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Reinforced soil embankment for London's Heathrow Express Rail Link

G.R.Carter & J.H.Dixon
Netlon Limited, Blackburn, UK

R.C.Watts
Scott Wilson MainLine, Swindon, UK

ABSTRACT: A reinforced soil embankment has been constructed as part of a major railway junction for the Heathrow Express to the west of London. Environmental constraints led to the design of a 7m high embankment with a 5 in 1 (vertical:horizontal) side slope reinforced with high density polyethylene geogrids and faced with turf. This paper describes these environmental considerations and the design and construction of the reinforced soil embankment.

1 AIRPORT JUNCTION

Current journeys by underground railway or bus from central London to Heathrow Airport can take more than an hour. The Heathrow Express Rail Link will provide a fast and frequent alternative with journey times from Paddington Station to the Heathrow Central Terminal Area of sixteen minutes.

The project is a joint venture between British Rail and the British Airports Authority. Railtrack Major Projects is responsible for the project management of the 20km section of surface level track between Paddington and West Drayton including Airport Junction. Scott Wilson MainLine are the consultants responsible for the Civil Engineering and Permanent Way design and site supervision. The remaining 6km tunnel section which takes the line into the airport itself is the responsibility of the British Airports Authority.

The construction of Airport Junction was carried out by Tarmac Civil Engineering Ltd. At Airport Junction the Heathrow Express line diverges from the Great Western main line. In order to avoid disruption to the existing 200km/hr main lines the Heathrow Express traffic will be carried over them on a 90m long, 6m high reinforced concrete flyover.

The siting of the junction was influenced by the wish to reduce expensive tunnelling and the need to minimise the environmental impact of the works. The only practicable route from the main line southwards to the airport lay in a relatively undeveloped narrow corridor of land to the east of Stockley Road between Hayes and West Drayton (Figure 1).

The constraints of the site dictated that a ramp with a tight curvature of only 300m radius was required to take the line down from the flyover towards the tunnel portal.

2 SELECTION OF REINFORCED SOIL TECHNIQUE

The curved ramp is bounded on the east side by industrial development and on the west side by woodland and lakes. On the east side a vertical reinforced soil wall faced with concrete panels was chosen to retain part of the embankment where proximity to occupied buildings precluded a conventional embankment slope. On the west side, environmental considerations dictated the choice of embankment retention. The area is a Site of Metropolitan Importance, similar to a Site of Special Scientific Interest, in the midst of a largely urban area. Stockley Lakes, which were previously disused gravel pits, have become naturalised and are one of only four Kingfisher nesting sites in Metropolitan London. The lakes lie adjacent to, and partly along the line of the proposed embankment so sensitive treatment was required both to preserve this habitat and not disturb the ecological balance of the area.

The use of a steep faced reinforced soil embankment with a 5 in 1 (v:h) side slope, was chosen to reduce encroachment into the area of the lakes. By forming the embankment from locally dug gravels the natural chemistry of the lakes could be maintained in order to preserve fish and other pond

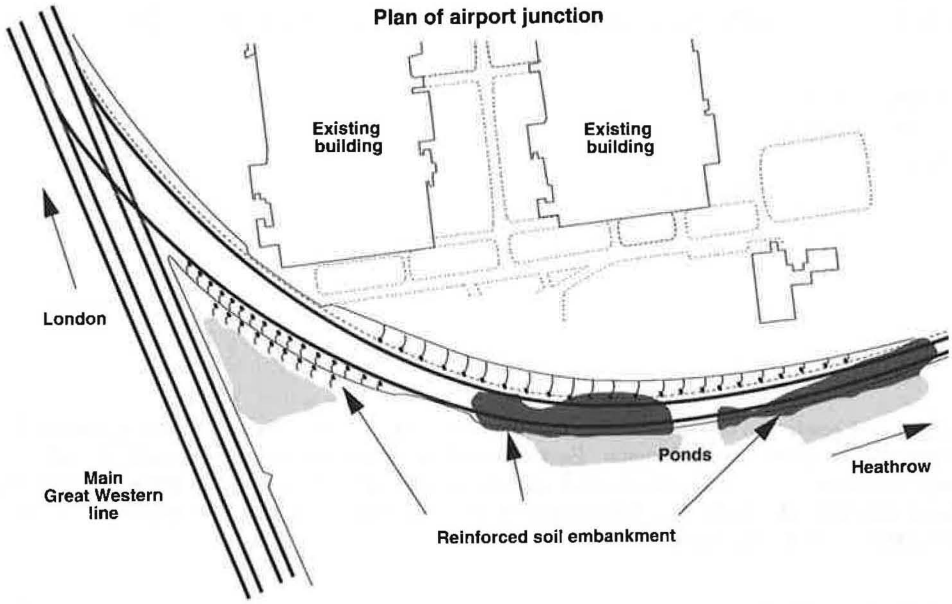


Figure 1

life. A turf facing was specified to minimise the visual impact of the embankment and to provide a medium on which plants and self set vegetation could establish in the longer term.

