

OFFICIAL



The  
Geological  
Society

*-serving science & profession*

# VARIABLE GLACIAL GROUND AND LIQUEFIABLE SOIL CONDITIONS

RYAN BEECH

14 DECEMBER, 2021

OFFICIAL



# Background

## 2009-2011

- ▶ AS / A-Level Geology

## 2011-2014

- ▶ BSc (Hons) Geology – University of Birmingham

## 2014-2015

- ▶ MSc Engineering Geology – University of Leeds

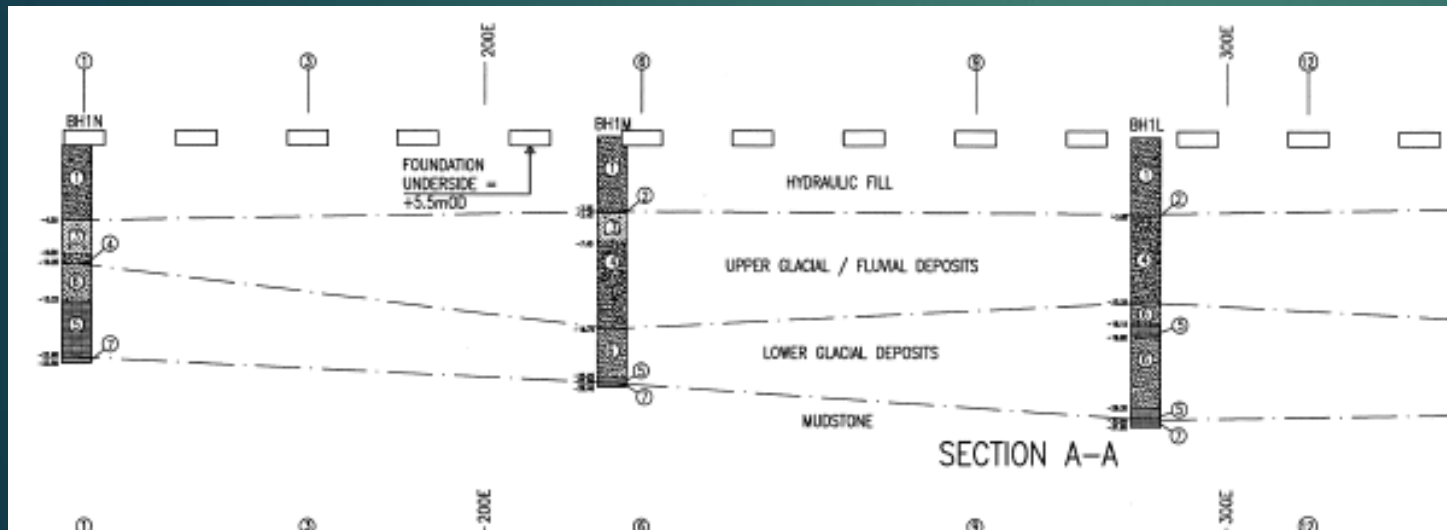
## 2015-Present

- ▶ Joined Civil Engineering industry
  - Preparation of Desk Studies
  - Ground Investigation Scoping
  - Site Supervision
  - Ground Modelling / Geotechnical Design
    - Utilities, Highways, Waste Remediation, Aviation, Nuclear sectors
- ▶ Fellow of Geological Society
- ▶ Member of Midlands' Geotechnical Society



# Project

- ▶ New (~40m x 190m) Dock Quay Wall
- ▶ Nuclear (MoD) Facility
- ▶ Sensitive project with confidentiality constraints
- ▶ Geotechnical Category 3 project (BS EN 1997-1) requiring a seismic assessment



(BGS, 2021a)

St Bees  
Sandstone  
FmSidmouth  
Mudstone FmTarpoley  
Siltstone FmPreesall  
Halite  
Mbr

(BGS, 2021b)

Tidal Flats

Diamicton

Glaciofluvial  
Deposits

Peat

# Involvement

## 2015

- ▶ Preliminary GI

## 2017

- ▶ Ground Investigation Report
- ▶ Preliminary Liquefaction Assessment and Strategy Document
- ▶ Data Gap Analysis
- ▶ GI Specification

## 2020

- ▶ Liquefaction GI
- ▶ Detailed Liquefaction Assessment and Outline Ground Treatment Specification
- ▶ Liaison with Principal Contractor & Ground Treatment Specialist & Value Engineering

# Involvement

## 2015

- ▶ Preliminary GI

## 2017

- ▶ Ground Investigation Report
- ▶ Preliminary Liquefaction Assessment and Strategy Document
- ▶ Data Gap Analysis
- ▶ GI Specification

## 2020

- ▶ Liquefaction GI
- ▶ Detailed Liquefaction Assessment and Outline Ground Treatment Specification
- ▶ Liaison with Principal Contractor & Ground Treatment Specialist & Value Engineering



OFFICIAL

# Proposed GI Plan

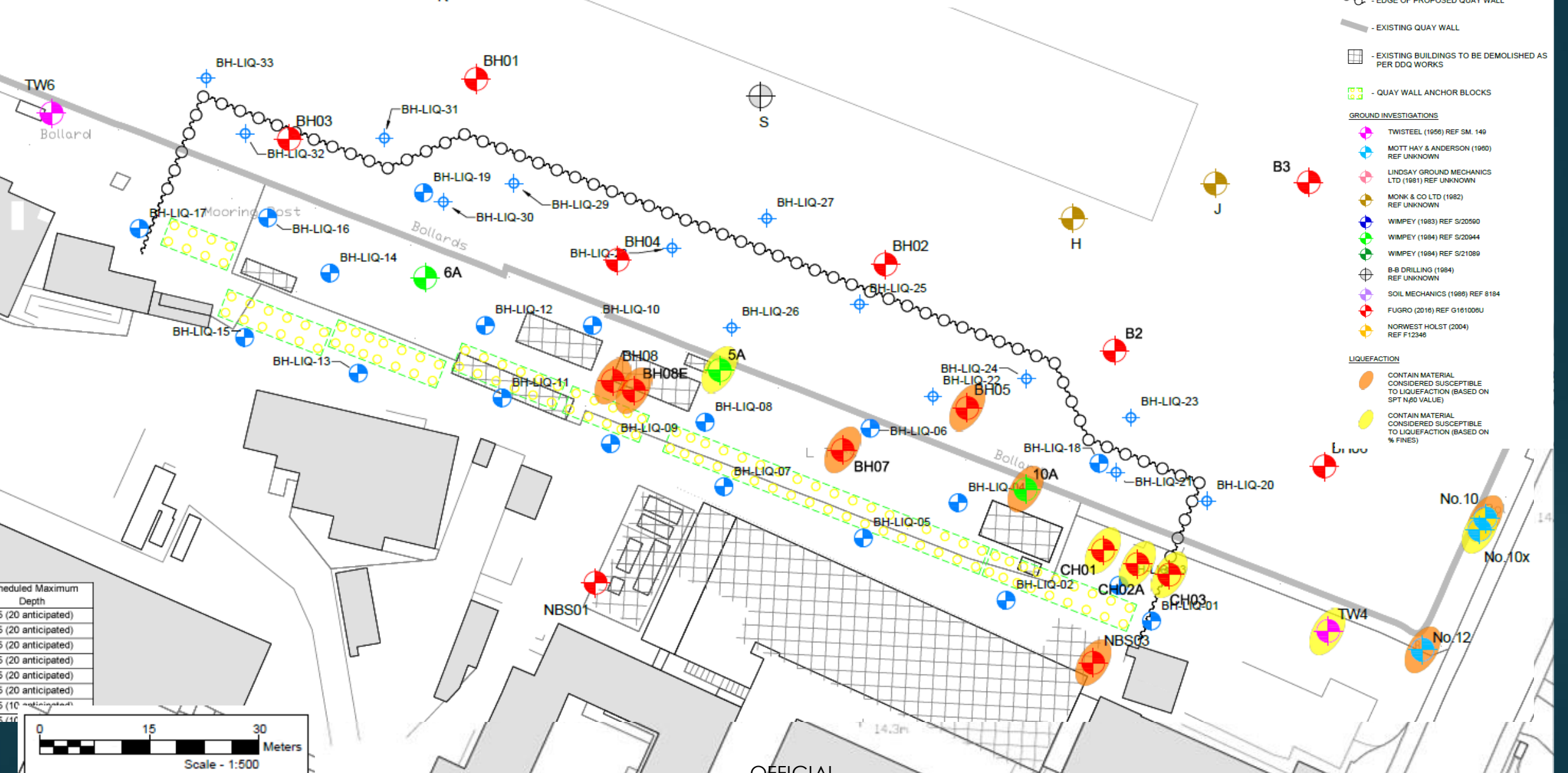
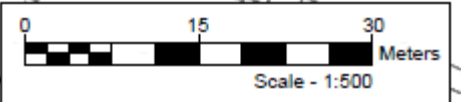
- KEY:**
- CABLE PERCUSSION BOREHOLE (CP)
  - STATIC CONE PENETRATION TEST WITH PORE WATER PRESSURE MEASUREMENT (CPTu)
  - EXISTING BUILDINGS TO BE RETAINED
  - EDGE OF PROPOSED QUAY WALL
  - EXISTING QUAY WALL
  - EXISTING BUILDINGS TO BE DEMOLISHED AS PER DDQ WORKS
  - QUAY WALL ANCHOR BLOCKS

- GROUND INVESTIGATIONS**
- TWISTEEL (1958) REF SM. 149
  - MOTT HAY & ANDERSON (1980) REF UNKNOWN
  - LINDSAY GROUND MECHANICS LTD (1981) REF UNKNOWN
  - MONK & CO LTD (1982) REF UNKNOWN
  - WIMPEY (1983) REF S/20590
  - WIMPEY (1984) REF S/20944
  - WIMPEY (1984) REF S/21089
  - B-B DRILLING (1984) REF UNKNOWN
  - SOIL MECHANICS (1988) REF 8184
  - FUGRO (2016) REF G161008U
  - NORWEST HOLST (2004) REF F12346

- LIQUEFACTION**
- CONTAIN MATERIAL CONSIDERED SUSCEPTIBLE TO LIQUEFACTION (BASED ON SPT N60 VALUE)
  - CONTAIN MATERIAL CONSIDERED SUSCEPTIBLE TO LIQUEFACTION (BASED ON % FINES)



