MAINTAINING SEWER SYSTEMS

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INDEVELOPMENT

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Edition 2006.

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1 INTRODUCTION

Sewerage systems are complex technical systems often composed of many different technical elements. Some times the systems is operated and owned by different actors. Usually all technical elements located on private property is owned, used and therefore should be maintained by the owner of the private property. The government or a governmental company usually owns the infrastructure located at the public domain.
In most countries different levels of government are involved in the provision of sanitation services. And in many low and middle-income countries NGOs tend to substitute the government's role as a provider and operator of the services.

2 MAINTENANCE OF PRIVATE INFRASTRUCTURE

A privy is basically a pit in the ground to collect the excreta, covered with a slab (and hole) and some kind of shelter. There are several types of privies varying from dry to wet disposal techniques. It goes without saying that privies should be thoroughly cleaned on regular basis. For a small family once per week is the minimum, but if privies are used for public use, they should be cleaned daily if not more frequent. It is necessary to inspect the privies for public use at least once per month. The slab should be examined for cracks or other damages. During these inspections special attention should be paid to the lid and the mosquito/fly screen. The surroundings of the privies should also be checked with regard to appearance of termites. Termites may cause damages in the timber structures and should therefore be killed. The fly screen should be cleaned every 6 months.

Pit latrine

The average replacement lives of latrines are usually:

- Pit latrine 4-6 years
- VIP 10 years

However this depends largely on the size of the pit and the number of users. A general rule of the thumb is to empty or start preparation for the construction of a new pit latrine when the contents in the pit reach 1.0 to 0.6 meters below the slab. 0.6 meters is considered the fatal limit, because this space must be refilled with soil after which vegetation can be planted.

Aqua privy

Aqua privies have drop pipes. These drop pipes need to be inspected at least once per six months. It should not be rusting or rotting and it should reach into the liquid. Every so many years the vault needs to be emptied. The emptying of the vault is a condition-based activity. If the depth of the sludge is more than half the liquid depth the vault needs to be emptied. Inspections are usually carried out on a yearly basis. Depending on the size of the tank and the number of users the tank requires emptying every one to five years. Furthermore monthly inspections are required to identify defects on the squatting pan, seat or U-trap.

Compost toilets

Compost toilets require many operation activities. It is recommendable to fill it each day with some grass, kitchen remaining, straw, etc. Once or twice per week the whole contents of the vault should be covered. Also once per week the toilet slab should be cleaned, but without using water. Usually ashes or powdered earth is used. The vault will fill with excreta and other materials. When the contents reaches 0.2 meter below the squatting slab the vault will be closed and another vault needs to be opened. The closed vault should be filled with fine soil. After 6 months the compost is ready to be removed from the vault.

A layer of leaves, weeds, grasses or similar material has to be thrown in the empty vault prior opening and use. Although compost latrines are reported to have a long life it is still recommendable to inspect the structure on a monthly basis.

Bucket latrines

Bucket latrines require emptying of the bucket whenever it is full. A bucket is likely to be full within one to three days. Once per month inspections are necessary of all the vital items, like: fly proof door, base of the latrine and the privy shelter.

3 SEWER SYSTEMS

3.1 OBJECTIVES AND DAMAGES

The objective of sewer systems is considered to be crucial in the design of their maintenance control systems. The main objective of maintenance control is to guarantee a well functioning sewer system against the lowest possible costs. To achieve this goal, it is necessary to carry out three kinds of activities:

1. Inspections
2. Repairs
3. Rehabilitation and renovation

Besides these activities it is necessary to develop maintenance plans and whenever required the plans have to be modified. These maintenance plans have to be designed on basis of the performance criteria for the whole sewer system. To be able to evaluate the performance of the system, the planner needs to generate information about the sewer system, like:

- What kind of water does it transport
- What is the composition of wastewater

Technical attributes of a system

Like roads it is possible to describe a sewer system in links (mains) and nodes (often access holes). There are different kinds of nodes that all have different functions. Certain nodes just connect two or more pipes but others actually have to lift the wastewater, the so-called pump-stations. The links are the pipes. The pipes all have more or less the same function but differ in materials, shape and size. Furthermore sewer systems may have other technical parts, e.g. air-loc balls, and overflows. And no sewer system is complete without a waste water treatment plant.

Performance objectives sewer systems

The performance targets of the overall objectives of the sewer systems can be summarized as:

- Protection of public health
- Drainage of storm water
- Protection of ground, and surface waters against pollution
- Reduction of inconveniences

Hydraulic capacity

These objectives need to be translated in aims, which can be measured with objective verifiable indicators. The most common aims are:

- Sufficient capacity to transport waste water to sewer treatment plant
- Sufficient storage capacity

This means that hydraulic capacity of the system should be adequate. Pipes should not be blocked. The pipes should be water tight. They should not leak and infiltration should not result in frequent spills and/or heavy surcharge. The frequency of flooding shall be limited to prescribed standards. Floods shall not unnecessary impair quality of life in society nor result in high social and/or economic costs.

Environmental performance targets

Typical environmental performance standards relate to odour nuisance and contamination of groundwater, soil and public water, which are used for swimming, washing and fishing.

Structural performance targets

Sewers must be structurally sound. They should remain in such a structural condition to fulfil its hydraulic and environmental functions. Thus, they should not collapse. They should also not contaminate the environment through leaks. Infiltration affects the hydraulic function of the sewer system. They also create voids in the soil mass that could lead to cracks in the pipes.

Damages

Damages of sewer systems can be grouped in three classifications:

1. Hydraulic capacity problems
2. Environmental problems
3. Structural damages

Very often these damages are interrelated. For example the insertion of new laterals is one of the major causes of failing sewer utilities. Population growth and increasing concentration, due to increasingly higher buildings, result in a demand for sewer connections. These new connection consume hydraulic capacity. They also change the stress composition in the pipes and the soil. If the new joint between the lateral and pipe does not allow for movements, the life of the sewer pipe may significantly be reduced.

Insufficient hydraulic capacity may eventually result in environmental problems. Signals that there are problems with regard to the hydraulic performance of the system are often environmental in nature e.g. flood during heavy rainfall, pump station overflows, sewer system overflows and by-passes, surcharging manholes and odour complaints. Another but very important indicator is larger than anticipated flows measured at the wastewater treatment plant. Such flows indicate infiltration of groundwater in the system. Infiltration occurs through the leakages in the pipes. Inflow is the result of rainwater that enters through connections like manholes.

