# CE394M: Finite Element Analysis in Geotechnical Engineering

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# TSP v ESP footing: Tresca failure

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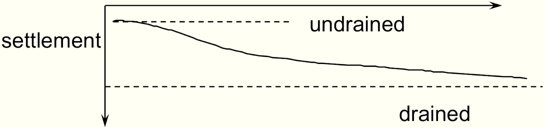
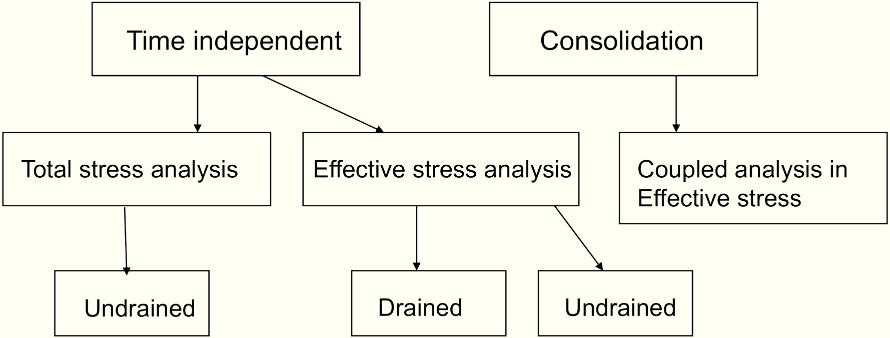
- Better! Conduct Total Stress Analysis: $s_u = \sigma_1 - \sigma_3$
  - But $s_u$ needs to be defined at different locations even if it is the same soil.
  - We can do quick undrained (UU) tests to obtain spatial variation of $s_u$. Hence, practical.
  - No information on pore pressure, so cannot assess the long-term consolidation deformation behavior.
- Effective analysis $= (\sigma_1' - \sigma_3')/(\sigma_1' + \sigma_3') = \sin\phi'$:
  - If it is the same soil, can use the same soil properties (such as $\phi'$) and need to conduct CU tests.
  - But need to compute the excess pore pressure at different locations.
  - This is difficult: only a good effective stress constitutive model that can predict the excess pore pressure correctly can do this.
  - If pore pressure profile can be computed, then it can be used to evaluate the subsequent consolidation process.

# Pore-pressure analysis in geotechnical engineering



# Pore-pressure analysis in geotechnical engineering

# Drained analysis - Effective stress

1. Need to assign initial effective stresses before the analysis.
2. Can use any effective stress model: Elastic, Mohr-Coulomb/Drucker Prager and Cam-Clay models.
3. If plasticity models are used, need to update the effective stresses at each increment:
4. Very common.

# Undrained analysis - Total stress

- Excess pore pressure cannot be calculated.
- Effective stress state of the soil cannot be examined.
- Elastic model is commonly used for deformation

- Von-Mises model is used for modeling undrained shear strength of clays. ($C_u$ or $s_u$ and undrained friction $\phi_u = 0$)
- Can assign different stiffness and strength at different depths explicity by assigning different model parameters at different depths.

# Undrained analysis - Effective vs Total stress

# Undrained analysis - Effective stress

- Need to assign initial effective stresses before the analysis.
- Can use any effective stress model, so the stiffness and strength variation with depth can be modeled implicitly with the one set of model parameters.
- The applied load is carried by the soil skeleton and pore water.
- The contribution of the bulk modulus of water needs to be added:
- Effective stress increment can be computed by:
- Need to update the effective stresses at each time step.

# Effective stress approach or undrained (A)

- Effective stiffness and effective strength parameters are used.
- *Pore pressures are generated*, but may be **inaccurate** depending on the model.
- Undrained shear strength is *not* an input parameter but an outcome of the constitutive model. The resulting shear strength must be checked against known data!
- Consolidation analysis can be performed after the undrained calculation, which *affects the shear strength*!

# Equivalent effective stress approach or undrained (B)

- Effective stiffness parameters and *undrained strength parameters* are used.
- *Pore pressures are generated*, but may be hightly **inaccurate**.
- Undrained shear strength is an input parameter.
- Consolidation analysis should not be performed after the undrained calculation, $s_u$ must be updated, if consolidation is performed anyway!

# Methods of undrained analysis for Mohr-Coulomb clay

| undrained analysis | material type | deformation parameters | strength parameters | initial conditions |
|---|---|---|---|---|
| **Total stress** | Non-porous / drained | $E_u, \nu_u$ | $c_u, \phi_u = 0$ | $K_{0,u}$ |
| **Effective stress** | Undrained (triaxial parameters) | $E', \nu'$ | $c', \phi'$ | $K_0$ |
| **Equivalent Effective stress** | Undrained (strength profile) | $E', \nu'$ | $c', \phi'$ | $K_0$ |

# Consolidation analysis - Effective stress

- Use Biot's 3D consolidation theory
- Pore pressure and displacement are computed at each time step.
- Need to use effective stress model
- Need permeability
- Lots of computational time
- More realistic. Undrained, partially drained, drained depending on the loading condition, drainage condition, permeability of soil.
- Stress path followed is correct, which should provide a good strain estimate when plasticity models are used.

