Technical Specification for the use of Lightweight Expanded Clay Aggregate (Optiroc LWA) as a Structural Backfill material

Preamble

Originally produced by the Transport Research Laboratory as a request for a departure from the Specification for Highway Works, (which is non-product specific) the following document may still be used to this end, or as part of a generic specification.

Situation

Backfill to bridge abutments and retaining walls over very soft soils such as peat, alluvium or estuarine deposits.

Objective

The use of lightweight expanded clay aggregate (Optiroc LWA), which has a bulk density approximately 25% that of natural fill materials, will considerably reduce earth pressures on the structures and settlement, both immediately and in the long term. The use of Optiroc LWA will minimise differential settlement between piled bridge abutments and the embankment fill. Use of Optiroc LWA, in conjunction with measures to drain the foundation, will eliminate the need for staged construction, which would be required if natural fill materials were used. The reduced earth pressures will also allow savings in the design for the retaining walls and bridge abutments. The use of Optiroc LWA thus offers significant savings in time; cost and quality compared to the use of natural fill materials.

Because of the method of production of Optiroc LWA, many standard tests in BS 1377 or BS 812 are not appropriate for use with it. If tested using the normal methods for earthworks, Optiroc LWA would not be considered acceptable. However, it can be shown to be fit for purpose as a lightweight Structural Backfill, particularly useful for embankments over soft ground. A departure from the Specification from Highway Works is therefore requested to allow the use of the Optiroc LWA. A general description of the material and its properties is given in the following sections. A site-specific departure will be prepared for each site where it is proposed to use Optiroc LWA, detailing the particular circumstances, methods, and quantities to be used in each particular situation.

Material

Optiroc LWA is a lightweight expanded clay, formed by heating and firing natural marine clay in a rotary kiln at temperatures up to 1150 °C. The process transforms the clay into lightweight rounded ceramic granules, which have a hard ceramic shell and a porous core. The material also has excellent insulating properties and is used for a variety of applications including lightweight concrete blocks and panels as well as lightweight granular fill. It is a fire resistant, frost resistant and chemically inert material with no hazardous properties for handling or storage. The grading for most geotechnical applications is 10-20mm, but it can also be supplied as 0-32mm material. The gradings of both materials fall within the category of Class 1B, uniformly graded granular material in Table 6/1 of the Specification for Highway Works (SHW).

Optiroc LWA is produced by the Optiroc Group under carefully controlled conditions at factories in Norway, Sweden, Denmark, Germany, Estonia, Portugal and Spain. The production process is controlled by an Environmental Management System. One factory is already certified under ISO 14001, and the others are working towards this, ensuring high standards of quality and consistency in the material. Records of the grading, particle density, dry loose bulk density, crushing resistance and moisture content will accompany each shipment. In the UK, the dry loose bulk density and moisture content are measured at the rate of one test per week. All test records relating to the material will be provided on delivery of the Optiroc LWA to site.

Design

The advantage of Optiroc LWA is its very low density in comparison with natural fill materials. A summary of the geotechnical properties is given in Table 1. There are differences between the 10-20mm and 0-32mm materials, with the former being lighter but the latter having higher strength, as a result of its less uniform grading.

Table 1. Design parameters for Optiroc LWA

Property	**Optiroc LWA 10-20mm**	**Optiroc LWA **0-32mm**	**Test method**
Particle density (kg/m^3)	750	800	prEN 1097-6
Uniformity Coefficient (D_{60}/D_{10})	1.2	3.0	EN 933-1 EN 933-2
D_{10} (mm)	10	5	EN 933-1 EN 933-2
Dry loose bulk density (kg/m^3)	280	335	EN 1097-3
Volume reduction by compaction (%)	10	10	-
Dry density after compaction (kg/m^3)	310	370	-
Typical moisture content as delivered to site (%)	7 - 15	7 - 15	EN 1097-5
Long-term moisture content above water table (%)	25	25	EN 1097-5
Long-term submerged moisture content (%)	40	40	EN 1097-5
Long-term unit weight above water table (kN/m^3)	3.75	4.5	-
Long-term submerged unit weight (kN/m^3)	8.35	8.45	-
Angle of friction, f' peak (degrees)	37	45	Triaxial tests
Cohesion, c' peak (kN/m^2)	0	0	Triaxial tests
Constrained modulus provided stress levels below crushing level (MN/m^2)	15-20	25	Large scale oedometer tests
Maximum level of effective stress to avoid crushing grains (kN/m^2)	100	150	Large scale oedometer tests