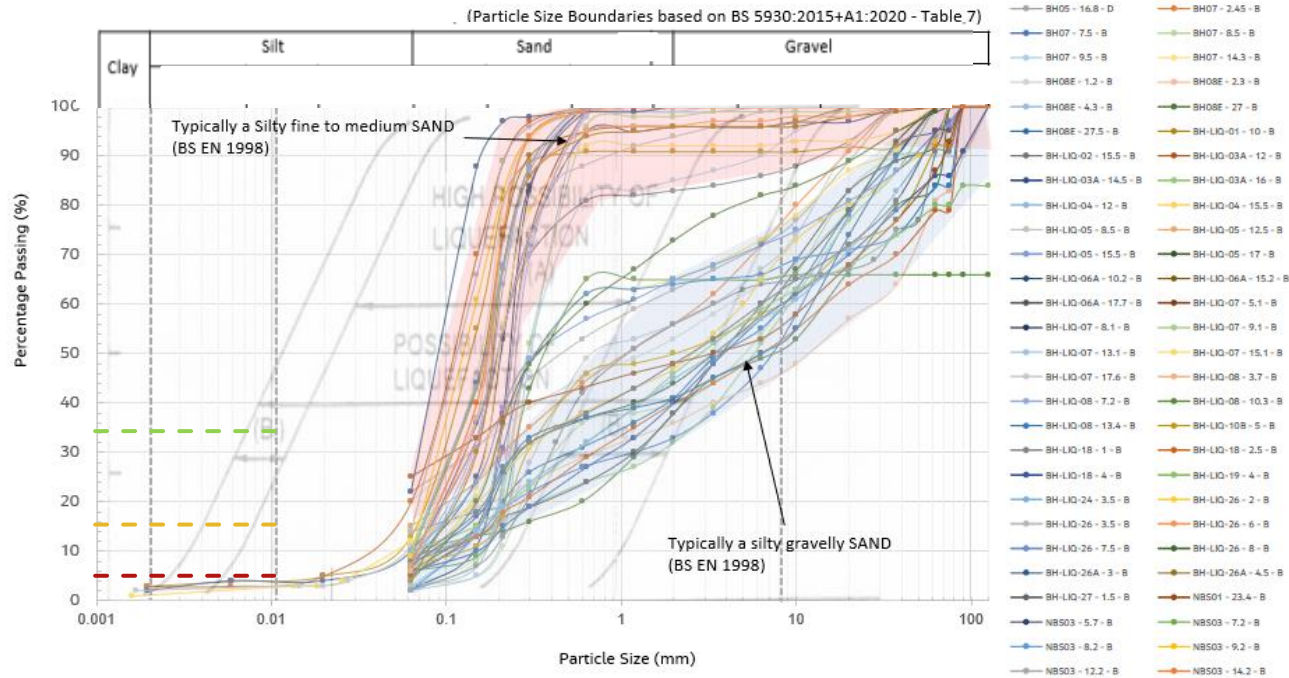
Scheduled Maximum Depth
5 (20 anticipated)
5 (20 anticipated)
5 (20 anticipated)
5 (20 anticipated)
5 (20 anticipated)
5 (20 anticipated)
5 (20 anticipated)
5 (10 anticipated)
5 (10 anticipated)



OFFICIAL

Balkema (1997)

OFFICIAL



REDACTED

Jacobs

Particle Size Distribution (Balkema 1997)

Figure Reference

A.1.4

Curve 3 (Refer

Key

$\tau_e/\sigma'_{vo}$  - cyclic stress ratio

A - clean sands;

B - silty sands

● curve 1: 35% fines

● curve 2: 15% fines

● curve 3: < 5% fines

Figure B.1 — Relationship between stress ratios causing liquefaction and  $N_1(60)$  values for clean and silty sands for  $M_s=7.5$  earthquakes.

Coefficient  $C_u =$

>3

# Liquefaction Assessment - Grading

REDACTED

CALCULATION SHEET

Section Design Base Event (DBE) - Evaluation of Liquefaction Susceptibility by Grading and SPT

Page No.	1	Cont'n Page No.	
Originator	RB	Date	08/09/2020
Checker	SCP	Date	16/09/2020

Hole ID: BH-LIQ-05    PGA ( $a_g$ ): 0.25 g    Max Depth of SPT (m): 17.2  
 Importance Factor ( $\gamma_I$ ): 1.4    Groundwater Level (mbgl): 3.00  
 Earthquake Magnitude (M): 5

(BS EN 1998-5)  
 (EN 1998-5 Cl. 4.4.1(10) Expression for  $\tau_e$   
 not applicable to depths >20m)

Chart 1 - Required SPT N1,60 Value vs Depth

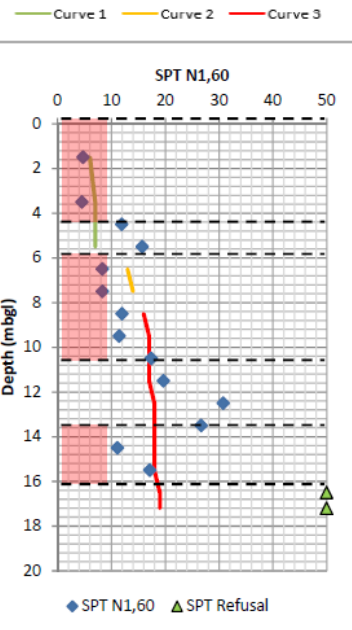


Chart 2 - Seismic Stress Ratio vs SPT N1,60 Value

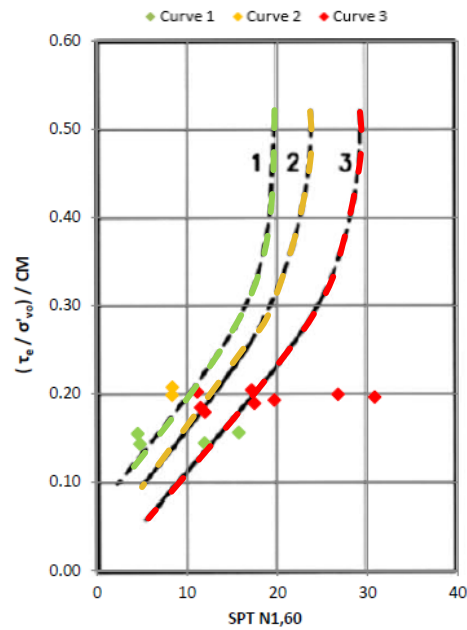
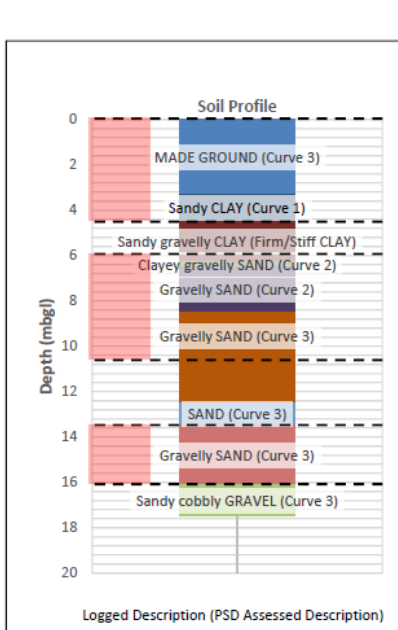


Chart 3 - Stratigraphic (Soil) Profile



Key

$\tau_e/\sigma'_{vo}$  - cyclic stress ratio  
 A - clean sands;

B - silty sands

- curve 1: 35 % fines
- curve 2: 15% fines
- curve 3: < 5% fines

Figure B.1 — Relationship between stress ratios causing liquefaction and  $N_1$  (60) values for clean and silty sands for  $M_s=7.5$  earthquakes.

# Liquefaction Assessment - SPT

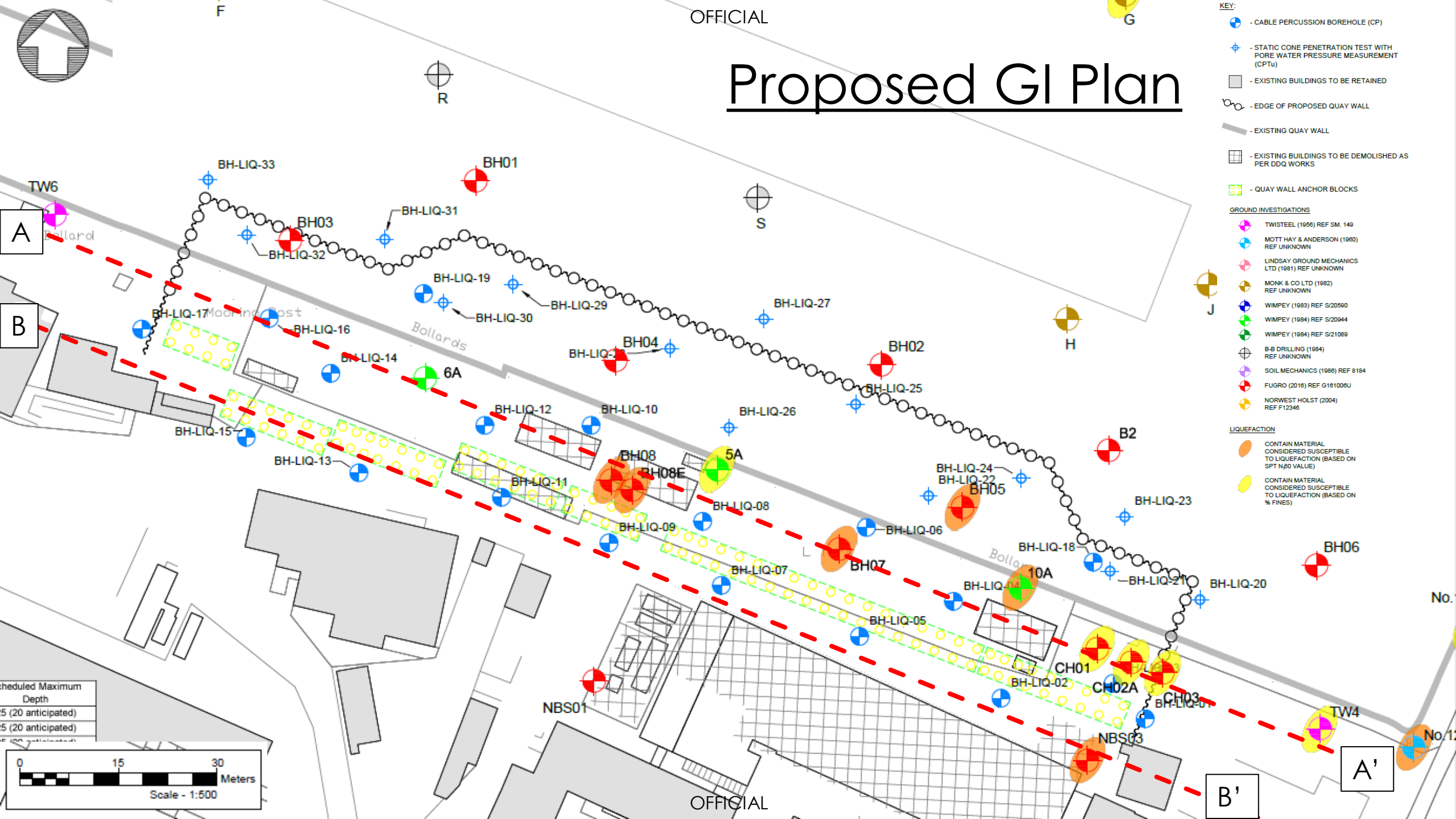


# Proposed GI Plan

- KEY:**
- CABLE PERCUSSION BOREHOLE (CP)
  - STATIC CONE PENETRATION TEST WITH PORE WATER PRESSURE MEASUREMENT (CPTu)
  - EXISTING BUILDINGS TO BE RETAINED
  - EDGE OF PROPOSED QUAY WALL
  - EXISTING QUAY WALL
  - EXISTING BUILDINGS TO BE DEMOLISHED AS PER DDQ WORKS
  - QUAY WALL ANCHOR BLOCKS

- GROUND INVESTIGATIONS**
- TWISTEEL (1958) REF SM. 149
  - MOTT HAY & ANDERSON (1980) REF UNKNOWN
  - LINDSAY GROUND MECHANICS LTD (1981) REF UNKNOWN
  - MONK & CO LTD (1982) REF UNKNOWN
  - WIMPEY (1983) REF S/20590
  - WIMPEY (1984) REF S/20944
  - WIMPEY (1984) REF S/21089
  - B-B DRILLING (1984) REF UNKNOWN
  - SOIL MECHANICS (1986) REF 8184
  - FUGRO (2016) REF G161008U
  - NORWEST HOLST (2004) REF F12346

