EFFECT OF INSTALLATION CONDITIONS ON BURIED PLASTICS PIPES: RESULTS OF SPECIFIC FIELD TRIALS

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ABSTRACTS

Results of deformation measurements carried out on buried plastics pipes installed at six different tests sites are discussed in this paper. The results show that the deflection of buried pipes is usually rather small and the time dependence is limited to a few years after installation. Traffic loading does not result in extra deformation. The results can be largely explained by consolidation processes of the soil surrounding the pipe. The quality of installation proved to be the most important parameter affecting the deformation of buried plastics pipes.

INTRODUCTION

Manufacturers and users of buried plastics pipes have always shown interest in the behaviour of their pipes in field practice.
Many measurements have been performed to monitor the behaviour of buried plastics pipes as part of a sewer or gas distribution system, or at special test sites. In the latter case the effects can be studied in more detail. Results of tests at various test fields set up by Wavin and VEG-Gasinstituut are reported in this paper.
The pipes with diameters varying between 110 and 400 mm, and having stiffnesses between 1 and 8 kPa, were buried in various soil types (gravel, sand, clay and peat), at depths varying between 50-200 centimeter. The installation conditions have been varied from extremely good to extremely poor. Various soil types, pipe diameters, pipe materials, pipe stiffnesses and different installations practices have been used in these test fields.

TEST SITES

Pipes have been installed by Wavin and Veg-Gasinstituut in gravel, sand, clay and peat using different pipe stiffnesses and installation conditions.
Figure 1 shows an overview of the materials and pipe diameters used at the test sites. An overview of the installed pipes according to soil type and installation condition is given in Figure 2.

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Five installation conditions are considered, from which three are regularly encountered in field practice, and two conditions are specially created at the test sites. The definition of installation condition is based on the compaction level obtained after installation. Therefore installation conditions can not be defined apart from the type of soil. For that reason the term "fill group" was introduced in the past. For instance Sand/A is an installation in sand in which a high degree of compaction is reached. The installation conditions are further described below.

A. <u>High compaction</u> In this case the backfill is applied in such a way that <u>hardly</u> no further densification of the embedment material would be expected. In the case of sand this means that the backfill has been compacted by using hand- or machine-compacters in layers with a thickness of approximately 20 centimeters. Gravel is higly self compacting, so that in most cases an A classification would be reached without much compaction effort.
For clay it is difficult to obtain an A classification. In this case it depends very much on the water content and the size of the clay particles. Only in dry fine clay, which can be obtained by using a chain digger would such a classification be reached.

B. <u>Moderate compaction</u> Here densification after installation would be expected, because the compaction during installation has not been so good. For sand it means, that thicker layers have been used for each compaction run, or low powered compaction devices such as vibrating plates are used. For clay it means that bigger clay particles have been used, as achieved when digging took place by means of other than chain diggers, or that the clay had a moderate water content.

C. <u>Low compaction</u> This classification is obtained, when a relatively low compaction level is obtained after installation. For gravel, which is highly self compacting, this classification would only be reached, if the native soil is very soft.
For sand this situation would be obtained in the case of strongly graded sand, when the embedment and backfill material is dumped, and no or almost no compaction is used.
For clay such a classification would be obtained, when big lumps of clay are dumped into the trench. Densification of clay then takes place by pressing out the air and the water, which takes time.

The above installation descriptions (A, B, C) are generally encountered in the field. At the test sites two extra installation qualities have been achieved. The extremely bad installation was used, to find the limit of application.

X. Extremely high compaction This condition was achieved on a test field in Hardenberg, where pipes were installed in sand and the embedment was extremely well compacted, causing the pipe to counter deform (Columbus effect, standing egg).

Y. Extremely low compaction This condition is met in a test field in Almere where the backfill was dumped in the trench by using big lumps of clay, and where the trench walls collapsed during installation.

TYPE OF MEASUREMENTS

Measurements have been carried out to classify the soil type, the installation condition, the type of loading and the pipe deformation. The soil was classified by means of grain size distributions, and at some sites the impact cone, static cone and compactability tests were used to provide some extra information about the soil stiffness.
Figure 3 shows an example of a grain size distribution.
The pipe deformations were measured immediately after installation, and at several time intervals after installation.

Pipe deformations were measured by using the Wavin sledge (Hardenberg, Almere, St.Jans klooster and Rufforth), and by using the Deflec (Apeldoorn and Wons).
The Wavin sledge measures the vertical and horizontal pipe diameter continuously along the pipeline (1).
The Deflec measures the shape of the pipe at several cross sections, from which the vertical and horizontal pipe diameter and strains are obtained (2). The distance between two cross sections is usually chosen to be 50 or 100 cm.
So, in conclusion the Wavin sledge provides a lot of information about the vertical and horizontal pipe diameter, due to its continuity during measuring, while the Deflec provides more information about individual cross sections of the pipe.