The loss of existing lake areas has been compensated for by the creation of a new lake on an area of isolated land in the triangle between the new ramp and the existing main line. Continuity of the trackside wildlife corridor has been maintained by constructing wildlife tunnels beneath the embankment.

The measures taken to preserve the environment at Stockley Lakes and the decision to use a reinforced soil embankment in this location were subject to scrutiny from a Parliamentary Select Committee at the planning stage. This would be the first time that steep sided reinforced soil embankments had been used to support a passenger railway in the United Kingdom.

3 EMBANKMENT DESIGN

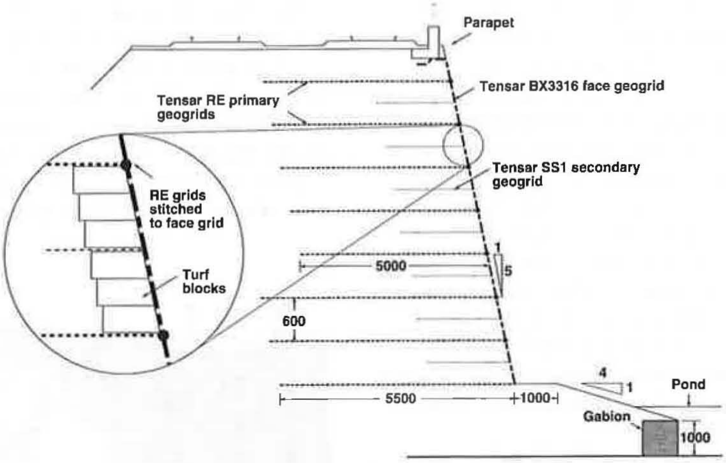
The design requirements set out by MainLine were for a contractor designed 7m high embankment with a 5 in 1 (v:h) slope face, formed from locally available as-raised gravels. High density polyethylene grids with a 120 year design life were specified as the soil reinforcement based on extensive testing (1) and on numerous reinforced soil structures constructed since 1980. The face support consisted of a grid with large apertures placed in front of a turf block liner to allow sufficient open space for vegetation growth.

The site is underlain by a medium dense deposit of sand and gravel overlying firm-stiff clay. The embankment was founded both on the natural sand and gravel deposit and on sand and gravel fill placed in the lakes.

Tarmac Civil Engineering awarded the contract for the embankment design and supply of grids to Netlon Limited based on the economics and buildability of their proposal.

A value of 35^0 for the constant volume (critical state) angle of internal friction, ϕ_{cv}, based on the client's site investigation information was assigned to both the granular embankment fill and the underlying sand and gravel foundation. The vertical live railway surcharge was taken to be $50kN/m^2$.

The external stability of the embankment to deep seated potential failure surfaces passing below and through and below and behind the reinforced zone was achieved using Netlon Limited's Tensar Reinforced Slope Design Program which is based on Bishop's Simplified Method of Slip Circle Analysis modified to take account of the restoring moment of each layer of reinforcement (2).



Typical section through reinforced soil embankment

Figure 2

Sliding along the base of the reinforced soil structure was checked to ensure a factor of safety in excess of 2 using Coulomb's equation and based on a coefficient of sliding interaction factor of 0.9 between the base grid and the granular fill and including a horizontal component of 30kN/m for the railway live load.

The internal stability of the reinforced soil embankment was achieved using the modified Bishop's Simplified Method. The design strength reinforcement of the primary grid was based on the creep limited tensile strength factored to account for the construction activity of placing and compacting fill. The in-service environment was considered benign to the high density polyethylene grids and no additional factors were required. The designed reinforcement layout was also checked for internal stability using a two-part wedge analysis.

A series of two-part wedges were examined with the lower part of the wedge originating at the structure face and passing through the block and the upper part of the wedge passing up the back face of the reinforced soil block. The active pressure above that point where the lower part of the wedge cuts the back face of the reinforced soil block, is added to the disturbing forces acting on the two-part wedge to give the total disturbing force.

Reinforcement must be provided to resist the disturbing force on each two-part wedge by intercepting the wedge being considered. The two-part wedge stability calculation was carried out from the toe of the structure and at the level where the primary grid type altered.

At the base of the embankment face a 1 in 4 (v:h) gradient slopes down to a 1m high gabion structure retaining the edge of the pond (Figure 2). In these areas the critical failure mode proved to be external stability with potential slip circles passing beneath the reinforced soil block and through the foundation, and so the length of the three lowest layers of grid reinforcement had to be increased to provide stability.

The internal stability requirements led to the adoption of Tensar 120RE and Tensar 80RE geogrids as primary reinforcement at 0.6m vertical centres. Creep limited tensile strengths of 50 and 33kN/m were used for these two grids in the design based on a 120 year design life and average in soil temperature of 10^0C. Tensar RE geogrids are uniaxial high density polyethylene grids which have been orientated in one direction by stretching during manufacture to produce a high strength in the direction of the roll length (Figure 3). They are supplied in 50m x 1.3m rolls.

