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Utilization of light weight aggregate in municipal engineering – experimental excavation study of full scale test structures

Utilisation de granulats légers en génie municipal - étude d'excavation expérimentale de structures d'essais à grande échelle

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ABSTRACT: Light weight expanded clay aggregate (LWA) material have several advantageous properties for infra construction purposes. It is light weight, it has low thermal conductivity, it has good bearing capacity and strong grain strength. Despite that there are some suspects concerning potential collapsing of the trench slopes in re-excavation of trenches in LWA in maintenance works of water supply and sewerage pipelines. However, no documentation of collapsed LWA excavations have been reported. In fact, there are several documented cases in Sweden, UK and Norway with successful excavation and innovative application of such LWA structures. It seems that a more feasible explanation is that the suspicion involving collapsing of LWA structure has developed from a fear rather than actual event that has eventually turned into a rumour. The full-scale sections were constructed in May of 2017. The test area was divided into clay basins that were filled with LWA each in a different manner and reinforcement. These four test structures where: 1) normal reference structure; 2) reference structure without the compaction of LWA-layer; 3A) reinforced LWA layer with wrap-around geotextile and 3B) reinforced LWA-layer with horizontal geotextile. The paper presents the results of the experimental excavation study. The aim of this research is to clear up suspicion towards the material behaviour with full-scale test structures and to develop guidelines for utilisation of LWA in pipeline trenches. In addition, there is an increasing demand for developing new methods to utilise LWA in infrastructural construction purposes.

RÉSUMÉ: Les agrégats d'argile expansée légers (LWA) ont plusieurs propriétés avantageuses pour la construction d'infrastructures. Il est léger, il a une faible conductivité thermique, il a une bonne capacité portante et une forte résistance du grain. Malgré cela, certains suspects pourraient craindre un effondrement éventuel des talus de la tranchée lors de la ré-excavation des tranchées dans le LWA lors des travaux de maintenance des conduites d'alimentation en eau et des canalisations d'égout. Cependant, aucune documentation sur les excavations du MRV effondré n'a été rapportée. En fait, il existe plusieurs cas documentés en Suède, au Royaume-Uni et en Norvège, avec des fouilles réussies et une application innovante de telles structures LWA. Il semble qu'une explication plus réaliste serait que la suspicion consistant en un effondrement de la structure du MRV est née d'une peur plutôt que d'un événement réel qui s'est finalement transformé en rumeur. Les sections à grande échelle ont été construites en mai 2017. La zone d'essai a été divisée en bassins d'argile qui ont été remplis de LWA de manière différente et renforcés. Ces quatre structures d'essai où: 1) la structure de référence normale; 2) structure de référence sans compactage de la couche LWA; 3A) couche LWA renforcée avec géotextile enveloppant et 3B) couche LWA renforcée avec géotextile horizontal. L'article présente les résultats de l'étude de fouille expérimentale. Le but de cette recherche est de dissiper les soupçons sur le comportement des matériaux avec des structures d'essai grandeur nature et de développer des directives pour l'utilisation du LWA dans les tranchées de canalisations. En outre, il existe une demande croissante pour la mise au point de nouvelles méthodes d'utilisation du LWA dans la construction d'infrastructures.

Keywords: Full-scale test structure, LWA, light weight aggregate

1 INTRODUCTION

Light expanded clay aggregate (LWA) has been used in geotechnical engineering applications throughout Europe from the 1950's onward and in Finland since 1951. It has been used to reduce weight of a fill structure, to protect underground structures and soil layers from frost penetration, and as generally fill material.

During the LWA manufacturing process, natural clay is kiln-fired at high temperature to create an incombustible ceramic material. The individual clay particles begin to fuse at 950°C, and the clay material begins to melt at temperatures exceeding 1150°C to form the ceramic shell of the honeycomb pellet. The resulting ceramic pellets are lightweight, porous and have a high crushing resistance.

LWA is a sustainable material. For thousands of years fired clay has been used in a variety of applications. It is highly durable material under changing weather conditions and exposure to natural and synthetic chemical compounds. The LWA is a natural product containing no harmful substances. It is inert with a neutral to slightly alkaline/basic pH value, has thermal insulation properties, is resistant to chemicals, is nonbiodegradable and non-combustible. Typical geotechnical engineering characteristics of Leca® LWA are presented in Table 1. The dry bulk density of Leca® LWA intended for earth works is approximately 15-20 % that of normal granular soil.

Mechanical properties of Leca® LWA vary according to the size and expansion rate of its constituent aggregate particles. In general, smaller particles are more durable.

