LIGHTWEIGHT AGGREGATES FOR CIVIL ENGINEERING.
TECHNICAL SOLUTIONS, MECHANICAL PROPERTIES,
CERTIFICATION AND QUALITY CONTROL.

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LWA used as frost insulation and light weight fill in railway embankment. Vestfoldbanen, Norway.

1 RESEARCH PROJECTS

SINTEF Civil and Environmental Engineering has for several years been working on research and development projects related to the use of light weight clay aggregates (LWA) in civil engineering applications. SINTEF has been technically responsible of projects which includes participants from public authorities, research institutes, universities, consultants and contractors. The projects include activities related to laboratory testing, large scale model tests, theoretical analyses and preparation of requirements and tests methods for verification of material characteristics.

The first part of the project, “MiljøIso”, was focusing on physical and mechanical properties of the material. The second part of the project, “Internordic Geoproject”, is focusing on the structural solutions and on design and on quality requirements for the material and construction.

2 APPLICATIONS

Light weight aggregates can be used both for insulation purposes and to reduce settlement and improve stability of fills on soft subsoil. The project has focused on the use of LWA as light weight fills in roads and railways, as insulation materials in roads and as insulation in ditches. LWA has already been used for these applications in a number of projects over the last years both in the Nordic countries and in other countries. Some examples of the use are presented in Figure 1-3.

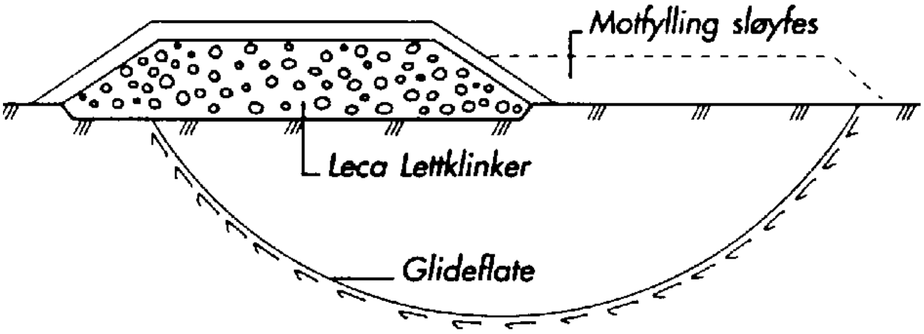

Figure 1 LWA to reduce weight and increase stability for fill on soft subsoil

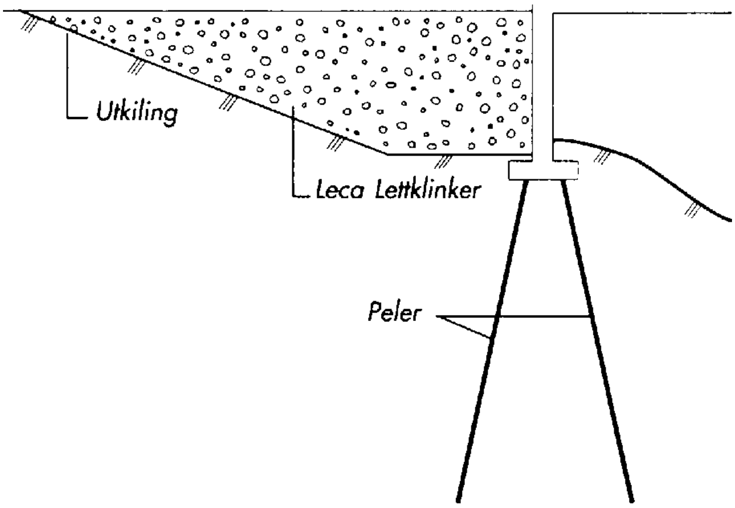

Figure 2 LWA to reduce weight and earth pressure in bridge foundations

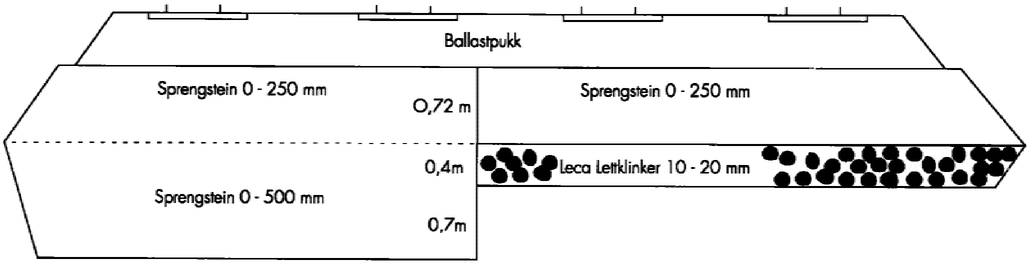

Figure 3 LWA as frost insulation in railroad embankment

3 TEST METHODS AND RELEVANT MATERIAL PROPERTIES

Physical, mechanical and thermal properties of *LWA* are essential to be able to design sound technical solutions. As *LWA* to some extent differ from conventional granular materials the project also have to evaluate relevant test methods to determine the material properties. The laboratory testing includes tests for thermal properties, physical properties and mechanical properties. In addition there are performed field investigations on *LWA* in existing fills, large scale model tests and a full scale instrumented field test is currently going on. The project has provided both informations on the relevant material properties and the test methods to determine these properties.

