深開挖工程漫談

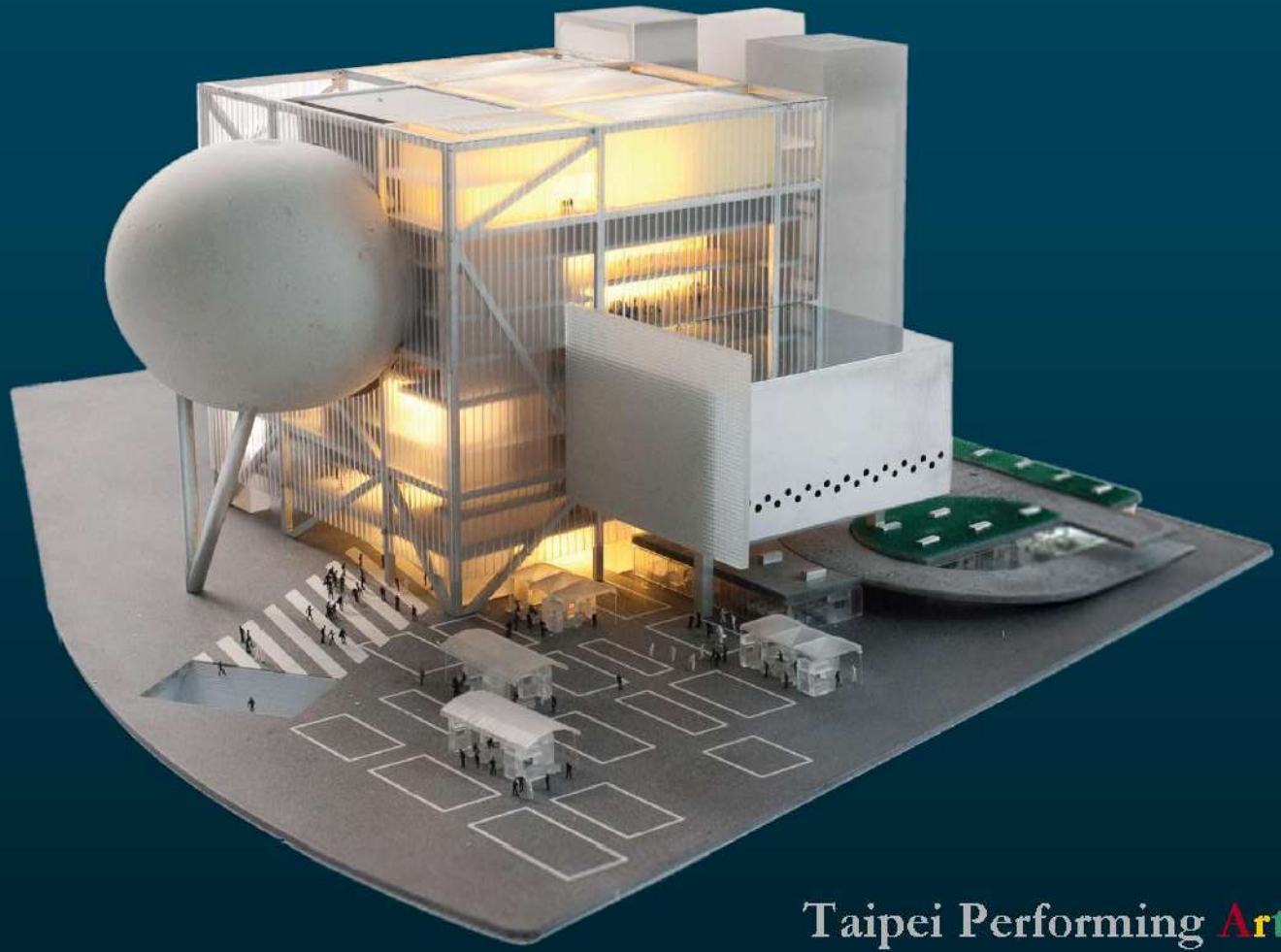
臺北表演藝術中心軟弱地層島式開挖工法案例

土木/大地技師　高世鍊





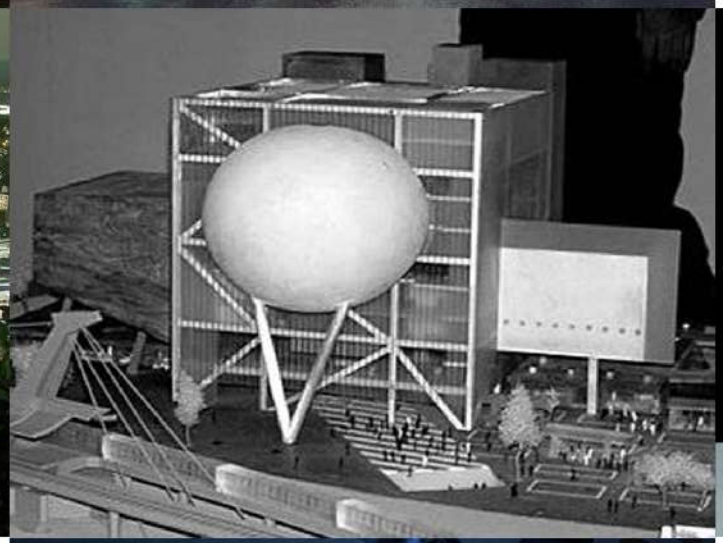

大也工程顧問
www.dalec.com.tw



Taipei Performing Art Center



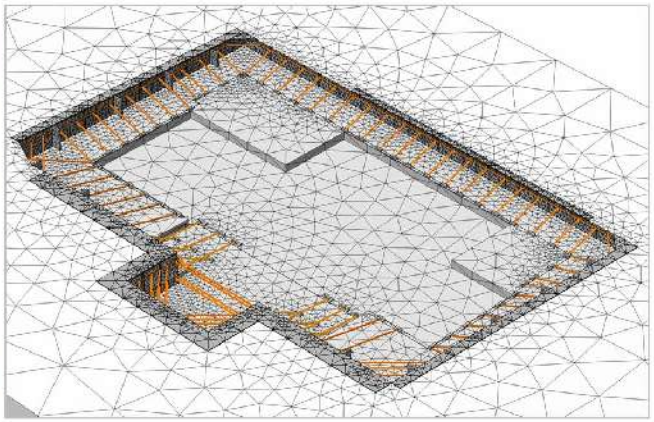






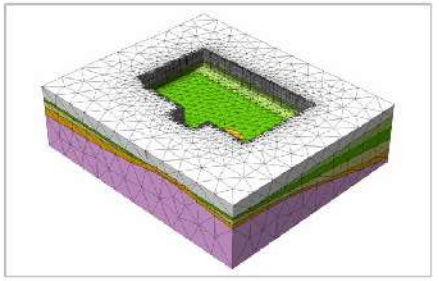
Contents / 簡報大綱

- Introduction
- Subsurface Geological Condition
- Retaining and Bracing System
- Numerical Analysis Methodology
- The Measurement Results During Excavation
- Conclusions

Introduction / 簡介

- Location
  基地位置
- Excavation area and depth
  開挖面積及深度
- Excavation method
  開挖擋土工法
- How to analyze and design ?
  分析設計方法

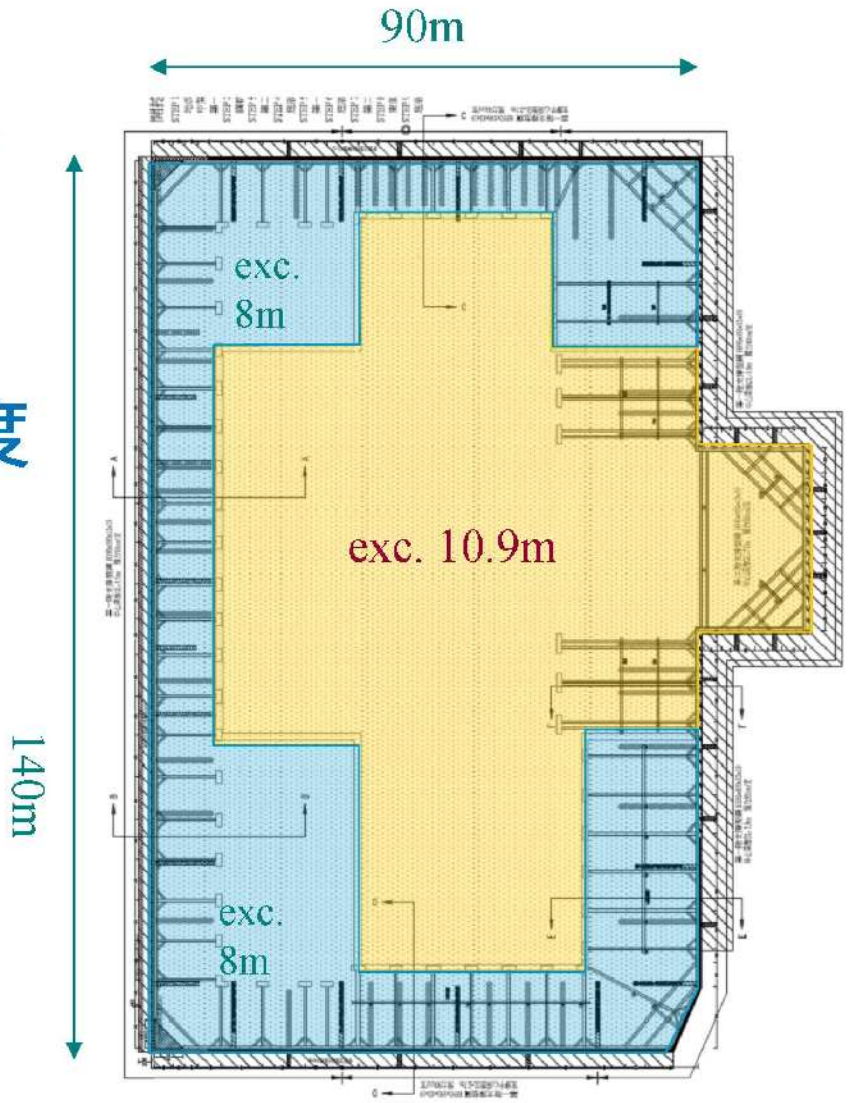


Location / 基地位置

- West side of MRT Jiantan station
  捷運劍潭站西側
- On old Keelung river course
  舊基隆河道上

Excavation area and depth
開挖面積及深度

- Excavation area / 開挖面積
  - 140m × 90m
  - More than 12000 m^2
- Excavation depth / 開挖深度
  - 8 meters in the side area
  - 10.9 meters in the central zone

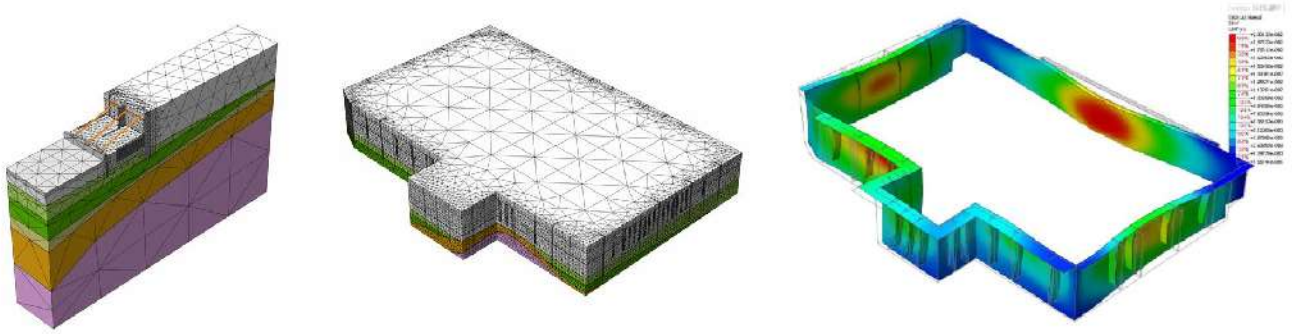


Excavation method
開挖擋土工法

- Original proposed excavation method / 原規劃開挖擋土工法
  - Internal steel bracing and lateral strut system
    全區型鋼內支撐配合順打工法
- Final excavation method / 變更後開挖擋土工法
  - Island excavation method / 島式開挖工法
  - Earth berms in combination of inclined bracings / 土堤及斜支撐
  - Concrete buttresses / 扶壁
  - Soil-cement mix buttresses / 地改式扶壁
  - Horizontal reinforced slabs / 加勁版
  - Soldier piles / 鋼軌樁
- Benefits / 效益
  - Time saving / 省時
  - Cost saving / 經濟

How to analyze and design ?
分析設計方法

- Mechanic behaviors are complex / 力學機制複雜
  - Due to the retaining structural and bracing systems are very complex, it is very difficult to simulate the actual condition by 2-D analysis.
    擋土支撐系統力學行為十分複雜，難以用二維分析
- 3-D numerical method / 三維數值分析
  - A 3-D geotechnical numerical method was adopted.
    以三維數值分析進行模擬

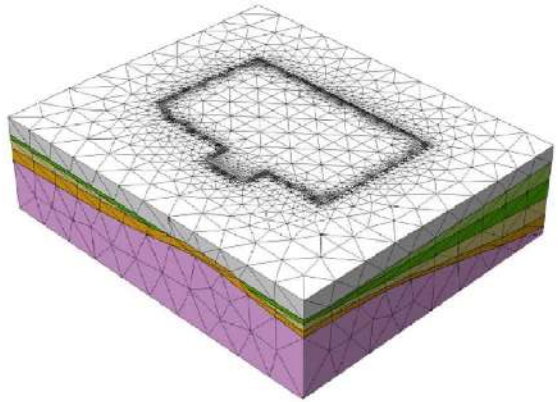


Subsurface Geological Condition
基地地質條件

- Strata and ground water table / **地層及地下水**
- Properties of backfilled silty sand (the fist layer)
  回填層/粉土質砂層特性
- Stratum distribution / **地層分布**
- Elevation of rock surface / **岩層分布**
- Simplified Soil Profile and Engineering Parameters
  簡化地層參數表

Strata and ground water table
地層及地下水

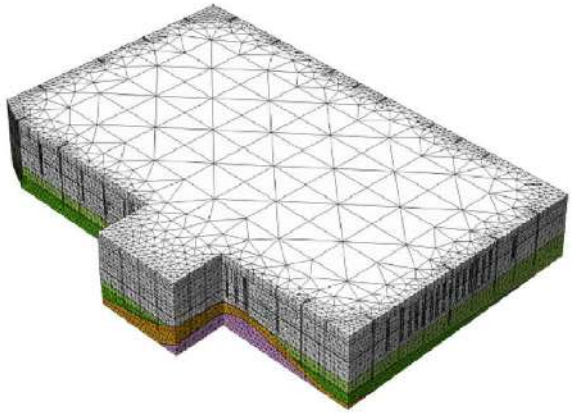
- Strata / 地層
  - 1st layer : Backfill and silty sand, SF/SM.
  - 2nd layer : upper silty clay, CL1.
  - 3rd layer : lower silty clay, CL2.
  - 4th layer : silty sand with silty clay, SM/CL.
  - 5th layer : rock fragments and soil mixture, SR.
  - 6th layer : rock mass, Rock.
- Ground water table / 地下水
  - GL-4m