The risk of corrosion due to Leca® LWA is typically low. When utilized as a fill material surrounding buried steel and plastic materials, Leca® LWA exhibits performance equivalent to that of coarse water permeable soil without organic substances or other impurities. In dry conditions, the corrosion progress in the Leca® LWA layer in extremely slow (TTY 2005).

2 CONSTRUCION OF THE TEST STRUCTURES

2.1 Background for construction

The aim of this research was to clear up suspicion towards the material behaviour during trench excavations with full-scale test structures and to develop guidelines for utilisation of LWA in construction sites where exist pipeline trenches. In addition, there is an increasing demand for developing new methods to utilise LWA in infrastructural construction purposes.

Table 1. Geotechnical properties of LWA 4-32

Parameter	Range of variation	Specific value	Unit
Grain size	4-32 or 4-20 (1)		mm
Under-/Oversize	<15/<10		p-%
Dry density	300(±15)		kg/m^3
Unit Weight			
Dry density		3.0	kN/m^3
Dry (2)		4.0	kN/m^3
Periodically submerged		6.0	kN/m^3
Permanently submerged		10.0	kN/m^3
In buoyancy dimensioning		3.0	kN/m^3
Water absorption			
24 h	< 20		w-%
28 d	< 30		w-%
300 d	< 60		w-%
Friction angle			
loose	33-40	34	°
compacted		37	°
Hydraulic permeability	10^{-3}-10^{-1}		m/s
Modulus of Elasticity (3)	30-80 (3)	50	MPa
Thermal conductivity	0.10-0.17	0.15	W/mK
Insulation factor, a_i (4)		4	-
pH	9-10		-

1) Specific values of LWA 4-20 deviates from LWA 4-32 values

2) w_{max}=30 p-%, always over water level

3) For bearing capacity dimensioning. Stress state dependent value

4) Factor describing thermal insulating properties (a_i) of Leca® LWA at 0.7 m depth, when its dry density is ≤ 400 kg/m^3, and 0.15 m thick drainage layer is located below. Sand is used as a reference material (a_i=1). In challenging conditions thermal conductivity may be bigger.

In this paper experiences are presented from test structures constructed in May 2017. After construction those three basins were examined in two phases. In the first phase the LWA was in dry-condition (material obtained from dry stockpiles) when test basins 1 and 3 were excavated. Later in the autumn basin 1 and 2 were excavated (basin 1 was re-excavated). The second excavation represented more actual conditions in streets. The LWA structures had achieved natural moisture content. The LWA used in the test structures was produced by *LECA®* Kuusankoski.

2.2 Preparation works

The test area was divided into clay basins of 6.5 m x 7 m that were filled with LWA each in a different manner and with or without reinforcement. The test structures were decided to be constructed into an existing ditch between two storage fields. After the project the structures will be left in place and they will connect the two separate fields as a larger field area.

Before construction of the test sections the ditch was cleaned from existing fill materials etc. and natural clay surface was revealed (Figure 2). After preparation works the clay embankments were constructed to separate the test structures from each other (Figures 3 and 4).

Figure 1 Forming the surface of clay and excavating the pipeline trench before construction of the test structures. (Photo: S. Frimodig 05/2017)

Figure 3 Complete clay basins before LWA fill. The size of one basin is 6.5 m x 7 m (Photo: S. Frimodig 05/2017)

Figure 4 One of the testing sections before LWA fill. (Photo: S. Frimodig 05/2017)

2.3 Construction of basins 1 and 2 (no reinforcement)

The first basin was compacted with the excavator and the second basin was done without any compaction on top of LWA layer (Figure 5a). The purpose of the two different structures was to compare the behaviour of a compacted LWA structure to a non-compacted one.

Compactors used in the construction work were 80 kg and 500 kg vibrating plates (Figure 6). Compaction with vibrating plates works well when compacting area is narrow, for example a pipeline trench. However, in a wider structure without any support on the sides (such as the test structure), the material escapes under the compactor and the compactor sinks gradually to the LWA layer.

