PLASTIC PIPES IN WATER DISTRIBUTION SYSTEMS. A STUDY OF FAILURE FREQUENCIES.

I Bjorklund*

Investigations of failure frequencies in municipal water distribution networks have been performed on several occasions over the past 15 years in Sweden. In a follow-up study, reasons for failure in PVC and PE water pipes during the period 1986-1990 have been studied. It was found that PVC pipes manufactured after -73 have significantly improved failure frequencies compared with pipes manufactured before this date. Pipe failures are rare for PE pipes in general and for PVC pipes manufactured after 1973. Joint failures are 2-4 times more frequent than failures in the pipe itself. The study indicates that for modern PVC and PE pipes, it is probably possible to achieve a failure frequency of around or below 0,1 failures/10 km,year which is roughly 10 times less than the average failure rate recorded for the current Swedish distribution network.

INTRODUCTION

PVC and PE pipes have been used for water mains and distribution lines in Sweden since the early 1960's. Other pipe materials used for water mains in Sweden are cast iron, ductile cast iron and steel. In order to check the performance of different pipe materials in water distribution systems the Swedish Water and Waste Water Works Association (VAV) carried out a series of investigations during the 1970's and 1980's. In a recent investigation the Nordic Plastic Pipe Association (NPG) has focused its attention on reasons for failure in PVC and PE water mains. Comparisons are also made between failure frequences for different pipe materials.

Previous failure investigations

An investigation of failure frequences in municipal water distribution networks was initiated by VAV in 1974. The first findings from 1974 have than been followed up by similar investigations in 1975-77, 1978 and 1986 in order to check whether the failure rate has changed in the meantime. A total of 8-20 municipalities have participated, and the network studied corresponds to approximately 10 % of the total water distribution network in Sweden. The findings from the investigations have been summarized in table I. As can be seen from table I, contrary to all other pipe materials, PVC and PE pipes have shown a decreased failure rate since 1975. A more detailed description of the findings from the first three investigations are given by Bjorklund and Janson (1).

* The Nordic Plastic Pipe Association, Stockholm

Table I: Failure frequencies for water mains and distribution lines in Sweden 1974-1986

Period of investigation	1974	1975-1977	1978	1986
Number of participating municipalities:	8	12	20	11
Total length of network studied (km)	5450	4400	7320	5517
Pipe material	**Failures/10 kms, year**			
PVC	2.8	3.5	1.9	1.0
PE	0.3	0.7	0.5	0.3
Ductile cast iron	0.2	0.1	0.1	0.4
Cast iron	1.0	2.0	1.4	1.9
Galvanized steel	1.0	0.8	0.7	1.4
Other steel	1.6	3.5	3.2	3.3
Average	1.0	1.6	1.2	1.3

Follow-up study performed by NPG

In a follow-up study, the type and reasons for failure were studied in detail for PVC and PE water distribution pipes during the period 1986-1990. The investigation comprised the same 11 municipalities as those included in VAV's investigation from 1986. The total length of PVC and PE water mains and distribution lines in the above municipalities are shown in fig. 1. In 1990, the total length of PVC and PE water pipes amounted to 727 and 745 km respectively. All failures have been studied and the reasons for failure assessed. Altogether, 349 failures were reported in PVC and PE pipes during the 5-year investigation period. A compilation of the results is given in table II.

