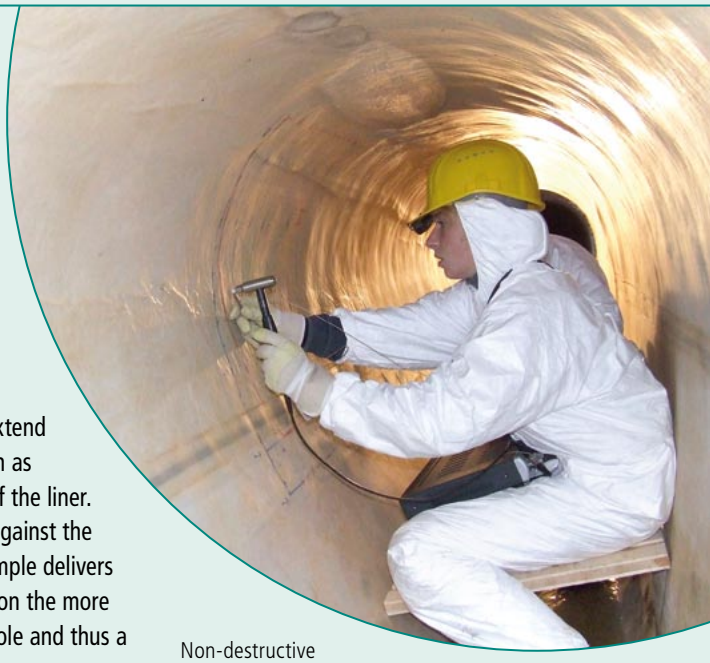
Acceptance of lining measures



Non-destructive testing procedure in the practical test

The IKT has taken a good look at non-destructive testing of lining measures [1]. Jointly with five project partners, six procedures found application in a practical test. Conclusions: Numerous non-destructive testing procedures are at disposal. For standard application to the „Acceptance of lining measures", further reaching investigations and adaptation are necessary, however, for inaccessible area.

Are random sample in rehabilitation measures sufficient?

In building and guarantee acceptance of tube liner rehabilitation, the TV camera navigation finds application as a rule for inaccessible cross-sections, and for inspection in the course of channel walk-through in accessible cross-sections. Relevant characteristics of liners like, e.g. the short time E-modulus, short time bending stress during fracture, statically workable liner wall thickness (combined thickness), and leakage tightness are verified supplementarily as random samples during construction acceptance by standard sampling in the manhole and investigation of these individual samples in the laboratory. It is questionable, however, whether this procedure permits sufficient assessment of the respective rehabilitation measure.

On the one hand, one can critically question whether the individual sample gained in the manhole is representative for the entire rehabilitation stretch. The gathered experiences from the building projects accompanied within the scope of the project as well as the IKT testing center show precisely that the liner quality is subject to variations. The determined material characteristics of the liner show differences independently of the place from where the sample is taken, for example in the manhole, in the bearing, and in different cross-section areas. That is, the material characteristics of the liner can scatter strongly. These scatter extend both in the longitudinal direction as well as over the circumference of the liner. Contrary examples were found against the hypothesis that the standard sample delivers worse mechanical values based on the more unfavourable ratios in the manhole and thus a result on the „safe side".

On the other hand, also the use of the above-cited inspection procedure on sewages rehabilitated with tube liners only gives limited information about the liner quality. Whereas optical peculiarities, for example transverse and longitudinal folds, peeling of the interior foil, freely lying fibres, bulges and waves in the course of inspection can be detected where appropriate for sure, evaluation of these peculiarities with respect to the influence on durability, functionality and leakage tightness of the liner is hardly possible. Especially, the statically relevant characteristics of the liner remain concealed, for example the modulus of elasticity, the bending stress, the liner wall thickness, a possible annular gap as well as the leakage tightness of the liner and its variations in longitudinal direction and over the circumference.

