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Connecting People

Geological works on EWR2

Kate Kendall

Simon Miles

Agenda

- Introduction
- Project Overview
- Geology of East West Rail Phase 2
- Geotechnical engineering solutions
- Q&A

Kate Kendall

- Engineering Geologist
- 8 years' at AtkinsRéalis
- EWR2 from 2016-2023
  - Ground Investigation & Interpretation
  - Trackbed Design
  - Site Delivery

Simon Miles

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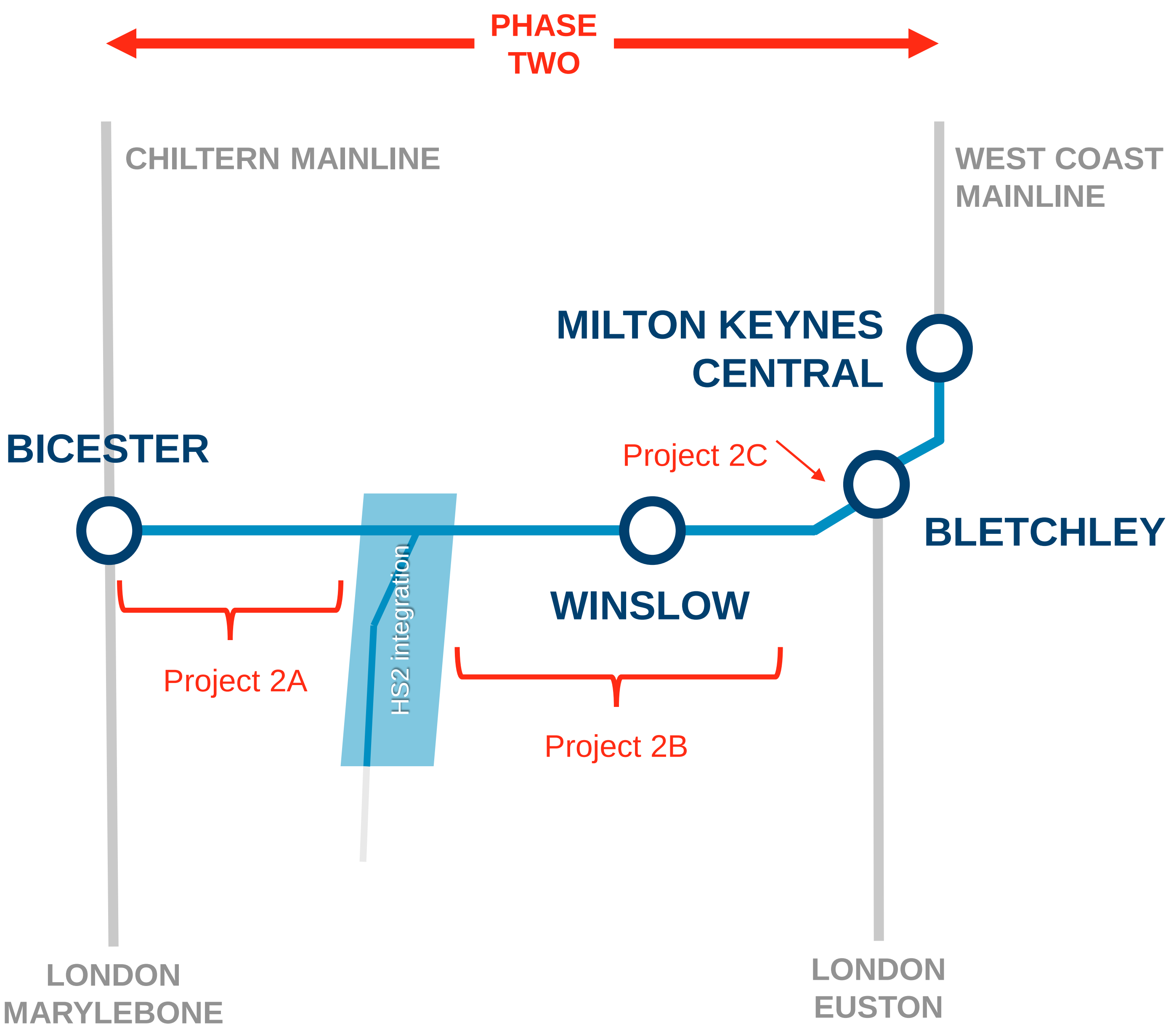
- Geotechnical Engineer
- 26 years at AtkinsRéalis
- EWR2 from 2021-present
  - Site design team supporting project delivery
    - Earthworks
    - Trackbed
    - Design Change/ Engineering challenge
    - Asset Handover

Project Overview



Project Scope

Permanent Works:

- 1million cu.m earthworks
- 70km new track & drainage
- 2 new stations
- 5 new overbridges
- 12 new footbridges
- 5 bridges with new deck
- 22 refurb bridges
- Bletchley Flyover rebuild
- 130km new fencing

Enabling Works:

- 360 hectares permanent land take
- 110 hectares temporary land take
- Construction logistics:
- 35km of site construction
- 12 construction compounds
- 150 highway interventions

EWR2 Project Programme Summary – February2024

2A	HS2	2B	2C

2019	2020	2021	2022	2023	2024

Early works
(Land purchase, highways, de-vegetation)

