COVERING THE HIGHWAY E12 IN THE CENTRE OF HÄMEENLINNA – INNOVATIVE USE OF FOAMED GLASS AS LIGHT WEIGHT MATERIAL OF APPROACH EMBANKMENT

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Abstract. The project is a part of a bigger scheme for improvements to the city center of Hämeenlinna. Highway E12 is to be covered with a concrete shell to form a tunnel of 250 meters in length. The construction site is located in a central location with a high traffic volume.

There are two bridges on the site that are rebuilt as a part of the coverage. Throughout the construction, traffic was redirected over the built parts of the cover, next to the bridges. The cover is positioned 8 m above the ground level. The issue of road access was solved with ramps constructed using foamed glass.

Foamed glass is a lightweight aggregate that is produced from clean recycled glass. Foamed glass has a long history of usage in Europe. In 2011 Uusioaines Ltd. started production of foamed glass in Finland. Foamed glass is used in earthwork construction; its bearing capacity and fractured granularity make it easy to use. The product is registered with the trademark Foamit. Due to its CE conformity (EN 13055-2), it is both a technically and environmentally risk-free product.

Foamed glass was chosen for its technical qualities, usability and recyclability. Foamed glass lightened the loads on the subsoil and its high friction angle coupled with a low unit weight minimized the lateral stresses. Foamed glass will be reused in the area. Limited work space near the abutments meant that a narrower structure needed to be constructed; this was achieved by placing the foamed glass between two sheet pile walls.

There is 3.5-7.3 m layer of foamed glass between sheet piles. A sloped foamed glass embankment up to 3.5 m high was used in areas where possible. At best, the embankment was 85 kPa lighter and earth pressure reduced about 60 % in comparison to a gravel embankment.

Keywords. Innovative planning. Design. Technologies. Construction and quality assurance.

INTRODUCTION

The construction of a concrete tunnel in a built-up area can have uncommon limitations. In Hämeenlinna, the encasing of the existing E12 highway in the center of the city required temporary access ramps that could not be built as sloped embankments out of gravel. A lighter and more compact solution was needed. Foamed glass aggregate and sheet piles were used to solve the issue.

1 FOAMED GLASS – THE MATERIAL

1.1 Production of foamed glass

Foamed glass is produced industrially by treating cleaned glass particles. These glass particles are ground into a powder of under 0.1 mm and mixed with a foaming agent. The powdered glass is then spread onto a conveyor belt and then slowly passed through a furnace. The furnace heats the powdered glass to a temperature of 900 °C. This causes the glass mass to expand to five times its original size and it subsequently hardens into foamed glass. 92 % of foamed glass´s composition is air bubbles. As the foamed glass cools, it breaks up into pieces and forms foamed glass aggregate.

1.2 Technical properties

Finnish foamed glass aggregate (Foamit®) has a relatively low unit weight, combined with a high angle of friction making it ideal for embankments. Technical properties from literature and actual measurements with Foamit® are presented in table 1.

Table 1. Technical properties of foamed glass. The parameters have been defined/evaluated on the basis of the following publications, reports and memorandum: Byggforsk [2005]; the Finnish Transport Agency [2011a]; Ramboll [2012 and previous laboratory tests]; Ramboll [2011a]; Ramboll [2010]; SGI [2008]; Sintef [2010]; Statens vegvesen [2008]; TTY [2012].

Properties	Variations recorded in technical literature	FOAMIT ® Measurement values
Granular size	10-50 / 10-60 mm	10-60 mm
Density (dry bulk)	180…230 kg/m^3	210 kg/m^3 ± 15 %
Density (dry compacted)*	225…290 kg/m^3	220…280 kg/m^3
Density (long-term in a road structure)	270…530 kg/m^3	350 kg/m^3
Density (long-term underwater , <1 year)	-	600 kg/m^3
Density (permanently underwater)	-	1000 kg/m^3
Bulk density (in buoyancy)	-	3.5 kN/m^3
Bulk density (permanently underwater)	-	10 kN/m^3
Friction angle	36…45°	36…45°
pH-value	-	10
Compaction factor	-	1.15-1.25
Water absorption** Short-term (4 weeks)	30…60 weight-%	60 weight-%
Water absorption** Long- term (1 year)	40…116 weight-% ˜	100 weight-% ***
Compression strength, 10 % compression	-	0.3-0.4 MPa
Compression strength, 20 % compression	0.77-0.92 MPa	> 0.9 MPa
Thermal conductivity (k-value)	0.11-0.15 W/mK	0.1 W/mK (dry) 0.15 W/mK (moist) 0.2 W/mK (saturated)
Load bearing properties		
E-modulus, based on plate load tests with thin…thick superstructure ****, *****	-	55-70 MPa
Resilient-modulus Mr , based on cyclical 3-axial test, average principle stress 40 kPa	-	75 MPa
Resilient-modulus Mr , based on cyclical 3-axial test, average principle stress 100 kPa	-	150 MPa

