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Old PVC gravity sewer pipes : Long term performance

by

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Synopsis

Wavin gained a lot of experience with operational PVC sewer pipes by monitoring installations and measuring pipe deflections over a period of about 35 years, as reflected in the database "PiPer". Some of the oldest pipes have been measured and dug up now to study the durability of these pipes. Furthermore the results are used to obtain a more accurate lifetime prediction of newly installed pipes.
Therefore, Wavin SA Varennes in France and Nordisk Wavin AS in Denmark cooperated closely with Wavin Marketing & Technology. At several locations pipes were measured before and after digging up by which the deformation and the recovery were determined. The pipes aged between 12 and 30 years. System owners were asked to select those sites from which they know that the pipes have been installed in a poor way or severely loaded by ground settlements. As a result, the deformations found in these severely loaded pipes are the upper level of what normally can be expected in the field.
The results of the functional tests showed that the pipes still fulfil the stiffness requirements, and their functional and structural integrity is still ensured.
The pipes will easily maintain their function for a much longer period than originally anticipated. Considering the fact that the raw material as well as the pipe production process have been improved since the early years, it can be expected that the currently produced PVC pipes fulfilling CEN requirements will last for several hundred years.

Introduction

Wavin gained a lot of experience with PVC sewer pipes by monitoring installations and measuring pipe deflection over a period of about 35 years, as reflected in the database "PiPer". Some of the oldest pipes have been measured and dug up now to study the durability of these pipes. Next the results are used to obtain a more accurate lifetime prediction of newly installed pipes. Firstly the state of deformation was determined by carrying out deformation measurements before and after digging up. Pipe samples were cut out and taken to Wavin Marketing & Technology's Sterlab certified laboratories where the pipes have been characterised from a raw material and production point of view. Then several mechanical tests have been carried out like stiffness tests and tightness tests of joints. The study has been conducted over a period of four years, starting as indicative only, to more detailed. As a result from this not all tests have been performed on all the pipe samples.

SITE INFORMATION

In order to find the extreme conditions, system owners were asked to select those sites from which they know that the pipes have been poorly installed or severely loaded. As a result the deformation and stresses found in these severely loaded pipes are the upper level of what normally can be expected in the field. If these pipes are able to fulfil their function, then there is no doubt on the functionality of the pipes installed according to national codes of practice. A general description of the sites is given below. The technical details are summarized in Annex 1, Table 1.

Project 1 : Gerzat, France
Gerzat is located in the centre of France close to Clermont Ferrand. In this town with a separate sewer system, since 1966, most of the foul water sewer pipes that are installed, are PVC ϕ 200 mm and today approximately 30 kms of such pipe have been installed with excellent performance and to the great satisfaction of the town authorities.
The section of pipe that has been studied in this particular case was of the SDR-class 51 and installed in the earliest days of using PVC in 1966 and is located in the centre of the town with a rather steep gradient. In 1991, after having being used for 25 years, the pipe was measured before digging up, half an hour after being cut out and 15 days afterwards, everytime at the same spots.

Project 2 : Montpellier, France
Completely in the South of France, in Juvignac Commune de Montpellier, PVC pipes have been applied in the sewerage network since the late sixties.
Although in general the local authorities are very content on the use of PVC, some sections proved to have somewhat high deformations. This was caused by insufficient care taken during installation. This particular section was dug up and studied.
The section in question, ϕ 315 mm SDR 51, was installed in 1968 without proper attention also; no preparation of the trechbottom (just a hard bed), several big stones in the embedment material, pipes badly cut off to sharp edges, etc.
Firstly the ovalisation of the complete sections were determined and then a length with 20% ovalisation was selected, which appeared to be caused by the presence of substantial amounts of stones in contact with the pipe. When digging up the pipe it showed that the ovalisation was at an angle of about 15° from the vertical axis, corresponding with the nearby location of the ϕ 800 mm concrete rainwater sewer which was installed at a later stage. It became obvious that in particular recommended installation practices here had not been followed.

Project 3 : Saint Agathe La Bouteresse, France
In this little village in the Loire Department close to Saint Etienne, it was decided in 1966 to extend the rainwater sewerage system. Because of the smoothness of bore, PVC pipes were adopted as the right products for this purpose. But not after careful consideration of the structural performance of PVC pipes. Before actually starting, first a test was carried out with ϕ 400 mm at a 40 cm depth of cover, just along a main road. With a recorded deformation of maximum 4%, the community got convinced that they made the right choice. Since, they have never regretted this choice and are now very content with PVC as material for their sewer system.

