

REINFORCED SLOPE OF ROAD EMBANKMENT WITH LIGHT WEIGHT AGGREGATES

A. Watn, E. Øiseth

SINTEF Civil and Environmental Engineering, Norway

R. Aabøe

Norwegian Public Roads Administration, Directorate of Public Roads, Norway

ABSTRACT: A 200 m long temporary road fill is constructed above a concrete road tunnel. The temporary road is going to be removed after 1.5 years. The upper part of the fill is built with light weight materials with design weight $4\text{--}5.5\text{ kN/m}^3$ to reduce the weight on the concrete tunnel. Approximately 150 m of this fill is built with expanded clay aggregate (LWA) combined with geosynthetic soil reinforcement and approximately 20 m with cellular glass granulate. The light weight fill is 6 m including pavement. The slope inclination is up to 1:1. A high strength polyester geotextile is used as reinforcement combined with a wrap-around solution as facing.

1 INTRODUCTION

In this project a cut and cover concrete tunnel of some 600 m length joins on to a new rock tunnel for Euroroad E6. In order to keep traffic running on E6 during the construction period a temporary diversion road with an embankment height of more than 15 metre is needed. The lower part of the embankment is with crushed rock. The upper 6 m is consisting of light weight fill materials to reduce the weight on the culvert and to improve stability and reduce settlement problems.

Figure 1 shows a model of the temporary embankment and the tunnel gate. The embankment crosses above the concrete tunnel. Figure 2 shows a map of the situation. As seen in the figures, there is a walkway outside the light embankment. Initially, the embankment was designed with cellular glass granulate (Hasopor® Light) with slope inclination 1:1.25. The cellular glass was assumed stable enough without any abutment at the embankment slopes. However, the contractor suggested the use of expanded clay aggregates (Leca®) stabilized with soil reinforcement towards the sides.



Figure 1 Model of the embankment

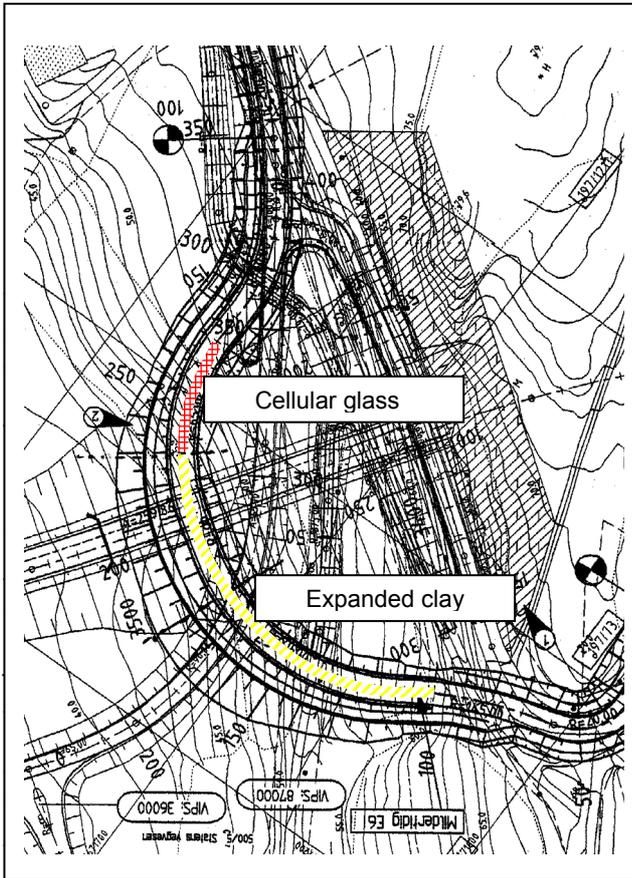


Figure 2 Map and sketch of embankment

2 LIGHT WEIGHT MATERIALS

2.1 Light Weight Clay Aggregate (LWA)

Figure 3 shows the expanded clay aggregate. By sintering clay in a special furnace, hard spheres of various sizes are formed (generally 0 – 32 mm). These spheres are used for producing building blocks and slabs.

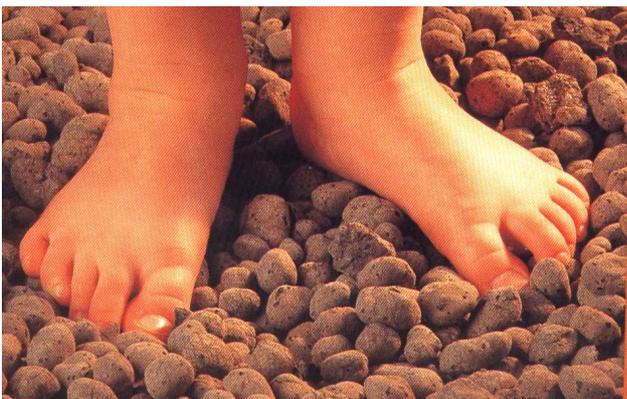


Figure 3 LWA (10-20 mm)

At the start in the late 1950ties waste products from this block production were used as lightweight filling materials, but it was also found suitable to use the LWA grains in fills directly.

