40 years of experience with the use of EPS Geofoam blocks in road construction

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Abstract:
Nearly 40 years of experience with Expanded Polystyrene (EPS) as a lightweight fill material in Norway has brought about both a wider use on a global scale and the introduction of a number of different design applications. In addition to reduced vertical loads, advantages from using EPS may also include reduced horizontal loads, simplified designs, foundations placed directly on EPS blocks and increased speed and ease of performing construction activities. This document describes practical experiences in Norway with long term performance and durability of EPS as a fill material based on observations and recorded data from monitoring programmes.

BLOCKS OF EXPANDED POLYSTYRENE USED IN ROAD CONSTRUCTION

When a major research project on frost action in soils was carried out in Norway during the period 1965 to 1976 this included the investigation of various insulation materials for frost protection of roads like 50 to 100 mm thick boards of foamed glass, extruded polystyrene (XPS) and expanded polystyrene (EPS). In this connection also fatigue tests were performed. It was then concluded that EPS material could sustain the repetitive stresses occurring in a road structure and the idea of applying EPS in greater layer thicknesses than boards emerged.

In 1972 the Norwegian Public Roads Authorities adopted the use of EPS as a super light filling material in road embankments. The first project involved the successful reconstruction of road embankments adjacent to a bridge founded on piles to firm ground. Prior to reconstruction the embankments, resting on a 3 m thick layer of peat above 10 m of soft marine clay, experienced a settlement rate of more than 200 mm per year. By replacing 1 m of ordinary embankment material with two layers of EPS blocks, each layer with 0.5 m thickness, the settlements were successfully halted. When placed, the EPS blocks had a density of 20 kg/m^3 nearly 100 times lighter than the replaced materials.

Figure 1. EPS used as lightweight fill material.

MONITORING PROGRAMME FOR EPS

Expanded polystyrene is a very stable compound chemically and no material decay should be expected when placed in the ground and protected according to the present design guidelines. Still, since the first road insulation project with EPS was performed in 1965 and the first EPS lightweight embankment was constructed in 1972, EPS embankments have also been monitored for long term performance along the lines followed for other lightweight fill materials used in road construction in Norway. Some of the results from the monitoring programme have been presented earlier ([1] and [5]) but is now updated with more recent data for EPS 2011.

The monitoring programme has over this period of nearly 40 years focused on the following material properties:

- **Material behaviour**
  - *Compressive strength*
  - *Water absorption*
  - *Decay*
- **Deformation**
  - *Total embankment deformation and deformation in EPS layers*
  - *Creep effects*
- **Stress distribution**
- **Reduced lateral pressure**
- **Bearing capacity**

Figure 2. An EPS embankment for a city tramline in Oslo with vertical walls as an alternative to a bridge.

TESTING FREQUENCIES

Since 1972, several tests have been carried out in order to monitor possible material changes. In this connection test samples have been retrieved from existing embankments to check for possible changes in strength and unit density. Also variations in water absorption for blocks placed in drained, submerged or semi-submerged positions have been observed. In order to determine the stress distribution within blocks and embankments both laboratory and field tests have been performed. Load creep effects have also been observed both in the laboratory and on existing embankments.

Table 1. Testing frequencies of EPS embankments

Embankment location	**Constructed Year**	**Test samples retrieved**			
		No. of years after construction			
National road 159 Flom bridges	1972 / 73	0	7	12	24
National road 154 Solbotmoan	1975	4	9	21	36*
County road 91 Lenken	1978	6			
County road 26 Langhus	1977	7			34*
National road 610 Sande - Osen	1982	9			
Løkkeberg bridge	1989		17		
Loenga bridge	1984		21		

* Results will be reported in a separate contribution to EPS 2011

Figure 3. Excavation of the first EPS embankment at Flom bridge (EPS and polyurethane as protective layer).

MATERIAL BEHAVIOUR

Material strength

According to the Norwegian specifications the design compressive strength of EPS blocks have been set to be at least σ = 100 kPa when not otherwise specified. In actual practice a shipment of blocks may be accepted if the average strength of tested blocks is $\sigma \geq$ 100 kPa. The average value for test specimens from one block (6 tests) should be $\sigma \geq 90$ kPa and no single tests should show values $\sigma < 80$ kPa.

One major indicator of possible deterioration of blocks with time would be a decrease in the material strength. The strength tests performed on retrieved samples from embankments that have been in the ground for up to 24 years are shown in figure 5 as a function of dry unit density and compressive strength. Bearing in mind the criteria mentioned above for accepting blocks to be placed in an embankment, all test results give values of compressive strength above $\sigma = 100$ kPa except for one test.

This one test was performed on samples taken from the first embankment shortly after it was completed in 1972. It is more an indication of variations in material quality of EPS with the production process used at that time. Still the observed value is within the accepted statistical variations in material strength.

Figure 4. Excavation of a 24 years old EPS block from the first EPS embankment at Flom bridge.

