Case Histories of Failures in Geotechnical Engineering Practice

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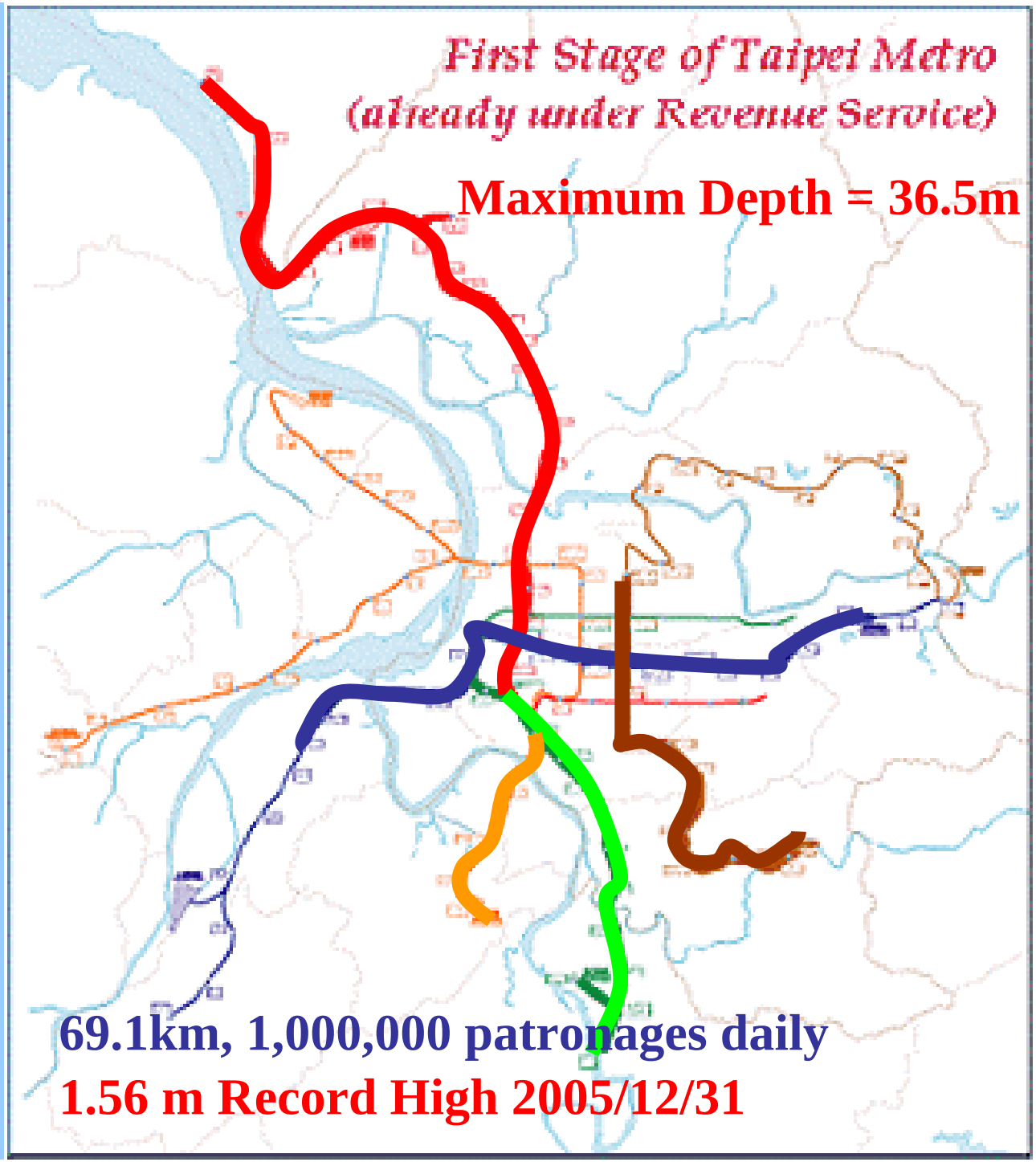
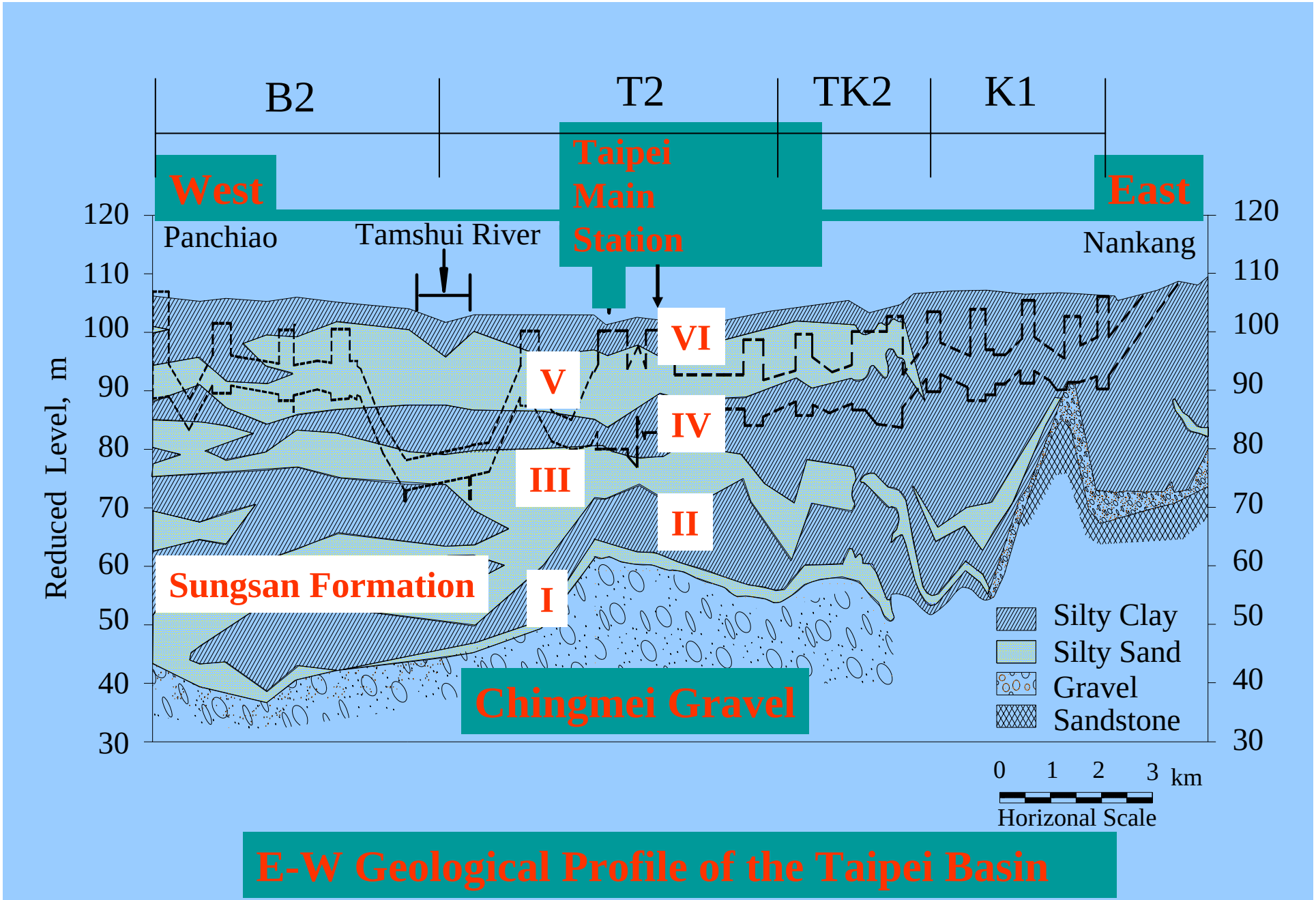
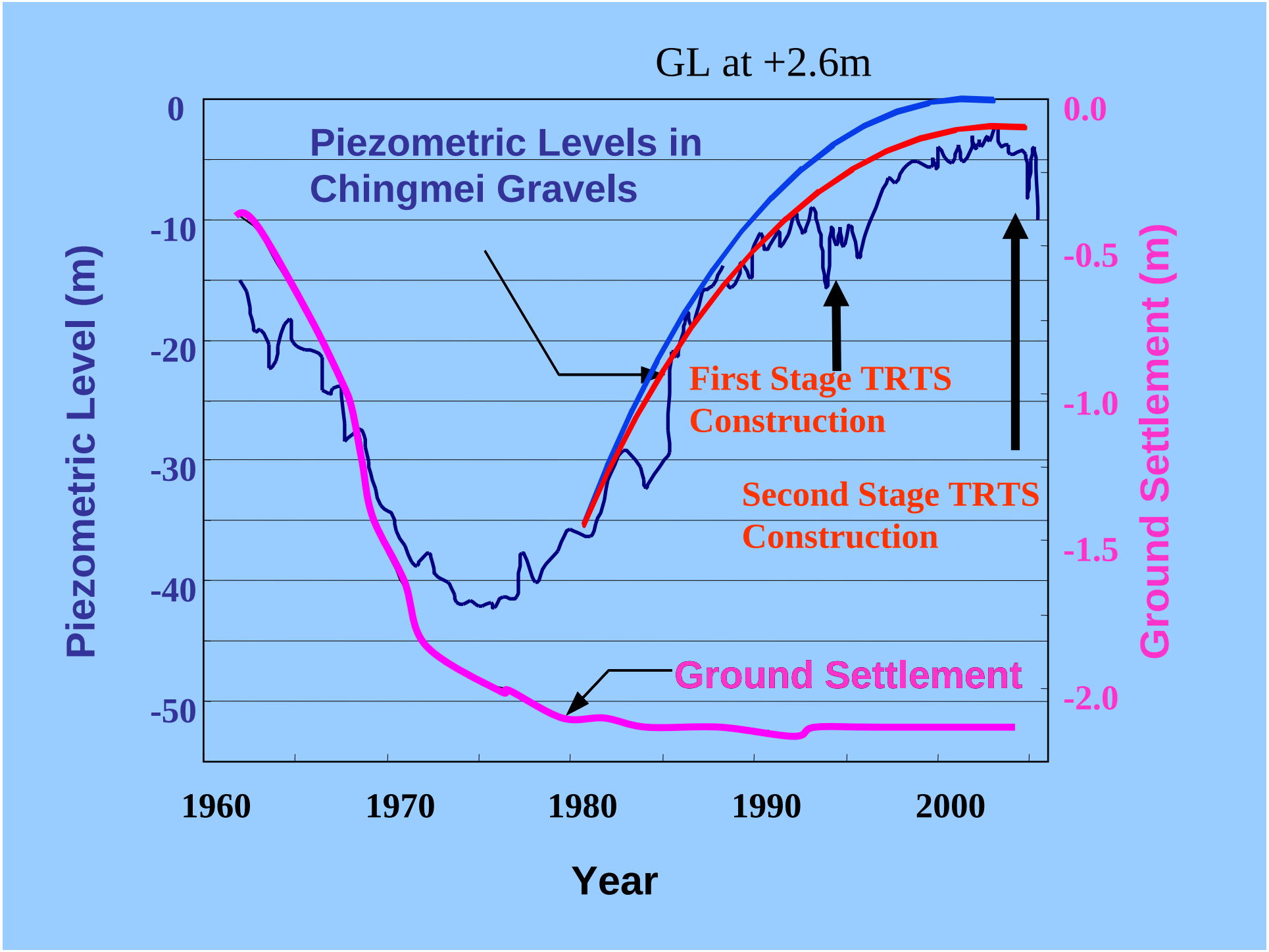
MAA Group

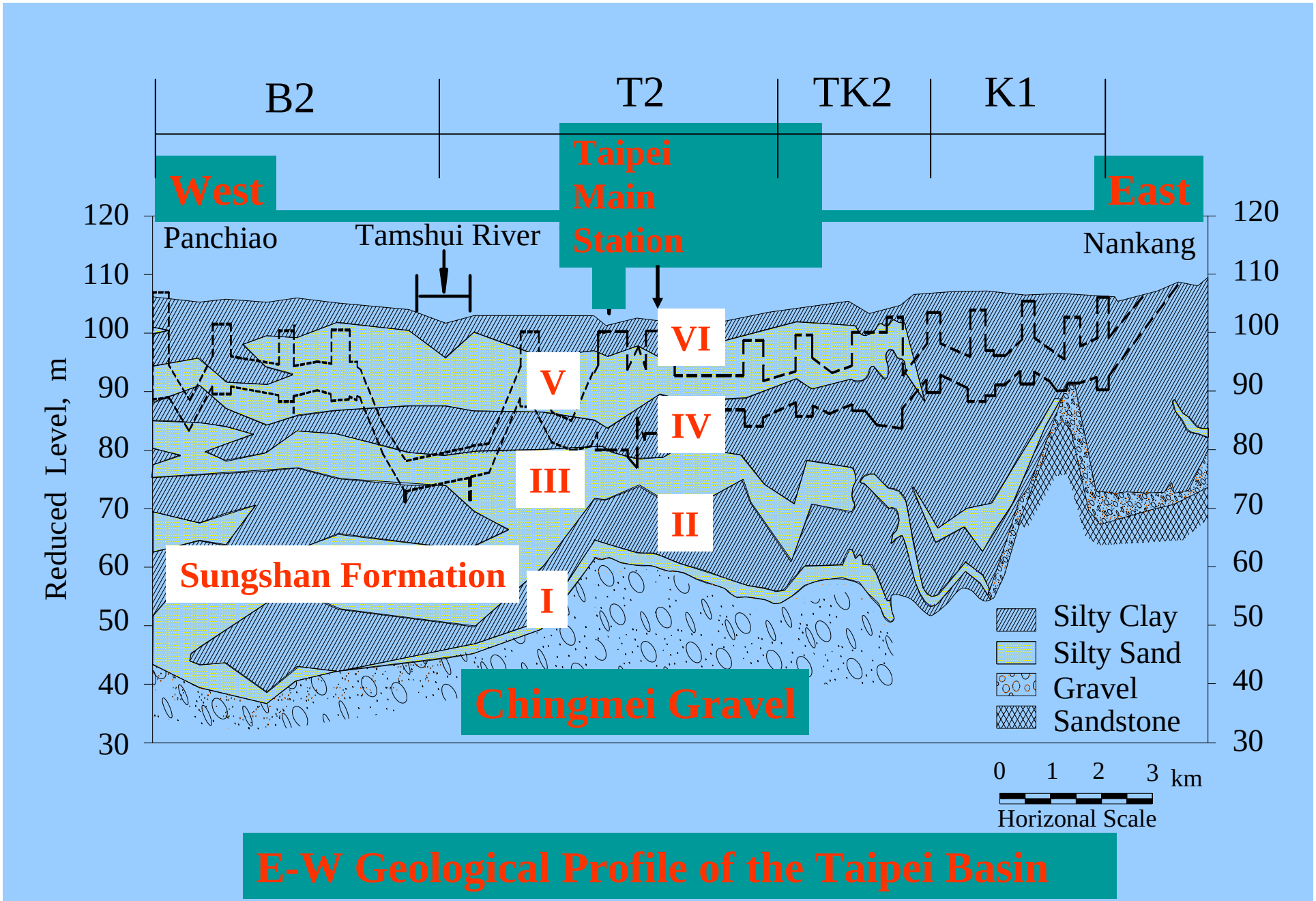

First Stage of Taipei Metro
(already under Revenue Service)
Maximum Depth = 36.5m
69.1km, 1,000,000 patronages daily
1.56 m Record High 2005/12/31



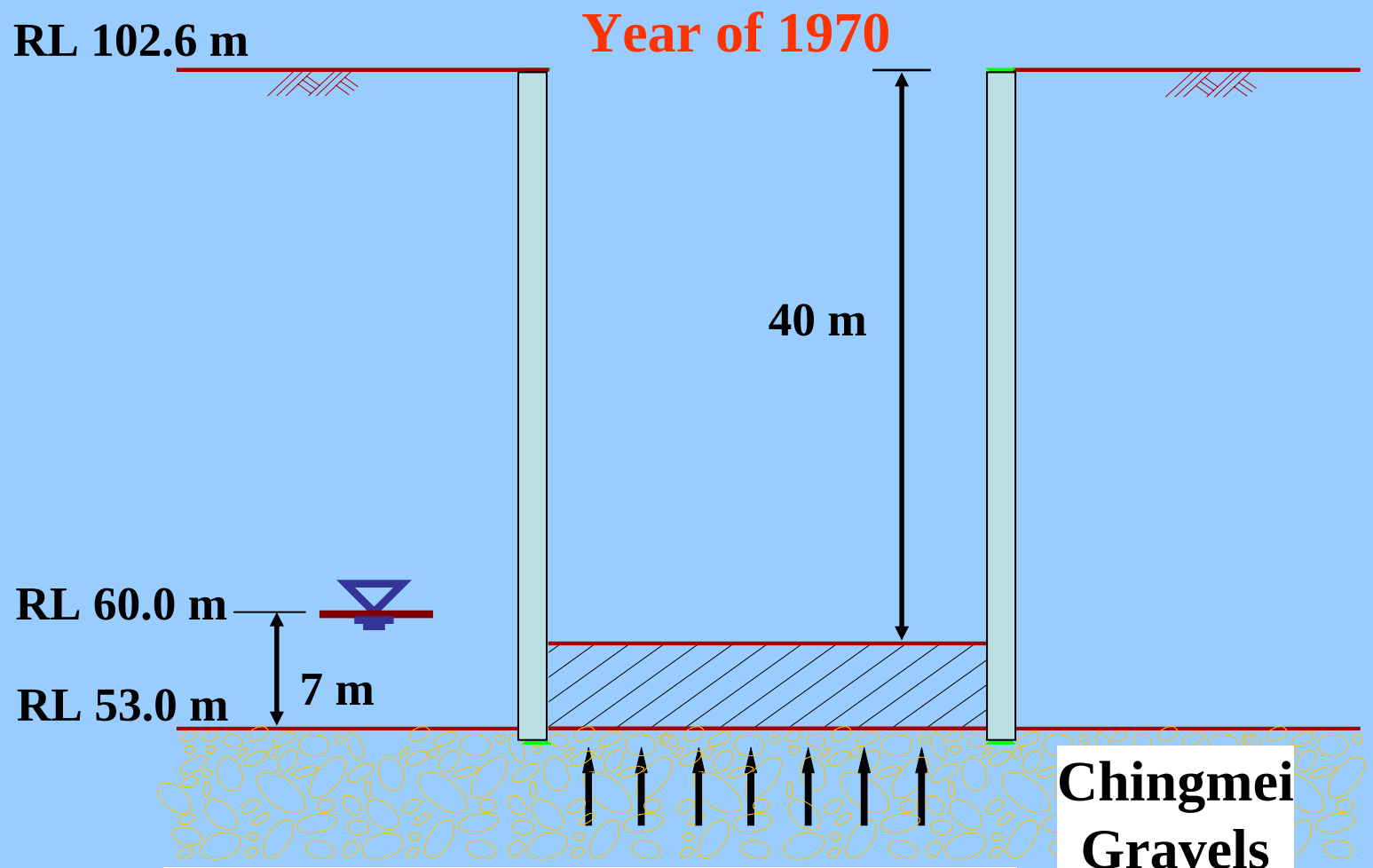
E-W Geological Profile of the Taipei Basin

Chingmei Gravels
Ventilation Shaft GL-43m


GL at +2.6m
Piezometric Levels in Chingmei Gravels
First Stage TRTS Construction
Second Stage TRTS Construction
Ground Settlement
Piezometric Level (m)
Ground Settlement (m)
Year
0
-10
-20
-30
-40
-50
0.0
-0.5
-1.0
-1.5
-2.0
1960
1970
1980
1990
2000

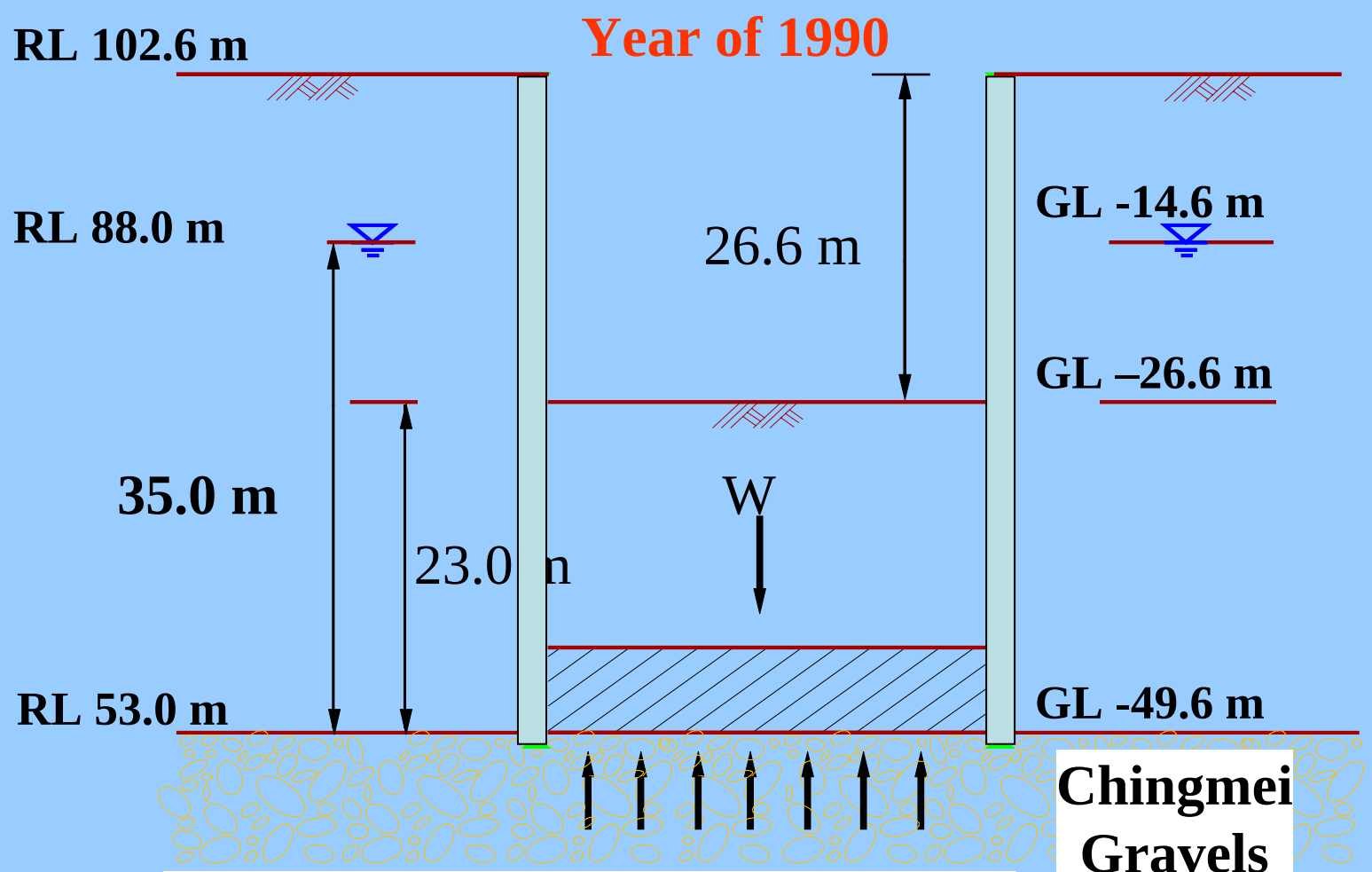


E-W Geological Profile of the Taipei Basin



Uplift = 10 x (88.0 - 53.0) = 350 kPa
Soil Weight = 19 x (76.0 - 53.0) = 437 kPa
Safety Factor = 437 / 350 = 1.25

