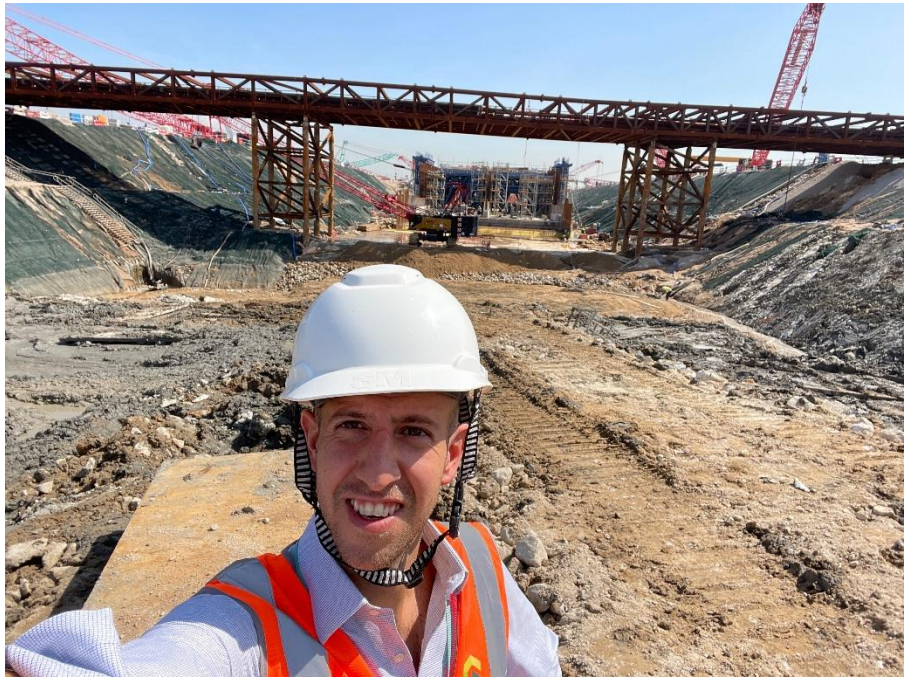
Observational Method Associated with 3D Analyses for HKBCF PCB Open Cut Excavation

AGS HK Technical Webinar

27 February 2025

About the Speaker

- Born and raised in Rome, Italy
- Studied at Universities in Rome, Finland and New York – MSc in Environmental and Civil Engineering
- Came to Hong Kong as graduate engineer for first full time job – supposedly for 1-2 years but finally never left
- Specialised in deep excavations, soft soils and reclamation
- Spent last 10 years working on HKBCF, 3RS and AICW



Content

- Background on Hong Kong Boundary Crossing Facilities (HKBCF) Reclamation and Passenger Clearance Building (PCB)
- Review of Ground Conditions at PCB after completion of reclamation ground improvement
- Temporary excavation design development

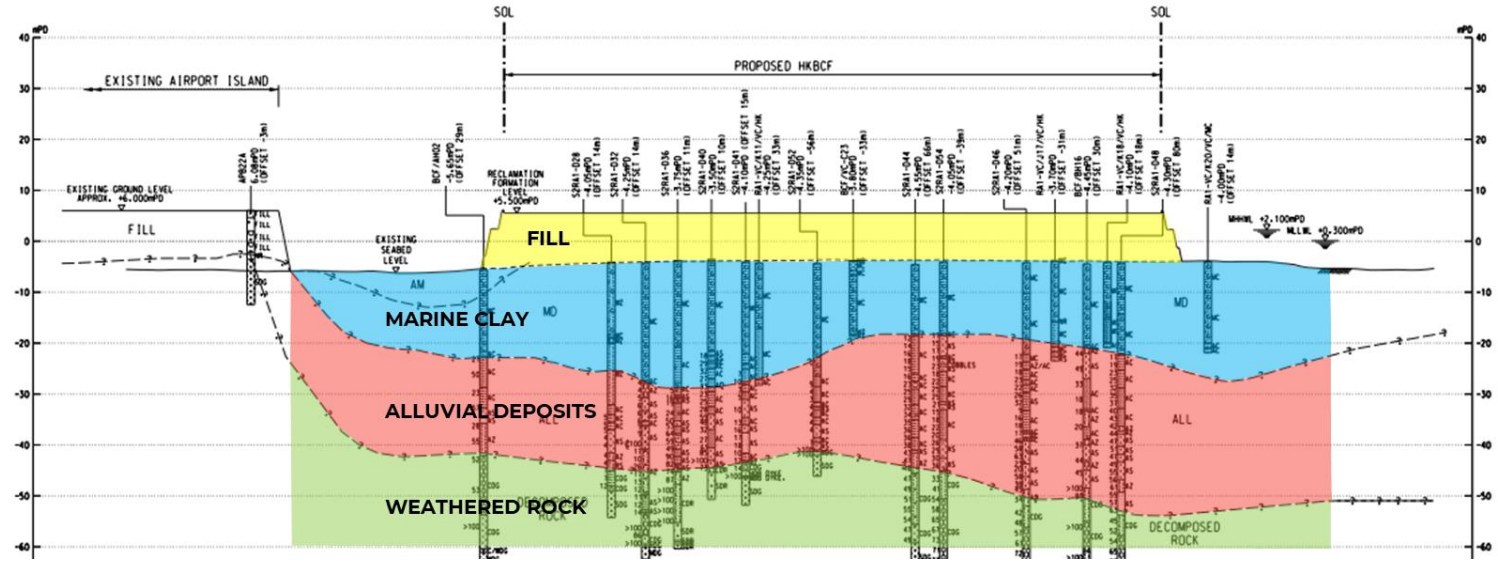
  2D → 3D → Observational Method
- Review of Excavation Performance
- Conclusions

Background on HKBCF Reclamation

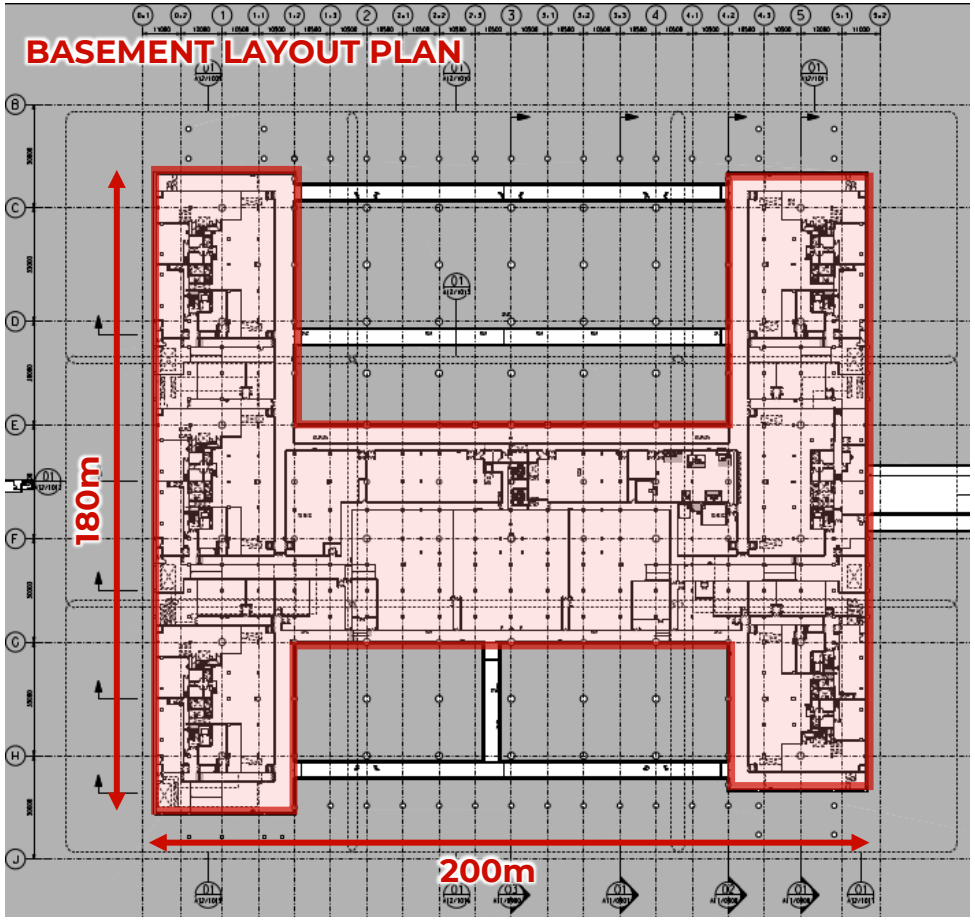
Hong Kong Boundary Crossing Facilities

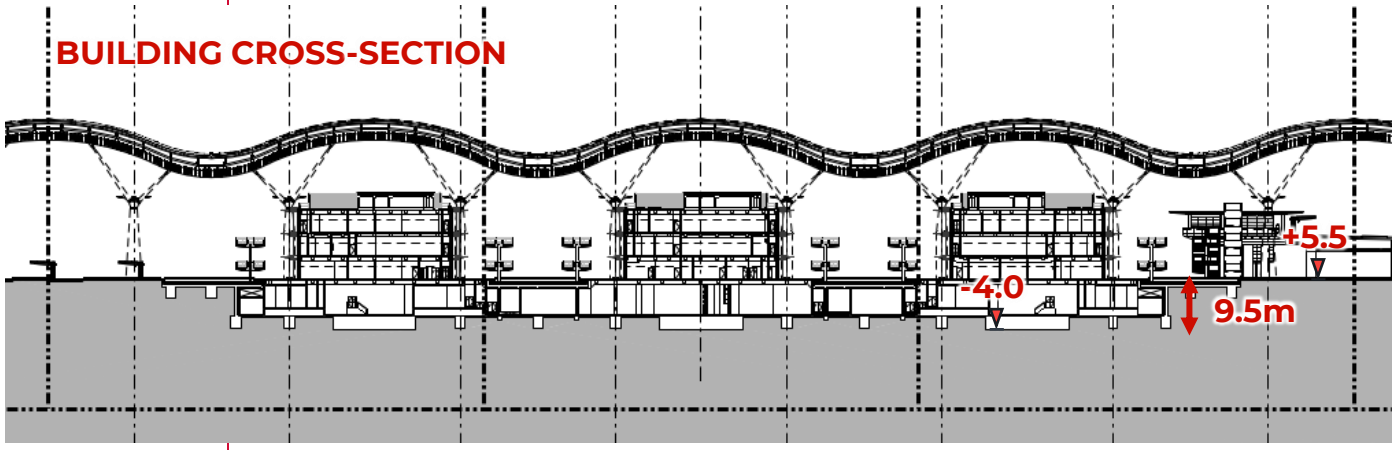
Hong Kong Boundary Crossing Facilities Reclamation

- 130 hectares reclaimed land, 6.5 km seawall length
- Seabed depth 4-12m. Very soft to soft Marine Clay 10-30m thick
- Seawalls: 26-30m diameter Steel Cells with Stone Columns for temporary stages. Sloping Seawall with rock armour installed in front of cells for permanent conditions
- PVD + 6m surcharge for the main reclamation. PVDs installed to top of Alluvium at 1.2m spacing.
- As soon as seawall are completed and surcharge is removed, the reclamation Contractor hands over the land to the Infrastructure Contractor.
- Key reclamation performance criteria: <500mm residual settlement after handover



