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Design and construction of a geogrid reinforced soil wall using lightweight fill for Spalding Western Relief Road, Lincolnshire, East Anglia, UK (Paper 1 of 2)

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ABSTRACT: Lincolnshire County Council planned a new road to the northwest of Spalding, to provide a new route around the west of the town, to support new sustainable housing and commercial growth, improve journey times, reduce traffic congestion and carbon emissions, improve road user safety and encourage active travel. The new route crosses a key regional railway line, requiring a new bridge and approach embankments of around 10m in height. Further to funding being secured, an options appraisal was undertaken to develop a preferred form of embankment to support the carriageway. The site is situated in the Fenlands of East Anglia with ground conditions comprising very soft marine clays with interbedded peat deposits to 10m depth, of very low shear strength. The challenge was to find a solution that would provide sufficient stability whilst minimising settlement of these highly compressible soils beneath the weight of the approach embankments. Various options were considered to deal with the poor soils including piled foundations and ground improvement techniques such as rigid inclusions. Various forms were considered for the bridge approach ramps including a cast in situ reinforced concrete U-shaped structure. Ultimately, the preferred solution chosen was to form the bridge approaches with a piled platform-supported flexible geogrid-reinforced modular block-faced retention system. To mitigate the effects of the embankment weight on the poor founding soils, a combination of lightweight aggregate (LWA) with conventional granular fill was adopted. This paper explores the various options considered and explains why the reinforced soil system was adopted for construction. Details of the design and construction of the reinforced soil wall is presented in a separate paper in this Conference (Paper 2). Construction commenced in 2022 and was largely complete by the end of 2024, proving to be a robust, aesthetically pleasing, cost-effective and low-carbon solution.

KEYWORDS: Soft soils, lightweight aggregate, low carbon, piles.

1 INTRODUCTION

The purpose of this paper is to present the background to the selection of a geogrid-reinforced lightweight fill embankment to support a new road over very soft soil deposits in Spalding, Lincolnshire, East Anglia, UK (Figure 1). This paper is the first part of a two-paper submission describing the evolution of the selected option, its detailed design and construction. This paper presents the geotechnical conditions at the site and how this influenced the solution adopted by the client working collaboratively with the designer, contractor and specialist geogrid designer/supplier to identify a solution that could satisfy design codes, incorporate value engineering opportunities to reduce costs, be built within programme and which aimed to reduce embodied carbon wherever possible.

Figure 1. Site location (Google Earth image)

2 PROJECT BACKGROUND

2.1 *Site location*

Section 5 of the Spalding Western Relief Road (SWRR) scheme is flat lying in the main with the exception of the open drainage ditches which form field boundaries in many cases. The site is bounded by a waterway to the south called Vernatt's Drain, part of the Fenland drainage system. Existing elevation of the ground surface along the alignment is between approximately 2.2 and 4.0 m OD. Figure 2 presents the general layout.

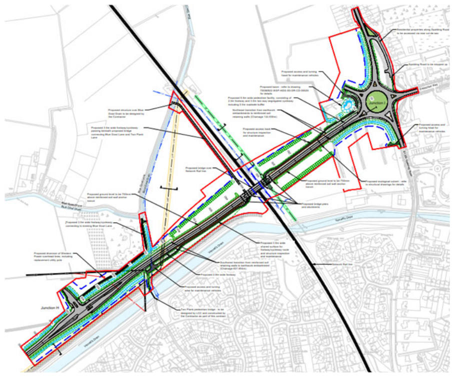

Figure 2. Section 5 of Spalding Western Relief Road

2.2 *Scheme background*

As part of the South East Lincolnshire Local Plan 2017 (WSP, 2019a) "all development proposals [are] required to demonstrate that the consequences of current climate change [have] been addressed, minimised and mitigated." Furthermore, landscaping was required to provide a more aesthetically pleasing aspect of the bridge and approach embankments, which would be a dominant feature of the surrounding landscape.