Leakages either cause pollution of the environment (groundwater and soil) or reduce the functional capacity of the sewer systems and treatment plants through additional inflows of groundwater. Wastewater treatment is often designed on basis of assumptions about the composition of the waste water. When this composition changes the efficiency of the treatment is affected.

Leaks are not the only cause of hydraulic problems. Sewer systems may be blocked by debris or in-growing roots. Due to settlements, the slope of the pipes changed and in the worst case reversed. The pipe may be deformed, etc.
It is also possible that original design criteria are no longer valid. The sewer system may have to collect more waste or rain water than originally foreseen, i.e. because of changes in the sewer catchment area, e.g. new built-up areas deposit in the existing system.

Structural damages

Leaks and in-growing roots are typically the result of cracks in the mains and manholes. Cracks and deformation are often the direct causes of collapsing mains and are usually the result of insufficient bearing capacity. The latter is often the result of the chemical processes in the pipe and the loading pattern on top of the pipe. Due to chemical process, the thickness of the pipe deteriorates and subsequently its bearing capacity. A typical example is the development of H_2SO_4 will develop in the sewer pipe. This gas may develop a sulphuric acid that chemically attacks concrete pipes if it is susceptible to microbial induced corrosion. This corrosion “eats” the cement cover away, exposing reinforcement bars.

Chemical composition of waste water

All materials react different to chemical and thermal pollution. Earthenware mains are extremely resistant against all sorts of chemical substances. Concrete has a low resistance against organic acids and its resistance against oils, grease, esters and salt solutions differs largely. PVC has low or mediocre resistances against substances like aromatic hydrocarbon, ketone bodies , esters, wastes from halogen chemical processes and ether.
PE’s and PP’s resistance against these component is better than that of PVC, but it is not as resistant as concrete. Glass reinforced plastics have high resistance against most chemical substances but its resistance is doubtful against exposures of ether and oxidation media. Stainless steel is another often used material for construction of mains. It has high resistance against most substances. Other metals are less suitable for transport of sewerage.
Various ISO norms present the resistance of the materials against different exposures. For example ISO TR 7473 and ISO TR 7474 describe respectively the resistance characteristics of PVC and PE. The resistance against diluted substances is considerable higher. The first step is to analyse the chemical composition of the sewerage. The second step is to determine if main is resistant against these chemical substances. For those substances for which the main is not resistant: Calculate the relative concentration of the substance in the sewerage. For example the sewage contains 100 mg benzene and 5 mg pentachlorophenol. The saturation concentration of these substances in water are respectively 1780 and 14 mg/l. Thus the sum of the relative concentration of these substances is $(100/1780 + 5/14)*100=$

41.33%

The maximum sum of the relative concentration in gravity and vacuum mains are respectively 10 and 5%.

This process can only be applied when the temperature of the sewerage is less than 40 degrees Celsius. When the temperature of the waste water is higher, special rules apply. Sewer utilities are advised to involve the producers of the pipes in the analysis.

The chemical processes are not the only cause of decay of the system. Other causes are:

- Erosion
- Construction, maintenance and design errors
- Damages because of (construction) activities by others
- Frost damages
- Aging and high temperatures (deformation of plastic pipes)

Grey Iron Pipes

The most common problem of grey iron pipes is corrosion. This graphitisation process results in weakened layers on both sides of the pipe wall. This damage is progressive in nature and eventually results in reduction in the structural thickness of the pipe.

Ductile Iron

Pinholing is more common with pipes made of ductile iron. Pinhole damages can progress very rapidly.

Asbestos cement

Acid conditions both in the waste water and in the soil seem to be the major cause for decay of asbestos cement pipes. Such attacks can be recognised by swelling and softening of the pipes surface, effectively reducing its wall thickness and subsequently its crushing strength.

PVC pipes

Over time PVC pipes tend to develop cracks and eventually in brittle fractures. This process is caused by aging and is slow and linear by nature. This process can be forecasted with the stress-rupture test.

Polyethylene (PE)

Like PVC, PE tends to develop cracks and brittle fractures. In addition another major deterioration process takes place. PE softens and loses its strength as a result to hydrocarbon.

Glass Reinforced Plastics (GRP)

Like other plastic pipes, GRPs are subject to stress-rupture. In addition it is sensitive for strain-corrosion. Strain corrosion is a loss of strength due to high levels of strain in an aggressive environment. It is not possible to provide generic information about the progression of these damages in GRPs, because of its relative young age and varying compositions from different producers.

Brick sewers

The most dominant cause of damages of brick sewers are the same of any brickwork erosion and degradation of the mortar joints. Loss of mortar can result in collapse of sections of brickwork. Regular pointing can result in eternal lives of brick sewer systems.

In a nutshell

Thus often the functional performance of the system is caused by structural damages of the system. Sewer pipe failures often start with cracks that evolve in fractures, potholes and finally collapsing mains. Other typical structural failures present themselves as sagging crowns, lateral deflections, open or displaced joints, surface damages and even exposed reinforcement bars.

3.2 INVENTORY

Any maintenance department needs a database about the inventory of the assets under its responsibility. Ideally this database is a GIS or organised on basis of geographic locations, like link and node numbers. The database would contain the following information per link/node:

- as-built drawings, including backfill
- inspection reports
- repair/rehabilitation/replacement reports
- customer service records
- system attributes
- Other critical decision-making factors (e.g., the presence of essential services, hospitals, schools)

System attributes

The system attributes describe network like:

- Type of waste water (storm, combined, sanitary)
- Operation (gravity, vacuum, open hannel)
- Year of construction
- inverts of pipes both upstream and downstream
- Pipe diameters, shape and material (name and address of producer)
- Elevation of manholes
- Type of backfill
- Ground water tables
- Capacity of pumping stations
- Direction of flow
- Road classification or traffic volume or loading
- Soil conditions
- Depth of bury
- Appurtenances:
  - air release chambers
  - catch basins
  - drain chambers
  - gates (check valves, flap gates, sluice gates)
  - inspection chambers (clean outs)
  - laterals (service connections)
  - manholes (maintenance holes)
  - pumping stations
  - retention reservoirs (ponds, storage tanks)
  - valve chambers.
- Nature of effluent (agricultural, residential, commercial, industrial)

Planners should indicate which pipelines will pose serious threats to the environment and public health, in case of a collapse. Ideally these mains are presented in red on a map.