# FE Disclaimer

**IMPORTANT WARNING AND DISCLAIMER**

PLAXIS is a finite element program for geotechnical applications in which soil models are used to simulate the soil behaviour. The PLAXIS code and its soil models have been developed with great care. Although a lot of testing and validation have been performed, it cannot be guaranteed that the PLAXIS code is free of errors. Moreover, the simulation of geotechnical problems by means of the finite element method implicitly involves some inevitable numerical and modelling errors. The accuracy at which reality is approximated depends highly on the expertise of the user regarding the modelling of the problem, the understanding of the soil models and their limitations, the selection of model parameters, and the ability to judge the reliability of the computational results. Hence, PLAXIS may only be used by professionals that possess the aforementioned expertise. The user must be aware of his/her responsibility when he/she uses the computational results for geotechnical design purposes. The PLAXIS organization cannot be held responsible or liable for design errors that are based on the output of PLAXIS calculations.

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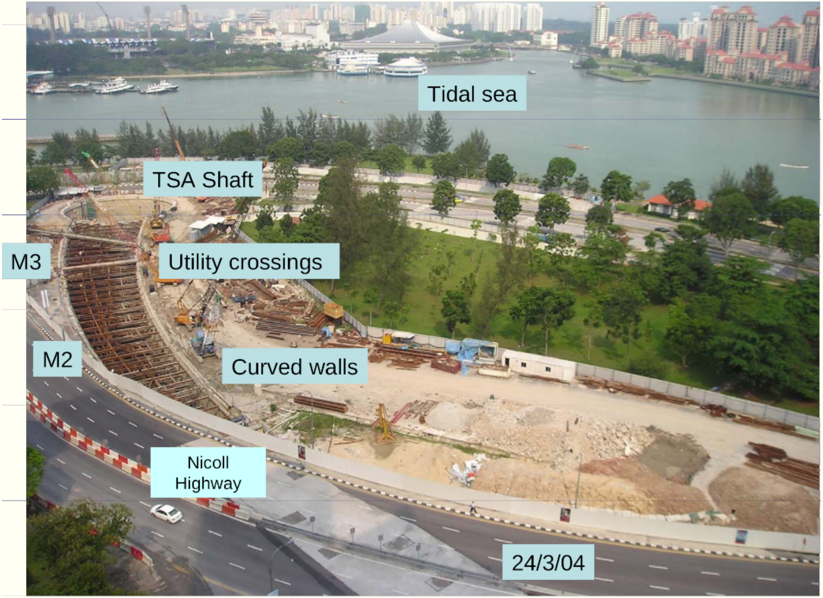
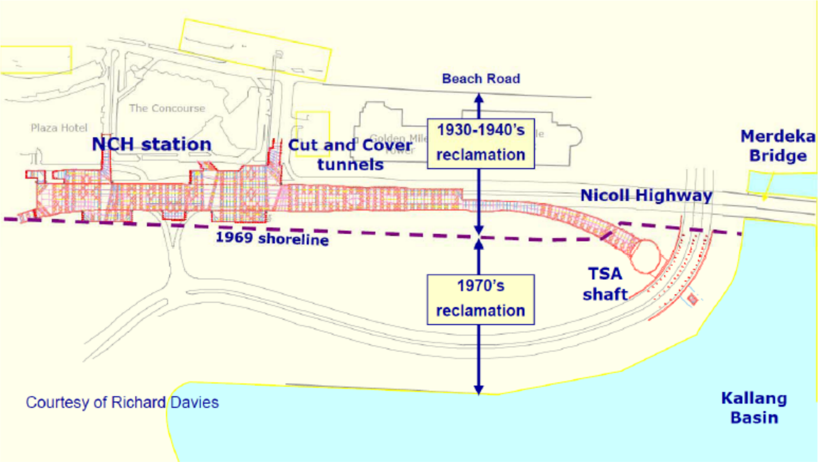
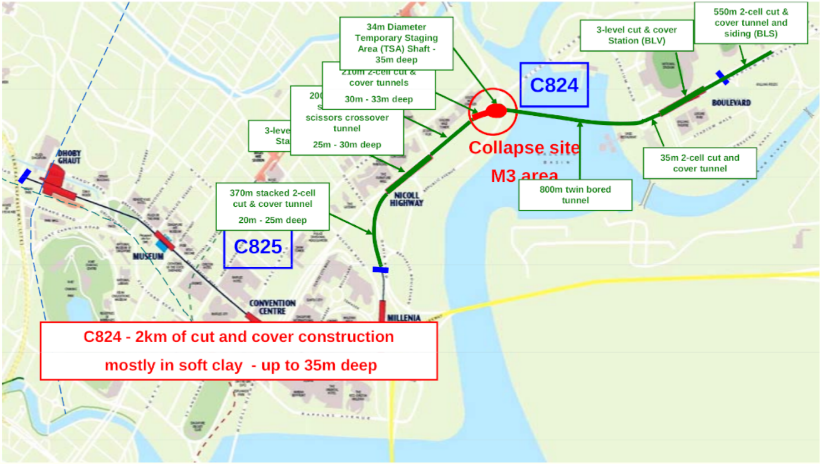
# Nicoll Highway, Singapore