** Due to increasingly high demand for the lower range of sieved gradings of LWA, minimum order quantities and/or extended delivery periods may apply to this grading of the material.

Because of the method of production of Optiroc LWA, it is different from natural soil materials in many respects. Due to the porous nature of the particles, it will absorb moisture after it has been placed. Experience with the material in Scandinavia indicates that the long-term maximum moisture content of Optiroc LWA above the water table is about 25%, and the unit weights corresponding to this moisture content should be used for calculations of settlement, bearing capacity and slope stability. Optiroc LWA should not be placed below the water table, but in areas subject to flooding the lower parts of the embankment may be temporarily saturated. In this case, the maximum moisture content rises to about 40%, and the unit weight increases accordingly. Optiroc LWA is a free-draining granular material, and the moisture content will rapidly reduce to the drained value once the floodwaters recede. If it is used in areas subject to flooding, the overlying material must provide sufficient mass to prevent the material becoming buoyant.

The porous nature of the particles also means that they have relatively low crushing strength compared to natural soil or rock particles. Tests in large scale oedometers show that Optiroc LWA has similar constrained modulus values to natural materials at low levels of stress, but that above a threshold value crushing of individual particles starts to occur and the modulus decreases. The threshold value was found to be about 100 kN/m^2 for the 10-20mm material and 150 kN/m^2 for the 0-32mm material (Table 1). The effective stress applied to the materials should thus not exceed these values. However, in practice, because of the very low unit weight of Optiroc LWA the embankment would have to be over 20m in height before the loading at the base exceeded the limiting value. Above the limiting values there is a steady reduction in modulus with increasing stress levels, but there is not a sharp 'yield point' at which the material loses all strength.

The peak angle of friction of the material was determined in drained triaxial tests over stress levels below the limiting values, and the values are given in Table 1. Details of the test procedures and results are enclosed. These values may be used for slope stability and earth pressure calculations using standard design methods, provided the limiting stress values are not exceeded.

Because of the low crushing strength of the particles, Optiroc LWA is not recommended for use as an unbound sub-base but may be suitable for use as a capping layer where low values of sub grade CBR exist.

(Further research will be undertaken to determine the products suitability for use in such conditions.)

Ordinary test methods for fill materials, such as CBR, MCV and Proctor compaction are not suitable for Optiroc LWA, as the stresses imposed may exceed the crushing strength of the particles, and the very low density and uniform grading mean that compaction-based tests are inappropriate.

(Further research will be undertaken to determine suitable test methods for performance related criteria.)

Experience from site has shown that a volume reduction of 10% can be achieved by light compaction with tracked vehicles, and that the compacted Optiroc LWA has an equivalent CBR of at least 5%.

Details of tests carried out on Optiroc LWA material are contained in the report by SINTEF entitled 'Environmentally friendly insulation products for the construction industry. Summary Report DP1: Leca frost protection in roads, railways and ditches'. A copy of the report is enclosed. A draft CEN standard defining test methods for lightweight fill in civil engineering applications has been prepared, and a copy is enclosed.

Construction control

Before placing the fill, a geotextile should be laid as a separator between the Optiroc LWA and the underlying soil. The type of geotextile will depend on the nature of the underlying soil. Optiroc LWA is particularly suitable for use in conjunction with drainage systems such as band drains, as it is a free-draining material and will allow water expelled from the subsoil to drain out of the structural fill.

