FOREWORD

In this report the results of a study into the design of buried thermoplastics pipes is reported. The study is a result of co-operative research, sponsored by the European Thermoplastics pipes and fitting association TEPPFA, and the Association of Plastics Manufacturers in Europe APME.

The project has been proceeded by experts from both the industries, as well as from external organisations. Six external leading experts in the field of pipeline design, not necessarily plastics pipes design, have been involved as consultants to the project.

The steering committee advises to bring the result to the public domain, because the information contained herein is valuable for all who are involved in the design of buried pipes systems, as well as to those who are considering improvements of existing methods or for the development of new methods.

The report summarises the experimental work carried out, and analyses the pipe soil interaction process as monitored in this study. Next to this a simple design graph is presented.

In order to make navigation in the report by the reader a little easier, figures, tables and enclosures are numbered using two digits separated by a dot. The first digit refers to the main heading in which the item is used. The second number is just a counter within that heading.

SUMMARY

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. Next to this, it was realised that still a lot of misunderstanding exists about how flexible pipes, and more specific thermoplastics pipes, behave in real life.

The following five objectives have been defined:

1. Several data sets 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 at the market place.

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 one is contained in the presentation of design graphs, in which the type of construction is the main parameter.The exercise with the different, sometimes extensive, design methods has shown that such designs are only appropriate when at the same time soil properties are well determined, and at the same time, the execution of the installation work is done according to the prescriptions. The Paradox became clear that under such circumstances installations are well carried out and monitored. So limit state conditions, conditions under which design really becomes important, are not likely to occur. The balance between design and installation methods has become clear by this, and also the relevance of the type of construction has become clear.

The study has shown the excellent behaviour of thermoplastics pipes under buried conditions, which success is especially caused by the huge strainability of the material. Although very poor installation condition has 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 now for over 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 Plastics pipes industry shall have to evaluate the current and future methods on their ability of predicting pipe performance in accordance with actual behaviour. So 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 plastics pipes industry has not yet thoroughly discussed the design and installation aspects of their pipes as an industry. It is felt that an unified design and installation advice is another very important objective of this project. Currently a lot of national methods are available and some of them are very detailed whereas others have refrained from such a high level of sophistication. It shall be emphasised that the objective of the industry with this study is to help in obtaining a better understanding of pipe soil interaction in general and for thermoplastics pipes more specific.

It shall be realised that establishing buried pipes systems is not a highly academic exercise. 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 to carry out the work on pipes with a diameter of 315 mm, as this is a rather good average pipe diameter used in many applications. All pipes are 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. Essential is that the structure of the structured wall pipes stay in shape when deflecting. The product standards however utilise a so-called ring flexibility test, to check upon this aspect. Where appropriate, guidance will be given about 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, so-called NO-DIG methods are used, still the major part of the 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 general they are in many countries not recommended, good experience has been gained when 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 more costly. Another negative, but in most cases not considered, effect of imported backfill is that the new soil has another density then the native soil, causing on the long term other effects, 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.

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 resistant that provides a firm basis for any statement on durability.

With regard to the 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 relaxation 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 thermoplastics pipes like PVC and PE no strain limit exists 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 turn is the basis for the determination of the design values. In this test the pipe is free to expand and gives as such a worse case design condition.

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 than 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. Essential is 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 can not 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.DESIGN METHODS

The methods used in this study are partly methods that have been nominated as established methods according to the definition of CEN TC164/165 JWG1, and are fully documented in EN1295 (2). The reader is referred to this document for a formal description of these methods. However next to these established methods also other methods have been used.
For the purpose of the workshop which was held in December 1997, all experts made a short summary explaining the basics of the methods. These descriptions are shown in Enclosure 4.1
In table 4.1 an overview of the methods used is shown.

