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Load reduction on buried rigid pipes below high embankments

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LOAD REDUCTION ON BURIED RIGID PIPES BELOW HIGH EMBANKMENTS

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SAMMENDRAG

This report is an article to Pipeline Crossings, Specialty Conference, Pipeline Division, American society of Civil Engineers, Denver Colorado, March 25-27 1991.

Abstract

A full scale test with the imperfect ditch method is described. Expanded polystyrene is used as the compressible material. The material characteristics and the long term behaviour of expanded polystyrene are well known. The disadvantages of using organic material are pointed out. The experimental results show that the average vertical earth pressure on the pipe was reduced to 43 % of the overburden. The measured earth pressure is compared with results from the finite element program CANDE and from a design method that is proposed.

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LOAD REDUCTION ON BURIED RIGID PIPES BELOW HIGH EMBANKMENTS

Jan Vaslestad [1]

Abstract

A full scale test with the imperfect ditch method is described. Expanded polystyrene is used as the compressible material. The material characteristics and the long term behaviour of expanded polystyrene are well known. The disadvantages of using organic material are pointed out. The experimental results show that the average vertical earth pressure on the pipe was reduced to 43 % of the overburden. The measured earth pressure is compared with results from the finite element program CANDE and from a design method that is proposed.

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 known to depend on the relative stiffness of the culvert and the soil. 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).

Spangler (1958) stated that, in some of Marston's early experiments, the loads on rigid embankment culverts were 90 to 95 percent greater than the weight of the soil directly above the structure. An attempt to avoid this increase in load on the structure led to the development of the imperfect ditch method (sometimes called induced trench method) of construction.

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Penman et.al. (1975) measured the earth pressure on a rigid reinforced concrete culvert below 53 m of rockfill. The measured vertical earth pressure on the culvert crown was about 2 times the overburden. Höeg (1968) performed model tests on a rigid pipe, and reported that the crown pressure was about 1.5 times the applied surcharge.

The imperfect ditch method involves installing a compressible layer above the culvert within the backfill. As the embankment is constructed, the soft zone compresses more than the surrounding fill, and thus induces positive arching above the culvert. The construction procedure is shown in fig. 1.

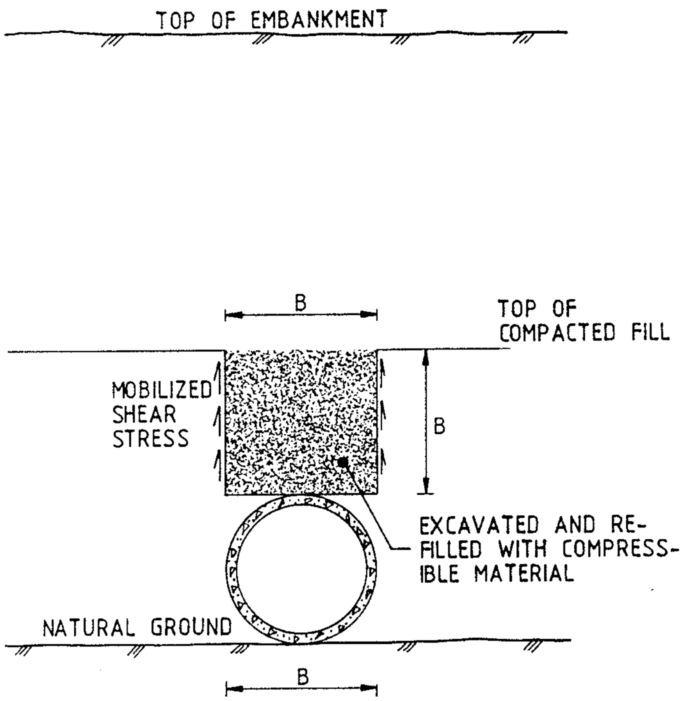

Fig. 1 Imperfect ditch culvert

The most common type of compressible material used in the imperfect ditch method is organic material (baled straw, leaves, hay, compressible soil). Old tires are used in France (Jean and Long, 1990).