RESULTS

The results of the field trials will be discussed in this section. Attention will be given to the following parameters on pipe deflection:

1. Effect of fill group (soil type and installation condition) as defined before.
2. Effect of soil type.
3. Effect of pipe stiffness.
4. Effect of traffic loading.

The effect of depth of cover, which varied between 50 cm and 2 m, pipe diameter and groundwater are not considered in this paper. The results are presented in graphs in which the vertical pipe deflection is plotted against the time after installation. The graphs which are shown are best fits of the measured average vertical deflection. The data have been fitted by applying a logaritmic function which is best in accordance with the physics in the soil-pipe interaction process, as will be shown in one of the following sections.

Sand

Figures 4 to 6 show the results for sand.
In Figure 4 the results are shown for an extremely careful installation in sand, called SAND/X.
The pipes were embedded in sand. The trench bottom was loosened, and the backfill was applied in layers of maximum 20 centimeter. Each layer was carefully compacted by extensive tamping using special manual devices. Results are shown for 1, 4 and 8 kPa pipes (PVC SDR 65, 41 and 34). Negative deflections (Colombus effect) were obtained as shown in the graph.
There is hardly no time dependent behaviour visible, due to the very good compaction during installation.

In Figure 5 the same type of presentation is shown, but now for SAND/A. The deflections are rather low, and a slight time dependence is shown, from which the major part takes place in the first 100 days after installation.

Figure 6 shows the results for SAND/B.
Here only results for 4 and 8 kPa are available.
The deformations are slightly higher than for fill group SAND/A.

Clay

The results for clay are summarized in Figures 7 to 10.
Figure 7 shows the results for pipes installed in clay according to fill group CLAY/A. This type of installation was obtained in Wons (NL) where the clay was rather dry. Some of the trenches at that test site were created by using a chain digger. The as dug material obtained was very fine providing the opportunity to install the pipes according CLAY/A.
The deformations are very low, and there is hardly no time dependent effect visible.

Figure 8 summarizes the results for fill group CLAY/B.
Higher deformations have been found for this type of installation, and the time dependent behaviour is also more pronounced. The effect of pipe stiffness is also more obvious than in the case of CLAY/A.

Figure 9 shows the results for fill group CLAY/C. In this graph it is shown that the pipe stiffness has a bigger influence on the pipe deformation, as compared to the graphs in Figures 7 and 8.

Figure 10 shows the deflection for pipes installed according to fill group CLAY/Y. This type of installation is typical for those installations where things get out of hand. Unstable soil, big lumps of fat clay and high ground water level are the keywords for such an installation.
The deflections are higher, and the effect of pipe stiffness is more pronounced.

Peat

The results for peat are summarized in Figure 11.
It is hard to classify the installation type of peat, because other phenomena are becoming important, and the behaviour is very much different from that in sand and clay. In one of the following sections more elaborated discussion about this behaviour will be given.
The deflections are rather low, and the effect of pipe stiffness is negligable.

The results shown sofar are the average vertical deflection.
The maximum deflections have also been determined, and related to the average value by $(\delta/D)_m = fmax*(\delta/D)_a$.
Table 1 summarizes fmax for each fill group.

Table 1 - Factor fmax which relates maximum to average deflection.

Fill group	Pipe stiffness [kPa]	fmax	Fill group	Pipe stiffness [kPa]	fmax
SAND/X	1 4 8	1.5 1.8 1.6	CLAY/B	1 4	2 1.8
SAND/A	1 4 8	1.5 2.1 1.5	CLAY/C	1 4 8	1.4 1.3 1.6
SAND/B	1 8	2.1 1.6	CLAY/Y	1 8	1.5 1.5
CLAY/A	4 8	1.8 1.8	PEAT	1 2 8	2.1 1.1 1.1

Multiplying the average deflection with a factor of 2 results generally in a conservative (relatively high) value for the maximum deflection, as shown in table 1.

Effect of traffic load

At a few test sites pipes have been installed after which heavy vehicles loaded the buried pipes.
The results of these tests are summarized in Figures 12 and 13.
The vertical pipe deflection versus the number of passes of the vehicle is plotted in these graphs.
Figure 12 shows the effect of trafficking for pipes installed in clay but embedded by gravel. The effect of pipe stiffness is negligable.
The major part of the increase of deformation takes place after a limited number of passes, as can be seen from the graph.

