Long-term instrumented field test using geofoam to reduce earth loads on buried concrete pipe

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ABSTRACT: The earth pressure on deeply buried culverts is significantly affected by arching. A full-scale instrumentation on a concrete pipe has been carried out by monitoring the earth pressure distribution during the construction process and in long-term measurements. The structure was a concrete pipe with inner diameter 1.4m and thickness of 0.164m. Expanded polystyrene geofoam(EPS) had been placed at a position 0.3m above the top of the pipe. A good quality gravel and sand was used as a backfill of the embankment to a depth of 23m. The culvert was monitored for over 17 years since the end of construction. The long-term measurements at seven hydraulic cells around the concrete pipe and one cell on the top of EPS have been recorded to evaluate the long-term performance of the pipe and EPS. Measurements had been also done during the construction progress and the vertical earth pressure was reduced to 20-46% of the overburden weight from the soil at all cells. Long-term measurements show that there is no increase in the vertical pressures and deformation on the pipe after the construction stage. A finite element program PLAXIS has been used to model the structure.

1 INTRODUCTION

The earth pressure on deeply buried culverts is significantly affected by arching. Both the magnitude and distribution of earth pressure on buried culverts are known to depend on the relative stiffness of the culvert and the soil. The so-called induced trench method (also called imperfect ditch) involves installing a compressible layer above the rigid culvert. As the embankment is constructed, the soft zone compresses more than the surrounding fill, and thus induces positive arching above the culvert.

The imperfect ditch method involves installing a compressible layer above the culvert with in the backfill. As the embankment is constructed, the soft zone compresses more than the surrounding soil. The deformation in the expanded polystyrene geofoam provides a mobilization of shear strength in the fill and reducing the expected vertical earth pressure. The properties of soil-structure interaction in the buried culverts highly depends on the mechanical properties of the backfill material and the stiffness of the compressible material, the expanded polystyrene (EPS) geofoam in this case. A better understanding of the arching effect on EPS on buried culvers has been obtained from a field based study using full-scale test measurements. Terzaghi (1943) stated that the amount of arching can only be obtained by direct measurement under field conditions.

Vaslestad et.al (1993) studied full-scale tests with the imperfect ditch method in a long-term basis. The tests had shown a reduction of the earth pressures and economic design of rigid culverts. The long-term effects can be influenced by the creep behavior of the EPS and soil. In regards with the EPS geo-foam, temperature variation and chemical effects may play a significant role in the long-run performance of the geofoam. Long-term measurements on a concrete pipe is performed using hydraulic pressure cells.

2 FIELD INSTALLATION

To measure the vertical and horizontal earth pressures around the concrete pipe, seven hydraulic earth pressure measuring cells has been installed as shown in Figure 1.The structure is situated below 23m high fill embankment, and serves as a drainage pipe for Euroroad 6 of Bogsrud-Minnesund in Norway.

Expanded polystyrene blocks with compressive strength of 100kN/m^2 and average density 20kN/m^3 were used. The stress-strain behavior of EPS geofoam depends on many factors such as density, magnitude of applied load, manufacturing process, and environmental factors. A typical stress-strain curve shows that the EPS geofoam has a non-linear relationship. The stiffness is varring at different ranges of stress levels.

The expanded polystyrene blocks were placed when the backfill had reached 0.3m above the top of the pipe. The foundation to the concrete pipe was a compacted crushed stone placed above the rock. A 40cm thick layer consisting of materials 0-32mm aggregate size was compacted to 97% Standard Proctor. To avoid stress concentration under the pipe a 10cm thick uncompacted layer has been used during construction.

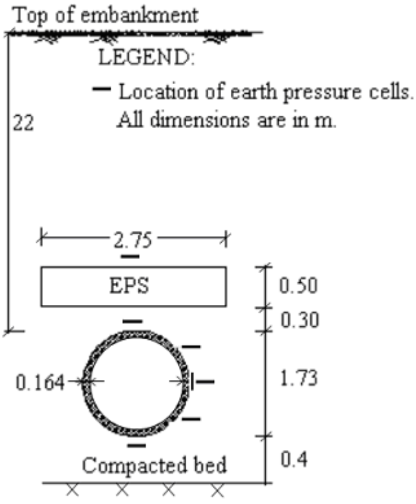

Figure 1 Location of cells around the pipe.

