

CE394M: Nicoll Highway Collapse: A case-study

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Overview

1 Geotechnical FEA

- Element types
- Discretization
- Boundary conditions
- Errors in FEA

2 Nicoll Highway Collapse, Singapore

- The Collapse
- Post collapse investigation

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.

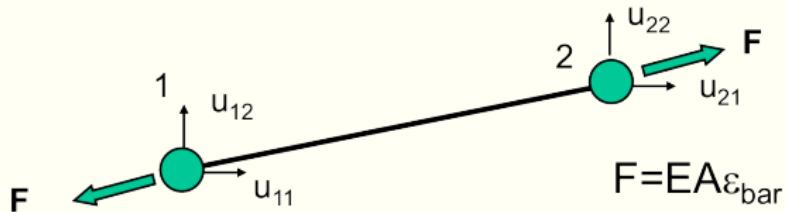
Consistent system of units

SI				
Length	m	m	m	cm
Density	kg/m^3	$10^3 \text{ kg}/\text{m}^3$	$10^6 \text{ kg}/\text{m}^3$	$10^6 \text{ g}/\text{cm}^3$
Force	N	kN	MN	Mdynes
Stress	Pa	kPa	MPa	bar
Gravity	m/sec^2	m/sec^2	m/sec^2	cm/s^2
Stiffness*	Pa/m	kPa/m	MPa/m	bar/cm

Problem definition

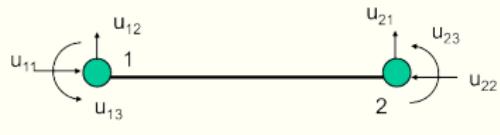
1D Finite Elements: Bar element

Two node element with axial stiffness only (no flexural or shear resistance).



1D Finite Elements: Beam element

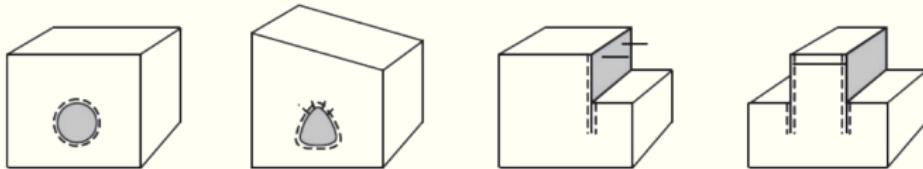
two node structure element with axial and bending stiffness (no transverse shear deformation). Three degrees of freedom for 2D beam element (1, 2 displacements and a moment)



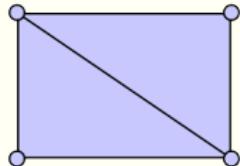
$$F_a = EA \epsilon_a$$

$$V = -EI(u_{12}-u_{21})/L^3 - 6EI(u_{13}+u_{23})/L^2$$

$$M = EI(u_{13}-u_{23})/L$$



2D plane-strain / axisymmetric elements



3 nodes element

linear variation of displacement
within the element = constant
strain in the element

$$d_1 = \alpha_1 + \alpha_2x + \alpha_3y$$

$$d_2 = \beta_1 + \beta_2x + \beta_3y$$



4 nodes element

linear variation of
displacement in both x and y
directions

$$d_1 = \alpha_1 + \alpha_2\xi + \alpha_3\eta + \alpha_4\xi\eta$$

$$d_2 = \beta_1 + \beta_2\xi + \beta_3\eta + \beta_4\xi\eta$$



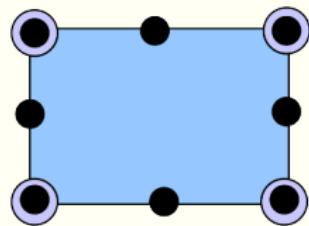
8 nodes element

quadratic variation of displacement in
both x and y directions.

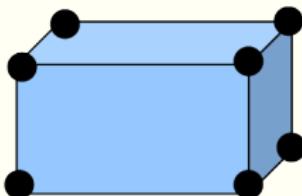
$$\begin{aligned} d_1 &= \alpha_1 + \alpha_2\xi + \alpha_3\eta + \alpha_4\xi^2 \\ &\quad + \alpha_5\xi\eta + \alpha_6\eta^2 + \alpha_7\xi^2\eta + \alpha_8\xi\eta^2 \\ d_2 &= \beta_1 + \beta_2\xi + \beta_3\eta + \beta_4\xi^2 \\ &\quad + \beta_5\xi\eta + \beta_6\eta^2 + \beta_7\xi^2\eta + \beta_8\xi\eta^2 \end{aligned}$$

2D/3D Finite elements

2D Consolidation element



8 node 3D brick element

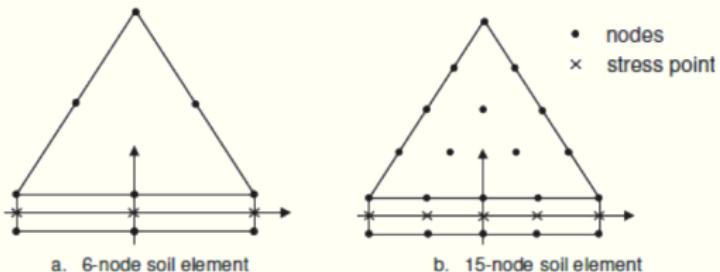
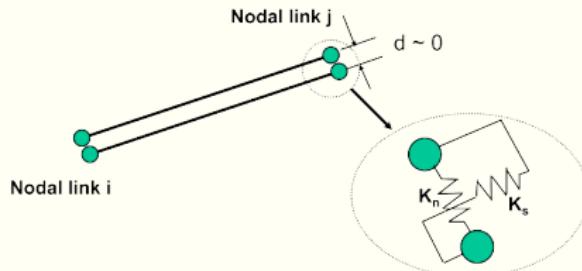


- Pore pressure and displacements
- Displacements

Linear variation of pore pressures and quadratic variation of displacements in x and y directions

Linear variation of displacements in x, y and z directions

Interface element



13 Distribution of nodes and stress points in interface elements and their connection to soil elements

13

Use a reduced strength at the interface

Interface elements for Soil Structure Interactions

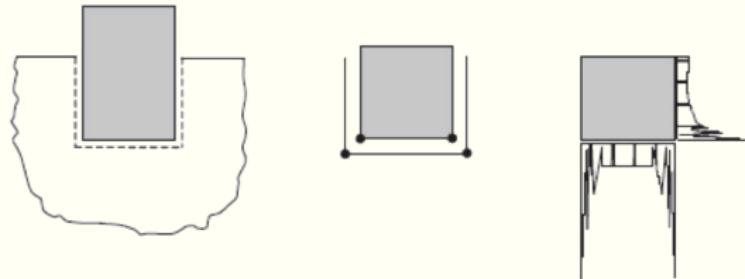


Figure 3.14 Inflexible corner point, causing poor quality stress results

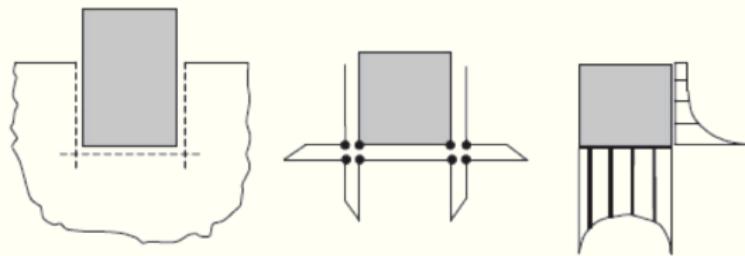
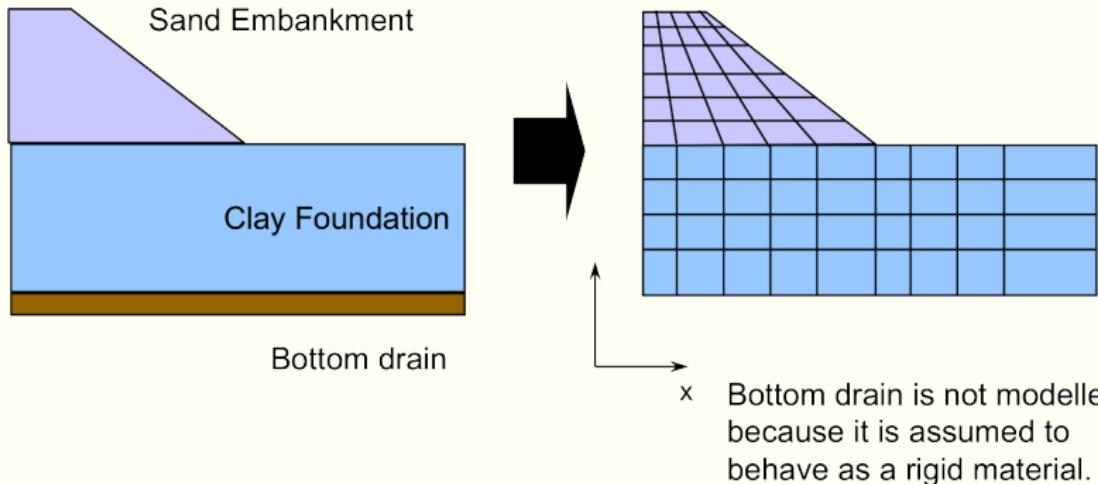
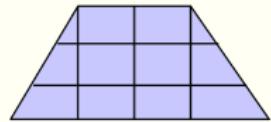


