Proceedings of the 21st ICSMGE, Vienna, Austria, 14 – 19 June 2026. Pistrol, Adam & Schweiger (eds.)
Published by: ÖGG, Austrian Society for Geomechanics, Salzburg, Austria, ISBN 978-3-9503898-4-5
https://doi.org/10.53243/ICSMGE2026-1492

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

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ABSTRACT: Lincolnshire County Council planned a new road, Spalding Western Relief Road (SWRR), to relieve traffic congestion, promote commercial growth, and support air quality improvement in Spalding town centre, Lincolnshire, UK. The new route crosses a key regional railway line, requiring a new bridge and up to 9m high retaining structures for approach embankments. The site investigation of the proposed bridge location revealed marine deposits with a high degree of variability in the foundation soil and constitute very soft clays with interbedded peat deposits to 10 m depth. Conventional approaches were considered to deal with the highly variable and poor ground conditions, including piled foundations and ground improvement techniques such as vibro-concrete columns and rigid inclusions. Various forms were considered for the approach embankments, including a cast-in-situ reinforced concrete structure. The weak ground conditions posed a challenge to design a solution for retaining walls that could meet the serviceability criteria of the adjacent bridge structure due to loading from a conventional granular embankment fill. Finally, the option of a modular block face, geogrid-reinforced soil wall supported by piled foundations with the combination of lightweight aggregate (LWA) as an alternative to granular fill reinforced with HDPE uniaxial geogrid was chosen for the 9m high retaining structures. The assessment of various alternatives and initial development of the preferred reinforced soil system are presented in a separate paper, also submitted in this Conference (Paper 1). The current paper summarises the successful design and construction of the permanent geogrid reinforced soil retaining walls for a 120-year design life, proving to be a robust, aesthetically pleasing, cost-effective, and low-carbon solution.

KEYWORDS: Reinforced soil wall, lightweight aggregate, foundation, low carbon.

1 INTRODUCTION

The SWRR project involves the construction of a new 6.5km road to the west of the town of Spalding, Lincolnshire, to support growth and to mitigate increasing traffic volumes through the town centre. The project comprises five different sections. The current paper covers the design and construction of two 160m long back-to-back, approximately 17m wide, approach ramps to a new bridge using geogrid-reinforced soil retaining structures for the proposed semi-integral bridge over the railway line for the SWRR-Section 5B Structure. Refer to Figure 1 showing an image of back-to-back approach ramps during construction. Paper 1 of the project covers geotechnical conditions at the site and how this influenced the solution adopted by the client and the current paper i.e. "Paper 2" focuses the successful design and construction of the permanent geogrid reinforced soil retaining walls for a 120-year design life.

Figure 1. LWA Fill and HDPE Geogrid

2 GROUND CONDITIONS

Paper 1 includes detailed ground conditions, related challenges and consideration of various options for retaining structures and their foundations. In brief, the ground conditions were quite complex under the footprint of the proposed ramp and are a heterogenous sequence of marine, estuarine and terrestrial deposits of the Fenland formation overlying bedrock of the Weymouth member of the Oxford Clay formation, formed of pale grey calcareous mudstones with thin, dark grey carbonaceous beds. The undrained shear strength of the very soft marine clays with interbedded peat deposits varied between 5 kPa to 20 kPa which clearly indicated the need for ground improvement to support the ~9m high retaining structure.

3 REINFORCED SOIL WALL SYSTEM

Paper 1 explains various options for retaining structures and embankment fill for the proposed ramps of the new bridge structure. The Specification for Highway Works (SHW Series 600 Earthwoks) for the UK does not cover Light Weight Aggregate (LWA) fill to be used as reinforced fills, which makes them non-standard fill for such purposes. Considering previous UK experience by WSP and Tensar, and the established performance of the modular block face geogrid-reinforced soil wall system using LWA with HDPE geogrid as soil reinforcement, the client accepted the proposal to use LWA fill for the permanent structure. The chosen option for the project as an alternative to a pile-supported reinforced concrete wall was a geogrid reinforced soil wall system supported by driven concrete piles via a granular load transfer platform using high-strength geosynthetic reinforcement layers. The reinforced soil retaining wall option also reduced the overall height from 10 m to ~8 m as the foundation depth of the reinforced soil retaining structure was reduced by over 2 m during the optioneering stage (discussed in Paper 1). Components of the reinforced soil system are explained below.