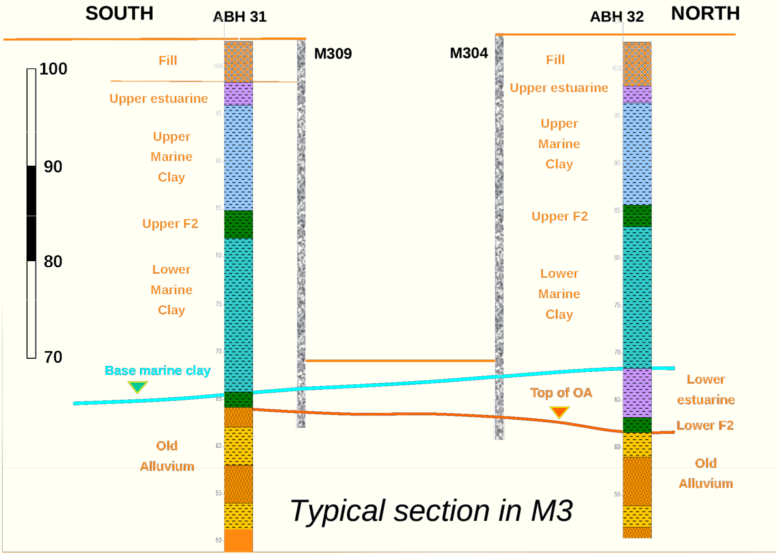
# Nicoll Highway, Singapore



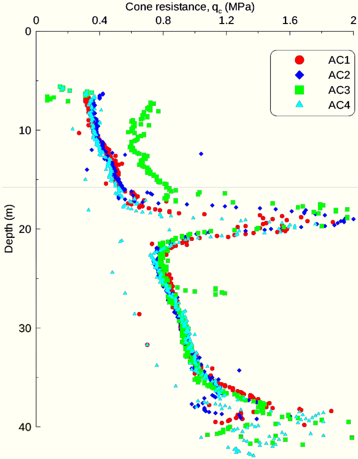
# Nicoll Highway, Singapore

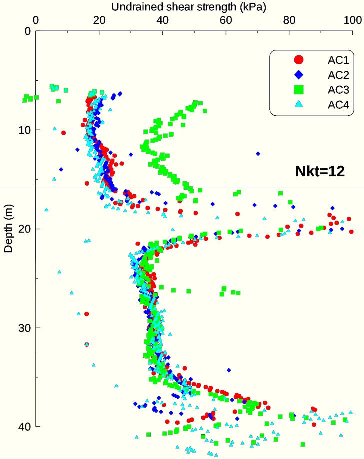


# Soil profile

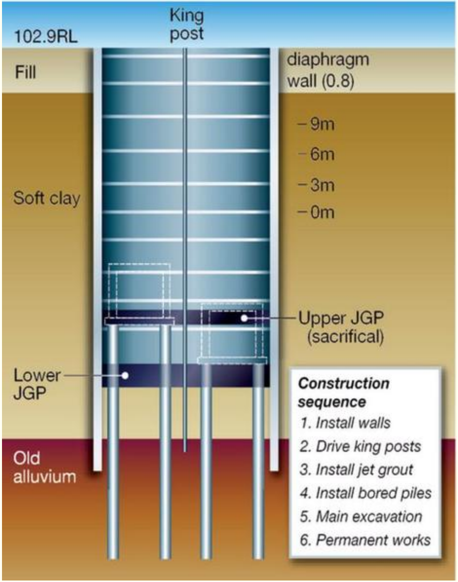


# Soil profile



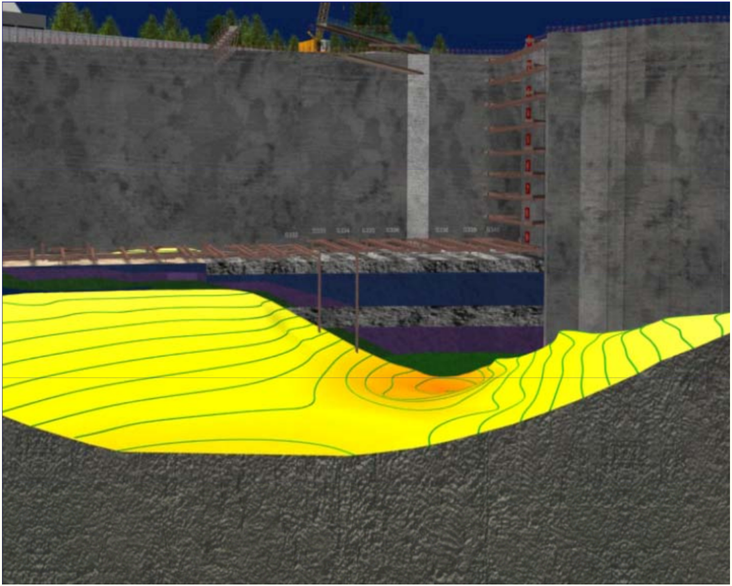
# Construction sequence



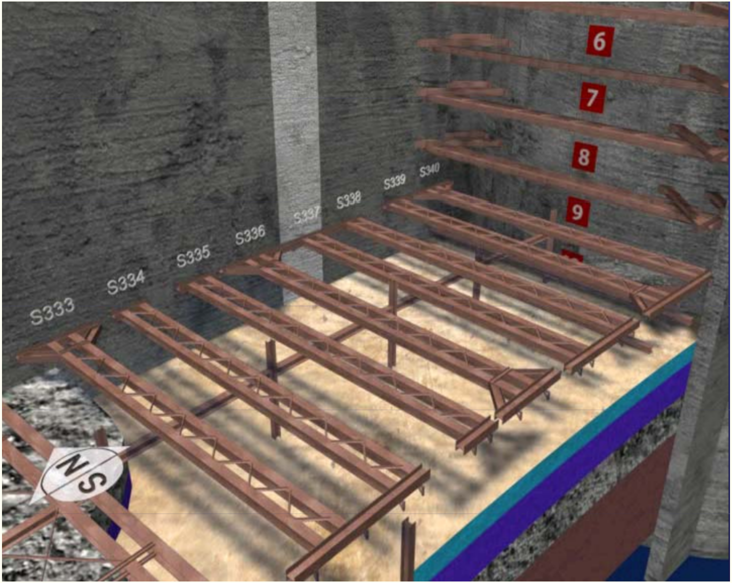
# Nicoll Highway: Excavation

# South side 13 March 2004

# Excavating 10th level of struts



# On the morning of collapse



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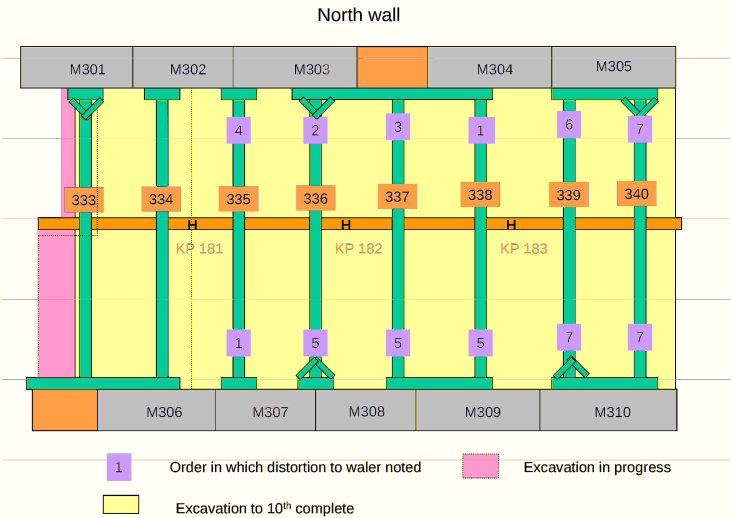