Non-destructive testing procedures

A new way for inspection of rehabilitation result arises from the use of non-destructive testing procedures. The goal herewith is to identify possible weaknesses of the tube liner rehabilitation and where appropriate to sample and perform destructive testing.

For this purpose an extensive investigation contact to specialty institutes, suppliers and service providers of non-destructive testing procedures were established. The researched procedures as a rule are generally used as standard in other fields, for example, in the biomedical technology, in the survey in the mountain mining and tunnel building and in the damage analysis of large, well accessible components.

The researched non-destructive testing procedures were examined and evaluated with respect to its usage capacity and/or transferability to the „Acceptance of lining measures" application. After successful investigations on sample material in the laboratory, the following non-destructive test procedures were selected out of the sum of the compiled procedures for a first practical application in accessible area:

- 3D-Laser scanning
- Temperature measurement by means of optical fibre cable
- Heat flux thermography
- Impact echo procedure
- Local resonance spectroscopy and
- Ultrasonic echo procedure

Practical application

The practical application took place in a rehabilitation measure put at disposal by the Stadtentwässerungsbetriebe Köln (city draining works in Cologne/Germany). It comprises two stretches of a combined sewer with a total length of 105m. A Polyester-synthesis fibre liner was selected as tube liner, which was procured from Insituform Rohrsanierungstechniken GmbH with hot water cure and a wall thickness of 36 mm prior to and 39 mm after the expansion of the sewer.

Characteristic data of the building project

The start manhole was created anew in cast-in-situ concrete in advance of the rehabilitation project. To facilitate execution of the rehabilitation project, the concrete slab of the manhole was first left out and thus the accessibility of the rehabilitation stretch guaranteed for the liner.

For the test application of the non-destructive testing procedure, the first stretch with a length of approximately 71 m and dimensions of B/H 1000/1500 was selected.

Local boundary conditions of the building project
a) Bricked inflow end of the sewer in the start manhole
b) View into the out-going sewer to be rehabilitated

3D laser scanning

With the 3D laser scanning (cf.[2], [3], [4]) objects can be recorded automatically in location, size, and form, contactless and almost completely. The measuring system delivers a scatter diagram in which the object can be described through a multitude of single points consist of three-dimensional coordinates and an intensity value. The scatter diagram can be represented on a computer and be processed further. A model development occurs subsequently to the actual measurement. This involves computation of geometric elements out of a multitude of object points by means of algorithms.

Execution of laser scanning in the sewer
a) Positioning of the scanner in the sewer
b) Ball prism for the tachymetric calibration of the scanner
c) Marking the station points in the sewer

Appropriate tools are available for the analysis and representation of measured results, which enable visualization via an Internet browser. Based on retroactive preparation possibilities, for example storage of views, inserting of dimensions, tapping of coordinates, lengths and heights or insertion of text descriptions, the readings can be evaluated individually. The 3D laser scanning finds application, for example, in the architecture or in tunnel building.

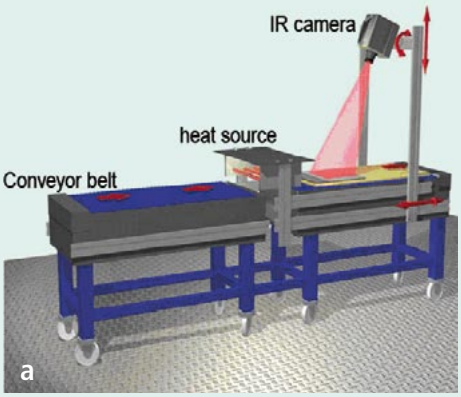
Temperature measurement by means of optical fibre cables