The vertical and horizontal earth pressures have been measured since the beginning of construction in July 1991, Johansen (1997). It has been observed a considerable reduction of earth pressure at the end of the construction phase. The earth pressure was 23% of the overburden pressure at the top of the pipe. The horizontal earth pressure measured at the side of the pipe was 49% of the overburden pressure and the total vertical stress beneath the pipe has been reduced to 25% of the total overburden using EPS geofoam at the top of the pipe. The deformation is about 16 cm at the full fill of the embankment which is about 30% of the initial thickness of the EPS at the end of the construction phase. The filling was started in July 1991 and ended in October 1992.

The measured earth pressures are normalized by the overburden pressure to evaluate the arching factor at different levels of the fill and is shown in Figure 2. At the end of the fill, it is clearly observed that the arching factor is in the range of 0.2-0.46 at all cells. These values are comparable with the arching factor coefficient, N_A, developed by Vaslestad(1990). This is a clear indication that how it could be efficient to use the EPS geofoam on buried culverts.

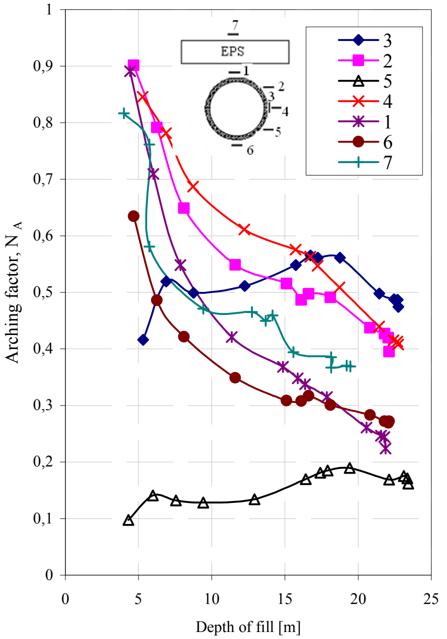

Figure 2 Arching factor (ratio of measured values to the overburden pressure, $N_A = \sigma_v / \gamma H$

Total settlement of an EPS geofoam over buried culverts consists of immediate or elastic settlement and consolidation of the foundation mass, settlement of the conduit into its foundation and deformation of the EPS itself. Immediate or elastic settlement of

EPS, fill mass and foundation soil occur during construction and will not affect the condition of the final pavement. Figure 3 shows the deformation of the EPS geofoam during the construction.

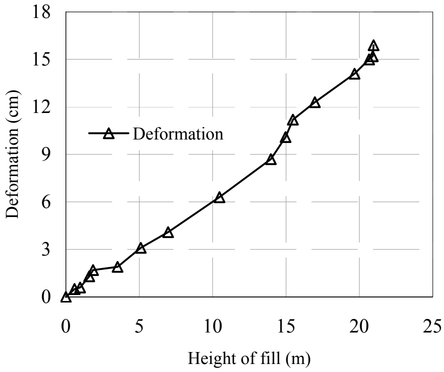

Figure 3 Deformation measured in the EPS.

3 LONG TERM FIELD MEASUREMENTS

To evaluate the performance of the pipe and the EPS during construction and on a long-term basis, the pipe and the surrounding backfill were instrumented with hydraulic earth pressure cells with the intention of long-term measurements.The meaurements have been monitered for 17 years and are shown in the following figures. The calculated overburden pressure in all figures is γH where γ is the unit weight of the soil [kN/m^3] and H is the height of the fill [m] over the level where the cells are located. The measurement on cell 1 on the top of the pipe in Figure 4 shows that the earth pressure increased to 100 kPa at the end of the construction phase. In a duration of 4 years this value was reduced to 64kPa which is 16% of the overburden and no significant change has been observed onwards.

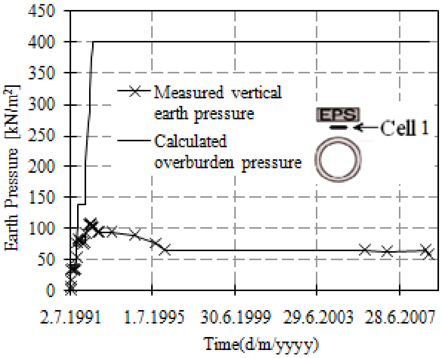

Figure 4 Long-term measurement at cell 1.