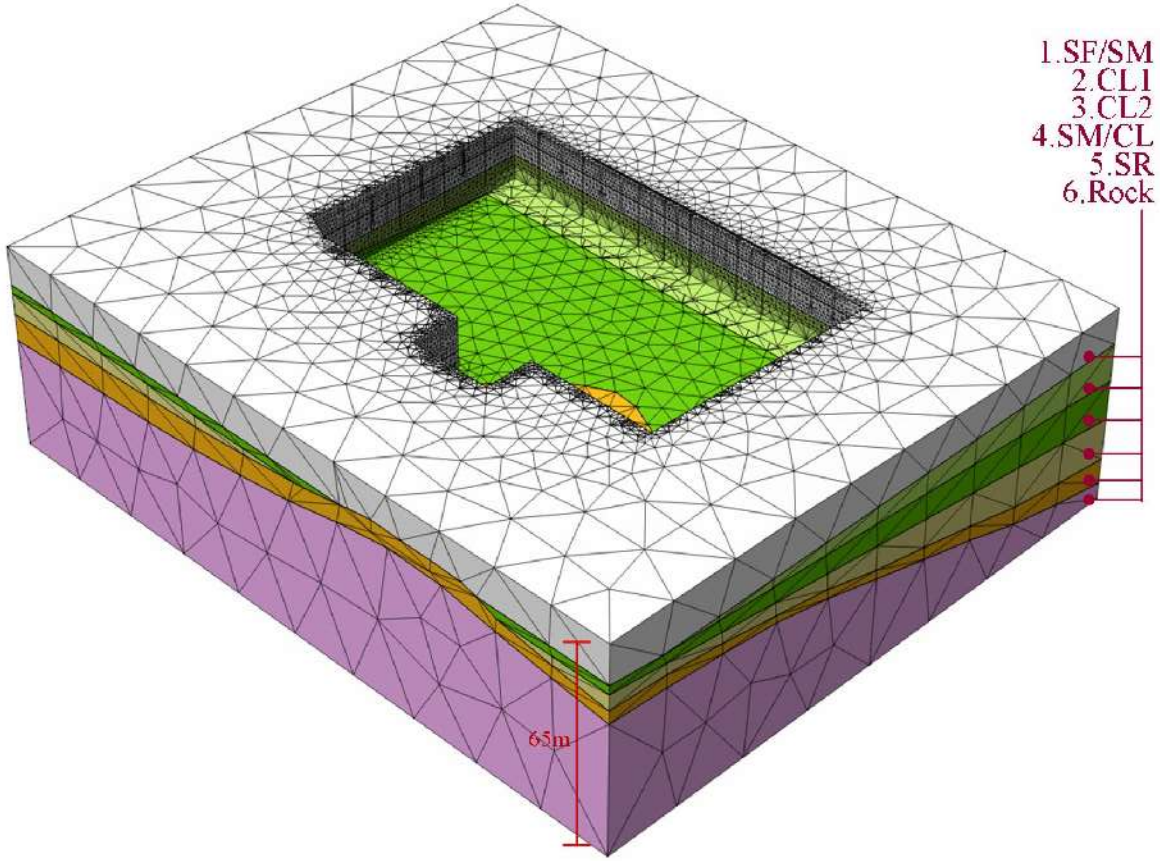


Properties of backfilled silty sand
回填層/粉土質砂層特性

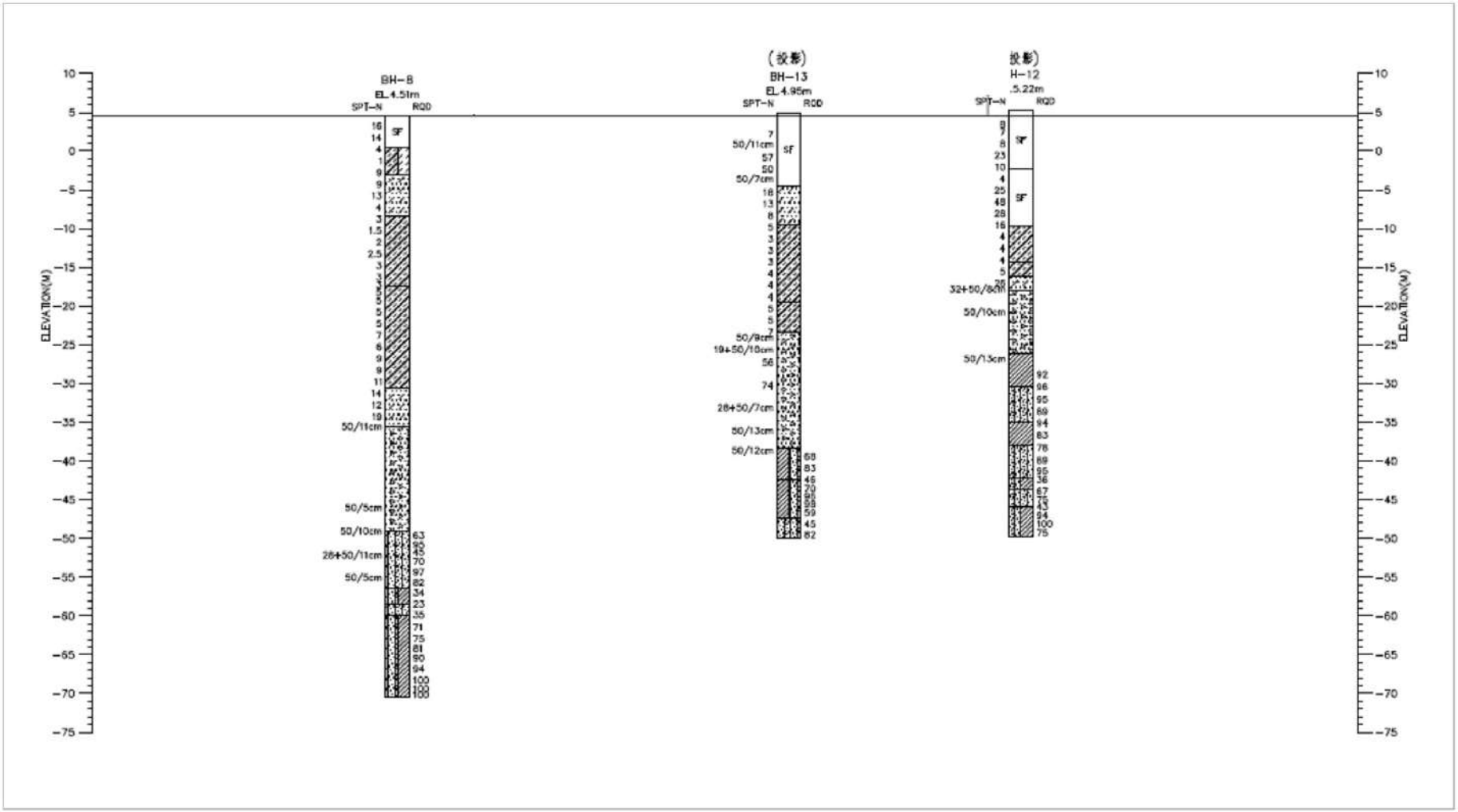
- The range of the first layer is about 12.3 to 17.7 meters below the ground. It's average thickness is about **14.2 meters**.
- brownish gray and gray **silty sand** occasionally with gravel, brick fragments and garbage.
- The N value is between 1 to 28, **the average N value is only 9**. Partially spot content with some concrete fragment and gravel, and the N value can be greater than 50.
- The upper part of this first layer is mainly **backfilled by dredge loose sand from Keelung river**.
- **The scope of excavation is mainly in this layer**.

Stratum distribution
地層分布





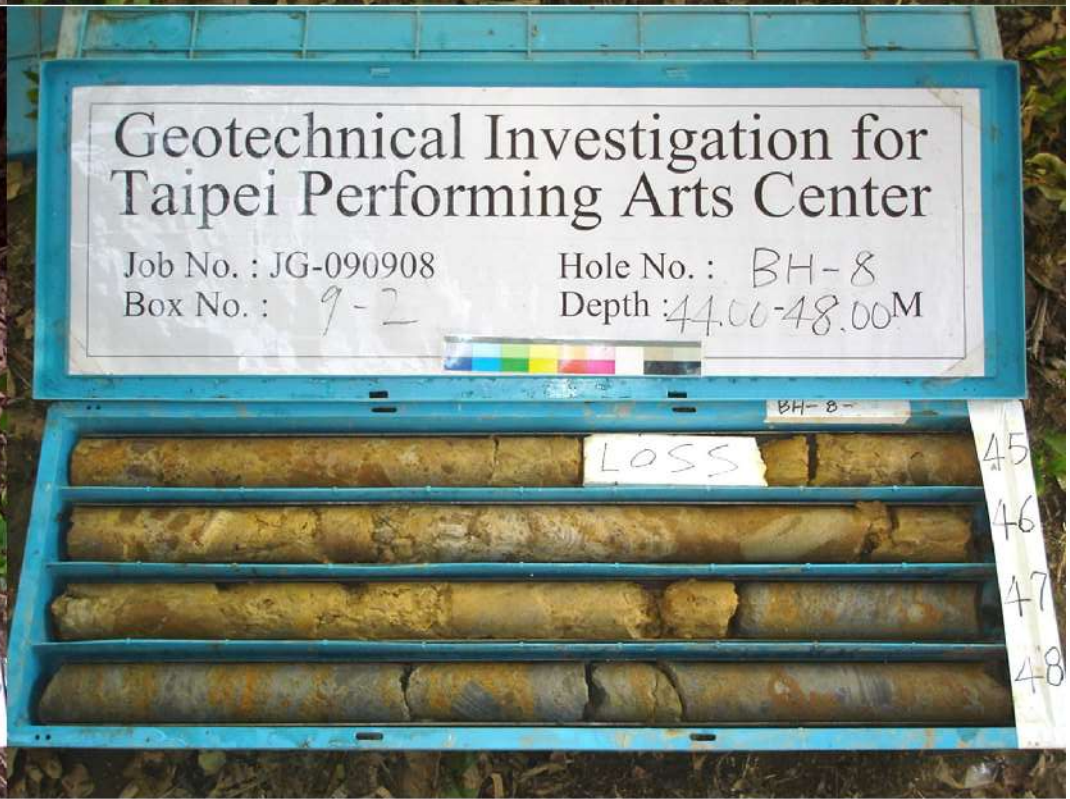
Stratum distribution
地層分布

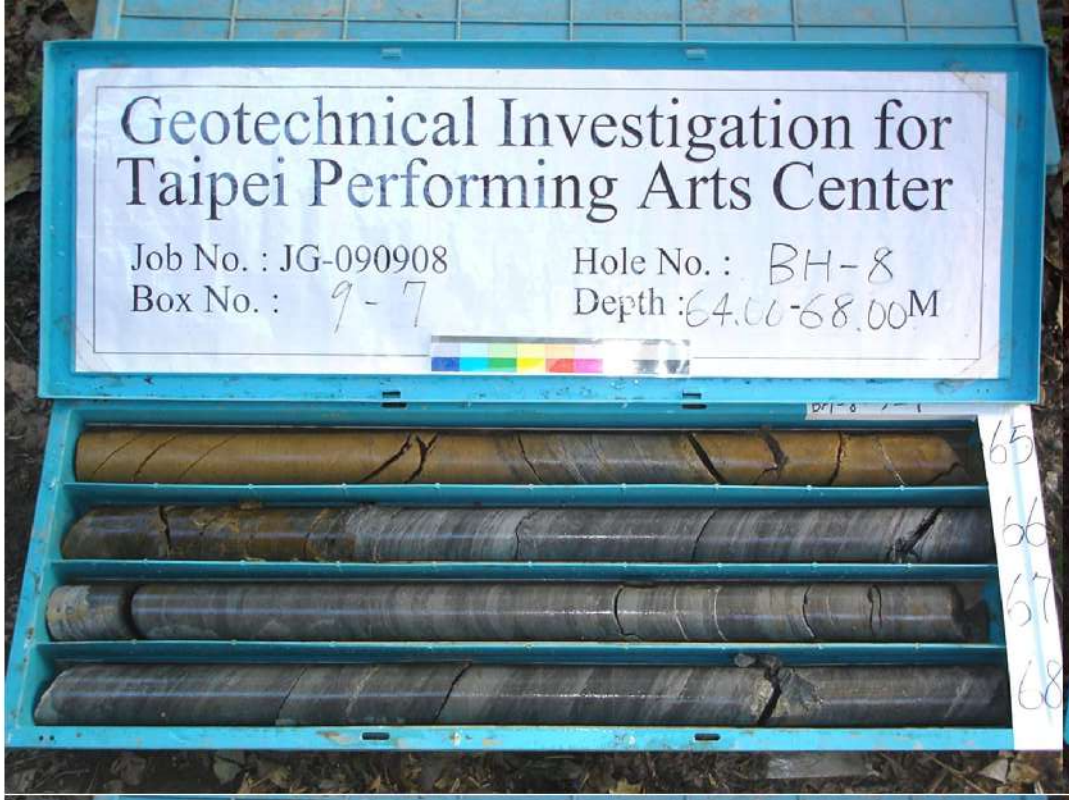



Geotechnical Investigation for
Taipei Performing Arts Center
Job No. : JG-090908
Box No. : 9-3
Hole No. : BH-8
Depth : 48.00-52.00M

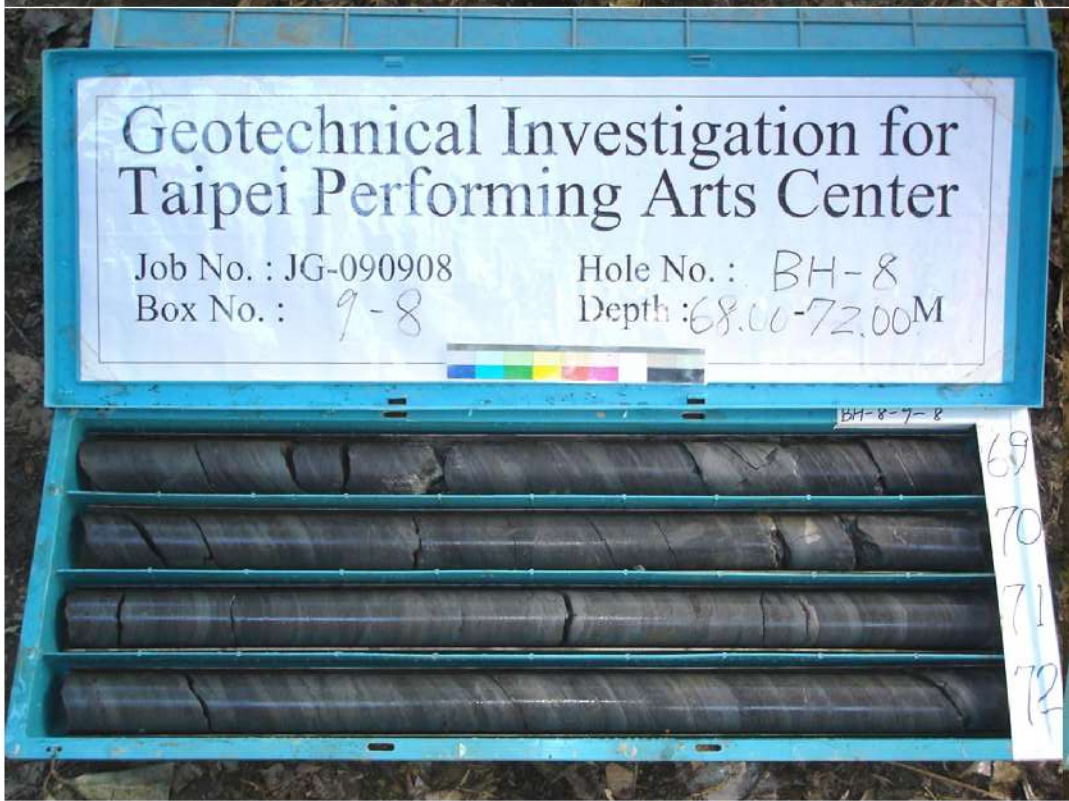

Geotechnical Investigation for
Taipei Performing Arts Center
Job No. : JG-090908
Box No. : 9-1
Hole No. : BH-8
Depth : 40.16-44.00M


Geotechnical Investigation for
Taipei Performing Arts Center
Job No. : JG-090908
Box No. : 9-4
Hole No. : BH-8
Depth : 52.00-56.00M


Geotechnical Investigation for
Taipei Performing Arts Center
Job No. : JG-090908
Box No. : 9-2
Hole No. : BH-8
Depth : 44.00-48.00M
LOSS

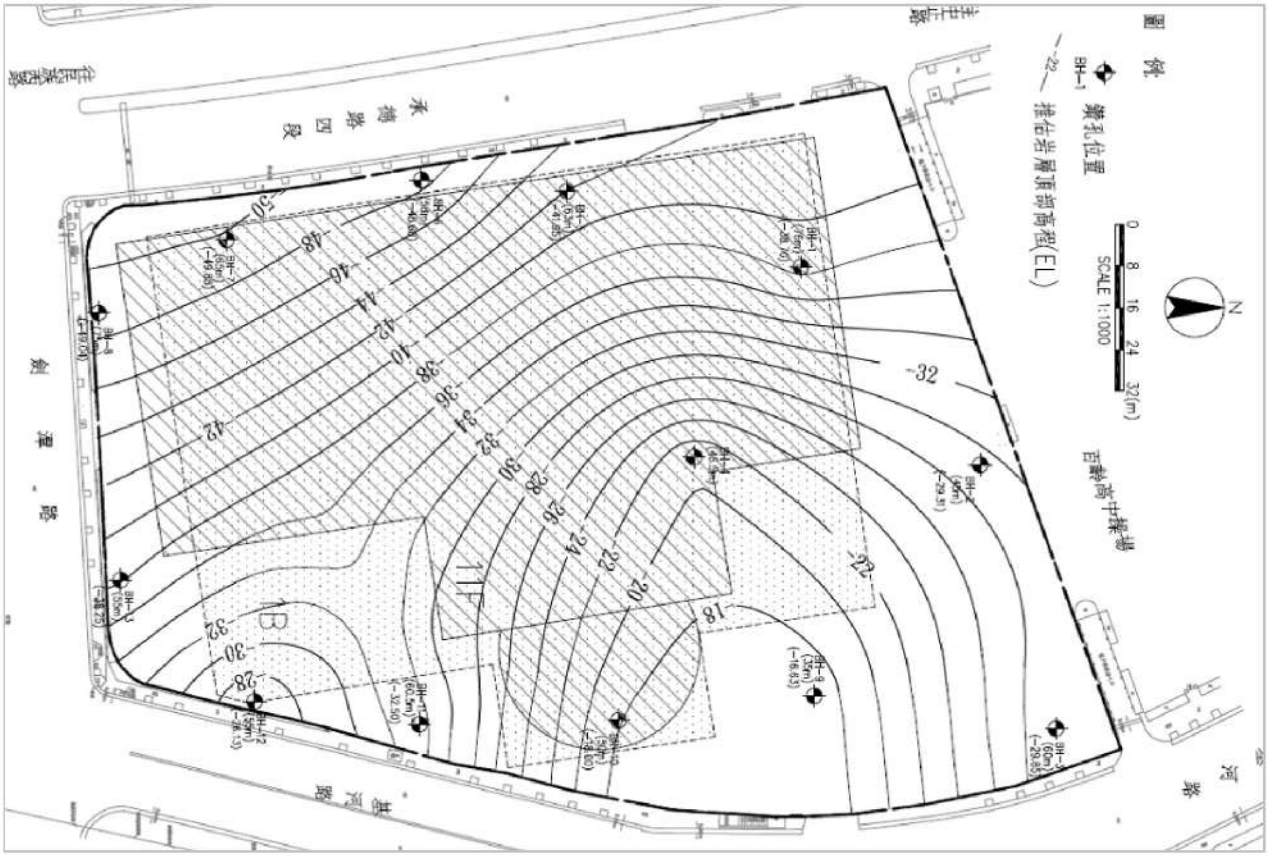

Geotechnical Investigation for
Taipei Performing Arts Center
Job No. : JG-090908
Hole No. : BH-8
Box No. : 9-7
Depth : 64.00-68.00M

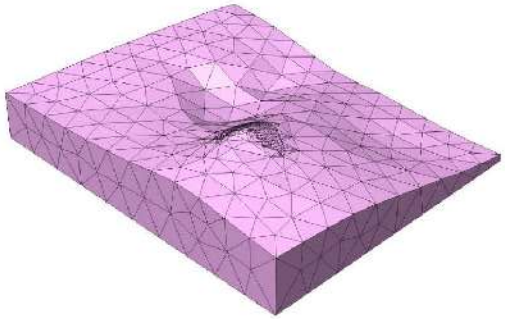

Geotechnical Investigation for
Taipei Performing Arts Center
Job No. : JG-090908
Hole No. : BH-8
Box No. : 9-5
Depth : 56.00-60.00M


Geotechnical Investigation for
Taipei Performing Arts Center
Job No. : JG-090908
Hole No. : BH-8
Box No. : 9-8
Depth : 68.00-72.00M

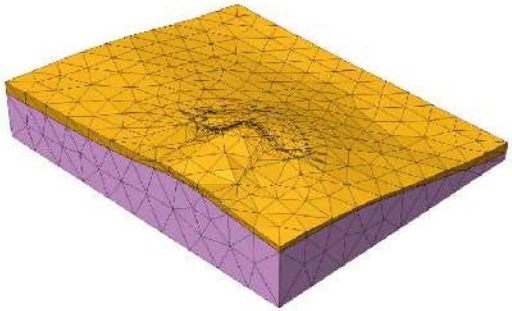

Geotechnical Investigation for
Taipei Performing Arts Center
Job No. : JG-090908
Hole No. : BH-8
Box No. : 9-6
Depth : 60.00-64.00M