Figure 3.15 Flexible corner point with improved stress results

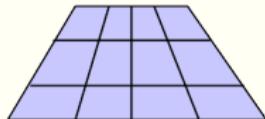
FE discretization



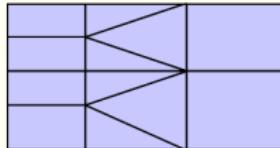
FE discretization



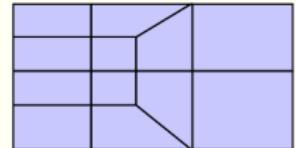
Not recommended



Better

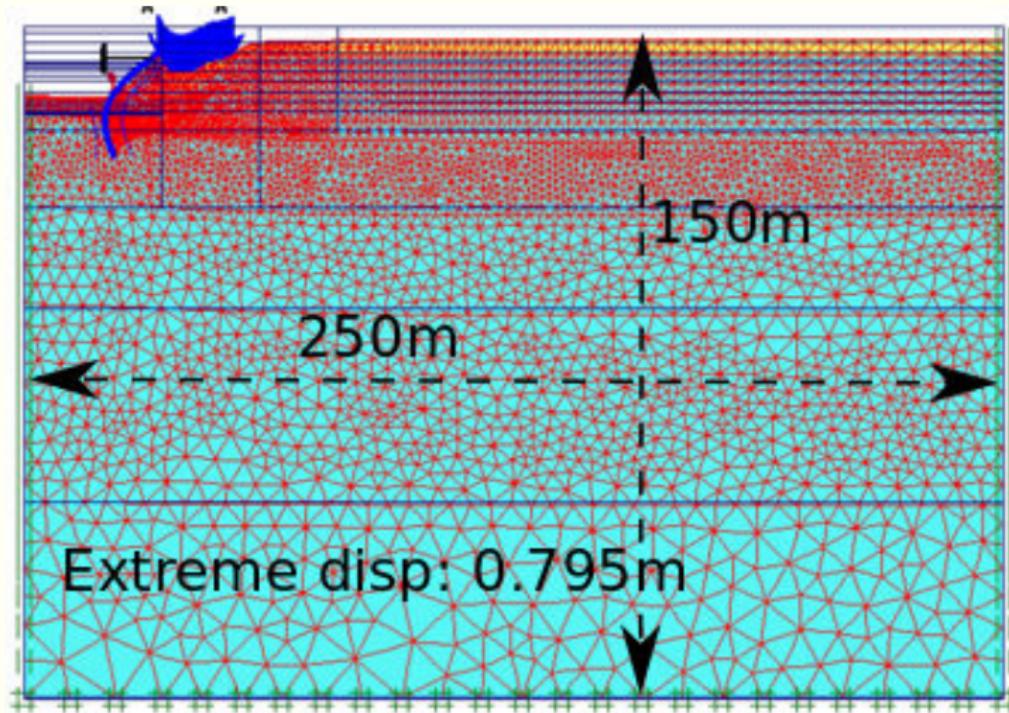


Not recommended



Better

FE discretization: Refining



Avoid large jumps in element size: size jump should be ± 3

FE boundary conditions

x direction fixed

y direction free

pore pressure fixed (if embankment
is assumed to be fully drained
condition)

Sand embankment

x and y directions free
pore pressure fixed

x direction fixed

y direction free

pore pressure free

x direction fixed

y direction free

pore pressure free

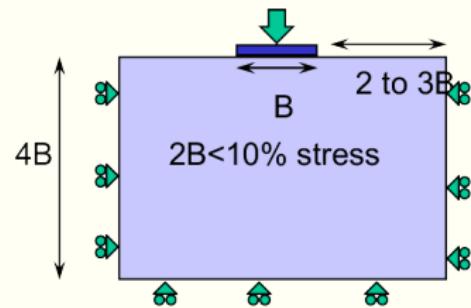
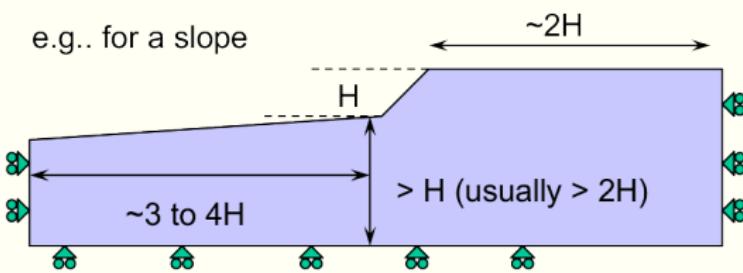
Clay foundation

x and y directions fixed

pore pressure fixed

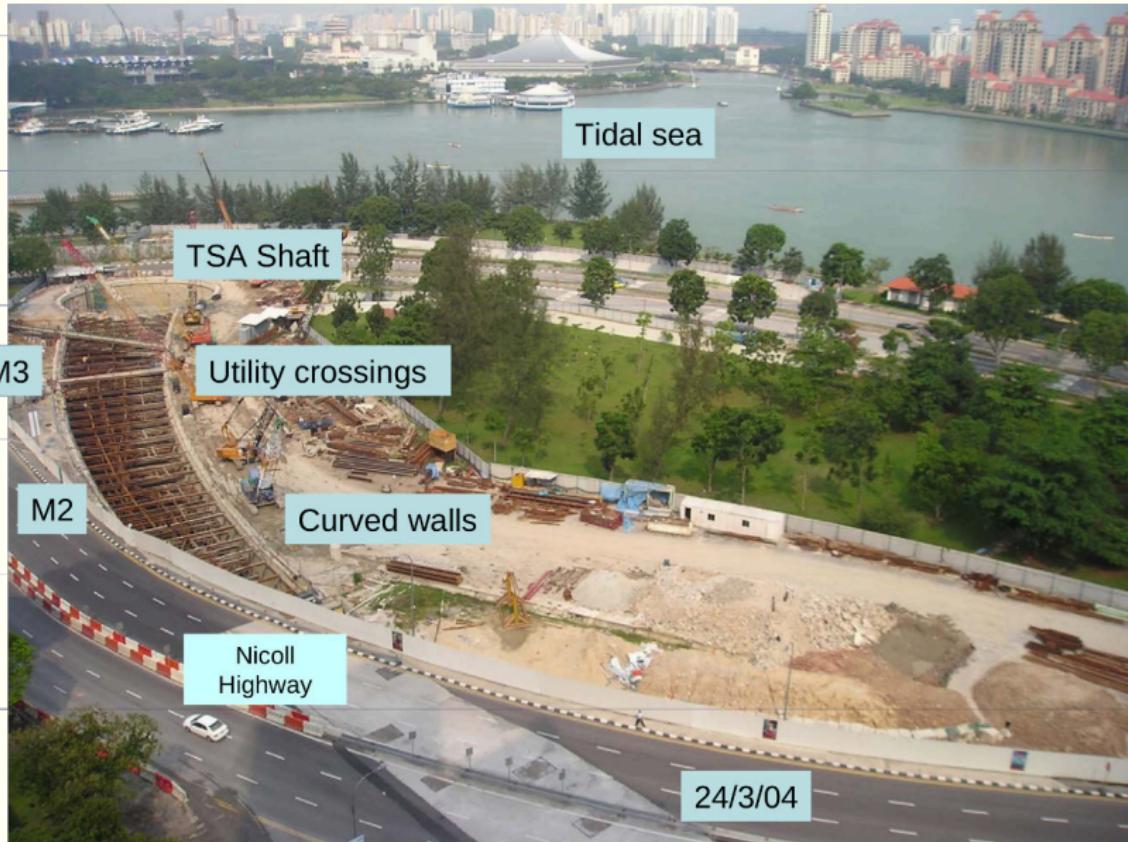
Pore pressure free = no water flow perpendicular to the boundary

