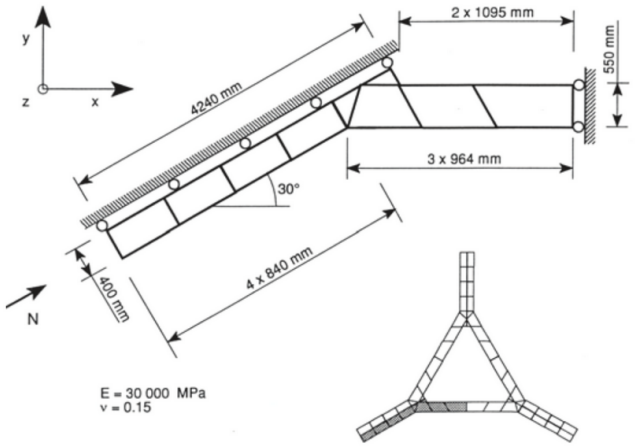
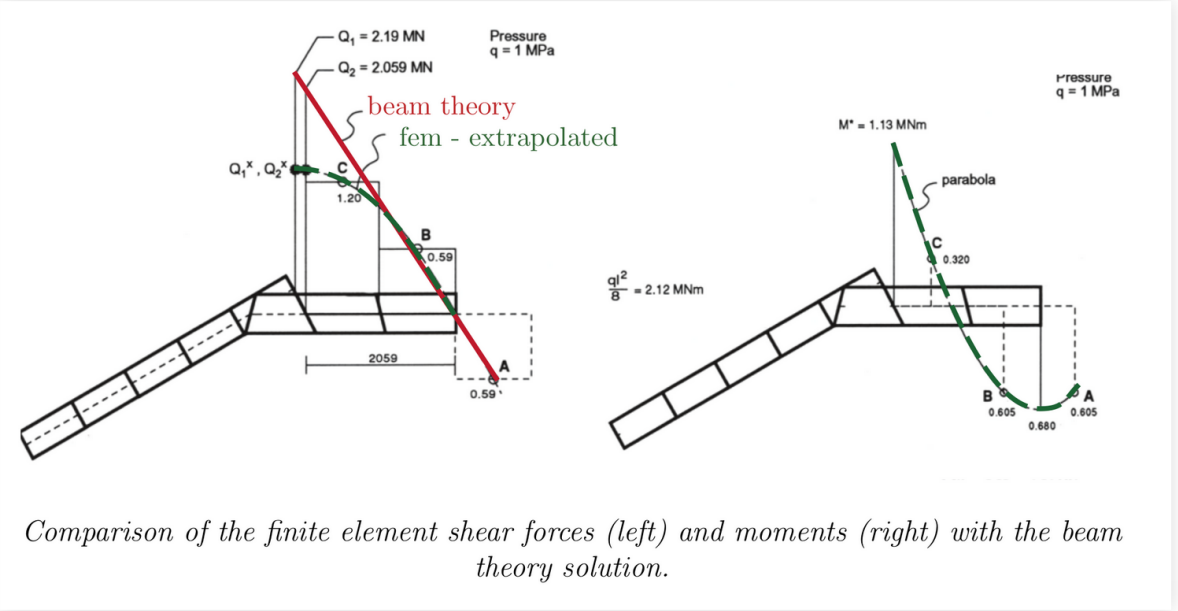
Sleipner A offshore platform sprang leak

Platform with a reinforced concrete base structure.



Concrete substructure during manufacturing on shore. Finite element mesh of a tricell detail. A tricell is a triangular concrete frame placed where three cells meet.

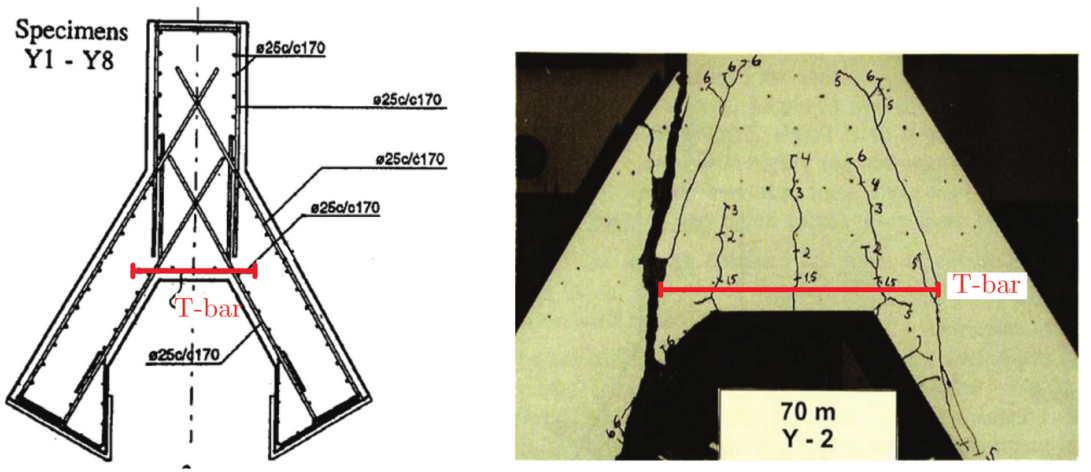
Sleipner A offshore platform sprang leak



Comparison of the finite element shear forces (left) and moments (right) with the beam theory solution.

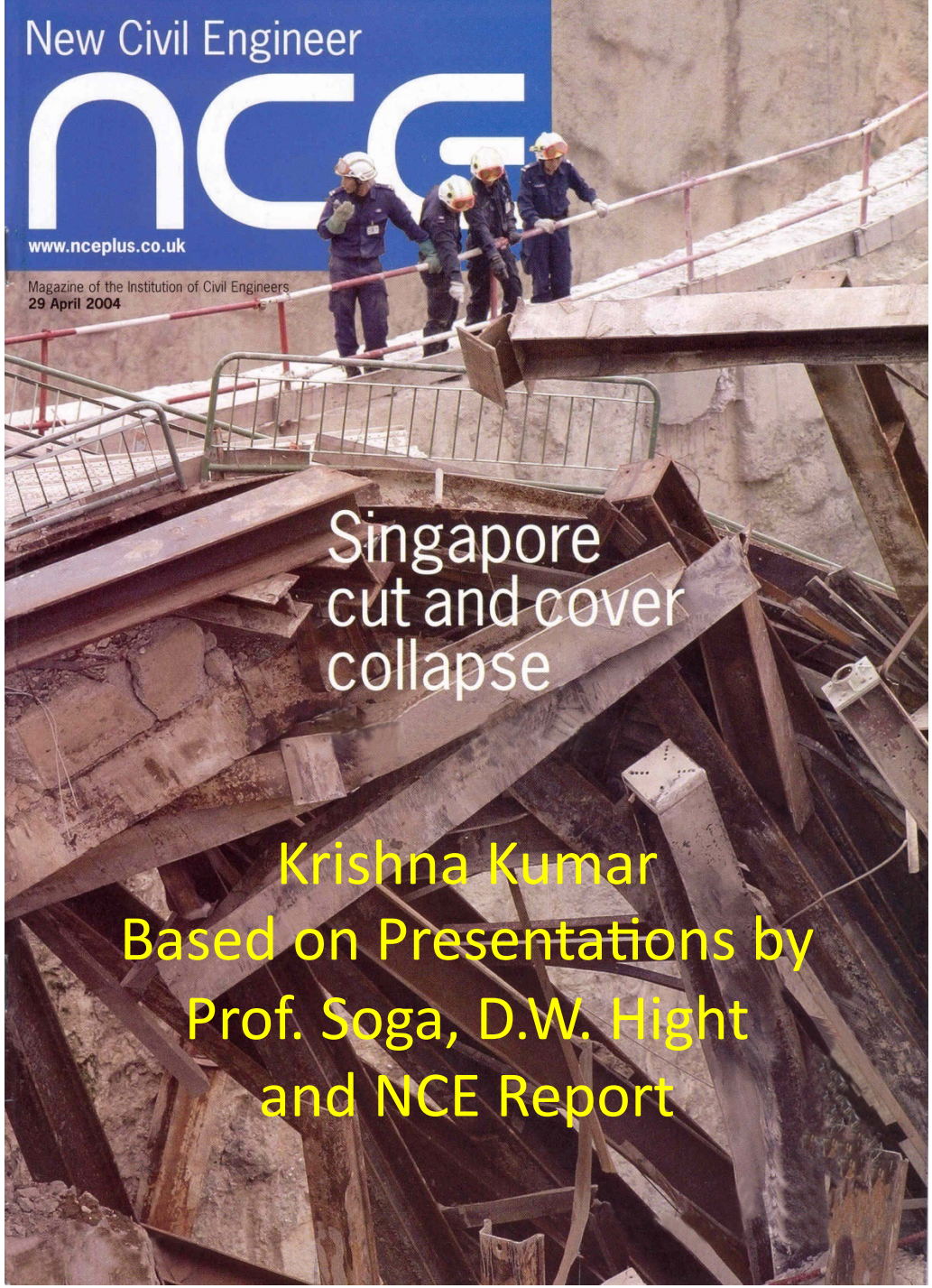
Second, the shear stresses at the boundary have been quadratically extrapolated using the shear forces at points A, B and C. We know however from beam theory that the shear force distribution is linear so that the shear force at the boundary is underestimated by ≈ 40%

