

Inspection of pressure lines and culverts

The IKT has now completed the first project phase on "Inspection and state-registration of pressure waste-water lines and culverts". The aim of this initial phase was that of obtaining information on the general inspectability of such conduits using the available technology, on the preconditions for use and usability of the various inspection methods, and on the necessary cost and labour inputs.

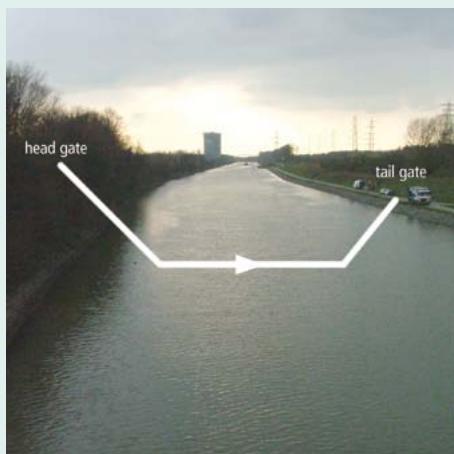
Results published

The German version of the detailed concluding report for the first project phase [1], and also an abridged version, are available for download on the Internet at: www.ikt.de

Pumping stations and waste-water pressure lines are frequent features of drain and sewer systems. They are used in sectors of these systems in which it is possible to implement drainage by means of gravity lines only with technical difficulty and/or at high cost. This is the case, in particular, where natural topographical gradients are lacking, where waste-water occurs only in small amounts and/or only periodically (due, for example, to low population densities), in case of the necessity of overcoming obstructions and in case of unfavourable underground circumstances as a result, for instance, of the presence of rock or of high groundwater tables.

In the German Federal State of North Rhine-Westphalia (NRW), some 90% of all drain/sewer operators (357 of a total of 396) operate pressure waste-water pipelines [2]. The total length of pressure waste-water pipes in the state is no less than 3,491 km, thus equating to just on 4% of the total public waste-water conduit system [2].

Waste-water culverts are among the "crossing elements" necessary when the course of pipelines encounters obstacles, such as rivers, for example. A total of 1,278 waste-water culverts are operated and maintained [2] by the 396 municipal waste-water system operators and eleven water boards in North Rhine-Westphalia. A survey of 208 system operators in NRW performed by IKT indicated that 131 (63%) of the operators polled have one or more culverts [3].



Course of a culvert underneath the Rhine-Herne Canal in Oberhausen; head and tail gate

Assurance of permanent good functioning is particularly important in the case of pressure lines and culverts. Blockages and resultant flooding (and thus hazards for the groundwater and for main drains), and also damage to connected property, may be the consequence if a pressure line or a pumping station fails, or if flow through a culvert becomes obstructed. Leaking conduits can result in waste-water escaping into

the groundwater and/or soil, and may cause cavitation in the surrounding soil, with the result that harm to the surface cannot be excluded.

The (visual) assessment of condition is one of the customary operational tasks in the field of gravity drains and sewers. The situation is different in the case of pressure conduits. Maintenance and inspection activities are generally restricted to pumping stations and the venting valves of the conduits. Inspections are generally not scheduled during the operating period of these lines, and they are classified as "maintenance-free" under DWA (German Association for Water, Wastewater and Waste) Code 116-2 [4]. Numerous system operators are nonetheless confronted with the question of the condition of their pipelines, particularly if operational problems have already occurred. A decision as to whether a conduit should continue in operation, in order to utilise possibly still existing reserves of service-life, and thus save costs, or whether the conduit should be renewed or refurbished, will need to be taken, at the latest, toward the end of the scheduled period of service. This, however, is a decision which can scarcely be made without knowledge of the condition of the conduit.



Provisions for the assessment of condition are necessary to permit appraisal of the state of pressure pipelines. Access ports are either present only at great intervals, if at all, however, since inspections of pressure lines during operation are generally not envisaged at the original planning stage. In addition, the conditions for inspection are made more difficult by bends, partial or complete filling of the conduits, and rising and falling gradients. Many system operators are therefore uncertain of the extent to which inspections and/or appraisals of condition are possible, and concerning the methods available for these activities.

The recently completed project was commissioned by the NRW environment ministry against the background of the fact that experience in the assessment of the condition of pressure waste-water conduits is virtually totally lacking.

The initial project phase was supported in terms of content by a steering committee featuring the representatives of twenty-seven system operators. Research was firstly conducted into the methods available on the market for condition assessment; the civil-engineering boundary conditions of pressure waste-water conduits, the operating experience of the participating system operators and the various types and forms of damage were compiled in parallel. Test deployments of selected methods on existing pressure conduits owned by the operators were then conducted by way of example. The objective of this first project phase was that of obtaining information on the general "inspectability" of

the conduits using the available technology, on the preconditions for use and general suitability for use of the inspection methods, and on the necessary financial and labour input, in order to permit derivation of initial recommendations for action concerning the inspection and appraisal of the condition of pressure waste-water conduits.

The operators' operating experience

As a survey of the participating system operators concerning measures for appraisal of the condition of pressure waste-water conduits illustrated, inspection and maintenance activities currently relate predominantly to pumping stations, valves, etc., and to venting stations. Pressure conduits in these systems had been tested for tightness by means of hydraulic pressure testing only in individual cases, or part-sections of conduits camera-inspected, generally in conjunction with operational problems and repairs.

On the basis of the experience of the steering committee, a large number of existing pressure conduits can continue to be operated without problems occurring and without any cleaning and/or inspection activities. The precondition for this is that the conduits were constructed in accordance with the requirements and have not, for example, proven to be overdimensioned, and that flow velocity does not fall below the specified minimum. Odour problems associated with pressure waste-water conduits do appear to be problematical for the overwhelming majority of operators, however. Such odour problems generally occur at the outlet from pressure conduits as a result of emissions of hydrogen sulphide, which

is evolved in waste-water in the absence of oxygen after prolonged periods of immobilisation.

Declining pump delivery heads and rates, depositions, grease fouling of venting valves, valve corrosion and also, in isolated cases, damage to the conduit and/or blockages causing operational failures, were stated as problems occurring in the operation of pressure waste-water conduits.

When operational problems occur, the conduits approach their design **service-life limit** and/or greater operational reliability is desired in the case of large transmission pipelines, failure of which would cause serious consequences, system operators are frequently confronted with the question of how to determine and evaluate the condition of their conduits.