Analysis for blow-in



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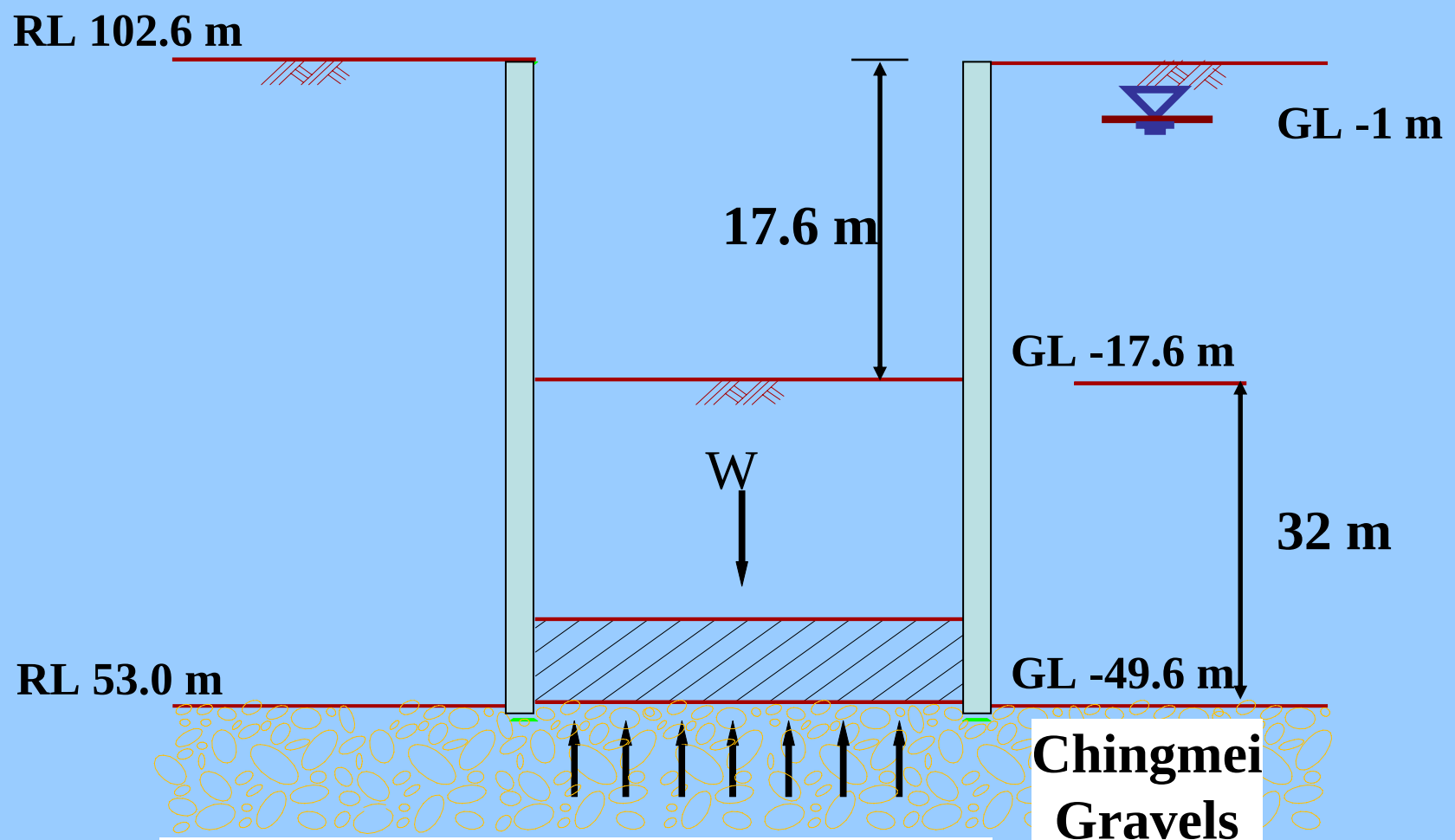
Analysis for blow-in



Uplift = 10 x (49.6 - 1.0) = 486 kPa
Soil Weight = 19 x (49.6 - 17.6) = 608 kPa
Safety Factor = 608 / 486 = 1. 25

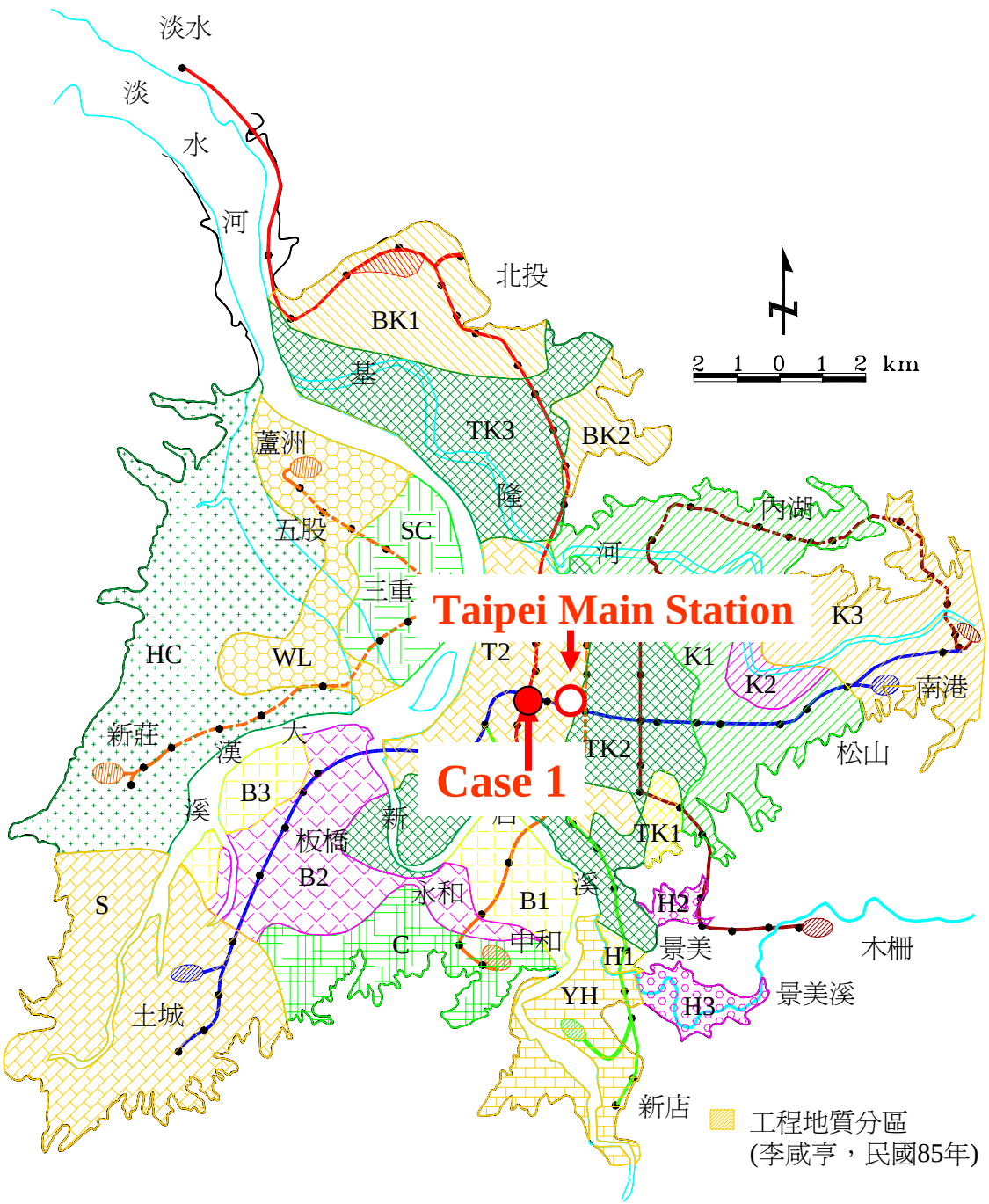
Analysis for blow-in

Contents

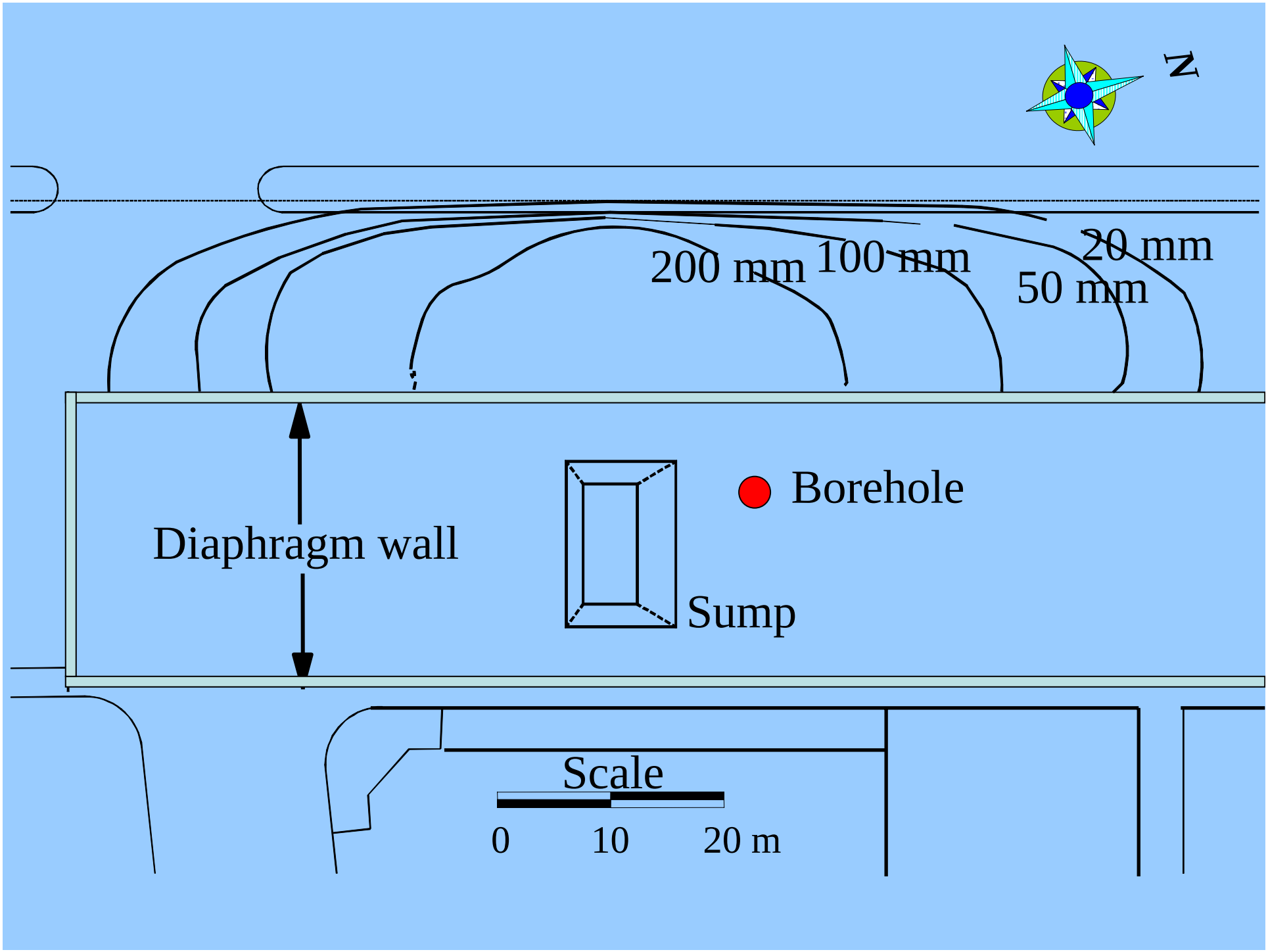
- Failure due to human errors
- Failure due to poor workmanship
- Failures due to Unforeseen Conditions

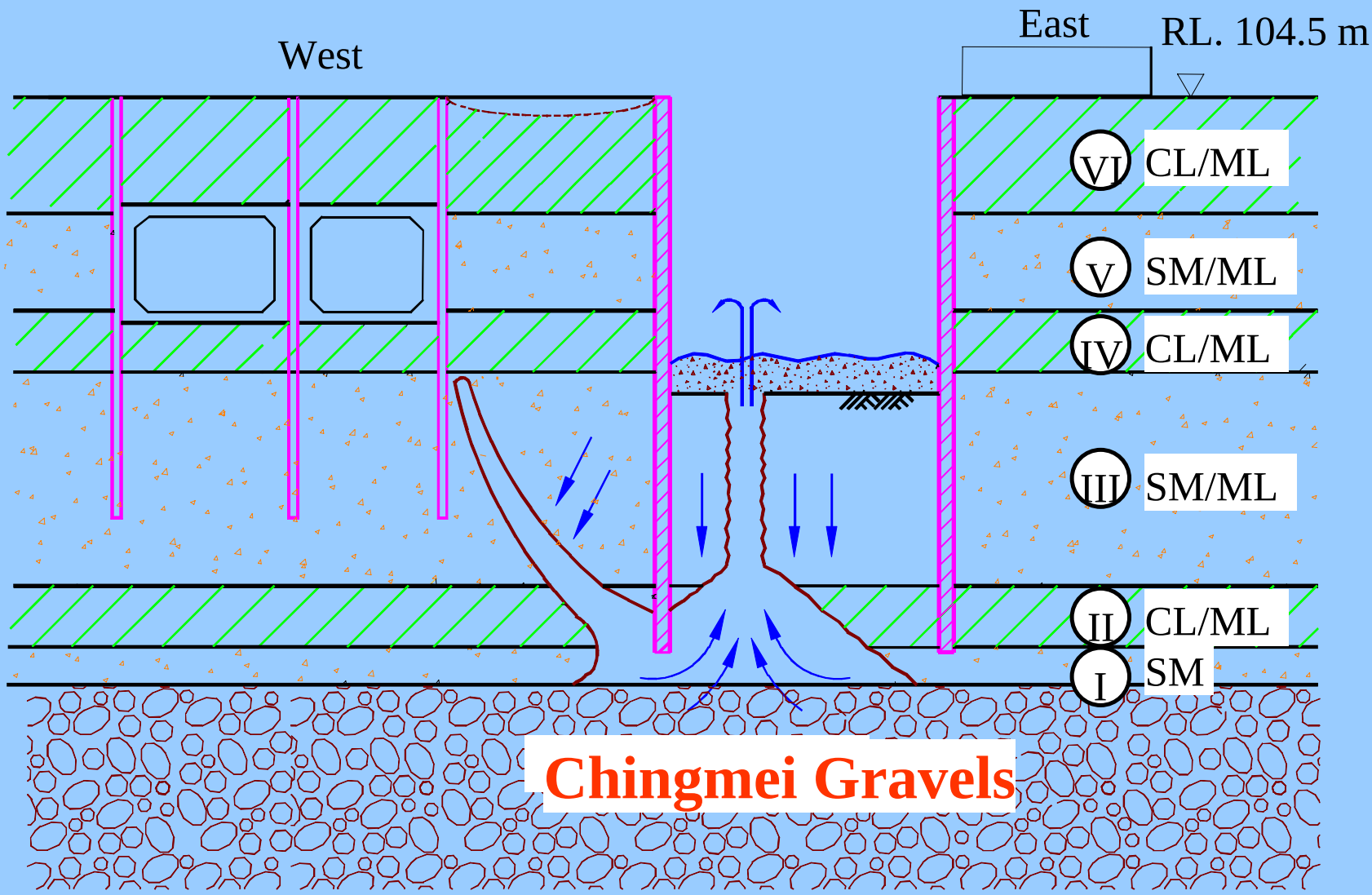
Case 1 – Human Error (Negligence)