Table 4.1 : Well-known established design methods
EN1295 Other methods
Method Used by
ATV 127Germany
WG14(GRP)
Materials Selection ManualUK
CalVisExperimental
Fascicule 70France
BossenNL
Önorm B5012Austria
VAV P70Sweden

EXPERIMENTAL WORK

5.1Test sites

The project group deliberately carried out the tests at a field instead of in a laboratory in order to fulfil the most important requirement of this study, which is that the result shall reflect real circumstances and installations. Therefore it is needed 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, because especially under these conditions limit state situation are to be expected if any.
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 area 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.

ACKNOWLEDGEMENT

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.

Next to these consultants, European design experts, where 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:

Project group

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L.E Janson SWECO (Supervisor)
J.L. Olliff Montgomery Watson (Project consultant)

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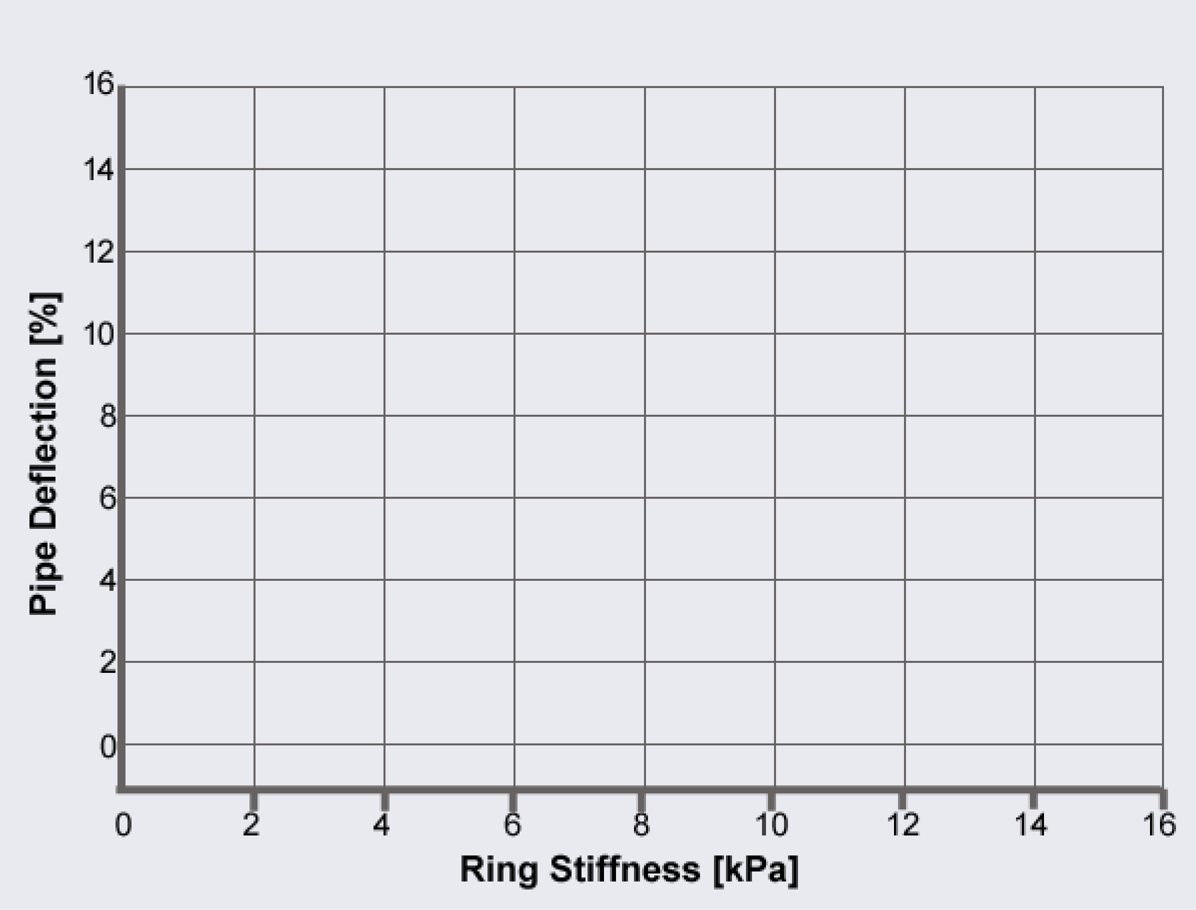
H. Schneider Comtec