Project Area 2A - Civil

2A Track

SP&C Install

Project Area 2B - Civil

2B Track

Project Area 2C - Civil

2C Track

HS2 - Civil

HS2 (2A) Track

SP&C Install test and commission

EWR2 Programme Management

TWAO Feb 2020

HS2 Give Nov 2023

Entry into Service Activities

NetworkRail

east west RAIL




General Works Photos

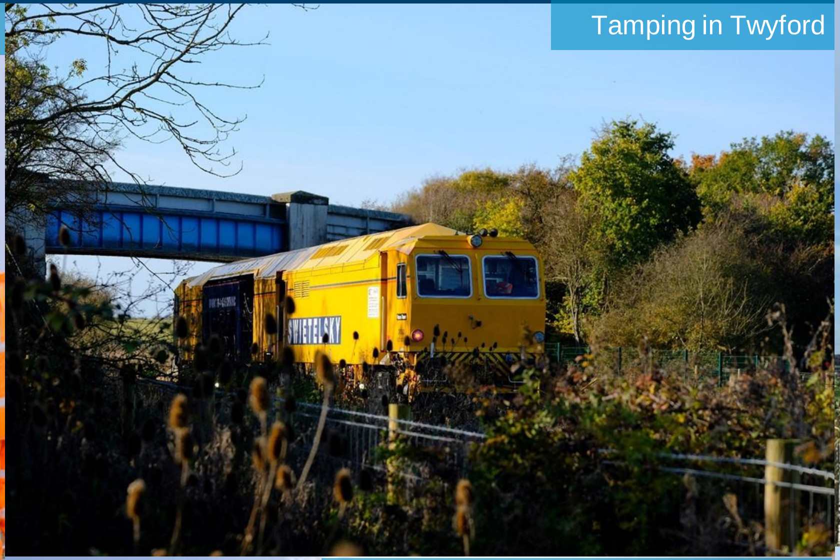


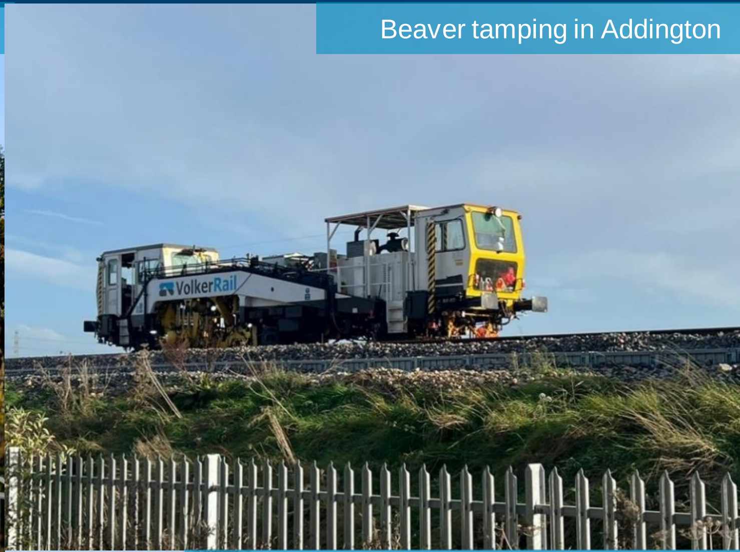

Track Progress

66km installed

%Track Installation (rail on sleepers): 100%

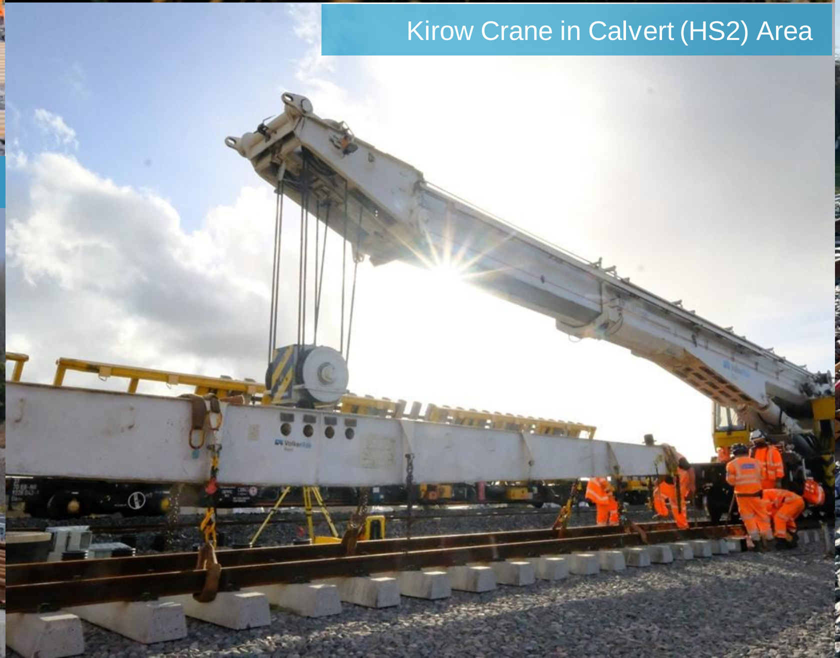

Final NTC shift in Calvert


Tamping in Twyford



Beaver tamping in Addington

Tilting wagons in Calvert (HS2) Area


Kirow Crane in Calvert (HS2) Area


Welding and stressing in the Calvert area

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Geology of East West Rail Phase 2

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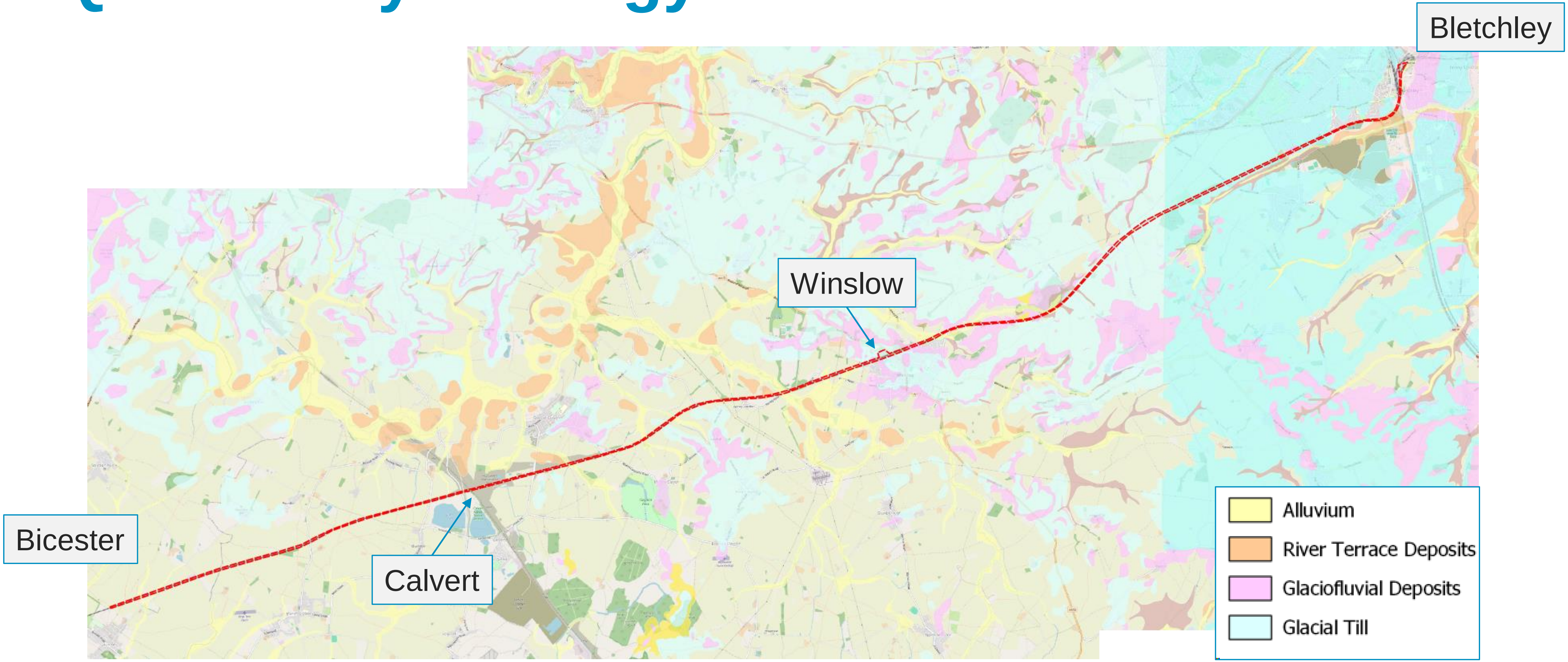
Bedrock Geology