Sleipner A offshore platform sprang leak

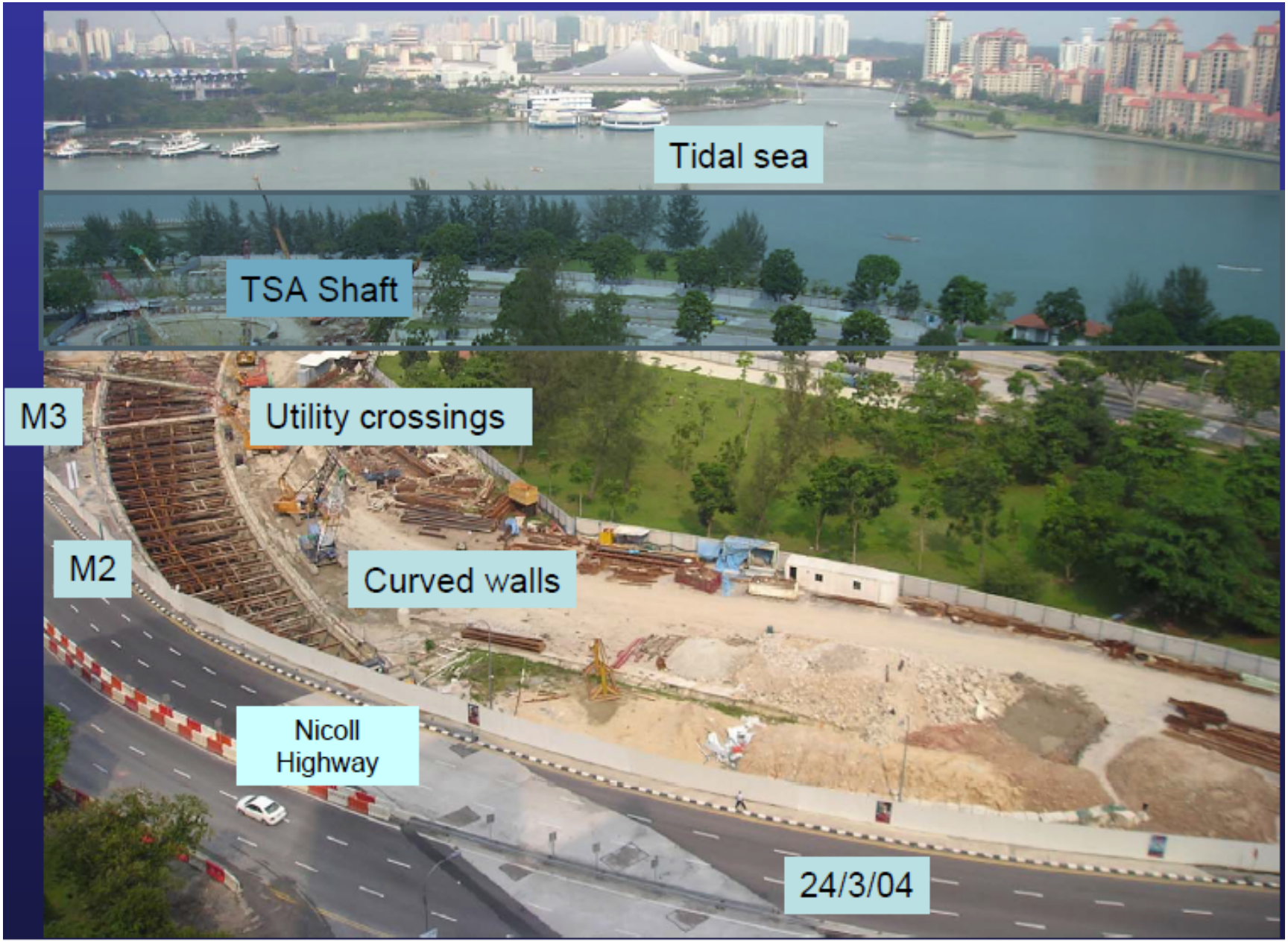


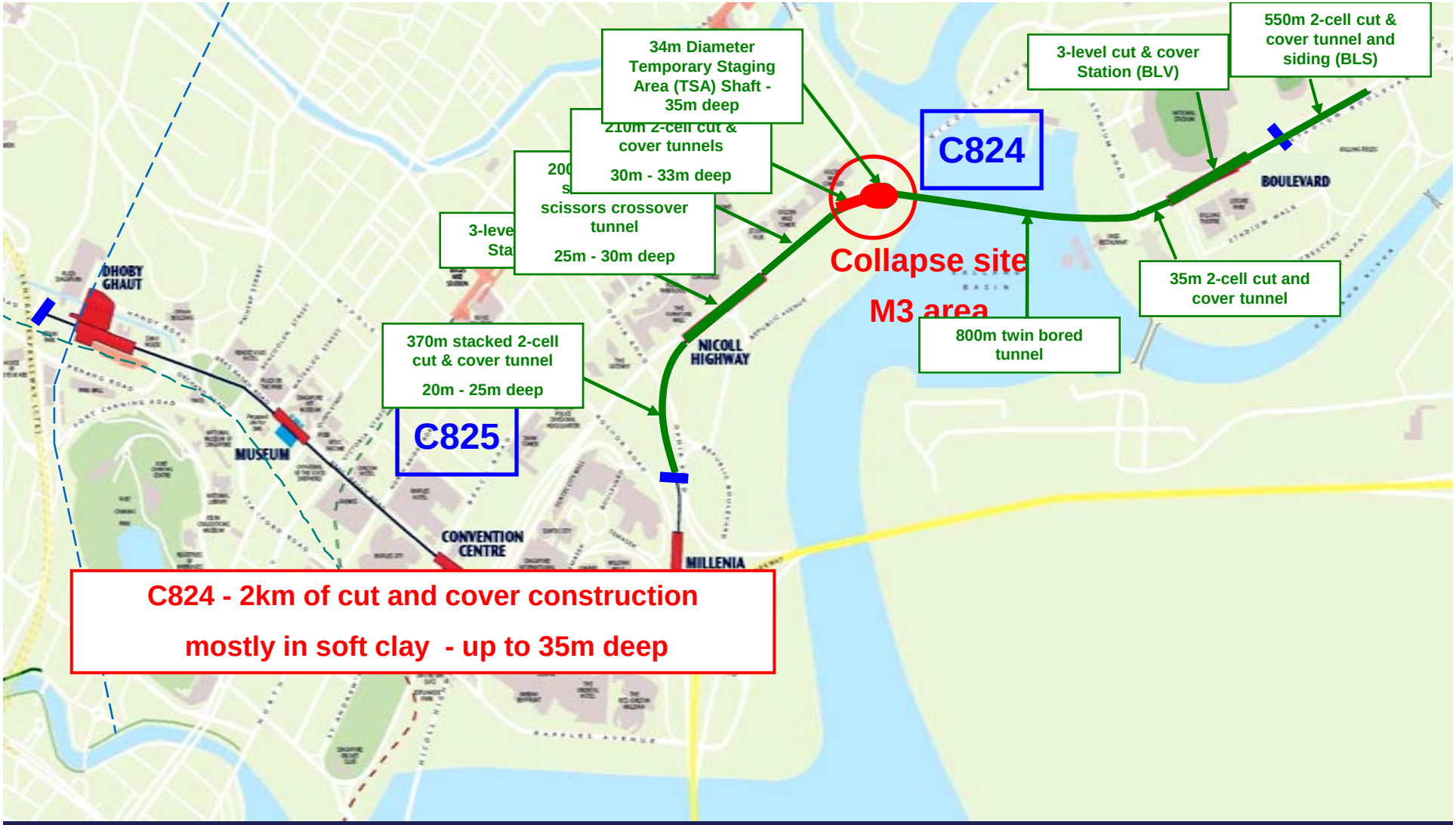
Experimental investigation of the tricell failure. As can be concluded from the failure mode the T-bar length is too short.

To make matters worse, the necessary reinforcement was automatically dimensioned based on the finite element results without any checking by an engineer.

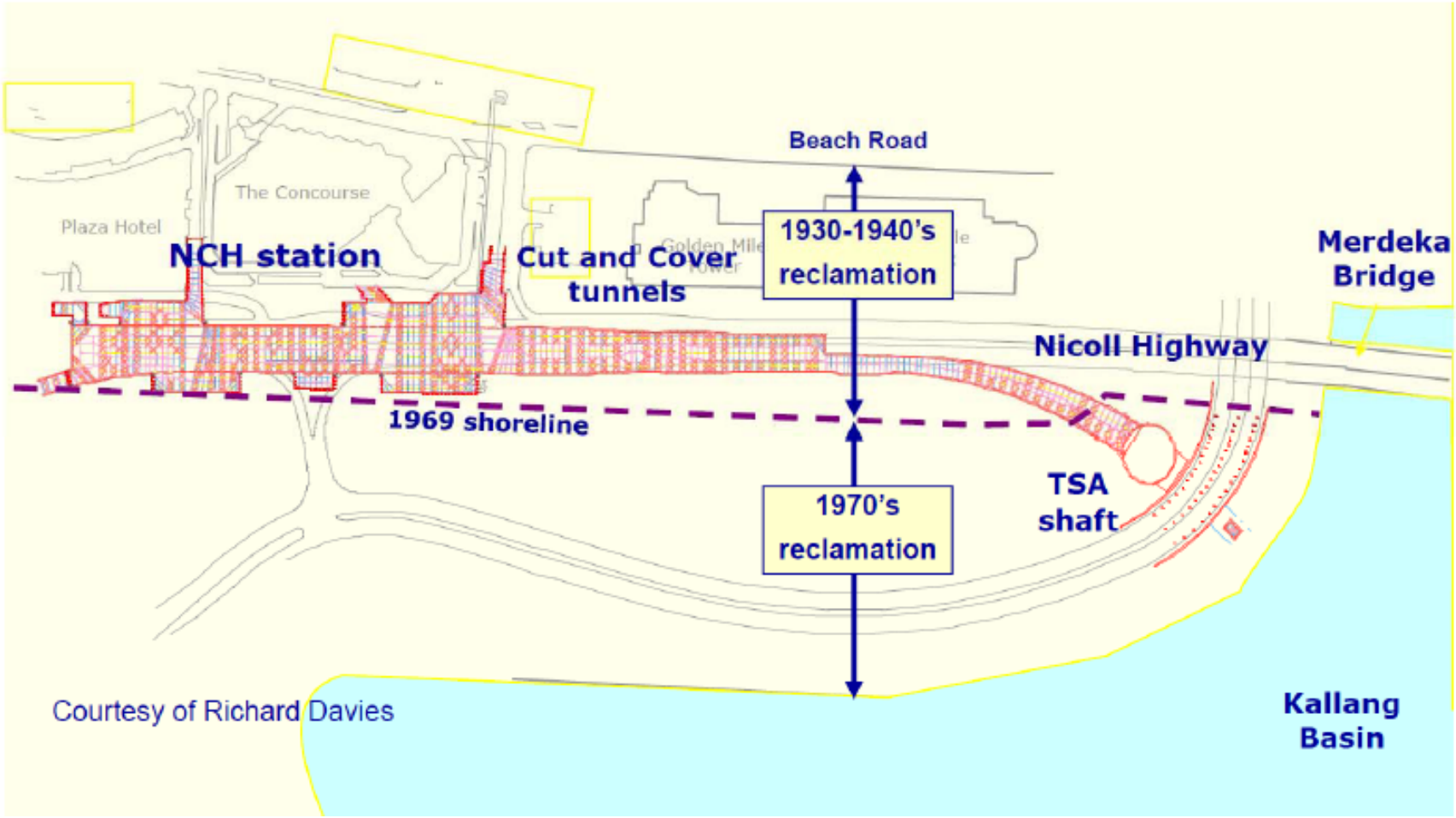

New Civil Engineer
nce
www.nceplus.co.uk
Magazine of the Institution of Civil Engineers
29 April 2004
Singapore cut and cover collapse
Krishna Kumar
Based on Presentations by
Prof. Soga, D.W. Hight
and NCE Report

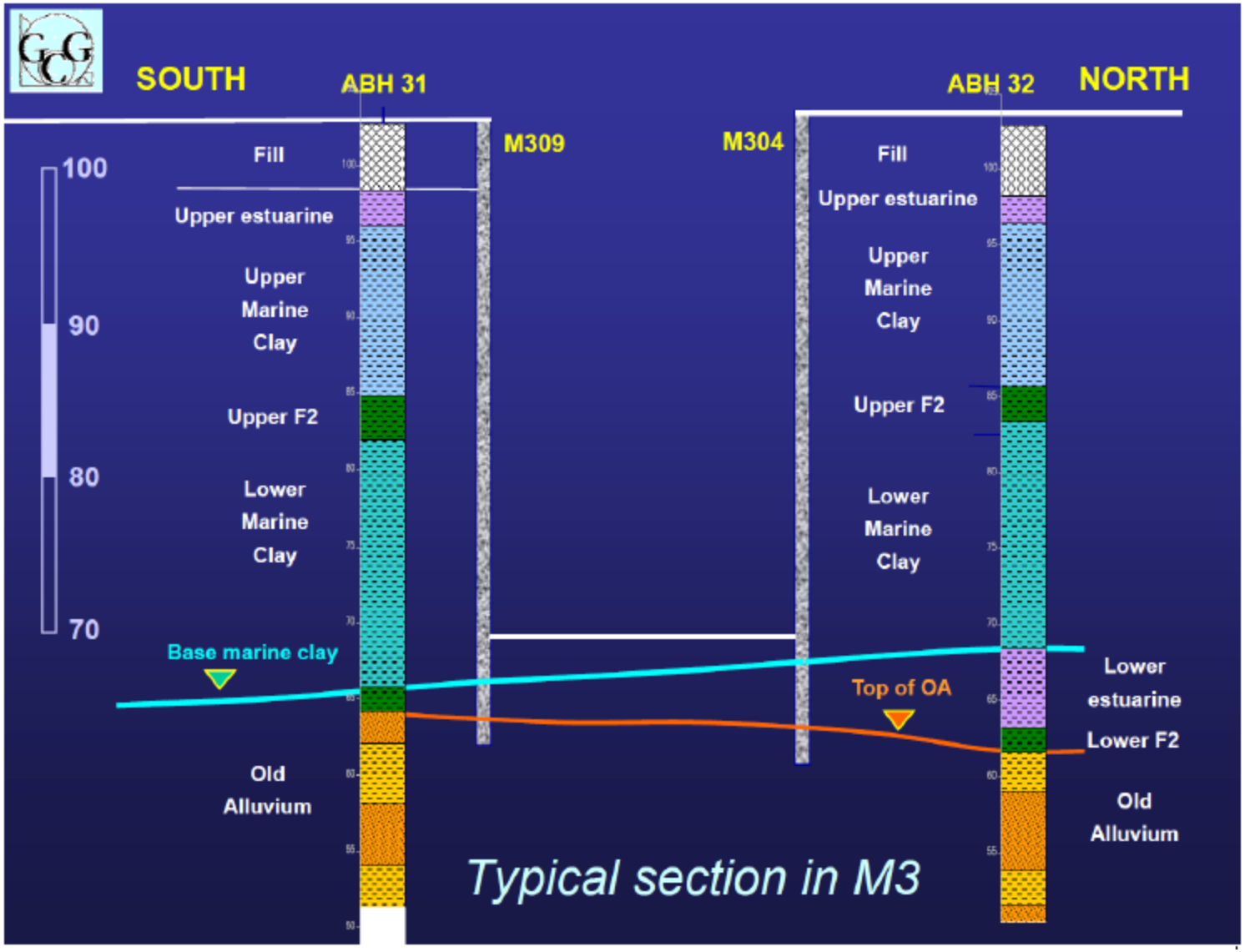
Nicoll Highway, Singapore





Circle Line Stage 1


Beach Road
The Concourse
Plaza Hotel
NCH station
Cut and Cover tunnels
1930-1940's reclamation
Merdeka Bridge
Nicoll Highway
1969 shoreline
TSA shaft
1970's reclamation
Courtesy of Richard Davies
Kallang Basin

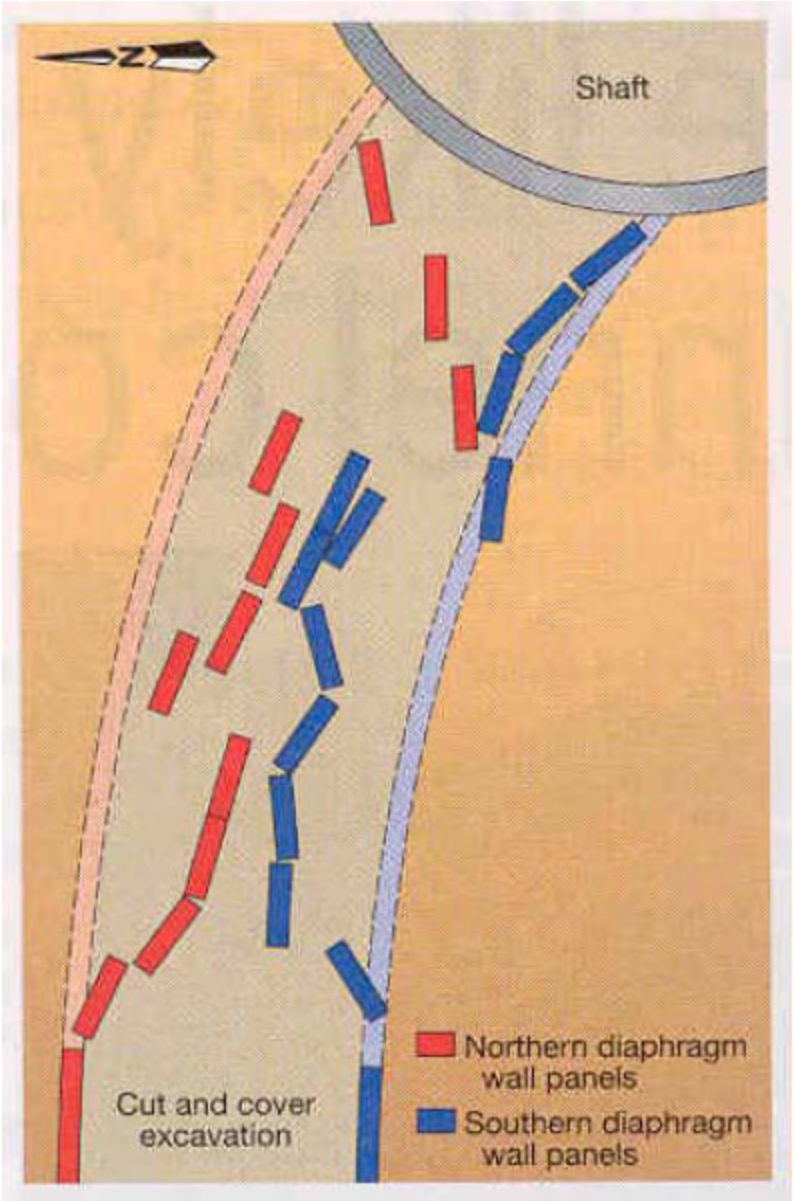

SOUTH
ABH 31
M309
M304
ABH 32
NORTH
100
90
80
70
Fill
Upper estuarine
Upper Marine Clay
Upper F2
Lower Marine Clay
Base marine clay
Old Alluvium
Fill
Upper estuarine
Upper Marine Clay
Upper F2
Lower Marine Clay
Top of OA
Lower estuarine
Lower F2
Old Alluvium
Typical section in M3