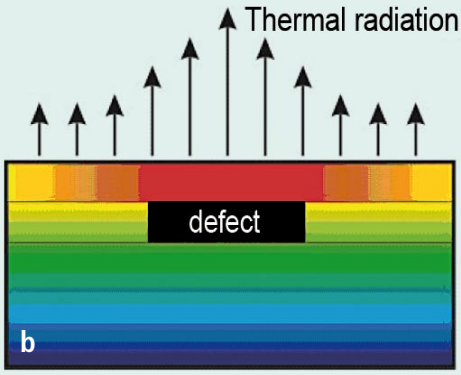
In the building project, fibre optical Raman temperature measurement (DTS = distributed temperature sensing) found application. The measuring system consists of an optoelectronic device (radar) and a fibre-optic cable (LWL cable) consisting of quartz optical fibre as a linear temperature sensor. The radar works with laser light that is coupled into the sensor cable. Heat effect on sensor cable causes thermal molecular oscillation within the optical fibre material, which lead to a light dispersion (Raman dispersion) of the laser light. A part of this Raman dispersion is guided back from the optical fibre to the analysing device and is converted into an electric signal with the help of photo detectors. Because the light intensity of the Raman scatter light is proportional to the thermal molecular oscillation, the temperature of the optical fibre cable can be calculated. The corresponding temperature measuring point is obtained according to the principle of optical backscattering principle. The place of effect of the temperature is determined from the delay between sending and reception of optical pulses.

By means of visualization software, the temperature values can be transformed into a thermographic image and assigned to the measured object. In an LWL cable with a length, for example, of 500 m up to 1,000 measuring points can be covered along the routing arrangement. In combination with the visualization software, the spatial temperature profile of the measured object can be portrayed in real time.

In energy technology, for example, the thermal load condition of high voltage cables can be monitored with the DTS measuring technology.

Equipment for temperature measurement
a) Cable drum with optical fibre cable
b) Connection of the measuring cables on a wall muff in the start manhole





Measuring principle of the heat flux thermography [6]
a) Schematic test arrangement for the online thermography
b) Thermal radiation in a sample with a defect

Heat flux thermography

The heat flux thermography is a test method (cf. [5]) with which the voids not visible from outside can be made visible. Moreover, through the manufacturing process, contingent heat flux or that induced from outside into the test object are exploited, and behave differently in voids spots compared to flawless spots. These differences in heat flux are reflected in the temperature distribution on the surface of the test objects. With a thermography camera, one can make this temperature distribution and hence the voids visible. Because it concerns an imaging procedure, many proven procedures of the classic image processing can be taken over for automatic defects detection.

As an active thermography procedure (cf. [6]), above all the heat flux or online thermography is used. Herewith, the measuring objects are heated with a heat pulse as homogeneous as possible, that in suitable material characteristics (leakage tightness, thermal conductivity, and heat capacity) triggers temperature difference in defective areas of the work piece, which can be proved in a thermography figure.

The heat flux thermography is used already as standard for the detection of defects on rotor blades made of GFK for wind power plants.