3.1 *Reinforced and Retained Fill*

LWA was considered as reinforced and retained fill for the approach ramps to reduce the load on the piled foundation. Figure 2 shows the 10/20 LWA fill, and HDPE geogrid soil reinforcement used in the project. LWA is a granular ceramic material made from natural clay. The clay is mixed with organic material, dried and is expanded to 4–5 times its original volume in rotary kilns at temperatures of about 1,150°C. The output lightweight expanded clay aggregate granules, in the range 0-32 mm, are sieved and blended into different grades of products and distributed in bulk or in bags. Each granule has a hard ceramic shell that surrounds a honeycomb core. Geotechnical properties of the LWA fill considered for the design are listed in Table 1.

Figure 2. LWA Fill and HDPE Geogrid

3.2 *Soil Reinforcement-HDPE Geogrid and Modular Block facings*

The RE500 uniaxial geogrids used in the current project as soil reinforcing layers are stiff monolithic geogrids with integral junctions and are made from high density polyethylene (HDPE), are inert to all chemicals naturally found in soils and have no solvents at ambient temperature. They are not susceptible to hydrolysis, are resistant to aqueous solutions of salts, acids and alkalis (pH 2.0 to 12.5) and are non-biodegradable. These properties, including high connection capacity with facing units, make RE500 uniaxial geogrids a reliable soil reinforcement option for temporary and permanent structures up to a design life of 120 years, including bridge approach ramps such as those required for the SWRR project. Long-term design strength parameters are independently certified through HAPAS certification issued by the British Board of Agrément.

There are many types of facing units which can be used with HDPE soil reinforcement, such as precast concrete segmental panels, full height panels, steel mesh facing units, gabions and different types of modular concrete blocks. The current project utilised TW3 type concrete blocks which are 200mm high and achieve a nominal face angle of ~89.6°. The uniaxial geogrids are connected to facing units using mechanical polymer connectors (Figure 3), made of HDPE, resulting in a high level of load transfer efficiency at the grid-block connection at all levels rather than relying purely on frictional interaction. Also, all the successive courses of blocks are connected using glass reinforced polymer dowels (GRP) as shown in Figure 3. The concrete blocks meet requirements as specified in standard BS8006-1:2010+A1:2016 for UK highways schemes and design life of 120 years.

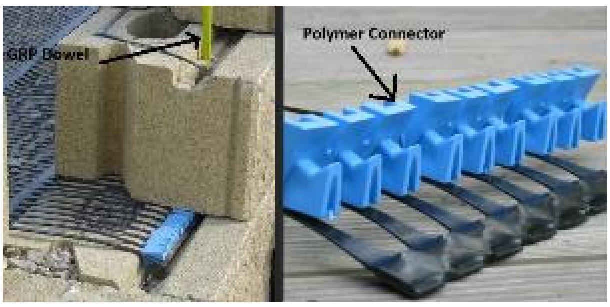

Figure 3. Facing Blocks showing GRP dowel, Polymer connector with HDPE Geogrid Reinforcement

4 DESIGN ASSESSMENT

The design of geogrid reinforced soil using LWA was assessed in accordance with BS 8006-1:2010+A1:2016 and carried out in two stages: external stability and internal stability, using geotechnical parameters as indicated in Table 1. The British standard is written in a limit state format and provides guidelines for partial material factors and load factors for various applications and design lives. Permanent structures in the UK are required to be designed for 120 years. The structure needed to satisfy the ultimate limit state (ULS) and serviceability limit state (SLS) criteria given in the standard for three different load cases (Table 1).