Quaternary Geology



Historic Railway

Historic Railway

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Ground Investigation

Investigation Type	Number – GRIP3 (Historic)	Number – GRIP4 & GRIP5	Total Investigation
Automatic Ballast Sample	-	70	70
Cable Percussion	55	-	55
Dynamic Cone Penetrometer	-	46	46
Dynamic Probe	380	469	849
Dynamic Sample	-	20	20
Dynamic Sample with Rotary Core	-	84	84
Rotary Core	5	9	14
Trial Pit	50	599	649
Window Sample	414	305	719

Ground Investigation

Investigation Type	Number – GRIP3 (Historic)	Number – GRIP4 & GRIP5	Total Investigation
Multichannel Analysis of Surface Waves (MASW)	-	4	4
Refraction Microtremor (ReMi)	-	4	4
Ground Penetrating Radar (GPR) – for Trackbed	-	Along Section 2B Trackbed	-

Monitoring Type	Number – GRIP3 (Historic)	Number – GRIP4 & GRIP5	Total Investigation
Inclinometer	-	12	12
Groundwater	59 (Historic boreholes monitored during GRIP 4)	59	118
Ground Gas	-	59	59
Vibrating Wire Piezometer	-	6	6

Ground Investigation

Ground Investigation

Ground Investigation

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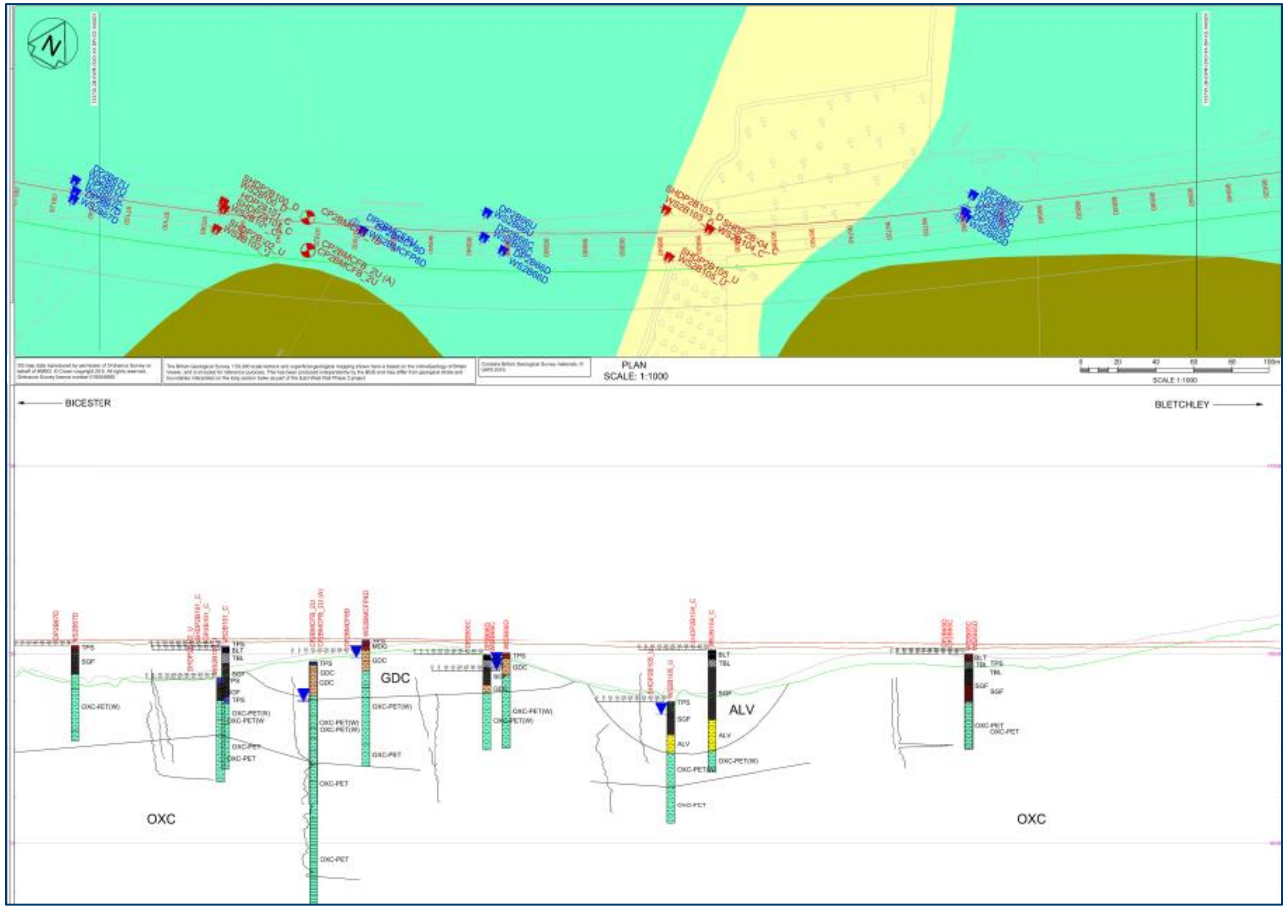
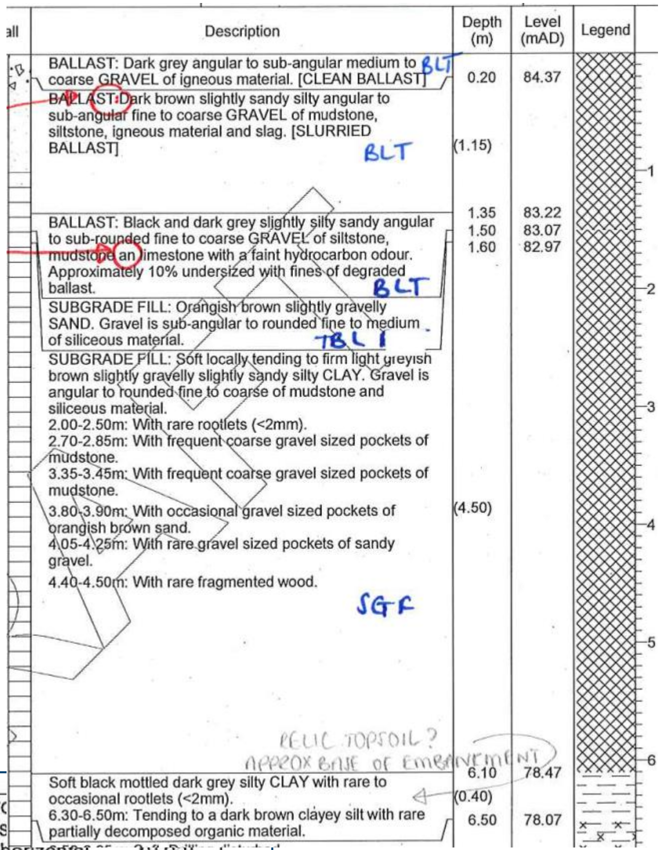
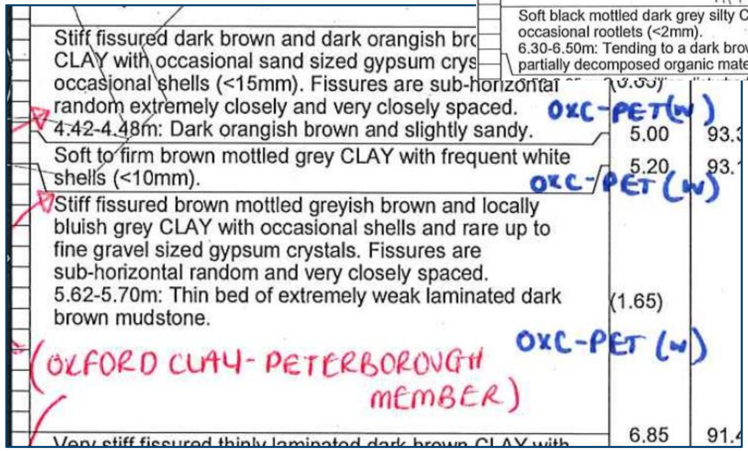
Geological Interpretation