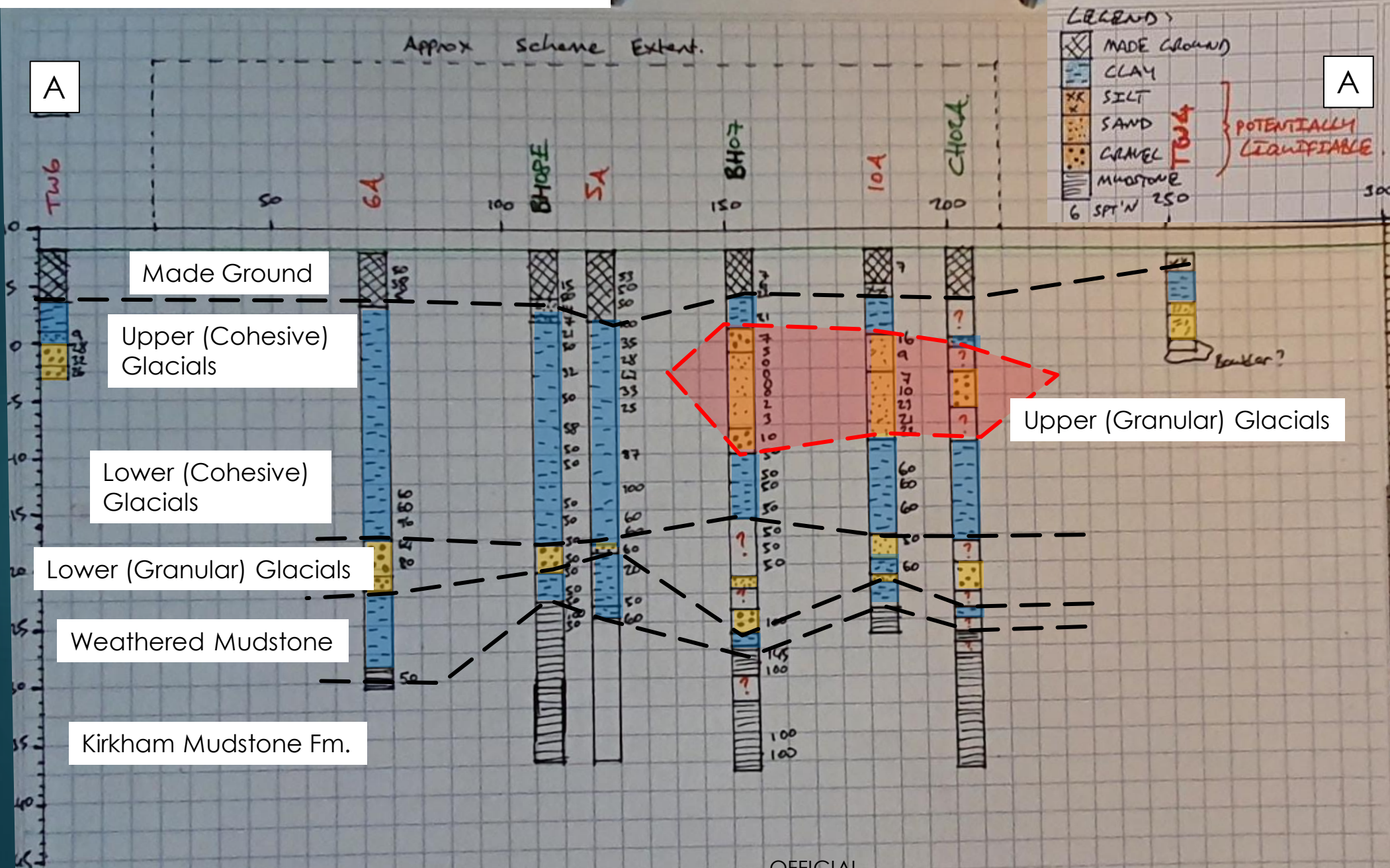
- LIQUEFACTION**
- CONTAIN MATERIAL CONSIDERED SUSCEPTIBLE TO LIQUEFACTION (BASED ON SPT N60 VALUE)
  - CONTAIN MATERIAL CONSIDERED SUSCEPTIBLE TO LIQUEFACTION (BASED ON % FINES)



Scheduled Maximum Depth	Number of Investigations
5	20 (anticipated)
15	20 (anticipated)

Scale - 1:500

# Site Sketch (1956-2015 GI)



**JACOBS**

Office

Job No

A Title

Section

Page No

Originator

Calculator

Da

Pa

Ca

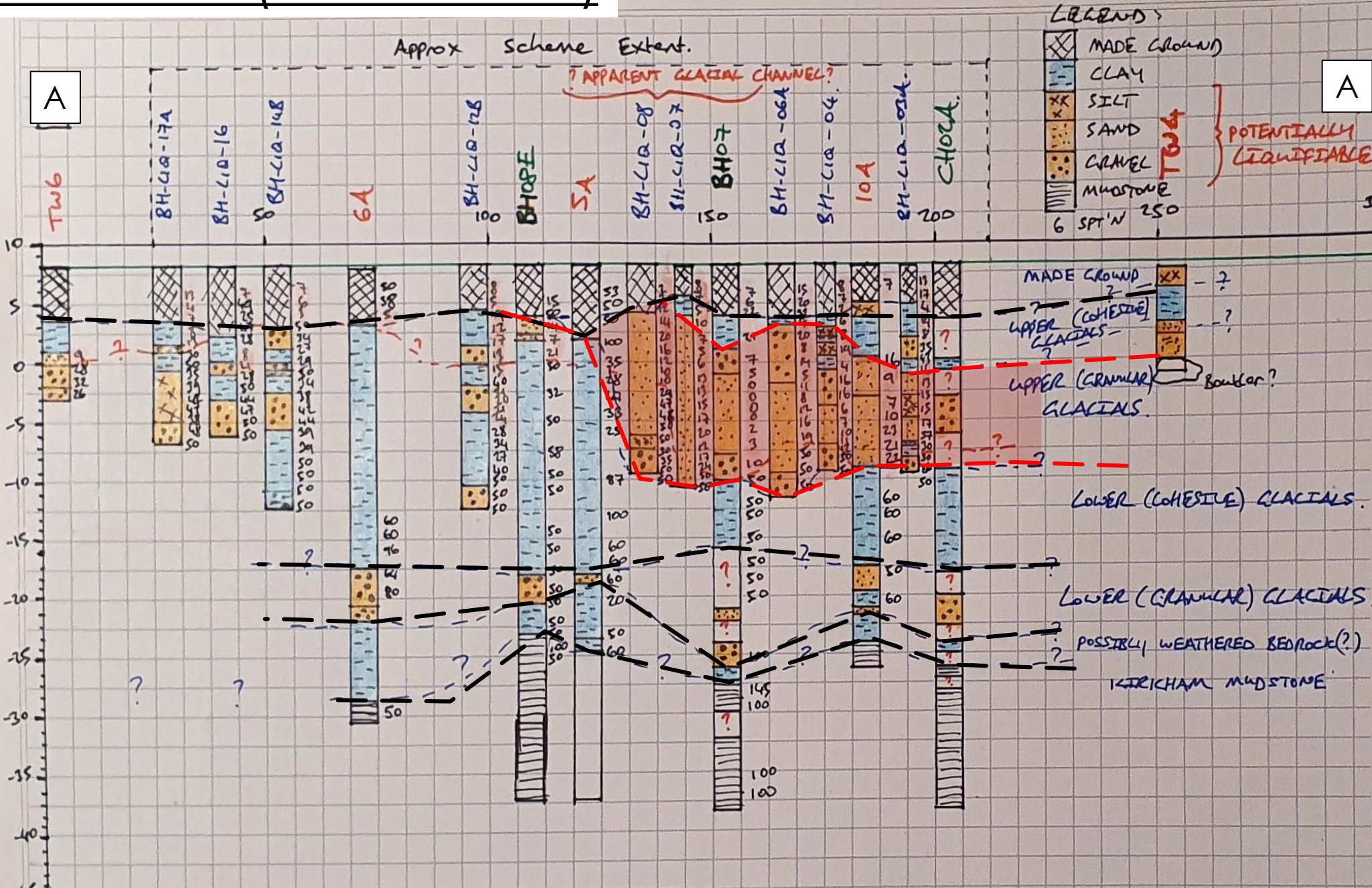
Da

CALCULATION

OFFICIAL



# Site Sketch (1956-2020 GI)



## LEGEND

- MADE GROUND
  - CLAY
  - SILT
  - SAND
  - GRAVEL
  - MUDSTONE
- 6 SPT'N 250

POTENTIALLY LIQUIFIABLE

Job No. & Title

Office

Section

← 200 Ground Level.

300

10

5

0

-5

-10

-15

-20

-25

-30

-35

-40

-45

Checker

Originator

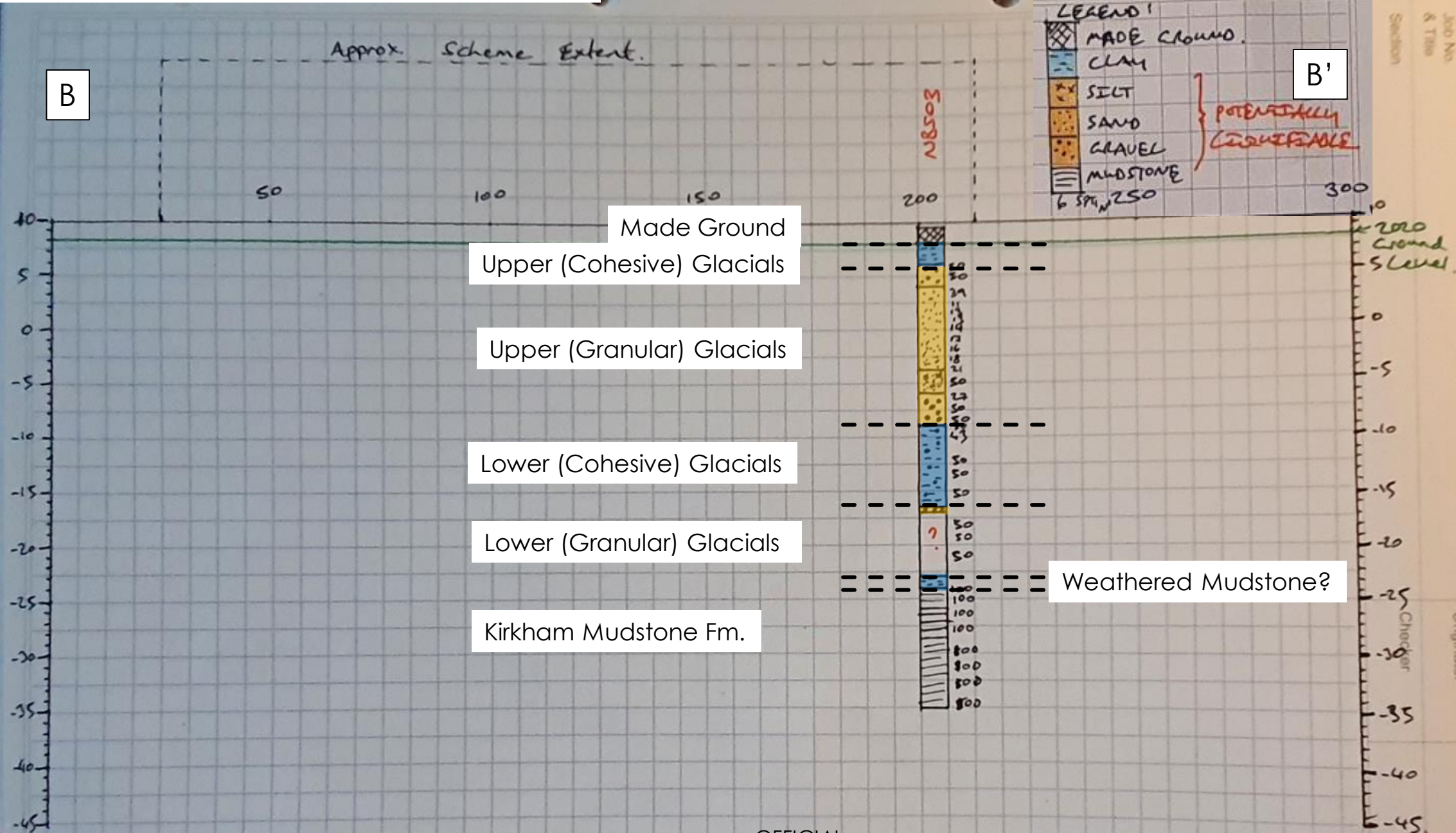
Page No.