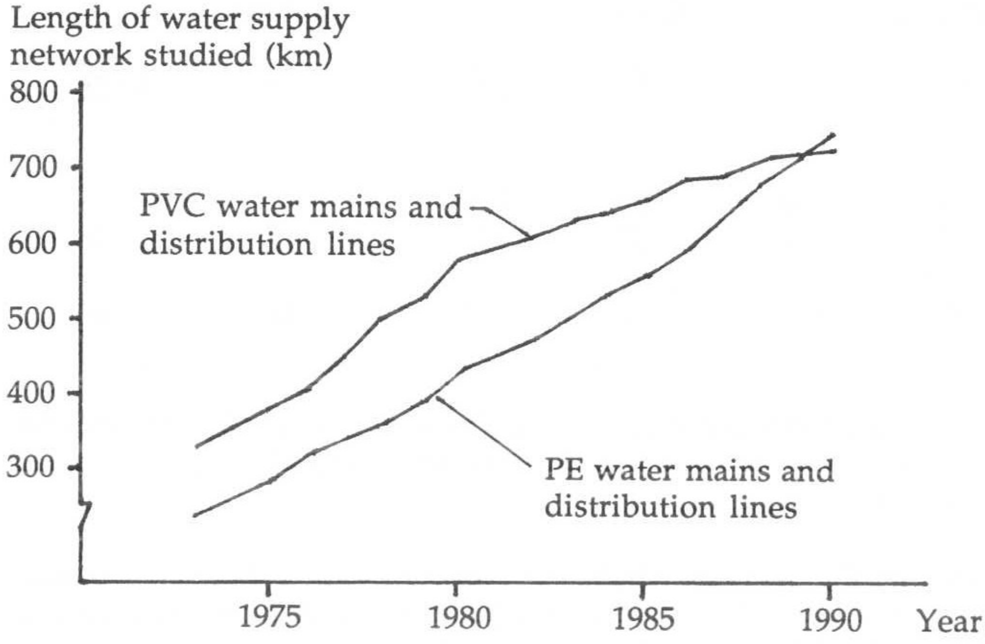

Figure 1 Total length of PVC and PE water mains and distribution lines in the 11 municipalities investigated in Sweden.

Table II: Failure frequencies for PVC and PE water mains and distribution lines in 11 municipalities in Sweden during the period 1986-1990.

	PVC	PE
Total length of network studied (kms)	727	745
Number of failures	288	61
Failure frequency/10 km, year	0.79	0.16

The results show that the failure rate for PVC and PE water pipes continues to decrease, cf table I.

REASONS FOR FAILURE

Failures in PVC pipes

In order to explain the reasons for failure, it was found beneficial to distinguish between PVC pipes manufactured before and after 1973, see table III.

Table III: Number of failures and failure frequencies (failures/10 km, year) for PVC water pipes in 11 Swedish municipalities during the period 1986-1990.

	All PVC pipes (727 km)		PVC pipes made before 1974 (328 km)		PVC pipes made after 1973 (399 km)	
	Number of failures	Frequency	Number of failures	Frequency	Number of failures	Frequency
Pipe failures	96	0.26	91	0.56	5	0.025
Joint failures in injection-moulded sockets	168	0.46	168	1.02	-	-
Other joint failures	24	0.07	17	0.10	7	0.035
Total	288	0.79	276	1.68	12	0.06

As can be seen from table III, there is a dramactic difference between failure rates for pipe manufactured before and after 1973. Similar findings have also been reported from the United Kingdom by Kirby (2).

A considerable number of the failures which have occurred in PVC pipes manufactured before 1974 can be attributed to failures in injection-moulded sockets (168 of a total of 276 reported failures). However, even if this type of failure (fig. 2), which is well-known and can be attributed to bad material quality, is excluded, PVC pipes manufactured before 1974 still show a failure rate that is roughly 10 times higher than

Table IV: Pipe failures in PVC water mains and distribution lines in 11 Swedish municipalities, 1986-1990

Type of failure	Number of failures/DN	Total number of failures	Years of operation
Lines built before 1974 (328 km):			
Crack in pipe[1)]	1/40, 1/63, 1/90, 11/110, 22/160, 38/225, 1/315	76	12-26
Broken pipe[2)]	1/63, 1/110, 2/160, 2/225	6	15-27
Crack in bend[3)]	1/90, 4/110, 2/160, 2/225	9	13-22
	Totally	91	
Lines built after 1973 (399 km):			
Crack in pipe[4)]	1/110, 1/160, 2/315	4	4-11
Crack in bend[5)]	1/110	1	15

1) 45 of 76 failures have occurred on 14 pipelines with 2 or more failures on each line. The other 31 failures are single failures. In 12 cases, stones were found to be resting against the pipe. Settlements were noted in 3 cases. One failure was caused by freezing. Typical failures are shown in figure 3.
2) 3 failures were caused by external damage. 1 failure was located at the point where the line crossed a DN 1200 pipe where settlements had occurred. 1 failure had occurred where the pipe rested on rock.
3) In 2 cases, missing thrust blocks or anchorages at bends were reported.
4) The second failure on the DN 315 pipe occurred the day after the first repair at the same place (bad repair work).
5) Occurred on a pipe installed in 1974.

