Instrumented field test and soil structure interaction of concrete pipe with high fill

Test instrumenté in situ et interaction sol-structure d'un tuyau de béton en remblai de grande hauteur

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ABSTRACT
The earth pressure on deeply buried culverts is significantly affected by arching. Both the magnitude and distribution of earth pressure on buried culverts depend on the relative stiffness of the culvert and the soil. In this paper instrumentation of field test with the induced trench method is described. The method involves installing a compressive material (expanded polystyrene) above a rigid culvert in order to reduce the vertical earth pressure(create arching).

The culvert is a concrete pipe with inner diameter 1.4m and thickness of 0.164m beneath a 23m high fill embankment, built with instrumented field installation in 1991. The instrumentation consisted of hydraulic earth pressure cells and a specially developed system for measuring deformation of the expanded polystyrene. Long-term measurements of earth pressure and deformation are performed in a period of 17 years. The interaction of the pipe, soil, and expanded polystyrene is modeled with the finite element program Plaxis. A simplified design method based on stress fields is developed. Comparison between field tests, Finite element modeling and a proposed design method are made.

RÉSUMÉ
La pression du sol s'exerçant sur les galeries profondes est notablement influencée par l'effet de voûte. L'amplitude et la distribution du la pression du sol sur les buses souterraines dépendent toutes deux de la rigidité relative de la galerie et du sol. Dans cet article est présentée l'instrumentation d'un test in situ à l'aide de la méthode dite « tranchée induite ». Cette méthode implique l'installation d'une couche de matériau compressible (polystyrène expansé) au dessus d'une buse rigide, dans le but de réduire la pression du sol verticale (créer un effet de voûte).

La buse en question est un tuyau de béton d'un diamètre intérieur de 1,4 m et d'une épaisseur de 0,164 m, sous un remblai d'une hauteur de 23 m, mis en place avec instrumentation in situ en 1991. L'instrumentation était composée de cellules manométriques mesurant la pression du sol ainsi que d'un système spécialement développé pour mesurer les déformations dans le polystyrène expansé. Les mesures de longue durée de pression du sol et de déformation ont eu lieu pendant une période de 17 ans. Les interactions tuyau, sol et polystyrène expansé sont modélisées à l'aide du programme de calcul aux éléments finis Plaxis. Une méthode simplifiée de conception est développée sur la base des champs de contrainte. Une comparaison est menée entre tests in situ, modélisation aux éléments finis et la méthode de conception proposée.

Keywords : expanded polystyrene (EPS), earth pressures, arching, buried pipes

1 INTRODUCTION

The problem of earth pressure on buried structures has a great practical importance in constructing highway embankments above pipes and culverts. Both the magnitude and distribution of earth pressure on buried culverts are to depend on the relative stiffness of the culvert and the soil. The current design methods distinguish between a rigid culvert and a flexible culvert. The vertical earth pressure on a rigid culvert is greater than the weight of the soil above the structure(negative arching). The vertical earth pressure on a flexible culvert is less than the weight of the soil above the culvert (positive arching).

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. Terzaghi (1943) stated that the amount of arching can only be obtained by direct measurement under field conditions. To measure the vertical and horizontal earth pressure 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 compression strength of $100kN/m^2$and average density was $20kN/m^3$. 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.

2 EXPERIMENTAL RESULTS

The earth pressures at the cells have been measured since the beginning of construction in July 1991 (Johansen 1997). The measured vertical earth pressures in cells at the top, side and bottom of the pipe are presented in the following figures. Figure 2 shows that the measured vertical earth pressure at the top of the pipe using the EPS geofoam increases until 5m depth similar to the overburden pressure. Further increase in the fill causes little increment of the vertical earth pressure. The earth pressure was 23% of the overburden pressure at the end of construction.