Description	Depth (m)	Level (mAD)	Legend
BALLAST: Dark grey angular to sub-angular medium to coarse GRAVEL of igneous material. [CLEAN BALLAST]	0.20	84.37	
BALLAST: Dark brown slightly sandy silty angular to sub-angular fine to coarse GRAVEL of mudstone, siltstone, igneous material and slag. [SLURRIED BALLAST]	(1.15)		
	1.35	83.22	
BALLAST: Black and dark grey slightly silty sandy angular to sub-rounded fine to coarse GRAVEL of siltstone, mudstone an limestone with a faint hydrocarbon odour. Approximately 10% undersized with fines of degraded ballast.	1.50	83.07	
SUBGRADE FILL: Orangish brown slightly gravelly SAND. Gravel is sub-angular to rounded fine to medium of siliceous material.	1.60	82.97	
SUBGRADE FILL: Soft locally tending to firm light greyish brown slightly gravelly slightly sandy silty CLAY. Gravel is angular to rounded fine to coarse of mudstone and siliceous material. 2.00-2.50m: With rare rootlets (<2mm). 2.70-2.85m: With frequent coarse gravel sized pockets of mudstone. 3.35-3.45m: With frequent coarse gravel sized pockets of mudstone. 3.80-3.90m: With occasional gravel sized pockets of orangish brown sand. 4.05-4.25m: With rare gravel sized pockets of sandy gravel. 4.40-4.50m: With rare fragmented wood.	(4.50)		
Soft black mottled dark grey silty CLAY with rare to occasional rootlets (<2mm). 6.30-6.50m: Tending to a dark brown clayey silt with rare partially decomposed organic material.	6.10 (0.40) 6.50	78.47 78.07	