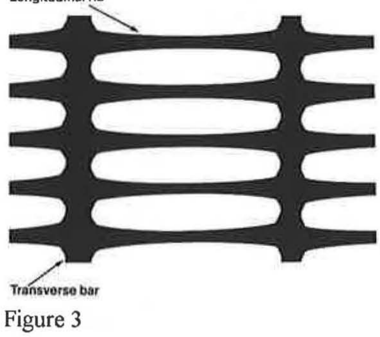


Figure 3

Short lengths of a lighter Tensar SS1, a biaxially orientated grid, were placed at intermediate locations between the primary grids to minimise face bulge.

Tensar BX3316, a biaxially orientated polypropylene grid supplied in 4m roll widths, was selected as the face support for two reasons. Firstly, the grid's geometry comfortably satisfied the design requirement as the aperture size is nominally 50mm x 50mm and it also has a high open aspect ratio i.e. aperture area:rib/node area, which is approximately 5:1. Secondly, this grid was originally developed for underground mining applications and is treated with a flame retardent which results in the product exhibiting self extinguishing behaviour when tested (3). It will therefore not spread flames away from any ignition source.

4 CONSTRUCTION

Prior to construction of the embankment the foundation was prepared by tipping sand and gravel directly into the lakes. A non-structural temporary sheet pile wall prevented disturbance and clouding of the main body of the lakes and eliminated the risk of damage to fish stocks and other aquatic life.

The large aperture size specified for the face support grid precluded the standard *wrap-around* grid face detail for steep vegetated reinforced soil slopes, whereby each layer of primary reinforcing grid is continued up the face, supported by temporary external formwork, and then returned horizontally back into the fill to overlap with the next layer above. This was not possible at Airport Junction because the aperture size of the primary grid reinforcement was too small.

A light, temporary scaffold with widely spaced boards was erected both to support the full height of the face grid, and to define the line of the embankment (Figure 4).

The uniaxial primary grid reinforcement layers were cut to the design length and laid horizontally onto compacted fill with their long axis running at right angles to the face. Connection between the horizontal primary reinforcement and the face grid was achieved by means of stitching with polyethylene braid (Figure 5), knotted off at 1.5m centres to prevent unravelling if a breakage occurs. Tensioning of the primary grid was carried out manually using a tensioning beam to remove slack from the face and from the grid prior to placing and compacting the granular fill (Figure 6). Adjacent strips of grid were butted together.

The 1m widths of secondary biaxial reinforcement were simply rolled out along the length of the embankment adjacent to the face. No face stitching was carried out on these grids.

The face was lined with turf for three reasons. Firstly, turf in the form of thick blocks or rolls provides an internal former against which to compact the fill, therefore eliminating the need for substantial external formwork. Secondly, it prevents the embankment fill from leaching out through the face

Figure 4

Figure 5

Figure 6

of the grid, and thirdly it provides a medium for establishment of a vegetated face in the long term. At first it was intended to use stacked turf blocks, at least 100mm thick and 200mm wide cut from an area adjacent to the site. However in the Summer of 1994 when construction commenced, the ground was too hard and the underlying topsoil too dry to enable the cutting of such deep blocks to be carried out. Instead thinner turves approximately 75mm thick were cut from this area and when the supply was exhausted commercially available standard rolled turves, placed in their rolled form, were used to compensate for the shortfall.

Despite the labour intensive nature of the stitching, good outputs could be achieved when the rate of supply of fill was sufficient. One gang of three men placing the grids with associated fill placing and compaction plant and labour were able to achieve a rate of 40 - 45m^2 completed face per working day

Among the benefits of this type of reinforced soil structure are that it can be constructed almost entirely within its own footprint and no large plant such as cranes are required. It is therefore ideally suited to construction in confined areas such as adjacent to a road, a live railway or overhead cables.

In accordance with standard practice for such reinforced soil structures, compaction within 2m of the face was carried out using a vibrating plate compactor and a vibrating roller with a mass per metre width $\leq$1300kg and a total mass $\leq$1000kg.

Upon completion of the embankment an insitu concrete parapet has been cast along part of it's length to carry a safety barrier (Figure 7).

Where the railway tracks are further from the embankment face, a simple safety fence with a 1.5m high, 1 in 2 (v:h) landscaped slope up to the tracks has been constructed (Figure 8).

Figure 7

Figure 8

5 PERFORMANCE

The embankment will be used for railway traffic when the remainder of the Heathrow Express Line is completed in June 1998. It has carried substantial construction traffic without suffering any significant deformations.

The turf face grew successfully in the early stages but the hot, dry summer of 1995 damaged the grass growth. Vegetation in the form of broom, blackberry, ivy and dogrose will be planted along the top and bottom of the embankment with bramble and dogrose on the face. The west and northwest facing aspect of the embankment face and the proximity to the lakes and areas of wild vegetation should promote growth which will eventually cover the face grid.

6 CONCLUSION

At Airport Junction reinforced soil techniques have been used to overcome the problems of a confined site and to reduce encroachment on an environmentally sensitive area.

A 7m high turf faced reinforced soil embankment with a 5 in 1 (v:h) slope face has been successfully constructed using polymer grid reinforcement.

This is the first application of a steep faced reinforced soil embankment to support a passenger railway in the United Kingdom and its use here has provided a safe, economic and environmentally acceptable solution.

ACKNOWLEDGEMENTS

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