

# BURIED PIPES DESIGN

## Summary

In this report, information is presented on the performance of pipes when buried under different conditions. The need for such a study became apparent with the demand by European legislation on buried pipelines design. Next to this, there was a gap in understanding how flexible pipes, and more specifically thermoplastic pipes, perform in real life.

The following five objectives have been defined:

1. Several data sets are to become available for validating current and future design methods.
2. One clear design and installation advice to customers.
3. Avoid overkill in installation requirements.
4. Design in balance with feasible installation methods.
5. Increase the confidence in thermoplastics pipes for buried application.

The result on the first objective is explained in detail in this report, by the presentation of 16 well-documented data sets, and several subsets.

The result on the second objective is contained in the presentation of design graphs, in which the type of construction is the main parameter. The exercise with different, sometimes extensive, design methods has shown that such designs are only appropriate when at the same time, the soil properties are well determined, and the execution of the installation work is done according to the recommendations. The paradox became clear, that under such circumstances, installations are carried

out well and effectively monitored. The balance between design and installation methods, as well as the relevance of the type of construction have become clearer.

The study has shown the excellent performance of thermoplastic pipes under buried conditions, for which success is especially the result of strainability properties of the material. Even when poor installation conditions have been used, no failure or stability problems have occurred during the 4 years of monitoring of the buried pipes. The results have shown to line up with earlier published long-term experience of buried plastics pipes.

## **1. Introduction**

In this report, information is given on the performance of buried pipes, when buried under different conditions. The need for such a study became apparent when at a European level, legislation on how to design buried pipelines became demanding. Although several European experts are working for more than ten years to establish such a method, no method has become available yet. One of their biggest problems is the absence of well-documented experimental data. At the end of the day, amongst many others, the plastic pipes industry will need to evaluate current and future methods, on their ability to predict pipe performance in accordance with actual behaviour. Also for the industry it was felt to be of prime importance that several data sets would become available for that purpose. Another important reason for the study was the fact that the plastic pipes industry has not yet thoroughly discussed the design and installation aspects of their pipes as an industry. It is felt that a unified design and installation advice is another very important objective of this project. Currently, a lot of methods are available on national levels, some of which are very detailed whereas others have refrained from such a high level of complexity. It shall be emphasised that the objective of this study is for the industry to obtain a better general understanding of Pipe-Soil Interaction, and more specifically for thermoplastic pipes.

It shall be recognised that establishing buried pipe systems is not a highly

academic exercise, but rather a technical one. Engineers need tools to predict the performance of the pipeline in order to be able to judge if the circumstances, including the pipe properties, soil properties and workmanship, will result in the establishment of the pipeline within a safe application window. This means that the balance between the design method, the input values and the execution of the construction needs to be correct. All the above items will be focussed upon in this study.

It was decided that the work would be carried out on pipes with a diameter of 315 mm, as this is a rather good average pipe diameter used in many applications. All pipes were of the so-called solid wall types. Solid wall pipes allow easy instrumentation, and next to this, the pipes could be studied as pressure as well as non-pressure pipes. The results of the tests on the solid wall pipes can be easily transferred to structured wall pipes as well. It is essential that the structured wall pipes stay in shape when deflecting. In order to ensure compliance with product standards, a so-called ring flexibility test is used. Where appropriate, guidance will be given on how to utilise the information for structured wall pipes.

Sand as well as clay was chosen as embedment material, in order to be able to judge the difference between granular versus cohesive soil types.

## **2. Installation practice**

Traditionally, pipes are buried by open trench methods. Although nowadays also No-Dig methods are used, still the major part of installation work is carried out using the traditional methods. Most of the installations are performed using granular materials as sidefill, in combination with some kind of compaction in order to avoid huge settlements of the surface after installation.

However, installations are performed in cohesive materials and organic materials as well. Although in many countries it is not generally recommended, good experience has been gained from using flexible pipes made out of strainable materials.

ISO as well as CEN have produced several versions of 'Recommended practices for the design of buried pipes'. Next to this, many national standards as well as manufacturers recommendations exist. These documents all recommend a certain installation procedure.

In practice, non-predictable circumstances affect the true installation of the buried pipes. For instance, the compaction level that can be reached for sand depends on its water content. So already depending on weather conditions, one obtains a better or worse installation than anticipated. In many cases the soil profile changes over a short distance. Using the as dug material again as embedment of the pipe, does not make an extensive design of any pipe very realistic. In order to obtain more reproducible installation conditions, it is sometimes recommended to import special embedment materials, like gravels and selected stones. This, however, makes the installation costlier. Another negative, but in most cases not considered effect of imported backfill, is that the new soil has a different density than the native soil, resulting in long term effects such as settlement differences along the pipeline. Therefore, using the as dug material as much as possible and providing flexibility and strainability in the pipeline system is the best (robust) solution for obtaining a proper functioning pipeline system. Robust here refers to the fact that the long life performance of the pipe is hardly affected by misfits in design and or installation.

