Design and construction of closed cell expanded polystyrene foam embankment with a heavy duty pavement

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ABSTRACT

Closed cell expanded polystyrene foam (EPS) was used for construction of embankments in sections of the Port of Brisbane Motorway, Brisbane, Queensland, particularly close to bridge abutments. There have been limited projects utilising this material in Australia and this paper is presented to outline issues encountered on the Port of Brisbane Motorway with EPS.

The paper discusses the basis for selection of EPS as the embankment fill material, the design principles for the embankments and construction issues, and the design and construction of heavy duty pavements over the EPS, where the pavement surface was as low as 0.9m over the top of the foam.

1 INTRODUCTION

Stage 1 of the Port of Brisbane Motorway runs east from the Gateway Motorway just south of Gateway Bridge to join to Lytton Road east of Hemmant. The alignment traverses predominantly gently sloping and undulating terrain and has a moderate to high relief on the western end of the Project from Gateway Motorway to Oxbow Creek. The ground surface drops in the vicinity of the Oxbow and the alignment continues eastbound on a relatively flat, low lying flood plain of the Brisbane River. The main characteristics of this east end zone are low lying topography, the presence of shallow groundwater and a variable thickness of recent alluvium, including clayey sand and soft to firm compressible estuarine clay, underlain by older alluvium and weathered rock. The thickness of compressible clay increases up to 30m towards the eastern end of the alignment.

Due to construction staging limitations, particularly at areas requiring high fills approaching bridge abutments, a number of abutment approaches and ramps to the Lindum Road bridge crossing of the Motorway were constructed using closed cell expanded polystyrene (EPS) foam fill to control settlements of the fill. EPS had been extensively used as a super-lightweight soil substitute material for embankment fill construction in Scandinavia [Refsdal, 1987; Aabøe, 2000] and Europe [Duškov, 2000; Sanders & Seedhouse, 1994], and on a small number of occasions in Australia [McDonald and Brown, 1993]. This paper discusses the reasons for selection of this method of construction and the approaches to using the material for support of heavy duty pavements designed in accordance with the Austroads design methodology [Austroads, 1992].

2 SUBSURFACE CONDITIONS

As noted in Section 1, the main characteristics of the areas where embankments up to 5m in height were proposed were low lying topography, the presence of shallow groundwater and soft to firm compressible estuarine clay about 30m thick underlain by older alluvium and weathered rock. The existing surface elevation along the alignments was between about RL 1m and RL 4m while the groundwater table was generally around RL 1m with a high tide level of around RL 1.5m.

Preliminary analyses indicated that conventional fill embankment heights exceeding about 3m could not be constructed without staging to ensure short-term stability of the embankments.

Furthermore, primary consolidation settlement of about 1200mm over more than 10 years was predicted for embankments of 5m height built on unimproved ground. These settlements were well outside the project specification limits and the expected period for primary consolidation was outside the project time frame. Accordingly, a range of options was considered to allow embankment construction within the available time frame and with acceptable settlement limits.

3 OPTIONS FOR EMBANKMENT CONSTRUCTION

Two general approaches for overcoming the embankment construction time and settlement issues were considered. The first was to accelerate the period for primary consolidation such that the in-service settlement of the fills was within acceptable limits. The second was to limit the magnitude of the primary consolidation to less than the acceptable limit.

3.1 Accelerate consolidation period

Consolidation could be accelerated by using wick drains to reduces the time for primary consolidation to less than 6 months, including staged construction to achieve a total height of 5m. While the in-service settlement was then anticipated to be about 150mm, within the specification requirements, the time for primary consolidation was not acceptable.

An alternative design to achieve primary consolidation (of about 1700mm) within about 3 months was to construct the full embankment height plus surcharge in one stage with batter slopes reduced to 8H:1V. Although theoretically feasible this solution was impractical due to its large footprint area.

3.2 Limit consolidation magnitude

Two solutions to limit consolidation magnitude were considered, light weight fill and piled embankments. Both solutions reduce the load applied by the embankment to the compressible clays.