These conduits must, in principle, be replaced upon the expiry of their design service-life, in order to keep the likelihood of operational problems caused by damage to a pressure conduit as low as possible. A number of operators do in fact adopt this procedure. Others continue to operate conduits which have up to now not exhibited any problems beyond the design service-life, in order thus to save costs but at the risk of incurring unforeseeable operational problems. The KVR (Ruhr Regional Alliance) guidelines [5] for pressure pipe and culvert lines state an average operational service-life of 30 to 50 years, irrespective of their material. DWA Code 116-2 [4] states a figure of 50 to 80 years. The assumptions made by the operators are diverse, with periods of 40 to 80 years mentioned as scheduled service-lives.



By way of preparation for possible test deployments, operators who had proposed test sections from their own systems compiled the information available on their conduits. An evaluation demonstrated that only little **data on the pressure conduits** usually existed, and that in many cases neither the precise course of a conduit, nor the location and nature of bends were known. It did, it is true, prove possible to provide plans in most cases, but these contained information and data which largely failed to reflect the actual circumstances, while it was possible to estimate the location and gradient profile of the conduits only using known reference points, such as manholes and venting valves.



Pitting corrosion in a grey cast iron pressure waste-water conduit (photo: Nuremberg Municipal Drainage and Environmental Analysis Services)

Types and forms of damage

A catalogue of types and forms of damage to pressure waste-water conduits was compiled in the context of a survey of the participating system operators. Evaluation demonstrated that only few damage patterns of informational value are available at present. Inspections, which could provide information on damage patterns, are not customary practice. Damage is therefore frequently only noticed when significant defects which restrict operation of the line occur, such as a ruptured conduit, for example. Such damage then necessitates immediate repair of the conduit, however. Further information obtained from the literature concerning types of damage



graphitised cast iron drinking-water pipe
(photo: H.-C. Sorge)

occurring in drinking-water conduits consisting of similar materials was therefore used in order to expand the data-base, with the result that an initial overview of possible damage types is available for pressure waste-water conduits. A summary of the various types of damage can be found in the concluding report [1].

Methods for determination of condition

Numerous methods for determination of the condition of pressure conduits are available on the market. These, however, have mainly been developed specifically for inspection of oil and/or gas pipelines, or of community-heating and water supply pipes and industrial piping systems. They are therefore generally orientated around steel as the pipe material, and around the common DNs, access facilities and bends encountered in such systems.

An overview of methods which can be considered in principle for determination of the condition of pressure waste-water conduits, and of their **functioning principles, preconditions for use and costs**, was drafted as part of this project. Commercially available technologies which have already proven their basic suitability for use in the context of waste-water drains/sewers and/or supply and industrial pressure conduits were primarily included in this overview:

● Internal inspection methods

- In-conduit cameras and add-on modules
- Inspection robots
- Inspection pigs
- Float-in and drawn inspection methods

● External inspection methods

- Inspections of exposed pipe wall
- Inspections of soil-covered pipes

● Hydraulic pressure testing

● Tests performed on material samples



Swollen asbestos-cement pipe in a pressure waste-water conduit
(photo: Eastern Holstein municipal alliance)



Section from a corroded asbestos-cement pipe in a pressure waste-water conduit
(photo Emmerich/Rhine municipal services)



Cracking at a flanged joint in a PVC pressure waste-water pipe at the pumping station
(photo: Emmerich/Rhine municipal services)



Ovality caused by point load in an HDPE pressure waste-water conduit
(photo: Emmerich/Rhine municipal services)



Deformation caused by point load in an HDPE pressure waste-water conduit
(photo: Emmerich/Rhine municipal services)



Blistering



Blistering



Detachment of material on the pipe wall of an asbestos-cement drinking-water conduit

(photo: M.J. Oomen BV)

Research on inspection methods, talks with manufacturers and practical deployments performed by way of example all illustrated that there is, at present, no "ideal" technology available on the market, using which inspections could be performed simply and cost-efficiently, as in the case of gravity conduits, and which would, in addition, supply adequate information on the condition of the conduit. Pressure waste-water conduits present more difficult boundary conditions than gravity conduits, due to the rarity or complete absence of access facilities, complete filling of the conduits, or at least of sections thereof, due to bends and, in addition, due to the in many cases not precisely known courses of the conduits and to the in some cases small nominal diameters (DNs).

It can be assumed that it will be possible to investigate the condition of many conduits only by means of a combination of various inspection methods, and with preparatory civil-engineering modifications involving a high technical and financial input. Conduits of diameters of 150/200 mm and above appear to be relatively easily inspectable, whereas the potentials are significantly poorer in the case of smaller diameters. The extent to which the necessary input is rational in each individual case will essentially depend on the operational importance of the individual conduit, and the hazard potentials its failure would present.

It remains, overall, to be ascertained that there are, up to now, no technologies available on the market which can, in general, be used for pressure waste-water conduits and/or culverts and which, simultaneously, will supply comprehensive information for evaluation of conduit

condition. Where determination of the condition of a pressure conduit is required, it is necessary to select appropriate procedures on the basis of civil-engineering boundary conditions such as material, DN, type and distances between access facilities, potentials for evacuation, the type and number of bends, and of the pressure conditions and inspection target, such as obtainment of information on tightness and/or corrosion, etc., and to combine these technologies correspondingly.

An appropriate procedure on cost:benefit criteria would be to firstly test conduits for tightness by means of a [hydraulic pressure test](#) and then perform TV inspections on accessible conduits sectors, and also to record operational data, such as delivery flows, power take-up at the pump and pressure at the pumping station.

The work, etc., input necessary for hydraulic pressure tests varies depending on the facilities for sector isolation, the elevation profile and the potentials for venting of the particular conduit. Pressure conduits which rise continuously from the pumping station, and which are (almost) completely filled, can be tested comparatively easily. Such testing will be more difficult in the case of conduits with high and low points, and also gradients which empty toward the end of the conduit. Here, filling is more complicated, and high points with no venting facility mean that pockets of air may occur in the conduit and falsify the test. Where great elevation differences exist, it may be necessary to isolate individual sectors for testing.

Despite the fact that DIN EN 1610 [6] draws attention to DIN EN 805 [7] for acceptance

inspection of pressure waste-water conduits, it should, nonetheless, be noted that this standard was, in principle, drafted for drinking-water conduits. The degree to which the respective detailed provisions can actually be applied to the situation in the waste-water sector must therefore be continuously assessed. The reasons for this are that, on the one hand, it is in many cases not possible to adhere to the civil-engineering boundary conditions assumed in DIN EN 805 in terms, for example, of accessibility, venting and isolation during the test. In addition, there are, on the other hand, no test criteria/limiting values for evaluation of the test result for tightness testing, since the hazard potentials relevant to the waste-water sector were not taken into account in EN 805. The question also arises of the extent to which the test pressures specified for acceptance inspection of new conduits are also in fact appropriate for tightness testing during ongoing conduit operation. Lower test pressures are specified in ATV-M 143, Part 6 [8] for tests performed on gravity lines than are required for acceptance testing of new conduits in accordance with DWA A 139 [9].