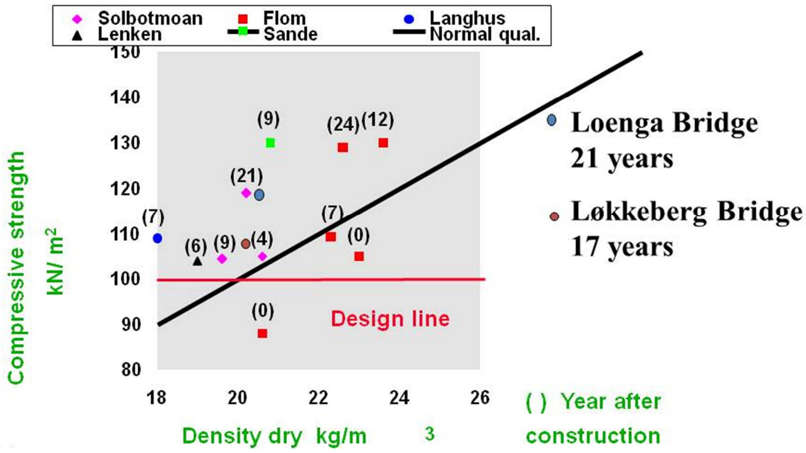


Figure 5. Compressive strength on retrieved samples from EPS embankments

From figure 5 and 6 it may also be observed that the majority of tests show values of compressive strength in relation to unit density above that of a normal quality material. It is of course impossible to make exact comparisons between material strength at the time of construction and sometime afterwards since tests cannot be performed on the same specimen twice. The results, however, indicate clearly that there are no signs of material deterioration over the total time span of 24 years. If a change tendency is to be noted, this would go towards a slight increase in material strength. If this is the case, such an increase could be explained by a continued chemical reaction leading to material hardening during the first few weeks after production. There is also a tendency that the material strength is slightly higher in the middle of the block than towards the outer sides. Furthermore there is no sign of variation in material strength whether the retrieved specimens are tested wet or dry. This indicates that water pickup over years in the ground will not affect material strength.

In 2005 most of the "Loenga bridge embankment" had to be removed due to changes in the traffic system in the Bjørvika area in Oslo. The excavation of EPS was monitored and the blocks examined by the road authorities both due to the monitoring programme and also because the blocks should be reused at other construction sites in Oslo. Tests on samples from the blocks (figure 6) showed that they were ready for reuse in new projects. Again all of the tests show values of compressive strength in relation to unit density above that of a normal quality material.

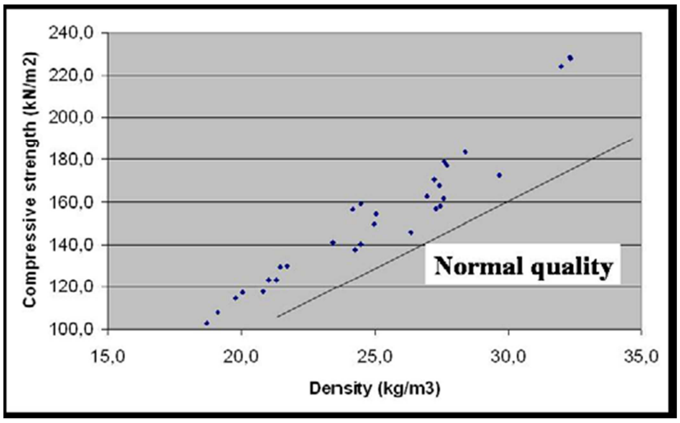


Figure 6 Loenga bridge 1983 Compressive strength after 21 years in the ground

In 2006 two embankments on Euroroad 6 in the southern part of Norway (Løkkeberg Bridge and Hjelmungen Bridge) have been removed partly due to widening but also due to changes in the alignment of E6. These blocks have also been examined and checked as part of the monitoring programme and it was decided to reuse more than 5000 m3 EPS blocks on other EPS embankments connected to the E6 project. Again the results 17 years after the blocks were placed are well above that of a normal EPS quality (average value of σ =104.6 kPa for 20 kg/m^3 material).

Figure 7 Reuse of EPS blocks from Løkkeberg Bridge

Unit density

The only change in design rules that have been introduced in Norway since the first embankment in 1972 is that the design unit weight for EPS blocks placed in a drained position is reduced from γ = 1.0 kN/m^3 (ρ = 100 kg/m^3) to γ = 0.5 kN/m^3 (ρ = 50 kg/m^3) when stability and settlement calculations are performed. For blocks placed in a submerged or semi-submerged position the value of γ = 1.0 kN/m^3 (ρ = 100 kg/m^3) is maintained. The change mentioned above is based on tests data from existing embankments.

Tests performed on samples retrieved from five EPS embankments (including results from Loenga bridge and Løkkeberg bridge) placed in a drained position, i.e. blocks are located above the highest groundwater or flood level, all show water contents below 1 % by volume after more than 20 years in the ground. Furthermore there is hardly any change in the water content with time. Samples retrieved from the outer parts of blocks facing the surrounding soil, may have higher water content. But only 50 mm further into the block the water content is again below 1 % by volume. So the average density of drained embankments therefore has values of ρ < 30 kg/m3. This is well below the specified design value for such embankments.