3.3 INITIATING MAINTENANCE ACTIVITIES

Flushing and cleaning

An important intervention is flushing or cleaning of pipes. Large sewers on adequate slopes may never require such interventions; other sewer systems require flushing and cleaning every month or every year. Depending on the system it is possible to indicate the frequencies for flushing and cleaning.

System	Annual Pollution	Frequency of Flushing and Cleaning
Combined systems	• 30-50% • 15-30% • 0-15%	• Every year • Every 3 years • Every 5 years
Sanitary sewer system	• 30-50% • 15-30% • 0-15%	• Every year • Every 2 years • Every 4 years
Storm water Sewer systems	• Pipes • Sand collection • Storm-water inlets	• Every 20 years • Every year • Twice per year

The pump stations need to be cleaned every two months. Once every five years it is necessary to paint the metal boxes covering the electronic control systems. Tide gates need to be cleaned after every heavy rain shower.

Inspection frequencies

It is necessary to inspect the collection systems for structural soundness at least once every ten years, when the sewer system is older than 15 years. It is advisable to inspect sewer systems more frequently when problems have been reported, e.g. gas or water leakages, deforming roads etc. Furthermore inspections should take place two to five years after cleaning/flushing the system. Combined systems are usually inspected every five years and sanitary sewer systems every four years. So-called critical pipes may have to be inspected more frequently. A link can be considered critical when the financial and socio-economic costs of repairs and rehabilitation are expected to be high. For example pipes under highways and urban arterials are often considered critical. When failure is expected due to age or other causes, pipes should also be earmarked as being critical. Concrete pipes that are subject to sulphuric acid attacks may require more frequent inspections. When pipes have a history of damages, they should also be earmarked as being critical.
The consequences of sewer collapses differ depending on the number of customers in low-lying areas of a sewer catchment area. Thus higher located mains may pose higher risks to the sewer utility, as more downstream customers will be affected by a collapse. Sewage may flow into homes and businesses, who may claim compensation for the damages.

Pumps and sewer systems under pressure should be inspected at least once per year but the inspection preferably takes place together with other activities.
For a non-man entry sewer a CCTV survey normally forms the basis from which a structural assessment is undertaken. The sewers may require pre-cleaning by jetting or flushing to enable the CCTV cameras to access the sewers and to improve what may be poor visibility.

Initiating replacement/ rehabilitation

The life expectancy of gravity sewer systems is very high, on condition that the quality of construction was high. The quality of the concrete and the joints are crucial for the life expectancy. If high quality products and construction were used, it is likely to expect that a sewer system will last for at least fifty years.

Use-based models to predict the end of asbestos and earthenware mains can be used. The average life of asbestos cement main is about 60 years and that of earthenware main is even 70 years. With regard to asbestos cement pipes it is recommendable to carry out replacements or rehabilitations anywhere between the age of 40 and 80 years old. With regard to earthenware mains it is reasonable to advance or delay replacement/rehabilitations in a time span of 40 to 120 years. In both situations, maintenance planners to rely on condition-based maintenance models, as mains from both materials can become well over 200 years of age.

It is not really justified to apply use-based models to initiate replacements/rehabilitation of concrete mains. For budgeting purposes; the average life of concrete mains is about 70 years.

Structural analysis

In most situations it pays of to conduct structural analysis to estimate the remaining life of mains. Advancing replacement or rehabilitation is very costly, but the consequences of collapses as a result of delayed maintenance are even larger.

Initiating repairs

Unlike with roads it is not possible to develop a use-based maintenance system where periodic maintenance is carried out. Sewer systems require condition-based maintenance. This means that the conditions will be observed and measured. Visual inspections like the use of CCTV equipment can be used to locate damages. But not all damages can be observed from the inside of the pipe. Some damages are initiated from the outside or even within the pipe material itself. The sewer can appear to be reasonable sound from an internal CCTV inspection, but might, in fact, be on the brink of a catastrophic collapse. Visual inspections, however do give first impressions about assessment of the size and cause of the damage, but do not present any information about remaining wall thickness. Information which is crucial to estimate the remaining structural life of the mains. It is very difficult to draw conclusions about the remaining structural life on basis of visual inspections alone. A practical approach is to plan repairs within timeframes of five years. The selection of the actual repair and year of implementation should depend on detailed assessment of the causes of the problem, assessments of the remaining life of the asset, the chance of collapse and their respective consequences. The chances that a sewer collapses and the respective consequences determine the urgency for preventive maintenance. Consequences are considered severe when they threat loss of life, collapse of buildings etc. The chance of collapse is a proxy of the remaining safety factor. This requires information about the loads on the sewer and its remaining load-bearing capacity. A safety factor of 1 means that the sewer is at the virtue of collapsing.

Intervention levels

The intervention levels of damages vary according to the performance requirements. Mains and sewer systems may have more or less over-capacity. This over capacity determines if a certain reduction of hydraulic capacity is still acceptable. Furthermore the materials of the mains all have there specific characteristics. Pipes may be rigid or flexible in nature. Concrete pipes are more sensitive for sulphuric acid attacks when the flow velocity is low. They are also less capable to deal with sagging inverts and crown unlike the more flexible plastic and metal pipes.

Planners can therefore not just copy and paste intervention levels presented by organisations like WCr, IRC or RIONED but have to analyse hydraulic performances and requirements and specific material characteristics. On basis of these analyses it can set intervention levels. Below you find suggestions for inspection classification.
Various organisations have developed sewer condition classifications, which allow engineers to quantify and analyse visual observed structural damages. Planners and engineers should be careful to develop the maintenance plan on basis of such coding system alone. It is strongly recommended to estimate residual lives of assets on basis of tests. If one insists to rely on visual inspections alone, it is suggested to follow the defect classification system presented in EN 13508. The scores give an impression of the condition of the pipe and suggest actions to be taken

Score	Description	Action Required
Over 150	Pipe has failed	Decide how to repair
70 to 150	Pipe is failing or has become unstable	Decide when to repair
30 to 69	Pipe showing indications that it may soon fail to perform	Decide if to repair
10 to 29	Pipe has initial signs of deterioration	Decide when to re-inspect
0 to 9	Pipe appears to be perfectly satisfactory	No action needed

Ingress roots

Ingress roots limit the hydraulic capacity of the mains. The more dense the roots, the higher the reduction of the hydraulic capacity. A practical approach is mitigating any ingress roots within a period of five years. And to carry out emergency maintenance when the reduction of hydraulic capacity is beyond upper limits. The IRC advises to use upper limits of 25%.