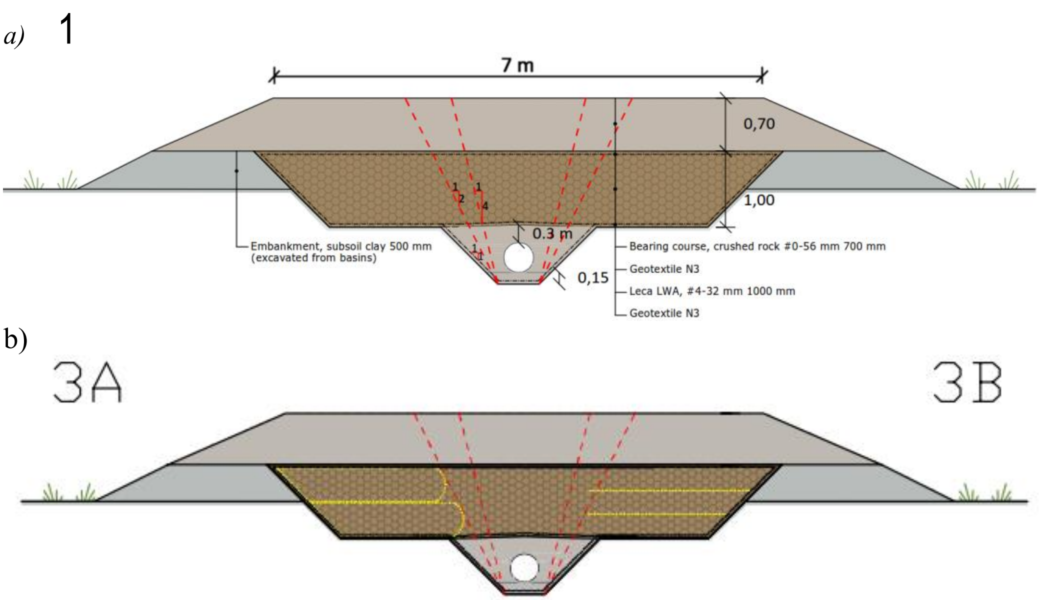

Figure 5 Schematic cross-section of the test structure 1 (a), 3A and 3B (b), 3A=geotextile wrap-around and 3B=geotextile multi-layers). Red lines determine the excavation slope tolerances (2:1 and 4:1)

Figure 6 Compaction method tested in wrap-around structure 3. (Photo: S. Frimodig 05/2017)

In the full-size road construction site, the compaction of LWA is usually done by driving along the layer with a bulldozer or an excavator while spreading the material.

After filling the basin with LWA a bearing course (crushed rock aggregate) was laid on top and compacted in 0.25 m to 0.35 m layers. Each layer was compacted four times with the 500 kg vibrating plate.

2.4 Construction of basin 3 – reinforced LWA structures

The aim of the reinforced LWA structures (wrap-around and multi-layered geotextile structures) was to test the reinforcing of the LWA structure with geotextiles. The geotextile used in the tests was typical separation and filtration geotextile GEO PP 3NG/08 by Geo&Tex 2000 S.P.A. The properties of the used geotextile are presented in table 2.

Table 2. Geotextile properties according to product Certificate (Geo&Tex 2000 S.P.A 2016)

Characteristic	Unit	Value
Mass per unit area	g/m^2	195
Tensile Strength	kN/m	16
Material		PP
Elongation at max. load	%	46
Static puncture test	kN	2.4
Velocity index	m/s	0.045
Chararacteristic opening size	µm	60

The geotextile wrap-around structure and the geotextile multi-layering structure were applied in the same basin on different sides of the basin. The cross-section of the structure is presented in Figure 5b. The side A of the basin consists of 0.5 m thick wrap-around layers and the side B a multi-layering structure with a geotextile vertical spacing of 0.30 to 0.35 m.

In the wrap-around structure (3A) the compaction was done with a vibrating plate 80 kg on top of each wrap-around layer. The compaction succeeded after two workmen tightened the geotextile while compaction. The working phase required additional time and man-work. In Figure 7 presents wrap-around structure before pulling the geotextile on top of the LWA layer.

In the multi-layered geotextile-structure the compaction could not be done as the geotextile crinkled under the vibrating plate and the compactor sank into the LWA layer (Figure 6).

Figure 7 Construction of the basin (wrap-around structure in the front). The geotextile is pulled over on top of the LWA layer. (Photo: S. Frimodig 05/2017)

3 EXPERIMENTAL EXCAVATION STUDY

3.1 Plate load test

Plate load tests were made on top of the bearing course. One plate load test was made on each different test structure (1, 2, 3A and 3B). Requirements of granular base course were applied for bearing course in this study. The requirements depend on a street class (1-6) and the bearing capacity of subsoil according to Finnish general specifications for infrastructural construction works (InfraRYL 2018). Requirements for a street class 5 in case the subsoil bearing capacity of 10 kPa are: E_2 over 75 MPa and E_2/E_1 under 2.1.

Both, the bearing capacities E_2 of structures 3A and 3B were generally slightly outside of the guideline ranges. The relations of E_2/E_1 shows that the compaction degree of bearing course did not fill the requirements set for a road structure. This was results from the difficulties with compaction of test structures. Although the measured bearing capacities were slightly outside the range given in the InfraRYL2018 it does not have a significant influence on the excavation study.