- Nankang Line
- Station Excavation to GL-24.5 m

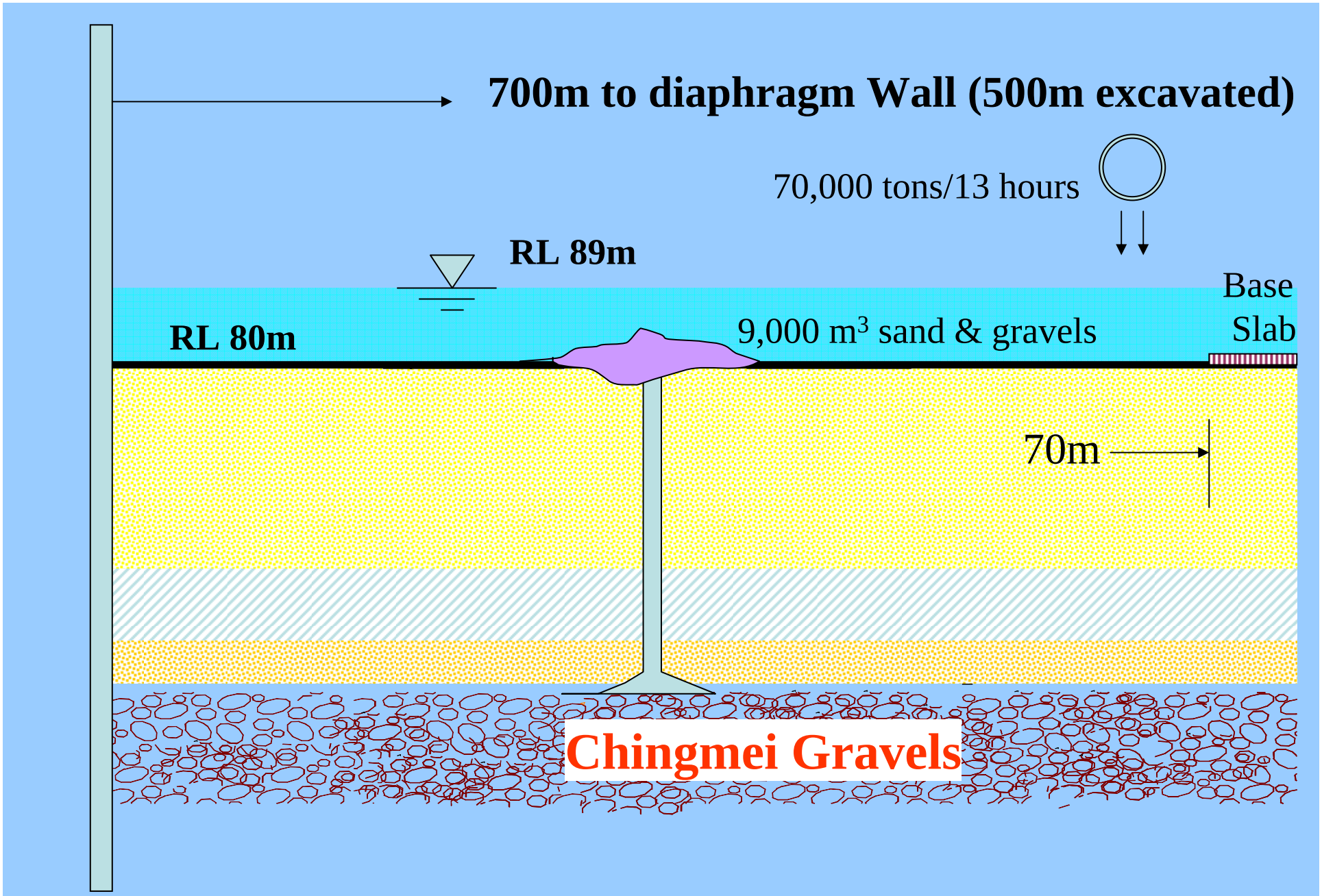


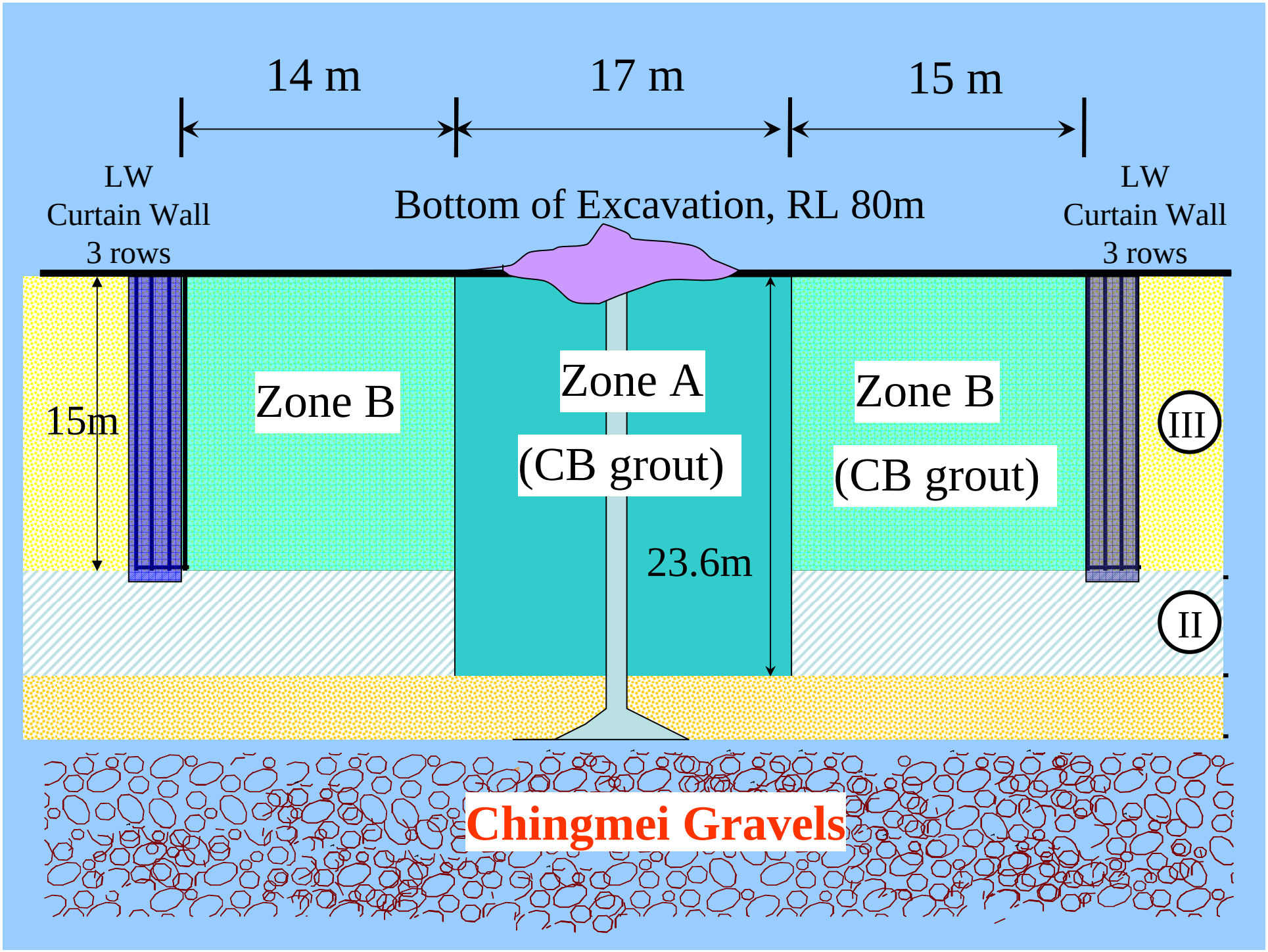
Geological Zoning of the Taipei Basin

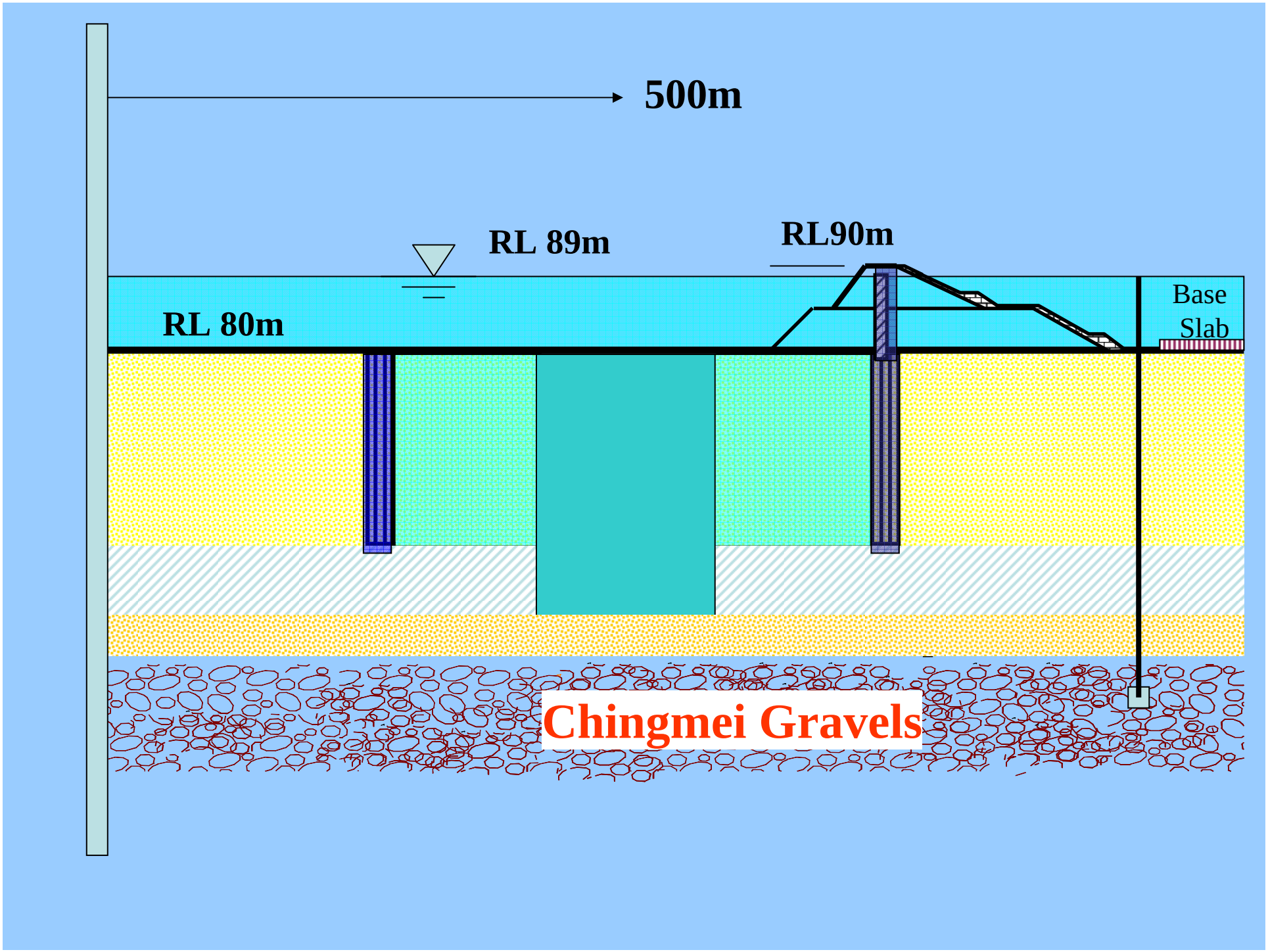

N
200 mm
100 mm
50 mm
20 mm
Diaphragm wall
Borehole
Sump
Scale
0
10
20 m

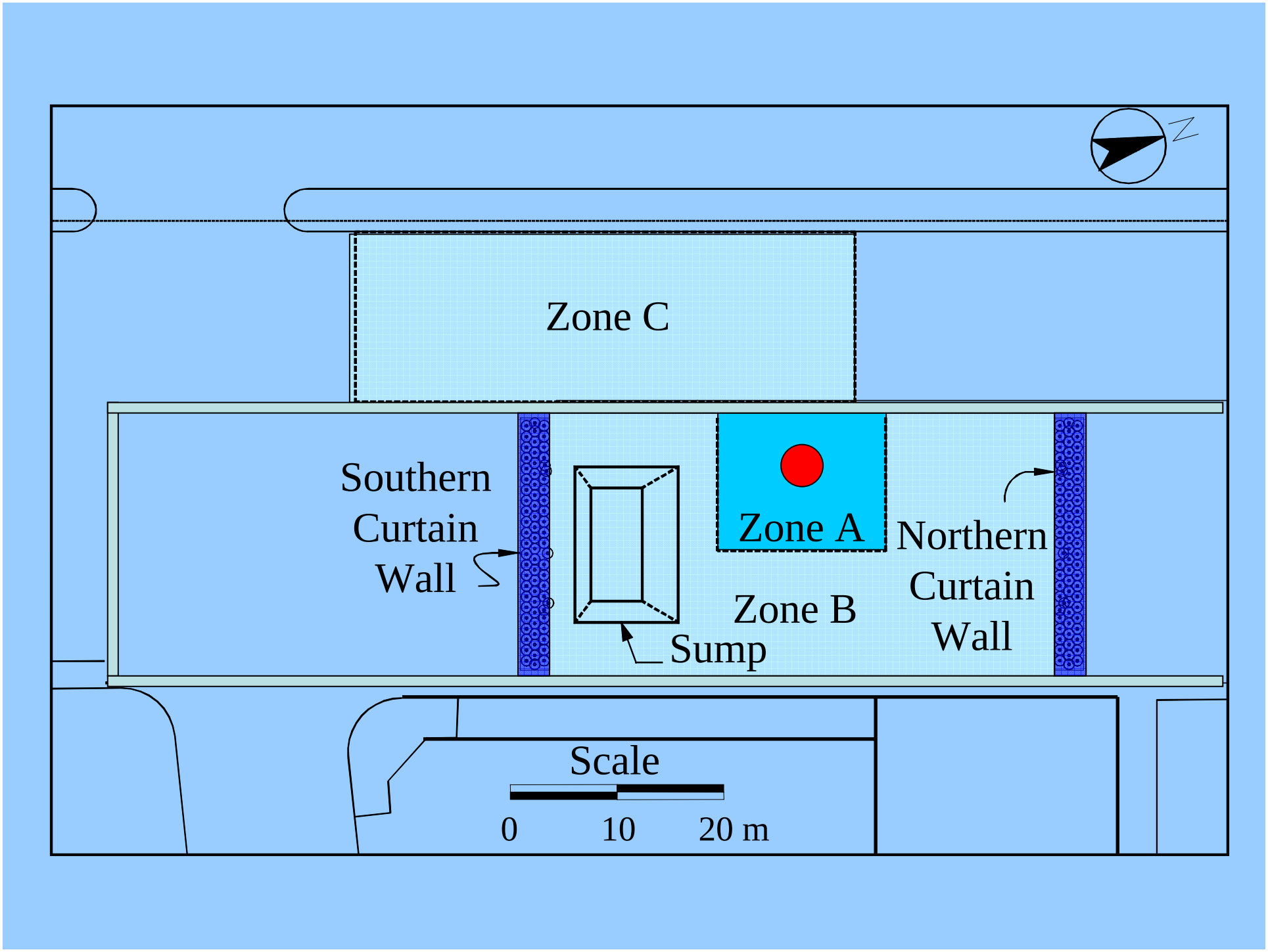


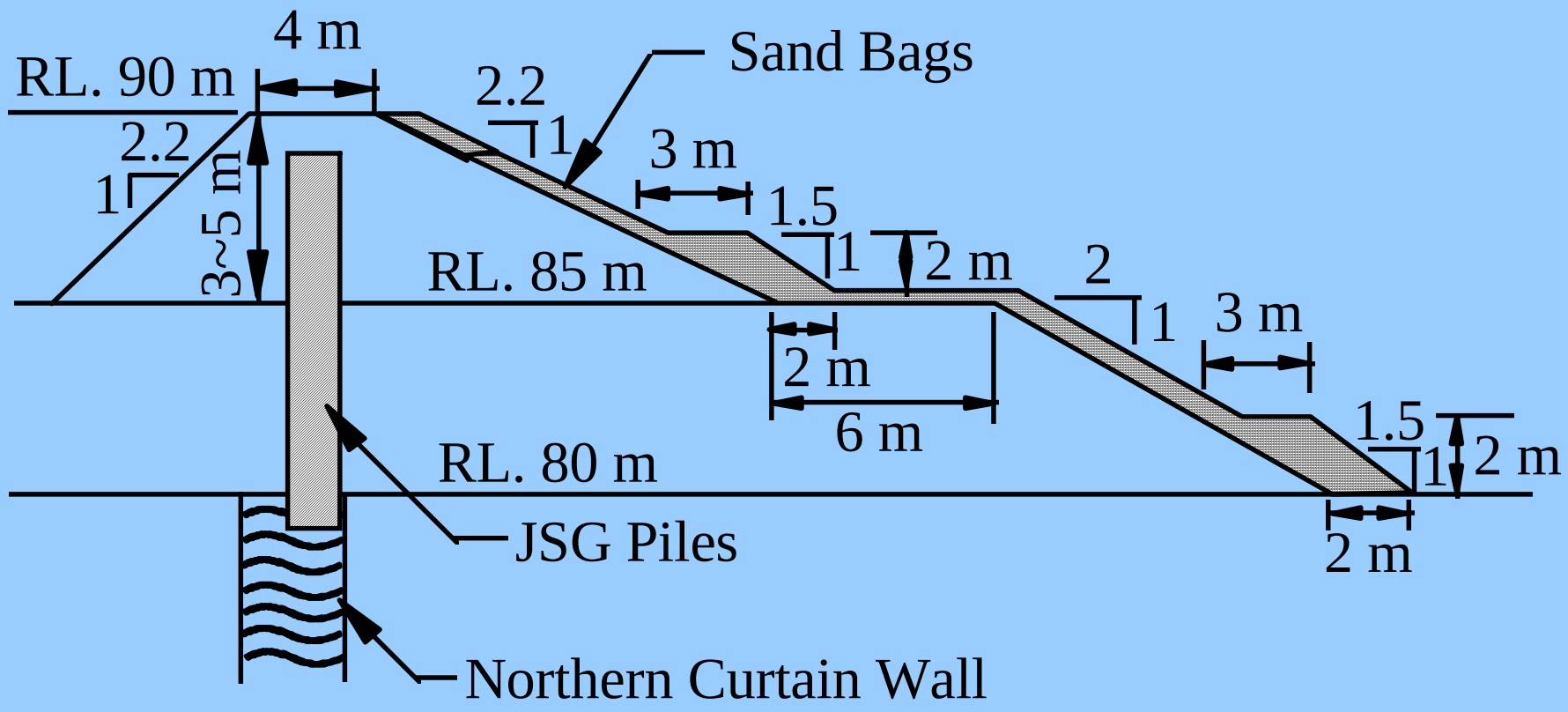
Scenario of the Incident


700m to diaphragm Wall (500m excavated)
70,000 tons/13 hours
RL 89m
RL 80m
9,000 m3 sand & gravels
Base Slab
70m
Chingmei Gravels


14 m
17 m
15 m
LW
Curtain Wall
3 rows
Bottom of Excavation, RL 80m
LW
Curtain Wall
3 rows
15m
Zone B
Zone A
(CB grout)
Zone B
(CB grout)
23.6m
III
II
Chingmei Gravels


500m
RL 89m
RL90m
RL 80m
Base
Slab
Chingmei Gravels

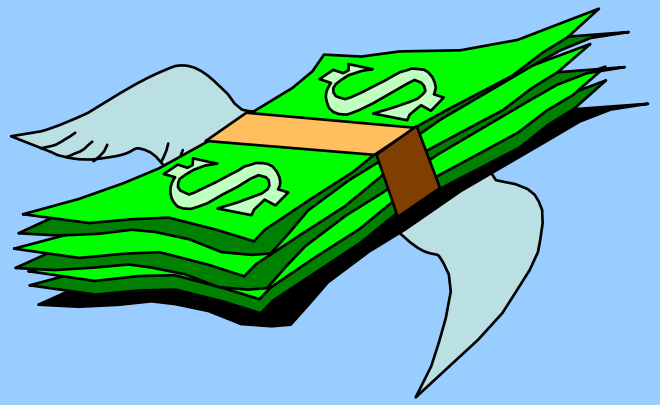

N
Zone C
Southern
Curtain
Wall
Zone A
Northern
Curtain
Wall
Zone B
Sump
Scale
0
10
20 m

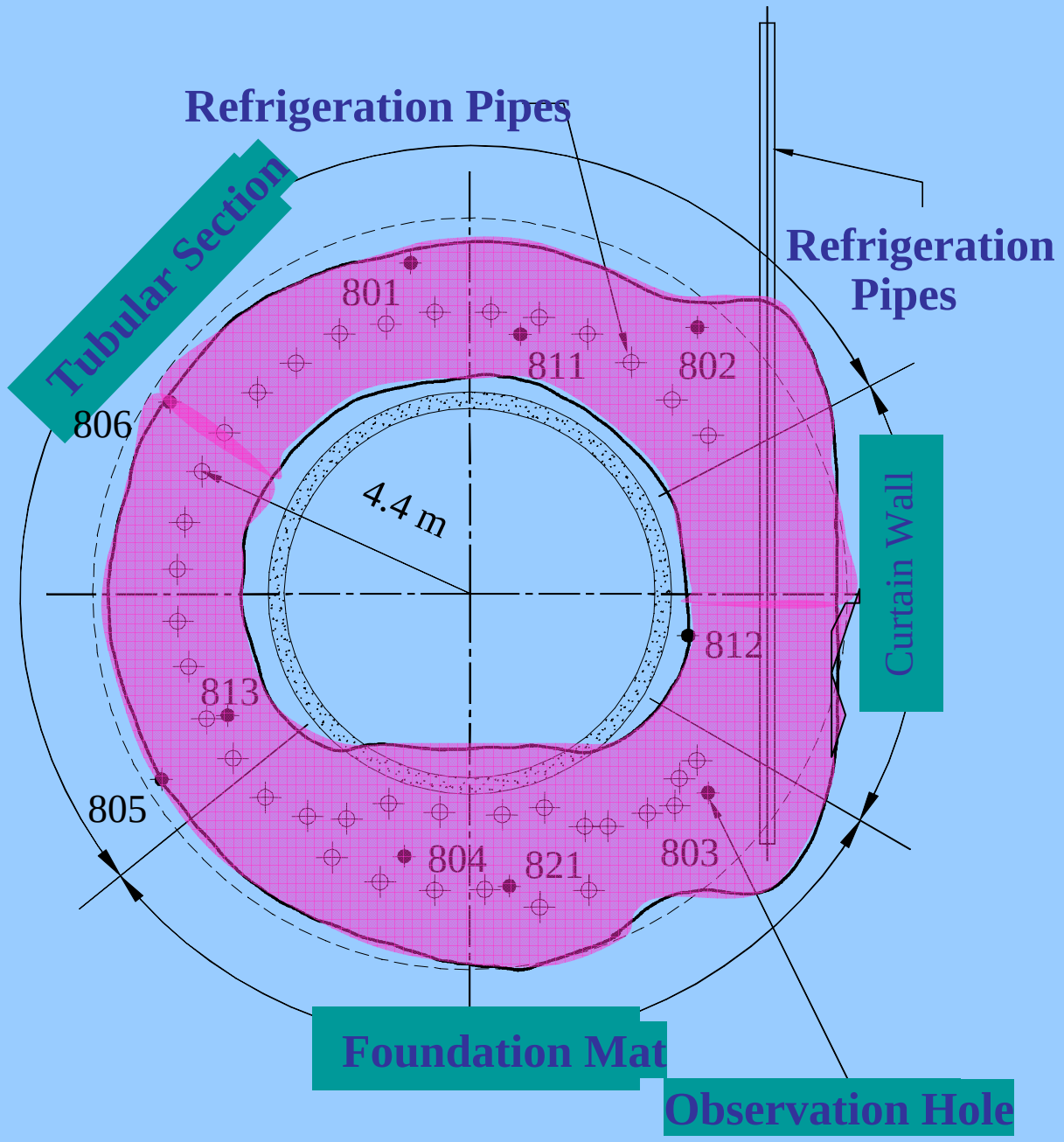

4 m
RL. 90 m
2.2
1
2.2
1
3~5 m
Sand Bags
3 m
1.5
1
2 m
RL. 85 m
2
1
3 m
2 m
6 m
1.5
1
2 m
RL. 80 m
JSG Piles
2 m
Northern Curtain Wall

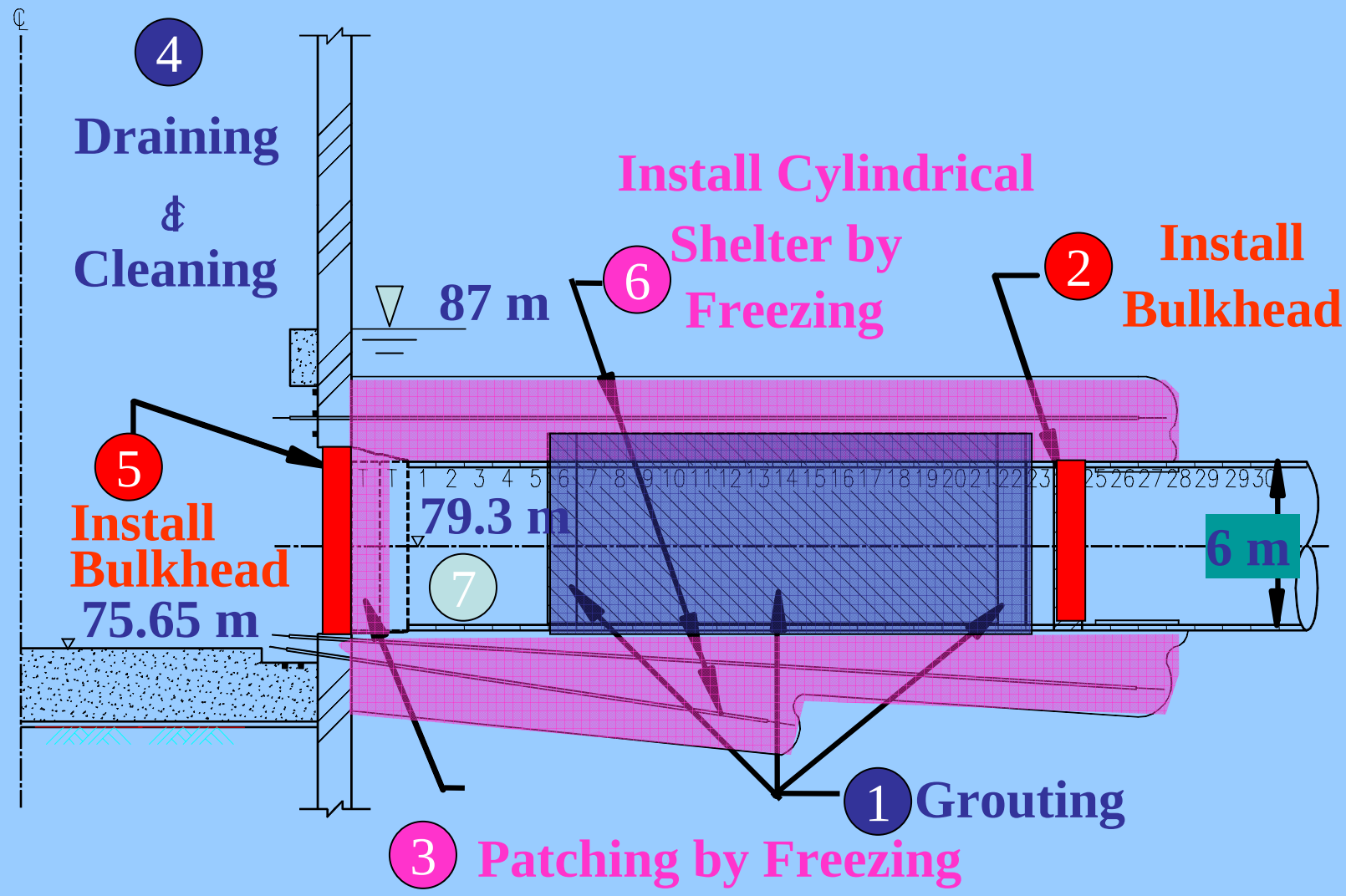
A Small Hole?

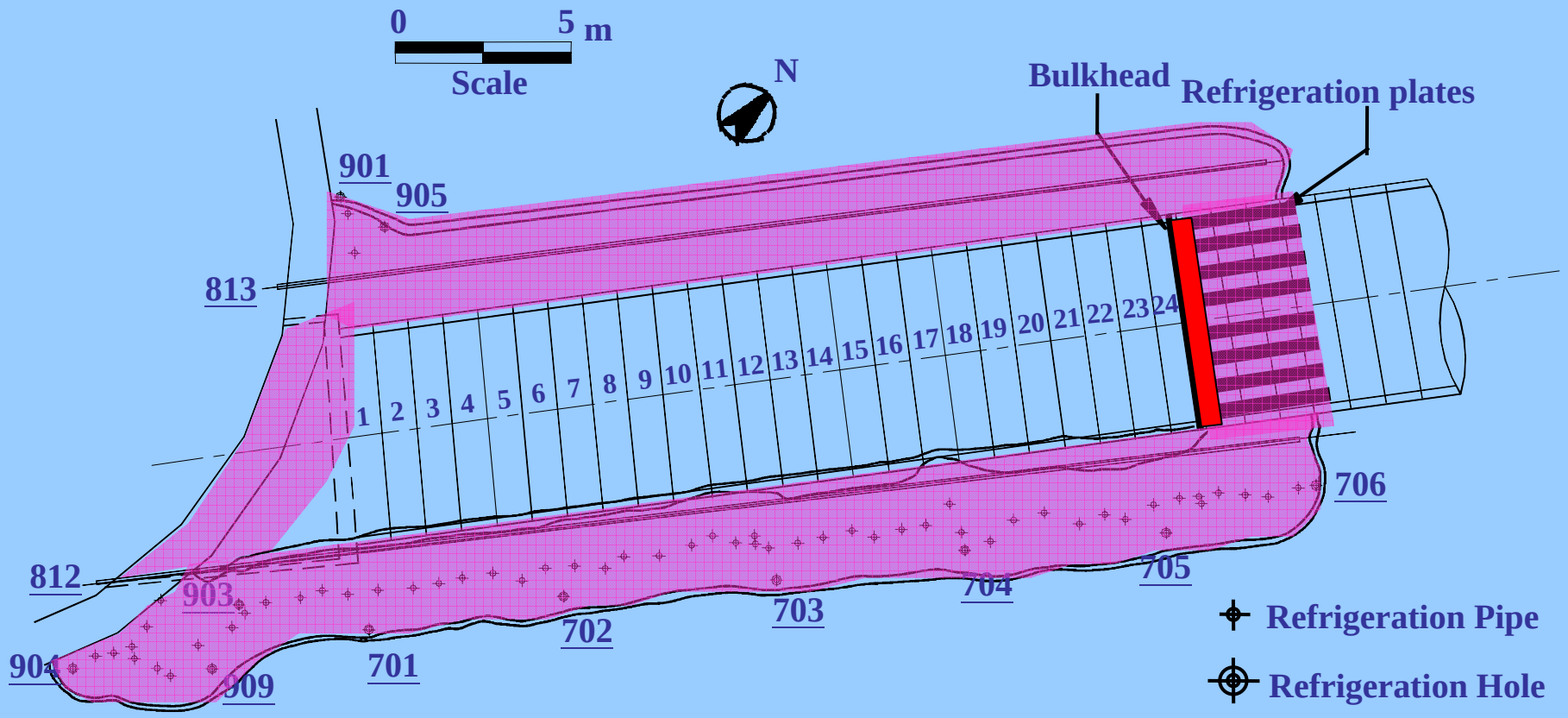
- 70,000 tonnes of water recharged
- 9,000 m^3 of sands and gravels dumped
- 5,400 m^3 of grout injected

A$4,000,000

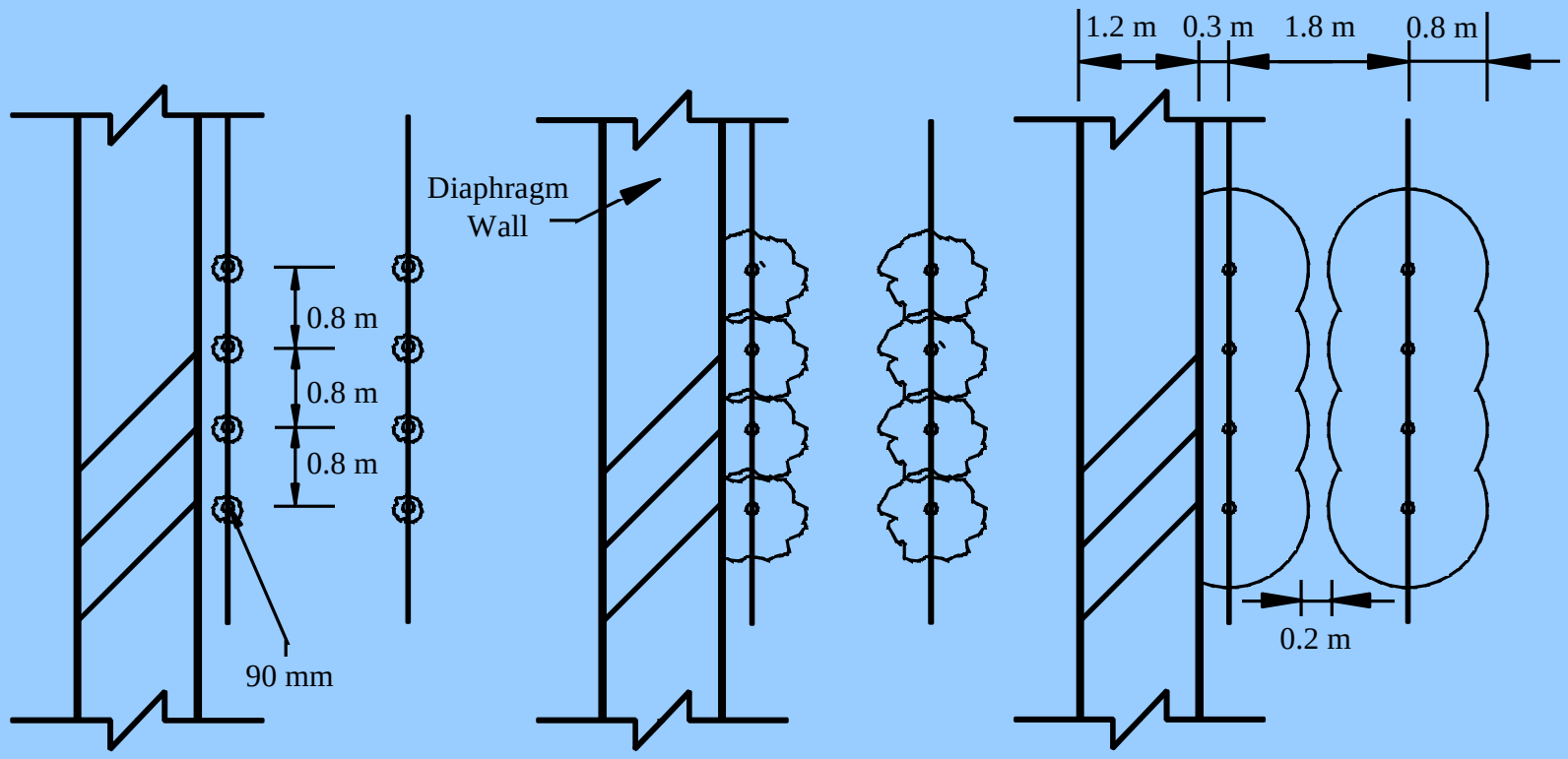



Refrigeration Pipes
Tubular Section
Refrigeration Pipes
801
811
802
806
4.4 m
Curtain Wall
812
813
805
804
821
803
Foundation Mat
Observation Hole


