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THE LONG TERM BEHAVIOUR OF BURIED uPVC SEWER PIPE

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One of the main reasons that plastics have not found more extensive use in non pressure sewer schemes has been concern about the long term deformation characteristics of the pipeline.
In order to investigate this phenomenon the flexural behaviour of uPVC sewer pipes installed in Western European countries, including the U.K., have been monitored by Wavin over the past 23 years.
The results of this programme of work is presented in the paper and illustrated by a number of specific case histories.

1. INTRODUCTION

The current use of plastics in sewer schemes in Western Europe differs from country to country. The penetration of plastics in sewers of 200 mm and above varies from over 25 % in the Netherlands and Scandinavia, via some 15 % in France to lower than 8 % in West Germany and the U.K. One of the main reasons why plastics have not been accepted for non-pressure applications in Germany and the U.K. is concern about the deformation characteristics of plastics pipes particularly the long term.
In order to counter these concerns amongst consultants and engineers from water authorities and municipalities, Wavin have conducted an extensive programme of deformation measurements on uPVC sewer pipes spanning over 20 years. This paper discusses the results of this study illustrated by some specific case histories.

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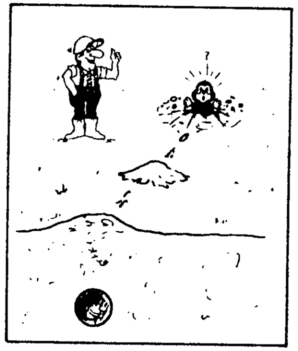
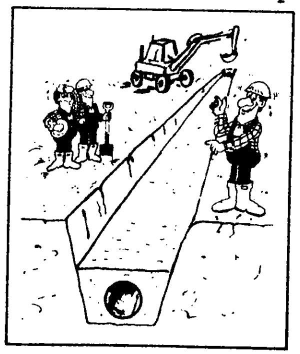
2. DEFORMATION CHARACTERISTICS OF FLEXIBLE PIPES

2.1. The pipe in the soil

Relative to the surrounding soil plastic pipes may be classified as flexible. Therefore buried plastic pipes will deform under the settlement load of the soil. This deformation process is beneficial as it equalises the loads on the pipe thereby minimizing wall stresses. The extent to which deformation takes place is fixed predominantly by the conditions where the pipe is being exposed to, in particular the quality of fill surrounding the pipe. This can be illustrated by the 'mole-hole-theory'. The ideal situation would be, a hole made by a mole. Such a hole, dug at a certain time, will stay intact if soil vibrations and water table variations do not occur.
In practice, however, a trench is dug, and after installation of the pipeline, is backfilled. This soil disturbance results in vertical settlement and consequently vertical pipe deformation. This vertical pipe deformation produces an increase in horizontal diameter, which in turn increases the horizontal soil resistance. So, the more soil settles, the more the pipe deforms, the more the soil reacts, and so on.
The interaction between the pipe and the soil and in particular the final deformation is dependent upon the quality of the surrounding soil. For example if the pipe is surrounded by a high density (well compacted) fill little deformation will take place.



Figures 1 , 2
Ideal and
common
practice



The interaction between a flexible pipe and the soil around it can be schematically represented by the progressive deformation shown in fig. 3.

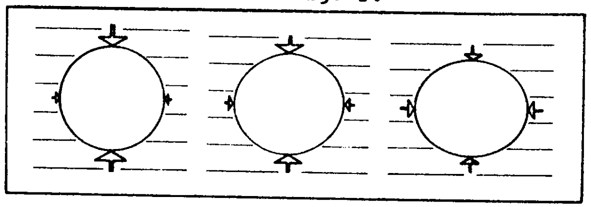


Figure 3
Pipe-soil
interaction

2.2. The soil around the pipe

There is a clear relationship between the pipe deformation and the quality of the fill (bedding, side fill and top fill)
This quality of fill depends on the type of fill material that is applied as well as on the manner in which this material is placed around the pipe. This is why the fill conditions are classified by means of so-called "fill groups". A fill group then is a combination of fill material and way of filling indicated as sand/B, gravel/A, clay/C, etc. In this system A, B and C are defined as follows:

A: regular pipe support with no line-and point loads; only minimal settlements take place
B: rather irregular pipe support with locally line loads; reasonable density given to the fill but not always uniform, implying that some irregular settlements occur
C: very irregular pipe support with frequent line- and point loadings; moderate to poor density of the fill effecting considerable settlements

The importance of the way of filling is illustrated when comparing parallel plate loading with uniform loading around the circumference of the pipe (fig. 4).

