9.1 General data on drinking water network in the Netherlands

Public drinking water supply started in the Netherlands in 1853 in Amsterdam, followed by the city of The Hague in the early 1870's. From that moment on the water companies started all over the Netherlands and the public drinking water supply grew gradually. With the growth of the coverage of the public supply, the network grew accordingly.
From the 1950's onwards the growth of the networks was the largest and resulted in the growth as shown in figure 1.

In 2001 the total length of the piped network in public ground, diameter 50 mm and larger is 110.000 kilometre. This network connects about 6 million household connections with the pumping stations and treatment works to supply drinking water to these houses. The network is still growing by 1000 tot 2000 kilometre per year due to the extension of the cities and new towns. The coverage percentage of 100% is already reached in the early 1970's.

The growth of the network can be divided in three periods:

- From the start of the public drinking water supply till the Second World War
- From WW II to the early seventies of the last century
- From mid-seventies till now.

Each period is characterised with specific use of materials and consequences for maintenance. This will be covered in the next paragraphs.

9.2 Development drinking water network

9.2.1 Development till WW II

The material used in the early years of the public drinking water supply is predominantly grey cast iron. With the start of the industrial revolution in de 19th century, especially in Great Britain the cast iron pipes were made. (In fact the start of the public drinking water supply in Amsterdam was possible through the cooperation of a British steel company.) Gradually also in the other European countries the cast iron pipes were made. There is a large variety in types of cast iron pipes. The most important distinguishing characteristics are:

- o The presence of an internal or external coating. As coating usually a bituminous material was used either as a paint or a thicker coating. The bituminous paint was used to protect the material during the periode between manufacturing and actual usage. The thin coating was called a 'shop-coating'. The thicker layers of bituminous coating were intended to prevent the water to contact the ferrous wall and prevent rusting. Externally the pipes were protected with the bituminous paint.
- o The sizing of the pipe, either in inches or in metric sizes.

As joining technique the lead joints were used in combination with hemp. Figure 2 shows the technique.

Most of the pipes laid in this period still are in function, especially in the older inner cities. The oldest pipes now have an age of 150 years, and the most recent (pre WW II) are 50 to 60 years old.

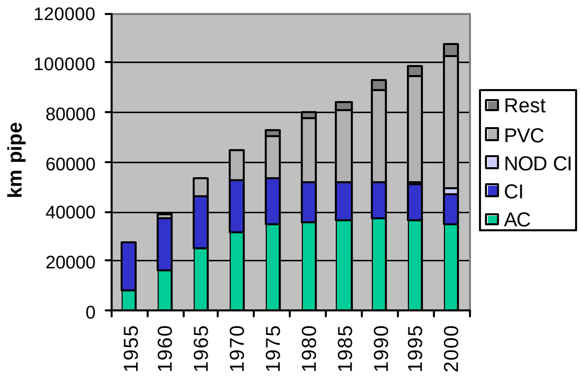

Fig. 1 - Growth of the network in the Netherlands

Fig. 2 - Hemp-lead joining of cast iron pipes

9.2.2 Period from 1945 till early 70's

This is the period of rapid growth of the network. The general post-war growing period combined with the policy of water companies and government to achieve a 100% coverage for the drinking water (as well as the gas distribution). In the first part of this period the new material asbestos cement was highly favourites although also cats iron pipes were laid in this period. The asbestos cement was popular because it was cheap and easy to handle. A length of 5 meters pipe with an internal diameter of 100 mm. Could be carried by one (strong) man and no mechanical equipment was necessary. The material could be processed with simple equipment as a saw. Joining of pipes was done with simple sockets with rubber rings.

Only during the seventies and eighties the dangers of asbestos fibres became well known and water companies stopped using the material.

The ages of the pipes that are still in function are 50 to 20 years old. The majority of the pipes have an age of roundabout 40 years.

Starting in the early sixties the new material PVC was developed and gained popularity very rapidly. Not surprisingly, because the advantages were the same and even stronger than those that made asbestos cement popular. It was cheaper and lighter and even easier to process and join. The production of PVC however was still experimental and recipes for the materials were not standardised. This led to a varying quality of the pipes. Failures of the material in an early stage did not affect the popularity of the material in the Netherlands, but for instance in the UK the material still suffers from the bad image it gained in the beginning days of the materials. Water companies have a very good memory for failures… The oldest PVC pipes have an age of 40 to 50 years.