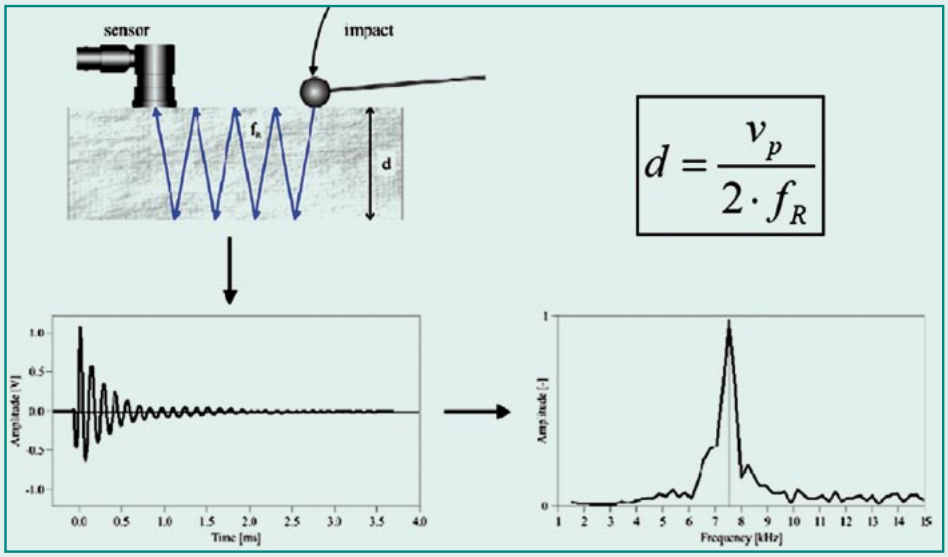
Impact echo procedure

The impact echo procedure (cf. [7], [8]) is classified between the local resonance spectroscopy and the ultrasonic echo procedure. The stimulation of the measuring signals takes place via an impact by means of a hammer or a steel sphere. In contrast to the local resonance spectroscopy, the body sound is recorded by means of a piezoelectric sensor. In the layers, resonances form through repeatedly reflected waves, which correspond with the layer thickness. In addition, the detection of structure changes within the component is possible. The data analysis occurs in the frequency range. By determining the resonance frequencies, it is possible to know the component thickness, provided the compression wave velocity is well known or can be measured separately. The procedure presently finds application above all use in civil engineering for the determination of minimum thicknesses of tunnel interior shells, however, it is suitable there only for component thicknesses greater than 5 cm.

Local resonance spectroscopy

The local resonance spectroscopy orients itself (cf. [8]) towards manual knock tests that are used among others in the aviation and space flight or in the test of rotor blades of wind power plants. The component is knocked by the inspector with a suitable object and the sound thus stimulated is evaluated. These procedures are usually very easily executable manually.

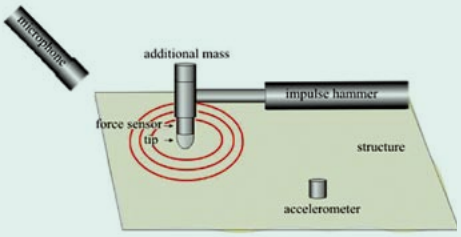
If an object is stimulated once from outside to oscillate it oscillates at its own frequency that depends on the structure and geometry. In production technology of metal and ceramics components, such defective work pieces can be

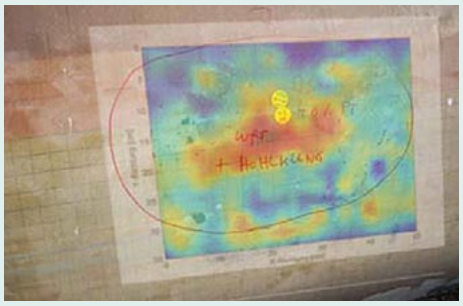


Measuring principle of the impact echo procedure [7]

sorted out quickly. Local resonance spectroscopy functions similarly. The difference is that the components to be examined is generally larger and oscillates only locally in the area of sound stimulation. The procedure reacts sensitively to damages located directly near the sound stimulation and hence does not permit locating the damage.

A record of the stimulation signal of the hammer by means of a force transducer permits an evaluation of the contact time and delivers additional information about the structure of the component.