Optiroc LWA is normally delivered to site in lorries like natural fill materials and is loose tipped. The Optiroc LWA should be spread by tracked vehicles in layers 1.0m thick (Note that in terms of required compaction energy this is equivalent to a 250mm layer of natural fill). The tracked vehicle should not impose a load of greater than 50 kN/m^2 for 10-20mm material and 80 kN/m^2 for 0-32mm material, to avoid any crushing of grains. A minimum of 3 passes is required to ensure full compaction. The compaction will produce a reduction of 10% by volume, or 0.1m in level. This can be measured with profile boards. Over compaction should be avoided, as it will not result in any further densification of the fill.

For smaller projects and in situations adjacent to retaining walls or foundations, the Optiroc LWA should be spread in layers not exceeding 600mm, and should be compacted with three passes of a vibrating plate compactor. The compactor should not impose a load of greater than 50 kN/m^2 for 10-20mm material and 80 kN/m^2 for 0-32mm material, to avoid any crushing of grains.

Optiroc LWA can also be delivered to site in tankers, and discharged pneumatically into position using compressed air. This gives a precompaction of 4 to 5% compared to loose tipped material. Pneumatically discharged Optiroc LWA should be placed in layers of 500mm and compacted in the same way as for loose tipped material. Because of the precompaction effect, further compaction will only produce a further 5% reduction in thickness.

A separating geotextile should be placed on top of the last layer of Optiroc LWA before the capping layer or sub-base is placed, to avoid penetration of this material into the Optiroc LWA.

At present there is no satisfactory method for determining the in-situ density of Optiroc LWA. The sand replacement test in BS1377: Part 9 is unsuitable for Optiroc LWA. Because of the very uniform grain size, the sides of the hole would collapse, and the sand would run out the base and sides of the hole into the fill. Research is underway on the use of nuclear methods to determine density and moisture content, however these are not fully developed and are not reliable. Currently, the best method of site control is to measure the settlement of the layer during compaction as indicated above.

Plate loading tests may be used to measure the modulus of the compacted Optiroc LWA. However, conventional plate loading tests are not suitable. Because of the very low density of the material a small (300mm diameter) plate will tend to punch into the fill. If plate loading tests are required, they should be carried out using a plate with a minimum diameter of 600mm directly on the Optiroc LWA, or with a 300mm diameter plate on a 200mm cover layer of natural fill. The tests should be carried out in the elastic range of the Optiroc LWA, and should not exceed the limiting loadings of 100 kN/m^2 for 10-20mm material or 150 kN/m^2 for 0-32 mm material. Typical values of constrained modulus, measured in large-scale oedometer tests, are 15-20 MN/m^2 for 10-20mm material and about 25 MN/m^2 for 0-32mm material (Table 1).

The Optiroc Group's Research and Development department is currently developing suitable methods for determining in-situ density of compacted Optiroc LWA which will then be published as a CEN standard. This report will be amended once this is available.

Environmental aspects

The Optiroc LWA is a chemically inert, non-hazardous material, as shown on the enclosed Health and Safety sheet. It is produced under an environmental management system (EMS), which working towards certification under ISO 14001. The EMS aims to minimise the impact of production on the environment. The material has a lifetime of several hundred years, and can be reused in future applications when the road reaches the end of its design life.

Optiroc LWA is also used as a filter material for water purification purposes. The material is known as Filtralite and has a finer grain size than the Optiroc LWA. It is manufactured from the same materials as Optiroc LWA, using the same rotary kiln, and differs from Optiroc LWA only in grain size. The results of leaching tests on samples of Filtralite are enclosed. The tests were carried out in accordance with prEN 12902: Product used for treatment of water intended for human consumption - supporting and filtering materials - methods of test. The leachate was tested for a range of metals and organic compounds. Most were below the detection limit, and all were well below the EC drinking water limits. Leaching from the Optiroc LWA will be even less than from the Filtralite, because of the coarser grain size of the Optiroc LWA. There is therefore no risk of pollution of controlled waters from the use of Optiroc LWA in earthworks.