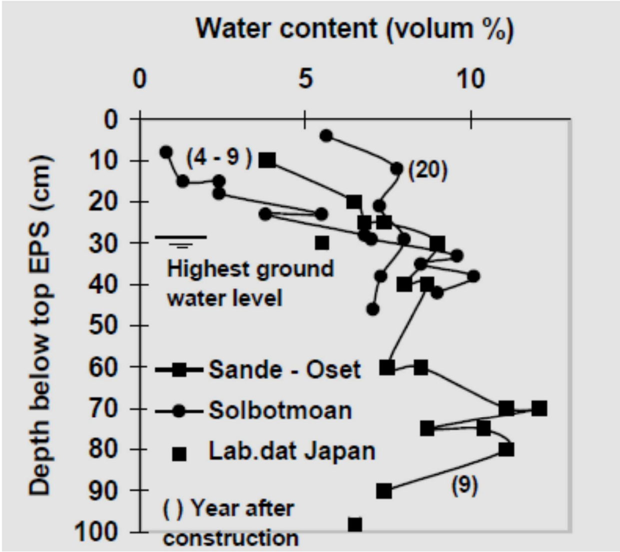


Figure 8. Typical water content in submerged EPS blocks

In blocks, which are periodically submerged, water contents of up to 4 % by volume have been measured. In permanently submerged blocks measured water contents have reached values close to 10 % by volume with some increase over the years, figure 8. Further increases above 10 % by volume are, however, not to be expected. For submerged fills the average density is therefore of the order of ρ = 90 - 95 kg/m^3 after some 20 years in the ground. The water content decreases rapidly above the water table and show values for drained conditions only some 200 mm above the highest water level.

LONG TIME PERFORMANCE OF EPS STRUCTURES

Full scale laboratory test

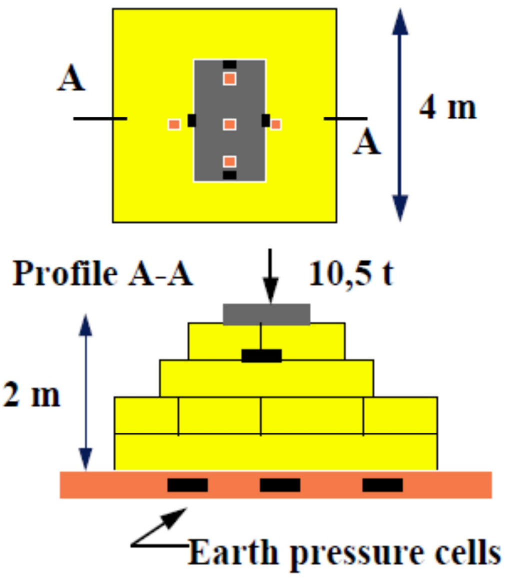


Figure 9. EPS test embankment at the Norwegian Road Research Laboratory.

In a laboratory test at the Norwegian Road Research Laboratory (now the Traffic Safety, Environment and Road Technology Department) a test embankment of height 2 m with normal size blocks and a compressive strength σ =100 kPa was loaded to a value of q_{dw} = 52.5 kPa and the resulting deformations observed over a period of 3 years. The results are shown in figure10 together with calculated deformations to be expected according to the theories introduced by Magnan & Serratrice. [4]. As may be seen, the observed deformations are only about half of the calculated values and creep deformations with time are also much smaller.

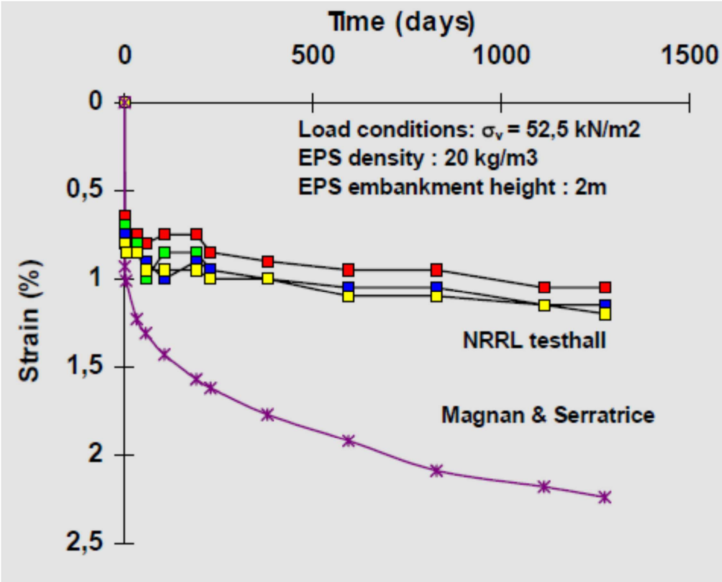


Figure 10. Deformation and creep results from calculated values and full scale laboratory test