Table 1. LWA design parameters

Parameter	φ'	c’	γ
Unit	(°)	(kN/m^2)	(kN/m^3)
Reinforced Fill-LWA	37	0	3-5*
Retained Fill-LWA	37	0	3-5*
Foundation Soil	Piled Foundation (Stable and Competent)		

*Range of unit weight used for design purposes

4.1 *External Stability*

The external stability check of the system follows principles involved in earth retaining structures which cover the basic stability of the reinforced soil structures as a unit or block. This includes assessment of sliding resistance, bearing resistance and stability against overturning of the reinforced soil block. Figure 4 shows a typical section of the wall showing the length (L) of the soil reinforcement and mechanical height (H) of the structure. The ratio L/H often determines the extent of the reinforced fill zone. Using standard weight granular fill, the minimum criteria of L/H=0.7 given in the design standard is often more critical than the reinforcement length requirements to satisfy the sliding, overturning and bearing capacity stability criteria. The situation using LWA as fill material in this project was different and the required reinforcement length (L) to satisfy the sliding criteria exceeded the criteria of 0.7H due to its lower weight and consideration of traffic surcharge and vehicle parapet loading.

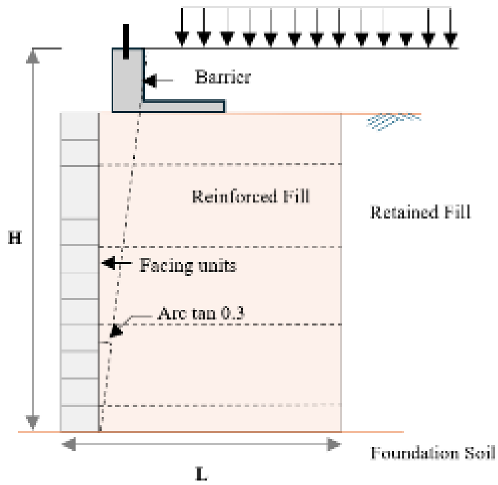

Figure 4. Typical section through reinforced soil wall

To avoid aggregate crushing of the LWA fill, the geogrid extent of each section was adjusted so that the maximum effective stress at the base of each wall did not exceed more than 100 kPa for permanent loading conditions. To facilitate concrete casting of the parapet slab (shown in Figure 5) and to avoid any lateral movement of the LWA layers, the upper section of the reinforced soil was designed with granular fill (UK Specification for Highway Works Class 6F5), resulting in two different sets of fill material for the retaining structures. Additional checks were carried out considering the lightweight fill material and project specific situations, which included loading from the 4.5m wide concrete parapet slab and weight of the 1.8m standard fill as shown in cross-section in Figure 5.

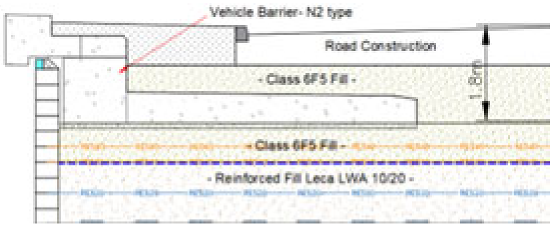

Figure 5. Vehicle barrier slab and fill boundary

4.2 *Internal stability*

Internal stability of the reinforced soil mass was assessed to calculate the required long-term design strength and spacing of the geogrid layers. The internal stability of the reinforced soil wall was carried out using the Tie-Back Wedge method as per BS8006-1:2010+A1:2016. To calculate forces within each geogrid layer, the method uses active earth pressure for both ULS and SLS criteria and are represented by a wedge of soil inclined at 45°-φ/2 from vertical (Refer to Figure 6). HDPE Geogrid reinforcement layers were checked for the following collapse mechanisms:

- Resistance to sliding (internal sliding)
- Stability of reinforcing elements (tensile rupture and adherence capacity/pull-out)