4
Draining
&
Cleaning
87 m
6
Install Cylindrical
Shelter by
Freezing
2
Install
Bulkhead
5
Install
Bulkhead
75.65 m
79.3 m
7
6 m
1
Grouting
3
Patching by Freezing



Ground Freezing



(a) t < 18 days
Phase I

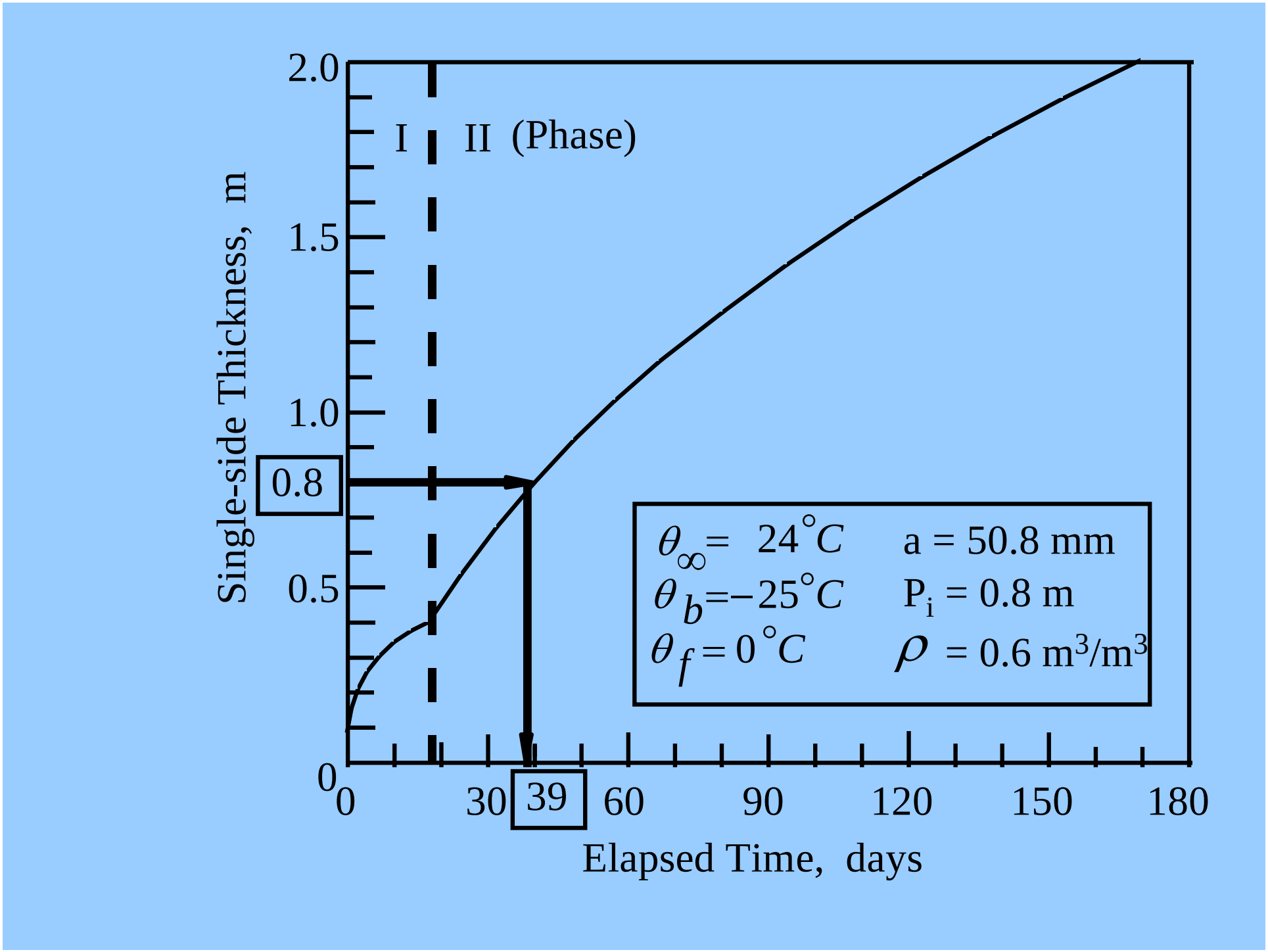
(b) 18 days < t < 39 days
Phase II

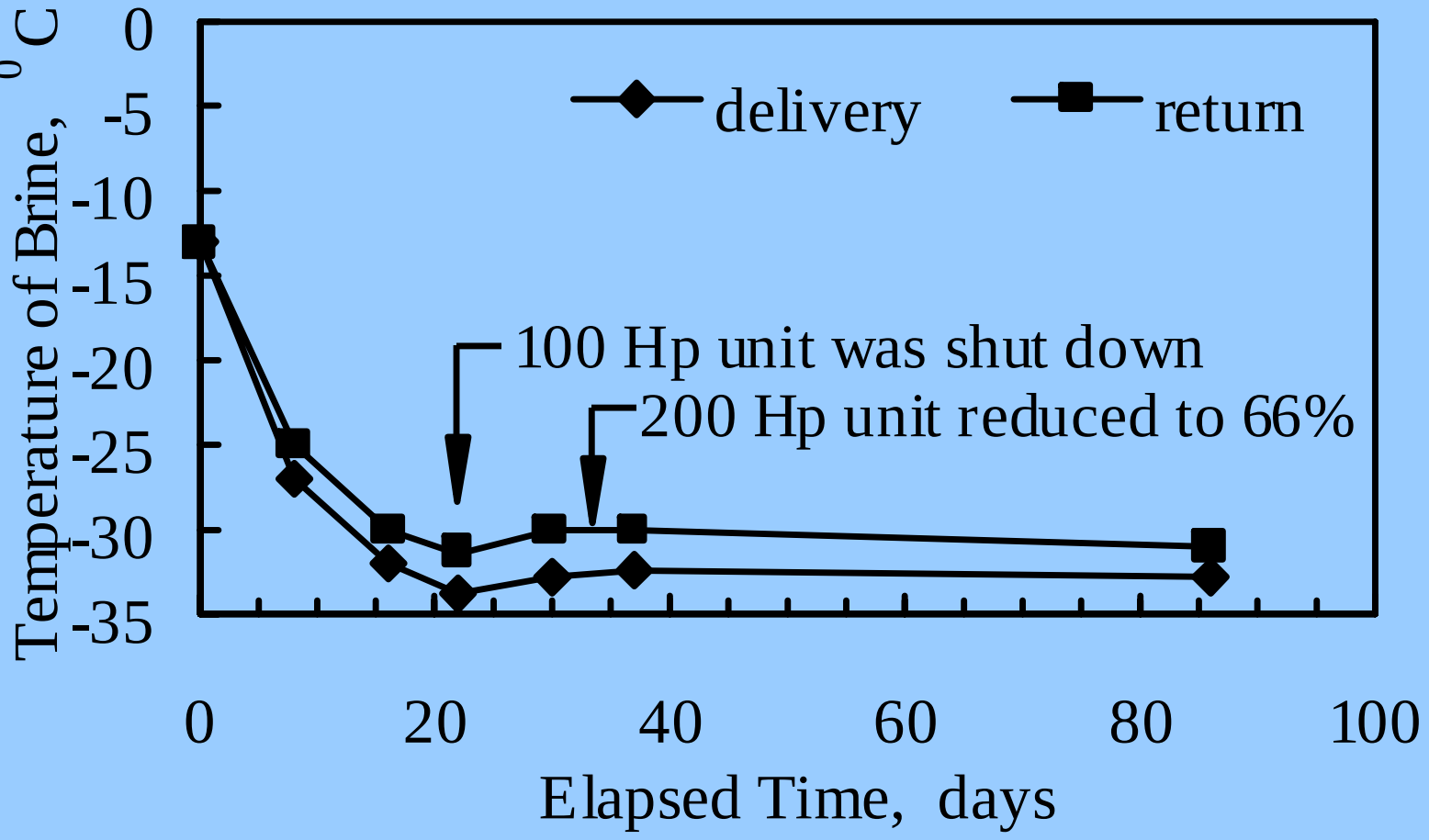
(c) t = 39 days

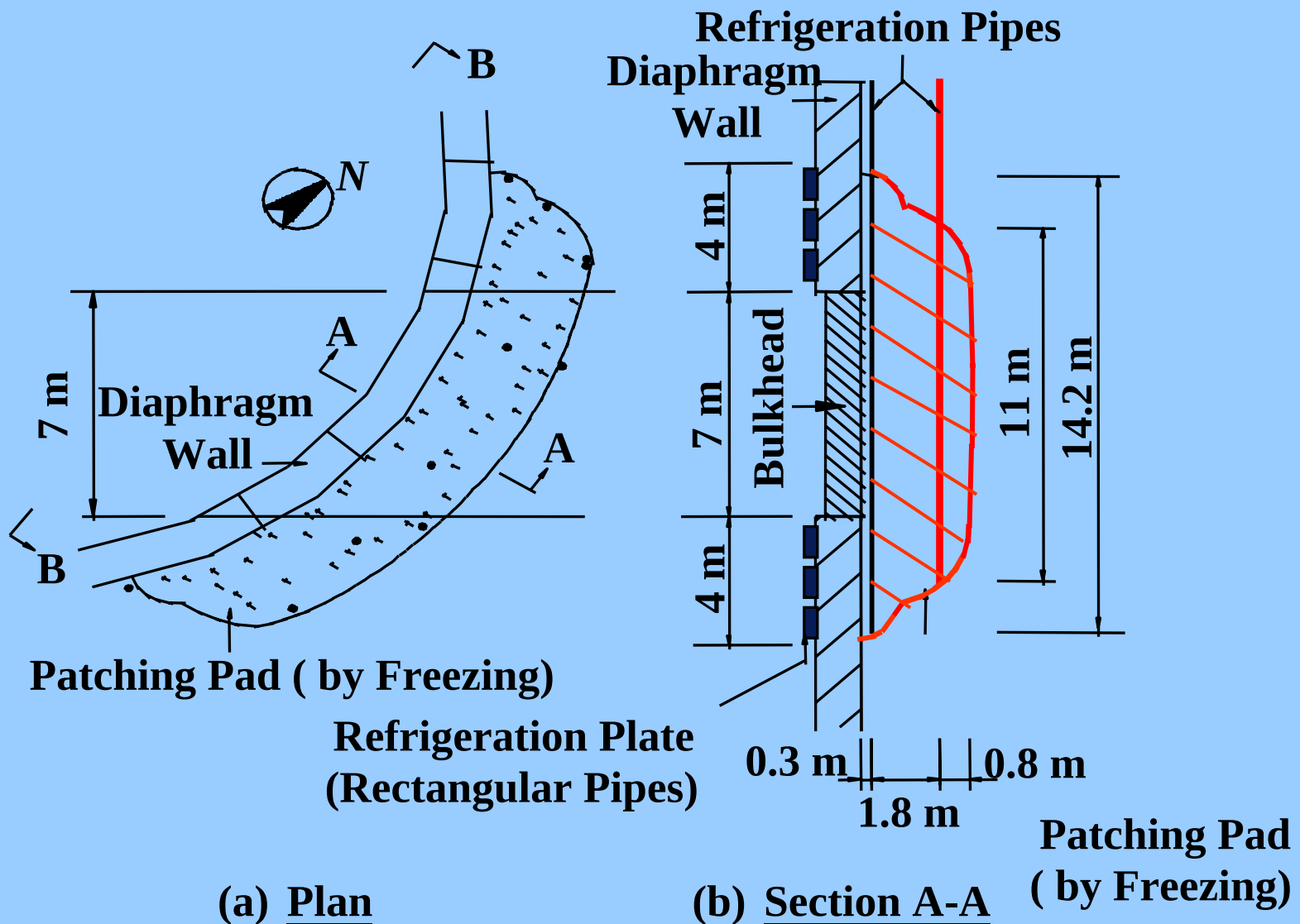
Rate of freezing for single pipe

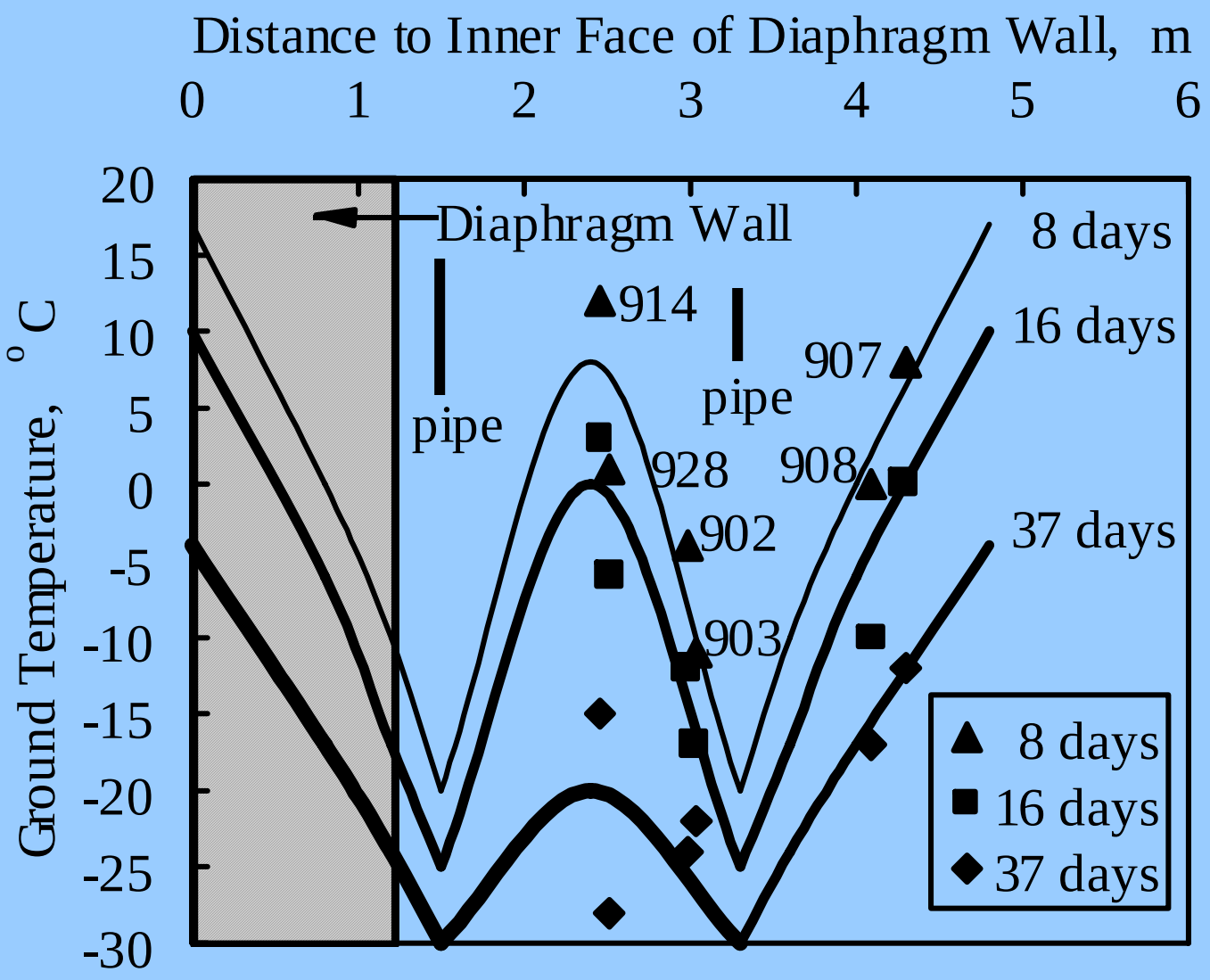
$$\lambda_1\theta_c\left[\frac{\frac{\partial F(x_1,a{:}r,t}{\partial r}}{F(x_1,a{:}r,t)}\right]+\lambda_2\theta_\infty\left[\frac{\frac{\partial F(x_2,a{:}r,t)}{\partial r}}{1-F(x_2,a{:}r,t)}\right]=Lr_1\left[\frac{\frac{\partial F(x_1,a{:}r,t)}{\partial t}}{\frac{\partial F(x_1,a{:}r,t)}{\partial r}}\right]$$

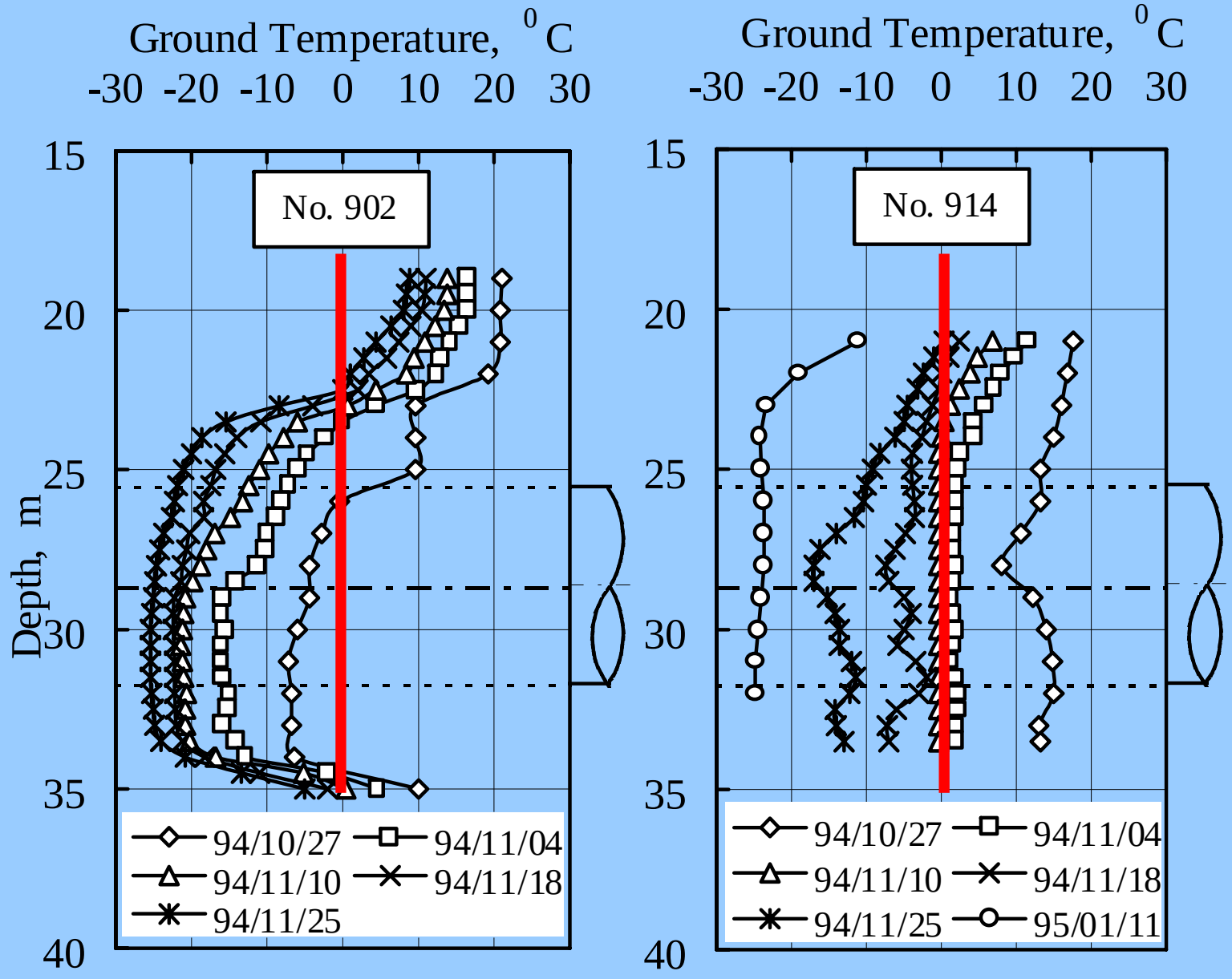
$$F(x,a{:}r,t)=-\frac{2}{\pi}\int_0^\infty e^{-x}\left(\frac{X}{a}\right)^2 t\frac{J_0(X\frac{r}{a})Y_0(X)-J_0(X)Y_0(X\frac{r}{a})}{J_0^2(X)+Y_0^2(X)}\frac{dX}{X}$$

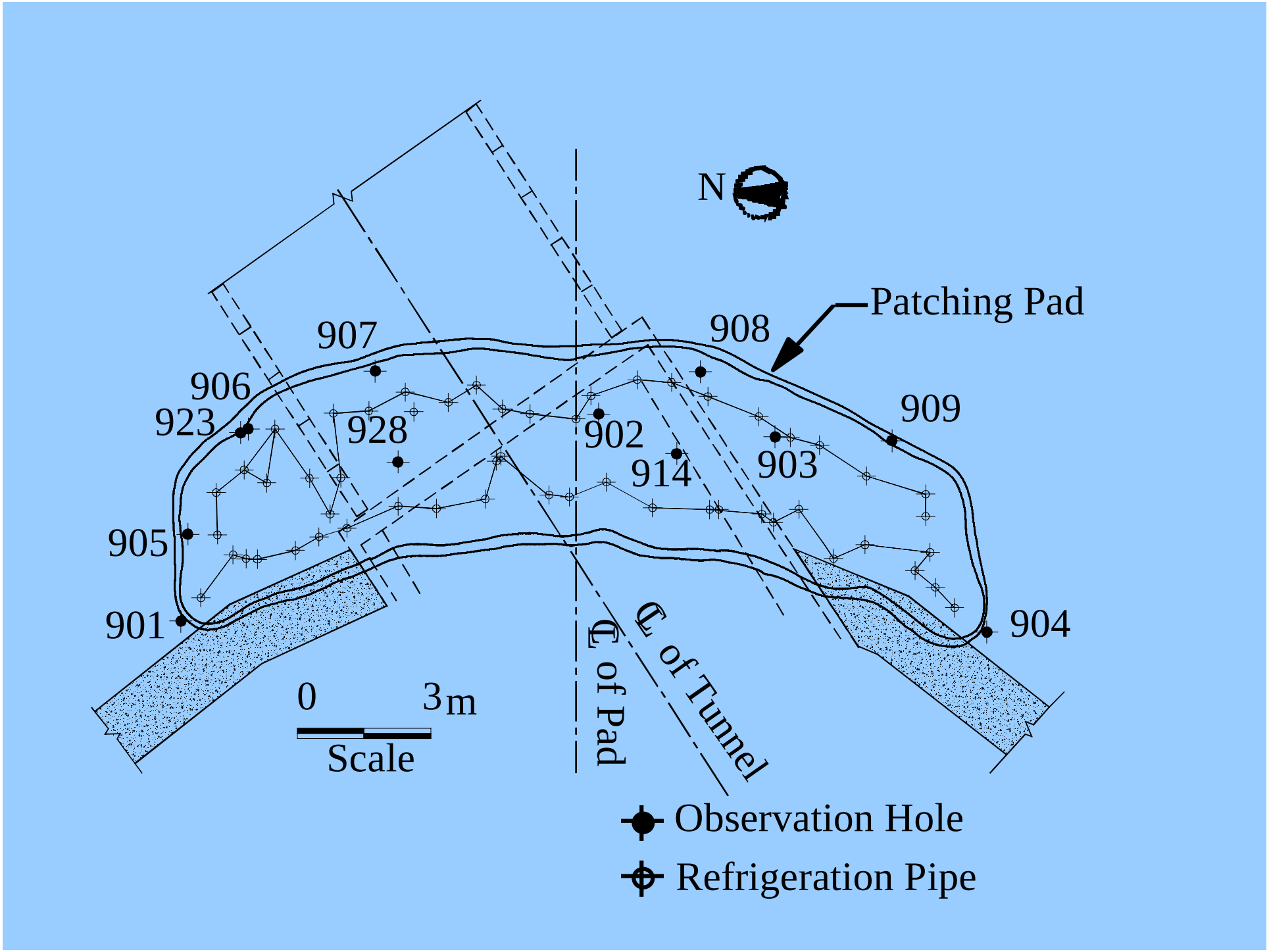

2.0
1.5
1.0
0.8
0.5
0
I
II (Phase)
Single-side Thickness, m
θ_∞= 24°C
θ_b=−25°C
θ_f= 0°C
a = 50.8 mm
P_i = 0.8 m
ρ = 0.6 m^3/m^3
0
30
39
60
90
120
150
180
Elapsed Time, days