* density depends on amount of compaction
** immersed in water
*** will be verified in further long-term studies
**** increasing factors for E-modulus are a thick superstructure, good bearing capacity of subsoil and supporting embankments beside foamed glass
***** E-modulus for Odemark calculation formula

The grain size distribution of foamed glass is quite homogeneous. Officially the particle size is 0…60 mm, but only a small percentage of the grains are under 10 mm in diameter, as shown in figure 1. The actual product is shown on figure 2.

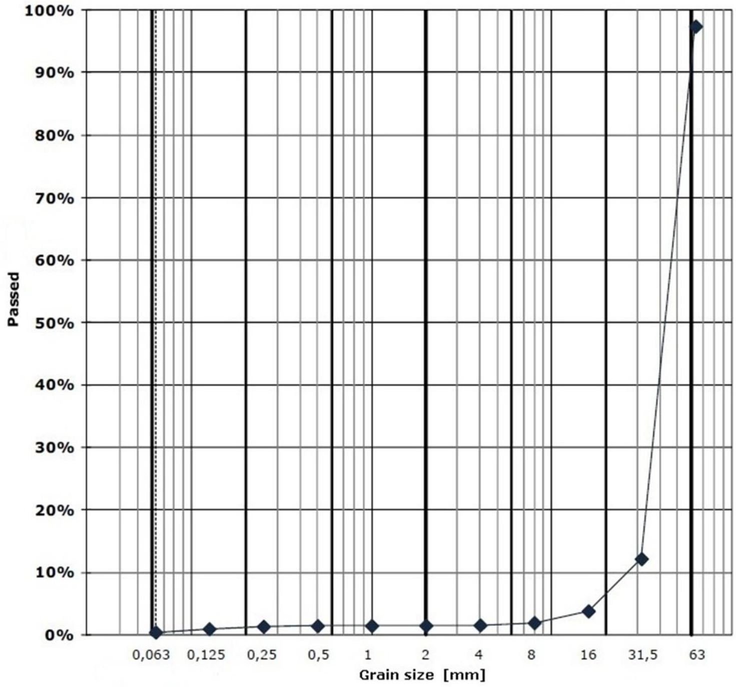

Fig. 1. Typical grain size distribution of foamed glass (Foamit®).