Attack on construction materials

Tests have been carried out on Optiroc LWA to assess the risk of corrosion to construction materials such as concrete or steel. The results are shown below:

- pH: 8 - 11
- Total sulfur: 2,000mg/kg (0.2%)
- Total sulfate: 1,700mg/kg SO_4 (0.17%)
- Chloride: 38mg/kg (0.004%)
- Total Carbon: <200mg/kg (<0.02%)

The pH is mildly to moderately alkaline. The higher values exceed the limiting values given in Table 6/3 of the Specification for Highway Works for fill for use with metal components in reinforced soil and anchored earth structures. The material lies in Class 2 with respect to sulfate attack on concrete according to BRE Digest 363. The chloride and total carbon (equivalent to organic content) values are well below the limiting values in Table 6/3.

In conclusion, in terms of corrosion of construction materials the LWA is suitable for general fill applications but not suitable as backfill to metallic elements because of the high pH. If it is proposed to use it as structural backfill to concrete, the sulfate content should first be determined in accordance with the most recent guidance (TRL Report PR/IS/111/2000, Revision to BRE Digest 363). According to Clause 601.13 of the Specification for Highway Works, backfill deposited within 500mm of concrete shall have a water-soluble sulfate content not exceeding 1.9 grams of sulfate (expressed as SO_3) per litre when tested in accordance with BS 1377: Part 3.

Durability

Optiroc LWA has been used in roads, railways and other structures for a number of years in Scandinavia. In the period 1996 to 1998 the volume of Optiroc LWA used for building and upgrading of railways in Norway was 250,000 m^3. For roads the comparable figure was 150,000 m^3. It is a durable lightweight insulation material that is not damaged by repeated freezing and thawing or by ageing. Because of its low thermal conductivity, it is used as an insulating layer to protect frost-sensitive materials. The particles are not degraded by oil spillages or by other pollutants.

An investigation of a section of Highway 753 in Nord-Trøndelag, Norway, where 0-32mm Optiroc LWA was used as General Fill up to 2.5m in thickness with a total overlay thickness of 400mm above the Optiroc LWA material was carried out after 1.5 years of use. No rutting or cracking was observed for the asphalt layer. A test trench was excavated in one of the lanes to allow inspection of the Optiroc LWA material. It was found to be well compacted and had good bearing capacity. The individual particles showed very little damage. Further investigations in the field and the laboratory confirmed the results from the visual inspections.

Investigations from five sites, ranging from 1.5 to 8 years in age, showed that the moisture content of the Optiroc LWA varied between 14% and 45% by weight. The maximum for Optiroc LWA in a drained state was about 25%. Higher values were encountered where the Optiroc LWA was below the ground water level. The 0-32mm material was used at most of the sites, with 10-20mm material at one site.

The low density of Optiroc LWA will lead to smaller settlements of the embankment, both during construction and in the long term, compared to natural fill materials. Data are available from several sites in Europe and the UK to demonstrate the beneficial effects. Examples are enclosed with this report.

In order to demonstrate the reduced settlement as a result of using Optiroc LWA on this scheme, it is proposed to install monitoring points on the finished road surface at 50m intervals from the abutment/retaining wall along the section of embankment constructed with Optiroc LWA. The levels of the monitoring points should be measured at the end of construction, quarterly for the first year after construction, then annually to provide a record of the settlement for comparison with the predicted values.

Conclusion

Optiroc LWA offers a number of advantages over natural fill materials as a structural backfill in bridge abutments and retaining walls, especially in areas of embankment over soft ground. It is inert, durable and easy to place and compact. The very low density of Optiroc LWA compared to natural fill materials will lead to greatly reduced earth pressures and settlements, both in the short and long term, and hence to improved ride quality. The use of Optiroc LWA will also greatly reduce differential settlement between bridge abutments and embankments. The material is produced under an environmental management system, and can be delivered to site with known and consistent properties - much more so than for most natural fill materials. There is a considerable body of experience on the use of Optiroc LWA in Scandinavia and other European countries, and this gives confidence in its use in the UK.