Location of walers, splays and Dwall gaps

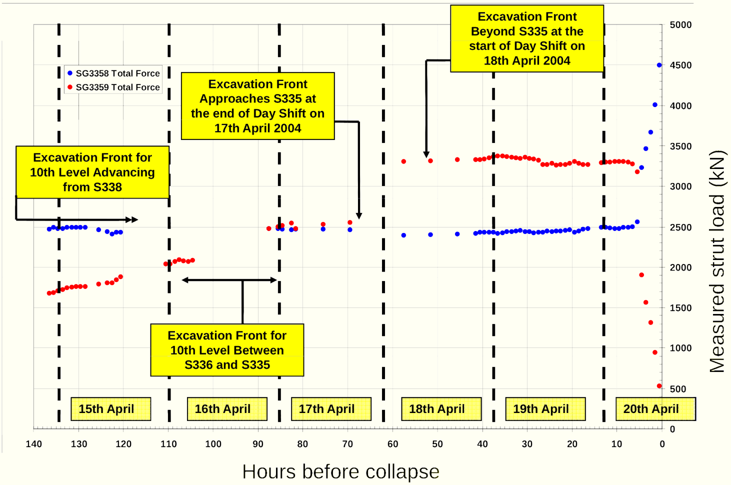
# On the morning of collapse


Strut 338 North side

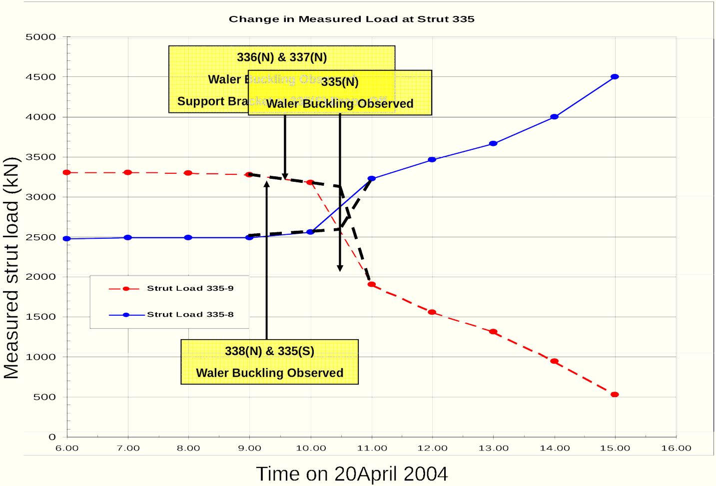
# On the morning of collapse


Strut 335 Sorth side

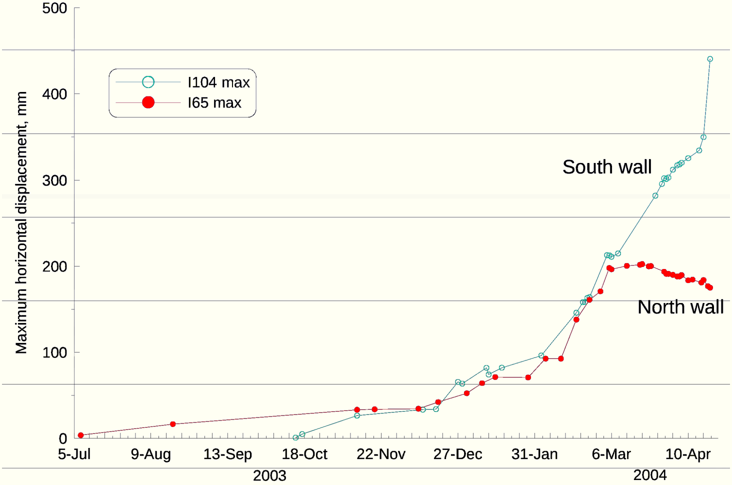
# Hours before collapse



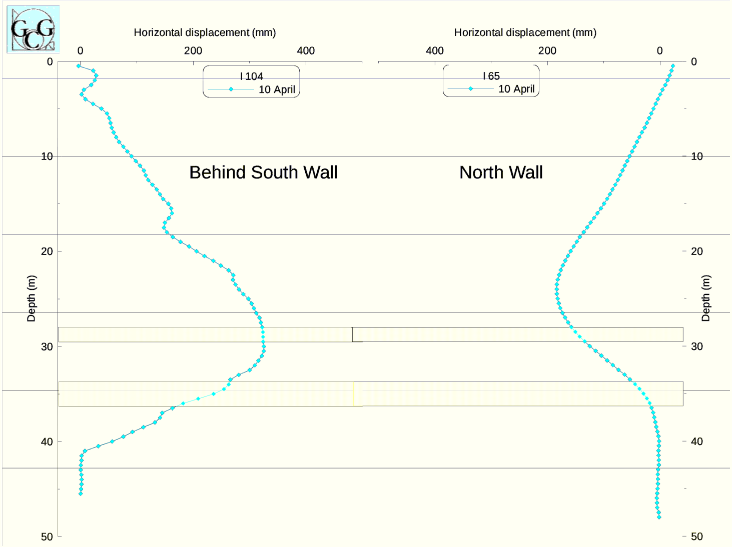