Figure 13 shows the results for pipes embedded in clay, according to fill group CLAY/B.

The deformations are not higher than for the non-traffic case, as can be seen by comparing the results with those shown in Figure 8. Traffic speeds up the consolidation process of the soil, and therefore the final state is reached in a shorter time.

From Figures 12 and 13 it is obvious, that in clay the time (number of passes) needed to reach this state is longer than in case of gravel.

This can be explained by the fact that in clay some time is needed to press out the porewater and air from the cavities, one of the mechanisms which controls consolidation. In gravel the flow of pore water is not restricted.

SOIL-PIPE INTERACTION

Some of the results shown in the foregoing section will be discussed in more detail in this section. It will be shown why plastics pipes can be used in soft soils like peat, and why the pipe-soil system shows time dependent behaviour.

A few shortcomings of the current calculation methods will be shown as well.

Current models

Most methods used for simulating soil-pipe interaction consider the pipe loaded by an arbitrary radial load distribution, resulting in a formula of the kind shown below:

$$(\delta / D) = \frac{\gamma * H}{a * S_r + b * E_s} \qquad \text{........(1)}$$

The main parameters in these models are the weight of the soil (H), the soil stiffness (Es), and the pipe stiffness (Sr).

The deflection as well as the stresses and strains in these pipes are calculated by using these models.

None of these methods consider the stresses and strains in the soil surrounding the pipe. One of the most important implications of this way of modelling is that pipes installed in soft soils will show excessive deformations and high stresses and strains because the soil stiffness in these models decreases to very low values. Furthermore, the models suggest that the pipes are loaded by a constant load.

The application of plastics pipes in soft soil types, and the way in which the time-dependent behaviour of the pipe soil system should be covered by calculation methods have always been items for elaborate discussions in the pipe line industry.

The current methods do not provide good tools to deal with these two items because they do not consider the stresses and strains in the soil, but only focus on the pipe.

Application of plastics pipes in soft soils

The application of plastics pipes in soft soils is not restrictive, as the results from the test sites in St. Jans Klooster, as well as the general experience in the Netherlands indicate.
High deformations caused by the soil-pipe interaction process are not found, although the calculation methods suggest the opposite. The reason for the good performance of plastics pipes in soft soils is, that these soils have rather low shear resistance. Shear resistance is needed to maintain the kind of stress distribution around the pipe that forces the pipe to deflect. The effect of shear resistance is not considered in the current calculation methods, and therefore they are not suitable for deflection calculations for pipes buried in soft soils like peat. A method in which the effect of low internal shear resistance can be taken into account is Hoeg's method (3) (Figure 14).
The following formule can be deduced from his work:

$$(\delta/D) = \frac{\dfrac{1-V_s}{3(3-4V_s)}\,\gamma \cdot H \cdot (1-k)}{\dfrac{8 \cdot E_p \cdot I_p}{(1-V_p^2)D^3} + \dfrac{(3-2V_s)(1-2V_s)}{12(3-4V_s)(1-V_s)}\,E_s} \qquad \ldots\ldots(2)$$

in which:

(δ/D)= vertical pipe deflection ....[%]
Es= soil modulus ....[MPa]
Ep= Young's modulus of the pipe ....[MPa]
Vs= Poisson ratio of the soil ....[-]
k = ratio between vertical/horizontal stress ...[MPa]

The K-value in the above formula depends on the angle of internal friction "phi" of the soil. According to Jaky (4) the K-value at rest can be described by 1-Sin(phi). The K-value at rest is the value that is found in the undisturbed soil. Hoeg proved that at a distance of 1.5 times the pipe diameter, this condition is fulfilled. For soft soils for instance peat, the value for phi approaches zero and hence K becomes zero.
From formula 2 it can be seen that the deflection decreases. Low, almost zero values for phi are obtained in water, peat and soft undrained clay.
In this way the low deflections of pipes buried in peat can be explained, and the designer should notice that the current calculation methods are not suitable for pipe deflection calculations of flexible pipes in soft clay and peat.
Using these methods in soft soils will lead the designer towards chosing more rigid pipes (thicker walls, stiffer materials) which is a wrong decision, because the application of plastics pipes or any other pipe in soft soil requires axial flexibility. The resaon for this is the occurrence of settlement differences along the pipeline which can be expected in soft soils. Flexibility can be achieved by means of special joints, or extra short pipe lengths. Plastics pipes in the stiffness range of 2 till 8 kPa have enough axial flexibility of their own, so in most cases there are no special components required to create axial flexibility in plastics pipes.