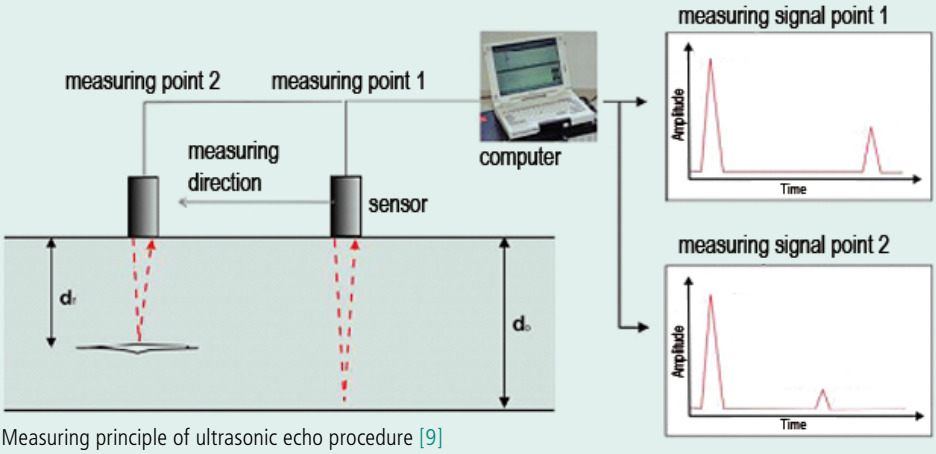


Local resonance spectroscopy [8]
a) Measuring principle
b) Analysis of the stimulation signals: Delamination in the GFK laminate

Ultrasonic echo procedure

The ultrasonic echo procedure (cf. [8], [9]) is an established procedure in many branches of industry. Wall thicknesses of different materials can be determined using it. As priority, this procedure finds application on materials with relatively uniform structures like, for example, metal or concrete components. Also on composite materials, like for example GFK, the procedure is used already successfully.

In contrast to the impact echo procedure and the local resonance spectroscopy, the ultrasonic echo procedure is a running time procedure, that is, the signals recorded here are observed in the

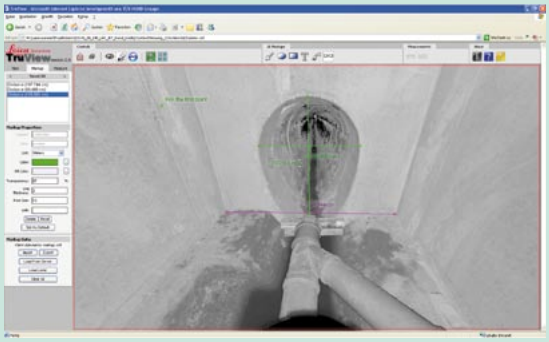


Measuring principle of ultrasonic echo procedure [9]

Photo examples for practical applications and measuring results

3D laser scanning (DMT, Essen)

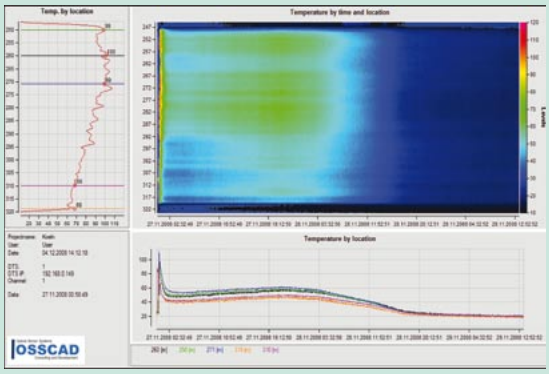
a) Surveying of the start manhole



b) Visualization of the readings

Building accompanying temperature measurement (OSSCAD, Bergisch Gladbach)

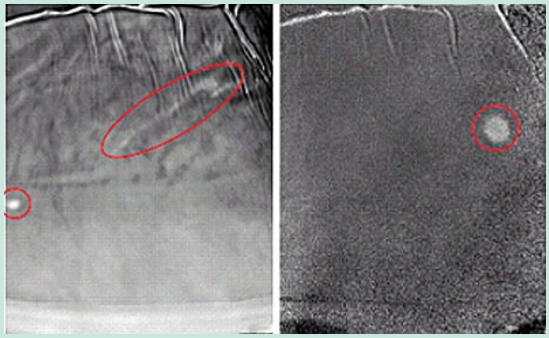
a) Installed measuring cable on the old pipe



b) Time and location temperature curve during liner hardening

Heat flux thermography (Fraunhofer WKI, Braunschweig)

a) Measurement in the sewer



b) Localized peculiarities in the liner material

time domain. An ultrasonic signal is brought via a sensor into the component and propagated from there. The waves are reflected at different material boundaries like defects or rear wall of the component and are recorded with the same sensor or a second one. From the chronological position t of the echoes, a defect depth or thickness d of the component can be determined for a given speed of sound v in the medium by using the formula d = v x t/2.