Elevation of rock surface
岩層分布





Rock surface



SR surface

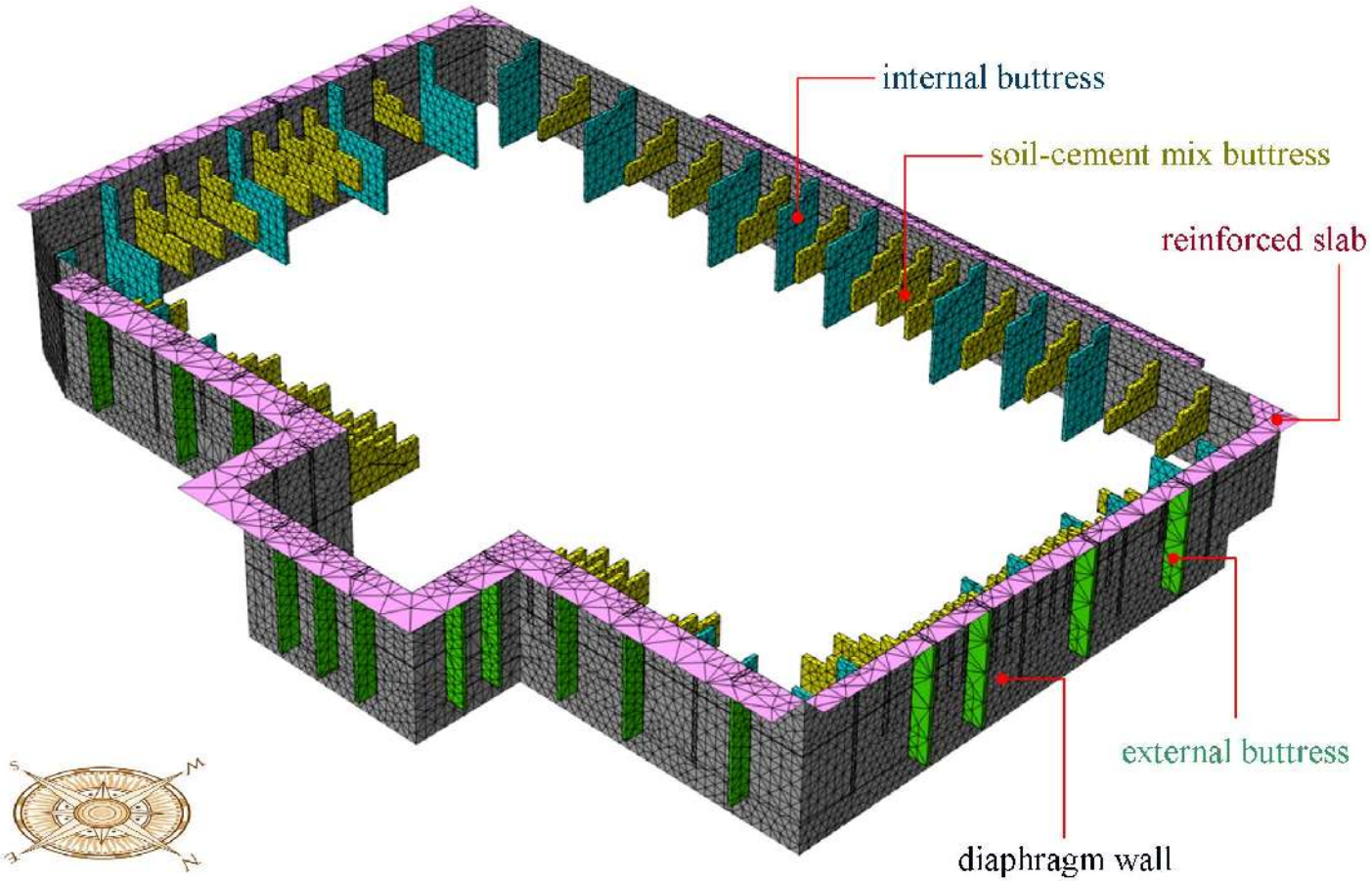
Simplified Soil Profile and Engineering Parameters
簡化地層參數表

土層	土層概述		分布範圍 (m)	平均分布 (m)	平均厚度 (m)	N值 (平均)	γ_t (t/m^3)	e	w_n (%)	LL (%)	PI (%)	C_c	C_s	c' (t/m^2)	ϕ' (deg.)	S_u (t/m^2)
1	回填層/粉土質砂 (SF/SM)		0.0~17.7	0.0~14.2	14.2	1~28 (9)	1.92	0.74	24	-	-	-	-	0	27	-
2	粉土質粘土	上層(CL1)	12.3~26.0	-	-	1.5~4 (3)	1.86	0.95	34	35	15	0.35	0.04	0	28	3.5
		下層(CL2)	13.0~38.5	-	-	4~11 (6)	1.88	0.93	34	36	15	0.30	0.03	0	29	5.0
3	粉土質砂夾粘土 (SM/CL)		15.0-44.8	-	-	8~26 (16)	1.97	0.72	25	-	-	-	-	0	31	-
4	岩塊混合層(SR)		17.7-54.3	-	-	>50 (>50)	2.10*	-	-	-	-	-	-	2	33	-
5	岩層(Rock)		>21.6	-	-	>50 (>50)	2.30*	-	-	-	-	-	-	5	35	-

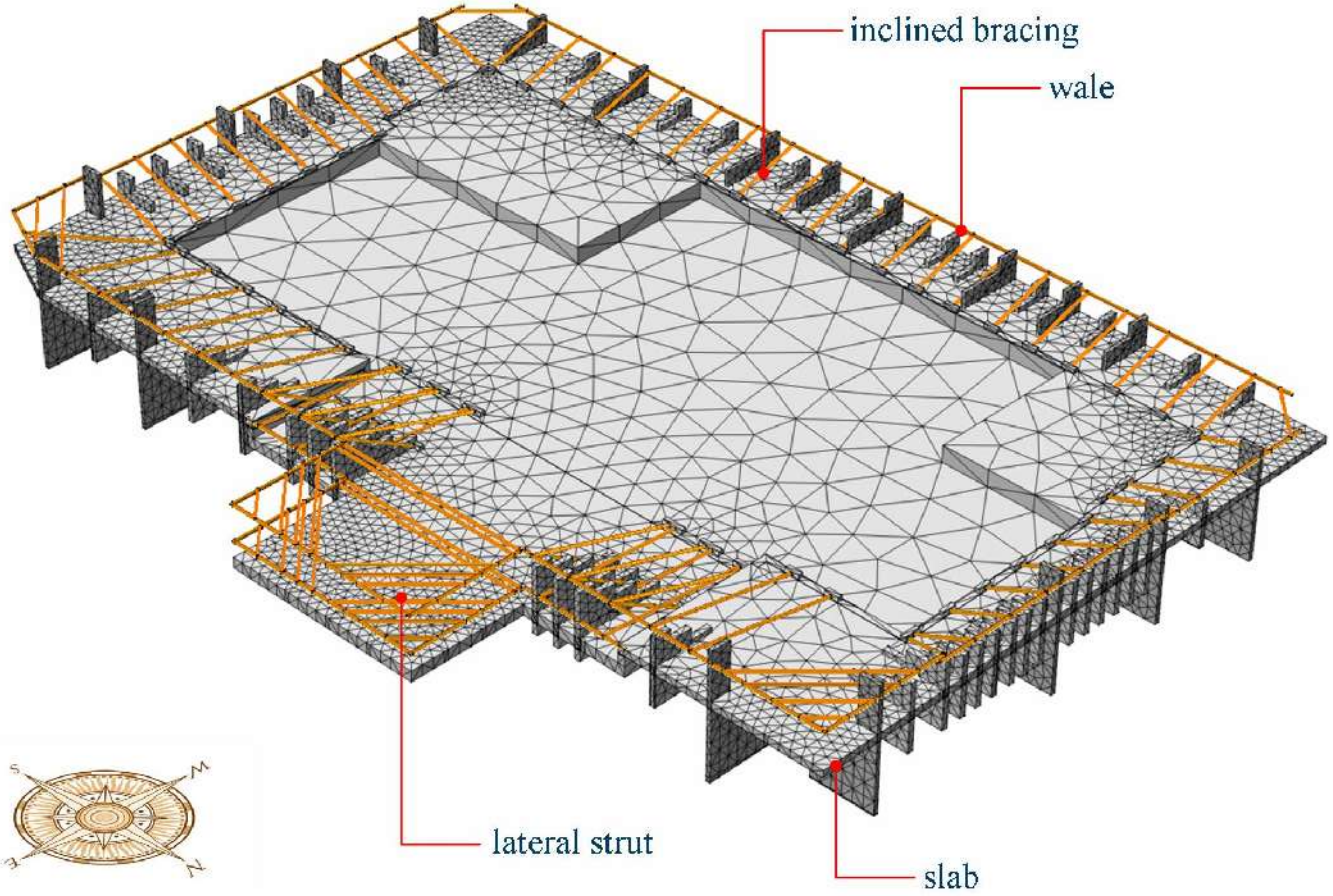
Retaining And Bracing System
擋土支撐系統

- Diaphragm wall / 連續壁
- Internal and external buttresses / 內外扶壁
- Soil-cement mix buttresses / 地改式扶壁
- horizontal reinforced slabs / 加勁版
- Earth berms / 土堤
- inclined bracings / 斜支撐
- Soldier piles / 鋼軌樁

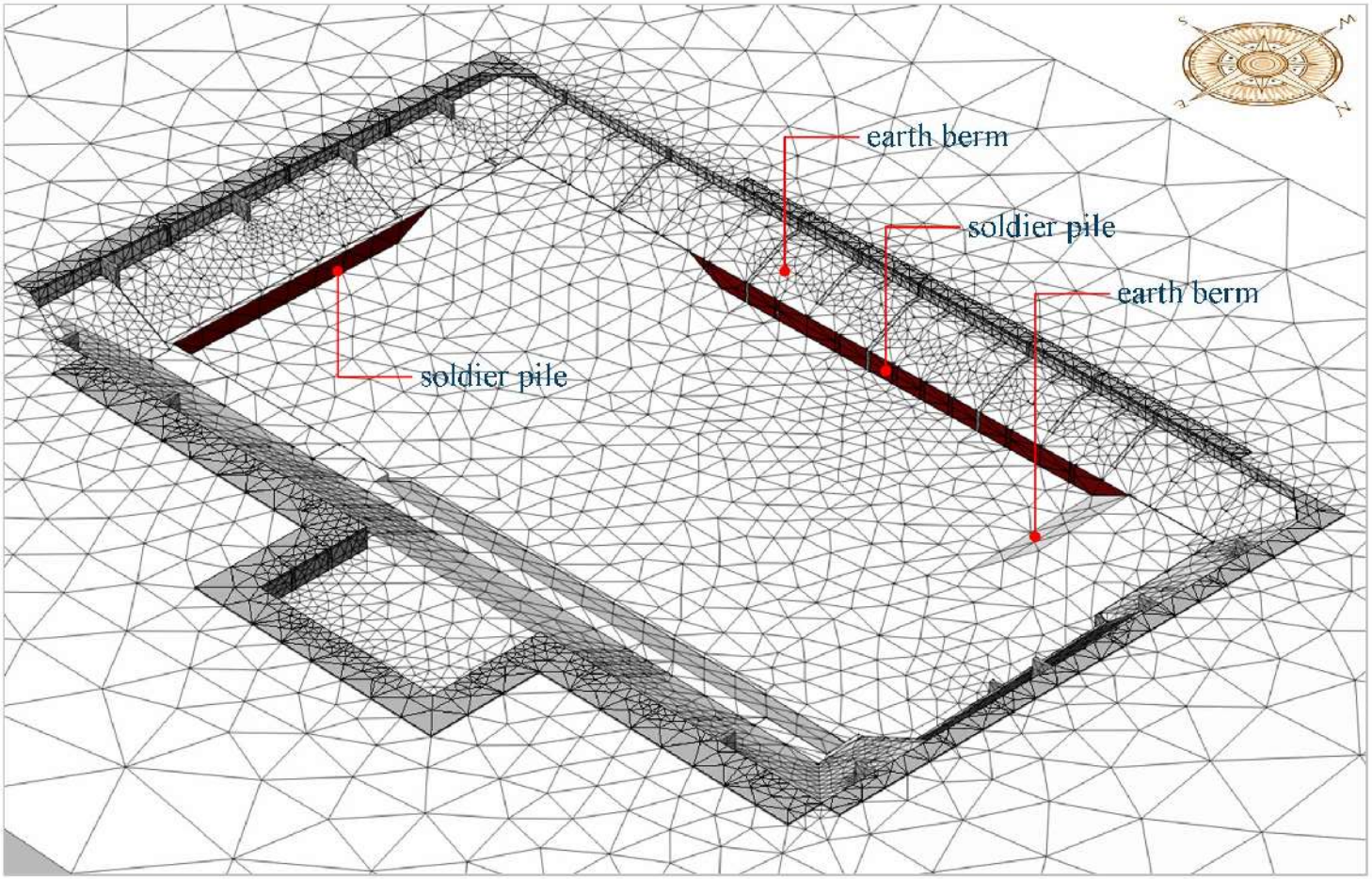
Diaphragm wall, buttress and reinforced slab
連續壁、內外扶壁、地改式扶壁、加勁版