Table V: Joint failures in PVC water mains and distribution lines in 11 Swedish municipalities 1986-1990

Type of failure	Number of failures/DN	Total number of failures	Years of operation
Lines built before 1974 (328 km):			
Cracked injection-moulded socket	-	168	>14
Slippage in mechanical fitting	2/40	2	17-18
Corrosion of metal fitting	1/110, 1/140, 1/160	3	16-22
Leakage in rubber ring joint[1)]	1/63, 5/110, 3/169	9	15-24
Broken pipe at connection[2)]	1/110, 1/160	2	20-26
Cracked PVC collar	1/160	1	-
	Totally	185	
Lines built after 1973 (399 km):			
Leakage in rubber ring joints[3)]	1/63, 3/110, 1/160, 1/280, 1/315	7	0-13

1) Two failures due to displaced rubber sealing. At least 6 failures caused by missing or bad anchorage of fittings.
2) Caused by a faulty saddle for house connection (a saddle intended for DCI pipes)
3) Two failures due to displaced rubber sealing. At least 4 failures caused by missing or bad anchorage of fittings (the latter failures have all occurred in a small municipality with a total of 29 km of PVC water pipes in the 399 km investigated).

that of pipes that were made later (0.66 against 0.06 failures/10 km, year). The difference in failure rate can be analyzed by a more detailed study of the reported failures, see tables IV and V.

Pipe failures It is obvius that there is a remarkable quality difference between PVC pipes made before and after 1973. Even if some pipes were found to have failed due to external damage and bad installation work, the difference in failure rates cannot be explained by any other reasons than an improved pipe quality. A comparison between the findings from the latest investigation and those of the previous ones is given in table VI.

Table VI: Failure frequencies for PVC water mains and distribution lines in Sweden.

Investigation	Year	Failure frequency (failures/10 km, year) Pipe failure	Joint failure	Tot.
VAV	1974	0.54	2.28	2.8
VAV	1975-77	1.14	2.31	3.5
VAV	1978	0.38	1.45	1.9
NPG* (pipes b.-73)	1986-90	0.56	1.12	1.7
NPG* (pipes a.-74)	1986-90	0.02	0.04	0.06

*) The 1986 VAV investigation is included in the NPG investigation.

Table VI shows that the pipe failure frequency for pipes manufactured before 1973 was found to be roughly the same in the last investigation as that found in 1974 (0.56 compared with 0.54) The failure rate for joint failure had decreased from 2.3 to 1.1, probably due to the fact that a considerable amount of injection-moulded sockets were replaced during the period 1974-1990. Laboratory tests performed on pipe samples taken from 6 old PVC pipes have revealed that a majority of the samples failed to pass the methylene chlorine test, see table VII.

Table VII: Tests performed on old PVC pipes.

Pipe sample No	1	2	3	4	5	6
Nominal diameter DN	110	160	160	400	110	63
Year of installation	1966	1967	1966	1970	1967	1968
Year of failure	1990	1989	1986	1991	-1)	1991 2)
MC test; Attack (%) on:						
- internal part of pipe wall	70	100	0	100	30	0
- middle part of pipe wall	100	30	100	100	100	0
- external part of pipe wall	100	100	100	100	0	0
MCT (°C)	2	<5	5	5	10	20
DSC (°C)	175	165	160	173	178	180

1) No failure 2) Failed due to external damage.

The reason for the significant improvement in pipe quality in 1973 is probably due to the fact that the pipe manufacturers in Sweden at that time started to use a new PVC raw material. The new PVC material had a higher K-value (increased from 65 to 68) and improved gelation properties. In addition, the methylene chlorine test started to be commonly used as a factory test for quality checking in the mid 1970's, which probably also helped to prevent inferior gelated pipes from entering the market. Based on the findings from the investigation, the main reason for pipe failures in PVC pipes can most probably be referred to inferior gelation properties of the pipes and to the fact that such pipes are considerably more sensitive to ground settlements and bad pipe installation work that good quality PVC pipes.

<u>Joint failures</u> The predominant cause of failure in older PVC pipelines is still cracked injection-moulded sockets, see table V. The reason for this type of failure can be attributed to inferior long-term strength properties of the sockets. The problem was already attracting a lot of attention at the beginning of the 1970's, since it was already causing a considerable number of failures in PVC pipes, see table VI. Even if the failure rate has subsequently decreased, in 1990 it was still by far the most common cause of failure in PVC pipes.

The second most common cause of failure is leakage in rubber ring joints (totally 16). For this type of failure, see figure 4, no major difference can be seen for pipes made before or after 1973. In almost all cases the leakage is either caused by displaced rubber sealings or bad anchorage of fittings. It is somewhat surprising that such failures do not reveal themselves to a greater extent. It seems that leakage in joints can generally be referred to bad workmanship during pipe installation.