9.2.3 Period from 1975 onwards

During the oil crisis the basic material for the PVC and the production process was not stable. This led to pipes with a inferior quality. In 1975 forces of manufacturers and buyers were joined and strict standardisation and controlling of the production process was introduced. This led to stable and good quality of the PVC pipes. At the moment PVC is almost exclusively used for new pipes. Half of the 110.000 km drinking water pipe in the Netherlands is now made of PVC.

Experiments were started to use another plastic: PE (Poly ethylene). Advantage of this material is that it can be welded which makes it possible to make a pipe that can absorb tensile tension. Large disadvantage of the PE is that it is semi permeable for oil compounds that are in polluted grounds. The water quality is affected without the pipe being damaged. Also the material gave rise to bacterial after growth in the network. These drawbacks prevented the material from becoming universally used. It is however used in situations that the resistance against tensile tension is imperative. It is also used as a material to make smaller diameters pipes to make the house connections because the material can be delivered on roll and house connections with a length of 10 to 15 meter can be made without junctions.

In the early 80's the use of the material asbestos cement was banned and a 'new' material was introduced: ductile iron. This material was used in situations that soil pollution was suspected or could be expected to be polluted in the near future. The ductile iron is equipped with an internal coating of cement mortar that is applied during manufacturing. Outside coating of PE is used, also applied during manufacturing. Advantage of cement mortar is that small cracks in the lining will repair themselves as a result of a local pH that can become very high. The PE outer sleeve can be easy applied. As joining technique the socket/rubber ring is used.

The pipes laid with these new materials now have an age between 40 and 0 years old.

9.3 The need for maintenance: Asset management

The average age of the network in the Netherlands now is just below 40 years. For a drinking water pipe this is relatively young. However: the oldest pipes are way over a century old, while the youngest ones are laid yesterday. The variety in age also urges for a variety in maintenance needed.

Networks will deteriorate over time, but the initial condition of the pipes is larger than strictly needed. There is some redundancy in the pipe strength. Basic question now is when the deterioration has grown so much that maintenance or replacement is necessary: shortly asset management.

Asset management is the concept that balances the economical and technical lifetime of the assets. In

other words: maintaining the asset in such a way that the optimal performance is reached against a minimum of costs. When we focus the assets to the piped network and the pumping stations a performance level has to be set and the condition of the network should be monitored in terms of this performance.
The minimum performance level is defined within the Water Act in global terms: Sufficient water under

Types of maintenance
Roughly two types of maintenance can be distinguished: reactive and proactive maintenance.
Reactive maintenance is for instance repair of breakdown or other failure. Proactive maintenance is applied to prevent failure. The main driver for reactive or proactive maintenance is the balance between the costs of repair or maintenance and the costs of failure. Also the costs or bare existence of condition assessment methodology is a driving factor.

Reactive maintenance is performed if the costs and impact of failure are low or if there is no economic way of condition assessment or prediction of failure. An example of the first is a light bulb. If it fails there are no extra costs involved and the bulb is easily replaced. An example of the second is the windshield of a car. Failure (breakage of cracking) is not predictable and repair is the reaction to failure.

Proactive maintenance on the other hand is performed when costs of failure are very high and there is a way of economically assessing the condition or a reliable failure prediction method. An example of the first is nuclear energy. Failure is realistically unacceptable and thus every maintenance action is aimed at preventing failure. Another example is the wearing of car tyres. The condition is easily (visually) assessable and costs of failure are high.

In maintenance of piped networks on the one hand the costs of failure are objectively low, but subjectively can be large. The financial impact of the fifth burst in a pipe in a short is the same as the first one, but the social impact of the fifth is much higher than that of the first. Condition assessment is difficult because the assets are mostly below ground and not easily accessible.

sufficient pressure as public health urges for. This indicates that not only a quantitative service level has to be maintained (sufficient water under sufficient pressure), but also a qualitative (concerning public health). The quantitative level is more specifically quantified in the minimum pressure requirement in the network and in the quantitative guideline for reliability (see chapter 6). The level for water quality is defined in the water Act as well as it concerns the health related parameters. Aesthetic parameters in term of taste, odour and colour are less strictly defined and leave space for company policy.
Apart from the legal requirements as laid down in the Water Act, water companies also use own policy requirements aiming at the overall level of service that has to be supplied to the customer. The definition of the level of service is subject to debate within the industry and is a true asset management issue. What level of service can be reached against optimal costs (notice Optimal instead of Minimal).
In this chapter a global concept for asset management is discussed. Interpretation can vary over the industry depending on how the company policy is focussed between the extremities of total customer focus and total technical focus.