FE boundary conditions



FE errors

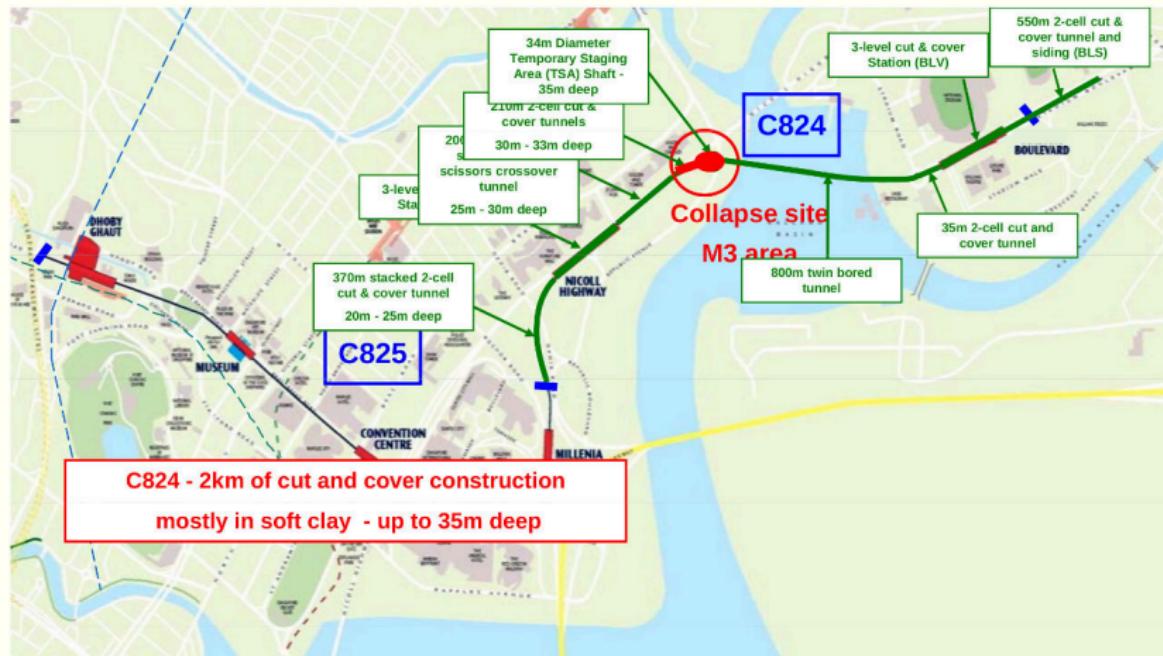
Nicoll Highway, Singapore



Nicoll Highway, Singapore

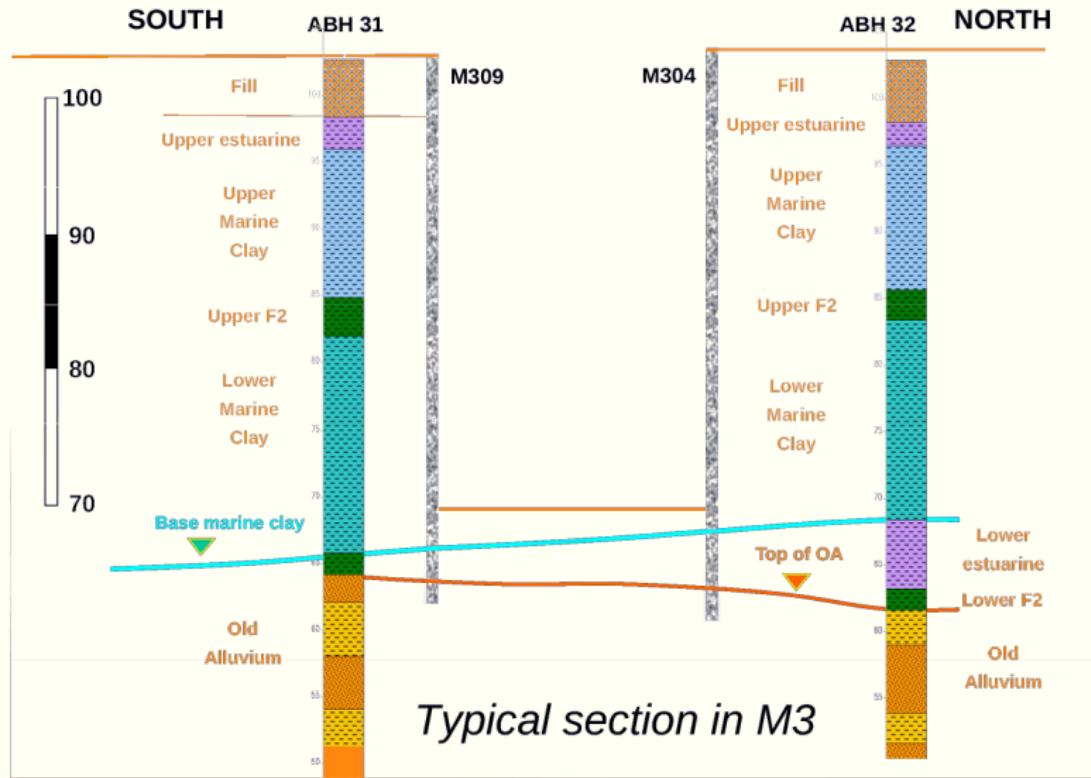


Nicoll Highway, Singapore

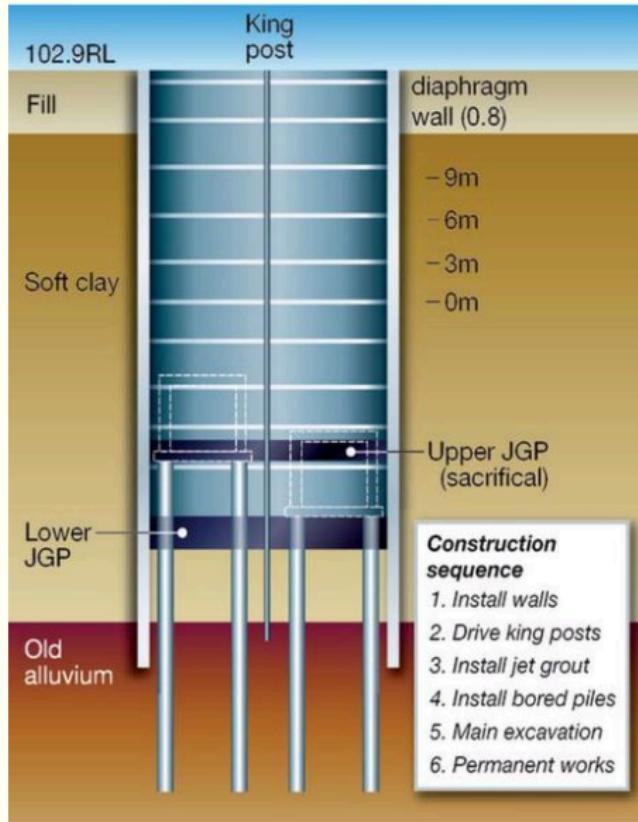


Cut and cover construction

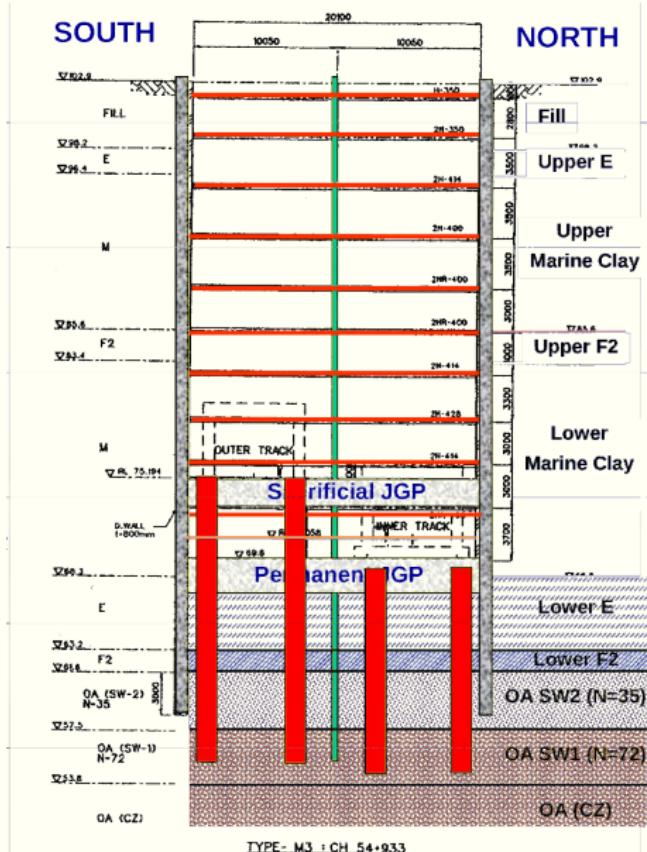
Soil profile



Construction sequence