Ingress Roots Condition per metre length	Action
No roots	None
Only finer roots at some locations	Repair within the next five years
Roots at some locations	
Roots hanging in front of main covering up to upper limit	
Roots hanging in front of main covering beyond upper limit	Emergency maintenance + Repair within the next fiscal year

Large deformation also reduces the hydraulic capacity. Sewer systems with additional hydraulic capacity may be able to cope with some loss of their hydraulic capacity, provided that the observed damages will not cause collapses of pipes or roads. For example a deformation of 25% in diameter change may not be a problem from a hydraulic point of view, but it is dangerously close to cause a structural collapse of the pipe.

Leaks

Corrective maintenance is needed when the sewer pipe or access hole can no longer fulfil its hydraulic function. This is the clearly the case when a pipe has collapsed. The hydraulic function also deteriorates when the system leaks contaminated water.
However the intervention level or the urgency to repair depends on factors like if the leak is likely to cause collapse of the sewer pipe. The soil conditions and the waste water characteristics determine if leaks cause pollution of ground water and the soil. Clay and loam tend to close leaks and prevent large transportation of leaked waste water. Leakages in sand are transported quickly. When the groundwater level is high, leaks will cause inward flows. This means that contamination of the groundwater and the soil is unlikely.
Leaks are caused by all sorts of structural damages, like cracks, in-growing roots, fractures, potholes, joint displacements and openings. It is important to repair all leaks, cracks, fractures, joint openings and joint displacement in the same area more or less simultaneously. If only the larger leaks are repaired, water pressure in the smaller leaks will increase and their deterioration will progress rapidly.
The below presented condition assessment of these damages are based on the assumption that the damages are reported per metre length of the sewer pipe.

Condition per metre length	Action
No leaks	None
Sweating Joints or cracks	Monitoring; Repair together with other leak repairs
Groundwater drips into the sewer	Repair within 5 years
Groundwater flows into the sewer	Repair within 5 years
Groundwater sprays into the sewer	Repair within next fiscal year

Cracks may not leak, but are still indications of structural problems. Without maintenance cracks turn into fractures and eventually into potholes or broken pipes. These structural damages may eventually result in collapses of the pipe or access hole. Surface damages are another form of structural damages and often result in potholes.
It is important to adequately describe the cracks in terms of:

- Direction
- Frequency per metre length
- No leaking and no. non-leaking
- Width

As soon cracks are observed, planners should carry out more detailed assessments about their causes and estimate the remaining life of the assets. Multiple longitudinal cracking is often a sign of general structural inadequacy. Radial fissures indicate beam bending failure. The below presented framework can be used by inspectors to report cracks and fractures.

Condition per metre length Cracks Longitudinal	Number
Cracks without leakage	
Cracks with leakage	
Light fracture <10 mm wide	
Fracture 10 to 25 mm wide	
Fracture >25mm wide	
Collapses (pipe section lost integrity)	Number: Area:

Condition per metre length Cracks Circumferential	Action
Cracks without leakage	
Cracks with leakage	
Light fracture <10 mm wide	
Fracture 10 to 25 mm wide	
Fracture >25mm wide	
Collapses (pipe section lost integrity)	Number: Area:

Condition per metre length Cracks Diagonal	Action
Cracks without leakage	
Cracks with leakage	
Light fracture <10 mm wide	
Fracture 10 to 25 mm wide	
Fracture >25mm wide	
Collapses (pipe section lost integrity)	Number: Area:

Voids in the soil may cause such cracks and eventually sewer pipes to collapse. It is possible to find such voids with ground probing radars. Once found, voids can be filled with a grout.

Deformation

Deformation of the pipe affects the hydraulic capacity of the pipe. It is also affect the bearing capacity of the pipe, as deformed pipes loose their strength. In both situations the intervention level depends on the specific situation. Over-capacities determine if deformation is acceptable from a hydraulic point of view. Pipe materials and remaining wall thickness are indications for the remaining life of the main. Deformations of 20% indicate imminent collapse. (Deformations are usually measured in percentage of change in diameter.) It might be possible to follow the progression of the deformation and predict the end of life accordingly. It is necessary to follow the progression of the deformation when it is larger than 5%.

Concrete mains

Concrete mains require visual inspections. With regard to the structural thickness, the following classifications have been identified.

1. No sedimentation
2. Scaling of surface
3. Gravel and/or reinforcement is visible
4. Ravelling and/or corroded reinforcement
5. Potholes

This problem may be caused by several other problems and often it pays off to study the causes of the failure in more detail. However action should be taken within five years after the scaling has resulted in visible gravel stones. Where concrete pipe has exposed reinforcing steel, the main will be considered for repairs in the next fiscal year. Potholes with diameters larger than 100 meters should be repaired in the next fiscal year.

Metal mains

As described earlier ductile iron pipes tend to develop pinholes due to corrosion. These pinholes may grow very rapidly. It is therefore advisable to take immediate action whenever possible. Corrosion in grey iron pipes is evenly spread around the surface and may occur on both sides of the pipe. It is possible to measure and monitor the surface affected. However it should be kept in mind that the development is progressive in nature.

Joint displacements and openings

Joints can open themselves or be displaced. Joint displacements are usually expressed in percentage of the wall thickness. Joint openings are usually measured in terms of width of opening, presence of gasket and whether the joint is leaking. Leaking joints will be dealt with like any other leak. Non-leaking joints are usually repaired at the same time as leak repairs in the same main or string of mains. Radially displaced joint Indicates differential settlement

IRC advises the following intervention levels:
Joint displacement >50% of wall thickness
Joint opening >50 mm wide

Pipeline gradient

Sagging of crowns and inverts affect the pipeline gradient and in gravity system therefore the velocity of the waste water. A minimum velocity of 0.7 m/s is required for drains and sewers with diameters up to 300 mm. Sewer pipes can be self-cleaning when the pipes have sufficient gradient.

1. For flows of less than 1 litre per second, pipe diameter not exceeding 100 mm; min. gradient 1:40
2. Daily peak flows larger than 1 litre per second; at least one WC is connected, pipe diameter not exceeding 100 mm; minimum gradient 1:80
3. At least 5 WC connected, diameter 150 mm; minimum gradient 150 mm

Roughness

For wastewater and combined flows, the roughness should be limited to 0.6 mm when daily peak velocity has to exceed 1.0 m/s. In the cases the daily peak velocity is in between 0.77 and 1 m/s the roughness value may increase to 1.5 mm.

