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TITLE

Leca LWA: Experiences from railway applications

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ABSTRACT

Leca LWA have been used in railways since around 1960, but it are more commonly used in the later years. The main purpose for using Leca LWA is to reduce settlements and to increase the geotechnical stability when constructing on soft soil. The material is also in use for frost insulation of the subsoil.

Mostly the experiences from using Leca LWA in railways are good. Some problems with settlements are reported, but these tend to be either lack of necessary compaction of the Leca LWA fill or problems with the subsoil. Generally, there is no need for extra maintenance of railway sections where Leca LWA have been used compared to sections with traditional fill materials.

Leca LWA embankments are successfully used to avoid problems with train catching up the shear wave in soft soil at high speed railways in Sweden, both alone and in combination with lime/cement piles.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Light weight expanded clay aggregate	Lettklinker
GROUP 2	Railway	Jernbane
SELECTED BY AUTHOR	Experiences from use	Brukserfaringer
	Light weight fill material	Lette fyllmasser

TABLE OF CONTENTS

1 Introduction and background

Lightweight aggregates, LWA, have been used in road building for several decades and in railways since the middle of the 1970s. The main objective has been to reduce settlements when constructing on soft ground but it is also widely used as a frost insulating layer. In Norway the LWA have been Leca, foam glass and extruded polystyrene.

Leca LWA have been used also in other European countries, but the material has still some potential both in Europe and in other parts of the world. It is believed that some of the reluctance to use the material is due to tradition, lack of experience and possible improper installation procedures.

Leca LWA has been used in several projects in railways, one of the examples are depicted in Figure 1.

Figure 1 Extension to double tracked railway in 1988, Tveter, Vestby, Norway /17/

In order to extend the use of Leca in railways, it is important to map and document the experience from the Leca LWA already installed. This is one of the main objectives with the current report.

In railways the installation of Leca LWA must be done with extra care in order to avoid settlements and crushing from the static and dynamic train loads. It is important that a railway track maintains its geometrical quality, not only for the ride comfort of the passengers, but also to minimise the derailment risk and maintenance costs. Also, these demands are even stricter when it comes to high-speed lines. Consequently, another important objective with report is to provide guidance in the use of Leca LWA in railways.

2 Technical properties of Leca LWA

Leca is is a ball-shaped granulate made of clay that has been expanded during a heating process in a rotating oven. It has a light weight, gives good thermal insulation and the product has longevity. In Norway 0 - 32 mm granulates are used for construction while both 8-14 and 12-20 mm granulates are used in Sweden. The thermal and mechanical properties may vary between different producers and over time due to production procedures and the basic clay material.

Table 1 Characteristic parameters of Leca LWA /12/

Producer	Material [mm]	Density, dry [kg/m^3]	Thermal conductivity [W/mK]	Static friction angle [°]	100 year creep [%]
Rælingen, Norway	0 - 32	245 - 325	0.11 – 0.15	> 37	< 1.0
Rælingen, Norway	10 - 20	220 - 295	-	> 37	< 1.5
Linköping, Sweden	12 - 20	221 - 299	-	> 37	< 1.5
Kuusankoski, Finland	10 - 20	250 - 320	-	> 37	< 1.5
Avelar, Portugal	10 - 20	235 - 315	-	> 37	< 2.5

3 Areas of application for Leca LWA in railways

LWA are used in the railway in the following areas:

- Lightweight material in embankments
- Frost protection
- Drainage

By using LWA as a light weight embankment material, settlements can be reduced and the stability in the ground increased, because of its low specificgravity. It is also a good insulation material because of its low thermal conductivity, and frost heave and frost problems in the drainage system can therefore be minimised or avoided.

3.1 Light weight material in embankments

3.1.1 The design of the substructure

The vertical stress level the Leca LWA layer will experience in a railway foundation depends on the thickness of the covering layers. The vertical pressure from the sleepers increases considerably from a passing train at a high velocity. According to /2/ a minimum 0.6 m thick reinforcement layer should be used on top of the Leca LWA layer. With an approximately 0.3 m thick layer of ballast between the reinforcement layer and the sleeper, a 15 % increase in the vertical stress can be expected from a passing train at 100 km/h /10/, /11/.

The fundamental design of the substructure when using LWA is shown in Figure 2.

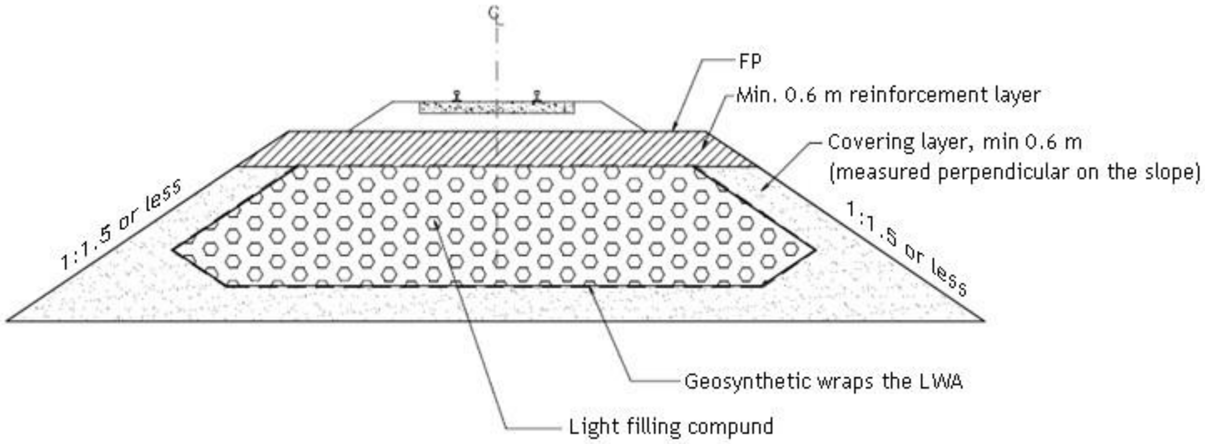

Figure 2 The design of the substructure when using LWA /2/

To avoid the LWA from mixing with the other materials, the whole bed of LWA is wrapped with a geosynthetic. Above the layer of LWA there shall be a subbase of minimum 0.6 m of rock material. To achieve inner stability and sufficient strength in the outer edge of the substructure there have to be a covering layer of minimum 0.6 m on the sides of the LWA embankment material /2/.