Choice of compressible material

Although the artifically induced arching action is desirable, experience has shown that considerable care should be exercised in the design of the compressible layer if the desired loading is to be realized. Indeed, some arrangements of compressible layers have led to serious stress concentration problems.

In addition, the compressible materials are often organic in nature, and they manifest a number of disadvantages, such as the difficulty of specifying their compressibility characteristics and the possibility of their decomposition.

Structural distress has been observed in some imperfect ditch full scale tests due to decomposing of the organic material with time as described by Rude (1979) and Krizek et.al. (1971). This can lead to an unsatisfactory load distribution on the culvert. The reason for the observed structural distress in some imperfect ditch installations could also be attributed to the use of low quality cohesive material at the sides of the culvert.

From the definition of the mechanisms of positive arching by Terzaghi (1943), it is clear that positive arching involves two phases. A reduction of the earth pressure on a yielding part of the structure, and an increase of the earth pressure on the adjacent nonyielding areas. Also Bjerrum et.al (1972) pointed out that the increase in pressure on the adjacent nonyielding areas are equal to or larger than the reduction in pressure on the yielding part.

A zone of maximum shear stress will develop at the sides of the culvert due to the arching phenomena. The soil in the zone of higher shear stress may yield with time if it is a low quality cohesive soil. Therefore it is important to use high quality well compacted granular soil at the sides of an imperfect ditch culvert. If the backfilling material is stable with time, equilibrium will be reached and the active arching will be a permanent state of stress.

Katona et.al. (1979) pointed out that very little quantifiable data is available about the stress-strain properties of the soft organic materials used to promote arching in imperfect ditch installations. The long-term stability of the organic material was also questioned. A survey was conducted on potential soft materials, for which the stress-strain properties are available. Expanded polystyrene (EPS) was pointed out as a possible material for culvert installations.

Hoff (1967) carried out tests on a wide range of possible materials that could be used to promote arching. He concluded that foamed or cellular materials (like expanded polystyrene) exhibited the desirable elastic-plastic behaviour. The ideal stress-strain curve for an elastic-plastic material was shown, and the curve was very similar to the one shown by Katona et.al. (1979). Expanded polystyrene is used as compressible material in imperfect ditch installations in Norway. The typical stress-strain curve for EPS is very similar to the ideal stress-strain curve pointed out by Hoff and Katona (see fig. 2).

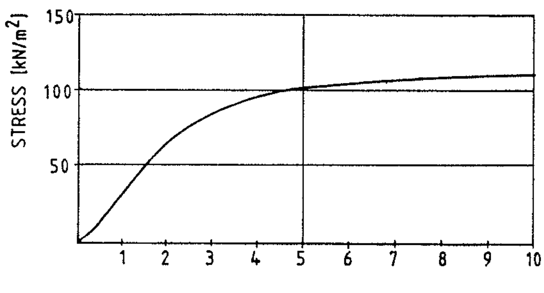

Fig. 2 Typical stress strain curve for expanded polystyrene with density 20 kg/m³.

Trade qualities of EPS are super light (20 kg/m³), and standard block dimensions are 0,5 x 1,0 x 2,0 m with volume 1 m³ and weight 20 kg. The compressive strength can be determined by an unconfined compression apparatus. The test specimens are 50 x 50 x 50 mm, and an average strength of minimum 100 kN/m² at 5% compression (2,5 mm) is required according to the Norwegian specifications.

The blocks are easy to handle, and are widely used in Norway for solving soft ground problems, Frydenlund (1987). Overall long term performance is good, as reported by Aabøe (1987). The moisture pickup is less than 1 % of a volume basis for drained conditions. Precautions must be taken against solvents e.g. petrol, that will dissolve EPS.

The long-term serviceability of imperfect ditch installations is an important question. Only full-scale tests and field observations will provide the information required to evaluate the time effects of an imperfect ditch installation.