Loose dry material has a unit density of $2.5 - 3.2 \text{ kN/m}^3$ (also dependent on the grain size distribution). The design values of such material are based on monitoring programmes and has been determined to be 6 kN/m^3 when positioned in a drained condition in the fill or 7 kN/m^3 when periodically submerged. These values are some reduced in the up coming guidelines from the Public Road Administration. The internal angle of friction is 35° .

In addition LWA has favourable thermal insulation effects and may therefore also act as a frost-insulating layer. LWA material is in common use as both lightweight filling material and frost insulation for road and building construction in Norway today.

2.2 Cellular Glass Granulate

Cellular glass granulate is produced using an environmentally friendly recycling technology for contaminated and toxic waste ranging from mercury lamps, industrial slag and flyash, PC- and TV-tubes, and laminated glass to batteries. The process is based on the concept of transforming finely ground glass powder from different glass sources mixed with an activator like silica carbide into glass foam. In the grinding process heavy metals are separated out and recycled to metal melting plants.

The powder is spread on a steel belt conveyor running through high temperature ovens whereby the powder expands above 4 times, to leave the oven as a glass foam material. When the product leaves the oven it will crack and separate into smaller units due to the temperature shock. Normal grain size will be in the range of 10 – 60 mm (Figure 4). During this process the toxic components are reduced below the detecting limits.



Figure 4 Typical cellular glass particle

Cellular glass generally consists of 8 per cent of glass by volume and 92 per cent gas bobbles. A thin impervious glass wall encloses each bobble. The unit bulk density (dry) is varying from 1.80 kN/m^3 for the light quality to 2.2 kN/m^3 for the standard quality. During transport and compaction a volume reduction of at least 25 – 30 % is usual. The internal angle of friction is assumed to be 45° . In addition also the cellular glass has favourable thermal insulation effects and may act as a frost-insulating layer. Cellular glass has since 1999 been used for several project in Norway as both lightweight filling material and frost insulation for road and building construction.

3 THE EMBANKMENT

The embankment is about 200 m long, of which 150 m were built with expanded clay aggregates (9000 m³) combined with reinforcement and 20 m of cellular glass (without reinforcement) (1000 m³). The map in Figure 2 shows where expanded clay aggregates and cellular glass are used in the temporary embankment. Conventional masses are filled in next to the culvert and rounded off to the sides with a steep rock embankment. The light embankment is built up from a new level, slightly above the top of the tunnel (approximately the same level as the walkway).

The lower 4 meters of the light weight embankment has an inclination of 1:1, while the upper 2 meters have an inclination of 1:1.5. Figure 6 shows a cross section of the build-up of the reinforced part of the light embankment.

The facing of the reinforced embankment is a wrap-around solution where the reinforcement is turned up in front and anchored into the layer above (as sketched in Figure 5). To prevent the light weight aggregates to vanish through holes in the reinforcement, it is required to use a high strength geotextile. This solution will provide necessary abutment for the expanded clay aggregate. The LWA will shape the wraps as tubes along the slope as seen in Figure 5 and Figure 7. Establishing an even shape with such a solution is challenging, but for a temporary construction (such as this) it is satisfactory.

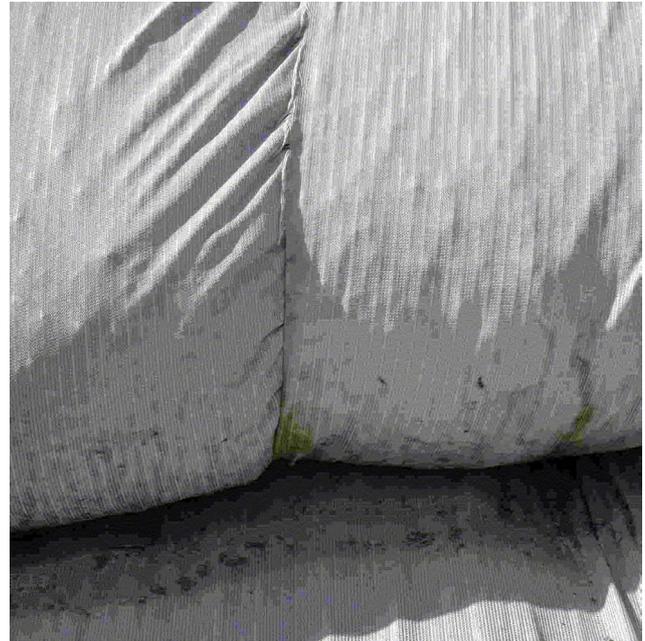


Figure 7 Overlap in cross machine direction along the embankment facing.