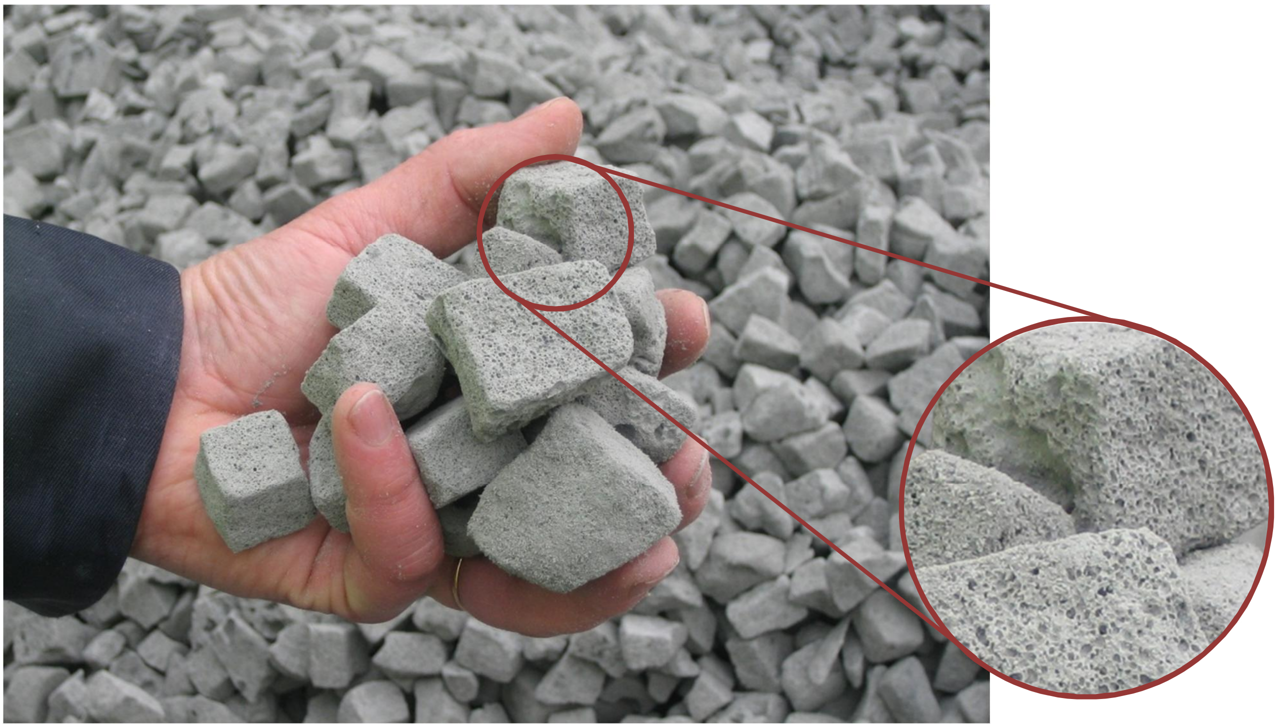

Fig. 2. Foamed glass on site, edges of particles have been slightly rounded during transport and handling.

2 FOAMED GLASS – TYPICAL STRUCTURES

Types of structures where foamed glass can be used are numerous. The main benefits of the use of foamed glass in infrastructure construction are; reduced settlements, increased slope stability, reduced lateral earth pressures, thermal insulation and frost heave protection. Typical structures are presented in figure 3. Foamed glass can also be used in the construction of buildings. It serves as an all-round light weight aggregate or thermal insulator around foundations and floor slabs or on the roof.

a) b) c) d)