Construction sequence



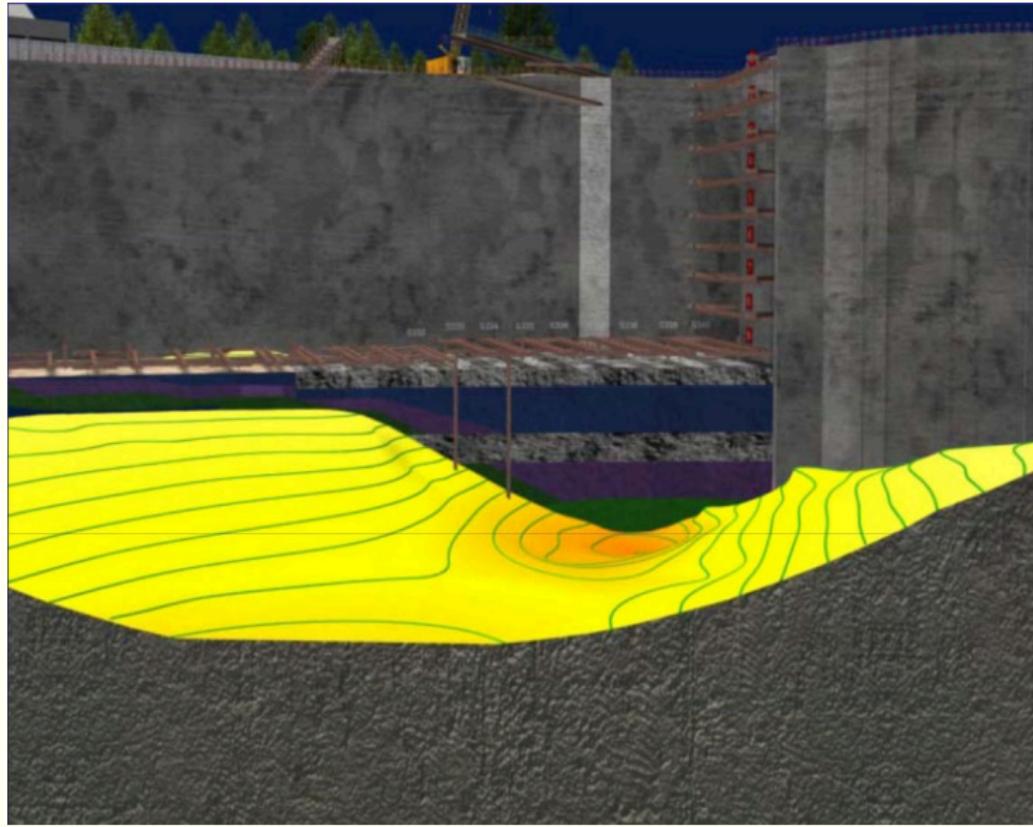
Nicoll Highway: Excavation



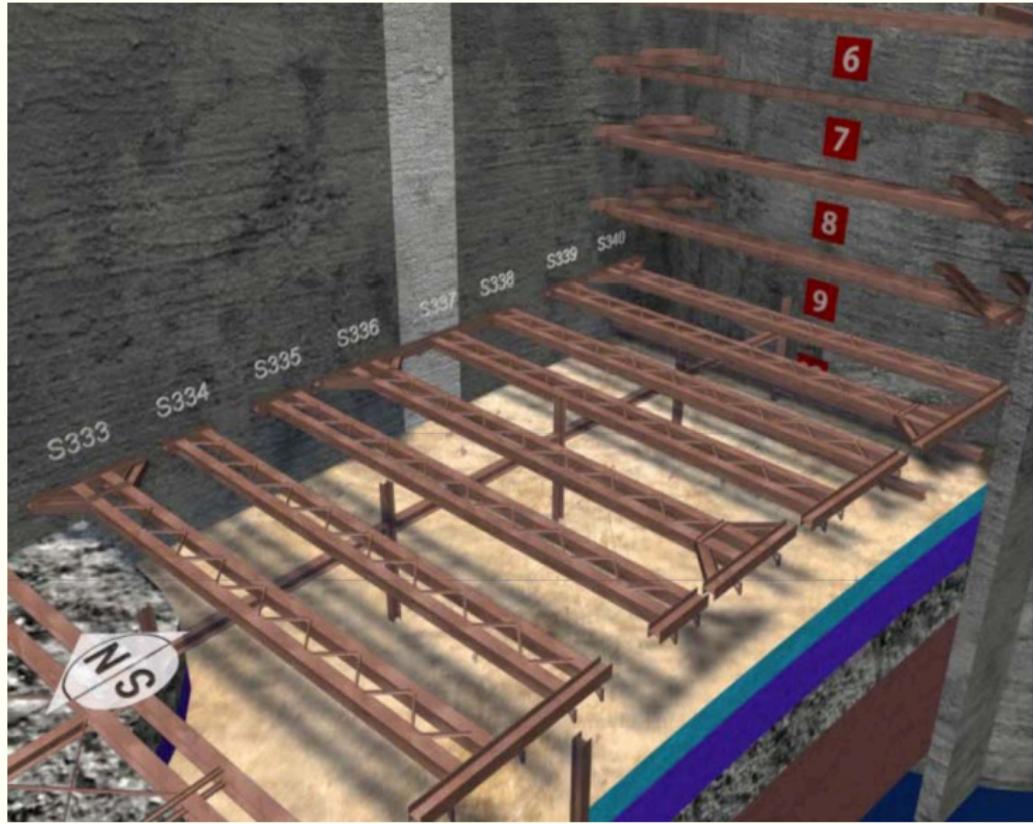
South side 13 March 2004



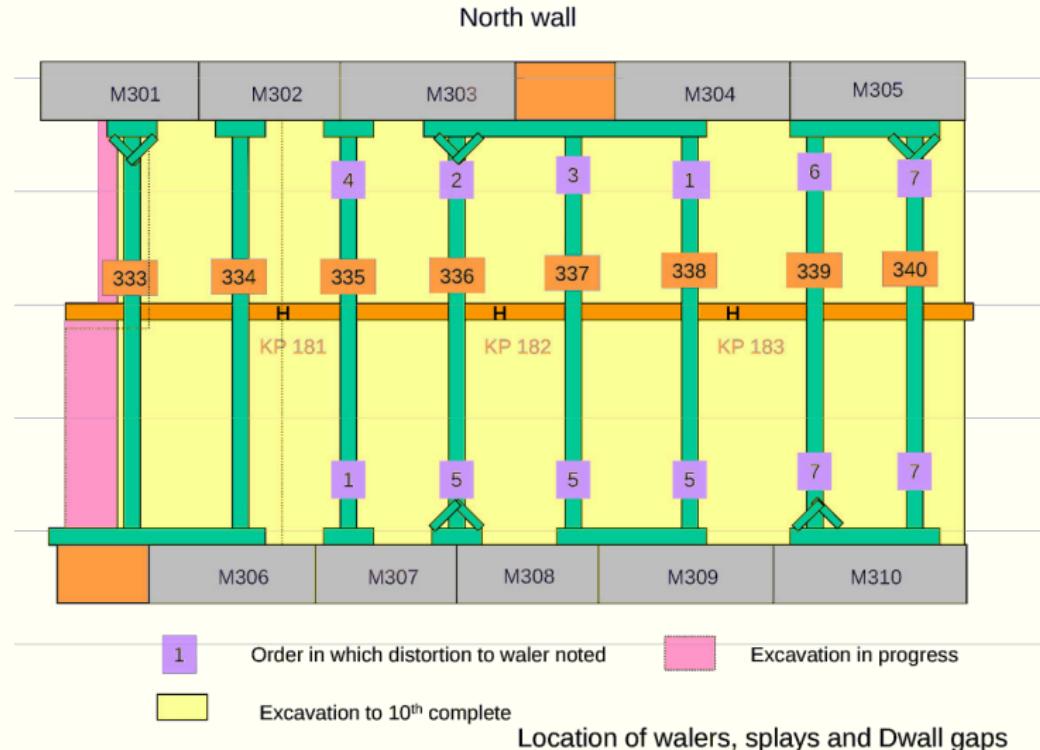
Excavating 10th level of struts



On the morning of collapse



On the morning of collapse



On the morning of collapse