CALCULATOR



# Site Sketch (1956-2015 GI)

OFFICIAL



OFFICIAL

JACOBS

CALCULATOR

Job No. & Title

Section

Originator

Checker

Page No

Originator

Checker

Page No

Originator

Checker

Page No

Originator

Checker

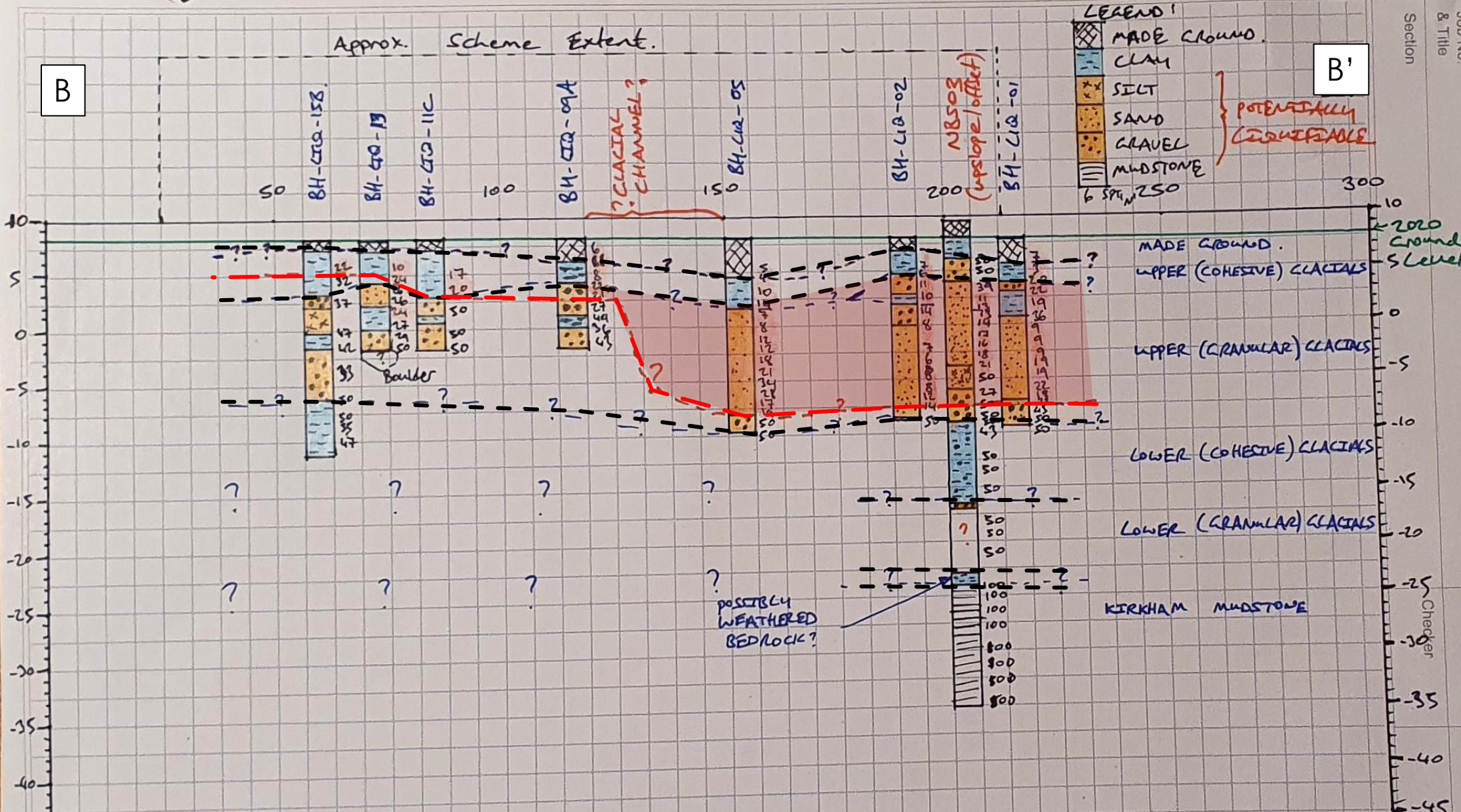
Page No

Originator



# Site Sketch (1956-2020 GI)

OFFICIAL



**JACOBS**

Office  
Job No. & Title  
Section

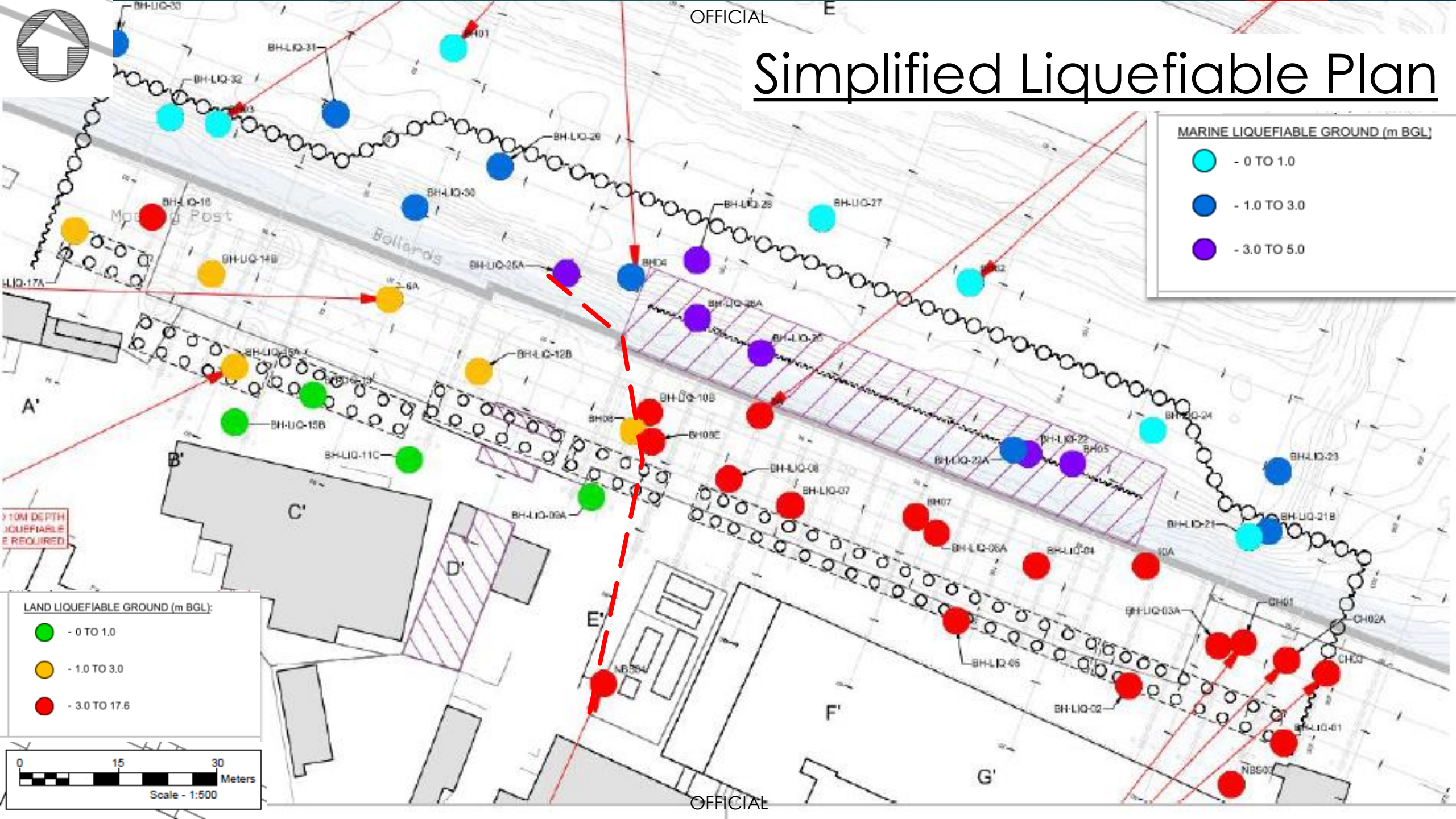
Page No.  
Originator

CALCULATION

OFFICIAL



# Simplified Liquefiable Plan



MARINE LIQUEFIABLE GROUND (m BGL)

- - 0 TO 1.0
- - 1.0 TO 3.0
- - 3.0 TO 5.0

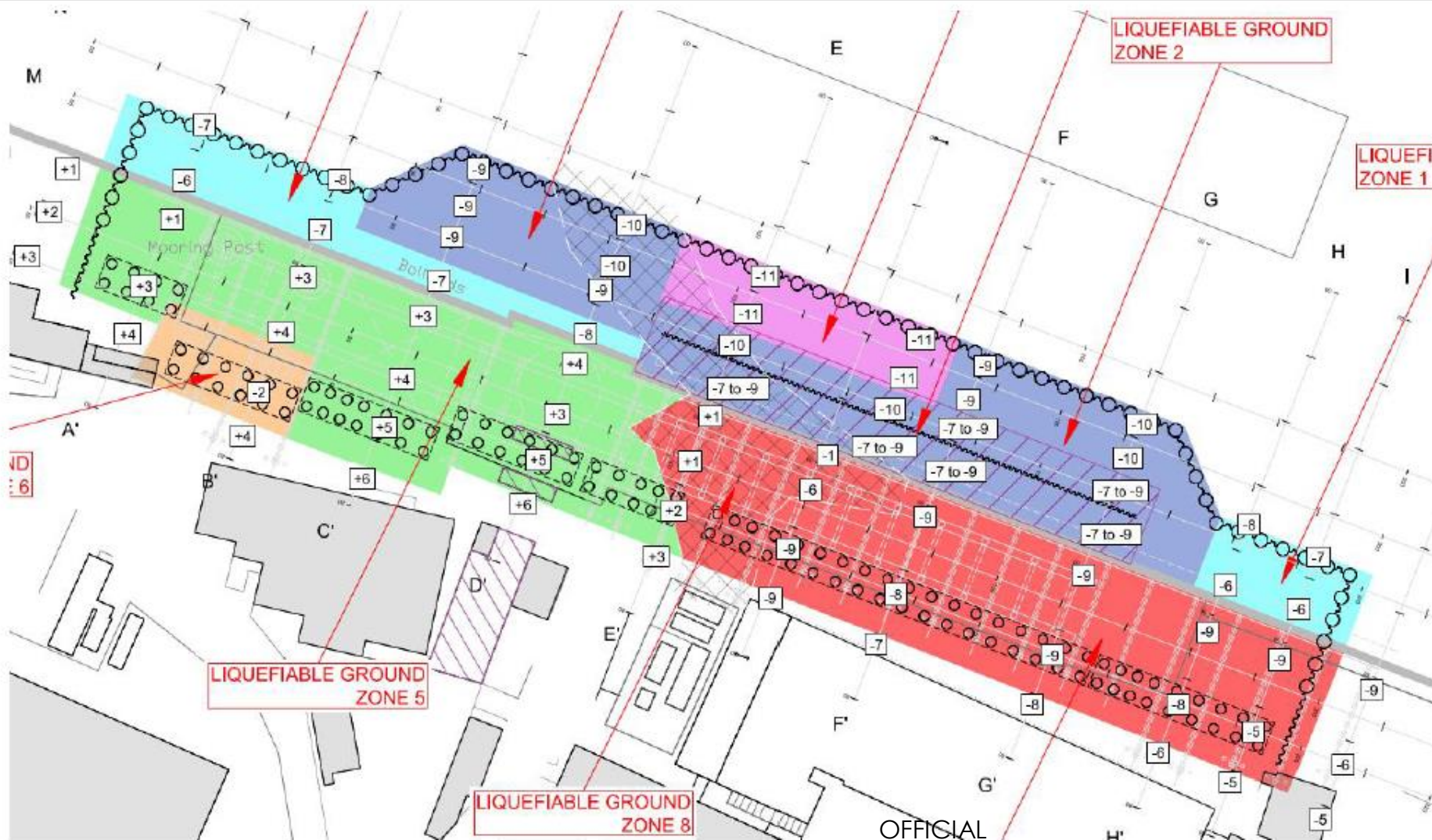
LAND LIQUEFIABLE GROUND (m BGL):