A piled embankment structure would have required a grid of closely spaced piles covered with either geotextile (tensile strength of about 500kNm) or a concrete slab. The earthen embankment is then constructed above the piled foundation and the load applied to the piles rather than the underlying clay. The major concern with this solution was the cost of constructing an extensive grid (2m to 3m separation) of 30m deep piles and the time required to cast and drive the piles.

A light weight fill solution involved the use of expanded polystyrene foam in place of soil for part of the embankment volume. The thickness of the EPS and overlying fill and pavement structure was designed such that the applied pressure gave a target post-construction settlement of 120mm. This solution was adopted as the least cost solution that met time, settlement and constructability constraints.

4 GEOTECHNICAL DESIGN OF EPS EMBANKMENTS

Although many factors affect the geotechnical design of EPS embankments major considerations are:

- buoyancy of the polystyrene under flood conditions,
- pavement design over the EPS, and;
- protection of the EPS under both traffic loadings and during construction.

For a 100 year frequency flood level for the area of RL 2.5m and a factor of safety of 1.5, soil cover of at least 1.25m was required to resist buoyancy. This material had to be placed in such a manner that the EPS was not stressed beyond its elastic limit to avoid the potential for long term creep settlement of the EPS.

The EPS used for the Motorway construction comprised Class H material (as defined by AS1366-Part 3) with a nominal density of 24 kg/m^3. It was wrapped in a 0.5mm thick textured HDPE membrane and covered by a layer of geotextile for protection against puncture of the embankment material. The nominal depth between the top of the highest EPS layer and the pavement surface was 1.3m, with a minimum depth of 0.9m. The embankments were constructed with 1V:2H side slopes with a minimum vertical cover of 700mm of soil over the geotextile on the embankment batter, and an average 1.25m cover across the whole embankment.

To allow construction over the soft ground, a preload about 2m thick was constructed by end dumping and spreading and the embankment footprint allowed to settle for at least 1 month prior to further construction. This soil platform was then removed to make way for the polystyrene fill, which was placed on a 300mm permeable filter layer to enable hydraulic conductivity across the underside of the embankment.

5 EPS SUBGRADE STIFFNESS FOR PAVEMENT DESIGN

As the EPS fill forms the subgrade for pavement thickness design, the stiffness of the EPS controls the pavement thickness. The stiffness was assessed based on the following data.

- An empirical relationship between the laboratory dynamic modulus of elasticity and the EPS density [Duškov, 2000] gives a stiffness of 9.9 MPa for EPS materials with a density of 24 kg/m^3. Direct measurements of resilient modulus for EPS with a density of 20 kg/m^3 [McDonald & Brown, 1993] are in agreement with this empirical relationship. Extrapolation of direct measurement data for EPS with densities of 15 and 20 kg/m^3 [Duškov,1997b] indicate a resilient stiffness of about 12 MPa.

- Full scale testing of a pavement constructed under laboratory conditions using Falling Weight Deflectometer, Benkelman Beam and repeated plate load testing [Duškov & Bull-Vasser, 1993] gave back-calculated stiffness for the EPS between 1.3 and 3.6 times the design stiffness calculated in accordance with the empirical relationship with density.

- Falling Weight Deflectometer field testing [Duškov, 1997a] also gave back-calculated stiffness for a 2-layer EPS system (comprising 0.5m thick 30 kg/m^3 EPS over 0.5m thick 25 kg/m^3 EPS layers) between about 1.0 and 1.4 times the design stiffness of 30 kg/m^3 EPS calculated in accordance with the empirical relationship with density.

Based on the above data, an isotropic design stiffness for the EPS fill of 10 MPa was adopted for design. Note that the 10:1 relationship between resilient modulus and CBR as used in the Austroads design methodology does not apply to EPS materials (McDonald & Brown, 1993; GeoPave, 2006). The design Poisson's ratio is about 0.1 [Duškov, 2000].

The Dutch design criterion for EPS fill, based on permanent deformation of the material, is a maximum vertical compressive strain under the design traffic loading of 0.4% (4,000 με). This criteria is independent of traffic repetitions.