If the thickness of the light weight aggregate layer goes beyond 3.0 m, the thickness of the subbase must be increased and the stability must undergo further evaluation /2/.

The steepness of the side slope depends on the material used in the covering layer and of the height of the LWA embankment. The height of the embankment is the entire height from the ground to the track. The side slope can never be steeper than 1:1.5. The steepest angle one can achieve by using broken rock, then gravel or sand. By using clay or silt, you get a more gentle slope /2/.

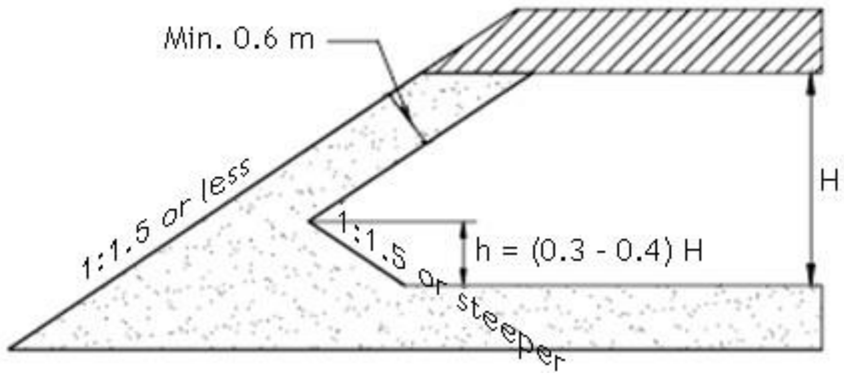

Figure 3 The design of the substructure /2/

The LWA must be placed as low as possible in the embankment if LWA is used only in parts of the light embankment. During installation the LWA must be compacted by a dozer having a maximum chain-to-ground pressure of 50 kN/m^2 or lower. Close to retaining walls etc. a vibrating plate with a weight between 50 and 200 kg has to be used /2/.

3.1.2 Settlements

If the ground is soft and compressible, or weak in other ways, there is a danger for long-lasting consolidation settlements. These settlements will affect the levelling geometry of the railway track and the position of the catenary, since they appear uneven.

An action that prevents the long-lasting settlements is to pre-load the ground a period of time before the construction starts, see Figure 4. By putting extra load on the ground the rate of settlement is increased, and since the final construction has less weight than the pre-load, further settlements are prevented /3/. This method can however be time consuming.

By using LWA as a light filling compound the pressure on the ground is reduced, because of the low specific gravity of the LWA, and therefore the settlements are reduced /2/. By replacing some of the gravel with LWA, settlements can be reduced by as much as 50 % /16/.

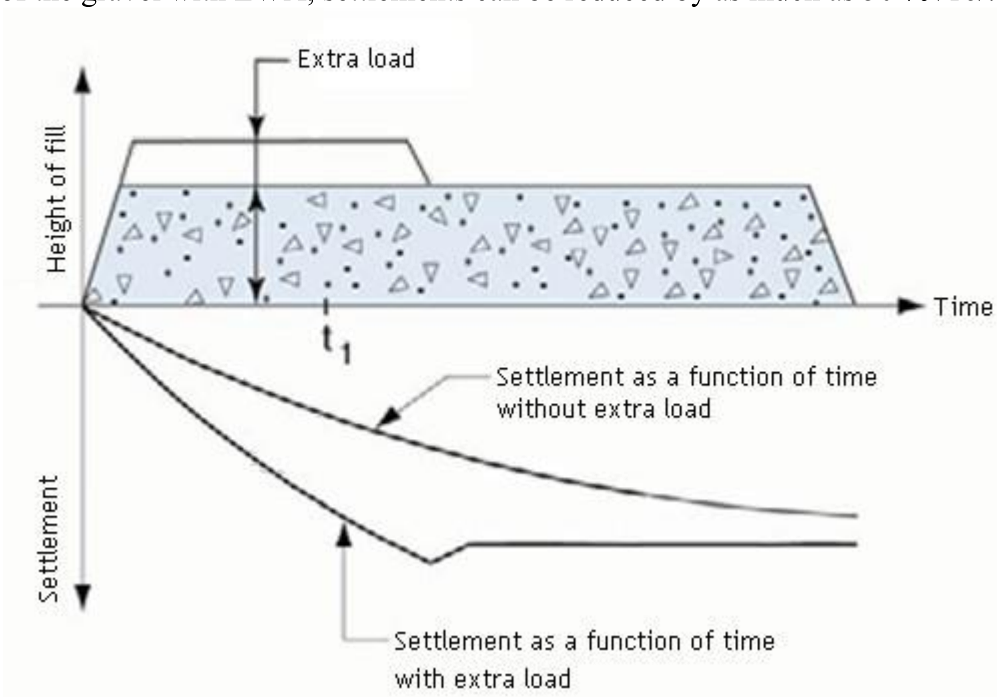

Figure 4 Pre-loading /3/

When building a new track next to an already existing railway, you avoid a great load increase on the original structure by using LWA and compensated foundation. Also a difference in the settlements between the old and the new embankment is avoided. An example is shown in Figure 5.