3.1 Thermal properties

The thermal properties of LWA has been determined in laboratory tests and the results have been verified by full scale field tests.

Figure 4 Test field with refrigerated building at the New Airport Express Line at Leirsund.

Based on the results the heat conductivity is dependent on the water content as presented in Figure 5.

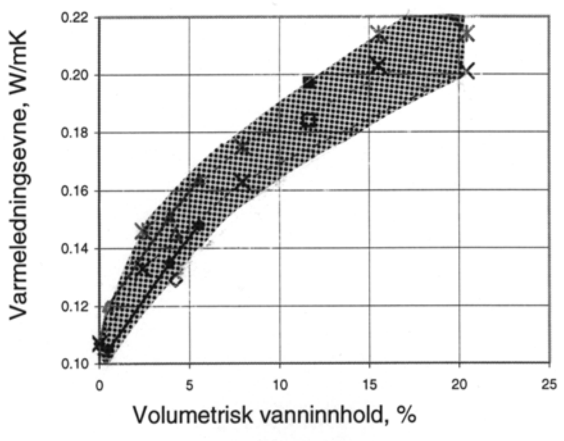

Figure 5   Measured heat conductivity, λ_{10}, at 10°C. From the MiljøIso-project.

3.2 Physical properties

A summary of the results for physical properties are given in the table 1.

Table 1 Physical properties of LWA

Properties	**Symbol**	**Leca 10-20**	**Leca 0-32**	**Comments**
Compact density	ρ_k	**2600 kg/m^3**	**2600 kg/m^3**	Dependent on the raw material
Pellet density	ρ_s	**750 kg/m^3**	**800 kg/m^3**	Mean value for the grading
Internal pore volume in the pellets	n_i	71%	69%	100 (1-ρ_s / ρ_k)
Dry bulk density before compaction	ρ_d	**280 kg/m^3**	**335 kg/m^3**	Dependent on loading or placing
Volume reduction by compaction	P	**10 %**	**10 %**	Dependent on construction method
Dry density after compaction	$\rho_{d,\,f}$	310 kg/m^3	370 kg/m^3	(1+P/100)ρ_d, used in the formulae below
Porosity of the fill	n	54%	49 %	100 (1-$\rho_{d,\,f}$ /ρ_s)
Total porosity (internal + external)	n_{tot}	88%	86%	100 (1-$\rho_{d,\,f}$ /ρ_k)
Water content	**w**	**25%**	**25%**	Drained *LWA*
Volume % water	w_{vol}	7.8	9.3	w ($\rho_{d,\,f}$ /ρ_w)
Air volume	n_{luft}	80%	77%	$n_{tot} - w_{vol}$
Unit weight	γ	3.75 kN/m^3	4.5 kN/m^3	$\gamma_{d,\,f}$ (1+ w/100)

3.3 Mechanical properties

The laboratory testing of the mechanical properties includes intial tests for preparation and compaction, triaxial tests, cyclic triaxial tests, and large scale oedometer tests. The results have been verified through large scale model tests and instrumented field tests.

Results from oedometer test in terms of idealised modulus curves are given in Figure 6.

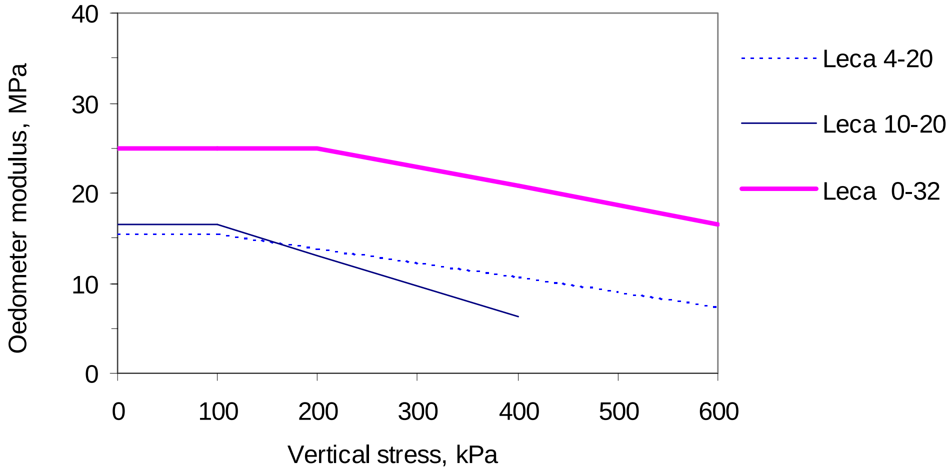

Figure 6 Idealised modulus curves for compacted LWA.