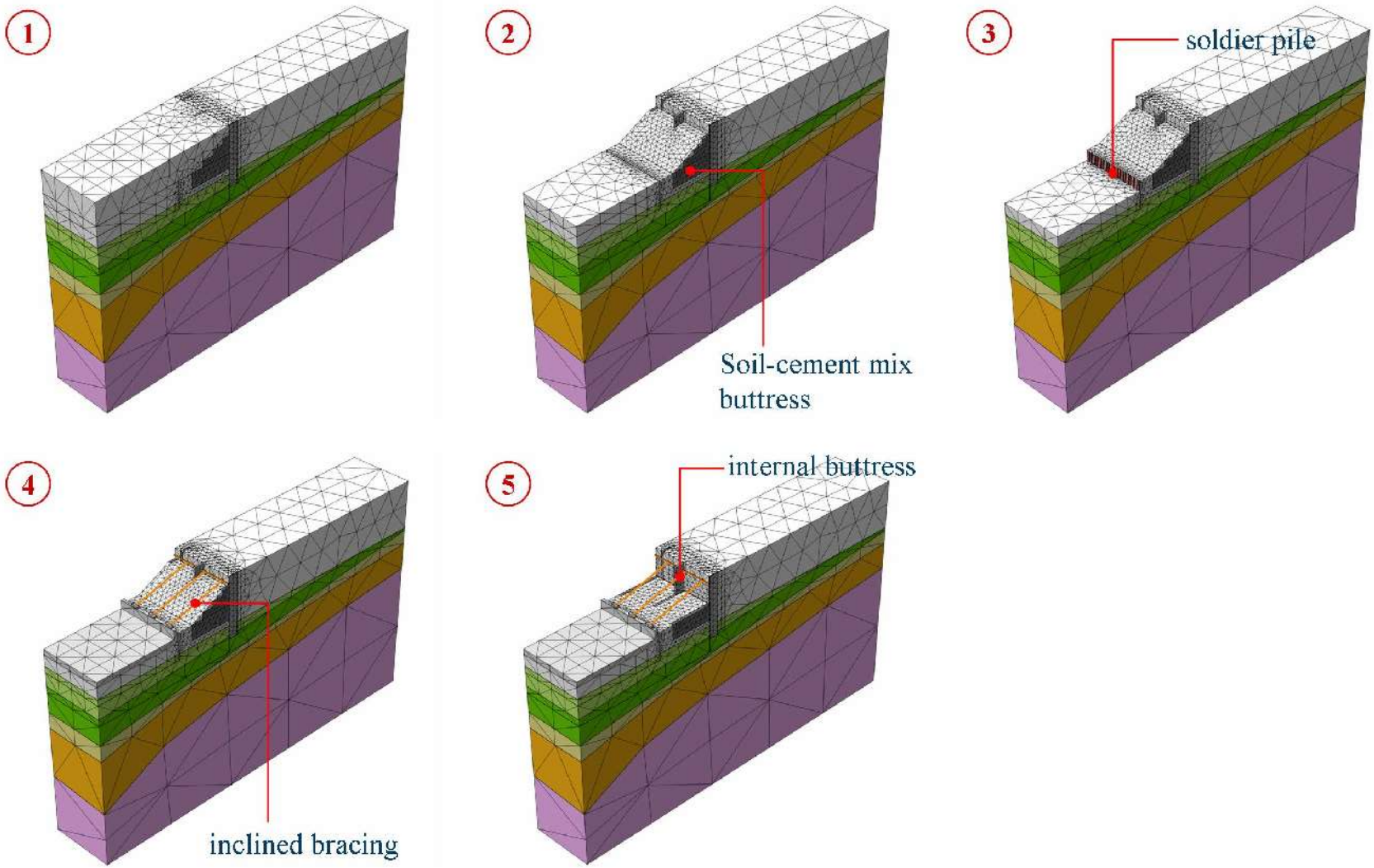
Bracing System / 支撐系統



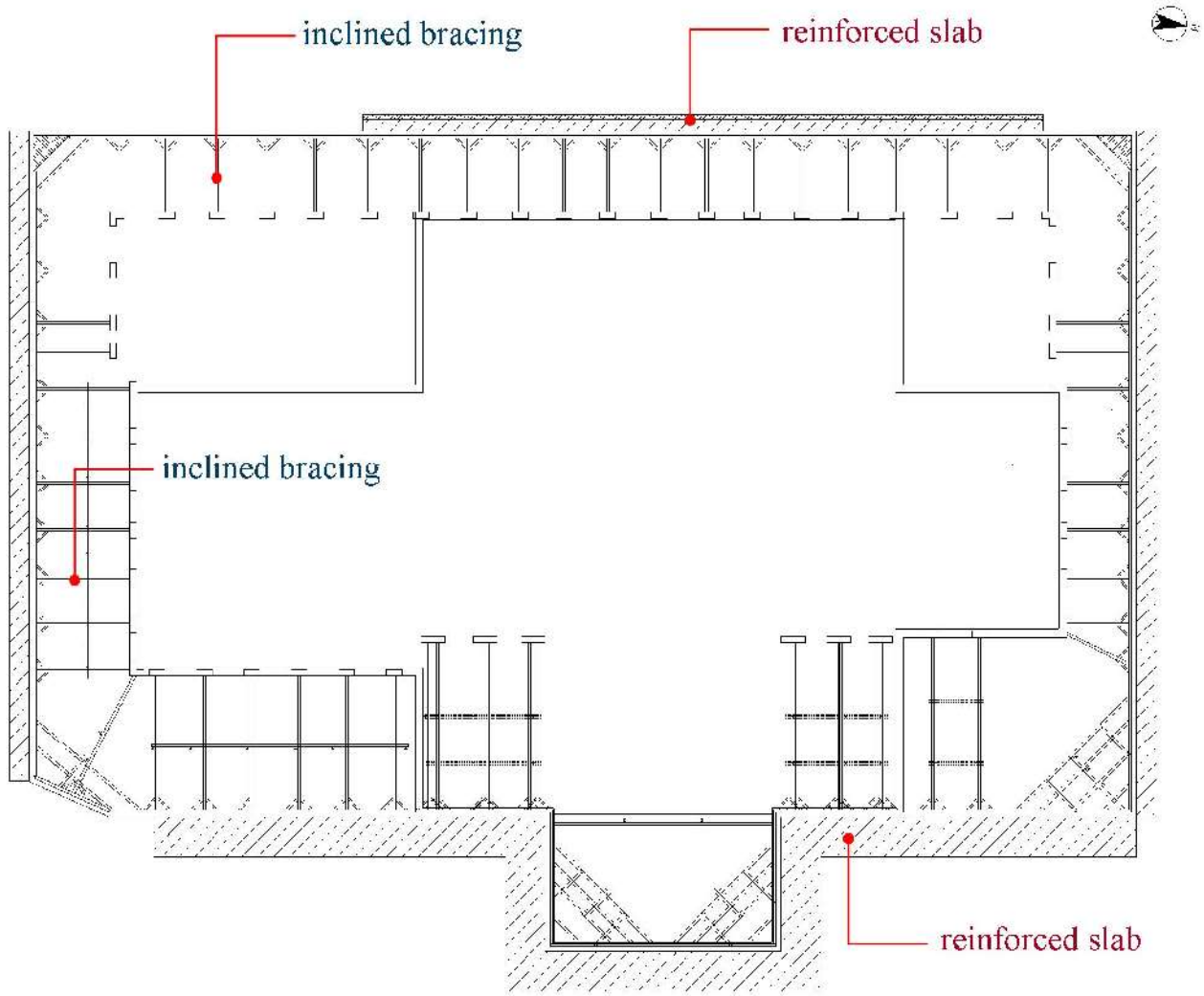
Earth berm and soldier pile
土堤及鋼軌樁



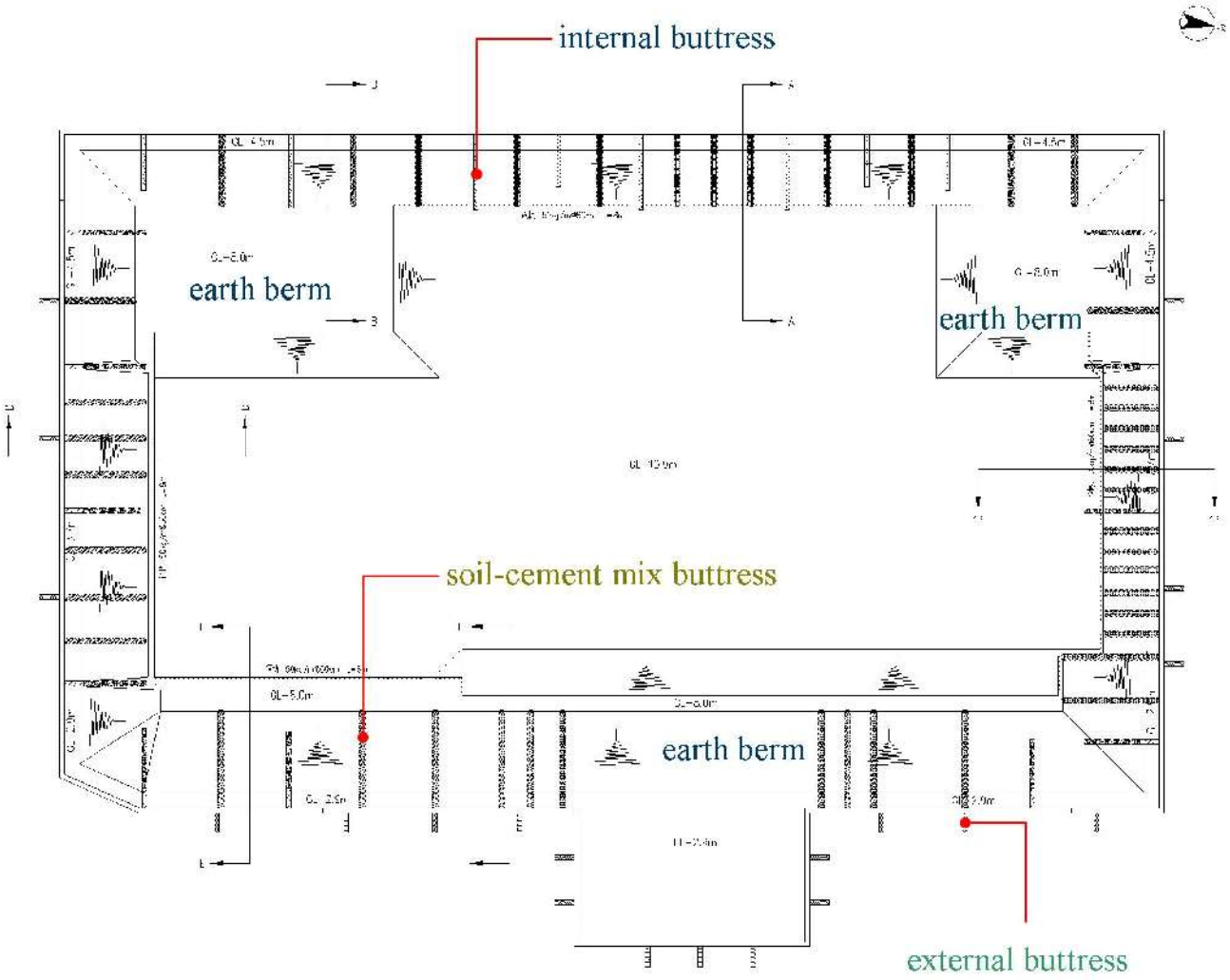
Details of soldier pile, buttress and bracing
鋼軌樁、地改式扶壁、內扶壁、斜支撐

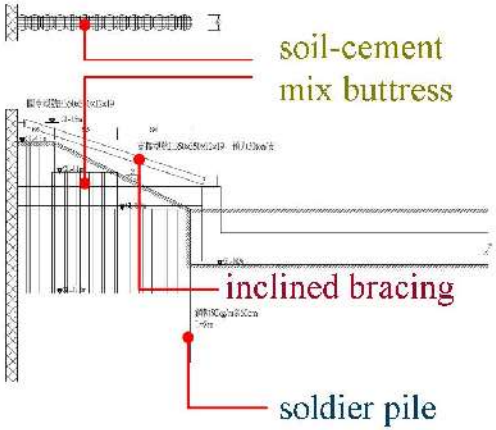


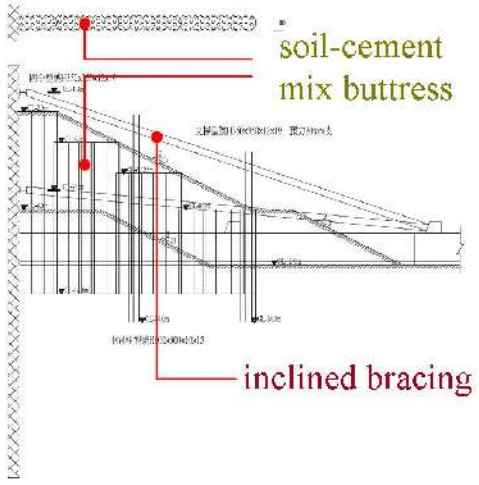
Bracing and reinforced slab
支撐及加勁版



Concrete buttress, soil-cement mix buttress and earth berm / 內外扶壁、地改式扶壁、土堤

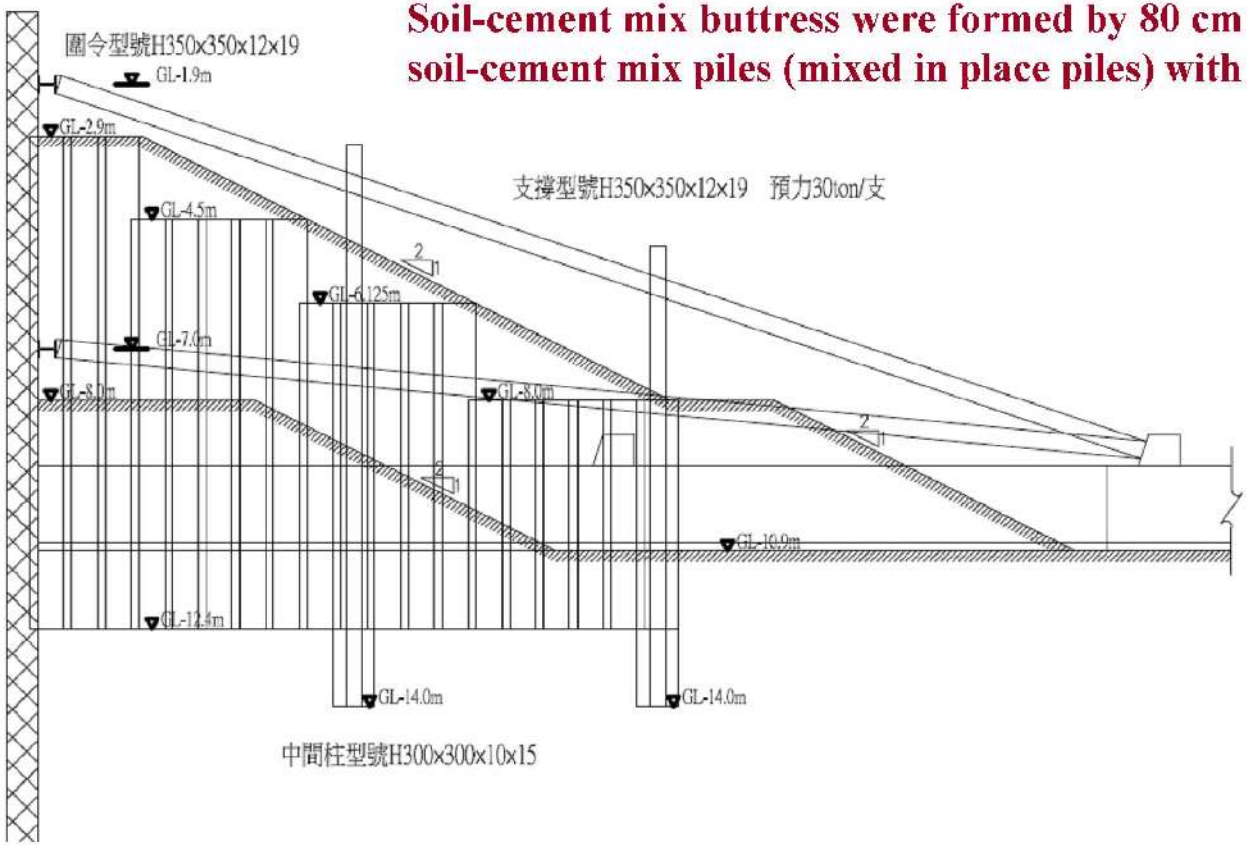






Details of soil-cement mix buttress
地改式扶壁

Soil-cement mix buttress were formed by 80 cm diameter of soil-cement mix piles (mixed in place piles) with 15 cm overlap.



Construction for reinforced slab in east side.
東側加勁板施做

Construction for soil-cement mix buttresses.
地改式扶壁施作

Installing of king post.
中間柱施作

Earth berms, king posts and soldier piles
土堤、中間柱及鋼軌樁

Soldier piles and internal buttress
鋼軌樁及內扶壁

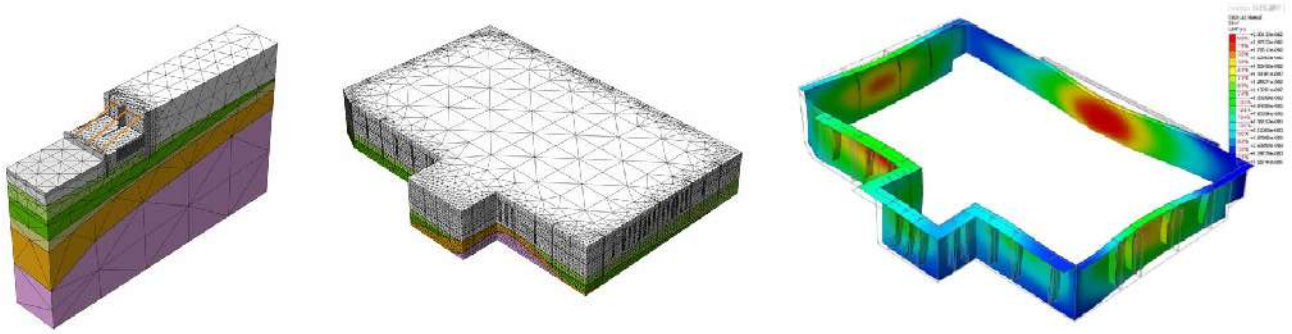
Internal buttress
內扶壁

Inclined bracings
斜支撐及墩座

Lateral struts
水平向大斜撐

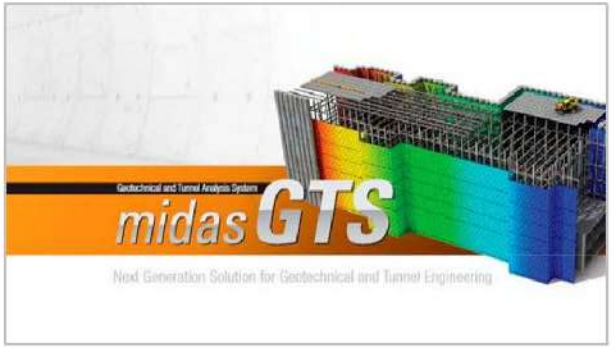
Numerical analysis methodology
數值分析方法

- Numerical Analysis Tool / 數值分析工具
- Mesh / 分析網格
- Strata and structure parameters / 分析參數
- Simulation of construction sequence / 分析工序
- Numerical analysis results / 數值分析結果



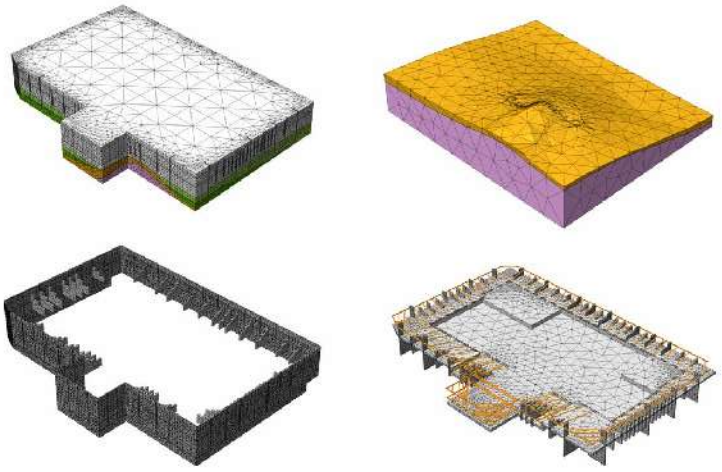
Numerical Analysis Tool
數值分析工具

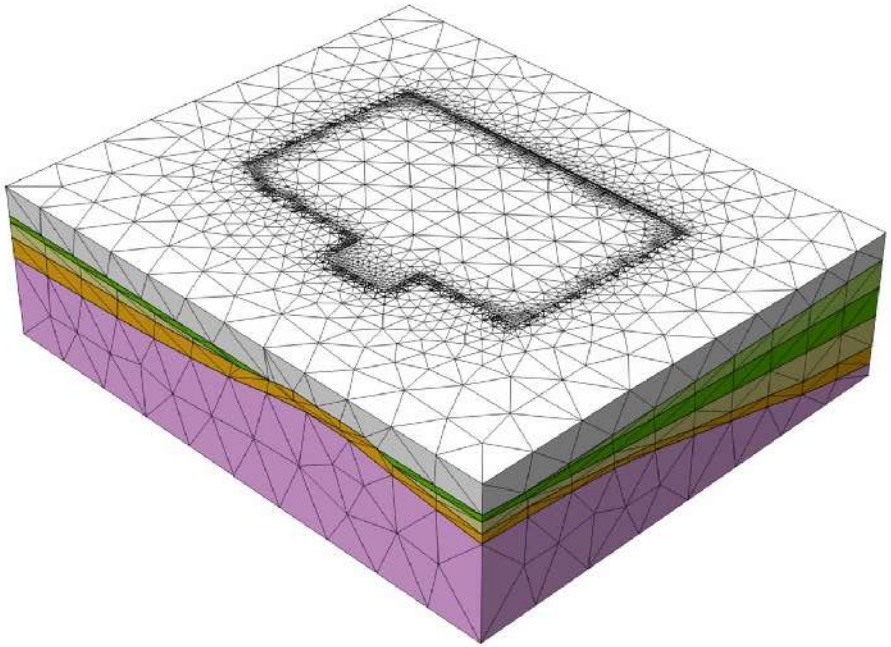
- **GTS** (Geotechnical & Tunnel analysis System) was adopted to stimulate the stages of the excavation.
- GTS is developed by MIDAS Information Technology Co., Ltd. It is a 3-D finite element program particularly developed for geotechnical and tunnel structural design and analysis.



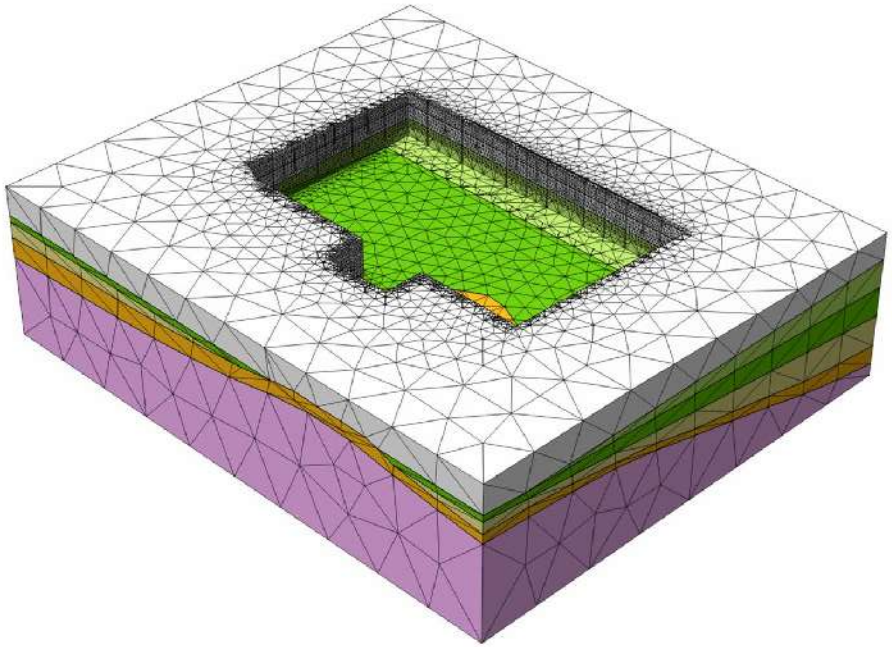
Mesh / 分析網格

- 3-D element (solid)
  - Strata
  - Concrete buttress, soil-cement mix buttress, mat foundation
- 2-D element (plane)
  - Diaphragm wall, reinforced slab, 1F slab, soldier pile
- 1-D element (line)
  - Strut, wale

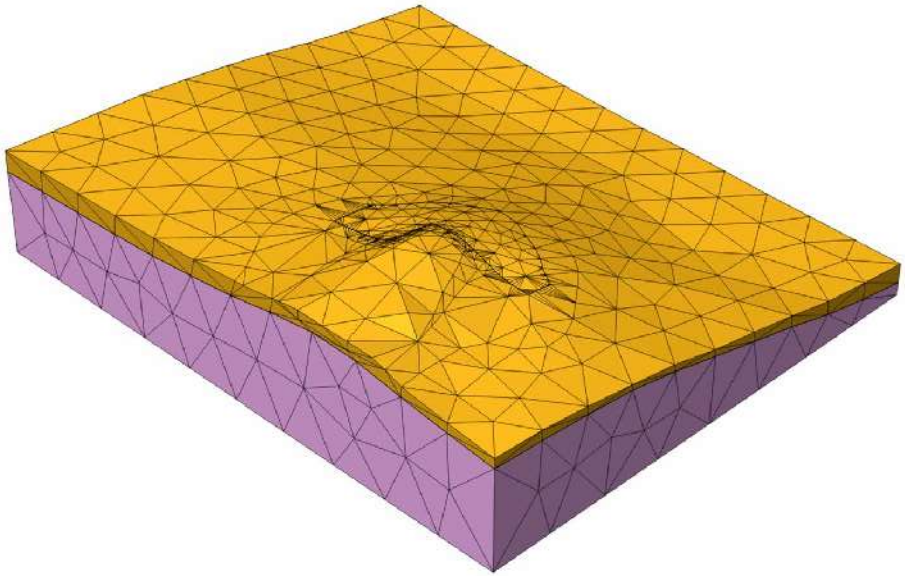




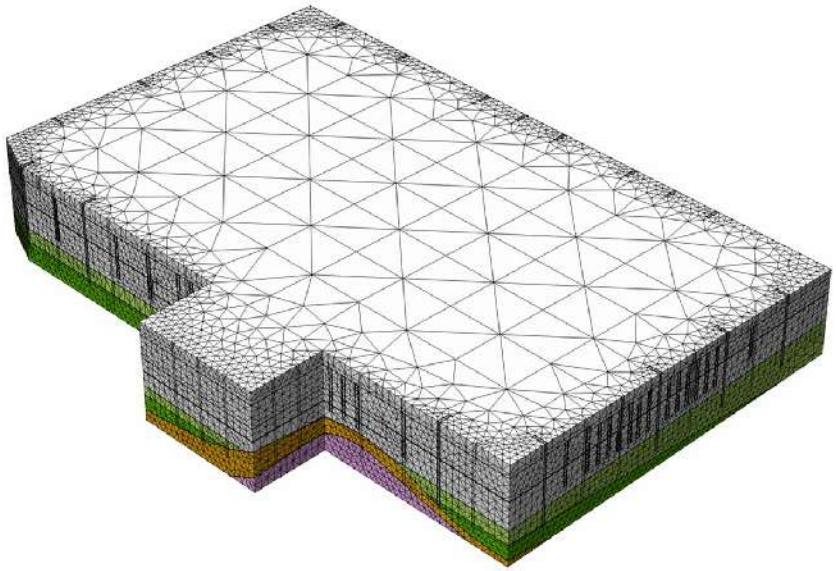
Meshes for soil stratum distribution (whole meshes)