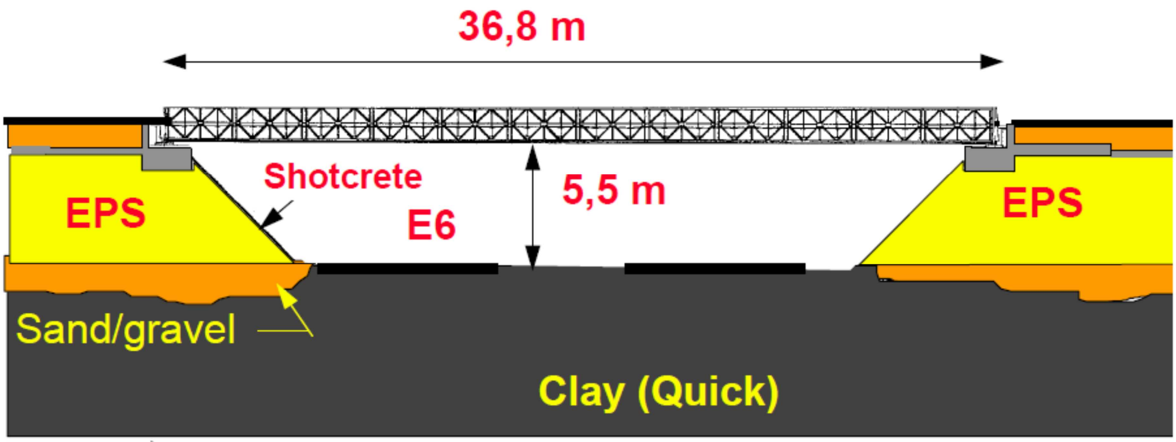
Full scale test at Løkkeberg Bridge

The Løkkeberg Bridge is a single lane Acrow steel bridge with a single span of 36.8 m crossing road E6 close to the Swedish border. The bridge was built in 1989 in order to temporary (planned for 3 - 5 years) improve traffic safety until the completion of a new motorway between Norway and Sweden. Due to low bearing capacity and expected large settlements, lightweight embankment materials (EPS) were considered in the embankments adjoining the bridge.

The project provided an opportunity to place the bridge foundation directly on top of the EPS embankments (height 4.5 and 5m) on both sides as an alternative to placing the bridge abutment on piled foundations. Since the bridge was a temporary solution and possible deformations could be adjusted during the period of operation, it was decided to carry out the project as a full scale test.

Figure 11. Construction of one abutment on the EPS embankments at Løkkeberg Bridge.

Three different types of EPS material strength have been used with design strengths of σ = 240 kPa in the upper layer directly below the bridge abutment, σ = 180 kPa in the remaining layers halfway down the embankment and σ = 100 kPa in the bottom half. In the upper layer only 25 % of the material strength has been utilised while in the bottom layer the corresponding figure is 60 %. Construction details are shown in longitudinal profiles in figures 12 and 13.



Figur 12. Løkkeberg bridge. Longitudinal profile

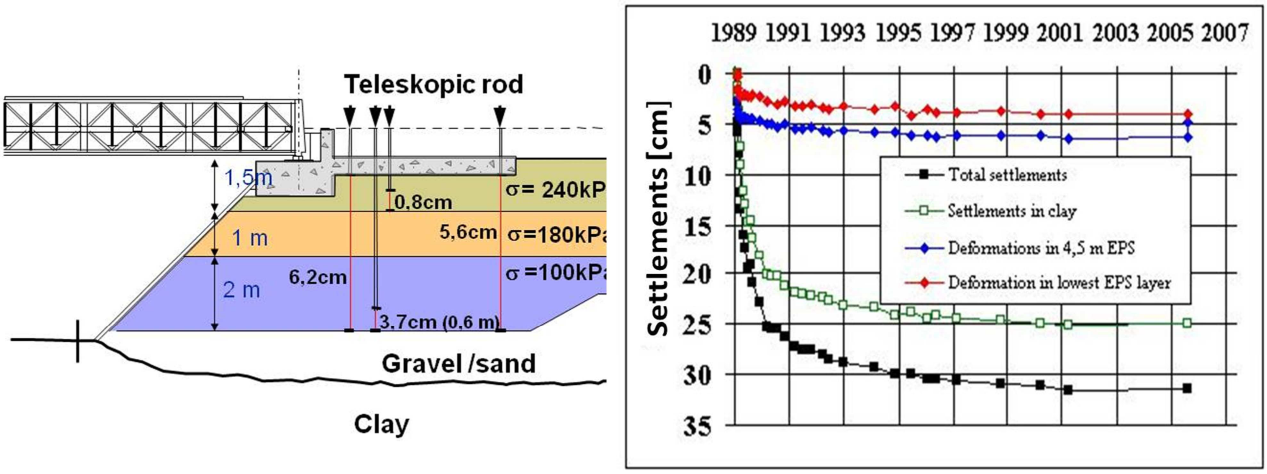


Figure 13. EPS types and deformations in EPS embankment at Løkkeberg.

The bridge was in operation for 17 years after completion. No signs of cracks or uneven deformation have been observed. The bridge support has been lifted 30 cm on one side due to subsoil settlements in accordance with the theoretical calculation. In June 2006 the bridge was removed and reused in connection with the widening works for E 6 in the same area.

Løkkeberg Bridge has provided a good opportunity for monitoring long time performance such as creep and stress distribution of an EPS embankment.