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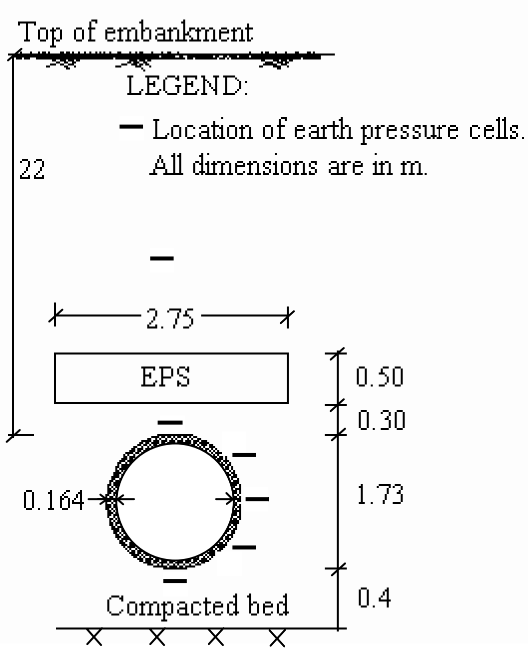

Figure 1. Location of cells around the pipe.

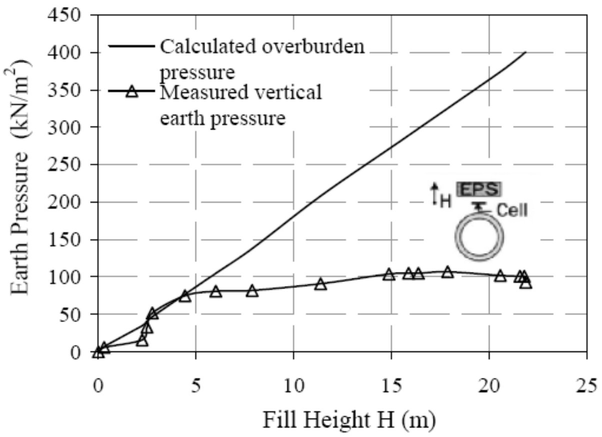

Figure 2. Measured vertical earth pressure above the pipe.

The measured horizontal earth pressure on the pipe springline is shown in Figure 3. The calculated horizontal at rest pressure ($K_0\gamma H$) is also shown in the same figure , and K_0=0.35 is assumed. Up to a fill height of 4m above the cell level, the measured earth pressure is slightly lower than the calculated horizontal earth pressure. Further filling to 21m above the cell level increases the measured earth pressure to 205 kN/m^2 which is 39.5% greater than the calculated horizontal earth pressure at rest. This horizontal earth pressure is 49% of the overburden pressure, and the horizontal earth pressure coefficient will be K_0=0.49. As it is shown in Figure 4 the total vertical stress beneath the pipe has been reduced by 73% of the total overburden using EPS geofoam at the top of the pipe. The measured vertical deformation in the EPS is shown in Figure 5. 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.

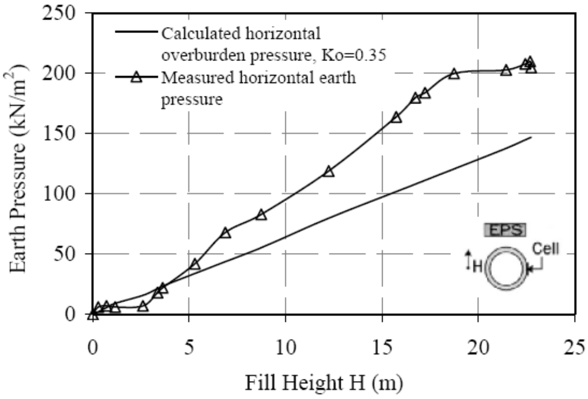

Figure 3. Measured horizontal earth pressure at side of the pipe.

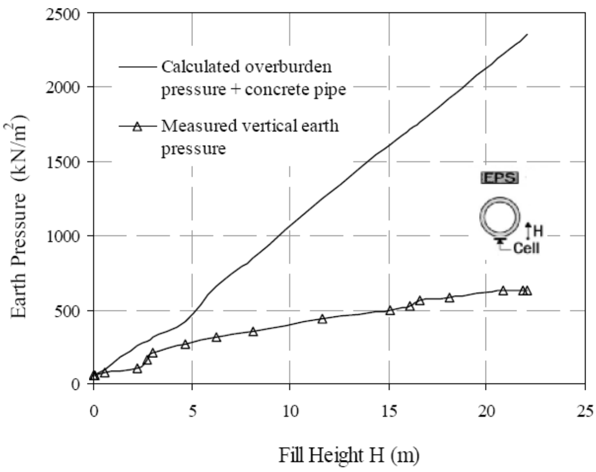

Figure 4. Measured vertical earth pressure at the bottom of the pipe.