For a composite of two different materials, the strength of the echo depends on how significantly the materials differ in their acoustic characteristics. The differences between solid bodies and air are very strong. Delamination defects, for example in glass-fibre-reinforced composite materials consequently appear as especially strong reflections.

Evaluation of verified non-destructive testing procedures

The six selected non-destructive testing procedures were able to prove all their basic suitability for the practical application to tube liner systems. Procedures are therefore available, which fundamentally enable following and thus if necessary permit a focused identification of possible weaknesses of the liner:

- 3D-surveying of old pipe for producing the liner
- Detection of the time and location temperature curve during the rehabilitation and hence
- inspection and where appropriate control of the hardening process
- 3D-surveying of the liner surface including optical peculiarities, like folds, waves and bulges
- Detection of defects and weakened structures, for example, like voids and delamination spots
- Detection of annular gaps between old pipe and liner
- Determination of liner wall thickness

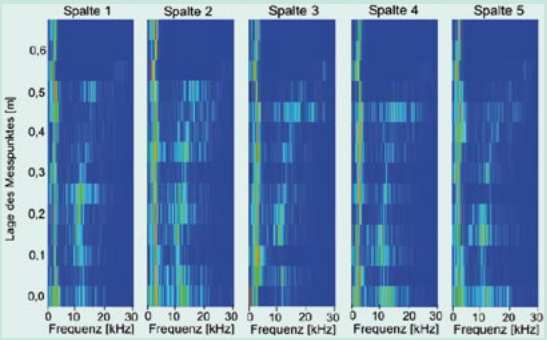
The tested non-destructive testing procedures were evaluated based on the construction site experiences with respect to their theoretical significance, practical usefulness, expense and costs as well as available improvement potential and compared against the classic standard sampling. In the table, the evaluation of the non-destructive testing procedures is represented with respect to the aspect named above as well as the resulting ranking order of the procedures.

The temperature measurement by means of optical fibre cables is the only one among the tested non-destructive testing procedures that is applicable accompanying the construction. It allows online monitoring and recording of prevailing temperatures in longitudinal direction and - according to arrangement of the measuring cables - over the cross-section of the liner during the entire duration of the rehabilitation process. An inspection and/or where appropriate the control of the hardening process of the liner is therefore possible. In contrast to the other investigated non-destructive testing procedures, the temperature measurement is already usable now in all nominal diameter ranges. The installation of the measuring cables in the stretch is costly. The preparation tasks by up to four workers lasted approximately four days. In the inaccessible area, the entrance of cables, for example, in the soffit and the invert is less costly and can be done by two workers for two selected stretches within a half day.

Photo examples for practical applications and measuring results

Impact echo procedure (MPA Stuttgart)

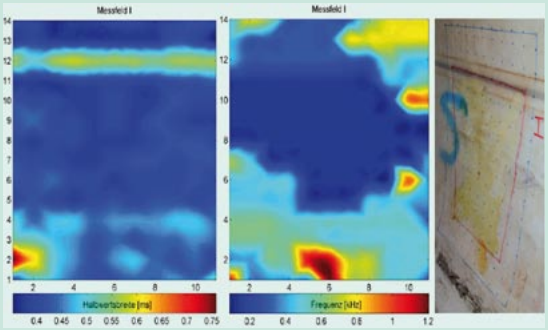
a) Measurement in the sewer



b) Measured resonance frequencies of the liner for qualitative ascertainment of ring columns

Local resonance spectroscopy (MPA Stuttgart)