Once funding had been secured, Lincolnshire County Council (LCC) appointed WSP as consultant to develop the design and Eurovia Infrastructure as Principal Contractor to provide construction, buildability and cost advice to inform the design at an early stage. Once reinforced soil was identified as the preferred option, Tensar (a Division of CMC) were engaged by Eurovia to provide design and supply of a geogrid-reinforced soil wall solution.

3 GROUND CONDITIONS

3.1 *General*

The typical ground conditions across the site are a heterogenous sequence of marine, estuarine and terrestrial deposits of the Fenland Formation overlying bedrock of the Oxford Clay Formation (Weymouth Member), formed of pale grey calcareous mudstones with thin, dark grey carbonaceous beds.

3.2 *Superficial deposits*

The Fenland Formation comprises varying thicknesses of Terrington Beds (marine alluvium of sandy silt, sand and clay), the Barroway Drove Beds (soft grey silty clays), Fen Lower Peat (discontinuous across the site) and Abbey Sand and Gravel (fluvially-deposited clayey sands and gravels). The predominant deposit is the Barroway Drove Beds (see Table 1).

Substantial ground investigation was undertaken in 2019-2020 to further understand the ground conditions and derive parameters suitable to support the developing design, which included a campaign of cone penetrometer testing. Data from across the site is presented in Figure 3.

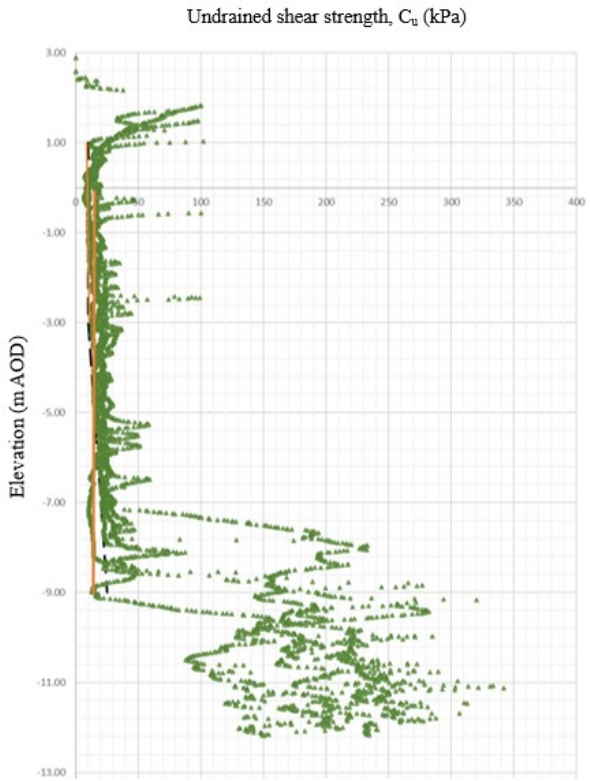

Figure 3. Undrained shear strength correlated from CPT results

3.3 *Bedrock geology*

The bedrock underlying the entirety of the site is the Weymouth Member of the Oxford Clay Formation (Middle to Upper Jurassic age), described as a pale grey, calcareous smooth mudstone (WSP, 2019b). A weathered upper layer of approximately 3.5m thickness is typically present, differentiated from the underlying Oxford Clay primarily based on its colour (light orangish brown rather than light grey) and consistency (firm to stiff' compared to 'stiff to very stiff').

3.4 *Groundwater*

Groundwater depths are typically 1.3-2.8m below ground level (bgl), within the Terrington Beds and contained within deeper granular lenses; and for design purposes groundwater was taken as 0.5m bgl.

3.5 *Design ground model*

The ground model adopted for design is summarised in Table 1 below, with associated characteristic material parameters in Table 2.

Table 1. Ground model.