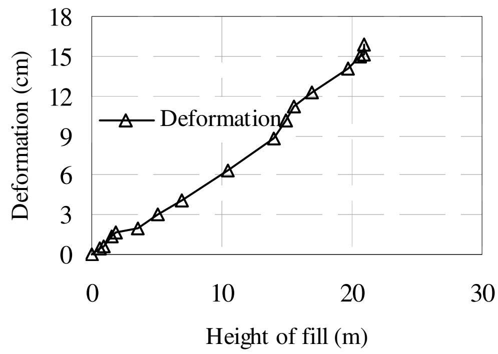

Figure 5. Deformation of the EPS.

The long-term behavior of the EPS and the earth pressure has been monitored for 17 years. It is shown in Figure 6 that the settlement in EPS geofoam has been increased from 30% of the thickness of the EPS at the end of the construction in 1992 to 36% of the EPS thickness in 2008. This has caused a reduction of the vertical earth pressure at the top of the pipe. A slight reduction of vertical earth pressures have been recorded at all cells. This is a good indication that EPS geofoam are suitable for long term applications. Long term measurements using geofoam are shown in Vaslestad et. al(1993).

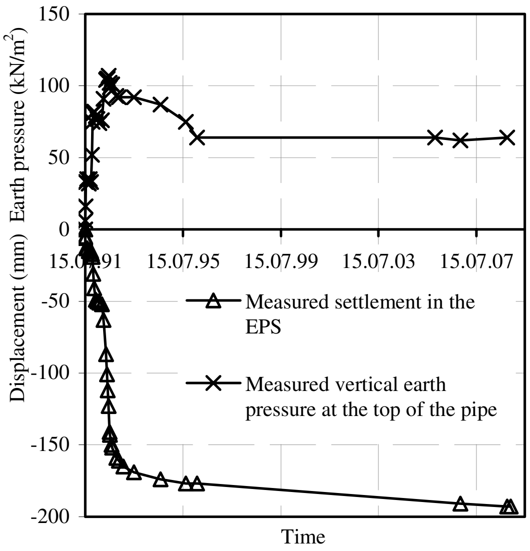

Figure 6. Long-term measurements.

3 FINITE ELEMENT ANALYSIS

The finite element program PLAXIS has been used to model the field instrumentation. The compressible layer, expanded polystyrene (EPS) is modeled using Mohr-Coulomb model and the backfill soil is modeled using the hardening soil model. The stiffness(E) of the EPS has been defined from stress-strain curve of EPS goefoam (Zou 2001) with a density of 20Kg/m^3. The stiffness depends on the range of overburden earth pressure as shown in Table 1.

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

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).

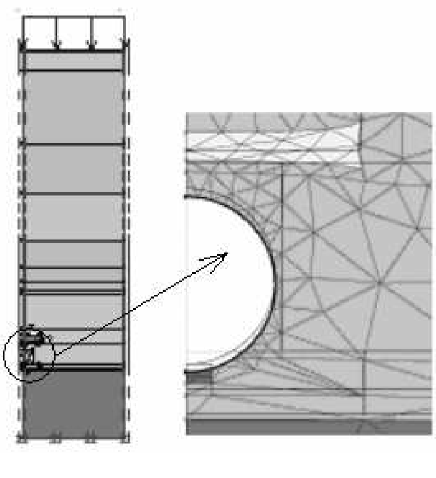

Figure 7. Finite element model using Plaxis. Geometry model and deformation out put.