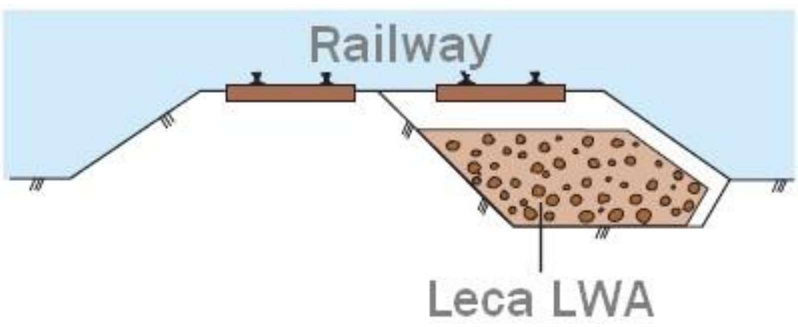

Figure 5 A new railway track next to an already existing track /1/

LWA as a material in embankments is practical in areas where the embankment heights are uneven, or in areas close to constructions free from settlements, to avoid uneven settlements /3/.

To avoid a very extensive maintenance work, the Norwegian National Rail Administration (Norw. “Jernbaneverket”) has introduced some requirements for the settlements in railway tracks, described in the technical regulations (“Jernbaneverkets Teknisk Regelverk”) /2/. The regulations put requirements both on the settlements in single profiles and on the differences in settlements between to profiles after a period of 3 years and 9 years /2/.

In a single profile the tolerated settlement are 24 cm after 3 years, and 40 cm after 9 years. The requirements for differential settlements in a single profile are 17 ‰ and 28 ‰ after 3 and 9 years, respectively. If the differential settlement is less than 70 % of the allowed value after 3 years, the requirement for 9 years is considered as fulfilled /2/.

When using LWA, there can be a problem with uplift when the water lever is high, because of the low specific gravity of the LWA. Therefore, one must reassure that the weight of the embankment is bigger than the uplift at maximum water level at a flood /2/.

3.1.3 Stability

Embankments, earth cuts etc. must be stable in such way that the soil bed is given the stability required. Good stability gives a security against landslip. To reduce the stresses, LWA can be used /2/.

Behind a retaining wall, the pressure from the LWA will be less than the pressure from sand or gravel in an equivalent embankment, as shown in Figure 6 /1/.

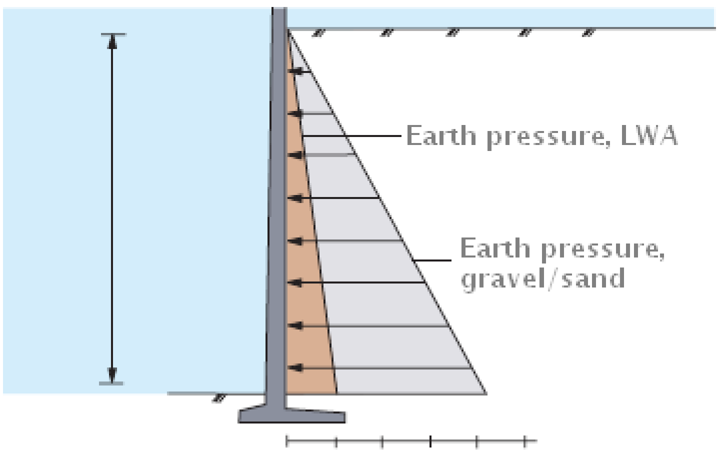

Figure 6 Reduced earth pressure with LWA /1/

When building a railway, or a road, Leca LWA can be used in combination with a retaining wall or filled in bags of geotextiles in a reinforced slope as shown in Figure 7.

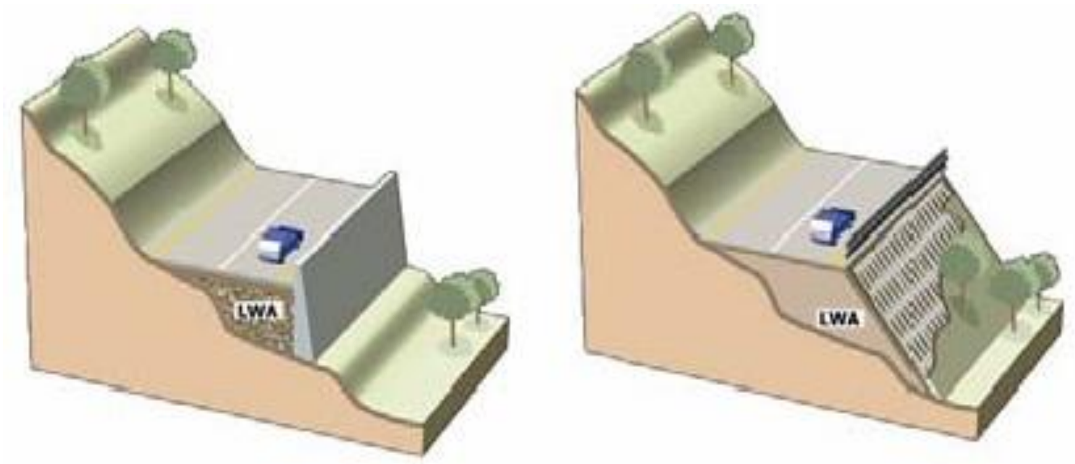

Figure 7 Leca LWA used in combination with a retaining wall or reinforced slope

3.2 Frost protection

Insulation of the ground is important to avoid frost heave, which gives deformations in the railway. When the ground is insulated, less of the grounds thermal heat will escape, and therefore it takes longer for the ground to freeze. The principle is shown in Figure 8 /3/.