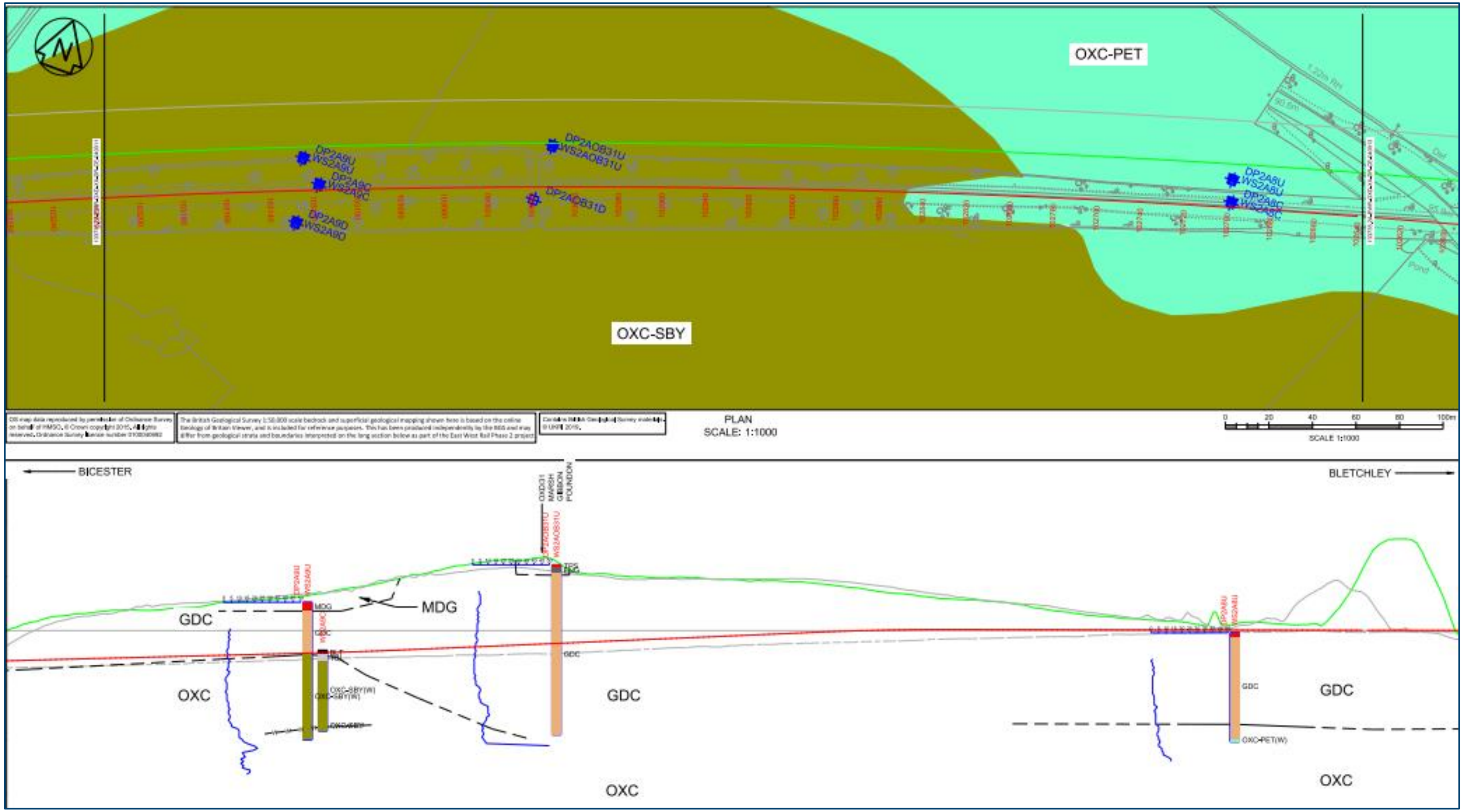


Stiff fissured dark brown and dark orangish bro CLAY with occasional sand sized gypsum crys occasional shells (<15mm). Fissures are sub-horizontal random extremely closely and very closely spaced. 4.42-4.48m: Dark orangish brown and slightly sandy.	5.00	93.3
Soft to firm brown mottled grey CLAY with frequent white shells (<10mm).	5.20	93.1
Stiff fissured brown mottled greyish brown and locally bluish grey CLAY with occasional shells and rare up to fine gravel sized gypsum crystals. Fissures are sub-horizontal random and very closely spaced. 5.62-5.70m: Thin bed of extremely weak laminated dark brown mudstone.	(1.65)	
	6.85	91.4
Very stiff fissured thinly laminated dark brown CLAY with		

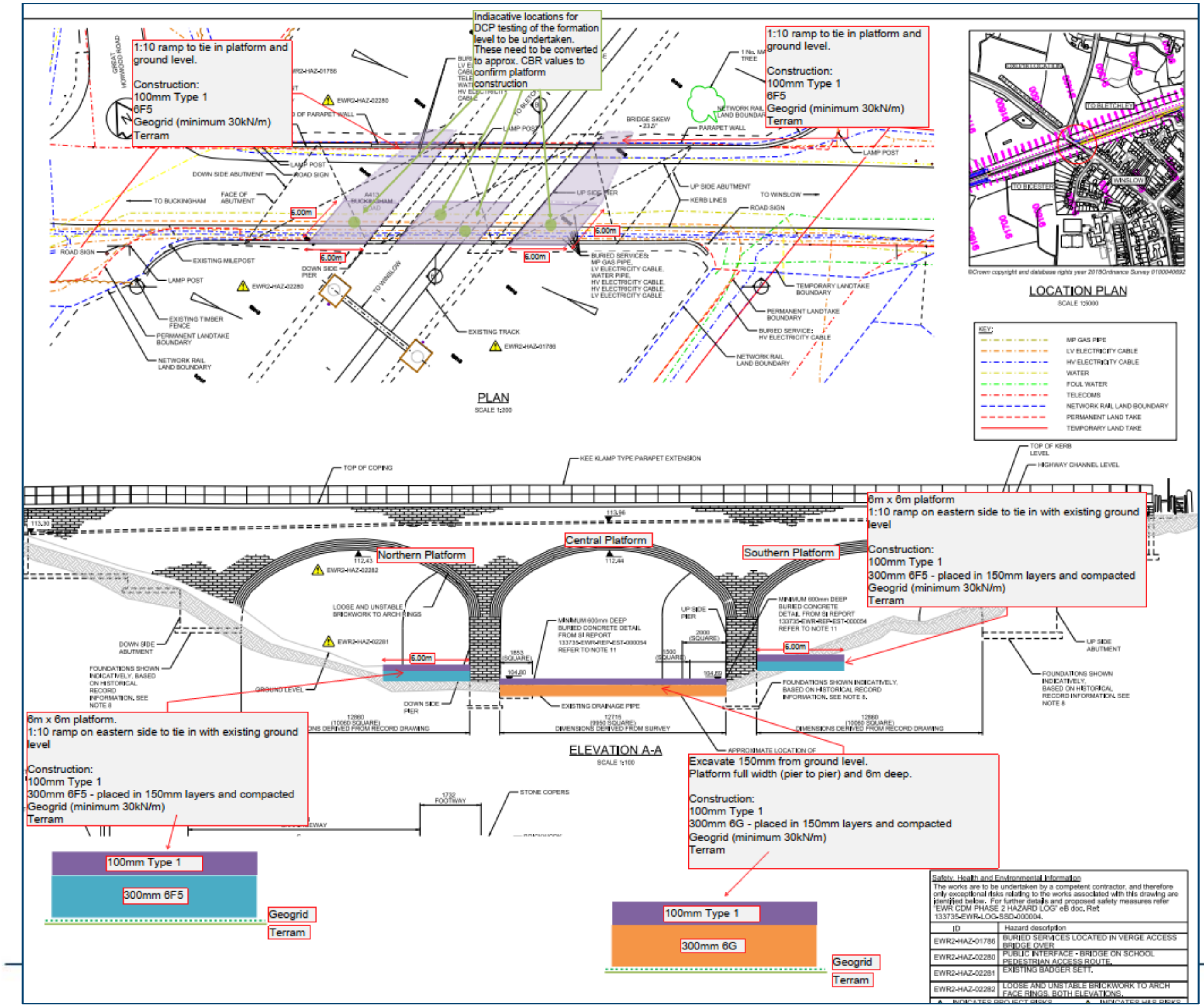
Geological Interpretation

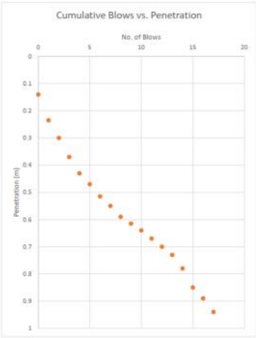
Strata	Regional Thickness (m)	Maximum thickness (m)
Alluvium	< 3	4.80
River Terrace	< 5	2.40
Head	< 3	2.00
Glaciofluvial	< 30	5.35
Glacial – Granular		1.30
Glacial - Cohesive		5.25 to 21.45 (significantly thicker in Section 2B)
West Walton Formation	10 to 15	6.45
Oxford Clay Formation	62 to 67	>29.00
Kellaways Sand Member	2 to 5	4.60
Kellaways Clay Member	1 to 4	3.40
Cornbrash Formation	1 to 4	5.10
Forest Marble Formation	2 to 7	6.45
White Limestone Formation	7 to 18	11.10
Rutland Formation	2 to 12	Not proven

Geological Interpretation



Geological Interpretation





North 21/12/2020

	Penetration	Cumulative blows	mm/blow	CBR (Kleyn)	CBR (CS 229)
Layer 1	290	4	72.5	1.78	3.26
Layer 2	260	8	32.5	4.93	7.62
Layer 3	160	3	53.33	2.63	4.51