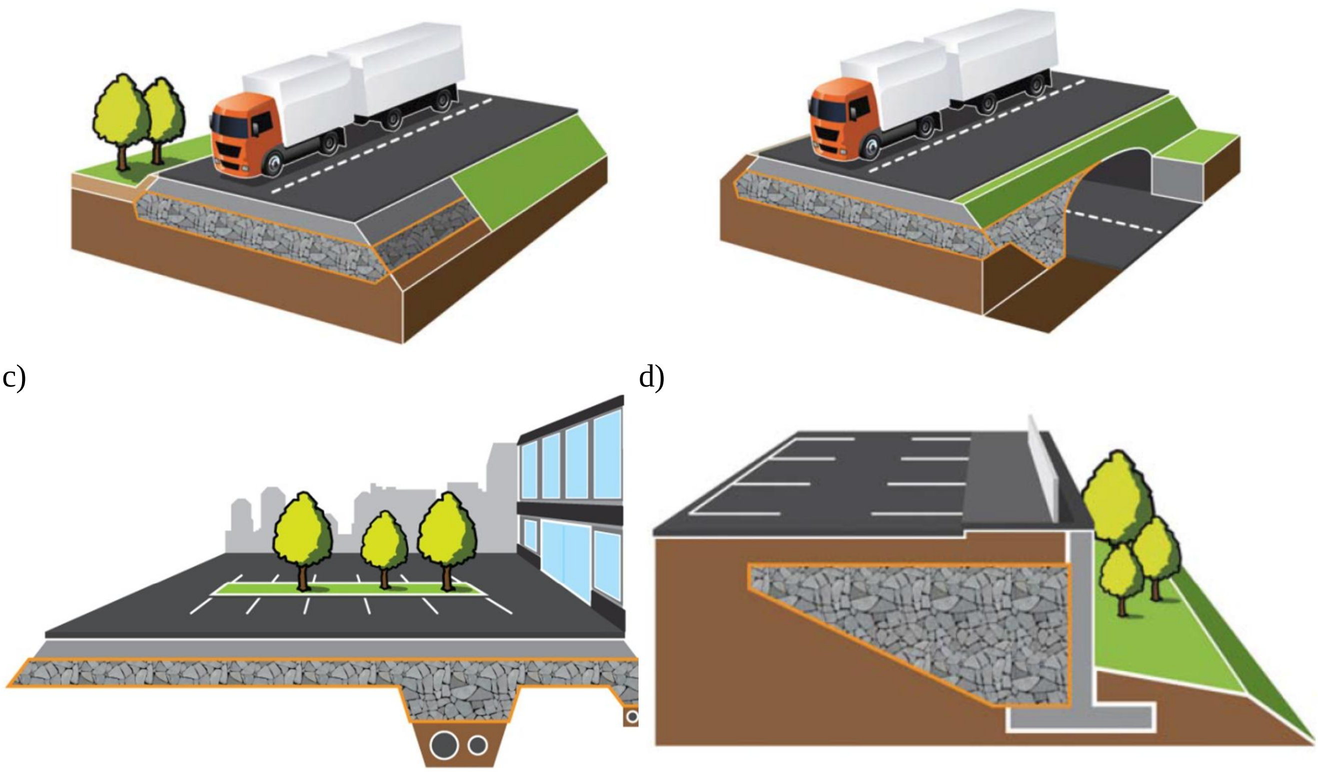

Fig. 3. Illustrations of different uses for foamed glass.

3 FINNISH GEOLOGY

The ground layers of southern Finland were largely formed during and after the last ice age. Typically, soils in Finland are well defined, consisting of areas of softer deposits of silt and clay between outcrops of bedrock or glacial till. The clay layers are typically very soft, with an average shearing resistance of 5-15 kPa. Additionally the layers are often very compressible leading to large deformations under load even after many years. A section showing typical soil conditions in Finland is shown in figure 4. The conditions on the Hämeenlinna site are similar to those in the lower right hand corner- comprising of clay and peat layers.

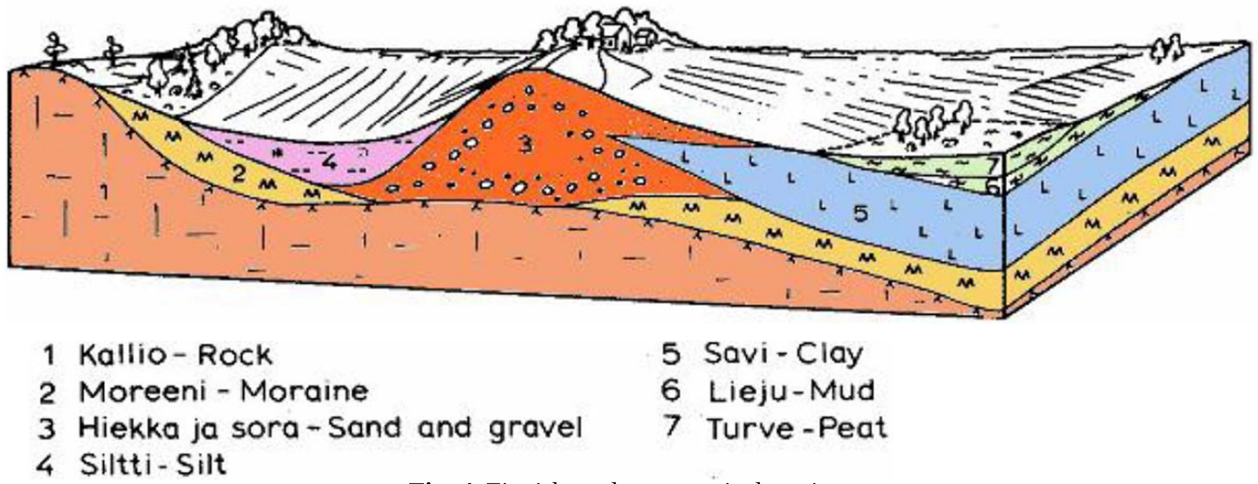

Fig. 4. Finnish geology, a typical section.

4 A GENERAL DESCRIPTION OF THE PROJECT

The aim of covering of the E12 highway in the center of Hämeenlinna is to create a more unified city center. At present, the city is divided as the highway runs through the middle. In addition to the construction of the concrete tunnel, surrounding streets will be refurbished and a shopping center will be built, partly on top of the cover. Maps of the location are presented in figure 5.