SEE SEPARATE DOCUMENTS FOR INDIVIDUAL FIELD RESULTS CASES

Pipe deflection

Design graph



The design graph shown provides the possibility to show the deflections, which are obtained after installation and the deflections that occur after the soil has settled.
The graph has been obtained by analysing the results of the work carried out by TEPPFA on the performance of buried thermoplastics pipes. The project was carried out in the period 1996-2001. The results of this analysis were verified with results from other studies, including the results of measurements performed in operational sewers throughout Europe.

The graph is valid for:
1. Burial depths of more then 60 cm. The data used for evaluation were representing depths between 30 cm and 6 meter. It was shown that traffic load and depth are insignificant parameters. In other words they do not affect the pipe deformation. It only speeds up the settlement of the soil, meaning that the final deflection is reached within a rather short period after installation.

2. Soil types varying from granular to cohesive like clay.

3.Traffic load included.
The effect of traffic is included in the final deflection graph. The final deflection will always be reached. When traffic is present it will be reached in an earlier stage. When the soil has reached it's maximum density, no further increase of deflection will occur.

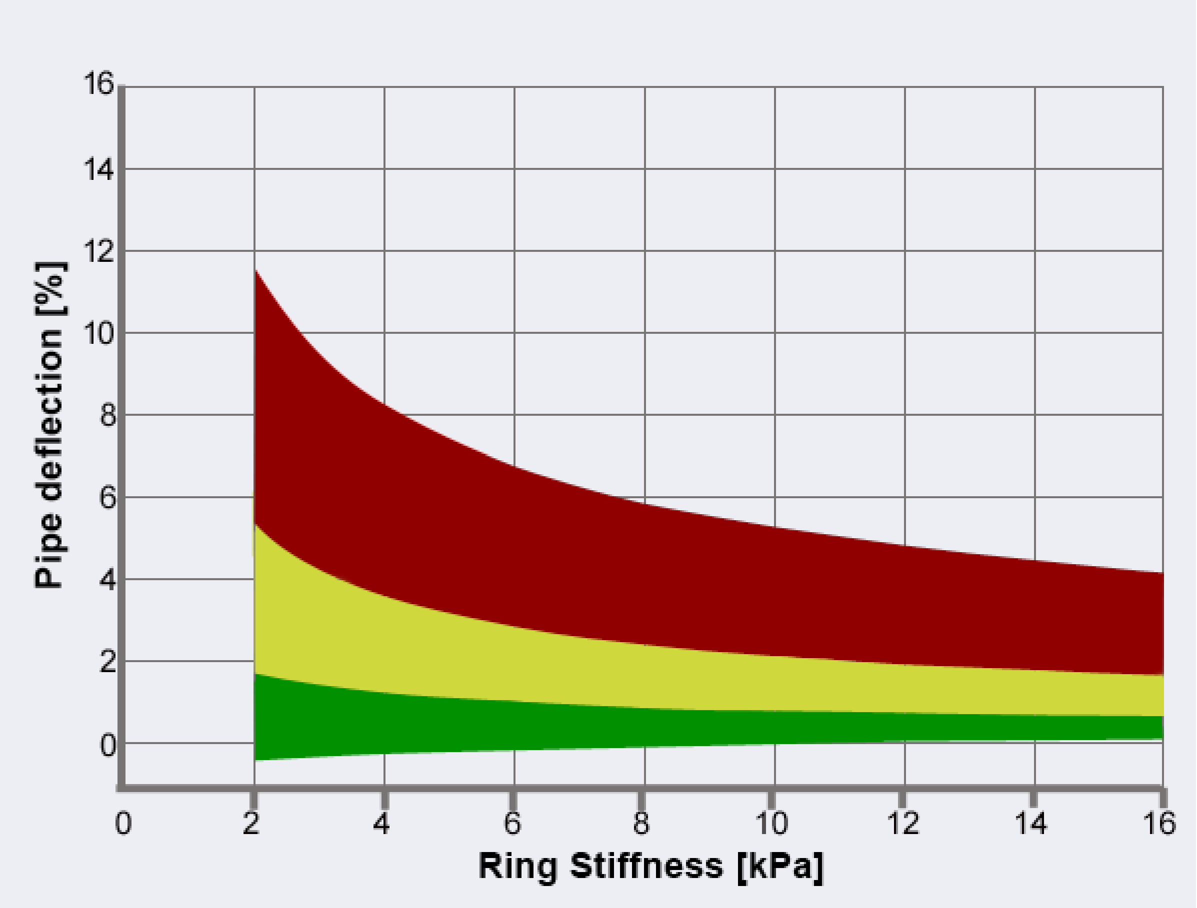
4.All thermoplastics pipes in the stiffness range of more than 2 KN/m2 at least fulfilling the ring flexibility test. Further they shall fulfil EN13476, EN12666, EN1852 and EN1401.

