FEM simulation of full scale and laboratory models test of EPS

Tewodros H. Tefera tewodros.tefera@vegvesen.no, Roald Aabøe roalda@vegvesen.no,
Hermann Bruun hermann.bruun@vegvesen.no, Kristian Aunaas kristian.aunaas@vegvesen.no.
The Norwegian Public Roads Administration, Norway

ABSTRACT: *EPS geofoam has been used for about 40 years in many geotechnical applications in many countries around the world. EPS geofoam possesses properties which are often advantageous in geotechnical construction. These include: an extremely low density, a high strength-to-weight ratio and very small or virtually zero lateral expansion under compressive loading. It has been used for backfilling retaining walls and embankments both with vertical and sloped sides. The behaviour of EPS in compression is a function of density, strain rate and sample size. Both small- and large-strain applications of EPS geofoam involve interactions with the surrounding soil. The stress - deformation response of this material in both small- and large-strain zones, however, differs significantly from those of the surrounding soil. This paper describes FEM simulation of full scale and laboratory test models of EPS geofoam using a calibrated advanced soil model implemented in PLAXIS.*

INTRODUCTION

Due to its light-weight, significantly reduced horizontal loads, simplified designs, speed and ease of performing construction activities, EPS geofoam have been used in road construction as a light weight material for nearly four decades. The positive experience with EPS as insulating material lead to the use of it as a lightweight substitute. EPS geofoam is currently well known as a lightweight fill material worldwide. The literature indicates that the Norwegian Public Roads Administration has successfully used EPS geofoam on more than 500 road projects (500 000 – 1000 000 m^3 EPS) particularly on soft soils as sub-grade fill material, backfill material for bridge abutments, embankments with vertical walls [1]. When EPS geofoam is installed as fill material under a foundation, some deformation of the EPS geofoam will occur. The stress–strain behaviour of EPS geofoam for such cases depends on many factors such as density, magnitude of applied load, manufacturing process, and environmental factors. In addition, interactions between geofoam blocks and geofoam-soil further complicate the understanding of the behaviour of EPS geofoam. Due to all of these factors, the estimation of the stress–strain behaviour of EPS geofoam in the ground is quite difficult and complicated [2][3]. The density of EPS geofoam can be considered the main parameter in which most of its properties such as compressive strength, stiffness, creep and other mechanical properties depend on.

The primary objective of this paper is to present the numerical simulation result of two physical models. The two models, full scale and laboratory test models of EPS geofoam were constructed at the Norwegian Public Roads Administration. A calibrated Hardening soil model implemented in the FEM program PLAXIS 2D version 2010 [7] is used to simulate the stress distributions.

STRESS-STRAIN BEHAVIOUR

Several models have been proposed to describe the stress–strain-time behaviour of EPS geofoam [2]. The stress–strain behaviour of EPS geofoam can be divided into two different categories: time-independent stress–strain models and time-dependent (creep) models. The immediate strain is a time-independent quantity generated under a static or rapid loading condition. The long term vertical creep of EPS geofoam is required to predict the total vertical deformation. The strain of a material showing time dependent viscoplastic behaviour can be expressed as follows:

$$\varepsilon_t = \varepsilon_o + \varepsilon_c \qquad (1)$$

where ε_t is the total strain; ε_o the immediate strain component; ε_c the time dependent strain component.

General stress–strain behaviour for immediate strain can be simulated in two different ways. It can be modelled using a linear elastic model using initial tangent modulus or using a nonlinear inelastic model. The nonlinear inelastic model is of interest due to its greater accuracy over a larger range of strain. A nonlinear Hardening soil model implemented in the FEM program PLAXIS is used in this paper.