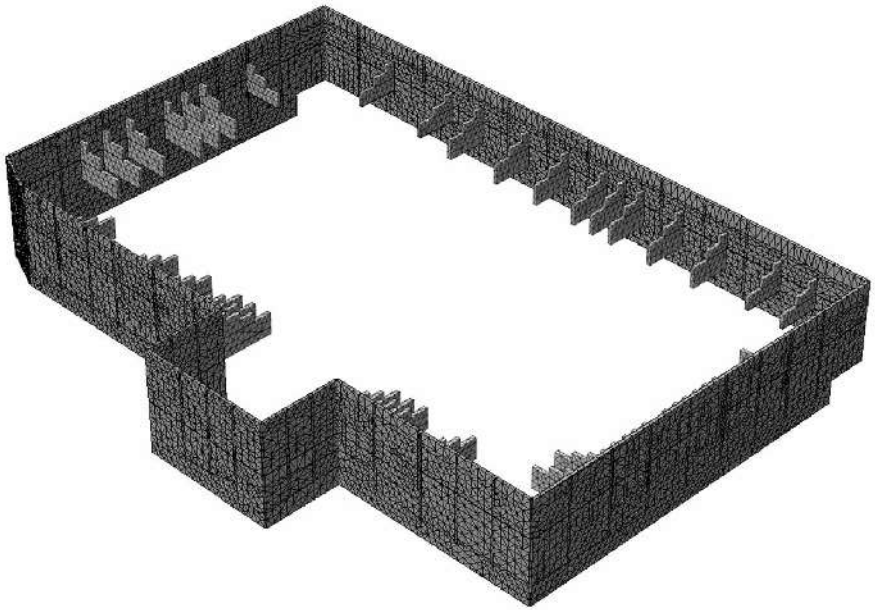
Meshes for soil stratum distribution (outside the exc. zone)



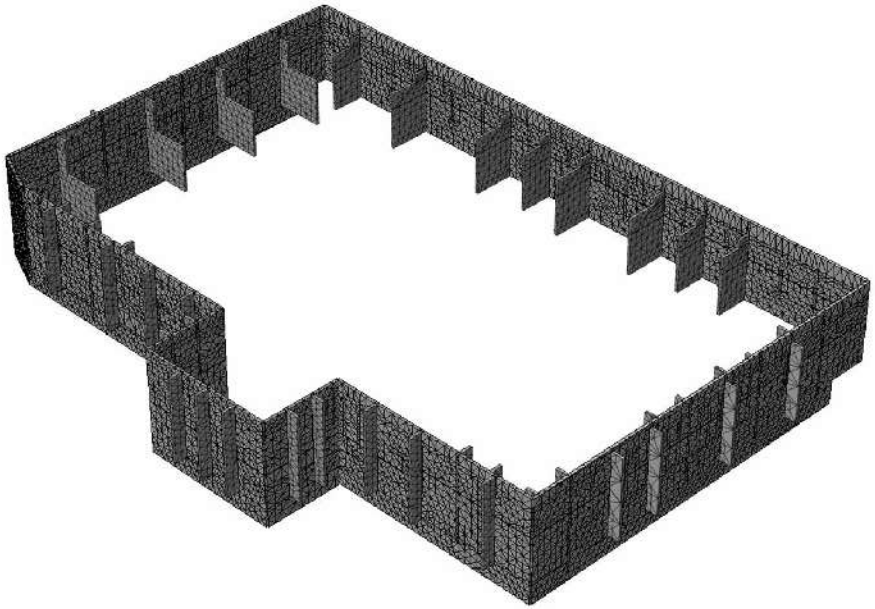
Meshes for SR and rock



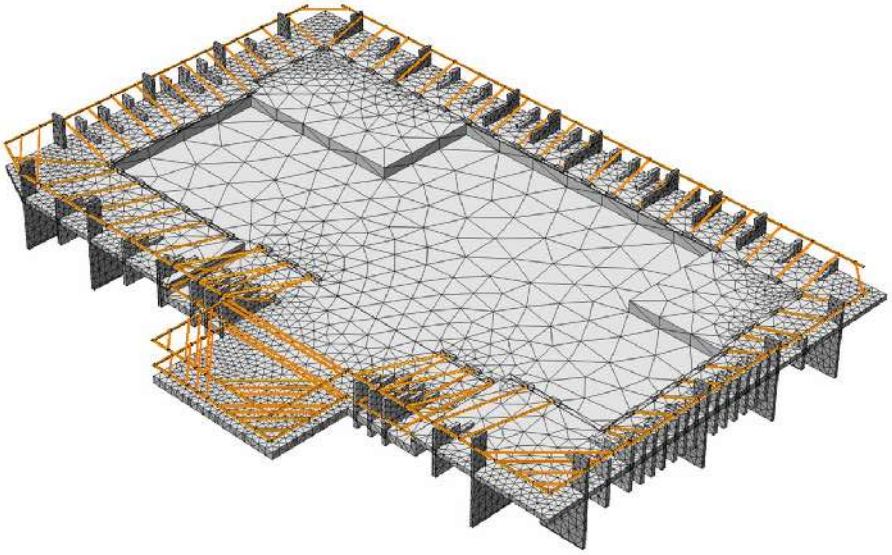
Meshes for soil stratum distribution (inside the exc. zone)



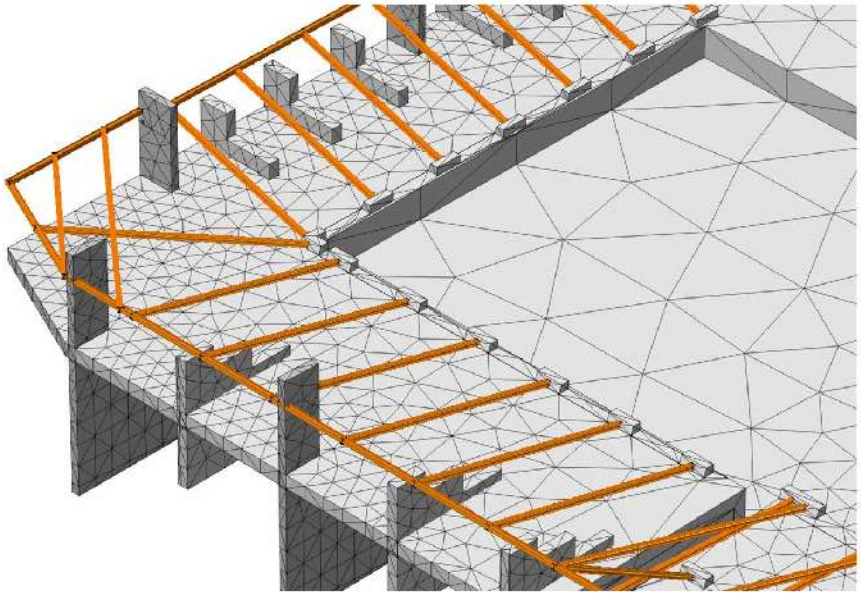
Meshes for diaphragm walls and soil-cement mix buttress



Meshes for diaphragm walls, internal buttress and external buttresses



Meshes for mat foundation, bracings, internal buttresses and soil-cement mix buttresses



Details of meshes for bracings

Strata and structure parameters
分析參數

- Strata Parameters Used in 3-D Analysis
  三維地層元素分析參數

Stratum	Depth (m)	E (tf/m^2)	ν	γ_t (tf/m^3)	c' (tf/m^2)	ϕ' (deg.)	K_o	Remark
SF/SM	0.0~14.2	2250	0.30	1.92	0.2	27	0.546	Mohr Coulomb
CL1	12.3~26.0	1750	0.35	1.86	0.2	28	0.531	Mohr Coulomb
CL2	13.0~38.5	2500	0.35	1.88	0.2	29	0.515	Mohr Coulomb
SM/CL	15.0~44.8	4000	0.30	1.97	0.2	31	0.485	Mohr Coulomb
SR	17.7~54.3	12500	0.30	2.10	-	-	0.455	Elastic
Rock	>21.6	25000	0.30	2.30	-	-	0.426	Elastic

Strata and structure parameters
分析參數

- Structural Parameters used in 2-D & 3-D Elements
  二維及三維結構元素分析參數

Element	Structure Type	E (tf/m^2)	ν	γ_t (tf/m^3)	K_o	t (m)	Remark
3D (Solid)	Concrete Buttress	1304224	0.16	2.3	0.190	-	Elastic
	Soil-Cement Mix Buttress	7500	0.20	2.3	0.250	-	Elastic
	Mat Foundation	2007984	0.16	2.3	0.190	-	Elastic
2D (Plane)	Diaphragm Wall	1304224	0.16	0	-	0.6	Elastic
	Reinforced Slab	1304224	0.16	0	-	0.4	Elastic
	1F Slab	2007984	0.16	0	-	0.25	Elastic
	Soldier Pile	12240000	0.25	0	-	0.073186	Elastic

Strata and structure parameters
分析參數

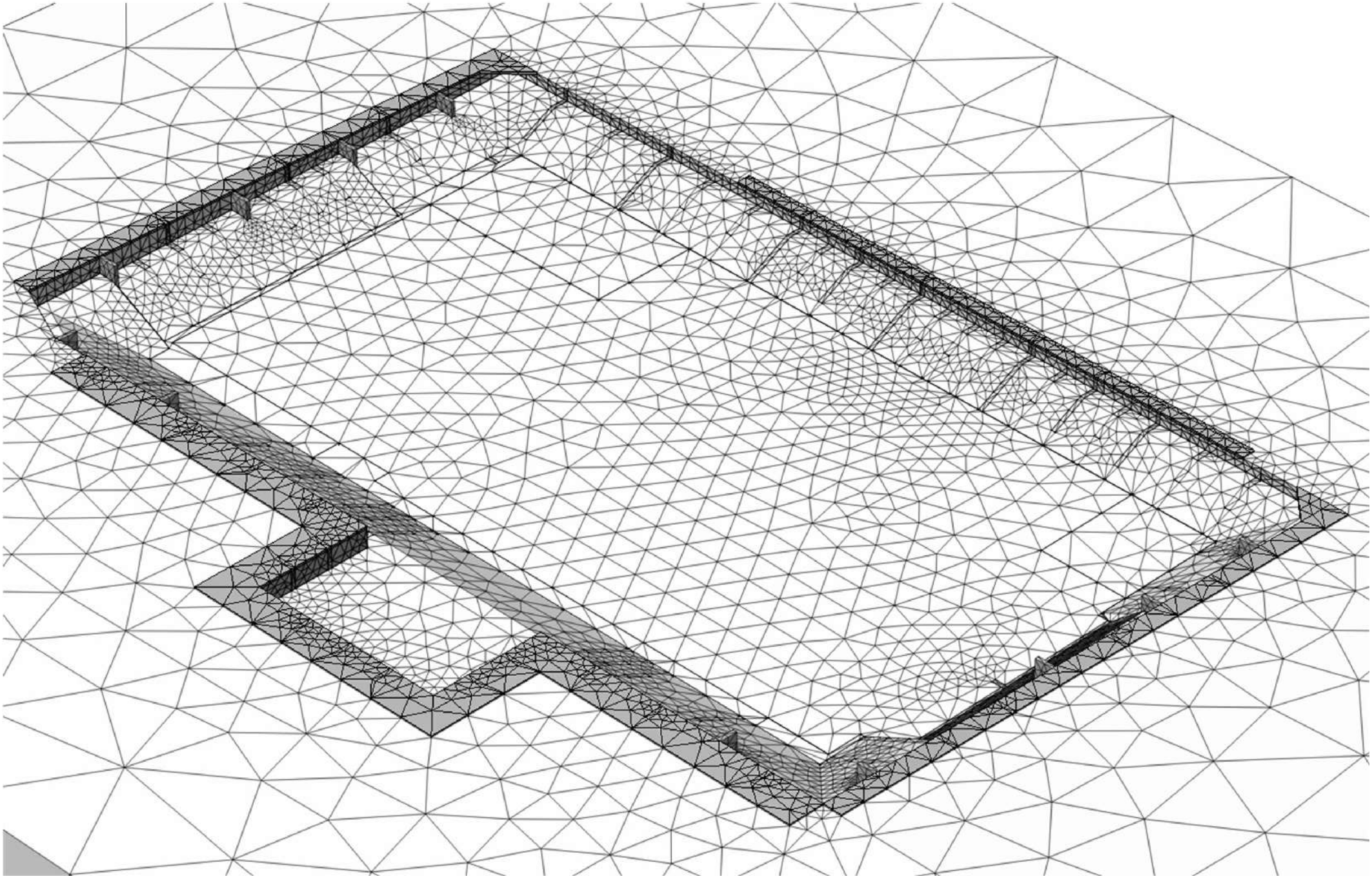
- Structural Parameters Used in 1-D Element
  一維結構元素分析參數

Element	Structure Type	E (tf/m^2)	A (m^2)	ν	I_x (m^4)	I_y (m^4)	Remark
1D (Line)	Lateral Strut H350×350×12×19	12240000	0.017044	0.25	-	-	Elastic Truss
	Wales H350×350×12×19	12240000	0.017044	0.25	0.000395	0.000136	Elastic Beam

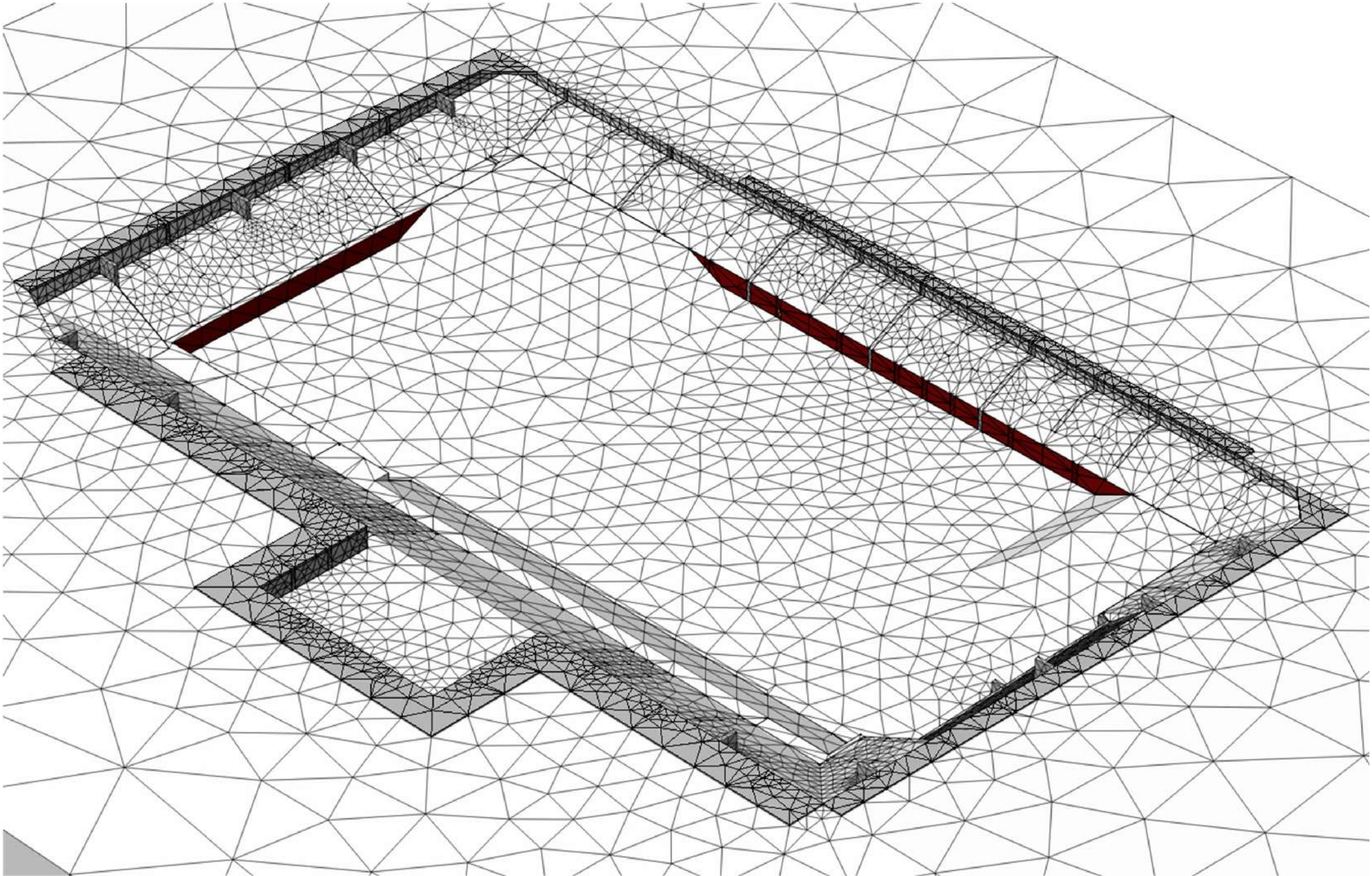
Simulation of construction sequence
分析工序

1. Excavate to GL -8.0m, maintain the stage 1 earth berms.
2. Excavate to GL -10.9m, maintain the stage 2 berms.
3. Construct mat foundation partially and set up stage 1 steel bracings.
4. Excavate the berm to GL-8.0m.
5. Construct non-damper installation zone and excavate the east side of berm partially.
6. Excavate east side and set up stage 2 steel bracings.
7. Excavate east side to the bottom.
8. Complete the whole mat foundation and transfer some of steel bracing to the blocks.
9. Construct first floor slab and remove all bracings.