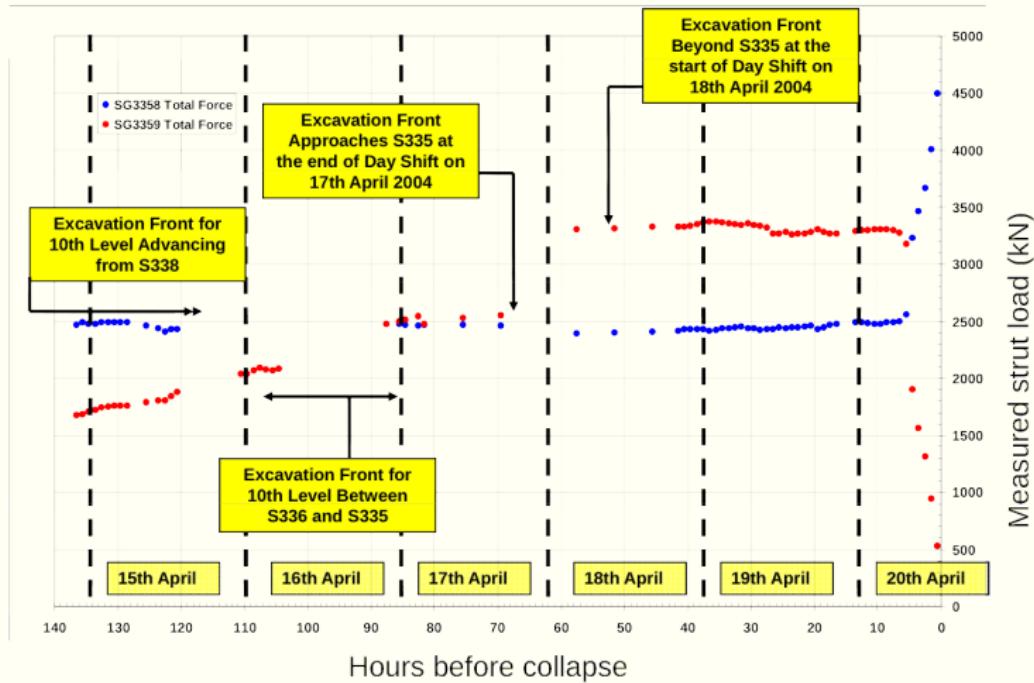
Strut 338 North side

On the morning of collapse

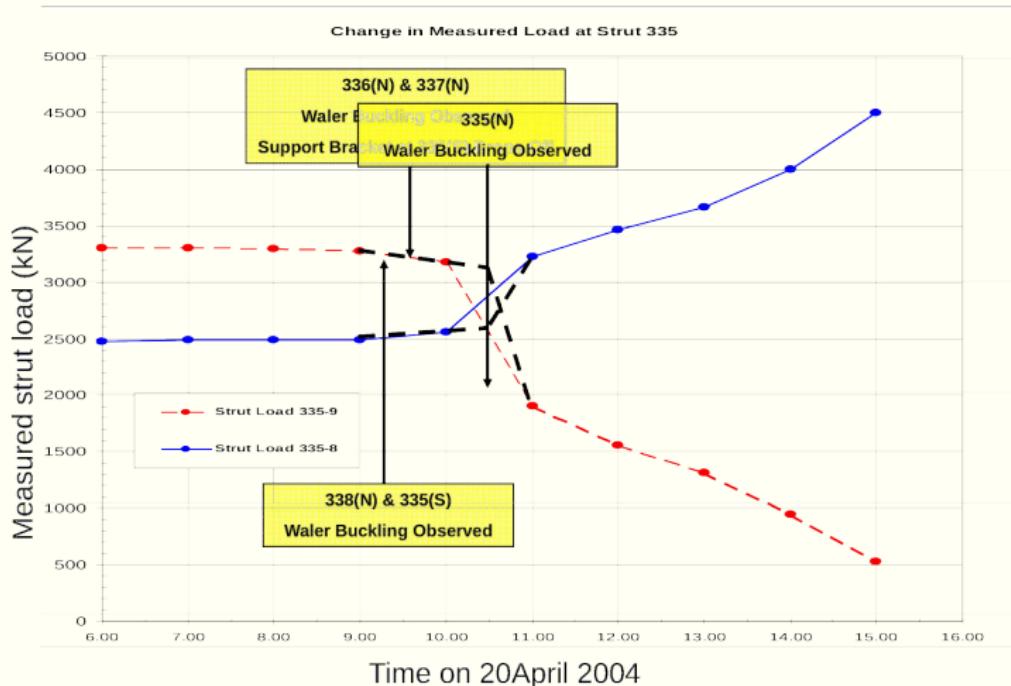


Strut 335 Sorth side

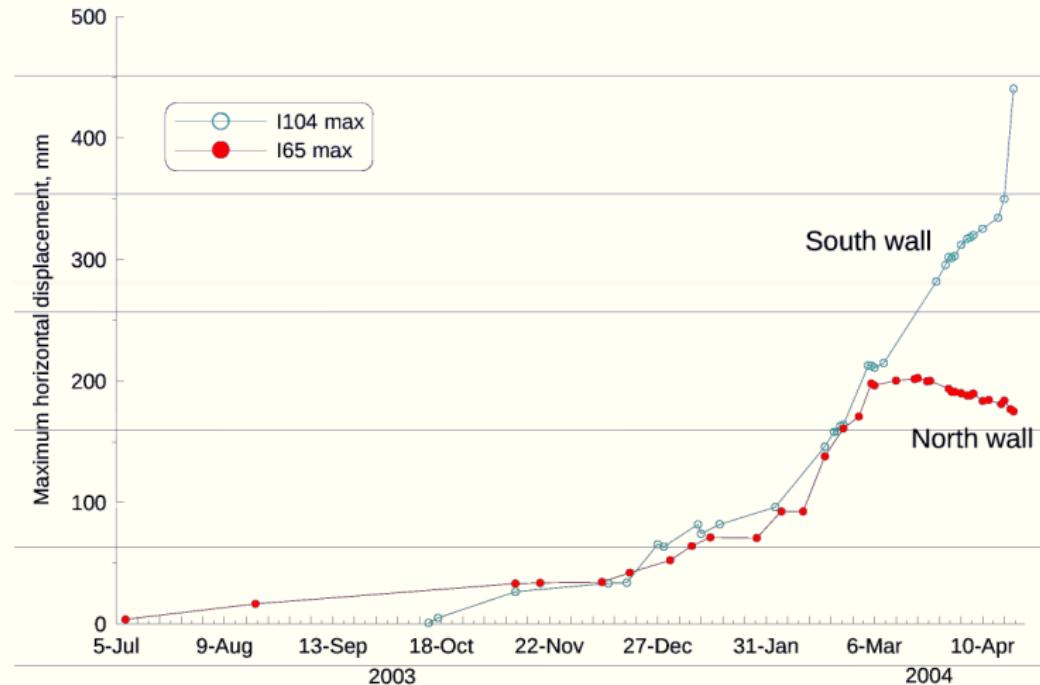
Hours before collapse



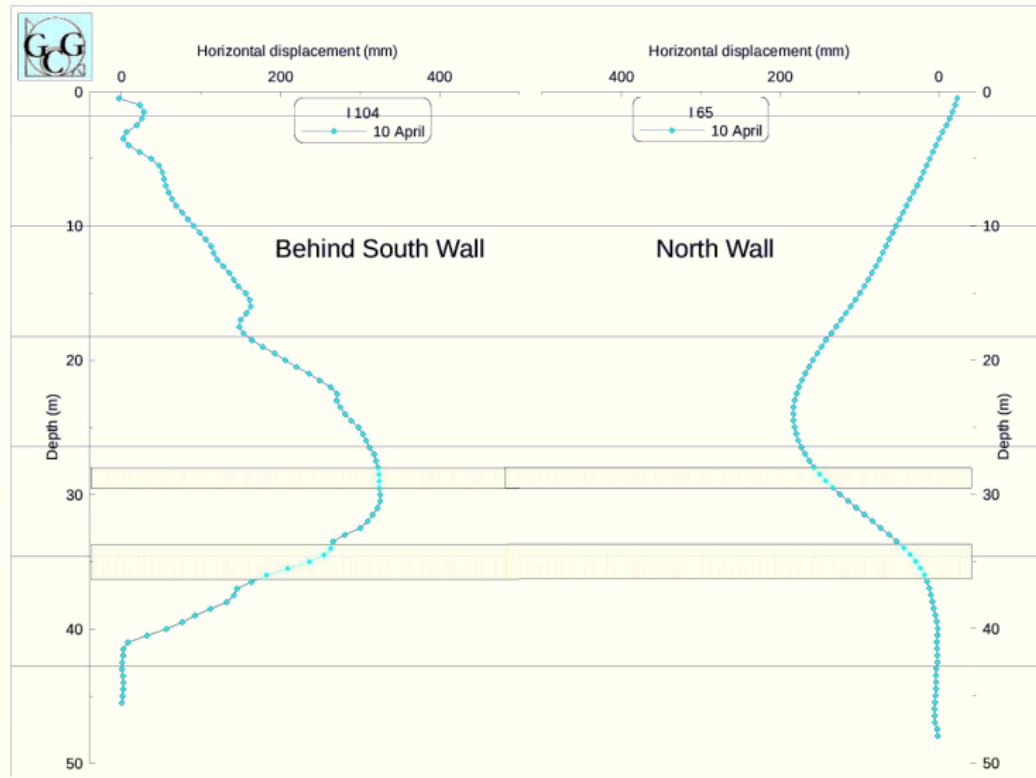
Hours before collapse



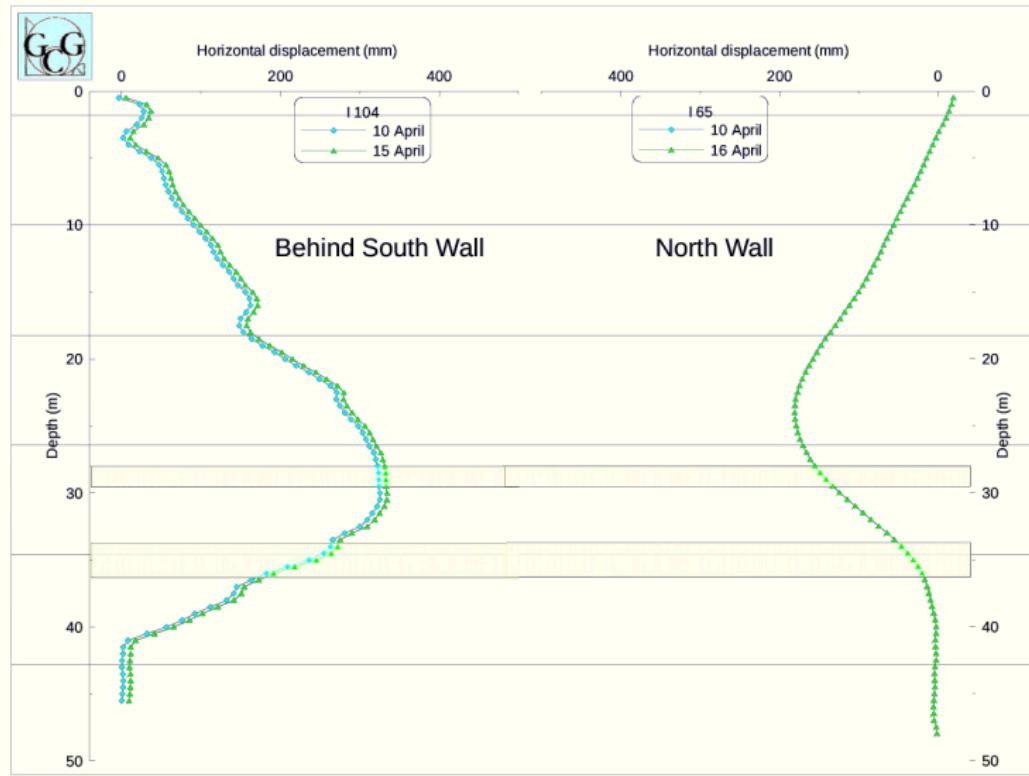
Leading up to the collapse: Inclinometer