5. Sheet piles shall be removed before compaction, in accordance with the recommendations in EN1610. If however the sheet piles are removed after compaction, then one shall realise that the "well" or "moderate" compaction level will be reduced to the "None" compaction level.

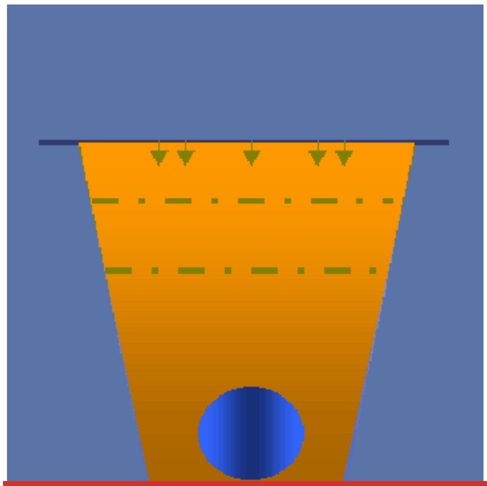
6. Pipe diameters.
Up to and including1100 mm.
Up to this diameter deflections were verified. However, when applying the volume approach technique, it is found that the graph is also valid for bigger diameters.

The graph does not cover the use of big lumps of dry clay, which are dumped on top of the pipe.

After installation:

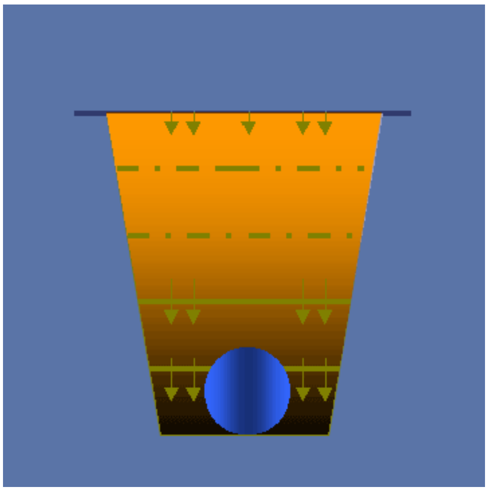


No Compaction Moderate Compacted Well Compacted



No Compaction

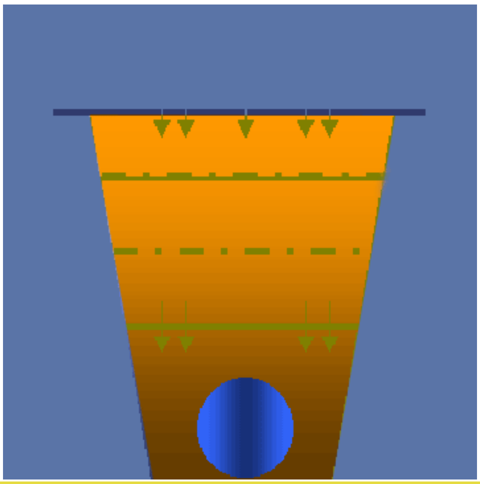
A moderate installation is achieved when a granular soil is placed around the pipe in shifts of 30-60 cm and then compacted.
Typical values of the density are between 95-98 % Standard Proctor