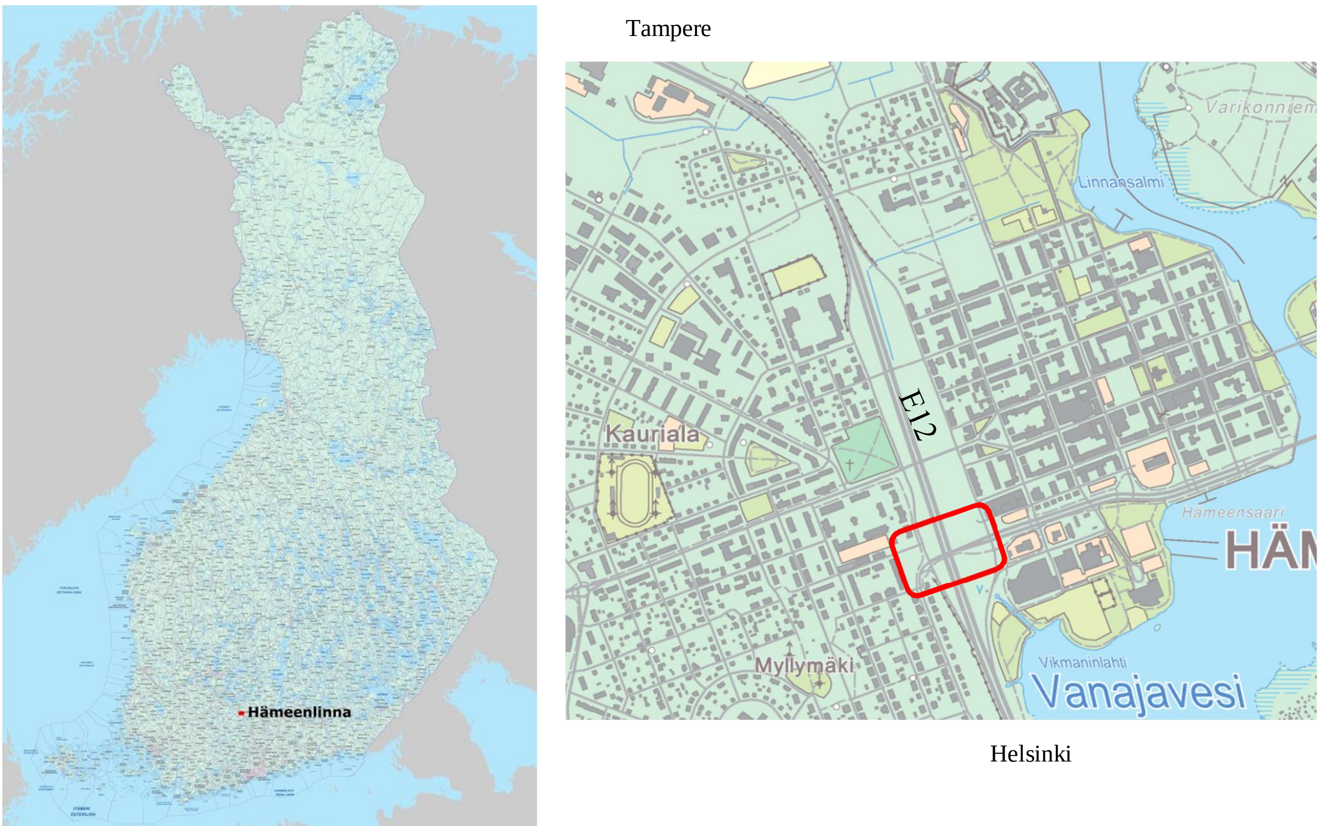

Fig. 5. Map of Finland and the city of Hämeenlinna, area presented in figure 6 is highlighted with a red square.

As a part of the tunnel, two bridges have been demolished and will be rebuilt as a part of the cover. During the period of this phase of construction, traffic flow is being directed over the constructed parts of the cover. As the bridges abutments are also to be rebuilt, driving across the site required access ramps of a maximum of 8 m in height. The soil conditions (described below) and the lack of space for the ramp's sloped embankments made it impossible to use standard solutions.