Parameter	Surface level (m)	Base level (m)	Thickness (m)
Terrington Beds	3.00	1.50	1.50
Barroway Drove Beds	1.50	-8.00	9.50
Fen Lower Peat	-8.00	-9.00	1.00
Oxford Clay (weathered)	-9.00	-12.50	3.50
Oxford Clay	-12.50	unproven	unproven

Table 2. Characteristic parameters.

Stratum	Bulk unit weight, γ (kN/m^3)	Angle of shearing resistance, φ_{pk}' (°)	Undrained shear strength, S_u (kPa)[1]	Drained Young's modulus, E' (MPa)[1]
Terrington Beds	17.0	25.0	20.0	3.0
Barroway Drove Beds	16.0	21.0	10+z	2+0.25z
Fen Lower Peat	11.0	12.0	5	0.5
Oxford Clay (weathered)	21.0	25.0	60+35z	14+8z
Oxford Clay	22.0	23.0	150+15z	50+3z

[1] 'z' is depth beneath top of stratum

4 DESIGN CONCEPTS

Due to the new relief road having to cross the Spalding to Sleaford railway line, a new bridge was required, with western and eastern approach ramps, to provide sufficient gauge clearances between deck soffit and rail levels for the safe passage of trains. The bridge is 90m long, of a 3-span semi-integral articulation, with two piers and simply-supported abutments, requiring approach embankments up to 9m in height. A view of the bridge is shown in Figure 4.

Figure 4. Railway bridge in construction

Conventional weight earthworks with unreinforced side slopes leading up to the bridge abutments would require a substantial footprint that would extend beyond the land boundaries made available by the client, impact Vernatt's Drain to the south and impart significant load upon the supporting ground (up to 180kPa of surcharge due to weight alone at the highest points). Given the high compressibility and low bearing resistance of the Barroway Drove Beds, alternatives were considered to reduce the weight of the embankments in combination with additional support to transfer load into more competent ground at depth.

4.1 *Ground improvement*

Whilst ground improvement options were considered at an early stage, e.g. rigid concrete inclusions installed via vibroflotation techniques, the very low shear strengths of the Barroway Drove Beds were considered to preclude their use due to likely excessive overbreak and bleeding of concrete before hardening due to poor confinement. It was considered at an early stage that the approach ramps would need to be supported by piles.

4.2 *Approach embankment options*

Several options were evaluated to identify a preferred solution considering technical constraints, cost, constructability, programme and environmental impact.

4.2.1 *Reinforced Concrete Retaining Wall*

Reinforced concrete (RC) retaining walls parallel to running lanes (Figure 5) were considered because they could be built independently of the backfill and allow steel beam installation for the main bridge spans to begin at the same time as wall construction, providing programme benefits over a reinforced soil wall that would need to be built upwards in continuous layers.

The backfill could be formed of either conventional Class 6N or lightweight fill; however, conventional fill increases loading and may cause greater differential settlement in the centre unless piled.

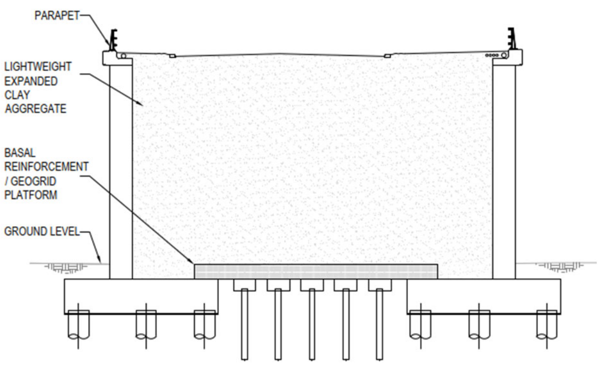

Figure 5. Reinforced concrete retaining walls

This option is somewhat more expensive than reinforced soil walls, but an early start on bridge construction could offset the longer programme. This solution has a relatively high embodied carbon demand.