Description of field installation with instrumentation

The structure is situated below a 14 m high rock-fill embankment, and serves as a drainage pipe for new Euroroad 18 in Telemark county, Eidanger. The concrete pipe has an inner diameter of 1,6 m, concrete thickness 0,176 m and outer diameter 1,952 m. The pipe was reinforced with two layers of reinforcing steel. The steel bars were 12 mm diameter and was laid with center to center distance 51 mm, this equals 0,222 cm²/cm area of reinforcing for both inner and outer layer.

The yield strength of the steel is 500 MPa. The compressive strength of the concrete is 50 MPa. The concrete pipe is made of sections 1,5 m long, and the total length is 70 m.

Standard EPS-blocks 0,5 x 1,0 x 2,0 m were used. Six test specimens of EPS were tested in the laboratory, and showed an average compression strength of 98,3 kPa. The measured density was 20,3 kg/m³. The EPS-blocks were laid out when the backfill had reached 0,5 m above the top of the pipe. Laying of the blocks is very fast and simple, and there is no need for excavating a ditch above the pipe as shown in Fig. 1.

The in-situ soil was excavated to about 0,5 m below the invert elevation, down to bedrock, and replaced by 0-16 mm sandy gravel. The same material (0-16 mm sandy gravel) was used for backfill, with an optimum dry density of 21,5 kN/m³ and optimum moisture content 9,3 %. A minimum of 97 % Standard Proctor was required. Nuclear field density tests showed an average of 100 % Standard Proctor (15 tests). The backfill was compacted in 20 cm thick layers. The pipe with the extent of the backfill zone and the instrumentation are shown in fig. 3.

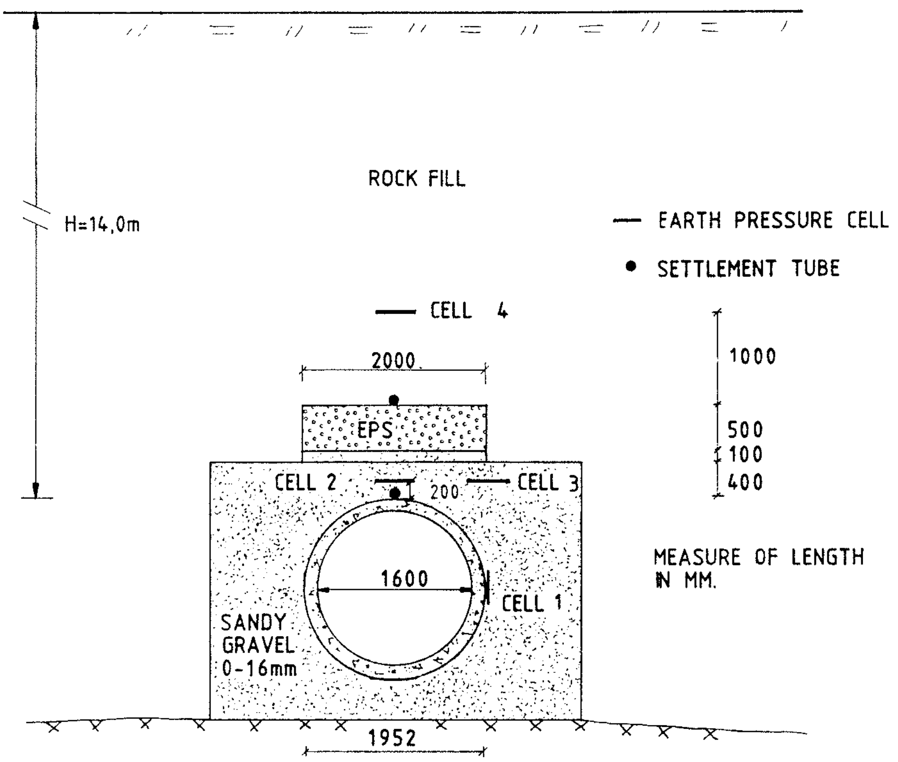

Fig. 3 Geometry of installation with instrumentation

The backfill extended 1 m out from springline and 0,5 m over the top of the pipe. The remaining fill in the embankment was rock-fill that was placed in 3 m thick layers, and compacted with 6-8 passes of a 6 ton vibratory roller. Based on field experience this equals 95 - 97 % Standard Proctor. The construction began in August 1988 and was completed in June 1989.