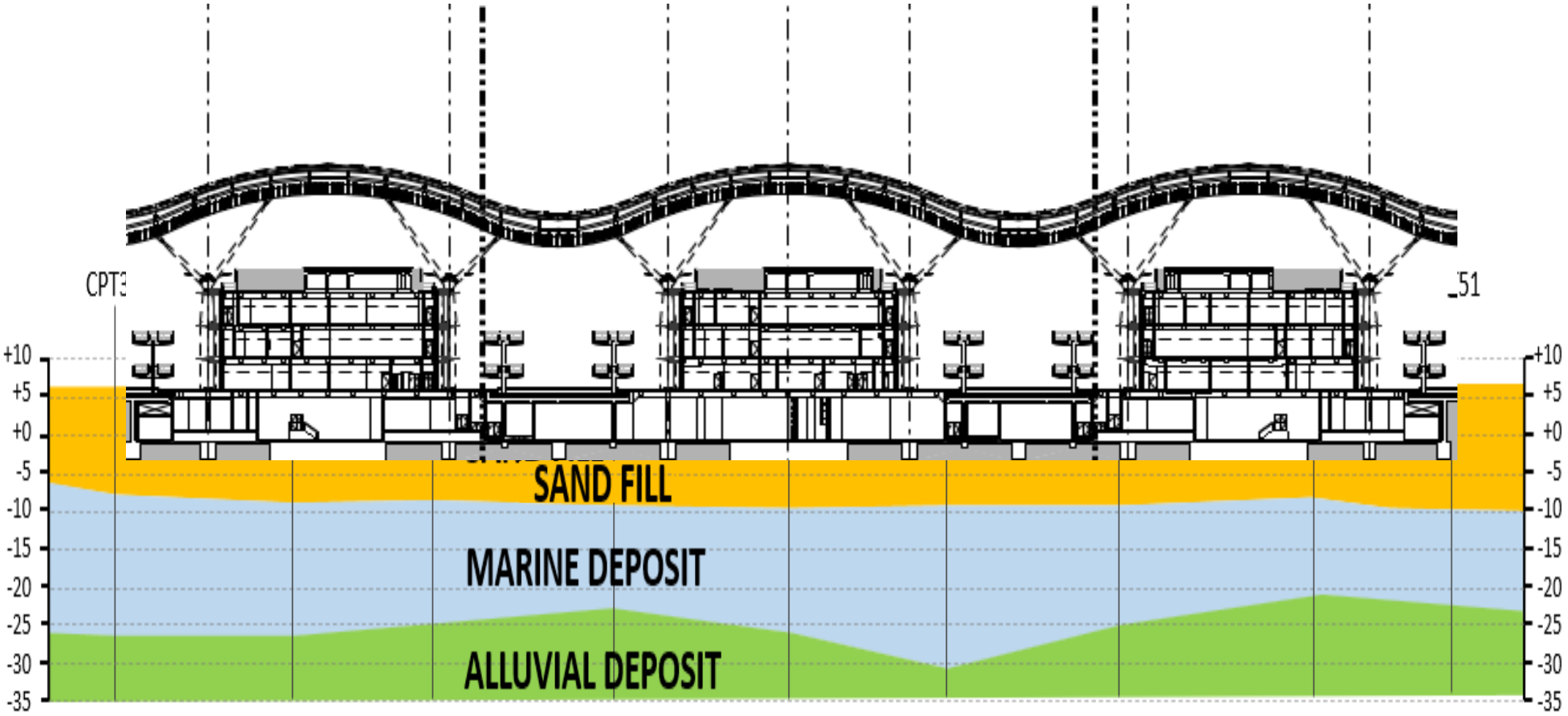
Passenger Clearance Building



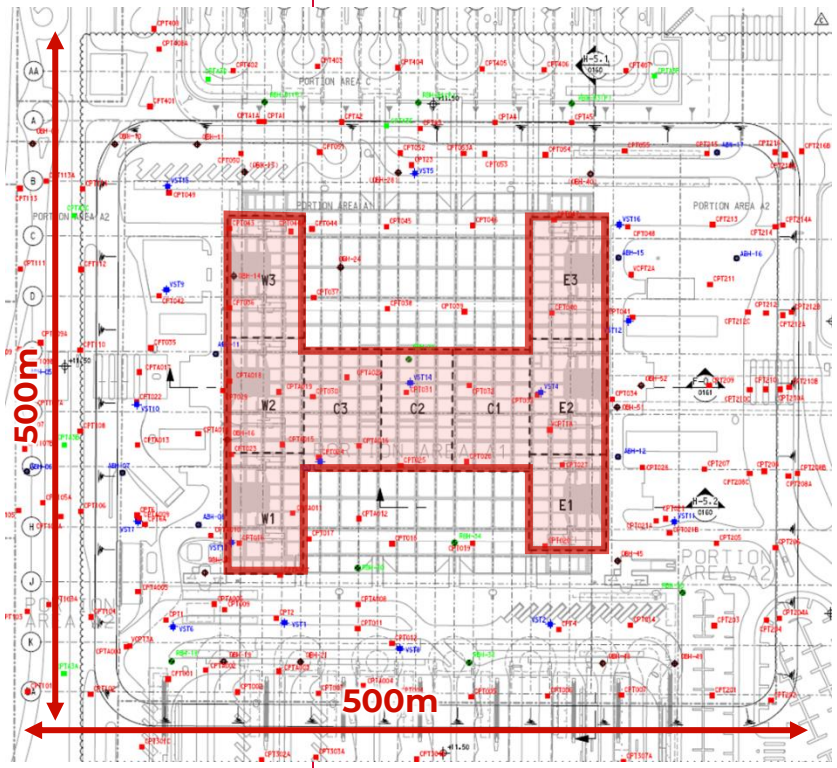


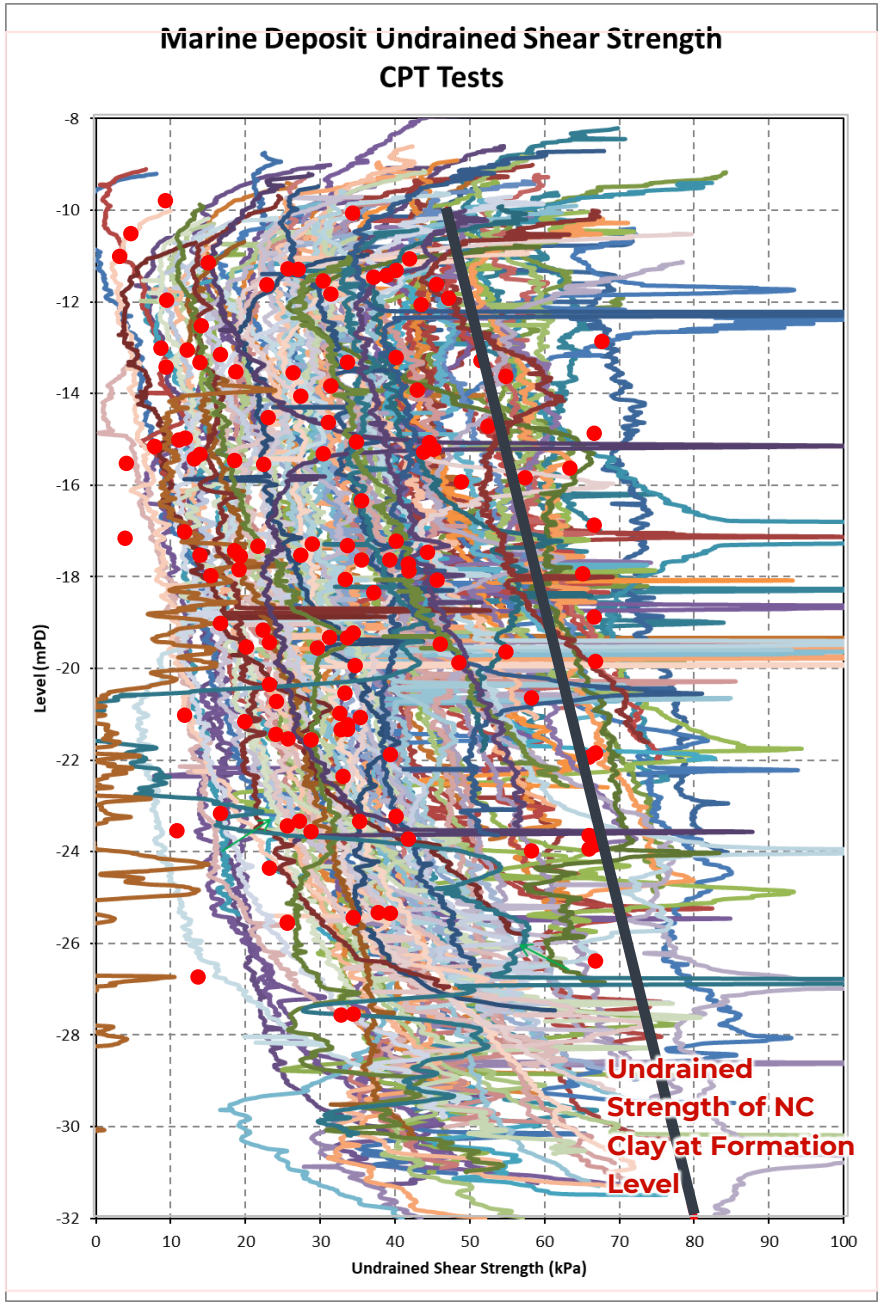
Review of Ground Conditions at PCB

Soil Profile



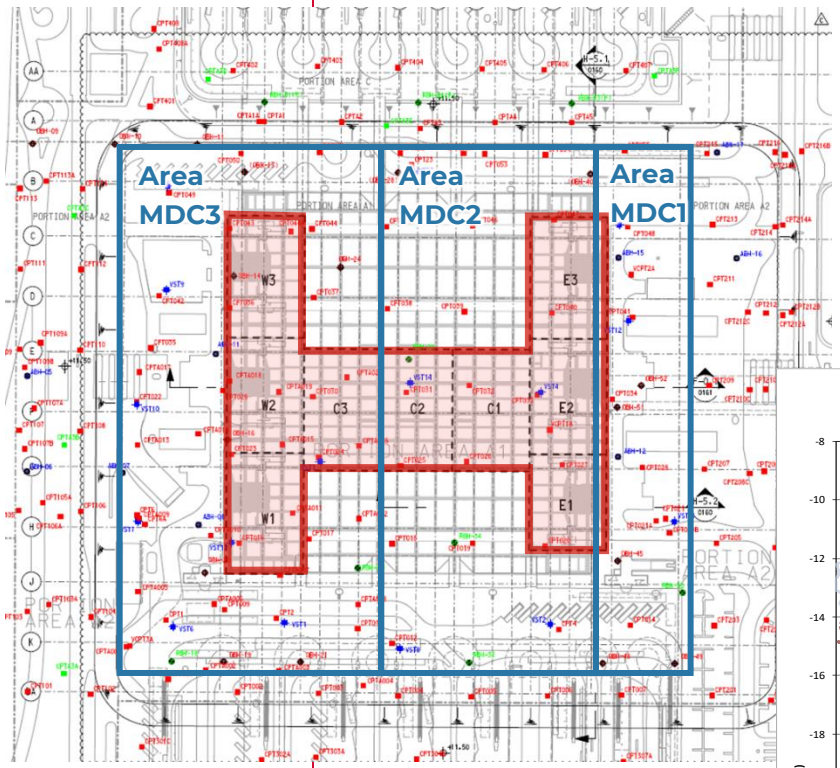
MD Strength Variability



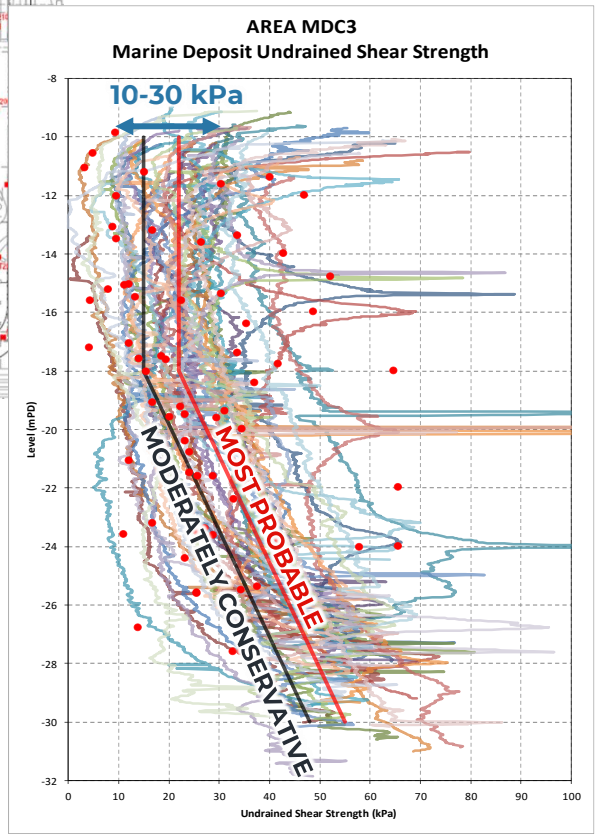


- Contractor envisaged to carry out only 20 no. of Vane Tests in the MD at tender stage to verify strength
- Due to lower than expected strength and high variability, 100+ no. of Vane Tests and 200+ no. of CPTs were carried out

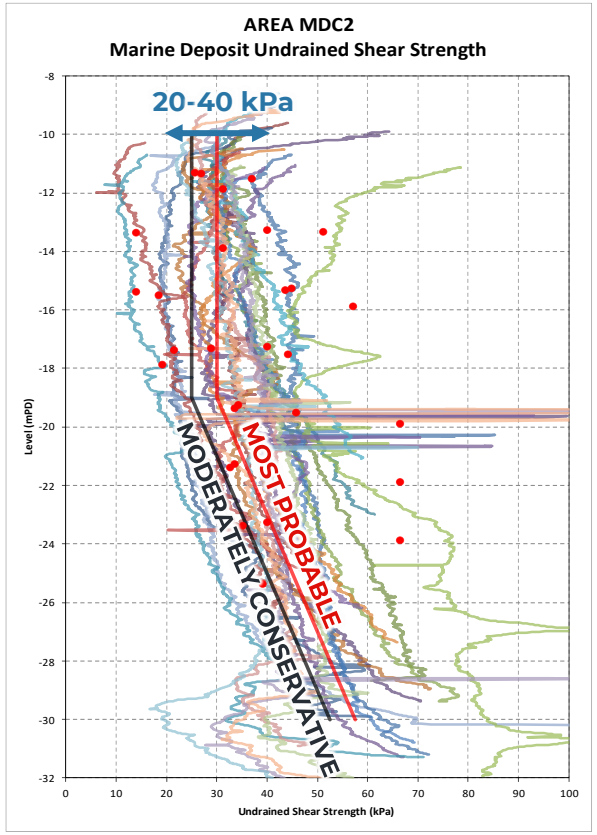
MD Strength Variability



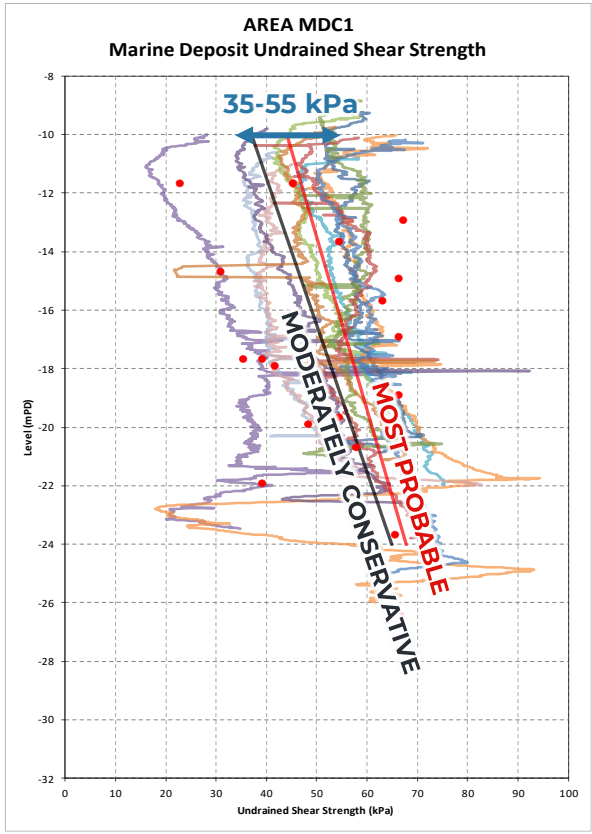
- Generally higher strength is encountered at eastern side of the site and lower strength at western side
- Significant relative variability still evident in all areas



Very Soft



Soft



Firm

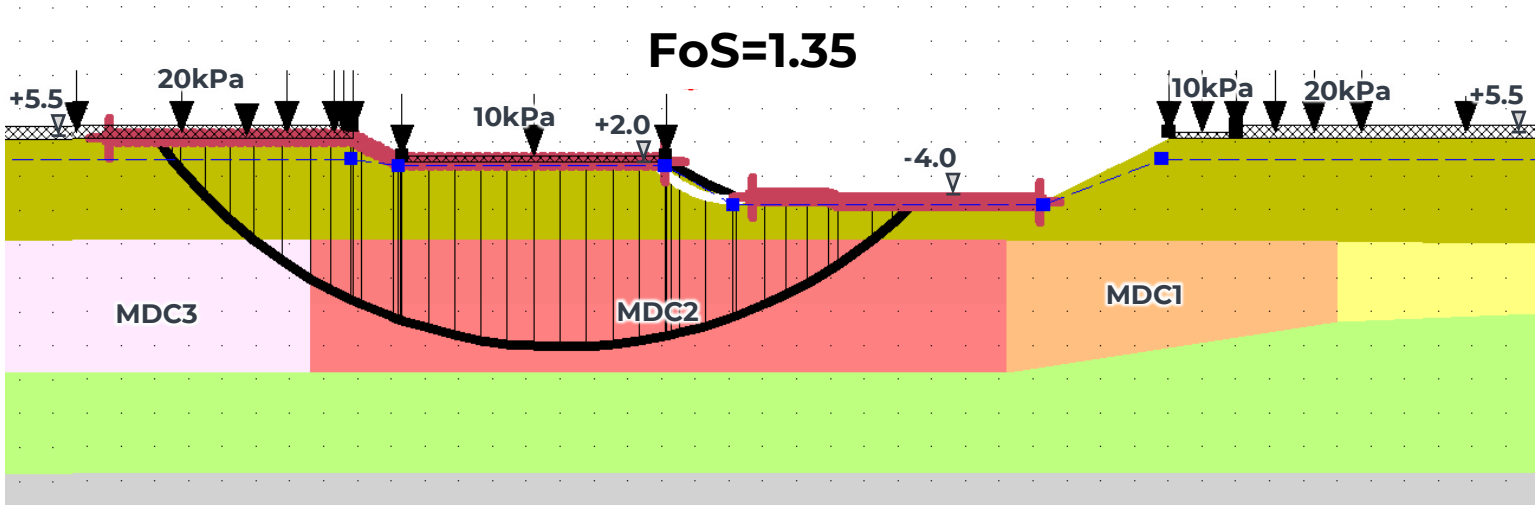
Temporary Excavation for Eastern Portion

2D → 3D

Design of Basement Eastern and Middle Portions

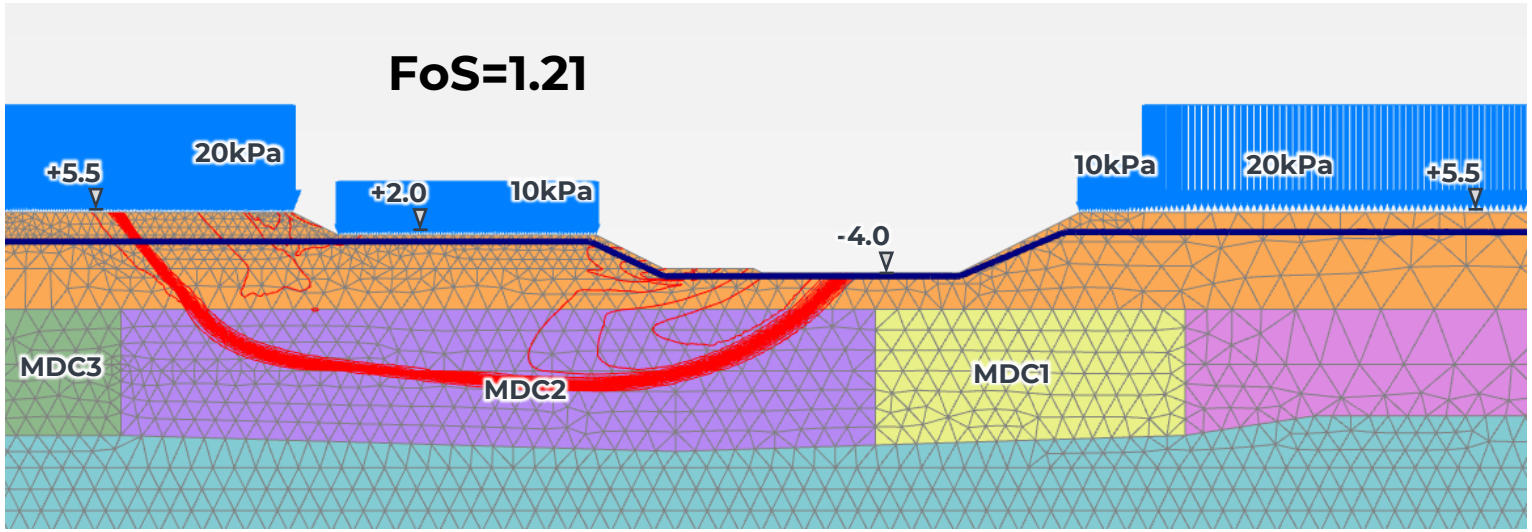
- Minimum required FoS>1.3 (excavation overlies soft and variable clay)

2D Slope/W



✗ Circular failure surfaces over-estimate FoS where long berms are provided

2D Plaxis

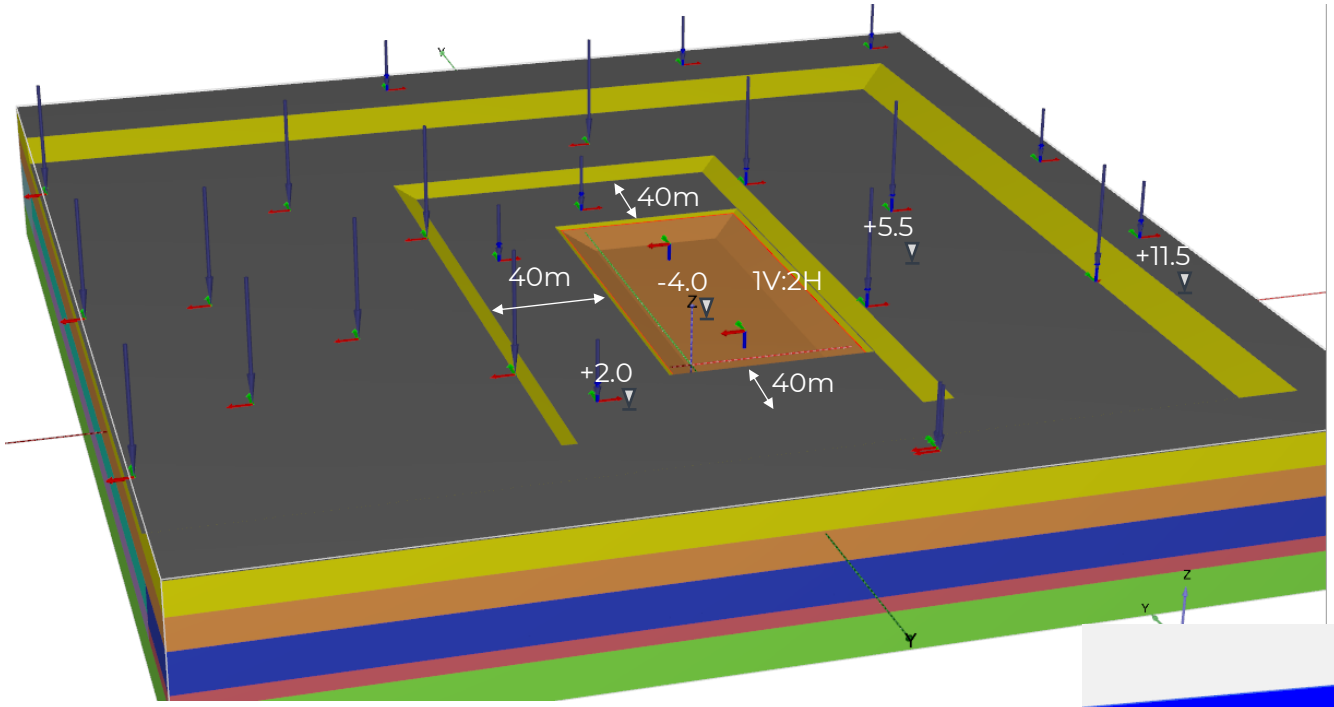


✓ Complex critical failure surface automatically identified

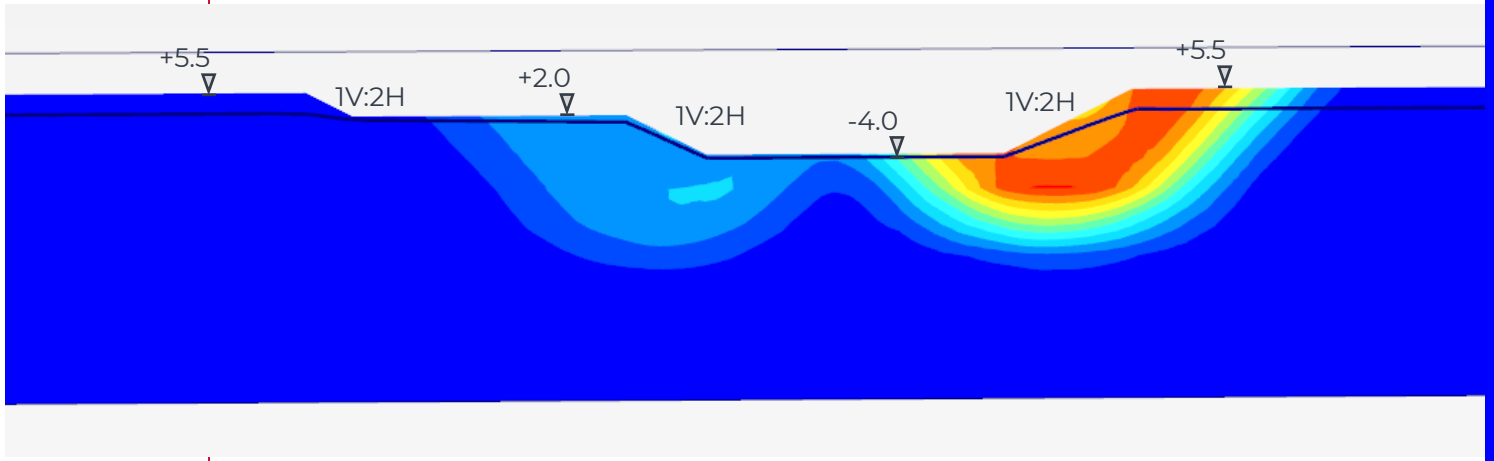
✗ Under-estimate FoS for excavations of limited size, where stabilising 3D edge effects can be significant

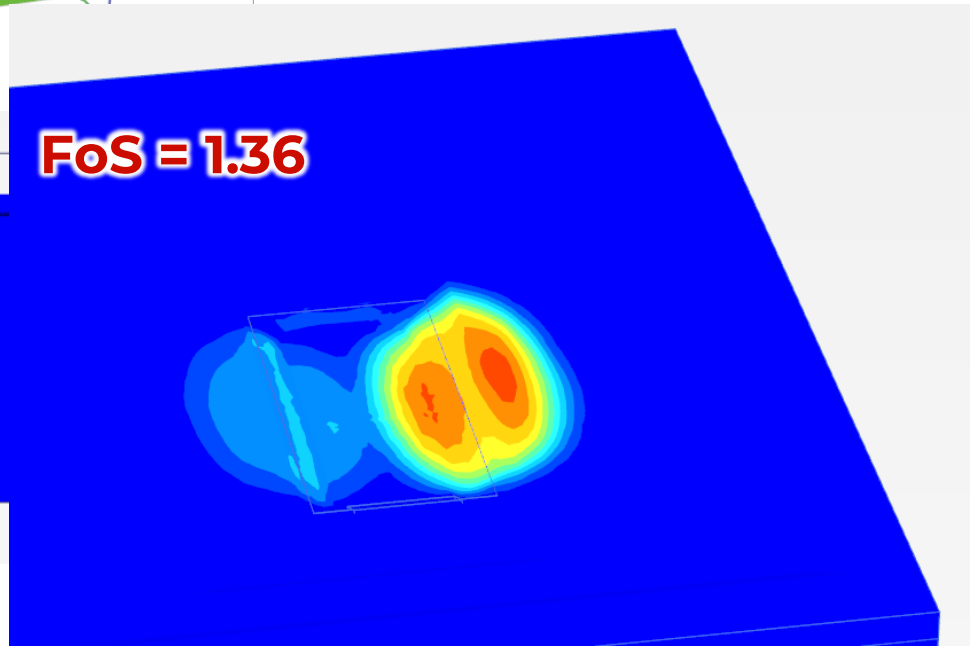
Design of Basement Eastern and Middle Portions