3.33pm


3.33pm

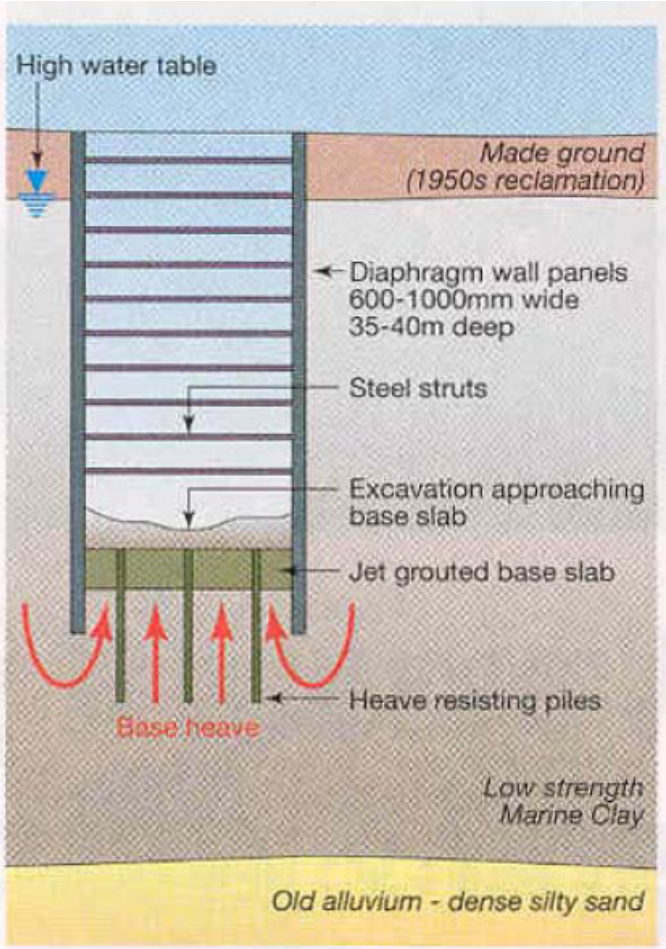

3.34pm


3:41pm


Shaft
Cut and cover excavation
Northern diaphragm wall panels
Southern diaphragm wall panels

Reasons for collapse

- Problem with Jet grouting at the base slab.
- Struts design – connector
- Use of **effective stress parameters** to do **undrained excavation**.




Support beam
Shaft
Kingpost
M3
No waler
C channel stiffener
Non-splayed strut
Jacking point
Walers
M2
Splayed strut

South side 13 March 04

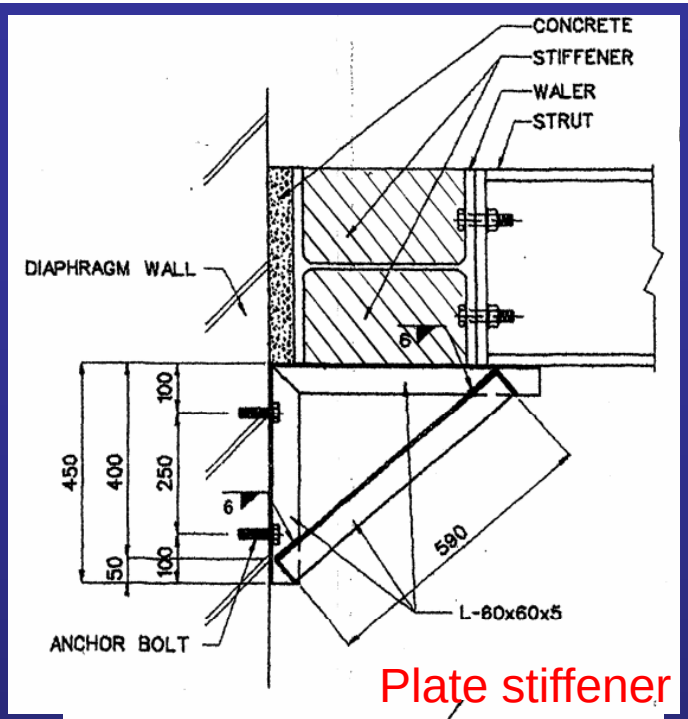
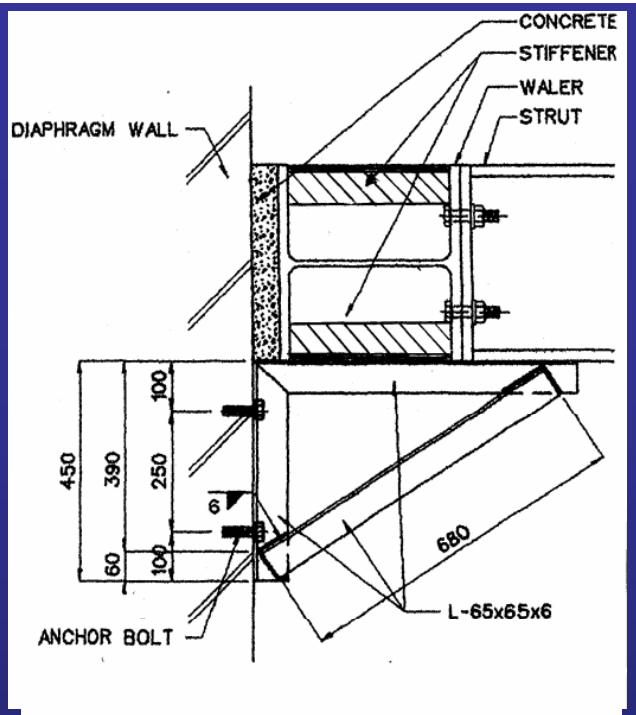
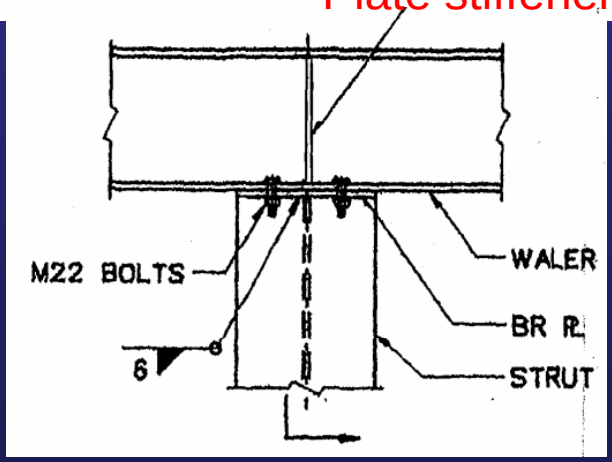
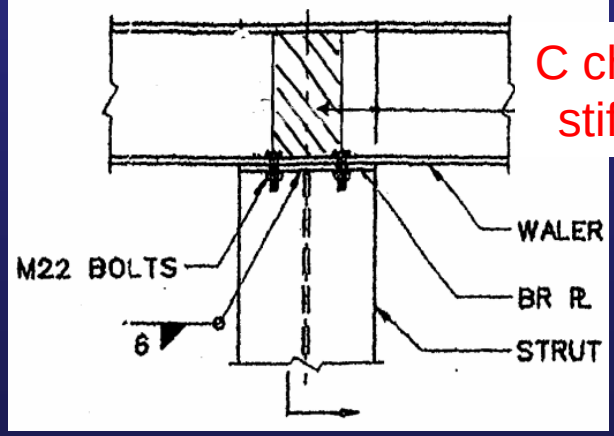


