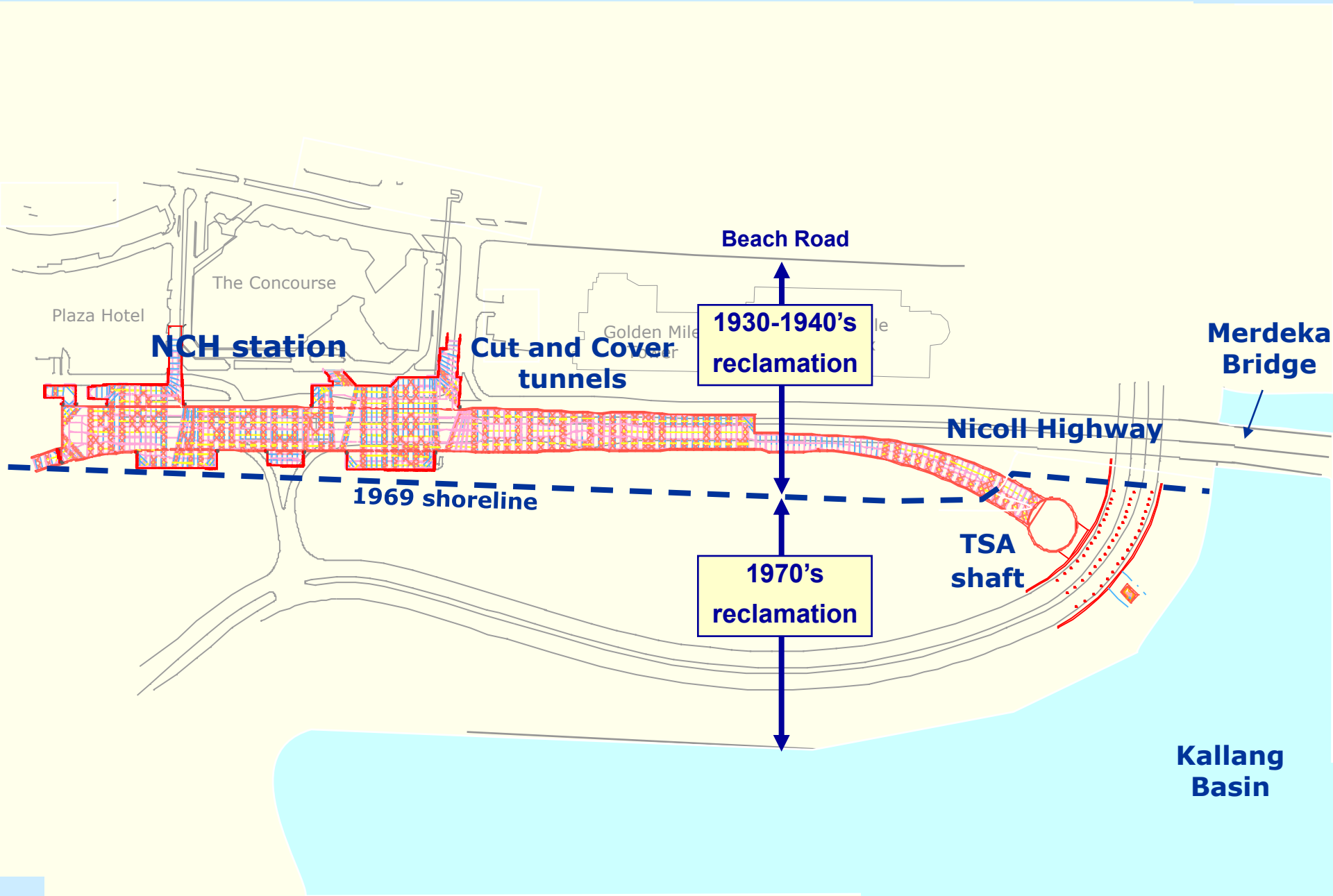


More Pictures on the failure

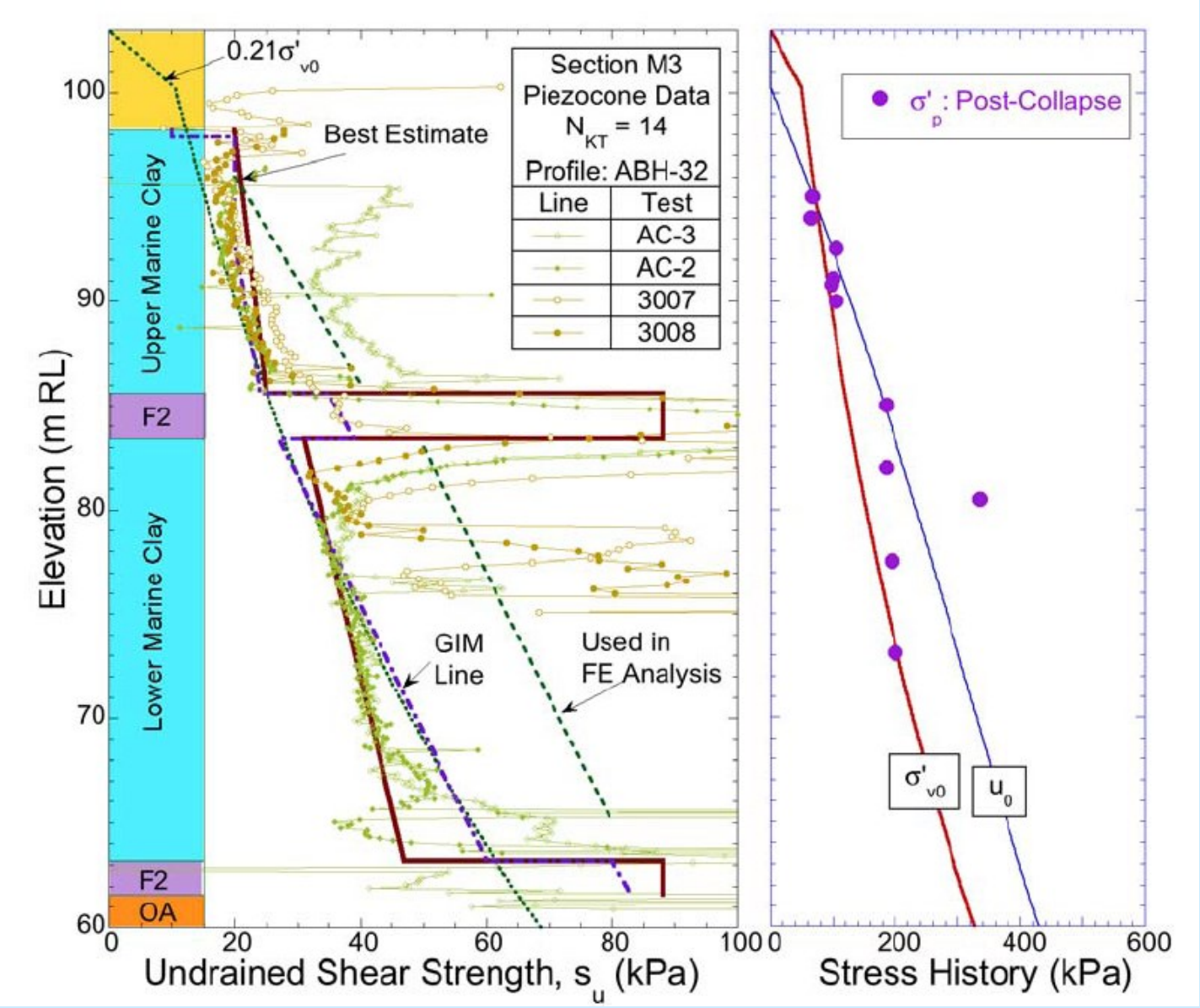
Geological Section



Reclamation Stages

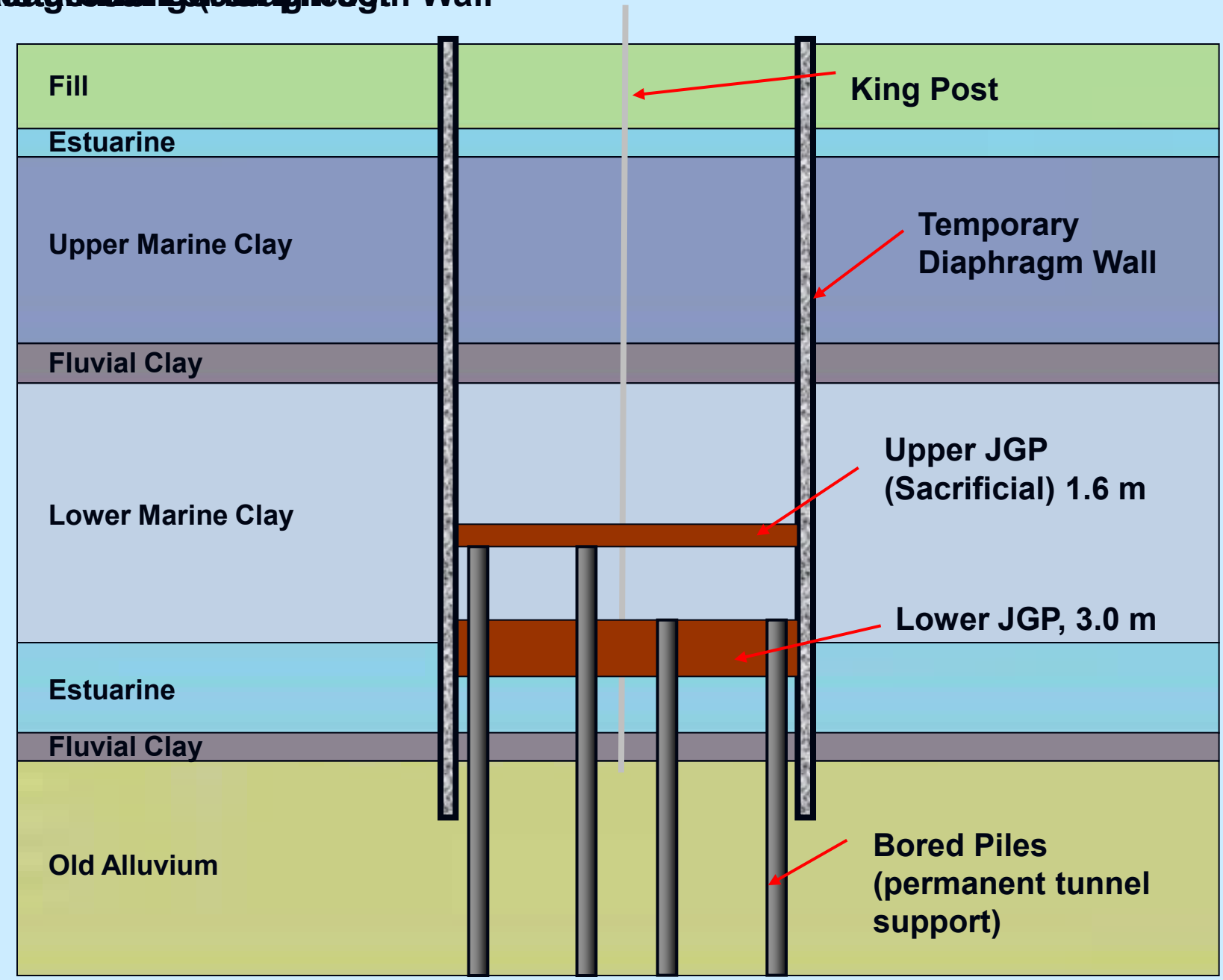


Undrained Shear Strength of Marine Clay

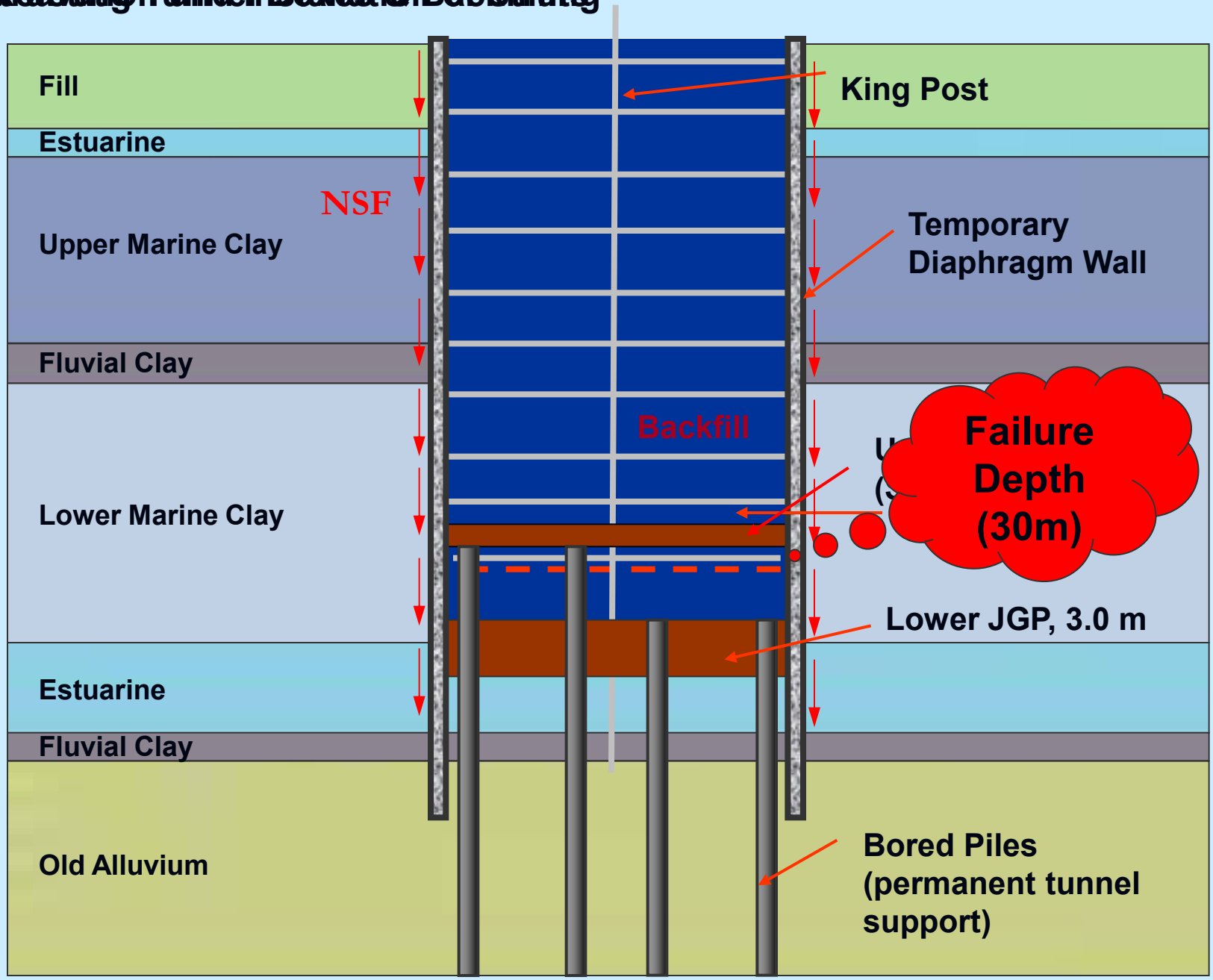


Construction Sequence

Installation of Diaphragm Wall