Removing the structure after 17 years in service and performing measurements show only small deformations 6 cm (1.3 % of the EPS height) in the EPS embankment. Most of the deformation occurred during the construction period and only minor creep effects have been measured. Creep deformations as an average and creep deformations for the lowest EPS layer (6.5 % of the layer thickness) are shown in figure 13. The last plot for 2006 of deformation in the EPS embankment is estimated from settlement tube observations since some of the telescopic rods were damaged during removal of the bridge.

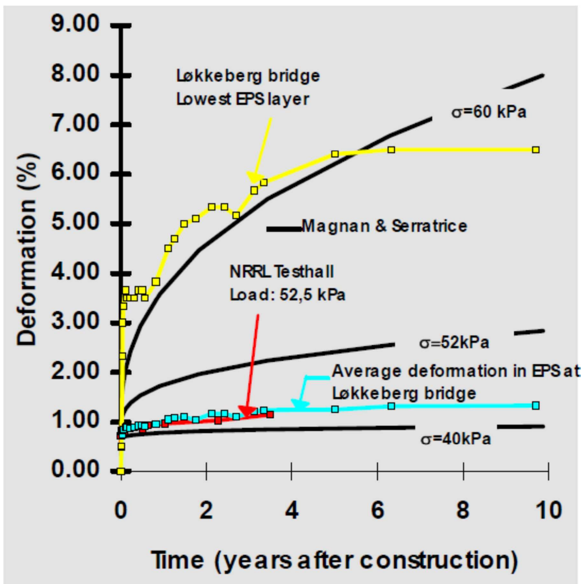


Figure 14. Creep deformations in EPS.

Observed deformations after 10 years in operation are plotted in figure 14 together with data from the laboratory test and theoretical values according to Magnan & Serratrice [4] calculated for various stress levels. The figure clearly shows that the average deformation at the Løkkeberg Bridge is small and slightly over 1 % of the total embankment height. Also observed creep effects are almost negligible for the total embankment although deformations in the bottom block layer was 4 % initially and later creep effects amount to further 2.5 %. Creep deformations in the bottom layer correspond to the theoretical values the first 5 years but have later slowed down to almost zero.

During removal of the bridge and excavation of the embankment in 2006 both the settlement tubes and the gauges measuring block thicknesses at the bottom of the embankment showed some elastic rebound. A short period after the load reduction approximately 2 cm of rebound deformation could be observed in the blocks with the major part in the lowest layer.

Stress distribution

In order to observe the stress distribution in the EPS material below the bridge abutment at Løkkeberg Bridge during construction and on a long term basis, 10 hydraulic earth pressure cells were placed at different levels in the embankment including 3 cells in the sand layer below the EPS fill. In figure 15 the measured stress levels after 10 years in service are indicated with red figures.

Observations indicate that cell boundary effects may have influenced the stress results, especially in the first loading stage, probably due to poor interaction between EPS and the steel casings for the earth pressure cells.

Long term measurements from 3 earth pressure cells below the fill and one situated 2 m higher up have been plotted in figure 16. During the first year of operation a stress decrease of 15 - 30 % was observed. Later only small variations with time have been observed. Measured stresses of 50 kPa corresponds well with the theoretical vertical load in the lower part of the EPS fill.

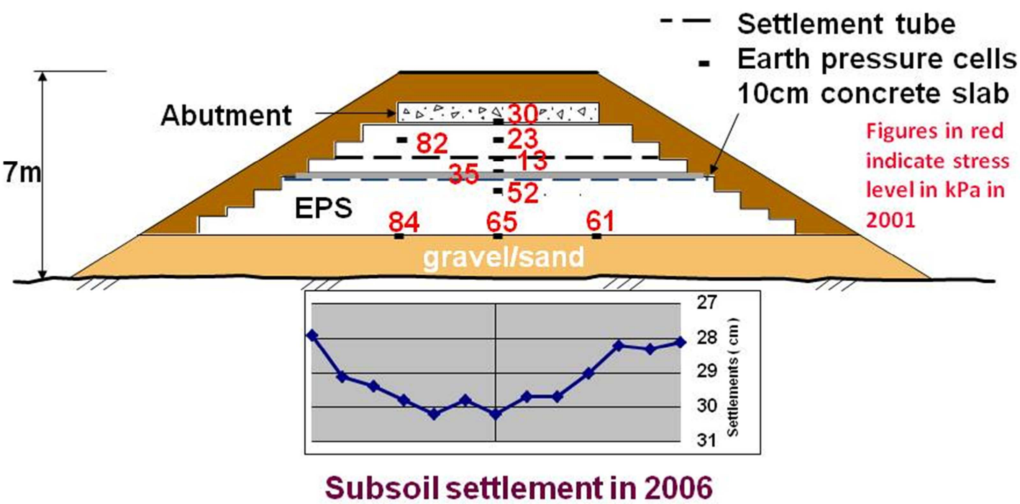


Figure 15. Løkkeberg Bridge. Observed stress distribution and settlements in the cross section.