Based on static triaxial tests the effective strength parameters of *LWA* are determined as:

- failure angle $\tan\varphi_b = 1.02$ $\varphi_b = 45°$
- characteristic friction $\tan\varphi_k = 0.85$ $\varphi_k = 41°$
- attraction $a = 0$ kPa

In Figure 7 results from cyclic triaxial test in terms of E-modulus are presented.

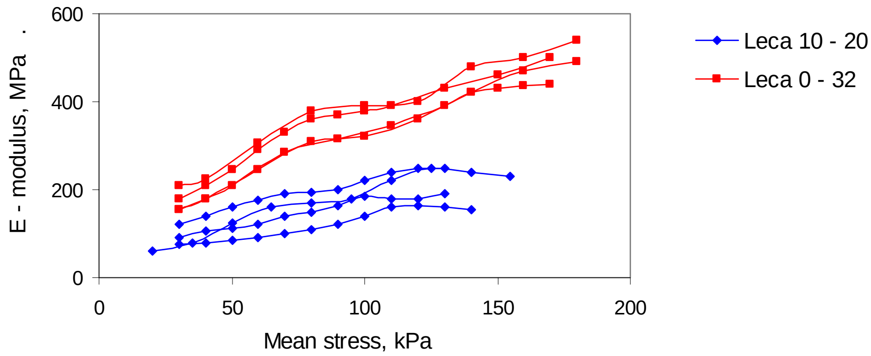

Figure 7 E-modulus as found from Cyclic triaxial tests

The tests have verified that LWA has strength and stiffness comparable to conventional granular materials, provided the stress level is not resulting in crushing of the grains. Based on the results it is concluded that the mechanical properties of LWA is sufficient for use as part of the sub-base

4 MODEL TESTS AND FULL SCALE FIELD TEST

4.1 Large scale model test

The results from the laboratory and the theoretical analyses are verified from a large scale model test, figure 8.

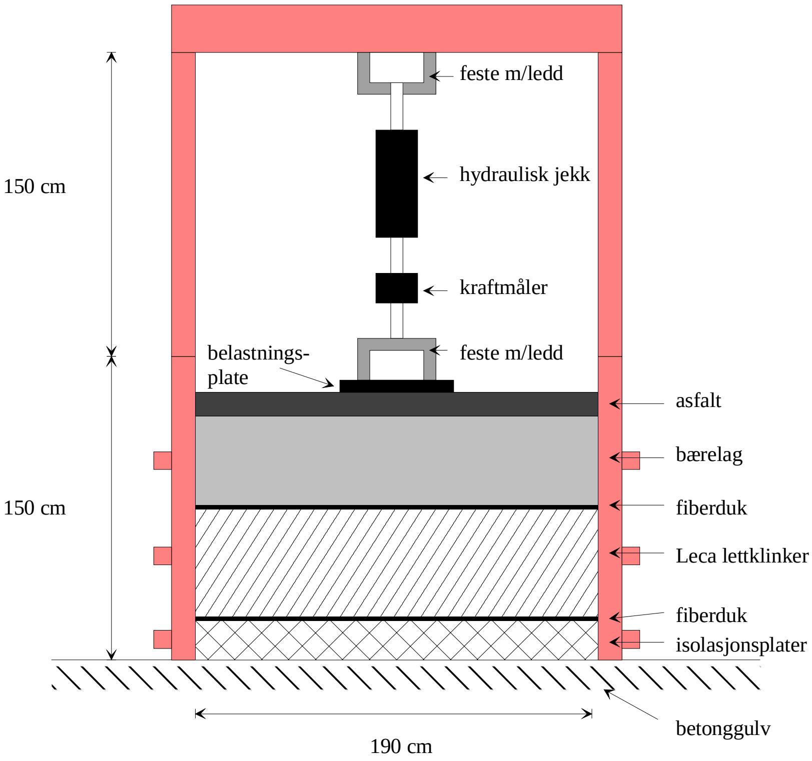

Figure 8. Large scale model test set up

The model test was run with a repetead loading for nearly 5.000.000 load cycles with a stepwise increased load pressure up to 700 kPa. Some results in terms of plastic deformations of asphalt layer and top of LWA is presented in Figure 9. The loads resulted in fairly small total deformations of the LWA layer and the interaction between LWA material and the other materials were good. After the test was fianished the LWA material was in the same condition as before the test. The large-scale test indicates that LWA can be used with far less cover than what has previously been recommended.