Man holes

It is possible to use more or less the same classification tables for manholes as for the mains. However it is necessary to add damages related to the frames, cover and ground surface settlements.
First indications of ground surface settlements are minor pavement surface cracks that evolve into major cracks and large bumps. The latter is usually perceived as unacceptable and requires maintenance activities in the next fiscal year. Covers are usually made from metal and as a result may corrode. Covers that are broken or heavily corroded need to be replaced. Displaced covers may cause serious accidents and need to be replaced immediately. The frames and their anchors are also steel products. Heavily corroded, displaced or broken frame elements need to be repaired.

Brick sewers.

Most old sewers were made of bricks. Common encountered damages in brick sewers are missing mortar in the joints, displaced and mission bricks; sagging of the pipes and dropping of inverts. The joints require pointing prior them being open and bricks falling out.

Concrete pipes

Concrete pipes are rigid in nature and therefore encounter problems which are not common in the more flexible plastic and metal pipes. Spalling is for example a problem that can only be observed in concrete pipes.

Sulphuric acid corrosion in concrete mains

Sulphuric acid corrosion is another typical problem affecting concrete pipes. Often the reinforcements are only covered with a minimum of concrete/cement (2 cm). The sulphuric acid may result in corrosion of the reinforcement within a time frame of 7 to 20 years. Where carbonisation takes place the corrosion may cut into the reinforcement with 1 to 3 mm/year. Sulphuric acid is more likely in sanitary sewer systems. Important factors influencing sulphuric acid are:

- Sulphide content (S in mg/l)
- Temperature of sewerage (Celsius)
- PH on the concrete surface
- Turbulence of sewerage

With help of the table below it is possible to indicate sulphuric acid sensitive locations. The table classifies three intervals:

A. Sulphuric acid is unlikely to take place
B. Sulphuric acid take place and penetrates the concrete with 1 mm/year
C. Sulphuric acid takes place and penetrates the concrete with 3 mm/year

There are various equipments available to determine the dissolved sulphide concentrations in waste water. Some models even allow continues sample taking and analysis.

Sulphide (mg/l)	PH-concrete	Turbulence Strong/Weak	Sulphuric classification		
			Temperature sewerage < 15˚C	Temperature sewerage 15- 20˚C	Temperature sewerage > 20˚C
<1	5	Strong	A	A	A
		Weak	A	A	A
	3	Strong	B	A	A
		Weak	A	A	A
	1	Strong	C	B	A
		Weak	B	A	A
1-5	5	Strong	B	A	A
		Weak	A	A	A
	3	Strong	C	B	A
		Weak	B	A	A
	1	Strong	C	C	B
		Weak	C	B	A
5-15	5	Strong	C	B	A
		Weak	B	A	A
	3	Strong	C	C	B
		Weak	C	B	A
	1	Strong	C	C	C
		Weak	C	C	B
>15	5	Strong	C	C	B
		Weak	C	B	A
	3	Strong	C	C	C
		Weak	C	C	B
	1	Strong	C	C	C
		Weak	C	C	C

Source: A.C.A. van Mechelen and R.B. Polder TNO-Bouw Rijswijk

3.3.1 Estimating remaining structural life of asset

Most countries have set out structural performance requirements or design recommendations for sewer mains in national standards or guidelines. These standards cover setting design loads and present calculation methods for load-bearing capacities of pipes. Individual product standards present data on the strength, stiffness and chemical resistance of pipes.

These set of formula can be used for the assessments of remaining structural lives of sewers and the design of rehabilitation of existing sewers.

Load bearing capacity

The load bearing capacity of the main is the result of the combined strength of the pipeline and its embedment. Whereby the strength of the pipeline is mainly determined by the material characteristics and the wall thickness. The loss of the effective wall thickness and the development of cracks thus impair the intrinsic strength of the pipeline. The strength of the rigid pipes can be measured in a crushing test or can be calculated with later described formulas. The embedment strengthens the load bearing capacity of buried pipelines. This additional strength is referred to as the bedding factor, which is a multiplier in the case of rigid pipes. As the soil settles, the bedding factors progress to values of 1.5 (most soils) up to 2.5 (granular materials)

The estimated load-bearing capacity has to be compared with the current and expected loads of the pipeline. Kindly note that besides the external (soil and traffic) loads, pumping can cause internal loads. The vertical soil pressure on buried pipes slowly reverts to geostatic value.

Measuring wall thickness

Thus one of the key issues is to measure the thickness of the pipeline. Ultrasonic meters are commonly applied as they allow direct reading of the thickness of the pipe wall. It is even able to measure corrosion depths, even pinholes in metal pipes. Often physical samples of the pipe are taken to check the information obtained with the ultrasonic meters. It is nowadays possible to drill cores in small diameter pipes with aid of remote controlled equipment.

These cores can be destructively tested to obtain information about the intrinsic strength of the pipe materials. Indications about the intrinsic strength of the concrete pipes can be obtained with Schmidt hammers. Similar indications can be obtained with hardness meters that can be applied on both concrete and asbestos cement. Deformation tests can also be applied to obtain values for intrinsic strength on pipes made of steel, asbestos cement, pitch fibre, PVC and PE. Crushing tests on full pipe samples provide useful information about the bearing capacity of deformed and cracked pipes.

3.4 MAINTENANCE TECHNIQUES

Over the years, engineers have developed a whole range of technologies to maintain sewer pipes, manholes, pumping stations and other elements of sewer systems. And it is likely that the market will continue developing such technologies. These repairs vary from replacements, renovation techniques, repairs that stop the progression of the damages and repairs that correct the damages. Most of these technologies can be carried out with different pipe materials.

Engineers will have to select technology on basis of their appropriateness. Some technologies may be counter effective. For example high pressure cleaning techniques have negative effects on the wall thickness of concrete pipes that are seriously affected by sulphuric acid.
Ideally planners would select repair options on basis of life cycle least cost analysis. Planners and engineers certainly need to select repair options on basis of needs to enlarge or decrease system capacity. Repair techniques range in price and life span. Complete replacements may cost ten times as much as grouting.