Plate stiffener





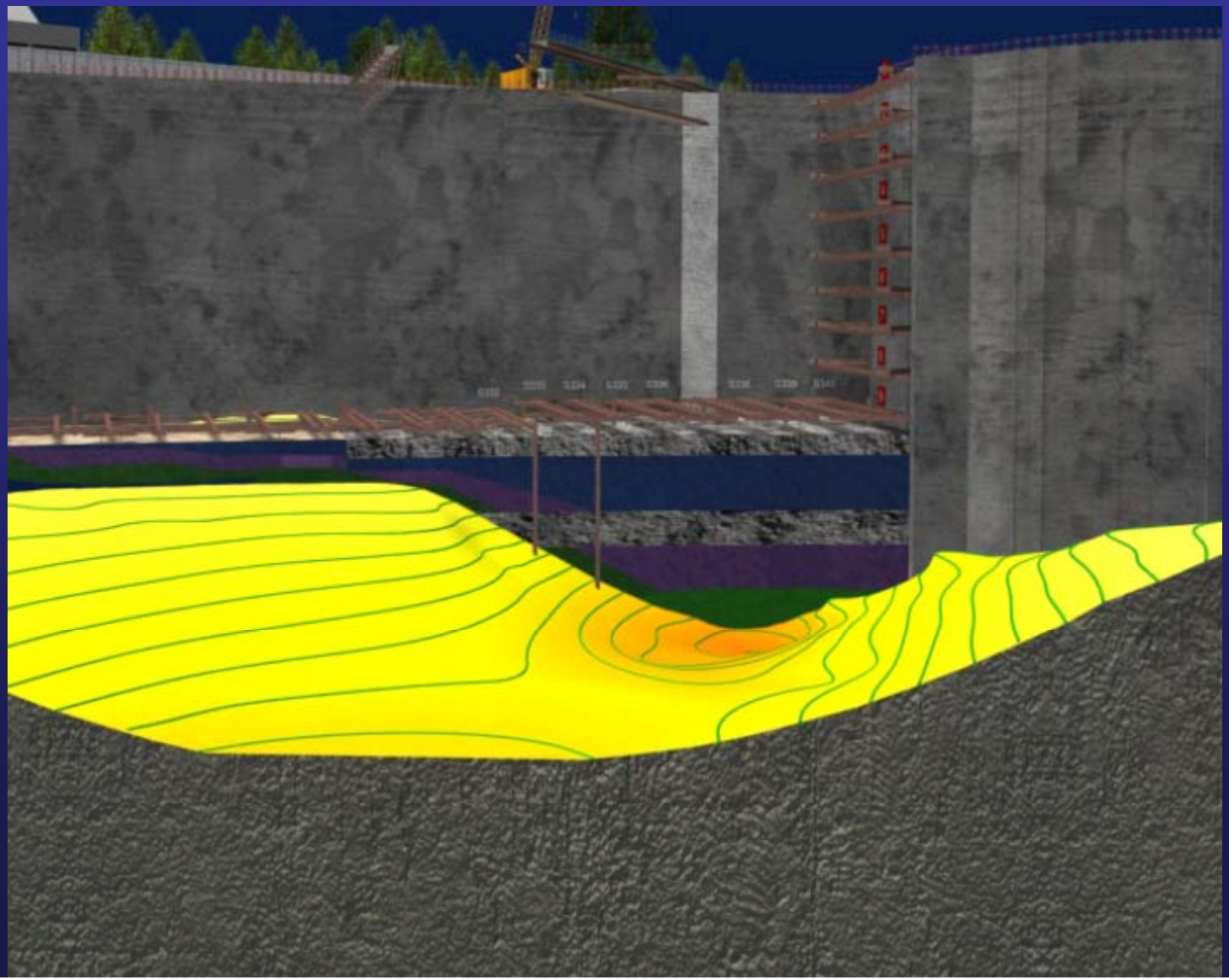
C channel stiffener



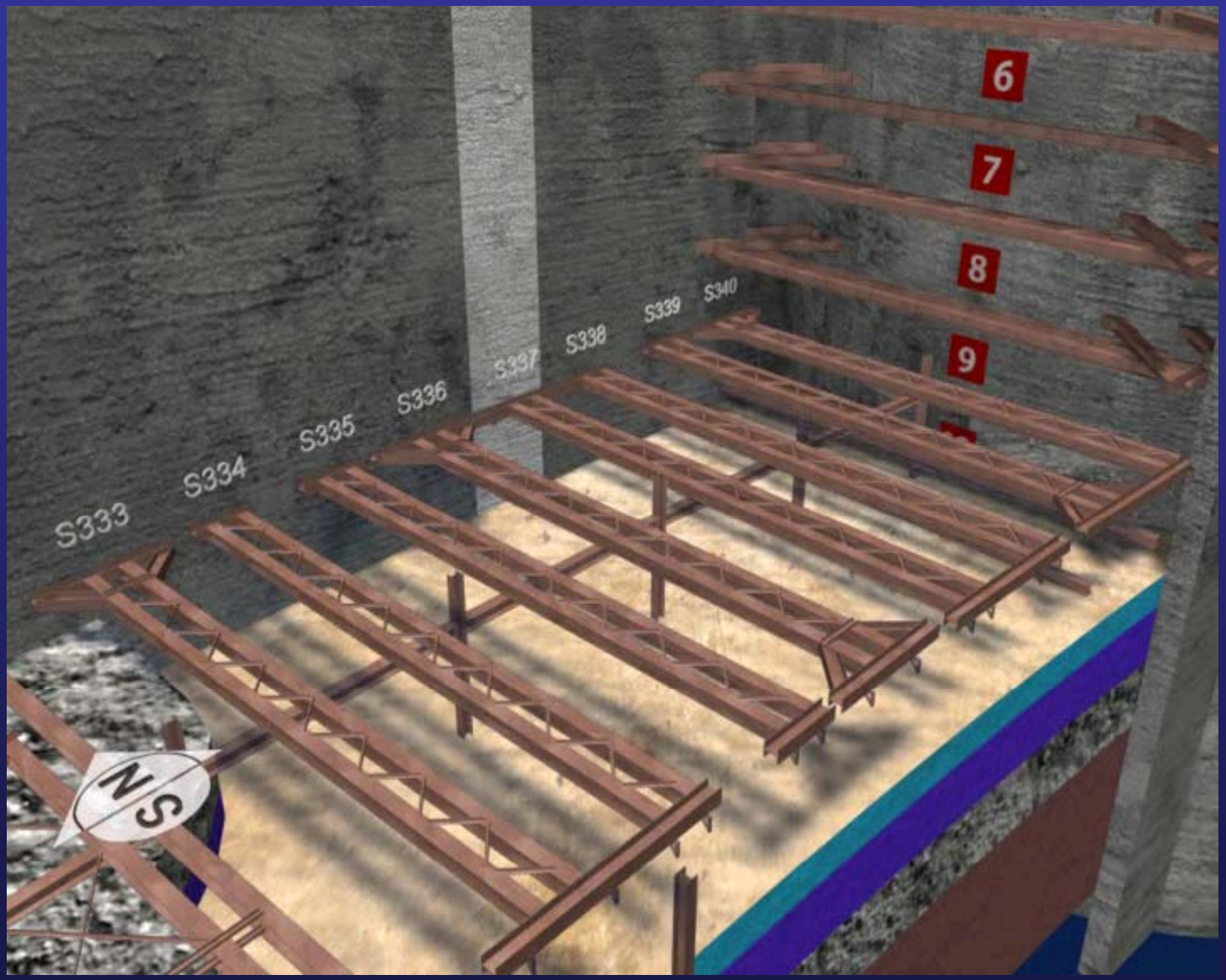
Replacement of plate stiffeners at strut-waler connection


Strut bearing directly on Dwall
C channel connection

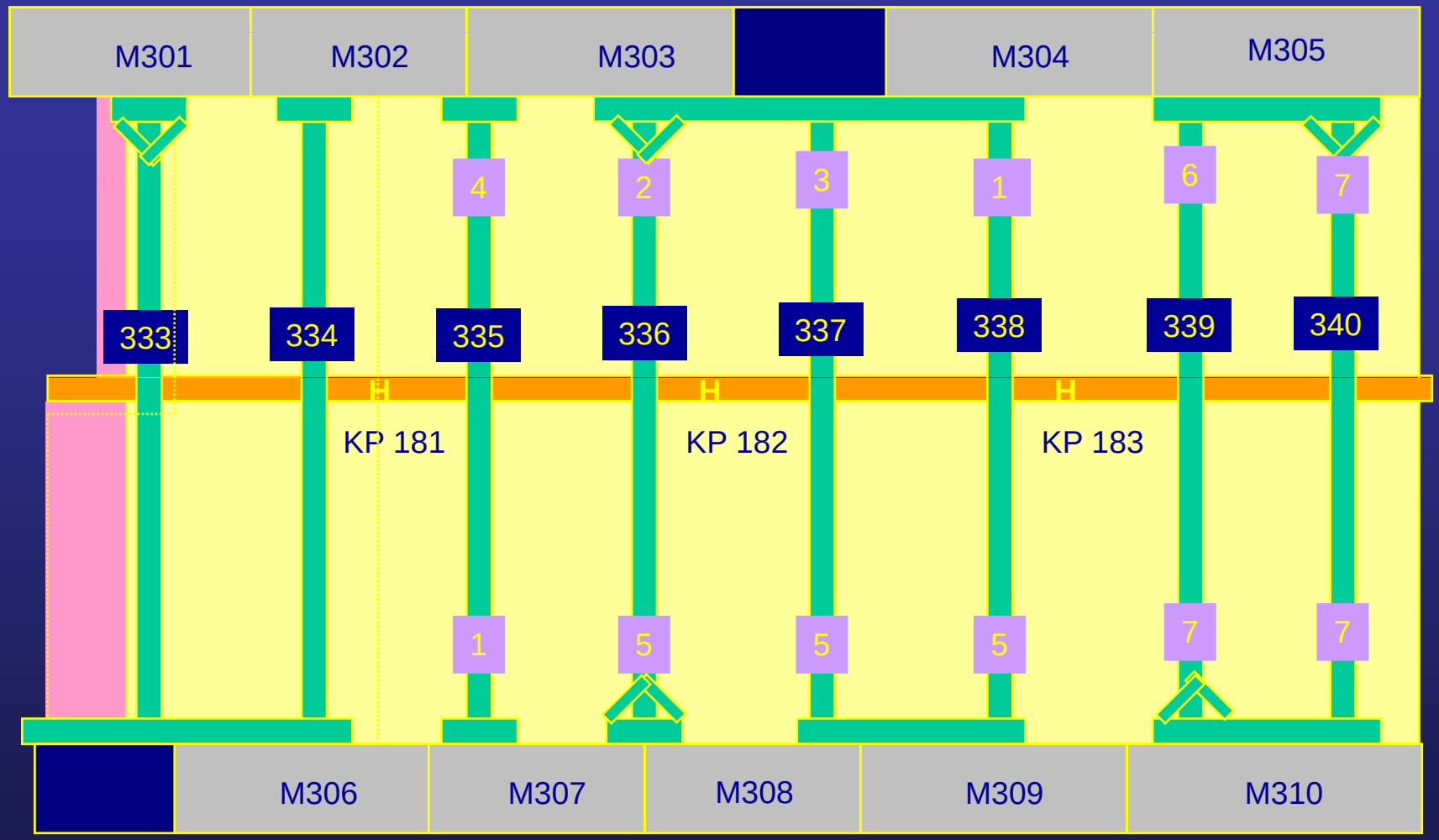
Excavation for the 10th level of struts, including removal of the sacrificial JGP