9.4 Basic concept for asset management

Within the joint research program of the Dutch water companies a model is developed to visualise the different components underlying the asset management. The model is extensive and complete, but also illegible as is shown in figure 3

In this model the coherence of all the possible elements that play a role in asset management are connected to each other. The start of the model is in the left with the network. The first step in analysing is to segment the network in elements that have the same characteristics. Following the line in the graph leads to the ageing model. The pipes age under influence of internal and external loads visualised in the model and will deteriorate over time. The critical level in deterioration will be given by the customer perception, which is flexible over time and place. A pipe in a busy shopping mall must meet higher standards than a pipe connecting only an individual dwelling to the network.
Other society impacts are the rates for insurance and

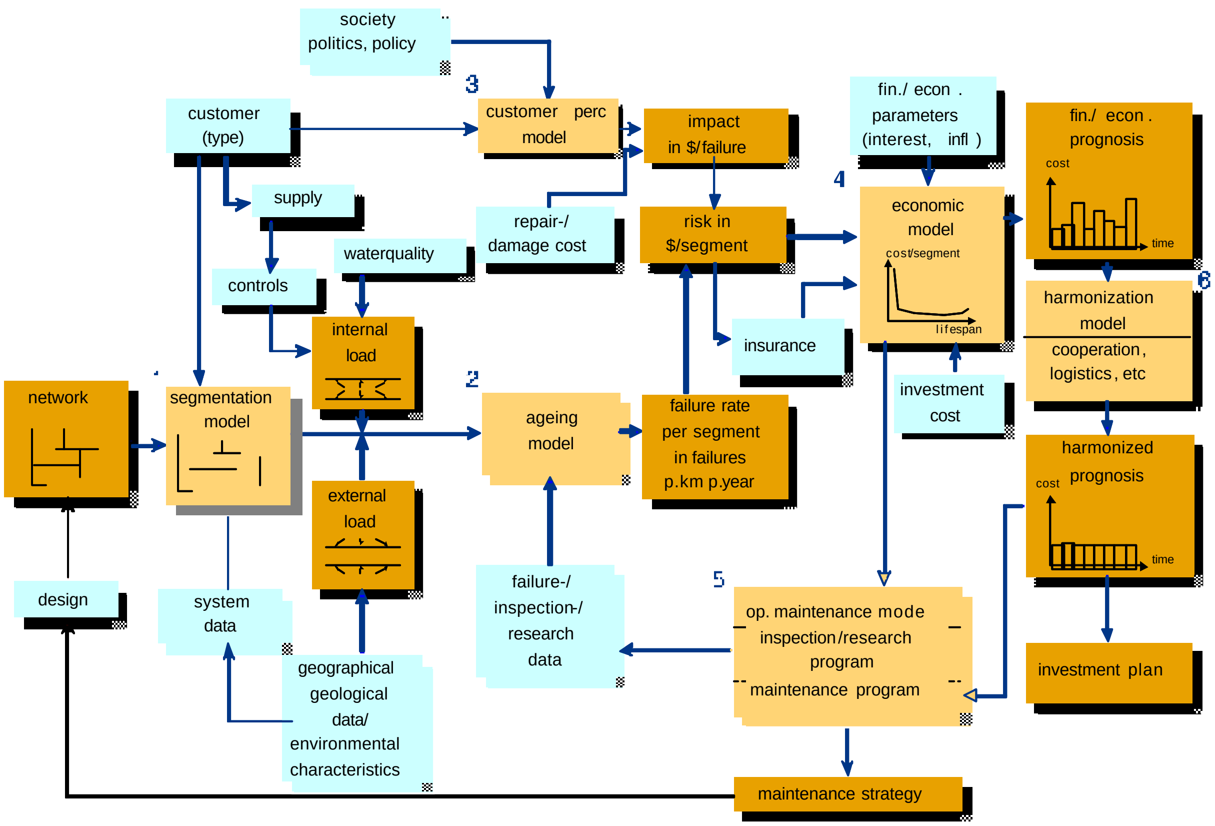

Fig. 3 - Asset management model

impact, political developments and will result in a risk per segment. This is monetarised into money per failure, but this a very subjective action. Eventually this leads to a financial prognosis that can be smoothed over time to a harmonised prognosis. This means that some maintenance is done before strictly necessary and some 'too late', with all its impact.

A simpler version, concentrating more on the degradation aspects of asset management is given in figure 4. This model has the form of a decision support model.

The elements of the model will be discussed in more detail.