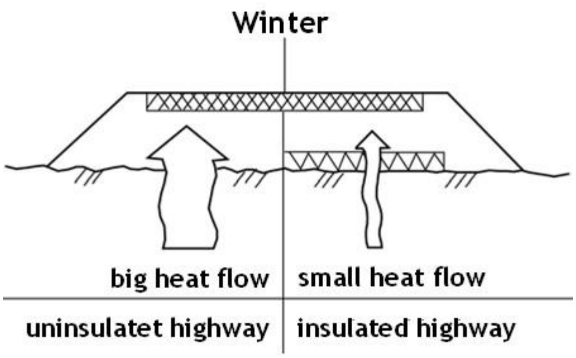

Figure 8 Frost insulation of the ground /3/

3.2.1 Frost protecting layer in the substructure

When building a railway, or a road, the demands of the frost protection decide the thickness of the frost protecting layer and thereof the thickness of the total substructure. The frost protecting layer prevents the frost from penetrating into the track foundation and into the subgrade, and at the same time it makes sure that the stability and the load capacity is sufficient for the structure /2/.

The frost protecting layer lies between the subbase and the reinforcement layer. It is constructed the same way as when LWA is used in lightweight embankments, as described in paragraph 3.1.1. The frost protecting layers' width at the top at a single track railway shall be at least 5.0 m. At a double tracked railway, or a railway with more than two tracks, the top of the insulating layer must be at least 2.5 m on each side of the middle of each track /2/.

LWA is a good insulation material compared to gravel and sand, because of the low thermal conductivity. Therefore, the necessary thickness of the insulating layer is less when using LWA. In other words, it is not necessary to dig as deep, as shown in Figure 9 /1/. This makes LWA a favourable method in places where the frost penetrates deeply, and places where the access of rocks along the railway being built is small /4/.

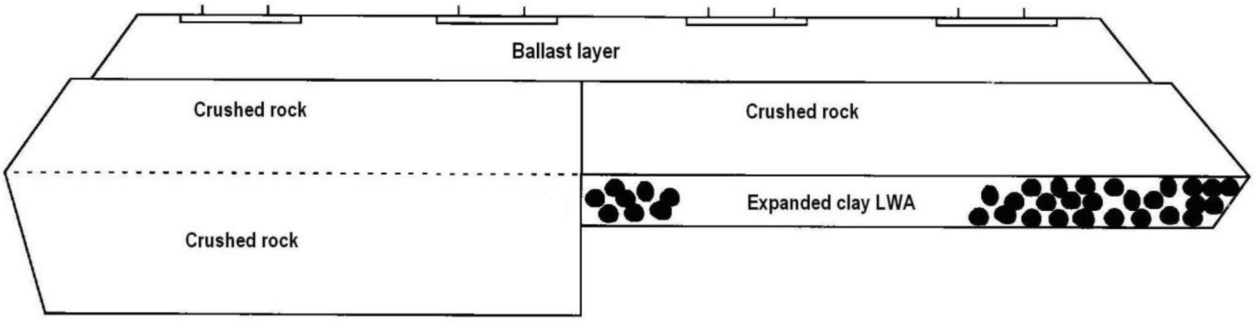

Figure 9 LWA as insulation /5/

In the areas where LWA is used as light filling compound to reduce settlements, or to increase the stability in the ground, it also works as an insulation material. In such cases, the need for an insulating layer will diminish or be totally absent /2/.

When using LWA as an insulation material the design frost index is always set to F_{100}. Statistically, it means that during a 100 years period it shall not be more than one freeze through that disturbs the drift of the railway. The frost protecting layer should always be 20 % thicker than what has been designed to compensate for other materials, i.e. rock material, penetrating into the layer /2/. Table 2 shows the requirements on LWA when it is used as an insulation material in railways.

Table 2 Demands on LWA /2/

Material	Density, dry (kg/m^3)	Thermal conductivity, dry (at -5°C) (W/mK)
Leca 0-32	Max. 400	0.12 (design value 0.15)

There must not be used a material with a higher thermal conductivity than the design value. It is important that the material is well graded, so that the embankment is compact and convection is avoided /2/.

3.2.2 Drainage

When doing changes in the terrain, or changes in the flow of water, the drainage system must be planned strictly. Overload can result in major damage as erosion or slope failure /2/. LWA can be used as a draining material in ditches. The round grain shape makes room for a lot of water, up to 400 litres per cubic meter of LWA /6/.

Because of the LWA's good insulation property, the ditches do not have to be deep to avoid frozen ground below the drainage pipes, as shown in Figure 10 /2/. Also, because of the LWA's low specific gravity, the risk for damaging the pipes during backfill is reduced /1/.

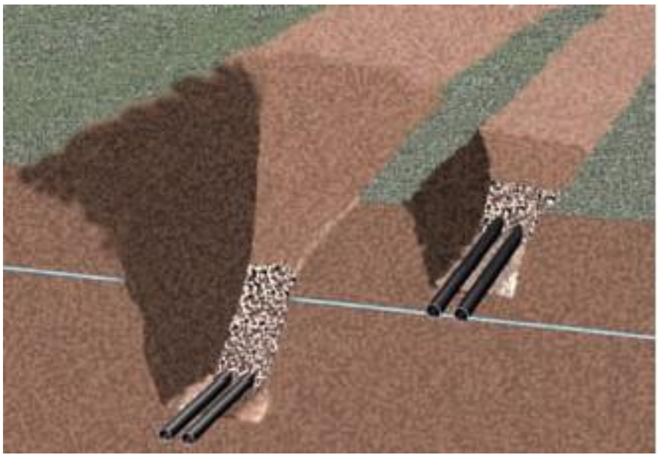

Figure 10 LWA for insulation of ditches /1/

LWA can also be used to add insulation to ditches where frosting is a problem by replacing the top layer of soil with LWA. The LWA is then covered with a geotextile and soil; see Figure 11 /1/.