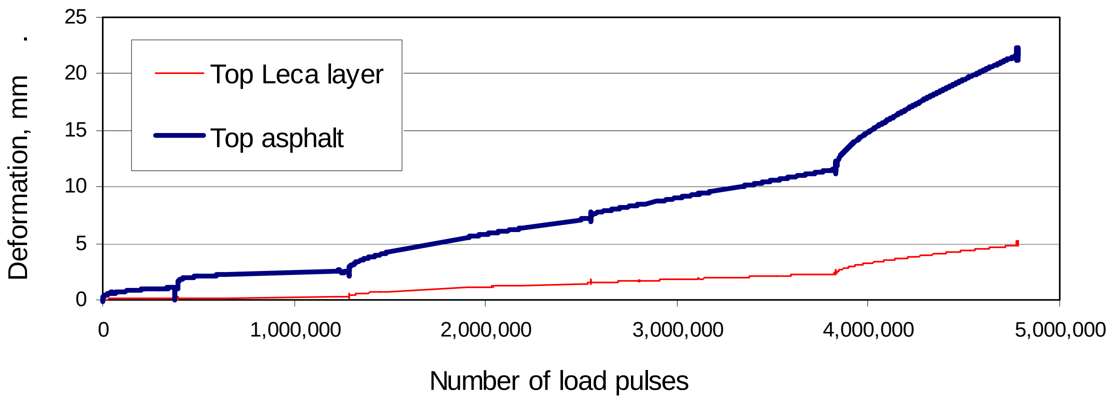

Figure 9 Permanent deformations in the pavement structure.

4.2 Full scale field test

The results from the laboratory tests and the large-scale model tests were used as basis for planning the full-scale field test, which is currently running, figure 10, 11.

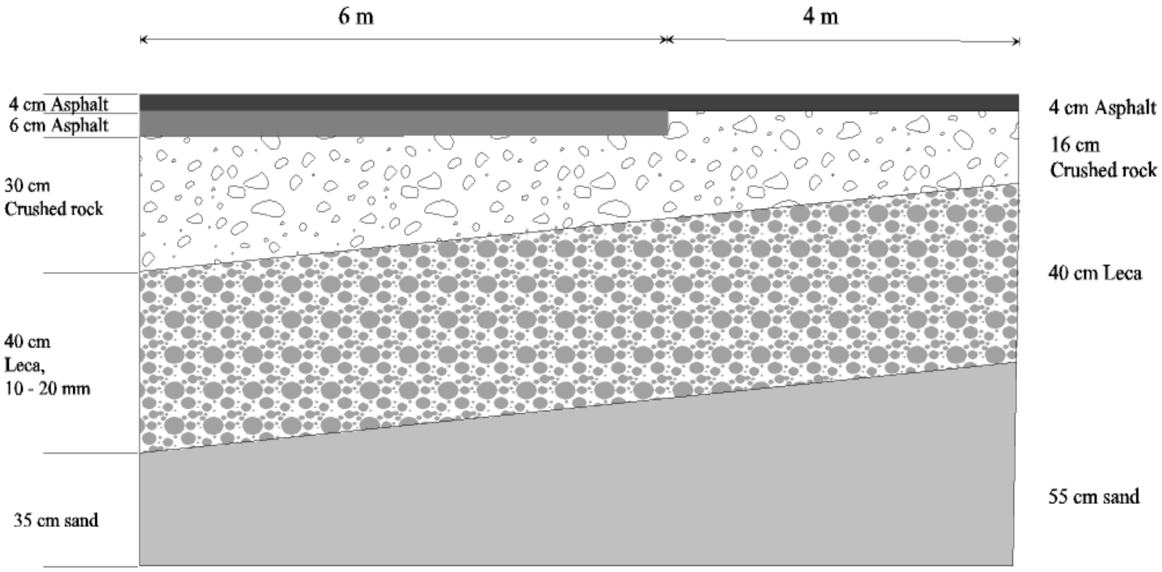

Figure 10 Lay-out, full scale field test. Sandmoen, Norway.

Figure 11 Construction of full scale field test

The results obtained so far from the full scale field test confirms what has been previously found. The measurements include falling weight deflectometer (FWD), figure 12, stress and strain measurements under controlled loading, figure 13 and continuos logging of deformations, figure 14.