Because of the nature of Optiroc LWA, many of the soil tests given in the Specification for Highway Works are not appropriate. A departure from the Specification is therefore requested for Optiroc LWA for use in the situations described above. It is proposed that the material be classed as Fill to Structures Class 6R, lightweight expanded clay aggregate (10-20mm) and Fill to Structures Class 6S, lightweight expanded clay aggregate (0-32mm) and that the following sections are inserted in Tables 6/1 and 6/2 of the Specification for this contract.

TABLE 6/1: Acceptable Earthworks Materials: Classification and Compaction Requirements

Class			General Material Description	Typical Use	Permitted Constituents
SELECTED GRANULAR FILL	6	R	Lightweight expanded clay aggregate (10-20mm)	Fill to Structures	Optiroc LWA EBU 10-20 R or EBU 10-20 RT lightweight expanded clay aggregate
	6	S	Lightweight expanded clay aggregate (0-32mm)	Fill to Structures	Optiroc LWA EBU 0-32 RC lightweight expanded clay aggregate

Material Properties Required for Acceptability				Compaction Requirements	Class	
Property	**Defined and tested in accordance with**	**Acceptable Limits Within: Lower**	**Upper**			
(i) grading	BS 1377: Part 2	Tab 6/2	Tab 6/2	Layer thickness 1.0m. Compact by not less than 3 passes of a tracked vehicle or with a vibrating plate compactor. Contact pressure not to exceed 50 kN/m^2	6	R
(ii) uniformity coefficient	See Note 5	-	2			
(iii) moisture content	BS 1377: Part 2	5	20			
(iv) dry loose bulk density	EN 1097-3	260	300			
(v) effective angle of internal friction (ø') and effective cohesion (c')	Triaxial tests	Ø' = 37° C' = 0	-			
(vi) permeability	Clause 640	1×10^{-2} m/s	-			
(i) grading	BS 1377: Part 2	Tab 6/2	Tab 6/2	Layer thickness 1.0m. Compact by not less than 3 passes of a tracked vehicle or a vibrating plate compactor. Contact pressure not to exceed 80 kN/m^2	6	S
(ii) uniformity coefficient	See Note 5	1.5	10			
(iii) moisture content	BS 1377: Part 2	5	20			
(iv) dry loose bulk density	EN 1097-3	320	350			
(v) effective angle of internal friction (ø') and effective cohesion (c')	Triaxial tests	Ø' = 45° C' = 0	-			
(vi) permeability	Clause 640	1×10^{-2} m/s	-			

Table 6/2: Grading Requirements for Acceptable Earthworks Materials

Percentage by Mass Passing the Size Shown											
Class	Size (mm) BS Series										Class
	37.5	28	20	14	10	6.3	5	3.35	2	1.18	
6R		100	90-100		0-15	0-5					6R
6S	100		80 - 100				0 - 15		0 - 5		6S

ENCLOSURES

1. Optiroc ExClay Ltd Brochure on Lightweight aggregate for civil engineering.
2. SINTEF Report. Environmentally friendly insulation products for the construction industry. Summary Report DP1: Leca frost protection in roads, railways and ditches. December 2000.
3. Draft CEN Standard: Optiroc LWA in CEA 00.12. Light weight fill and frost insulation products for civil engineering applications. In-situ formed expanded clay lightweight aggregate products.
4. Optiroc Report Sheet on triaxial tests on 0-32mm LWA, 1990 (Norwegian).
5. Leaching tests of 2 different Filtralite filter materials from Norsk Leca. Report by Aquateam - Norwegian water technology centre A/S, 1999.
6. Optiroc Project Report Sheets on performance of Optiroc LWA in road and railway embankments and bridge abutments.

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