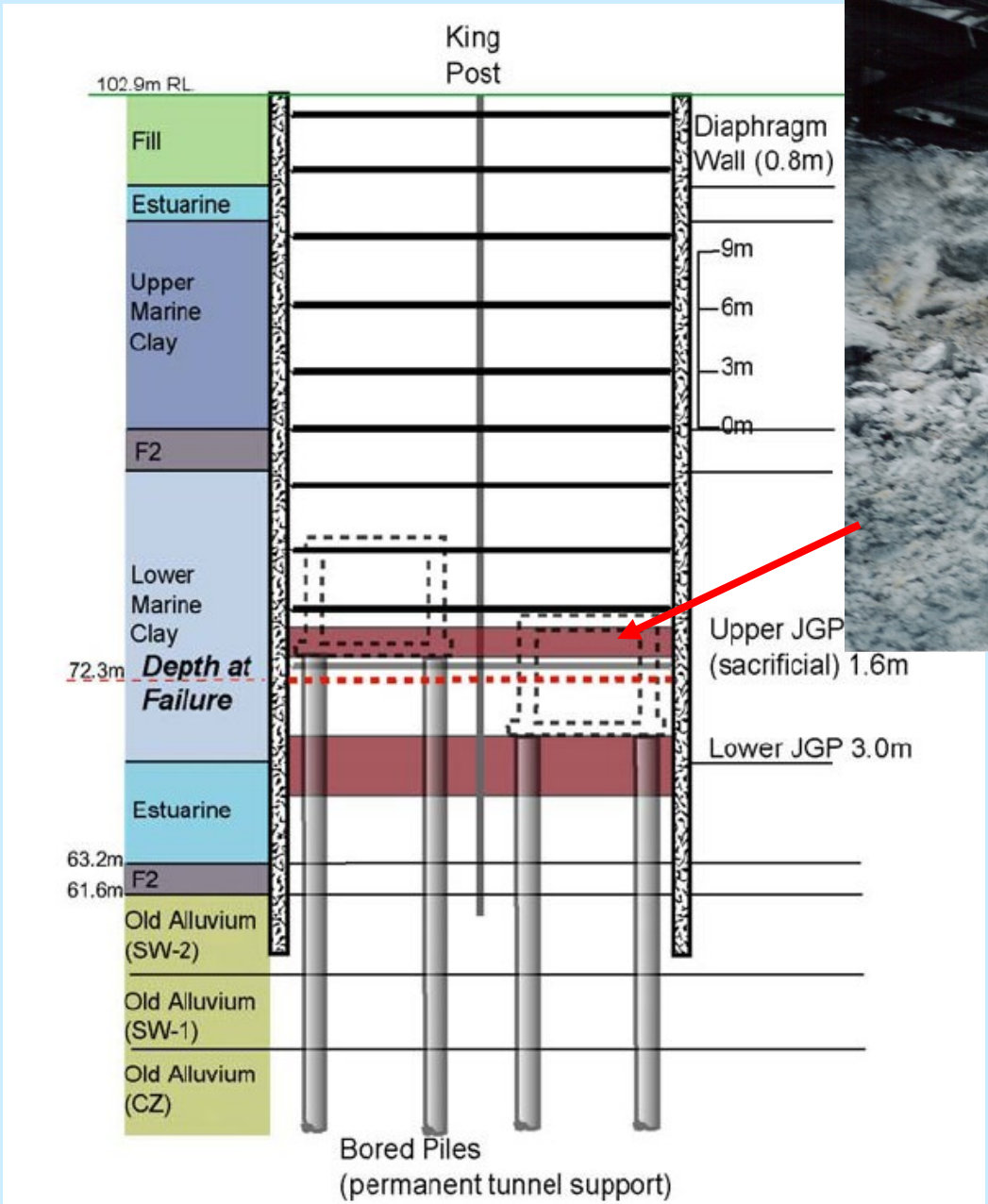
Construction Sequence: Excavation and Installation of Struts



What were new in this Project?

- Deepest excavation in soft clay (~33 m)
- Temporary diaphragm wall (0.8 m thk) was used
  - Eliminate NSF on the piles & the tunnel box
  - Early starting of wall installation
- Deepest jet grouting –QC issues