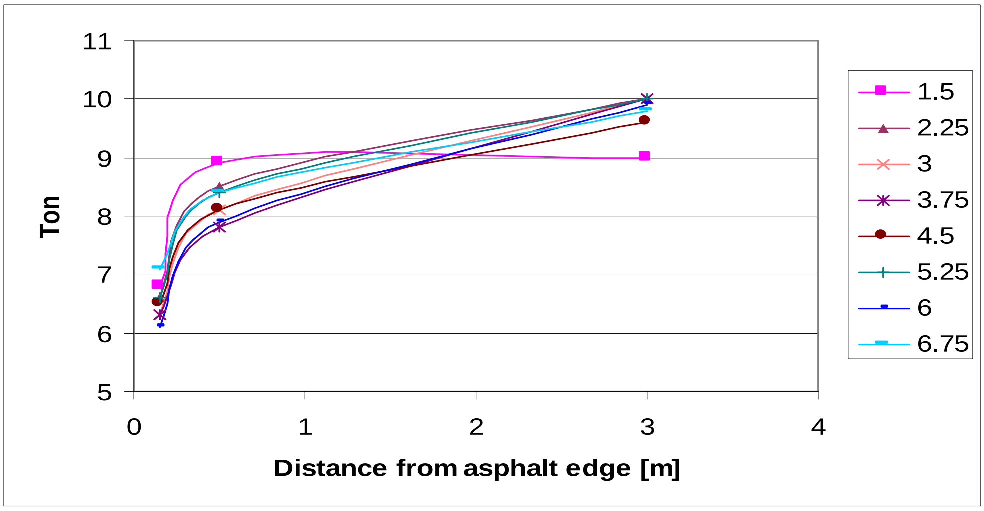

Figure 12 Bearing capacity from falling weight deflectometer

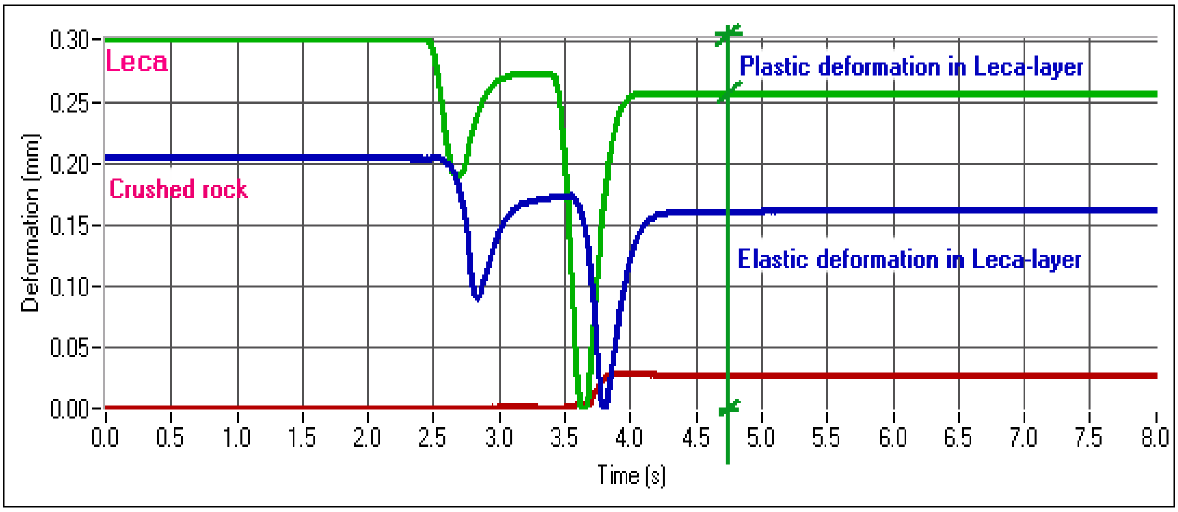

Figure 13 Measured deformations of pavement structure under controlled loading

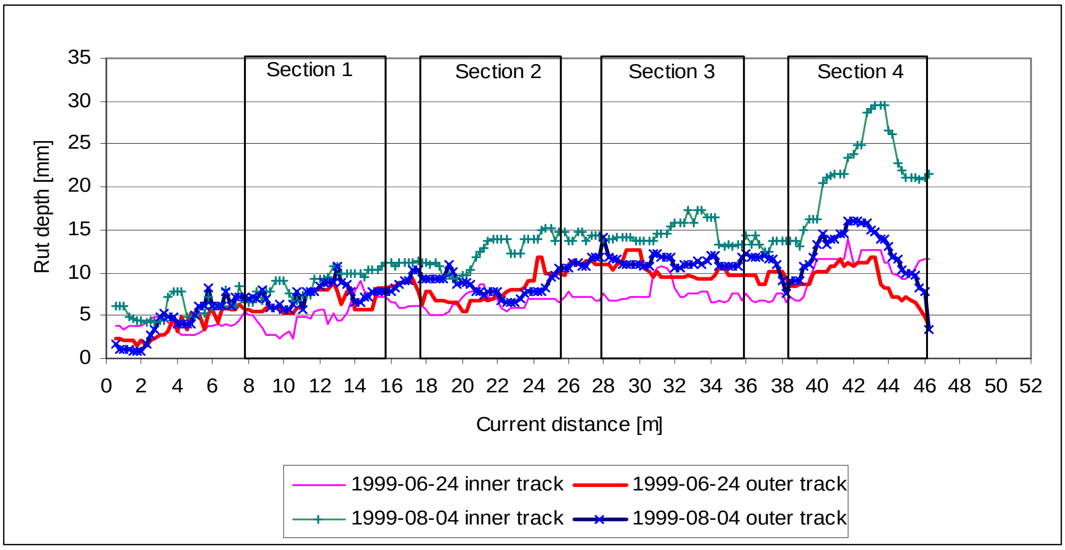

Figure 14 Accumulated extreme measured rut depth in pavement

5 QUALITY REQUIREMENTS

The ongoing Internordic Geoproject is currently preparing a proposal for quality requirements for LWA construction works. The quality requirements are related to different aspects:
-the LWA material itself
-the handling of the material
-the construction procedures (filling procedures, compaction etc)
-field control measurements

To obtain a proper end results all this aspects have to be considered and taken care of.

5.1 Material quality requirements

The Internordic Geoproject includes an activity related to the preparation of a Nordtest method on relevant properties and corresponding test methods for the material. This is divided into methods for quality documentation and quality product control. This work is currently going on but a list of material characteristics and relevant test methods are given in Appendix A

5.2 Handling and construction

LWA has low weight and low inner friction and is therefore easily handled. Handling and storage of the material should be done in a way that takes into account the need for reduction of water absorption and also to reduce the risk for crushing of the grains.

Placing the LWA by help of machines can be done in several ways:
- dozing
- by help of belt driven excavator
- blown from car up to 40 meters horizontally and up to 20 meters vertically (only for some gradings.)

Figure 11 Blowing of LWA

The slopes of a Leca fill must be covered by other non-organic fill materials. In roads and railways it is recommended that the covering fill is 80 cm thick, measured normal to the fill slope. When building fills that are higher than 3 meters stone materials should be built to support the lower half of the fill during compaction.

Levelling of the fills can be done by help of light hand held tools.

For the execution of the work the following aspects should be noted:

- use of geotextile on soft cohesive soil
- filling in layers of maximum 0,6 meter thickness (maximum 0,4 meter layer thickness close to retaining walls, abutments etc)
- levelling and compaction by use of caterpillar, recommended maximum contact pressure during compaction is 50 kN/m^2.
- minimum 6 passages after levelling