Plaxis 3D



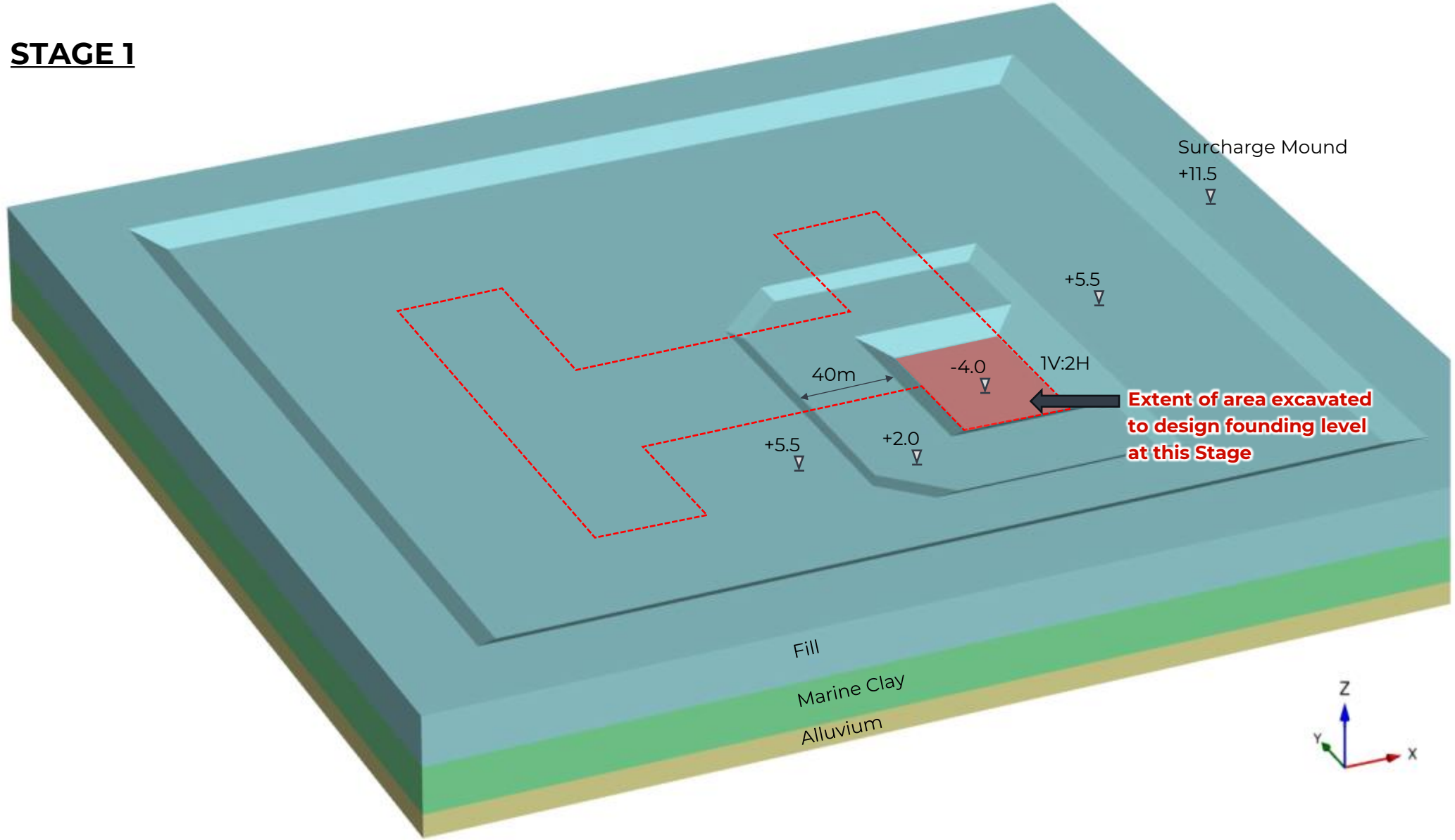
- Predicts complex 3D failure surfaces (spoon-shaped)
- Fully account for beneficial 3D effects





Design of Basement Eastern and Middle Portions

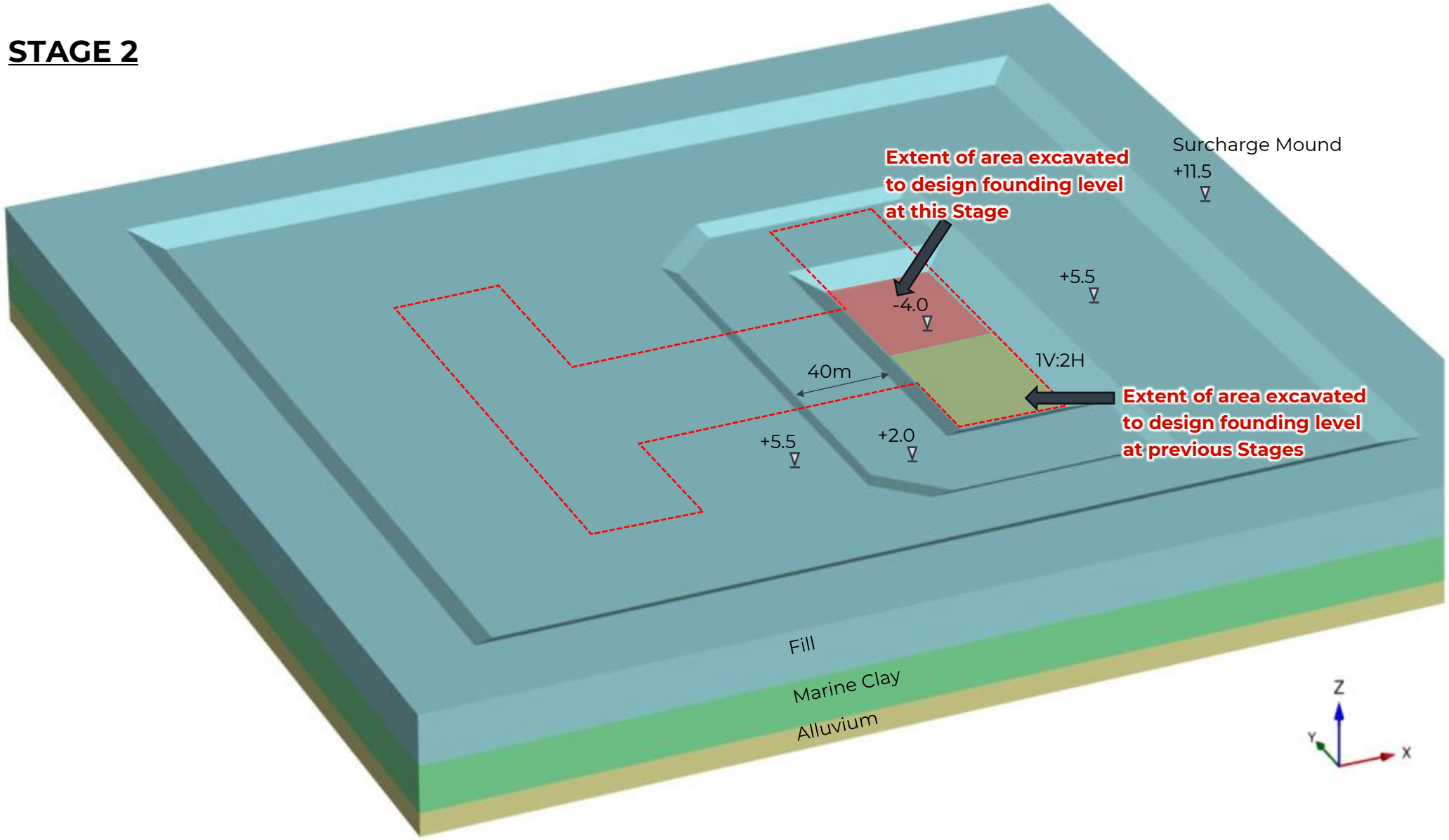
STAGE 1



All levels shown are in meters above Principal Datum

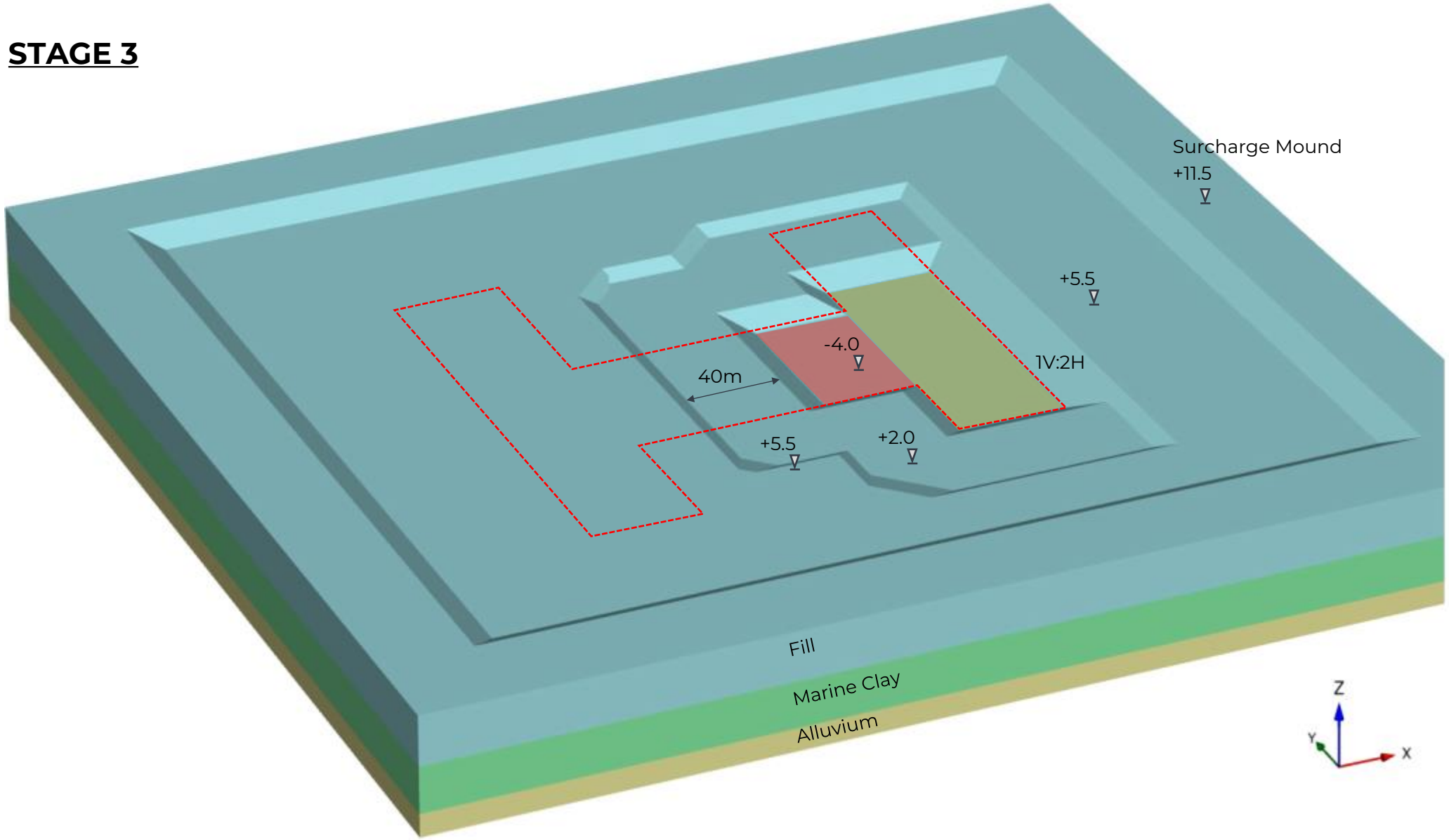
Design of Basement Eastern and Middle Portions

STAGE 2



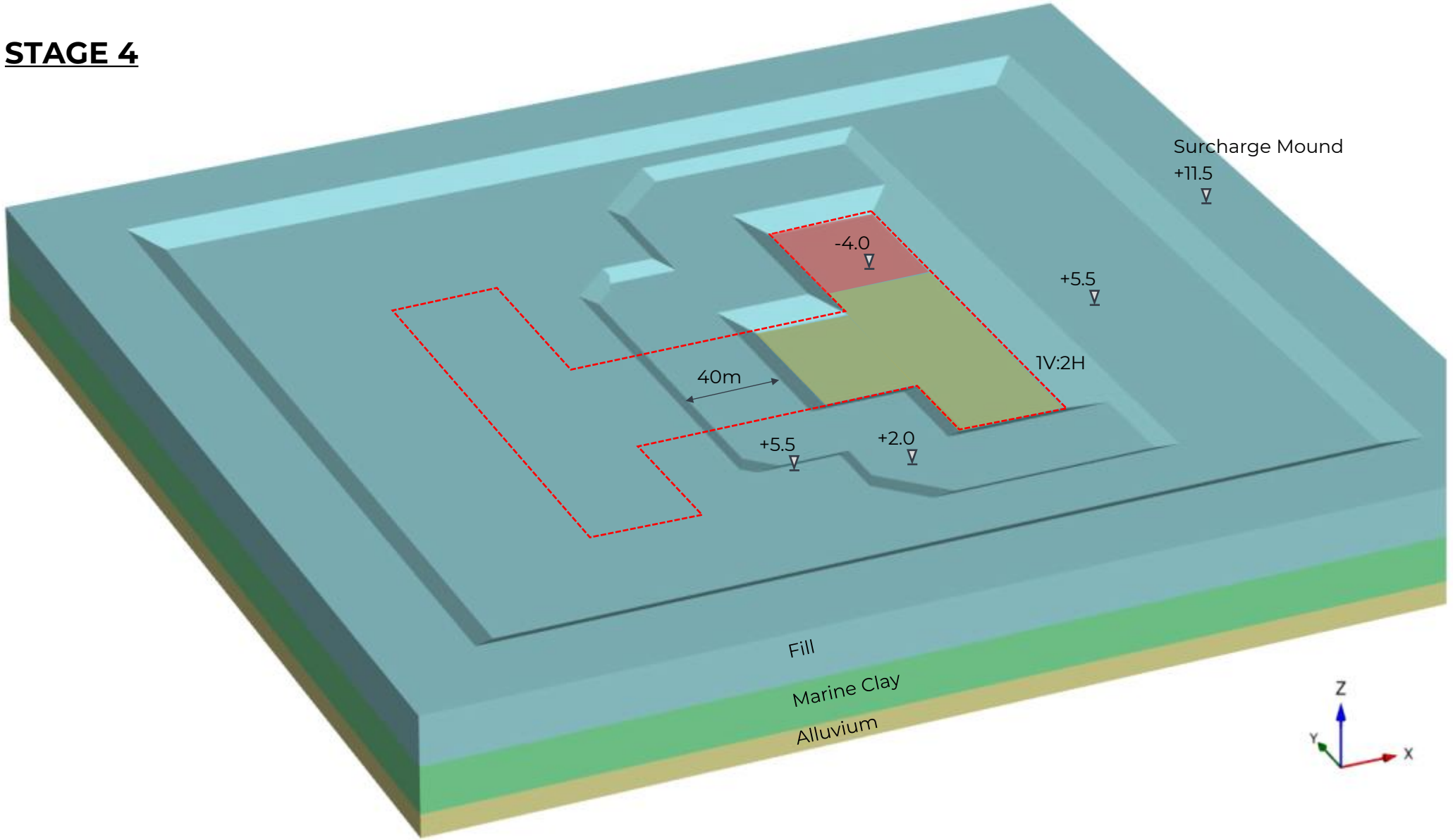
Design of Basement Eastern and Middle Portions

STAGE 3



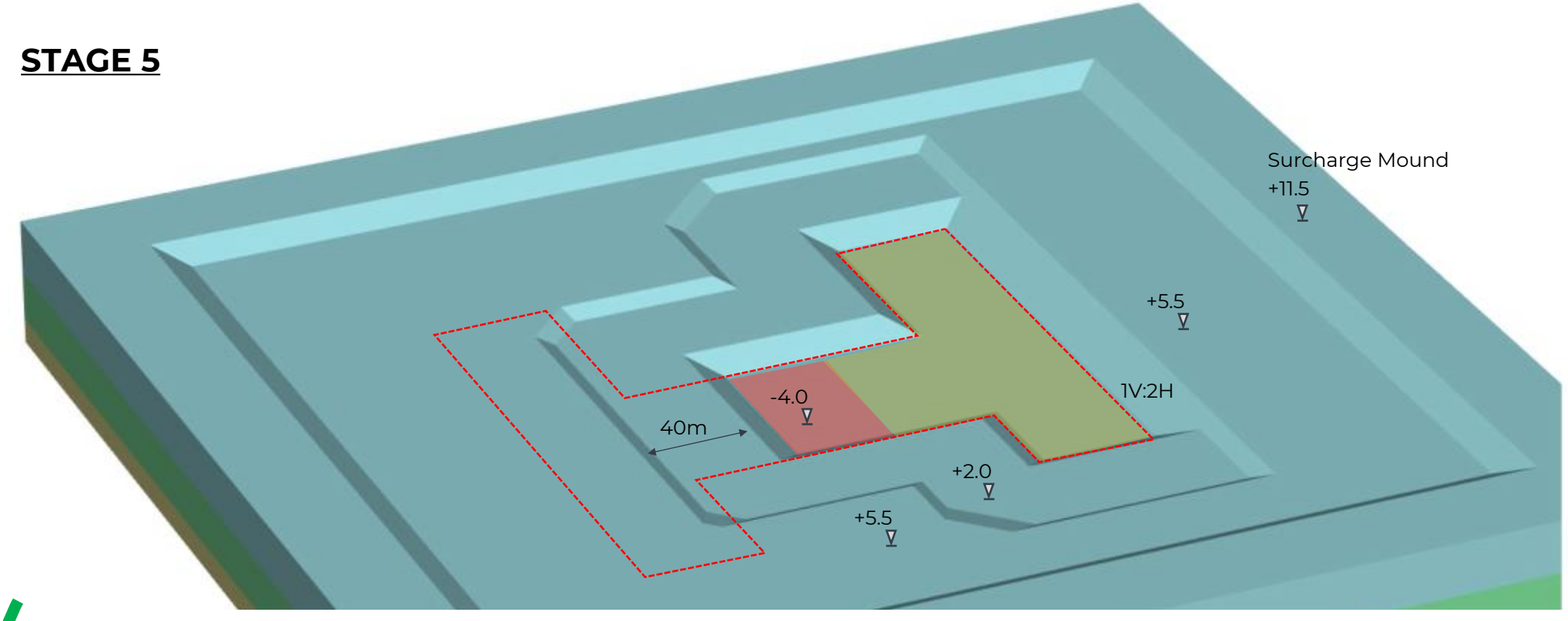
Design of Basement Eastern and Middle Portions

STAGE 4



Design of Basement Eastern and Middle Portions

STAGE 5



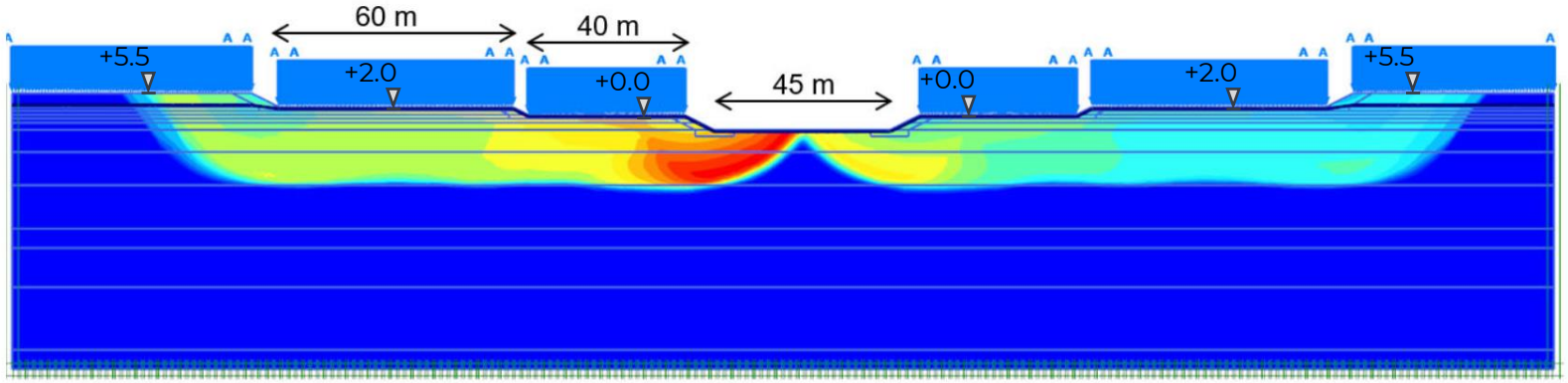
- ✓ Complete the excavation of the eastern half of the basement with relatively small bench requirements
- ✓ Limited 3D beneficial effects on 180m wide eastern slope, but ok due to higher MDC1 strength
- ✓ Stability of other slopes above weaker MDC2 rely more on 3D effects thanks to the particular basement geometry
- ✗ Stability issues encountered with this method if the excavation progresses further to the west, due to lower strength encountered in MDC3 area