For PVC pipes laid before 1974, certain other joint failures have also been found, see table V. For the additional failures, see figure 5, either a certain time is needed for the failure to occur (i e failures caused by corrosion or excessive stresses) or failures have occurred in fittings no longer used for PVC pipes (mechanical couplings), which is probably the reason why no such failures have been reported for pipes made after -73.

<u>Failures in PE pipes</u>

For PE pipes, there is no marked difference in failure frequencies between pipes manufactured before and after 1973, see table VIII. Irrespective of age, joint failures are the most common cause of failure in PE pipes (roughly 3-5 times more frequent than pipe failures).

<u>Pipe failures</u>. Pipe failures in PE pipes are rare. During the 5-year investigation period, only 13 pipe failures have been reported, see table IX. Of the 13 failures recorded, 5 can most probably be attributed to external damage to the pipes. Of the remaining 8 failures, 5 have occurred in PE pipes of DN 63 or less in a small municipality with a total of 29 km of the 745 km PE pipes studied. In all cases, stones were found resting against the pipe.

Unfortunately, pipe samples from the failed PE pipes were not available when the investigation was performed. Consequently, the strength properties of the failed pipes are unknown, and it is therefore not possible to conclude whether or not low pipe quality has contributed to the failures.

Table VIII: Number of failures and failure frequencies (failures/10 km, year) for PE water pipes in 11 Swedish municipalities, 1986-1990.

	All PE pipes (745 km)		PE pipe made before 1974 (245 km)		PE pipes made after 1973 (500 km)	
	Number of failures	Failure frequency	Number of failures	Failure frequency	Number of failures	Failure frequency
Pipe failures	13	0.03	7	0.06	6	0.02
Joint failures	48	0.13	22	0.18	26	0.10
Totally	61	0.16	29	0.24	32	0.13

Table IX: Pipe failures in PE water mains and distribution lines in 11 municipalities, 1986-1990

Type of failure	Number of failures/DN		Total number of failures	Years of operation
Lines built before 1974 (245 km):				
Crack in HDPE pipe 1)	3/50		3	14-17
Crack in LDPE pipe	1/75		1	21
Hole in LDPE pipe	1/32		1	19
External damage	1/42, 1/50		2	21-22
		Totally	7	
Lines built after 1973 (500km):				
Crack in PE pipe 2)	1/50, 1/63, 1/110, 1/225		4	3-14
External damage	1/32, 1/63		2	0-10
		Totally	6	

1) All failures occurred in the same municipality to pipes installed in 1972. In all cases stones were found to be resting against the pipe.

2) In two cases, stones were found resting against the pipe. One failure occurred at a place where the pipe had been earlier repaired.

Joint failures Joint failures in PE pipes are considerably more frequent than failures of the pipe itself, see table VIII. A compilation of the different joint failures which have been reported for PE pipes is given in table X. As can be seen from the table joint failure almost always occurs at mechanical joints (47 of 48 failures).

Of joint failures at mechanical joints, leakage is the most common failure (27 of 47 failures). There seems to be no specific correlation between this type of failure and the age of the pipe. Leakage at mechanical joints, se figure 6, has been found on old water pipes (after 27 years' operation) as well as on more recently installed pipes (after a couple of years' operation).

Another interesting finding is the high amount of broken mechanical fittings (16 of 47 failures). Of the 16 failures, at least 11 occurred in connection with the same make of fitting. In addition , one failure occurred in a home-made copper pipe fitting.

Table X: Joint failures in PE water mains and distribution lines in 11 Swedish municipalities, 1986-1990

Type of failure	Number of failures/DN	Total number of failures	Years of operation
Lines built before 1974 (245 km):			
Broken mechanical fitting[1]	3/40, 2/50, 1/63	6	14-25
Corroded mechancial fitting	2/63	2	23-28
Leakage at mechancial fitting[2]	1/32, 1/40, 4/50, 2/63, 3/75 1/110	12	16-27
Broken PE pipe at mechanical fitting	1/40, 1/90	2	15
	Totally	22	
Lines built after 1973 (500km):			
Broken mechanical fitting[3]	2/32, 4/40, 1/63, 3/75	10	1-14
Leakage at mechanical fitting	1/32, 1/40, 2/50, 9/63, 1/75 1/110	15	2-15
Crack in stub end of PE	1/400	1	8
	Totally	26	

1) All failures occurred for the same make of fitting.
2) One failure was caused by external damage
3) One failure occurred in a home-made fitting of copper pipe. At least 5 of the broken fittings are of the same make as those that failed on pipes made before 1974 .