Time-dependent behaviour of the soil-pipe system

A second important item for discussion is the behaviour of the pipe-soil system in the course of time.
The results of test fields show that the time dependence is a function of the installation quality and the type of soil. Soil types which are well compacted during installation, or which are even highly self compacting, for instance gravel, show low installation deflection and only a slight increase of pipe deflection in the course of time.
In wet lumped clay a more significant time dependent effect is found, because it is much more difficult to reach a high degree of compaction during installation. Increasing the compaction in clay means that air and water have to be pressed out of the clay, which takes some time.
The time dependence of the pipe deflection is in most calculation methods accounted for by means of putting a long term pipe stiffness in the calculation formula. It is, however, the soil that controls the time dependence.
Soil consolidates, which is a process of continuing compaction. This is sometimes referred to as a creep or consolidation process. Chua and Lytton (5) utilized this phenomenen in a method that takes Hoeg's equation as a basis, and in which the time dependency is taken into account by both the viscoelastic soil as well as the viscoelastic pipe behaviour.
Their work is reflected in the computer programme TAMPIPE (6). In the following section some of the results of a few run's with this programme are presented. For an elaborate discussion about the basis of this method, it is referred to literature (5, 7).

Results of TAMPIPE runs

Calculations have been carried out for two different configurations:

1. Native soil : clay
   embedment : gravel
   backfill : gravel

2. Native soil : clay
   embedment : clay
   backfill : clay

The pipe used in the calculations has a diameter of 315 mm SDR 41 PVC. The depth of cover is 1.8 m.

The deflection in the course of time is shown in Figure 15. Here it can be seen that the pipe embedded in gravel has a lower installation deflection and shows a lower increase in the course of time, as compared to the pipe embedded in clay.

The stress in the pipe wall in the course of time is shown in Figure 16.
The relaxation of the stress is more pronounced for the pipe embedded in clay than for a pipe embedded in gravel as was expected.

Clay creeps more, and therefore the deformation will increase more significantly. On the contrary a pipe buried in clay shows less stress relaxation.

So, in conclusion, the less the soil consolidates after installation, the less increase of pipe deflection, and the more the stresses in the pipe relax.
Little consolidation can be achieved by using self compacting embedment and backfill material like gravel or well graded sand, or by using other materials but then put more effort in compaction during installation of the embedment and backfill material.

CONCLUSIONS

Results from test fields have shown, that the amount of deflection of buried plastics pipes depends mainly on the fill group (combination of soil type and way of installation) and the pipe stiffness.
Pipes with stiffnesses of 1, 4 and 8 kPa installed in gravel, sand, clay and peat showed acceptable deflections in the order of 4 %. The deflection was only slightly time-dependent.
Only the installation of 1 kPa (PVC SDR65) pipes in clay, utilizing a very poor way of installation showed relatively high deflections. Buckling was however never encountered.

Traffic loading did not result in extra deformation of buried plastics pipes.
It accelerates the consolidation process of the soil. So, there is no need to use stiffer pipes, when traffic loading is expected.

Current calculation methods are not suitable to be used in calculating pipe deflections for pipes installed in soft soils, like peat, because they do not take the internal shear resistance of the soil into account.

The method proposed by Chua and Lytton to take the time dependent behaviour of the pipe-soil system into account seems most promising. It would be useful to test this method more extensively using real field experience.
Little increase in deformation in the course of time and hence stress relaxation can be achieved by using self compacting embedment and backfill materials, or putting more effort in the compaction of the soil surrounding the pipe.

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7. Petroff L J, "Stress relaxation characteristics of the HDPE pipe soil system", Proceedings/PL Div./ASCE Las Vegas, NV/ March 25-27 1990, pp. 280-294.

Figure 1 Overview of soil types and fill quality.