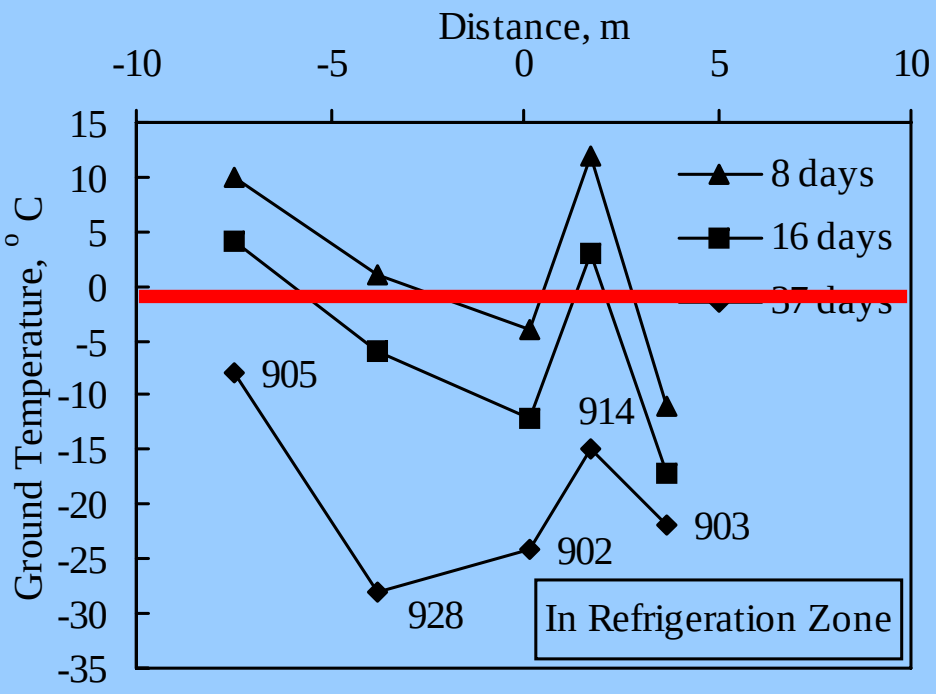

Temperature of Brine, ^{0}C
0
-5
-10
-15
-20
-25
-30
-35
delivery
return
100 Hp unit was shut down
200 Hp unit reduced to 66%
0
20
40
60
80
100
Elapsed Time, days


B
N
A
7 m
Diaphragm
Wall
A
B
Patching Pad (by Freezing)
Refrigeration Pipes
Diaphragm
Wall
4 m
7 m
Bulkhead
4 m
11 m
14.2 m
Refrigeration Plate
(Rectangular Pipes)
0.3 m
0.8 m
1.8 m
Patching Pad
(by Freezing)
(a) Plan
(b) Section A-A

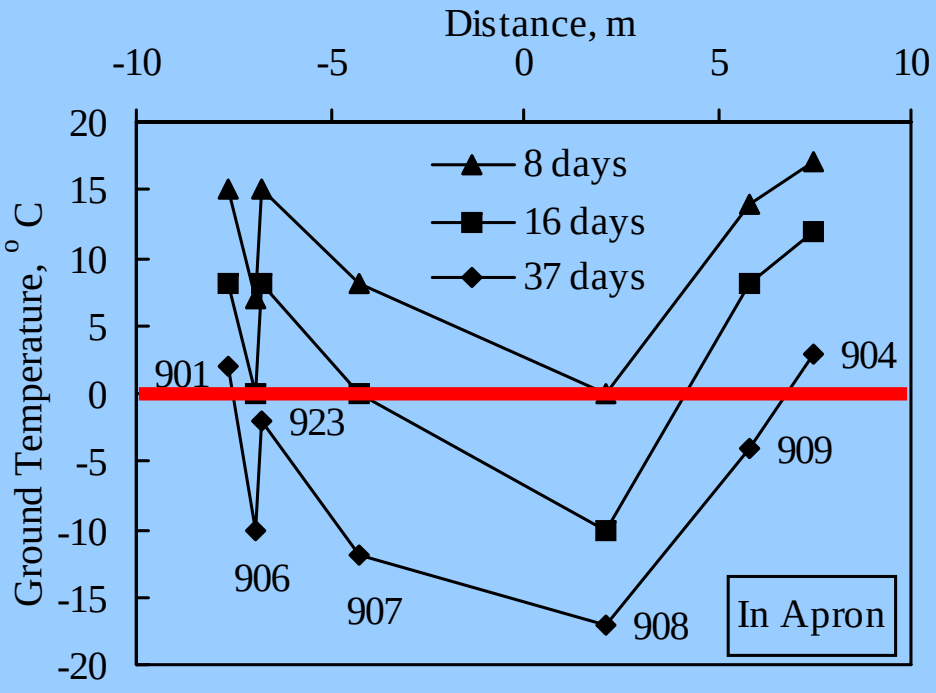

Distance to Inner Face of Diaphragm Wall, m
0
1
2
3
4
5
6
Ground Temperature, °C
20
15
10
5
0
-5
-10
-15
-20
-25
-30
Diaphragm Wall
pipe
pipe
914
928
902
903
907
908
8 days
16 days
37 days
8 days
16 days
37 days


Ground Temperature, 0 C
-30 -20 -10 0 10 20 30
Depth, m
15
20
25
30
35
40
No. 902
94/10/27
94/11/04
94/11/10
94/11/18
94/11/25
Ground Temperature, 0 C
-30 -20 -10 0 10 20 30
No. 914
94/10/27
94/11/04
94/11/10
94/11/18
94/11/25
95/01/11

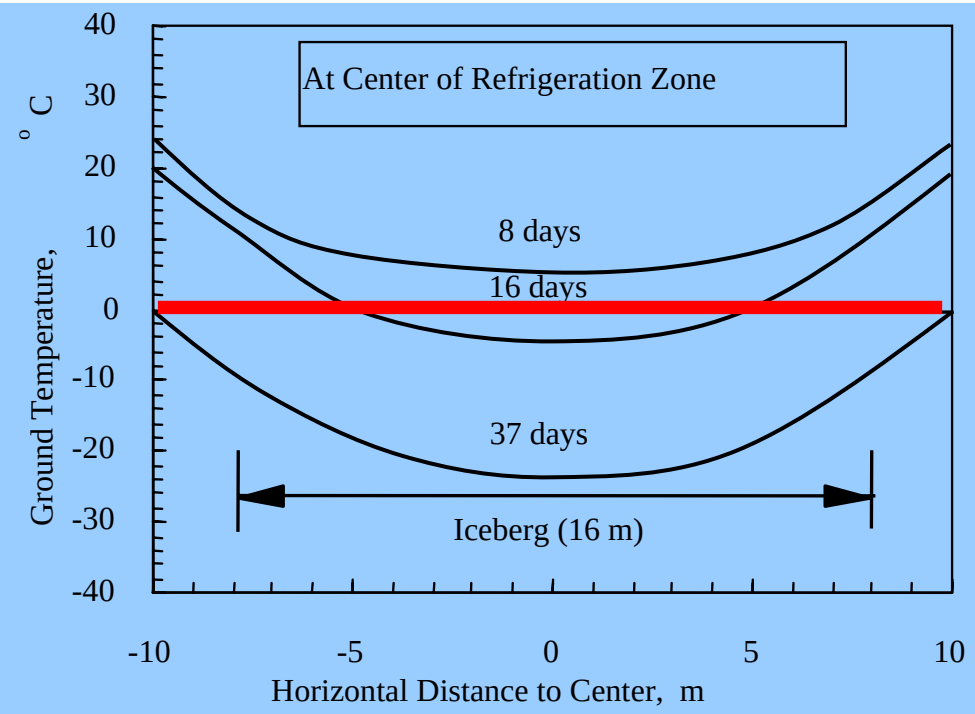

N
Patching Pad
907
908
906
909
923
928
902
914
903
905
901
904
0
3m
Scale
℄ of Pad
℄ of Tunnel
Observation Hole
Refrigeration Pipe

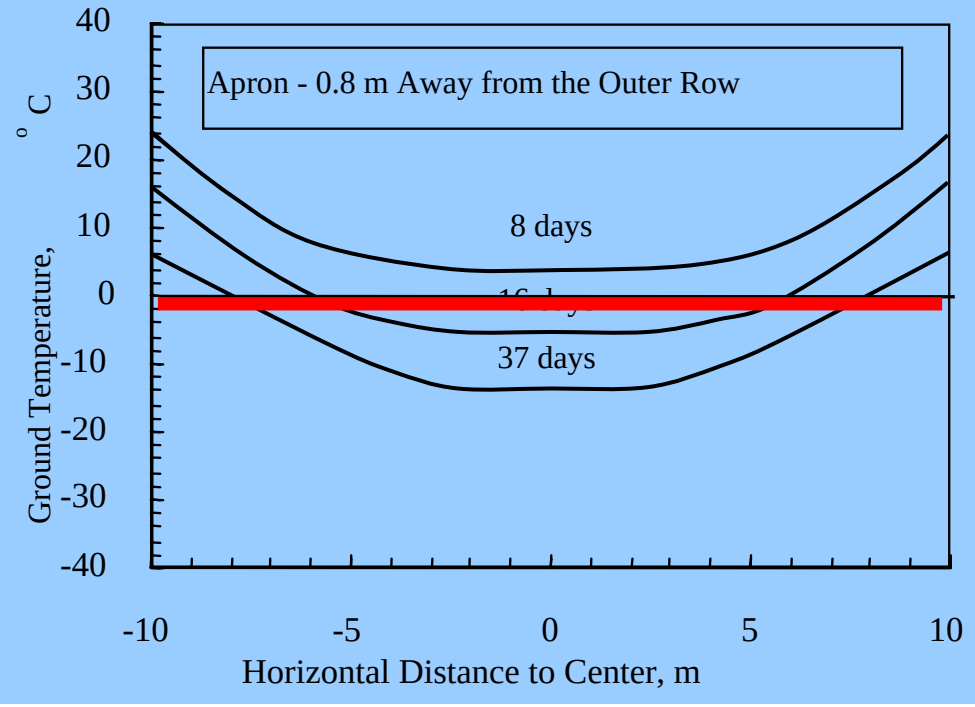

Distance, m
-10
-5
0
5
10
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
Ground Temperature, ° C
8 days
16 days
905
914
903
902
928
In Refrigeration Zone

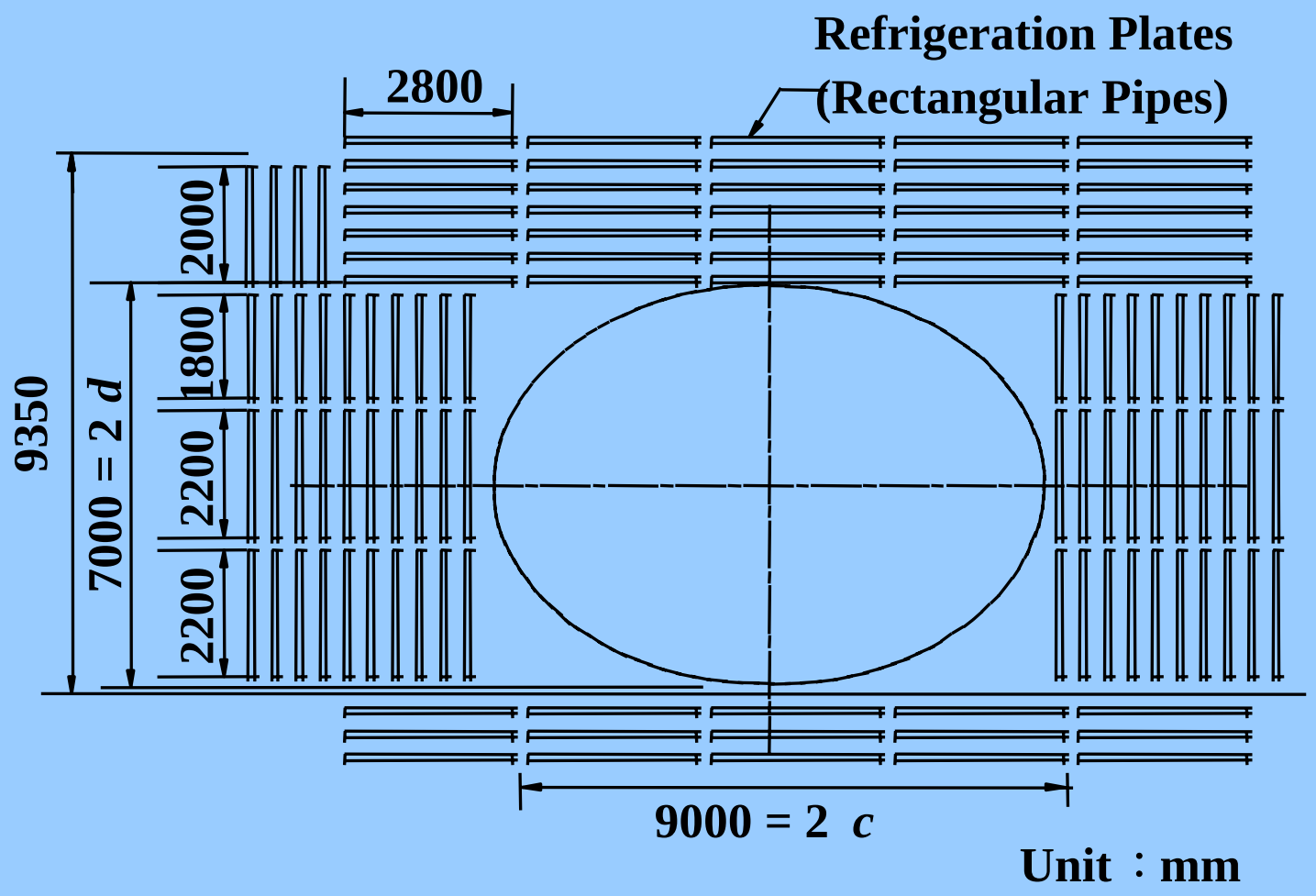
16 (a)


Distance, m
-10
-5
0
5
10
20
15
10
5
0
-5
-10
-15
-20
Ground Temperature, ° C
8 days
16 days
37 days
901
904
923
909
906
907
908
In Apron

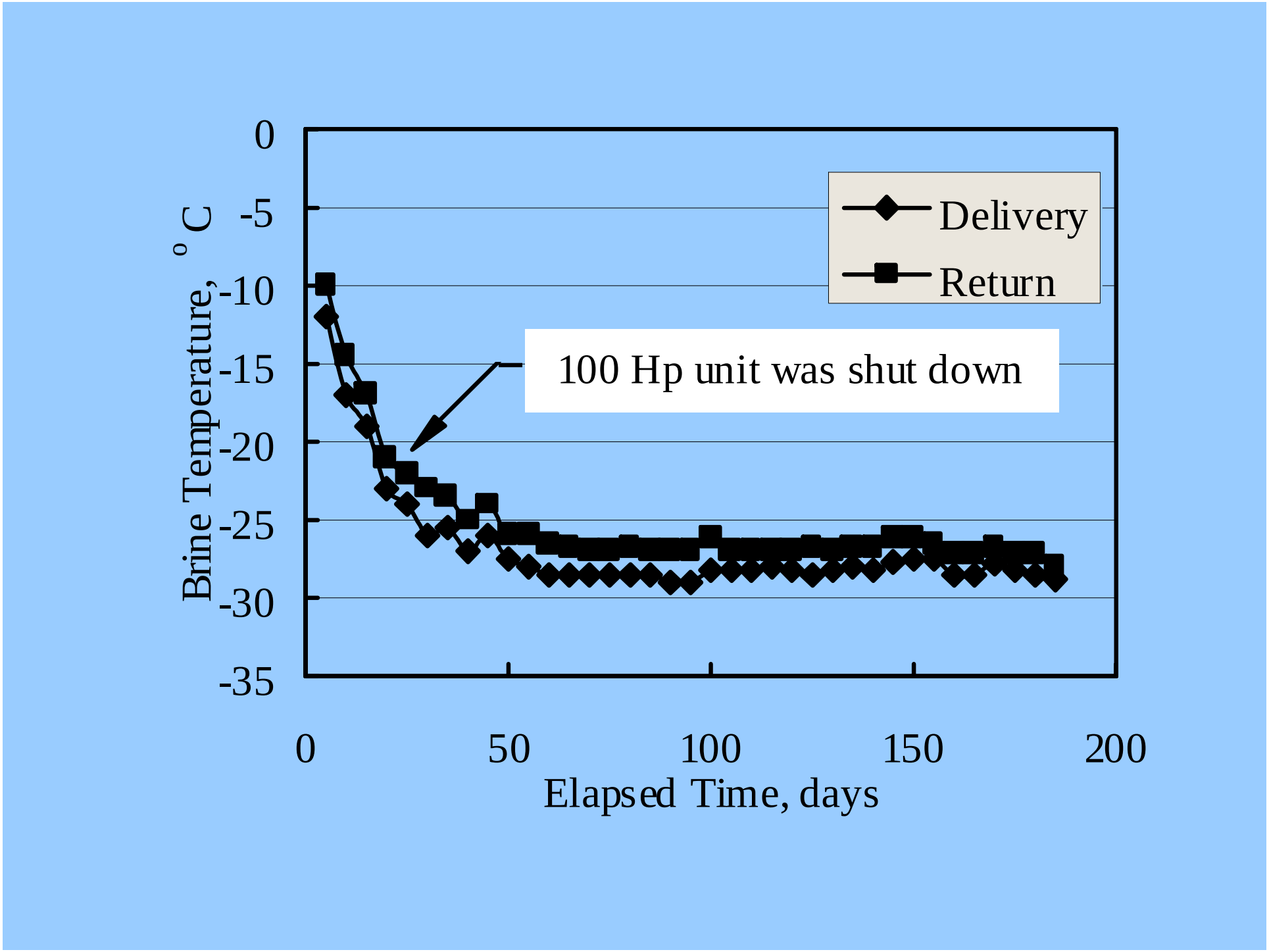
16 (b)

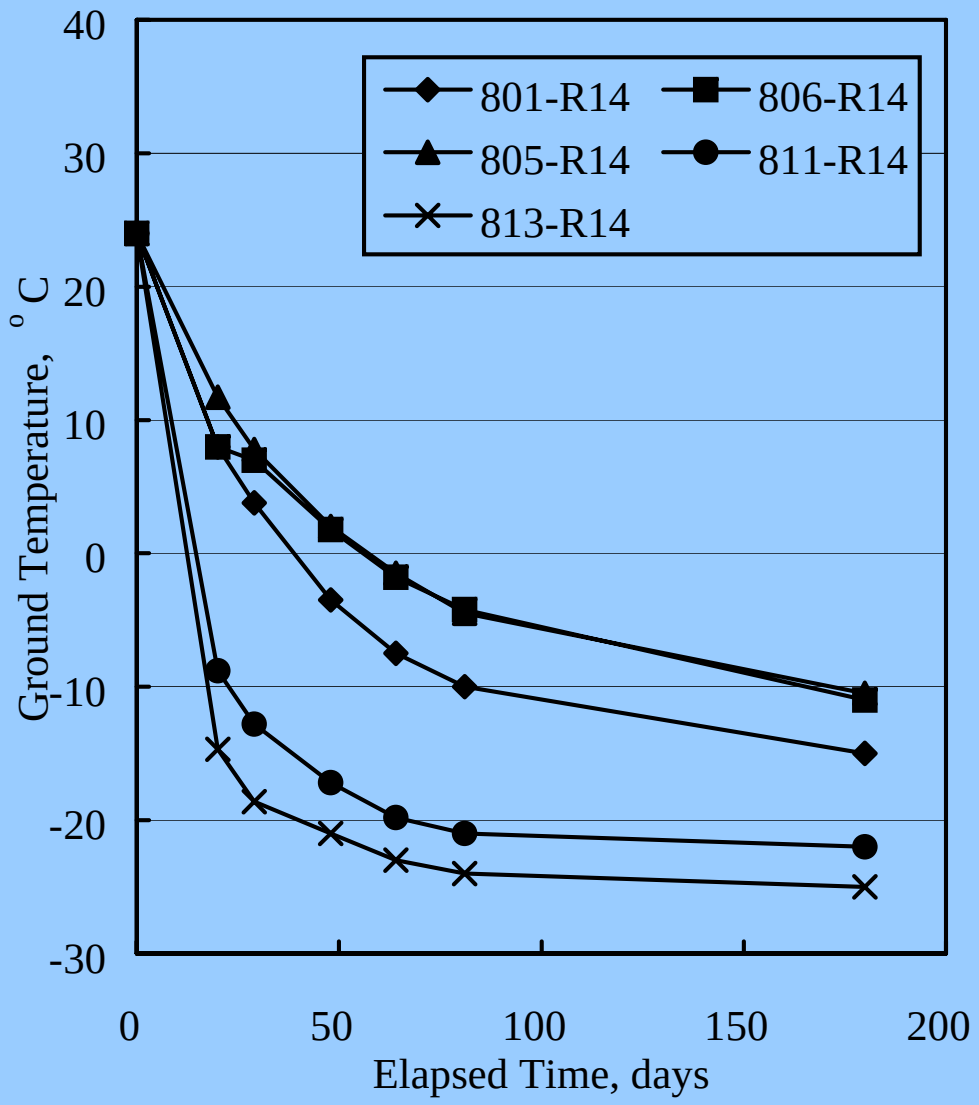

At Center of Refrigeration Zone
8 days
16 days
37 days
Iceberg (16 m)
Ground Temperature, °C
Horizontal Distance to Center, m
40
30
20
10
0
-10
-20
-30
-40
-10
-5
0
5
10