The section selected for studying the long term performance in closer detail was a ϕ 400 mm, SDR 41, installed in 1966 and located in the verge of a major road.

Project 4 : Courchevel, France

In the French Alps, at an altitude of 1600 m, PVC pipes were installed from the late seventies onwards to discharge the water coming from the mountains.

In this special high mountain area substantial amounts of proper embedment material have to be dragged upon the roads in order to install pipes. This procedure is required for PVC pipes as well as for pipes of traditional materials.

It is obvious that contractors like to only carry the very minimum amount of sand upon the mountains, as every truck load takes half a day or more. Now and then (or regularly), just the excavated soil material is applied for embedment of the pipes. It needs no saying that the presence of large pieces of rock can cause severe detrimental effects to rigid pipes and high deformations to flexible pipes like PVC pipes.

This was also evident at the site chosen to evaluate the performance of PVC pipes in these extremely severe conditions. During digging up of the pipe at points with the highest deformation, it became very clear that these deformations were caused by large rocks denting the pipes.

Project 5 : Odense Kommune, Bådvej, Denmark

The area is a typical housing estate development from the seventies. The site is located close to a small river the Odense Å . The soil is of an acid nature.

The PVC pipes were installed in 1970. The pipe is located in the bank of the river.

The soil consists of peat/moor. The pipe was partially embedded with sand. The installation conditions were difficult. The supervising engineer of Odense Kommune remembered having hesitated to install sewage lines under such conditions. Therefore, the decision was made to carry out CCTV inspection afterwards which indicated deformations of 10-15% at that time. In 1992 the deformation was found to be max. 17% on this particular line.

During the last 22 years, Odense Kommune has had no operational problems whatsoever with this line. After 22 years of operation, the PVC pipes and the joints (rubber rings) are still fully functional even though they have been subjected to both chemically and physically extreme impacts. They meet the requirements of a modern sewage system.

Project 6 : Sydfalster Kommune, Natuglevej, Denmark

Marielyst is a seaside (the Baltic) recreational area. Part of the area is old sea-bed consisting of sand with large methane deposits. The PVC pipes were installed in the autumn of 1963 at high groundwater levels. This level was not lowered during installation. To avoid collapse of the line, the installation was carried out at high speed, i.e. not very carefully. Couplers with cemented joints were used to join the pipes.

The pipeline has been in satisfactory operation since its installation. No exceptional cleaning measures have been required until now.

A CCTV inspection in 1993 showed a water level in the pipeline of 10-30% owing to low points in the pipeline which was to be expected following the extremely poor laying conditions. After 30 years of operation this pipeline has fulfilled its job in spite of the severe installation conditions, having been subjected to sewage water and aggressive soils and settlements.

Project 7 : Sydfalster Kommune, Bøtøvej, Denmark
The PVC pipes were installed in 1965. The Groundwater level was lowered during installation. The installation was carried out with some care. Couplers with cementing joints were used to join the pipes. The pipeline has been in satisfactory operation since its installation. A CCTV inspection in 1993 showed leaking cemented joints.
During the first 28 years of operation, this pipeline has fulfilled its job in spite of settlements. However, the joints of the cementing sockets did not fulfil the tightness requirements for sewage pipes with regard to infiltration and exfiltration. This is not due to material failure, but poor workmanship as far as the joints are concerned. Generally the lifetime of correctly cemented joints is the same as that of the PVC pipes.

Project 8 : Nφtterφy Kommune, Norway
Nφtterφy comprises a number of minor communities: Borheim, Støyten, Gipø, Skjerve and Vollen whose sewage water is collected in an interceptor. The interceptor (collector pipe) is established in a soft clay area along a stream. The ground water level depends on the time of the year. The PVC pipes were installed in February 1972 at a temperature of -5 degrees Centigrade at a laying depth of 2.0 m and with a gradient of 3 o/oo. Rubber rings were used to join the pipes. The pipes were embedded on a levelled bottom of soft clay without specially prepared bedding.
Whenever possible, clay mixed with black earth was used as backfill material, otherwise soft clay in layers on top of the pipe was used, tampted with a shovel and run over by a heavy vehicle from time to time. Extreme severe laying conditions!
The line has been cleaned once in 1990 by means of high-pressure jet cleaning equipment. The line was full of stones etc. which is, no doubt, due to the pipes being installed under such extreme conditions. The pipeline was not cleaned before it was taken into service. After 22 years of operation and with laying conditions being extremely poor, this pipeline has fulfilled its job in spite of large deformations and a low gradient. No operational failures occurred. The line is also tight; neither exfiltrations nor infiltrations have occurred.