  - Designed as a structural member/as a soil improved layer
- Sacrificial jet grout layer
- 2-D FEM model (Plaxis) used for the first time

Sacrificial Jet Grout Layer



What design shear strength should be used for the sacrificial layer?

-- Range of values

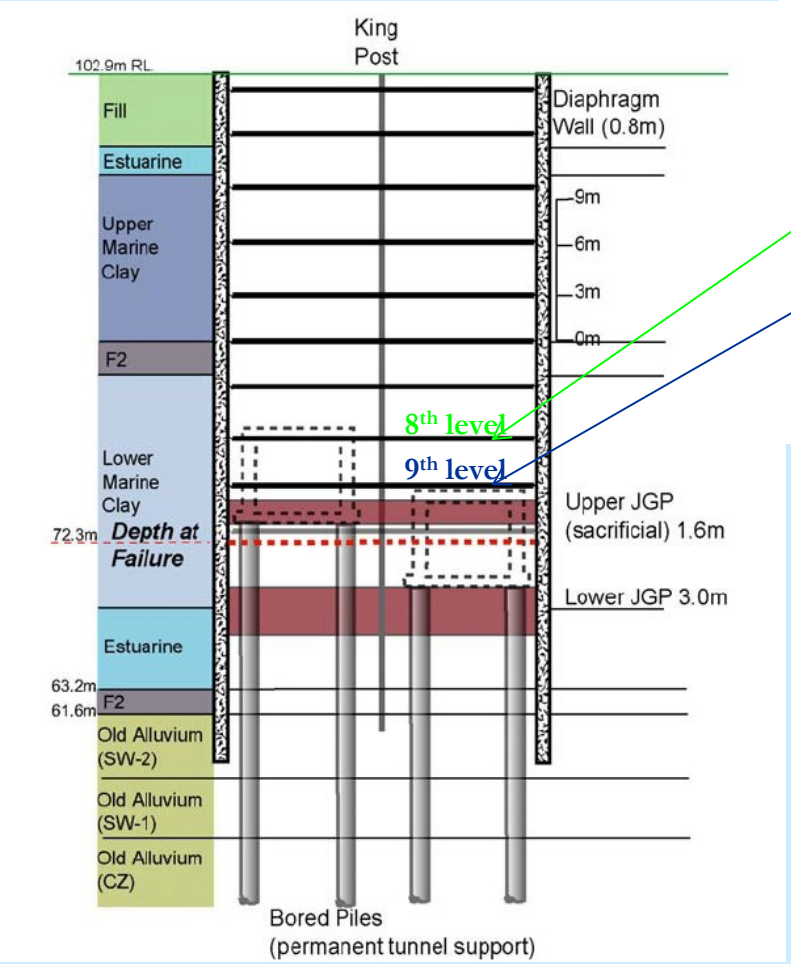
Was the jet grout layers contributed to the failure?