In most cases planners will try to carry out as many repairs possible with the available budget and at the same time reduce overall life cycle costs of the utility. Planners and engineers have to work together to select the most appropriate repair. Planners need to supply the engineers with information about the required life of the repair. This is in particular important when reconstructions of pavements are planned, which allows easy replacement of pipelines. Without such information engineers should assume that the repaired sewer should have an economic life in excess of 50 years.

Engineers subsequently will use this information to design and propose the most appropriate repair option. An important task is to analyse the causes of the damages. Many structural damages may be caused by one or more problems. Pipes may crack as a result of void in the soil, which on their turn are a result of leakages. Repairs will only be successful if they address the underlying causes of such damages. Suitability of the repair also depends on the requirements of the society. For example, road users and the road authorities are not pleased when road pavements are removed because of repairs or installation of new pipes. Numerous trenchless technologies are available to carry out structural repairs. Typical examples are sliplining or inversion lining. Furthermore engineers have to assess if the repair option and the materials to be used have sufficient intrinsic strength, chemical and thermal resistance. Producers of the various technologies are happy to inform the engineers about the specific characteristics of their technologies and materials.

Planners have to decide if engineers should opt for repairs with long lives (50 years or more) but consumes a considerable amount of budget like replacement or lining or should opt for medium or even short term solutions. Planners aim at reducing the life cycle costs of the utility, but at the same time may be constraint in their budget. Life cycle analysis would take into account the costs of the repairs but also the (financial) risks of failing sewer performance. Planners thus need information from the engineers about deterioration rates of the assets, costs of the different repair scenarios and the risks of postponing maintenance. Budget constraints often force planners to choose patching techniques to extend the life of the assets till money is available for more structural repairs.

3.4.1 Analyzing damages

It is important to fix all leaks in sewer segments at the same time, irrespective the size of the cracks or holes. Otherwise water will flow through the smaller cracks and holes, accelerating these damages. Engineers have the challenging task to find out how to segment pipelines. This requires insight about groundwater levels and flows. It is often assumed that groundwater flows follow the surface, but this may not at all be the case due to different compositions and characteristics of soil layers. Engineers may also analyse if leak flows are inwards or outwards. The main techniques for excluding infiltration from the sanitary sewer are grouting of joints, sliplining, inversion lining, applied-in-place concrete lining, coatings, lateral repair or replacement, and manhole repair.

When hydrogen sulphide attack is the major cause of the damages in concrete pipes, repairs over the full length like lining or replacements are most likely to be more cost-effective than the sum of spot repairs over a number of years.

3.4.2 Repair information

Grouting

Sealing of leaking joints and smaller cracks are typically carried out with chemical grouting techniques. A remote controlled small grouting rig with a TV camera is run through the pipe. The rig can test the integrity of the joints by inflating a seal on each side and pressurizing them. Grouting does not strengthen the structural strength of the pipes and may reduce the hydraulic capacity of the pipe. Acylamide grouts have bad reputations with regard to health and safety issues.

Coatings

Like grouting, coatings also do not add to the structural strength of the pipe. Coatings are used to improve resistance against corrosion and erosion.

Sliplining

Sliplining is a method by which pipes are inserted to an existing line by pulling or pushing continuous or short-length pipes into the sewer. The annulus between the existing pipe and liner pipe should be grouted. There are many pipe types available. If a pipeline has numerous cracks and leaking joints, but is still continuous and not very misaligned, slip lining, or insertion, may be a good rehabilitation option. If there were any lateral connections to the old pipe, these will have to be recut in the new pipe to allow a connection. This methodology does improve structural strength and prevent infiltration, and it slightly reduces the diameter of the line.

Inversion lining

Another technology that results in a new inside pipe surface is inversion lining. This technique has a number of advantages over sliplining. First of all it can be used in case of considerable misalignment and secondly its installation can be done through existing manholes. The intrinsic strength of the material is similar that of slip lining.

Rolldown and Swagedown Deformed Pipe

Roll down and Swagedown Deformed Pipe lining systems is a technique to strengthen the structural capacity of deformed pipes. A smaller circular PE pipe is inserted into the deformed existing pipe. The inserted pipe is inflated to form a tight fit with the existing pipe. This technology requires detailed structural analysis.

Replacement

The old method to rehabilitate sewers was the replace them. This technology is to be used when the sewer has completely collapsed, severely blocked or was undersized. Replacement is often cheaper than lining technology, but requires more construction time and needs open trenches. This means that a part of the sewer is longer out of service, which may be unacceptable in certain areas (industries, hospitals and other areas with chemical emissions). The open trenches pose safety problems to the traffic.

Trenchless replacements

In recent years, trenchless replacement and construction techniques have been used more frequently, including pipe bursting, microtunneling, directional drilling, fluid jet cutting, impact moling, impact ramming, and auger boring. Minimum excavation techniques, such as narrow trenching, are also being used more in less-congested environments.

Pointing

Brick sewer need regular pointing of the deteriorated mortar. It is important to select the mortar composition. Inappropriate mortars may easily erode or worse cause spalling of the brickwork. Pointing is only useful when the existing sewer is still intact, meaning no deformation or disturbed bricks.

Manhole repairs

Various repairs may be needed to manholes, like levelling the frame and lid to avoid ponding of rainwater or bumps in the road surface. The walls may need repairs like grouting or the whole manhole may need replacement.

Coating manholes

Non-cement coatings can be used to provide protection against chemical corrosion and acid attacks. Coatings do not improve the intrinsic strength of the manhole. Therefore the manhole should still be intact and have no evidence of settlement or other movements. Cement and bituminous coatings have proven not to be effective in protecting walls from corrosion of sulphuric acid.

Grouting

Grouting is a successful technique to reduce leakages in manholes. Yet they do not add to the structural strength of the manhole.

3.4.3 Product information

Engineers need obtain product information about:

- Crushing resistance
- Comprehensive properties
- Tensile properties (modulus)
- Flexural strength
- Ring stiffness
- Ring flexibility
- Thermal stability
- Joint seal strength
- Hardness/ density
- Shear/bond resistance
- Abrasion resistance
- Resistance to crack propagation
- UV radiation resistance
- Creep factor
- Long-term circumferential strength
- Flexural creep modulus
- Integrity of jointing
- Pressure service
- Chemical/acid/corrosion resistance
- Impact strength (outside)
- Water/air tightness

The following website presents an overview of various repairs and some of their characteristics.
http://www.wrcplc.co.uk/srm/buyersguide/volume2/buy2index.htm

Due to installation techniques, the renewed pipes loose 5 to 10% percent of the strength, presented by the producers. Engineers should take this loss into account while designing the repair.