- - 0 TO 1.0
- - 1.0 TO 3.0
- - 3.0 TO 17.6

10M DEPTH LIQUEFIABLE GROUND REQUIRED



# Ground Treatment Plan



**MARINE: LIQUEFIABLE GROUND (LAYER 1A)**

- ZONE 1: BASE OF LAYER BETWEEN -6.0 AND -8.0m OD
- ZONE 2: BASE OF LAYER BETWEEN -9.0 AND -10.0m OD
- ZONE 3: TOP OF LAYER AT -7.0m OD  
- BASE OF LAYER BETWEEN -9.0m OD AND -10.0m OD
- ZONE 4: BASE OF LAYER AT -11.0m OD

**LAND: LIQUEFIABLE GROUND (LOWER LAYER 2)**

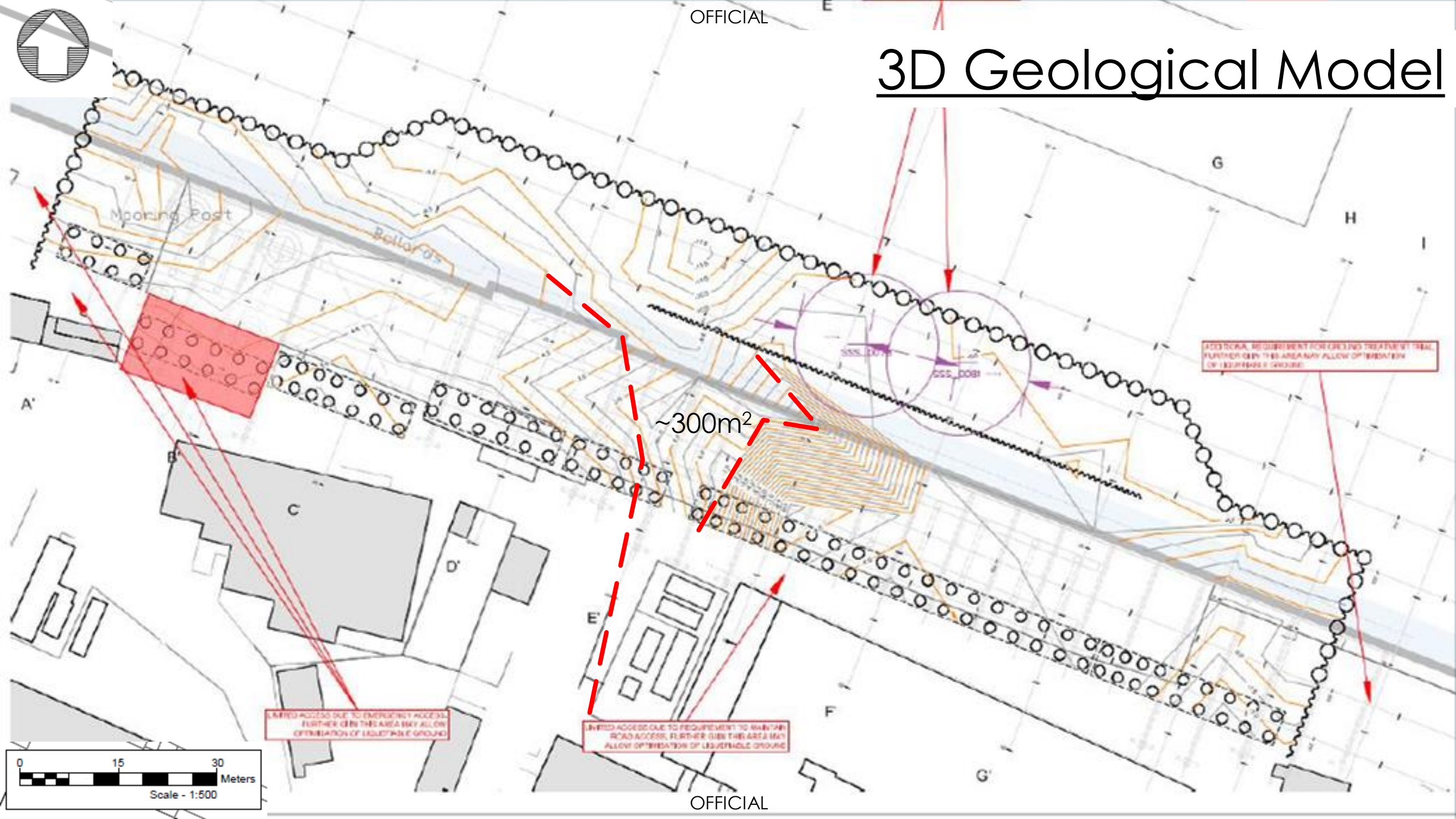
- ZONE 5: BASE OF LAYER BETWEEN +1.0m OD AND +6.0m OD
- ZONE 6: BASE OF LAYER AT -2.0m OD (APPROXIMATE)  
- REQUIRES FURTHER INVESTIGATION TO CONFIRM BASE LEVEL
- ZONE 7: BASE OF LAYER BETWEEN -5.0m OD AND -9.0m OD

**Legend:**

- [Hatched Box] - INDICATIVE SLOPING INTERFACE OF GLACIAL CHANNEL
- [Box with -6] - MAXIMUM LEVEL OF LIQUEFIABLE LAYER m OD



# 3D Geological Model



Mooring Post

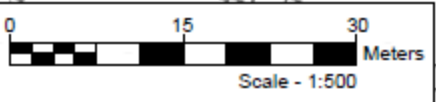
Bollards

~300m²

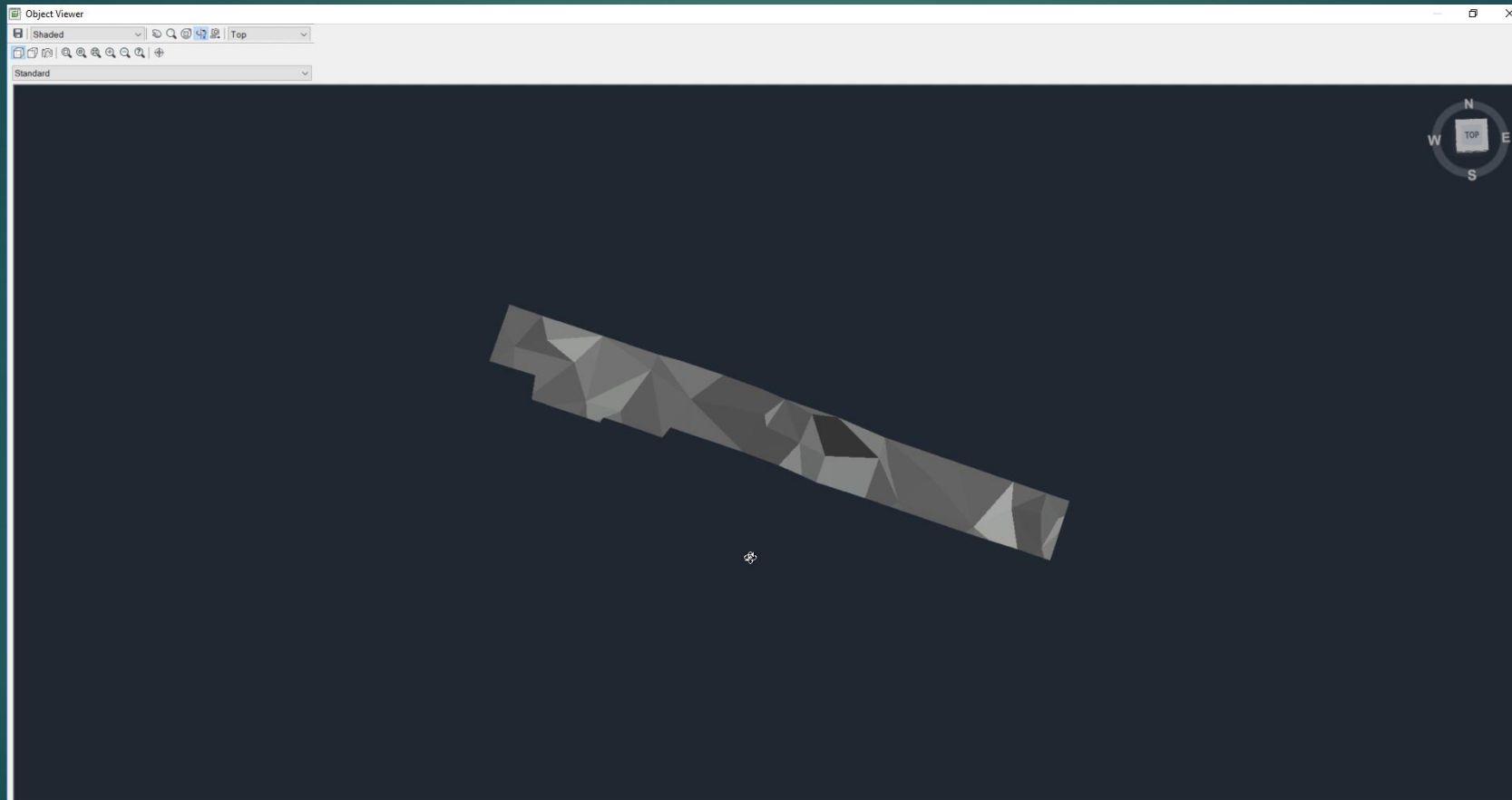
LIMITED ACCESS DUE TO EMERGENCY ACCESS  
 FURTHER CBN THIS AREA MAY ALLOW  
 OPTIMIZATION OF LEASURABLE GROUND