### **3. Features of thermoplastics**

For the application of buried flexible pipes of all materials, the following pipe characteristics are of importance:

- Pipe ring stiffness
- Corrosion resistance
- Elongation at break

The pipe ring stiffness is one of the aspects that will be considered in this study and as such further discussed.

Corrosion resistant properties are in general very good for all plastics materials and the pipe will therefore not deteriorate when placed in the soil. It is this corrosion resistance that provides a firm basis for any statement on durability.

In regard to strainability properties, one needs to distinguish between elongation at break as found in a tensile test, the strain developed under creep conditions and the strain under relaxed conditions. For pressure pipes the strain controlled by the stress is the covering factor, although the buried pipe transfers part of the load (internal pressure) to the surrounding soil. For gravity pipes it is known that after installation the pipes are not loaded by a constant load, but they become under a condition of constant strain, giving rise to a stress relaxation process. For the latter case several studies have been performed in Germany and Scandinavia. Tests carried out in Sweden (1) showed that PE and PVC pipes can be subjected to significant strain without any risk of cracking. Constantly deflected pipe samples with strain of the pipe wall exceeding 10% have been tested for more than 9 years without showing any cracks. In Germany, Hoechst has tested PE pipes, which have been expanded circumferentially by 5%. After 40 years of testing, there is still no sign of cracks in the material. It is concluded that for thermoplastic pipes like PVC and PE, no strain limits exist under stress relaxation conditions; however, it is proposed to limit the strain to reasonable values anyway. Table 3.1 summarises the values proposed in Reference 1.

**Table 3.1: Allowable strain in buried gravity pipes**

Pipe material	Allowable strain [%]
PVC	2.5
PE	5.0

For pressure pipes, another test exists to determine the design values. For these pipes, so-called Internal Hydrostatic Pressure testing is used to determine the failure curve, which on the turn is the basis for determining design values. In this test, the pipe is free to expand and demonstrates the condition of the worst-case design.

The fact that the design has to be treated differently for gravity than for pressure pipes is because of the visco-elastic behaviour of the material. For linear elastic materials, a direct relation between stress and strain is valid. For visco-elastic materials this is not the case. The performance under load is history and time dependent. When the load consists of a pre-scribed displacement, then the holding force will decline with time. The issue described here is called "stress relaxation". In order to satisfy the traditional relationship between stress and strain, one needs to apply a lower (apparent) modulus. As stated, it is an apparent modulus, since any new loading of the sample utilises the true modulus again.

The same type of process exists when the load is a constant load instead of a pre-scribed displacement. In such a case the strain will increase. Again, in order to satisfy the traditional relationship between stress and strain, one needs to use the apparent modulus. Also in this case the material will respond with the true modulus to any new load. The situation of creep, as the above description is called, occurs during Internal Hydrostatic testing of pipes. It is essential that the load is able to follow the creep of the material. As soon as this is hindered, the stress relaxation process becomes active.

It is for the above reasons that the design stress determined in the Internal Hydrostatic pressure test cannot be applied straight away to pipes that are not fully loaded to the creep condition. In any other case then free creep, the strain limits as shown in table 3.1 shall be applied.

The Minimum Required tensile Stress values valid for determining the design stress at free creep conditions are shown in table 3.2.

**Table 3.2: Minimum Required Stress values (LCL values)**

Pipe material	Long term [mPa]
PVC X	X/10
PE 63	6.3
PE 80	8.0
PE 100	10.0
PP X	X/10

\*Note : X refers to ISO 12162

## **4. Experimental work**

### **4.1 Test sites**

The project group deliberately carried out the tests in the field instead of a laboratory in order to fulfil the most important requirement of this study, that the result shall reflect real circumstances and installations. Therefore, it is required that a regular contractor is involved to carry out the tests, and that the pipeline length is sufficiently long to allow the proceeding of a normal installation. The European experts as well as the project group emphasised that the study shall at least reflect the less ideal installation circumstances. Therefore, it was decided to create installations at the border of the normally accepted installation window.

Two different sites were selected for that purpose. One located at the foot of a hilly area, which was created during the second ice period some 130.000 years ago, when ice was pushed from Finland /Sweden to the south. About 1 million years ago this area presented the coastline of the European continent. The soil consists of sand with small to moderate amounts of silt. The other site is located near the seaside to current where the soil consists of clay.

## Acknowledgments

The project was steered by experts from the industry. A small project group consisting of the project manager and two external experts in the field of design of buried pipes supervised the project.

In addition to these consultants, European design experts were contracted to provide the design using the different established methods, as well as to assist in the results evaluation.

The persons working in the different groups are listed below:

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