In the case of older PE pipes, corrosion of fittings, see figure 7, and broken pipes close to the fitting have also been reported (2 failures each).

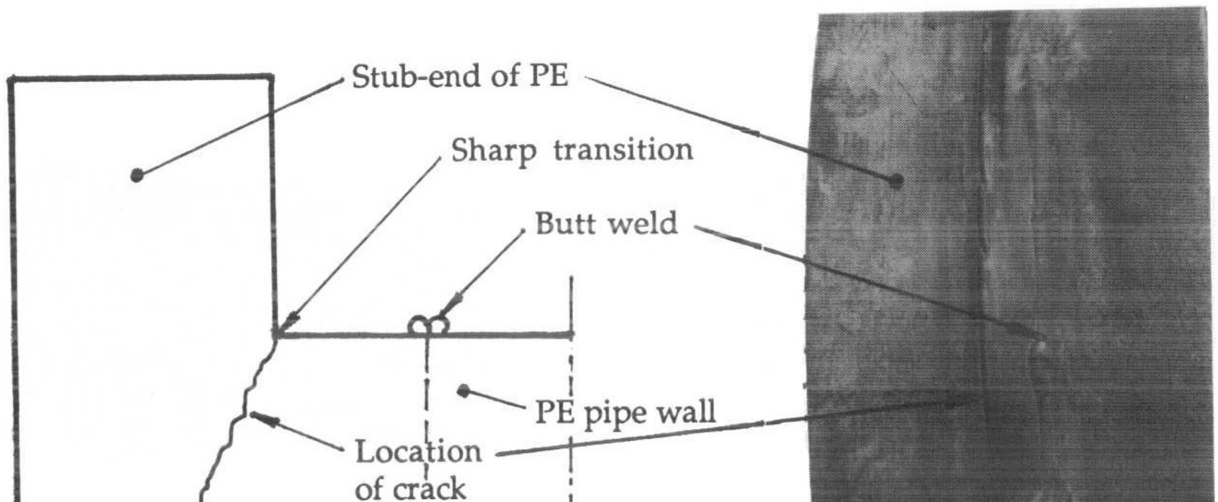

Figure 8: Crack in stub-end of PE

During the 5-year investigation period only 1 failure has been reported from a welded joint. The failure had not occurred in the weld itself but in a stub-end of PE welded on to the pipe. The transition from the pipe barrel to the flanged part of the stub-end was sharp, which probably caused stress concentrations in the stub-end which in turn led to the failure, see figure 8.

CONCLUSIONS

A significant increase in pipe quality can be seen for PVC pipes made more recently compared to those manufactured before 1974. For PE pipes in general, and PVC pipes manufactured after 1973, pipe failures are rare. In a total of 1144 km studied, only 18 failures of such pipes have been reported over a period of 5 years. Of the failures reported, at least 5 were caused by external damage.

Joint failures are roughly 2-4 times more frequent in PVC and PE pipes than failures in the pipe itself. Joint leakage prevails and can generally be referred to bad workmanship during pipe installation.

Even though it will not be possible to eliminate failures in PVC and PE pipes for water distribution systems in practice, the results from the investigation show that a failure rate of less than 0.1 failure/10 km, year might not be impossible to achieve for PVC and PE pipes in the future.

REFERENCES

1. Bjorklund I. and Janson L-E., 'Swedish experience of the use of thermoplastic pipes for water and sewage transport'. Int. Conf. Underground Plastic Pipe Proceedings, New Orleans 1981.

2. Kirby P.C., 'PVC pipe performance in water mains and sewers'. Int. Conf. Underground Plastic Pipe Proceedings, New Orleans 1981.