Observations on the morning of the collapse



North wall



1 Order in which distortion to waler noted

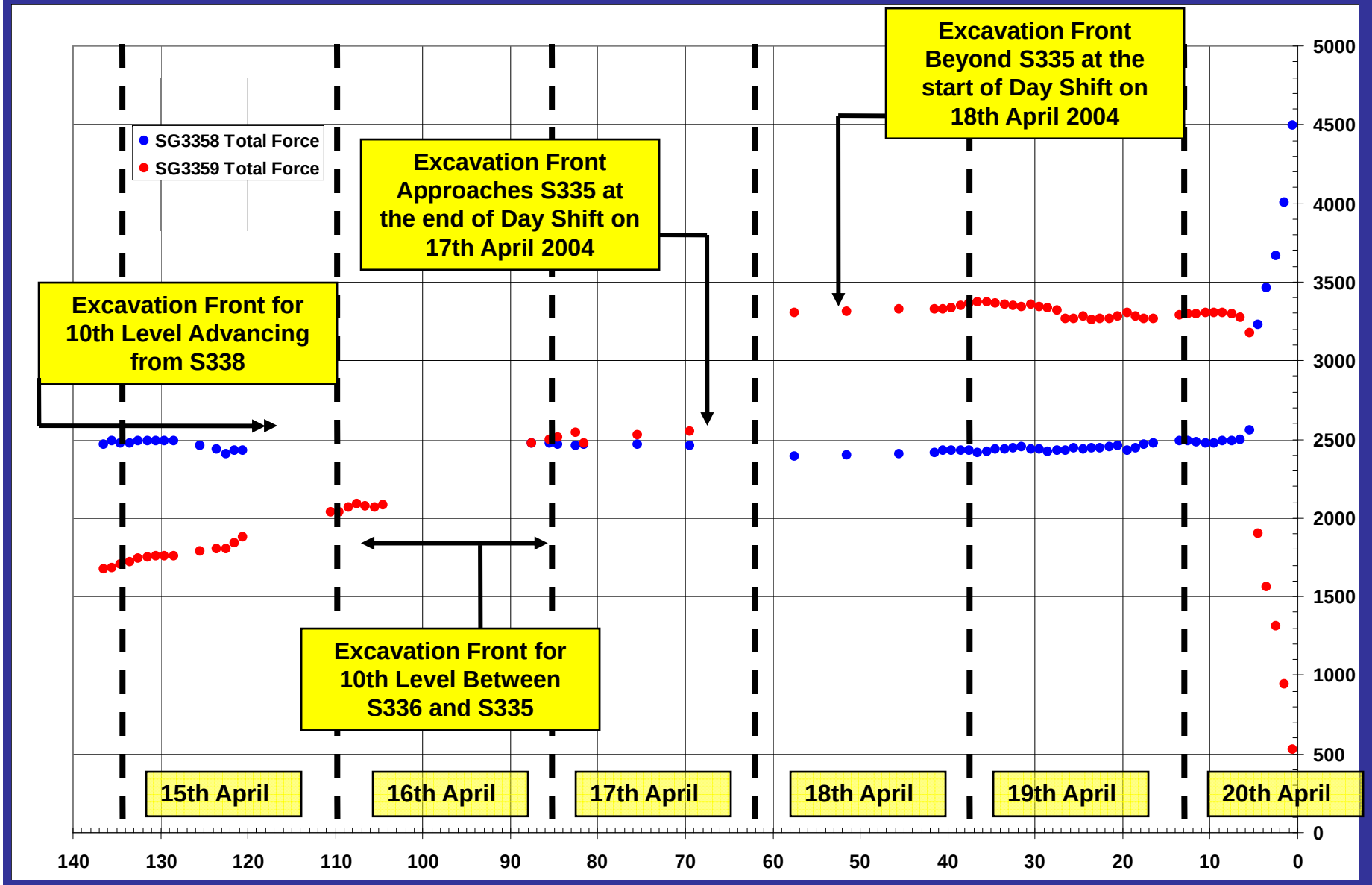
Excavation in progress

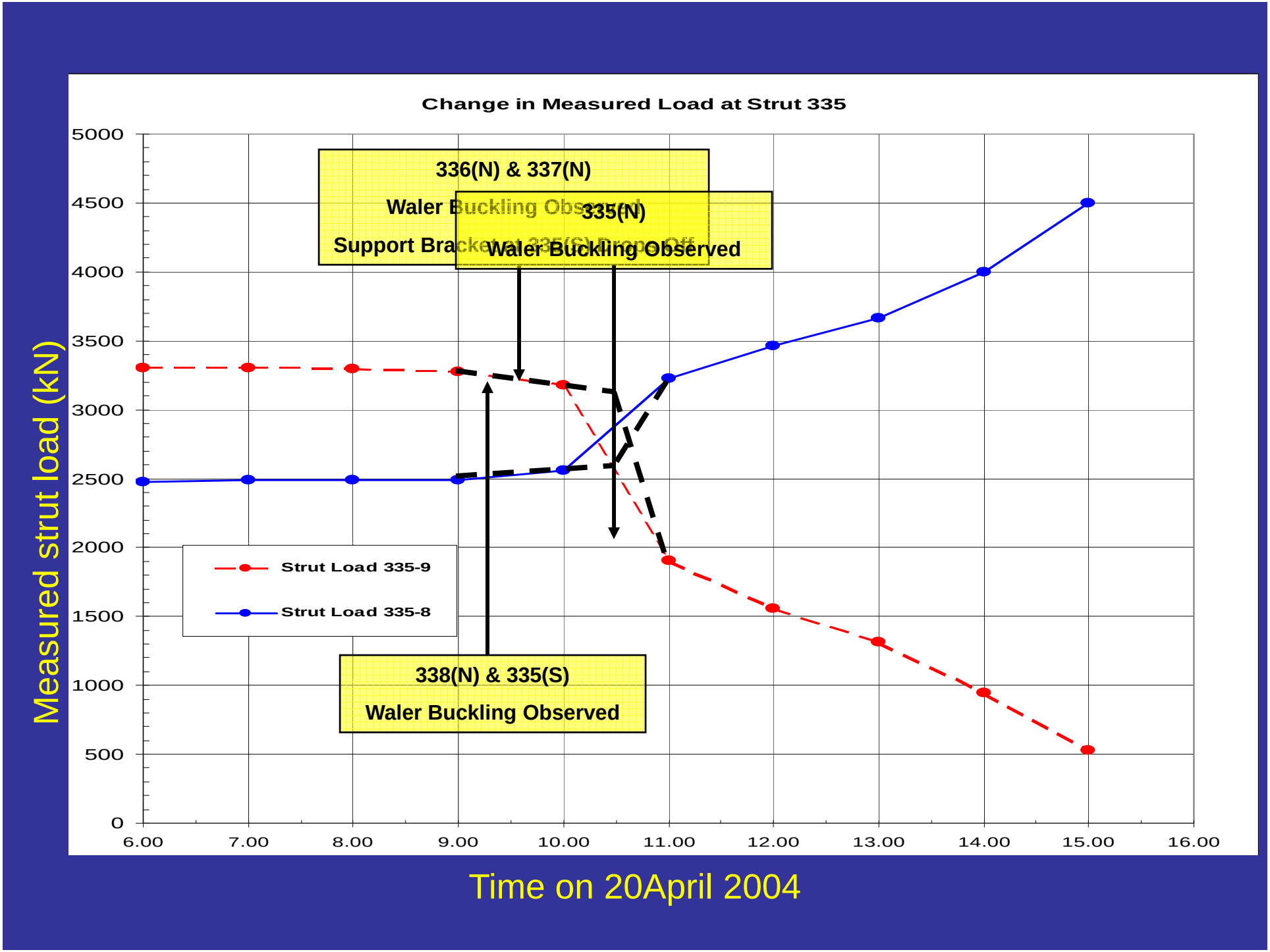
Excavation to 10th complete

Location of walers, splays and Dwall gaps

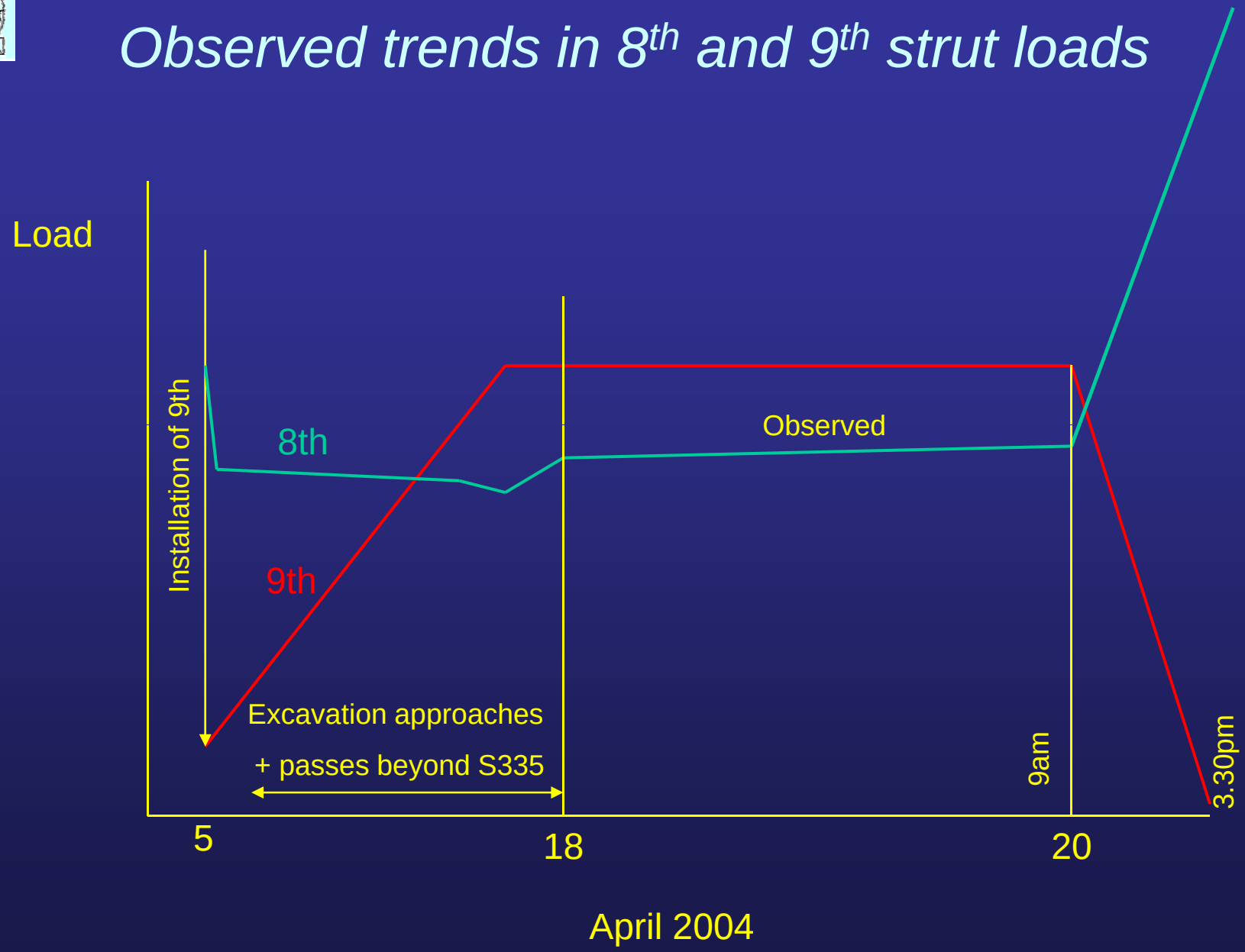
Strut 335-9 south wall

Strut 338-9 north wall

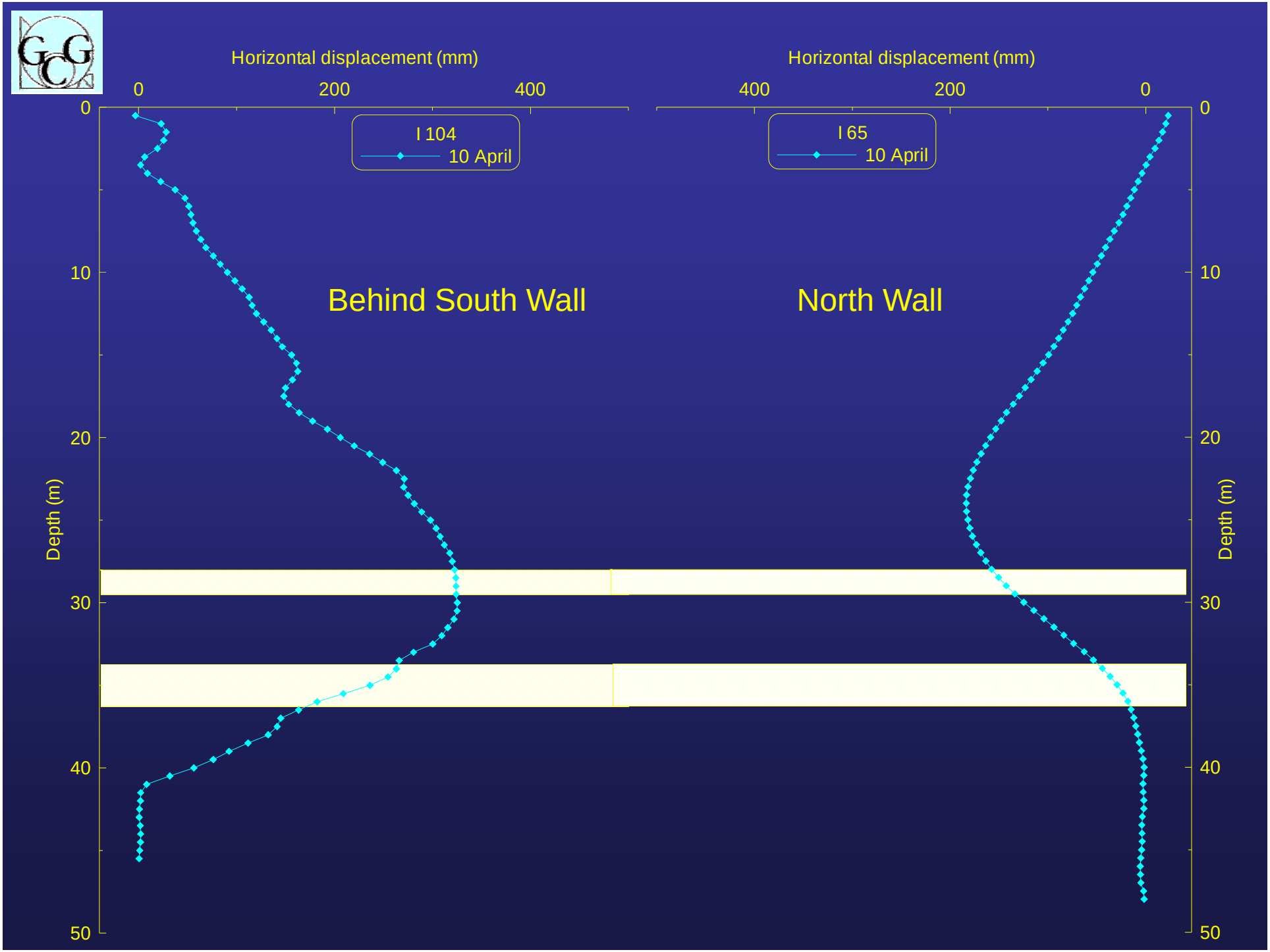

SG3358 Total Force
SG3359 Total Force
Excavation Front Beyond S335 at the start of Day Shift on 18th April 2004
Excavation Front Approaches S335 at the end of Day Shift on 17th April 2004
Excavation Front for 10th Level Advancing from S338
Excavation Front for 10th Level Between S336 and S335
15th April
16th April
17th April
18th April
19th April
20th April
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Measured strut load (kN)
Hours before collapse

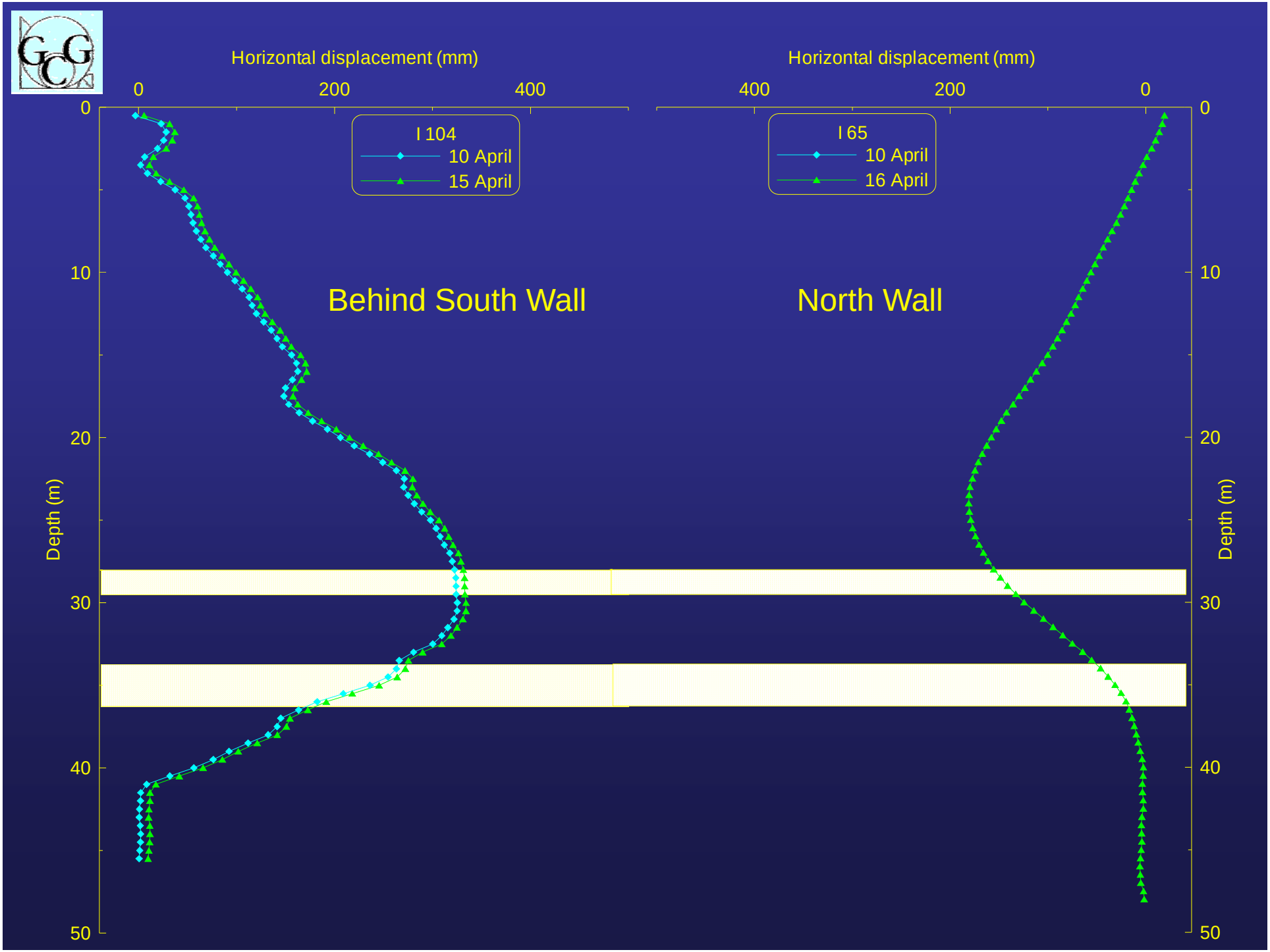

Change in Measured Load at Strut 335
Measured strut load (kN)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
336(N) & 337(N)
Waler Buckling Observed
335(N)
Waler Buckling Observed
Strut Load 335-9
Strut Load 335-8
338(N) & 335(S)
Waler Buckling Observed
Time on 20April 2004