LIMITED ACCESS DUE TO REQUIREMENT TO MAINTAIN  
 ROAD ACCESS FURTHER CBN THIS AREA MAY  
 ALLOW OPTIMIZATION OF LEASURABLE GROUND

ADDITIONAL REQUIREMENT FOR GRINDING TREATMENT  
 FURTHER CBN THIS AREA MAY ALLOW OPTIMIZATION  
 OF LEASURABLE GROUND



# 3D Modelling / Design Integration





# Future Work

- ▶ Development of Sitewide 3D Model
  - ▶ Geology
  - ▶ Liquefiable Layers
  - ▶ Obstructions
- ▶ Ground Treatment
  - ▶ Value Engineering and Outline Solution to Mitigate GeoHazard
  - ▶ Trials
  - ▶ Further GI to reduce ground risk
  - ▶ Construction
  - ▶ Verification

# References

- ▶ Balkema 1997 Handbook on liquefaction remediation of reclaimed land. Port and Harbour Research Institute, PHRI, Rotterdam, Brookfield, Netherlands.
- ▶ BGS 2021a: GeoIndex 1:50,000 Superficial Deposits
- ▶ BGS 2021b: GeoIndex 1:50,000 Bedrock / Linear Features
- ▶ BSI, 2004a. BS EN 1997-1: 2004: Eurocode 7: Geotechnical design–Part 1: General rules.
- ▶ BSI, 2004b. BS EN 1998-1, 2004: Eurocode 8: Design of Structures for Earthquake Resistance
- ▶ BSI, 2004c. BS EN 1998-5: 2004: Eurocode 8: Design of structures for earthquake resistance. Foundations, retaining structures and geotechnical aspects



# Any Questions?

Contact: [Ryan.Beech@jacobs.com](mailto:Ryan.Beech@jacobs.com)



**ATKINS**

Member of the SNC-Lavalin Group

**West Midland Regional Group**

14/12/2021

**Rock Slope Modelling**

Hamish Strachan

# Contents

- › Scope
- › Geology
- › Parameter Derivation
- › Modelling
- › Results
- › Questions



# Scope

- › Undertake a review of the stability of two rock slopes
- › Assess deformation and adequacy of installed support as well as likely levels of movement for trigger level purposes
- › Summarise findings in a Technical Note

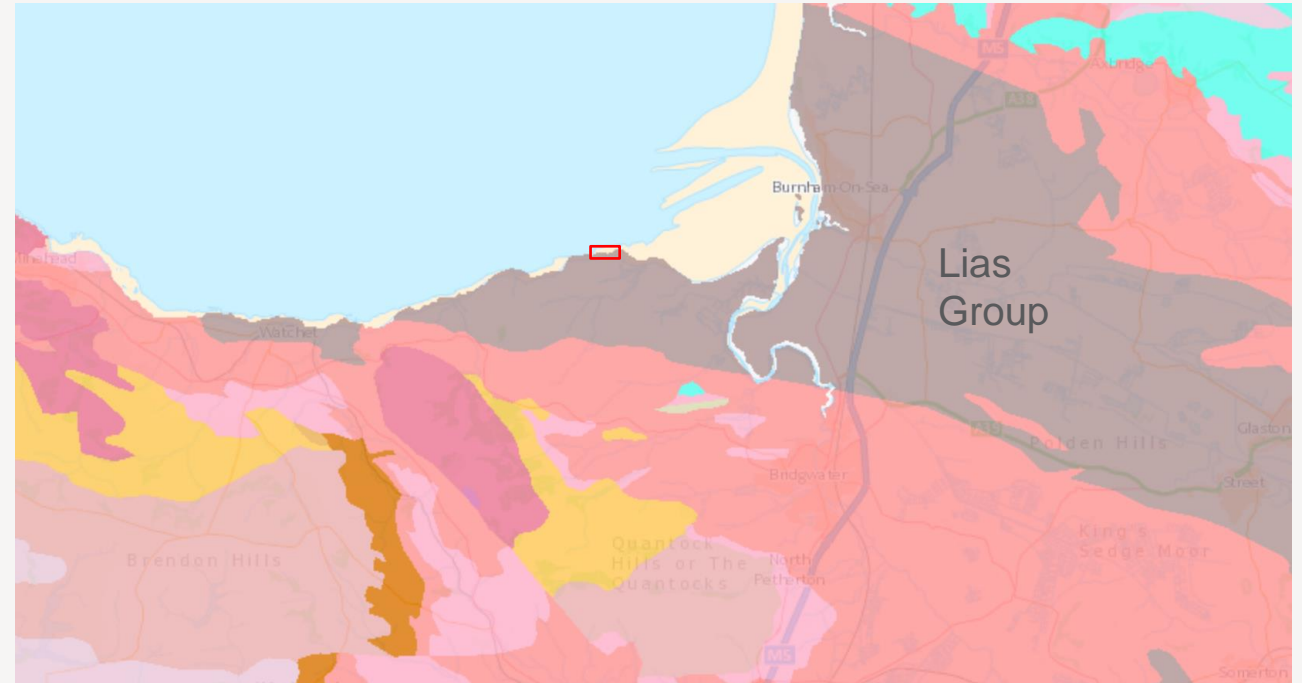
## Previous Work

- › Design Study
- › Face Logs



# Geology

- › Lias Group and Penarth Group:
- › Blue Lias Formation
- › Lillstock Formation and Westbury Formation



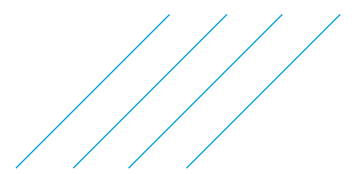
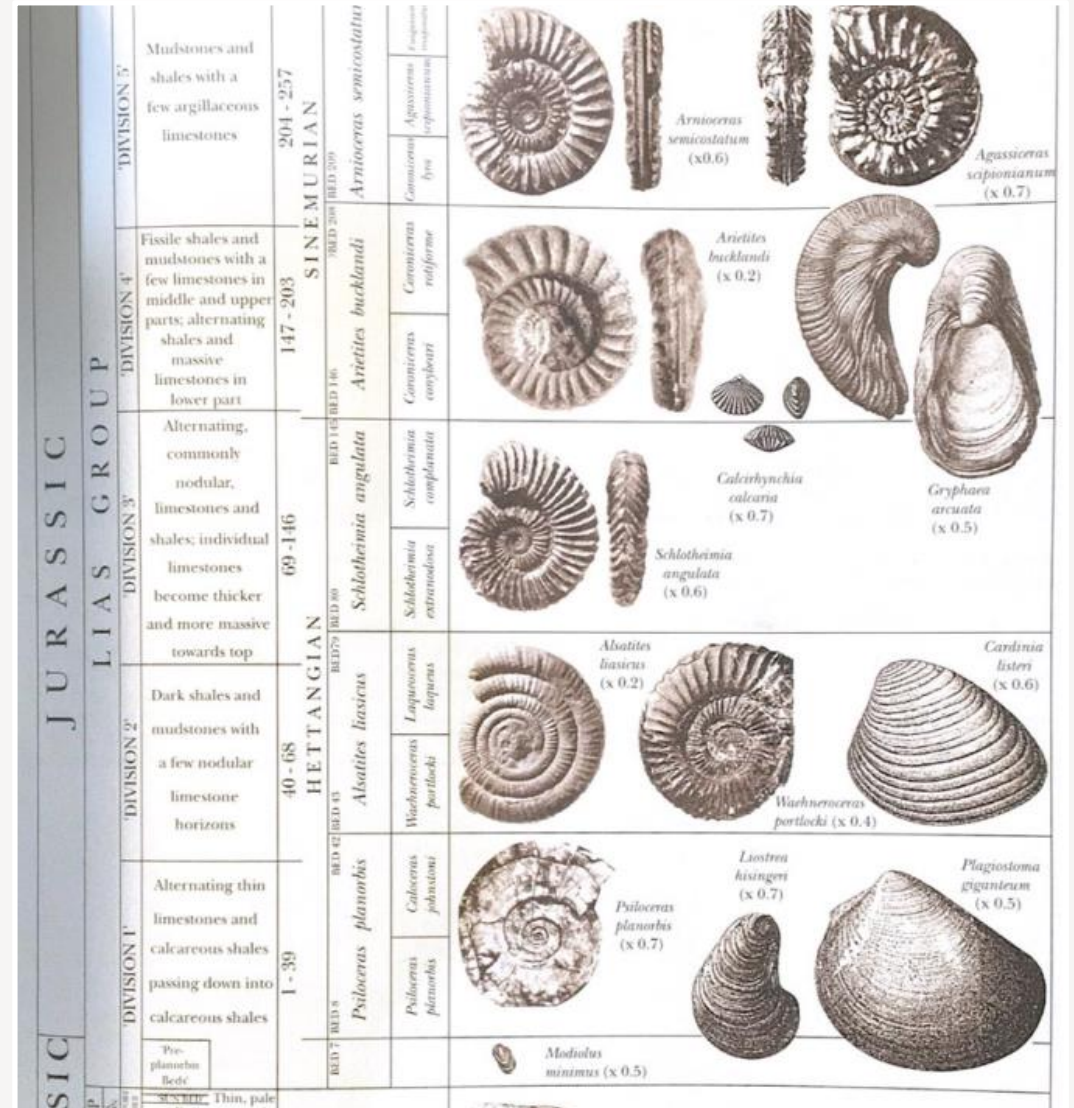
GeoIndex - British Geological Survey (bgs.ac.uk)





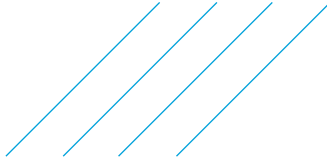
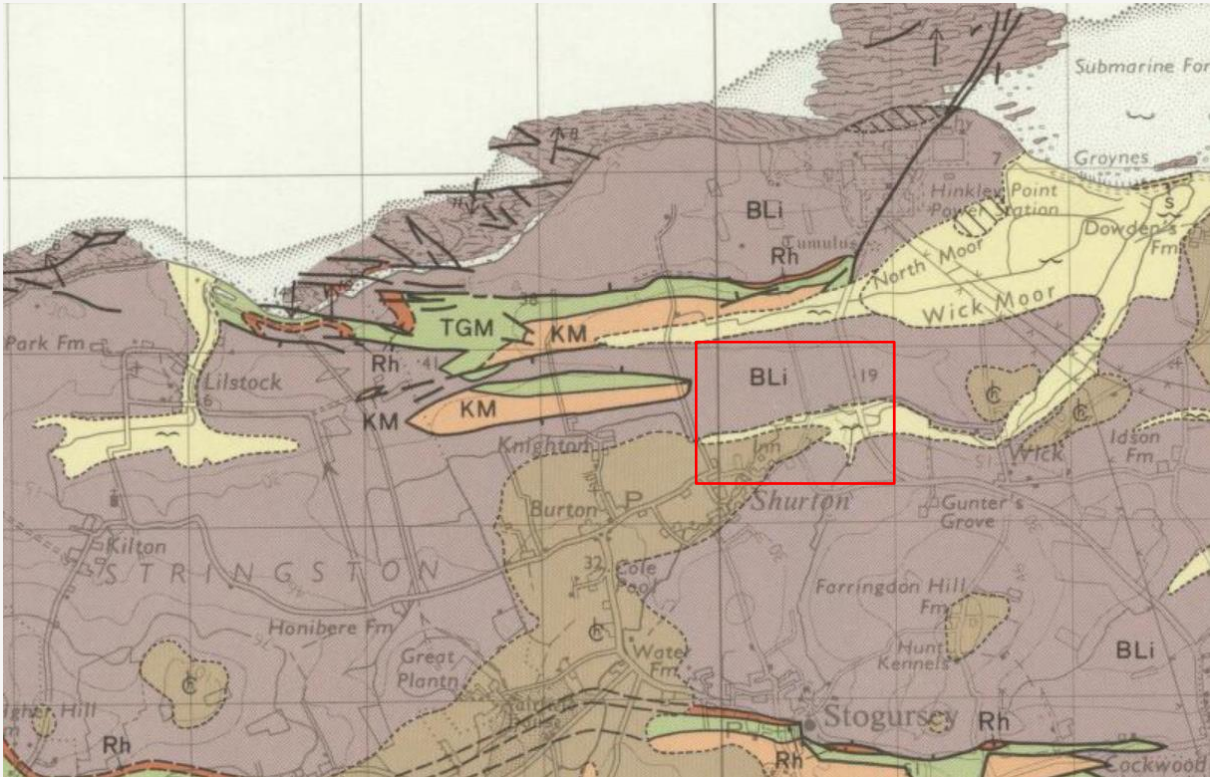
# Geology