CumulativeBlows	Penetration	DynamicConePenetrometerGeneral.Zero Reading	Correction	Plot curve	(mm/blow)	CBR Following up to date Kleyn (i.e. 410*(mm/blow)^(-1.27))	CBR Following CS 229 (i.e 10^((2.48-1.057*LOG10(mm/blow))))
0	140		140	0.14	#DIV/0!	0.00	#DIV/0!
1	235		235	0.235	95.00	1.26	2.45
2	300		300	0.3	65.00	2.04	3.66
3	370		370	0.37	70.00	1.86	3.39
4	430		430	0.43	60.00	2.26	3.99
5	470		470	0.47	40.00	3.79	6.12
6	515		515	0.515	45.00	3.26	5.40
7	550		550	0.55	35.00	4.49	7.05
8	590		590	0.59	40.00	3.79	6.12
9	615		615	0.615	25.00	6.88	10.05
10	640		640	0.64	25.00	6.88	10.05
11	670		670	0.67	30.00	5.46	8.29
12	700		700	0.7	30.00	5.46	8.29
13	730		730	0.73	30.00	5.46	8.29
14	780		780	0.78	50.00	2.85	4.83
15	850		850	0.85	70.00	1.86	3.39
16	890		890	0.89	40.00	3.79	6.12
17	940		940	0.94	50.00	2.85	4.83

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Geotechnical engineering – challenges & solutions

Secretary of State's Challenge

Department for Transport

- Track alignment VfM exercise
  - Raise in cuttings
  - Lower on embankments
  - Horizontal adjustments to minimise impact on 3rd Parties
- Corridor x-section
  - Reduce the earthworks footprint;
    - Reduce cess level on embankment (520mm below rail)
    - Raise cess level in cutting (75mm above rail), and at-grade (170mm below rail)
    - Reduced offset to drainage
- Revised construction methodology
- Structures de/re-scoping
- Earthwork task and Finish

Design Principles

Treatment options apply to 'Earthworks' i.e. H >= 3m

A design fully compliant with NR/L3/CIV/071 & BS EN 1997-1:2004 was not achievable:

- economically prohibitive;
- excessive additional landtake.

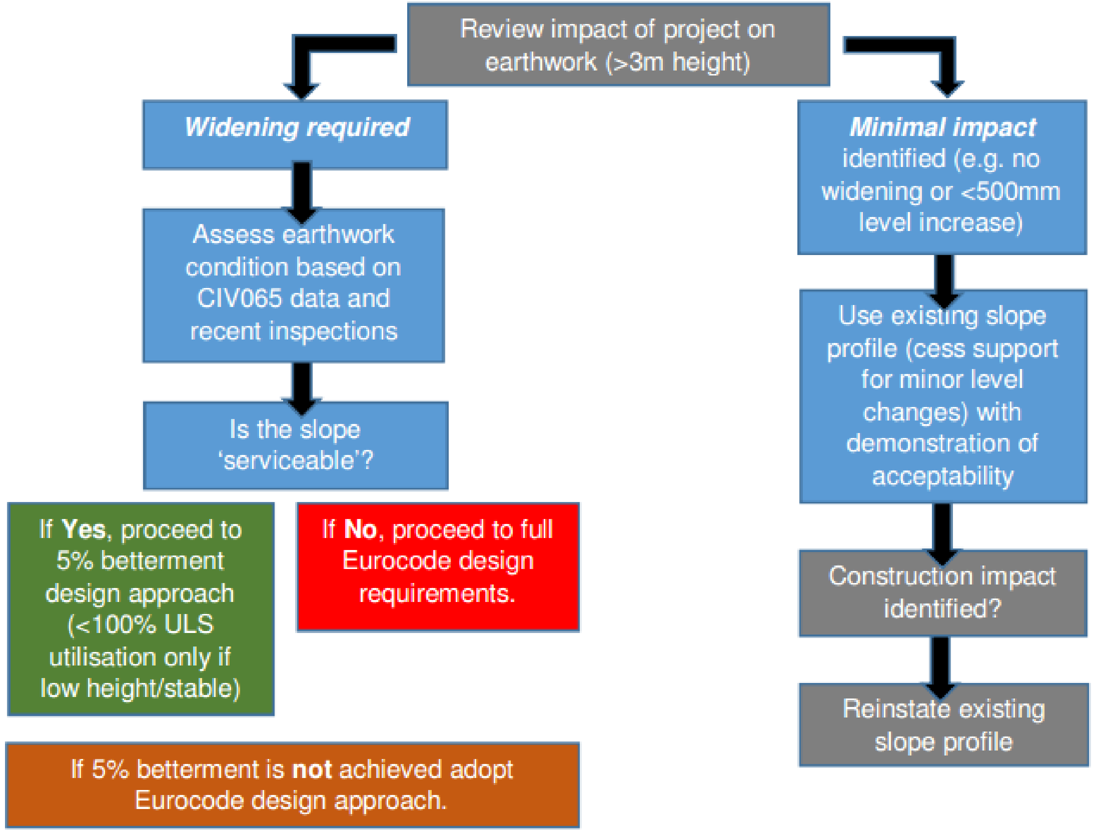
A 'betterment' approach adopted

- for 'serviceable' earthworks

A Eurocode compliant design adopted

- for 'marginal' or 'poor' earthworks

EHC classifications used to define 'poor' / 'marginal' / 'serviceable'

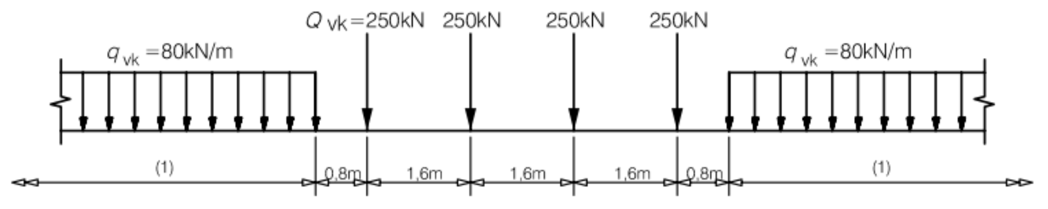


Design approach

Case	Does the proposed corridor/works impact the existing slopes?	Earthwork Condition	Proposed approach
Em-1	No	Serviceable	The slope is to be left untouched, i.e. no solution is to be provided.
Em-1a	No	Marginal	The slope is to be left untouched, provided that 'no worsening'** can be proven (>0% increase in SLS slope stability).
Em-2	No	Poor	A design with 5% betterment (>5% increase in SLS slope stability) is to be achieved.
Em-3	Yes	Serviceable	A design with 5% betterment (>5% increase in SLS slope stability) is to be achieved.
Em-4	Yes	Marginal/Poor	EC7 design compliance is to be achieved.

Case	Does the proposed corridor/works impact the existing slopes?	Earthwork Condition	Proposed approach
Ct-1	No	Serviceable/Marginal	The slope is to be left untouched, provided that 'no worsening' can be proven (>0% increase in SLS slope stability).
Ct-2	No	Poor	A design with 5% betterment (>5% increase in SLS slope stability) is to be achieved.
Ct-3	Yes	Serviceable	A design with 5% betterment (>5% increase in SLS slope stability) is to be achieved.
Ct-4	Yes	Marginal/Poor	EC7 design compliance is to be achieved.