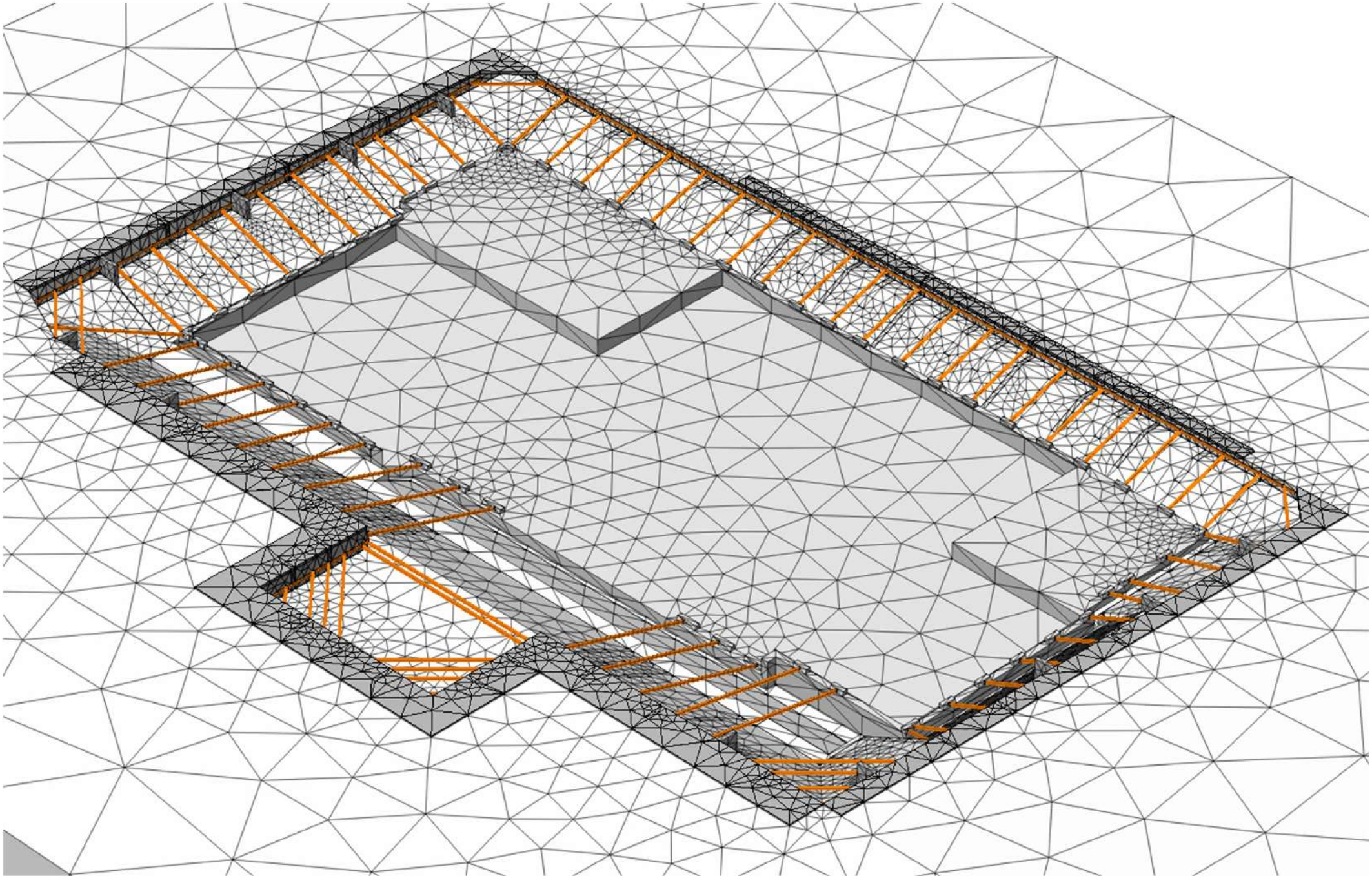
Step 1 : Excavate to 8.0 meters, retain stage 1 earth berms.



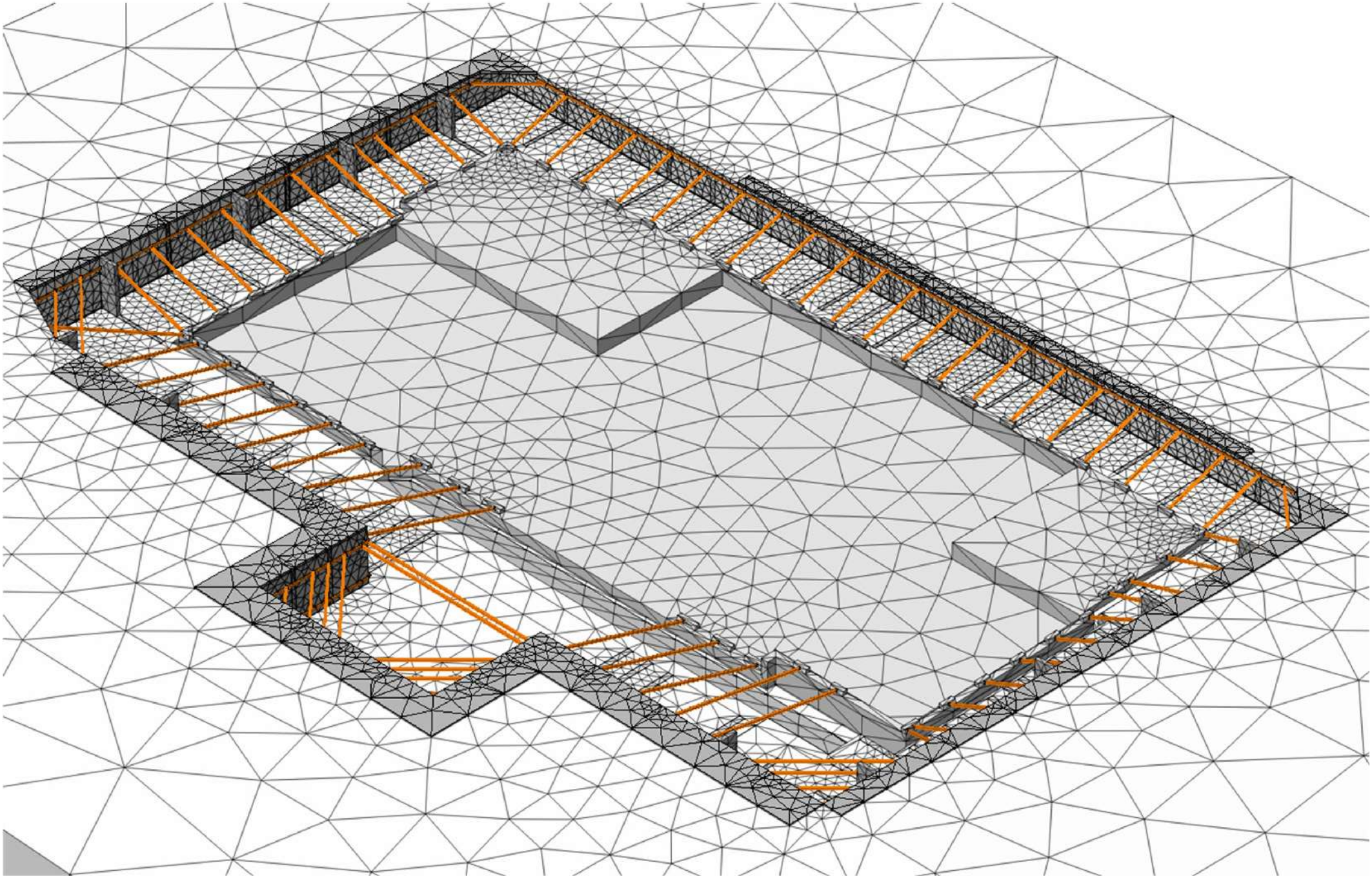
Step 2 : Excavate to 10.9 meters at center area, retain stage 2 earth berms.



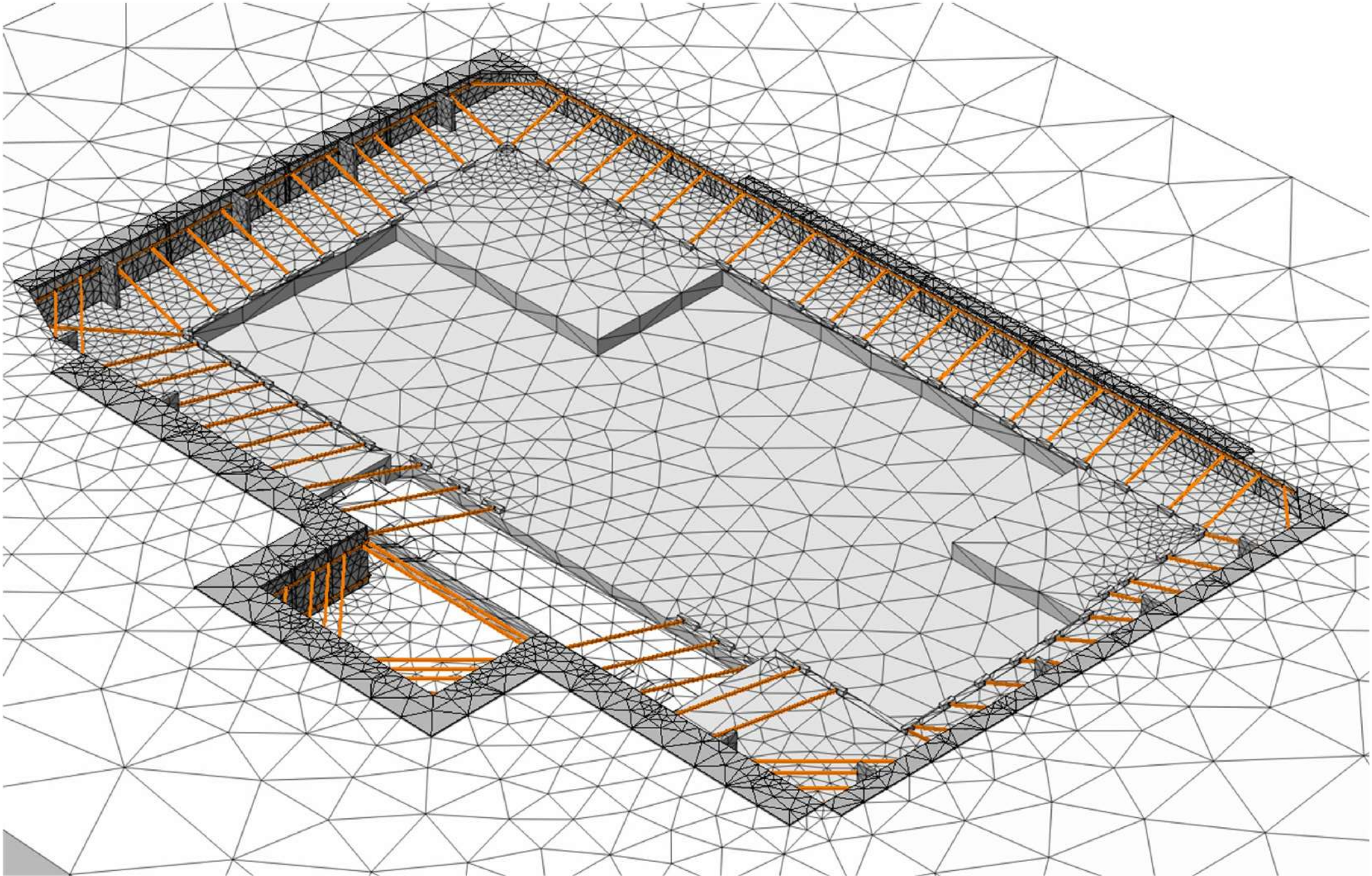
Step 3 : Excavate to the bottom, construct mat foundation and lateral struts and bracings partially.



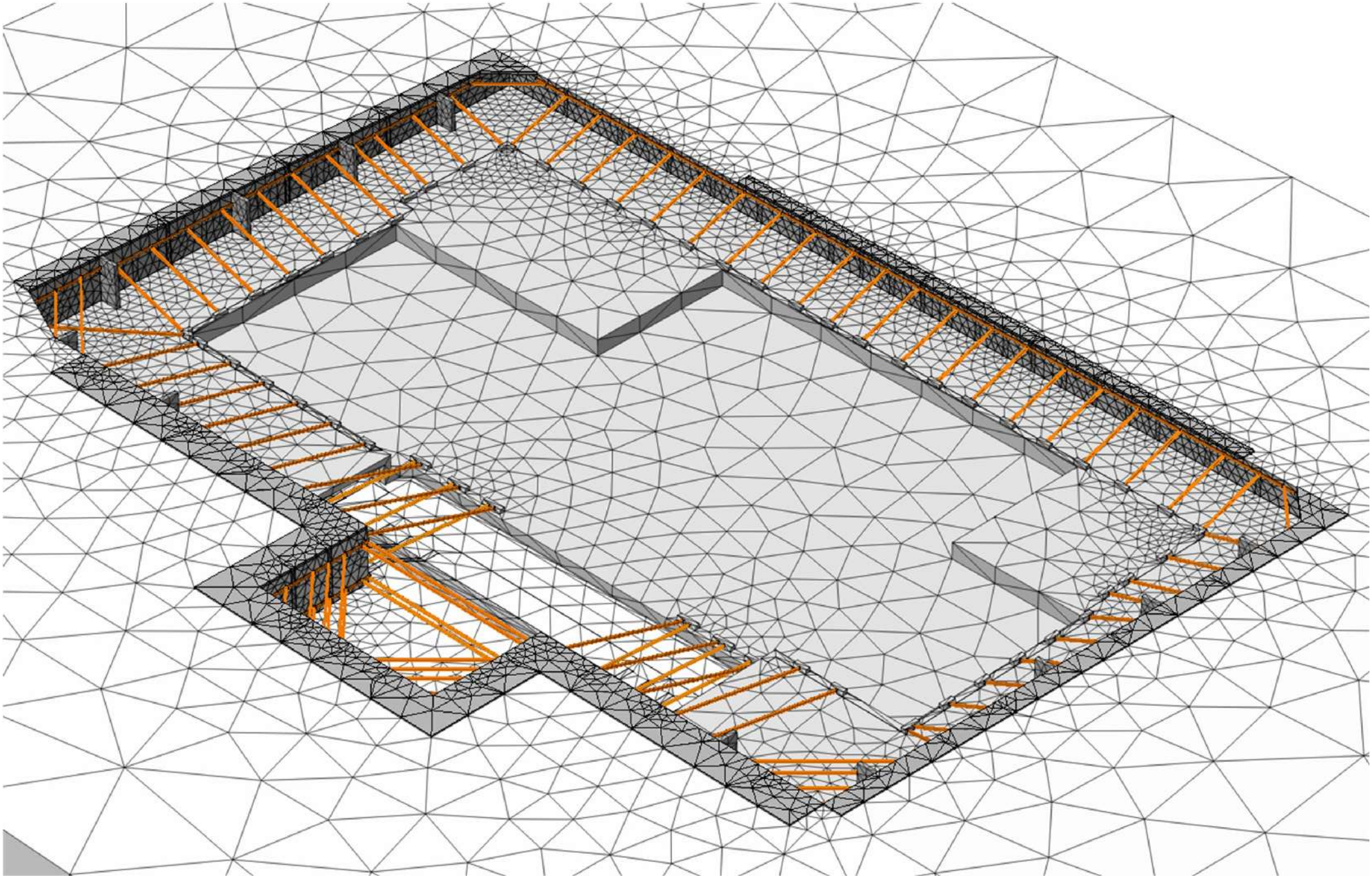
Step 4 : Excavate to 8.0 meters, retain stage 2 earth berms.



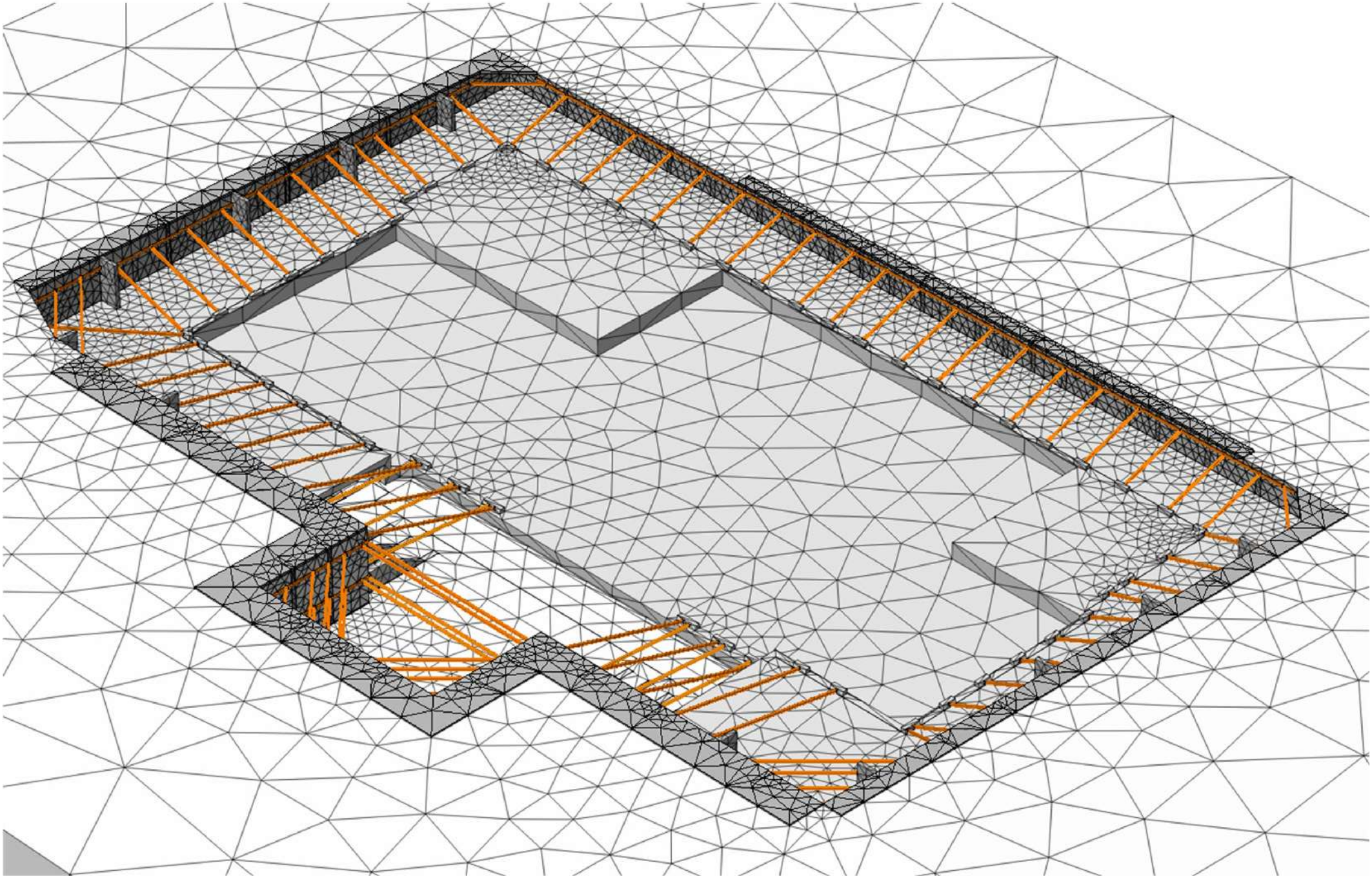
Step 5 : Construct slabs of non-damper installation zone and excavate the east side of berm partially.