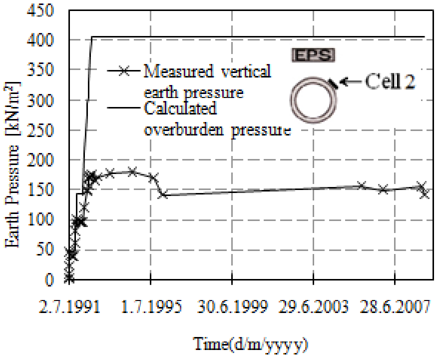

Figure 5 Long-term measurement at cell 2.

The earth pressure in cell 2 at the end of construction was 172 kPa as shown in Figure 5. The earth pressure seemed to remain the same with an average value of 180kPa for a duration of 4 years after the construction was finished. For the next 12 years i.e. from February 1996 to December 2008 the measured earth pressure has varied between 142 and 157 kPa. This is 35-39% of the overburden.

The measured horizontal earth pressure on the pipe springline is shown in Figure 6. The horizontal pressure at the end of construction was 211kPa. The measured earth pressure has been varying between 195 and 218 kPa for 16 years which is about 46-52% of the overburden. This value can be comparable with the coefficient of earth pressure at rest, K_0. If the value of K_0 is supposed to be lower, the width of EPS should be increased and a good quality of back fill material should be provided. Figure 7 shows that the vertical earth pressure at the side of the pipe reached to 178kPa at the end of the construction and has reduced to 142 kPa in the long-term measurement.

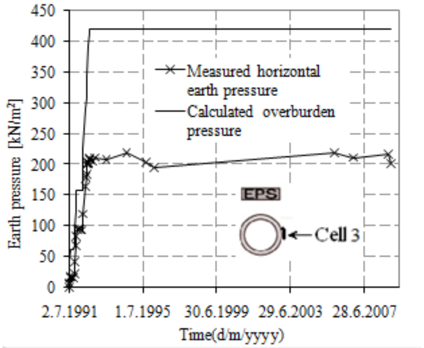

Figure 6 Long-term measurement at cell 3.

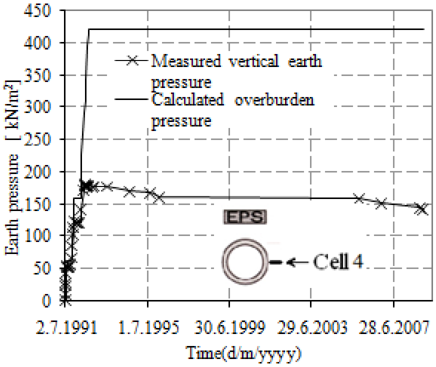

Figure 7 Long-term measurement at cell 4.

The measured earth pressure at cell 6 is significantly low as it is shown in Figure 8. It has remained with an average value of 73 kPa. This is about 17% of the overburden pressure. The measured vertical earth pressure at the bottom of the pipe(cell 6) shown in Figure 9 was 640 kPa at the end of the construction and has reduced gradually in the long-term measurement.

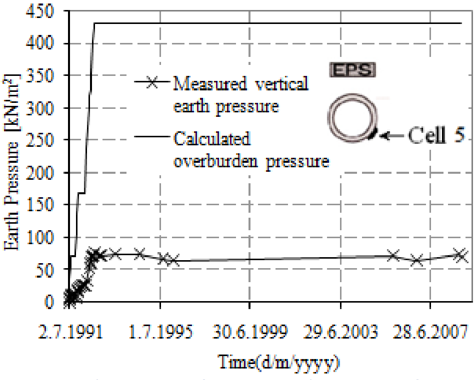

Figure 8 Long-term measurement at cell 5.

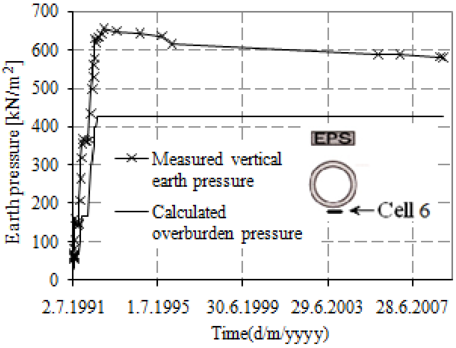

Figure 9 Long-term measurement at cell 6.