# Hours before collapse



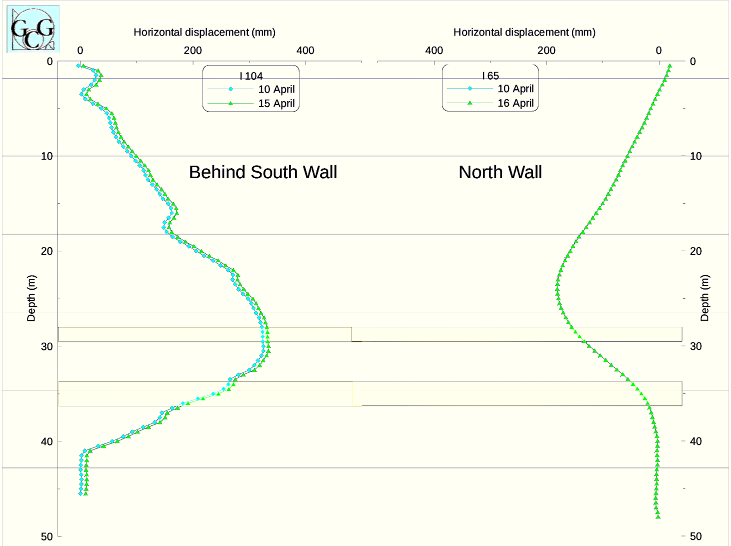
# Leading up to the collapse: Inclinometer



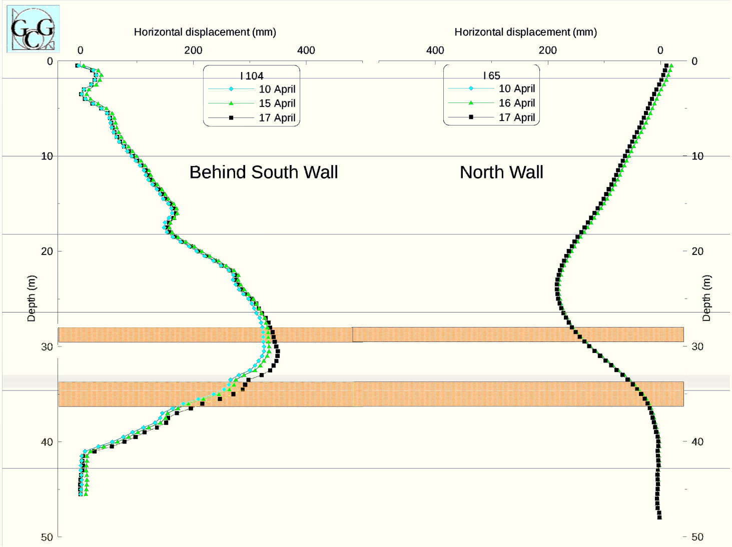
# Leading up to the collapse: Wall displacements



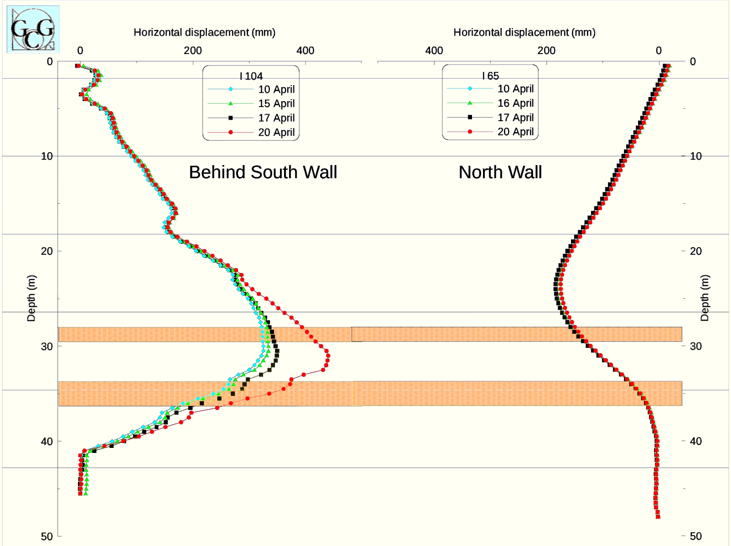
# Leading up to the collapse: Wall displacements