Temporary Excavation for Western Portion

3D ⟶ Observational Method

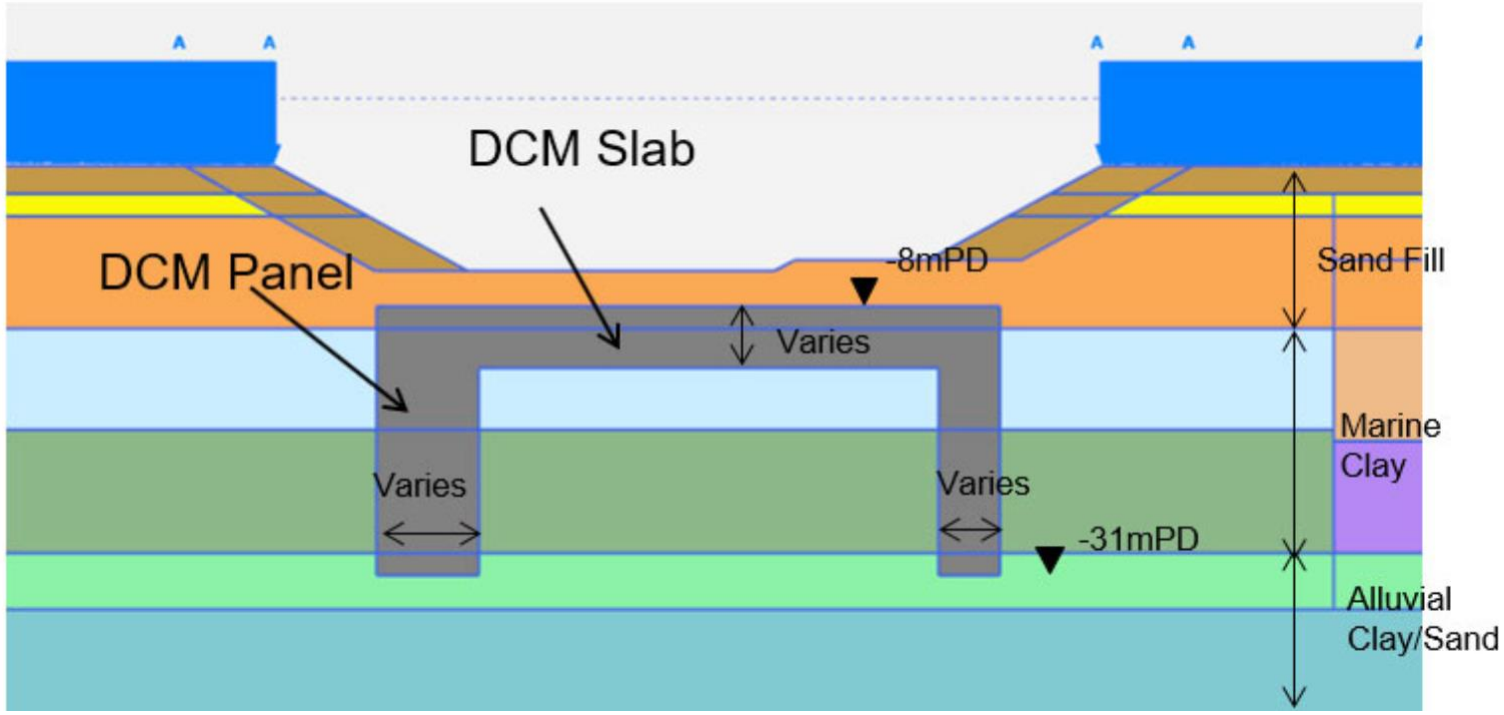
Design of Basement Western Portion

Option 1
Very Long Benches even with 3D analyses



- ✓ Can complete entire excavation without any basement construction
- ✓ No additional ground improvement
- ✗ Excessive excavation and backfilling volumes
- ✗ Programme delays, need to wait until surcharge mounds are removed

Option 2
Additional Ground Improvement (Deep Cement Mixing or Jet Grouting)

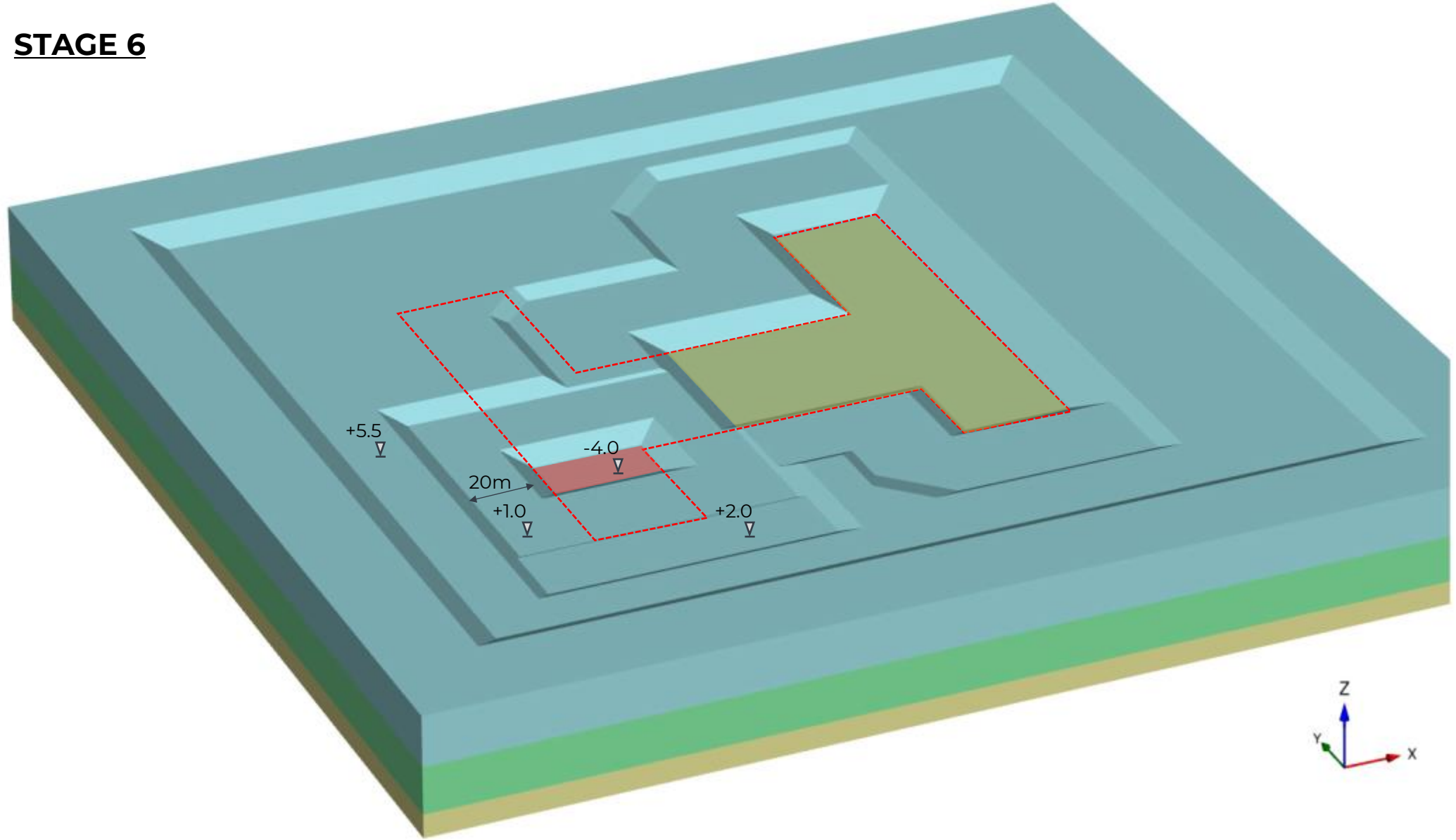


- ✓ Can complete entire excavation without any basement construction
- ✓ Minimise excavation and backfilling volumes
- ✗ High cost (approx. 8M US$)
- ✗ Low sustainability (approx. 14,000 tons cement injected)
- ✗ Programme delays