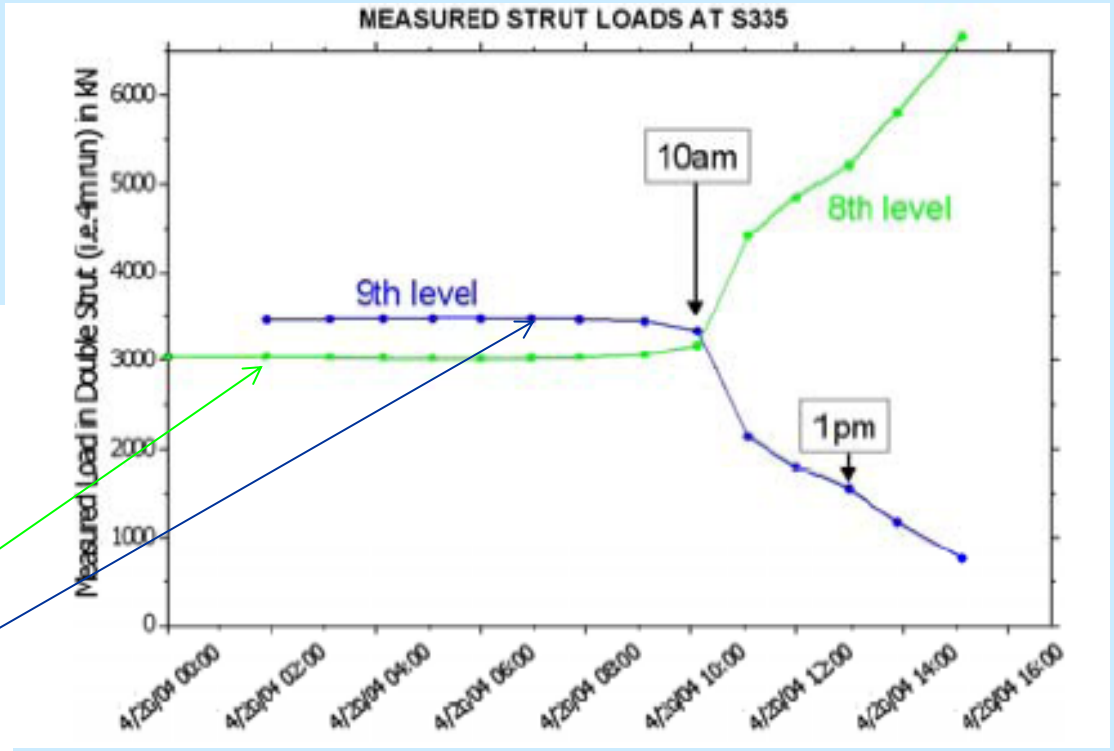
The jet grout layers were not considered as the main cause for the failure

This is because

- of the reported good quality 'sacrificial' jet grout layer; and
- there were not sufficient evidence to suggest any defects in the bottom jet grout layer

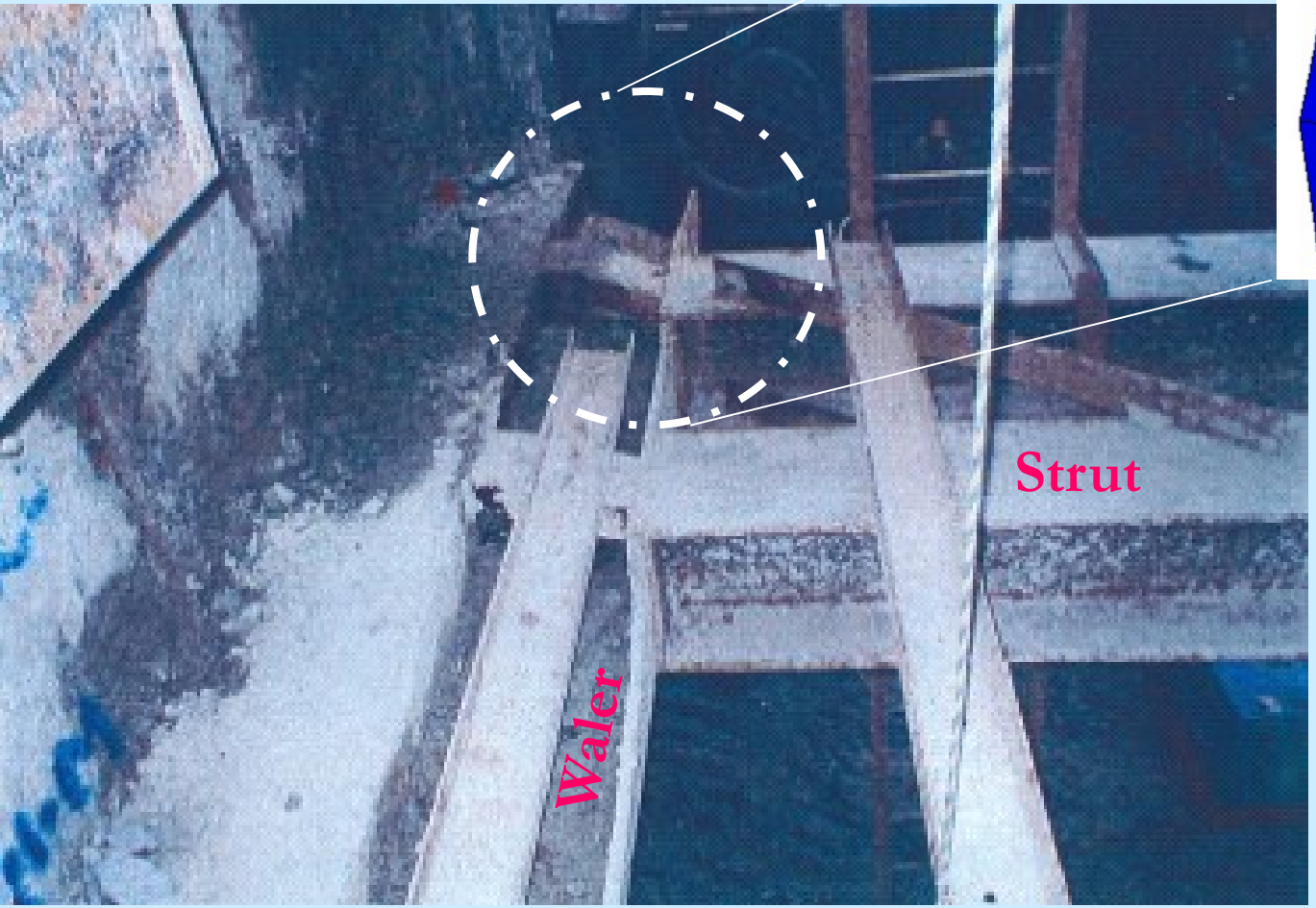
Strut Load

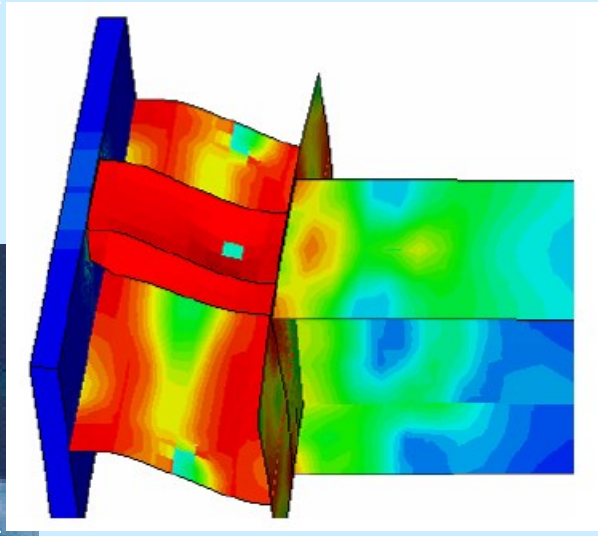




The strut load measurements showed that, on the day of the collapse, load was being transferred from the 9th to the 8th level of struts.