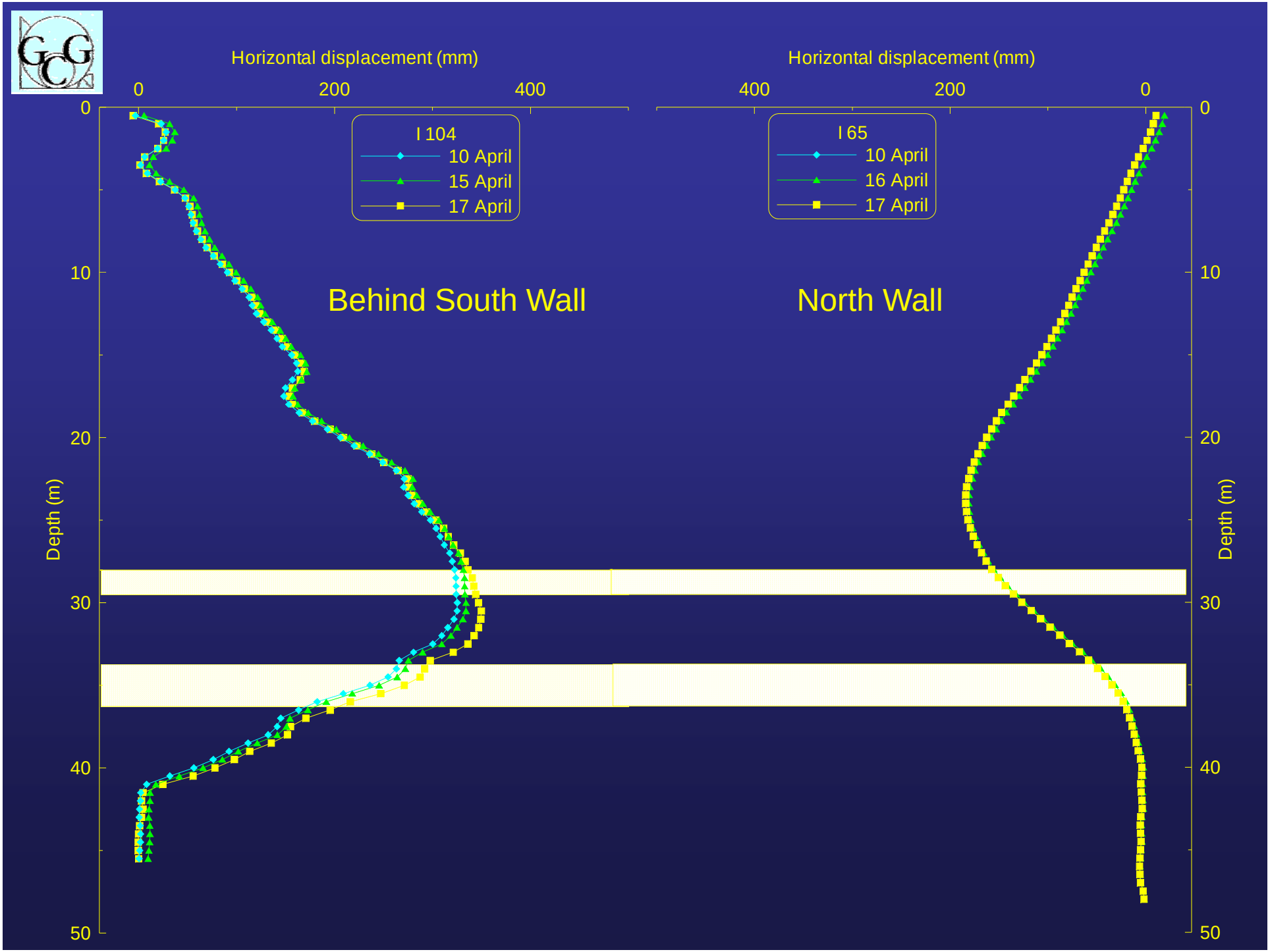
Observed trends in 8th and 9th strut loads

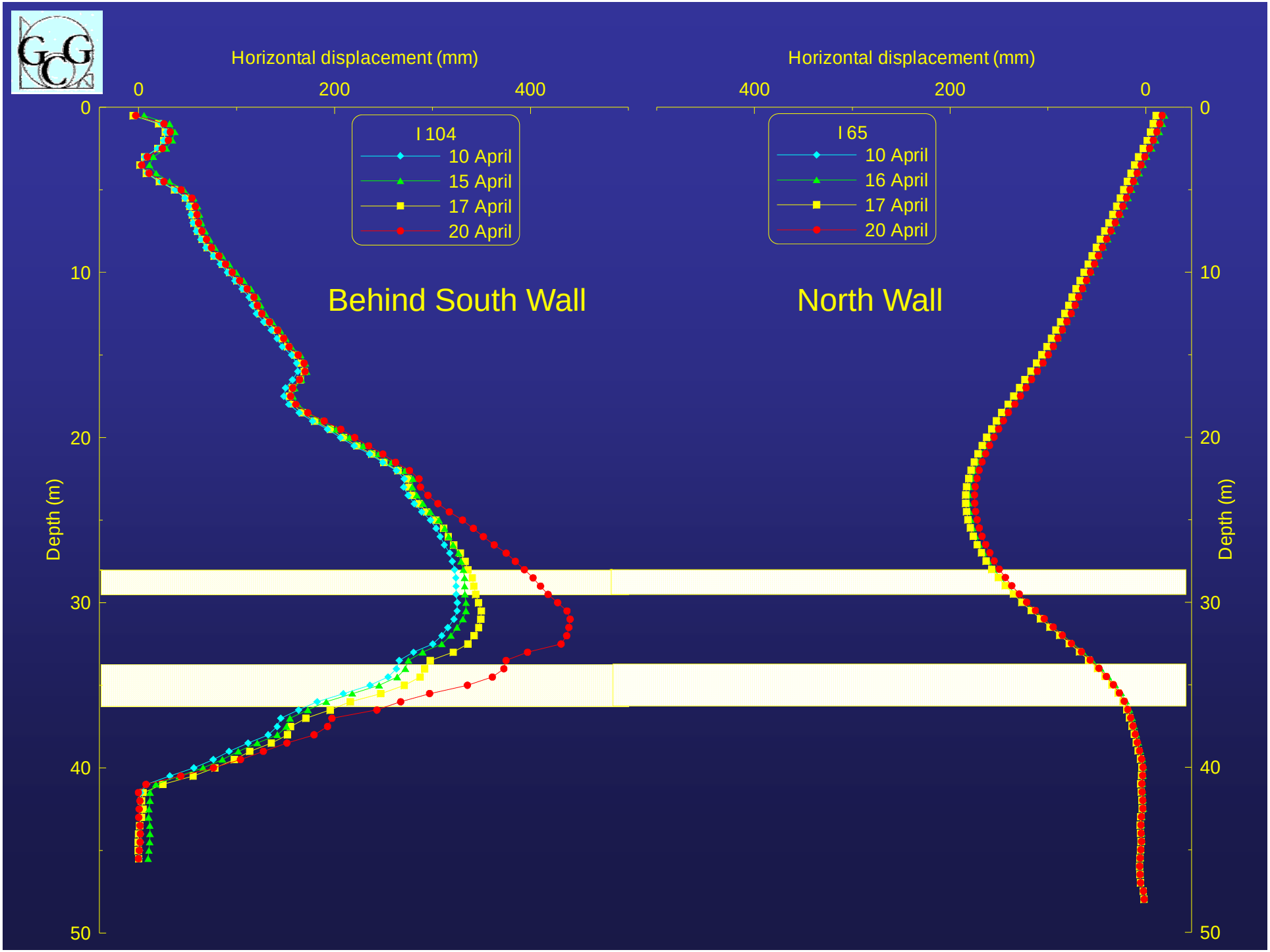


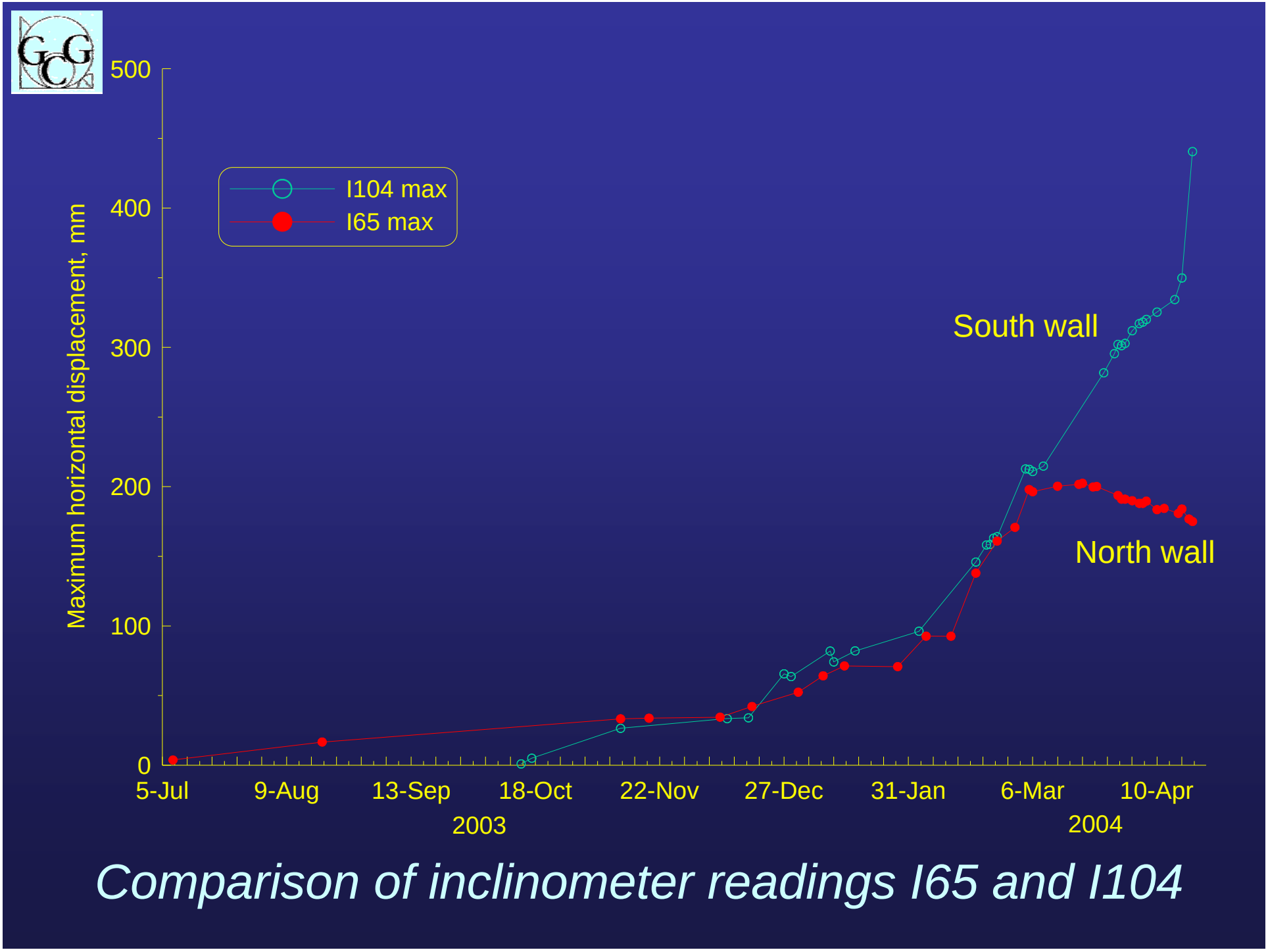
The trends were consistent with there being yielding of the 9th level strut-waler connection when the excavation passed beneath but with no further significant changes in load in either the 9th or 8th level struts until the collapse was initiated


Horizontal displacement (mm)
0
200
400
I 104
10 April
Behind South Wall
Horizontal displacement (mm)
400
200
0
I 65
10 April
North Wall
Depth (m)
0
10
20
30
40
50
Depth (m)


Horizontal displacement (mm)
0
200
400
I 104
10 April
15 April
Behind South Wall
Horizontal displacement (mm)
400
200
0
I 65
10 April
16 April
North Wall
Depth (m)
0
10
20
30
40
50


Horizontal displacement (mm)
0
200
400
I 104
10 April
15 April
17 April
Behind South Wall
Horizontal displacement (mm)
400
200
0
I 65
10 April
16 April
17 April
North Wall
Depth (m)
0
10
20
30
40
50

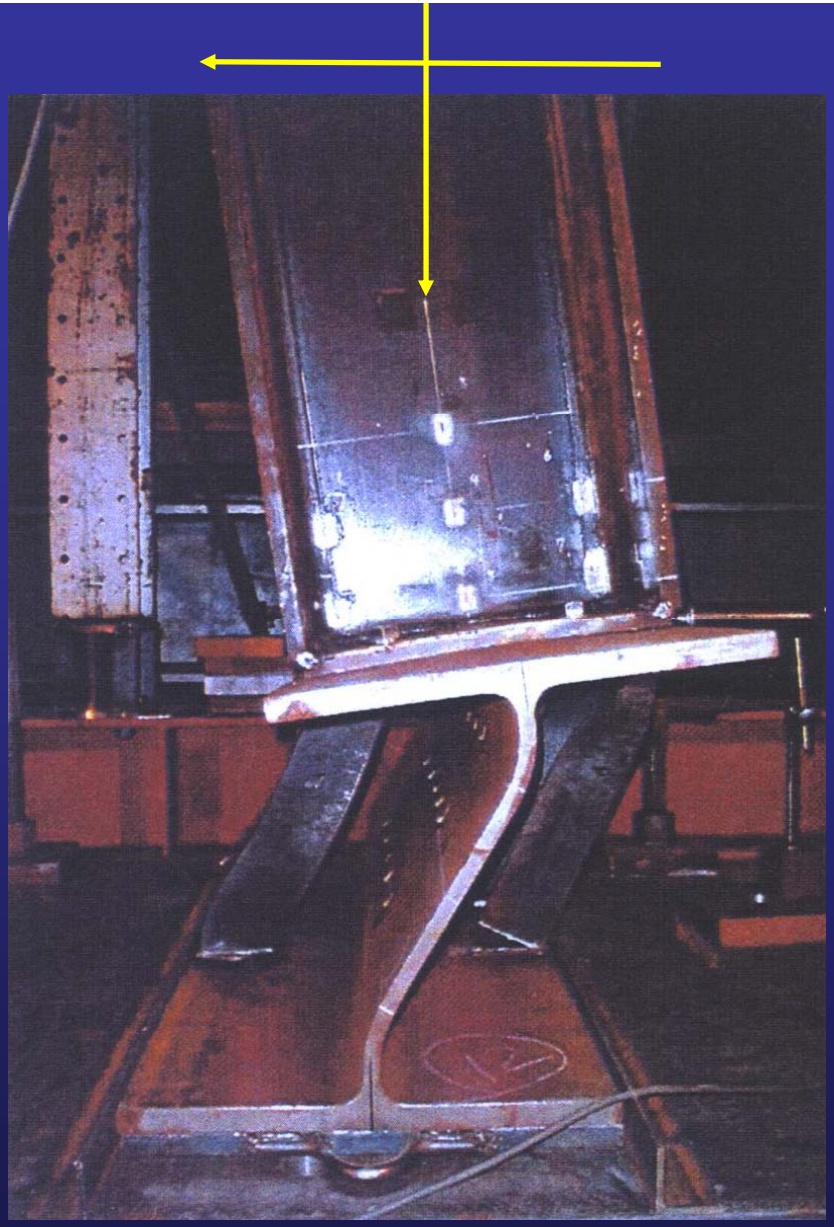

Horizontal displacement (mm)
0
200
400
I 104
10 April
15 April
17 April
20 April
Behind South Wall
Horizontal displacement (mm)
400
200
0
I 65
10 April
16 April
17 April
20 April
North Wall
Depth (m)
0
10
20
30
40
50