The finite element analysis has shown similar earth pressure with the field instrumentation at the top of the pipe. The stress-strain curve in EPS geofoam with density 20kg/m^3 shows that the yielding stress is approximated about 100kN/m^2. The comparison between the field instrumentation and the FEM analysis is shown in Figure 8.

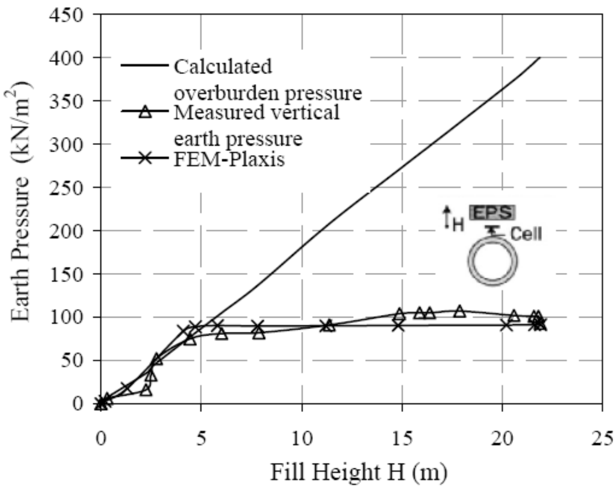

Figure 8. Comparison of vertical earth pressure at the top of the Pipe.

At it has been observed from the field instrumentation the horizontal earth pressure measured at the field is higher than the calculated horizontal earth pressure. A sensitivity analysis with different stiffness of the back fill material has been done using Plaxis as shown in Table 2. The horizontal earth pressure as well as the vertical earth pressure can be reduced with the appropriate selection of back fill material with higher stiffness.

Table 2. Sensitivity analysis on back fill material

Stiffness of backfill (kN/m^2)	Vertical pressure at the top of the pipe(kN/m^2)	Horizontal pressure at the side of the pipe(kN/m^2)
10000	97.63	164.71
15000	91.99	150.12
40000	62.93	134.59

4 DESIGN METHOD

The vertical earth pressure σ_v on an imperfect ditch culvert can be found from, Vaslestad(1990):

$$\sigma_v = N_A \gamma H \qquad [\text{kN/m}^2] \tag{1}$$

Where
N_A = arching factor
γ = unit weight of the soil [kN/m^3]
H=height of cover [m]

And
$$N_A = \frac{1-e^{-A}}{B} \tag{2}$$

$$A = 2S_v \frac{H}{B} \tag{3}$$

B =width of culvert [m]

The friction number S_v was used by Janbu (1976) to determine friction on piles

$$S_v = |r| \tan \rho K_A \tag{4}$$

Where $\tan\rho = f\tan\varphi$ =mobilized soil friction,

f =degree of mobilization and $\tan\varphi$ = Soil friction

K_A= active earth pressure coefficient.

$$K_A = \frac{1}{\left[\sqrt{1+\tan^2\rho} + \tan\rho\sqrt{1-|r|}\right]^2} \tag{5}$$

$$r \text{ =the roughness ratio} = \frac{\tan\delta}{\tan\rho} \le 1$$

The roughness ratio can also be defined as the ratio between the mobilized shear stress and the equilibrium shear stress in the soil. Analysis have shown that no other single factor has a greater influence on the value of earth pressure than the roughness ratio, r Janbu (1957). With constant H/B, the arching factor N_A is a unique function of r and $\tan\rho$ only. Figure 9 shows the arching factor for H/B=12.7(considering the actual fill height).