- it is important to use construction methods that hinder crushing and separation in the material
- blowing in place is recommended for Leca 10-20
- placement should preferably be done in temperatures above 0ºC

5.3 Quality control in the field

5.3.1 Tests for control of compaction

Traditional methods like Proctor could not be applied for expanded clay aggregates. Possible methods for control of compaction could be divided into two groups:
-direct control of compaction; i.e. methods for measuring of density or porosity
-direct control of compaction; i.e. methods for measuring of one of more effects of compaction

<u>Control of density or porosity</u>
Volumetric methods with use of sand or water could be applied, but these methods are rather work consuming. It is proved that rapid methods based on X-rays not will work in expanded clay aggregates.

<u>Indirect methods for recording effects of compaction</u>
Compaction will influence on a lot of properties of granular materials; for instance:

- elastic stiffness
- shear strength
- drilling or penetration resistance

5.3.2 Tests for bearing capacity control

There are several methods available for bearing capacity investigations of roads and similar constructions. The most commonly used methods are shown in table 5. Also a brief evaluation of the fitness when applied on expanded clay layers are given.

Table 3. Some available methods for control of bearing capacity of expanded clay

Principle	Method	Brief evaluation
Elastic deflection under static load	Plate bearing test	very work consuming require heavy vehicle as balance weight scattered results dependent of underground experience available
	Benkelman Beam Measurements	fairly fast to operate just one decided load level will normally tested require truck traffic on the material
Elastic deflection under dynamic load	Falling Weight Deflectometer	require expensive special equipment rapid to operate the surface must be passable for cars known experience are missing
	Light Falling Weight (various models)	rapid to operate the total layer could be tested need for research to establish basis for interpretation tried with success
	Clegg Hammer	proved to be unsuitable on expanded clay
Shear strength of material	Dynamic Cone Penetrometer (DCP)	handhold and easy to operate need for research to establish basis for interpretation or quality criteria

It could be questionable to what extent the different test methods reflect real bearing capacity. However, these tests are the most widely used methods for bearing capacity investigation of roads, railroads and airfields.