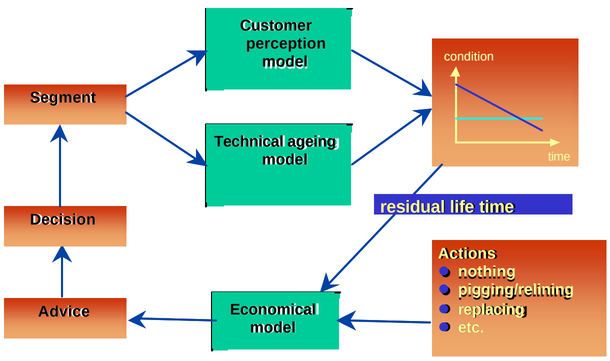

Fig. 4 - Decision support system for piped networks

9.5 Technical ageing of pipe materials

Basically the material pipes are made off will deteriorate over time. Cast Iron will rust and loose strength, as will AC as result of leaching of material. Based on a assessment of the present condition the deterioration over time can be determined considering that the original condition was 100%. This is visualised in figure 5.

In the figure 5 the assessment of the condition took place in the year 2000 and was found to be X% of the original 100%. How this is determined will be explained later on. Based on a minimum requirement for this pipe, the customer perception, and an assumption on how the deterioration will propagate

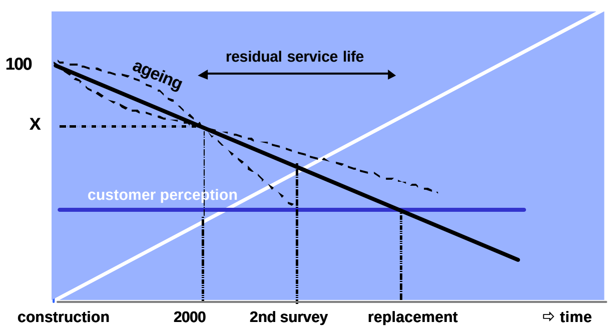

Fig. 5 - Estimated residual lifetime

over time, the residual lifetime can be determined. In this picture a simple rectilinear relation is assumed, but more complicated relations are also possible. However with a relative lack of knowledge the rectilinear relation gives a good impression of the expected lifetime. It is also an indication on when to do a second survey of the condition to see how the development is and base decisions on it.

9.6 Condition assessment of cast iron

Cast Iron is the oldest material in the drinking water networks. The oldest pipes date from 1850's and the youngest around the late 1940's. The original condition of the pipes is often not well documented. The main deterioration process of the material is corrosion (rusting), which has consequences for:

- Strength
- Hydraulic capacity
- Interaction with water quality

On this three criteria the condition is assessed.

Strength

First analysis concerns the failure rates of the pipe. A failure is a good indication that something is wrong with the pipe and analysis of the failures gives information about the condition of the rest of the pipe. Basic question is what the major cause of the failure was and whether it was material related or environment related. A failure a result of someone damaging the pipe has obviously nothing to do with the material and can be considered as an incident.
Taking a coupon out of the pipe and examine this is a proactive assessment of the strength of the pipe. (see figures 6 and 7)

Fig. 6 - Coupon sampling

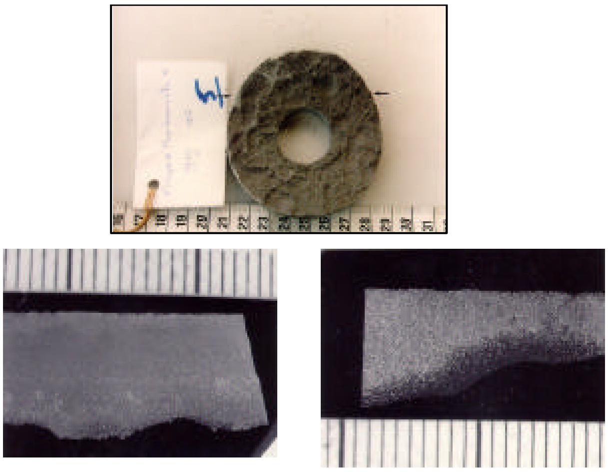

Fig. 7 - Coupon after sandblasting and assessment of residual wall thickness

Hydraulic capacity

The hydraulic capacity of the pipe is affected by the growing of corrosion products at the inner wall of the pipe. This corrosion results in voluminous deposits in the pipe as is shown in figure 8.