5 SOIL CONDITIONS

At the site of the tunnel there is 1-3 m of fill because of the old highway. The fill layer mainly consists of sand and gravel and is thickest around the Turuntie and Paasikiventie bridges at the ends of the section to be covered. The current road is founded on ground without any ground improvement and presumably the peat has been removed. Outside the road area, there is a layer of peat 1-2.5 m thick that is partially under a layer of fill. There is a 10-17 m thick layer of silt and lean clay under the fill and peat layers. Boring resistance of the cohesive soil distinctly increases at the depth of 10 m. The water content of soil samples taken from the silt and clay layers is 17-72 %. Vane shear test results from the upper and softer cohesive soil layer were 12-32 kN/m^2 (shearing resistance). Top surface of moraine layer is in 13-15 m depth and its thickness is 0-5 m. On the basis of the static-dynamic penetration tests, the moraine is very loose and in some places rocky. Rock surface is at the depth of 13-21 m. Groundwater is partially pressurized. Groundwater level is at 0.5 m depth on average.

6 SOLUTIONS

Normal gravel filling was not an option, since it would have caused stability problems, lateral stresses to the piles and increased the strength demands on piles and sheet pile wall anchors. Organizing the temporary traffic over piled structures would have been a costly solution. For these reasons foamed glass was chosen to lighten the embankment load.

Foamed glass was also chosen because of its technical and structural qualities, usability and recyclability. Foamed glass's low unit weight lightened the loads on the subsoil and high friction angle together with low unit weight minimized the lateral stresses against the sheet pile walls. Because of the high friction angle, it was even possible to construct steep embankments without support levels and structures beside foamed glass embankment. Up to 10 000 m^3 of foamed glass was delivered to four different embankments on the construction site. The foamed glass will be reused, after the construction of the new bridge abutments, for example in backfills of the market building and the surrounding roads. Lack of work space near the abutments required a narrower structure, which was achieved by placing the foamed glass between two sheet pile walls. The site layout and longitudinal and cross sections are presented in figures 6-8.

7 RAMP (STRUCTURE AND DESIGN)

The design value of friction angle used for the foamed glass in calculations was 40 degrees and the unit weight used was 4 kN/m^3. There is 3.5-7.3 m of foamed glass between sheet piles and up to a maximum of 3.5 m thick layer of foamed glass in unsupported sloped embankments. On top of the embankment are 650 mm layer of crushed aggregate and a 50 mm layer of asphalt, as pavement. A sloped embankment was used in areas where the stability was good enough and the workspace was not too limited. The sloped embankment was constructed from foamed glass without separate support embankment. At some places, steel-net reinforcements were used under the foamed glass to ensure the stability of the structure perpendicular to the highway. At best, the foamed glass lightened embankment was 85 kN/m^2 lighter and earth pressure reduced about 60 % in comparison to a typical gravel embankment. The situation was modeled with a number of different geotechnical calculation programs such as Plaxis and GeoCalc to calculate the settlements, stability and the earth pressures.

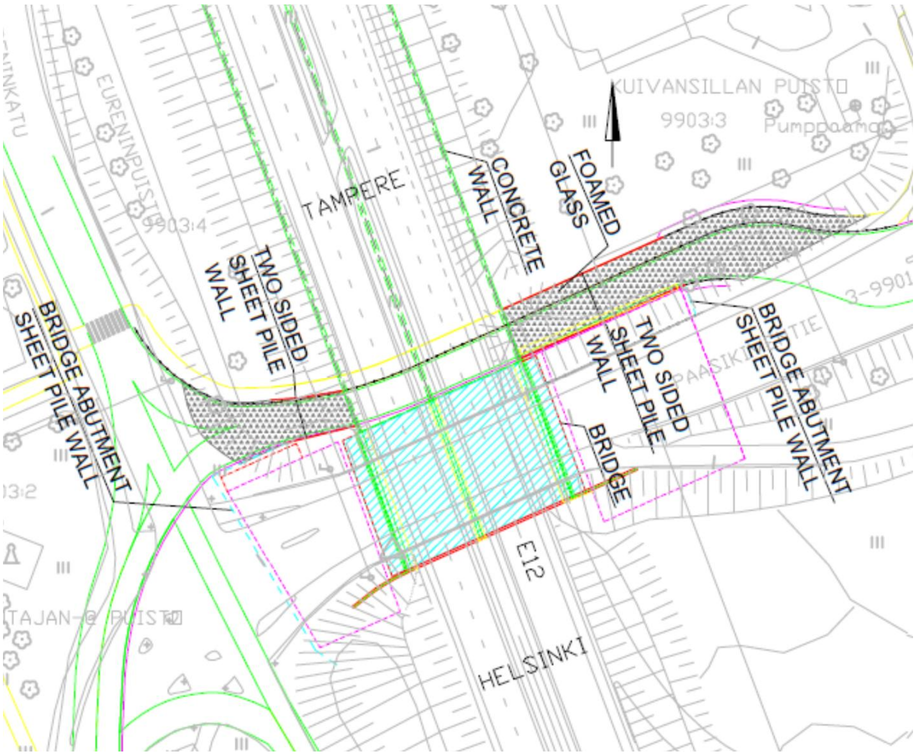

Fig. 6. Layout of foamed glass embankments during rebuilding of bridge.