5.3.3 Tests for control of integrity of the aggregates

The following methods are available for control of the integrity of the aggregates under and after compaction:
-sieve analysis
-visual inspection and counting of damaged and crushed particles

Experience from the “MiljøIso” project show that just limited information about the degree of damage could be obtained from sieve analysis. Such analyses will give scattered results due to inhomogeneities in the aggregates. For reliable verification of the integrity of the aggregates one probably have to study a number of single particles and count damaged and crushed particles. The samples should be taken both at the surface and in some depth intervals. Fitted sampling methods for the purpose are needed.

6 FINAL COMMENTS

The performed research work and experiences from real projects have verified that LWA has physical, mechanical and thermal properties which makes it suitable for use as frost insulation and light weight fill in roads and other traffic areas.

To ensure high quality of roads and railroads with fills or insulation layers of LWA the following challenges has to be met:
proper design founded on well proved material properties
quality of performed construction in accordance with specifications

Suitable quality requirements for materials and construction are of great significance both to make sure that the material properties are as supposed and that the work is correctly performed.

Material quality requirements should emphasise generally decisive material properties in road and railway constructions, which are *bearing capacity properties* (stiffness and resistance against permanent deformations) and *durability* (relevant here: resistance against crushing under traffic loads).

Proper directions for work performance (and particular compaction guidelines) are very important to obtain a proper end result.

7 LITTERATURE LIST

VEGVERKET (1987):"Lättfyllning i järnvägsbankar". Publication 1986:78. (Swedish guidelines for application of expanded clay aggregates as light weight fill materials in roads).

BANVERKET (1996): "Lättfyllning i järnvägsbankar". Håndbok BVH 585.111. (Guidelines for application of plastic materials and expanded clay aggregates as light weight fill materials in railway fills).

Länsivaara, T. (2000): "Quality requirements for Light Weight Clay Aggregates. Present status in Finland". Report from SCC VIATEK as part of this project. May, 2000. (In English).

Furuberg, T., Hoff, I. and Solheim, O.M. (2000):"MiljøIso-Leca isolasjon i veg og bane. Sluttrapport for delprosjekt 1: Leca frostsikring –veg, bane, grøft". Final SINTEF-report in the "MiljøIso"-project.

APPENDIX A

LIGHT WEIGHT MATERIALS

RELEVANT PROPERTIES AND TEST METHODS

Requirements on test methods for physical and mechanical properties for light weight insulating aggregates in roads and railways

Properties	Test methods (references)			Comments to tests or references	Tests carried out by participating institutions
	Design related	Quality documentation	Production control		
Dry loose bulk density	EN 1097-3	EN 1097-3	EN 1097-3	Loose bulk density and voids	FIN: Max density/vibr. impact
		Norm from Deutche Gesllshaft fur Bodenmechanic.			Used by SINTEF/NTNU.
		SP A1 722	SP A1 722	Loose bulk density	Used by SP and in certification
Grain size distribution	EN-933-1	EN-933-1	EN-933-1	Dry sieving	FIN: EN 933-1
		NS 8005 (ISO/ASTM)		Dry sieving	Used by SINTEF/NTNU.
		EN-933-2	EN-933-2	Test sieves, nominal size of apertures (openings).	FIN: EN-933-2
		SS 13 21 23	SS 13 21 23	Dry sieving	Used by SP and in certification
Particle density		prEN 1097-6	prEN 1097-6	Particle density and water absorption	FIN
		SP-method 758	SP-method 758	Measuring cylinder method	Used by SP and in certification
Water content	EN 1097-5	EN 1097-5		Drying in ventilated oven	
	SFS 5279	SFS 5279	SFS 5279		FIN
	NS 8013	NS 8013			Used by SINTEF/NTNU
	SS 13 21 22	SS 13 21 22	SS 13 21 22	Drying in ventilated oven	Used by SP and in certification

Properties	Test methods (references)			Comments to tests references	Tests carried out by participating institutions
	Design related	**Quality documentation**	**Production control**		
Water absorption		prEN 1097-6, annex C		Water absorption for aggregates > 4 mm	
		BVH 585.11	BVH 585.11	Water absorption after 300 days	Used by SP and in certification
Compressibility static loading		prEN 13055-2 annex A.		Load bearing capacity and compactability	
	Oedometer Ref. (2).			Step loading in large oedometer, Ø 500 mm, H 580 mm.	Used by SINTEF/NTNU The test procedures are based on NS 8071. A large number of tests have been performed.
		Nordtest method (1) (SP-method 2670)		Compressive strenght and compressibility. Prepared by SP	Used by SP
		SP-method 01-46-77		Deformation after vibration at 3 load levels	Used by SP and in certification
	Oedometer			FIN: Ø 360 mm, H 360 mm	

(1): The compressibility is defined as the deformation after a certain load of a vibrated sample.