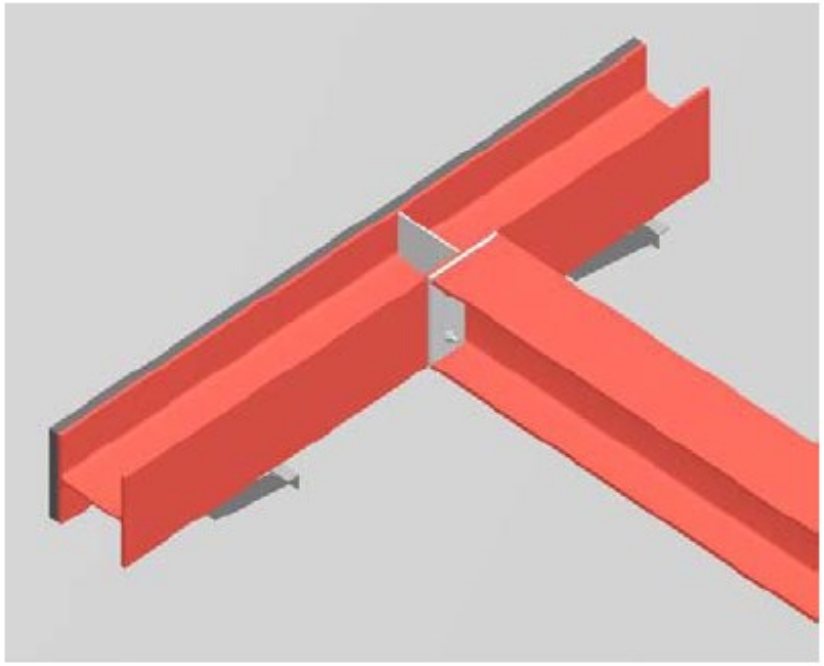
Observed Sway Failure of the Wailing



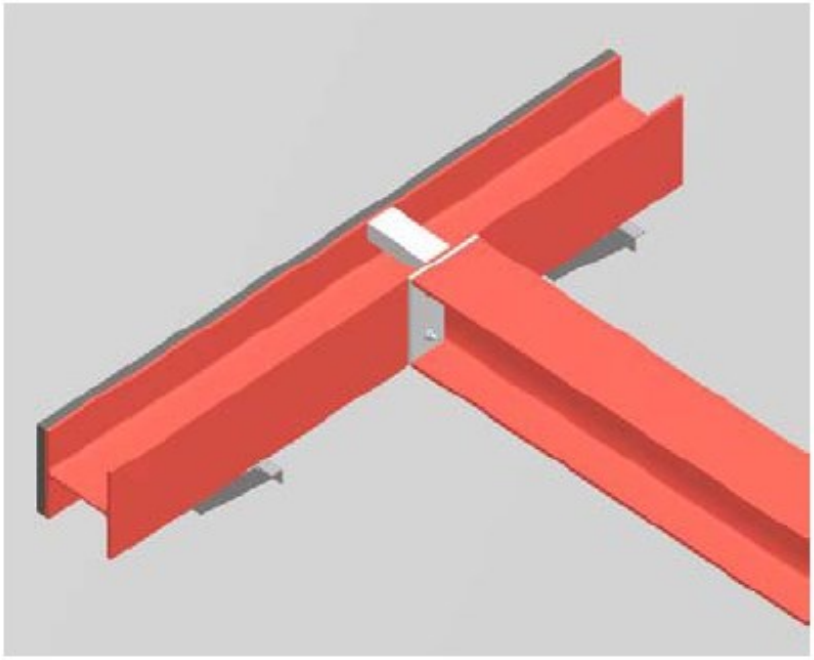


(picture was taken a few hours before the collapse)

Details of Strut-Waler Connections



(a) Plate stiffener



(b) C-Channel stiffener

Failure is mainly due to the in-plain buckling of the plate and/or web with little or no side sway of the waler flange

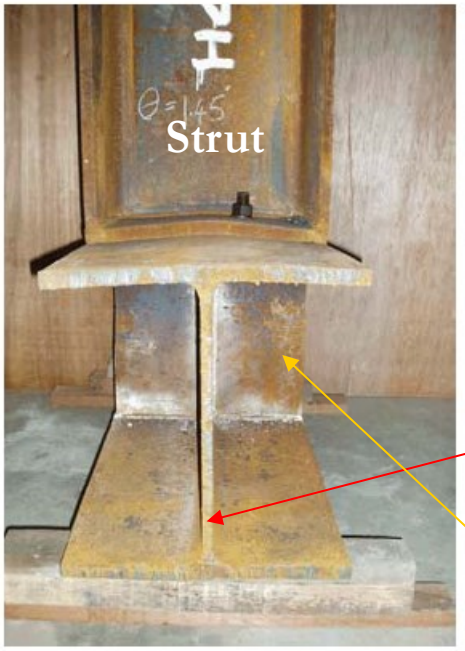
C-channel stiffener and web to sway and failure can occur in a sudden manner with drastic reduction in capacity.

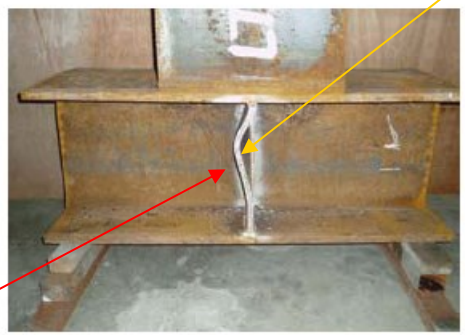
More sensitive to the effective length used in calculating the web buckling capacity

Typical Failure Modes Observed In Laboratory Physical Tests

Front View

Side View





(a) Plate stiffener (non-sway)