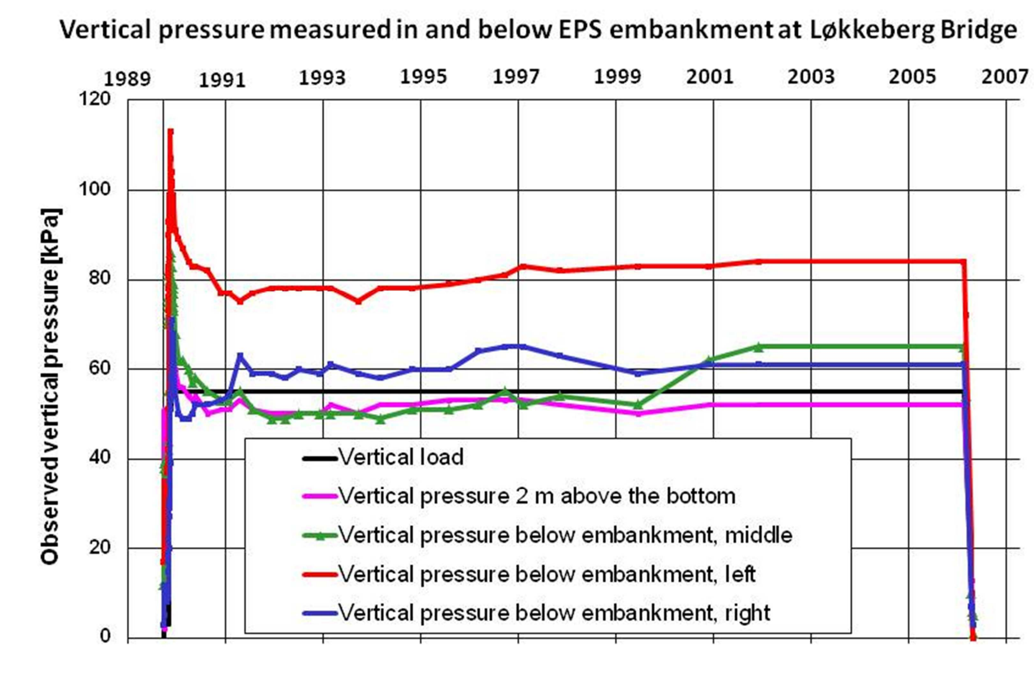


Figure 16. Long term measurements of vertical pressures at Løkkeberg Bridge

In the upper part of the embankment (with a higher material strength) lower stress than expected has been measured in a zone under the central part of the embankment. One explanation could be some kind of arching effect due to large subsoil settlements in the middle of the embankment. This can clearly be seen in figure15 where the measurements from the settlement tube are shown. Changes in settlements between 2001 and 2006 only vary with a few mm. In the lower part of the fill it is difficult to explain load concentration and deformation in the lowest EPS layer and likewise the low stress values in the upper part of the EPS fill. The earth pressure cells were, however, tested in connection with the excavation work and they showed correct readings and could be reused in new projects.

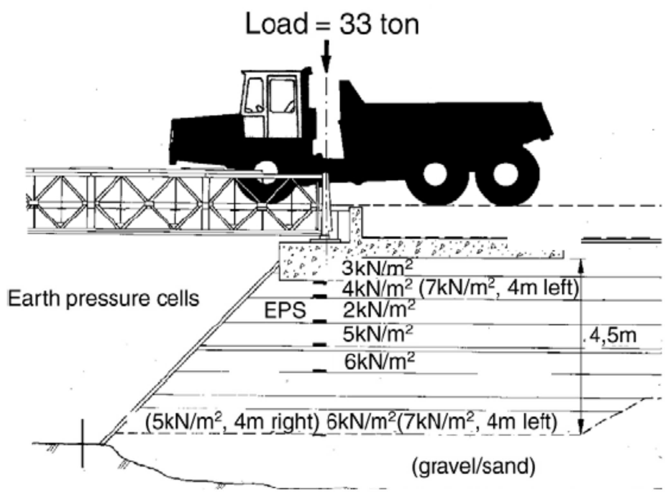


Figure 17. Stress levels in EPS fill at Løkkeberg

Another test was performed to check the stress result. A dumper with a weight of 33 tons was placed at different distances from the abutment. When the dumper was placed directly on the abutment an increase of 6 kPa was expected. The measured stress increases in the various embankment levels with the additional load from the dumper correspond well with the stress distribution without the dumper. The increase in stress levels from the dumper is shown in figure17. The same tendency to reduced vertical pressure in a zone beneath the abutment was also observed here. After removing the dumper, the pressure cells immediately returned to the previous stress levels.

Attempts have been made to evaluate the stress distribution in EPS blocks based on stress observations from the test hall experiments and stress observations at the Løkkeberg Bridge compared to stress analyses using a calibrated soil model implemented in PLAXIS. The result of this work is reported to the conference in a separate paper.

Repair of Hjelmungen bridge (1996) and reconstruction (2006).

Hjelmungen Bridge is a three spans, 54 m long continuous concrete deck bridge completed in 1992 with abutments and pillars founded on concrete piles to firm ground. The 5 m high embankments adjoining the bridge consisted partly of ordinary embankment materials partly of waste material from the production of Leca building blocks. The embankments rested on subsoil consisting of some 10 – 14 m of soft sensitive marine clay, partly quick and with high water content.