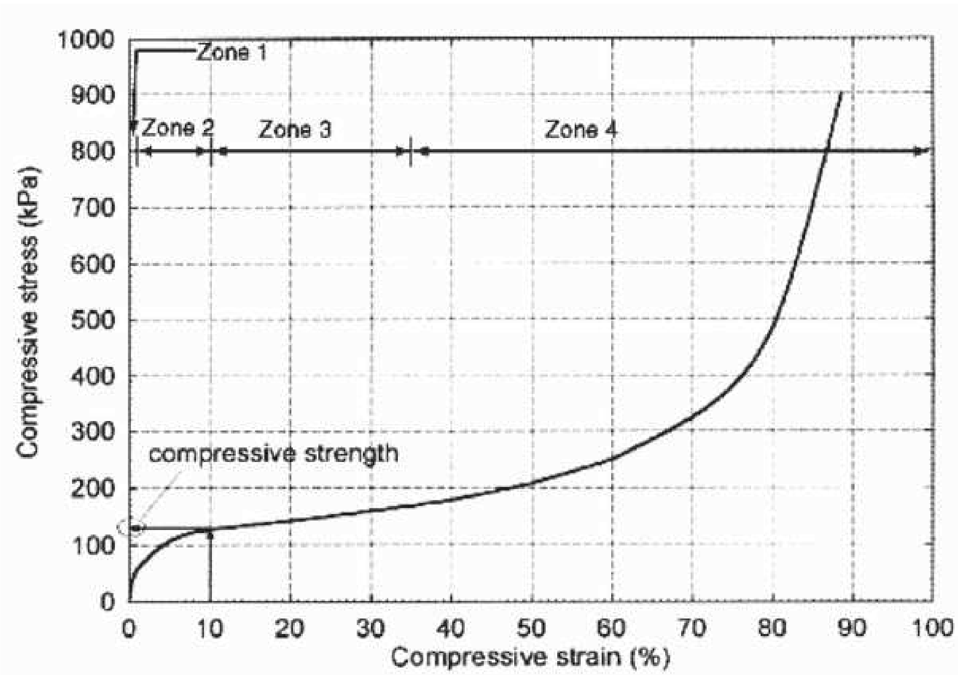

Figure 1. Stress-strain behaviour of 21 kg/m^3 EPS block under rapid, strain controlled, unconfined axial compression [5].

Figure 1 shows the typical uniaxial compression stress-strain response of an EPS-block specimen. The test was performed on a block-moulded EPS sample with a density of 21 kg/m^3. However, the stress-strain responses for other densities are qualitatively similar [4]. As shown in Figure 1, EPS does not typically exhibit failure like other solid materials used in construction (metals, concretes, wood) by a physical rupture of the material when uniformly loaded. Furthermore EPS does not behave like soil or other particulate materials where inter-particle slippage occurs and a steady state or residual strength develops at large strains. The stress-strain behaviour of EPS shown in Figure 1 can be divided into the following four zones: zone 1 an initial linear response zone, zone 2 a yielding zone, zone 3 a linear and work hardening zone, and zone 4 a non linear but still work hardening zone [4]. The limit of the initial linear response of Zone 1 extends to strains between 1 and 1.5 percent with the larger strain at the end of the linear region occurring with an increase in EPS density. Therefore, for design it can be conservatively concluded that the stress-strain behaviour of EPS-block geofoam is both linear and elastic up to a compressive strain of approximately 1 percent [4].

TIME-DEPENDENT STRESS-STRAIN BEHAVIOUR (CREEP)

A reliable mathematical model to estimate long-term vertical strain of EPS blocks under sustained loads is currently not available. Therefore, the current state of practice for considering creep strains in the design of EPS block embankments is to base the design on laboratory creep tests on small specimens trimmed from the same EPS block that will be used in construction or to base the design on published observations of the creep behaviour of EPS [4].