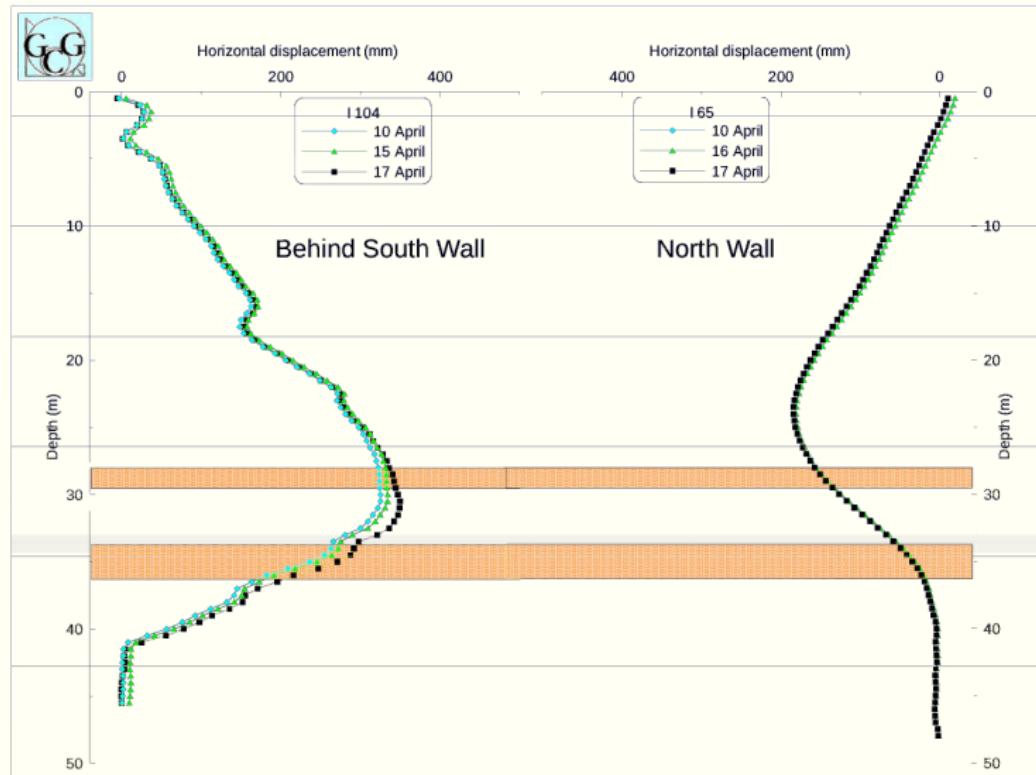
Leading up to the collapse: Wall displacements



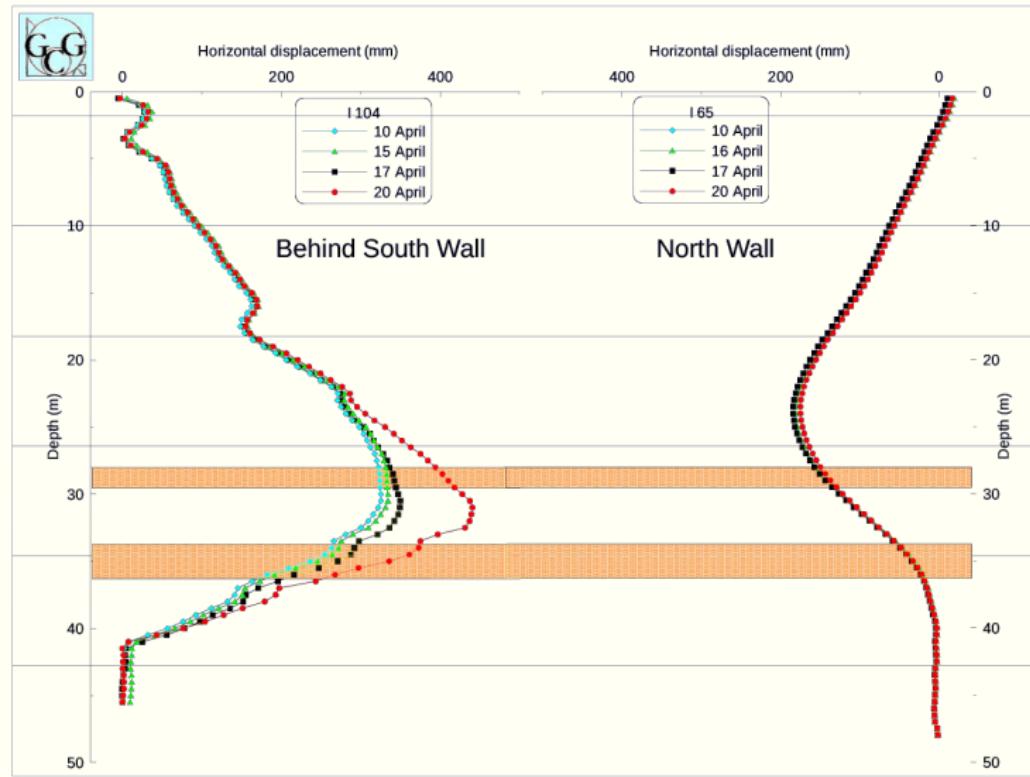
Leading up to the collapse: Wall displacements