- › Blue Lias Formation sub divided based on biozones:
  - › Planorbis
  - › Lower Liasicus
  - › Upper Liasicus / Angulata



# Geology

› In situ stress regime –  $K0 = 1.5$



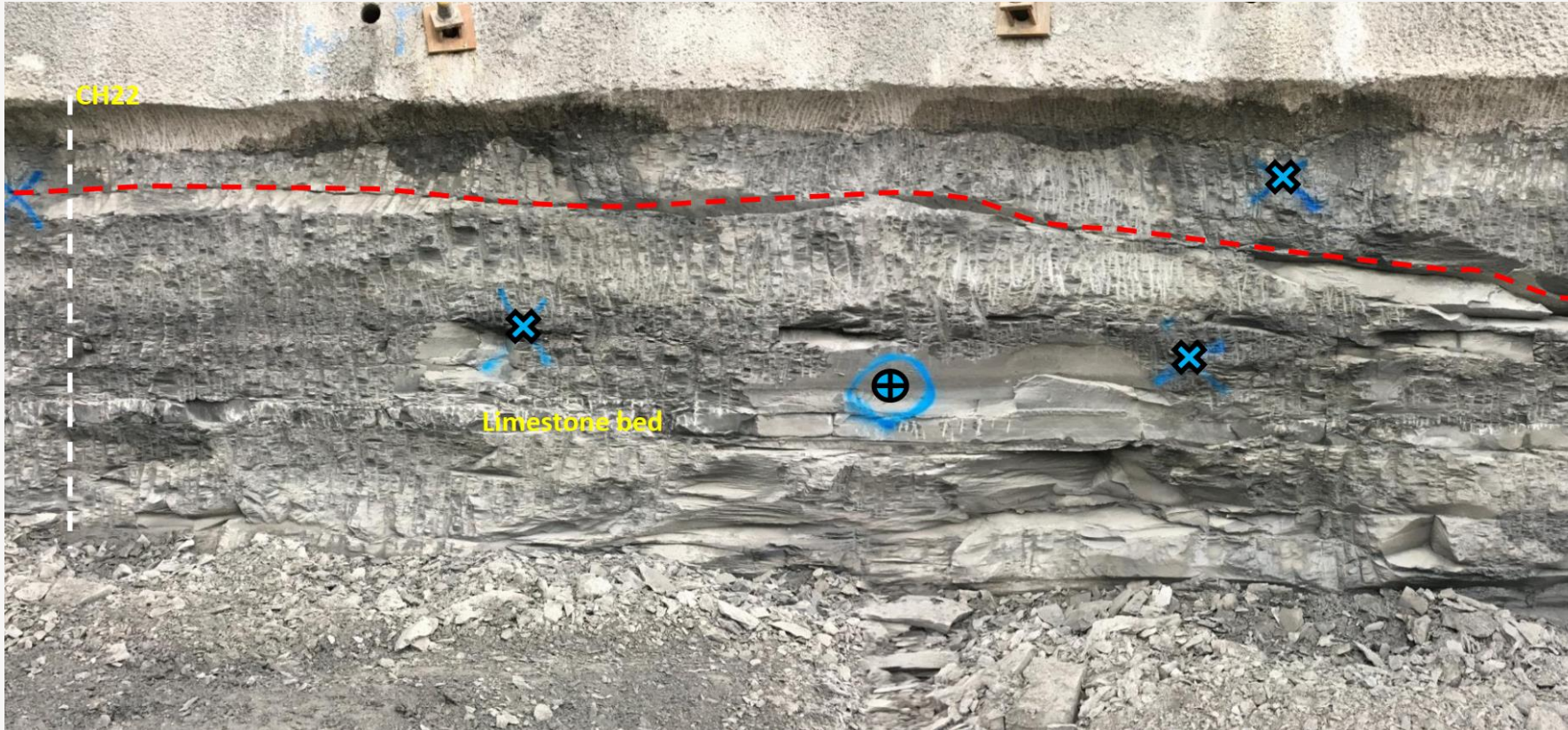


# Geology





# Geology



Interbedded units of calcareous MUDSTONE and LIMESTONE. Very weak to weak Calcareous Mudstone makes up most of the cut faces and is interbedded with medium strong to strong LIMESTONE.

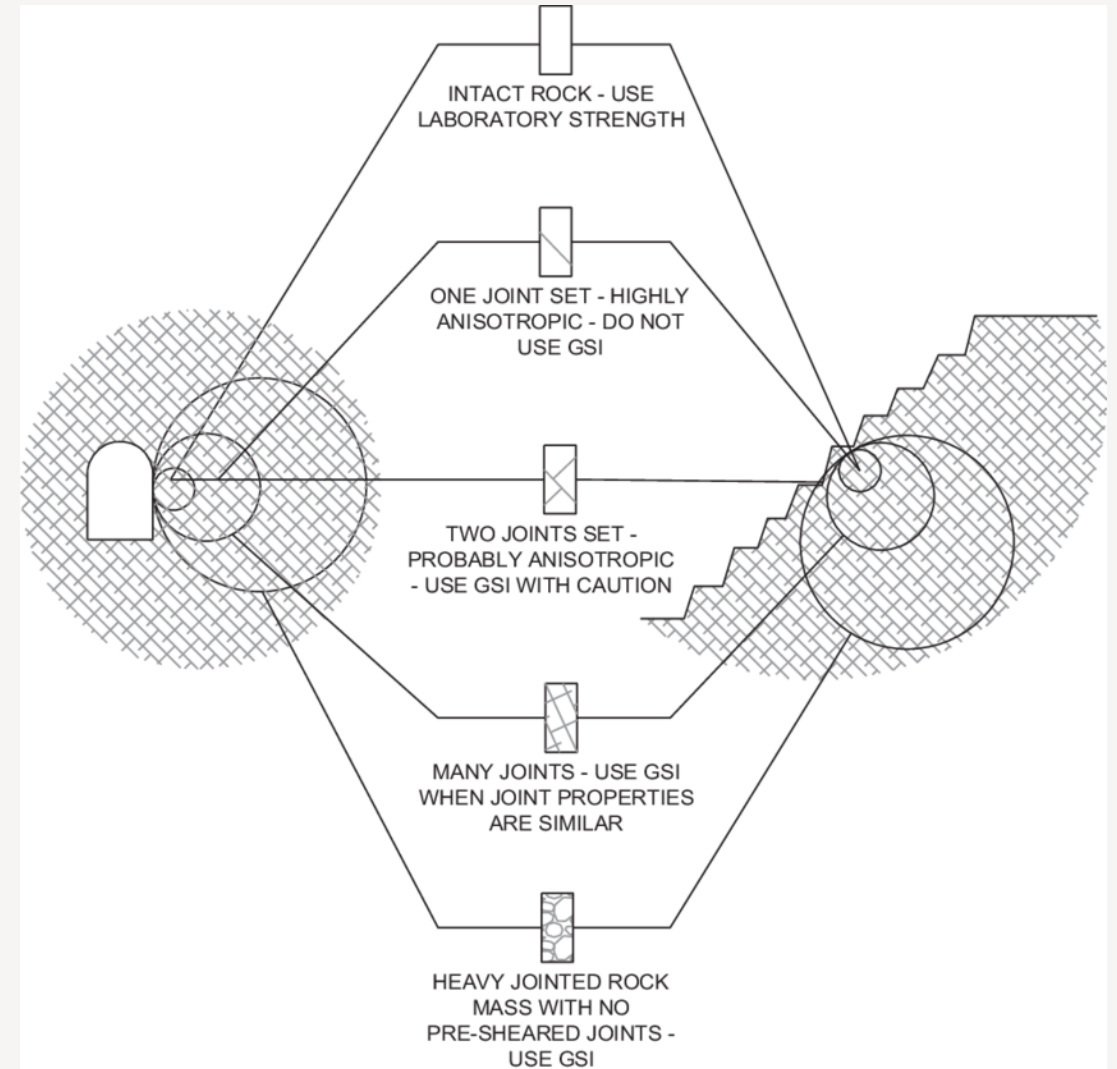


# Parameter Derivation

## Rock Mass Parameters

- › Hoek-Brown rock mass strength criterion
- › GSI selected from logging or previous reports
- ›  $E_m$  derived using the recommendations of Hoek and Diederichs (2006)

$$E_{rm} = E_i \left( 0.02 + \frac{1 - D/2}{1 + e^{((60+15D-GSI)/11)}} \right)$$



# Parameter Derivation

## Rock Mass Parameters

- › Hoek-Brown rock mass strength criterion
- › GSI selected from logging or previous reports
- ›  $E_m$  calculated derived using the recommendations of Hoek and Diederichs (2006)

$$E_{rm} = E_i \left( 0.02 + \frac{1 - D/2}{1 + e^{((60+15D-GSI)/11)}} \right)$$

- › Disturbance factor of 0.5 was applied to a depth of 1m

Table 4.6 Guidelines for estimating disturbance factor  $D$




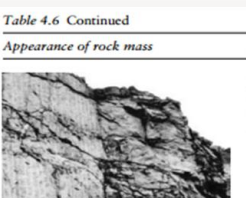
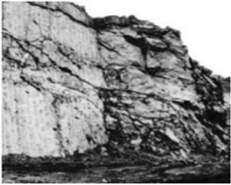

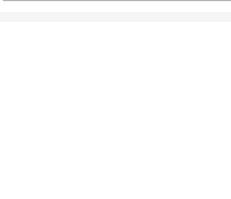
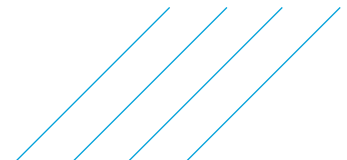
Appearance of rock mass	Description of rock mass	Suggested value of $D$
	Excellent quality controlled blasting or excavation by Tunnel Boring Machine results in minimal disturbance to the confined rock mass surrounding a tunnel.	$D = 0$
	Mechanical or hand excavation in poor quality rock masses (no blasting) results in minimal disturbance to the surrounding rock mass.	$D = 0$
	Where squeezing problems result in significant floor heave, disturbance can be severe unless a temporary invert, as shown in the photograph, is placed.	$D = 0.5$ No invert
	Very poor quality blasting in a hard rock tunnel results in severe local damage, extending 2 or 3 m, in the surrounding rock mass.	$D = 0.8$