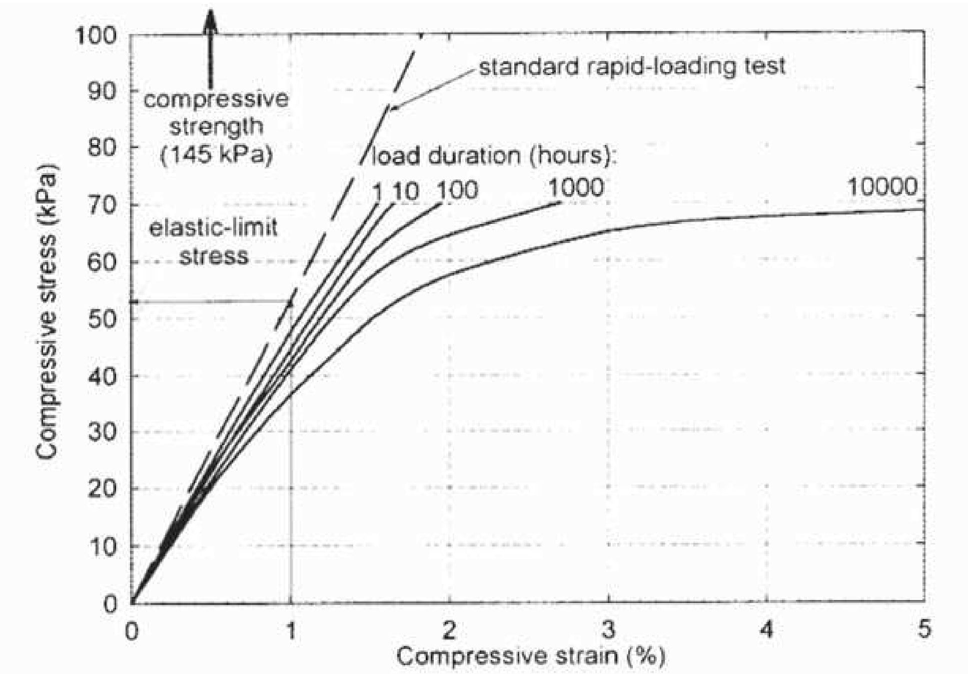

Figure 2. Isochronous stress-strain curves for 23.5 kg/m^3 block-moulded EPS based on unconfined axial compression creep tests [5].

Figure 2 shows isochronous stress-strain relationships based on the results of creep tests. As shown in Figure 2, EPS will exhibit large creep deformations almost immediately if stresses are near the compressive strength. Therefore, to produce acceptable strain levels in lightweight fill applications, stress levels must be kept low relative to the compressive strength. Also, the isochronous relationships tend to be predominantly linear up to strains of about 1 to 1.5 percent. Lower density EPS tends to creep more than higher density EPS at the same relative stress level [4].

Based on summarized published observations [5], if the applied stress produces an immediate strain of 0.5 percent or less, the creep strains will be negligible even when projected for 50 years or more. If the applied stress produces an immediate strain between 0.5 percent and 1 percent, the geofoam creep strains will be tolerable (less than 1 percent) in lightweight fill applications even when projected for 50 years or more. If the applied stress produces an immediate strain greater than 1 percent as shown in Figure 2, creep strains can rapidly increase and become excessive for lightweight fill geofoam applications.

MODEL CALIBRATION

The Hardening soil model is an advanced hyperbolic soil model formulated in the framework of hardening plasticity. In the Hardening soil model in PLAXIS 2D V2010 the total strains are calculated using a stress-dependent stiffness, different for virgin loading and un-/reloading. The plastic strains are calculated by introducing a multi-surface yield criterion. Hardening is assumed to be isotropic depending on both the plastic shear and volumetric strain. For the frictional hardening a non-associated and for the cap hardening an associated flow rule is assumed [6] [7]. For the construction of laboratory model test EPS20 were used. And for the construction of full scale model test three types of EPS material; EPS20, EPS30 and EPS40 were used. The material properties of the different EPS material during the time of the model tests are shown in Table 1.