Well Compacted

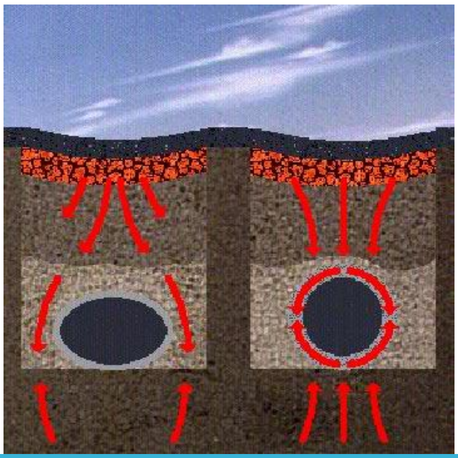
A well or good type of installation is achieved when granular soils are used. The soil shall be placed in layers of 30 cm and then compacted. The pipe shall at least be covered with 15 cm of soil before compaction is applied over the crown of the pipe.

The amount of compaction effort depends very much on the quality of the granular material. When so-called free floating materials are used, then hardly any effort is required. If the granluar material becomes more cohesive, like in the case of silty sand, more effort is required to obtain a good compaction.



Moderate Compacted

A moderate installation is achieved when a granular soil is placed around the pipe in shifts of 30-60 cm and then compacted.
Typical values of the density are between 95-98 % Standard Proctor