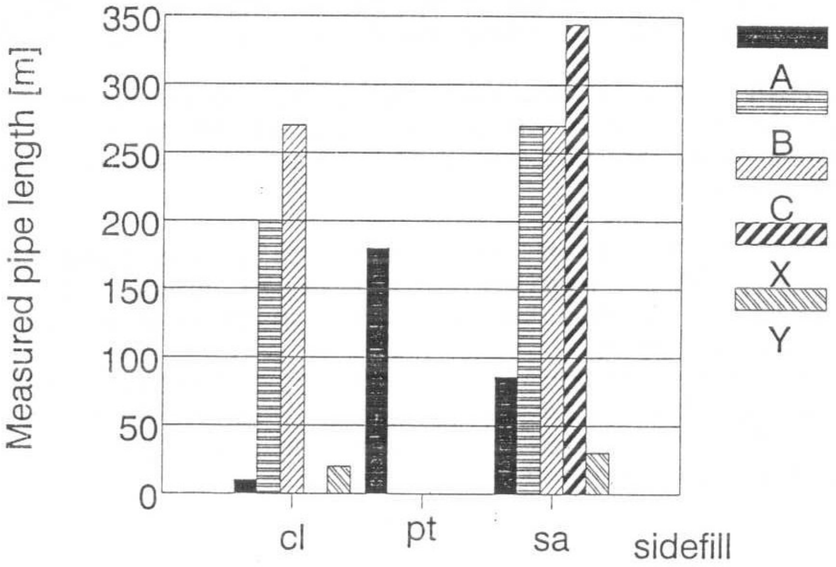

Figure 2 Overview of materials and pipe diameters.