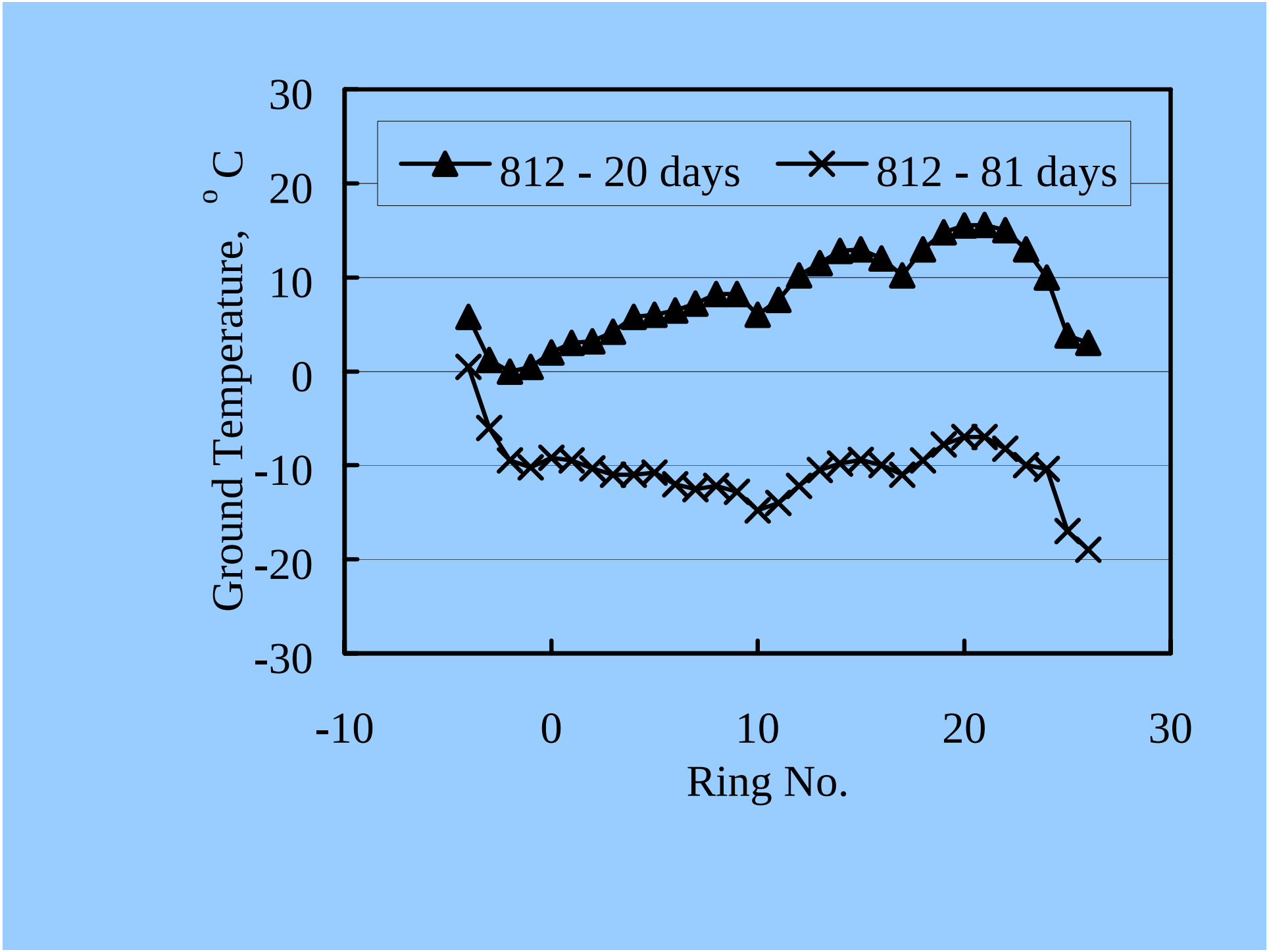

Apron - 0.8 m Away from the Outer Row
8 days
37 days
Ground Temperature, °C
Horizontal Distance to Center, m
40
30
20
10
0
-10
-20
-30
-40
-10
-5
0
5
10

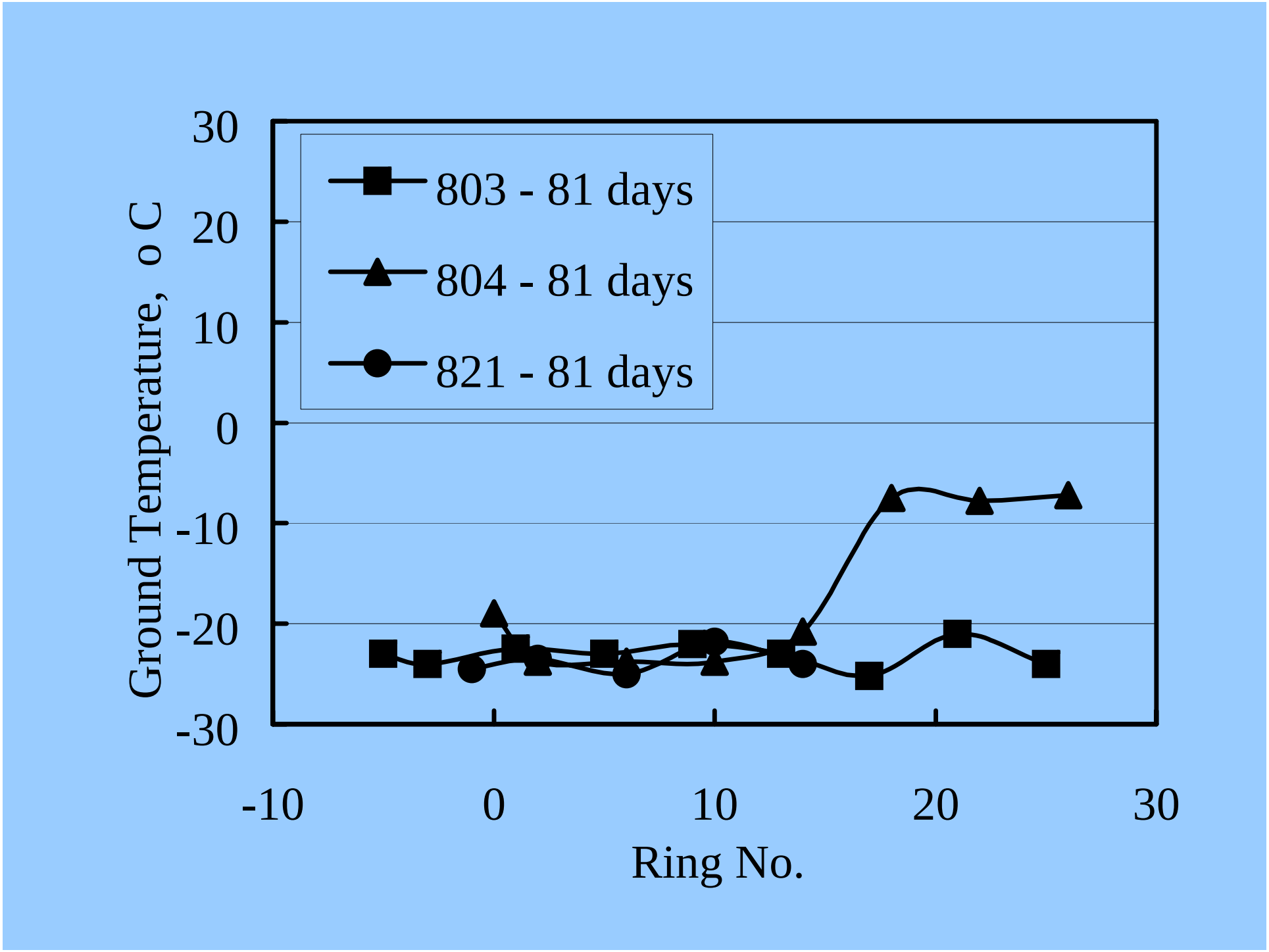

Refrigeration Plates
(Rectangular Pipes)
2800
2000
1800
2200
2200
9350
7000 = 2 d
9000 = 2 c
Unit：mm

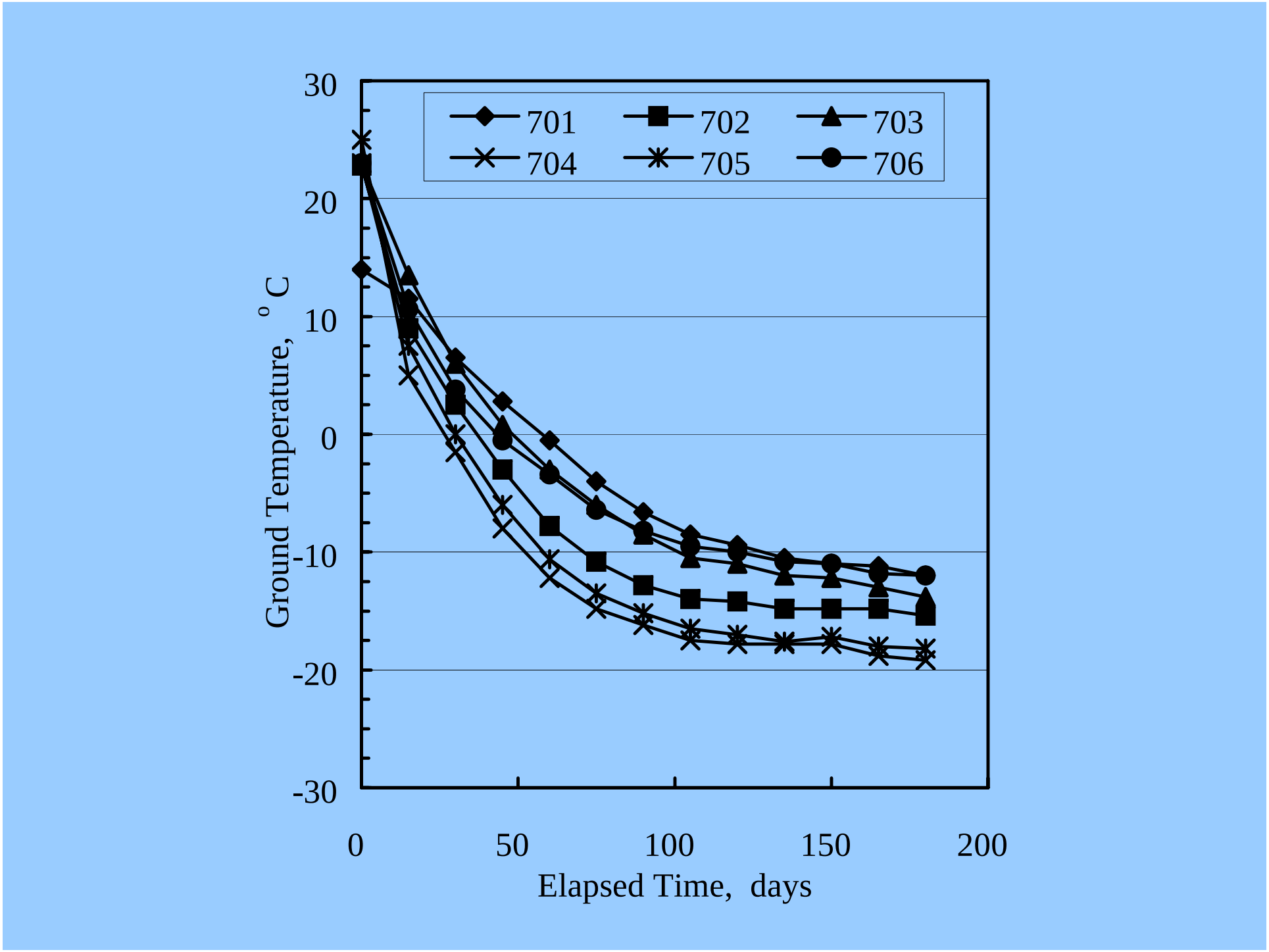
(c) Section B-B

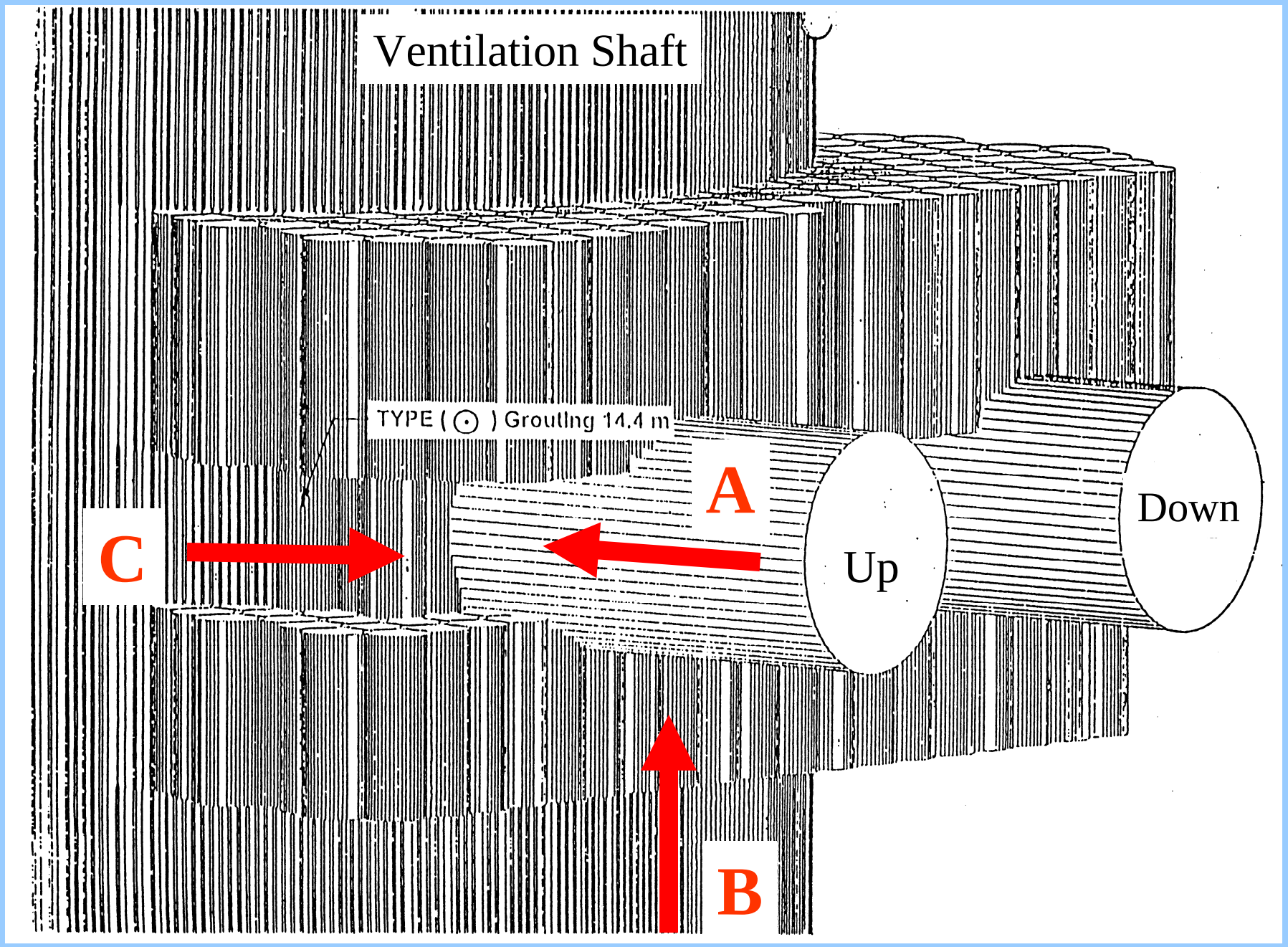

0
-5
-10
-15
-20
-25
-30
-35
Brine Temperature, °C
0
50
100
150
200
Elapsed Time, days
Delivery
Return
100 Hp unit was shut down

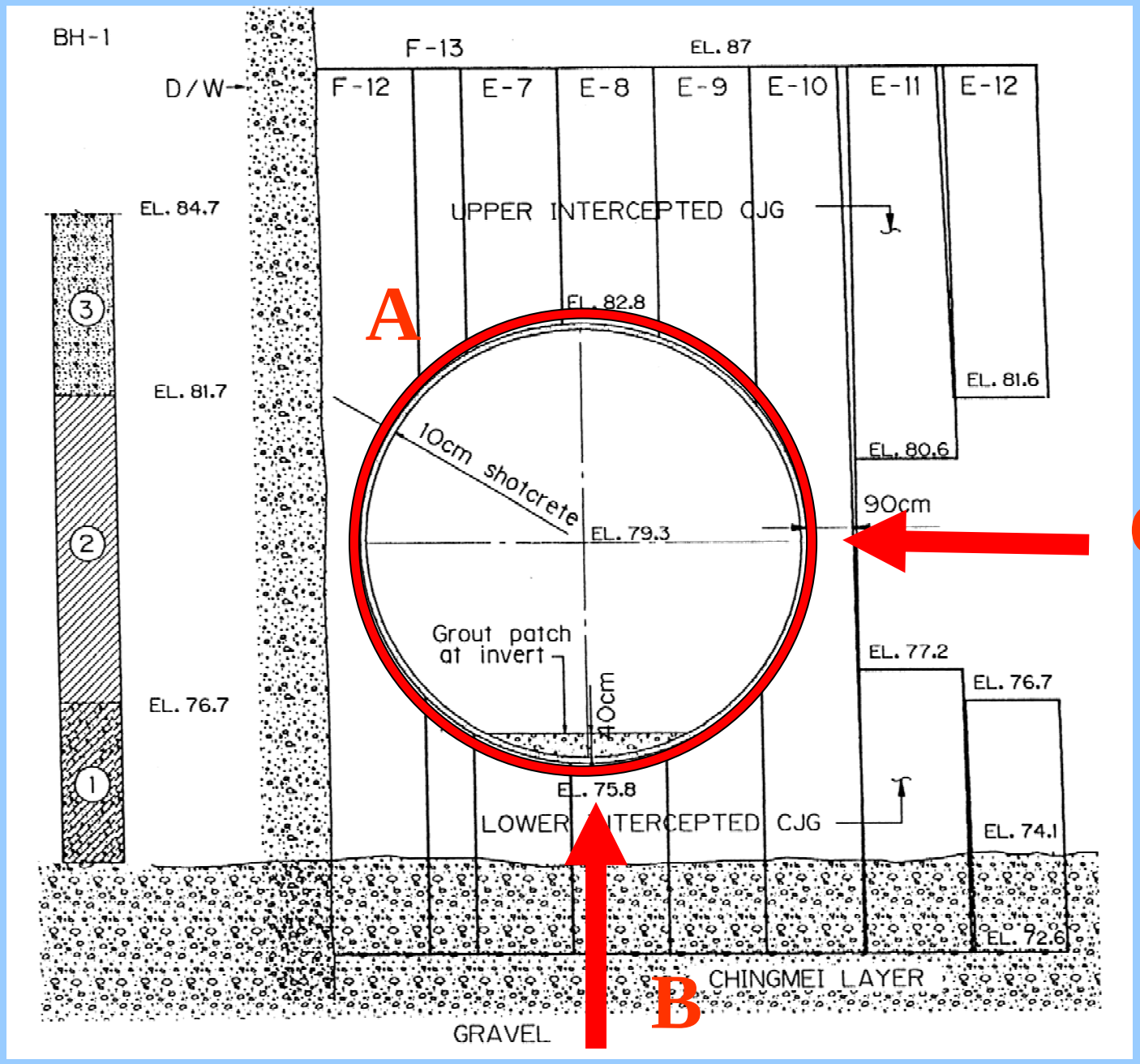

801-R14
806-R14
805-R14
811-R14
813-R14
Ground Temperature, °C
40
30
20
10
0
-10
-20
-30
0
50
100
150
200
Elapsed Time, days

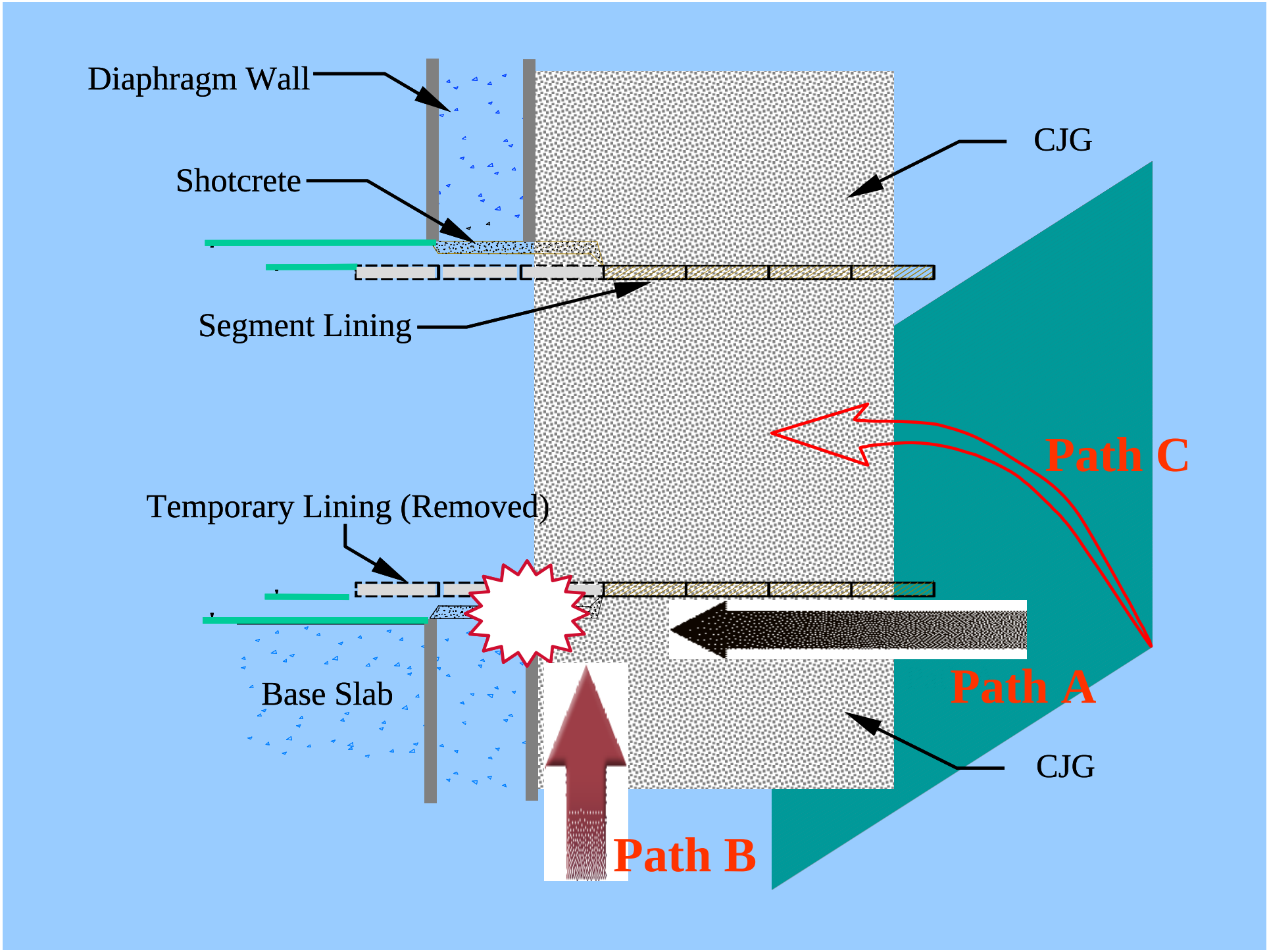

812 - 20 days
812 - 81 days
Ground Temperature, °C
30
20
10
0
-10
-20
-30
-10
0
10
20
30
Ring No.


803 - 81 days
804 - 81 days
821 - 81 days
Ground Temperature, o C
30
20
10
0
-10
-20
-30
-10
0
10
20
30
Ring No.


30
20
10
0
-10
-20
-30
Ground Temperature, °C
701
702
703
704
705
706
0
50
100
150
200
Elapsed Time, days


Ventilation Shaft
TYPE (⊙) Grouting 14.4 m
A
B
C
Up
Down


BH-1
D/W
F-13
EL. 87
F-12
E-7
E-8
E-9
E-10
E-11
E-12
UPPER INTERCEPTED CJG
EL. 84.7
EL. 82.8
A
EL. 81.7
EL. 81.6
EL. 80.6
10cm shotcrete
90cm
EL. 79.3
C
Grout patch at invert
EL. 77.2
EL. 76.7
EL. 76.7
40cm
EL. 75.8
LOWER INTERCEPTED CJG
EL. 74.1
EL. 72.6
CHINGMEI LAYER
B
GRAVEL


Diaphragm Wall
Shotcrete
Segment Lining
CJG
Path C
Temporary Lining (Removed)
Base Slab
Path A
CJG
Path B

Opinions of Committee Members on Water Paths

	Member A	Member B	Member C	Member D	Member E
Path A	H	H	L	L	L
Path B	M	M	H	L	L
Path C	L	L	M	H	H

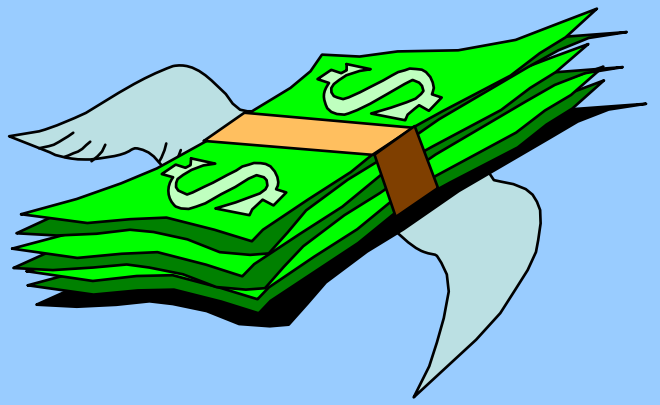
Notes: H – high possibility
M – medium possibility
L – low possibility

Opinions of Committee Members on Water Paths

	Member A	Member B	Member C	Member D	Member E	
Path A	3	3	1	1	1	9
Path B	2	2	3	1	1	9
Path C	1	1	2	3	3	10

Notes: 3 – high possibility
2 – medium possibility
1 – low possibility

A$30,000,000?