Table 4.6 Continued

Appearance of rock mass	Description of rock mass	Suggested value of $D$
	Small-scale blasting in civil engineering slopes results in modest rock mass damage, particularly if controlled blasting is used as shown on the left hand side of the photograph. However, stress relief results in some disturbance.	$D = 0.7$ Good blasting $D = 1.0$ Poor blasting
	Very large open pit mine slopes suffer significant disturbance due to heavy production blasting, and also due to stress relief from overburden removal.	$D = 1.0$ Production blasting
	In some softer rocks, excavation can be carried out by ripping and dozing, and the degree of damage to the slopes is less.	$D = 0.7$ Mechanical excavation





# Parameter Derivation

## Rock Mass Parameters

- › Hoek-Brown rock mass strength criterion
- › GSI selected from logging or previous reports
- ›  $E_m$  calculated derived using the recommendations of Hoek and Diederichs (2006)

$$E_{rm} = E_i \left( 0.02 + \frac{1 - D/2}{1 + e^{((60+15D-GSI)/11)}} \right)$$

- › Disturbance factor of 0.5 was applied to a depth of 1m

Parameter		Source
Unit Weight (kN/m <sup>3</sup> )		Design study
Unconfined Compressive Strength, UCS (MPa)		Design study
Geological Strength Index, GSI		Logging / Design Study
Poisson's Ratio		Design Study
Intact Rock Stiffness, $E_i$ (MPa)		Design Study
Rock Mass Stiffness (MPa)		Calculated
Hoek brown material constants	$m_i$	Design Study
	$m_b$	Calculated
	$s$	Calculated
	$a$	Calculated



# Parameter Derivation

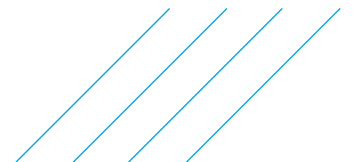
## Joint Strength Parameters

- › Barton-Bandis rock joint strength formulation
- › Joint stiffnesses calculated equations below

$$k_n = \frac{E_m E_r}{s (E_r - E_m)}$$

$$k_s = \frac{G_m G_r}{s (G_r - G_m)}$$

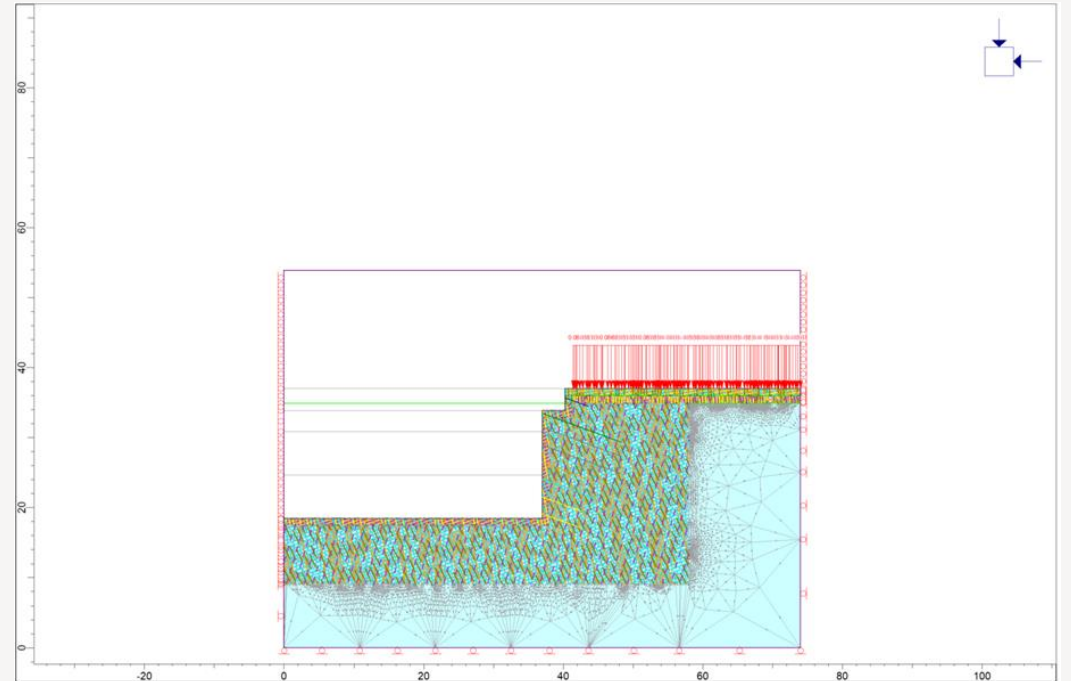
Joint Set			Source
Dip			Logging
Dip Direction			Logging
JRC			Logging
JCS			Design Study
Residual Friction Angle			Design Study
Spacing			Logging
Persistence			Logging
Joint Undisturbed	Normal	Stiffness	Calculated
Joint Disturbed	Shear	Stiffness	Calculated



# Numerical Modelling

## Key Points:

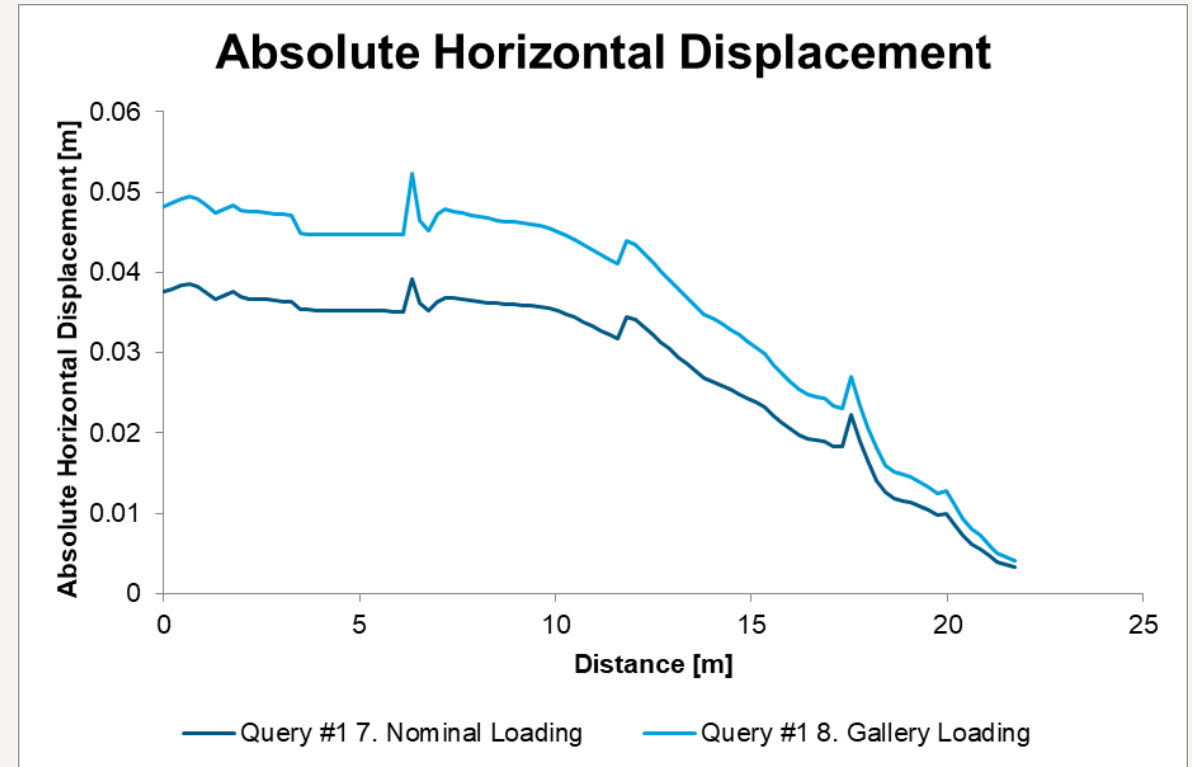
- › 2D model
- › No groundwater modelled
- › 4 material zones with 4 joint sets
- › Modelled in stages to replicate excavation sequence
- › Support consisting of fully bonded rock dowels wished in place
- › Shotcrete not modelled as primary purpose is to prevent weathering of excavated face
- › Area of focus modelled as a discontinuum with extents modelled as a continuum





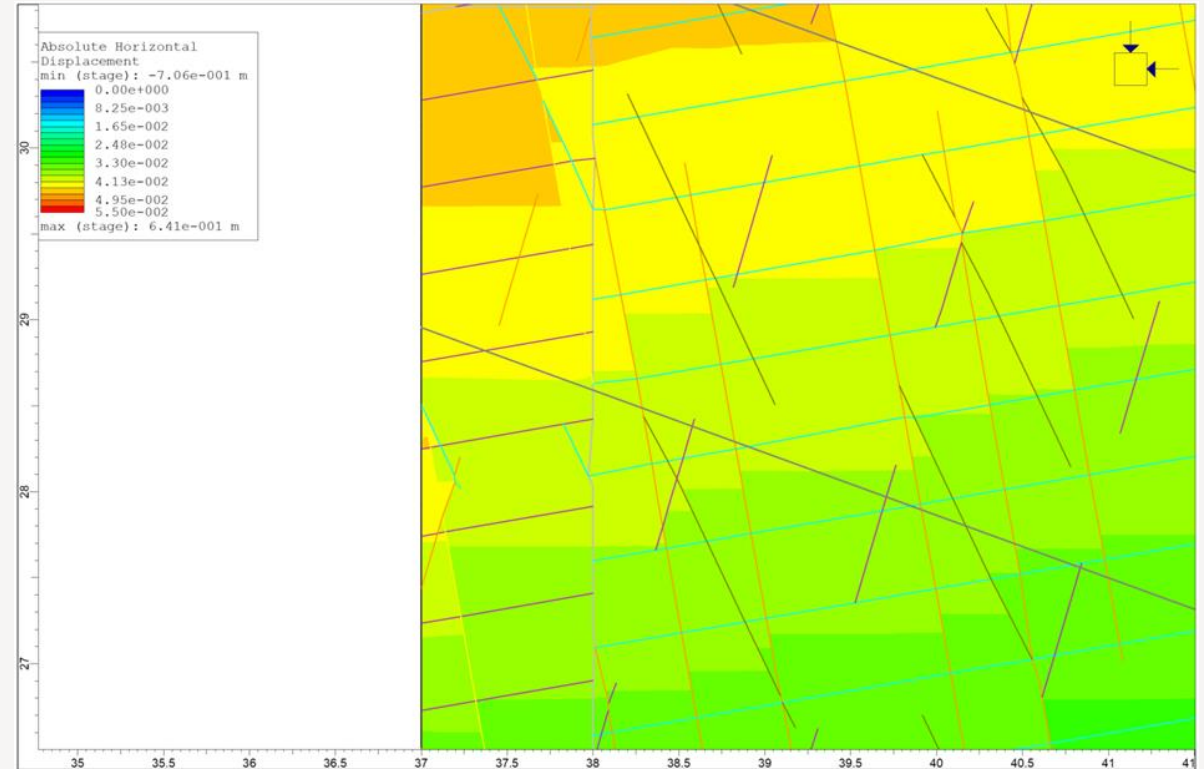
# Results

- › Differential horizontal displacement upon loading was less than 13mm
- › Bolt capacity utilisation less than 100% for all



# Results

- › Differential horizontal displacement upon loading was less than 13mm
- › Bolt capacity utilisation less than 100% for all



# Any Questions?

Contact: [Hamish.Strachan@atkinsglobal.com](mailto:Hamish.Strachan@atkinsglobal.com)