As most sewer systems are cleaned with water jetting technologies, sewer pipes and thus the repairs should be able to withstand 180 bar for 5 minutes. When local conditions limit the pressure used or different cleaning technologies are used, engineers may adopt different standards.

APPENDIX A: STRUCTURAL DESIGN OF NEW BURIED PIPELINES

See Appendix A at the following website:
http://www.hi.ihe.nl/srguide/een_frame.html

APPENDIX B: APPLICATION OF EN1295 APPROACH TO EXISTING SEWERS

See Appendix B at the following website:
http://www.hi.ihe.nl/srguide/een_frame.html

APPENDIX C: STRUCTURAL BEHAVIOUR OF SEWER MATERIALS

The following text is an extract from Appendix C, of the Guidelines for Structural, Hydraulic and Environmental Rehabilitation of Sewers (EU Commission Working Group 22 of TC165), which can be downloaded at http://www.hi.ihe.nl/srguide/een_frame.html

Cast iron pipe sewers and pumping mains

Investigation and testing methods

These must aim at establishing the residual thickness of sound metal in the middle layer of the pipe wall, and the tensile strength of that material.

At the initial assessment stage, the residual thickness should be estimated by assuming similar corrosion rates to those determined for similar pipes installed in similar soil conditions. Material strength should be assumed to be related to the age of the pipes, and the following values are suggested:

Pre 1930 pipes 45 MN/sq.m.

1930 – 1975 (up to 70 cm dia.) 90 MN/sq.m.

(over 70 cm dia.) 75 MN/sq.m.

Investigations for the final assessment should aim to establish thicknesses and strengths using actual measurements. The extent of external corrosion on pipes can be measured using ultrasonics, after the pipeline has been exposed in exploratory excavations. The ultrasound measurements should first be used to establish which part of the pipe circumference is the most corroded, and should then be taken at the corresponding position on the circumference along the length of the exposed pipe. A large number of readings is desirable, so as to permit statistical analysis and the establishment of confidence limits.

Sample pipes, or sections of pipe, should be removed at selected points, via the trial holes excavated for ultrasound measuring. These samples should then be grit blasted, to remove graphitised layers, so as to permit verification of the external corrosion measurements using ultrasound, and to provide data on internal corrosion.

Tensile test pieces should be cut from the sample pipes, and tested to destruction, to establish the tensile strength of the material. Sufficient tests should be carried out to permit statistical analysis.

The trial excavations sunk to permit the ultrasound measuring, and the removal of pipe samples, will also permit the type of pipe embedment to be noted. Soil and groundwater samples may also be taken, so as to permit testing for corrosivity.

(c) Procedure for structural analysis

i. Crushing strength of pipes:

$$W_t = 1.048\, f_b . t_r^2 / D (kN/m)$$

where f_b = ultimate bending strength of the cast iron, in kN/sq.m.

(assume equal to ultimate tensile strength, f_t)

t_r = design value of residual pipe wall thickness in m.
(from statistical analysis of measured values, where

available)

D = mean pipe diameter, in m.

ii. Bursting pressure of pipes:

$P_{ult} = 2 f_t . t_r / D$

where f_t = design value of tensile strength of the cast iron in kN/sq.m.
(from statistical analysis of test measurements where available)

iii. Load-bearing capacity of pipes, in buried condition, but without internal water pressure:

$W_{lb} = F_m . W_t$

where F_m = bedding factor

= 2.5 for "granular" embedments

= 1.5 for other soil embedments

iv. External load-bearing capacity of buried pipes, whilst subjected to internal water pressure:

$$W_{lb}' = W_{lb} \left(1 - P_i / P_{ult}\right)^{0.5}$$

$$= \left(\frac{1.048 F_m . f_t . t_r^2}{D}\right)\left(1 - P_i\, D/2 t_r\, f_t\right)^{0.5}$$

C3 Ductile iron pipe sewers and pumping mains

(a) Outline of likely deterioration processes

As with grey iron pipes, corrosion by oxidation of the iron is the predominant deterioration process. In ductile pipes, however, the corrosion generally takes the form of pitting, which can progress very rapidly in the absence of adequate corrosion protection.

(b) Investigation and testing methods

The tensile strength of ductile iron is much more consistent than they of grey iron, and can be taken as the specified value, 420 MPa.

The time-related reduction in the load-bearing capacity of ductile iron pipes is thus effectively controlled by the loss of wall thickness due to corrosion. This loss can be estimated, if data is available for similar pipelines in truly comparable circumstances. Estimates made in this way should ideally be confirmed by a few direct measurements using trial holes and ultrasonics. If reliable data is not available for estimating corrosion, then more direct measurements will be required. The main form of corrosion consists of the formation of localised, discrete "pits", which eventually can penetrate the full pipe wall thickness.

(c) Procedure for structural analysis

The structural design of new ductile iron pipelines consists of checking that neither the cross-sectional deformation ("deflection"), nor the ring bending stress, will exceed allowable limits. Deterioration of the pipes by pitting corrosion (the normal form of deterioration) will not significantly affect either of these conditions, and will lead, if unchecked, to a different form of failure, the formation of holes through the pipe walls. Though initially small ("pinholes"), these holes will gradually enlarge, as the escape of effluent at high velocity erodes further metal from the perimeter of the hole.

Analysis of the risk of pinholing developing as the result of corrosion, consists of using observed depths of pits to estimate a rate of penetration (usually calculated in millimetres per year) and to estimate the time required for full wall penetration, assuming that the future corrosion rate is the same as the historic rate.

Some authorities suggest that the corrosion rate should be calculated as the sum of the rate of growth of both external and internal pits, i.e. assuming that the deepest external pits are precisely coincident with the deepest internal pits. This will often be an excessively conservative assumption, and is only likely to occur in practice if the pits on at least one surface are extremely closely packed.

Asbestos cement pipe sewers and pumping mains

(a) Outline of likely deterioration processes

Asbestos cement is adversely affected by acidic conditions, both internally due to the water composition, and externally due to the soil conditions. When subjected to acidic conditions, asbestos cement tends to swell and soften, reducing its crushing strength.