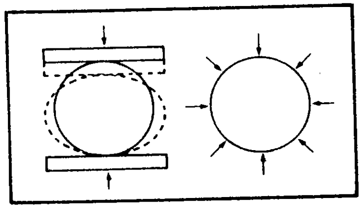


Figure 4
Extremes in loading
conditions

2.3. Calculation of pipe deformation

A large number of papers have been published predicting the relationship between pipe deformation and pipe and soil properties. (Ref. 3, 4, 6, 10). Although they differ in detail, all deflection relationships can be re-written as a general formula:

$$\text{deflection} = \frac{\text{installation factor x vertical load}}{\text{pipe stiffness + bedding stiffness}}$$

Under the headings "bedding stiffness", "installation factor" and "vertical load", a number of influencing parameters are hidden: original soil type, trench dimensions, groundwater table, fill group, depth of cover and transient loads.
Pipe stiffness is derived from the dimensions of the pipe and the characteristics of the material from which it is made (Ref. 10).

2.4. Deformation measuring techniques

Pipe deformation may be measured using amongst others two different commercially available systems:

* The Lancier Calibrator, a simple mechanical piece of equipment consisting of a cylinder with 8 feelers assembled to it, with which continuous measurements of internal bore and pipe length are recorded.
* The Pearpoint Profiling Camera, a more complex electronical set of equipment consisting of a light head, a camera mounted on a trolley, a closed circuit television monitor and a software programme with which local deformations can be recorded.

In the programme outlined in the paper all measurements were made using a specially designed research tool, known as the Wavin Sledge. This sledge contains vertical and horizontal feelers which contact the pipe wall, while it is being pulled through a pipe section. The feeler positions are being transferred to a recorder, thus producing a continuous reading.

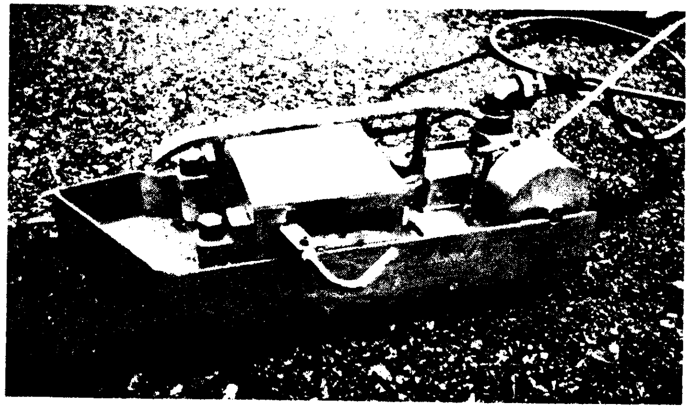


Figure 5
The sledge ready to be led in

3. PRACTICAL OBSERVATIONS

Over the past 23 years pipe deformations have been measured on uPVC sewer pipes, installed in a number of European countries (fig. 6)

The pipes which were all in operation, ranged in diameters from 160 to 630 mm and were subjected to a wide variety of fill conditions and loading types. By mid 1988 the total number of measurements amounted to 900 with a total length of 37.000 m. The conditions have been recorded in order to complete this data bank of practical information.

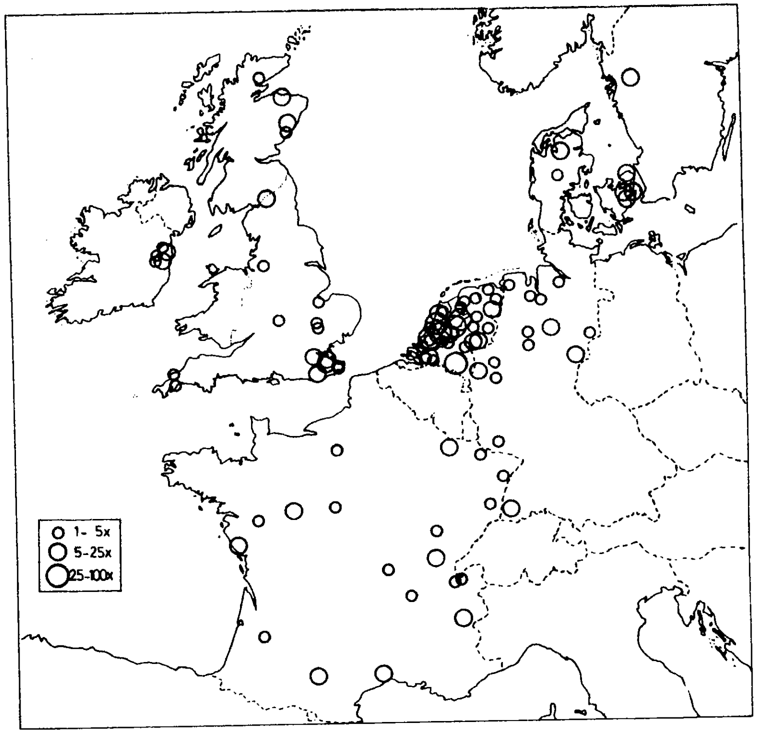


Figure 6 Geographical distribution

To illustrate the results four typical case studies are presented.