Where a pressure test supplies indications of leaks, the question arises of the conduit components on which the leaks are located. Leak detection using helium appears highly promising for this purpose. According to the supplier, dissolved helium is pumped with water through the conduit and then enters the soil via any leaks, and is detected using detectors at the surface. It has not yet been possible to observe any practical deployments of this method in the context of the project, however. The extent to which [leak detection](#) would also be possible using hydrophones,

which register the typical sounds of escaping water, and can, for example, be floated in a ball through the conduit, or conveyed on a pig, is also questionable. Leaks in a long-distance drinking-water pipeline were detected in a monitored practical deployment of the SmartBall®, but the experience of the Water Research Centre (WRc, Swindon, UK) indicated that leaks in pressure waste-water conduits remain undetected if they have become covered with fouling.

TV inspections are possible, at least on a distributed pattern at accessible points, in order to obtain approximate reference data concerning conduit condition. High points possibly featuring air pockets, in which corrosion can occur in the case of asbestos cement and cast-iron pressure conduits, in particular, are sites predestined for such inspections. It must be noted that purely visual inspection is of only limited informational value in the case of precisely these conduit materials, however, since not all types of corrosion and/or material abnormalities are visually perceptible. Inspection of the course of the conduit as a whole is possible only rarely without structural changes in pressure conduits, due to lack of accessibility, frequently restricted facilities for evacuation, and bends in the course of the conduit. Optical inspection using a tractor camera is, in any case, significantly more complex than in a gravity conduit, since it is necessary to stop operation of the conduits and drain them.

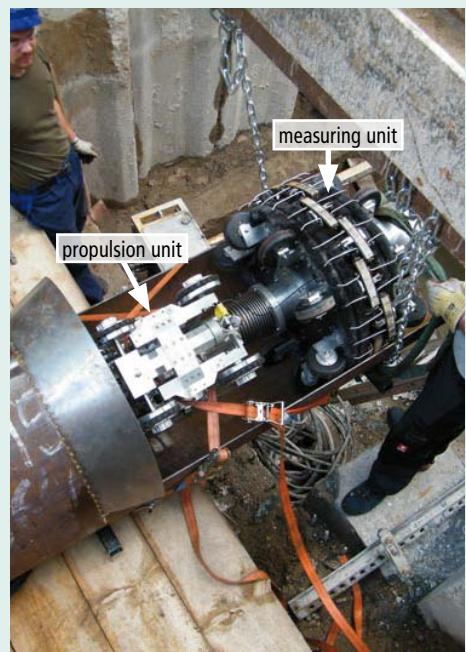


Towed video camera – an axial camera with suction-mount screen



Radar antenna on a camera tractor

The “towed video camera”, an axial camera with a suction-mount screen for nominal diameters of between DN 50 and DN 250, is drawn into a pressure conduit by means of a partial vacuum, and proved to be a technology well suited to pressure waste-water conduits. Experience gained in practical deployments appears to indicate that it is realistic to assume inspection of up to 750 m of conduit in a single operation using this method, depending on nominal diameter and bends. The camera proved to be extremely capable of negotiating bends. Friction between the pipe wall and the cable naturally becomes higher, the more bends a conduit features, reducing actual range as a result. An estimate should be made in advance to determine whether evacuated pressure conduits will withstand a partial vacuum of up to 0.8 bar, i.e., a uniform external overpressure of the same magnitude. As in the case of the customarily used tractor cameras, it is necessary to ascertain the extent to which the types of damage relevant to the particular pipe material are visually perceptible.



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It may be possible to use [sewer radar](#) for determination of the thickness of the remaining intact pipe wall in the case of asbestos-cement conduits. Potential uses are correspondingly limited by the fact that the sewer radar is conveyed through the conduit in combination with a tractor camera. It is also possible to determine the pH of the pipe wall by means of a [phenolphthalein test](#) on pipe specimens, in order to obtain information on any material abnormalities. The precondition for this is that the conduit can be exposed and a pipe specimen taken, however.

[Electromagnetic methods](#) can be used, where possible, for examination of cast-iron conduits for corrosion. The primary operation currently practicable is the external examination of a conduit, after its exposure. Pigs and robots incorporating such technology are also available; these are currently suitable for use in pressure waste-water conduits only in individual cases, however, due to the high costs involved and the lack of explosion-protection provisions. According to information from manufacturers, the prototype of a robot incorporating electromagnetic inspection technology, and to be tailored to the needs of pressure waste-water conduits, is currently undergoing testing. In addition, [pipe specimens](#) can also be taken and analysed in the laboratory for corrosion and other materials properties.

Instruments for [measurement of deformation and/or cross-section](#) are of interest for inspection of flexible pipes, for example, and in the context of preparations for refurbishing projects. Here, inspection using a calibration pig is, for instance, conceivable; it must be ensured in advance, however, that the conduits do not include any bend radii of less than $1.5xD$ or other obstructions such as major fouling deposits, for example. The laser light ring methods used in the gravity-line sector have, up to now, not featured explosion-safety provisions, and can therefore not be used with assured safety. Mechanical measuring systems which are conveyed through the conduit by means, for example, of a rope winch or a flushing hose, are also suitable for use only to a limited degree, due to these systems' restricted bend capability and/or the lack of suitable access to the conduit.

Inspection employing [smart pigs](#) derived from pipeline technology is conceivable for steel, and possibly also for cast-iron conduits (electromagnetic technology), and can, in the manufacturers' opinion, possibly also be adapted for inspection of PE and PVC systems (ultrasonics). These machines are suitable for the waste-water sector only in exceptional cases, however, as a result of their high mobilisation costs.

It must be remembered, in the case of random-sampling examination of a conduit, that conclusions concerning overall condition are permissible only to a limited extent. The damaged pipe elements obtained during repairs should in all cases be kept and further analysed if appropriate.