(b) Investigation and testing methods

The best way of establishing the residual wall thickness of asbestos cement pipes is by taking out a sample, scraping away the softened deposits and calipering the remaining sound wall thickness. This wall thickness can then be substituted into a Barlow-Schlick combined stress analysis in order to determine the residual strength of the pipeline.

The phenolphthalein test is not appropriate for use in connection with asbestos cement pipes, since it is only capable of determining the *pH* through the wall of the pipe. This is very useful for reinforced concrete pipes, since it gives an indication of the susceptibility of the steel reinforcement to corrosion, but does not allow any inference of strength to be made for unreinforced pipes.

(c) Procedure for structural analysis

i. Crushing strength of pipes:

$W_t = f_b . t_r^2 / n(3D + 5t)$

where f_b = ultimate bending strength of material (assume 28 MN/sq.m.)

t_r = design value of residual pipe wall thickness in mm. (from statistical analysis of measured values where available)

n = 0.3 for diameters greater than 100 mm, and 0.26 for diameters of 100 mm or less

D = internal diameter of pipe in mm.

ii. Bursting pressure of pipes:

$$P_{ult} = 2 f_t t_r / D \qquad N / sq.mm$$

where f_t = ultimate tensile strength of material (assume 22.5 N/sq.mm.)

t_r = design value of residual pipe wall thickness in mm. (From statistical analysis of measured values where available)

D = internal diameter of pipe in mm.

Maximum allowable working pressure:

$$P_{mw} = P_{ult}\left(1 - W / W_{lb}\right) / F_{si}$$

where the factor of safety F_{si} has values of 3.5, 3.0 and 2.5 respectively for pipes in the diameter ranges 175 to 225, 250 to 500, and 600 to 1000 mm.

iii. Load bearing capacity of pipes in buried condition, but without internal pressure:

$$W_{lb} = Fm.W_t$$

where F_m = bedding factor

= 2.5 for "granular" embedments

= 1.5 for other soil embedments

iv. External load bearing capacity of buried pipes, whilst subjected to internal water pressure:

$$W'_{lb} = W_{lb}\left(1 - P_i / P_{ult}\right)$$

$$= \left(F_m \cdot f_b \cdot t_r^2 / n\left(3D + 5t\right)\right)\left(1 - P_i / 2t_r \cdot f_t\right)^{0.5}$$

Maximum allowable external load

$$W_{ma} = W'_{lb} / F_{se}$$

where the factor of safety F_{se} is recommended to have a value of 2.5.

PLASTICS PIPE SEWERS AND PUMPING MAINS

PVC

(a) Outline of likely deterioration processes

PVC pipes are essentially immune from corrosive attack by substances naturally occurring in the ground. They will, however, be weakened by contact with oils, petrol, tar and other hydrocarbons, and this risk should be borne in mind in any location where spillages, or other events could have exposed the pipes to such materials.

The primary time-related deterioration process that can affect PVC pipes is slow crack growth, leading to brittle fracture. It is a natural process, just as is the corrosion of ferrous metals, but fortunately it is more predictable, and the tests which are used to establish the pressure ratings of thermoplastics pipes (PVC and PE) are intended to take account of it. The test procedure (known as "stress-rupture" testing) consists of subjecting a series of 18 sample pieces of pipe to various levels of hoop tensile stress, and measuring the time to failure. When the latter is plotted against stress, on a log-log basis, the result is essentially a straight line. This line can readily be extrapolated forward to predict the stress that should be sustainable for 50 years (or any other selected period). The pressure ratings of pipes are established by applying a factor of safety to the 50 year stress, to arrive at an "allowable stress", and converting this to an allowable pressure, using Barlow's formula.

b. Investigation and testing methods

It follows from the description of how stress-rupture testing is used to establish the pressure ratings of PVC pipes, that once the "stress/failure time" plot is available for particular pipes, then given the applied stress level, the expected time to failure can be read off the graph.

In order to use this technique to predict the remaining life of PVC pipelines, the necessary investigations consist of establishing the stress levels to which the pipes have been exposed, and the date of commissioning the pipeline.

c. Procedure for structural analysis

Attention is particularly drawn to the two broken lines that branch off the basic performance line of PVC-U (previously known as uPVC). These broken lines represent the onset of brittle fracture, as a result of slow crack growth, and show how drastically this failure mode can cut short the life of pipes. It is important to appreciate that the broken lines still represent the performance of various types of "conventional" uPVC/PVC-U. The points at which the various broken lines depart from the flatter, continuous line (known as "knees") depend on the fracture toughness and/or gelation level of the PVC. For well-made pipes, the "knee" will not occur before 50 years. For poorly made pipes of low fracture toughness, it can occur much earlier, and this is one of the reasons for the premature failures which affected many PVC pipelines around 30 years ago (the other being poor design and/or installation, resulting in excessively high stresses).

Polyethylene

(a) Outline of likely deterioration processes

Polyethylene is a thermoplastic material, as is PVC, and the description of the deterioration processes which can affect PVC applies equally to polyethylene pipes.

The two relevant deterioration processes are softening and loss of strength as a result of exposure to hydrocarbon compounds, and slow crack growth leading to brittle fracture.

b. Investigation and testing methods

The investigations necessary for the structural assessment of polyethylene pipelines are similar to those required for PVC pipelines, and consist of establishing the operating pressure history of the pipeline.

Glass reinforced plastics

(a) Deterioration, investigation and analysis

Such problems as do occur with GRP pipes are generally due to poor pipeline design, and/or construction, and come to light very early, often before commissioning.

There are time-related deterioration processes that will, in theory, eventually lead to failure. These are stress-rupture, as already described for PVC pipes, and strain-corrosion, which consists of loss of strength resulting from the existence of high levels of strain in the presence of an aggressive environment (which water itself can constitute). In practice, however, there do not appear to have been any cases of water mains failing from either of these causes in the 30 years that GRP have been used in water supply.

Because GRP is a composite material, in which the proportions of glass, resin and filler may vary, general stress-rupture and strain-corrosion performance data or graphs are not available. If there are particular reasons to question the condition of a GRP pipeline, then specific performance data would need to be obtained from the pipe manufacturers. Investigations would involve establishing the pressure-stress-time history of the pipes (to permit checking of any stress-rupture limitations) and inspecting internally to establish the extent of distortion (which could accelerate strain-corrosion).

Analysis would involve comparing the cumulative stress-time data with the stress-rupture performance of the pipes, and comparing the assessed strain magnitudes with the strain-corrosion performance of the pipes, in water.