Project 9 : Eskilstuna Kommune, Torshalla, Sweden
Torshalla is a typical housing estate development from the sixties on the outskirts of a large city (Eskilstuna). The area has its own sewer system. The area is old lake-ground, mainly clay. The PVC pipes were installed in 1970 in a combined trench, Swedish model, sewage line, rainwater and clean water in the same trench, at different depths. Bedding and backfill material is a well-graded sand. Differential settlements of up to 30 cm occurred in this area caused by significant ground water lowering after installation.
This has caused for instance a negative slope in certain parts of the line, thus causing operational problems to some of the end-users. But there have been no actually cracked pipelines as they have been capable of absorbing these large settlements. The joints are still tight. After 24 years of operation this pipeline has fulfilled its job despite severe settlements.

' METHODS

·ial characterisation

· tests were carried out for documentation purposes, and in order to characterize the ıaterial and production of the pipe. The results are compared with those of currently ıced PVC pipes.

·rial composition : Since the early years of PVC pipe production the chemical ɔsition of PVC recipes have undergone substantial changes. Therefore, some ..tive tests were carried out to get some insight in these changes. For this the ash nt is determined indicating the amount of filler and/or stabilizer used. The chalk ıt is determined by FTIR measurements. The stabilizers are determined by means of (X-Ray Fluorescent) analyses.

ꞔe of gelation : This test is carried out in order to characterize the extrusion ·ss. The homogeneity of the network structure of PVC molecules which is formed ꞔ the processing of the material, is of great importance regarding the long term ꞔth. This network structure, the so-called degree of gelation, should have a minimum to give a good long term strength to the pipes.
ıegree of gelation can be determined by means of a methylene chloride test which a global indication of the degree of gelation over the total wall thickness and the nference of the pipe, expressed as a percentage attack. This type of test is part of a al production control routine. According to PrEN 1401-1:1995 no attack is allowed rrently produced pipes.

·ional tests

functional requirements for gravity sewer pipes can be summarized as follows: g able to discharge rain and foul water in a sound way over a long period of time ›ut infiltration or exfiltration". The latter means that the system should be tight. the above general requirements, many other sub requirements can be derived, such xibility, strainability, continuous discharge capacity and tightness of joints.
ıll tests have been performed on all the pipe samples, for reasons as already mentio- ı the introduction. Annex 1, Table 1 shows an overview of the pipes tested.

deformation
ıe pipes have been measured before digging up, in order to determine the actual pipe ction after so many years of service. Furthermore, measuring the deflection after ng up and by comparing with the in service pipe deflection indicates the stress in the The method of measurement has been discussed several times (Lit. 1,2).

time however, the strain is not determined from the change in curvature but from the ı-deflection relation :

$$\epsilon = Df*(\delta/D)*(s/D) \quad .... (1)$$

In which :

ϵ	=	Tangential bending strain	[MPa]
δ/D	=	Pipe deflection	[-]
s	=	Pipe wallthickness	[mm]
D	=	Pipe diameter	[mm]
Df	=	Shape factor	[mm]

Here a shape factor of 6 is chosen. Earlier work on buried pipes proved that this is a conservative value (Lit.3)

Pipe stiffness
Although Wavin has proven over it's many years of field experience that pipe stiffness affects the pipe deflection in a minor way when considering proper installations and stiffnesses of 2 KPa and up, ring stiffness of the pipe is still used in many design methods as a factor of prime importance. Pipe stiffness is also used to classify pipes. Furthermore, questions are sometimes raised at the market place to where stiffness declines with age. Struik (Lit.4) and Janson (Lit.5) already discussed the effect of ageing on pipe stiffness. Still measuring the stiffness of pipes that have been in service for more than 25 years is probably the most supportive proof to the previous mentioned work.
The pipe stiffness has been determined on almost all the samples using the stiffness test as described by ISO 9969.