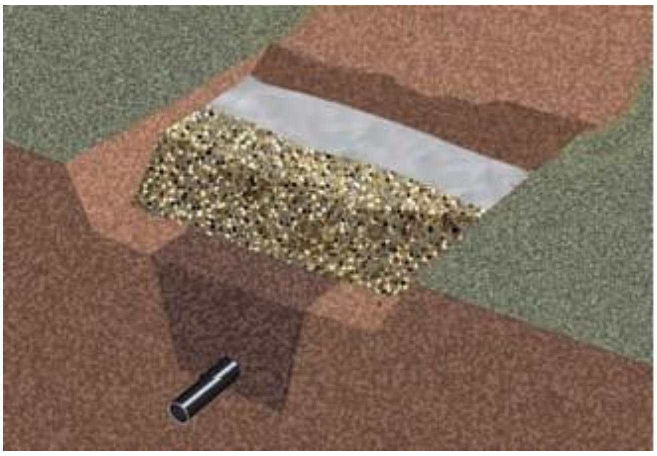

Figure 11 New insulation as a covering layer for ditches with frost problems /1/

3.3 Frost protection of culverts and subdrains

It is very important to insulate subdrains under the railway, and roads, to avoid frost heaving /4/. For subdrains, culverts etc. the cross-section of the pipeline will decide the necessary thickness for the frost insulating layer.

4 Experience from use of Leca in railway tracks

Leca has been used at several railway lines in Europe. The objective of the use has varied. Most common has been the need for lightweight embankments on weak ground to reduce settlements and the use as an frost insulating material in the substructure. In Norway, Leca has also been used as an insulating and draining material around drainage pipes in tunnels. A list of railway sections where Leca LWA has been used is found in Table 3.

Table 3 Railways sections with registered use of Leca LWA

Railway distance	Country	Construction Year	Experience
Bremen Huchting-Grolland	Germany	1997	Good
Helsinki-Turku	Finland	1995	Good
Tveter - Vestby	Norway	1988	Good
Sandnes - Stavanger	Norway		Some problems
Sandeparsellene	Norway		Some problems/no problems
Ofotbanen	Norway		Good
Gardermobanen: Åråsen - Leirsundveien	Norway	 1998	(Not reported)
Leirsundveien - Arteid bru	Norway	1998	Good
Arteid bru - Langeland	Norway	1998	Small settlement the first years
Gardermoen Nord - Bekkedalshøgda	Norway	1998	(Not reported)
Bekkedalshøgda - Ålborgsveien	Norway	1998	(Not reported)
Eidsvoll Sør - Eidsvoll N	Norway	1998	(Not reported)
Berg krysningsspor	Norway	2009	(Not reported)
Ski-Ås-Vestby stasjoner	Norway		(Not reported)
Såstad - Haug 1208	Norway		(Not reported)
Tveter - Vestby	Norway	1988	(Not reported)
Bergsenga - Bremsa	Norway		(Not reported)
Bremsa - Åshaugen	Norway		(Not reported)
Åshaugen - Holm	Norway		(Not reported)
Sandnes - Lurahammeren	Norway	2009	(Not reported)
Hinna - Stavanger	Norway	2009	(Not reported)
Lysaker stasjon	Norway	2007 – 2009	(Not reported)
Daler passing loop	Norway		No problems reported
Rudshøgda passing loop (Moelv)	Norway		(Not reported)
Skøyen station	Norway	1995	Some problems, but mainly due to soft ground conditions.
Bohusbanan, several places	Sweden	1995	Good
Västkustbanan: Fjärås, Göteborg-Malmö	 Sweden	 1997	 Good
Rävsnäs	Sweden	2004	Good
Midjan, Göteborg C	Sweden	2005	Good
Godstågsviadukten i centrala Göteborg	Sweden	2009	Good
Norge-Vänerbanan, Marieholm	Sweden	2009-2010	Some settlements, but only a smaller part is believed to be due to the Leca itself.

In addition there are several railways under construction where Leca LWA will be used:

Barkåker	Norway
Jarlsberg	Norway
Tunnel, Lysaker - Sandvika, Sandvika Øst	Norway
Tunnel, Lysaker - Sandvika, Lysaker Vest	Norway
Norge/Vänerbanan, several places /15/ Hede – Älvängen (Leca LWA will be used in 18 % of the 7.6 km section)	Sweden

The experience from using Leca LWA in railways is good, as can be seen from Table 3. In most cases there is not observed increased need of maintenance.

4.1 Settlement reduction

Due to its low weight, Leca LWA is suitable for use on soft soil in stead of crushed rock in the substructure of a railway. By replacing most of the crushed rock in the substructure with Leca LWA the pressure on the underground is reduced.

- Reduced total settlement when building on soft soil
- Reduced risk for differential settlements on the existing track when building a new parallel track
- Reduced load on existing substructure from the new one

In the following some projects where Leca LWA has been used for this purpose are described closer:

Bremen Huchting-Grolland, Germany /7/
Subsoil with 1.5 to 3 m sand above 1.7 to 5 m clay partially with peat. Ground water level was at 0.7 m below ground level. Water content in clay varied between 30 % and 110 %.

Strong subsidence in the affected section of line, dam 1.5 m high, permanent improvements needed.

Partially replacement of the sand with LWA wrapped in geotextile.

The use of LWA has been very positive. No visible deformation of the railway track seven years after installation.

Helsinki-Turku, Finland /7/
Sensitive, soft subsoil with 15-20 m clay with 100 - 150% water content above layers of silt and gravel. Artesian ground water under the clay, pore pressure ranging from 1.5 to 2 m above the ground level.

There was up to 1.5 m settlement in parts of the railway. The goal was to reduce the need for levelling the track to every second year.

The subgrade was replaced with a layer of LWA varying between 0.7 and 2 m over a distance of approximately 1.2 km. The work was performed within five days.

Subsidence of ground is expected to continue, but the maintenance interval could be extended. There are no details of the damage.

Tveter – Vestby, Norway /7/
Weak subsoil consisting of soft, unconsolidated clay with a high organic content.

The railway between Tveter and Vestby had to be upgraded to two tracks while the line was in continuous operation.

Organic material in the ground was excavated before the underground was partially pre-loaded. Then Leca LWA was placed and compacted up to the existing railway with a dozer. A cross section of the railway is shown in Figure 12.