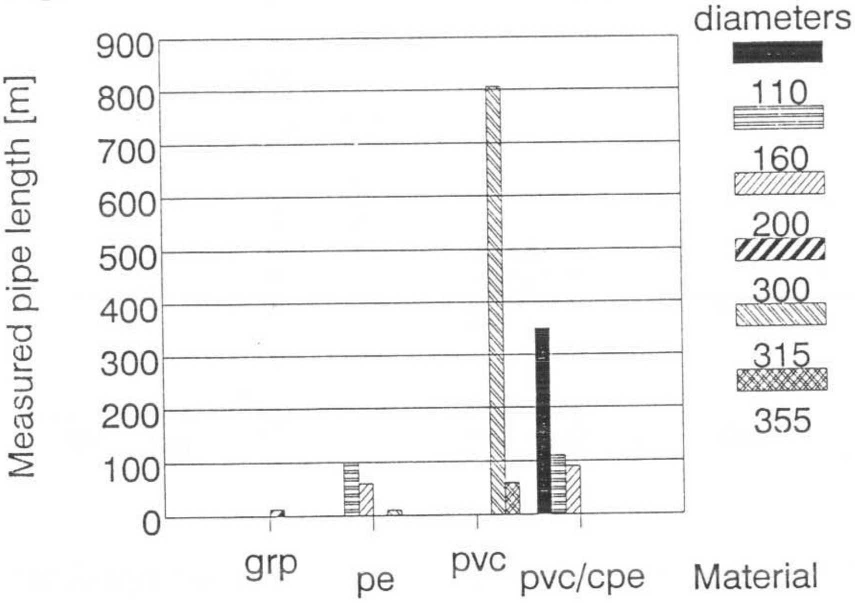

Figure 3 Grain size distribution

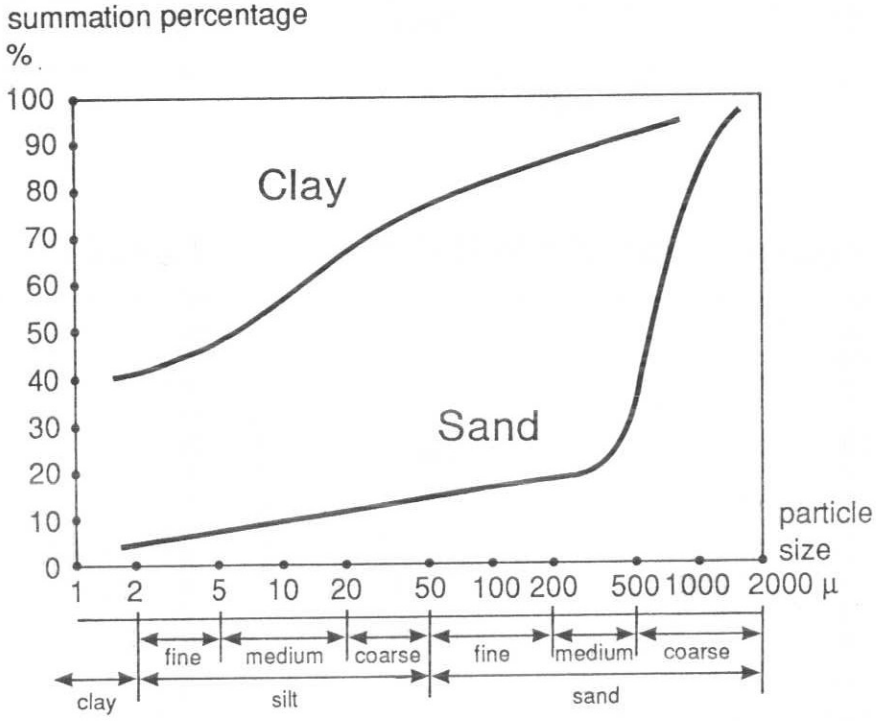

Figure 4 Pipe deflection for SAND/X

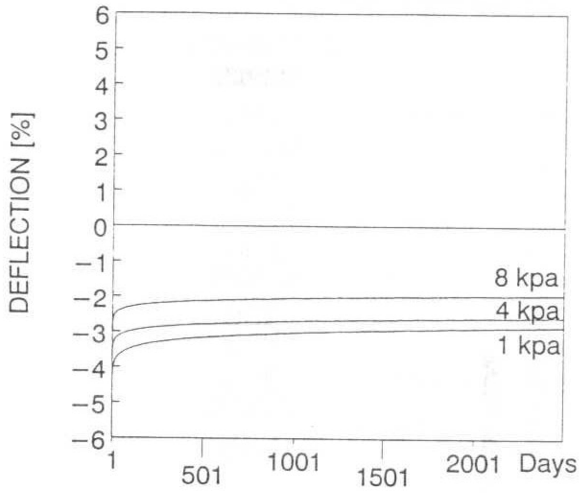

Figure 5 Pipe deflection for SAND/A

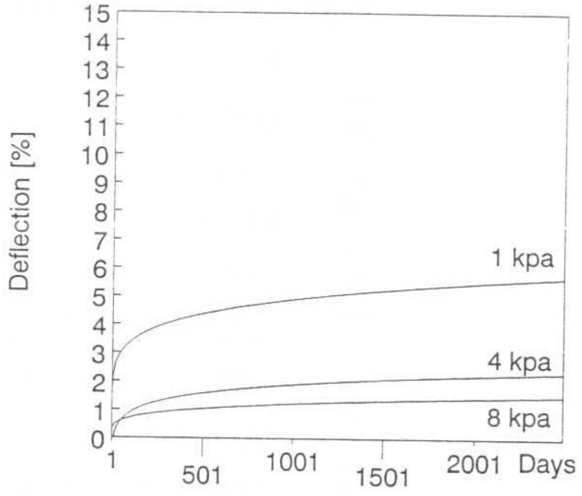

Figure 6 Pipe deflection for SAND/B

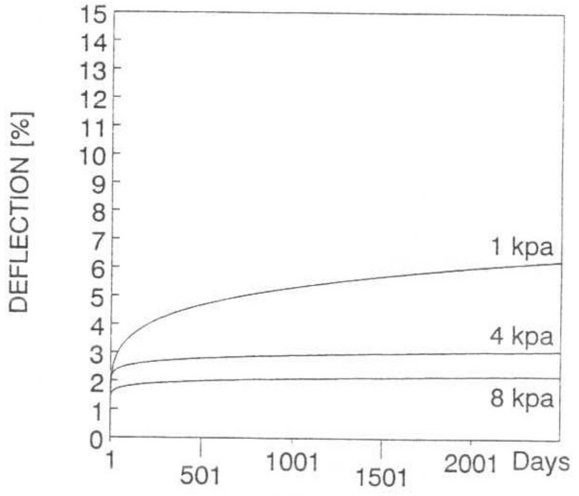

Figure 7 Pipe deflection for CLAY/A