Strainability
One very important property of buried pipes is their flexibility. The most likely, but underestimated cause for pipe failure are the effects of longitudinal bending of pipes. This bending occurs as a result of uneven bedding, in case of poor installations, or as a result of soil settlements which can always occur after installation, for instance due to mining activities, lowering ground water level, by landslide during wet seasons or by partly installation in expansive partly in non-expansive soils. The ability of a pipe system to follow soil movements is a very benificial property of a buried thermoplastics pipe system. Therefore, tensile tests were carried out on the pipes that have been dug up in two more recent projects, those from Nϕtterϕy and Thorshalle.

RESULTS OF TESTS

Colour
Some of the pipes shows discoloration on the surface.
The discolouration is caused by the presence of Sulfuric acid, see also Table 1 of Annex 1.

Pipe deformation
The results are shown below in Table 1.

Table 1: Results of deformation measurements.

Pipe	In use [Yr]	Installation	(δ/D)_1 mean [%]	(δ/D)_2 mean [%]	(δ/D) max. [%]	(δ/D) PiPer [%]	ε buried [%]
Gerzat	25	Sand/B	2.5	1.6		2.5	.29
M.pellier	23	Rock/C	7.5	-	20.5	-	.89
St.Agathe	22	Sand/B	5.5	-	11.5	4.5	.81
Courchevel	12	Sand/C	7.5	-	20	8	1.1
Odense	22	Sand/C	13	7	17.5	8	1.32
Nykobing 1	30	Sand/B	2.5	-	6	3	.44
Nykobing 2	28	Sand/B	4	2	7	4	.59
Notteroy	22	Clay/C	10	5	16	-	1.17
Thorshalle	24	Sand/C	8	3.5	12.5	7.5	1.17

(δ/D)_1 = Deflection when installed.
(δ/D)_2 = Deflection measured 30 minutes after dug up.
(δ/D) PiPer = Deflection from field experience, as listed in Wavin's database.
\- = No data available.
B = moderate installation }
C = poor installation } sec (ref. 1, 2)

The allowable strain for PVC according to Lit. 5 is 2.5 % as a conservative value.
From the results the following observations can be made:

* The deflection and strain strongly depends on the type of installation. This is in accordance with the results as listed in PiPer. (Lit.1,2)
* Some of the deformation are rather high. The factor of safety against failure however is still considerably.
* Comparing the pipe deformation when installed, with those 30 minutes after dugup shows, that the pipes all recover quickly. This recovery process will continue, but at a slower rate, thsn during the first minutes. The pipe responds in the same way, as when the pipe is loaded for the first time. (Lit. 3)
* The deflection values were compared to those in Wavin's PiPer database. The results clearly shows that the values are comparable. Furthermore, it should be realized that the results in PiPer are gained in the range of 0-10 years after installation. The results confirm that the deflection does not increase with time after a first consolidation process after installation. (Lit. 1,2,5)

Pipe stiffness
In Figure 1 of Annex 1 the results are summarized. Also the minimum required stiffness according to the pipe class is shown.
The wall thickness of pipes is normally a little bigger than according to the SDR value. This also means that the stiffness is a little higher than according to the requirement. Therefore, the measured stiffness has been corrected for the wall thickness.
The ring stiffness is affected by the wall thickness in the 3rd power as follows:

$$Corr\_fac = [(D/SDR)/s\_true]^3 \quad \ldots\ldots (2)$$

in which : Corr_fac = Multiplication factor on measured stiffness. [-]
D = Nominal Outside diameter [mm]
SDR = Standard Dimension Ratio [-]

Figure 1 of Annex 1 clearly shows that the pipe stiffness does not show any significant change and still fulfils the minimum requirement.

Strainability
The results of the tensile tests are summarized in Table 2.

Table 2 : Results of tensile tests.

Pipe	Yield stress [MPa]	Strain at failure [%]
Nφtterφy	50	142
Thorshallle	46.1	33
Reference	50	170

The results show that the strain at failure and the yield stress of the pipe from Thorshalle are significantly lower than that of the reference pipe. This correlates with the poor gelation. Furthermore, in the pipe of Thorshalle a lot of impurities and a skin effect was found. Still, strains of 33 % are generally far sufficient.
The pipe from Nφtterφy is comparable to the reference pipe.

Resistance to abrasion
In a few cases (Nφtterφy and Thorshalle) the abrasion has been determined by measuring the wall thickness along the pipe circumference. Figure 2 of Annex 1 shows the results of the measurements.
When abrasion would have taken place, the bottom part should show a thinner wall. The graph shows that this is not the case. So, abrasion is not a big issue for plastics pipes. Remember from the site description, that in the Nφtterφy pipe a lot of stones have been found during cleaning.