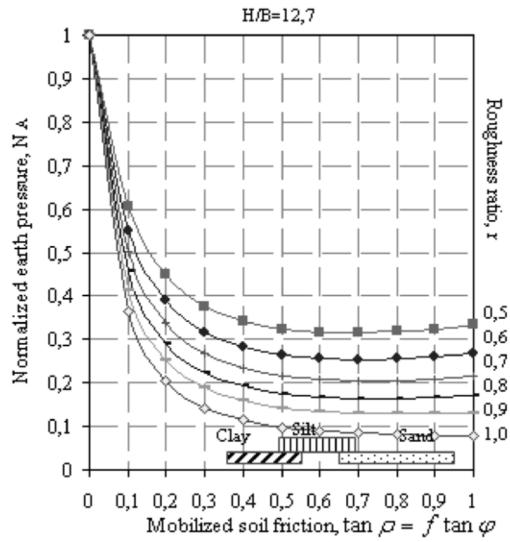

Figure 9. Earth pressure on imperfect ditch culvert with H/B=12.7

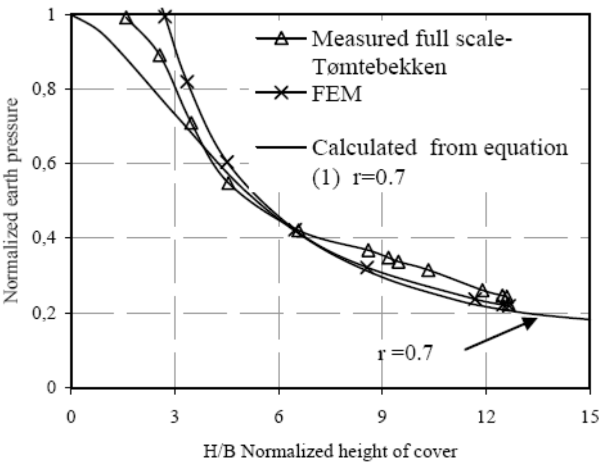

Figure 10. Measured earth pressure compared with proposed design method and FEM result.

The measured vertical earth pressure is compared with the proposed method to determine earth pressure on imperfect ditch culverts as shown in Figure 10 . The calculated curve from the design approach with roughness ratio r= 0.7 is comparable with the measured full scale test and the FEM analysis as well.

5 CONCLUSION

The full scale test that is described shows that the imperfect ditch method can be used to reduce the vertical earth pressure on rigid pipes. Expanded polystyrene blocks were used as a compressible material. The blocks are super light and easy to handle, and use of expanded polystyrene simplifies the construction procedure.

The average measured earth pressure on the pipe was reduced to 23% of the overburden pressure. The horizontal earth pressure increased to 39.5% greater than the at rest pressure. This shows the importance of using high quality well compacted granular soil at the sides of an imperfect ditch culvert. This has been also understood from sensitivity analysis in Plaxis. The expanded polystyrene was compressed 30% of its initial thickness during the construction of embankment above the pipe. Much of the deformation in the expanded polystyrene occurs during the construction phase and no problem has been observed on the road surfaces due to the long-term settlement of the expanded polystyrene. Long-term observations for 17 years show that there is no increase in earth pressure.

The finite element analysis has shown similar vertical earth pressures on the top of the pipe. A good correlation of the analysis with the field instrumentation can be obtained by defining the EPS with the appropriate range of stiffness for varying overburden pressures during the stage of construction.

REFERENCES

Janbu, N. 1957. *Earth pressure and bearing Capacity calculations by generalized procedure of slices*. Int. Conf. SMFE, London, proceedings, Vol. 2, pp 207-212

Janbu, N. 1976. *Static bearing capacity of friction piles. 6th European conference SMFE*, Wein, proceegings, Volume III, pp 479-488

Johansen,T.H.1997. *Concrete pipe under high fil,l longterm-measurements*, Internal report nr. 1927, 1997 E6 Tomtebekken, Norwegian Public Roads Adminstration. (in Norwegian)

Terzaghi, K. 1943. *Theoretical soil mechanics*. John Wiley and Sons, Inc.

Vaslestad, J. 1990. *Soil structure interaction of buried culverts.* Ph.D. Thesis, The Norwegian Institute of Technology.

Vaslestad, J., Johansen, T.H. & Holm, W. 1993. *Load reduction on rigid culverts beneath high fills- long term behaviour*. Transportation Research Record, *Journal of the Transportation Research Board* No. 1415, Transportation Research Board of the National Academies, Washington DC: 58-68.

Zou, Y. 2001. *Behavior of the expanded polystyrene(EPS) geofoam on soft soil*. Ph.D.d Thesis, The University of Western Sydney Nepean.