Leading up to the collapse: Wall displacements



Leading up to the collapse: Wall displacements



The collapse



The collapse



The collapse



3.34pm

The collapse



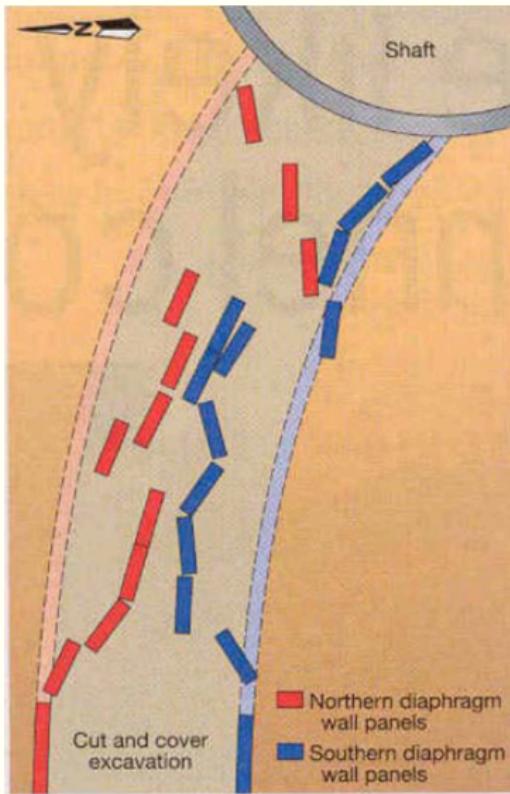
The collapse



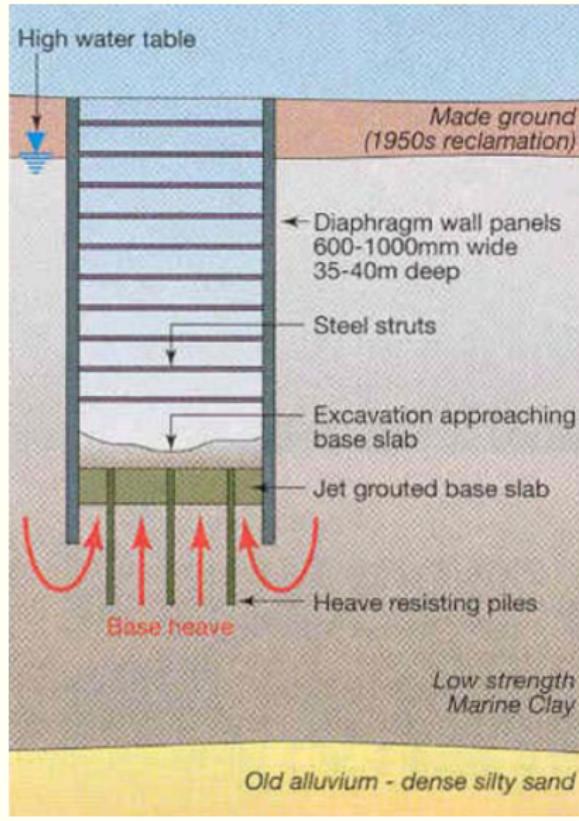
Post collapse



Post collapse



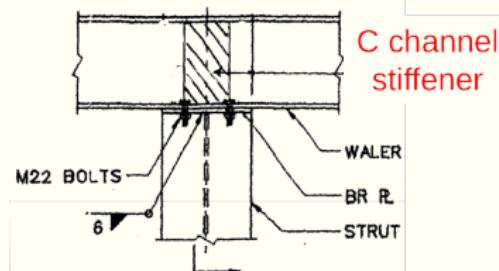
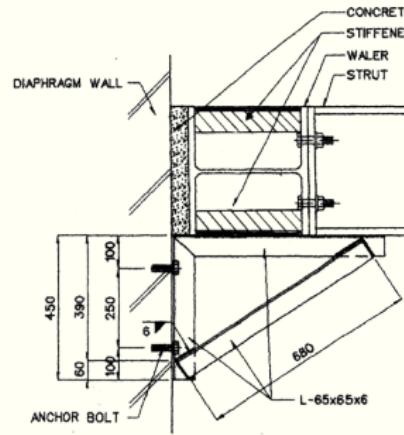
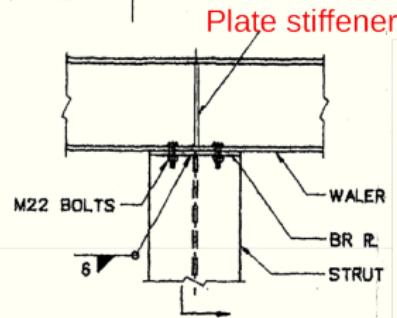
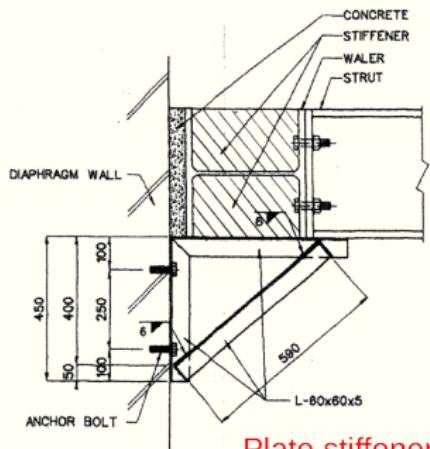
Reasons for collapse