Properties	**Test methods (references)**			**Comments to tests references**	**Tests carried out by participating institutions**
	Design related	**Quality documentation**	**Production control**		
Compressive strength		SP A1 861	SP A1 861	By cylinder method	Used by SP and in certification
					FIN: Modified SP, VTT
	DIN 4226 Part 3	DIN 4226 Part 3	DIN 4226 Part 3		FIN
		Nordtest method (2) (SP-method 2670)		Compressive strenght and compressibility. Prepared by SP	
Dynamic compression		BVH 585.11 Draft SP		Cyclic load	After 2 000 000 load cycles Used by SP and in certification
		Nordtest method (SP Method 2563)		Prepared by SP Cyclic load, small cylinder	Used by SP
Elastic stiffness and resistance against permanent def.	Cyclic triaxial tests: Ref. (3)			The proposed EN standard for crushed rock and gravel is not directly applicable because the stress levels are too high.	Used by SINTEF/NTNU A specially designed procedure has been used. with constant confining pressure (three levels) and steps with increasing deviatoric load FIN: Testing done

(2): The compressive strength is defined as the load where the deformation, after vibration is 10%.

Properties	Test methods (references)			Comments to tests references	Tests carried out by participating institutions
	Design related	Quality documentation	Production control		
Resistance to degradation by cyclic shear loading		Gyrator. Ref. (1)		Wear/crushing of particles by gyratory shear action.	Used by SINTEF/NTNU FIN: not used so far
Resistance to mechanical degradation (crushing)			prEN 13055-1, annex A	Bulk crushing strength	Has not been used by FIN ?
					SINTEF/NTNU documents mechanical degradation by sieving before and after tests. Visual inspection and separation of pellets into three "damage categories" is also done.
Frictional angle	Triaxial tests,				SINTEF/NTNU uses a procedure based on ETC 5 recommendations for triaxial compression tests on saturated soils.' FIN: VTT has done tests
Sampling		EN 932-1 EN 932-2			SINTEF/NTNU uses guidelines from the Norwegian road laboratory.
		EN 932-1 EN 932-2	EN 932-1		Used by SP and in certification
Water suction height		prEN-1097-10			FIN: VTT has done tests
		SP BT 867	SP BT 867		Used by SP and in certification
	Ref. (4)				NBI has done measurements ,VTT also

Properties	Test methods (references)			Comments to tests references	Tests carried out by participating institutions
	Design related	Quality documentation	Production control		
Resistance to disintegration		prEN 13055-1, annex B			
Chemical analysis		EN 1744-1		Test for chemical properties of aggregates	
		SP method 0658		Sulfur content in aggregate for concrete	Used by SP and in certification
		SP method 0665		Chloride content in aggregate for concrete	Used by SP and in certification
Thermal capacity		SP method 2296			Used by SP
Thermal resistance		prEN 12664		Dry and moist products of low and medium thermal resistance	
Thermal conductivity		prEN 12667		Dry and moist products of high and medium thermal resistance	
	Ref. (4)				NBI has measured heat conductivity of frozen Leca according to ISO 8302. Unfrozen Leca according to ISO 10051
		SS 02 42 11			Used by SP and in certification
					FIN: Thermal needle probe, and uniaxial cylinder ϕ100 mm used at VTT for frozen/unfrozen
Freezing and thawing resistance		prEN 13055-2, annex B		20 frost cycles	SINTEF/NTNU may do these tests. FIN: VTT has capability
		prEN 1367-1		10 frost cycles	Used by SP

References:

Ref. (1): Gyrator: ”Leca isolasjon i veg og bane, Laboratorieundersøkelser av mekaniske egenskaper” (In Norwegian)

Ref. (2): Oedometer. "Leca isolasjon i veg og bane - Stivhet av Leca. Laboratorieforsøk i storødometer." Rapport O98.02.01 fra NTNU Institutt for Geoteknikk, Trondheim. (In Norwegian).

Ref. (3): Triaxial test: ”MiljøIso–prosjektet, Leca isolasjon i veg og bane, Sykliske treaksialforsøk på løs Leca” (In Norwegian)

Ref. (4): Water suction and thermal resistannce: "Måling av fukt og varmetekniske egenskaper til løs lettklinker" , Trondheim 1998, Rapport fra Norges byggforskningsinstitutt til as Norsk Leca. (in Norwegian).

Abbreviations:

NBI	Norwegian Building Research Institute
NS	Norwegian Standard
SP	Swedish National Testing and Research Institute.