4.2.2 *Reinforced concrete U-shaped wall*

A reinforced concrete U-shaped wall (Figure 6) could reduce the need for large diameter piles, and smaller (250mm square) piles for the embankment could be utilised. This option offers similar advantages to an RC wall. The backfill may consist of either conventional or lightweight fill; with the same implications as 4.2.1, thereby necessitating a greater number of piles beneath the approach embankment.

This alternative is more costly than the RS wall and requires a longer construction programme, however offers an early start to the main bridge works to mitigate the longer duration due to additional piling.

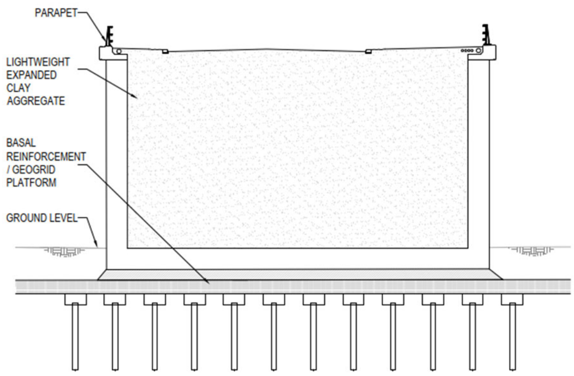

Figure 6. Reinforced concrete U-shaped wall

4.2.3 *Reinforced Soil Walls*

A reinforced soil wall (Figure 7) typically does not require a substantial foundation; however, a piled embankment was proposed beneath the approach to address poor ground conditions and to support the loads from the embankment fill and carriageway. The backfill is usually UK Specification for Highways (National Highways, 2020) Class 6I/6J fill but using lightweight fill could reduce the number of piles needed beneath the approach embankment (discussed in 4.3 below).

This option requires a ground beam at the carriageway level to support the parapets. Construction works for the main bridge and wall could not be simultaneous in this project, especially adjacent to the RC abutments; hence would extend construction duration. This option offers the lowest capital cost, if there are no programme constraints.

Wall construction uses alternating layers of soil and reinforcement, such as geogrids, to form a stable, near-vertical face, typically with blockwork or concrete panels (Figure 7).

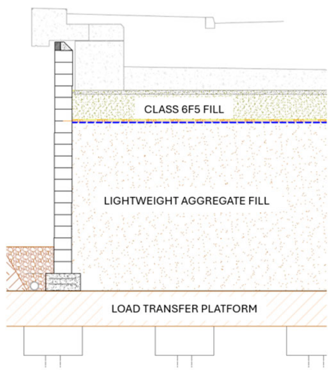

Figure 7. Reinforced soil wall (typical section)

This solution provides the lowest capital cost due to use of precast blocks and geogrids. These walls are recognised for their cost-efficiency, capacity to accommodate differential settlements, reduced carbon footprint and adaptability across a wide range of applications.

4.3 *Use of lightweight aggregate (LWA) fill*

In order to reduce the weight of the approach embankments, fill of reduced bulk density was required. Lightweight expanded clay aggregate (LWA) presented a viable option due to its intrinsic properties (an inert material of 75% lower unit weight than standard earthworks fill, i.e. γ=5kN/m^3) and its reduced compaction effort. The use of such fill would reduce the demand on the load transfer platform (LTP) and supporting piles. A comparison of pile layout and sizing was made to compare the piling demands of a standard weight embankment fill and a lightweight fill, based on a typical axial capacity of 500kN for a 250mm square section driven concrete pile, and from Section 8.3.3.4 of BS8006-1 (British Standards Institution, 2016), from equation 1:

$$s = \sqrt{\frac{Q_p}{\gamma H + w_s}} \tag{1}$$

where: s is the maximum permissible spacing
Q_p is the axial pile capacity (500kN)
γ is the representative unit weight of the fill
H is the height of the earthwork
w_s is the surcharge at surface (20kN/m^2)

Table 3. Maximum pile spacing for different fill types

Fill type	Unit weight, γ (kN/m^3)	Embankment Height, H (m)	Pile spacing, s (m)
Conventional	20	9.5	1.54
LWA	5	9.5	2.72
Conventional	20	4.0	2.23
LWA	5	4.0	3.54

For the carriageway width of 20m, use of LWA fill and a design pile grid spacing of 2.25m reduced the number of piles required by 550 per 100m length of the road, a reduction of ~40%. This offered substantial savings in cost, programme and embodied carbon.