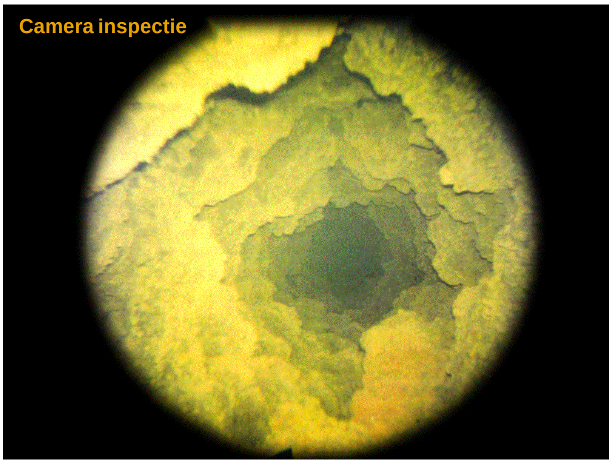

Fig. 8 - Vast iron pipe with corrosion products

The effect of the deposits can be visually assed by camera inspection. The camera is inserted in the pipe (figure 9) and pictures can be taken. One must realise that only a limited part of the pipe can actually be seen.

To get a more general impression of the hydraulic capacity of the pipe a hydraulic capacity test can be carried out. A schematic of this test is demonstrated in figure 10.

At two points the pressure is measured while a known volume flow is transported through the pipe. With the known length between the pressure measuring

Fig. 9 - Camera for inspection of the pipe

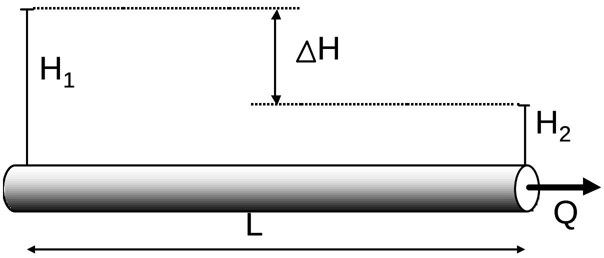

Fig. 10 - Hydaulic capacity test

points and the assumption that the roughness of the pipe is 0,05 (equal to a PVC pipe) the hydraulic diameter of the pipe can be calculated using Darcy Weissbach.

Interaction with water quality

The corrosion of the cast iron can have an effect on the water quality. The water will discolour and become more turbid if the corrosion process actively releases parts to the water. With a continuous monitoring of the turbidity this can be assessed. Figure 11 gives two patterns of turbidity in a cast iron network.

The left graph shows a pattern that is smooth and equals the pattern as it leaves the treatment plant. The second pattern has a daily fluctuation, which has no correlation with the treatment plant pattern. A rise of turbidity during night hours indicates a release of corrosion products causing this increase in turbidity.

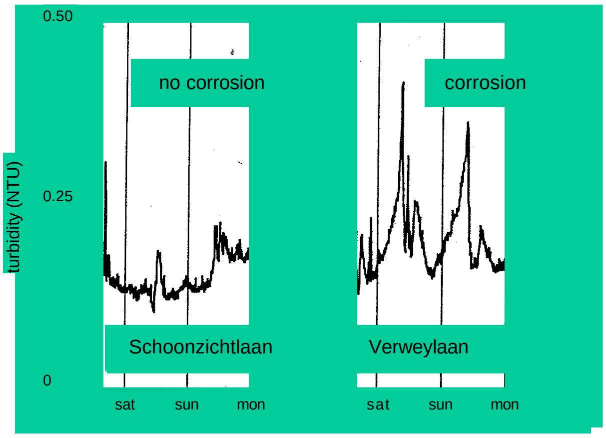

Fig. 11 - Turbidity patterns in a cast iron network

The ris is not recognisable during the day hours because residence times then are smaller and the water does not have the opportunity to pick up the particles to a level of increase of turbidity.
This pattern is typical for an active corrosion process. An intense form of this corrosion often in seen after a too rigorous cleaning of the cast iron. The protective layers of corrosion products are damaged giving the material a chance to release corrosion products again.

Overall condition valuation

The values obtained with the several methods are weighed and an overall valuation of the condition is obtained. Strange as it may seem this is dependant of company policy and customer perception and not an absolute figure. If for instance the tolerance for bursts is high, then strength is of less importance than hydraulic capacity.
The various condition factors are weighed on a scale from 0-100%, mostly through classification in three to five classes. Every factor weighs in its turn in the overall condition assessment and will give an indication of the overall conditions. This method allows for several factors to be considered but also to assess the condition based on only one factor. If for instance only the hydraulic resistance is known, the overall condition is equal to the score for the hydraulic condition. If more factors are known, for instance the hydraulic resistance, the impact on water quality and the residual strength a more reliable condition assessment is feasible, if possible with a weighted impact. If burst has severe consequences residual strength is more important than hydraulic capacity. This leads to a sophisticated judgement on the condition.