As became apparent during this project, the precise course of pressure lines is in many cases not known. Location methods are therefore the first necessity in conjunction with leak detection and/or with the refurbishing or replacement of the conduit along the same route. Here, bend-capable foamed-plastic ("polly") pigs carrying locating transmitters, and possibly also ground-

penetrating radar (GPR) methods, can be used, depending on factors such as installation depth, conduit material and conduit overcover (and also other factors, such as soil type, and salt and water contents). The use of pigs bearing measuring systems for determination of location is also conceivable, always assuming adequate bend-capability.

The most important preconditions for the use of the inspection technologies examined here, and approximate cost horizons for inspection services, are compiled in the following tables in the form of an evaluation matrix; an initial estimation of applicability to pressure waste-water conduits and culverts is also provided. These tables can be used as an aid to preliminary selection of an inspection method suitable for determination of the condition of a pressure waste-water conduit. Detailed discussions of functional principles, applications and preconditions for use of these technologies can be found in the full version of the report, available at: www.ikt.de (German version)

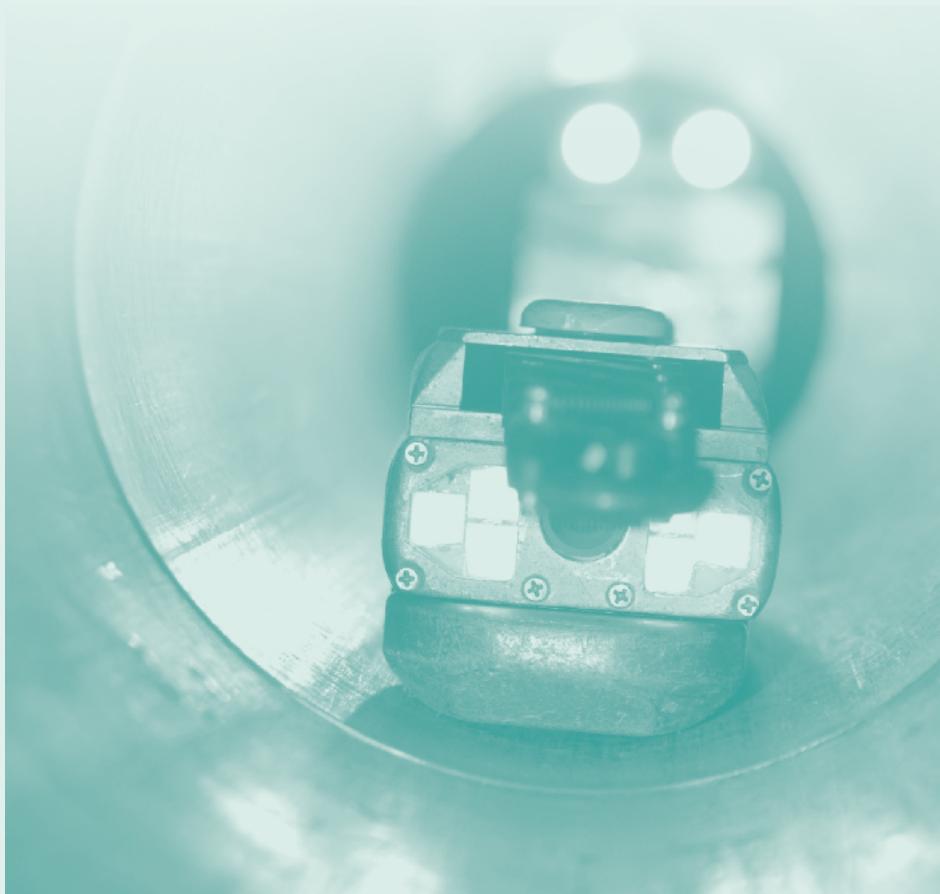


Table 1: Internal inspection methods: Sewer cameras and add-on modules – Preconditions for use and applicability in pressure waste-water conduits and culverts

Method	Inspection aim ¹	Conduit material and nominal diameters ²	Most important preconditions for use ²	Cost rates, examples ³	Suitability for use in pressure waste-water conduits and culverts ⁴
Sewer cameras and add-on modules					
Tractor camera	Optical inspection	<ul style="list-style-type: none"> Not material-dependent As from DN 100, frequently bend-capable only from DN 125/150 onward 	<ul style="list-style-type: none"> Inspection ports in course of conduit Port spacings dependent on bends, nominal diameter, surface condition, etc. (from a few metres to several hundred metres) Shut-down and drainage of the conduit 	<ul style="list-style-type: none"> approx. 800 €/d Daily average practical deployments: 35–175 m/h 	<p>Pressure waste-water conduits:</p> <ul style="list-style-type: none"> Suitable for random inspection of accessible zones, in particular Inspection frequently possible only in sub-sectors (inadequate access, bends) <p>Culverts:</p> <ul style="list-style-type: none"> Suitable for partial or complete inspection, depending on culvert bends, gradients, length, etc. <p>General:</p> <ul style="list-style-type: none"> Inspection lengths restricted by conduit bends, gradients, etc.; experience indicates significantly less than the tractor's maximum range (maximum inspection length system-dependent: 200 to 1,000 m) Informational value of optical inspection restricted
Axial camera with suction-mount screen	Optical inspection	<ul style="list-style-type: none"> Not material-dependent DN 50 – DN 250 	<ul style="list-style-type: none"> Access at start and end of conduit Inspection ports in course of conduit in conduits > 1,000 to 1,500 m in length Shut-down and drainage of the conduit Possibility of connecting a suction vehicle to the conduit Maximum height difference in conduit: 8 to 9 m 	<ul style="list-style-type: none"> approx. 1,400 €/d Daily average practical deployments: 60 m/h 	<p>Pressure waste-water conduits:</p> <ul style="list-style-type: none"> System tailored to pressure waste-water conduits, with good bend capability Range restricted to max. 500 m (DN 50) to 750 m (DN 250); actual range dependent on number of bends Capability of conduit to withstand partial vacuum of approx. 0.8 bar must be determined <p>Culverts:</p> <ul style="list-style-type: none"> Deployment conceivable only in individual cases <p>General:</p> <ul style="list-style-type: none"> Informational value of optical inspection restricted
Sewer radar	<ul style="list-style-type: none"> Residual wall thickness and bedding anomalies in asbestos cement, concrete, PVC, GRP, stoneware Thickness of cement-mortar lining in cast-iron and steel As from DN 200 		<ul style="list-style-type: none"> Inspection ports (see "Tractor camera") Shut-down and complete drainage of the conduit Knowledge of original wall thickness/coating thickness (sampling/measurement if necessary) 	<ul style="list-style-type: none"> approx. 2,500–3,000 €/d not including tractor approx. 3,500–4,000 €/d not including tractor 	<p>General:</p> <ul style="list-style-type: none"> Method of interest for non-destructive inspection of the pipe wall in asbestos-cement conduits and culverts, in particular <p>Pressure waste-water conduits:</p> <ul style="list-style-type: none"> Suitable primarily for random inspection, due to limited range (see "Tractor camera") <p>Culverts:</p> <ul style="list-style-type: none"> Suitable for partial or complete inspection, depending on culvert bends, gradients, length, etc. <p>Pressure waste-water conduits/culverts:</p> <ul style="list-style-type: none"> Method not explosion-safe up to now, suitability for use in pressure waste-water conduits and culverts therefore dubious (complete exchange of air necessary) Otherwise suitable for measurements of deformations in PE and PVC pressure conduits/culverts and may possibly supply information concerning material erosion caused, for example, by abrasive damage to internal coatings and/or by corrosion in cast-iron conduits see also "Tractor camera"
Laser cross-section measurement	Cross-section measurement	<ul style="list-style-type: none"> Not material-dependent DN 150 to DN 1500 	<ul style="list-style-type: none"> Use in combination with tractor (see "Tractor camera") Shut-down and drainage of the conduit 	approx. 1.80 – 2.25 €/m	