3.1. Dartford - England

The principal trunk-highway A2 from London eastwards to Dover was under construction in 1970 - 1971 to by-pass Dartford. For the stormwater discharge pipelines uPVC pipe was used. Three sections of pipelines have been monitored from time to time in order to find out how uPVC pipes perform under extreme heavy traffic conditions.
Section 1.1 and 1.2, repectively consisted of 18"/457 mm and 16"/406 mm uPVC pipes with wall thickness ratio SDR 41, were installed in a cutting of approx. 5 m. In the soil, consisting of chalk, very narrow perpendicular trenches (width: dia + 0,3 m) were excavated with depths down to 3 m. The pipes were installed with pea gravel surround, a 150 mm bed under the pipe up to 150 mm initial topfill. Compaction was not carried out on this surround. The rest of the trench was backfilled with selected as-dug material and thoroughly compacted.

Figure 7
A2 near Dartford
during
construction

Section 1.1, 87 m in length is situated under the side-verge and section 1.2, 16 m in length is situated under the three lane highway to the central reservation.
Section 1.3, consisting of 10"/273 mm uPVC pipes with SDR 41, was installed in an embankment consisting of silty sand. A trench with wall angles of approx. 30° was excavated and the pipes were installed in a similar way to section 1.1 and 1.2. This section 1.3. is situated under the side-verge of the motorway, 77 m in length.

The results of the deformation measurings are given in the table 1.

Table 1 - Deformation measurements at Dartford England

Time after installation	Average/maximum deformations		
	SDR 41 Ø 457 mm Section 1.1	SDR 41 Ø 406 mm Section 1.2	SDR 41 Ø 273 mm Section 1.3
2 years	1½ / 3 %	1½ / 2 %	2 / 4½ %
3 years	1½ / 3 %	1½ / 2 %	2½ / 5 %
8 years	1½ / 3 %	1½ / 2 %	2½ / 5 %
13 years	1½ / 3 %	1½ / 2 %	2½ / 5 %
17 years	1½ / 3 %	1½ / 2 %	2½ / 5 %

Figure 8
A2 near Dartford
during measuring

Whilst all the pipes performed well section 1.3, installed in an embankment has appearently been subjected to a higher settlement of its top fill than section 1.1 and 1.2 buried in a firm stabilized soil. All three sections however have obtained their final shape within two years after installation.

3.2. Dragör - Denmark

In Dragör, situated just South of Copenhagen, uPVC pipes of diameter 400 mm have been used in a sewerage scheme. The installation of the SDR 34 and SDR 41 pipes took place in 1971. The depths of cover are 5.0 m to 5.3 m.

The original soil consists of sand with fine clay parts and the pipe was surrounded by sand. The installation can be qualified as moderate to reasonable: the compaction of the sidefill was done by walking next to the pipes (treading) and the weather was not cooperative. The sandy surround was taken up to 150 mm over the pipe crown. The rest of the trench was backfilled with excavated material.
The sections measured have each a length of 80 m. The deformation measurments are given in table 2.

Table 2. Deformation measurements at Dragör - Denmark

Time after installation	Average/Maximum deformation	
	Ø 400 SDR 34 Section 2.1.	Ø 400 SDR 41 Section 2.2.
½ year	2 / 5 %	2½ / 7 %
1 year	2½ / 5 %	3½ / 7 %
4 years	3 / 5 %	4 / 7 %
13 years	3 / 5 %	4 / 7 %

It appears that the SDR 34 pipes have stabilized to an average of 3 % and the SDR 41 pipes to 4 % deformation (within 1-2 years).

3.3. Lelystad - the Netherlands

In 1967, uPVC pipes were used in the sewerage scheme of Lelystad, a new town some 3.5 m beneath the sea level, in the reclaimed Flevopolder. Some sections have been monitored under official auspices of KOMO (the Dutch approval authority of Building Materials). The pipes involved are 250 mm in diameter and have a SDR of 41. They are situated under the road in a housing estate with 1.7 m depth of cover.
The excavated material, consisting of fat clay was re-used for backfill with the exception of the pipe surround. The pipe bedding and sidefill were constructed with sand. The sidefill has been compacted moderatedly by treading.
The results of deformation measurements are given in table 3.