Table 1. EPS material used for the model tests

EPS type[1]	Density (kg/m^3)	Compressive stress at 5% strain (kPa)
EPS20	20	100
EPS30	30	180
EPS40	40	240

[1]note that the EPS type classification is not according to the current NS-EN-14933:2007

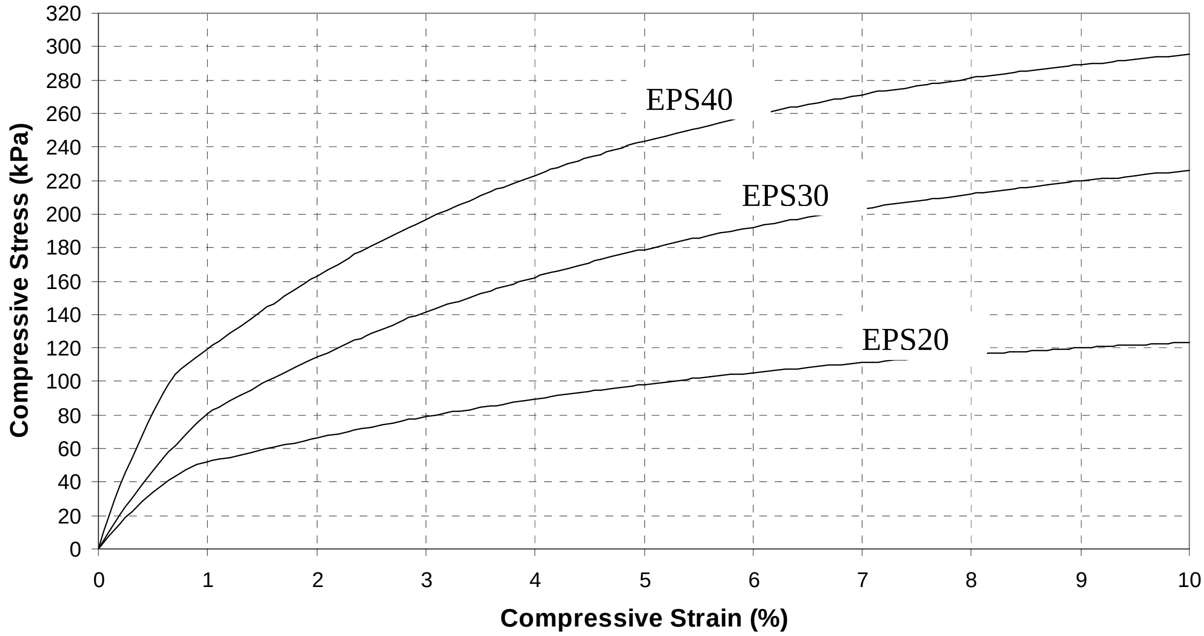

Figure 3. Calibrated stress strain curves for EPS20, EPS30 and EPS40 using Hardening soil model implemented in FEM program PLAXIS.

The different parameters of the Hardening soil model used for the simulation were calibrated against the EPS material properties shown in Table 1. Figure 3 shows the calibrated stress strain curves for EPS20, EPS30 and EPS40 using the Hardening soil model implemented in FEM program PLAXIS. The calibrated model parameters are shown in Table 2.

Table 2. EPS properties used in the calibrated Hardening Soil model

Hardening -Soil model parameter	EPS Type		
	EPS 20	EPS 30	EPS40
Unit weight (kg/m^3)	20	30	40
Cohesion, c (kN/m^2)	35	60	75
Friction angle, φ (^{0})	30	42	40
Dilatancy angle, ψ (^{0})	0	0	0
Secant stiffness, E_{50}^{ref} (kPa)	6000	9000	15000
Power, m	0,5	0,5	0,5
Poisson's ratio, υ	0,1	0,1	0,1
Reference stress, p^{ref} ((kPa)	100	100	100

MODEL TESTS

In Norway the Public Roads Administration has a long tradition of testing and applying various types of lightweight fill materials for road construction. Since the first road insulation project with EPS performed in 1965 and the first EPS lightweight embankment was constructed in 1972 the projects have been monitored with periodical inspections and measurements [1]. Since then several tests have been carried out in order to monitor possible material changes. In this connections test samples have been retrieved from existing fills to check changes in strength, water absorption and unit densities of the samples. To study the stress distributions within the blocks and fills both laboratory and field tests have been performed. The load creep effects have also been studied on EPS fills both in the laboratory and in the field. The laboratory model and the full scale tests carried out to study the stress distributions within the EPS blocks and fills are simulated in this paper using a calibrated advanced Hardening soil model implemented in PLAXIS 2D V2010.