Figure 5 Wrap-around solution

To make sure that the LWA cannot move and disappear through holes in the facing, it is vital that the overlap in the cross machine direction along the embankment facing is sufficient (Figure 8). The minimum specified overlap is 30 cm.



Figure 8 Excavator laying LWA on the reinforcement preparing for the next reinforcement layer

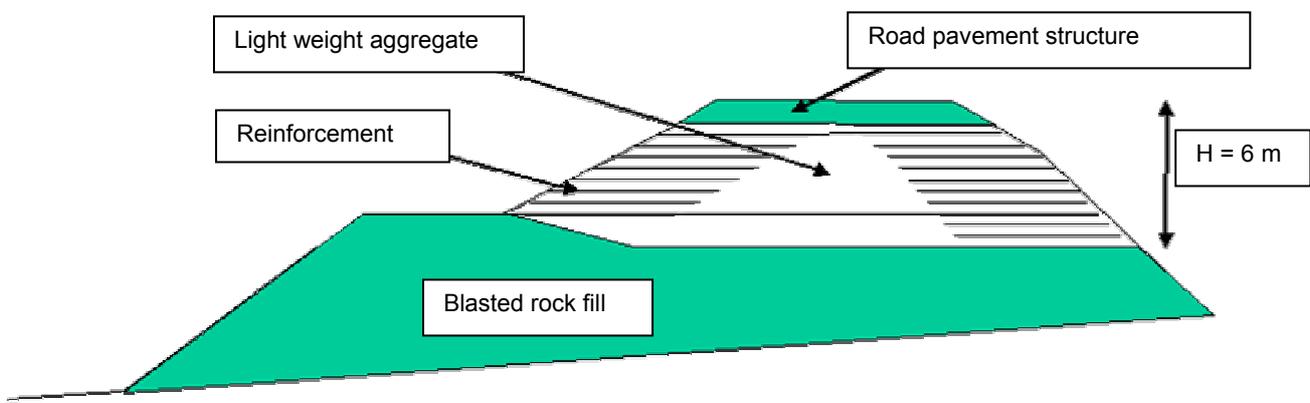


Figure 6 Cross section of reinforced embankment

4 DESIGN OF REINFORCEMENT

For the design the computer programme ReSlope is used together with hand calculations. Hand calculations were required because ReSlope do not handle embankments with slopes on two sides properly. In this case the calculations in ReSlope give unrealistic high horizontal pressures. Hence the calculated reinforcement length is too long. In combination with the gentle slopes in this project the design based on ReSlope was not acceptable. Using light filling compounds, there is no need for very strong reinforcement.



Figure 9 Compacting

For design we have used the following parameters:

- Internal friction angle Leca: 35°
- Unit densitet Leca: $3.5 - 5.5 \text{ kN/m}^3$
- Interaction coefficient Leca-geotextile: 0.7
- Partial material factors: 1.3
- External load: 17 kN/m^2

The following design was recommended:

- Reinforcement spacing: 0.5 m
- Reinforcement length left side: 4.5 m
- Reinforcement length right side: 5.0 m
- Long term design tensile strength: 8.5 kN/m
- The reinforcement at the top layer should be continues through the embankment.
- The reinforcement should be either a knitted or woven high strength geotextile.

The design length of the reinforcement is slightly longer than what is usual for conventional embankments of this height and with this slope angel. This is mainly due to the fact that LWA embankments get very sensitive to loads acting behind the reinforcement. The friction capacity along the reinforcement is lowered because of the low stress level, and this requires increased reinforcement length to achieve sufficient capacity.

It is also prescribed a longer minimum anchoring length for the wrap-around into the layer above than usual for conventional structures. Minimum 1.5 m was prescribed, but to simplify the construction works this was increased even further.

The layer thickness chosen was 0.5 m . It is not recommended to increase the layer thickness when using this construction method combined with a wrap-around facing.

A thinner layer thickness may give a more even facing. Combined with other facings, e.g. concrete bricks, the layer thickness may be increased.

The reinforcement used is a knitted polyester geotextile.

Other product specifications:

- Short term tensile strength, MD/CMD: $70 / 70 \text{ kN/m}$.
- Area weight : 230 g/m^2
- Deformation (both directions): 10%
- Strength at 2%, MD/CMD: $10.5 / 10.5 \text{ kN/m}$
- Strength at 6%, MD/CMD: $35 / 35 \text{ kN/m}$

It is usually required that such reinforcements is covered if no special treatment is applied to prevent decomposing due to sunlight/UV-radiation. Since this is a temporary construction, and due to the limited load on the reinforcement, this has not been found necessary.