Figure 9
Lelystad
during construction

Table 3. Deformation measurements at Lelystad - The Netherlands

Time after installation	Average/maximum deformations	
	SDR 41 ø 250 mm Section 3.1	SDR 41 ø 250 mm Section 3.2
	3 / 4½ %	3½ / 4½ %
2 years	3½ / 5½ %	3½ / 6 %
4 years	3½ / 5½ %	3½ / 6 %
6 years	3½ / 5½ %	3½ / 6 %
11 years	3½ / 5½ %	3½ / 6 %
14 years	3½ / 5½ %	3½ / 6 %

Deformation stabilized at an average of 3½ % after a period of 2 years.

3.4. Buckie - Scotland

In Nothern Scotland, in Buckie (east of Inverness) uPVC pipes were first applied for sewerage in 1967. In the Highfield Road Housing Site, 4" and 6" diameter pipes were used for foulwater sewer and 9" and 12" diameter pipes for surface water drains. In the latter sections were monitored by carrying out periodic deformation measurements.

The pipes had been installed in narrow perpendicular trenches, excavated in the soil ranging from sandy loam to medium stiff loam with gravel (similar to boulder clay), the trenches were approx. 2 m in depth.

Coarse sand has been used to surround the pipes: a 100 mm pipe bed, a sidefill compacted by treading up to the initial topfill 150 mm over the crown. Mechanical compaction was applied on the initial topfill. Exceptions were section 4 and 5 where no compaction at all was applied. For the rest of the backfill excavated material was used.

Figure 10
Buckie,
during
measuring

Table 4. Deformation measurements at Buckie - Scotland

Time after installation	Average/maximum deformation				
	ø 244 mm SDR 44			ø 323 mm SDR 44	ø 244 mm SDR 44
	Sect.4.1	Sect.4.2	Sect 4.3	Sect.4.4	Sect.4.5
6 years	3½/5½ %	3½/7 %	4½/9½ %	3½/7 %	7 /13½ %
11 years	4 /5½ %	4 /7 %	4½/10 %	4 /7½ %	7½/14 %
16 years	3½/5 %	3½/7 %	4½/10 %	3½/7½ %	7½/14 %
20 years	3½/5½ %	3½/7 %	4½/10 %	3½/7½ %	7½/14 %

Section 4.5, with no treatment of sidefill or topfill appears to have a higher deformation than the others: Approx. 7½ % and approx. 4 %. This is due to the additional soil settlement, which was visible in the road surface.

These results show that coarse sand is a suitable surround material and pipe deformations can be kept low by just foottamping the sidefill. If the sidefill had been mechanically compacted, (not possible in in the narrow trenches of only 600 mm width) an average percentage of 1½-2 % would have been obtained.

4. RESULTS FROM PRACTICAL TESTS

Experience from measurements on operational uPVC sewer systems may be summarized by the following general statements:

* In no case has a PVC pipe failed to operate as part of an operational sewer system due to excessive deformation.
* In all cases the rate of increase of deformation deminishes and in general the final deformation is reached within two years of installation.
* The final deformation is pre-dominantly influenced by the 'fill group', i.e. type of fill material and method of application.
* Traffic loading has little influence on the final deformation, but reduces the time to achieving equilibrium conditions.
* The deformation limits accepted within Europe can be achieved by uPVC SDR 41 pipe using a wide range of fill materials.

For more background information on the above the reader is referred to (2), (8), (9), (10). In the U.K. BS 5955: part 6 permits 5 % deformation as a maximum for buried uPVC gravity systems. However, buckling due to excessive deformation does not occur below 30 %, and therefore the 5 % limit contains a very high factor of safety. In other European countries the trend has been to accept long term deformation in the order of 10 to 15 % (1), (5), (6).

5 DEVELOPMENTS IN PLASTIC SEWER PIPES

In recent times a number of novel pipe constructions have been developed to provide the optimum performance of uPVC pipe. A leading example is a rib-reinforced solid wall uPVC pipe (ULTRA-RIB) which has been extensively tested in the U.K. and Scandinavia prior to launch into the sewer market. The tests comprised trials in the WRC test pit and field trials on a site near York, where comparisons with traditional solid wall pipes were made and where a wide variety of fill groups was tested on suitability for application. In addition to these tests, live trials under operational conditions have been carried out in the U.K. and Scandinavia.
These tests illustrate that this new type of pipe perform better than the solid wall uPVC pipes to BS 5481.

6. CONCLUSIONS

Practical observations over a number of years have clearly demonstrated that uPVC pipe perform satisfactory as sewer system with the wide variations of conditions encountered. Short term results on the novel rib-reinforced solid wall uPVC pipe indicate that better performance will be achieved from these new sewer pipes.

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