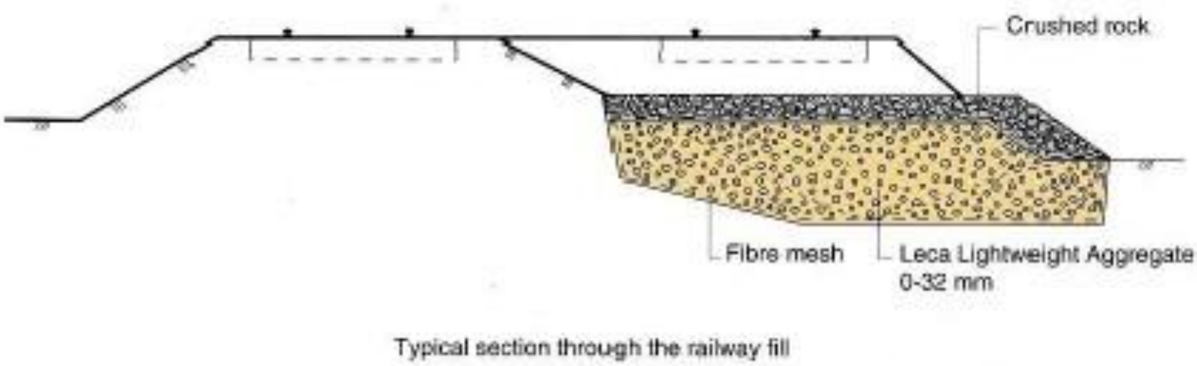

Figure 12 Cross section of Tveter - Vestby /7/

The behaviour of the Leca LWA has been as expected. Only minor settlements and minor damage on culverts and embankments has been registered.

Sandeparsellen, Norway /14/
There is no description of the subsoil, but Leca LWA was used in a 600 m long section to avoid settlements. In addition Leca LWA was used beneath a platform and in embankments close to bridge abutments to increase stability and to reduce settlement.

The Leca LWA was put on place with a dozer. According to Jernbaneverket there has not been any compaction of the Leca LWA beyond the compaction you get when the dozer put the material in place. A geotextile is used to separate the Leca LWA from the other materials in the track foundation and the embankment. A 500 mm thick layer of crushed rock is used on the sides and on top of the Leca LWA in the embankment and railway section.

In the 600 m section where Leca LWA was used the experience of this use is good. There are not registered any settlements on the railway section.

In the case where Leca LWA was used in embankments close to bridge abutments there were huge settlements shortly after construction; up to 10 % was registered, even though load transfer plates were used. There has, though, not been experienced any increased need of maintenance during operation of the railway after the initial settlements.

Sandnes – Stavanger, Norway /14/
There is no description of the subsoil, but the Leca LWA was used in embankments close to bridge abutments to increase stability and to reduce settlements.

The Leca LWA was put in place with a dozer. A geotextile is used separating the Leca LWA from the other material in the embankment. A 500 mm thick layer of crushed rock is used on the sides and on top of the Leca LWA. According to Jernbaneverket there has not been any compaction of the Leca LWA beyond the compaction you get when the dozer put the material on place.

Also in this case there were huge settlements in the embankments, just as at Sandeparsellen. Up to 10 % settlement was registered, even though a load transfer plate is used.

Skøyen station /13/
There were constructed two embankments next to Skøyen station, one at each end of the station area. On the one side there was a 30 to 50 m thick layer of sediment above rock. The other side had less thickness of sediments. On both sides there were used Leca LWA in a 50 to 60 m long section of the railway to reduce settlements, but the construction of the embankments were different.

Embankment no 1, on top of a layer of less sediment thickness:
The embankment at this side was built first and has a 3 m thick layer of Leca LWA. The Leca LWA was put in place with a dozer in several layers each up to 1 m thick, but the Leca LWA was not supported on the sides until each layer had reached its full thickness. Because of this the dozer could not traffic close to the sides. When the side support was built a new layer of Leca LWA was laid. There was no extra compression of the Leca LWA.

There was a problem of settlements up to 3 % quickly after the embankment was completed. There have not been reported problems after that.

Embankment no 2, on top of a thick layer of sediments:
The embankment built at the station area was constructed after embankment no 1. Here a supporting wall was built at each side of the embankment before the Leca LWA was put in place. Due to the need of an anchoring plate to take breaking forces in the embankment the Leca LWA layer became not as thick as intended. The anchoring plate was placed above the Leca LWA and then heavy masses were placed on top of it.

There were no problems of settlement in the Leca LWA immediately after the embankment was completed, but the construction as a whole is still settling. This is probably related to the need of heavy masses on top of the anchoring plate which lead to a reduction of the thickness of the Leca LWA layer. This has resulted in a too high pressure on the subsoil in relation to what was originally planned.

Västkustbanan: Fjärås, Göteborg-Malmö /15/
Near Fjärås is a section where Leca LWA is the only tool used to reduce settlement and better stability. Long time measurement shows very good results, better than for sections further south where lime/cement piles are used for this purpose.

Västkustbanan, Marieholm /15/
Where the railway crosses an old river bottom of the Göta River there is a 5 meter high Leca LWA embankment where they have problems with settlements. The settlement is however not

considered to come from the Leca LWA but from settlements in the ground. This case is being reviewed at present.

4.2 Stability

The low weight of the Leca LWA makes it suitable for use on top of slopes or along hillsides where there is a need to reduce stresses to obtain sufficient security against landslip.

Gardermobanen /14/

This railway connects the capital of Norway, Oslo, with its airport at Gardermoen and is trafficked by trains travelling at a maximum speed of 210 km/h. Leca LWA has been used both in embankments and as a part of the substructure on several parts of the railway. The first 6 – 8 years after the railway was opened for traffic there was a need for minor adjustment of the track due to settlements, but there has not been reported any major problems or increased need of maintenance of the railway where Leca LWA is used.