¹ According to manufacturer's information

² According to manufacturer's information, supported by experience from practical deployments in some cases

³ Typical net costs, delivery costs to be added; according to supplier's information, costs vary greatly depending on local boundary conditions and order volume in individual cases

⁴ Estimation on the basis of preconditions for use of the methods and civil-engineering boundary conditions of pressure conduits, supported by experience from practical deployments in some cases

Table 2: Internal-inspection methods: Inspection robots – Preconditions for use and applicability in pressure waste-water conduits and culverts

Method	Inspection aim ¹	Conduit material and nominal diameters ¹	Most important preconditions for use ¹	Cost rates, ² examples	Suitability for use in pressure waste-water conduits and culverts ³
Inspection robots					
Camera	Optical inspection	<ul style="list-style-type: none"> Not material-dependent DN 75 – DN 750 	<ul style="list-style-type: none"> Inspection ports in course of conduit, spacing 500 m as from DN 130, every 100 m below this Shut-down and drainage of the conduit 	approx. 3,000-5,000 €/d	Pressure waste-water conduits/culverts: <ul style="list-style-type: none"> Method not explosion-safe up to now, suitability for use in pressure waste-water conduits and culverts therefore dubious (complete exchange of air necessary) Inspection robots appear to be suitable for conduits featuring bends and gradient lengths Informational value of optical inspection restricted
Ultrasonics	Measurement of wall thickness	<ul style="list-style-type: none"> Steel DN 130 – DN 750 	<ul style="list-style-type: none"> Inspection ports in course of conduit, spacing 200 to 1,000 m, depending on conduit diameter Shut-down and drainage of the conduit Clean pipe surface Complete filling of the conduit with particle-free water 	approx. 7,000-10,000 €/d	Pressure waste-water conduits/culverts: <ul style="list-style-type: none"> Method not explosion-safe up to now, suitability for use in pressure waste-water conduits and culverts therefore dubious (complete exchange of air necessary) For use only in steel conduits, therefore only infrequent potentials for use Complete filling with clean, particle-free water in clean pipe difficult to implement
Eddy current, combined with permanent magnet	Detection of changes in wall thickness and/or corrosion	<ul style="list-style-type: none"> Steel, DN 400 – DN 750 Prototype for cast-iron conduits DN 400 – DN 600 	<ul style="list-style-type: none"> Inspection ports in course of conduit every 300 m 	approx. 7,000-10,000 €/d	Pressure waste-water conduits/culverts: <ul style="list-style-type: none"> Method not explosion-safe up to now, suitability for use in pressure waste-water conduits and culverts therefore dubious (complete exchange of air necessary) Possible of interest for the inspection of cast-iron conduits once the inspection technology has been completed

¹ According to manufacturer's information

² Typical net costs, delivery costs to be added; according to supplier's information, costs vary greatly depending on local boundary conditions and order volume in individual cases

³ Estimation on the basis of preconditions for use of the methods and civil engineering boundary conditions of pressure conduits, supported by experience from practical deployments in some cases



Table 3: Internal-inspection methods: Inspection pigs – Preconditions for use and applicability in pressure waste-water conduits and culverts