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 of the Glötzl-type. In addition, settlement tubes were installed on top of the pipe and on top of the EPS to measure vertical deformation. The Glötzl-cells were 20 x 30 cm, and 4 cells were used. The location of the cells is shown in fig. 3.

One cell was placed in springline to measure the horizontal earth pressure on the pipe (CELL 1). Two cells were placed 20 cm over the top of the pipe to measure the vertical earth pressure. One cell in centerline (CELL 2), and one cell over springline (CELL 3). The last cell (CELL 4) was placed in centerline 2 m over the top of the pipe to measure the vertical earth pressure in the embankment. The temperature in the soil at the cell locations was measured with thermistors, and temperature corrections were made.

Experimental results

The measured vertical earth pressure in cells No. 2 and 3 are shown in fig. 4.

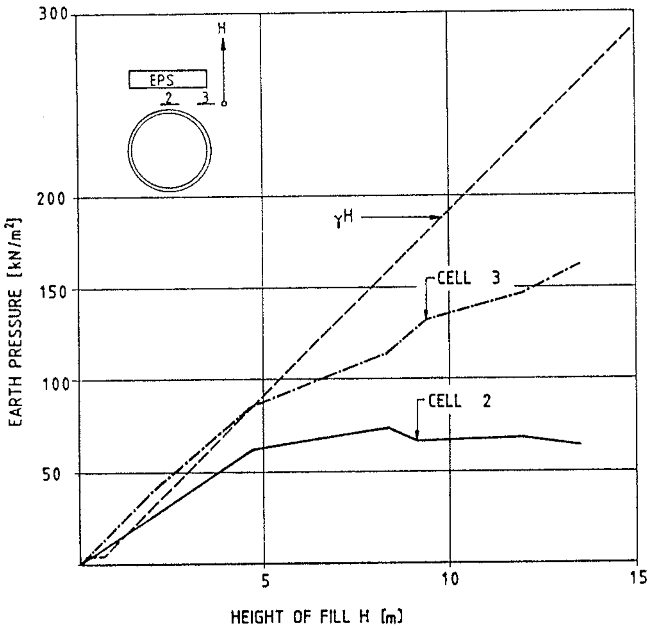

Fig. 4 Measured vertical earth pressure above the pipe

The earth pressure on cells 2 and 3 is nearly linear up to a fill height of 4,7 m. Further increase in fill height from 4,7 m to 13,7 m does not increase the earth pressure on cell 2 and at full fill height 13,7 m, it is 67 kN/m^2, which is 25 % of the overburden. The earth pressure on cell 3 is 161 kN/m^2 at full height, which is 61 % of the overburden. The average earth pressure on the top of the pipe is then 43 % of the overburden.

The measured vertical earth pressure on cell 4 in the fill 2 m above the top of the pipe was slightly larger than the overburden up to a fill height of 7,5 m above cell level. At full fill height the measured earth pressure was 205 kN/m², which is 86 % of the overburden.

The measured horizontal earth pressure on the pipe spring-line is shown in fig. 5.

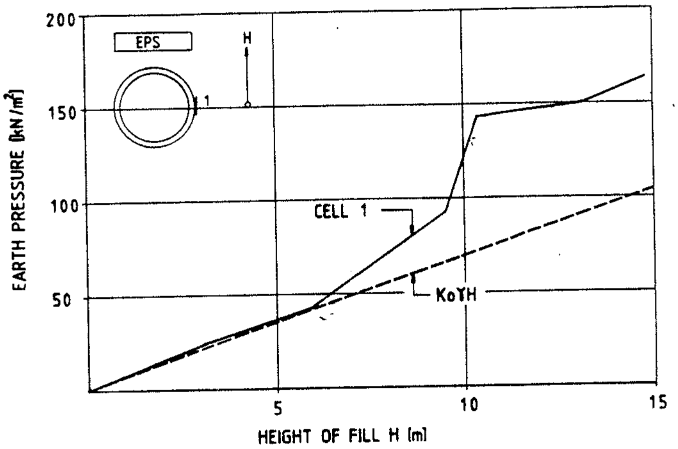

Fig. 5 Measured horizontal earth pressure on the pipe

The calculated horizontal pressure at rest ($K_0 \gamma H$) is also shown in the figure, and K_0 = 0,35 is assumed.