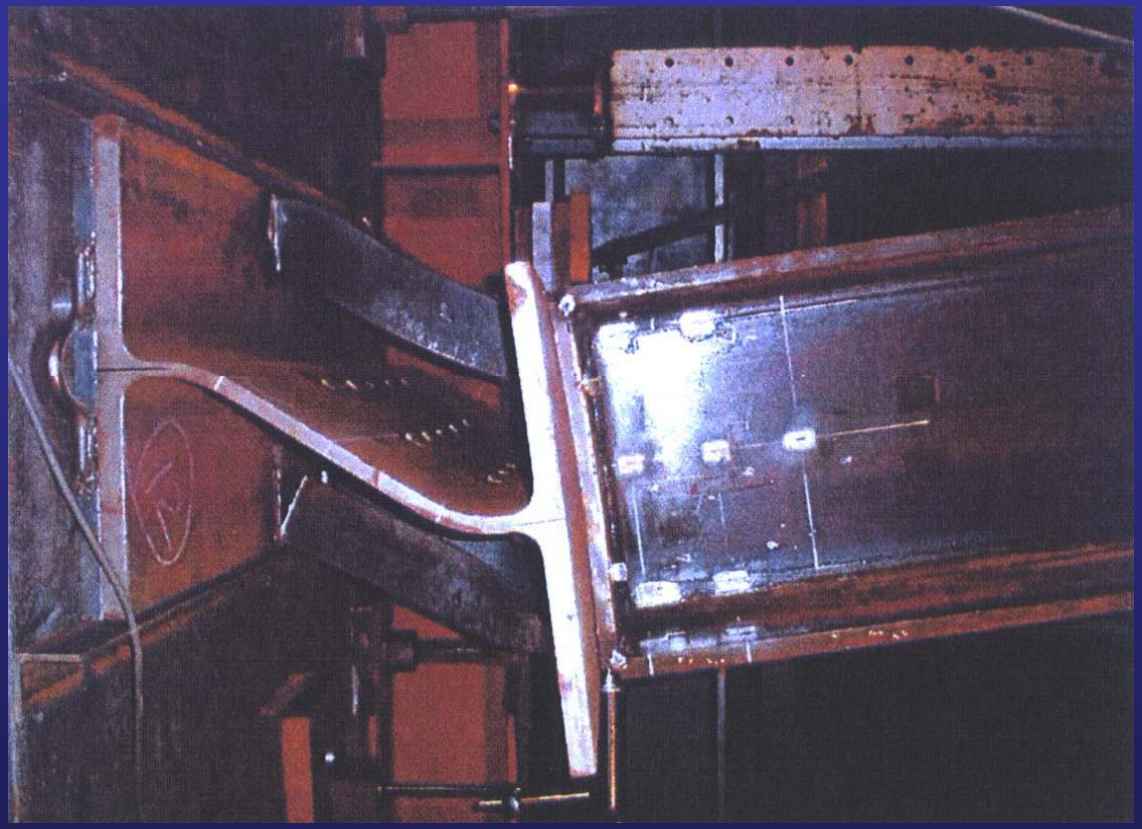
Comparison of inclinometer readings I65 and I104

- S338-9 stood for 8 days under load and was 20m from excavation front
- S335-9 stood for 2.5 days under load and was over 8m from excavation front
- Both S335-9S & S338-9N buckled within 10 minutes
- Load in S335-8 and S335-9 was almost constant between 18 April and initiation of collapse
- All C-channel connections failed downwards at both ends
- The south wall was pushing the north wall back