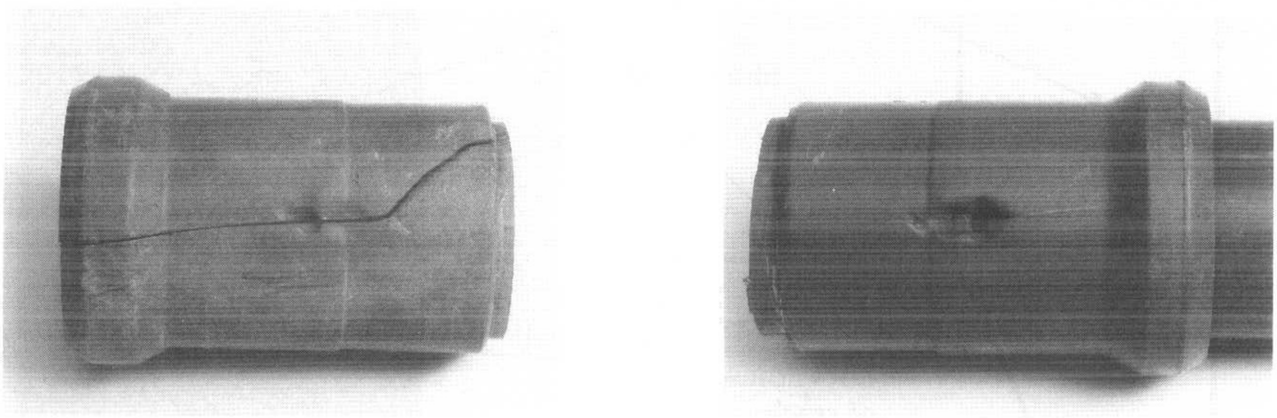

Figure 2. Cracked injection-moulded sockets of PVC pipes (in the socket to the right, the leakage has abraided the socket at a small crack).

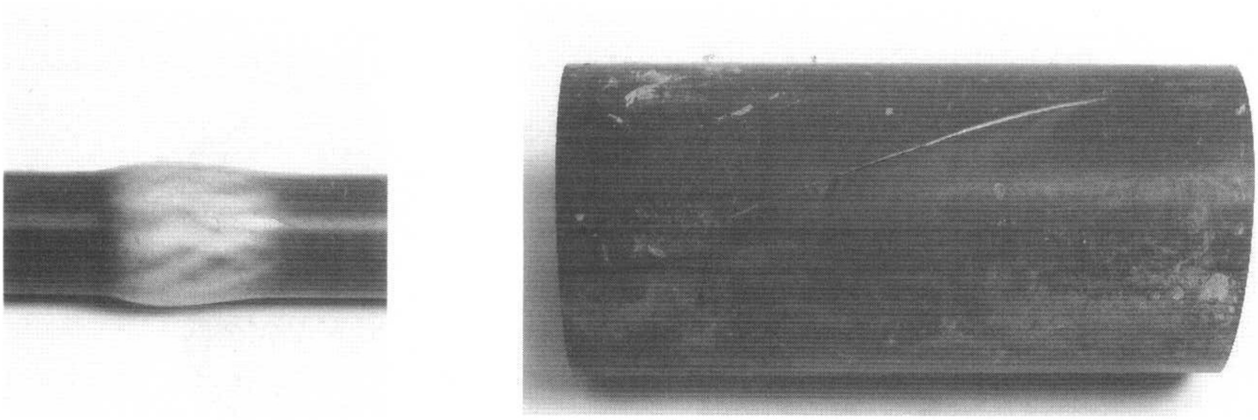

Figure 3. Examples of failed PVC pipes (to the left freezing in a PVC pipe; to the right a crack where the pipe has rested against a stone).