LABORATORY MODEL TEST

In one of the laboratory model tests built at the Norwegian Road Research Laboratory (now the Traffic safety, Environment and Road Technology Department) to study the stress distribution and creep a test fill of EPS with 2 m height was built. The EPS test fill was built on a thin 15 cm sand layer placed on a concrete floor. Standard EPS20 normal sized blocks with density 20 kg/m^3 and a corresponding compressive strength of 100 kPa at 5% strain were used to build the model. The stress distributions in the model was monitored by 5 hydraulic earth pressure cells placed at different levels as shown in Figure 4. Pressure cells number 2, 3, 4 and 5 were placed just under the fill and one pressure cell was placed just under the top EPS block. The model was then loaded with a vertical load of 10.5 ton which is equivalent to 52.5 kPa. The stabilised measured result from the pressure cells shows some variation in measurements. Pressure cells 2, 3 and 4 which are placed just under the fill in the thin sand layer measured a vertical pressure of 3 - 5 kPa and pressure cell 5 measured higher value of 12 kPa. Whereas pressure cell 1 placed just under the top EPS block measured 17 kPa.

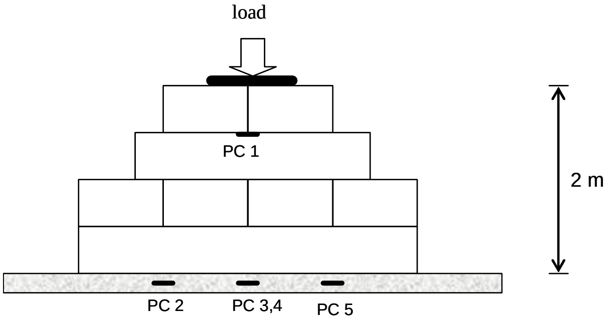

Figure 4. EPS geofoam laboratory test model built on a thin 15 cm sand layer at NPRA.