Design of Basement Western Portion

Option 3
Carefully Planned Sequence of Excavation and Base Slab Construction

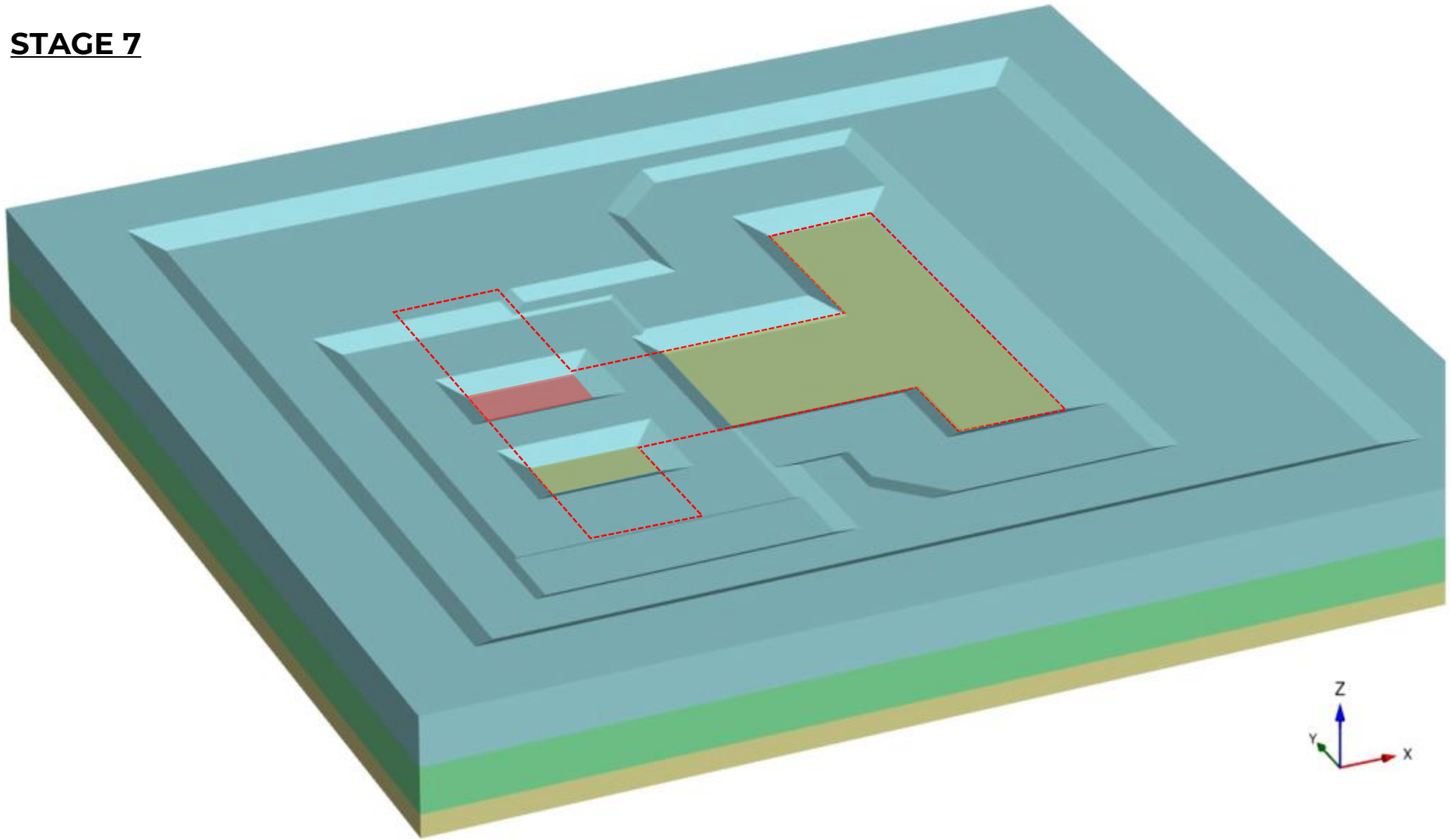
STAGE 6



Design of Basement Western Portion

Option 3
Carefully Planned Sequence of Excavation and Base Slab Construction

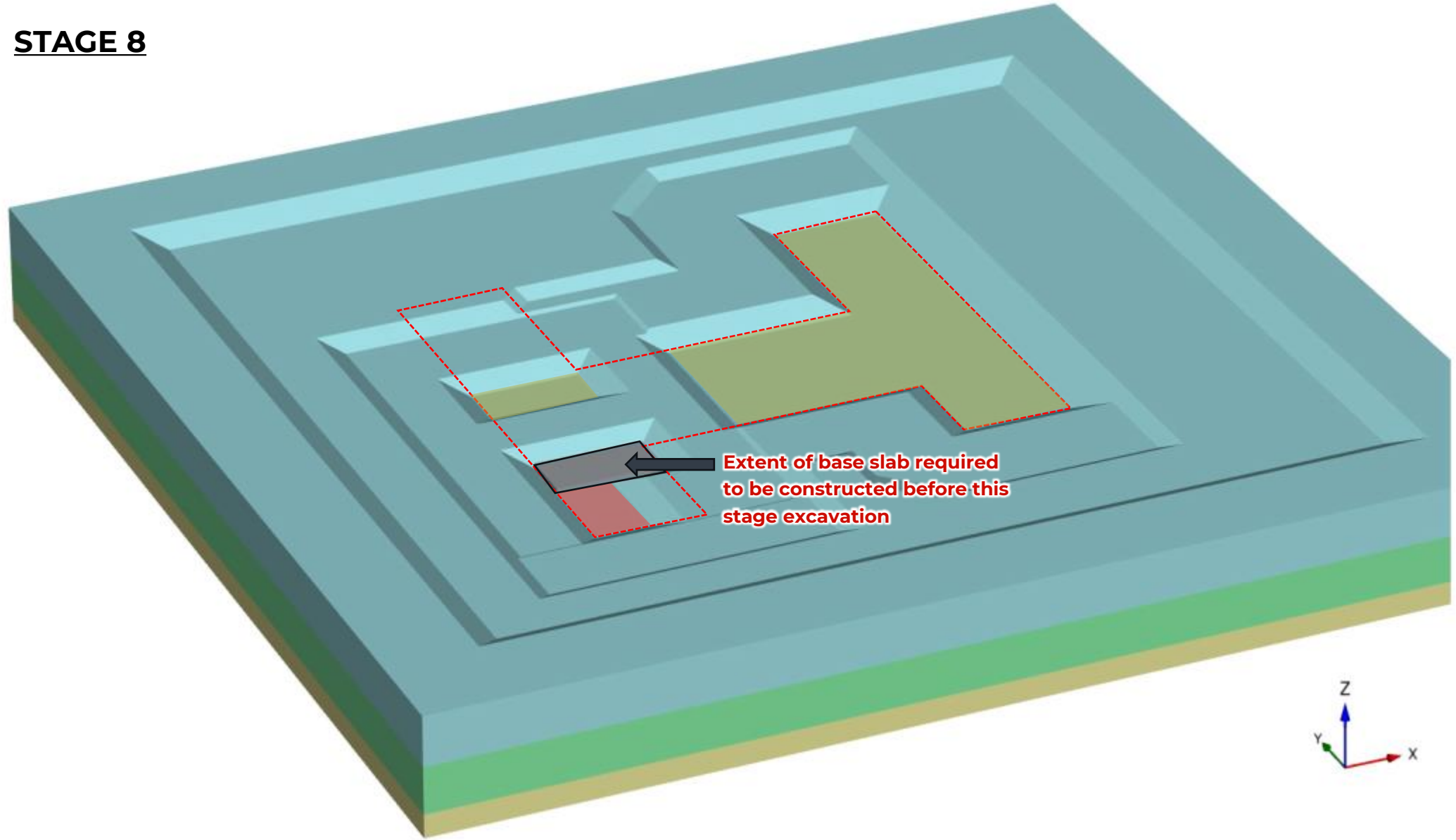
STAGE 7



Design of Basement Western Portion

Option 3
Carefully Planned Sequence of Excavation and Base Slab Construction

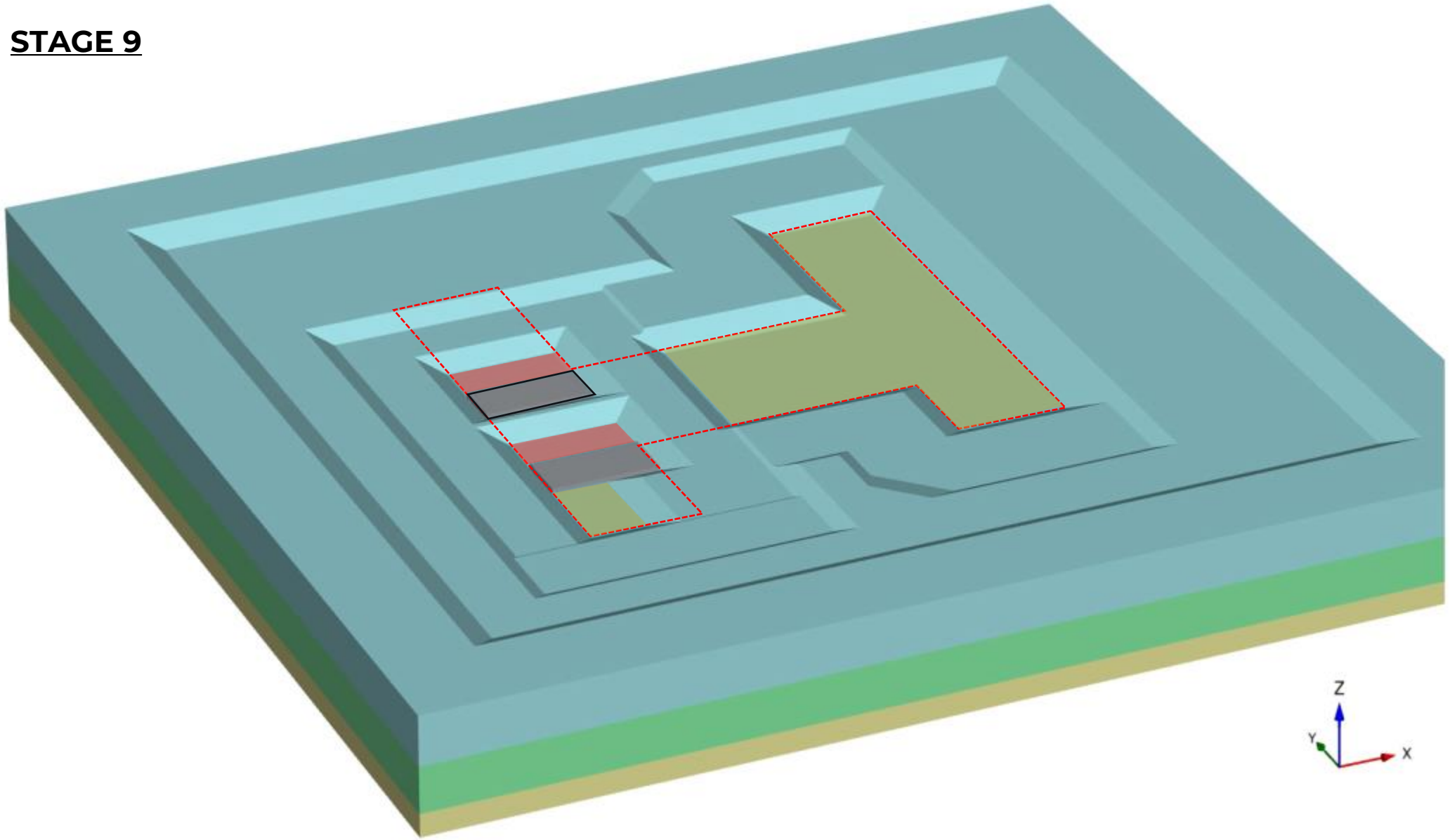
STAGE 8



Design of Basement Western Portion

Option 3
Carefully Planned Sequence of Excavation and Base Slab Construction

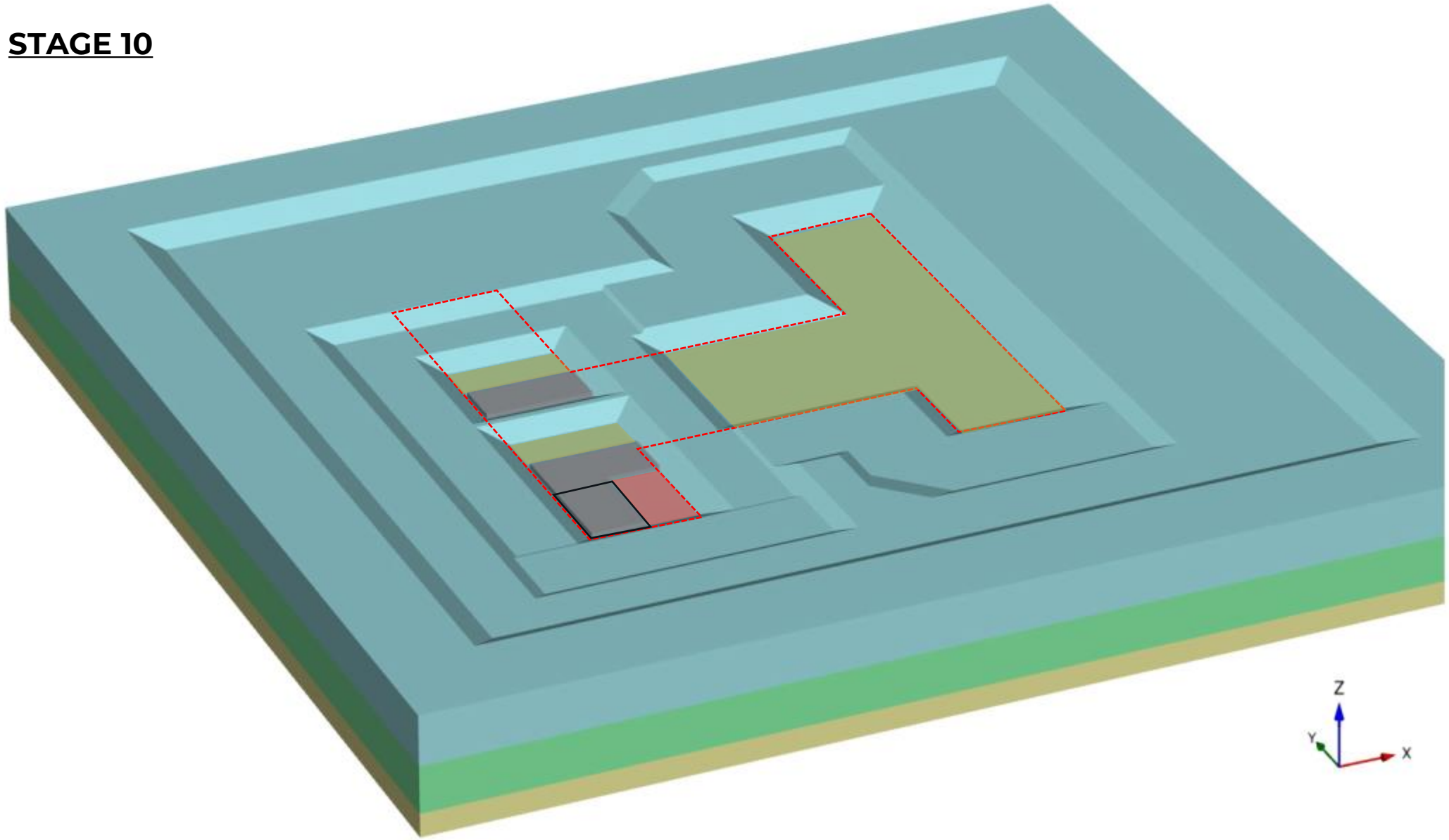
STAGE 9



Design of Basement Western Portion

Option 3
Carefully Planned Sequence of Excavation and Base Slab Construction

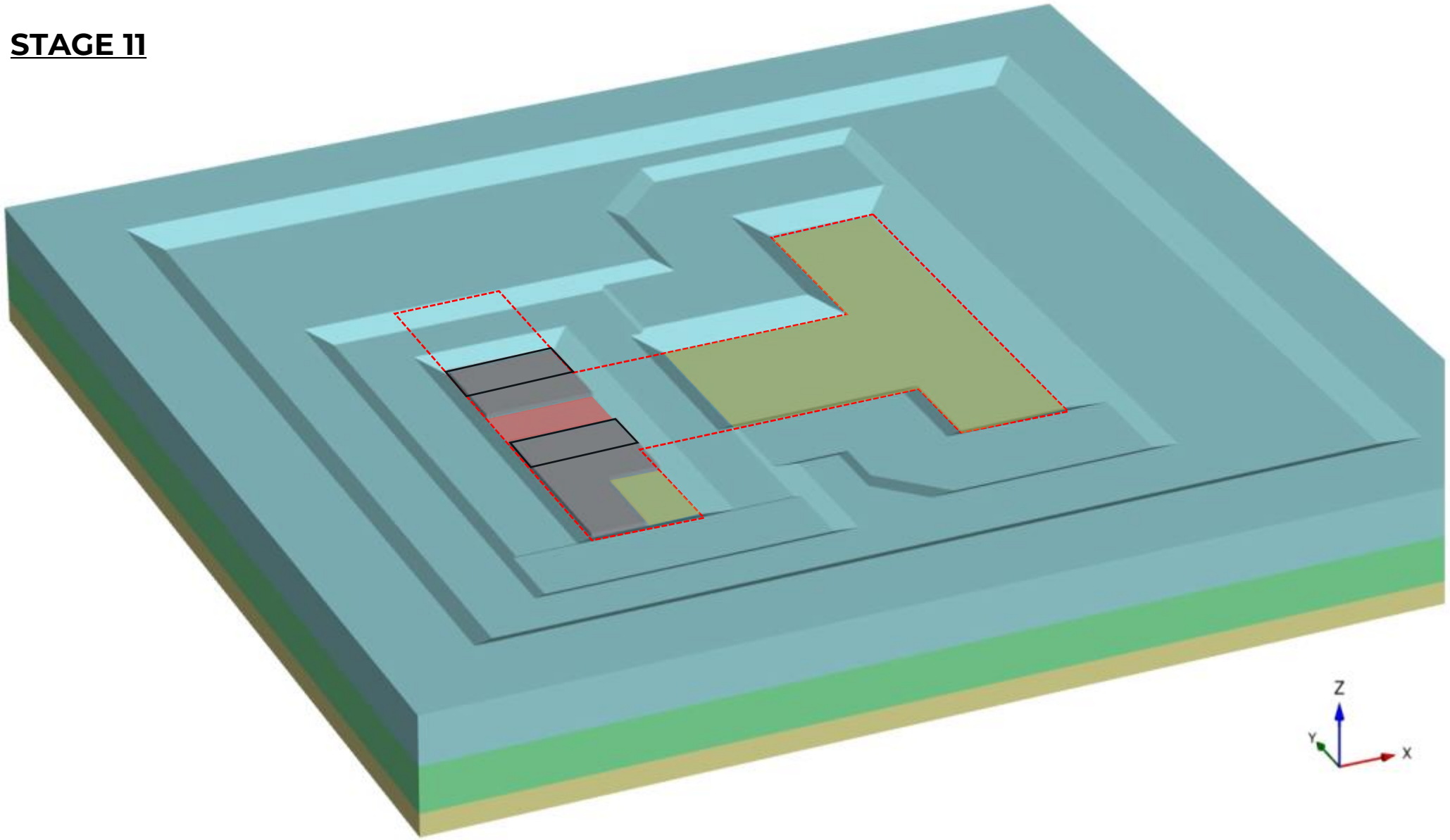
STAGE 10



Design of Basement Western Portion

Option 3
Carefully Planned Sequence of Excavation and Base Slab Construction

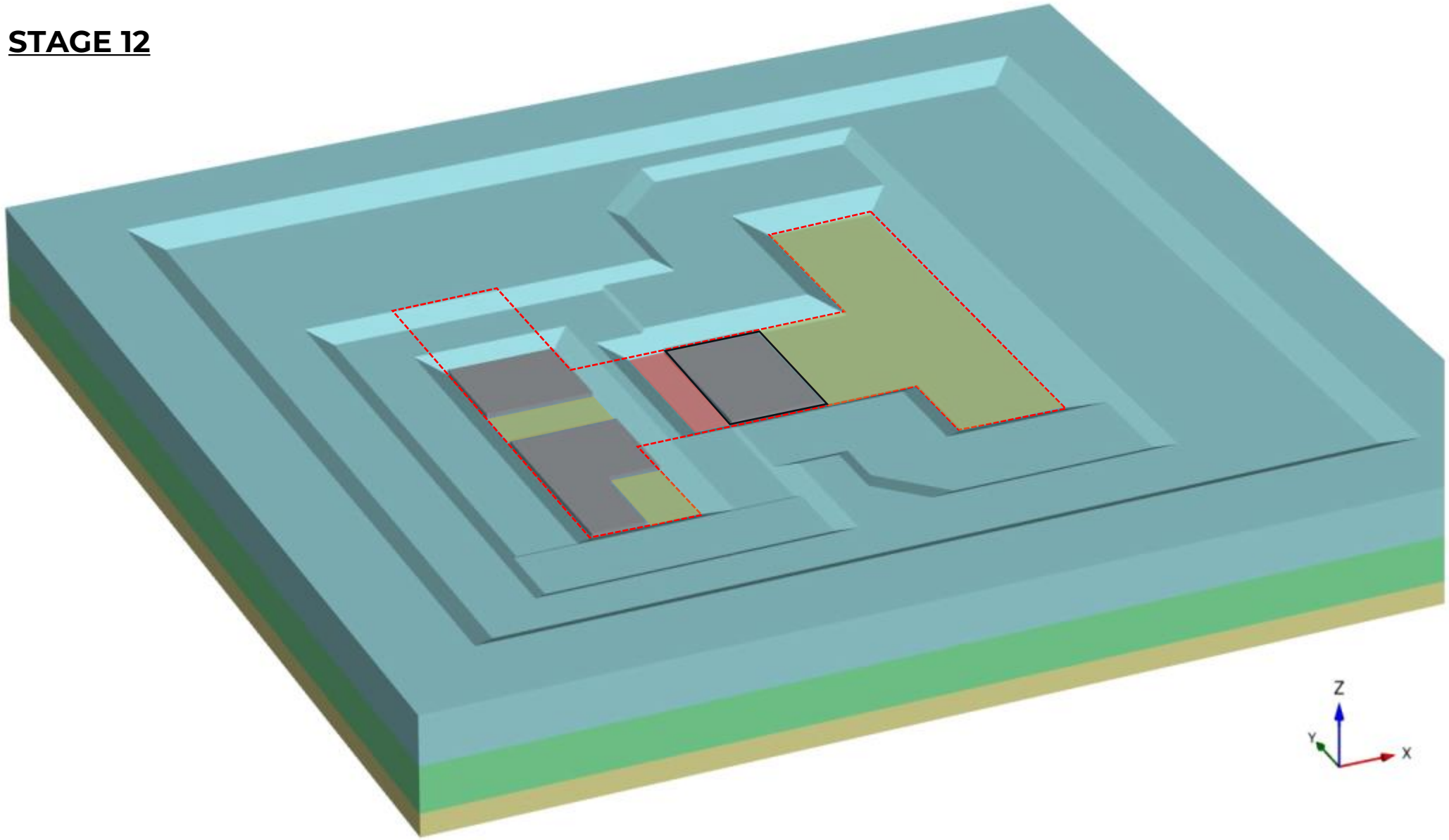
STAGE 11



Design of Basement Western Portion

Option 3
Carefully Planned Sequence of Excavation and Base Slab Construction

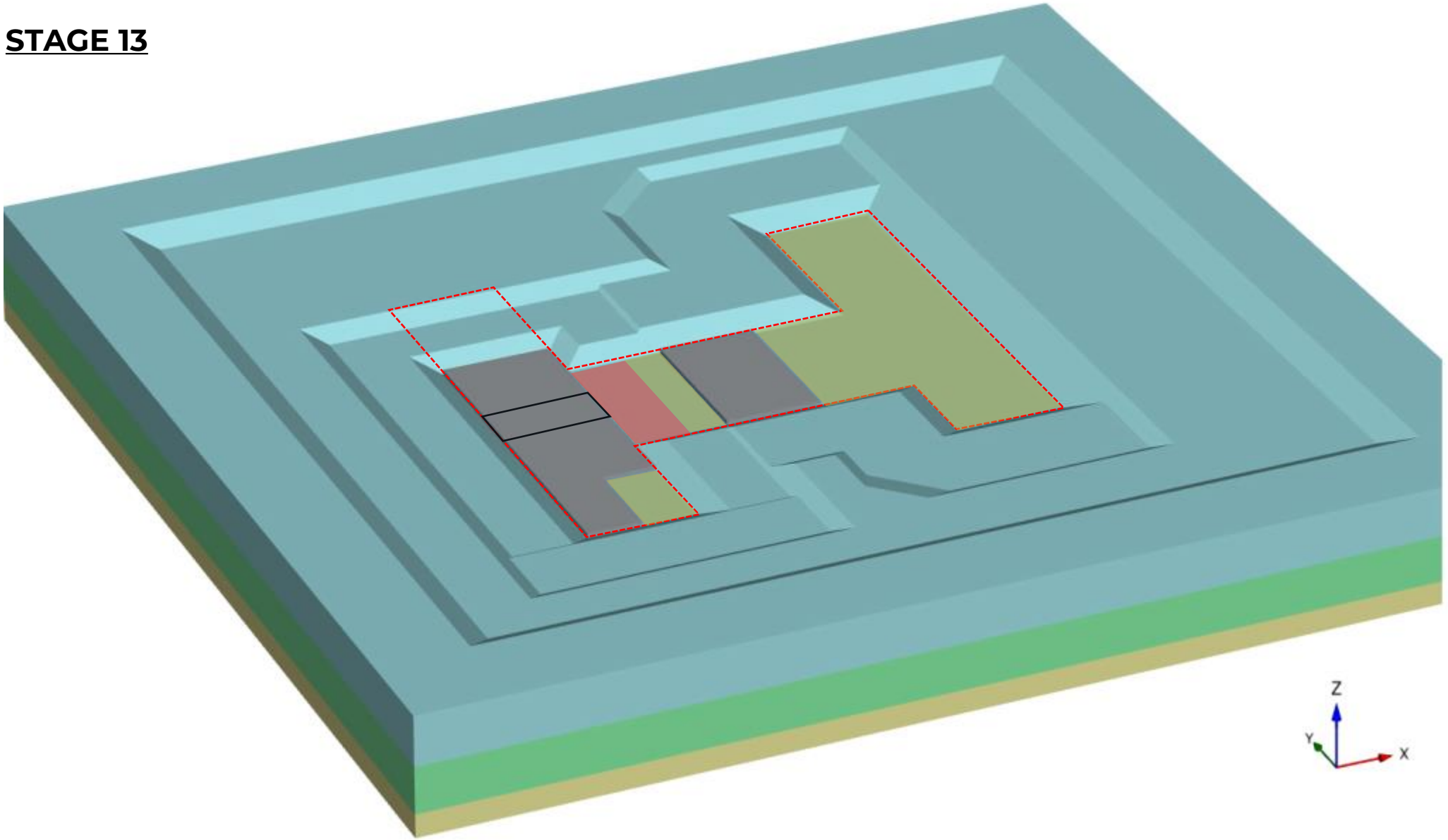
STAGE 12



Design of Basement Western Portion

Option 3
Carefully Planned Sequence of Excavation and Base Slab Construction

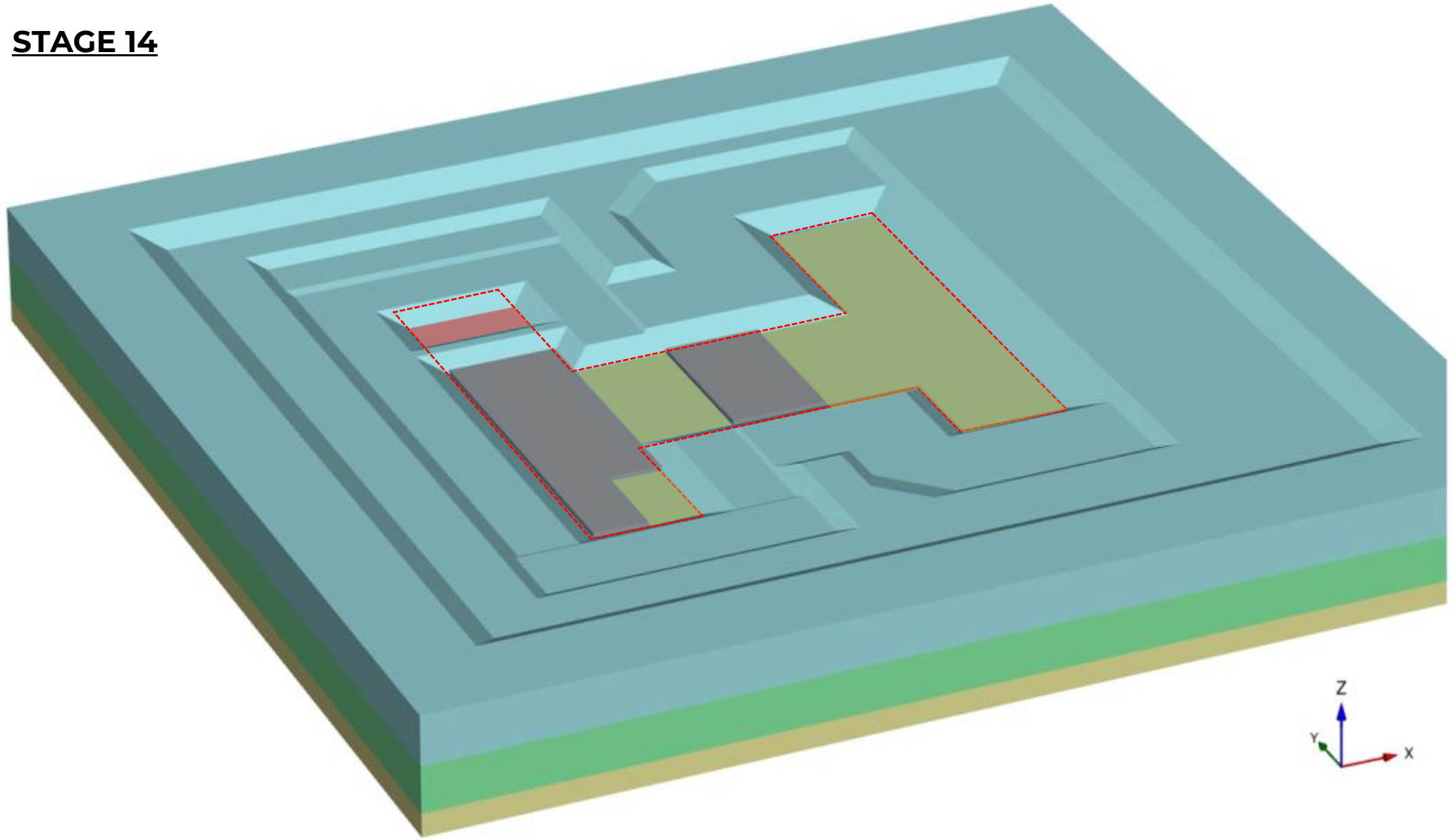
STAGE 13



Design of Basement Western Portion

Option 3