Up to a fill height of 6,0 m above cell level, the measured earth pressure is 43 kN/m² and is slightly larger than the horizontal at rest pressure. Further filling to 14,8 m above cell level, increases the measured earth pressure to 164 kPa, which is 58 % greater than the rest pressure. This horizontal earth pressure is 55 % of the overburden, and corresponds to a horizontal earth pressure coefficient K= 0,55.

The earth presure is measured over a long period of time and there is no increase in earth pressure 14 months after construction.

The measured vertical deformation of the EPS is shown in fig. 6.

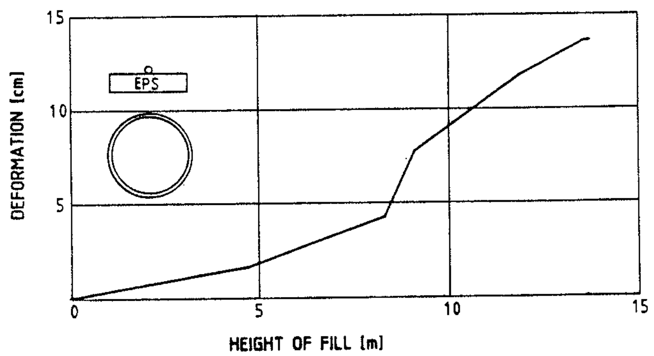

Fig. 6 Deformation of the EPS

The deformation is 1,7 cm at a fill height 4 m above the EPS. The deformation increases to 4,2 cm at a fill height of 7,8 m, and from this fill height up to 8,3 there is a marked increase in deformation to 7,7 cm. Further filling to 12,7 m increases the deformation to 13,6 cm, which is 27 % of the initial thickness of the EPS.

Long-term observation shows that there is no increase in vertical deformation of the EPS 14 months after the end of construction.

Finite Element Analyses

The finite element program CANDE, Katona et.al. (1976), was used to model the structure. The extended level 2 in CANDE was used. The compressible layer of EPS was modelled with the overburden dependent model, using a Poisson's ratio = 0,12 (K_0 =0,14). For the elastic zone Young's modulus was E=2800 kN/m² and a tangent modulus of E=250 kN/m² was used in the plastic zone. The material characteristics are based on investigations by Hjorteset (1987).

The soil was modelled with the hyperbolic Duncan model, Duncan et.al. (1980), and the following soil parameters were used (95% Standard Proctor compaction):

Parameter	K	n	R_f	K_b	m	ϕ	$\Delta\phi$
Value	300	0,4	0,7	75	0,2	36°	5°

The results clearly showed the mobilization of shear stress and redistribution of soil stress due to the presence of the compressible layer.

Parameter studies on the compressible layer using the finite element program gave the following results:

- Increasing the width of the EPS to 1,5 times the width of the pipe has a positive effect on the structural response of the pipe. This is in accordance with the findings of Sladen and Oswell (1988) and Leonhardt (1978).

- Varying the thickness of the EPS from 200 to 800 mm has a very small effect on the structural response of the pipe.

- Stiffer EPS with compressive strength of 250 kN/m² gives larger vertical earth pressure than EPS with compressive strength of 100 kN/m² .

Design method

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

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

where N_A = arching factor

γ = unit weight of soil [kN/m³]

H = height of cover [m]

and

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

where

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

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 $\tan\rho$ = mobilized soil friction = $f\tan\phi$

f = degree of mobilization

$\tan\phi$ = soil friction

K_A = active earth pressure coefficient

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

r = the roughness ratio = $\dfrac{\tan\delta}{\tan\rho} \leq 1$

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

Fig. 7 shows the arching factor N_A for H/B=4.