LM71 Load Model:
Equivalent UDL of 57kPa
Cess loading of 10kPa



Key
(1) No limitation

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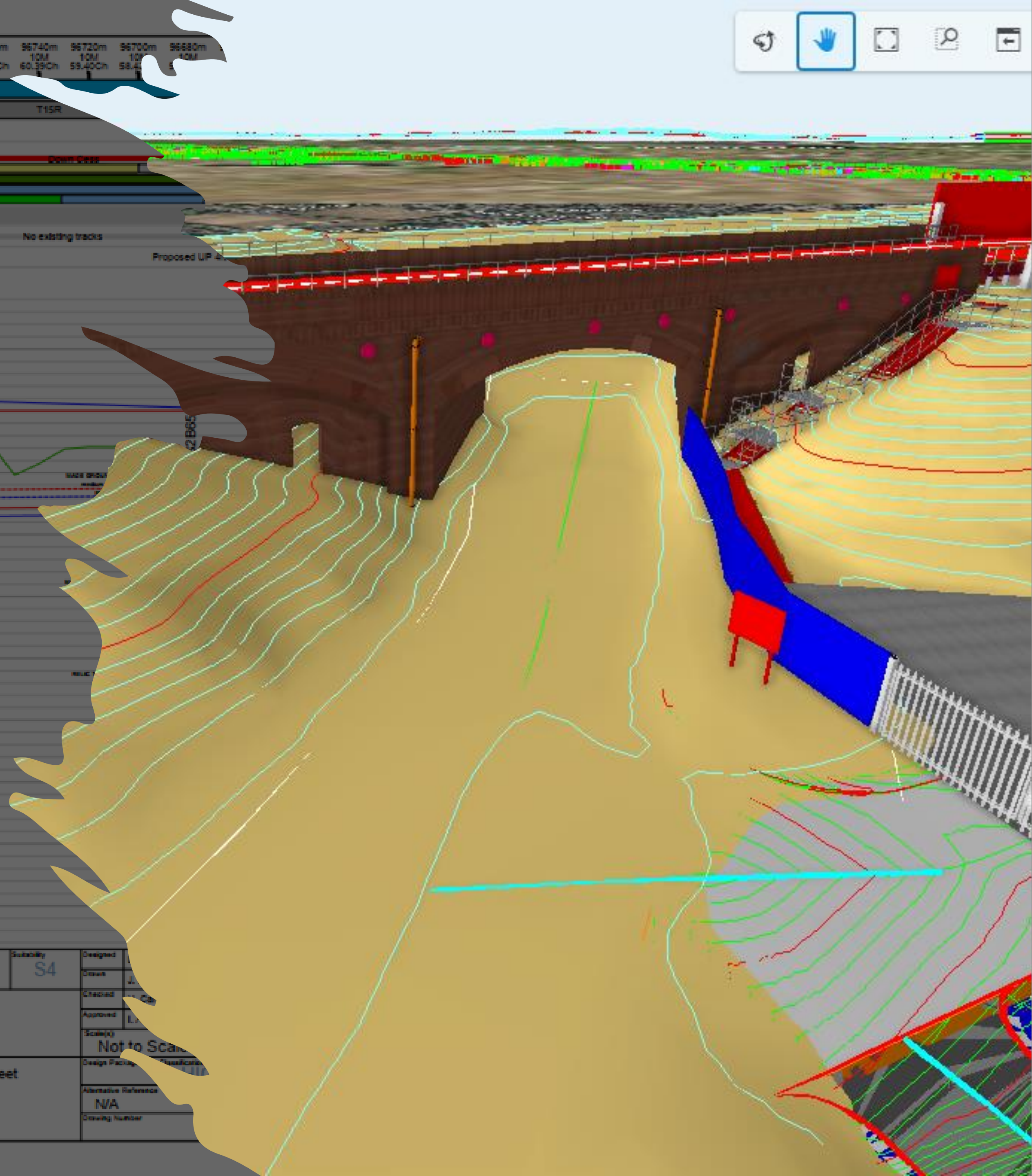
Digital Tools

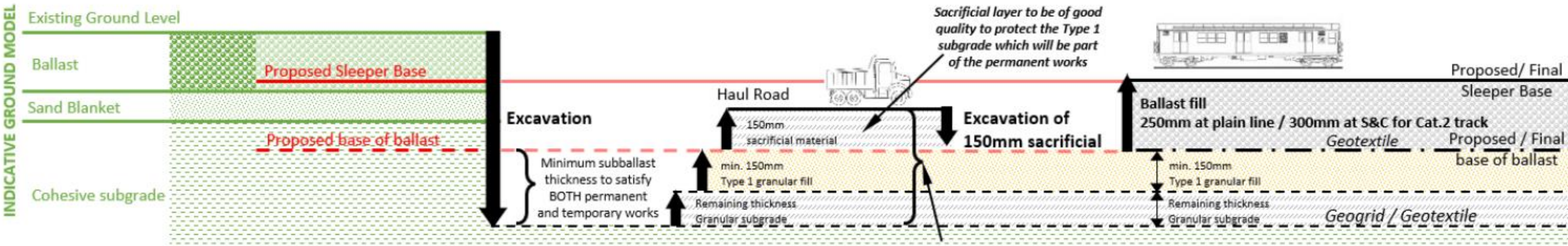
- Trackbed Design Summary Sheets combining GI/TBI data from HoleBASE, vertical alignment data from survey and trackbed condition/treatments from the design
- Bentley iModel (3D)
- Model controlled plant & setting out (surface levels & strings)



Trackbed

- For track category 1A; design speed 100mph
- GI/TBI informed subgrade stiffness;
- Standards determine required dynamic sleeper support stiffness, and ballast depth;
- Combined, these determine the required treatment for the foundation layers
- Existing subgrade – old trackbed over weathered clays -> got softer with depth!
- Also acts as the haul road
- Specification gave minimum surface stiffness to achieve.