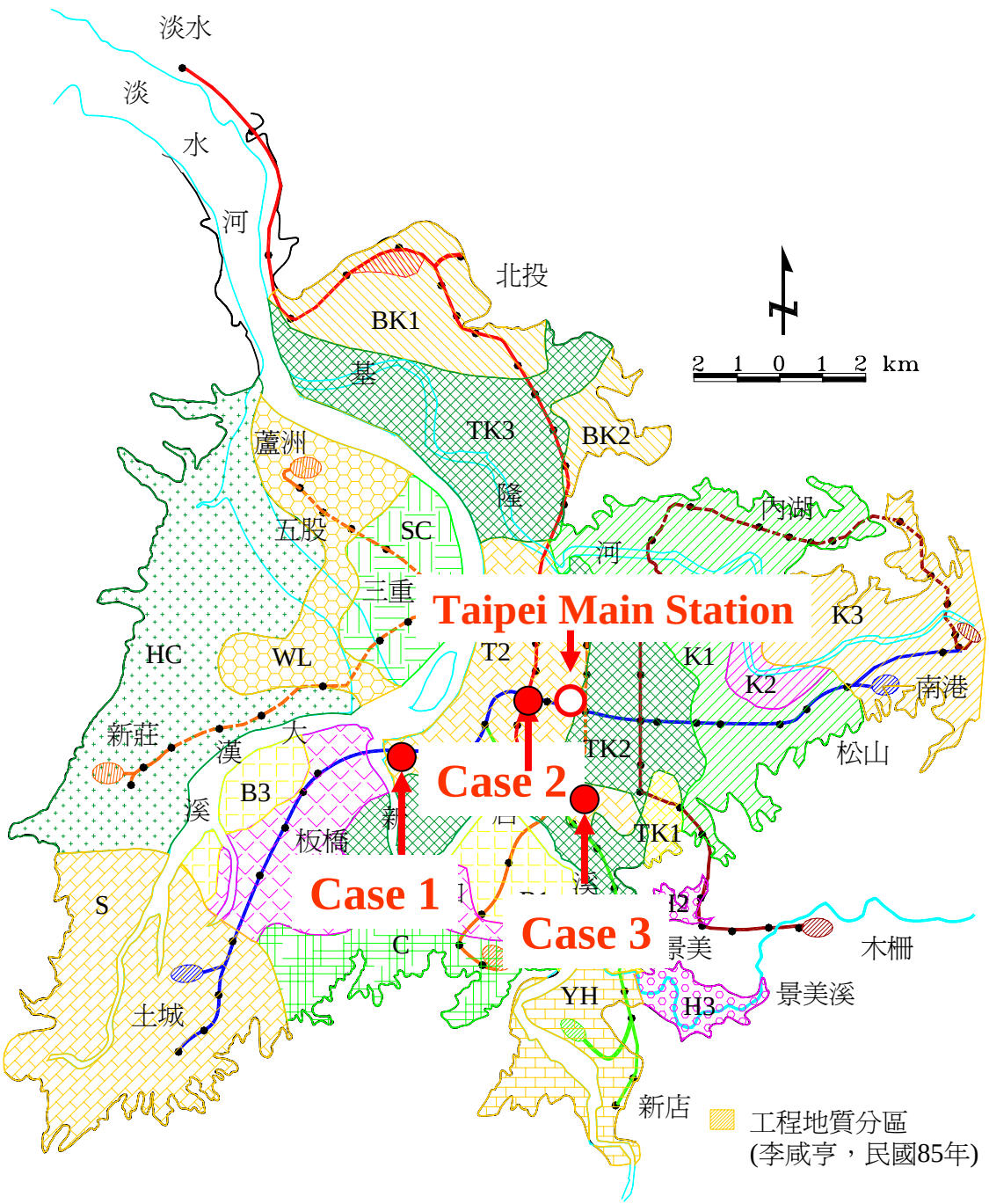


Lessons Learned

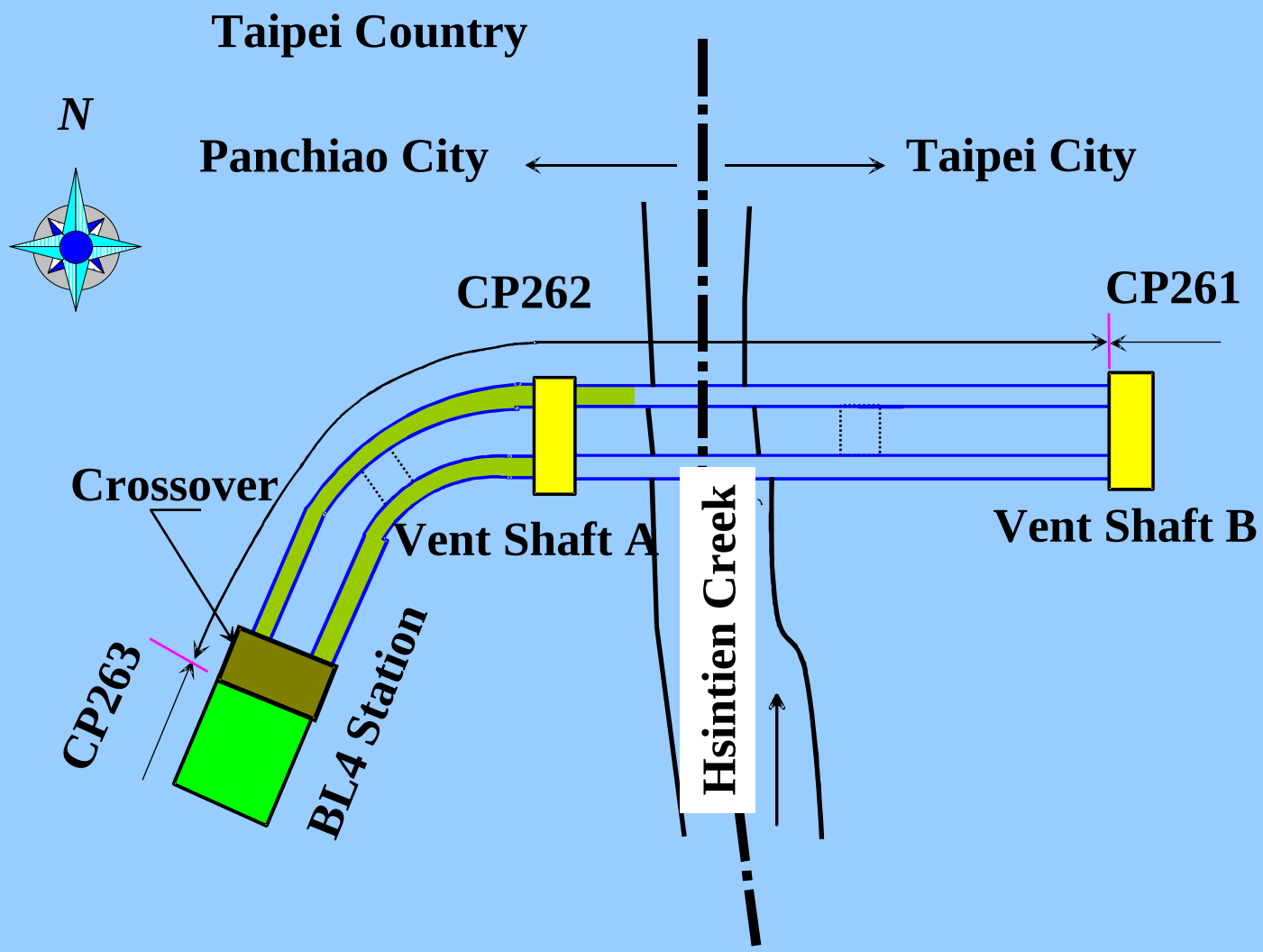
- Never under-estimate water problem
- Ground treatment can not be relied on
- Extra thickness is required when groundwater is a serious threat

Case 3 - Unforeseen Condition

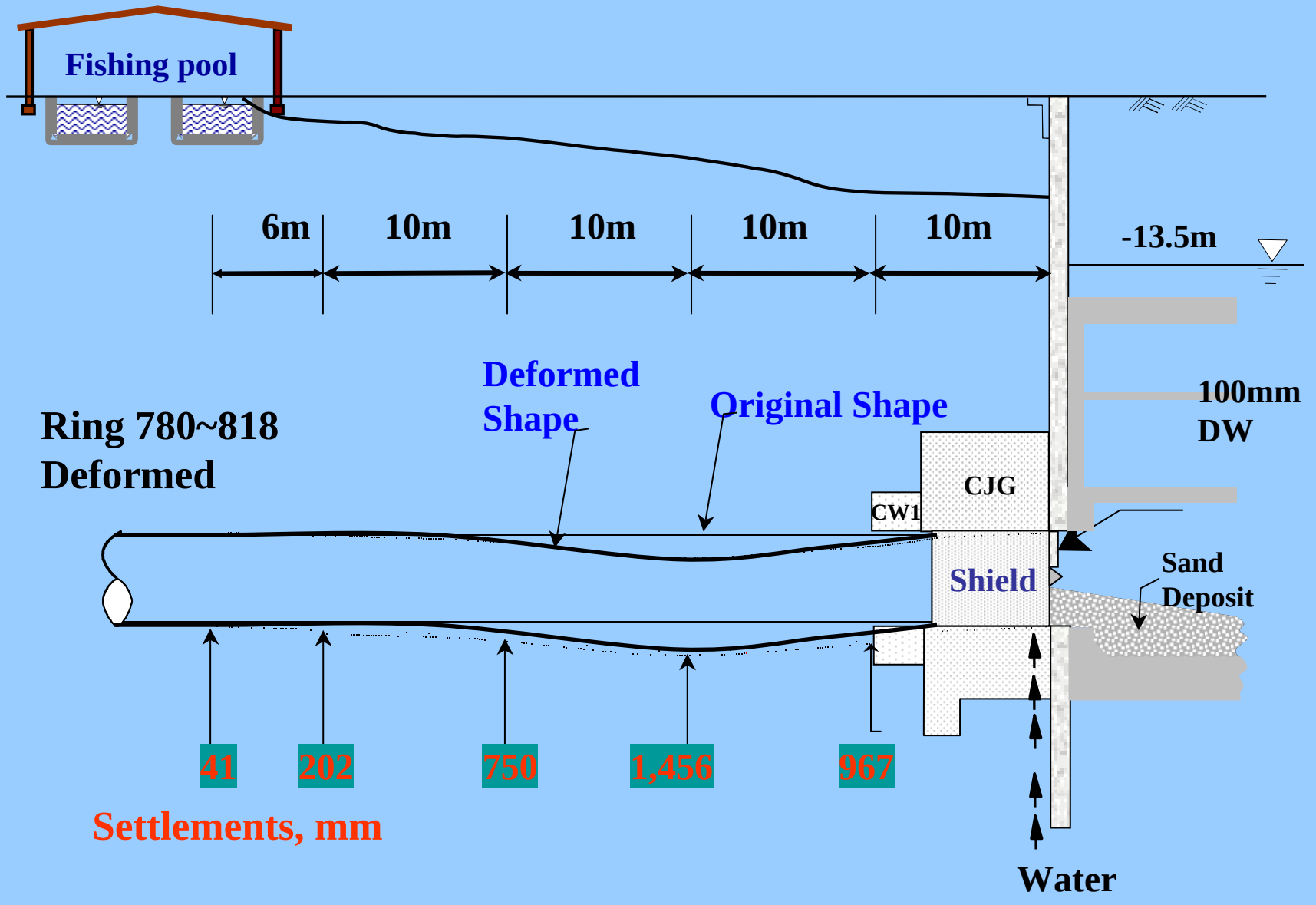
- Panchiao Line
- Opening of A Tunnel Eye at Ventilation Shaft A