5 CONSTRUCTION WORKS

Little experience has been made combining light masses and soil reinforcement. The contractor therefore had to acquire experience and find suitable solutions during the construction phase. One challenge was the anchoring of the wrap-ups in front of the slope. The reinforcement has to be tightened until masses are placed on the end for anchoring. That makes some additional length to the theoretical length necessary, to have something to "hold on to", and also to achieve sufficient anchoring due to relatively little weight on top. An excavator drove along the edge of the surface layer of LWA and placed some LWA on the reinforcement. A slight push in the downwards direction with the shovel filled the wrap-up completely with LWA. This makes the facing more even, and also eliminates any voids in the fill.

Driving with the excavator partly on top of the reinforcement gives the reinforcement increased friction capacity because of a higher vertical stress level. Driving behind the reinforcement gives a load increase that acts outwards on the reinforced zone, at the same time as the anchoring capacity is relatively low due to a low stress level. It may be difficult for the driver to realize that it actually may be safer to drive as close to the edge that the machine drives across the reinforcement on the layer below, rather than driving behind this layer.

6 EXPERIENCES

The driver managed to place the LWA with satisfactorily progress, but the consumption of reinforcement became somewhat higher than initially assumed.

Samples were taken of the embankment for minimum every second layer (every meter), and the unit density and water content was measured (Figure 10). The degree of compaction became higher than presupposed. The material was laid out in layers of 0.5 m between each compaction. Additionally the material was trafficked with truck, bulldozer and excavator during the laying of the following layer and reinforcement. This caused some crushing of the material. For later projects it should be considered to perform compaction for every second layer, possible combined with a light compaction in the reinforced zone in every layer. Also, the trafficking causing crushing should be kept at a minimum.

So far, no problems have been registered for any of the solutions.



Figure 10 Sampling of compacted material



Figure 11 Finished reinforced road embankment of LWA

7 OTHER CONSIDERATIONS

7.1 Design weight of light masses

In Handbook 018 Road construction from the Public Road Administration the design density of LWA was at the time of construction said to be 6 kN/m^3 (600 kg/m^3). This is some reduced in the revised version coming up. The measured average density for this embankment is 4.1 kN/m^3 (after compaction), significantly lower than recommended by Handbook 018. This is in spite of a significant higher compaction than normal. The deviation is partly caused by a lower water content than assumed for the design density, but also due to the fact that the LWA quality delivered now is lighter than some years ago. The average water content in older embankments that has been investigated is 25 % (mass), but single values of more than 45 % (mass) have been measured.

The fact that the embankment is lighter than presupposed at design is usually not a problem, and will usually give a higher factor of safety and less settlement than assumed. However, when designing with reinforced soil one must be aware that a lighter embankment giving a lower stress level at the reinforcement, will reduce the shear capacity between the reinforcement and LWA. This can cause a need for increased reinforcement lengths, depending on where the loads act. Also, the reinforced structure with light weight materials will be more sensitive to changes in the loading conditions.

7.2 Comparison to cellular glass embankment

The cellular glass embankment is smaller than the LWA embankment and without geosynthetic reinforcement, but otherwise quite similar. This embankment was built without reinforcement, and the layers were thicker before they were compacted. Compacted density varied between 3.5 kN/m^3 with a water content between 15 and 20 % (mass). Compared to loose density this gives a degree of compaction of about 1.25. Another 5 % volume reduction was anticipated due to transport on site from local storage areas.

The cellular glass embankment is about 85% of the weight of the LWA embankment per m^3 . However, it should be possible to compact the LWA less by reducing the trafficking causing crushing, and perform the prescribed compaction on every second layer only. For permanent embankments the long term water content will have a significant influence on the density.

7.3 Other facing designs

Structures combining LWA and reinforcement will probably be simpler to build with other facing solutions were the LWA can be filled towards a steady front. An alternative design with wrap-up solution could be to use a formwork at the facing that is stepwise moved upwards during construction. For permanent structures many of the products on the market must be covered to reduce the degradation caused by UV-radiation.

8 CONCLUSIONS

This project shows that LWA may be combined with reinforcement to design steep slopes and embankments. A wrap-around solution is well suited for temporary structures. For permanent structures other facing solutions may be better. In design it is important to evaluate all possible load conditions. The necessary reinforcement length is more sensitive for changes in load conditions (both the magnitude and the acting points) than for conventional masses.

9 REFERENCES

- Norwegian Public Road Administration (1999): Handbook 018 Road construction
- Frydenlund T., Aabøe R. (2003): Foamglass – A new vision in road construction. The XXIIInd PIARC World Road Congress in Durban 19 - 25 October 2003
- Furberg T. et. al. (2000): Environmental friendly insulation products for the construction industry. Summary Report DP1. SINTEF report no. STF22 F00601.
- Adama Engineering (1998): ReSlope 3.0