# Leading up to the collapse: Wall displacements



# Leading up to the collapse: Wall displacements



# The collapse

# The collapse

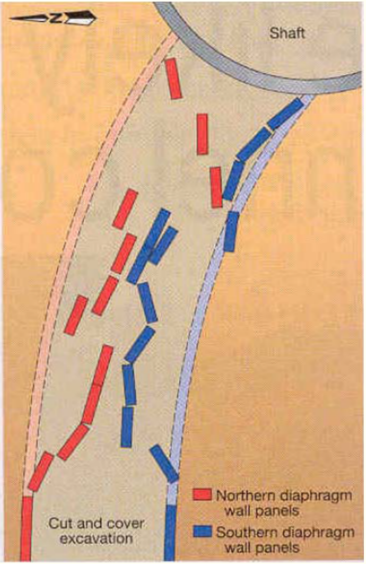
# The collapse

# The collapse

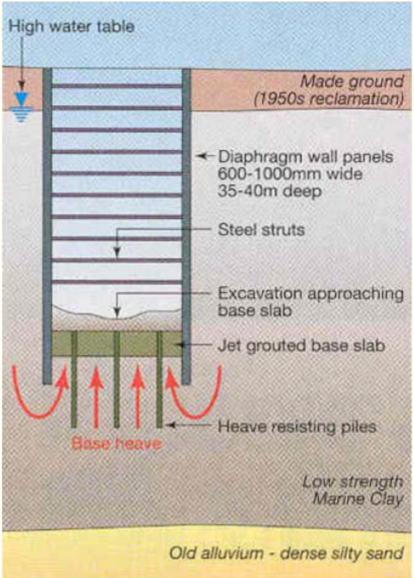
# The collapse

# Post collapse

# Post collapse



# Reasons for collapse



# Strut design: Replacing plate-stiffener with C-channel

# Strut design: Waler connection

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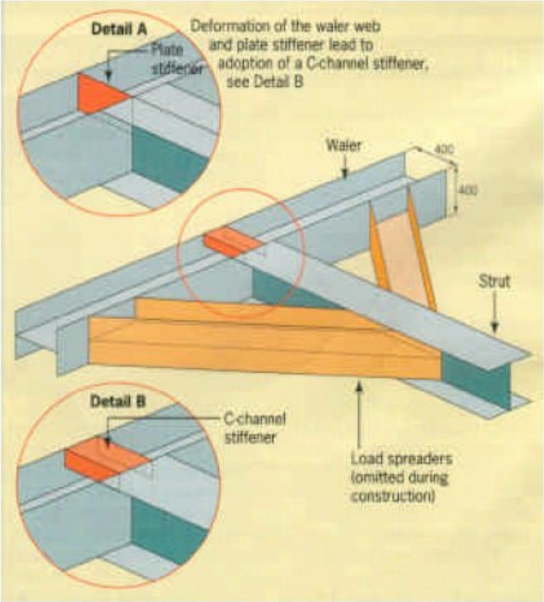
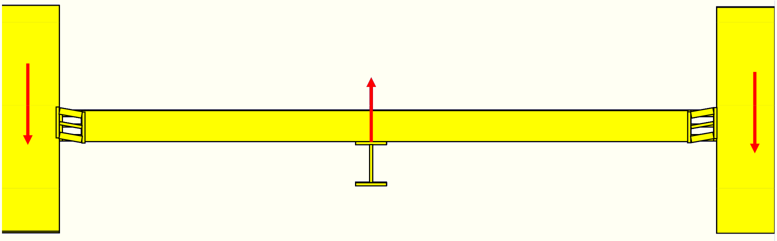
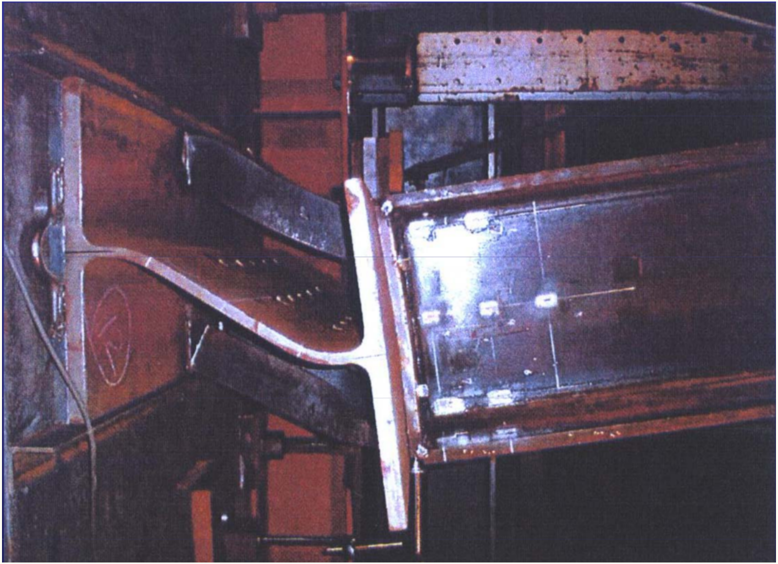