Key observations



Test on C channel stiffened connection by Nishimatsu

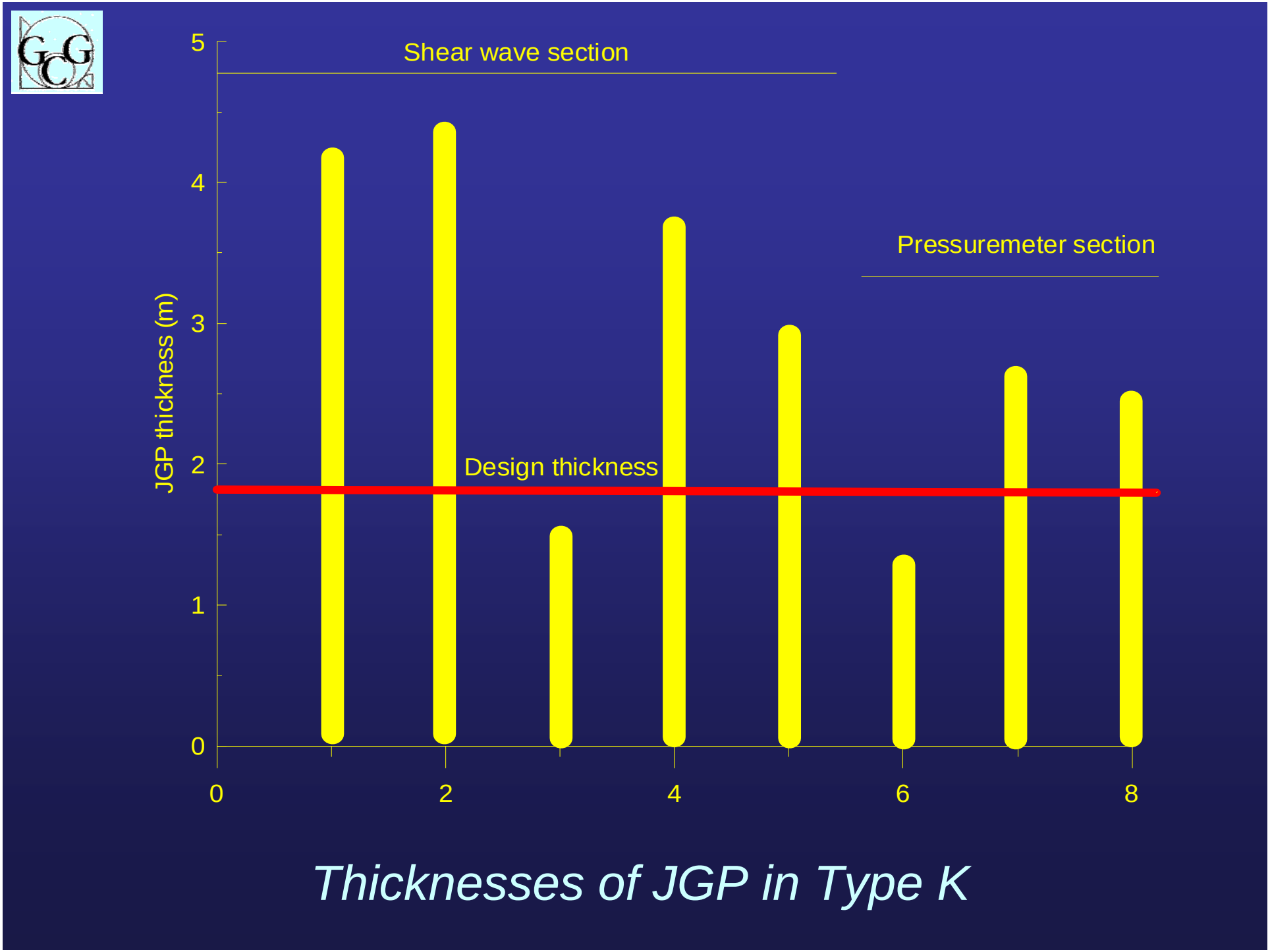


Test on C channel stiffened connection by Nishimatsu

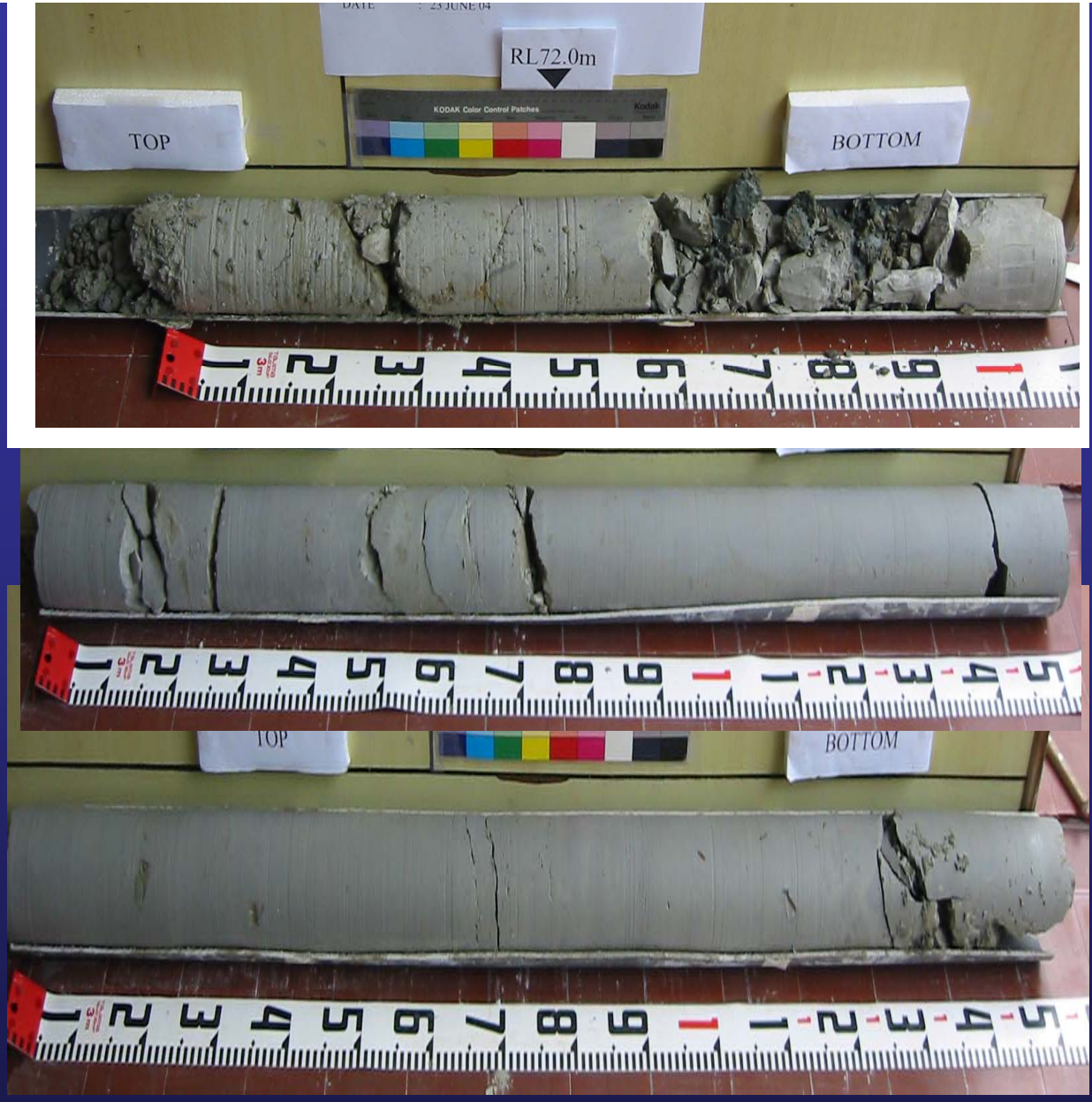
Post-collapse investigations

Jet grout

Excavation of sacrificial JGP in Type H



Thicknesses of JGP in Type K

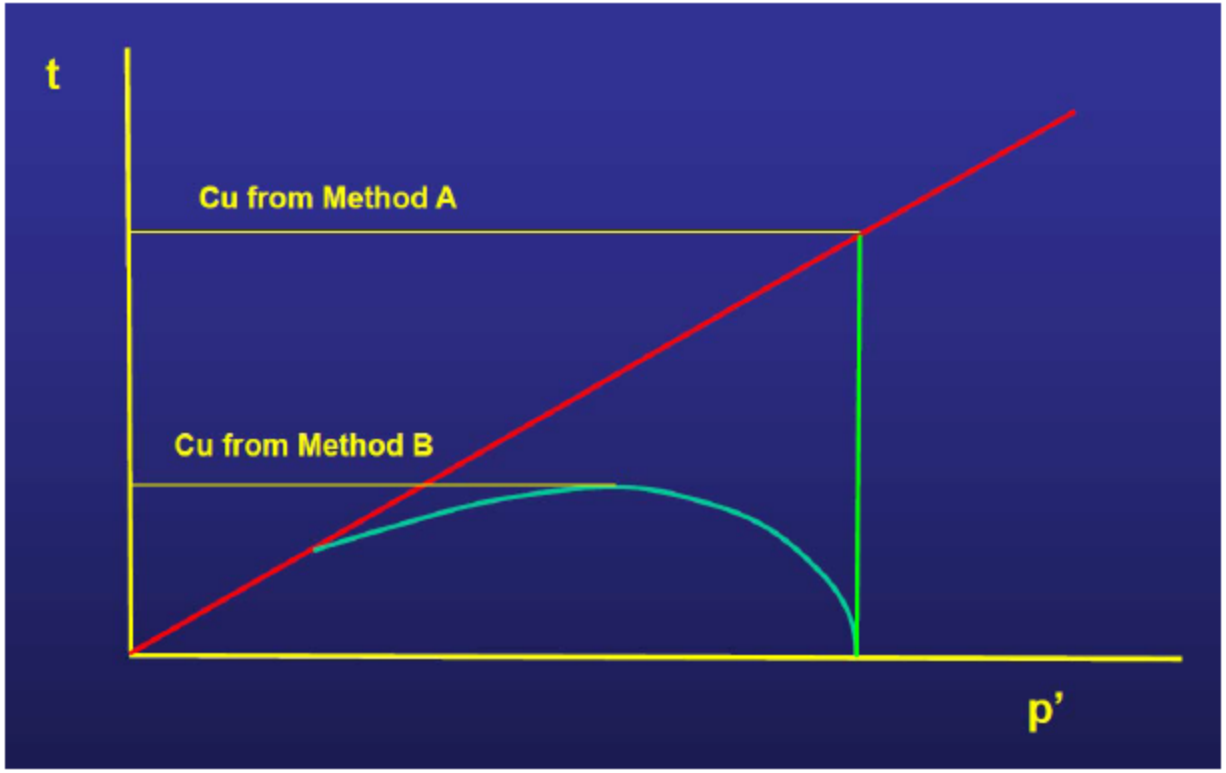


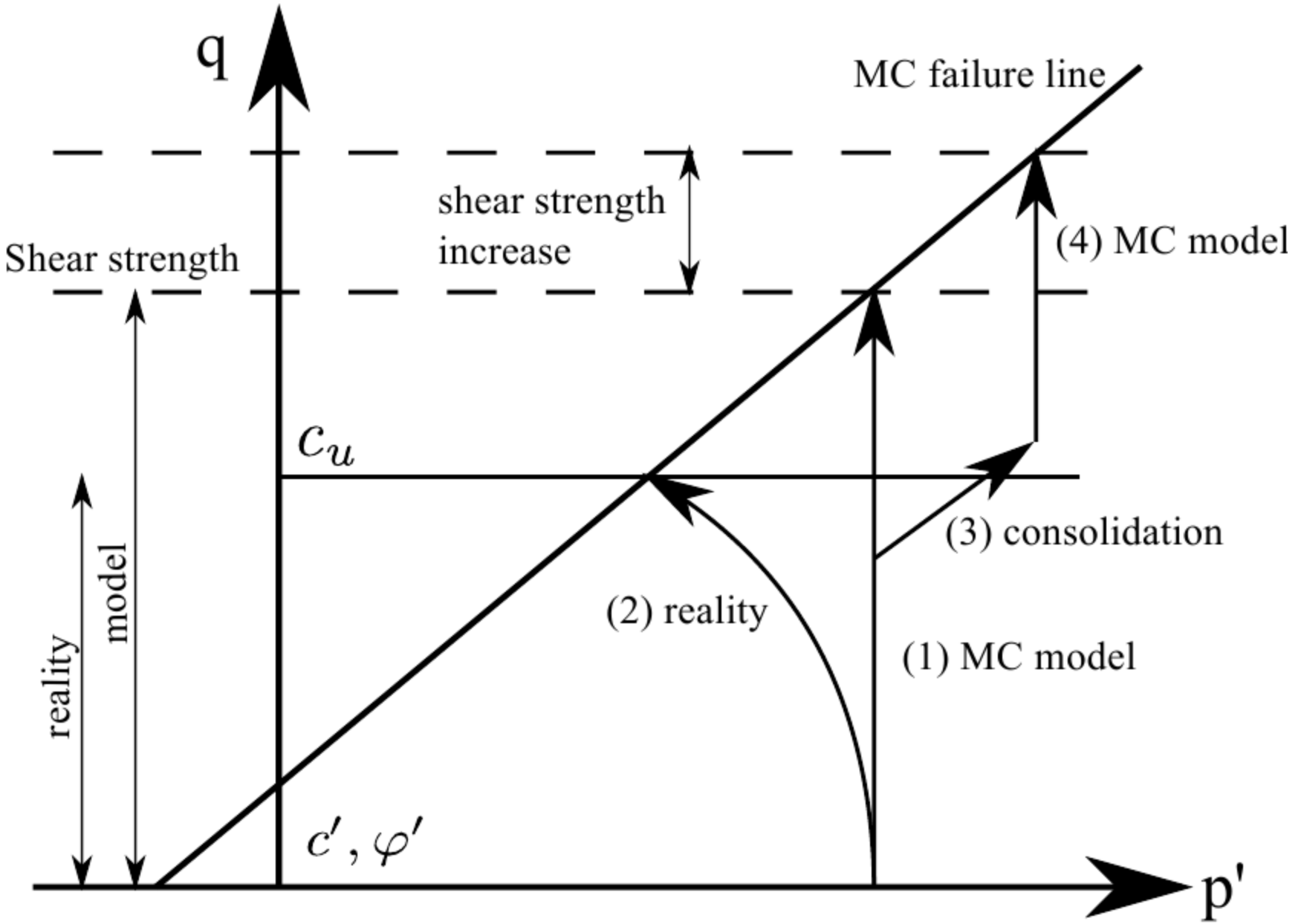
JGP quality in 100mm cores from borehole M1 in Type K

Undrained Analysis

- Method A and Method B refer to two alternative ways of modelling undrained soil behaviour in Plaxis
- Method A is an effective stress analysis of an undrained problem assumes isotropic elastic behaviour and a Mohr-Coulomb failure criterion
- As a result mean effective stress p' is constant until yield
- Method A was being applied to marine clays which were of low over-consolidation or even under-consolidated because of recent reclamation

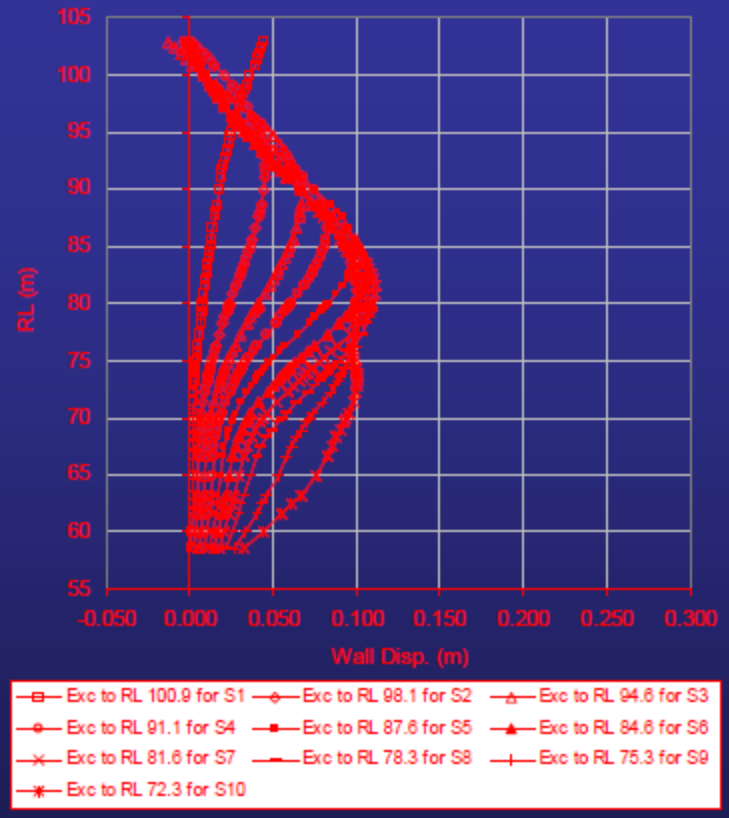
Undrained Analysis




q
MC failure line
shear strength
increase
Shear strength
(4) MC model
c_u
(3) consolidation
(2) reality
(1) MC model
reality
model
c', φ'
p'

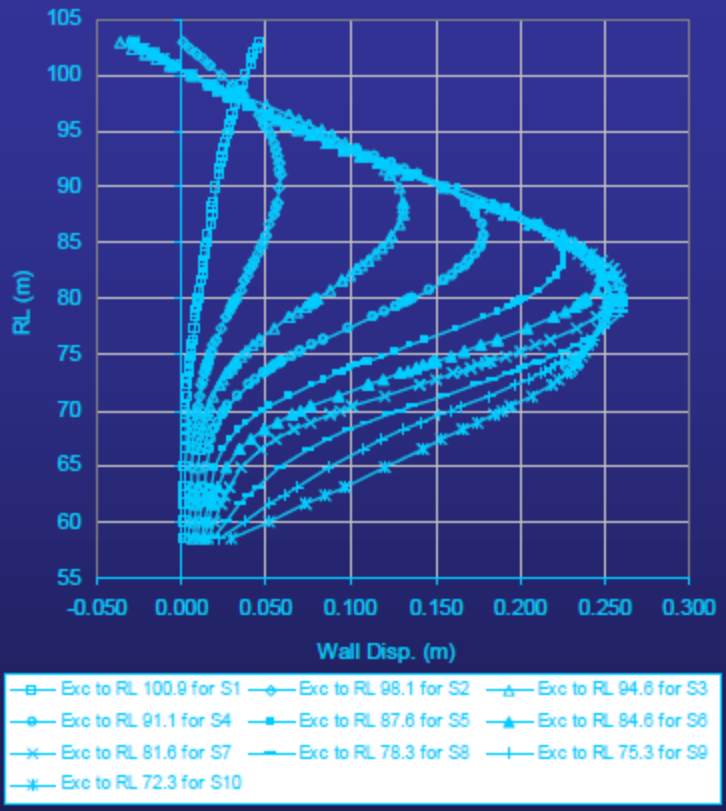
Effective Stress Parameters

Method A



Undrained Strength Parameters

Method B

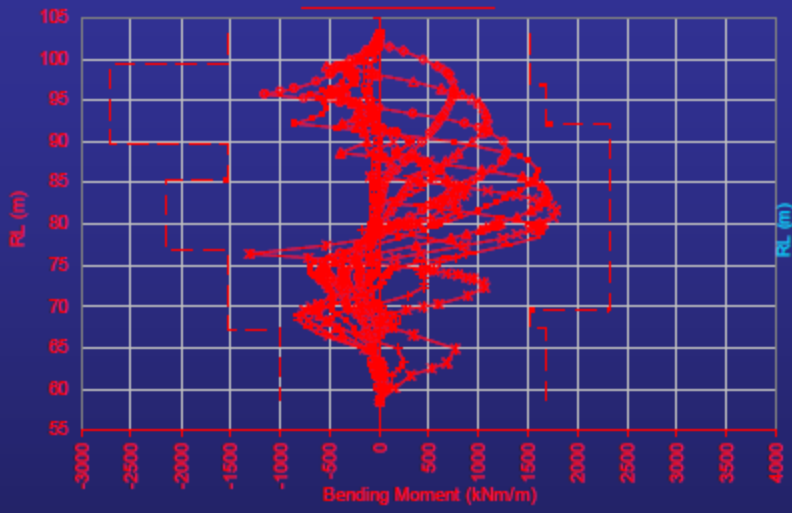


M3 - South Wall Displacement
Method A versus Method B

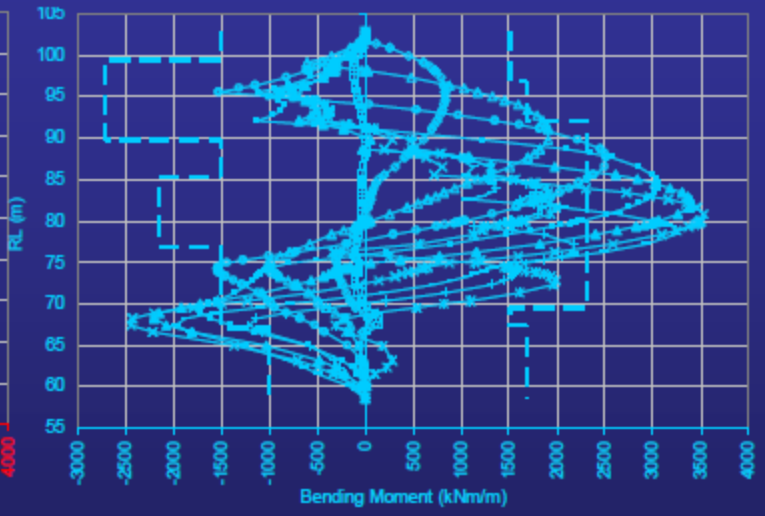
Effective Stress Parameters

Undrained Strength Parameters

Method A



Method B



M3 - South Wall bending moments
Method A versus Method B

Reasons

- 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 9th level strut force of 10%