The measured vertical earth pressure is compared with the proposed method to determine the earth pressure on imperfect ditch culverts, fig. 8. A roughness ratio r = 0,8, and a mobilized friction of $\tan\rho = f\tan\phi = 0{,}7\tan 40^\circ = 0{,}59$ are used for the backfill.

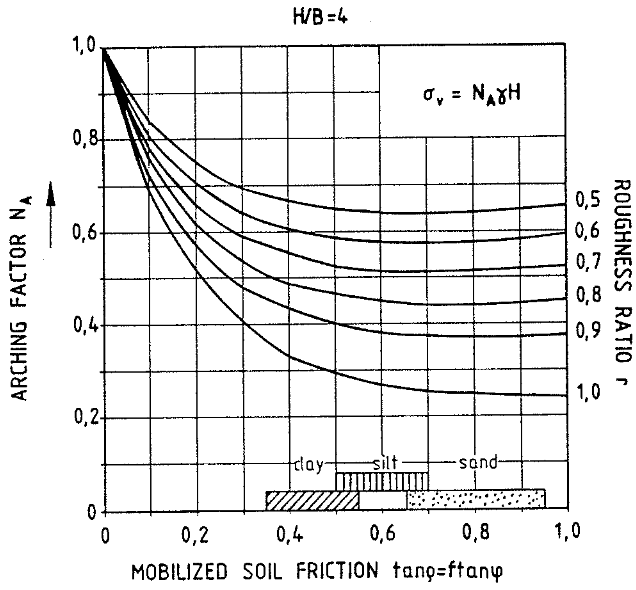

Fig. 7 Earth pressure on imperfect ditch culvert with H/B=4.

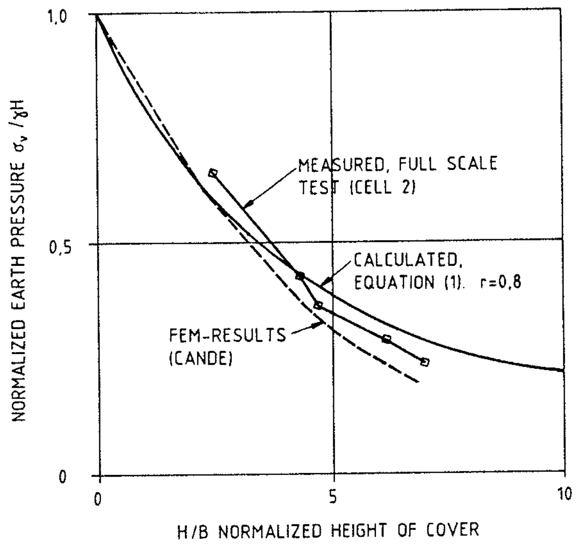

Fig. 8 Measured earth pressure compared with proposed design method and FEM-results.

Summary and conclusions

The full scale test described shows that the imperfect ditch method can be used to reduce the vertical earth pressure on rigid pipes. Expanded polystyrene blocks, used as the compressible material, are super light, easy to handle, and they simplify the construction procedure. Use of organic material in imperfect ditch culverts is not recommended due to the possibility of decomposition and the difficulty of specifying the material characteristics.

The average measured earth pressure on the pipe was reduced to 43% of the overburden. The horizontal earth pressure increased to 58 % 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. The expanded polystyrene was compressed 27% of its initial thickness during construction of the embankment above the pipe. Long term observations shows that there is no increase in earth pressure and deformation 14 months after construction. The steel reinforcement in the concrete pipes can be reduced by using this method, and using one layer of steel reinforcement also simplifies the construction of the concrete pipes and reduces the costs. Use of this method in Norway have shown cost reductions in the order of 30%.

Finite element analyses have shown that the optimum width of the compressible layer are 1,5 times the width of the pipe. A design method are proposed, and the results shows good correlation with the measured earth pressure and results from the finite element program CANDE.

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