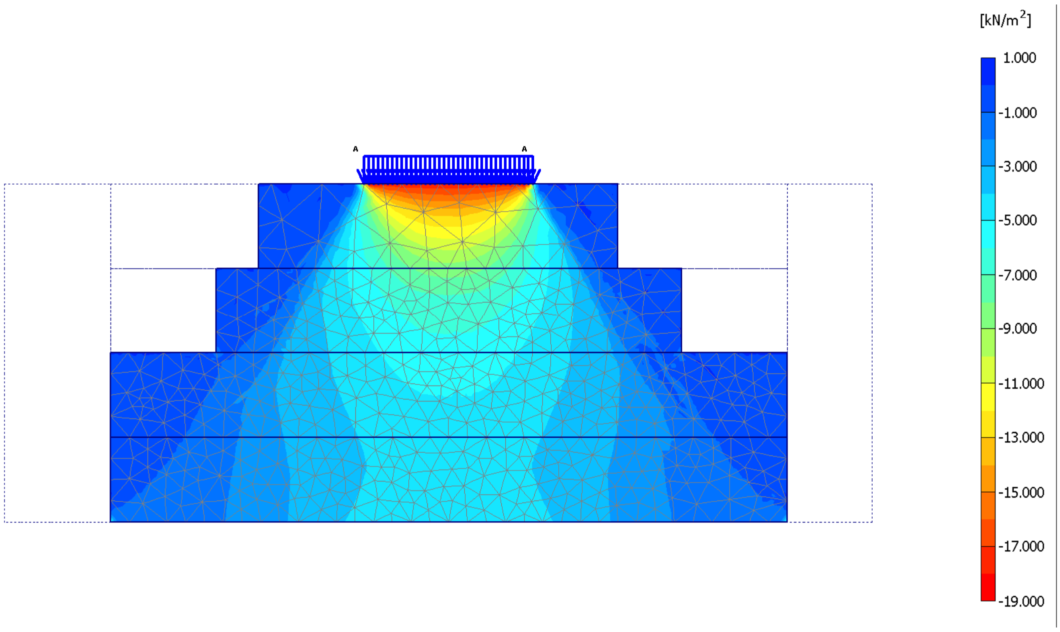

Figure 5. FEM simulation showing the vertical stress distribution of laboratory test model

The simulation result in Figure 5 shows the vertical pressure distribution just under the fill is in the order of 5 kPa and the vertical pressure just under the top EPS block is in the order of 10 kPa.

FULL SCALE MODEL TEST

The temporary Løkkeberg bridge built in 1989 across the Euroroad 6 (E6) close to the Swedish boarder was used as a full scale model test. The Løkkeberg bridge was built to temporary improve the traffic safety until the completion of the new E6 motorway between Norway and Sweden. The bridge was a single lane Acrow steel bridge with one span 36.8 m. The bridge and the adjoining embankments are located in an area with soft clay deposits overlying bedrock. Beneath a drying crust of about 1.5 m, the soil layer has a thickness of 6 to 16 m and consists of mainly quick clay.