Waler

Plate stiffener

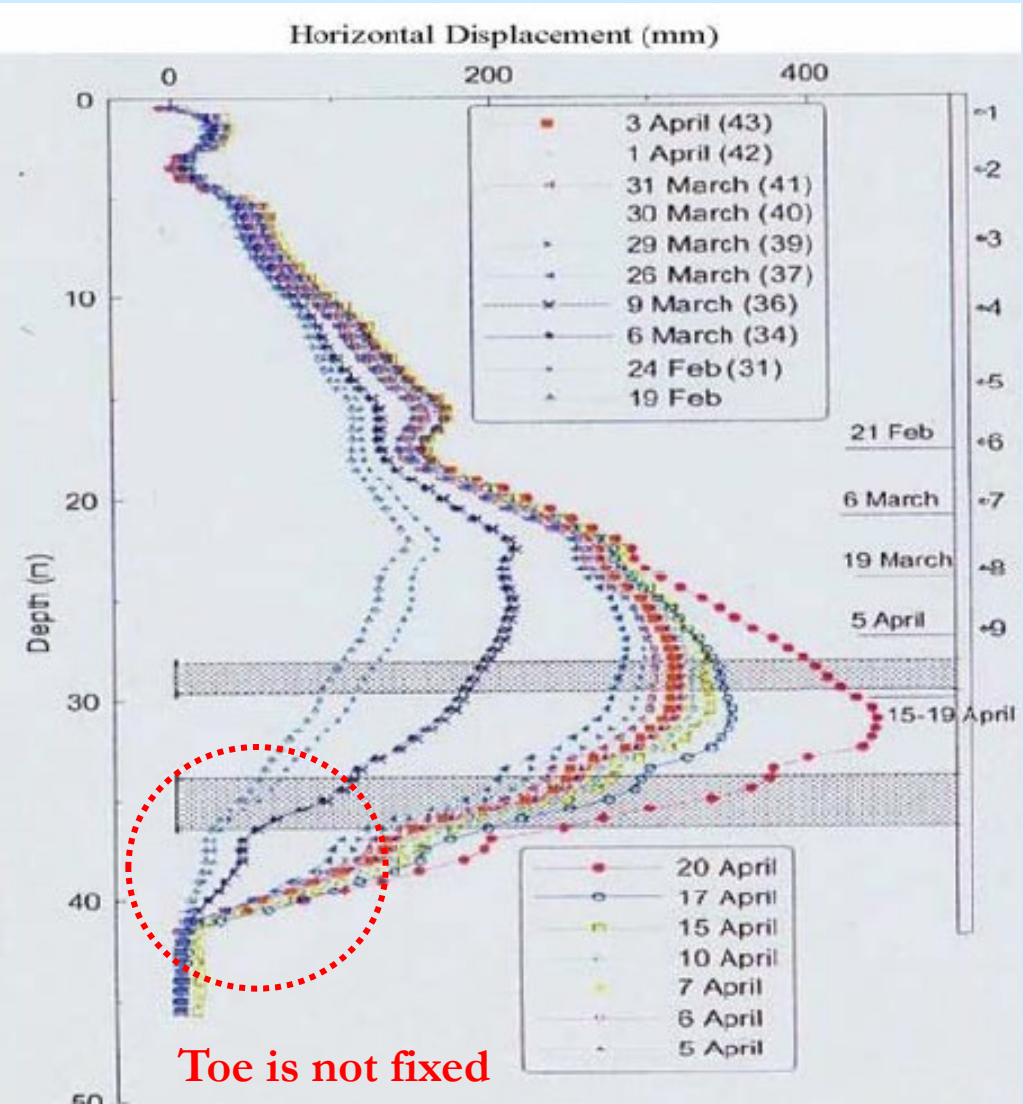
In-plain buckling

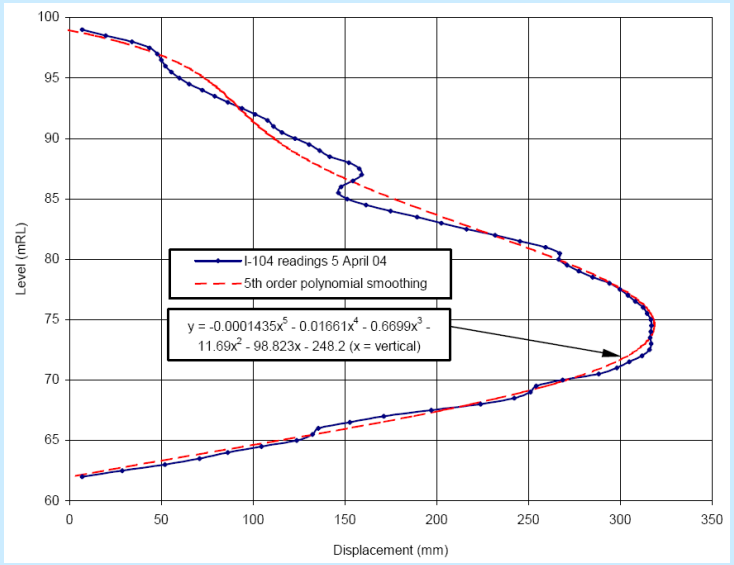
(b) C-channel stiffener (brittle-sway)