Some 2 years after completion it became evident that the bearing capacity of the soil beneath the abutments had been exceeded as excessive settlements occurred and the abutments inflicted damage to the bridge deck. Deformation monitoring was initiated and it soon became clear that immediate repair measures had to be initiated. Since settlement caused by the approach embankments was the main problem, it was decided to reduce the load on the subsoil by some 30 – 40 kN/m^2 in order to re-establish the initial subsoil stress conditions. This involved replacing parts of the embankments with EPS blocks and supporting new bridge abutments directly on the EPS. The repair design is indicated in figure 18.

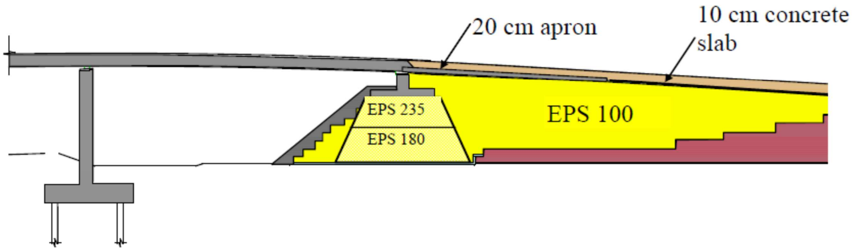


Figure 18. Supporting bridge abutments directly on EPS

Repair works were initiated in December 1995 and completed in the spring of 1996. One abutment was treated at a time while the bridge deck was provided with a temporary support as shown in figure 19. Thickness and densities of the original fill materials were recorded as they were removed in order to have accurate data for control of load and settlement calculations. After removing the old abutments, the concrete piles were inspected regarding possible damage before being cut at ground level. No pile damage was observed. Construction of the EPS embankments could then start. In this case three different types of EPS were utilized. In the zone directly beneath the bridge abutment, as indicated by the trapezoidal shaped lines in figure 19, a material quality of σ = 235 kPa was specified for the first three block layers beneath the bottom slab of the abutment. Further down a material quality of σ = 180 kPa was specified within the indicated zone.

Figure 19. Temporary support of abutments at Hjelmungen

For the rest of the EPS fill a material quality of σ = 100 kPa was used. These quality requirements have been decided based on evaluation of stress distribution in the material in order to keep the stress level for dead loads within 30 % of the material strength. Stricter geometric requirements than normal were also enforced related to block dimensions in order to obtain an even embankment and reduce initial deformations when the load from the bridge deck was transferred to the new abutment.

Behind both abutments a 10 m long and 200 mm thick concrete transition slab (apron) was specified to be cast above the EPS embankment as a friction plate in order to take up horizontal forces on the abutment. On the rest of the EPS embankment a concrete slab of 100 mm thickness was specified. To complete the road pavement 400 mm of pavement material was placed on top of the concrete slab.

In order to monitor the behaviour of the reconstructed bridge both settlement and stress gauges have been installed. The different types of gauges and their locations in relation to the bridge abutment are indicated on the cross section in figure 20. Prior to reconstruction the settlement rates of the adjoining embankments were observed to be 100 mm/year and constant.

Observed stresses beneath the EPS embankment indicate a higher stress under the central part of the abutment than under the edges as shown in figure 20. Calculated loads on the abutment are indicated by the heavy line drawn in the diagram.