Results of long term assessment of cast iron

Within an extended evaluation of cast iron condition assessments some general conclusions can be drawn.

The corrosion process is not homogeneous. It is possible that a number of pipe segments are heavily corroded while other segments in the same pipe are not corroded. Also the corrosion is local, leading to weak spots in a segment. The weak spot may cause a leakage and some times a burst. Repairing these weak spots gives a good pipe in return. A leak or a burst is not necessarily an indicator for further trouble with the pipe.

All this makes it difficult to give a reliable estimation of the lifetime expectation of cast iron pipes. The impact on water quality and hydraulic capacity are the most important factors to built a decision for rehabilitation on.

9.7 Condition assessment of asbestos cement

Asbestos cement is the material that was used for the major expansion of the network post 1950. At present 33% of the totale length of the network is composed of AC. The main deterioration process of AC is the leaching of $Ca(OH)_2$ leading to loss of material and strength. The attack can be both internally because of the water transported and externally because of acid ground water. The consequences are towards the strength of the pipe and to the water quality.

A complicating factor in the handling of AC is that it is strictly regulated because of health consequences of working with asbestos. Basically this restricts any routine testing to the location in which the AC pipes are found. Testing methods should be field tests. Also the material should be wet to prevent the asbestos fibres to be released from the base material.

Strength

To assess the amount material lost c.q. the amount of material left the so-called Phenolphthalein field test is developed. In this test a pipe sample is taken and the chemical indicator Phenolphthalein is dripped on the surface. In the places the material has lost its integrity because of the leaching the Phenolphthalein stays colourless, while in the sound areas the Phenolphthalein will colour purple. This is demonstrated in figure 12.

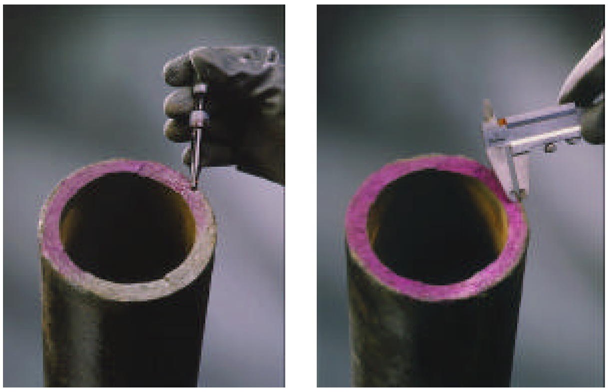

Fig. 12 - Phenolphthalein field test

Simply simply measuring the grey areas can assess the degree of deterioration. Of most of the pipes data on the original pipe wall thickness is available.

Disadvantage of the method is that it is a destructive one. As alternative the geo radar method is developed. The principle of the method is shown in figure 13.

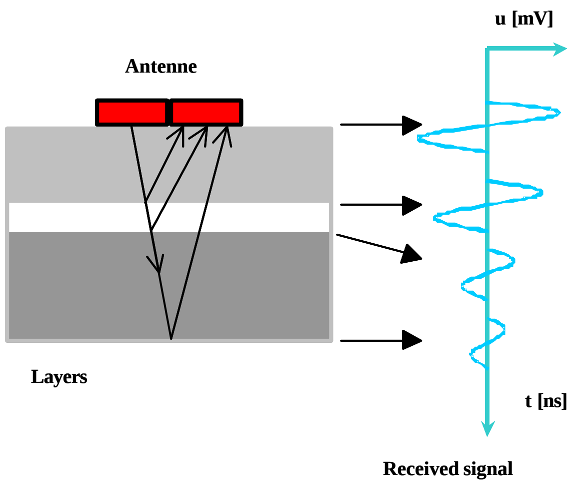

Fig. 13 - Principle geo radar method

The method is based on the principle that the reflection of radar waves is different in the layers saturated with water and the water free layers. A layer that is saturated with water the calcium, hydroxide is leached and strength is lost.

Interaction with water quality

Leaching of calcium hydroxide changes the pH of the water. With continuous monitoring of water quality this can be measured in the network. An example of this is shown in figure 14.