Carefully Planned Sequence of Excavation and Base Slab Construction

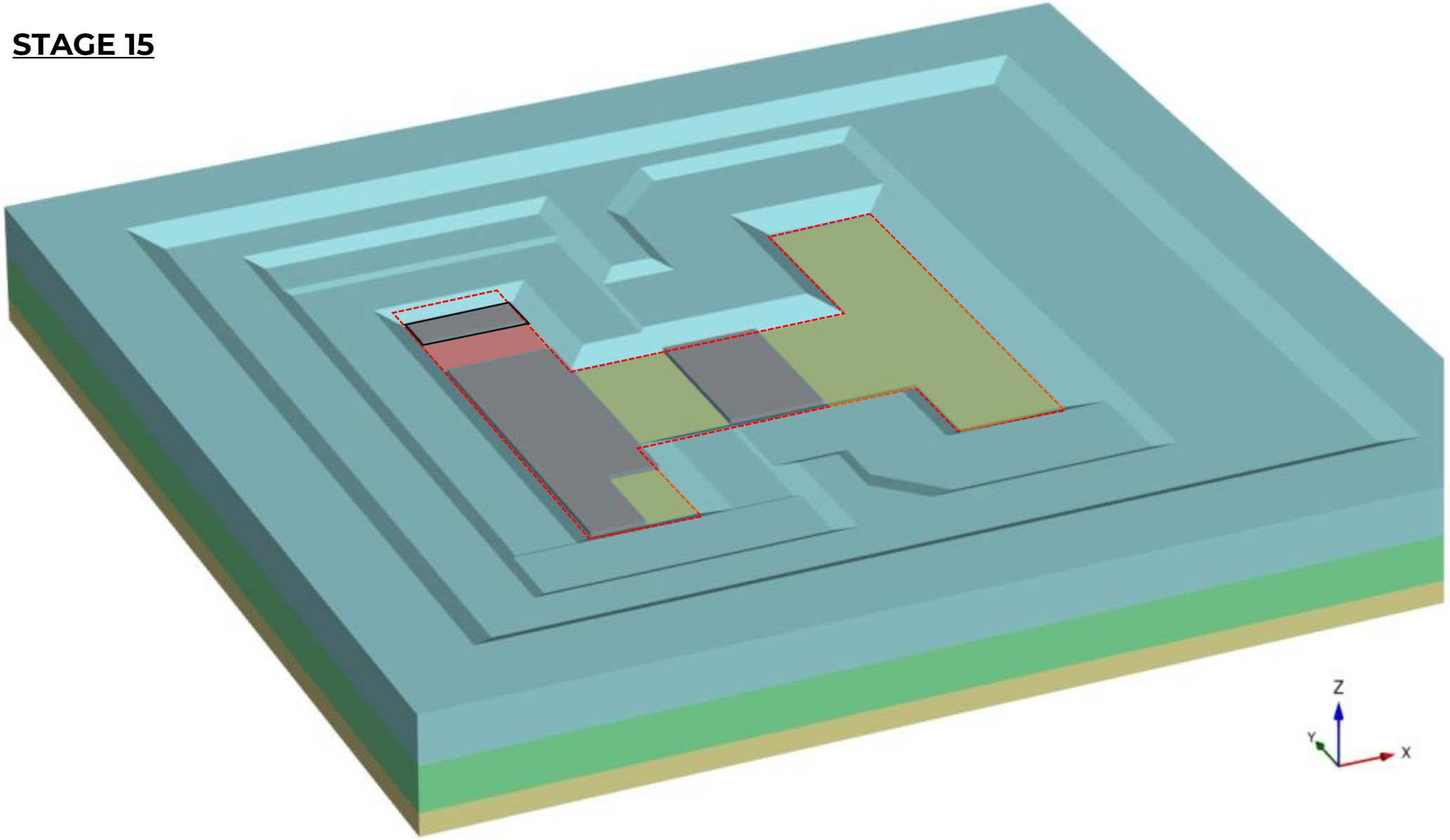
STAGE 14



Design of Basement Western Portion

Option 3
Carefully Planned Sequence of Excavation and Base Slab Construction

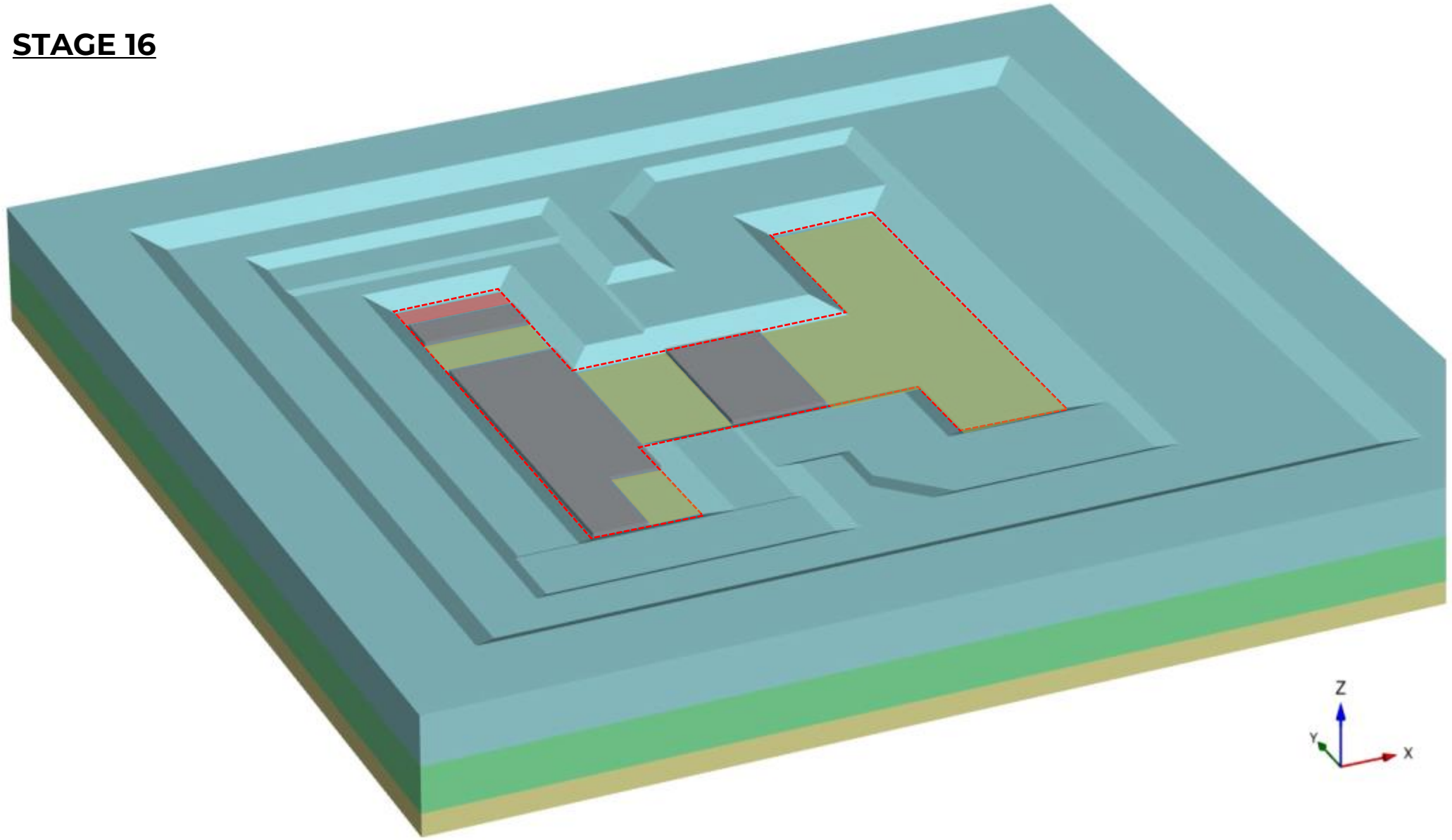
STAGE 15



Design of Basement Western Portion

Option 3
Carefully Planned Sequence of Excavation and Base Slab Construction

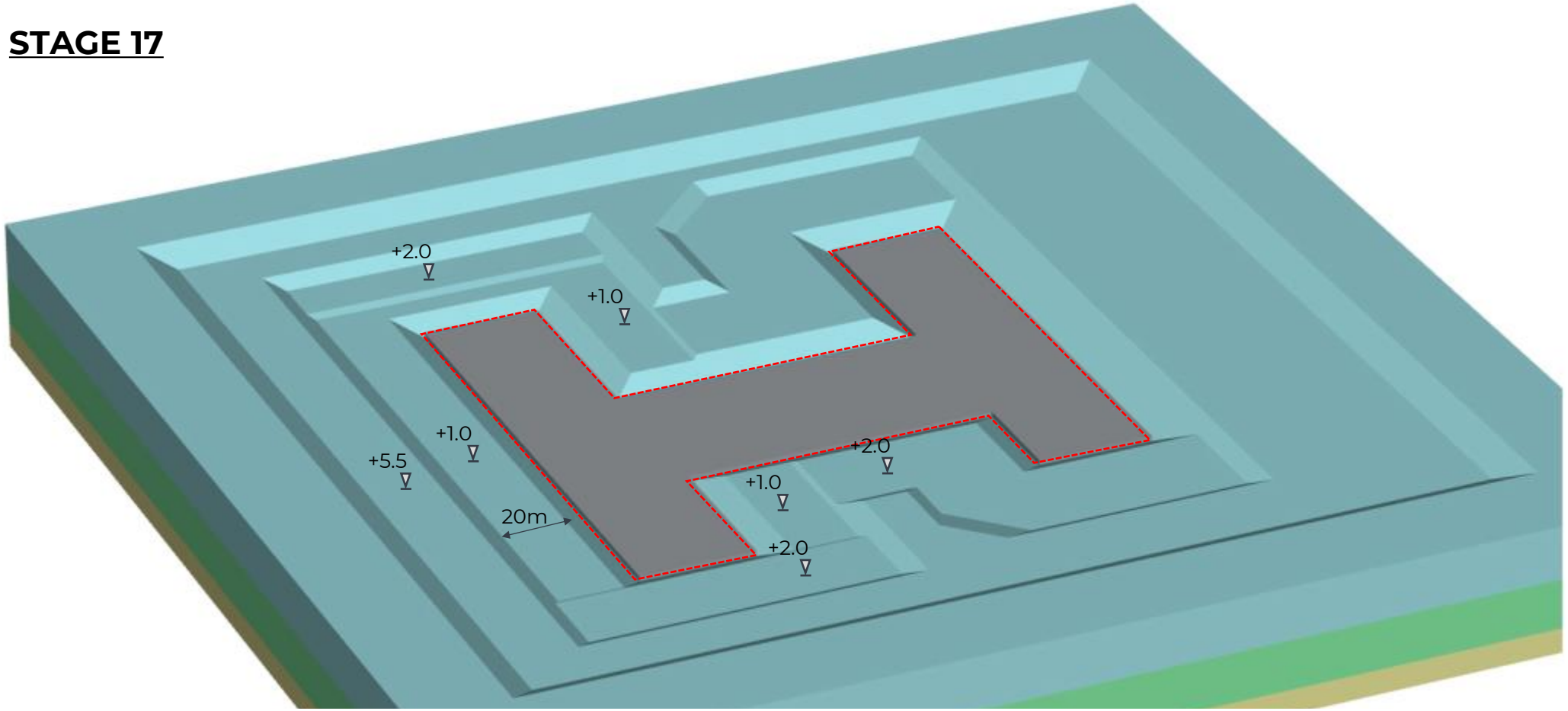
STAGE 16



Design of Basement Western Portion

Option 3
Carefully Planned Sequence of Excavation and Base Slab Construction

STAGE 17



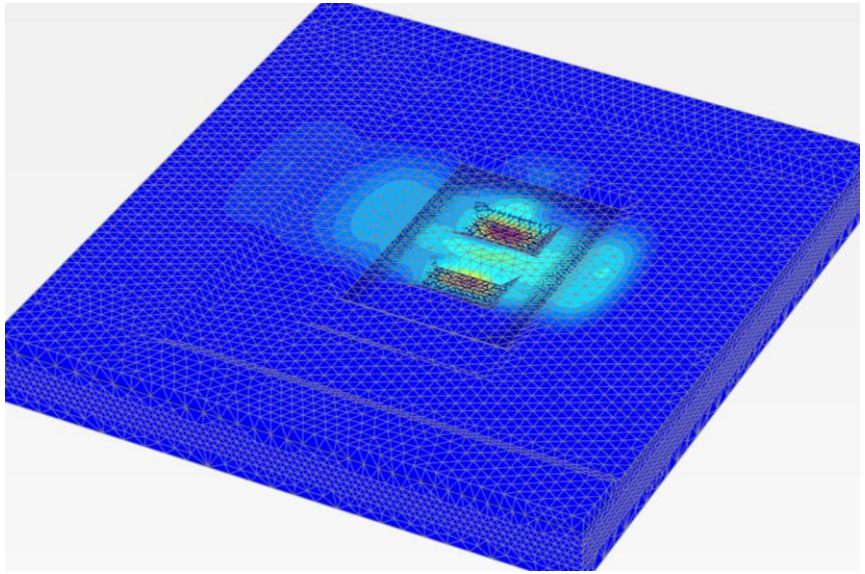
✓ Complete the excavation of the entire basement without any form of additional ground improvement and with relatively small bench requirements

✗ Significant programme impact due to requirements to continuously stop excavation and for construction of key portions of foundations

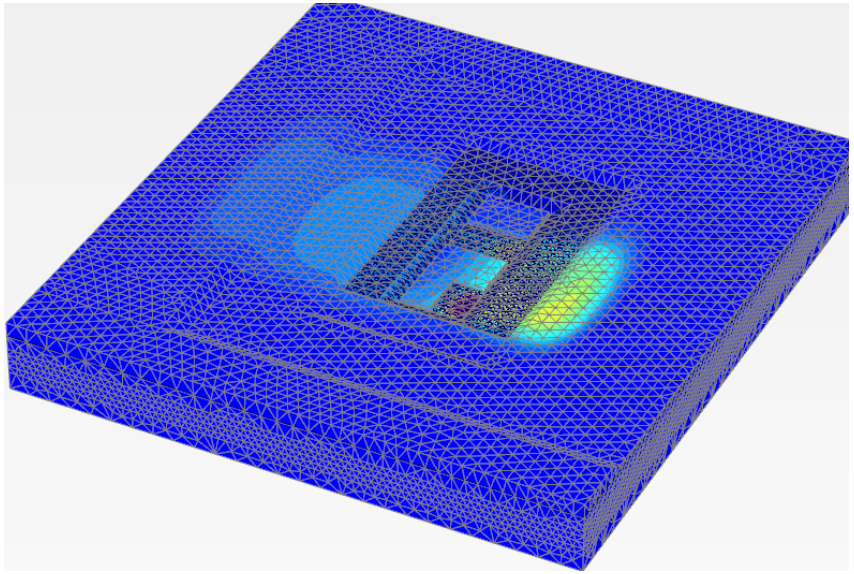
Stability Results and Failure Mode for Selected Stages

Option 3
Carefully Planned Sequence of Excavation and Base Slab Construction

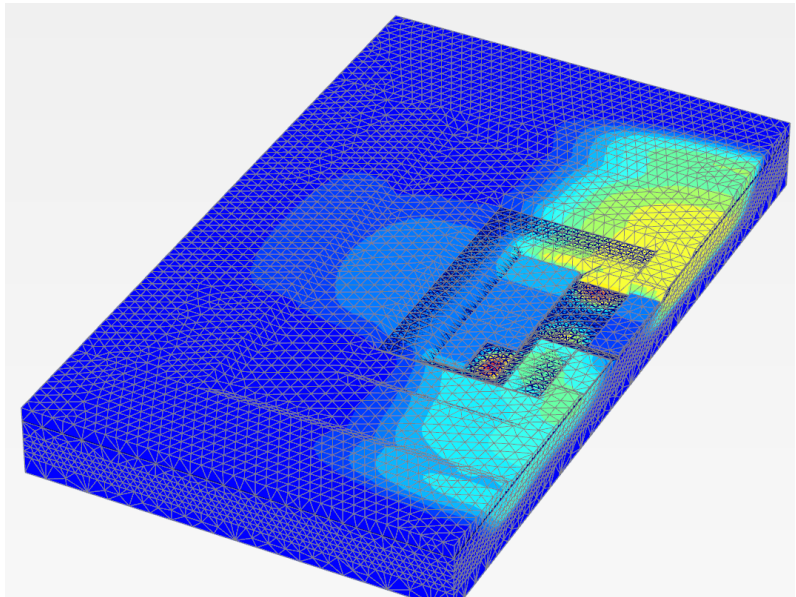
STAGE 7 – FoS = 1.38



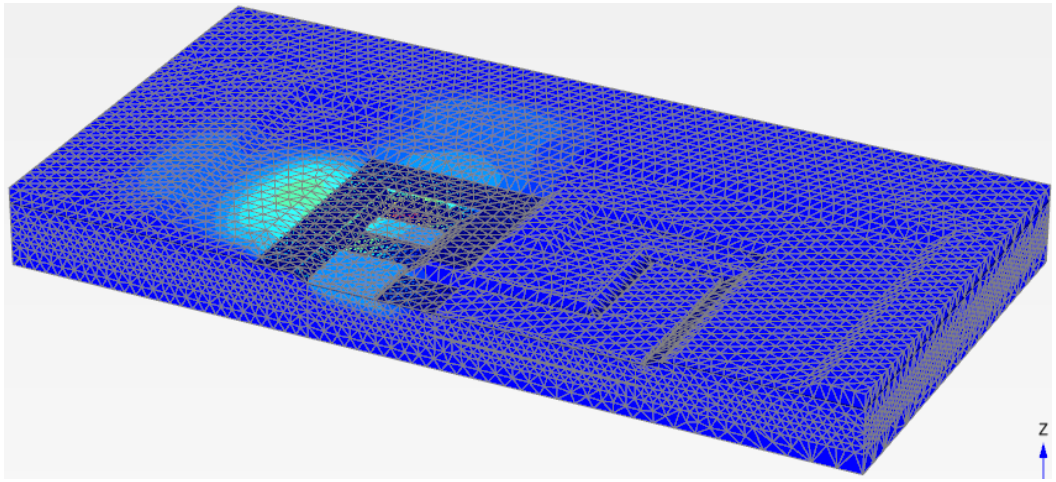
STAGE 11 – FoS = 1.43



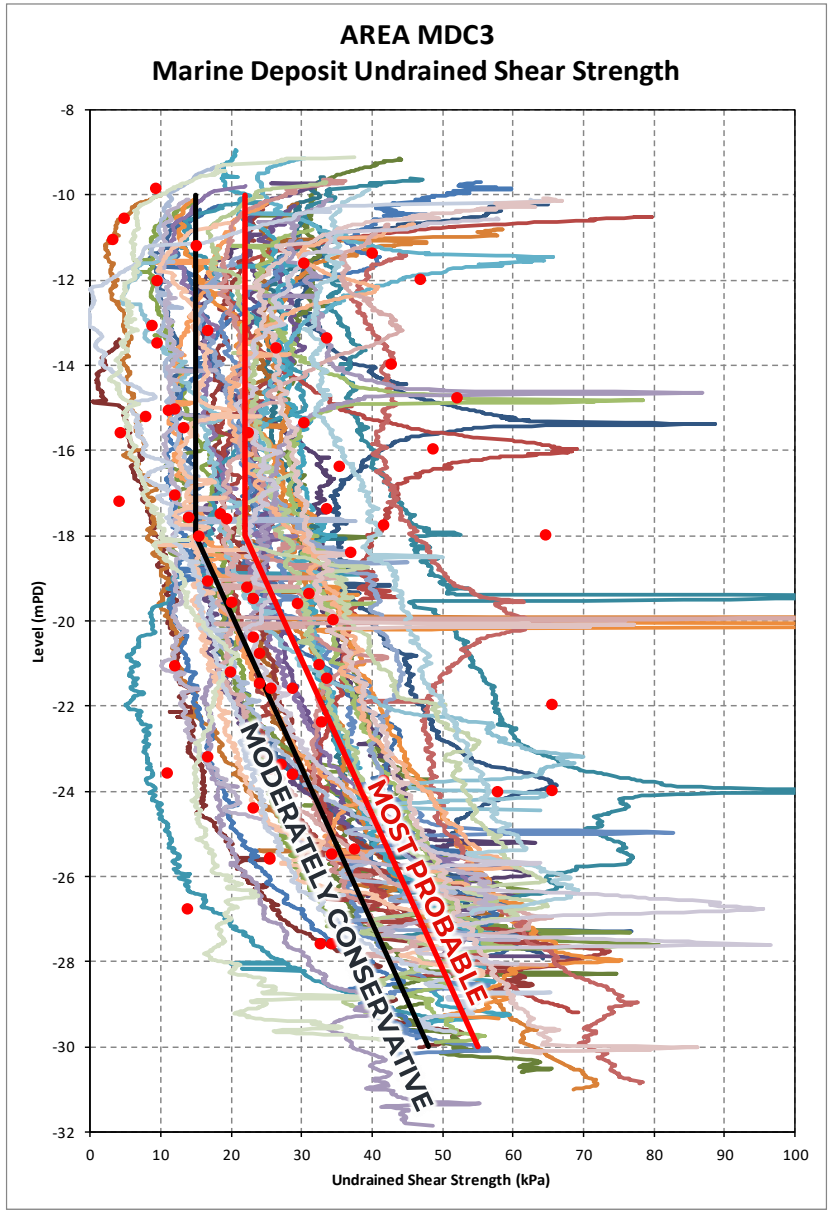
STAGE 13 – FoS = 1.41



STAGE 13 – FoS = 1.37



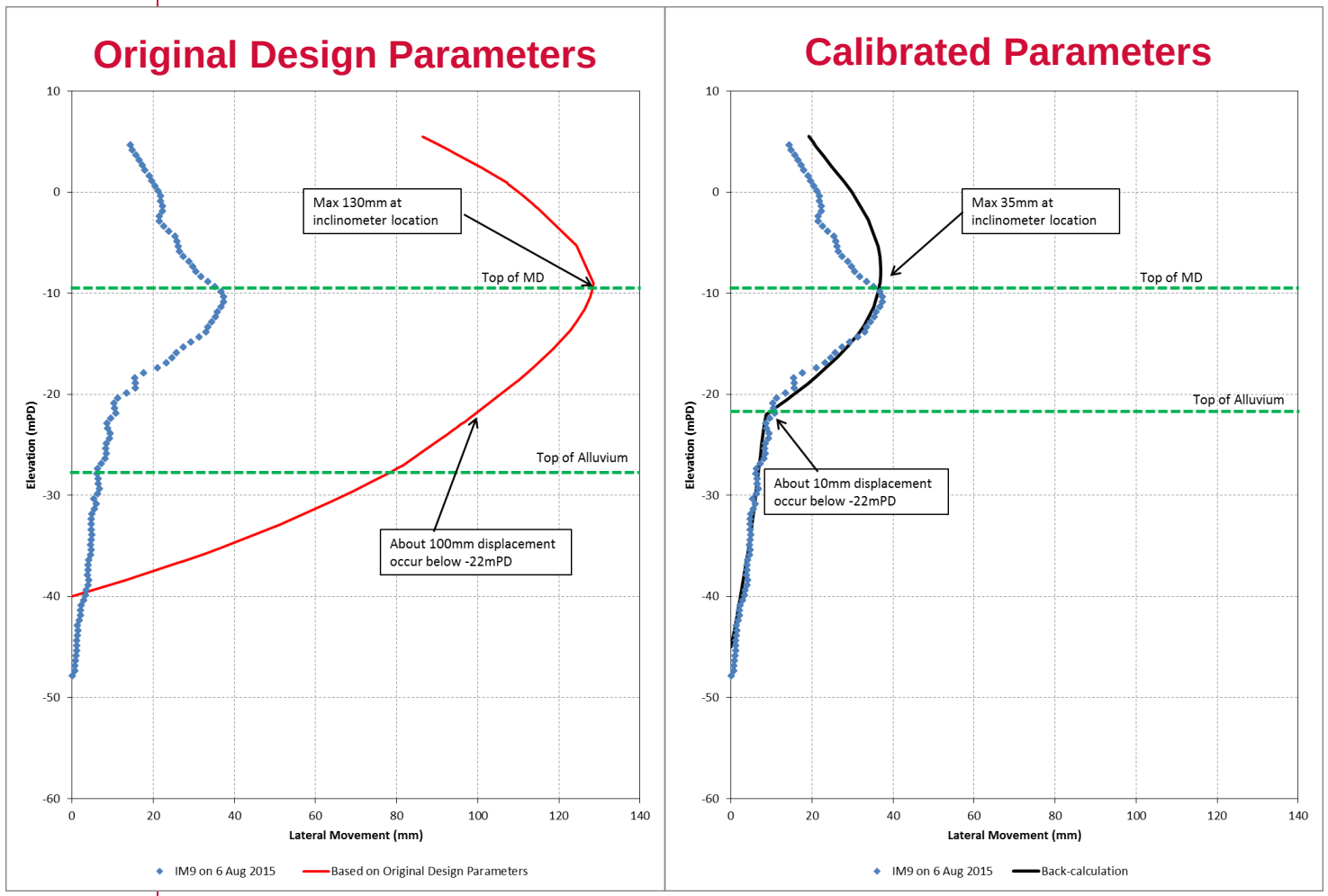
Development of Observational Method
Key Objectives