# Strut design: Relative vertical displacements

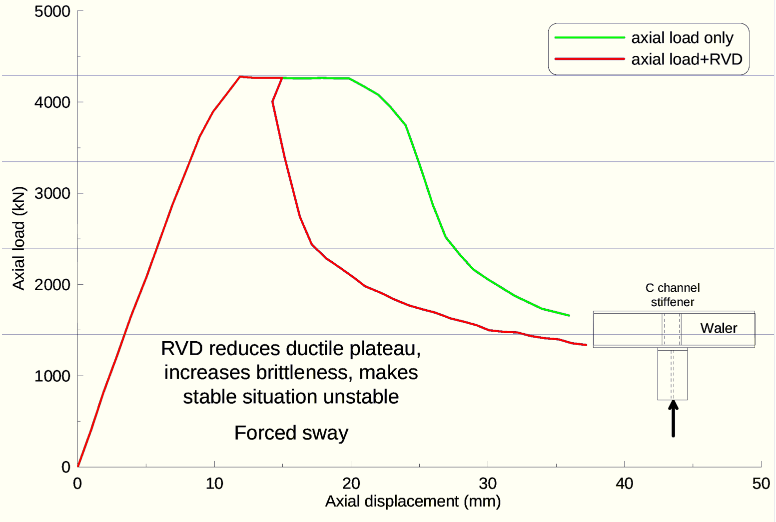


Relative vertical displacement between the King Post and the Dwall

# Strut design: C-channel

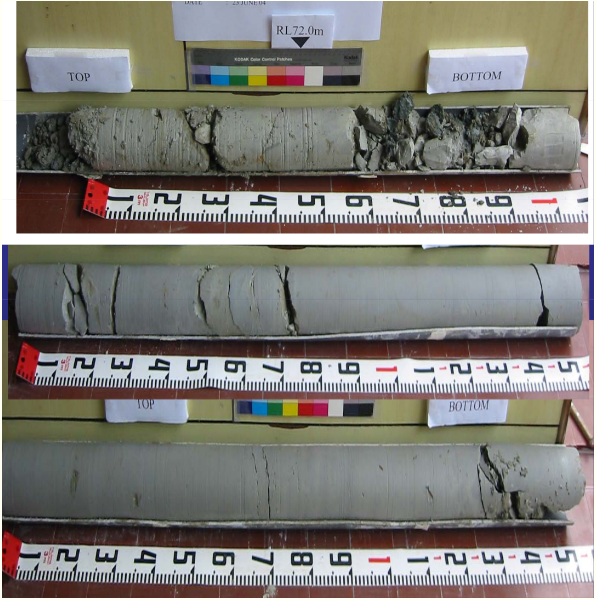


# Strut design: C-channel relative vertical displacement

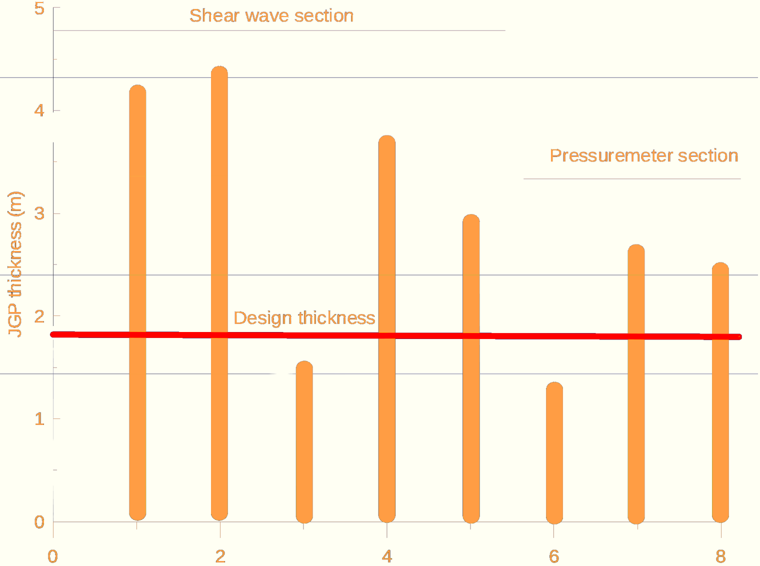


# Excavation of sacrificial jet grout

# Quality of jet grouting



# Quality of jet grouting

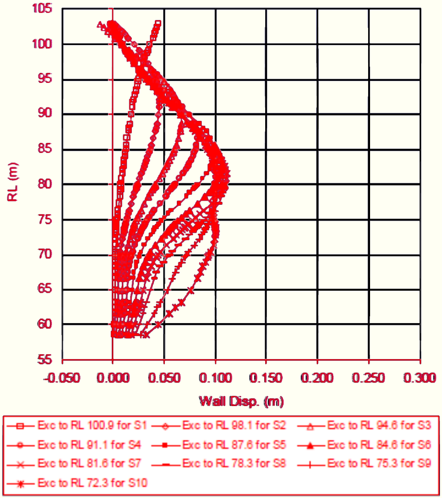


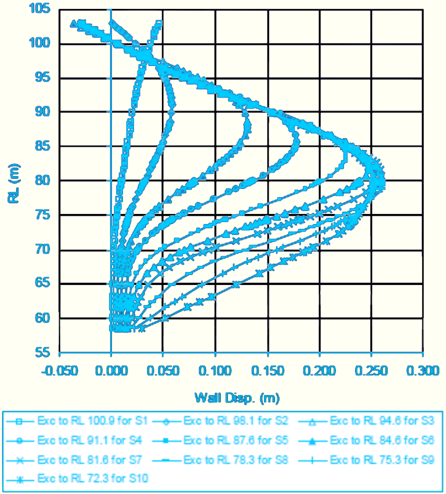
# Undrained analysis

# Undrained effective stress analysis

# Effect of depth on Su

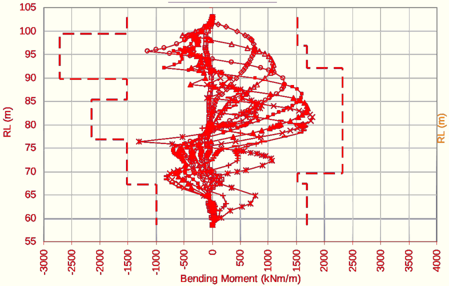
# Wall displacements: Effective stress vs Undrained strength

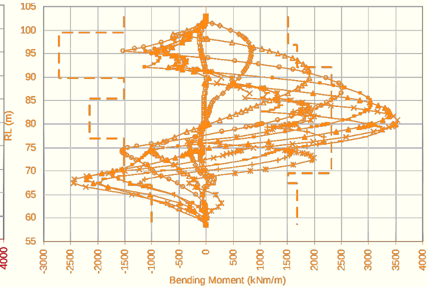



Method A vs Method B

# Bending moments: Effective stress vs Undrained strength



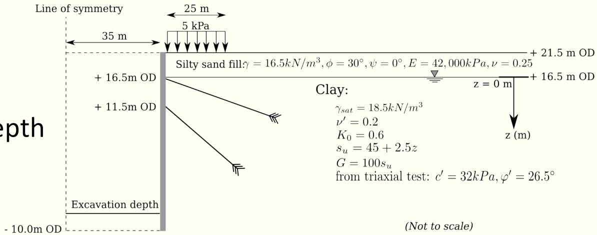

Method A vs Method B

# Undrained effective stress analysis

- Method A over-estimates the undrained shear strength of normally and lightly overconsolidated clays
- Its use led to a 50% under-estimate of wall displacements and of bending moments and an under-estimate of the 9 th level strut force of 10%
- The larger than predicted displacements mobilised the capacity of the JGP layers at an earlier stage than predicted

# Total stress evaluating varying $K_0$

- $K_0$ Varies with depth

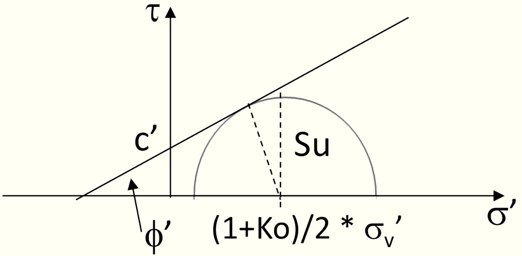



| Depth | $\sigma_v$ | u | $\sigma_v'$ | $k_0\sigma_v'=\sigma_h'$ | $\sigma_h$ | $K_0$ | $K_0$ Layer |
|---|---|---|---|---|---|---|---|
| 0 | 82.5 | 0 | 82.5 | 49.5 | 49.5 | 0.6 | |