Sway failure

C-channel stiffener

Wall Deflection

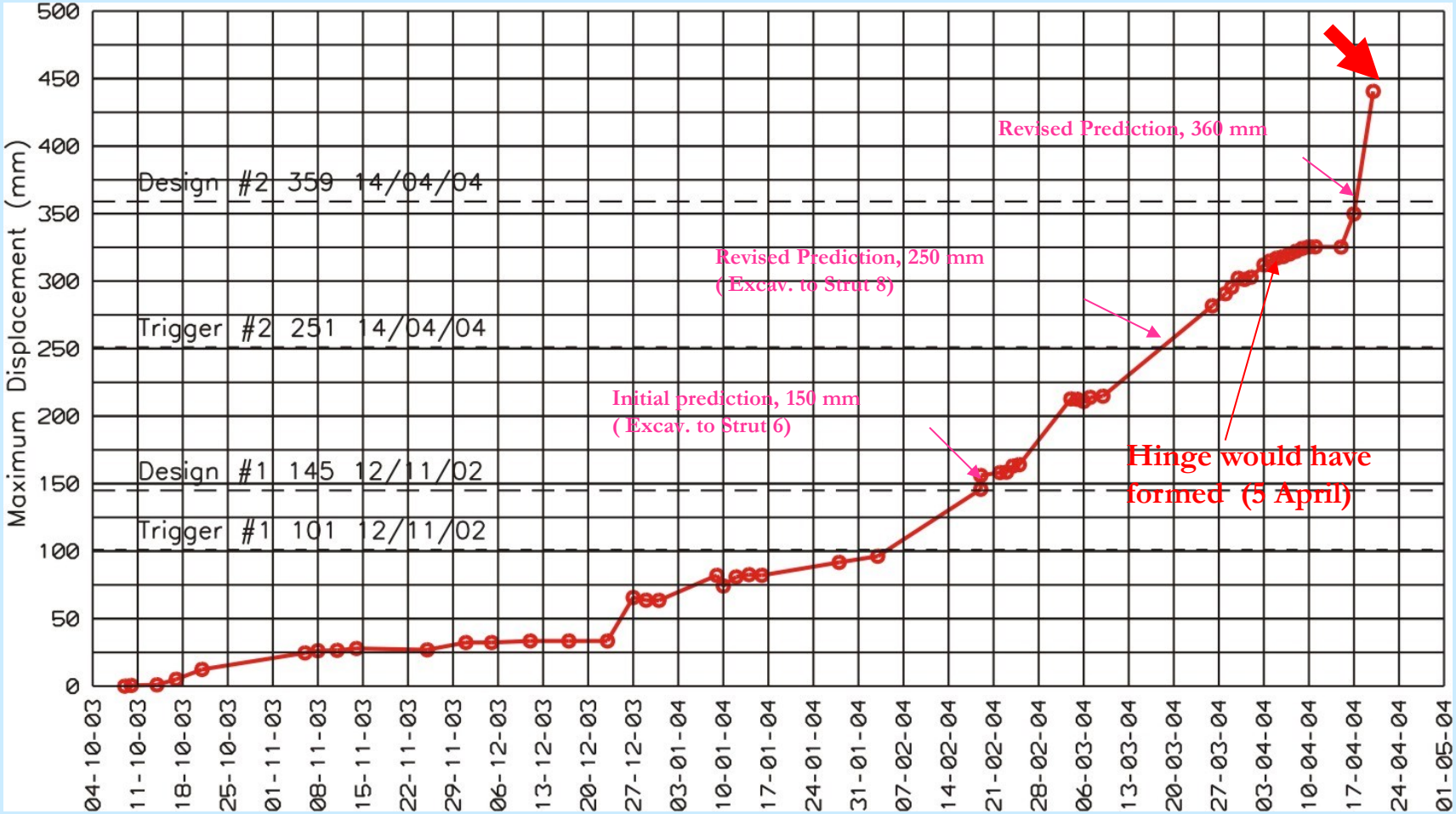




Radius of curvature ~ 200 m

Hinge would have formed by 5 April

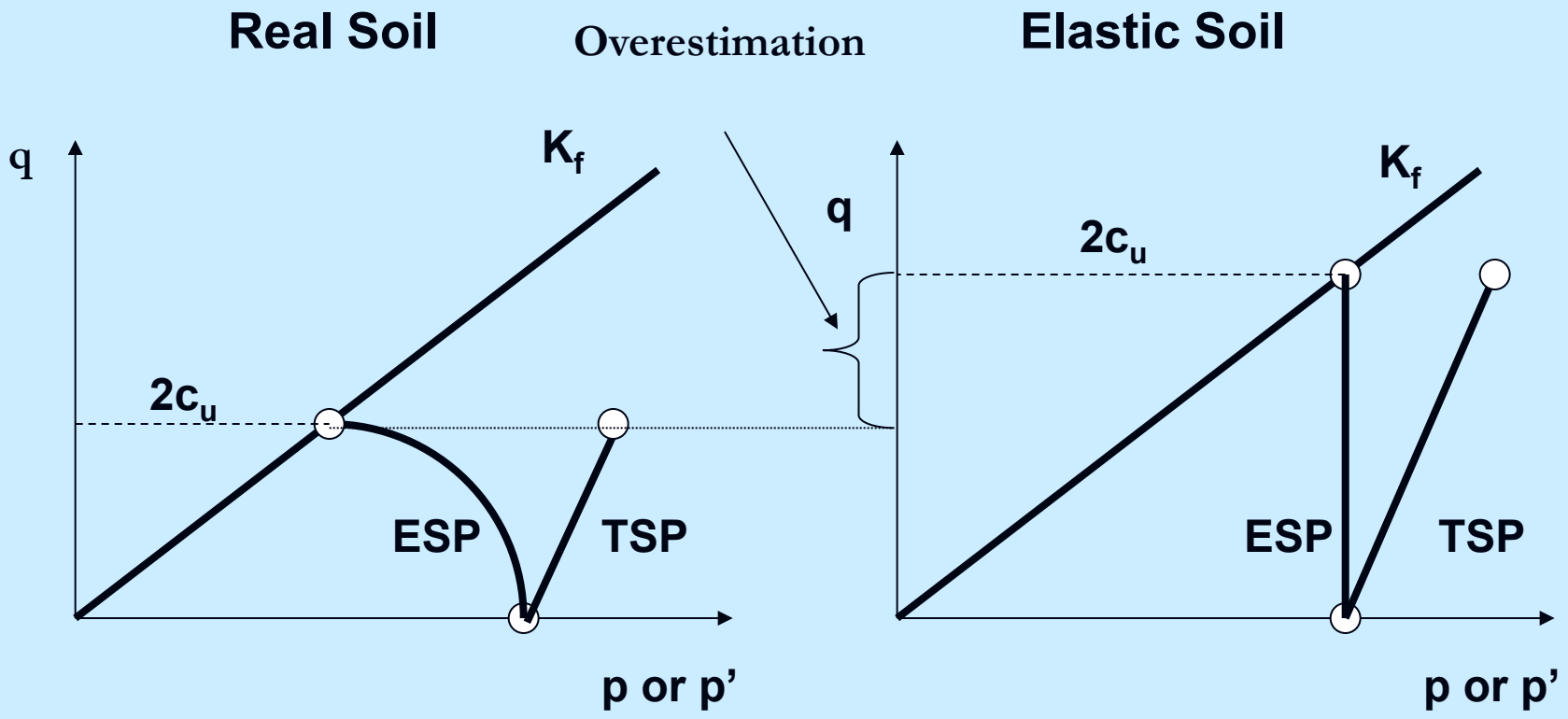
Wall Deflection—Trend Plot (Max. Displ. Vs Time) and Back analyses



Some Key Questions

- Why the excavation was not stopped?
- When should have stopped the excavation?
- Who should have stopped (PM, PE,QP or the BCA) ?
- If stopped
  - What next, i.e., what type of remedial action to go for?
  - What are the implications?

Modeling Undrained condition using M-C Model and Effective Stress Parameters—Why it is wrong for soft clays?