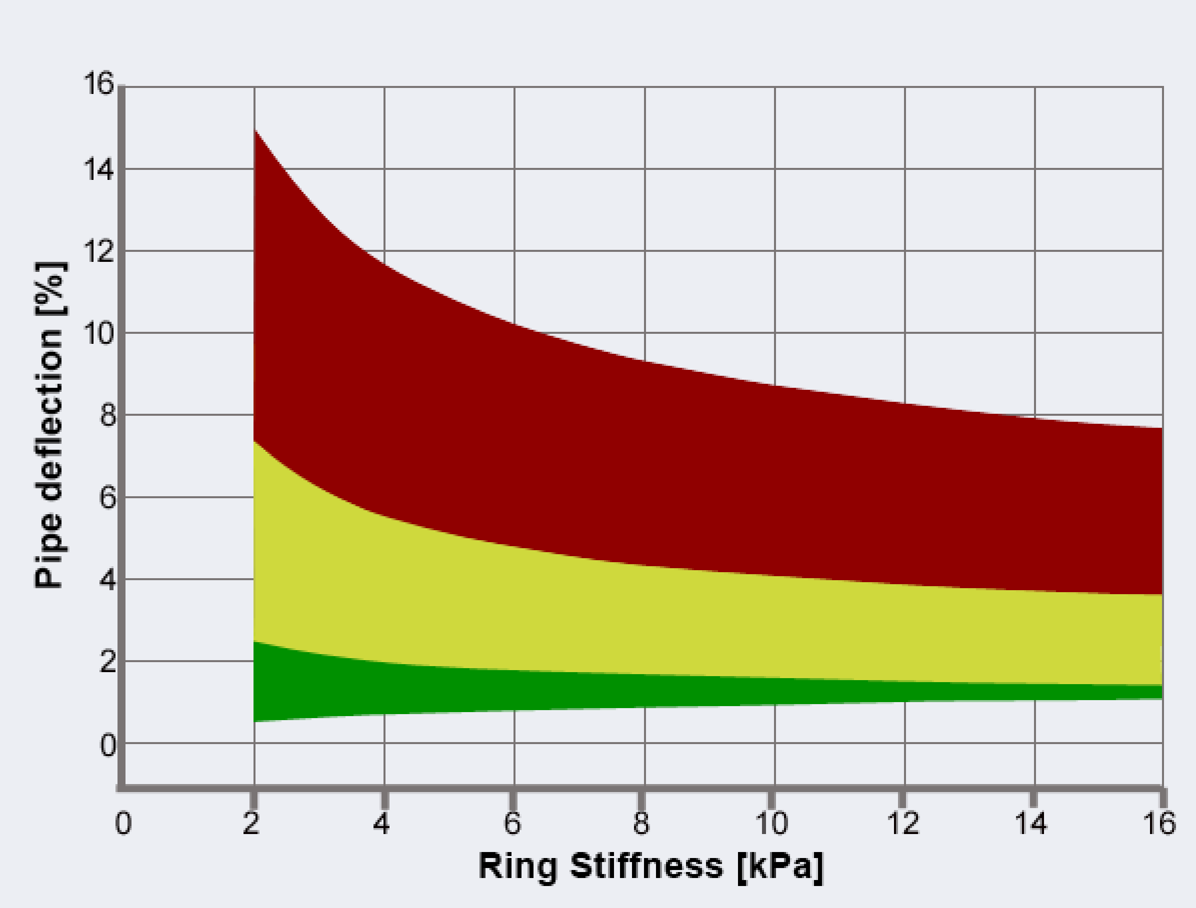
Recommendation

It is recommeded to utilise always a 'well' to 'moderate' type of installation,in order to prevent subsidence of the street caused by the settlement of the soil after installation. It shall be realised that most of the effort and hence cost of urban pipeline projects are related to instalation and street works.

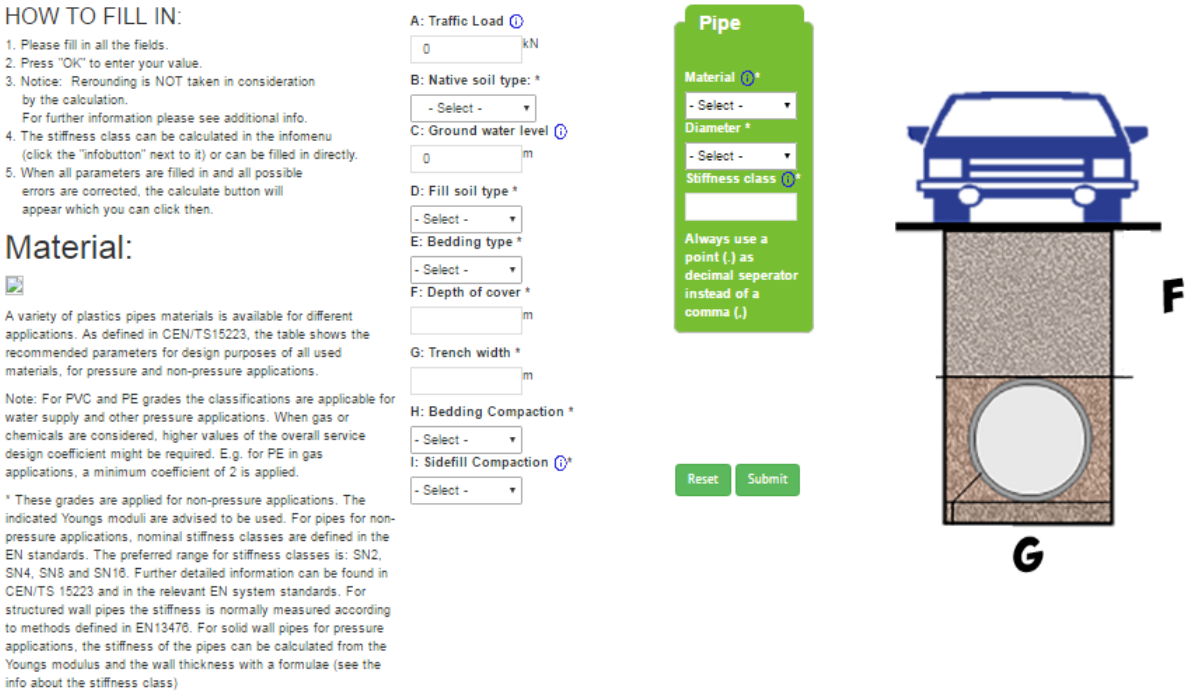
The recommended pipe stiffnesses is in the range of 4 till 16 kPa, for reason that if an installation is performed less optimal as recommended, one still faces a reasonable low deflection.