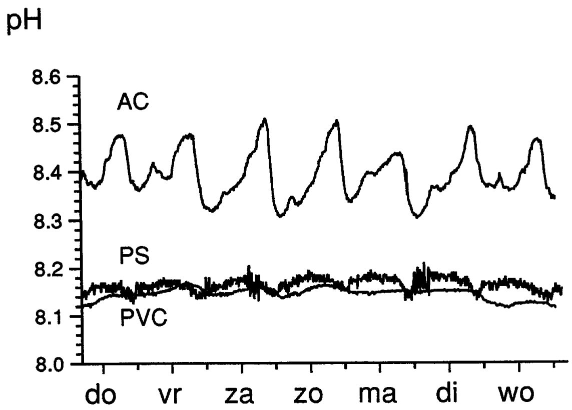

Fig. 14 - Changing of pH as results of passage to AC pipes

In unfavourable circumstances (long residence times and aggressive water) the pH can reach values like 11 or 12. Although extreme and rare these values do appear.

Results of long-term assessment of Asbestos Cement

The condition assessment methods for AC pipes are fairly reliable in giving a good picture of the material lost and the residual strength. The deterioration mechanism is more global, meaning that the condition found is representative for almost the complete pipe. This also indicates that failure of the pipe that can be related to a poor condition an indicator is for future bursts.

9.8 Condition assessment of PVC

PVC is the most modern material and is the predominant material in the Dutch drinking water network. Almost half of the pipes are made of PVC.
At present there is little known about the chemical degeneration of PVC drinking water or sewerage water pipes. Likely is that the chemical degeneration is almost non-existent. Recently some research has been done to the degeneration of PVC pipes.

Quality differences in PVC

Up till 1975, manufacturers of PVC used different and sometimes experimental recipes for the production of PVC pipes. This resulted in different qualities and properties. Moreover some material features like the degree of fusion were not used as a quality feature.

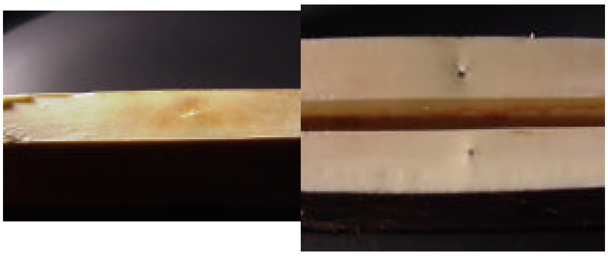

Fig. 15 - Typical break surfaces of PVC. Left the micro cracks in the material itself and right the impurity os origin of the crack

Ageing processes PVC

The degeneration of PVC is physical/chemical or mechanical.
For chemical degeneration mostly an external agent is involved and will result in weakening of the material. Weakening can occur as result of the influence of glue or soap (sometimes used as a greasing agent to fit the joints) of polluted soils with benzene or toluene and similar agents. UV-degradation is the most well known aspect of degeneration of PVC, but that only works for water pipes when they are stored in open air. In normal practice UV-degradation is of no importance for drinking water pipes.
Recently some more insight in the behaviour of PVC has emerged. The influence of micro-cracks seems to be most important in the behaviour of the PVC.
In the production process of the PVC pipes, micro cracks will be generated in the material. At the ends of these cracks tension will occur that can lead to a propagation of the cracks, if loading of the material is varying. If loading is constant or the variation is limited the cracks will not propagate. Eventually under unfavourable conditions the cracks will grow and weaken the material locally and at some point the crack will break through leading to the typical failure of a PVC pipe with a long break surface and a sudden impact (split pipe).
Another cause of failure can be a crack around an impurity of the material. This can be a small piece of iron or other material originating from the machines the PVC pipe is produced with.
Figure 15 shows the two types of failures with the typical break surface.

Condition assessment methods for PVC

As condition indicators for PVC the K-value, the degree of fusion or gelation and the ring stress test are available.
The K-value is determined by specialised laboratories and basically determines the molecular weight of the material. This is a quality indicator for the raw