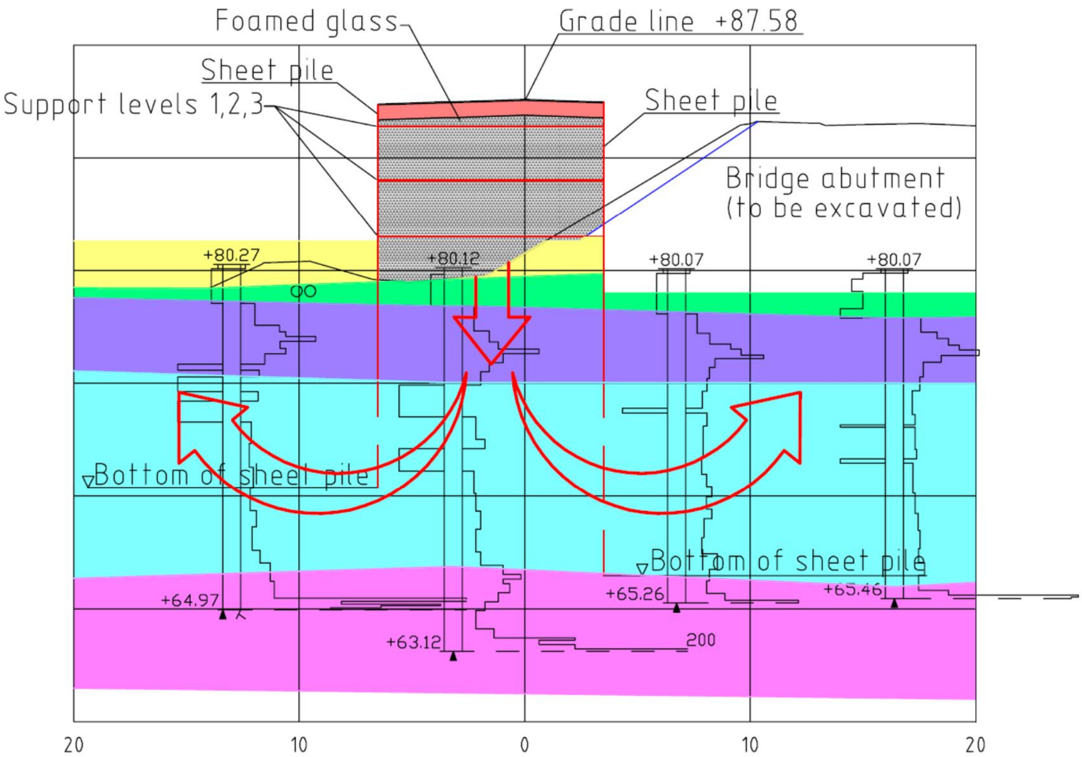

Fig. 7. Cross-section of foamed glass between sheet pile walls.