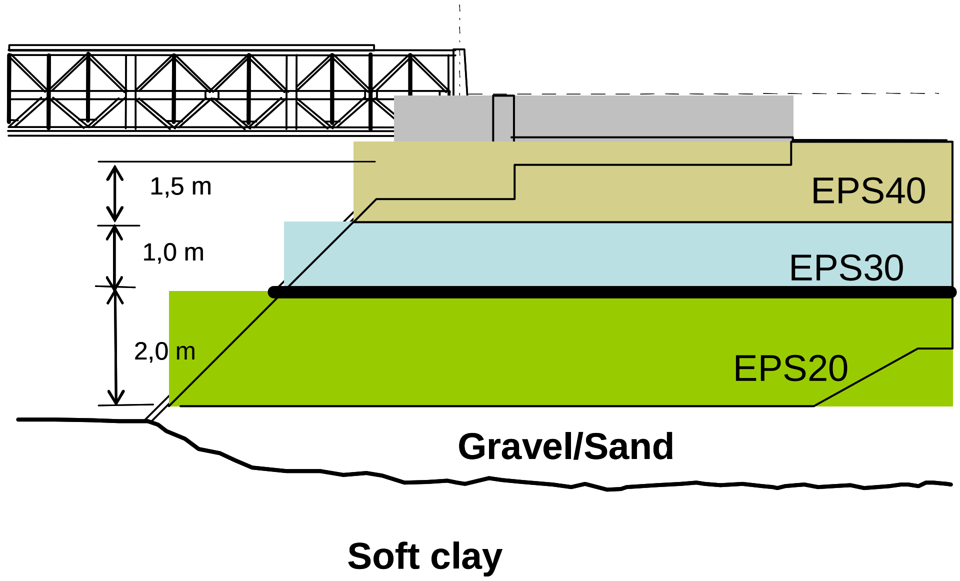

Figure 6. Longitudinal section of Løkkeberg bridge

Due to low bearing capacity and expected large settlements in the foundation soil, lightweight fill materials (EPS) were used in the embankments adjoining the bridge. The bridge foundation was placed directly on top of the EPS fills. Three different types of EPS were used for the construction of the fill. In the upper layer just beneath the bridge foundation EPS40 normal sized blocks with density 40 kg/m^3 and a corresponding compressive strength of 240 kPa at 5% strain were used. In the remaining layers just halfway down the fill EPS30 normal sized blocks with density 30 kg/m^3 and a corresponding compressive strength of 180 kPa at 5% strain were used. And in the remaining layers half way down the fill EPS20 normal sized blocks with density 20 kg/m^3 and a corresponding compressive strength of 100 kPa at 5% strain were used. The dimensions of the abutment were 7.4m x 7.5m. The foundation is 1.0 m thick directly under the bridge support and 0.5 m on the remaining part as shown in Figure 6. Shotcrete was sprayed on the front slopes of the EPS, while ordinary soil protection was provided on the side slopes. The total pavement thickness constructed on top of the bridge abutments was 80cm. Figure 7 shows the Løkkeberg bridge during construction and during service.

(a)

(b)

Figure 7. Løkkeberg bridge during construction (a) and during service (b)

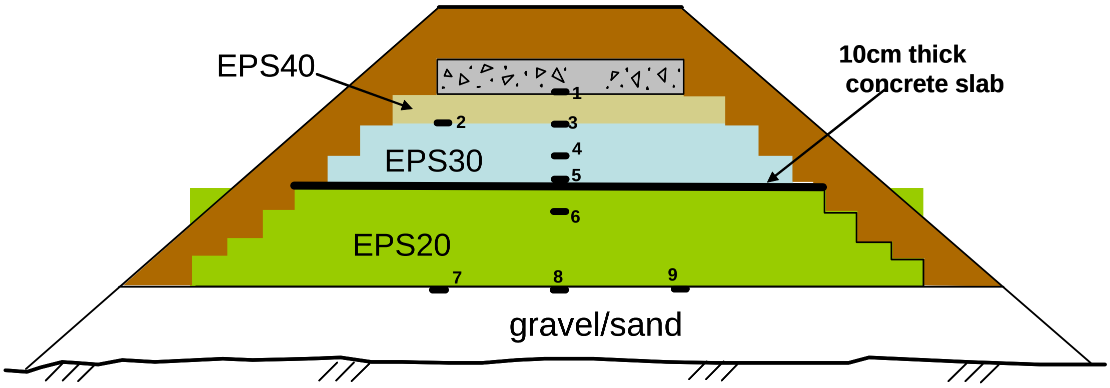

Figure 8. Section through the fill showing the locations of pressure cells

The stress distributions in the EPS material below the bridge abutment during construction and on the long term basis were measured by 10 hydraulic earth pressure cells placed at different levels in the fill. The locations of 9 of the pressure cells are shown in Figure 8. In order to check the stress distribution in the fill, a dumper with a weight of 33 ton was placed directly upon the abutment. The resulting change in vertical pressure is shown in Figure 9.