Table 3. Results of plate load tests

TEST	E_2 [MPA]	E_2/E_1
1	88.2	3.1
2	97.3	3.0
3a	52.4	2.7
3b	60.1	2.1

Basin 1, compacted LWA structure
Basin 2, non-compacted LWA structure
Basin 3A, wrap-around geotextile structure
Basin 3B, multi-layered geotextile structure

3.2 Compacted LWA structure (basin 1)

The measured thickness of the bearing course layer was approximately 0.6 m. The thickness of the LWA layer was 0.85 m. During excavation the geotextile was torn easily with the excavation bucket. The excavation was continued to the bottom of the LWA layer. The slopes remained steep and LWA was easy to excavate (Figure 8).

Figure 8 The excavation of compacted LWA structure with natural water content (Photo: T. Dettenborn 08/2017)

The moisture content of the excavated structure resembled the same as is generally met in normal excavation work. The difference in workability between the dry and moist LWA structure was noticeable. Dry LWA was more loose. This is most probably due to the apparent cohesion. The apparent cohesion in moist LWA results from negative pore pressure between the particles which sticks the grains together.

Figure 9 The excavation of non-compacted LWA structure with natural water content (Photo: T. Dettenborn 08/2017)

3.3 Non-compacted LWA (basin 2)

The excavation was done in similar way to basin 1. The excavation of non-compacted LWA was difficult as the LWA material rolled down and collapsed to the bottom of the trench while excavating and the slopes became gradual. The slopes settled to gradient between 1:1-1:1.5 and the trench became wider (Figure 9). The measured thickness of the LWA layer was approximately ≈0.8 m.

It seems that the compaction of the LWA structure is the most important factor. The compacted LWA structure excavation had steeper and more stable slopes. Furthermore, there was found a noticeable difference between dry LWA structure and LWA structure with natural water content (Figure 10).

Figure 10 Effect of the compaction and the water content in LWA structures. Top left: compacted LWA in dry conditions. Top right: non-compacted LWA in dry conditions. Bottom left: compacted LWA in natural water content. Bottom right: non-compacted LWA in natural water content. (Photo: S. Frimodig and T. Dettenborn 08/2017)

3.4 Reinforced LWA structures

The measured thickness of bearing course was approximately 0.5 m. Thickness of the LWA layer was 1.0 m. The difficulty detected with the wrap-around structure was to find the edge of wrap-arounds without breaking the bagged structure. This required additional work. Closer to the structure the excavation had to be done by hand. In practise, for example in case of pipeline repair works, it would have been even more difficult as before starting the excavation the geotextile location or existence is unknown.

The multi-layered structure was more easily excavated and the trench slopes settled steeper than in the non-compacted LWA structure. The only difficulty was that geotextiles were not torn very easily with the shovel resulting in loose material to the trench from the upper layers as the textile stretched before tearing. In case the bearing course was thicker and the structure correctly compacted, these difficulties could have been avoided.

4 CONCLUSIONS

The test structures were constructed inside Leca Kuusankoski, Kouvola, factory area.

Construction of the wrap-around reinforced structure was easy but the compaction work required additional time and man-work. In normal road construction circumstances, the compaction can be done with an excavator (or a bulldozer) on top of LWA layer before installing a geotextile. In the multi-layered structure the installation of the geotextile was faster and less demanding than in the wrap-around version.

During the excavation study, there was a very clear difference between compacted and non-compacted LWA structure. The compacted LWA structure excavation had steeper and more stable slopes. The compaction of the LWA structure is the most important factor to achieve high quality structure. Furthermore, there was found a noticeable difference between dry LWA structure and LWA structure with natural water content (Figure 10).

The wrap-around structure was difficult to excavate without damaging the geotextile even when the precise location was known. In the maintenance construction site where the location or existence of wrap-around structure is not known it can be assumed that damage to geotextile wrap-around structure is probable.

Multi-layered geotextile structure prevented the collapse in the excavation in more efficient way than non-reinforced. The reinforcement prevented the gradual collapsing of the trench. The top layers on top of the LWA have to be thick enough (at least 0.7m) to ensure that geotextile will be torn smoothly with an excavation bucket rather than stretching and pulling loose material to the excavation.

The multi-layered geotextile structure should be constructed to the whole width of cross-section. With this modification the structure performance reinforcing the excavation would have been more reliable. With continuous layering the construction site does not have to have previous knowledge about the reinforcement in LWA-layer.

5 ACKNOWLEDGEMENTS

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