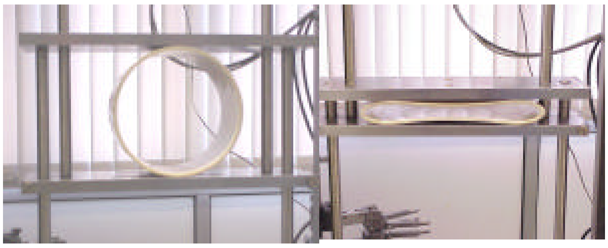

Fig. 16 - Ring stress test on PVC pipe

material the pipe is made of. This value is now a quality index for new material and doesn't change much over time, as the chemical ageing process is not significant. This test is applied to the older material (pre 1975) to determine the original quality. The test is costly and is not used on a routine base.
The degree of fusion or gelation gives an indication on the homogeneity of the material and is a measure for the quality of the extrusion process. If gelation is too much the pipe can break brittle and with too low degree of fusion the pipe can tear or craze. This degree of fusion is also a factor that doesn't change much over time and mostly applied to categorize pre-1975 pipes. Degree of fusion is a quality parameter that was not used in the early days of PVC and can vary over different pipes.
In the ring stress test a ring of the pipe is tested on the behaviour under extreme circumstances. A brittle crack is an indication for too much gelation, a tearing or crazing for too little gelation and a plastic distortion for a 'good' pipe. Figure 16 shows a ring test on a good pipe.

Results of long-term assessment of PVC
As the material PVC is relatively young, not so much data is available for a long-term assessment of the ageing of the material. As a schism the production year 1975 can be used. Pre 1975 pipes were subject to less strict material specifications, leading to a varying quality of pipes, even from the same manufacturer.
Post 1975 pipes are subject to more strict material specifications that even develop further. Indications at this moment are that the expected lifetime of PVC pipes is very long as circumstances are good. The stress situation and more importantly the variation in stress is a deciding factor in the expected lifetime.
If failure occurs the analysis of the break surface in combination with an evaluation of the stress situation gives an indication of the residual lifetime. If the break is induced by a material impurity one can speak of an accident that will only be repeated if more impurities are present. If the break is induced through a micro-craze that cannot be avoided in the material, than more breaks should be expected. The combination of loads and the variation has propagated the micro-cracks, and this will happen again.

9.9 Customer perception

Customer perception determines the minimal conditions a pipe or network should meet. This is visualised in figure XX. Customer perception is not equal over the whole system, because the consequence of failure is not the same all over the network. The consequence of a break in itself can be very large in for instance a busy shopping area or near heavy traffic points. The disruption of a street has more consequences if a busy traffic lane is affected than when a street in a residential area is affected.
Customer perception is also quantified on a scale from 0-100 and can be related to the condition on the same scale. This method is still experimental and is tested and further developed within the water industry. Basically two types of criteria are used. First category criteria determine the impact of failure. Examples are the sensitivity of the supply (a hospital or office building is presumed to be more sensitive than a group of households), the time it takes to restore the supply, traffic disturbance, safety factors in the actual repair, possibilities for follow-up damage or flooding, etc.
The second category is the frequency of failure. The psychological impact of the first failure is different (less) than that of the second, third and more failures within a period of time. The failure frequency has a multiplying effect on the impact criteria. This is visualised in figure 17

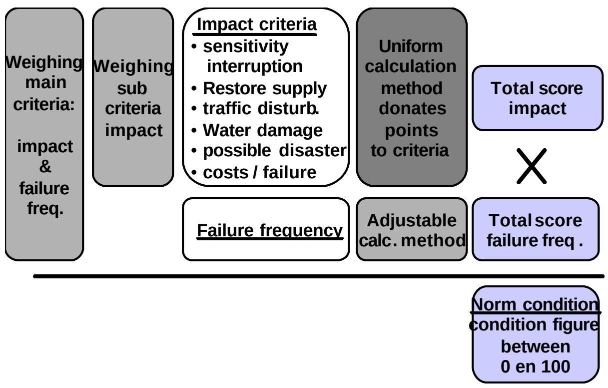

Fig. 17 - Customer perception calculation

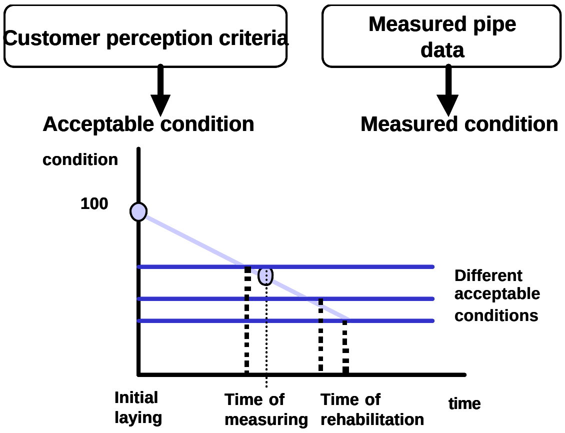

Fig. 18 - Dynamic customer perception

Customer perception is a dynamic item. The customer perception can change over time and will change when multiple failures occur in a restricted area and limited time. Figure 18 summarises this.

Both methods for determining the actual condition of a pipe and the customer perception are still being developed and implemented.