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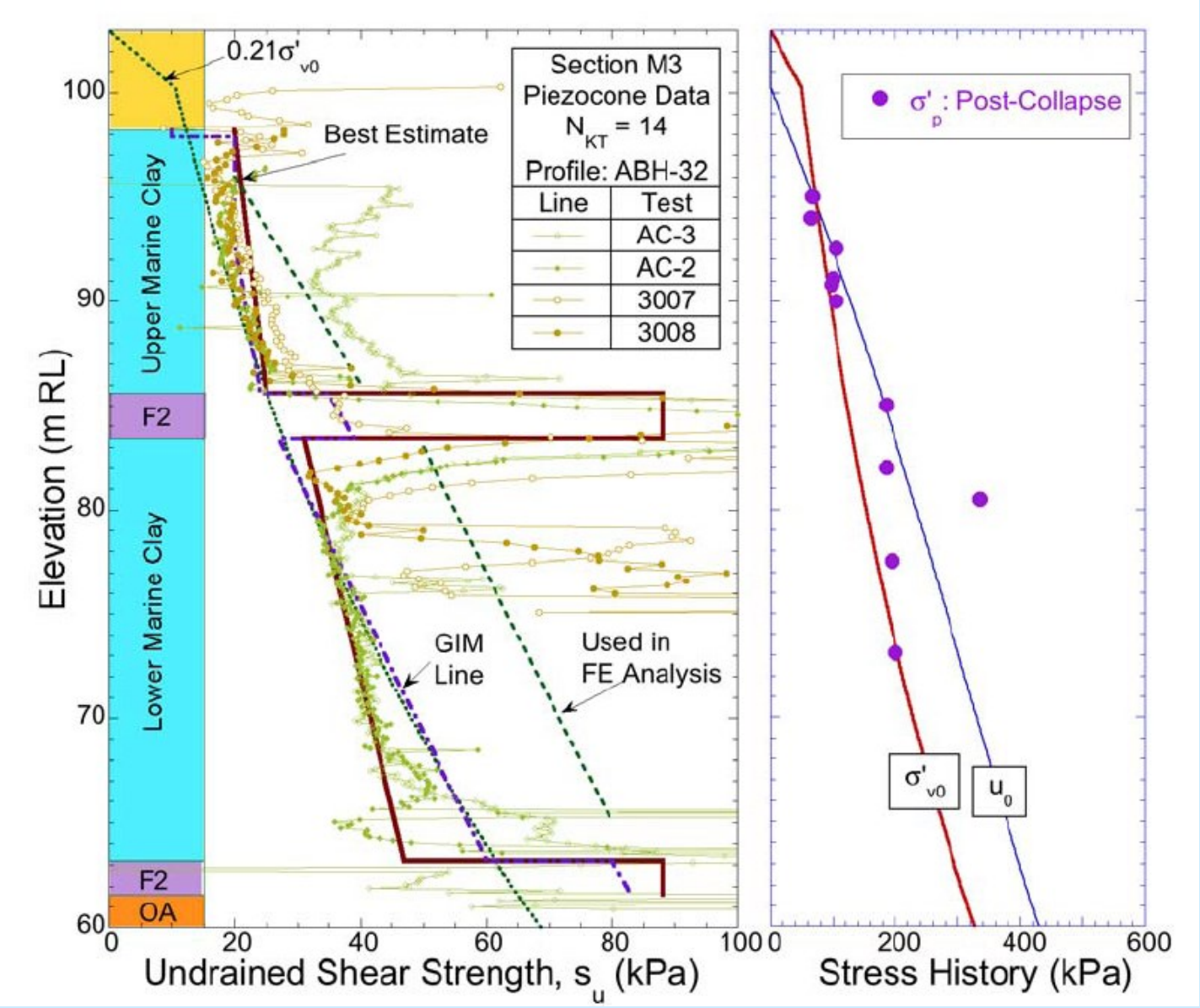
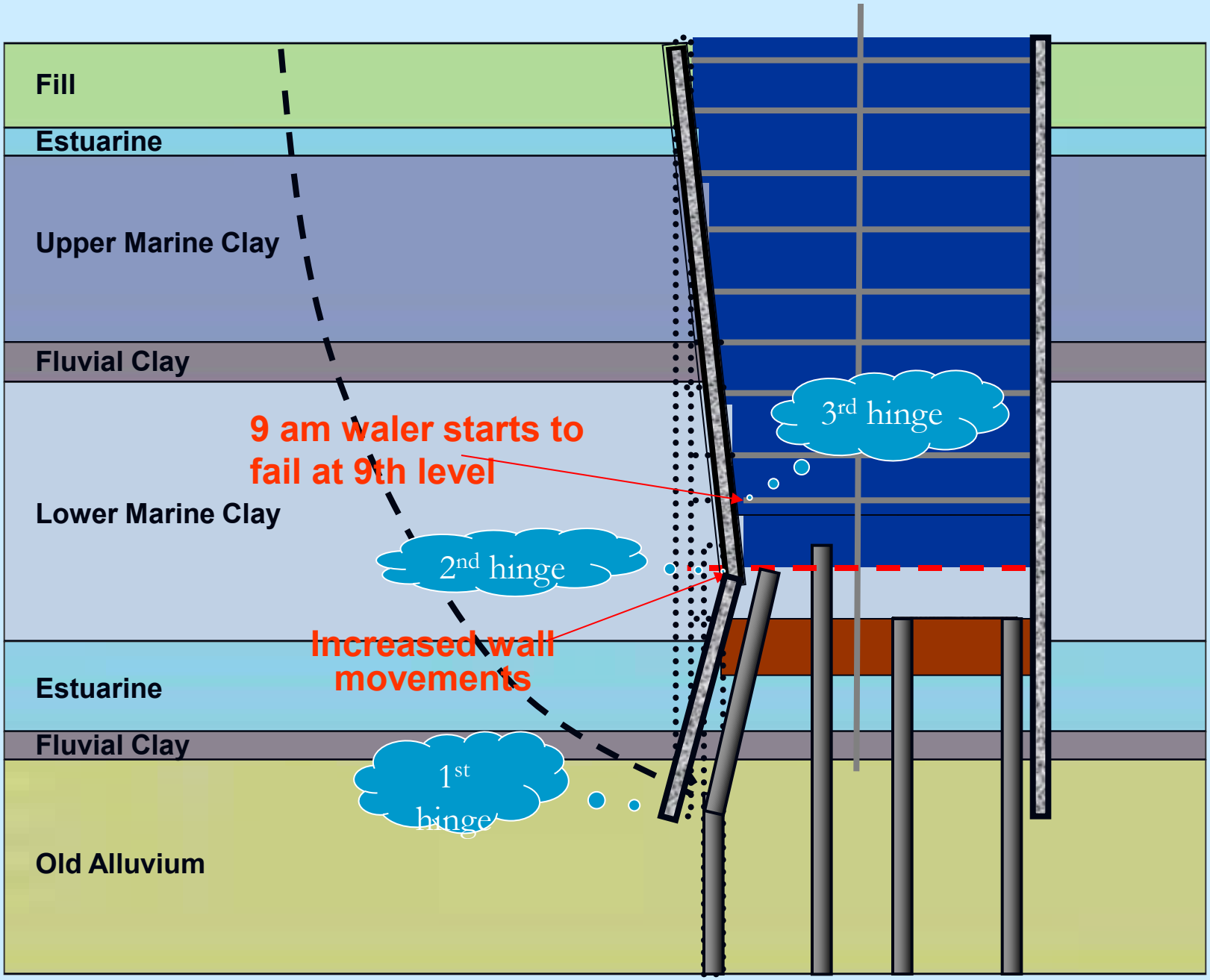


Plastic Hinges & Progressive Failure



Tension Crack in the Cricket Field

Major Causes of Collapse—A Summary

- **Errors in the design of the strut/waling connection resulted in this connection having about one half of the required capacity**
  - **This happened because of the substitution of 'C' channel for plate stiffeners in the waling**
- **Use of effective stress parameters + Mohr-Coulomb failure + 'undrained' analysis, to model soft marine clay in PLAXIS**
  - **This led to the underestimation of moments and movements of wall by a factor of about 2.**

Some Other Contributory Causes

- **Diaphragm walls installed short of 3m design penetration in Old Alluvium – in one case by only 0.6m**
- **Monitoring and monitoring review had been inadequate in quality**
- **Backanalyses incorrectly carried out**

Lessons Learnt

- Design
  - Effective stress parameters + Mohr-Coulomb FEM model should not be used to model undrained condition in soft clays
  - Design of strut-waler connection is very important
    - Design should be done jointly by experienced geotechnical & structural engineers
    - Design should be checked by an independent design checker

Lessons Learnt

- The following would enhance the robustness of Temporary Earth Retaining System
  - Capping beams for the temporary walls
  - Continuous walers (especially in a curved alignment)
  - Concrete packing of the waler at the strut location
  - Effective lateral restraints of struts
- Adequate wall penetration into competent soil strata.
  - Closely spaced boreholes/CPTs

Lessons Learnt

- **Monitoring**
  - **The monitoring should be carried out & reviewed by experienced specialist**
  - **Agreed monitoring frequency should be strictly adhered to**
  - **Damaged instruments should be replaced immediately**

Lessons Learnt

- Site Supervision
  - Site personal should be properly briefed and trained
  - The job description must match the appointee's background and experiences
  - The project manager should have adequate relevant design and construction knowledge

Follow-Up Actions

- Independent checks for temporary works required
- No reduced FOS for temporary works (previously allowed under Singapore codes)
- Risk Assessments & Risk Registers now have to be more rigorous
- Instrumentation being installed and read by independent consultant for latest LTA works
- PE (Temporary Excavations and Retaining Systems) introduced