The earth pressure at the cell located above the EPS geofoam was reduced as compared to the overburden pressure at the end of construction. However, there has been an increment of the measured earth pressure since the end of construction.

There is no considerable change of deformation in the EPS after the construction was ended. The long-term compression of the EPS has varied from 32% at the end of construction in 1992 to 38% in 2008. Much of the deformation happened during the construction phase and no settlement has been observed at the existing road. The concrete pipe is also functioning without any problem.

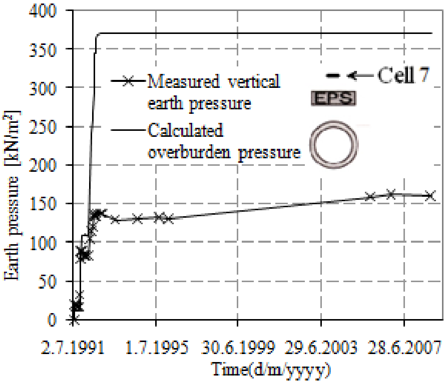

Figure 10 Long-term measurement at cell 7.

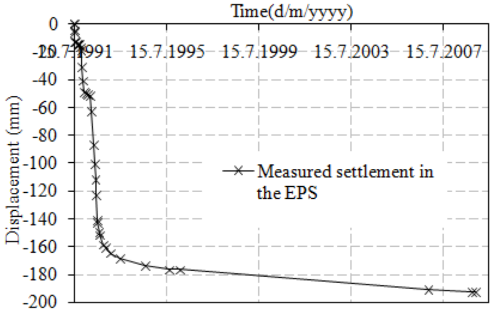

Figure 11 Long-term settlement in the Expanded polystrene.

4 TIME DEPENDENT BEHAVIOUR OF EPS (LONG-TERM CONSIDERATION)

The time-dependent deformation can be represented by two separate parts, i.e. the immediate response and the time dependent component,

$\varepsilon = \varepsilon_0 + \varepsilon_c(t)$

Where

ε = total strain at time t after a stress application

ε_0 =the immediate strain upon a stress application

$\varepsilon_c(t)$ =creep strain at time t.

The immediate strain can include both the elastic and plastic strain components (Horvath 1998). Findlay(1989) showed empirical equations that many plastics(polymers) do not exhibit a pronounced secondary deformation. (Zou 2001; Horvath 1998) have evaluated a laboratory creep-test data for EPS block geofoam. A laboratory test on a 50mm cube EPS sample with a density of 20kg/m^3 were subjected to unconfined axial compression conditions with stress magnitudes of 30kPa, 40kPa and 50kPa. For lower stress level, the strain rates are very small. The strain rate increases as the level of stress increases to 50 kPa(Horvath 1998). This is a good indication that the EPS geofoam should be loaded in the elastic range of stress in applications where only small-strain is desirable. When the EPS is used as a compressible material in buried culverts large stains are expected to reduce the earth pressures acting on the pipe.

5 FINITE ELEMENT ANAYSIS

Nowadays finite element programs have been used in a range of geotechnical analyses. It is significantly helpful in studying the effect of soil parameters in the soil or soil-structure models.

The finite element program PLAXIS has been used to model the field instrumentation. The compressible layer, expanded polystyrene (EPS) is modeled using linear elastic model and the backfill soil is modelled using the hardening soil model. The stress-strain behaviour of EPS geofoam depends on many factors such as density, magnitude of applied load, manufacturing process, and environmental factors. A typical stress-strain curve shows that the EPS geofoam has a nonlinear relationship. The stiffness is varying at different ranges of stress levels. The stiffness (E) of the EPS has been defined from stress-strain curve of EPS geofoam (Zou 2001) with a density of 20Kg/m^3. The stiffness depends on the range of overburden earth pressure as shown in Table 1.

For the EPS geofoam the values of cohesion (c): 40kPa; Friction angle (φ): 0; Poisson ratio (ν): 0.1 are considered. The backfill material is gravel (E=15MPa, c=0, φ=40).

Table 1 Stiffness of EPS for different stress range.