A part of the section Arteid bru – Langeland runs partly along E6 south of Gardermoen at a length of approximately 4 km. In this area there are weak soil conditions and Leca LWA is used to reduce stresses in the ground. For this section there was a 10 – 30 mm settlement for the first years with train traffic, but after that there has not been any need for maintenance different to other sections where rock has been used in the substructure.

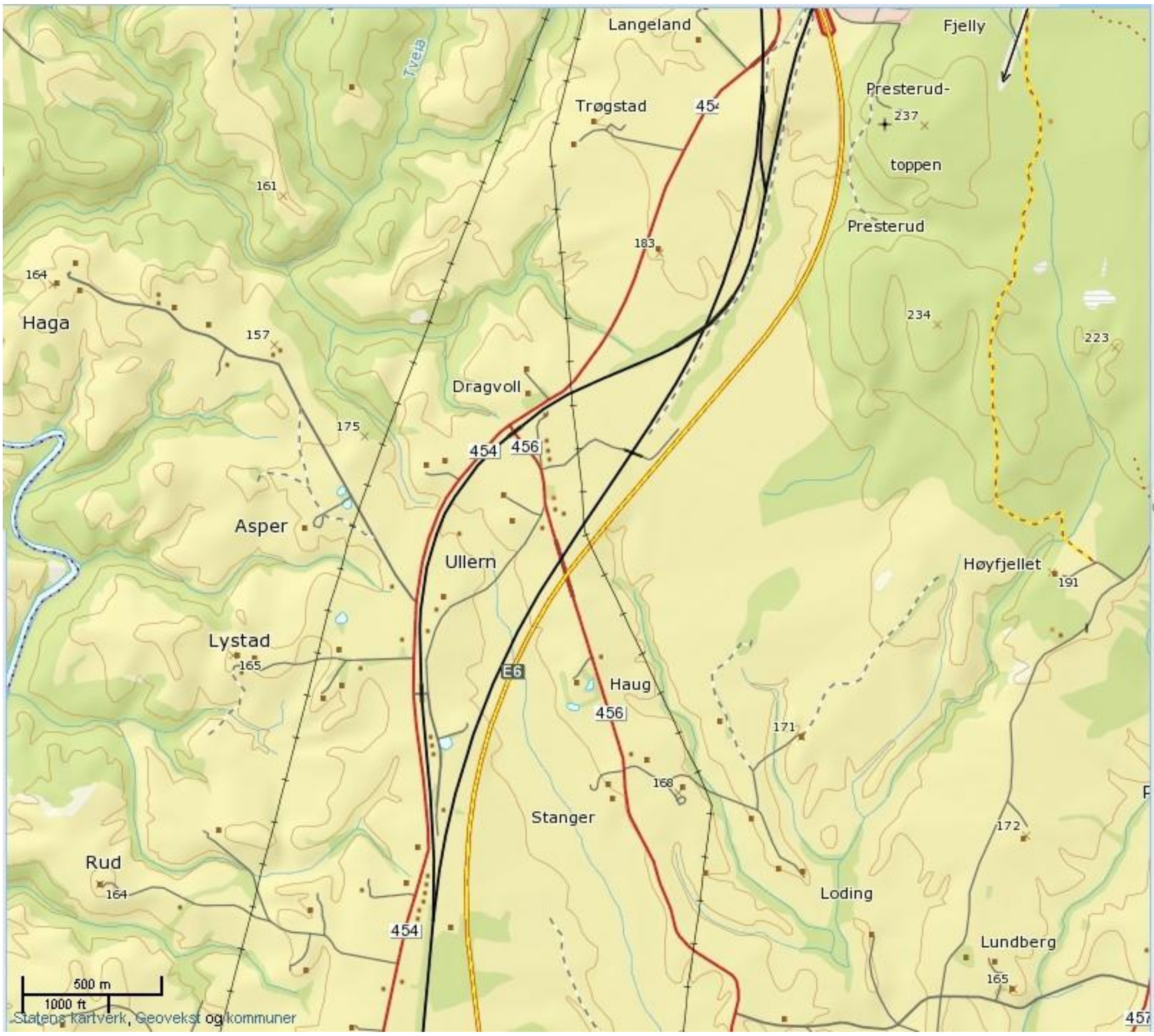

Figure 13 The section Arteid Bru - Langeland on Gardermobanen where Leca LWA is used on weak soil conditions /9/

At the section Leirsundveien - Arteid Bridge the railway runs on an embankment built in a slope down to the river Leira for approximately 250 m before it crosses the same river as shown in Figure 14. To reduce the load on the slope Leca LWA was used in the embankment.