5 VALUE ENGINEERING

A number of opportunities to reduce construction costs and programme duration were developed by the contractor, which included incorporating the working platform for pile installation into the permanent LTP and thickening of the LTP from 300mm to 600mm. A granular working platform was required from which to operate piling rigs for driven pile installation. Incorporating this into the permanent LTP offered several benefits: cost and time savings on removal of previously placed material, reduction in embankment height and easier placement of geogrids within the granular Class 6I/6J fill material.

The corollary to raising the LTP above ground level was to design an alternative anchorage for the transverse geogrids, and to provide additional fill on the outside of the reinforced soil walls: to bury the geogrid anchorage system and to provide protection against frost penetration at the base of the walls. In place of a buried anchor trench, a gabion was designed to run along the length of the wall (Figure 8).

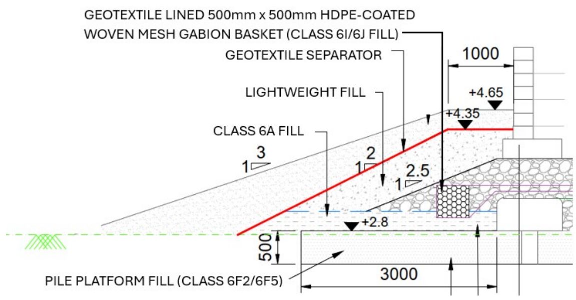

Figure 8. Raised load transfer platform with gabion anchorage

Raising the LTP, whilst involving some additional costs (longer piles, additional fill on the outside of the reinforced soil walls) offered a reduction in installation time of ~4 weeks and provided cost savings of ~85% on this aspect of construction. A permissible initial reinforcement strain of 4% and creep strain of 2% was designed for. For the highest section of embankment, a ULS tensile resistance, $T_{D(ULS)}$, of 670kN/m and SLS tensile resistance, $T_{D(SLS)}$, of 220kN/m was required. To promote the full mobilisation of tension within the geogrid reinforcement, the scheme specification required the inclusion of a thin initial loose compressible layer of soil placed between the pile caps directly beneath the reinforcement.

To optimise the pile design further, two preliminary sacrificial piles were specified and subjected to maintained load testing. The total resistance determined by the analysis of the static load test results compared to the pile design in ULS demonstrated that the installed piles had a 17-18% higher ultimate resistance.

Figure 9. Finished pile layout (pile caps visible, 2.5m spacing)

6 CONCLUSIONS

The selected solution involved a detailed understanding of the ground conditions at the site that precluded direct loading due to the extensive deposits of soft soils (marine clays). The use of lightweight aggregate (LWA) fill, although not covered by the UK Specification for Highway Works (National Highways, 2020), offered a viable means of building 9m approach ramps to the railway bridge, providing reductions in the number of piles required and in geogrid demand (strength and coverage).

The preliminary options considered required open and collaborative relationships between client, contractor and designer, each appreciating (i) the technical constraints presented by the ground and existing sensitive infrastructure (e.g. the railway) at the site, and (ii) development of value engineering opportunities may offer immediate cost savings, e.g. raising the LTP; however careful consideration of the geotechnical implications is needed, such as an alternative geogrid anchorage and additional outer fill.

The selected form of approach ramp was designed to mitigate the environmental impact of the new road, and through thorough appraisal of opportunities with the client and contractor, realised substantial savings in cost, programme and embodied carbon. The detailed design of the reinforced soil walls and aspects of the LTP, and further discussion on carbon comparisons, are presented in the accompanying Paper 2.

7 ACKNOWLEDGEMENTS

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