Range of overburden pressure (kN/m^2)	Stiffness of EPS (kN/m^2)
σ<60	E=3600
60<σ 70	E=800
70<σ<90	E=200
σ>90	E=50

The choice of stiffness for the back fill was made to obtain similar deformation of EPS as in the instrumented project.

The Long term creep effect has been modeled using the Soft Soil Creep Model (SSCM) in plaxis. The SSC model is characterized by a stress-dependendent stiffness which follows a logarithmical compression; secondary compression(creep) under loading, which is constant with time. The most important parameters for the SSC model are λ^*(modified compression index), κ^*(modified swell index) and μ^*(modified creep index). The approximation of parameters is obtained from the following expressions.

Modified compression index:

$$\lambda^* = \frac{\lambda}{1+e_0} = \frac{C_c}{(1+e_0)\ln 10}$$

Where C_c is the compression index and e_0 is the initial void ratio. λ^*/μ^* is in the range between 15 to 25 and λ^*/κ^* is in the range between 5 to 10

(Plaxis manual, 2002). $\lambda^* = 0.555$, $\kappa^* = 0.056$ and $\mu^* = 0.222$ have been used in the analysis for the EPS geofoam.

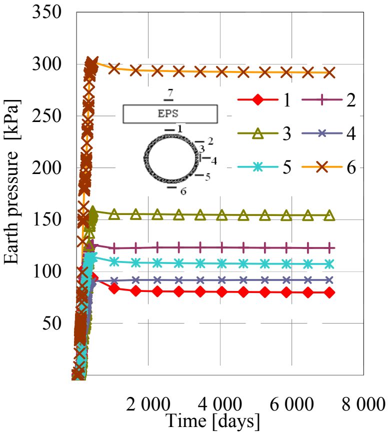

Figure 12 Earth pressures around the pipe, Finite element analysis.

As it is shown in Figures 12 and 13, the finite element analysis has shown the arching effect of using EPS geofoam on the buried culvert. The earth pressure obtained on the top of the pipe is comparable with the earth pressure measured at the field. Different trials of parameters are considered to match the values with the full scale test. However consistent conclusions can not be drawn.

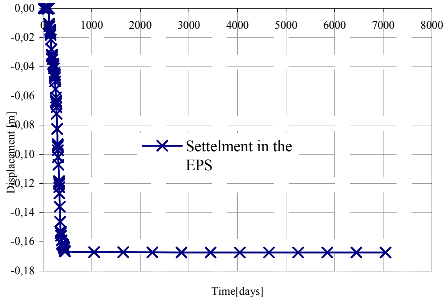

Figure 13 Settlement in the EPS, Finite element analysis.

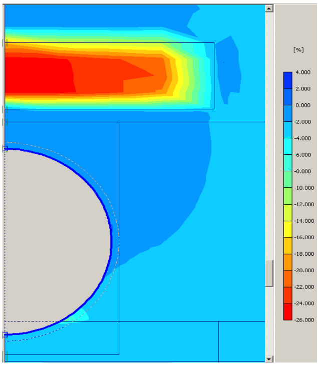

Figure 14 Volumetric stain, Finite element analysis.

Figure 14 shows the total strain obtained using Plaxis. The strain within the geofoam cross-section is varying greatly. A maximum strain of 26% is seen at the center of the EPS geofoam and decreases along the width.

6 CONCLUSION

The EPS geofoam as a compressible material applied on the top of the pipe causes a considerable reduction of the earth pressure as compared to the overburden pressure. Expanded polystyrene blocks, used as the compressible material, are super light, easy to handle, and they simplify the construction procedure. In this full scale test it was shown that the vertical earth pressure was reduced to 20-46% of the overburden pressure in all cells at the end of construction. Long-term measurements show that there is no marked increase in vertical earth pressure since end of construction. The long-term compression of the expanded polystyrene has varied from 32% to 38%.

In applications of the EPS geofoam in buried culverts for vertical load reducing mechanism, the creep deformation in the geofoam allows mobilization of the back fill so that there will be less vertical earth pressures acting on the buried culvert. But in areas where the long-term creep deformation of the EPS geofoam is undesirable, the EPS must be used with in an appropriate load range. In this full-scale test it is clearly indicated that the influence of geofoam creep is observed predominantly during the construction phase and no noticeable increment of earth pressure is measured for a period of 17 years.

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