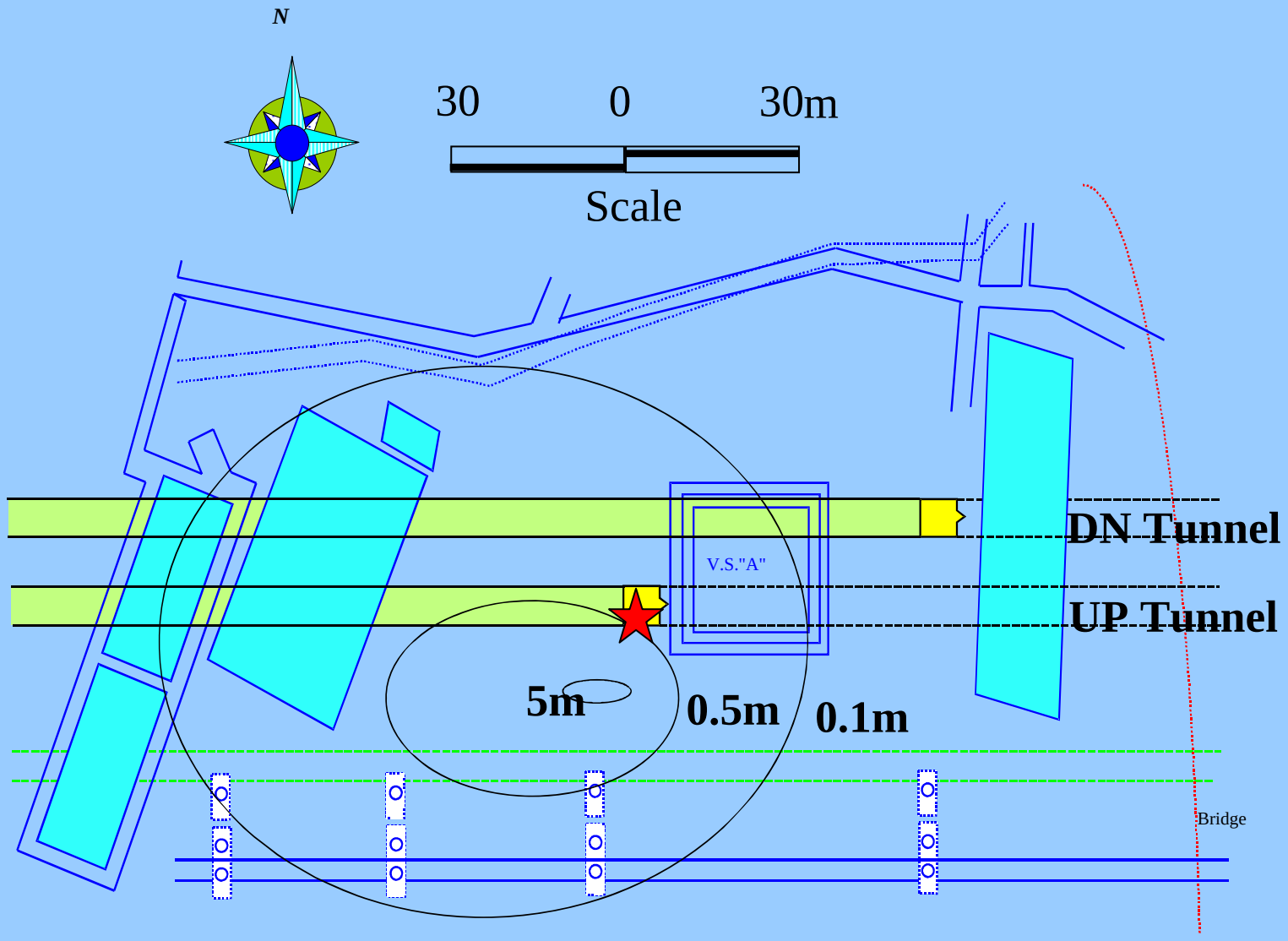
Geological Zoning of the Taipei Basin



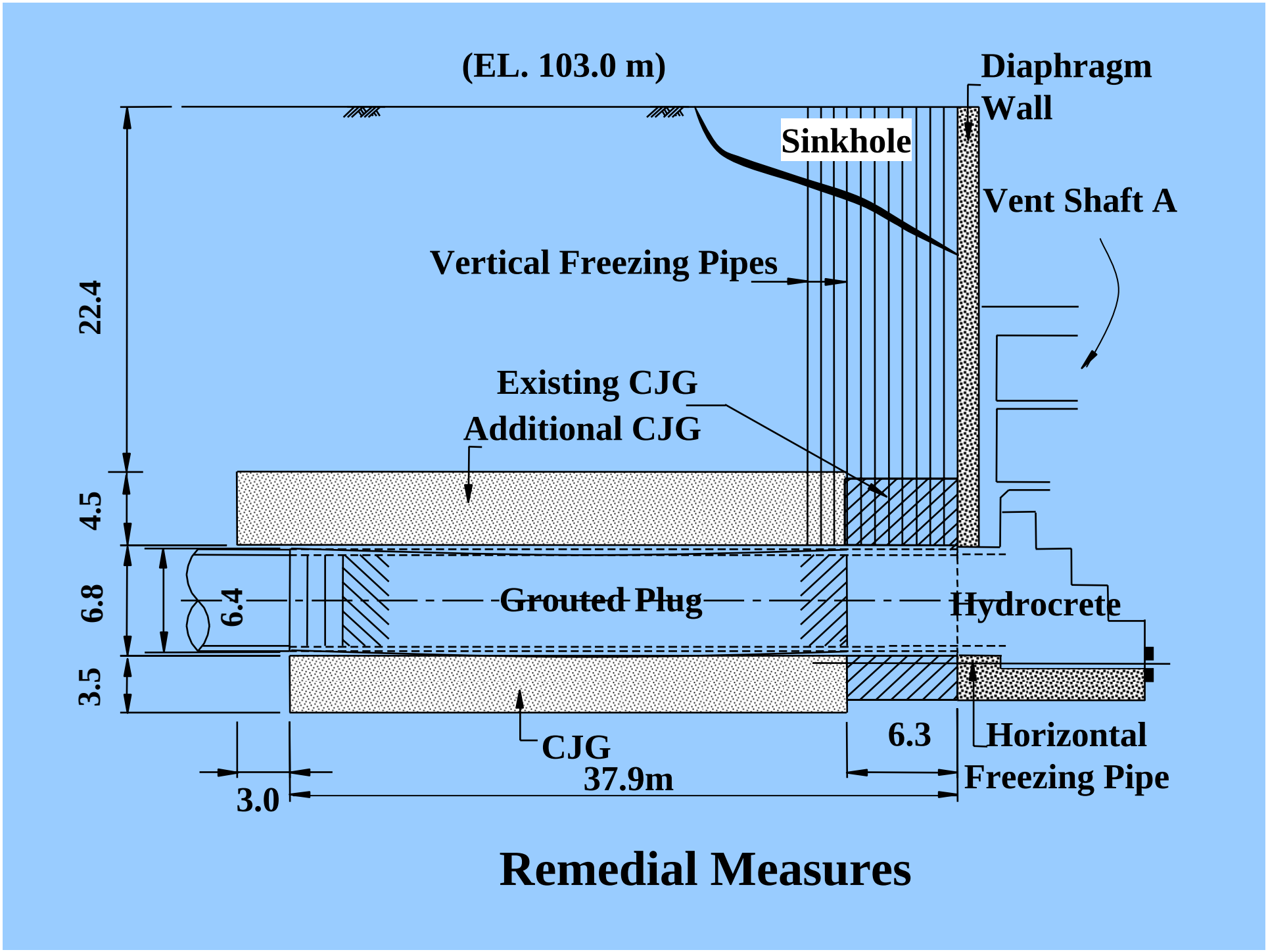
Plan of Panchiao Line Contract CP262



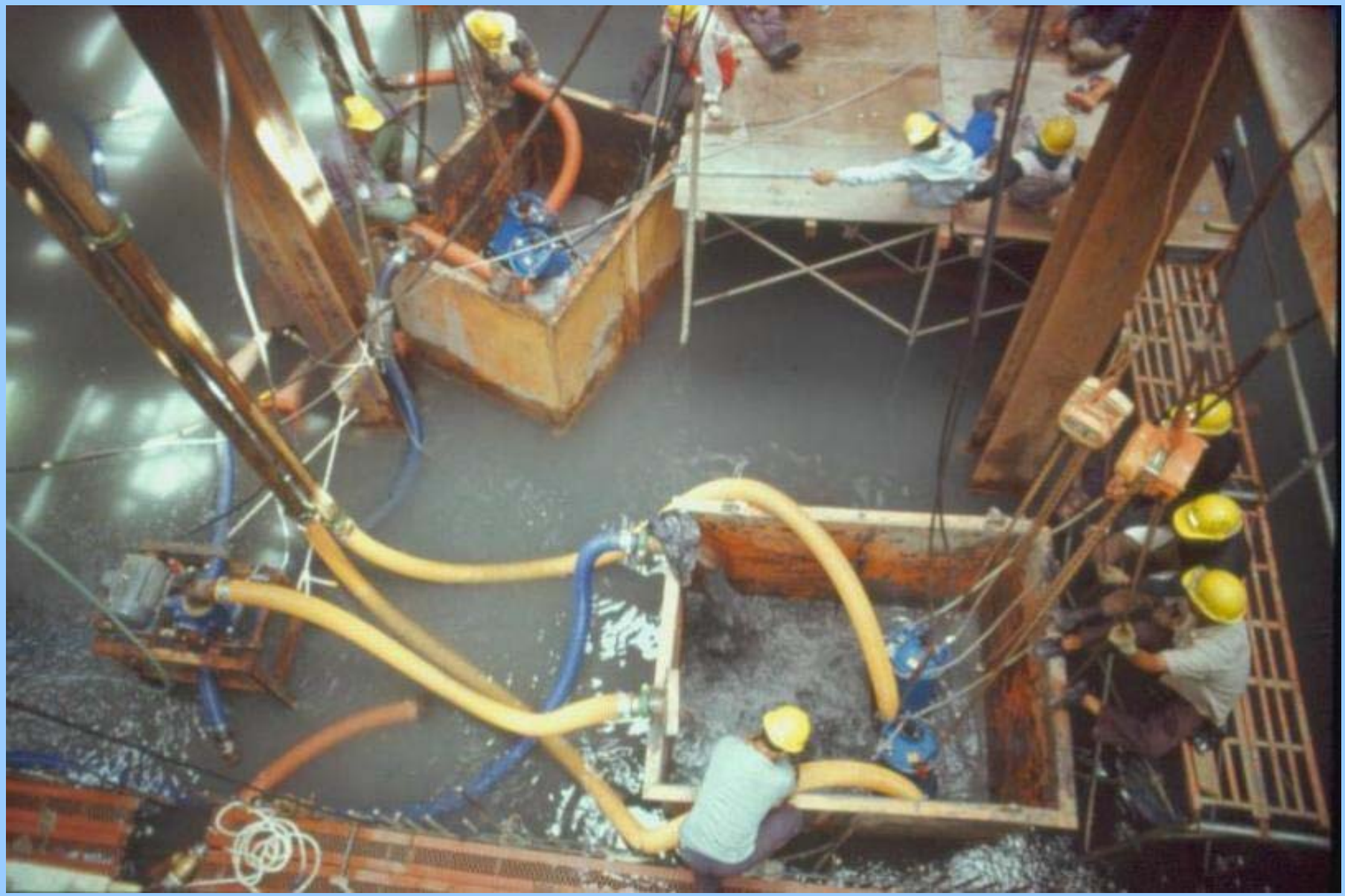
Settlement Profile



Settlement Contours



Remedial Measures

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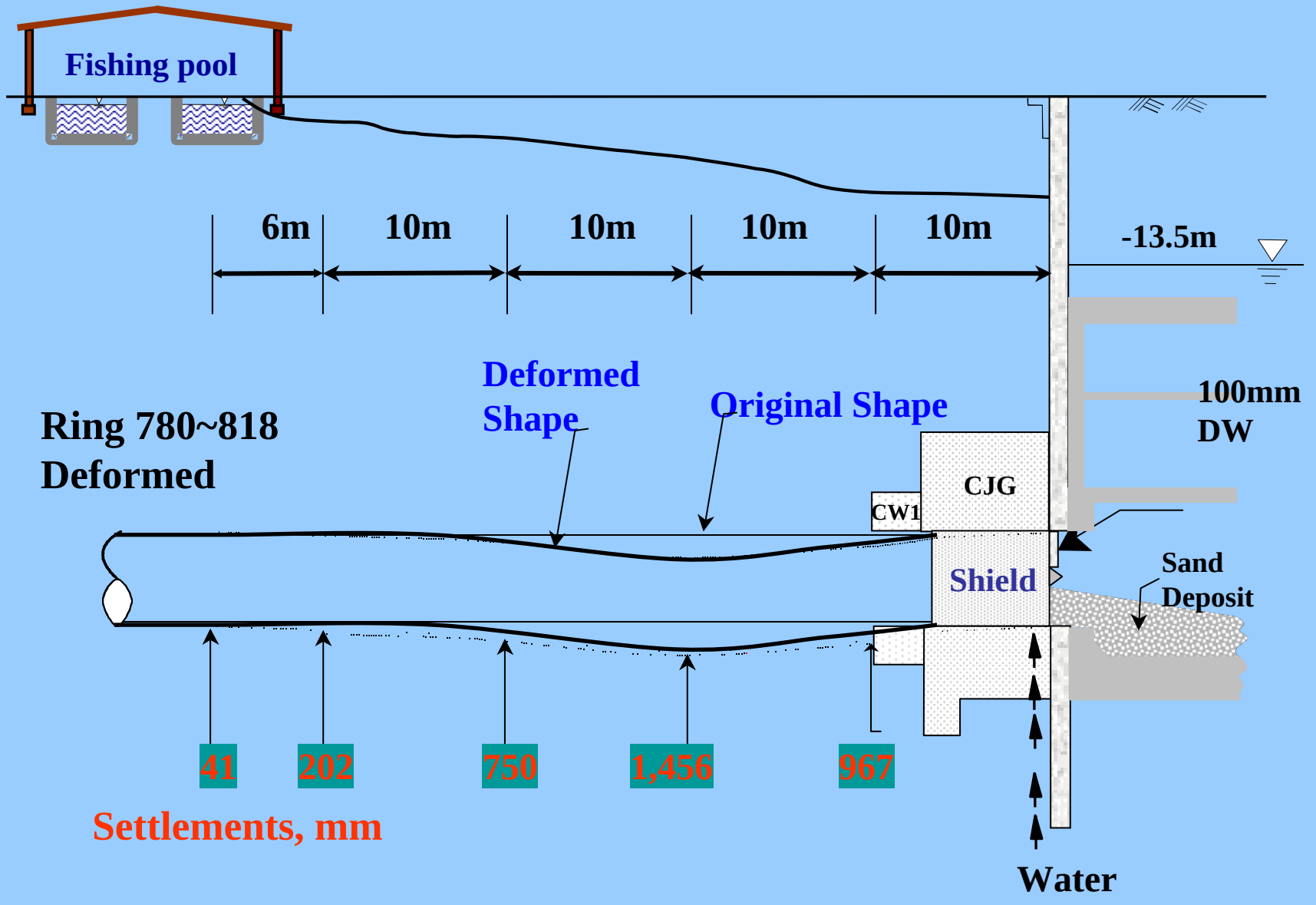
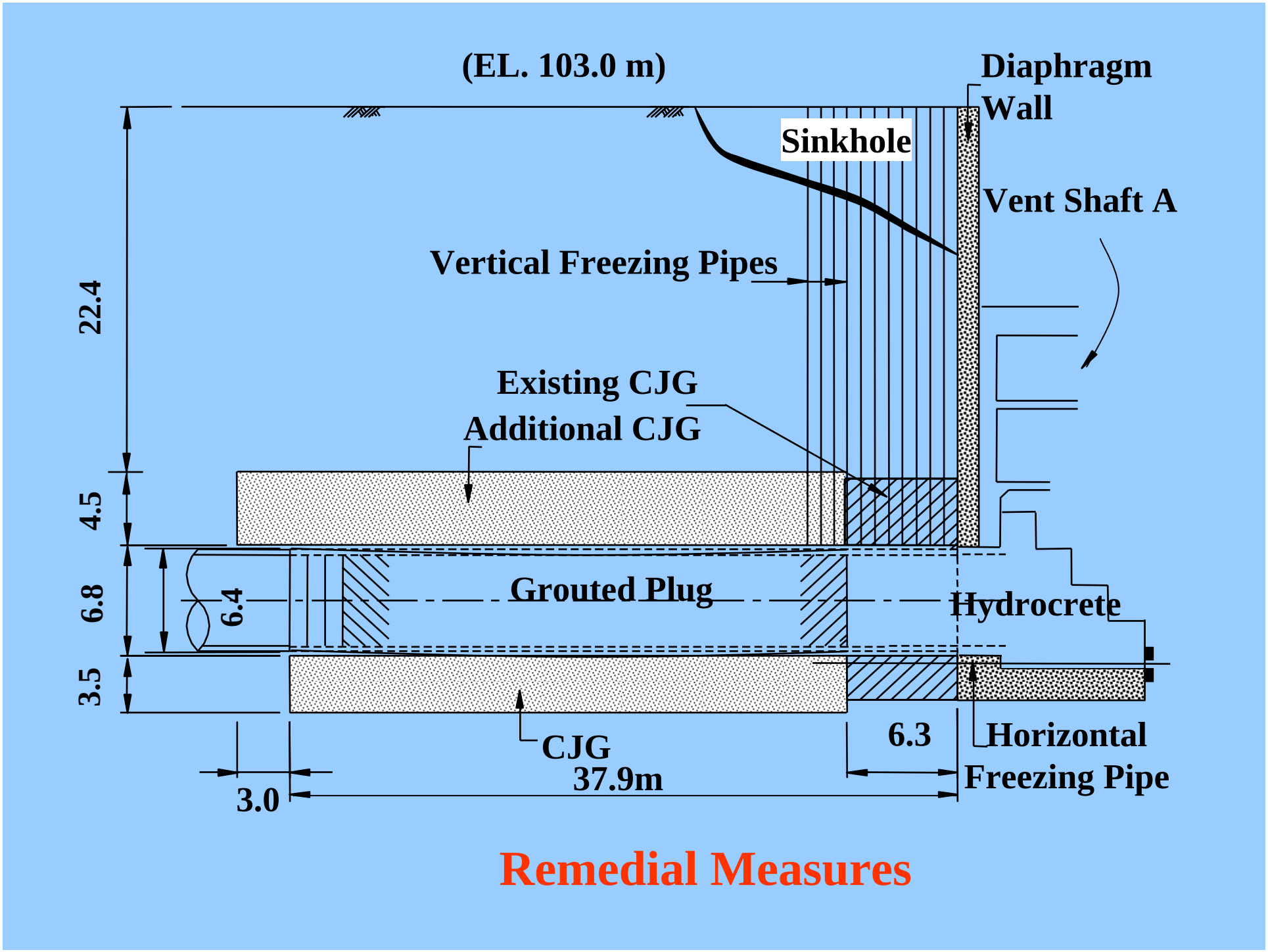
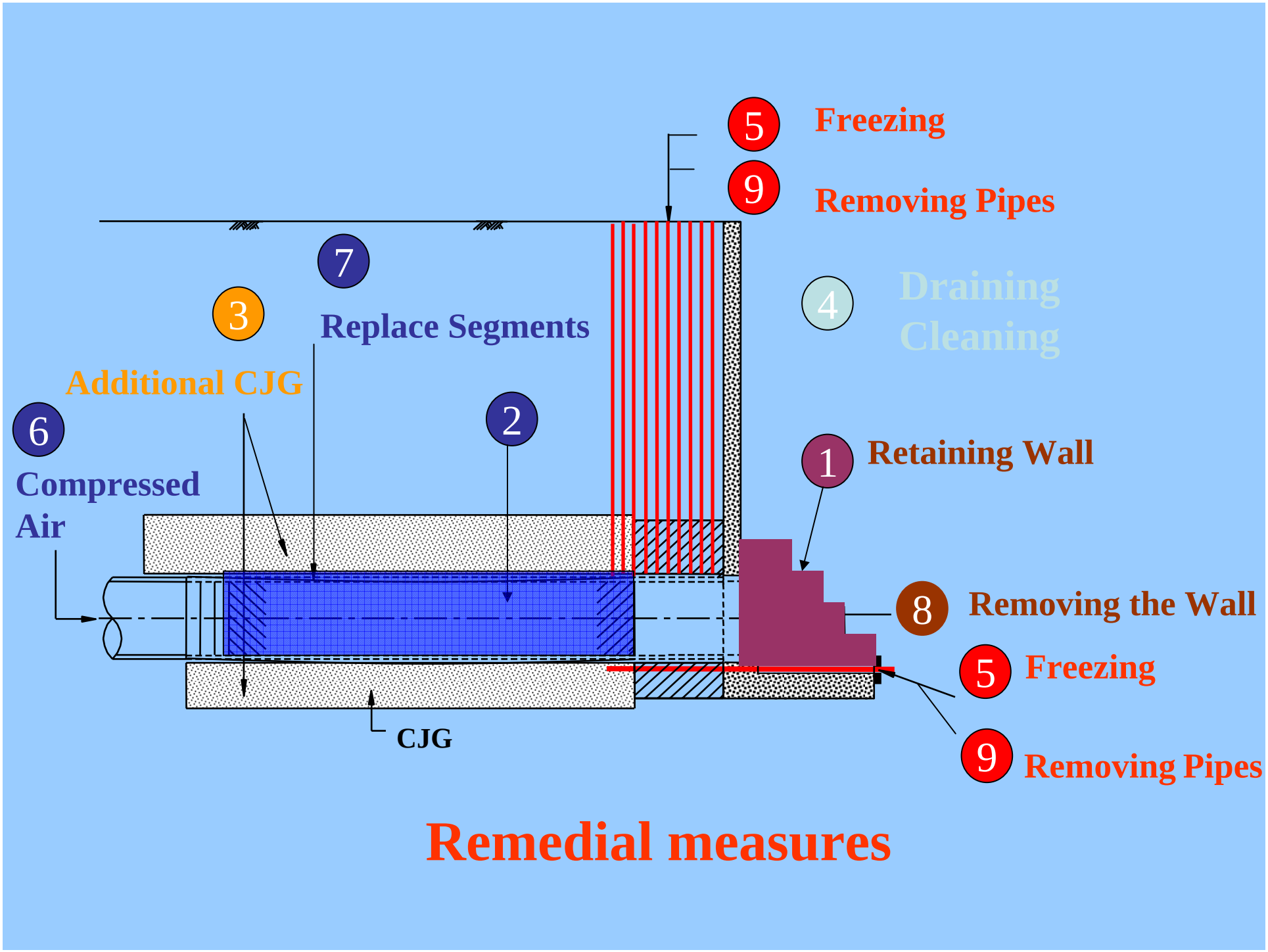


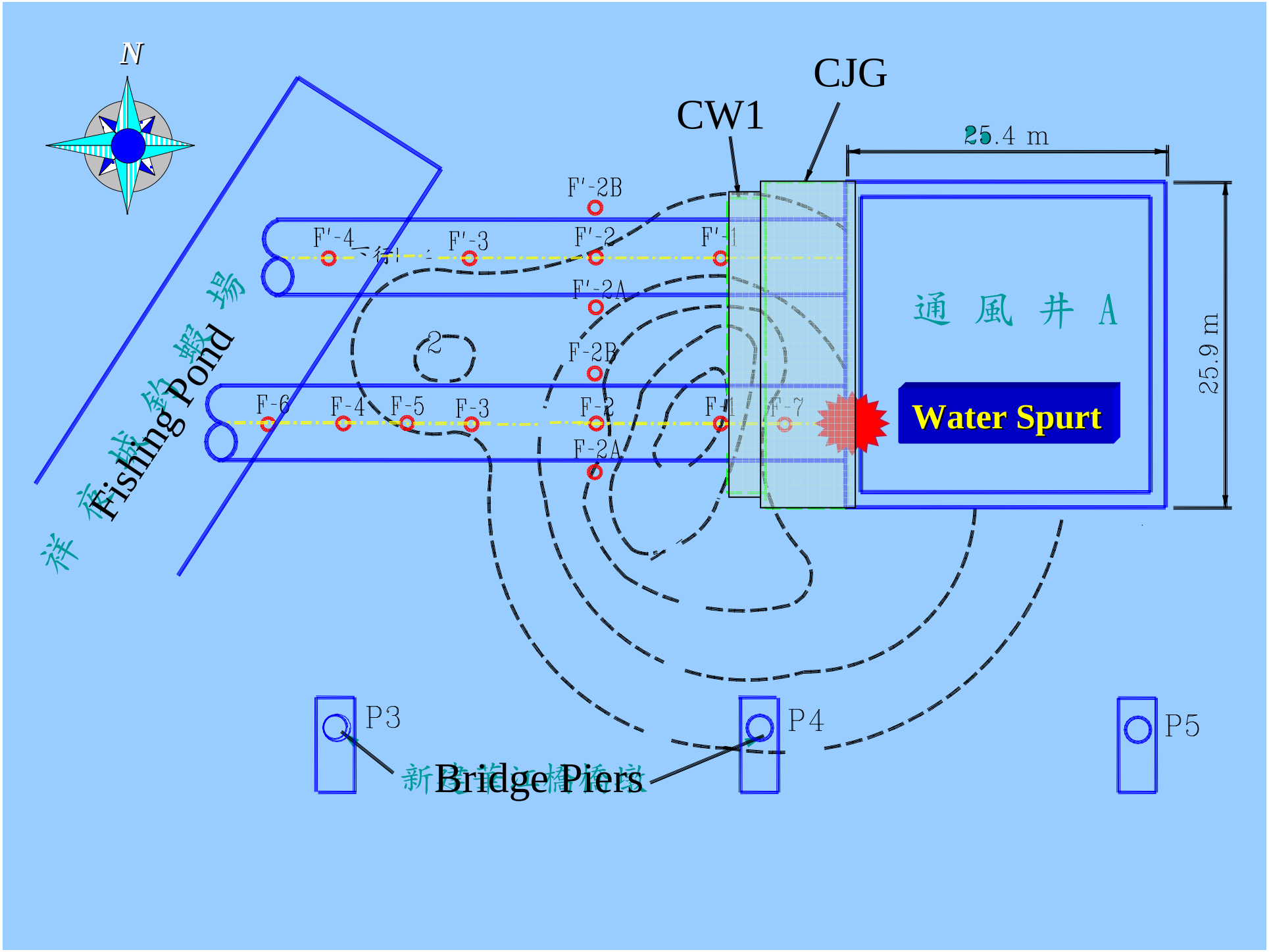
Settlement Profile

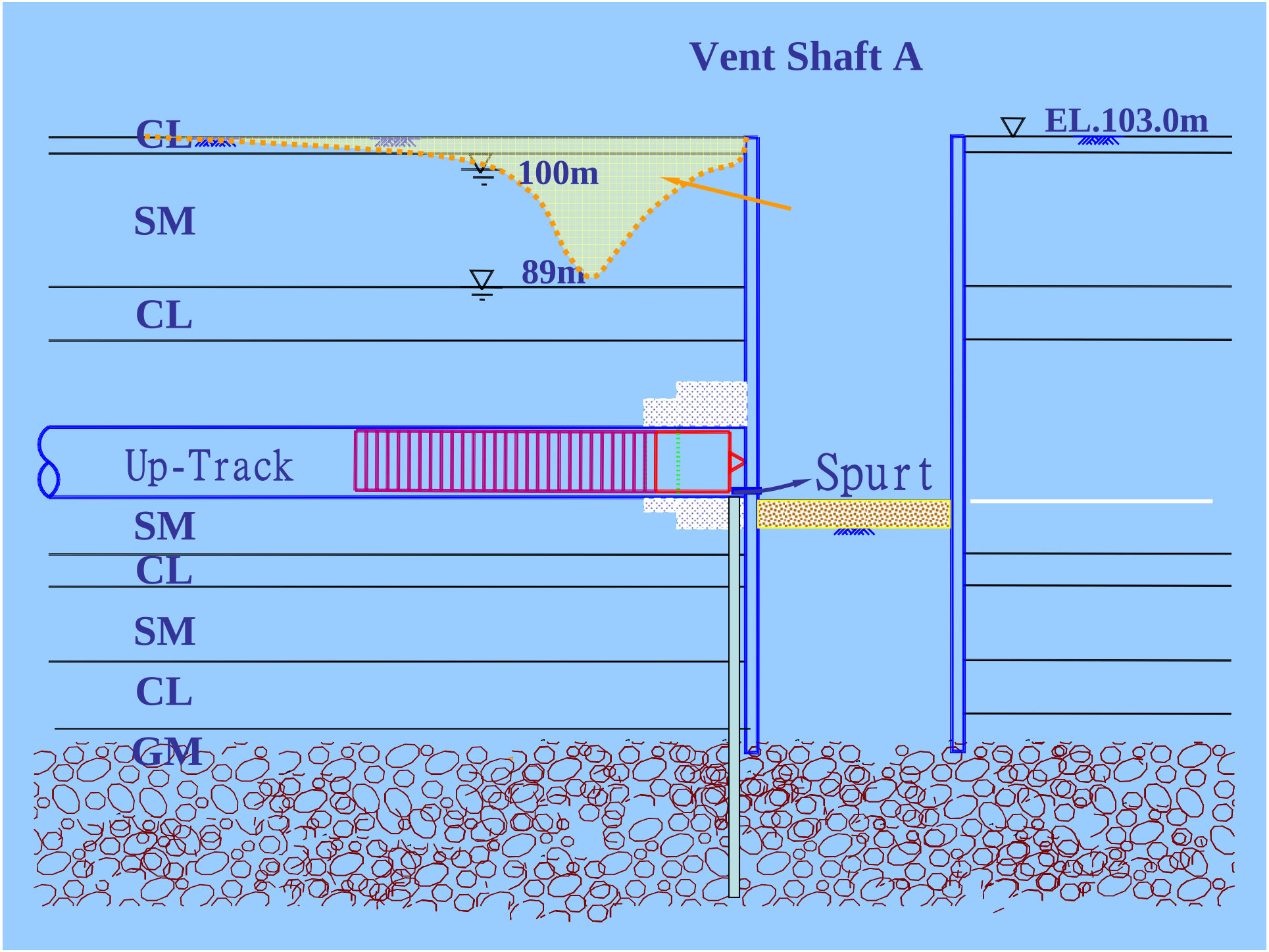


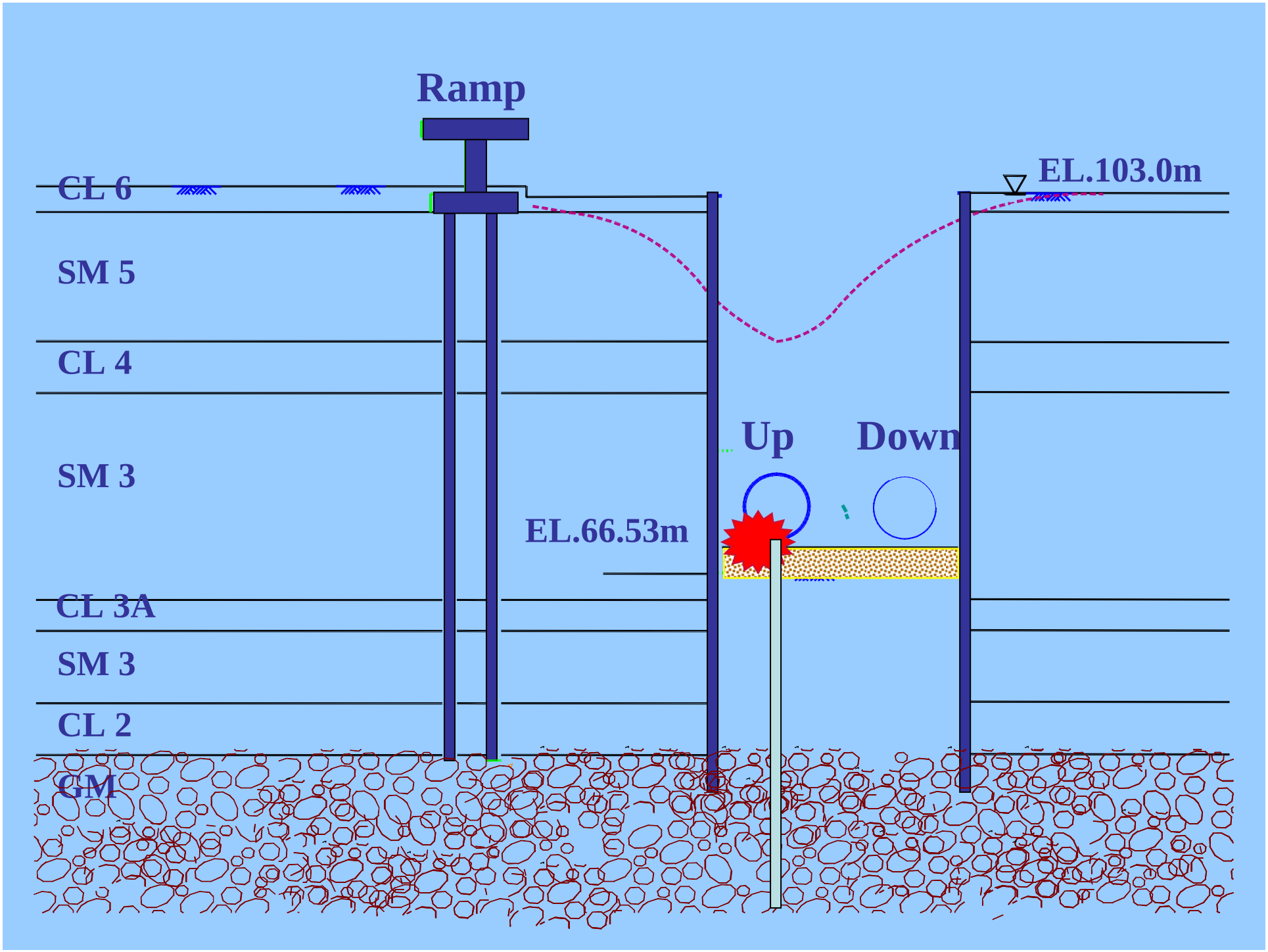
Remedial Measures



Remedial measures

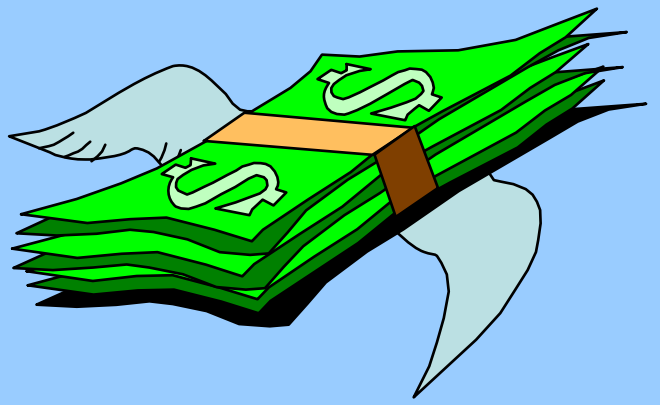

N
CJG
CW1
25.4 m
F'-2B
F'-4
F'-3
F'-2
F'-1
F'-2A
通 風 井 A
2
F-2B
F-6
F-4
F-5
F-3
F-2
F-1
F-7
F-2A
25.9 m
Water Spurt
Fishing Pond
P3
P4
P5
Bridge Piers

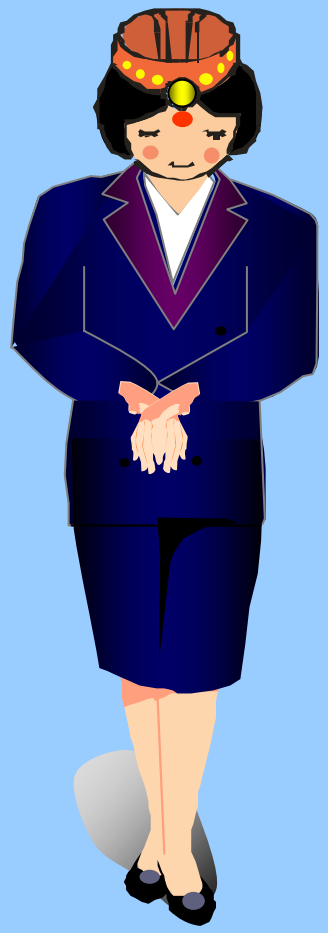

Vent Shaft A
CL
EL.103.0m
100m
SM
89m
CL
Up-Track
Spurt
SM
CL
SM
CL
GM


Ramp
EL.103.0m
CL 6
SM 5
CL 4
SM 3
Up
Down
EL.66.53m
CL 3A
SM 3
CL 2
GM

- Purchasing one new shield machine
- Overhauling one shield machine
- Replacing

A$60,000,000





Thank You