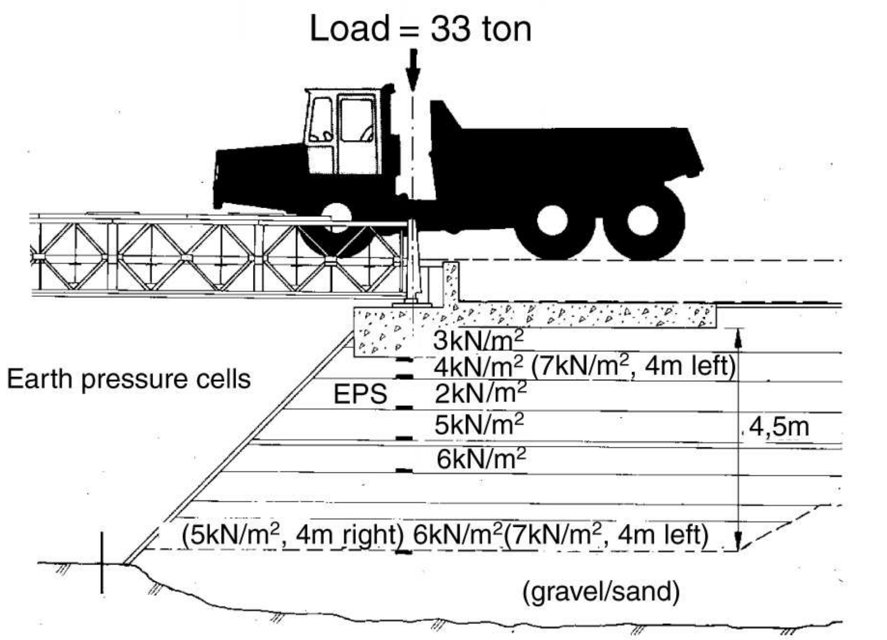

Figure 9. Stress distribution from an additional load [8], the location of pressure cells are shown in figure 8

The stress distribution from the additional load, Figure 9, is simulated using the calibrated model for the different EPS types. The simulation result in Figure 10 shows that the vertical pressure distribution just under the abutment in the top half part of the fill is of the order of 6 kPa and the vertical pressure just under the fill is in the order of 4 kPa.

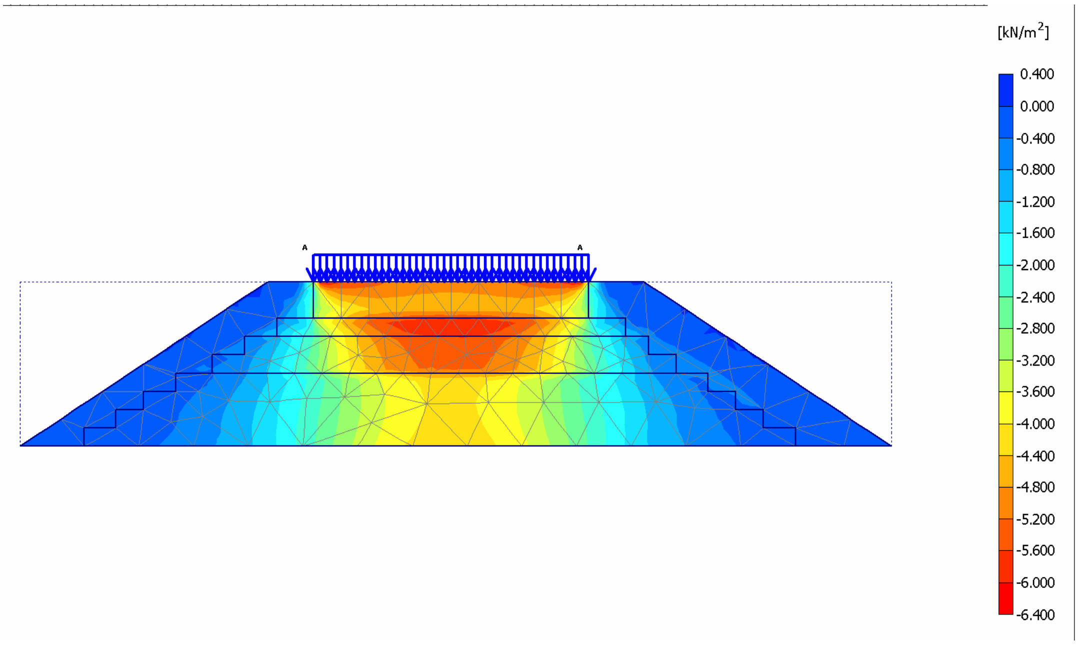

Figure 10. FEM simulation showing the vertical stress distribution due to the additional load shown in Figure 9

CONCLUSION

The stress–strain behaviour of EPS geofoam in the relatively low strain range can be fairly simulated using Hardening soil model. However, unlike soil the model parameters can be determined by curve fitting as shown in this paper. The stress distribution in EPS geofoam fill also depends on the interaction between EPS geofoam blocks. This could have been the reason for some variation in the measured values from the model tests and between the FEM simulation result and experimental result.

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