Method	Inspection aim ¹	Conduit material ¹	Most important preconditions for use ¹	Cost rates, examples ²	Suitability for use in pressure waste-water and culverts ³
Inspection pigs					
Ultrasonics	<ul style="list-style-type: none"> Measurement of wall thickness/corrosion (quantitative) Inspection for cracking 	<ul style="list-style-type: none"> Steel Possibly cast steel Possibly suitable for use with PE and PVC 			Pressure waste-water conduits: <ul style="list-style-type: none"> Use tested only in steel conduits up to now; rational in individual cases only, due to high costs Culverts: <ul style="list-style-type: none"> Not suitable in principle for civil-engineering boundary conditions
Stray magnetic flux	<ul style="list-style-type: none"> Detection of changes in wall thickness and corrosion (qualitative) Inspection for cracking 	<ul style="list-style-type: none"> Steel possibly cast-iron 		from approx. 60,000-80,000 €/deployment	Pressure waste-water conduits: <ul style="list-style-type: none"> Use tested only in steel conduits up to now; rational in individual cases only, due to high costs Culverts: <ul style="list-style-type: none"> Not suitable in principle for civil-engineering boundary conditions
Eddy current	<ul style="list-style-type: none"> Measurement of geometry Detection of changes in wall thickness and/or corrosion (qualitative)* Inspection for cracking* 	<ul style="list-style-type: none"> Steel possibly cast-iron 	<ul style="list-style-type: none"> Methods generally available from DN 80 to 200, depending on procedure and manufacturer 		Pressure waste-water conduits: <ul style="list-style-type: none"> Use tested only in steel conduits up to now; rational in individual cases only, due to high costs Culverts: <ul style="list-style-type: none"> Not suitable in principle for civil-engineering boundary conditions
Mechanical measurement of geometry	<ul style="list-style-type: none"> Measurement of geometry 		<ul style="list-style-type: none"> Access port with fixed or temporary pigging valve Differential pressure of 0.5 to 2 bar above operating pressure for pig propulsion, plus 0.5 to 2 bar for starting of the pig (depending on pig and pipe material) 	approx. 15,000 €/deployment	Pressure waste-water conduits: <ul style="list-style-type: none"> Use conceivable, necessary to determine conduit negotiability (in terms of bends and obstructions) Culverts: <ul style="list-style-type: none"> Not suitable in principle for civil-engineering boundary conditions
Acoustic leak location	<ul style="list-style-type: none"> Leak location 		<ul style="list-style-type: none"> Conduit negotiability: minimum conduit bend radii generally 1.5 to 3-fold pipe diameter necessary; no obstructions caused by fouling or impinging valve discs, etc. Ultrasonics: complete filling of the conduit with clean, particle-free water 	approx. 6,000-11,000 €/deployment	Pressure waste-water conduits: <ul style="list-style-type: none"> Use conceivable for leak location following tightness testing, but restricted suitability due to necessity of complete filling and a minimum pressure Detectability of leaks possibly restricted by the sealing effects of fouling Culverts: <ul style="list-style-type: none"> Not suitable in principle for civil-engineering boundary conditions
Geodetic locating	<ul style="list-style-type: none"> Locating 		<ul style="list-style-type: none"> Acoustic leak location: a minimum pressure necessary (approx. 3 bar) 	No data	Pressure waste-water conduits: <ul style="list-style-type: none"> Use conceivable (depending on costs), necessary to determine conduit negotiability (in terms of bends and obstructions) Culverts: <ul style="list-style-type: none"> Not suitable in principle for civil-engineering boundary conditions
Camera	<ul style="list-style-type: none"> Optical inspection 			No data	Pressure waste-water conduits: <ul style="list-style-type: none"> Visibility restricted due to propulsion using water, in addition to restricted informational value of optical inspection: use therefore not recommended Culverts: <ul style="list-style-type: none"> Not suitable in principle for civil-engineering boundary conditions
Locator transmitter (foamed-plastic pig from waste-water sector)	<ul style="list-style-type: none"> Conduit location 			Cost example: Conduit DN 80, 420 m length: 2,300-3,900 €/deployment	Pressure waste-water conduits: <ul style="list-style-type: none"> Good bend-capability thanks to combination of foamed-plastic pig and locator transmitter, use therefore possible in principle Costly, due to necessity of walking the route on the surface Culverts: <ul style="list-style-type: none"> Not suitable in principle for civil-engineering boundary conditions

* Purely eddy-current inspection applicable only in case of low wall thicknesses, therefore combination with other inspection technologies in some cases ** where typical background noise generated by the conduit material can be filtered out

¹ According to manufacturer's information

² Typical net costs, delivery costs to be added; according to supplier's information, costs vary greatly depending on local boundary conditions and order volume in individual cases

³ Estimation on the basis of preconditions for use of the methods and civil-engineering boundary conditions of pressure conduits, supported by experience from practical deployments in some cases

Table 4: Internal-inspection methods: Flated-in and drawn technologies – Preconditions for use and applicability in pressure waste-water conduits and culverts

Method	Inspection aim ¹	Conduit material and nominal diameters ¹	Most important preconditions for use ²	Cost rates, ³ examples	Suitability for use in pressure waste-water conduits and culverts ⁴
Float-in and drawn methods					
Drawn-in mechanical diameter and deformation measuring system	<ul style="list-style-type: none"> • Determination of diameter Not material-dependent • Measurement of deformation (ovality) Flexible pipes • DN 150 - DN 1200 	<ul style="list-style-type: none"> • Floating/drawing-in of a flushing hose/rope winch and/or insertion of a camera for conveyance of the measuring instrument; corresponding access ports necessary • No shapes (bends) in the conduit 	<ul style="list-style-type: none"> • Floating/drawing-in of a flushing hose/rope winch and/or insertion of a camera for conveyance of the measuring instrument; corresponding access ports necessary • Range restricted due to cable length (max. 400 m) and insertability/float-in capability of the conveying element (flushing hose, winch, camera) 	approx. 1.80-3.00 €/m	<p>Pressure waste-water conduits/culverts:</p> <ul style="list-style-type: none"> • Measurement conceivable, but rarely useable, due to lack of bend-capability • Range restricted due to cable length (max. 400 m) and insertability/float-in capability of the conveying element (flushing hose, winch, camera)
Float-in hydrophone (e.g. SmartBall®)	<ul style="list-style-type: none"> • Leak location • Location of air pockets 	<ul style="list-style-type: none"> • In principle not material-dependent* • DN 200 – DN 1600** 	<ul style="list-style-type: none"> • Complete filling of the conduit for leak location; otherwise, detection of air pockets • Minimum pressure 3-4 bar • Minimum flow velocity 0.15-0.5 m/s • Conduit accessibility every 1,100-1,300 m for positioning of sensors • Necessary to assure conduit negotiability 	approx. 4 €/m	<p>Pressure waste-water conduits:</p> <ul style="list-style-type: none"> • Use conceivable for detection of leaks following tightness test/detection of air pockets; detectability of leaks possibly restricted due to sealing action of fouling • Restricted usability, since minimum pressure, minimum flow velocity and complete filling necessary <p>Culverts:</p> <ul style="list-style-type: none"> • Not suitable in principle for civil-engineering boundary conditions
Drawn-in hydrophone (e.g. Sahara®)	<ul style="list-style-type: none"> • Leak location • Location of air pockets 	<ul style="list-style-type: none"> • In principle not material-dependent* • DN 100 – DN 2700 	<ul style="list-style-type: none"> • Complete filling of the conduit for leak location; otherwise, detection of air pockets • Minimum pressure > 1 bar • Access ports every approx. 100 – 1,000 m, depending on flow velocity and bends 	No data	<p>Pressure waste-water conduits:</p> <ul style="list-style-type: none"> • Usability severely restricted: in the supplier's experience, fouling in the pressure waste-water conduit tends to seal leaks • Further restricted usability, due to necessary minimum pressure and complete filling • Only partial inspections possible if access ports lacking along the course of the conduit <p>Culverts:</p> <ul style="list-style-type: none"> • Not suitable in principle for civil-engineering boundary conditions
Drawn-in carrier-unit with ring laser gyroscopes and position encoders (e.g. DuctRunner™)	• Locating	<ul style="list-style-type: none"> • In principle not material-dependent • DN 40 – DN 1200 	<ul style="list-style-type: none"> • Floating-in of a steel cable for subsequent drawing-in of the measuring instrument • Conduit negotiability: minimum bend radii in conduit must be 1.5 to 3-fold pipe diameter; also, no obstructions caused by fouling deposits and/or impinging valve disks, etc. 	approx. 4,000 €/d	<p>Pressure waste-water conduits/culverts:</p> <ul style="list-style-type: none"> • Measurement conceivable, given corresponding bend-capability for the instrument • Inspectability primarily dependent on ability to flush in steel cable • Conduit's capability to withstand loads exerted by steel cable in bends must be investigated, particularly in the case of asbestos-cement conduits