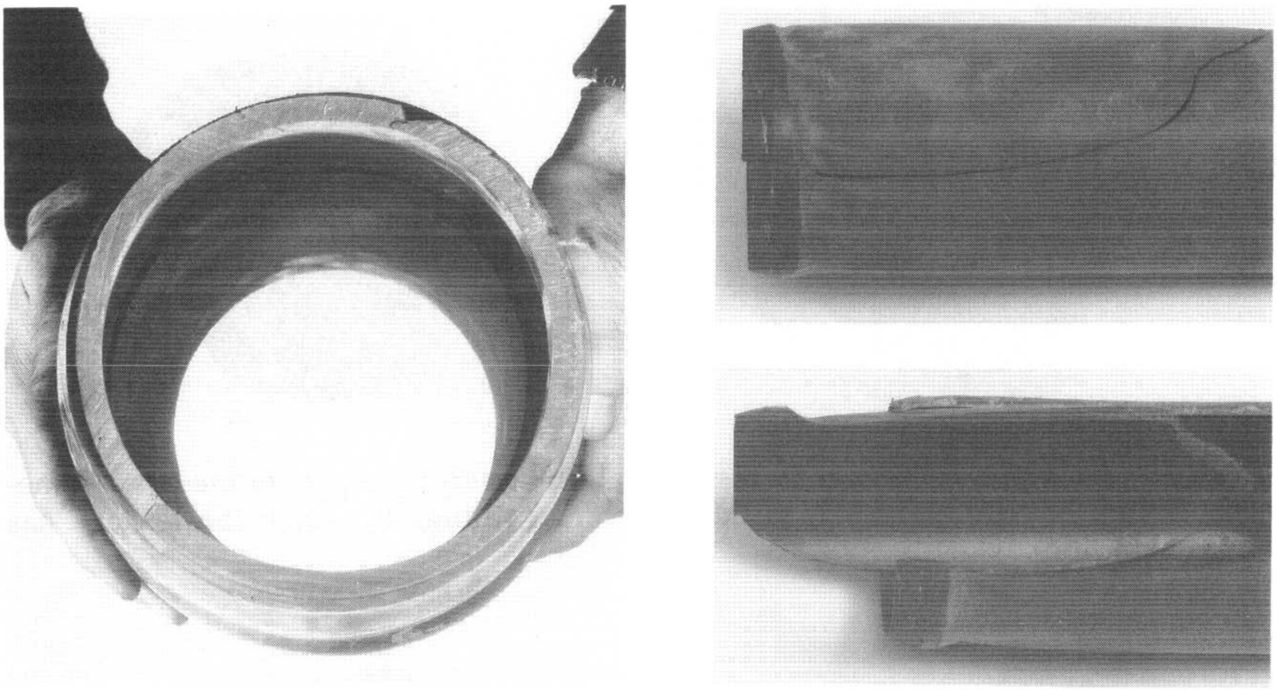

Figure 4. Leakage in rubber ring joints on PVC pipes (to the left a displaced rubber sealing, to the right a spigot end which has not been correctly inserted in the socket and where the leakage abraided the spigot end until it finally failed).

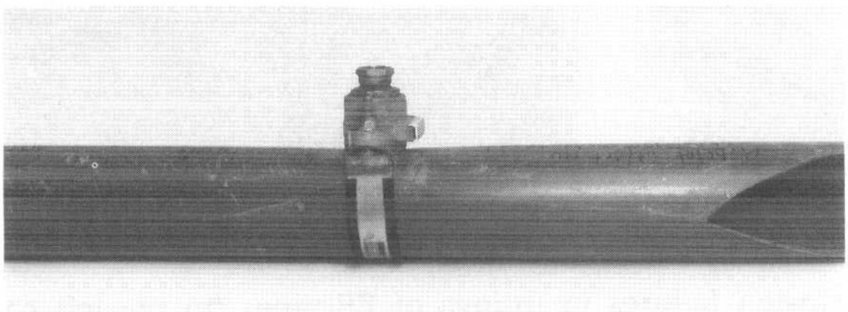

Figure 5. A failed PVC pipe at a saddle for house connection intended for DCI pipes.