Fitness of joints
In two dug up pipes, joints were included. One joint was tested on tightness for 48 hours at a pressure of .5 Bar. No leakage was found. Both rubber rings were tested on it's elasticity. No brittleness could be observed.

CONCLUSIONS

* The results of the deformation measurements shows that the majority of the pipes studied have been loaded in a severe way. This correlates with the information given on the sites. When the standard installation practices are used much lower deflections will be found. Still the pipes are not damaged nor failure has occurred.

* Some pipes showed to be black on the outside caused by an acid soil environment. This discolouration does not seem to affect the mechanical properties of the pipe.

* The results of MC tests showed that some of the pipes have a poor gelation level, as compared to the currently produced pipes.

* Two pipes were tested on strainability. One showed to be in the same order of magnitude as the reference pipe. The other poor gelated and impurities containing pipe showed less strainability and strength.

* Most of the pipes have been subjected to settlement differences, causing the slope of the pipe to change gradient or even to locally negative slopes. However, due to the excellent hydraulic properties of PVC no blokkage or other discharge problems leading to increased maintenance costs have occurred.

* The results of the functional tests showed that the pipes still fulfil the stiffness requirements, and their functional and structural integrity is still guaranteed.
  The pipes will easily maintain their function for a much longer period than originally, anticipated.
  Considering the fact that the raw material as well as the pipe production process has been improved a lot since the early years, it can be expected that the currently produced PVC pipes fulfilling CEN requirements will last for several hundred years.

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Annex 1

Table 1 : Overview of test sites and results of material characterisation tests.

No	Place	Diam. [mm]	Wallth. [mm]	SDR [%]	Installed	Digged up	Soil type	Installation	Depth [M]	colour	Ash [%]	Chalc [%]	PVC type	Gelation Champfer [%]	Gelation Circumf. [%]
1	Gerzat	200	3.50	51	1966	1991	Sand	Moderate	1.85	Grey	1.42	0.00	Emulsion	0	0
2	Montpellier	315	6.00	51	1968	1991	Rock	Poor	1.75	Grey	0.72	0.60	Emulsion	25	30
3	St. Agathe	400	9.80	41	1966	1991	Sand	Moderate	1.70	Yellow	0.43	0.00	Emulsion	100	100
4	Courchevel	315	7.90	41	1980	1992	Sand	Poor	1.10	Yellow					
5	Odense	160	3.90	41	1970	1993	Sand	Poor	1.20	Orange	0.97	0.50	Emulsion	75	100
6	Nykobing 1	200	6.20	34	1963	1993	Sand	Moderate/poo	2.00	Grey	0.86	0.00	Emulsion	65	100
7	Nykobing 2	200	5.40	41	1965	1993	Sand	Moderate	1.80	Cream	0.80	0.00	Emulsion	25	90
8	Notteroy	250	5.50	51	1972	1994	Clay	Poor	2.00	Brown	1.70	1.80		35	100
9	Thorshalle	200	4.90	41	1970	1994	Sand	Poor	2.00	Brown	1.10	0.83		50	100
10	Reference	250	6.20	41						Grey	2.00	2.30	Suspen.	0	0