* provided typical background noise generated by the conduit material can be filtered out

¹ According to manufacturer's information

² According to manufacturer's information, supported by experience from practical deployments in some cases

³ Typical net costs, delivery costs to be added; according to supplier's information, costs vary greatly depending on local boundary conditions and order volume in individual cases

⁴ Estimation on the basis of preconditions for use of the methods and civil-engineering boundary conditions of pressure conduits supported by experience from practical deployments in some cases

Table 5: External-inspection methods: Methods for inspection of exposed pipes - Preconditions for use and applicability in pressure waste-water conduits and culverts

Method	Inspection aim ¹	Conduit material and nominal diameters ¹	Most important preconditions for use ²	Cost rates, ³ examples	Suitability for use in pressure waste-water conduits and culverts ⁴
Inspection of exposed pipes					
Electromagnetic inspection systems (e.g. SLOFEC™)	• Detection of changes in wall thickness and/or corrosion (qualitative)	• Steel, cast iron • from approx. DN 50	• Uncovering of the pipe sector to be inspected • Possibly necessary to remove anti-corrosion coatings, depending on material and thickness • Knowledge of the conduit material and original wall thickness necessary for calibration of the measuring instrument	approx. 2,000 €/d	Pressure waste-water conduits: • Method suitable in principle for use with cast-iron and steel pressure waste-water conduits • Limited informational value of random-sampling inspection Culverts: • Uncovering of culvert normally not possible, due to the obstacles traversed
Ultrasonic measuring systems (e.g. DSM1GO)	• Measurement of wall thickness (distributed measurement of pipe wall)	• for steel, cast iron, PE, inter alia • Not dependent on DN	• Uncovering of the pipe to be inspected • Possibly necessary to remove anti-corrosion coatings, depending on material and thickness • Knowledge of the conduit material and original wall thickness necessary for calibration of the measuring instrument	approx. 50–90 €/h (Measuring instrument approx. 8,000 €)	Pressure waste-water conduits: • Method suitable in principle for use with cast-iron and steel pressure waste-water conduits • Extremely restricted informational value due to only distributed inspection using ultrasonic probe Culverts: • Uncovering of culvert normally not possible, due to the obstacles traversed
Ultrasonic measuring systems (e.g. Wavemaker™)	• Detection of extensive corrosion and cracking (inspection of conduit sections)	• Steel, cast iron • DN 25 – DN 1000	• Uncovering of the conduit at intervals of 1 to 50 m, depending on conduit material, included sockets, flanges, welds, bends, etc. • Knowledge of the conduit material and original wall thickness necessary for calibration of the measuring instrument	approx. 2,000 €/d	Pressure waste-water conduits: • Method not practicable, due to necessity of uncovering pipe sections at short intervals, range of ultrasonic signal in the case of bitumen-coated conduits is estimated at 1 to 5 m, for example Culverts: • Uncovering of culvert normally not possible, due to the obstacles traversed

¹ According to manufacturer's information

² According to manufacturer's information, supported by experience from practical deployments in some cases

³ Typical net costs, delivery costs to be added; according to supplier's information, costs vary greatly depending on local boundary conditions and order volume in individual cases

⁴ Estimation on the basis of preconditions for use of the methods and civil-engineering boundary conditions of pressure conduits, supported by experience from practical deployments in some cases



Table 6: External-inspection methods: Methods for inspection of soil-covered pipes – Preconditions for use and applicability in pressure waste-water conduits and culverts⁴

Method	Inspection aim ¹	Conduit material and nominal diameters ¹	Most important preconditions for use ²	Cost rates, examples ³	Suitability for use in pressure waste-water conduits and culverts ⁴
Inspection of buried pipes					
Acoustic leak location (ground microphone)	• Leak location	• In principle not material-dependent • In principle not dependent on DN	• Minimum pressure of 1 to 10 bar, depending on pipe material • Complete filling of the conduit	approx. 270 €/2h, for every further hour approx. 75 €/h	Pressure waste-water conduits: <ul style="list-style-type: none">• Suitability dubious, due to a number of factors, such as interference from pump noise, and also the necessary minimum pressure and complete filling• In the supplier's estimation, fouling in pressure waste-water conduits tends to seal leaks Culverts: <ul style="list-style-type: none">• Not possible, due to passage under obstructions in the conduit route
Leak location using dissolved helium	• Leak location	• In principle not material-dependent • In principle not dependent on DN	• Facility for connection of a metering system (e.g. flange in the pumping station) • Minimum pressure of 1 bar, with corresponding complete filling of the pipe section to be inspected	approx. 5,300 – 6,300 € for leak location on a 1 km conduit	Pressure waste-water conduits: <ul style="list-style-type: none">• Leak location using dissolved helium appears to be possible and practicable; the precondition is filling of the conduit sections with helium-enriched water (ponding at the end of the pressure conduit may be necessary) Culverts: <ul style="list-style-type: none">• Restricted suitability, depending on the obstacle traversed (e.g. river), must be anticipated
Thermography	• Leak location • Conduit location	• In principle not material-dependent • In principle not dependent on DN	• Temperature differences generated by pressure conduit/leaks necessary • Only suitable for conduits not located in built-up areas • Necessity for most precise possible knowledge of the conduit route, and also of factors such as soil type and vegetation	Walking of the route with a hand-held camera: 1,500 €/d Overflight (aerial survey): > 9,000 €/d	Pressure waste-water conduits: <ul style="list-style-type: none">• Leak location may be possible, but presupposes variations in soil moisture content caused by leak; conditions made more difficult in many cases by lack of knowledge of the precise conduit route• Conduit locating appears not to be possible, due to only slight temperature differences between the waste-water and the soil, and also in many cases to lack of knowledge of the precise conduit routes Culverts: <ul style="list-style-type: none">• Normally not possible, due to passage under obstructions in the conduit route
Ground-penetrating radar	• Conduit location • Detection of bedding anomalies	• In principle not material-dependent • In principle not dependent on DN	• Pedestrian/vehicle accessibility of the area to be investigated • Suitability dependent on numerous boundary conditions (such as soil type, water content, groundwater table, salt content, terrain surface), and must be estimated by suppliers in each individual case	Individual radar antenna: 2,500 – 3,000 €/d; Complex measuring technology*: 12 €/m ²	Pressure waste-water conduits: <ul style="list-style-type: none">• Use conceivable, but as many boundary conditions of the sub-surface zone (and all conduit routes, in particular) should be known, in order to exclude possibility of incorrect interpretations• Conduit locating complex (movement at right-angles to the pipe axis) Culverts: <ul style="list-style-type: none">• Suitability dependent on pedestrian/vehicle access to the obstacle traversed (see "Pressure waste-water conduits" for further notes)