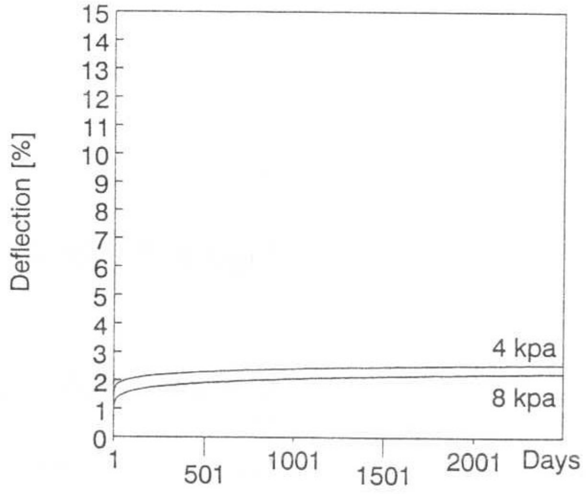

Figure 8 Pipe deflection for CLAY/B

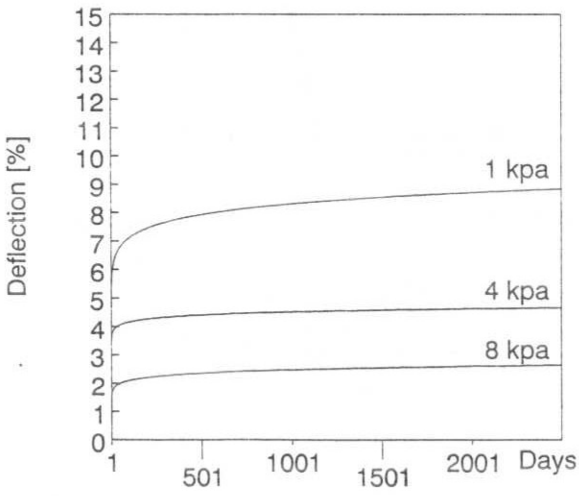

Figure 9 Pipe deflection for CLAY/C

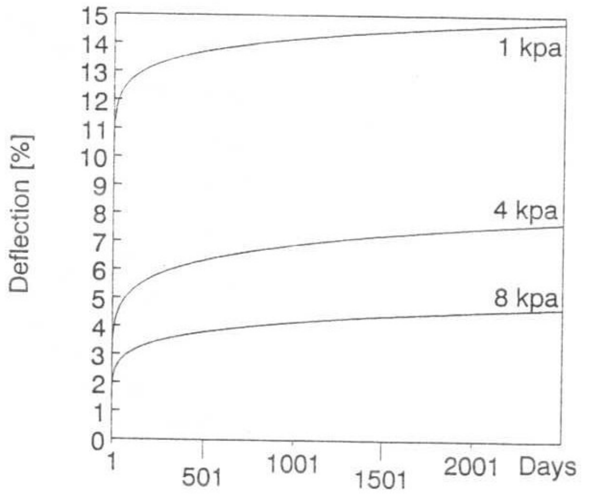

Figure 10 Pipe deflection for CLAY/Y

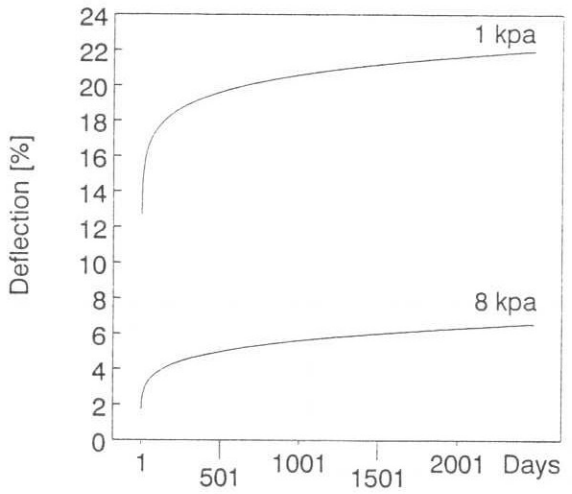

Figure 11 Pipe deflection for PEAT

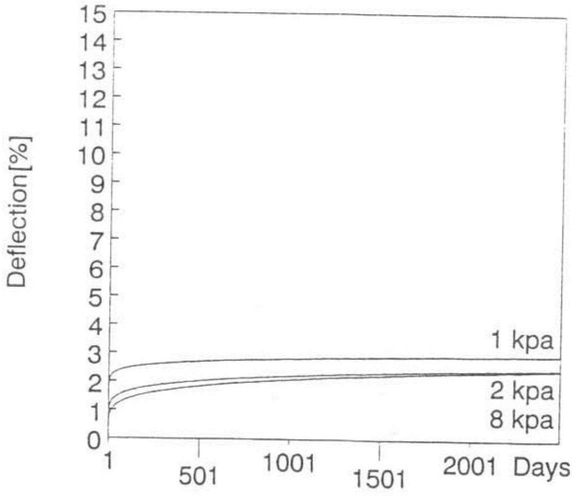