| 6.5 | 202.75 | 65 | 137.75 | 82.65 | 147.65 | 0.728 | 0.664 |
| 11.5 | 295.25 | 115 | 180.25 | 108.15 | 223.15 | 0.756 | 0.742 |
| 16.5 | 387.75 | 165 | 222.75 | 133.65 | 298.65 | 0.77 | 0.763 |

# Undrained analysis using effective stress method

**Effective stress Method A**

- Define $c'$ and $\phi'$ in terms of the real effective stress parameters, assuming zero dilation.
- $\nu'$ is the effective Poisson ratio
- $E$ and $K_0$ should be '*effective stress*' based.



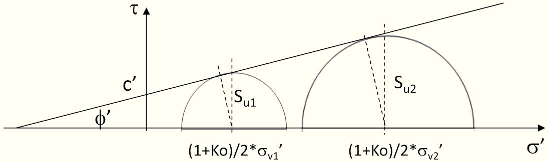

Mohr-Coulomb failure criteria: $\tau = c' + \sigma' \tan \phi'$

$$s_u = c' \cos \phi' + (1 + K_0)/2 \cdot \sin \phi' \cdot \sigma'_{v0}.$$

# Undrained analysis using equivalent effective stress method

**Effective stress Method B**

- Define $c'$ and $\phi'$ in terms of the "*equivalent*" effective stress parameters, with zero dilation. Parameters are defined based on the strength profile with depth.
- $\nu'$ is the effective Poisson ratio
- $E$ and $K_0$ should be '*effective stress*' based.




Mohr-Coulomb failure criteria: $\tau = c' + \sigma' \tan \phi'$

$$s_u = c' \cos \phi' + (1 + K_0)/2 \cdot \sin \phi' \cdot \sigma'_{v0}.$$

# Methods of undrained analysis for Mohr-Coulomb clay

| undrained analysis | material type | deformation parameters | strength parameters | initial conditions |
|---|---|---|---|---|
| **Total stress** | Non-porous / drained | $E_u, \nu_u$ | $c_u, \phi_u = 0$ | $K_{0,u}$ |
| **Effective stress** | Undrained (triaxial parameters) | $E', \nu'$ | $c', \phi'$ | $K_0$ |
| **Equivalent Effective stress** | Undrained (strength profile) | $E', \nu'$ | $c', \phi'$ | $K_0$ |