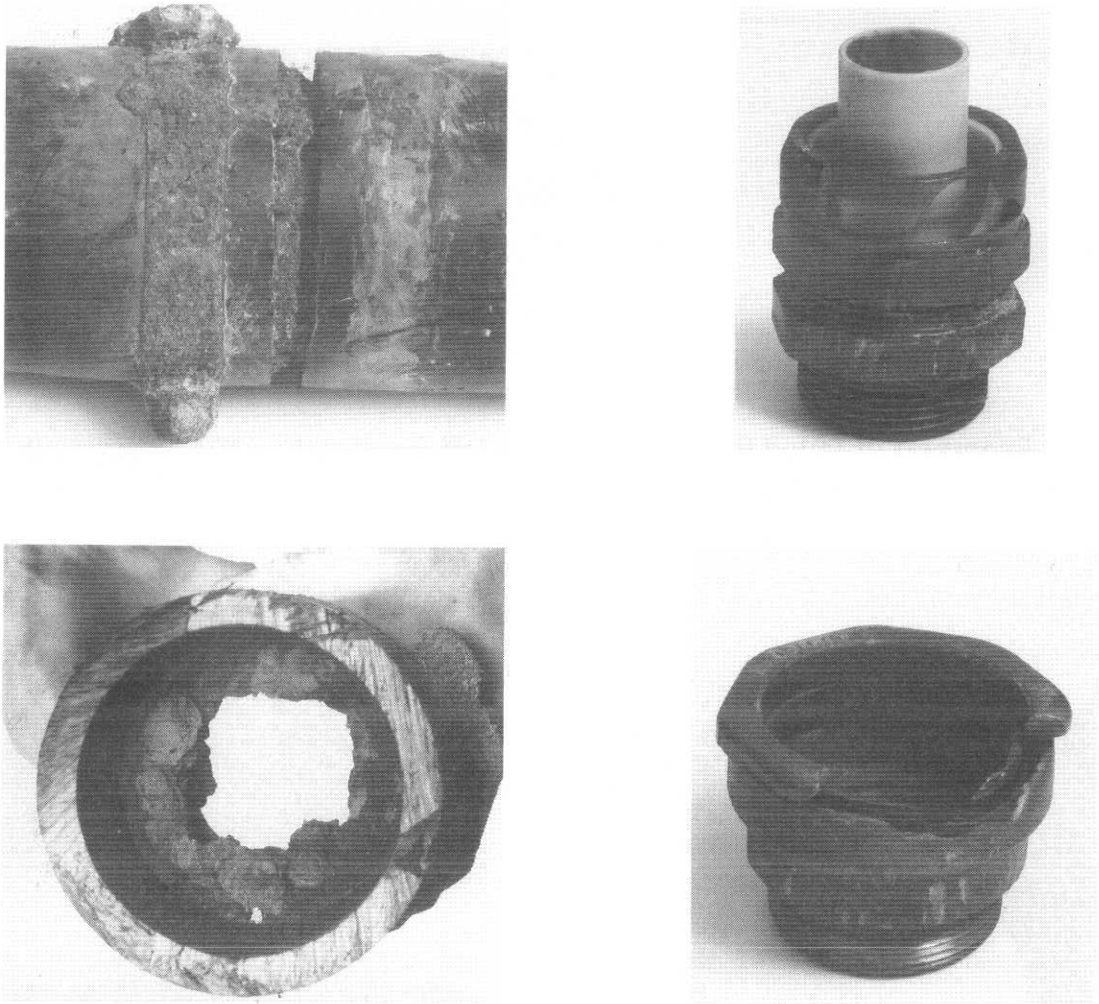

Figure 6. Examples of leakage in mechanical fittings on PE pipes (to the left a home-made fitting, heavily corroded, to the right brass fittings in which the leakage has caused abraision).

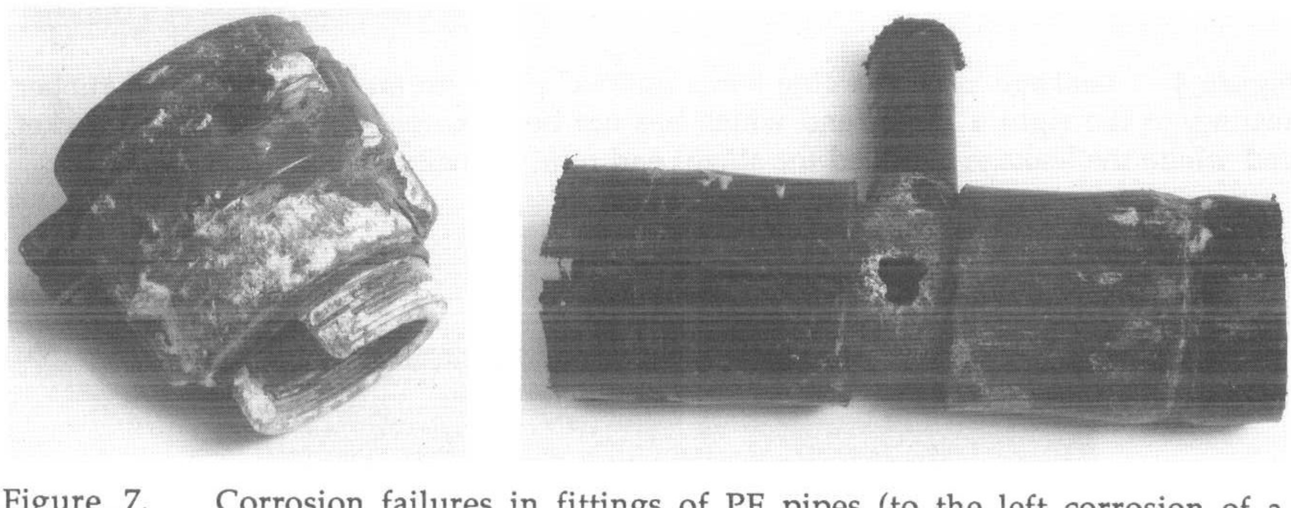

Figure 7. Corrosion failures in fittings of PE pipes (to the left corrosion of a mechanical fitting of aluminium alloy, to the right corrosion in a steel fitting).