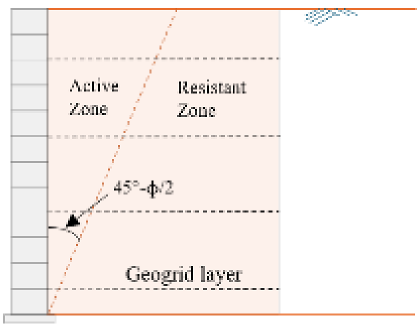

Figure 6. Rankine active failure wedge angle

The interaction between soil reinforcement layers and both LWA and standard granular fill was modelled two ways: direct sliding and bond (pull-out). Appropriate interaction factors, which are essentially a reduction factor to the soil shear strength to take account of the sliding on the reinforcement to soil interface, were applied based on previous experience. The internal stability layout was assessed for two different unit weight conditions, i.e. 3kN/m^3 and 5kN/m^3 to account for different tensile forces from higher and lower unit weights to address internal sliding and pull-out of reinforcement layers. The effect of unit weight of standard granular fill and LWA fill was assessed for a typical section height and project loading for stable and competent foundation. Figure 7 shows the tensile force comparison in ULS for both types of fills, suggesting the standard granular fill generates tensile forces over two times for the lower layers to reach a similar tensile force near the upper wall section. A similar trend was noted for the SLS criteria, showing the average post-construction strain in the reinforcement layers will be significantly lower when LWA fill is used. In brief, the long-term design strength of soil reinforcing layers is lower to satisfy the tensile rupture criteria, but it demands higher soil reinforcement length, often greater than 0.7H to satisfy pull out and sliding resistance. Finally, the detailed design and construction drawings submission were submitted for approval.

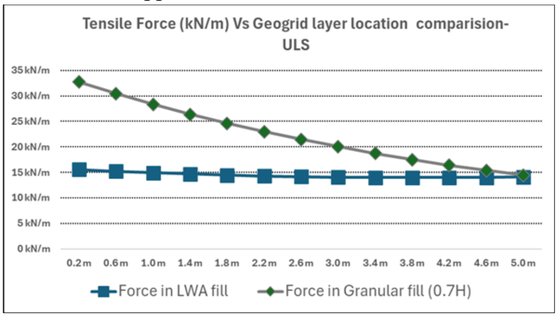

Figure 7. Tensile force comparison (kN) to location (m)

4.3 *Foundation Design*

Foundation for the reinforced soil wall structures comprised a load transfer platform (LTP) using two layers of high strength geosynthetic reinforcement layers, placed orthogonally within a 600mm thick Class 6I selected granular fill, supported by piled foundations. The LTP design was carried out in accordance with BS8006-1:2010+A1:2016 including global stability assessment. The Class 6I/6J fill was loosely placed between pile caps to promote sag of the transverse geosynthetic reinforcement to generate tension. Rotational failure of the reinforced soil block through the outer pile rows was not a specific limit state consideration (unlike sloped embankments) given the near-vertical faces of the reinforced soil embankment, with vertical load-shedding through the LTP directly to the piles beneath. Furthermore, a continuous gabion wall anchorage to the transverse geosynthetic reinforcement was built running the length of the embankment, and outer slopes built up beyond the walls above the base of the blockwork wall foundation, further mitigating against lateral forces at the edge.(Refer figure 8 of Paper 1 of 2) Following an initial assessment of pile capacity based on use of 250mm square precast driven piles with 1m square pile caps, the pile spacing and geosynthetic reinforcement arrangement were developed based upon the following limit states:

- ULS: pile group capacity, vertical load shedding onto pile caps, lateral sliding and tension in the reinforcement
- SLS: excessive strain of the reinforcement

Pile spacings were adjusted based on the design height, vertical pressure and ground conditions. The levelling pad below the modular block facing was designed to span between the pile cap spacing of 1.5 m below the load transfer platform as a conservative assessment.