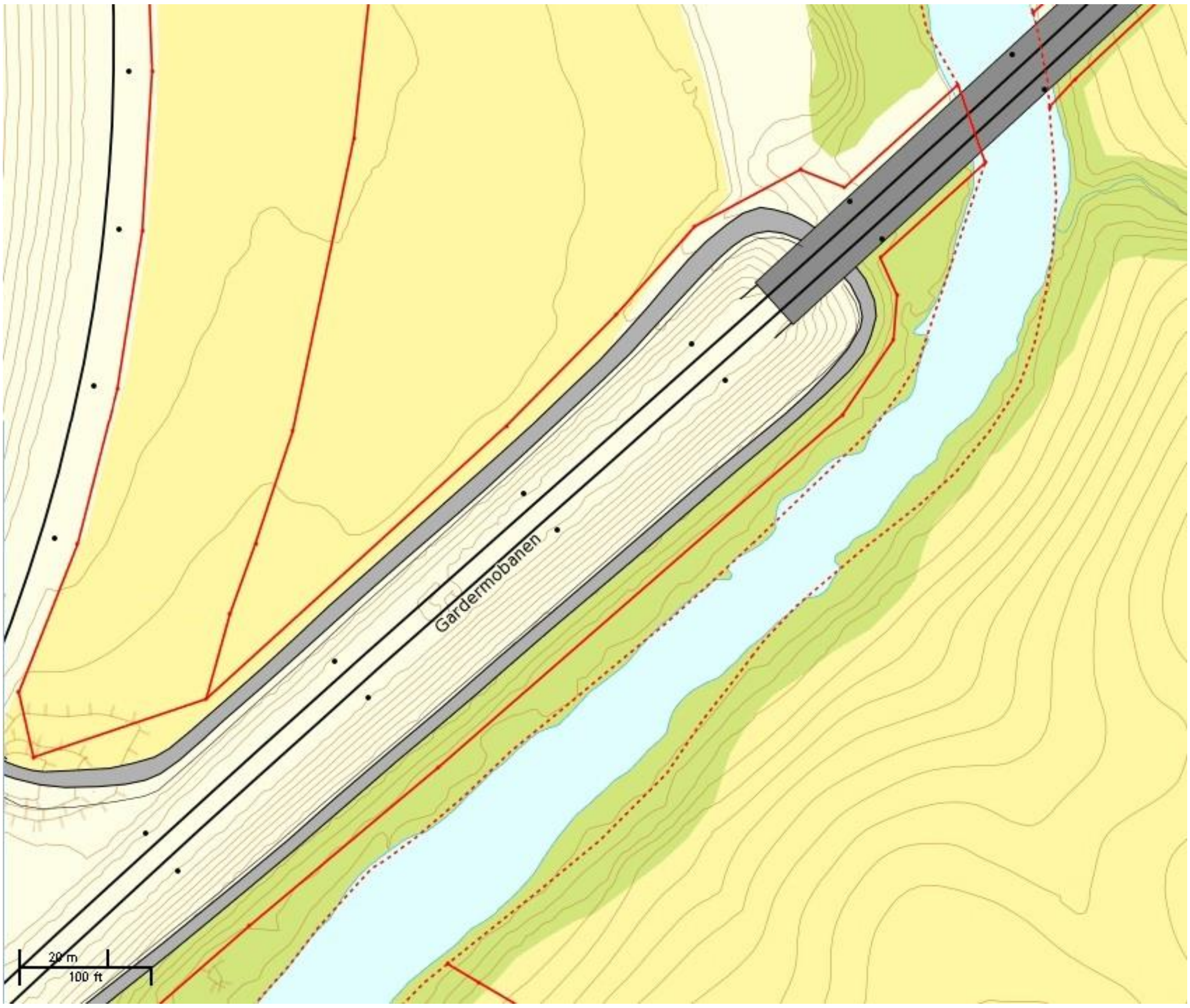

Figure 14 Embankment built in the slope down to the river Leira, equidistance 1 m /8/

4.3 Frost insulation in substructure

In the northern countries of Europe railways may have to be insulated to avoid frost from getting into the ground under the substructure causing frost heave and subsequent damage on the railway. Compared to rock and gravel the advantages of Leca LWA are:

- Low thermal conductivity
- Reduced thickness of insulating layer
- Reduced excavation in the subsoil

A project where Leca LWA has been used for this purpose is **Sandeparsellen, Norway /14/**
The railway line is double tracked and the subsoil consists of clay. A 10 m wide and 32 cm thick layer of 10-20 mm granulate Leca LWA was used as insulation in the track foundation for a length of 14.5 km. The Leca LWA was installed by blowing the material directly into place.

There is not reported any need for increased maintenance, frost heave or other problems regarding the use of Leca LWA in this section.

4.4 Drainage

The combination of low thermal conductivity and low water absorption makes Leca LWA well suited for use in combination with drainage systems.

At **Ofotbanen, Norway /14/**, there was a problem with freezing water in the tunnels along the railway. Water at the sides of the track caused ice build-up behind the frost insulation at the tunnel walls and towards the track, causing lifting of the track and the track being shifted laterally.

To solve the problem, ditches with drainage pipes along the track were filled with 40 cm Leca LWA. The ditches were then covered with crushed stone. Since then, the water freely drains out of the tunnels and there have not been any problems with ice on the sides of the track in the tunnels.

Ofotbanen still have a problem with water freezing beneath the track in the tunnels and have plans using Leca LWA also to solve this, but this is more complicated because of the shallow depth from the track to the rock, and the heavy axle loads from the iron ore trains.

4.5 High speed on soft soil

Soft soil is a problem when building high speed railways. In areas where soft soil is present the speed of the train may reach the wave velocity of the shear force in the ground. This will then cause heavy vibrations in the track. In Sweden they have used Leca LWA in combination with lime/cement piles to avoid this. At Västkustbanan near Rävsnäs there is used a Leca LWA embankment beneath a load distributing plate with reinforcement bars in a cement and Leca LWA mixture to avoid the shear wave problem for speeds up to 250 km/h.

5 Discussion

When using Leca LWA in a railway embankment it is important to avoid crushing of the Leca LWA and to compact the material properly, approximately 10 % compaction is necessary, but this may wary depending on the exact origin of the Leca. Therefore it is important to relate to the product documentation from the producer. The intended compaction is obtained by following the recommendations in /5/ on how to put the Leca LWA in place and how to compact the material. If the Leca LWA is not sufficient compacted the applied static and dynamic loads during the use of the railway will cause the Leca LWA to compact. In such cases settlements up to 10 % of the thickness of the Leca LWA layer can be observed.

The number of passes necessary to obtain the intended degree of compaction depends both upon the thickness of the Leca LWA layer and the compacting equipment used. Close to structures or other materials thinner layer of Leca LWA and lighter equipment have to be used /5/.

When designing embankments with Leca LWA where an anchor plate is going to be used it is necessary to take extra care in the design of that part of the embankment so that local settlements are avoided. If it is necessary to use heavy masses on top of the anchor plate, more of the underground may have to be excavated and replaced with Leca LWA to obtain the needed off-loading of the ground.

For the foundation of catenary posts, some care should be taken in order to achieve proper stability.

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