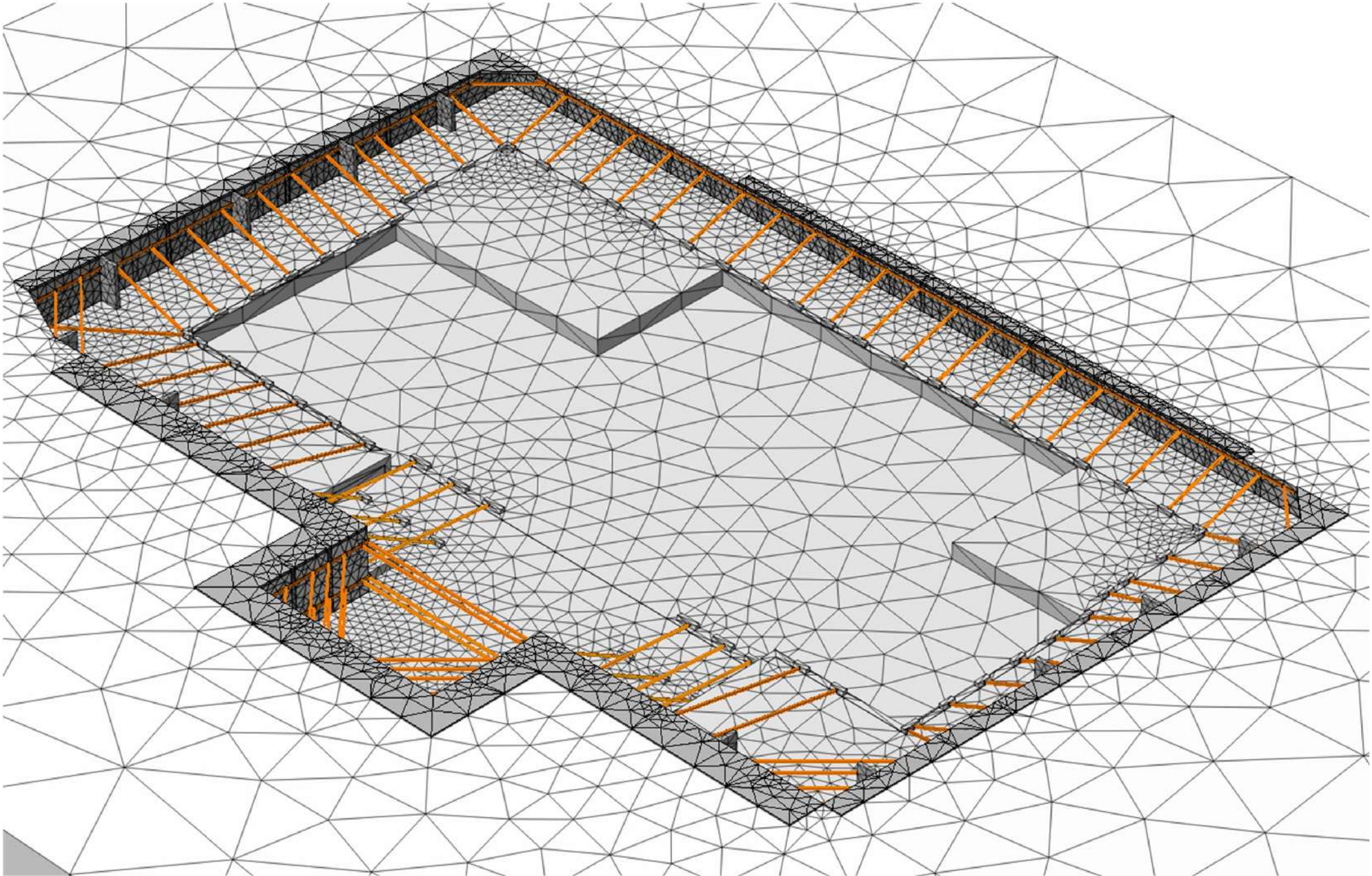
Step 6 : Set up stage 2 steel bracings in east side.



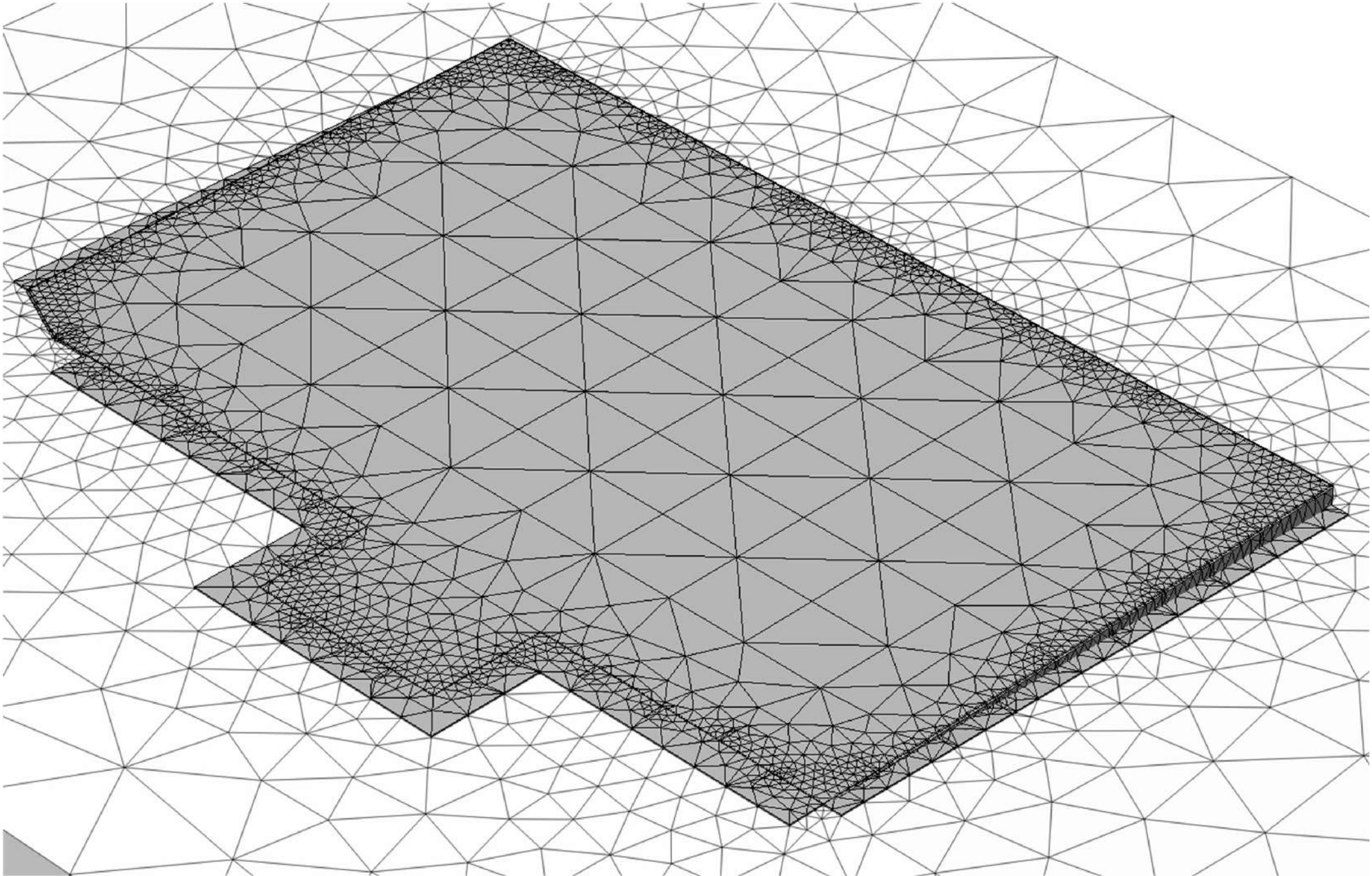
Step 7 : Excavate all the berms to the bottom at east side.



Step 8 : Complete the whole construction of mat foundation and transfer some of steel bracing to block.



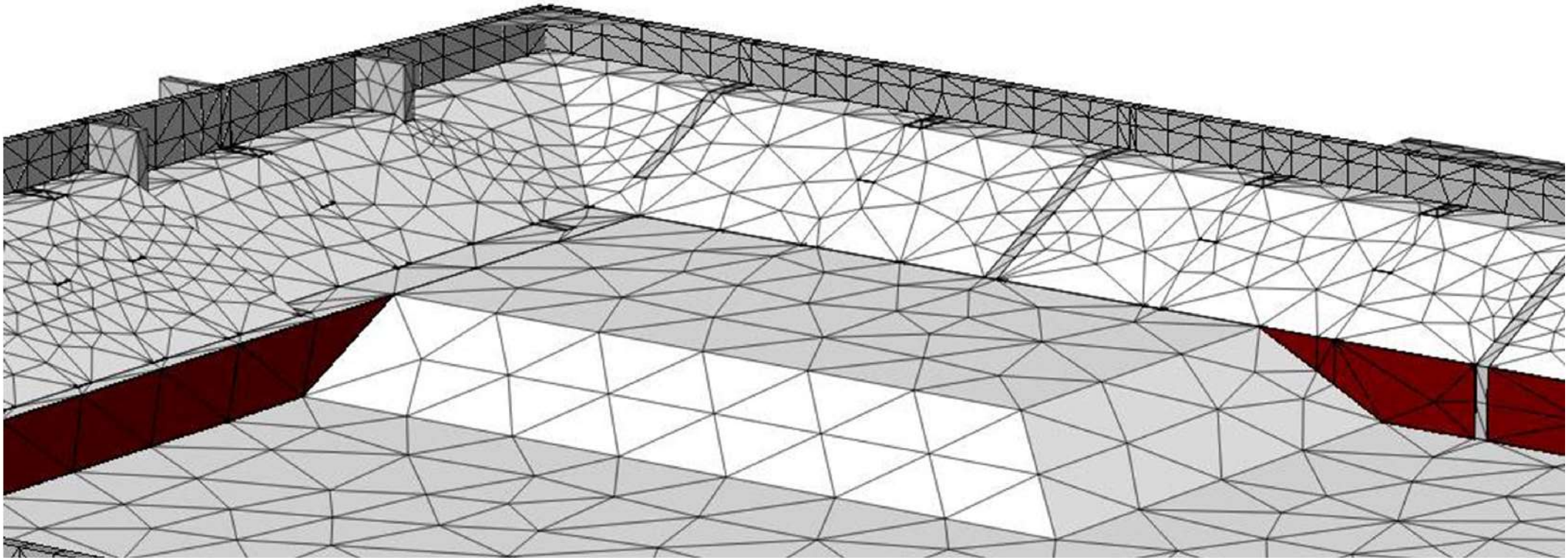
Step 9 : Construct first floor slab and remove all bracings.