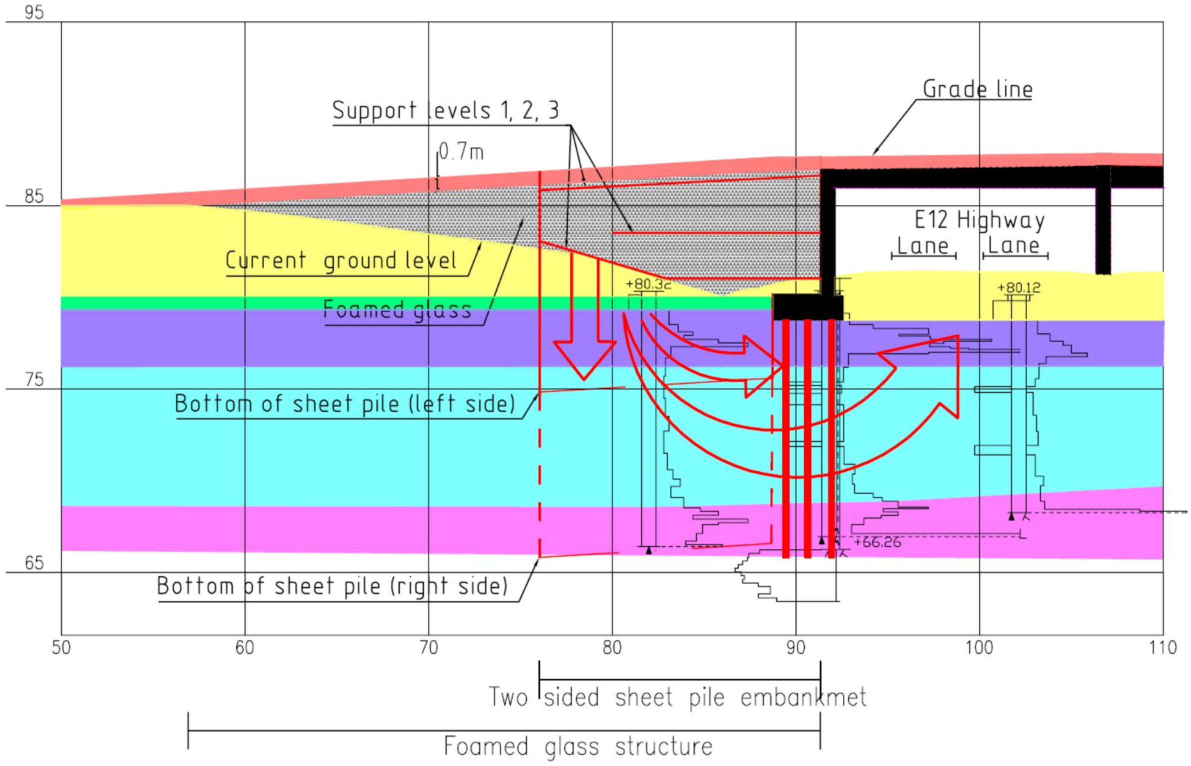

Fig. 8. Longitudinal section of the foamed glass ramp onto concrete shell of tunnel.

Fig. 9. Aerial photo of site.

Sheet pile type was regular and the extensions joint by welding. Sheet piles were anchored together with 32 mm steel rods from 2…3 different levels, depending on the height of the embankment. Installation depth of sheet piles depended on the requirement of local stability. On the bridge abutment excavation's side, sheet piles were driven 5-10 m deeper than on the other side, where the natural ground level is higher. The maximum length of the sheet piles was approximately 20 m.
An aerial photo of the construction site is presented in figure 9. At the time of the picture the embankments have been constructed between the sheet piles, and the old bridges and abutments have been demolished.

8 CHALLENGES

Excavating and removing of the bridge abutments, pile driving and construction of the pile slabs right next to pile sheet wall, required using long and extended sheet piles to ensure local stability. Tight schedule and a logistically challenging site caused challenges which were emphasized by the busy traffic in the area.

9 CONSTRUCTION

Crushed foamed glass embankment was built with 0.7 m layers that were compacted with a tracked loader. After the compaction, normal trucks were able to drive on the embankment, directly over compacted foamed glass layer. Layers were built so that the lateral steel bars could be placed at the top of a compacted layer. At the sides and corners, a vibrating plate was used to ensure the compaction. The compaction was successful as the tires of trucks driving on the embankment did not sink at all into the foamed glass. The material was delivered with trucks with a capacity of up to 120 m^3. Thus truck traffic was reduced to a quarter of what it would have been with regular trucks for gravel. Over 1000 m^3 of embankment was built per day. A sloped embankment several meters high was able to be built of foamed glass without supports. A picture of the embankment during construction is presented in figure 10, the sheet pile section is visible behind the sloped embankment.

CONCLUSIONS

The covering of the E12 highway and the rebuilding of two bridges needed temporary ramps to ensure access across the site during construction. Due to difficult soil conditions and limited working space, the standard solution for embankments up to 8 m high was not possible. Embankments of foamed glass aggregate between sheet pile walls were designed to meet the criteria for a lightweight and compact structure. Foamed glass is a lightweight aggregate made of recycled glass and has a high angle of friction combined with a low unit weight making it ideal for embankments. The construction of the embankments was rapid and served the needs of the project well.

Fig. 10. Foamed glass embankment during construction.

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** Currently only available as a Swedish language version

*** Currently only available as a Norwegian language version