Figure 12 Effect of traffic
pipes embedded in GRAVEL

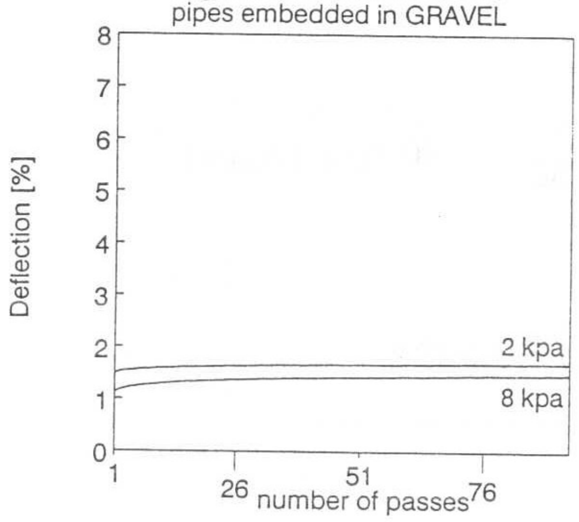

Figure 13 Effect of traffic
pipes embedded in CLAY/B

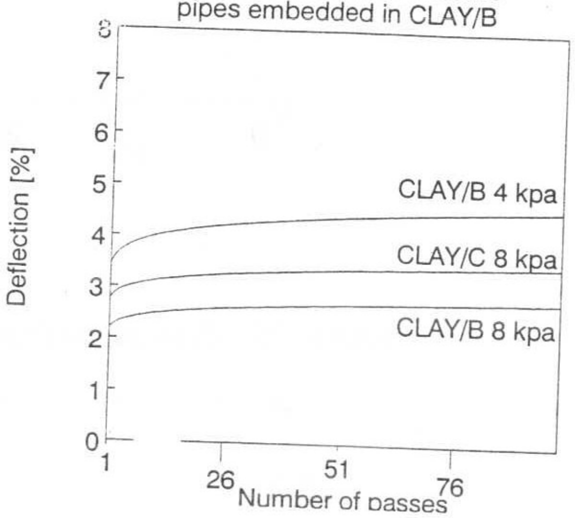

Figure 14 Hoeg's model

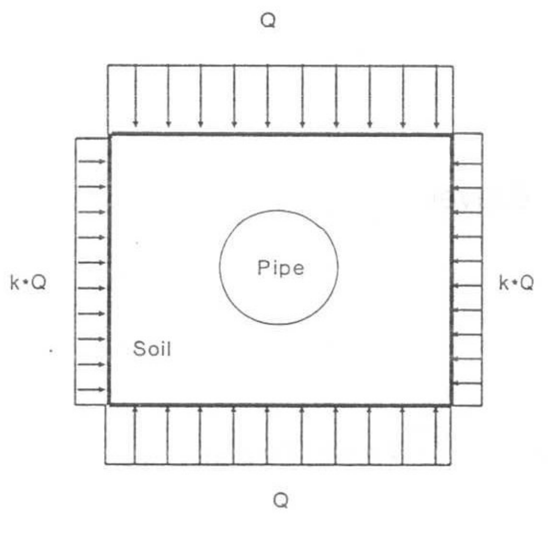

Figure 15 Deflection according to TAMPIPE

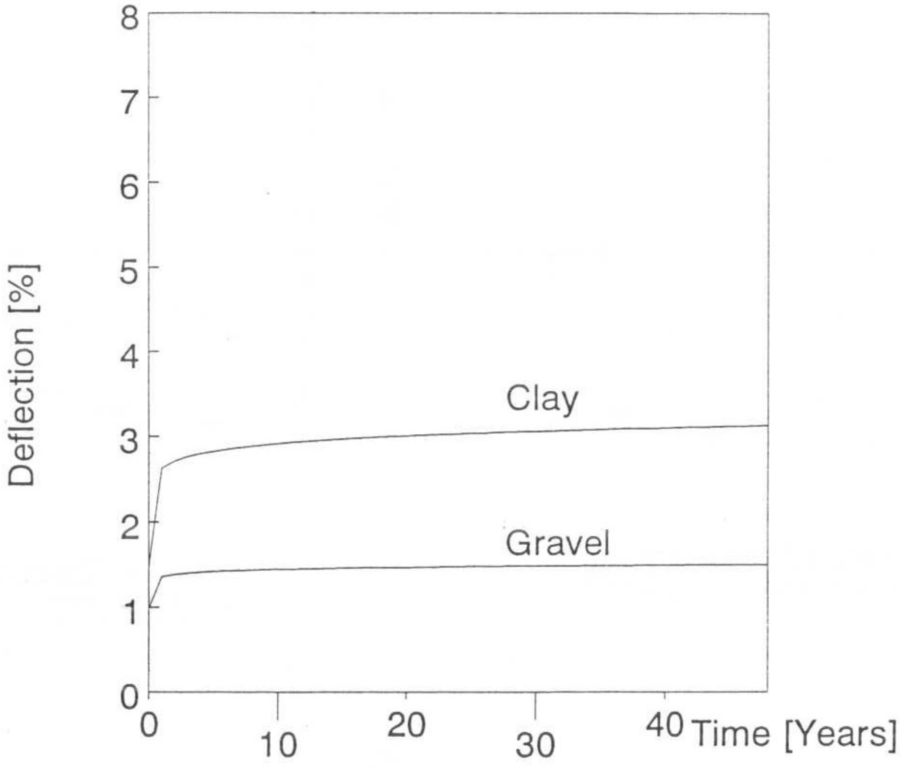

Figure 16 Stress according to TAMPIPE