* Example: "Detectino" ground-penetrating radar, featuring five radar antennas, referencing function and electromagnetic sensors

¹ According to manufacturer's information

² According to manufacturer's information, supported by experience from practical deployments in some cases

³ Typical net costs, delivery costs to be added; according to supplier's information, costs vary greatly depending on local boundary conditions and order volume in individual cases

⁴ Estimation on the basis of preconditions for use of the methods and civil-engineering boundary conditions of pressure conduits, supported by experience from practical deployments in some cases

Determination of conduit condition: recommendations for action

The appropriate and rational scope of investigation, and the investigation targets for pressure conduits, taking account of cost:benefit aspects, have been discussed on a co-operative basis with the steering committee of participating system operators on the basis of the information concerning the preconditions for use and costs of currently available methods, and the experience gained in test deployments. Generalised and regular inspection of all pressure conduits, as is customary in the case of gravity lines, is consequently deemed to be unreasonably complex and expensive. The market can thus be said not to provide the technologies necessary to permit inspection of all conduits at rational expense. There are, for conduits of less than 100 mm diameter, scarcely any potentials for determination of condition, while inspection of larger-diameter conduits is possible only to a limited degree, and/or at extremely high complexity

and cost. In addition, the experience of the system operators participating indicates that pressure lines can be operated without problems occurring and without further examination throughout the design service-life, and beyond this in some cases, if odour problems caused by hydrogen sulphide are set aside. The efficiency of pressure waste-water conduits vis-à-vis gravity lines is also revealed in their daily operation. Functional problems are discovered significantly earlier than in the case of gravity lines, particularly if delivery rates are MID-monitored and assessed against delivery pressures at the pumping station, machine speeds and energy consumption.

Operationally and cost-optimised provisions for determination of condition, rather than generalised periodic inspections, therefore appear rational in the case of pressure waste-water conduits. The IKT has, jointly with the participating system operators, drafted a three-stage procedure:

Stage 1: Data acquisition concerning the pressure-conduit system

As a first stage, all available data on the pressure conduits operated should be compiled and continuously updated. An obvious procedure here is to collate and record information on, for example, year of manufacture/installation and planned service-life, material and nominal diameter, information concerning any operational problems, damage and/or repairs which have occurred, and also data concerning catchment area and waste-water yield.

Stage 2: Risk assessment

The best option for the second step is a risk assessment for every conduit, to permit a decision concerning whether, and to what extent, inspections are necessary. Risk classifications of "Low", "Medium" and "High" can be derived via estimation of the probability of occurrence of damage/operational failure and of the consequences/severity of damage. The risk levels which are tolerable,



and those at which provisions for minimisation must be initiated, must then be ascertained on the basis of the operator's safety requirements.

Stage 3: Provisions for determination of condition

Priorities, and the scope of any further provisions to be applied to the pressure conduit system, can be defined during the next stage, on the basis of the operator's risk assessment. There is always, in principle, a greater need for action in the case of high-risk conduits than in the case of medium-risk conduits.

The detailed recommendations for action can be found in the report – available for download at: www.ikt.de (German version)

Outlook

Discussion of the project results with the participating system operators confirmed the great need for more extensive investigations into the topic of "Determination of the condition of pressure waste-water conduits". Five main focuses were established:

1. The recommendations for action elaborated during this project provide for the initiation of inspection provisions of a type and scope based on a risk assessment orientated around the probability and effects of damage to/failure of/operational problems in pressure waste-water conduits. Up to now, however, there has been a lack of reliable evaluation criteria to permit substantiated determination of failure risks for estimation of the probability of damage/operational failure of such conduits.
2. The technologies currently available, including those intended for other types of conduit (gas systems, pipelines, etc.), do not permit economically rational use in pressure waste-water conduits. There is therefore an immense need for development of systems for the determination of the condition of pressure waste-water conduits. It may be possible to combine methods already in widespread use in the waste-water sector, such as tractor cameras and foamed-plastic pigs, with more extensive inspection techniques used in the industrial sector. The use of new technologies is of interest in this context not only for determination of condition during conduit operation, but also

for the planning and tendering procedures for renewal and repair projects. Here, suitable requirement profiles for the (further) development of inspection methods have been drafted in close co-operation between system operators and technology suppliers.

3. Tightness tests can be performed on pressure waste-water conduits only with significantly greater difficulty than on gravity lines as a result, for example, of the lack of facilities for access and/or venting. There are no dedicated technical codes and rules for the inspection of existing soil-covered pressure waste-water conduits. DIN EN 1610 [6] merely draws attention, for the purpose of project acceptance, to the inspection procedures set down for drinking-water conduits in DIN EN 805 [7]. The extent to which this inspection method can be applied to existing pressure waste-water conduits at all, and the appropriate inspection criteria and limits, requires clarification.
4. The action chart developed does not, up to now, include any recommendations for the stipulation of intervals for determination of condition. Operational planning (estimation of expenditure) is significantly dependent on this, however. The extent to which general principles for the specification of intervals for determination of condition, or even guide figures for these intervals, can be developed, remains unclear at present.
5. Knowledge of the refurbishing/repair methods available on the market, and of their preconditions for use and their costs, is needed. The costs and the use of provisions for the determination of the condition of pressure waste-water conduits should, on the one hand, be lower and simpler than those for repair and for renewal. Preparations for a repair/refurbishing project may, on the other hand, necessitate separate determination of condition, such as, for example, measurements of deformations in the existing conduit.

Results available in the Internet

This article discusses only extracts from the research project. Both an abridged and a detailed complete version of the concluding report can be downloaded from the Internet at: www.ikt.de (German Version)

The Author

Dipl.-Ing. (FH) Kathrin Sokoll

IKT - Institute for Underground Infrastructure

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ABOUT IKT




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a) IKT-Association of Network Operators:

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IKT – Institute for Underground Infrastructure

Exterbruch 1
45886 Gelsenkirchen
Germany

phone: +49 209 178060
fax: +49 209 17806-88
email: info@ikt.de

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International Airport.

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