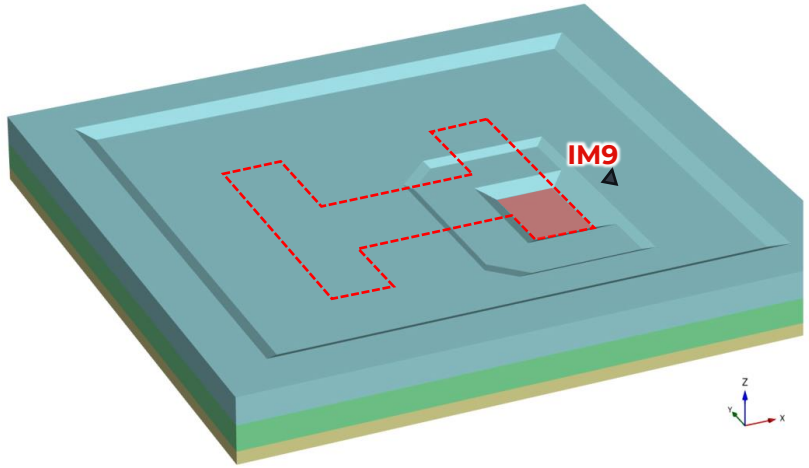


- The objective of the Observational Method is to minimise the requirements for basement foundations construction, allowing excavation works to progress without interruption, provided that the ground performance is satisfactory.

Parameter	Traditional Design	Observational Method
Soil Strength	Moderately Conservative	Most Probable
Monitoring	Minimum Requirement	Comprehensive, with emphasis on continuous review
Soil Stiffness	Assumed design correlations	Back-analysis

Development of Observational Method
Back-analysis of Stages 1 & 2 Excavation





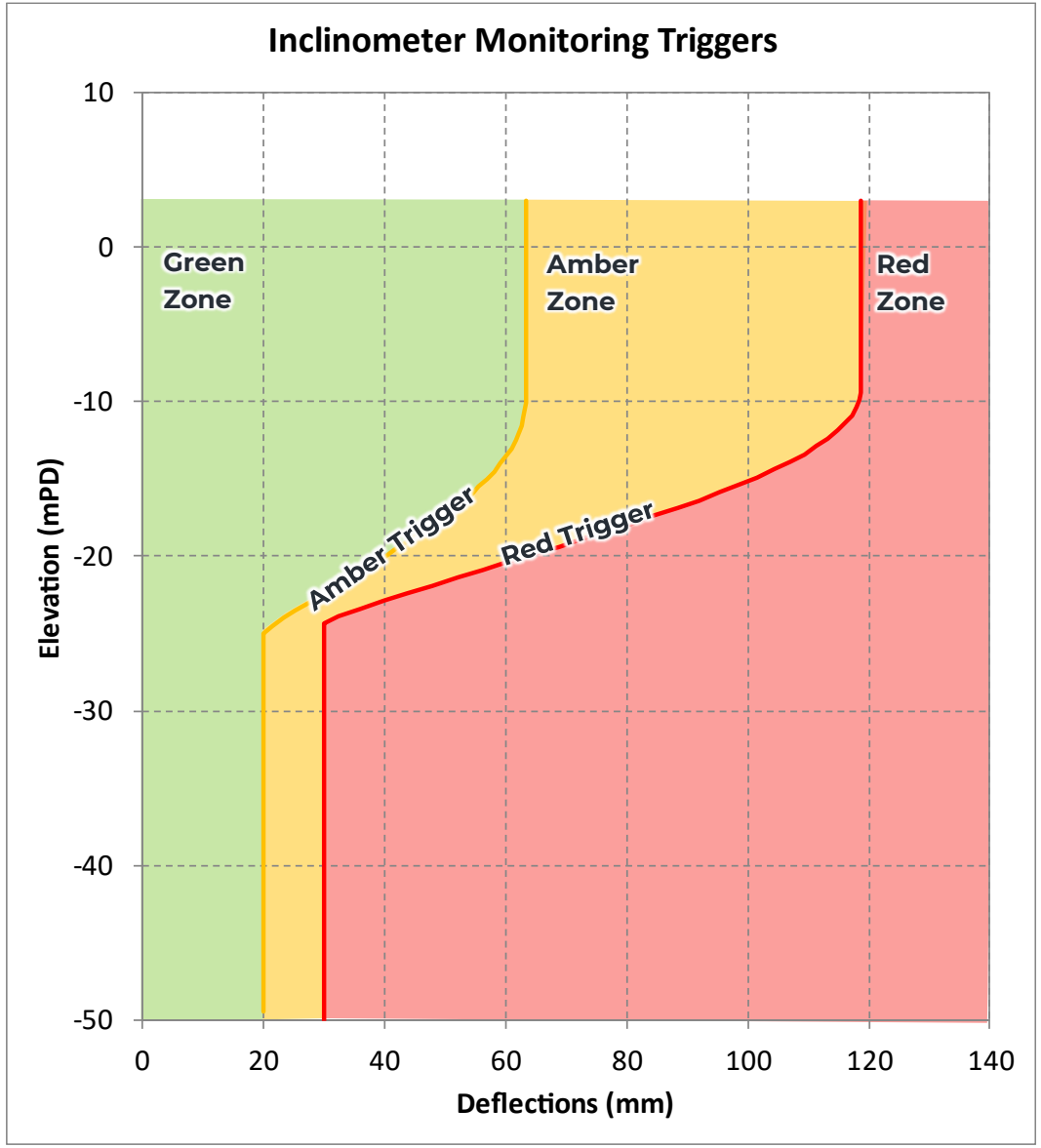
Key Findings

- Increase Marine Clay Eu from 350Cu to 450 Cu
- Revise top of Alluvium level
- Increase Alluvium Eu from 25 MPa (400Cu) to 200 MPa (small strain stiffness)

Development of Observational Method Monitoring System

- Intensive Monitoring Proposed with inclinometers and settlement markers at approximately 25m c/c
- Instruments within 50m from active excavations to be monitored and reviewed daily
- Readings compared to amber and red triggers to verify performance of excavations against predicted values

Development of Observational Method Traffic Light System

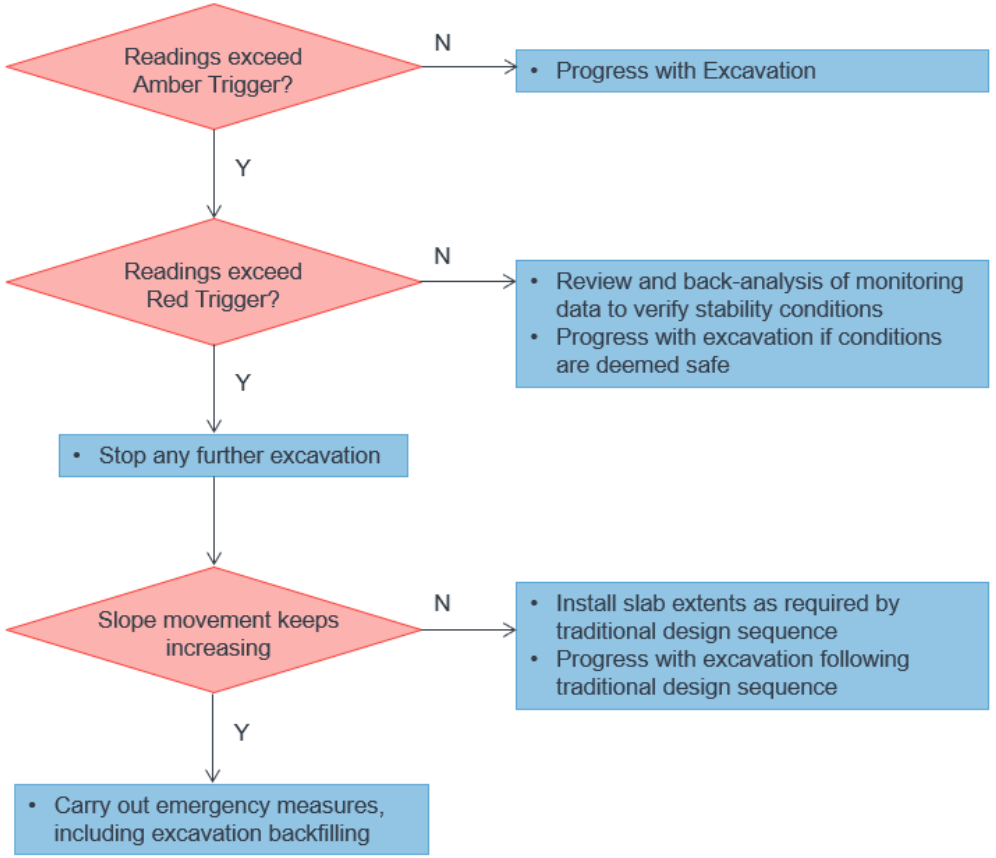


TRIGGERS DEFINITION

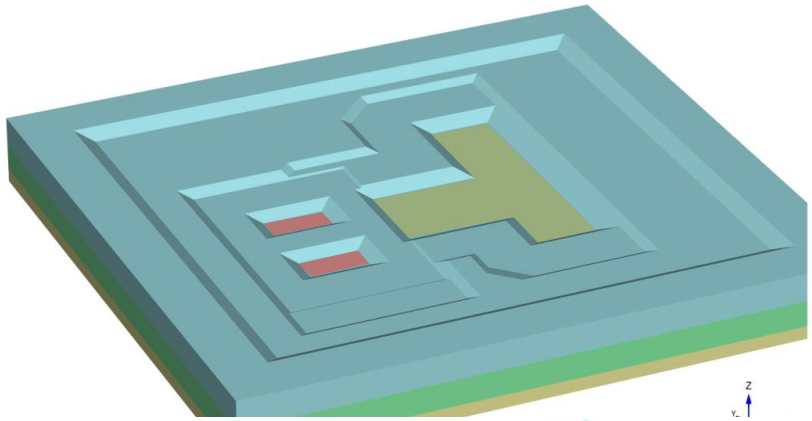
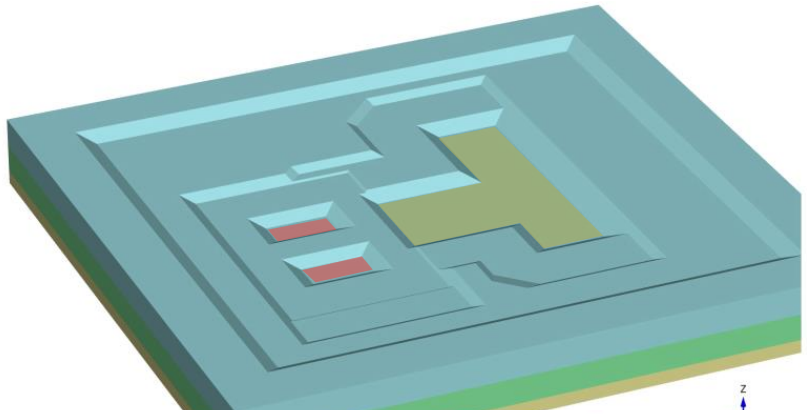
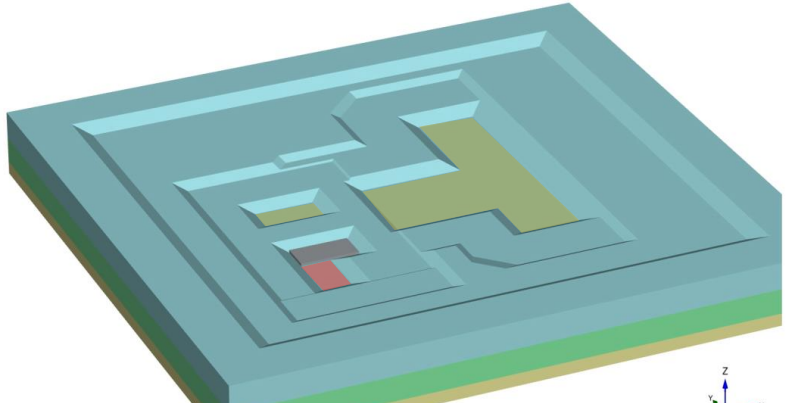
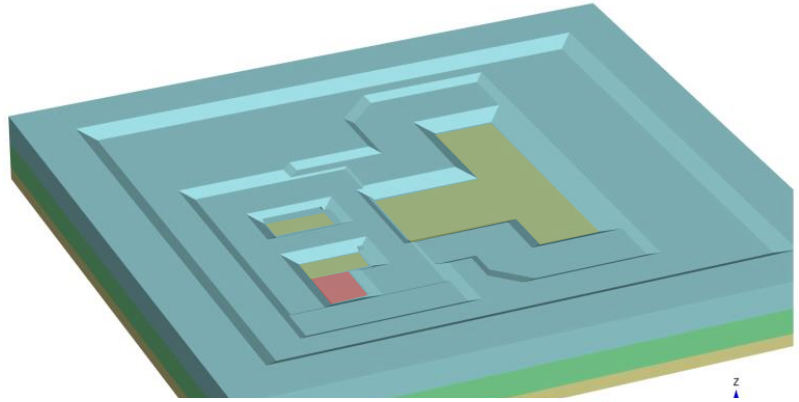
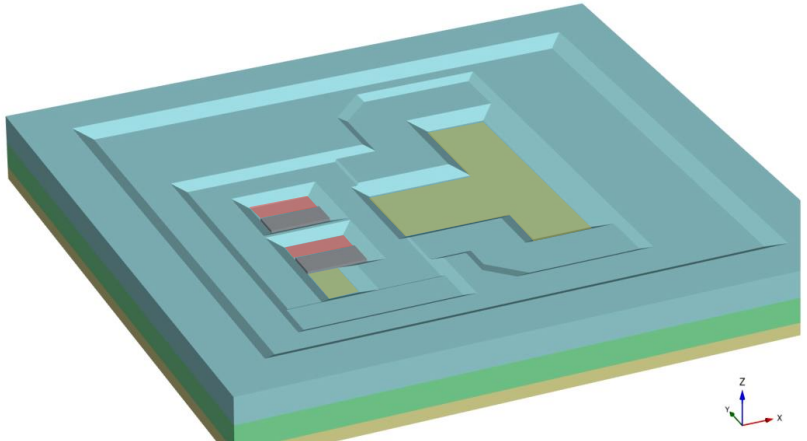
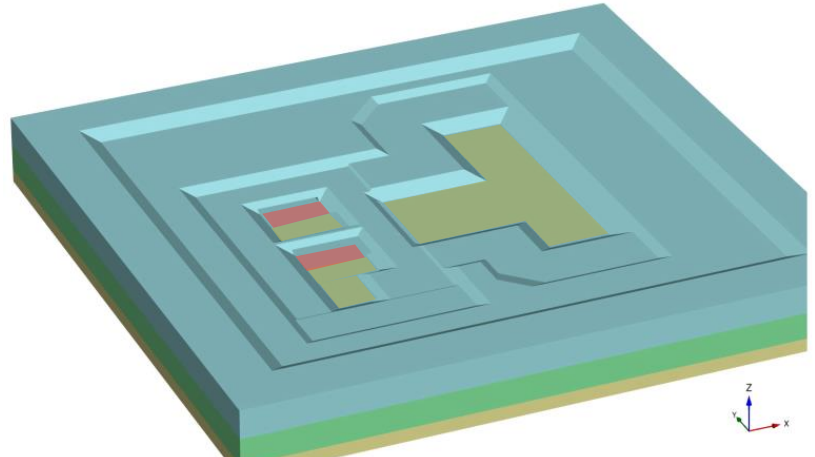
Amber Trigger: ground movement prediction using most probable parameters and following the Observational Method sequence

Red Trigger: 80% of the ground movement prediction using moderately conservative parameters and following the traditional design approved sequence