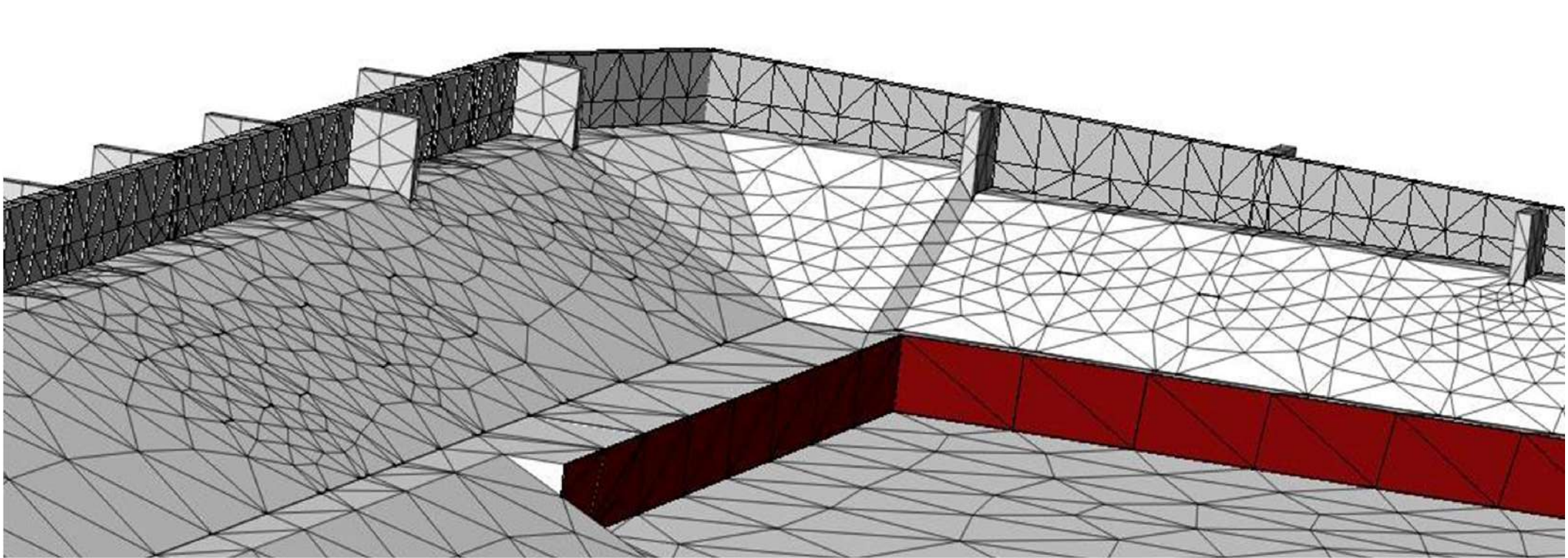


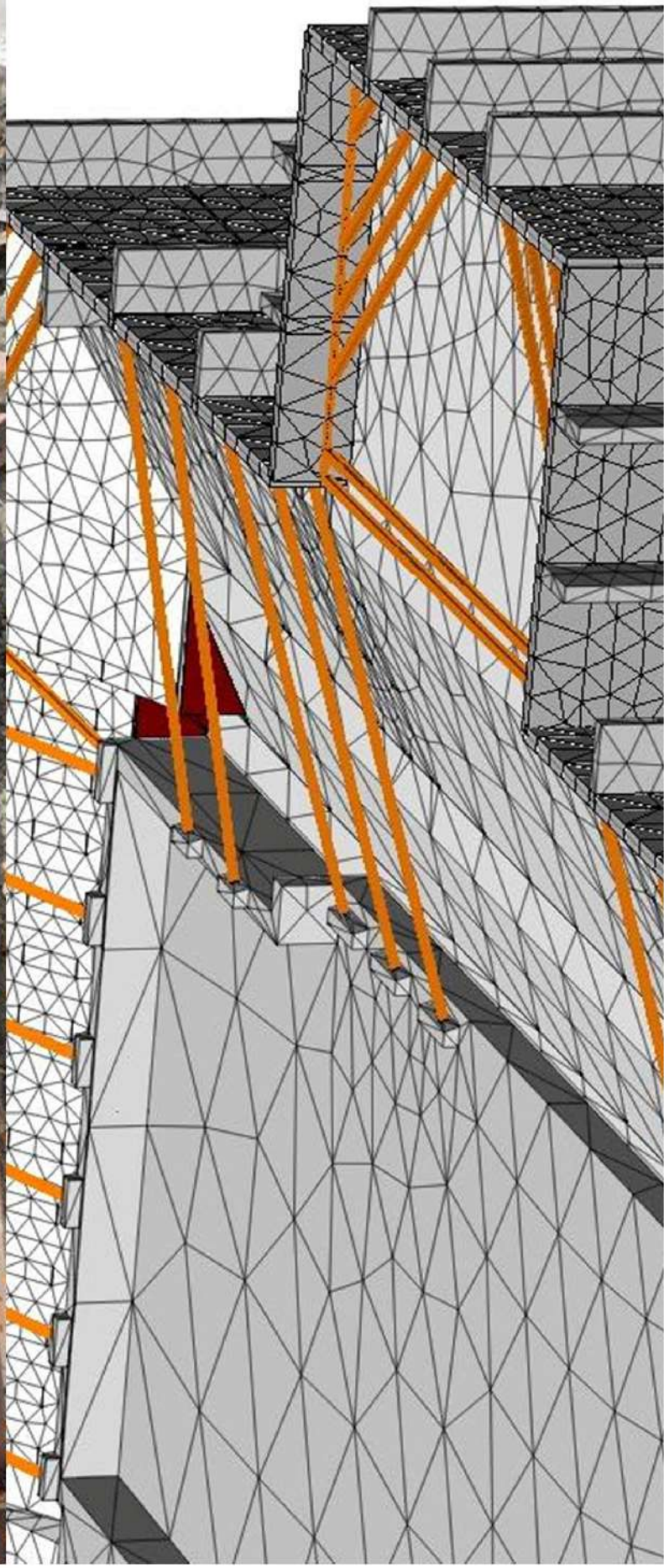

KOMATSU


KOMATSU
PC 300 LC
VOLVO
KOMATSU
PC 210
KOMATSU


inventec





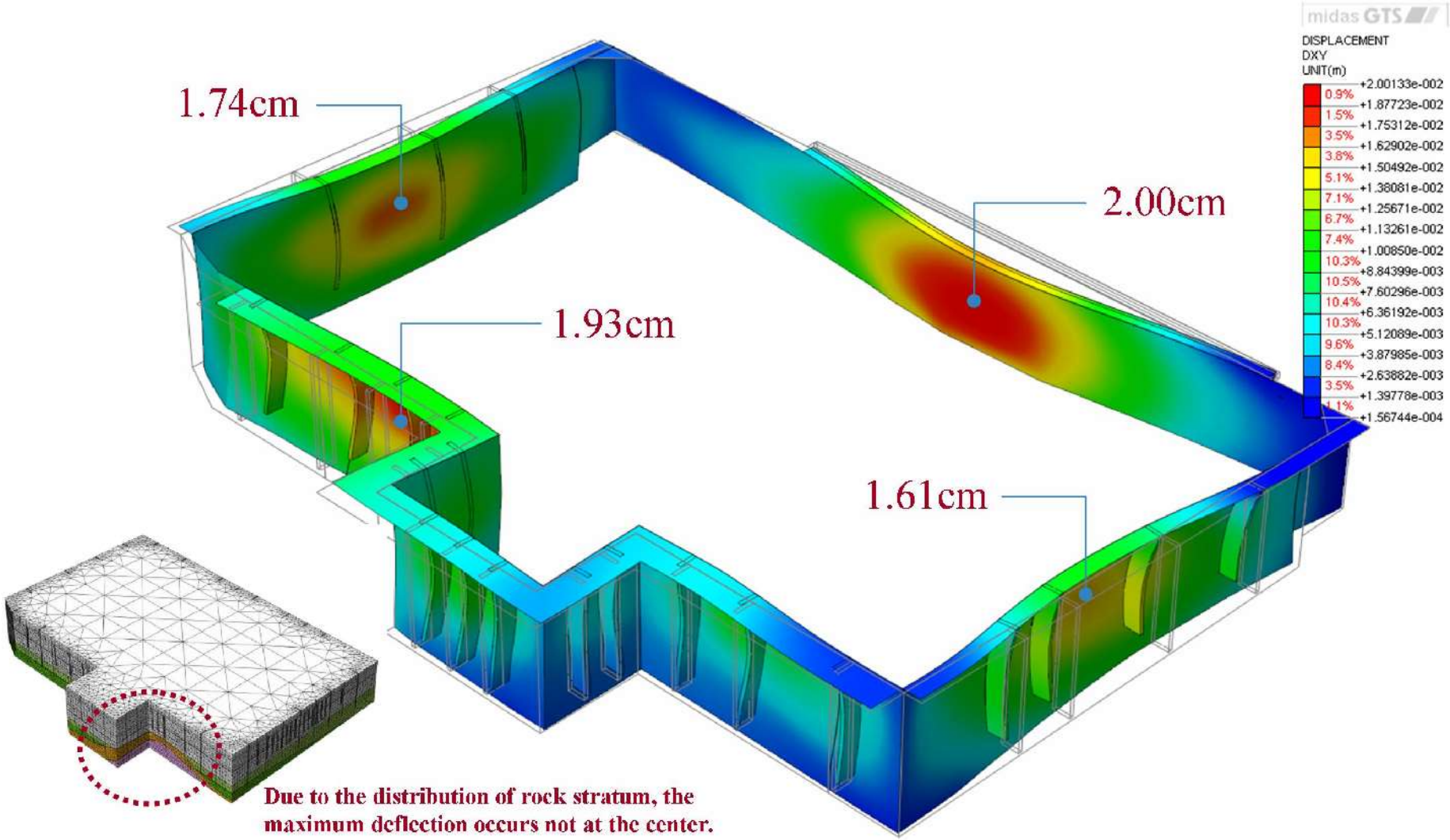



賽福帶
(02)29094518
請勿靠近
施工危險


請勿靠近
施工危險
請勿靠近
施工危險
請勿靠近
施工危險

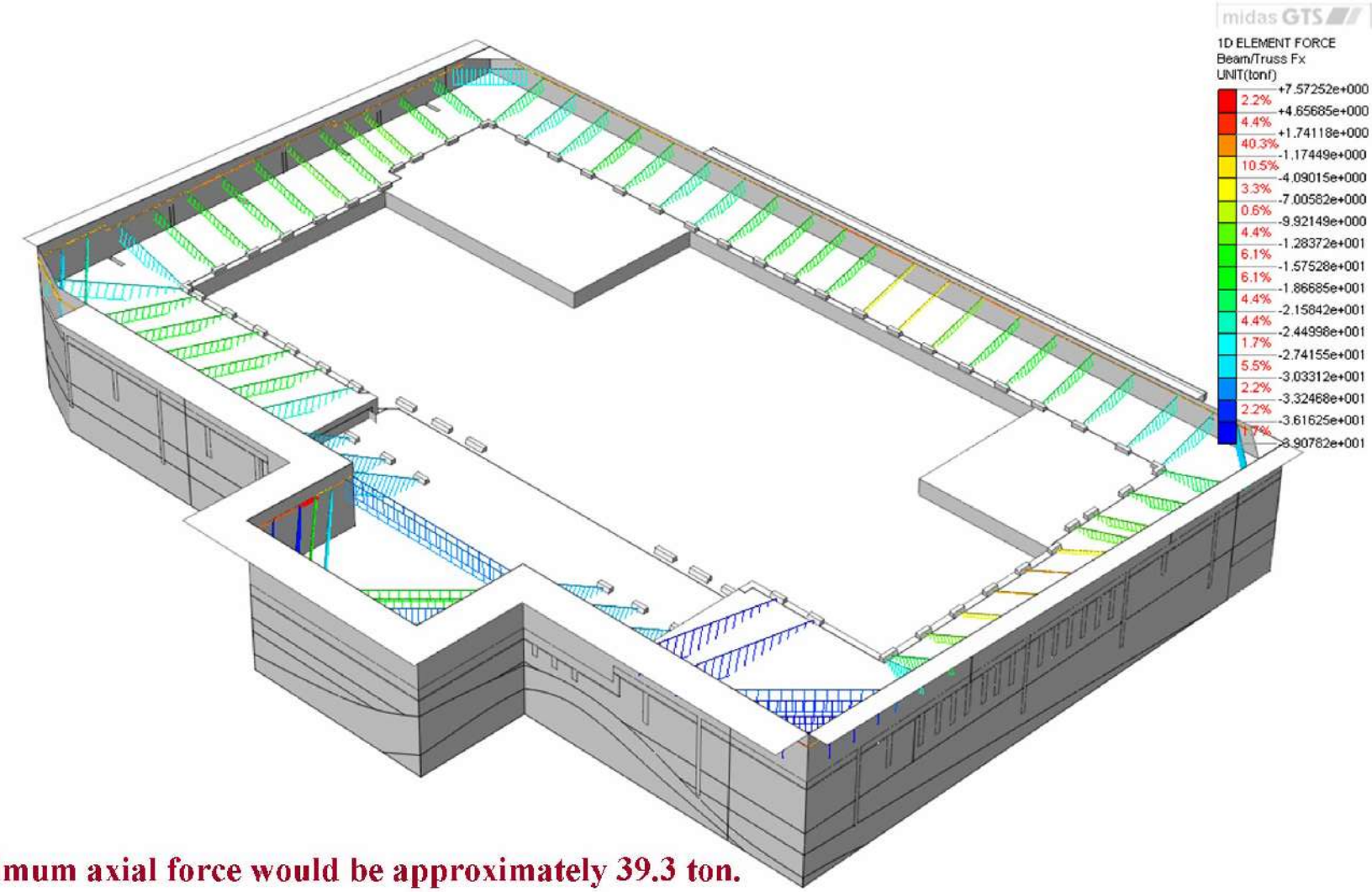
Site condition during excavation.
開挖施工全景

Numerical analysis results - Final displacement
數值分析結果：最終變形量



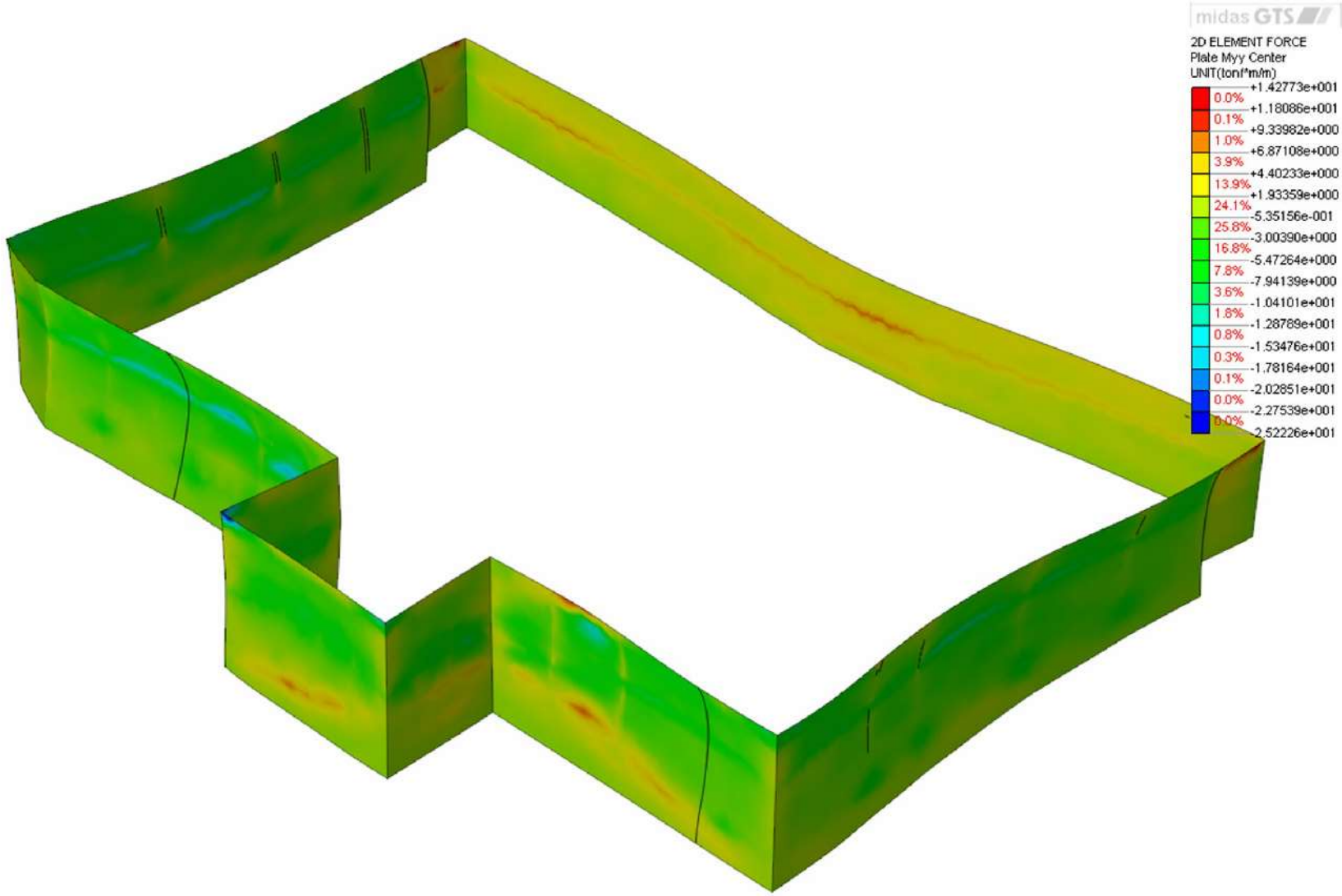
Due to the distribution of rock stratum, the maximum deflection occurs not at the center.

Numerical analysis results – Final strut load
數值分析結果：支撐軸力



The maximum axial force would be approximately 39.3 ton.

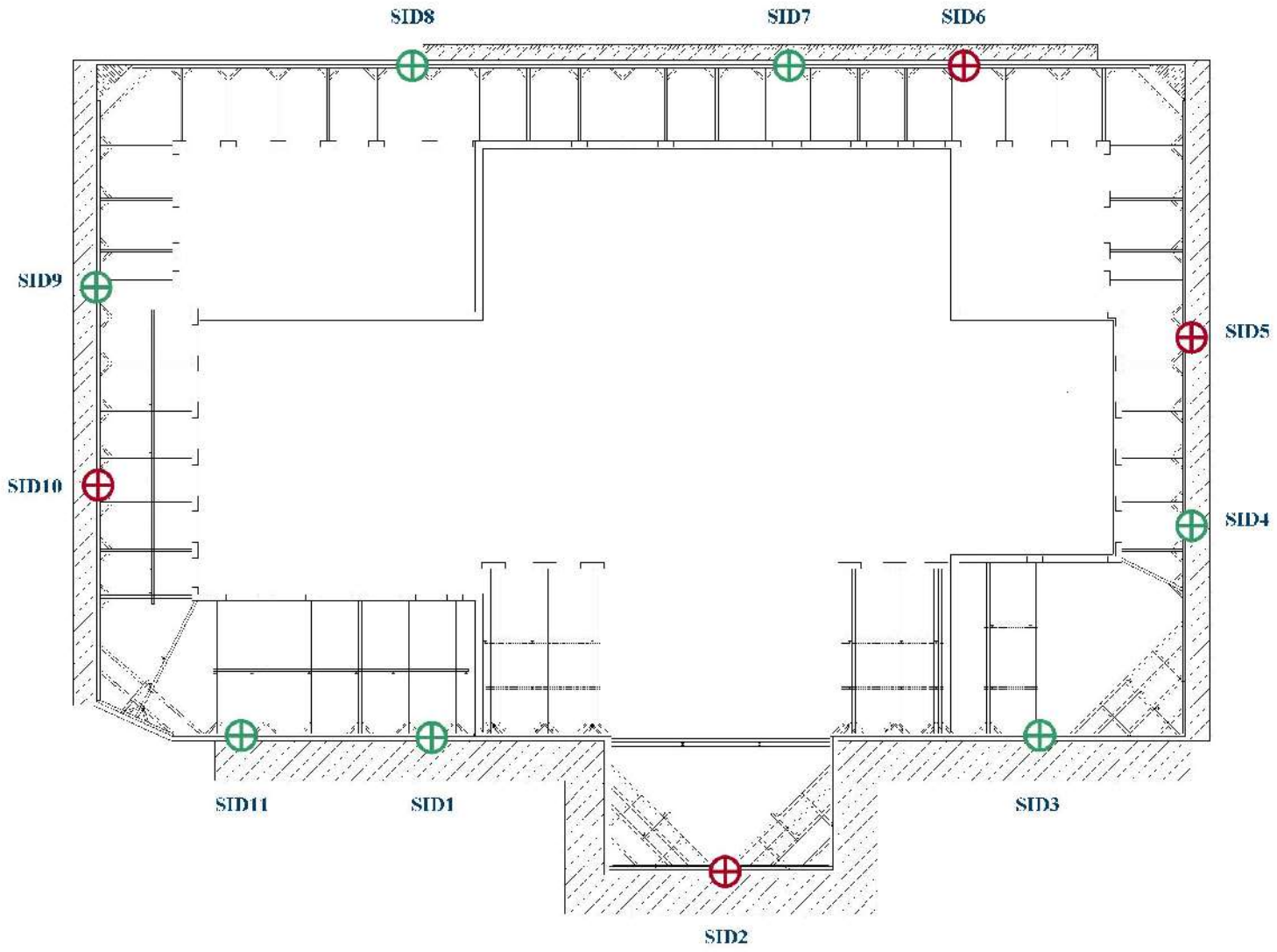
Numerical analysis results – Final moment of DW
數值分析結果：連續壁彎矩



The measurement results during excavation
開挖監測結果

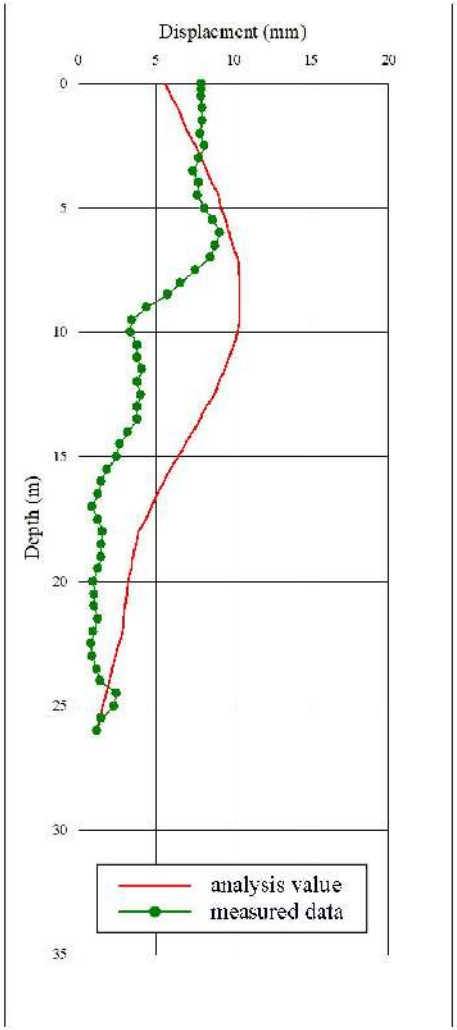
- The layout for monitoring system
  監測儀器配置
- Analysis results vs. measured data
  實測值與分析值比較

The layout for monitoring system
監測儀器配置

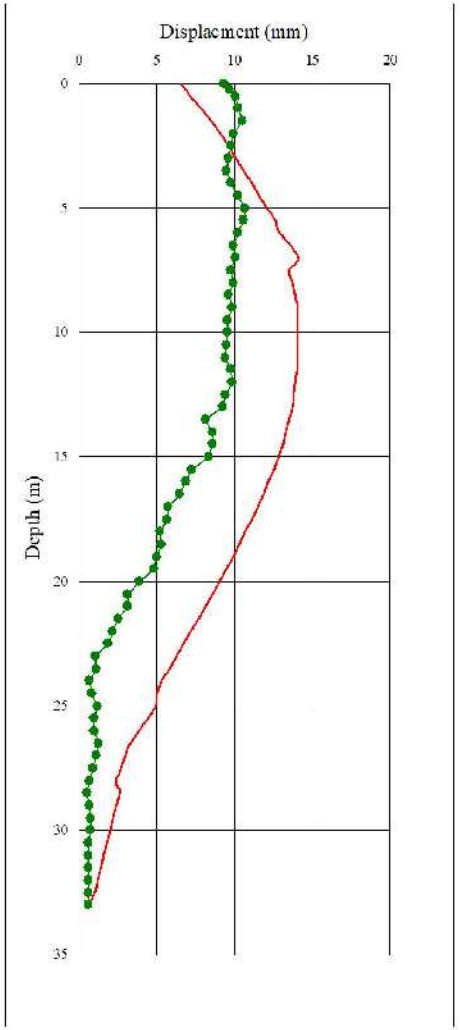


Analysis results vs. measured data
實測值與分析值比較

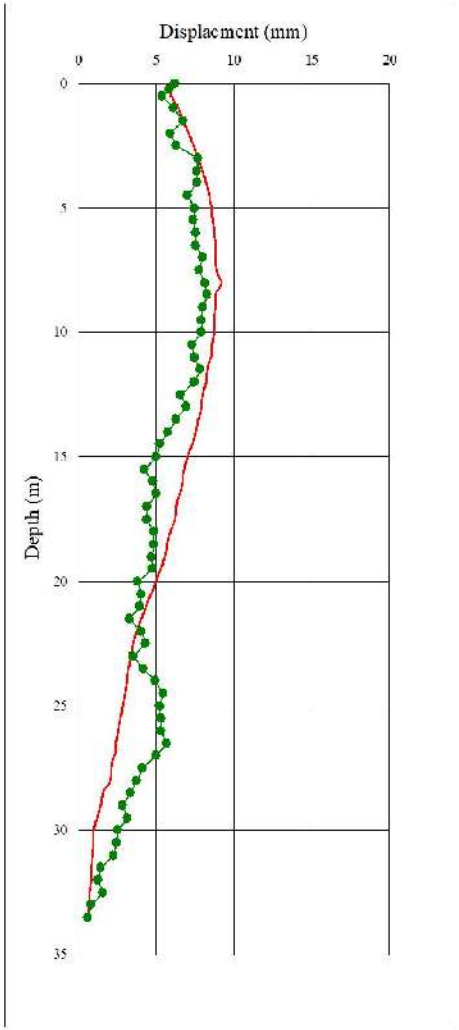
SID2



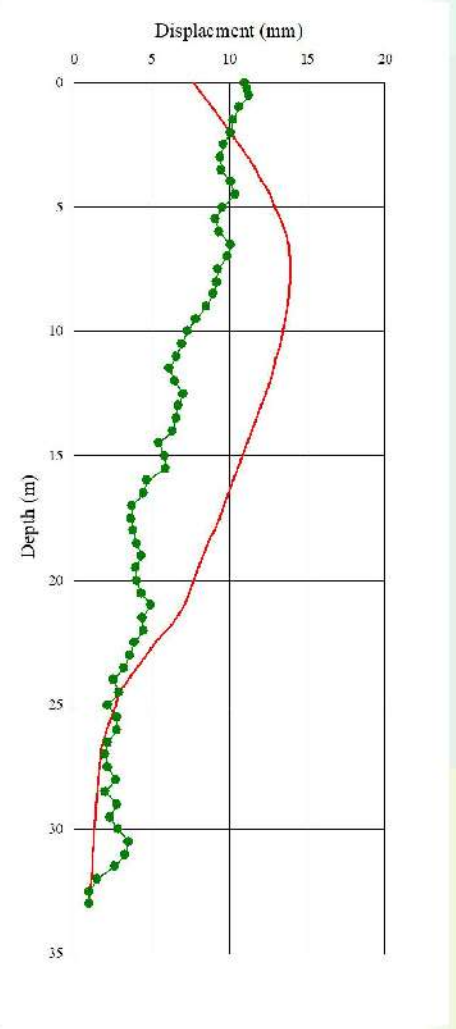
SID5



SID6



SID10



Conclusions / 結論

1. The subsoil stratum of this site is mainly backfilled by dredged loose sand from Keelung river. Island excavation method in combination of the concrete buttresses, soil-cement mix buttresses, reinforced slabs and bracing with diaphragm wall system in large area of excavation is very efficient and cost saving.

   本案例位在基隆河舊河道內，地層軟弱，先天條件不佳。本案採用之開挖擋土支撐系統（內扶壁、外扶壁、地改式扶壁、加勁板、斜支撐，並配合島式開挖工法）可有效發揮功能，節省大量工期及施工經費。

Conclusions / 結論

2. The excavation behavior is very complicated. A 3-D numerical analysis program, GTS, was successfully applied to simulate the construction stages.

   本案分析採用三維數值分析軟體 GTS，可成功模擬本基地複雜的開挖施工力學行為。

3. The results showed that the maximum deflections obtained from numerical analysis were little greater than those obtained from the actual measured results. However, the trends are all the same, the errors were in a reasonable range.

   數值分析之擋土壁最大變形量略大於開挖實測值，實測變形趨勢與分析結果一致。

Conclusions / 結論

4. The deformations predicted from the numerical analysis are feasible used to establish the control points for the monitoring system during excavation.

   本案三維數值分析可以合理地預測開挖造成之變形量，並可做為研擬監測管理值之依據。

THANKS FOR YOUR ATTENTION







大也工程顧問
www.dalec.com.tw