5 CONSTRUCTION

The construction of the reinforced soil structure started once approval of the design was given by the client and following completion of the driven precast concrete piling and load transfer platform installation. The construction of a geogrid reinforced retaining modular block wall is a relatively straightforward and well-established process; however, the LWA fill placement needs careful attention and specific advice was sought from the LWA material producer to avoid any crushing of grains due to an incorrect compaction procedure. LWA fill material was placed by tipping and spreading using a tracked dozer or excavator. All spreading plants were tracked up to a maximum ground bearing pressure of 50kN/m². The restriction on maximum ground bearing pressure was to limit the potential surface crushing of the LWA compaction layer, and 3-4 passes of the tracked plant were adequate. Figure 8 shows LWA placement at the site.

Figure 8. Placement of LWA fill using tracked plant

The upper part of the reinforced soil wall section was constructed using Class 6F5 granular fill, directly beneath the concrete parapet and road pavement. The thickness of the granular material varied between 400mm to 600mm, considering compaction requirements and block height. A geotextile separator layer was used at the interface of LWA and Class 6F5 fill to avoid any intermixing of the two different fill material types. Considering the gradient of the approach embankment, the uppermost concrete blocks were replaced with 95 mm thick slip blocks to reduce the cutting of 300 mm thick concrete blocks, resulting in a reduction of concrete dust generation. The reinforced soil system allowed the design team to incorporate site-specific features such as the construction of a badger tunnel through the reinforced soil ramps, which helped reduce the structure's impact on the local ecosystem. As a part of the value engineering exercise, the level of LTP for the reinforced soil wall was raised. This created a level difference of 2 m between the top of LTP and the top of RC pile cap of the bridge abutment. Therefore, construction joints were provided at the interface of the RC bridge abutment and reinforced soil walls to mitigate differential settlement, considering and the difference in foundation stiffness between the LTP and adjacent cast in situ RC pile cap.

Figure 8. Badger tunnel construction

6 CARBON COMPARSION OF RC WALL VERSUS REINFORCED SOIL SOLUTION (MATERIAL COMPONENTS ONLY)

Paper 1 explained various options for the form of approach ramp retaining structure and its foundation. The design of the piled foundation using a standard weight granular fill material for the RC structure would have resulted in an impractical pile layout to transfer loads to competent strata at depth. It was not possible during the design stage to prepare a detailed comparison of total carbon demand between a RC retaining wall with a piled foundation, and a geogrid-reinforced retaining wall with lightweight aggregate for both types of retaining structure, whilst considering all the relevant aspects, i.e. reduced excavation, reduced disposal, reduced compaction, reduced temporary works and other construction activities. However, an approximate comparison was carried out for material savings for 9m high RC wall versus an 8m high reinforced soil wall. The difference of 1m in height for the 9 m high wall is due to the piling layout of the RC abutment. The author's calculation indicates a saving of more than 60% in structural concrete and 50% in steel reinforcement for the 9m high section. This equates to an estimated carbon saving of more than 50% that would arise from the material itself by considering only product stage A1 to A3 as explained in BS EN 17422:2022. The calculation does not consider construction activities which may likely increase the saving in carbon footprint, considering concrete pouring and use of machinery involved for RC construction compared to a reinforced soil wall.

7 CONCLUSION

The weak ground conditions posed a significant challenge to design a solution for retaining walls that could meet the serviceability criteria of the adjacent bridge structure. The open and collaborative relationships between client, contractor and designer at an early design stage, each appreciating the technical complexities presented by the ground conditions and impact on existing important infrastructure assets (e.g. the railway), resulted in the successful design and construction of a permanent geogrid reinforced soil retaining walls for a 120-year design life, meeting the local authority's planning requirements and mitigating the project's environmental impact; proving to be a robust, aesthetically pleasing, cost-effective, and low-carbon solution (Figure 9).

Figure 9. Completed Structure

8 ACKNOWLEDGEMENTS

The authors are grateful to Lincolnshire County Council and Eurovia Contracting for support in the project.

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