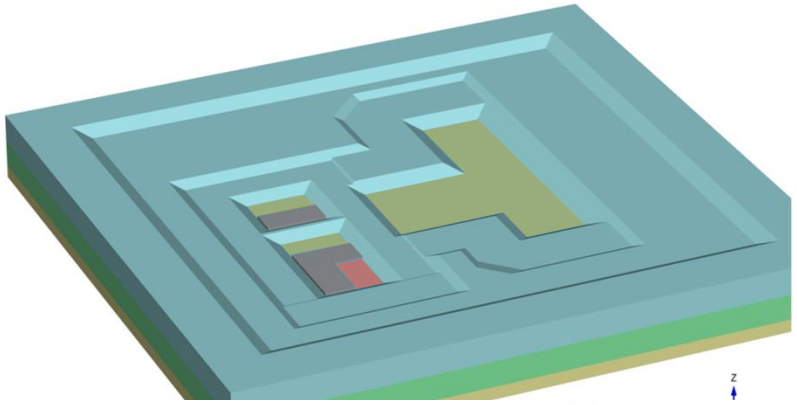
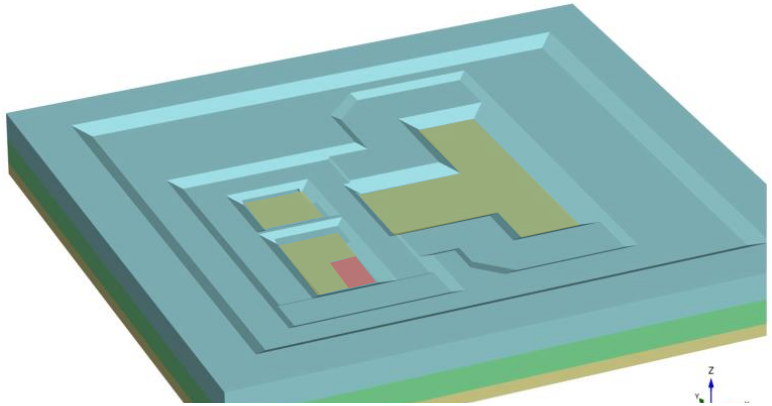
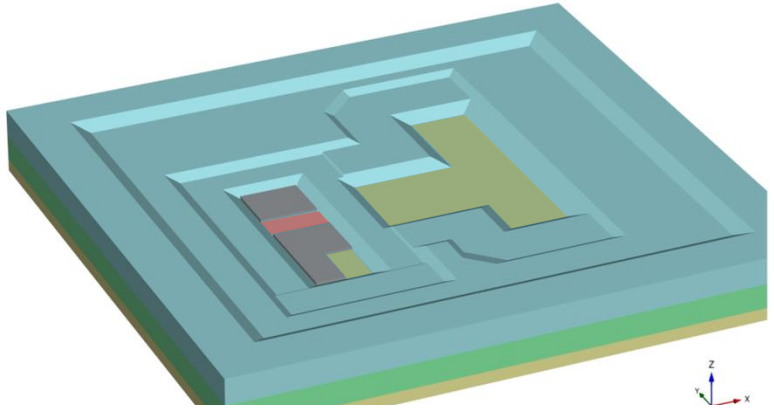
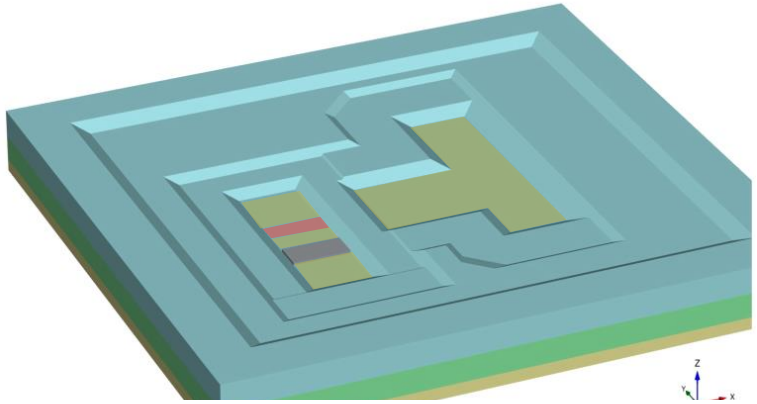
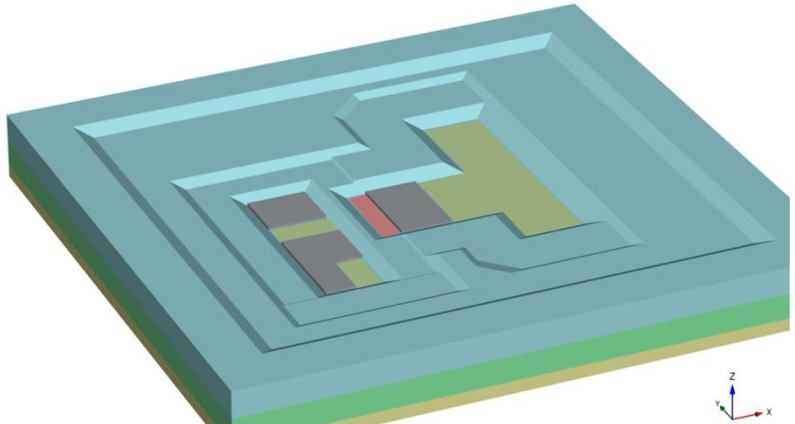
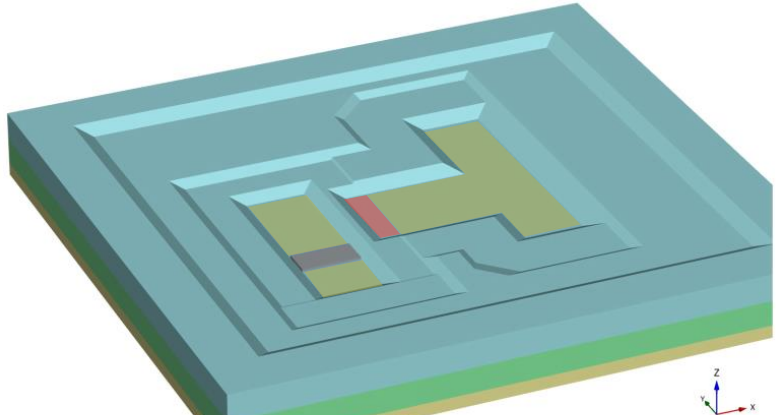
OM REVIEW WORKFLOW



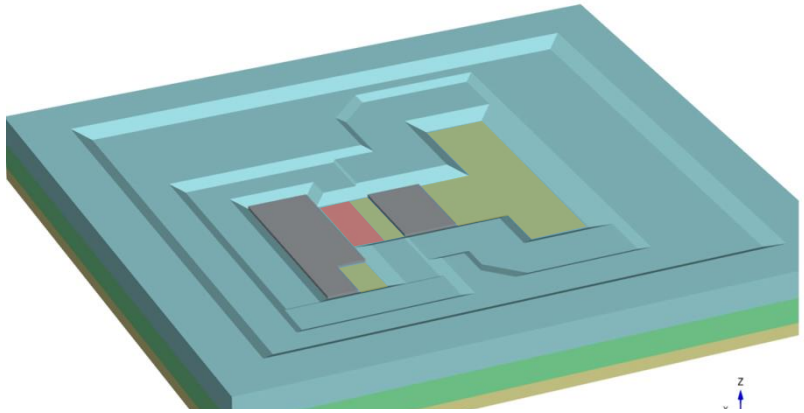
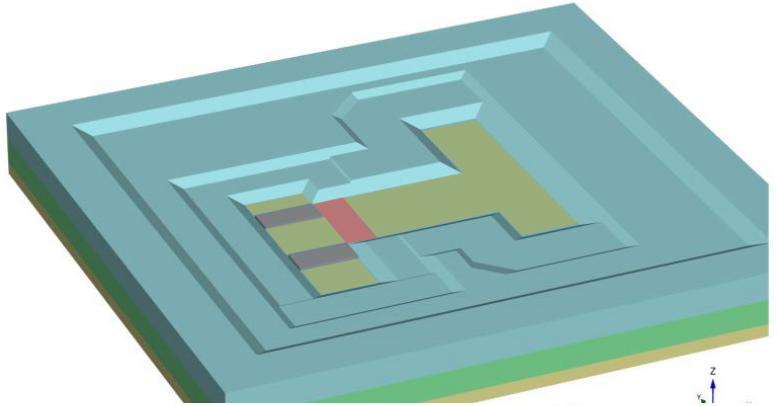
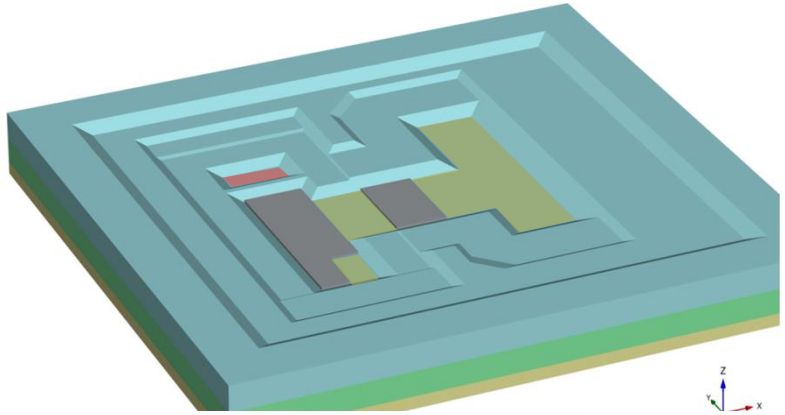
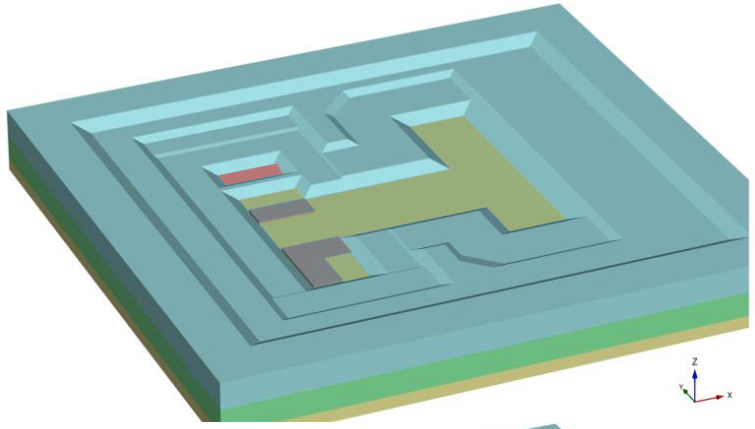
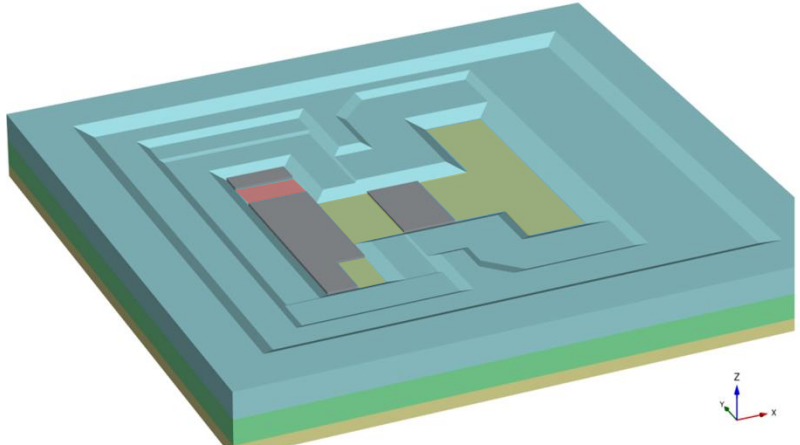
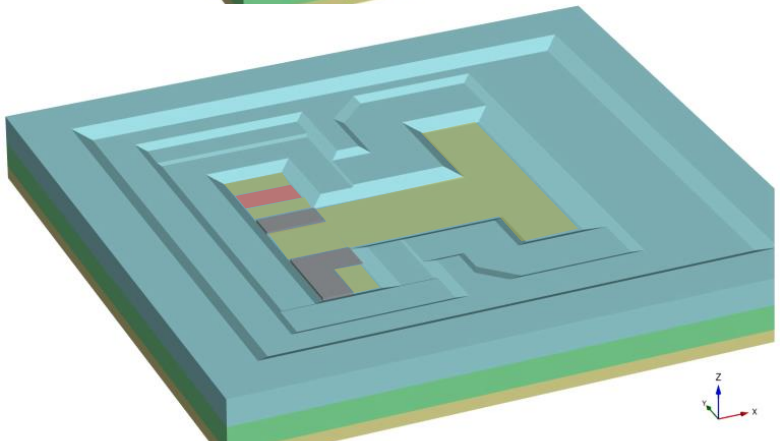
Observational Method Sequence

	Traditional Design	Observational Method
STAGE 7		
STAGE 8		
STAGE 9		

Observational Method Sequence

	Traditional Design	Observational Method
STAGE 10		
STAGE 11		
STAGE 12		

Observational Method Sequence

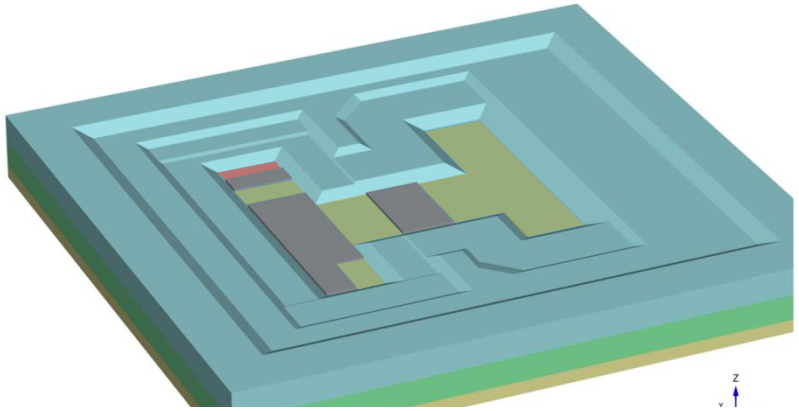
	Traditional Design	Observational Method
STAGE 13		
STAGE 14		
STAGE 15		

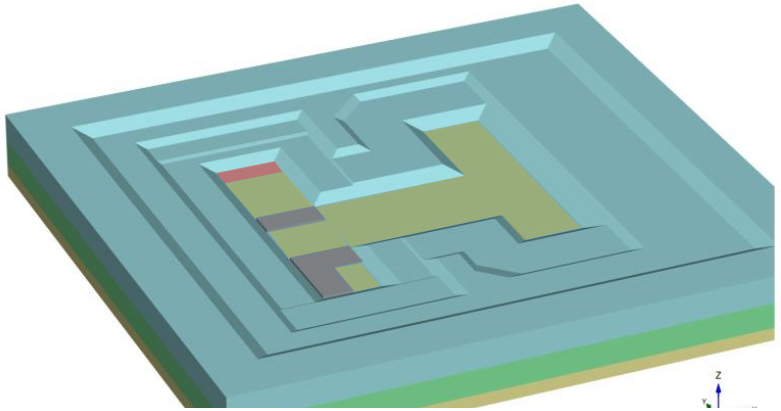
Observational Method Sequence

Traditional Design

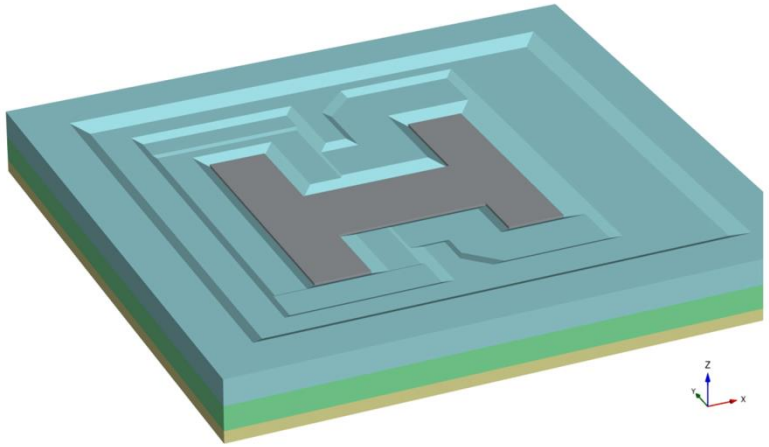
Observational Method

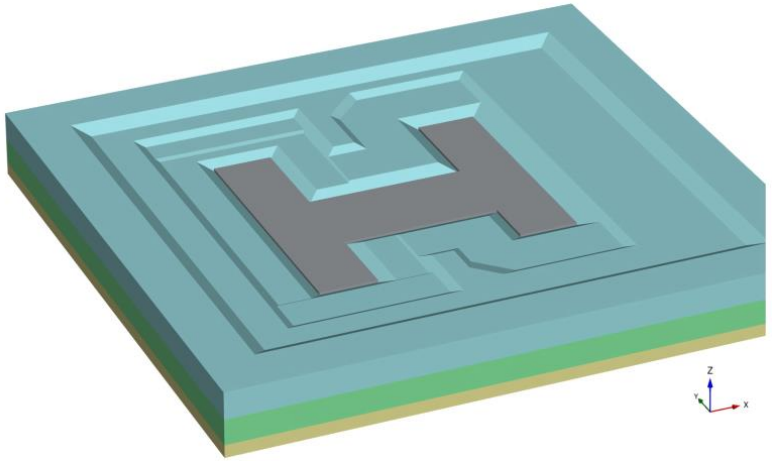
STAGE 16





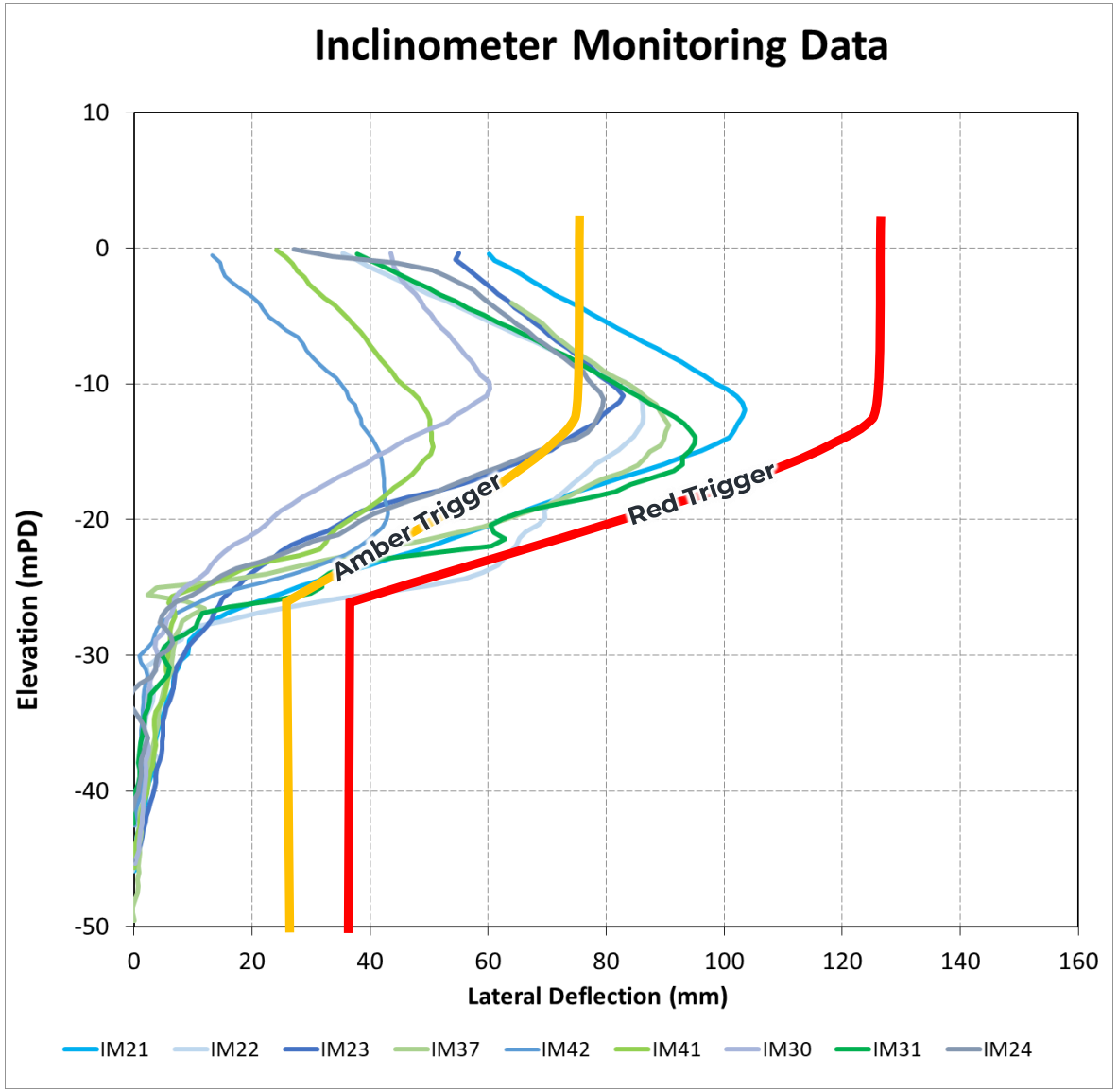
STAGE 17

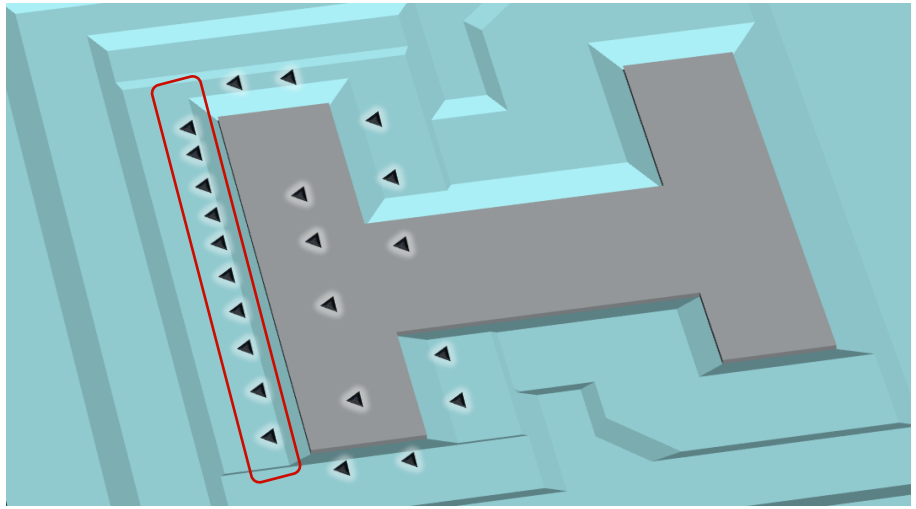




Excavation Performance and Conclusions

Excavation Performance





- Complete the excavation of the westerm half of the basement with minimal requirements to install foundations
- All OM objectives were achieved and excavation works could progress continuously until the entire basement was excavated
- OM resulted in 2 months programme saving compared to traditional design sequence

Conclusions

- Ground conditions at PCB posed significant challenges to the basement excavation, due to low strength and high variability within the Marine Clay
- Innovative solutions were developed step-by-step through constructive collaboration between Contractor, Engineer and Designer to solve the challenges encountered.
- First time that 3D analyses were adopted for Open Cut design in Hong Kong. To the author knowledge, first and last time that Observational Method successfully adopted in Hong Kong in a large infrastructure project
- The 3D approach resulted in saving of 8M US$ and 14,000 tons cement compared to a ground improvement solution
- All Observational Methods objectives were achieved resulting in 2 months saving in the excavation programme

Thank you

Alessandro.Martucci@Tonygee.com

www.linkedin.com/in/AlessandroMartucci