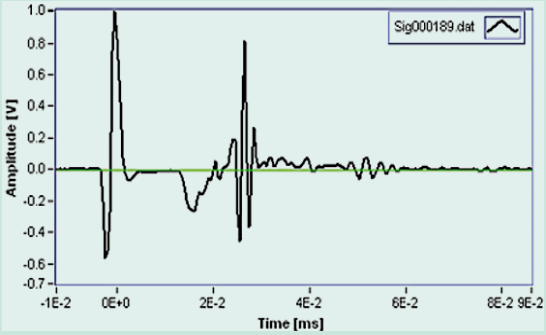
a) Measurement in the sewer



b) Determined half-value widths and measured maximum frequencies to ascertain noticeable structures in the liner wall

Ultrasonic echo procedure (Fraunhofer IBMT, St. Ingbert; MPA Stuttgart)

a) Measurement in the sewer



b) Recorded time signal for determining the liner wall thickness

Table: Evaluation of the non-destructive testing procedures based on the test application in accessible area

	Theoretical significance	Practical fitness	Scope/costs	Improvement potential	Remarks
Constr. accomp. temperature measurement	+	++	-	+++	3-4 workers Automatic measuring Approx. 4 days preparation Approx. 4 days measuring
	Temp. curve Heat input	Established measuring procedures, application in all nominal widths Several measuring points Result validation unclear	Preparation costly Higher personnel demand Low measuring scope Costly evaluation	Position protection for cable Integration of cable in liner Validation	
Ultrasonic echo	++	-	-	+++	Only applicable after liner's installation 2 workers Approx. 5 measuring grids per day
	Wall thickness	Only accessible sewages Testing of identified points Result validation unclear	Medium personnel demand Long measuring duration Costly evaluation	(Further development of instruments) (Miniaturisation) Automation Validation	
Impact echo	++	-	-	++	Only applicable after liner's installation 2 workers Approx. 5 measuring grids per day
	Annular gap detectable (wall thickness)	Only accessible sewages Testing of identified points Result validation unclear	Medium personnel demand Long measuring duration Costly evaluation	(Miniaturisation) Automation Validation	
Thermography	+	-		+++	Only applicable after liner's installation 3 workers Approx. 7 measuring grids per day
	Inhomogeneity spots	Only accessible sewages Testing of identified points Result validation unclear	Higher personnel demand Long measuring duration Costly evaluation	(Miniaturisation) Automation Validation	
3D laser scanning	++	-		++	Only applicable after liner's installation 4 workers 4h measuring for 1 stretch
	Full coverage of shell surface	Established measuring procedures, Only accessible sewages Measuring accuracy for wall/ annular gap too low	Higher personnel demand Long measuring duration Costly evaluation	(Miniaturisation) Automation Measuring accuracy	
Resonance spectroscopy	+	-		++	Only applicable after liner's installation 2 workers Approx. 5 measuring grids per day
	Inhomogeneity spots	Only accessible sewages, Testing of identified points, Result validation unclear	Medium personnel demand Long measuring duration Costly evaluation	(Miniaturisation) Automation Validation	

The measuring effort during the rehabilitation is comparatively little, if desired after the start of the measurement the measuring process proceeds even without personnel on site. Improvement potential appeared above all in the site security of cables in the inaccessible area and/ or in the reduction of assembly expense in the accessible area. Both could be cleared by a works integration of measuring cables in the liners.