Strut design: Replacing plate-stiffener with C-channel



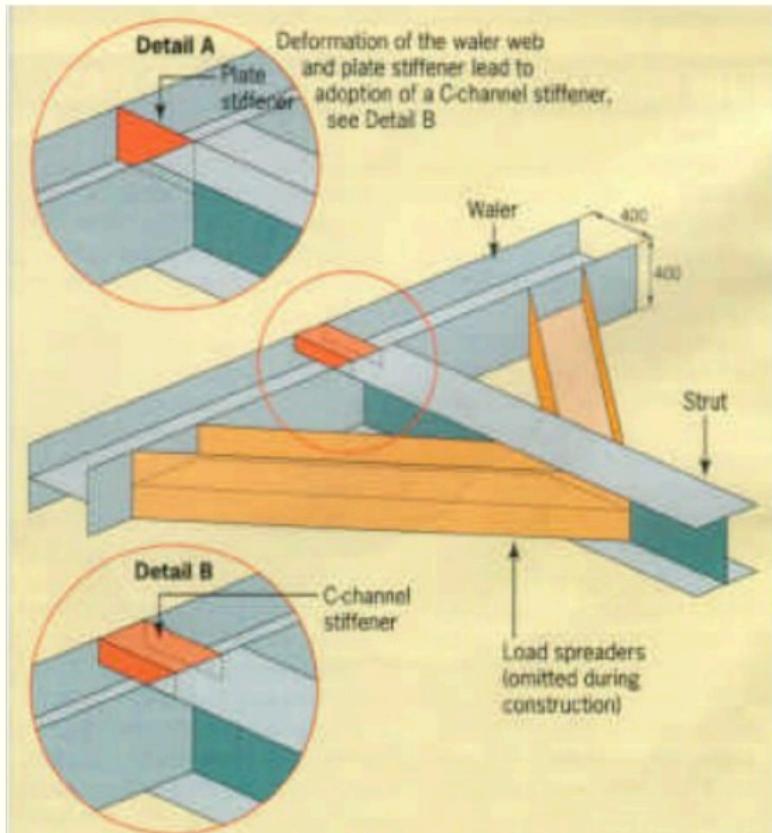
Strut design: Waler connection



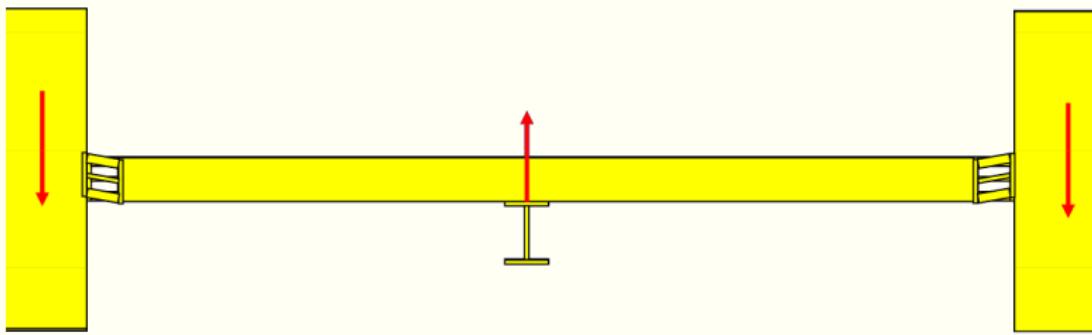
Strut design: Waler connection



Strut design: Waler connection

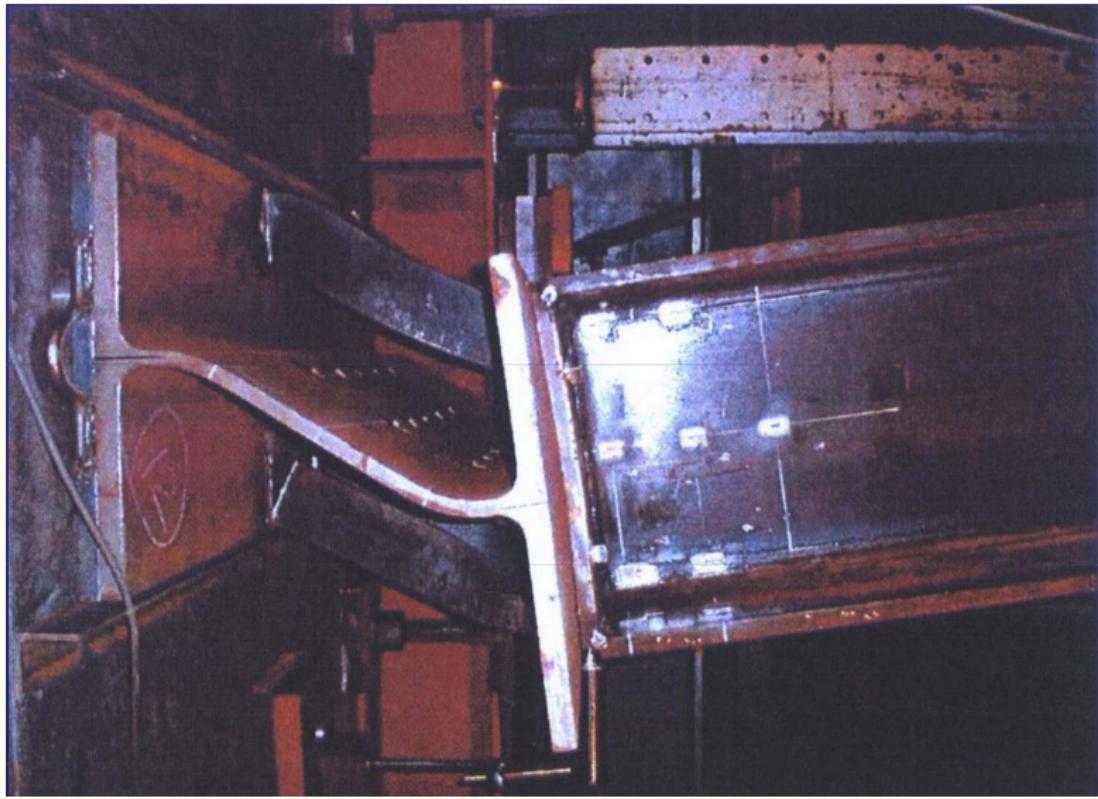


Strut design: Relative vertical displacements

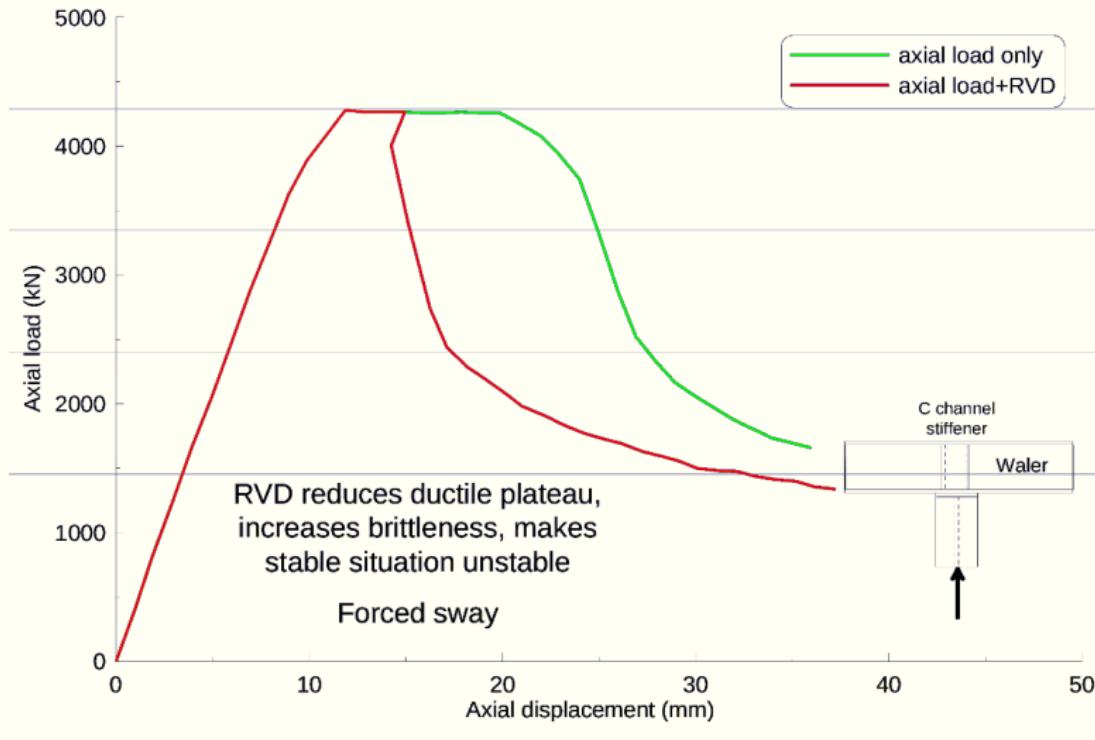


Relative vertical displacement between the King Post and the Dwall

Strut design: C-channel



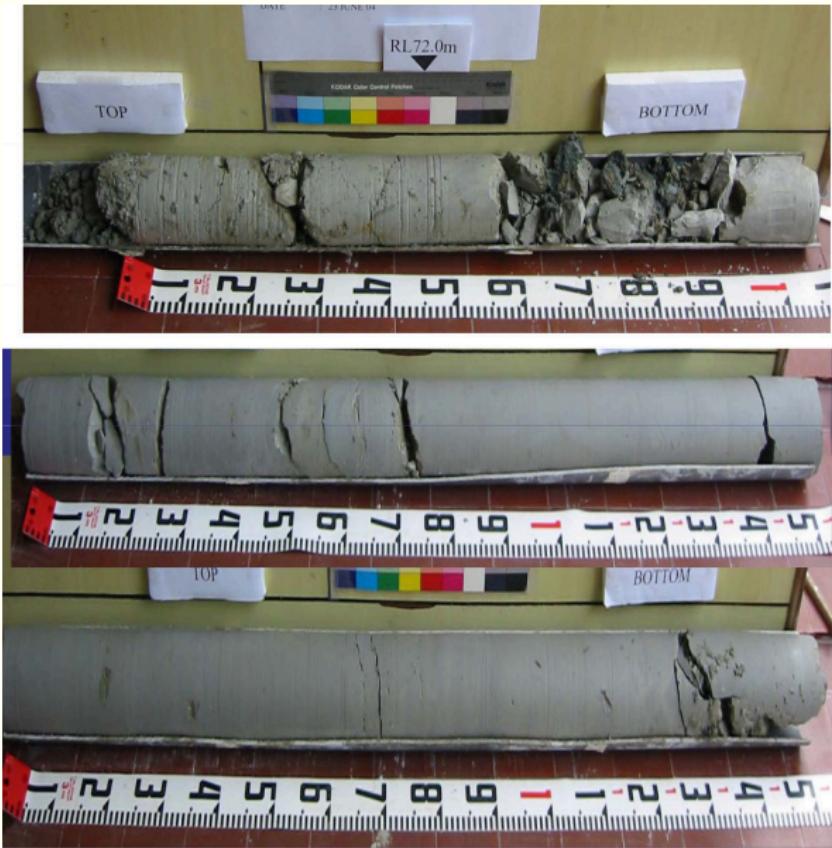
Strut design: C-channel relative vertical displacement



Excavation of sacrificial jet grout



Quality of jet grouting

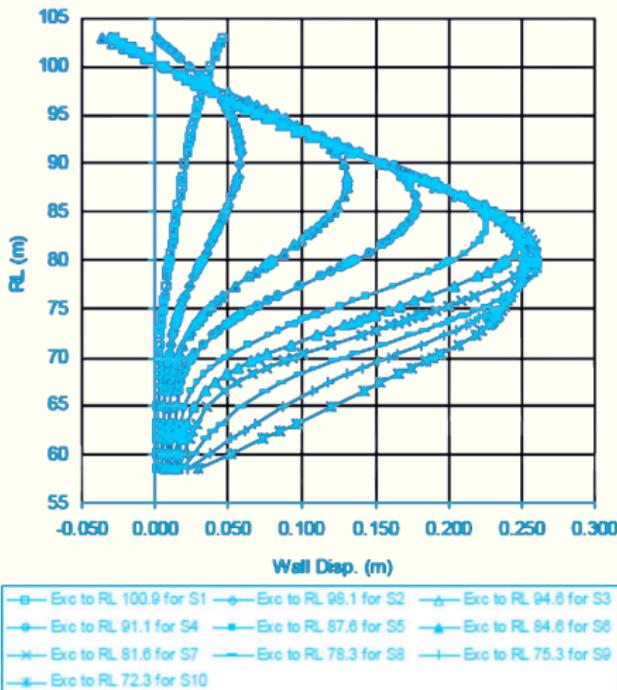
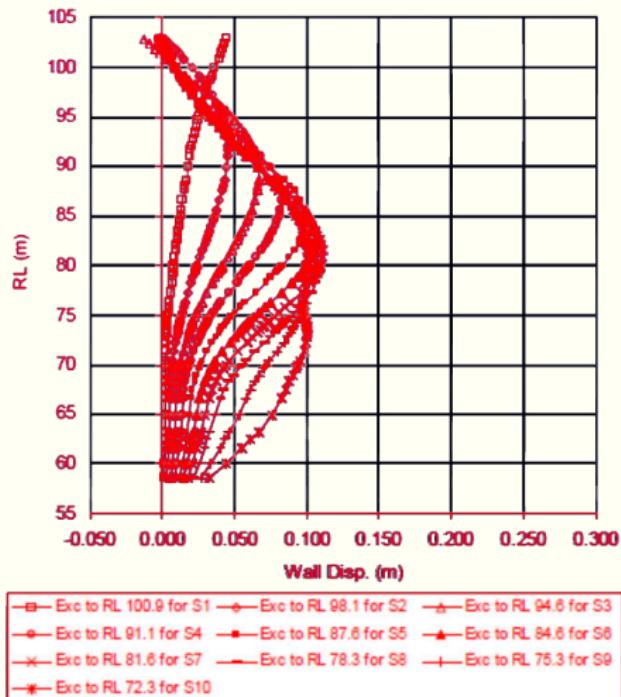


Porepressure analysis in geotechnical engineering

Undrained analysis

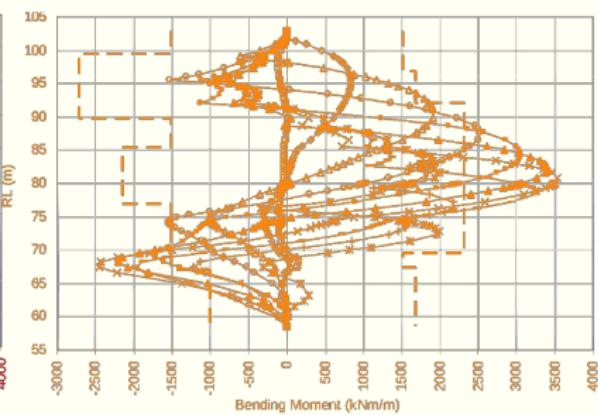
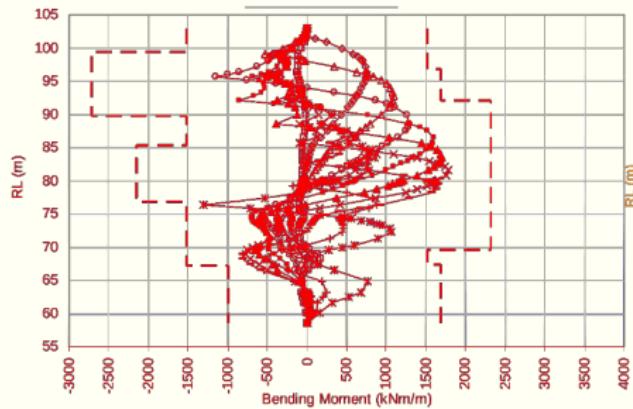
Undrained effective stress analysis

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