All pipes are stabilised by lead

Figure 1 :Pipe stiffness

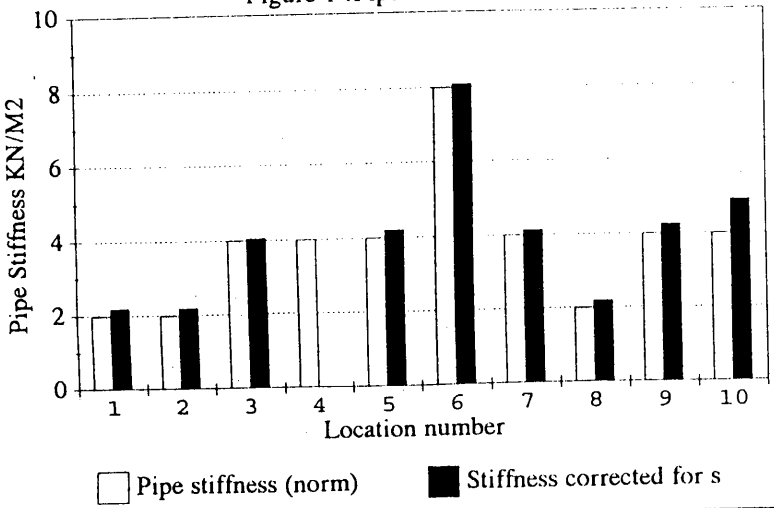
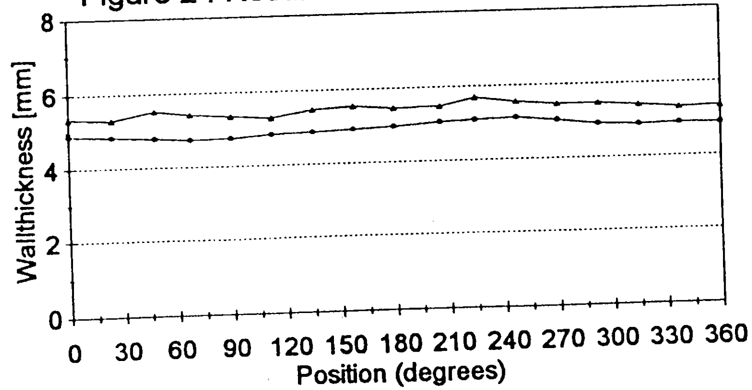


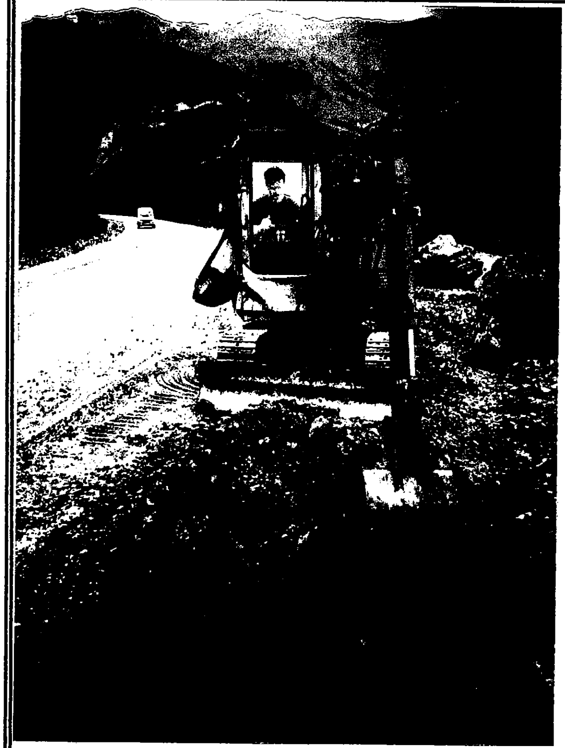
Figure 2 : Results of wear measurement



180 degrees represents the bottom of the pipe.

Wallthickness 250 mm — Wallthickness 200 mm

Annex 2 : Impressions of Digging up the old pipes.

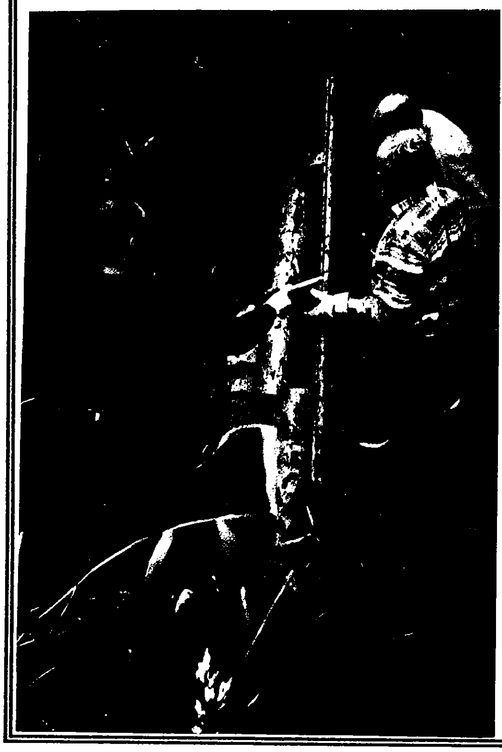


Digging in the French Alps, Courchevel. ▲

Removal of big stone contacting the pipe. ▼

"Patchwork" type of pavement due to settlements, Thorshalle, Sweden. ▶

Cutting out part of the old pipe in Nøtterøy, Norway. ▼



Remeasuring the digged up pipe in Nøtterøy, Norway. ▶