Further developments required

The other non-destructive procedures are used exclusively for verification of the rehabilitation result after conclusion of the rehabilitation project and in the existing device configuration; they are presently usable only in the accessible nominal widths range. Although the sensor technology in the impact echo procedure, in the ultrasonic echo procedure and in the local resonance spectroscopy is sufficiently small in order to use this also in inaccessible sewers, to be sure further reduction of the device technology is required for an automated execution of the measurement, for example by means of a robot system. Miniaturisation of device technology and automation at is currently put in perspective for the ultrasonic echo procedure, impact echo procedure and the local resonance spectroscopy of the MPA Stuttgart and for the heat flux thermography of the Fraunhofer WKI. The test procedures permit a local and/or extensive verification of selected spots of the liner. The execution of the respective measurements without automation is connected with great time demand; in daily use, approximately five measuring screens with about 800 measuring points and/or with seven measuring fields could be examined. The analysis of the measuring results is at present costly for all procedures and can mostly take place after the measurements reach the office. With the local resonance spectroscopy, the impact echo procedure and the ultrasonic echo procedure an automated data analysis could be implemented for a simplified data analysis in a robot system in future.

The ultrasonic echo procedure permits local determination of liner wall thicknesses for selected spots and detection of minor thicknesses and/ or delamination. For the measuring process, two workers were required on the spot; personnel expense and test costs lie in the middle range. By means of the impact echo procedure, detection of annular gaps (yes/no) between liner and old pipe and, where appropriate, the determination of liner wall thickness is possible. In the measuring process, middle-range personnel expense of two workers and test costs must be anticipated. After modification of the sensor technology and measuring hardware, the measurements can also be carried out and accelerated by one person. Noticeable structures, inhomogeneity spots and weakened structures of the liner wall - in different deep locations - are detectable by means of heat flux thermography and local resonance spectroscopy. The personnel expense and the test costs are high in heat flux thermography, moderate in local resonance spectroscopy (two workers).

The 3D laser scanning allows a complete detection of the shell surface of the liner. Based on the too low measuring accuracy of the procedure, no determination of the distance between the interior surface of the old pipe and the liner is possible and consequently the desired determination of ring column measure is not possible.

Validation of the results

All used test procedures of the practical application still need another extensive validation of the obtained results. Detailed, continuing investigations are required for this. For example, an adjustment of identified noticeable areas and structures, detected annular gaps as well as measured liner wall thicknesses could occur based on samples taken from and/or in the sewer. This very costly verification of the results of the non-destructive testing procedures was not component of this research project and is currently still outstanding. Prior to a standard use of tube liner rehabilitation in the accessible area, these open questions must be answered.

Conclusion

In the result it can be established that numerous non-destructive testing procedures are available, which possess a high potential for an application to tube liner systems. However, the non-destructive testing procedures at the present state of devices technology (yet) represent no alternative to the previous samples for a verification of the achieved rehabilitation quality. For a standard use, the application as regards the obtained results is to be validated, further developed and the device technology mainly reduced and/or automated with respect to the obtained results. The test procedures could then represent a meaningful supplement to the previous quality assurance in the form of optical inspection and laboratory test on taken liner samples. In the accessible area, the introduced non-destructive testing procedures are however already usable now for random-samples-like investigations and examinations of the liner quality.

Results on the Internet

This article provides the research results only as excerpts. The complete research report is on the Internet ready for download: www.ikt.de

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neutral
independent
non-profit institute

IKT - Institute for Underground Infrastructure

ABOUT IKT

IKT - Institute for Underground Infrastructure is a research, consultancy and testing institute specialized in the field of sewers. It is neutral and independent and operates on a non-profit basis. It is oriented towards practical applications and works on issues surrounding underground pipe construction. Its key focus is centred on sewage systems. IKT provides scientifically backed analysis and advice.

IKT has been established in 1994 as a spin-off from Bochum University, Germany.

The initial funding for setting up the institute has been provided by the Ministry for the Environment of the State of North-Rhine Westphalia, Germany's largest federal state.

However, IKT is not owned by the Government. Its owners are two associations which are again non-profit organizations of their own:

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Members are more than 120 cities, among them Berlin, Hamburg, Cologne and London (Thames Water). They hold together 66.6% of IKT.

b) IKT-Association of Industry and Service:
Members are more than 60 companies. They hold together 33.3% of IKT.

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