The accompanying picture shows that irrespective of pipe stiffness, subsidence of the street will occur due to the settlement of the soil
in case the soil is not compacted during installation

Long term



INTERACTIVE DESIGN TOOL



HOW TO FILL IN:

1. Please fill in all the fields.
2. Press "OK" to enter your value.
3. Notice: Rerounding is NOT taken in consideration by the calculation.
   For further information please see additional info.
4. The stiffness class can be calculated in the infomenu (click the "infobutton" next to it) or can be filled in directly.
5. When all parameters are filled in and all possible errors are corrected, the calculate button will appear which you can click then.

Material:

A variety of plastics pipes materials is available for different applications. As defined in CEN/TS15223, the table shows the recommended parameters for design purposes of all used materials, for pressure and non-pressure applications.

Note: For PVC and PE grades the classifications are applicable for water supply and other pressure applications. When gas or chemicals are considered, higher values of the overall service design coefficient might be required. E.g. for PE in gas applications, a minimum coefficient of 2 is applied.

* These grades are applied for non-pressure applications. The indicated Youngs moduli are advised to be used. For pipes for non-pressure applications, nominal stiffness classes are defined in the EN standards. The preferred range for stiffness classes is: SN2, SN4, SN8 and SN16. Further detailed information can be found in CEN/TS 15223 and in the relevant EN system standards. For structured wall pipes the stiffness is normally measured according to methods defined in EN13476. For solid wall pipes for pressure applications, the stiffness of the pipes can be calculated from the Youngs modulus and the wall thickness with a formulae (see the info about the stiffness class)

A: Traffic Load ⓘ
0 kN
B: Native soil type: *
- Select - ▾
C: Ground water level ⓘ
0 m
D: Fill soil type *
- Select - ▾
E: Bedding type *
- Select - ▾
F: Depth of cover *
m
G: Trench width *
m
H: Bedding Compaction *
- Select - ▾
I: Sidefill Compaction ⓘ*
- Select - ▾

Pipe

Material ⓘ*
- Select - ▾
Diameter *
- Select - ▾
Stiffness class ⓘ*

Always use a point (.) as decimal seperator instead of a comma (,)

Pressure pipes

When pressure pipes are buried, the pipes are still without pressure and will act as gravity pipes. After installation however,
the pipes will be pressurised and try to recover the pipe deflection that was obtained. It shall be noted that the pressure pipes used in this study had a stiffness of 6KN/m2 and hence deformation will stay low. On the other hand it is noted in real practice that pressure pipes are laid in a less careful way then gravity pipes. The process of recovery of the pipe due to internal pressure is shown in the graphs. The pipes were buried in soft (3 meter cover) and firm (1.15 meter cover) clay. When burying the pipes in granular material less re-rounding will take place.

For pressure pipes actually two basic conditions exist:
1: A pressure pipe buried in very weak soils like water. This is the most severe condition. The pipe is in a state of full creep and rerounds fully. This most severe condition is also used in the classification of the pipes. That means that the PN rating on the pipe is based on that most severe condition.

2: The other condition is when pipes are installed in firm soils. They will not be able to reround fully. The pipe is fit in a deflected shape and the state of bending stress is relaxation. Those stresses do not result in failure. At the same time the expansion of the pipe is hindered by the firm soil and as a result the stresses are not fully developed as indicated by the Barlow or Lame formulas. Therefore, thermoplastics pipes shall be designed using the most severe loading condition for the pipes, which is a full creep condition, using the Barlow formula. (same procedure as in their classification).

Combined loading : For linear elastic materials the flexural stresses are added to the tensile stresses caused by internal pressure. This approach is however not valid for thermoplastics pipes, as has been proven by material testing. For thermoplastics pipes, one can use the PN rating (Determined in worst condition, which is free creep) for design. More information can be found in the "Additional Information" section (click the button on top of the page).