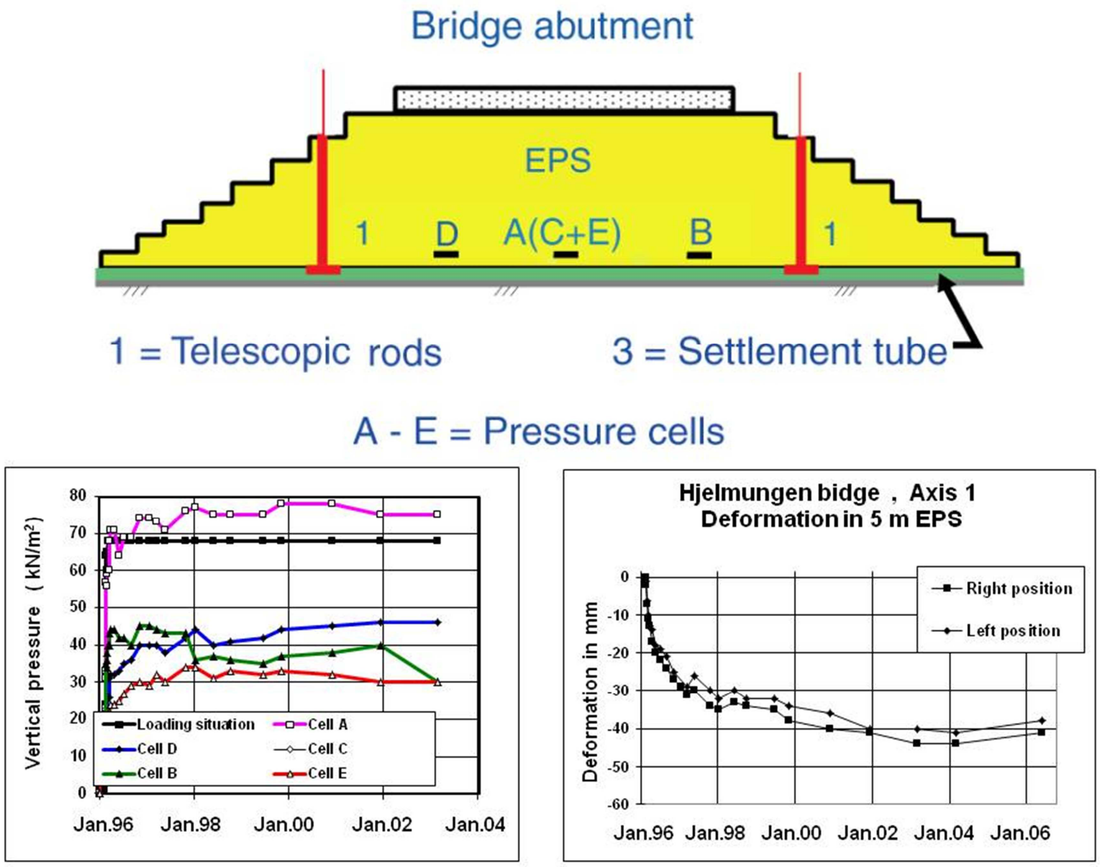


Figure 20. Measured stress and settlements at Hjelmungen

Problems associated with providing enough lifting force when jacking up the bridge deck may, however, indicate that reaction forces from the bridge deck are somewhat higher than calculated.

In spring 2006 Hjelmungen Bridge as a consequence of widening E 6, again had to be reconstructed. The monitoring equipment was removed and the last measurements were performed although some of the equipment, like the cables to the earth pressure cells, was destroyed in the dismantling process. Visually the EPS blocks seemed to perform well and they certainly were acceptable for reuse The bridge was reconstructed with a new pillar in the EPS embankment area and a new EPS foundation was constructed exactly with the same design concept as in the 1996 reconstruction.

E 6 Grimsøyvegen Bridge

The Grimsøyvegen Bridge is a single lane temporary steel bridge with a single span of 30 m crossing Eutroroad E6. The bridge was built in order to temporary (3 months) replace the permanent bridge at the site which had to be extended with a new span. The EPS design solution with bridge abutments directly on top of the EPS embankments (height 4.5) on both sides was used as an alternative to placing the bridge abutments on piled foundations. Due to low bearing capacity and expected large settlements, lightweight fill materials (EPS) were necessary in the embankments adjoining the bridge. The EPS embankment was partly built up with reused EPS blocks from the Løkkeberg Bridge.

Figure 21. Grimsøyvegen Bridge

This was an alternative solution that the contractor came up with in last second. Therefore the time frame did not provide possibilities to follow up the structure with monitoring equipment. However, deformation of the EPS embankment and settlements in the ground were monitored.

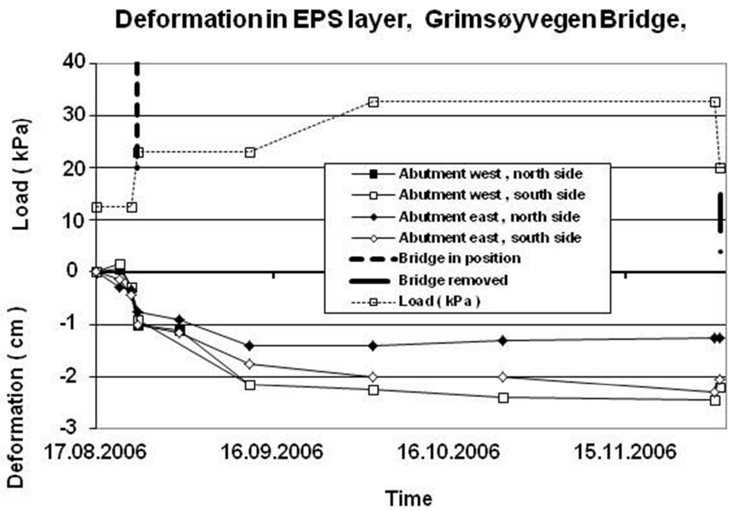


Figure 22. Deformation in EPS embankment at Gimsøyvegen Bridge

The height of the EPS embankments at Gimsøyvegen Bridge was 4.5 m. With observed deformations of the order of 2 – 2.5 cm during the time the bridge was in operation, this corresponds to a deformation of approximately 0.5 % of the embankment height.

CONCLUSIONS

From the observations discussed above it may be fair to conclude that no deterioration effects are to be expected from EPS embankments placed in the ground for a normal life cycle of 100 years. This should hold true provided possible buoyancy forces resulting from fluctuating water levels are properly accounted for, the blocks are properly protected from accidental spills of dissolving agents and the applied stress level from dead loads is kept below 30-50 % of the material strength. The observed performance of the many projects designed and constructed on these principles around the world so far supports this conclusion.

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