Trackbed



1a

Subgrade CBR (%)	Subgrade Cu (kPa) [Cu=27.15*(CBR^0.586)]	Haul Road Section - Plain line: Minimum thickness requirement (mm)	Remaining thickness after 150mm sacrificial removal (mm)	Type 1 fill thickness (mm) FIXED	Subballast thickness below Type 1 fill (mm)	Roundup Subballast thickness below Type 1 fill (mm)	Total subbalast thickness for haul road ONLY (mm)
1.5	34.43	550	400	150	250	250	400
2	40.75	500	350	150	200	200	350
2.5	46.45	450	300	150	150	150	300
4	61.18	400	250	150	100	100	250
5	69.72	300	150	150	0	0	150

1b

Subgrade CBR (%)	Subgrade Cu (kPa) [Cu=27.15*(CBR^0.586)]	Trackbed All Sections - Plain line. For plain line, the minimum total thickness comprise: MINIMUM Total thickness of Granular Trackbed Layers (mm) [Fig.4, NR/L2/TRK/4239]	Ballast thickness (mm) FIXED	Type 1 fill thickness (mm) FIXED	Subballast thickness below Type 1 fill (mm)	Roundup Subballast thickness below Type 1 fill (mm)	Total subbalast thickness for trackbed ONLY (mm)
<1.5			250	150	500	500	650
1.5	34.43	630	250	150	230	250	400
2	40.75	590	250	150	190	200	350
2.5	46.45	550	250	150	150	150	300
4	61.18	470	250	150	70	100	250
5	69.72	410	250	150	10	0	150

2

Compare temporary and permanent minimum subballast requirement – *the minimum subballast requirement is 150mm*

3

Total subballast thickness for BOTH trackbed and haul road for Plain line for Section (mm)	Subballast below Type 1 fill for Plain line for Section (mm)
650	500
400	250
350	200
300	150
250	100
150	0

Trackbed

Treatments determined by design and confirmed on-site by DCP testing (CBR)

- Thickness ranged between 150mm (T15R) and 650mm (T65R – for soft subgrades) plus 250mm clean ballast, depending on expected subgrade condition
- All included at least one layer of geogrid reinforcement
- Transitions to structures treated separately

Should in situ CBR be less than design, then installed treatment was reassessed to suit.

Installed trackbed subject to confirmatory stiffness testing, with a target Formation Stiffness

Earthworks

- Cuttings
  - Examples of full-height regrades – equivalent to the full Eurocode compliant design for 'poor' condition earthworks where the works also impact the slopes.
  - Gives an idea of how much intervention some of these earthworks required to bring them up to an acceptable standard.

Earthworks

- Cuttings
  - Examples of partial regrades – equivalent to a 5% betterment design for ‘poor’ condition earthworks where the corridor doesn’t impact the slopes.

Earthworks

- Embankments
  - Examples of reconstruction – a brand new embankment fully Eurocode compliant;
  - And a cess regrade - equivalent to a 5% betterment design for ‘serviceable’ condition embankments where the corridor impacts the slopes (to widen the cess).
  - (Opposite you can just make out a cess retention wall – where a purely earthwork solution wouldn’t fit in the space constraint)

Structures

Existing structures

- Assessed for stability/gauging for new alignment, &
    - Left as is;
    - Demolished and replaced;
    - Strengthened (side arches infilled); or
    - Lifted - New conarch main spans

Structures

- New structures
  - Generally piled with precast shell abutments;
    - Piles into Oxford Clay;
    - Skin friction
  - One with ground bearing reinforced earth abutments
    - 3m depth of excavate/replace to give a firm foundation
    - Superficial deposits entirely removed

Engineering challenges

Ancient earthworks!

- Unstable embankment (OXD/24) - failed during construction
- About 150 years old
- Showed signs of having failed before – grout inclusions in the slipped mass

Cut face seepage

- Persistent seepage out of the slope, threatened instability of the earthwork – a danger to the railway
- Shallow sub-surface flow from the up hill catchment
- Solved with installation of very deep cut off drain at crest

Engineering challenges

Engineering challenges

Trackbed stiffness

Original specified stiffness: 45 MPa

- which generally couldn't be achieved.

A review of the Standards requirements reduced this to 30MPa, as measured by LWD:

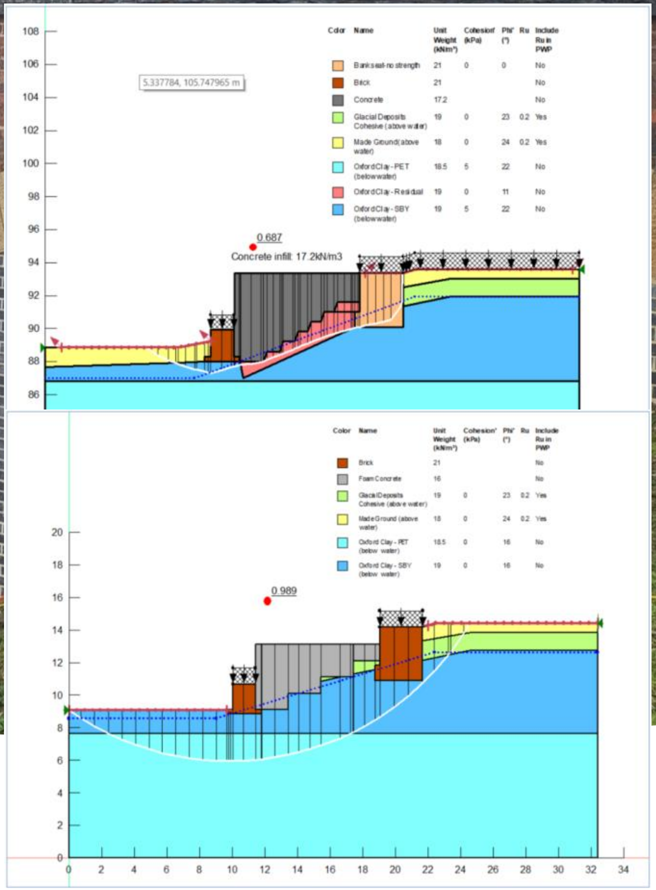
- NR/L2/TRK/2102 – requires Formation Stiffness = 45N/m
- NR/L2/TRK/4239 – requires Dynamic Sleeper Support Stiffness, K = 60 kN/mm/sleeper end;
  - BUT allows reducton to 30kN/mm/sleeper end if including geogrid reinforcement.
- NR/L2/TRK/4239 – states that K = 60 kN/mm/s-e is equivalent to Formation Stiffness = 30 MPa

It was also apparent that testing immediately after laying generally gave a lower stiffness than testing some days later – thought to be due to the beneficial effect of allowing excess PWP – generated during the laying and compaction - to dissipate.

Engineering challenges

Settlement of a bridge (OXD/24C)

- Greater than expected; For longer than anticipated
- Reinforced earth abutment, on 3m of dig&replace engineered fill
- Founded on Oxford Clay



Structural instability(OXD/29)

Engineering challenges

- Bridge constructed 1850; Strengthened by infilling side spans and placing a concrete saddle - to accommodate track lower; Founded on Oxford Clay
- Extensive cracking of the piers, spandrel walls, parapets and the main span arch – first observed 12 mths after trackbed works & 15mths after completion of bridge strengthening
- Circular or wedge failure; possibly on pre-existing slip surface

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Engineering challenges

Structural instability(OXD/29)

- 6 no. inclined ground anchors; 24m long, into Oxford Clay
- 7 No. inclined mini-piles; 12m long into Oxford Clay
- Connecting reinforced concrete capping beam dowelled into the brickwork

Q&A