6 HEAVY DUTY PAVEMENT DESIGN AND CONSTRUCTION

6.1 Construction over the EPS fill

To prevent damage to the polystyrene by heavy axle loads a thin (100mm) concrete slab, laid immediately above the textured HDPE, has commonly been used prior to soil fill and pavement construction over the slab. Due to the grade on bridge approach ramps and the potential for sliding on the geotextile, this slab was proposed to have a terminal anchor at the downslope limit of the EPS fill with a 3m to 4m continuation past the terminal anchor to act as a relieving slab. This construction posed significant time constraints due to curing and strength gain requirements and an alternative approach using cementitiously modified materials was adopted to create a working platform over the weak EPS materials for structural pavement construction as follows.

- Following placement of the geotextile layer over the textured HDPE, a nominal 200mm compacted thickness of cementitiously modified subbase quality material was placed over the geotextile as a construction expedient to reduce the potential for damage to the EPS when constructing further layers. The modifying agent was 60% cement / 40% flyash to achieve a target unconfined compressive strength not exceeding 2 MPa at 7 days.

The layer was placed by end dumping and spreading from on top of the layer, such that at no time did plant or equipment traffic directly on the EPS, HDPE or geotextile. Compaction equipment for this layer was limited to rollers not exceeding one tonne mass operating on top of the layer without vibration due to the proximity to the surface of the EPS. The layer was compacted with at least eight passes of this equipment, without a density specification being imposed. It was assumed that 100% dry density ratio was probably not achieved for this layer and for pavement design purposes it was therefore assumed that the layer stiffness was no better than for an unbound granular material.

- Commencing not less than seven days after placement of the above layer, select fill materials with a soaked CBR value of at least 15% were placed and compacted up to 200mm below the underside of pavement (or higher if required to achieve a minimum thickness of these materials of at least 150mm). Roller weights within 0.5m of the top of the EPS layers were limited and so the thickness of the select fill layers was reduced if necessary to achieve specification compaction levels.

- Cementitiously modified subbase quality materials as above were placed and compacted to specification levels to the underside of the structural pavement (top of working platform).

Some variations to the above general procedures were required in some areas but in all cases, following completion of the construction, the subgrade for pavement design purposes comprised EPS fill (in excess of 1m thickness) overlain by select fill and cementitiously modified subbase materials such that the distance from the top of the EPS fill to the final surface level was at least 0.9m. For the purpose of structural design of the heavy duty pavement, the select fill and cementitiously modified subbase materials were treated as unbound granular materials in accordance with the Austroads procedures.

6.2 Structural pavement design

Pavements underlain by EPS fill were designed for various traffic levels ranging between 5.6×10^7 and 6.8×10^8 equivalent standard axles (ESA). Structural designs were prepared in accordance with the project-specific amendments to the Queensland Pavement Design Manual [Queensland Transport, 1990], with is based on the Austroads elastic layer design methodology. Subgrade design parameters were adopted as set out in Section 5 and the select fill and cementitiously modified subbase materials had stiffness decreasing with depth [Austroads, 1992]. Full depth asphalt pavements were adopted as providing high resistance to possible unanticipated fatigue stresses and relative ease of maintenance, with a total thickness ranging between 440mm and 535mm.

Because the EPS extended almost to the edge of the embankments, the heavy duty pavement also extended across the full width of the EPS embankments, except below footpaths or road furniture. Accordingly, separate verge treatment in areas of EPS subgrade were not required.

7 CONCLUSIONS

This paper has outlined the reasons behind the choice of expanded polystyrene foam as fill embankment materials for the Port of Brisbane Motorway. The use of these materials gave challenges in designing and gaining acceptance of the design of the heavy duty pavements and challenges to the contractor, not only to construct high EPS embankments but also to construct the fill materials over the EPS that could support construction equipment for the asphalt surfacing without causing damage to the EPS itself.

At the present date, some five years after construction, the performance of pavements in these areas of EPS fill are similar to those in adjacent, non-EPS areas.

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